NICK HAMPSHIRE
WITH RICHARD FRANKLIN AND CARL GRAHAM

THE COMMODORE 64 KERNAL AND HARDWARE REVEALED

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Also by Nick Hampshire

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0 00 383087 X

Advanced Commodore 64 Graphics and Sound
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Preface

Whether you program the CBM 64 in Basic or machine code, an understanding of how the kernal software works and how the system hardware functions is essential before writing many programs, particularly those involving connecting the CBM 64 to external devices. This book looks at the way the operating system and system hardware work and should be used in conjunction with Volume 1 of this series, *The Commodore 64 ROMs Revealed*, which gives the entire operating system kernal software source code.

A knowledge of how the operating system and hardware work enables one to perform many interesting functions. Notable amongst these is the high speed tape load and save routines, which allow the tape deck to operate at speeds equivalent to that on a 1541 disk drive. The whole area of program security is also covered. Without an understanding of the system software and hardware, the operation and use of the serial and RS232 ports is often quite mysterious.

This book is the product of many year's work on Commodore machines, and I am confident that it provides the most complete and useful set of information available from any one source. All serious programmers should find this an invaluable and constant reference book.

Nick Hampshire

Chapter One
Inside the Commodore 64

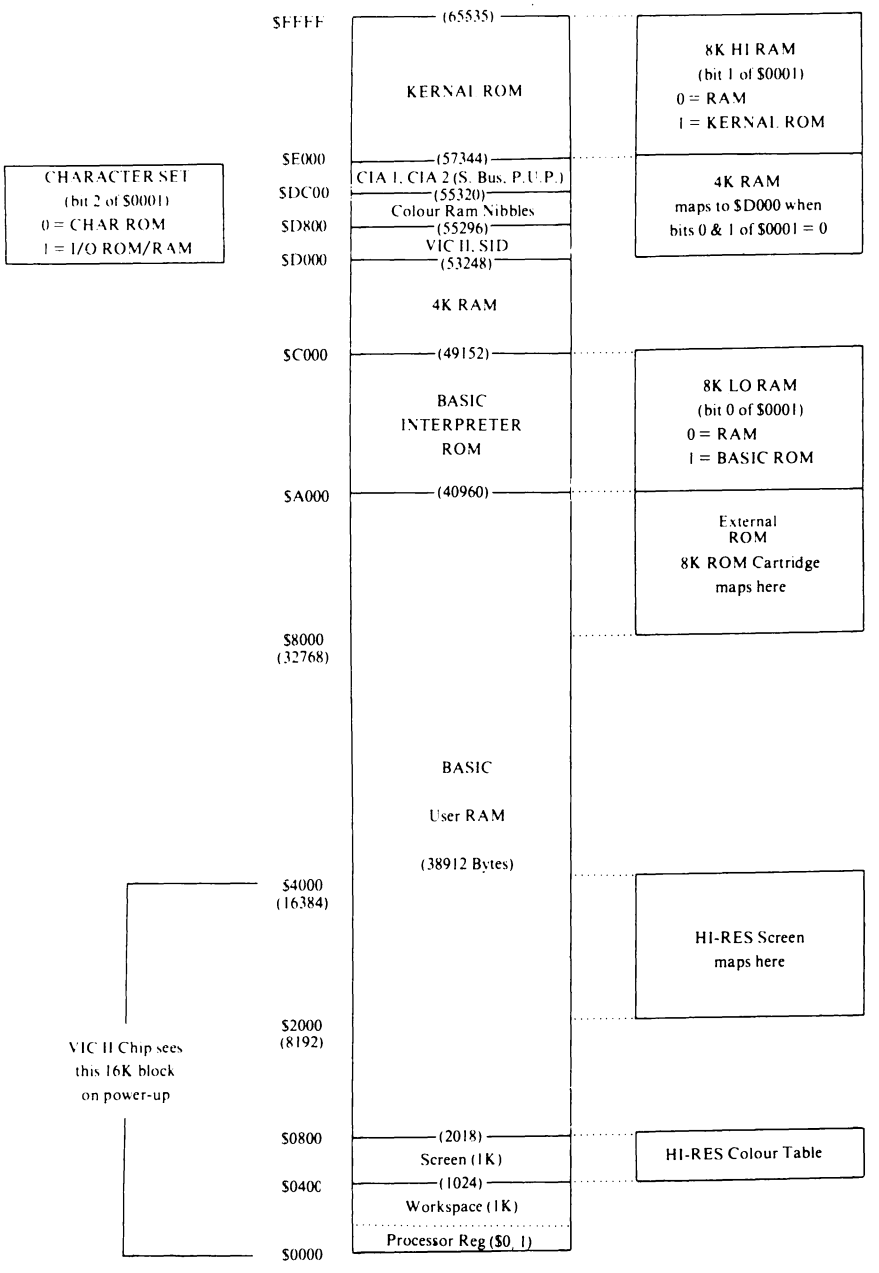


Fig. 1.1. Commodore 64 memory architecture map.

1.1 Commodore 64 design concept

The division of memory space into blocks in the Commodore 64 is shown in Fig.1.1. The Commodore 64 is built around the VIC chip and the 651Ø microprocessor. As with all microcomputers the Commodore 64 is designed to use the minimum number of chips. This is to reduce component and assembly costs.

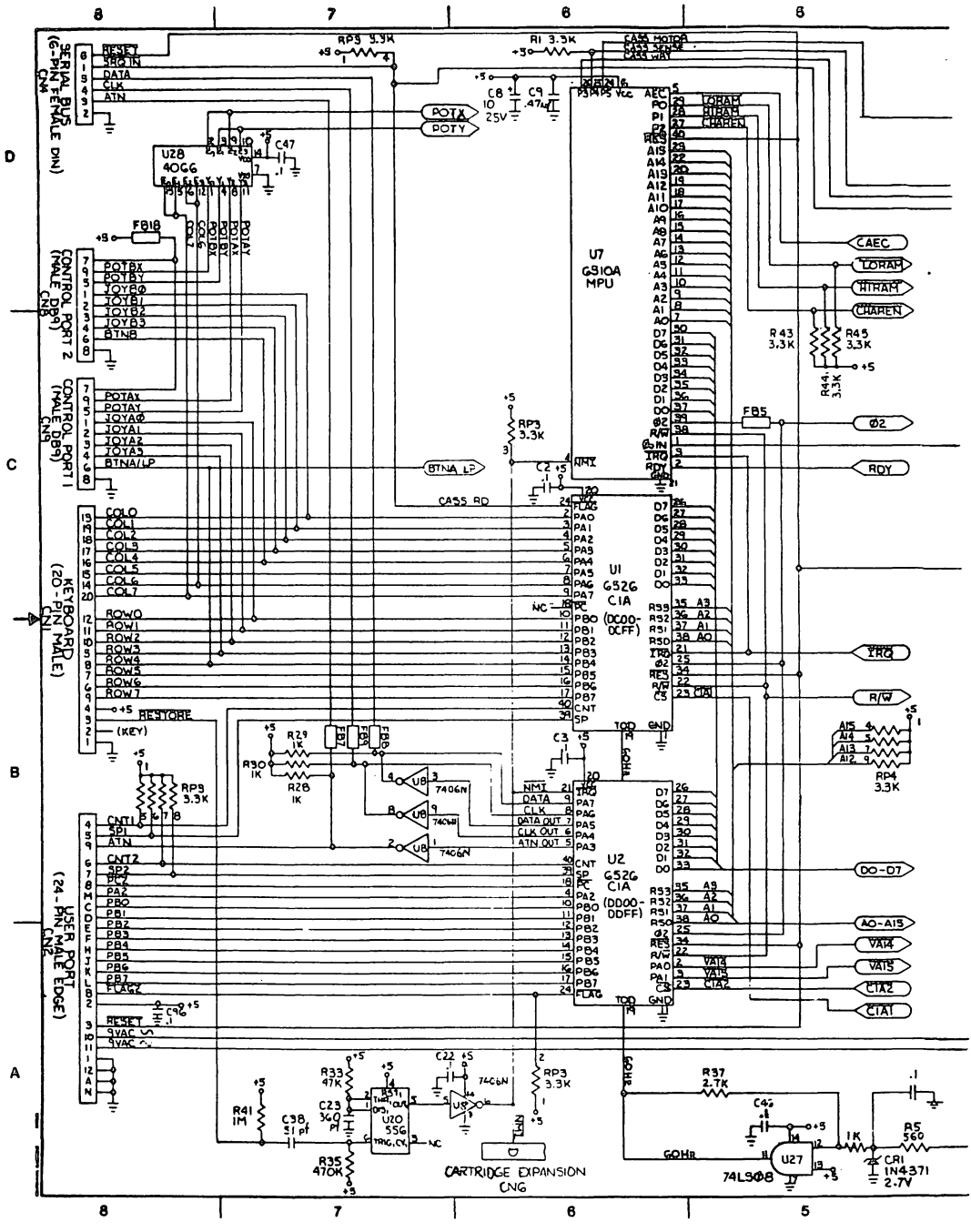


Fig. 1.2. Commodore 64 schematics (Reproduced by courtesy of Commodore Business Machines (UK) Ltd).

The main computer circuit (see Fig. 1.2) consists of the 651Ø, the VIC chip with clock circuit and the eight 64K bit RAM chips. These chips are enough to make a computer circuit that can perform machine code instructions. Note that the VIC chip is required as it supplies most of the computer's RAM control signals and timing. However, to make a usable personal computer the 64 needs a few chips for I/O and sound, also a Basic interpreter and operating system in ROM.

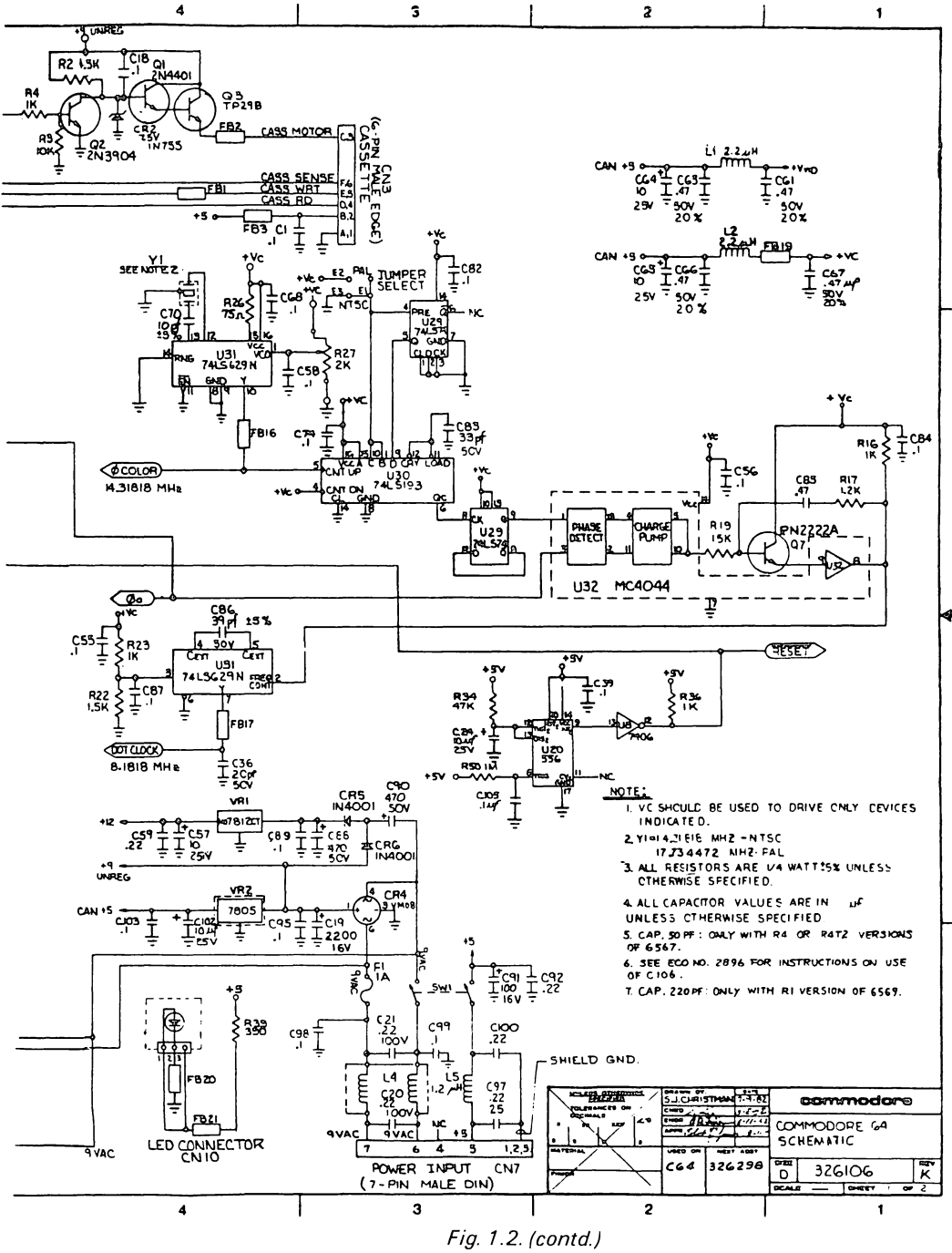


Fig. 1.2. (contd.)

The required input/output is supplied by two 6526 CIA chips. Together these two chips supply 4 timers used for IRQ timing, the tape system and serial. Their I/O ports are used for keyboard scanning, the user port, serial ports and VIC chip bank select. These chips also have serial ports and time of day clocks but these are not used in the CBM 64.

Lastly sound is generated by the SID chip. This has 3 voices each with 4

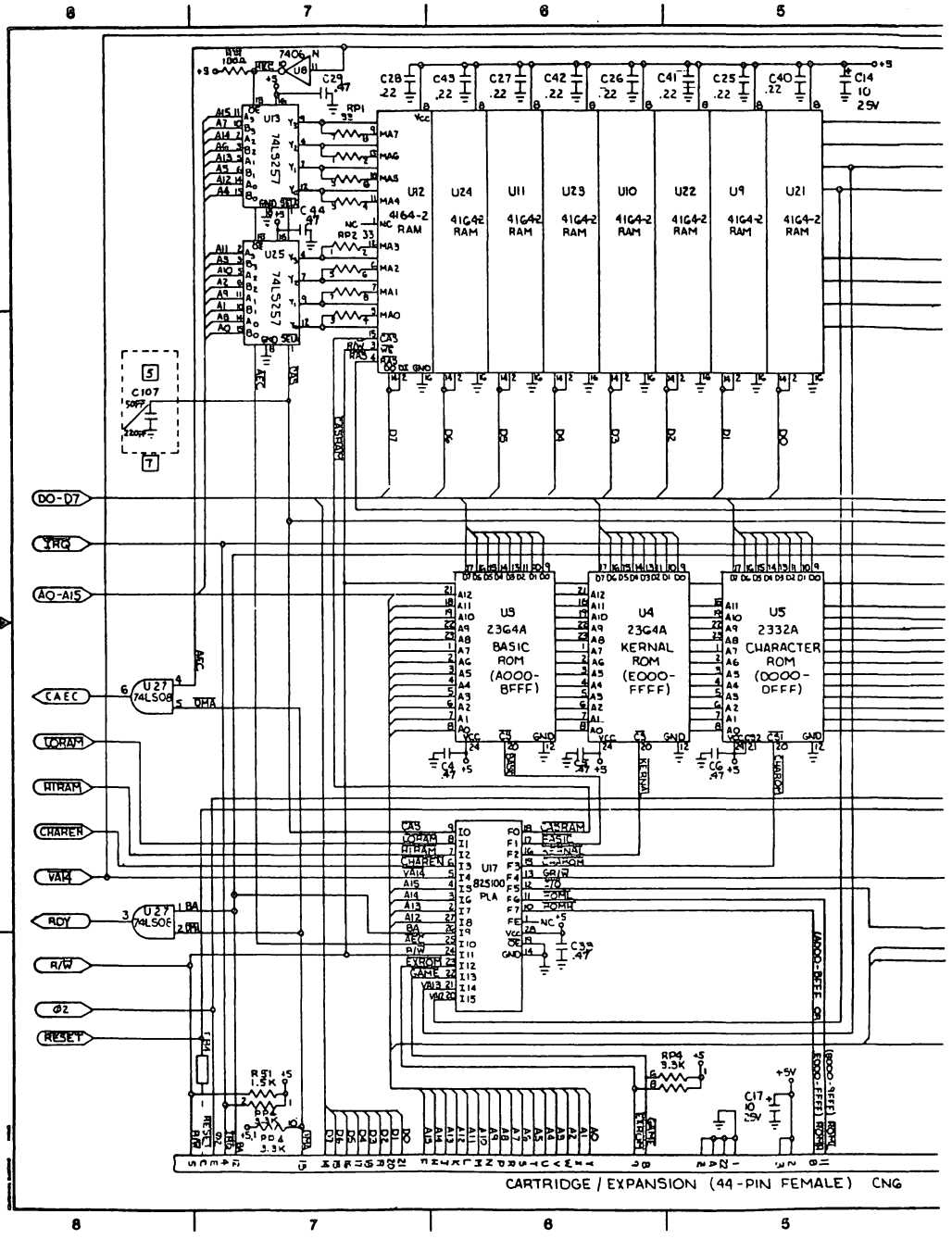


Fig. 1.2. (contd.)

waveforms an envelope control and filters. The 2 channel analog to digital converter on this chip is connected to the joystick ports.

1.2 Chips in the Commodore 64

The Commodore 64 consists of a plastic case holding a double sided printed

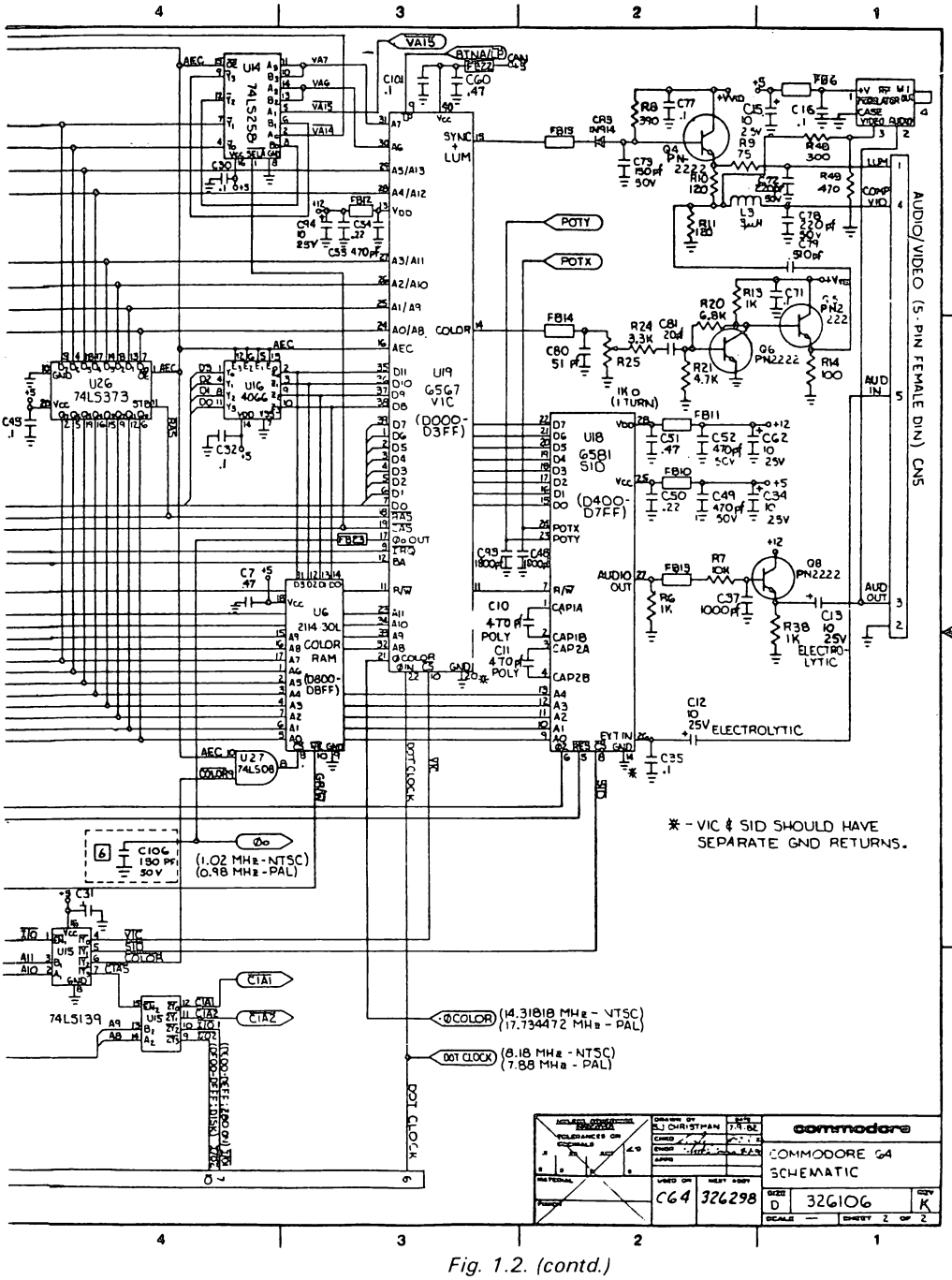


Fig. 1.2. (contd.)

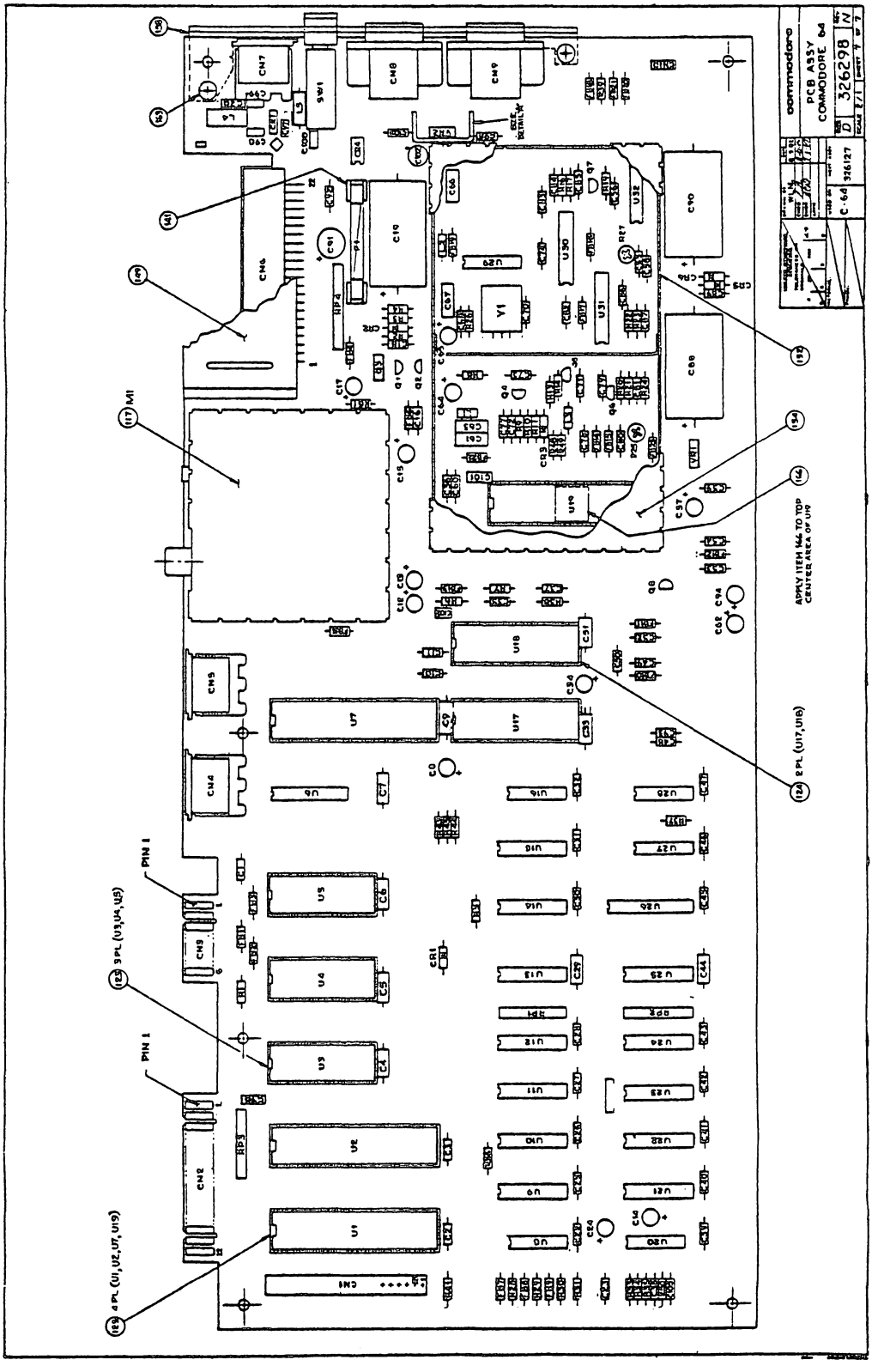


Fig. 1.3. Printed circuit board assembly for the Commodore 64 (Reproduced by courtesy of Commodore Business Machines (UK) Ltd).

circuit board, a 66 key keyboard and assorted plugs and sockets, not forgetting the power switch and LED.

1.2.1 The PC board

The printed circuit board (see Fig. 1.3) has soldered onto one side of it, a few hundred assorted resistors, capacitors, ferrite beads, diodes, coils, 2 voltage regulators, a fuse and 31 integrated circuits (chips). The power supply box supplies the board with 5 volt dc regulated, 9 volt ac and a shielded ground line. The 5 V line is used to power most of the main chips but not the VIC chip or the clock circuit. The 5 V and 12 V for these chips is generated on the board using diodes and voltage regulators to convert the 9 volt ac supplied. This is done to limit interference from the VIC chip and clock circuit which are in a shielded can. (Do not run the computer with this can open as the lid of this provides the heat sink for the VIC chip.)

1.3 The main chips

1.3.1 651Ø microprocessor (MPU)

The microprocessor (Fig. 1.4) is a version of the very common 65Ø2. The main difference is that the 651Ø has a 6 pin I/O port. In the CBM 64 this port is used for controlling memory configurations through the PLA chip, controlling output lines to the tape deck and sensing keys being pressed on the tape deck.

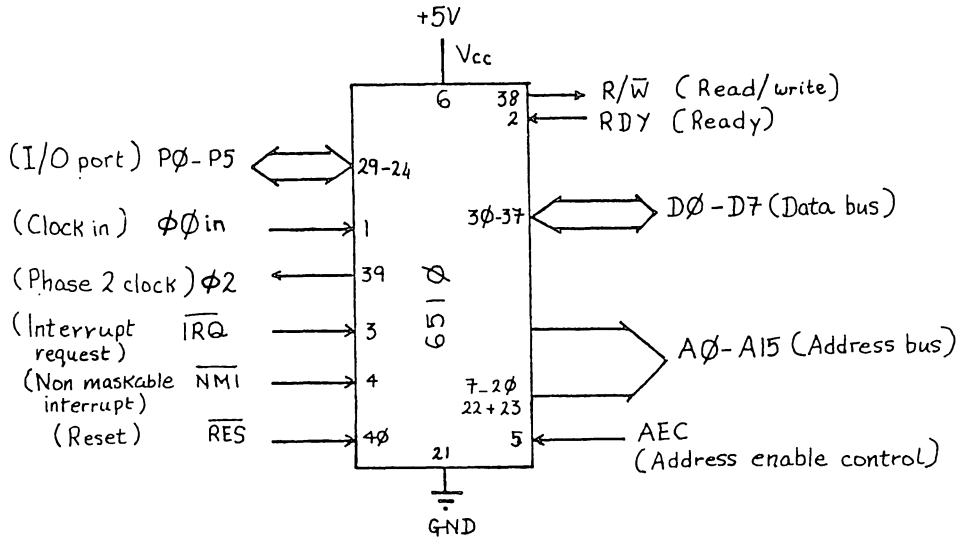


Fig. 1.4. 651Ø microprocessor (MPU).

6510 Signals and Lines

Pin 1	ϕ0in	Clock in (from VIC chip)
Pin 2	RDY	Ready. Processor waits in current state while this line is low. If this line is low and interrupts are enabled at the end of the current instruction cycle then an interrupt will be initiated
Pin 4	NMI	Non maskable interrupt (negative edge sensitive input). When this line goes from high to low an interrupt will be initiated at the end of the current instruction
Pin 5	AEC	Address bus enable control. When this line goes low the processor frees the address bus for use by other chips (VIC in the 64)
Pin 6	Vcc	Supply voltage (+5 V)
Pins 7–20 & 22,23	A0–A15	Address bus (enabled by AEC)
Pin 21	GND	Ground (0 V)
Pins 24–29	P5-P0	Processor I/O port
Pins 30–37	D7-D0	Data bus
Pin 38	R/$\overline{W}$	Read/write. (Output: low flags for processor write.)
Pin 39	ϕ2in	Phase 2 clock input
Pin 40	$\overline{RES}$	Reset (Active low)

1.3.2 6526 complex interface adapter (CIA)

There are two of these chips in the Commodore 64. The first CIA#1 is used for

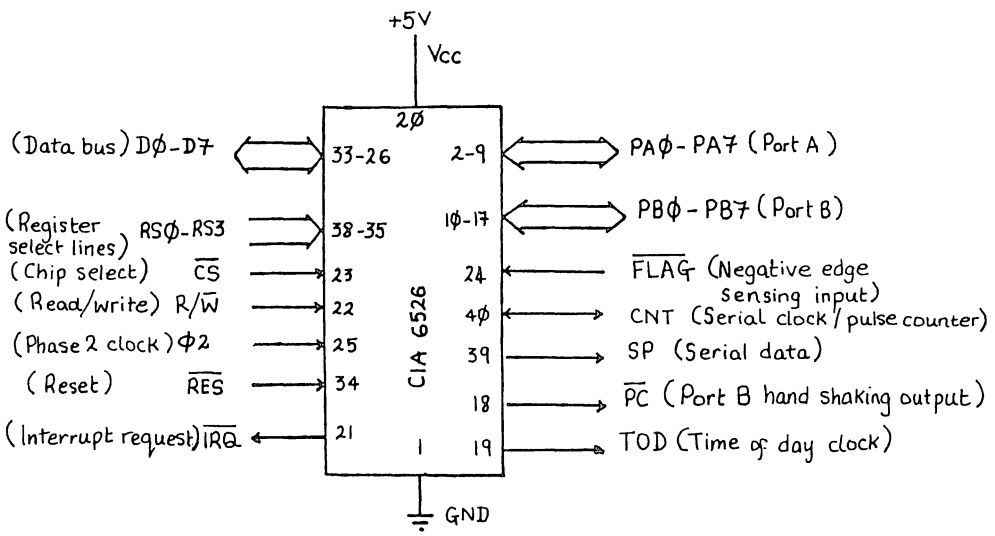


Fig. 1.5. 6526 complex interface adapter (CIA).

scanning the keyboard and inputting from the cassette and serial port. The second CIA#2 supports the user port and most of the other serial port lines. It also is used as a latch for the VIC chip bank select value. CIA chip 2 has its IRQ output connected to the NMI line so that its timers can generate NMIs instead of IRQs. The chip select lines for the two chips are decoded from the processor address bus by the PLA chip to addresses $DCØØ & $DDØØ (Fig. 1.5).

6526 Signals and Lines

Pin 1	GND	Ground (Ø V)
Pins 2–9	PAØ–PA7	Data port A (Bi-directional data port)
Pins 1Ø–17	PBØ–PB7	Data port B (Bi-directional data port)
Pin 18	$\overline{PC}$	Handshaking output for port B
Pin 19	TOD	Clock input for TOD clock
Pin 2Ø	Vcc	Supply voltage (5 V)
Pin 21	$\overline{IRQ}$	Interrupt request output
Pin 22	R/$\overline{W}$	Read/write. Input from processor (low for processor write)
Pin 23	$\overline{CS}$	Chip select. Low indicates a processor read or write to the CIA
Pin 24	$\overline{FLAG}$	Negative edge sensing input
Pin 25	$\phi 2$	Phase 2 clock input
Pins 26–33	D7–DØ	Data bus (Bi-directional depending on R/W)
Pin 34	$\overline{RES}$	Reset (Active is low)
Pins 35–38	RS3–RSØ	Register select. Connected to the lower order address lines to one of the 16 registers
Pin 39	SP	Serial input. Not used for Commodore serial bus
Pin 4Ø	CNT	Pulse counter, serial clock. Not used for serial bus

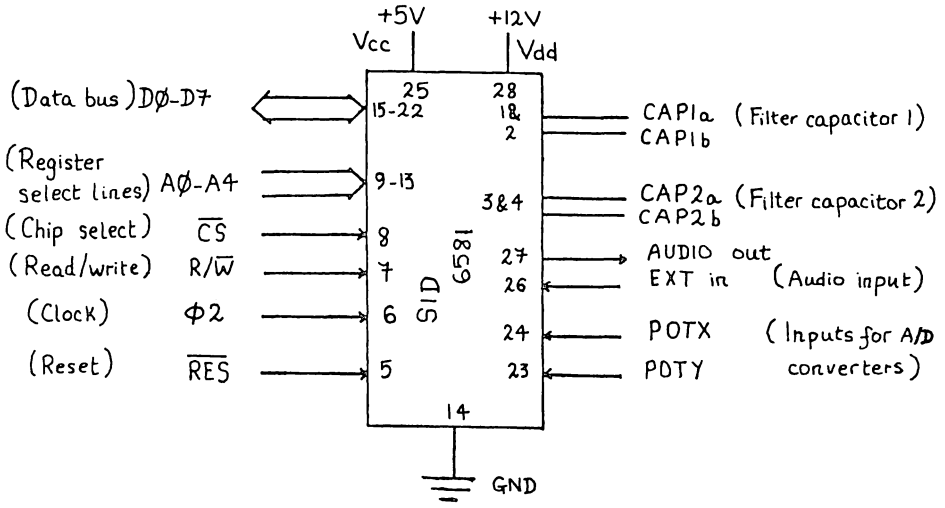


Fig. 1.6. 6581 sound interface device (SID).

1.3.3 6581 sound interface device (SID)

SID is a music/sound effects generator for computer games. Its output goes to the modulator and audio/video socket, and has a sound input from a pin on this socket (see Fig. 1.6).

SID Signals and Lines

Pins 1 & 2	CAP1a–b	Filter capacitor
Pins 3 & 4	CAP2a–b	Second filter capacitor
Pin 7	R/$\overline{W}$	Read/write
Pin 8	$\overline{CS}$	Chip select. Decoded from address bus by PLA to $D4ØØ
Pins 9–13	AØ–A4	Register select
Pin 14	GND	Ground (Ø V)
Pins 15–22	DØ–D7	Data bus
Pin 23	POT Y	Analog input for A/D converter
Pin 24	POT X	Analog input for second A/D
Pin 25	Vcc	Supply voltage 5 V
Pin 26	EXT in	Audio input
Pin 27	AUDIO	Audio output
Pin 28	Vdd	Supply voltage 12 V

1.3.4 6567-9 video interface chip (VIC)

This video display generator chip (Fig. 1.7) also produces most of the internal timing and control signals for the CBM 64, including the processor clock.

VIC generates its own address bus like the 651Ø. This is used to fetch display data from RAM and character ROM, but since the computer cannot have two completely separate address and data bus systems, VIC and the processor have to share them. 65xx series processors use the system buses only during phase 2 of the clock cycle. The VIC chip takes advantage of this and uses phase 1 of the clock (ϕ2 low ϕØ high).

This chip has been given a higher internal bus priority than the 651Ø processor. VIC can disable the 651Ø and free the address bus for its own use during phase 2 by sending the lines AEC & BA low. The AEC line disables the 651Ø address drivers so that its own can drive the address bus. The VIC chip can send the AEC line low during phase 1 and use the address bus without interfering with the processor's operation. The line BA is connected to the 651Ø's RDY (ready) pin. This can be set low during phase 1 and then held low causing the 651Ø to pause at the end of its next read cycle. (This is ignored during 651Ø write operations. VIC accessing memory with R/$\overline{W}$ low would not be desirable anyway!). BA will go low three cycles before AEC is used in phase 2. This ensures that all write operations have finished and avoids conflict with DMA (direct memory access) from any cartridge port device (Z8Ø card).

VIC also refreshes the dynamic RAM chips using its RAS line and its lower order address bus during phase 1.

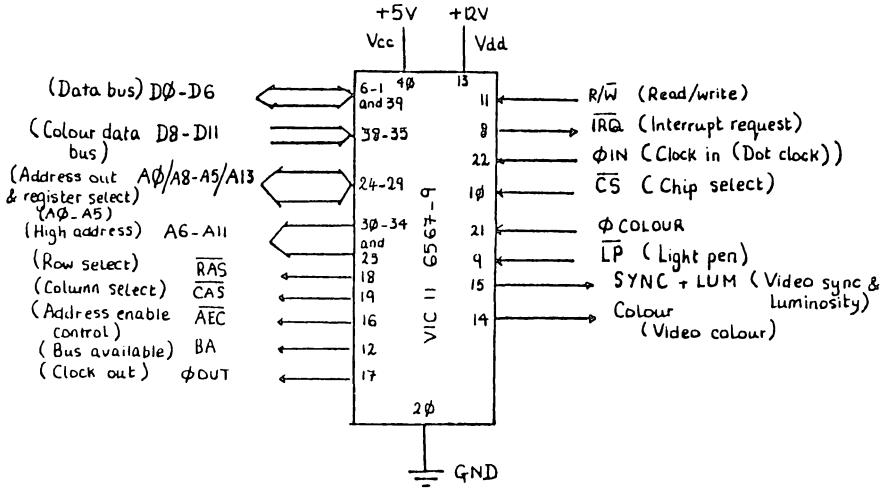


Fig. 1.7. Video interface chip (VIC II).

VIC Signals and Lines

Pins 1–6 & 35–39	D6–DØ & D11–D7	Data bus DØ–D7 are bi-directional and are used for register access and VIC memory fetches D8–D11 are used for reading colour RAM
Pin 8	$\overline{\text{IRQ}}$	Interrupt request output
Pin 9	$\overline{\text{LP}}$	Light pen input
Pin 10	$\overline{\text{CS}}$	Chip select
Pin 11	R/$\overline{\text{W}}$	Read/write
Pin 12	BA	Bus available
Pin 13	Vdd	Supply voltage +12 V
Pin 14	Colour	Colour output
Pin 15	S/LUM	Sync/luminance
Pin 16	AEC	Address bus enable
Pin 17	ϕØ	Phase one clock out
Pin 18	$\overline{\text{RAS}}$	Row address select. Dynamic RAM control signal, used for low order of multiplexed address and for refreshing
Pin 19	$\overline{\text{CAS}}$	Column address select. Dynamic RAM control signal for high order address
Pin 20	Vss	Ground (Ø V)
Pin 21	ϕcolour	Colour clock in 14–18 MHz
Pin 22	ϕin	Clock in 8 MHz
Pins 23 & 30–34	A11 & A6–A10	High order address output
Pins 24-29	AØ/A8–A5/A13	Address lines AØ–A13 multiplexed together. Gives address for VIC for memory fetches in output mode or register select in input mode
Pin 40	Vcc	Supply voltage 5 V

1.3.5 Programmable logic array (PLA)

This is an array of logic gates programmed together at the time of manufacture to give most of the required logic circuits of the 64 (see Fig. 1.8). The chip has 16 inputs and 8 outputs. A very complicated logic table relates the outputs to the inputs. The pin names of this chip are IØ–I15 and FØ–F7!

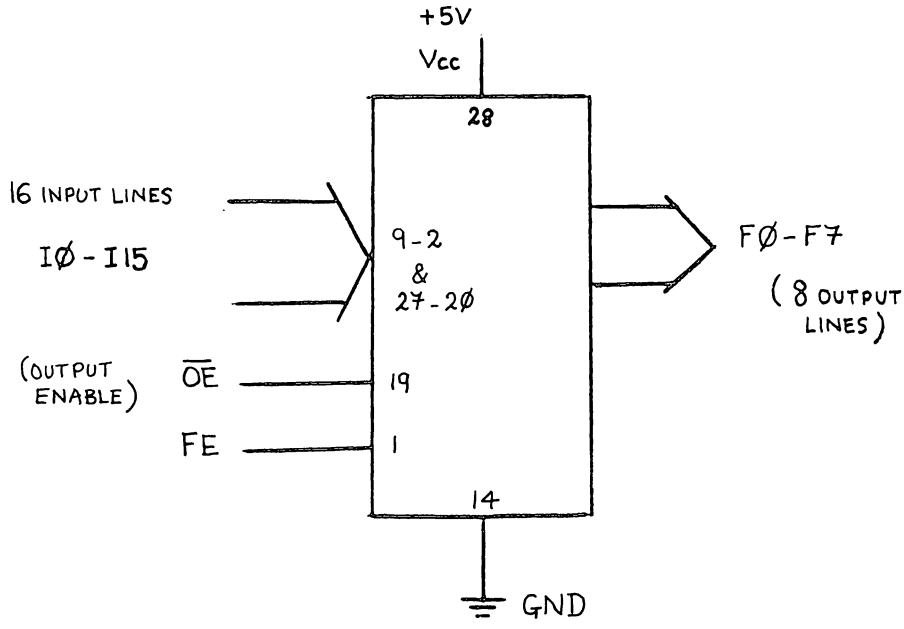


Fig. 1.8. Programmable logic array (PLA).

The other main chips in the 64 are the RAM and ROM chips. The RAM comprises eight 4164 dynamic RAM chips. One chip gives 1 by 64K bits of memory, so the eight chips give 8 by 64K bits or 64K bytes. The 4164 has 8 address lines. The 16 bit address is multiplexed in (low byte first) and timed with the RAS and CAS lines. The main improvement with this chip over older dynamic RAMs is that it requires only a single 5 V supply instead of −5,+5 and +12 V for a 4116. The colour memory RAM is a 2114 chip; this is a 4 by 1Ø24 bit static RAM.

The Basic and kernal ROMs are 8 bit by 8K ROMs. The character ROM is an 8 by 4K. These chips are Commodore's own manufacture and type. The 651Ø, 6526 CIA, VIC and SID chips are all manufactured by Commodore's chip manufacturing subsidiary, MOS Technology Inc. It is unfortunate that none of these devices appears to be second sourced and consequently replacements are either very difficult or impossible to obtain.

1.4 System logic and timing

Like all computers the Commodore 64 is a group of chips linked together by address and data buses. The main chips which are connected to the data and address buses are instructed to send to, take from or ignore the data bus by the

control system lines. There are, in addition, lines controlling the use of the address bus. These control lines are defined as follows:

1.4.1 Clock lines

ϕ colour clock

This is the colour clock used by the VIC chip for generating colour signals. It is divided by part of the clock circuit and used as a reference for producing the VIC chip's dot clock.

Dot clock

This signal produced by the clock circuit is the clock input to the VIC chip. VIC uses this as the timing for producing pixels on the sceen. Also VIC divides this signal by 8 and supplies it as the processor phase zero clock.

Phase 2 processor clock ϕ2

This clock line controls all 651Ø read and write operations. It is produced by the 651Ø from the VIC chip's ϕØ line. The 65xx series processors require only the system buses while this line is high (5 V).

1.4.2 Main system control signals

Read/$\overline{\text{Write}}$ R/$\overline{\text{W}}$

If this line is low when a byte of memory or I/O device register is selected by the address bus, then the contents of the data bus will be transferred to the selected byte or register. If the line is high then the contents of the selected address are transferred onto the data bus.

$\overline{\text{Reset}}$ $\overline{\text{RES}}$

This line is connected to all the main chips including the processor. On machine power up this line is held low for a few clock cycles to ensure the supply voltages have stabilised. This holds all chips in their reset state until they are ready.

Ready RDY

RDY is a processor input which, if low, causes the 651Ø to pause at the end of the read cycle. It is used with the AEC line to disable the processor during phase 2 clock cycles for direct memory access.

Interrupt request $\overline{\text{IRQ}}$

When this line is low it signals that one or more of the CIAs or VIC is requesting an interrupt service.

Non maskable interrupt $\overline{\text{NMI}}$

When this line goes from high to low the processor will be interrupted at the end of the current instruction cycle. Only a change from high to low will cause an interrupt, so if this line is held low after an NMI it will disable future NMIs.

Bus available BA

When this line is low it flags that the VIC chip needs the system buses during phase 2. It disables the processor via the RDY line.

RAM control signals $\overline{\text{CAS}}$ $\overline{\text{RAS}}$ & $\overline{\text{CASRAM}}$

The 4164 dynamic RAM chips have their 16 bit addresses fed to in two lots of 8

bits. This is because the 16 pin chip has only an 8 bit address bus. RAS, the row address and CAS, the column address are used to strobe in the low and high bytes. In the 64, CAS and RAM chip select are combined into CASRAM, so when this line is low it flags the high byte of address on the chip's address pins and the chip is selected for read or write.

Chapter Two
The Keyboard, Joysticks and Screen

2.1 Keyboard

2.1.1 Keyboard hardware and software operation

The CBM 64 keyboard has a total of 66 keys, the layout of which is shown in Fig. 2.1. These 66 keys can be divided as follows:

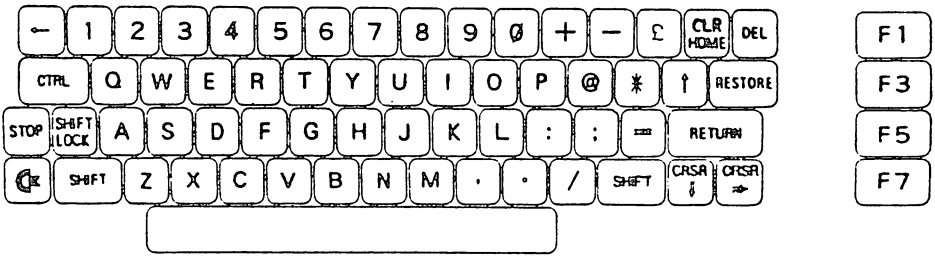


Fig. 2.1. The keyboard layout.

1. RESTORE key; this is connected directly to the NMI line.
2. The left shift key and the shift lock are connected together.
3. All other 63 keys.

The main section of the keyboard thus has a total of 64 keys. These are organised electrically as an 8 by 8 matrix. The keyboard scanning is performed by the operating system software. The matrix is organised such that the columns are set as outputs by the scanning routine and the rows return a value if a key is pressed. These 8 row inputs and 8 column outputs from the keyboard matrix are connected to the computer via the CIA#1 I/O chip, where the output is via address $DCØØ and the input is via address $DCØ1. The scanning routine loops through 8 times, and each time sends a different line on the output to a low state. It then reads the input port connected to the matrix row lines, which will return values for 8 keys (each key takes up one bit, Ø=down, 1=up). Therefore, looping 8 times through the scanning routine will look at each of the columns and return all keys which are pressed.

The keyboard is laid out as follows:

Row # (input)	Column # (output)							
	Ø	1	2	3	4	5	6	7
Ø	DEL	3	5	7	9	+	£	1
1	RET	W	R	Y	I	P	*	←
2	→	A	D	G	J	L	;	CTRL
3	F7	4	6	8	Ø	-	CLR	2
4	F1	Z	C	B	M	.	R.SH	SPACE
5	F3	S	F	H	K	:	=	
6	F5	E	T	U	O	@	↑	Q
7	↓	L.SH	X	V	N	,	/	STOP

The scanning of the keyboard matrix, and the testing for depression of the RESTORE key, are all under software control. The entire processor time cannot be devoted to keyboard scanning, therefore scanning is initiated by a regular 1/6Ø second interrupt. Keyboard scanning is one of the functions of the IRQ interrupt servicing routine. The 1/6Ø second regular interrupt is generated by Timer A of CIA#1. The interrupt service routine starts at location $EA31 and the keyboard scanning portion at $EA87.

The keyboard scanning routine goes through a sequence of operations, the result of which is to place each input character into a special section of memory; the keyboard buffer. The sequence is as follows:

1. Check if key pressed; if not then exit from routine.
2. Initialise I/O ports of CIA#1 for keyboard scan and set pointers into keyboard character table 1. Set character counter to Ø.
3. Set one line of port A low and test for character input on port B by performing eight right shifts of the contents of port B register; if carry is clear then key present. Each shift increments key count; store key count in .Y.
4. Go back to step 3 and repeat for next column; if key found then continue.
5. Use key count value as index pointer into keyboard character table to get ASCII code corresponding to depressed key.
6. See if it is SHIFT or STOP key.
7. Evaluate shift function
   If SHIFT key then use table 2
   If CBM key then use table 3
   If CONTROL key then use table 4
8. Use key count value as index pointer into keyboard character table designated in step 7.
9. Check for repeat key operation.
1Ø. Do repeat if required.
11. Put ASCII character obtained from keyboard character tables into the keyboard buffer; increment the pointer into the keyboard buffer.

The contents of the 1Ø character keyboard buffer are accessed on a first in first out basis by the INPUT and GET character routines. These routines take the first character in the keyboard buffer, decrement the buffer pointer and close up

the buffer by moving the contents down one byte thereby leaving space for new input characters.

The characters put into the keyboard buffer are removed by either the INPUT or GET kernal routines. Both these routines call a subroutine at $E5D4 which removes the first character and puts it in register .Y then moves the whole buffer down by one byte. This routine is only called if at least one character is in the buffer.

Warning: Do not call the routine at $E5D4 when there are no characters in the keyboard buffer as this will crash the computer.

The GET character routine which is accessed by the kernal jumpblock at location $FFE4 (vectored at $Ø32A) will return the Commodore ASCII code of the next character in the keyboard buffer in register .A. If no character was present, the value of zero is returned.

The INPUT routine, when called, will set the cursor flashing and will input characters from the keyboard buffer until a carriage return is found. Each character received is printed to the screen using the routine at $E716 and when a carriage return is found, the routine inputs the first character on the line from the screen and returns it in register .A. Subsequent calls to this routine will return one character at a time until they have all been returned. At this point, if the ASCII value of SHIFT/STOP is found, the LOAD/RUN combination is stored to the buffer replacing all characters following it. The routine is accessed via the kernal jumpblock at location $FFCF (vectored at $Ø324). A Basic program to emulate the keyboard scanning routine is given in Program 1.

```
1000 REM KEYBOARD SCAN SIMULATION PROGRAM
1010 REM ********************************
1020 REM
1030 REM  THIS BASIC PROGRAM SIMULATES
1040 REM THE IRQ SCANNING ROUTINE WITH
1050 REM A FULL SCREEN DISPLAY OF WHAT
1060 REM IS HAPPENING. THE ROUTINE FIRST
1070 REM WAITS FOR A KEY TO BE PRESSED
1080 REM AND THEN SCANS THROUGH TO PICK
1090 REM UP THE KEY(S). ANY KEY PRESSED
1100 REM WILL BE DISPLAYED AS A REVERSE
1110 REM KEY IN THE BOX LABELLED 'KEY'.
1120 REM
1130 REM  YOU MUST HOLD DOWN A KEY UNTIL
1140 REM IT IS RECOGNISED.
1150 REM
1160 REM  A KEYBOARD BUFFER IS KEPT AND
1170 REM THE ROUTINE WILL EXIT WHEN
1180 REM EITHER THE RETURN KEY IS FOUND
1190 REM OR WHEN THERE ARE TEN CHARACTERS
1200 REM IN THE BUFFER.
1210 REM
1220 P$="[illegible]"
1230 DIM K$(71):FORI=0TO71:READK$(I):NEXT
1240 DIM K(3,64):FORJ=0TO2:FORI=0TO64:K(J,I)=PEEK(60289+J*65+I):NEXTI,J
1250 FORI=0TO64:K(3,I)=PEEK(60536+I):NEXTI
1260 PRINT"[illegible]          KEYBOARD SCAN SIMULATION"
1270 PRINT"[illegible]  OUTPUT: $DC00        INPUT : $DC01"
1280 PRINT"[illegible]     BIT: 76543210       BIT : 76543210"
1290 PRINT"               ┌──────────┐          ┌──────────┐"
1300 PRINT"               │          │          │          │"
1310 PRINT"               └──────────┘          ├──────────┤"
1320 PRINT"                              KEY :  │          │"
1330 FORI=1TO4:PRINTP$;:FORJ=1TOI:PRINT"[illegible]";:NEXT
1340 PRINT"│          │":NEXT
```

```
1350 PRINTP$"■■■■■└──────┘"
1360 PRINT"■■■■■■■■■■CURRENT SHIFT : 0"
1370 PRINT"CURRENT KEY   : 64"
1380 PRINT"■           KEY BUFFER"
1390 GOSUB 1990
1400 POKE 56333,1:FORI=0TO7:P2(I)=2↑I:NEXT
1410 KT=0:CS=0:CK=64:VL=8:A=255:GOSUB1700
1420 V=0:POKE56320,V:GOSUB1660:A=PEEK(56321)
1430 IF A=255 THEN 1420
1440 GOSUB 1700
1450 V=254:FORVL=0TO7
1460 POKE 56320,V:GOSUB 1660  DISPLAY OUTNEW
1470 A=PEEK(56321):GOSUB 1700 DISPLAY INPUT
1480 GOSUB 1860 CHECK FOR ANY NEWS DOWN
1490 V=((V*2)AND255)+1:NEXT
1500 IF CS<>3 THEN 1550
1510 IF (PEEK(53248+24) AND 2)=2 THEN 1540
1520 POKE 53248+24,PEEK(53248+24)OR2
1530 GOTO1560
1540 POKE 53248+24,PEEK(53248+24)AND253
1550 KT=CS:IFKT>3THENKT=3
1560 CC=K(KT,CK)
1570 IF CC=255 THEN 1650
1580 KB(BP)=CC:BP=BP+1
1590 IF(BP<>10)AND(CC<>13)THEN 1640
1600 FOR I=0TOBP-1:POKE 631+I,KB(I):NEXT
1610 POKE198,BP:POKE 56333,129
1620 PRINT"■■■■■■■■■■■■■■■■■■■■■■■■■"
1630 END
1640 GOSUB 1990
1650 GOTO1360
1660 REM
1670 REM DISPLAY OUTPUT VALUE BITWISE
1680 REM
1690 A=V:PRINT"■■■■■■■■■■■■■■■■■";:GOTO 1800
1700 REM
1710 REM DISPLAY INPUT VALUE BITWISE
1720 REM
1730 PRINT"■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■";:GOSUB 1800
1740 FORI=7TO0STEP-1:PRINTP$;
1750 FORJ=7TOISTEP-1:PRINT"■";:NEXTJ
1760 C=VL*8+I:FORJ=1TO5
1770 C$=MID$(K$(C)+"      ",J,1)
1780 PRINT"■";:IF(A AND P2(I))=0 THEN PRINT"■";
1790 PRINTC$"■■";:NEXT:NEXT:PRINT"■";:RETURN
1800 REM
1810 REM DISPLAY VALUE IN A BITWISE
1820 REM
1830 FOR I=7 TO 0 STEP -1
1840 C$="0":IF A AND P2(I) THEN C$="1"
1850 PRINT"■"C$"■";:NEXT:RETURN
1860 REM
1870 REM CHECK FOR A KEY FROM THIS COLUMN
1880 REM
1890 FOR X=0 TO 7
1900 IF(A AND P2(X))=0 THEN 1950
1910 NEXT
1920 PRINT"■■■■■■■■■■■■■■■■■■■■■■■■■";CS
1930 PRINT"■■■■■■■■■■■■■■■■■■■■■■■■■";CK;"■ "
1940 RETURN
1950 IN=K(KT,X+VL*8)
1960 IF IN>4 THEN CK=X+VL*8:GOTO1910
1970 IF IN=3 THEN CK=X+VL*8:GOTO1910
1980 CS=CSORIN:GOTO1910
1990 REM
2000 REM DISPLAY KEYBOARD BUFFER
2010 REM
2020 PRINT"■■■■■■■■■■■■■■■■■"
2030 FOR I=0 TO 9
2040 PRINT"■■■■■■■■■■■■■■■■";KB(I):NEXT
```

```
2050 PRINT"■■■■■■■■■■■■■■■■■■";
2060 IF BP=0 THEN 2080
2070 PRINTLEFT$("■■■■■■■■■■■■",BP-1);"■■■■■■■■■■■■■■■■■■ "
2080 PRINT"■■■■■■■■■■■■■■■■■■←"
2090 RETURN
2100 REM
2110 REM MNEMONICS FOR KEY PRESS
2120 REM
2130 DATA DEL,RET,C.RT,F7,F1,F3,F5,C.DN
2140 DATA 3,W,A,4,Z,S,E,L.SH
2150 DATA 5,R,D,6,C,F,T,X
2160 DATA 7,Y,G,8,B,H,U,V
2170 DATA 9,I,J,0,M,K,O,N
2180 DATA +,P,L,-,.,":","@",","
2190 DATA \,*,";",CLR,R.SH,=,↑,/
2200 DATA 1,←,CTRL,2,SPC,CBM,Q,STOP
2210 DATA  ,  ,  ,  ,  ,  ,  ,
```

Program 1.

2.1.2 Modification of keyboard operation

Program 2 shows how a wedge can be made into the INPUT routine to give the function keys text definition. This follows the same principle as the expansion of the SHIFT/STOP character, with the exception that subsequent characters are not lost. Each function key definition can be up to 255 characters long and the definitions are stored behind the Basic ROM.

```
033C          ! FUNCTION KEYS FOR THE 64.
033C          !**************************
033C          !
033C          ! EACH KEY CAN HAVE A MAXIMUM
033C          !DEFINITION OF 255 CHARACTERS LONG
033C          !(MAXIMUM BASIC STRING LENGTH)
033C          !
033C          ! DEFINE A FUNCTION KEY USING:
033C          !SYS 49163,N,DEFINITION$
033C          !
033C          ! INITIALISE FUNCTION KEYS WITH:
033C          !SYS 49152.
033C          !
C000          *=$C000
C000 A963               LDA #<FUNCTION
C002 8D2403             STA $0324
C005 A9C0               LDA #>FUNCTION
C007 8D2503             STA $0325
C00A 60                 RTS
C00B          !
C00B 20F1B7 DEFINE      JSR $B7F1                 !GET KEY#
C00E E009               CPX #$09                  !LESS THAN 8?
C010 9005               BCC DEF1                  !YES
C012 A20E   ERROR       LDX #$0E                  !ILLEGAL QUANTITY
C014 6C0003             JMP ($0300)               !SEND ERROR
C017          !
C017 E000   DEF1        CPX #$00                  !IS IT ZERO?
C019 F0F7               BEQ ERROR                 !YES
C01B CA                 DEX
C01C 8A                 TXA
C01D 48                 PHA
C01E 20FDAE             JSR $AEFD
C021 209EAD             JSR $AD9E                 !GET STRING
C024 20A3B6             JSR $B6A3                 !DISCARD STRING
C027 8D51C0             STA STLEN
C02A 68                 PLA
C02B 0A                 ASL A
C02C AA                 TAX
C02D BD53C0             LDA POINT,X
C030 8524               STA $24
C032 BD54C0             LDA POINT+1,X
```

```
C035 8525              STA $25
C037 A000              LDY #$00
C039 B122    DEF2      LDA ($22),Y
C03B 9124              STA ($24),Y
C03D C8                INY
C03E CC51C0            CPY STLEN              !END OF STRING?
C041 F005              BEQ DEF4               !YES
C043 C000              CPY #$00               !END OF ROOM?
C045 D0F2              BNE DEF2               !NOT YET
C047 60      DEF3      RTS
C048 C000    DEF4      CPY #$00               !STRING LENGTH=256?
C04A F0FB              BEQ DEF3               !YES
C04C A900              LDA #$00               !ZERO TERMINATOR
C04E 9124              STA ($24),Y            !STORE IT
C050 60                RTS
C051           !
C051 00      STLEN     BYT 0
C052 00      FUNCFLG   BYT 0
C053           !
C053 00B800  POINT     WOR $B800,$BC00,$B900,$BD00
C05B 00BA00            WOR $BA00,$BE00,$BB00,$BF00
C063           !
C063 A599    FUNCTION  LDA $99                !FROM KEYBOARD?
C065 F003              BEQ FUNC02             !YES
C067 4C57F1            JMP $F157              !DO NORMAL
C06A           !
C06A A5D3    FUNC02    LDA $D3                !SAVE CURRENT CURSOR
C06C 85CA              STA $CA                ! COLUMN
C06E A5D6              LDA $D6
C070 85C9              STA $C9                ! AND ROW
C072 98                TYA                    !SAVE .X AND .Y
C073 48                PHA
C074 8A                TXA
C075 48                PHA
C076 A5D0              LDA $D0                !SCREEN OR KEYBOARD?
C078 F006              BEQ FUNC04             !KEYBOARD
C07A 4C3AE6            JMP $E63A              !DO FOR SCREEN
C07D           !
C07D 2016E7  FUNC03    JSR $E716              !DISPLAY CHAR TO SCREEN
C080 AD52C0  FUNC04    LDA FUNCFLG            !DOING FUNCTION KEY?
C083 D066              BNE FUNC09
C085 A5C6              LDA $C6                !ANY CHARS IN BUFFER?
C087 85CC              STA $CC                !IF NOT, BLINK CURSOR
C089 8D9202            STA $0292              !AUTO SCROLL DOWN
C08C F0F2              BEQ FUNC04             !REPEAT UNTIL CHAR
C08E 78                SEI                    !DISABLE KEYBOARD
C08F A5CF              LDA $CF                !CURSOR BLINK?
C091 F00C              BEQ FUNC05             !NO
C093 A5CE              LDA $CE                !RESTORE ORIG CHAR
C095 AE8702            LDX $0287              ! AND COLOUR
C098 A000              LDY #$00
C09A 84CF              STY $CF                !SWITCH OFF BLINK
C09C 2013EA            JSR $EA13              !RESTORE CHAR
C09F 20B4E5  FUNC05    JSR $E5B4              !REMOVE CHAR
C0A2 C983              CMP #$83               !RUN/STOP?
C0A4 D010              BNE FUNC07             !NO
C0A6 A209              LDX #$09               !COPY TEXT INTO BUFFER
C0A8 78                SEI
C0A9 86C6              STX $C6
C0AB BDE6EC  FUNC06    LDA $ECE6,X
C0AE 9D7602            STA $0276,X
C0B1 CA                DEX
C0B2 D0F7              BNE FUNC06             !REPEAT UNTIL DONE
C0B4 F0CA              BEQ FUNC04             !DONE
C0B6 C90D    FUNC07    CMP #$0D               !CARRIAGE RETURN?
C0B8 D003              BNE FUNC08             !NO
C0BA 4C02E6  FUNCEXT   JMP $E602              !END INPUT
C0BD           !
C0BD A6D4    FUNC08    LDX $D4                !QUOTES?
C0BF D0BC              BNE FUNC03             !YES
```

```
C0C1 C985           CMP #133          !LESS THAN F1?
C0C3 90B8           BCC FUNC03
C0C5 C98D           CMP #141          !GREATER THAN F8?
C0C7 B0B4           BCS FUNC03
C0C9 38             SEC
C0CA E985           SBC #133          !CHANGE VALUE TO 0-7
C0CC 18             CLC
C0CD 69B8           ADC #$B8          !SET HIGH BYTE OF
C0CF 85FE           STA $FE           ! DEFINITION POINTER
C0D1 A900           LDA #$00
C0D3 85FD           STA $FD
C0D5 A000           LDY #$00
C0D7 2003C1         JSR GETVAL        !GET FIRST BYTE
C0DA C8             INY
C0DB 8C52C0         STY FUNCFLG       !FLAG FUNCTION
C0DE C90D           CMP #$0D          !CARRIAGE RETURN?
C0E0 F0D8           BEQ FUNCEXT       !YES
C0E2 C900           CMP #$00
C0E4 D097           BNE FUNC03
C0E6 8D52C0         STA FUNCFLG
C0E9 F095           BEQ FUNC04
C0EB          !
C0EB AC52C0 FUNC09  LDY FUNCFLG
C0EE 2003C1         JSR GETVAL        !GET CHARACTER
C0F1 D005           BNE FUNC10
C0F3 8D52C0         STA FUNCFLG
C0F6 F088           BEQ FUNC04
C0F8 C8     FUNC10  INY
C0F9 8C52C0         STY FUNCFLG
C0FC C90D           CMP #$0D          !CARRIAGE RETURN?
C0FE F0BA           BEQ FUNCEXT       !YES, EXIT
C100 4C7DC0         JMP FUNC03
C103          !
C103 A501   GETVAL  LDA $01           !BASIC ROM OUT
C105 29FE           AND #$FE
C107 8501           STA $01
C109 B1FD           LDA ($FD),Y       !GET CHARACTER
C10B 48             PHA
C10C A501           LDA $01           !BASIC ROM IN
C10E 0901           ORA #$01
C110 8501           STA $01
C112 68             PLA
C113 60             RTS
```

Program 2.

To enable the function keys enter:

```
SYS 49152
```

To define a function key use:

```
SYS 49163,k#,def$
```

where k# is the number on the function key (without the 'f') and def$ is any string expression.

The text on the function keys will appear only if the function key character is removed by the input routine. This means that when using the GET command, the ASCII character for the function key is returned rather than a character from the text. The function key is not expanded if it is within quotes.

The following is an example definition of a function key:

```
A$="":FOR I=Ø TO 79:A$=A$+CHR$(32)+CHR$(2Ø):NEXT
SYS 49163,7,A$
```

This will set up a function on key 7 which deletes from the cursor position to the end of the line, leaving the cursor at the same position (space-delete 8Ø times).

2.2 Joysticks

There are two different types of joystick which can be connected to the CBM 64; a simple paddle switch joystick and a potentiometer or analog joystick. The switch joystick is widely used in games programs to move a cursor about the screen or to move an object. A switch joystick is primarily capable of only very simple directional input. It is, however, a very low cost device. The analog joystick is fairly expensive but is capable of far greater positional control. An interesting version of the analog joystick has started to appear in the form of low cost digitising pads which, when combined with the appropriate software, can produce some excellent computer art on the CBM 64.

2.2.1 The switch joystick

These joysticks are not part of the keyboard hardware but they are connected to the same lines on the CIA#1 chip: port 1 to the read line and port 2 to the write line:

$DCØØ:	Bits 7–5	Not used
	4	JOY2 fire button
	3	JOY2 east
	2	JOY2 west
	1	JOY2 south
	Ø	JOY2 north
$DCØ1:	Bits 7–5	Not used
	4	JOY1 fire button
	3	JOY1 east
	2	JOY1 west
	1	JOY1 south
	Ø	JOY1 north

As with the keyboard, both joysticks must be read assuming that when the bit is zero, the contact is made. Because port 1 is connected to the same line as the keyboard read, any switches on joystick 1 will affect the character read in. Program 3 demonstrates the operation of the switch joystick.

```
10 REM EXAMPLE OF READING THE JOYSTICK
20 REM
30 PRINT"▮▮*";
40 A=PEEK(56320):REM PORT 2, 56321 FOR PORT 1
50 F=0:IF (AAND16)=0 THEN F=1
60 E=0:IF (AAND8)=0 THEN E=1
70 W=0:IF (AAND4)=0 THEN W=1
80 S=0:IF (AAND2)=0 THEN S=1
90 N=0:IF (AAND1)=0 THEN N=1
100 IF F THEN RUN
110 IF E THEN PRINT"▮ *";
120 IF W THEN PRINT"▮▮* ▮";
130 IF S THEN PRINT"▮ ▮▮*";
140 IF N THEN PRINT"▮ ▮▮*";
150 GOTO 40
```

Program 3.

2.2.2 Potentiometer joystick

A potentiometer joystick consists of two potentiometers mounted at right

angles to each other in a mechanism which allows the joystick when moved to change the wiper position of either one or both of the potentiometers. One potentiometer registers the potentiometer movement in the X axis and the other in the Y axis. The rotational movement of either potentiometer is divided by the computer into 255 divisions. With the joystick centered vertically the X and Y potentiometers will both have a value of 128. The position of the joystick can thus be mapped in terms of 2D graph coordinates.

The two potentiometers are connected to the SID chip. SID has two analog inputs, and the two analog lines from each joystick port are multiplexed onto each input using a 4Ø66 quad analog switch. The 4Ø66 switching is controlled by lines PA6 and PA7 on CIA#1. Program 4 allows the input of values from two joysticks using the USR command.

```
C000          *=$C000
C000          !*****************************
C000          !ROUTINE TO READ PADDLE PORTS
C000          ! USES BASIC USR COMMAND
C000          ! TO INITIALISE USR COMMAND
C000          ! POKE 785,0
C000          ! POKE 786,192
C000          !
C000          ! P= USR( PADDLE NUMBER)
C000          ! NOTE PADDLE NUMBER = 0 TO 3
C000          !*****************************
C000 20BFB1 USR          JSR $B1BF          !FLOAT TO FIXED
C003 A565                LDA $65            !LOW BYTE
C005 2903                AND #3
C007 A8                  TAY
C008 A240                LDX #$40
C00A 2902                AND #2             !PORTS 0,1 OR 2,3
C00C F002                BEQ P0OR1
C00E A280                LDX #$80
C010 78      P0OR1       SEI                !KEYBOARD SCAN
C011 8E00DC              STX $DC00          !USES $DC00
C014 A280                LDX #$80
C016 CA      LOOP        DEX                !DELAY FOR A/D
C017 10FD                BPL LOOP           !CONVERTER
C019 98                  TYA
C01A 2901                AND #1
C01C AA                  TAX
C01D BC19D4              LDY $D419,X        !READ PORT
C020 58                  CLI
C021 A900                LDA #0             !ZERO HIGH BYTE
C023 4C91B3              JMP $B391          !FIXED TO FLOAT & EXIT
```

Program 4.

2.3 The screen

2.3.1 The hardware

The screen display on the Commodore 64 is created and controlled by one chip; the VIC II (video interface controller 6567/9). A detailed description of the VIC II hardware can be found in Chapter 1.

2.3.2 The screen display operating system software

None of the wide range of potential features of the VIC II chip are implemented by the software of the 64 with the exception that on power-up the default screen and border colours are set up, and the case bit is toggled. The kernal software to control the text screen is split into two sections; print a character to the screen,

and scroll the screen. The routine to print a character to the screen is located at $E716. This routine prints the character in register .A to the screen taking into account colour control codes, etc. This routine does several tasks before the character is printed; these tasks are shown in the flow chart in Fig. 2.2.

The flow chart in Fig. 2.3 shows how the screen scrolls. This routine can be called from Basic with SYS 59626.

Readers interested in the addition of extra commands which utilise the capabilities of the VIC II chip should consult the companion volume in this series, *Advanced Commodore 64 Graphics and Sound.*

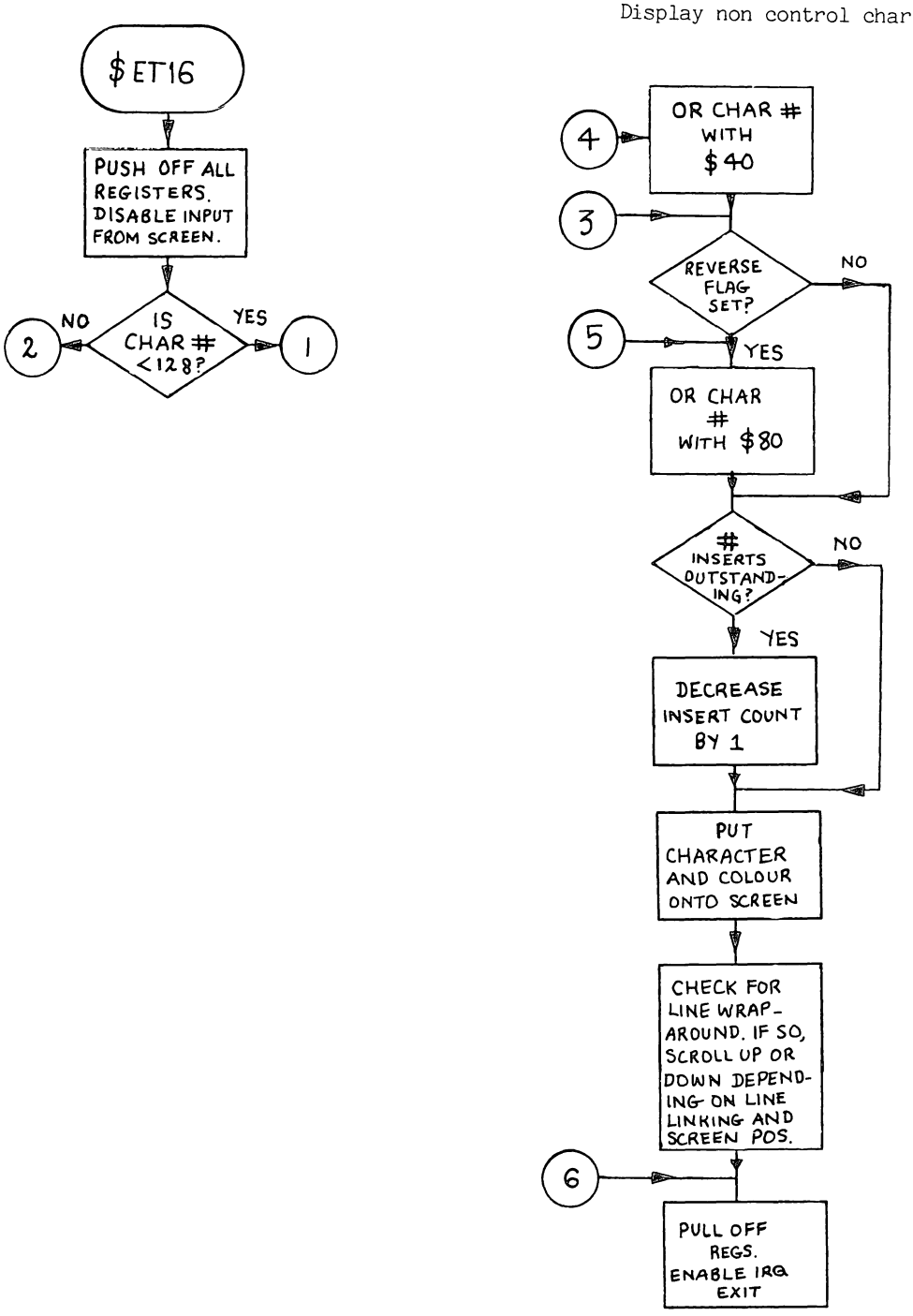


Fig. 2.2. Character output flowchart.

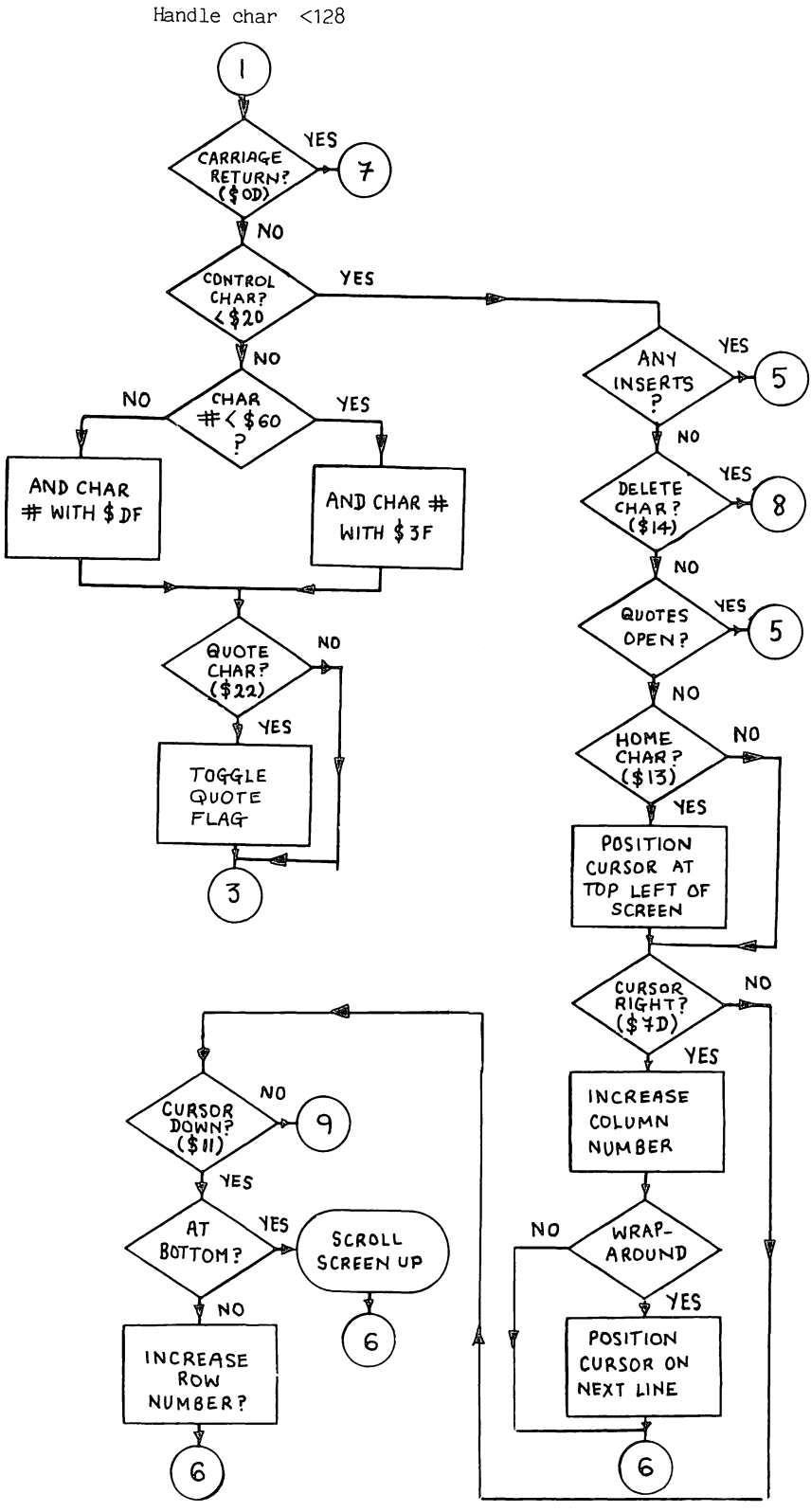

Handle char <128
1
CARRIAGE RETURN? ($0D)
YES
7
NO
CONTROL CHAR? <$20
YES
NO
CHAR # < $60 ?
NO
YES
AND CHAR # WITH $DF
AND CHAR # WITH $3F
QUOTE CHAR? ($22)
NO
YES
TOGGLE QUOTE FLAG
3
ANY INSERTS ?
YES
5
NO
DELETE CHAR? ($14)
YES
8
NO
QUOTES OPEN?
YES
5
NO
HOME CHAR? ($13)
NO
YES
POSITION CURSOR AT TOP LEFT OF SCREEN
CURSOR RIGHT? ($1D)
NO
YES
INCREASE COLUMN NUMBER
WRAP-AROUND
NO
YES
POSITION CURSOR ON NEXT LINE
6
CURSOR DOWN? ($11)
NO
9
YES
AT BOTTOM?
YES
SCROLL SCREEN UP
6
NO
INCREASE ROW NUMBER?
6

Fig. 2.2. (contd.)

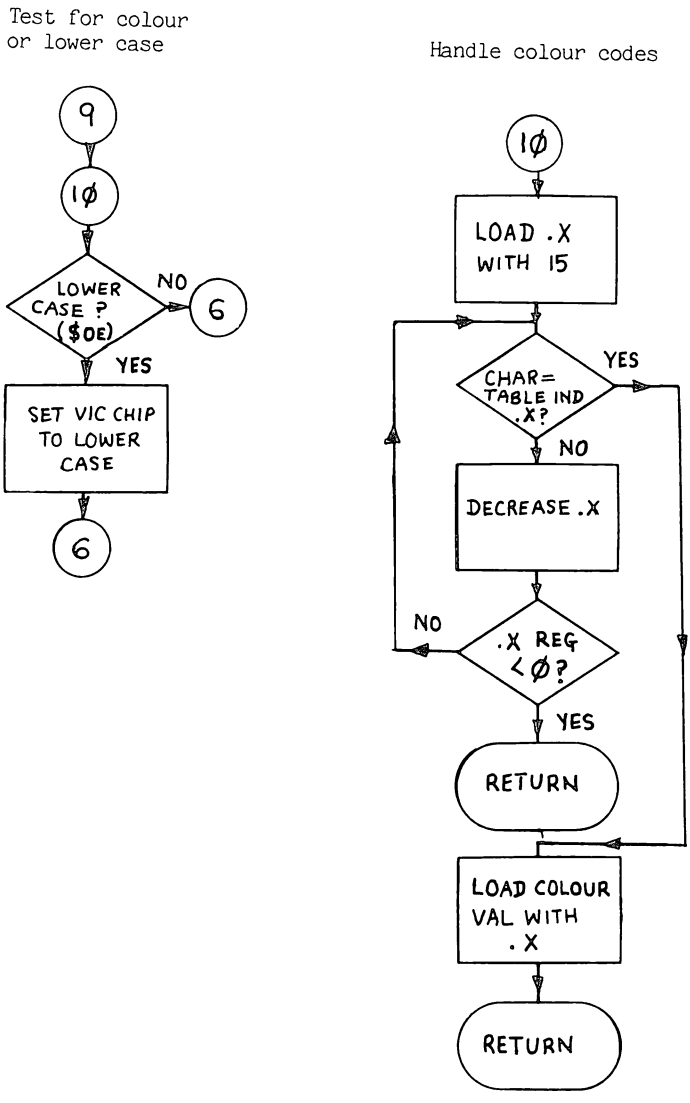

Test for colour
or lower case
9
10
LOWER
CASE ?
($0E)
NO
6
YES
SET VIC CHIP
TO LOWER
CASE
6
Handle colour codes
10
LOAD .X
WITH 15
CHAR=
TABLE IND
.X?
YES
NO
DECREASE .X
NO
.X REG
<0?
YES
RETURN
LOAD COLOUR
VAL WITH
.X
RETURN

Fig. 2.2. (contd.)

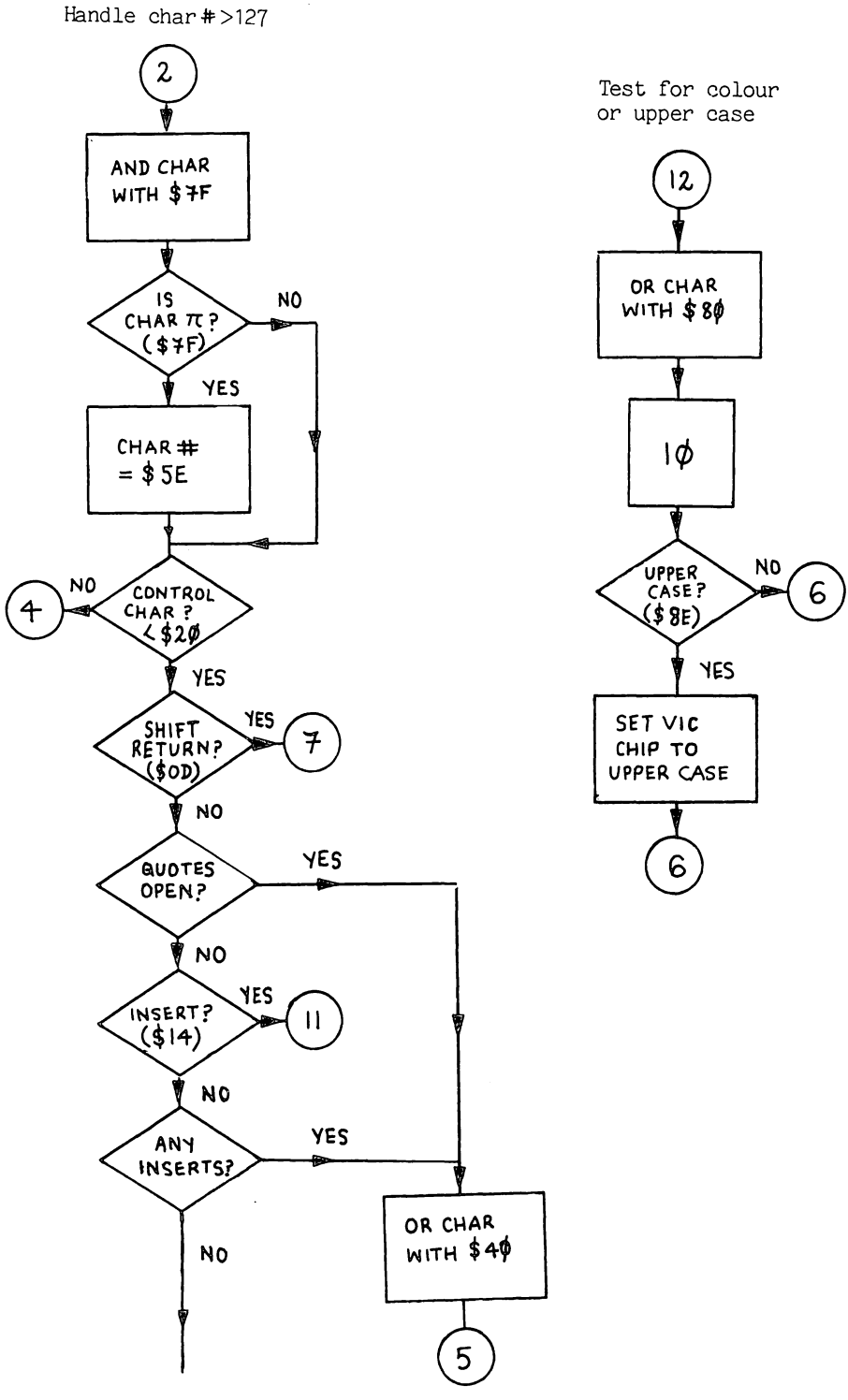

Handle char# >127
2
AND CHAR WITH $7F
IS CHAR π ? ($7F)
NO
YES
CHAR # = $5E
4
NO
CONTROL CHAR ? < $20
YES
SHIFT RETURN? ($0D)
YES
7
NO
QUOTES OPEN?
YES
NO
INSERT? ($14)
YES
11
NO
ANY INSERTS?
YES
NO
OR CHAR WITH $40
5
Test for colour or upper case
12
OR CHAR WITH $80
10
UPPER CASE? ($8E)
NO
6
YES
SET VIC CHIP TO UPPER CASE
6

Fig. 2.2. (contd.)

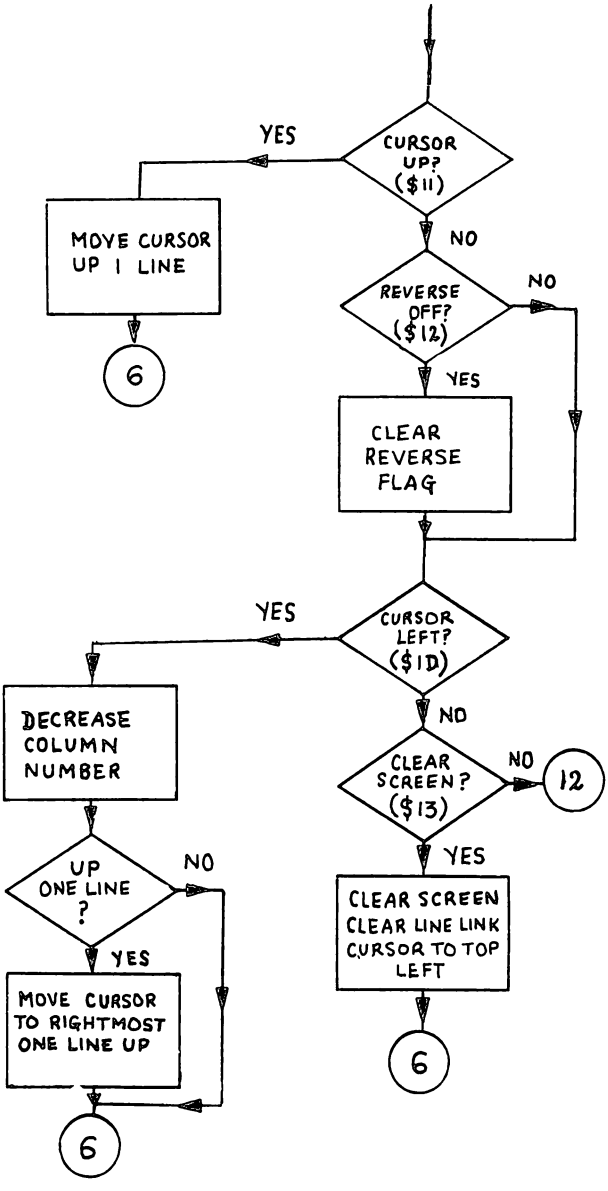

CURSOR UP? ($11)
YES
MOVE CURSOR UP 1 LINE
6
NO
REVERSE OFF? ($12)
NO
YES
CLEAR REVERSE FLAG
CURSOR LEFT? ($1D)
YES
DECREASE COLUMN NUMBER
UP ONE LINE ?
NO
YES
MOVE CURSOR TO RIGHTMOST ONE LINE UP
6
ND
CLEAR SCREEN? ($13)
NO
12
YES
CLEAR SCREEN CLEAR LINE LINK CURSOR TO TOP LEFT
6

Fig. 2.2. (contd.)

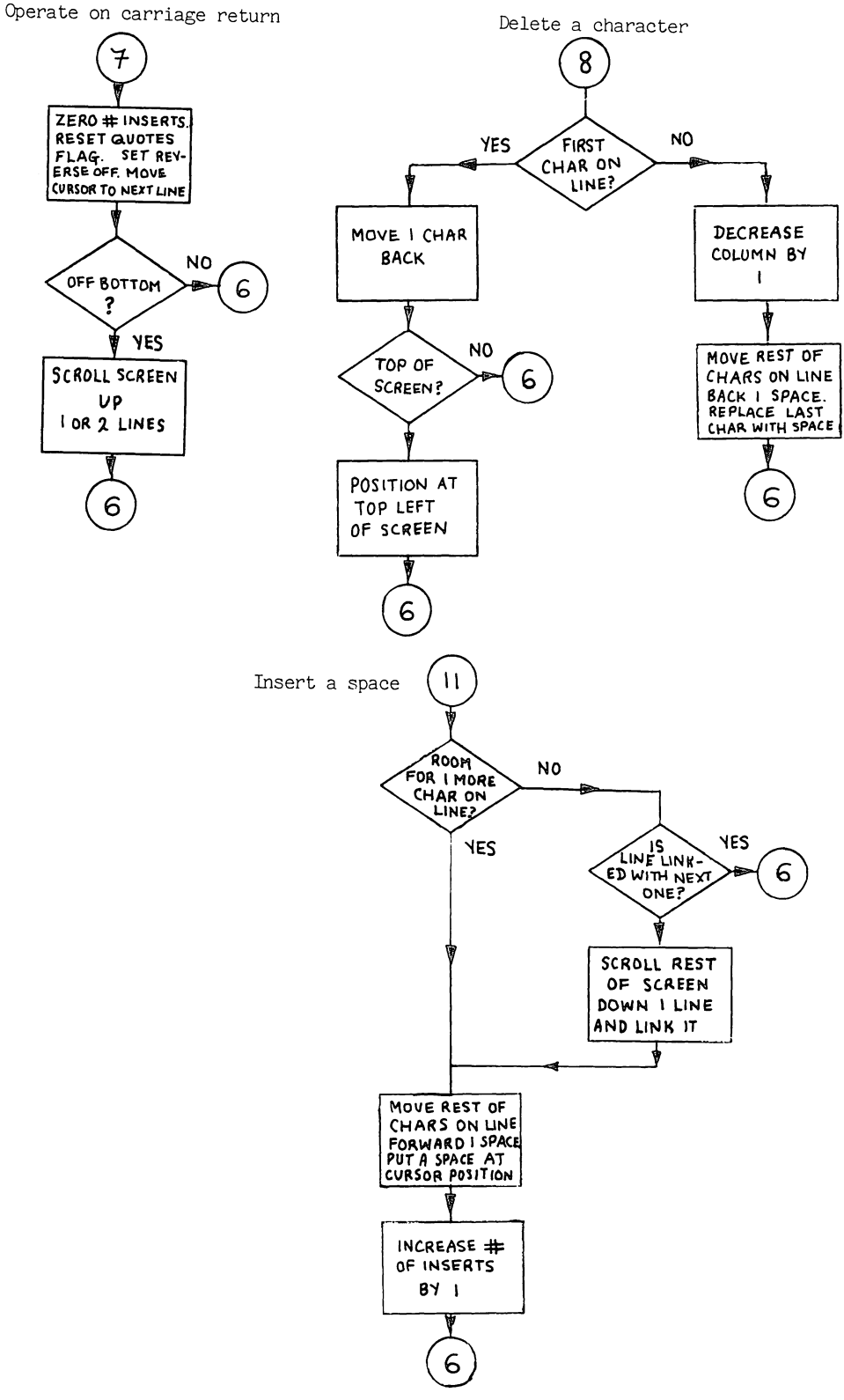

Operate on carriage return
7
ZERO # INSERTS. RESET QUOTES FLAG. SET REVERSE OFF. MOVE CURSOR TO NEXT LINE
OFF BOTTOM ?
NO
6
YES
SCROLL SCREEN UP 1 OR 2 LINES
6
Delete a character
8
FIRST CHAR ON LINE?
YES
NO
MOVE 1 CHAR BACK
TOP OF SCREEN?
NO
6
YES
POSITION AT TOP LEFT OF SCREEN
6
DECREASE COLUMN BY 1
MOVE REST OF CHARS ON LINE BACK 1 SPACE. REPLACE LAST CHAR WITH SPACE
6
Insert a space
11
ROOM FOR 1 MORE CHAR ON LINE?
NO
YES
IS LINE LINKED WITH NEXT ONE?
YES
6
SCROLL REST OF SCREEN DOWN 1 LINE AND LINK IT
MOVE REST OF CHARS ON LINE FORWARD 1 SPACE PUT A SPACE AT CURSOR POSITION
INCREASE # OF INSERTS BY 1
6

Fig. 2.2. (contd.)

Scroll screen up

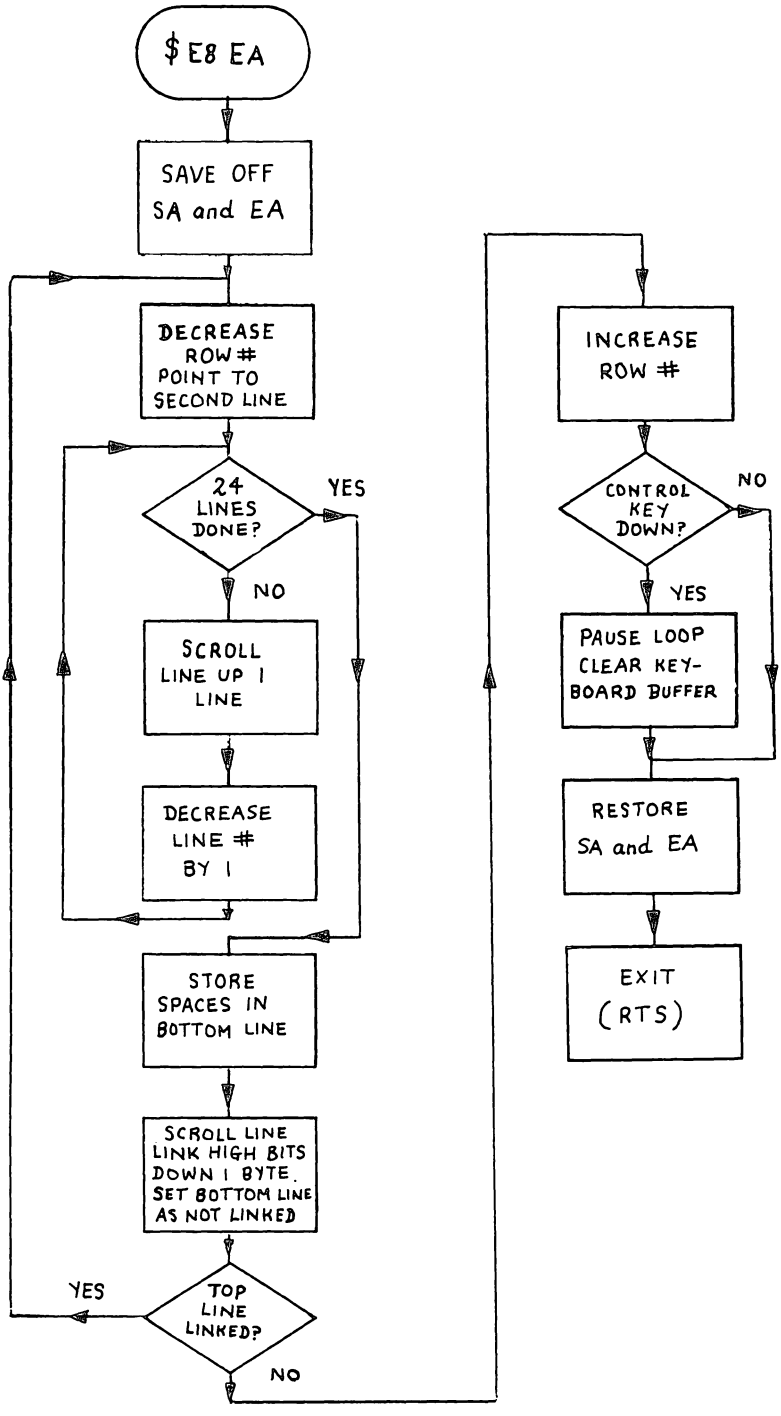


Fig. 2.3. Screen scrolling flowchart.

Chapter Three

Serial Communications

The CBM 64 has two different forms of serial communications capability; these are the Commodore serial interface and the RS232 interface. The Commodore serial interface is designed to allow the CBM 64 to be connected to other Commodore peripherals, in particular the 1541 disk drive. The RS232 serial interface is a simplified version of an industry standard communications interface widely used when connecting computers to printers and modems. Unfortunately the RS232 interface does not conform to the correct industry standards and therefore requires a small additional circuit to make it function properly.

3.1 Commodore serial bus

The Commodore serial bus connects the Commodore 64 to its peripherals such as a disk drive and printers. This serial system has an effective speed of 3ØØØ baud. This is not a true baud rate but is given just for comparison with the 3ØØ baud normal cassette or 36ØØ baud for the high speed tape system in Chapter 4. A speed of 3ØØØ baud is adequate for communicating with printers but makes the 1541 disk drive a little slow. The serial bus uses 5 lines including the ground line.

3.1.1 Commodore serial bus lines

Serial service request
Input: This enables a serial device to generate an IRQ in the 64. (No CBM 64 firmware support is available for this feature.)

Signal ground
This is a common ground line for serial devices. It is for signal reference and shielding the cable.

Serial attention
Input and output: Normally the CBM 64 can use this line only as an output. The 64 pulls this line low when sending command bytes to serial devices. It instructs all serial devices to listen for a command.

Serial clock and serial data lines

These two lines are both inputs and outputs. The current talking device uses these lines to send data and clock signals. Together these lines carry all data and perform the required handshaking.

The serial bus signals are produced in the CBM 64 by port A of CIA chip 2. The following table shows the line connections.

Serial Data	in on PA7
	out on PA5
Serial Clock	in on PA6
	out on PA4
Serial Atn	in to user port pin 9
	out on PA3
SRQ	in to CIA chip 1 $\overline{\text{FLAG}}$ pin

Fig. 3.1 shows the serial port line driver. The serial port lines are driven by a

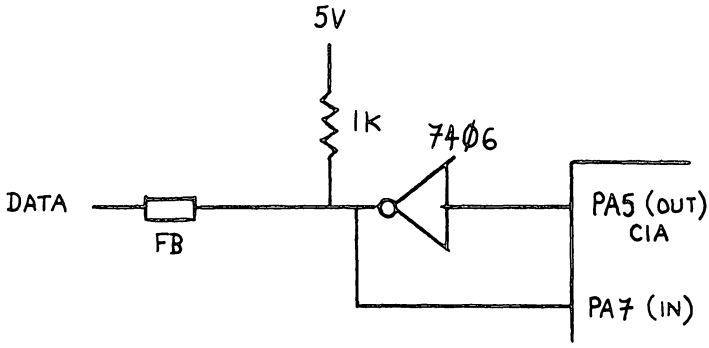


Fig. 3.1. Serial port line driver.

74Ø6 inverting buffer/driver chip with its outputs tied to 5 V with 1K resistors (Fig. 3.2). The 74Ø6 was chosen for its open collector outputs. An open collector

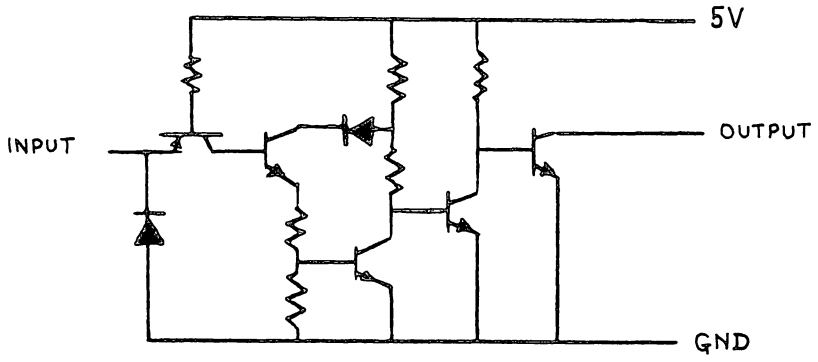


Fig. 3.2. 74Ø6 schematics (one gate).

output can only drain current, not source it. So when the output of a 74Ø6 gate is low it can pull the serial line low but when the output is high the serial line has to be pulled to 5 V by the 1K resistor. The 64 uses this by having the 5 V state as the release state i.e. available for use by other devices. When a line is in the released state the open collector outputs on another serial device can pull the line low.

The 74Ø6 is an inverting buffer/driver, so all clock, data and attention signals sent are transmitted inverted. Therefore release or line high is sent as a zero but received as a logic one.

Only one device on the serial bus can talk at any one time but any number can listen. The Commodore 64 controls which device talks and which listens by commands sent with the attention line low (true). A timing diagram for serial operation is shown in Fig. 3.3.

1. Command byte sent under attention.

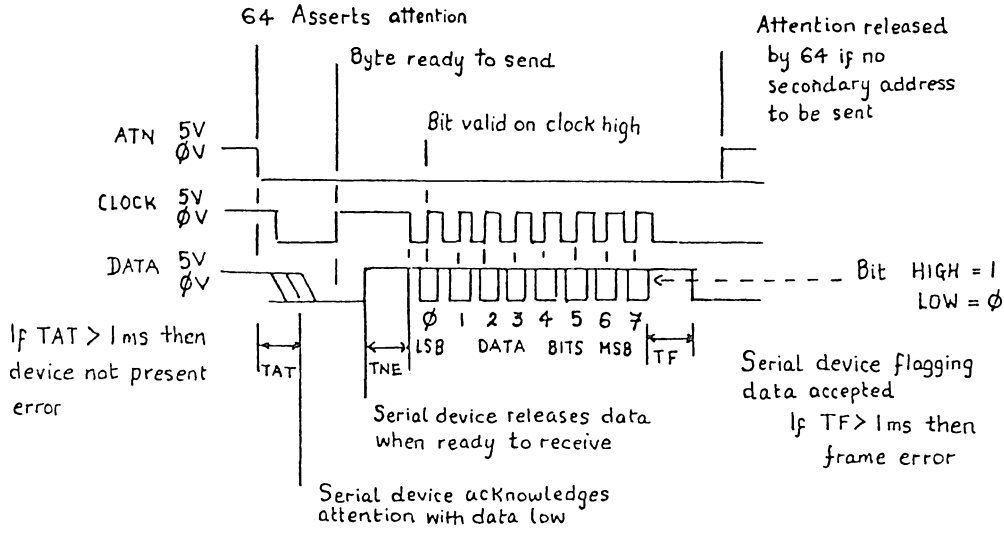


Fig. 3.3. Serial bus timing.

2. Normal bytes on serial.

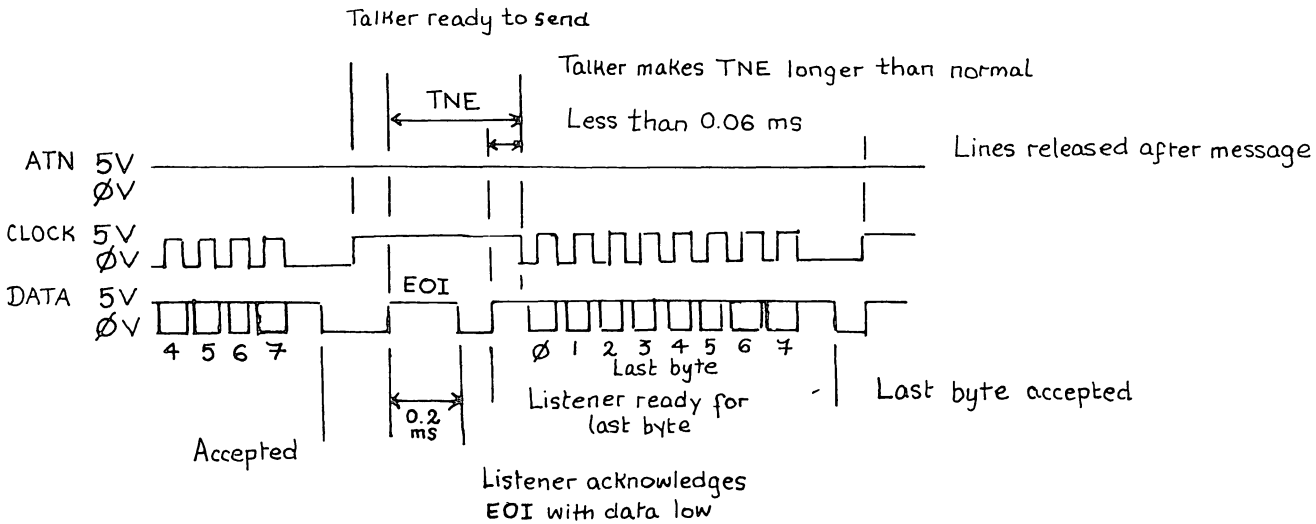


Fig.3.3. (contd.)

3. Last byte of a message (EOI handshake).

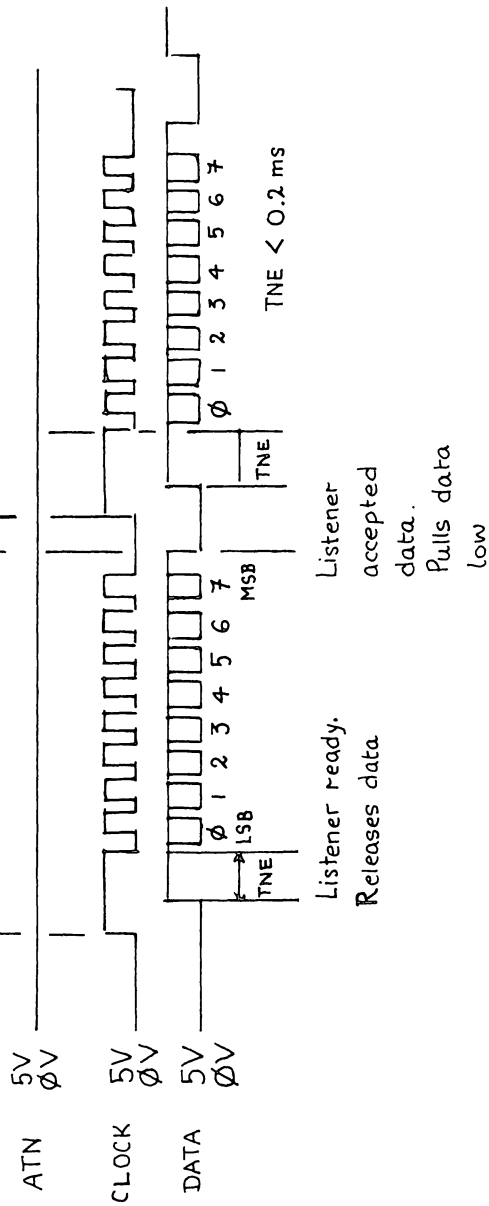


Fig.3.3. (contd.)

4. Listener becomes talker.

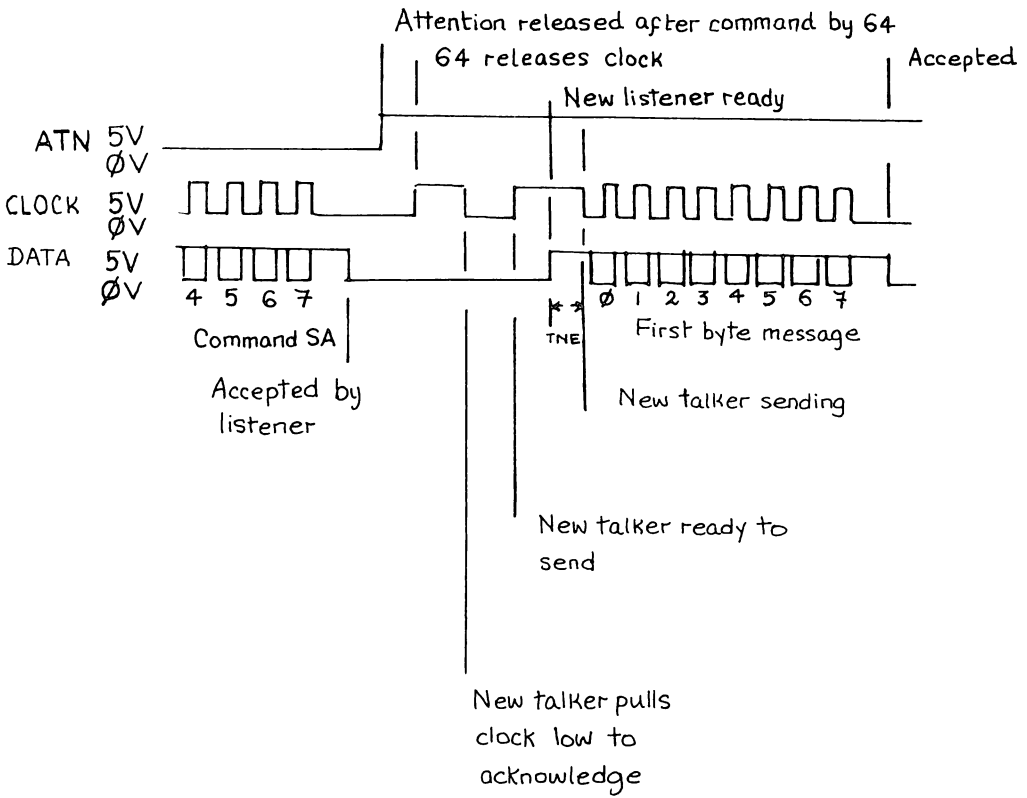


Fig.3.3. (contd.)

3.1.2 Serial commands

LISTEN Command device to listen
TALK Command device to talk
UNLSN Commands all listening devices to unlisten
UNTLK Commands talking device to stop talking (UNTALK)

3.2 Serial ROM routines

```
LOC   CODE        LINE

0000              ;***********************
0000              ; SERIAL SYSTEM
0000              ;***********************
0000                      .LIB KDECLARE
0000                      * =$90
0090              ;
0090              ;
0090              ;KERNAL VARIABLES
0090              ;
0090              STATUS *=*+1          ;I/O OPERATION STATUS BYTE
0091              STKEY  *=*+1          ;STOP KEY FLAG
0092              SVXT   *=*+1          ;TEMPORARY
0093              VERCK  *=*+1          ;LOAD OR VERIFY FLAG
0094              C3PO   *=*+1          ;IEEE BUFFERED CHAR FLAG
0095              BSOUR  *=*+1          ;CHAR BUFFER FOR IEEE
0096              SYNO   *=*+1          ;CASSETTE SYNC #
0097              XSAV   *=*+1          ;TEMP FOR BASIN
0098              LDTND  *=*+1          ;INDEX TO LOGICAL FILE
0099              DFLTN  *=*+1          ;DEFAULT INPUT DEVICE #
009A              DFLTO  *=*+1          ;DEFAULT OUTPUT DEVICE #
009B              PRTY   *=*+1          ;CASSETTE PARITY
009C              DPSW   *=*+1          ;CASSETTE DIPOLE SWITCH
009D              MSGFLG *=*+1          ;OS MESSAGE FLAG
009E              PTR1                  ;CASSETTE ERROR PASS1
009E              T1     *=*+1          ;TEMPORARY 1
009F              TMPC
009F              PTR2                  ;CASSETTE ERROR PASS2
009F              T2     *=*+1          ;TEMPORARY 2
00A0              TIME   *=*+3          ;24 HOUR CLOCK IN 1/60TH SECONDS
00A3              R2D2                  ;SERIAL BUS USAGE
00A3              PCNTR  *=*+1          ;CASSETTE STUFF
00A4              BSOUR1                ;TEMP USED BY SERIAL ROUTINE
00A4              FIRT   *=*+1
00A5              COUNT                 ;TEMP USED BY SERIAL ROUTINE
00A5              CNTDN  *=*+1          ;CASSETTE SYNC COUNTDOWN
00A6              BUFPT  *=*+1          ;CASSETTE BUFFER POINTER
00A7              INBIT                 ;RS-232 RCVR INPUT BIT STORAGE
00A7              SHCNL  *=*+1          ;CASSETTE SHORT COUNT
00A8              BITCI                 ;RS-232 RCVR BIT COUNT IN
00A8              RER    *=*+1          ;CASSETTE READ ERROR
00A9              RINONE                ;RS-232 RCVR FLAG FOR START BIT CHECK
00A9              REZ    *=*+1          ;CASSETTE READING ZEROS
00AA              RIDATA                ;RS-232 RCVR BYTE BUFFER
00AA              RDFLG  *=*+1          ;CASSETTE READ MODE
00AB              RIPRTY                ;RS-232 RCVR PARITY STORAGE
00AB              SHCNH  *=*+1          ;CASSETTE SHORT CNT
00AC              SAL    *=*+1
00AD              SAH    *=*+1
00AE              EAL    *=*+1
00AF              EAH    *=*+1
00B0              CMPO   *=*+1
00B1              TEMP   *=*+1
00B2              TAPE1  *=*+2          ;ADDRESS OF TAPE BUFFER
00B4              BITTS                 ;RS-232 TRNS BIT COUNT
00B4              SNSW1  *=*+1
```

```
LOC   CODE        LINE

00B5              NXTBIT                ;RS-232 TRNS NEXT BIT TO BE SENT
00B5              DIFF    *=*+1
00B6              RODATA                ;RS-232 TRNS BYTE BUFFER
00B6              PRP     *=*+1
00B7              FNLEN   *=*+1         ;LENGTH CURRENT FILE N STR
00B8              LA      *=*+1         ;CURRENT FILE LOGICAL ADDR
00B9              SA      *=*+1         ;CURRENT FILE 2ND ADDR
00BA              FA      *=*+1         ;CURRENT FILE PRIMARY ADDR
00BB              FNADR   *=*+2         ;ADDR CURRENT FILE NAME STR
00BD              ROPRTY                ;RS-232 TRNS PARITY BUFFER
00BD              OCHAR   *=*+1
00BE              FSBLK   *=*+1         ;CASSETTE READ BLOCK COUNT
00BF              MYCH    *=*+1
00C0              CAS1    *=*+1         ;CASSETTE MANUAL/CONTROLLED SWITCH
00C1              TMP0
00C1              STAL    *=*+1
00C2              STAH    *=*+1
00C3              MEMUSS                ;CASSETTE LOAD TEMPS (2 BYTES)
00C3              TMP2    *=*+2
00C5              ;
00C5              ;VARIABLES FOR SCREEN EDITOR
00C5              ;
00C5              LSTX    *=*+1         ;KEY SCAN INDEX
00C6              NDX     *=*+1         ;INDEX TO KEYBOARD Q
00C7              RVS     *=*+1         ;RVS FIELD ON FLAG
00C8              INDX    *=*+1
00C9              LSXP    *=*+1         ;X POS AT START
00CA              LSTP    *=*+1
00CB              SFDX    *=*+1         ;SHIFT MODE ON PRINT
00CC              BLNSW   *=*+1         ;CURSOR BLINK ENAB
00CD              BLNCT   *=*+1         ;COUNT TO TOGGLE CUR
00CE              GDBLN   *=*+1         ;CHAR BEFORE CURSOR
00CF              BLNON   *=*+1         ;ON/OFF BLINK FLAG
00D0              CRSW    *=*+1         ;INPUT VS GET FLAG
00D1              PNT     *=*+2         ;POINTER TO ROW
00D3              PNTR    *=*+1         ;POINTER TO COLUMN
00D4              QTSW    *=*+1         ;QUOTE SWITCH
00D5              LNMX    *=*+1         ;40/80 MAX POSITION
00D6              TBLX    *=*+1
00D7              DATA    *=*+1
00D8              INSRT   *=*+1         ;INSERT MODE FLAG
00D9              LDTB1   *=*+25        ;40/80 LINE FLAGS
00F2              LINTMP  *=*+1         ;TEMPORARY FOR LINE INDEX
00F3              USER    *=*+2         ;SCREEN EDITOR COLOUR IP
00F5              KEYTAB  *=*+2         ;KEYSCAN TABLE INDIRECT
00F7              ;
00F7              ;RS-232 Z-PAGE
00F7              ;
00F7              RIBUF   *=*+2         ;RS-232 INPUT BUFFER POINTER
00F9              ROBUF   *=*+2         ;RS-232 OUTPUT BUFFER POINTER
00FB              FREKZP  *=*+4         ;FREE KERNAL ZERO PAGE
00FF              BASZPT  *=*+1         ;LOCATION ($00FF) USED BY BASIC
0100              ;
0100                      *=$100
0100              BAD     *=*+1
0101                      *=$200
0200              BUF     *=*+89        ;BASIC/MONITOR BUFFER
0259              ;
0259              ;TABLES FOR OPEN FILES
0259              ;
0259              LAT     *=*+10        ;LOGICAL FILE NUMBERS
0263              FAT     *=*+10        ;PRIMARY DEVICE NUMBERS
026D              SAT     *=*+10        ;SECONDARY ADDRESSES
0277              ;
0277              ;SYSTEM STORAGE
0277              ;
0277              KEYD    *=*+10        ;IRQ KEYBOARD BUFFER
0281              MEMSTR  *=*+2         ;START OF MEMORY
```

```
LOC   CODE        LINE

0283              MEMSIZ *=*+2          ;TOP OF MEMORY
0285              TIMOUT *=*+1          ;IEEE TIMEOUT FLAG
0286              ;
0286              ;SCREEN EDITOR STORAGE
0286              ;
0286              COLOR  *=*+1          ;ACTIVE COLOUR NIBBLE
0287              GDCOL  *=*+1          ;ORIGINAL COLOUR BEFORE CURSOR
0288              HIBASE *=*+1          ;BASE LOCATION OF SCREEN (TOP)
0289              XMAX   *=*+1
028A              RPTFLG *=*+1          ;KEY REPEAT FLAG
028B              KOUNT  *=*+1
028C              DELAY  *=*+1
028D              SHFLAG *=*+1          ;SHIFT FLAG BYTE
028E              LSTSHF *=*+1          ;LAST SHIFT PATTERN
028F              KEYLOG *=*+2          ;INDIRECT FOR KEYBOARD TABLE SETUP
0291              MODE   *=*+1          ;0-PET MODE, 1-CATTACANNA
0292              AUTODN *=*+1          ;AUTO SCROLL DOWN FLAG (=0 ON,<>0 OFF)
0293              ;
0293              ;RS-232 STORAGE
0293              ;
0293              M26CTR *=*+1          ;6526 CONTROL REGISTER
0294              M26CDR *=*+1          ;6526 COMMAND REGISTER
0295              M26AJB *=*+2          ;NON STANDARD (BITTIME/2-100)
0297              RSSTAT *=*+1          ;RS-232 STATUS REGISTER
0298              BITNUM *=*+1          ;NUMBER OF BITS TO SEND (FAST RESPONSE)
0299              BAUDOF *=*+2          ;BAUD RATE FULL BIT TIME
029B              ;
029B              ;RECIEVER STORAGE
029B              ;
029B              RIDBE  *=*+1          ;INPUT BUFFER INDEX TO END
029C              RIDBS  *=*+1          ;INPUT BUFFER POINTER TO START
029D              ;
029D              ;TRANSMITTER STORAGE
029D              ;
029D              RODBS  *=*+1          ;OUTPUT BUFFER INDEX TO START
029E              RODBE  *=*+1          ;OUTPUT BUFFER INDEX TO END
029F              ;
029F              IRQTMP *=*+2          ;HOLDS IRQ DURING TAPE OPS
02A1              ;
02A1              ;
02A1                     *=$0300        ;PROGRAM INDIRECTS(10)
0300                     *=$0300+20     ;KERNAL/OS INDIRECTS (20)
0314              CINV   *=*+2          ;IRQ RAM VECTOR
0316              CBINV  *=*+2          ;BRK INSTR RAM VECTOR
0318              NMINV  *=*+2          ;NMI RAM VECTOR
031A              IOPEN  *=*+2          ;INDIRECTS FOR CODE
031C              ICLOSE *=*+2          ;CONFORMS TO KERNAL SPEC 8/19/80
031E              ICHKIN *=*+2
0320              ICKOUT *=*+2
0322              ICLRCH *=*+2
0324              IBASIN *=*+2
0326              IBSOUT *=*+2
0328              ISTOP  *=*+2
032A              IGETIN *=*+2
032C              ICLALL *=*+2
032E              USRCMD *=*+2
0330              ILOAD  *=*+2
0332              ISAVE  *=*+2          ;SAVESP
0334              ;
0334                     *=$0300+60
033C              TBUFFR *=*+192        ;CASSETTE DATA BUFFER
03FC              ;
03FC                     *=$0400
0400              CBMSCN *=*+999        ;64 SCREEN
07E7              ;
07E7                     *=$0800
0800              ;RAMLOC
0800              ;
```

```
LOC   CODE        LINE

0800                    *=$D000
D000              VICREG *=*+47          ;VIC REGISTERS
D02F              ;
D02F                    *=$D400
D400              SIDREG *=*+29          ;SID REGISTERS
D41D              ;
D41D                    *=$D800
D800              CRMCOL *=*+999         ;64 COLOUR NIBBLES
DBE7              ;
DBE7              ;I/O DEVICES
DBE7              ;
DBE7                    * =$DC00         ;6526 (IRQ)
DC00              COLM                   ;KEYBOARD MATRIX
DC00              D1DPA  *=*+1
DC01              ROWS                   ;KEYBOARD MATRIX
DC01              D1DPB  *=*+1
DC02              D1DDRA *=*+1
DC03              D1DDRB *=*+1
DC04              D1TAL  *=*+1
DC05              D1TAH  *=*+1
DC06              D1TBL  *=*+1
DC07              D1TBH  *=*+1
DC08              D1TOD1 *=*+1
DC09              D1TOD2 *=*+1
DC0A              D1TOD3 *=*+1
DC0B              D1TOD4 *=*+1
DC0C              D1IODB *=*+1
DC0D              D1ICR  *=*+1
DC0E              D1CRA  *=*+1
DC0F              D1CRB  *=*+1
DC10              ;
DC10                    *= $DD00         ;6526 (NMI)
DD00              D2DPA  *=*+1
DD01              D2DPB  *=*+1
DD02              D2DDRA *=*+1
DD03              D2DDRB *=*+1
DD04              D2TAL  *=*+1
DD05              D2TAH  *=*+1
DD06              D2TBL  *=*+1
DD07              D2TBH  *=*+1
DD08              D2TOD1 *=*+1
DD09              D2TOD2 *=*+1
DD0A              D2TOD3 *=*+1
DD0B              D2TOD4 *=*+1
DD0C              D2IODB *=*+1
DD0D              D2ICR  *=*+1
DD0E              D2CRA  *=*+1
DD0F              D2CRB  *=*+1
DD10              ;
DD10              ;TAPE BLOCK TYPES
DD10              ;
DD10              EOT    =5              ;END OF TAPE
DD10              BLF    =1              ;BASIC LOAD FILE
DD10              BDF    =2              ;BASIC DATA FILE
DD10              PLF    =3              ;FIXED PROGRAM TYPE
DD10              BDFH   =4              ;BASIC DATA FILE HEADER
DD10              BUFSZ  =192            ;BUFFER SIZE
DD10              ;
DD10              ;TAPE ERROR TYPES
DD10              ;
DD10              SPERR  =16
DD10              CKERR  =32
DD10              SBERR  =4
DD10              LBERR  =8
DD10              ;
DD10              ;SCREEN EDITOR CONSTANTS
DD10              ;
```

```
LOC   CODE        LINE

DD10              LLEN   =40              ;SINGLE LINE 40 COLUMNS
DD10              LLEN2  =80              ;DOUBLE LINE 80 COLUMNS
DD10              NLINES =25              ;25 ROWS ON SCREEN
DD10              BLUE   =6               ;BLUE SCREEN COLOUR
DD10              LTBLUE =14              ;LT BLUE CHAR COLOUR
DD10              CR     =$D              ;CARRIAGE RETURN
DD10              MAXCHR =80
DD10              NWRAP  =2
DD10              .END
DD10                     .LIB KSER1
```

TALK

Entry point: $FFB4

Function: Command serial device to talk (transmit data)

Input parameters: .A device number

Output parameters: None

Registers used: .A

Error messages:
Device not present (returned in STatus var. $9Ø) – attention not acknowledged by data low within 1 ms
Frame error (in ST) – no data accepted response (data low) within 1 ms of last bit of byte being sent.

Description: This routine ORs the device number in the .A register with $4Ø. Before the command is sent the single character serial buffer is checked for being empty. If it is not the character in it is sent (with end message marker (EOI)). After this the attention line is set low (bit 3 set in chip 2 port A (assembler label D2DPA in listing). Then the command byte is sent with the attention line held low.

```
LOC   CODE        LINE

DD10              *=$ED09
ED09              ;****************************************
ED09              ;*COMMAND SERIAL BUS TO TALK.
ED09              ;*THE ACCUMULATOR MUST BE LOADED WITH THE
ED09              ;*DEVICE NUMBER THAT YOU WISH TO TALK.
ED09              ;****************************************
ED09  09 40       L836   ORA #$40         ;MAKE ADDR TALK
ED0B  2C                 .BYT $2C         ;SKIP NEXT COMMAND
```

LISTEN

Entry point: $FFB1

Function: Command serial device to listen

Input parameters: .A device number

Output parameters: None

Registers used: .A

Error messages:
Device not present (returned in STatus var. $9Ø) - attention not acknowledged by data low within 1 ms
Frame error (in ST) - no data accepted response (data low) within 1 ms of last bit of byte being sent

Description: This routine ORs the device number in the .A register with $2Ø. Before the command is sent the single character serial buffer is checked for being empty. If it is not the character in it is sent with an EOI handshake to mark it as the last byte of its message. After this the attention line is set low. Then the command byte is sent with the attention line held low. This routine includes the main routine to send a byte to the serial bus. This is done as follows :

```
L842 - Set clock low
       Set data high
       Delay 1 ms
L859 - Set data high (released)
       Set clock line high
       If EOI no handshake required then L85Ø
       ; Wait with clock high for End Or Identify handshake
       Wait for data high
       Wait for data low
       ; That is end of hold, until serial device is ready
L85Ø - Wait for data high
       Set clock low
       Put 8 in counter
L848 - If data not high framing error
       Get next bit of byte to send
       ; Low bit first
       If bit is zero then set data low
       Set clock high ; flag bit
       Sort pause
       Set data high and clock low
       Decrease bit counter
       Go to L848 if not all sent
       Set timer for 1 ms
L855 - Has timer expired?
       If so then L847 (framing error)
       If data not low go back to L855
       Exit
```

```
LOC   CODE        LINE

ED0C              ;****************************************
ED0C              ;*COMMAND SERIAL BUS TO LISTEN.
ED0C              ;*TO USE THIS ROUTINE, THE ACCUMULATOR MUST
ED0C              ;*FIRST BE LOADED WITH THE DEVICE NUMBER THAT
ED0C              ;*YOU WISH TO LISTEN (RECEIVE DATA).
ED0C              ;****************************************
ED0C  09 20       L966    ORA #$20          ;MAKE ADDR LISTEN
ED0E  20 A4 F0            JSR $F0A4         ;PROTECT FROM RS323 NMI
ED11  48          L980    PHA
ED12  24 94               BIT C3PO          ;CHAR IN BUFFER?
ED14  10 0A               BPL L864          ;NO
ED16              ;
ED16              ;SEND BUFFERED CHAR
ED16              ;
ED16  38                  SEC               ;SET EOI FLAG
ED17  66 A3               ROR R2D2
ED19  20 40 ED            JSR L859          ;SEND LAST CHAR
ED1C  46 94               LSR C3PO          ;BUFFER CLEAR
ED1E  46 A3               LSR R2D2          ;CLEAR EOI FLAG
ED20  68          L864    PLA               ;TALK/LISTEN ADDR
ED21  85 95               STA BSOUR
ED23  78                  SEI
ED24  20 97 EE            JSR L844
ED27  C9 3F               CMP #$3F          ;CLKHI ONLY ON UNLISTEN
ED29  D0 03               BNE L839
ED2B  20 85 EE            JSR L875
ED2E  AD 00 DD    L839    LDA D2DPA         ;ASSERT ATTENTION
ED31  09 08               ORA #$08
ED33  8D 00 DD            STA D2DPA
ED36              ;
ED36  78          L842    SEI
ED37  20 8E EE            JSR L843          ;SET CLOCK LINE LOW
ED3A  20 97 EE            JSR L844
ED3D  20 B3 EE            JSR L846          ;DELAY 1 MS
ED40  78          L859    SEI               ;DISABLE IRQ
ED41  20 97 EE            JSR L844          ;MAKE SURE DATA IS RELEASED
ED44  20 A9 EE            JSR L854          ;DATA SHOULD BE LOW
ED47  B0 64               BCS L856
ED49  20 85 EE            JSR L875          ;CLOCK LINE HI
ED4C  24 A3               BIT R2D2          ;EOI FLAG TEST
ED4E  10 0A               BPL L850
ED50              ;DO EOI
ED50  20 A9 EE    L840    JSR L854          ;WAIT FOR DATA HI
ED53  90 FB               BCC L840
ED55  20 A9 EE    L849    JSR L854          ;WAIT FOR DATA LO
ED58  B0 FB               BCS L849
ED5A  20 A9 EE    L850    JSR L854          ;WAIT FOR DATA HI
ED5D  90 FB               BCC L850
ED5F  20 8E EE            JSR L843          ;SET CLOCK LO
ED62              ;
ED62              ;SET TO SEND DATA
ED62              ;
ED62  A9 08               LDA #$08          ;COUNT 8 BITS
ED64  85 A5               STA COUNT
ED66  AD 00 DD    L848    LDA D2DPA         ;DEBOUNCE BUS
ED69  CD 00 DD            CMP D2DPA
ED6C  D0 F8               BNE L848
ED6E  0A                  ASL A
ED6F  90 3F               BCC L847          ;DATA MUST BE HI
ED71  66 95               ROR BSOUR         ;NEXT BIT INTO CARRY
ED73  B0 05               BCS L851
ED75  20 A0 EE            JSR L841
ED78  D0 03               BNE L853
ED7A  20 97 EE    L851    JSR L844
ED7D  20 85 EE    L853    JSR L875          ;CLOCK HI
ED80  EA                  NOP
ED81  EA                  NOP
ED82  EA                  NOP
```

```
LOC   CODE         LINE

ED83  EA                   NOP
ED84  AD 00 DD             LDA D2DPA
ED87  29 DF                AND #$DF          ;DATA HI
ED89  09 10                ORA #$10          ;CLOCK LO
ED8B  8D 00 DD             STA D2DPA
ED8E  C6 A5                DEC COUNT
ED90  D0 D4                BNE L848
ED92  A9 04                LDA #$04          ;SET TIMER FOR 1 MS
ED94  8D 07 DC             STA D1TBH
ED97  A9 19                LDA #$19
ED99  8D 0F DC             STA D1CRB
ED9C  AD 0D DC             LDA D1ICR
ED9F  AD 0D DC      L855   LDA D1ICR
EDA2  29 02                AND #$02
EDA4  D0 0A                BNE L847
EDA6  20 A9 EE             JSR L854
EDA9  B0 F4                BCS L855
EDAB  58                   CLI               ;ENABLE IRQ
EDAC  60                   RTS
EDAD  A9 80         L856   LDA #$80          ;DEVICE NOT PRESENT
EDAF  2C                   .BYT $2C
EDB0  A9 03         L847   LDA #$03          ;FRAMING ERROR
EDB2  20 1C FE      L852   JSR $FE1C         ;SEND MESSAGE
EDB5  58                   CLI               ;ENABLE IRQ
EDB6  18                   CLC
EDB7  90 4A                BCC L1004         ;ALWAYS
```

SECOND

Entry point: $FF93

Function: Send secondary address after listen

Input parameters: Secondary address in .A register ORed with $6Ø

Output parameters: None

Registers used: .A

Error messages:
Device not present (returned in STatus var. $9Ø) – attention not acknowledged by data low within 1 ms
Frame error (in ST) – no data accepted response (data low) within 1 ms of last bit of byte being sent

Description: The secondary address is stored in the serial buffer and then sent to listening devices. Next the attention line is released (set high).

```
LOC   CODE         LINE

EDB9                ;****************************************
EDB9                ;*SEND SECONDARY ADDRESS AFTER LISTEN.
EDB9                ;*THIS ROUTINE IS USED TO SEND A SECONDARY
EDB9                ;*ADDRESS AFTER A CALL TO THE LISTEN COMMAND.
EDB9                ;****************************************
EDB9  85 95         L871   STA BSOUR         ;BUFFER CHAR
```

```
EDBB  20 36 ED          JSR L842        ;SEND IT
EDBE                ;
EDBE                ;RELEASE ATTENTION
EDBE                ;
EDBE  AD 00 DD      L983    LDA D2DPA
EDC1  29 F7             AND #$F7
EDC3  8D 00 DD          STA D2DPA       ;RELEASE
EDC6  60                RTS
```

TKSA

Entry point: $FF96

Function: Send secondary address after talk

Input parameters: Secondary address in .A register

Output parameters: None

Registers used: .A

Error messages:
Device not present (returned in STatus var. $9Ø) – attention not acknowledged by data low within 1 ms
Frame error (in ST) – no data accepted response (data low) within 1 ms of last bit of byte being sent

Description: The secondary address is loaded into the serial buffer and then sent to the serial bus. This routine then waits for the new talking device to acknowledge it is the new talker by changing the clock line. This is done as follows:

Hold data low
Set attention high (release)
Set clock high
Then wait for clock to go low

```
LOC   CODE          LINE

EDC7                ;*****************************************
EDC7                ;*SEND TALK SA.
EDC7                ;*THIS ROUTINE IS USED TO SEND A SECONDARY
EDC7                ;*ADDRESS TO A DEVICE THAT HAS ALREADY BEEN
EDC7                ;*COMMANDED TO TALK.
EDC7                ;*****************************************
EDC7  85 95         L860    STA BSOUR       ;BUFFER CHAR
EDC9  20 36 ED              JSR L842        ;SEND SA
EDCC                ;
EDCC                ;SHIFT OVER TO LISTENER
EDCC                ;
EDCC  78            L970    SEI             ;DISABLE IRQ
EDCD  20 A0 EE              JSR L841        ;DATA LINE LO
EDD0  20 BE ED              JSR L983
EDD3  20 85 EE              JSR L875        ;CLOCK LINE HI
EDD6  20 A9 EE      L968    JSR L854        ;WAIT FOR CLOCK LO
EDD9  30 FB                 BMI L968
EDDB  58                    CLI             ;DONE
EDDC  60                    RTS
```

CIOUT

Entry point: $FFA8

Function: Send byte to serial bus

Input parameters: Byte to send in .A

Output parameters: None

Registers used: .A

Error messages:
Device not present (returned in STatus var. $9Ø) – attention not acknowledged by data low within 1 ms
Frame error (in ST) – no data accepted response (data low) within 1 ms of last bit of byte being sent

Description: Any character in the serial buffer is sent to the serial port. Then the current character is stored in the buffer.

```
LOC   CODE         LINE

 EDDD               ;****************************************
 EDDD               ;BUFFERED OUTPUT TO SERIAL BUS
 EDDD               ;****************************************
 EDDD  24 94        L861    BIT C3PO          ;BUFFERED CHAR?
 EDDF  30 05                BMI L949          ;YES, SEND LAST
 EDE1  38                   SEC               ;NO
 EDE2  66 94                ROR C3PO          ;SET BUFFERED CHAR FLAG
 EDE4  D0 05                BNE L862          ;ALWAYS
 EDE6               ;
 EDE6  48           L949    PHA               ;SAVE CURRENT CHAR
 EDE7  20 40 ED             JSR L859          ;SEND LAST CHAR
 EDEA  68                   PLA               ;RESTORE CURRENT
 EDEB  85 95        L862    STA BSOUR         ;BUFFER IT
 EDED  18                   CLC               ;GOOD EXIT
 EDEE  60                   RTS
```

UNTLK

Entry point: $FFAB

Function: Send command UNTALK

Input parameters: None

Output parameters: None

Registers used: .A

Error messages:
Device not present (returned in STatus var. $9Ø) – attention not acknowledged by data low within 1 ms

Frame error (in ST) - no data accepted response (data low) within 1 ms of last bit of byte being sent

Description: This routine sends the $5F under attention to serial bus. This tells the current talking to stop. After a delay this routine ends by releasing clock and data lines.

```
LOC   CODE          LINE

 EDEF               ;***************************************
 EDEF               ;*SEND UNTALK.
 EDEF               ;*THIS ROUTINE SENDS AN 'UNTALK' TO THE SERIAL
 EDEF               ;*BUS. IT WILL TELL ALL DEVICES IN TALK
 EDEF               ;*MODE TO STOP TALKING (SENDING DATA).
 EDEF               ;***************************************
 EDEF  78           L863   SEI
 EDF0  20 8E EE             JSR L843
 EDF3  AD 00 DD             LDA D2DPA       ;PULL ATN
 EDF6  09 08                ORA #$08
 EDF8  8D 00 DD             STA D2DPA
 EDFB  A9 5F                LDA #$5F        ;UNTALK
 EDFD  2C                   .BYT $2C        ;SKIP NEXT COMMAND
```

UNLSN

Entry point: $FFAE

Function: Send command UNLISTEN

Input parameters: None

Output parameters: None

Registers used: .A

Error messages:
Device not present (returned in STatus var. $9Ø) - attention not acknowledged by data low within 1 ms
Frame error (in ST) - no data accepted response (data low) within 1 ms of last bit of byte being sent

Description: This routine sends the $3F under attention to serial bus. This tells the current listening devices to stop. After a delay this routine ends by releasing clock and data lines.

```
LOC   CODE          LINE

 EDFE               ;***************************************
 EDFE               ;*SEND UNLISTEN.
 EDFE               ;*THIS ROUTINE SENDS AN 'UNLISTEN' TO
 EDFE               ;*THE SERIAL BUS. IT WILL TELL ALL DEVICES
 EDFE               ;*IN LISTEN MODE TO STOP LISTENING.
 EDFE               ;***************************************
 EDFE  A9 3F        L1006  LDA #$3F         ;UNLISTEN COMMAND
 EE00  20 11 ED             JSR L980        ;SEND
 EE03               ;
 EE03               ;RELEASE ALL LINES
 EE03               ;
 EE03  20 BE ED     L1004  JSR L983         ;RELEASE ATN
 EE06               ;
```

```
EE06                ;DELAY THEN RELEASE CLOCK AND DATA
EE06                ;
EE06  8A            L858   TXA              ;DELAY APPROX 60 MICRO SECS
EE07  A2 0A                 LDX #$0A
EE09  CA            L876   DEX
EE0A  D0 FD                 BNE L876
EE0C  AA                    TAX
EE0D  20 85 EE              JSR L875
EE10  4C 97 EE              JMP L844
```

ACPTR

Entry point: $FFA5

Function: Input byte from serial port

Input parameters: None

Output parameters: Character in .A

Registers used: .A

Error messages:
Read timeout (in ST) - no clock low response within Ø.2 ms of data being released

Description: This routine gets a byte from serial bus and returns it in the .A register. It does this as follows:

L865 - Zero COUNT
Release clock line
Wait for clock to go high
L866 - Set timer to 256 ms
Release data
L872 - If timer expired go to L868
If clock still high go back to L872
Otherwise go to L87Ø, to read byte
L868 - If COUNT non zero flag read timeout in ST and exit via a routine to release lines
Otherwise assume EOI
; Handshake EOI
Set data low
Pause and release data
Flag EOI in ST
Increase COUNT
Go back to L866, to wait for clock
; Get a byte
L870 - Set COUNT for 8 bits
L869 - Wait for clock to go high
Get next bit of byte from data line
Wait for clock to go low

Decrease COUNT
If COUNT not zero go back to L869 to get next bit
Acknowledge byte by sending data low
Check EOI flag in ST
; EOI flags end of message
If set then delay and release data
Exit this byte read in .A

```
LOC   CODE        LINE

EE13              ;***************************************
EE13              ;INPUT A BYTE FROM SERIAL BUS
EE13              ;***************************************
EE13  78          L865   SEI              ;DISABLE IRQ
EE14  A9 00              LDA #$00         ;SET EOI/ERROR FLAG
EE16  85 A5              STA COUNT
EE18  20 85 EE           JSR L875         ;RELEASE CLOCK LINE
EE1B  20 A9 EE    L943   JSR L854         ;WAIT FOR CLOCK HI
EE1E  10 FB              BPL L943
EE20  A9 01       L866   LDA #$01         ;SET TIMER B FOR 256 US
EE22  8D 07 DC           STA D1TBH
EE25  A9 19              LDA #$19
EE27  8D 0F DC           STA D1CRB
EE2A  20 97 EE           JSR L844
EE2D  AD 0D DC           LDA D1ICR
EE30  AD 0D DC    L872   LDA D1ICR
EE33  29 02              AND #$02         ;CHECK THE TIMER
EE35  D0 07              BNE L868         ;RAN OUT
EE37  20 A9 EE           JSR L854         ;CHECK THE CLOCK LINE
EE3A  30 F4              BMI L872         ;NOT YET
EE3C  10 18              BPL L870         ;YES
EE3E              ;
EE3E
EE3E  A5 A5       L868   LDA COUNT        ;CHECK FOR ERROR
EE40  F0 05              BEQ L867
EE42  A9 02              LDA #$02
EE44  4C B2 ED           JMP L852         ;ST=2, READ TIME OUT
EE47              ;
EE47              ;TIMER RAN OUT, DO AN EOI
EE47              ;
EE47  20 A0 EE    L867   JSR L841         ;DATA LINE LO
EE4A  20 85 EE           JSR L875         ;DELAY, SET DATA HI
EE4D  A9 40              LDA #$40
EE4F  20 1C FE           JSR $FE1C        ;OR AN EOI BIT INTO ST
EE52  E6 A5              INC COUNT AND AGAIN FOR ERROR CHECK
EE54  D0 CA              BNE L866
EE56              ;
EE56              ;BYTE TRANSFER
EE56              ;
EE56  A9 08       L870   LDA #$08         ;SET UP COUNTER
EE58  85 A5              STA COUNT
EE5A  AD 00 DD    L869   LDA D2DPA        ;WAIT FOR CLOCK HI
EE5D  CD 00 DD           CMP D2DPA        ;DEBOUNCE
EE60  D0 F8              BNE L869
EE62  0A                 ASL A
EE63  10 F5              BPL L869
EE65  66 A4              ROR BSOUR1       ;ROTATE DATA IN
EE67  AD 00 DD    L873   LDA D2DPA        ;WAIT FOR CLOCK LO
EE6A  CD 00 DD           CMP D2DPA        ;DEBOUNCE
EE6D  D0 F8              BNE L873
EE6F  0A                 ASL A
EE70  30 F5              BMI L873
EE72  C6 A5              DEC COUNT
EE74  D0 E4              BNE L869         ;MORE BITS
EE76  20 A0 EE           JSR L841         ;DATA LO
```

```
EE79  24 90              BIT STATUS      ;CHECK FOR EOI
EE7B  50 03              BVC L874        ;NONE
EE7D  20 06 EE           JSR L858        ;DELAY AND DATA HI
EE80  A5 A4        L874  LDA BSOUR1
EE82  58                 CLI             ;ENABLE IRQ
EE83  18                 CLC             ;GOOD EXIT
EE84  60                 RTS
```

3.3 General routines

All routines change only the .A register.

Set clock high, set clock low, set data high & set data low all just set or unset a bit in port A of CIA chip 2. Note that the bit is set to send a line low.

Debounce CIA routine first loops until a consistent value is read from port A of the CIA. It then sets the carry flag to the state of the data line, and the sign flag to the state of the clock line.

The 1 millisecond delay is a software delay loop lasting approx 1 ms.

```
LOC   CODE         LINE

EE85                ;
EE85                ;SET CLOCK LINE HI (INVERTED)
EE85                ;
EE85  AD 00 DD      L875   LDA D2DPA
EE88  29 EF                AND #$EF
EE8A  8D 00 DD             STA D2DPA
EE8D  60                   RTS
EE8E                ;
EE8E                ;SET CLOCK LINE LO (INVERTED)
EE8E                ;
EE8E  AD 00 DD      L843   LDA D2DPA
EE91  09 10                ORA #$10
EE93  8D 00 DD             STA D2DPA
EE96  60                   RTS
EE97                ;
EE97                ;SET DATA LINE HI (INVERTED)
EE97                ;
EE97  AD 00 DD      L844   LDA D2DPA
EE9A  29 DF                AND #$DF
EE9C  8D 00 DD             STA D2DPA
EE9F  60                   RTS
EEA0                ;
EEA0                ;SET DATA LINE LO (INVERTED)
EEA0                ;
EEA0  AD 00 DD      L841   LDA D2DPA
EEA3  09 20                ORA #$20
EEA5  8D 00 DD             STA D2DPA
EEA8  60                   RTS
EEA9                ;
EEA9                ;DEBOUNCE THE PIA
EEA9                ;
EEA9  AD 00 DD      L854   LDA D2DPA
EEAC  CD 00 DD             CMP D2DPA
EEAF  D0 F8                BNE L854
EEB1  0A                   ASL A
EEB2  60                   RTS
EEB3                ;
EEB3                ;DELAY 1 MS
EEB3                ;
EEB3  8A            L846   TXA
```

```
EEB4  A2 B8             LDX #$B8
EEB6  CA          L845  DEX
EEB7  D0 FD             BNE L845
EEB9  AA                TAX
EEBA  60                RTS
EEBB              .END
EEBB                    .LIB KSER2
```

GETIN

Entry point: $FFE4

Function: Get a character from the current input device

Input parameters: None

Output parameters: .A holds character, CARRY clear

Registers used: .A

Error messages: None

Description: For serial devices, GETIN is redirected to BASIN.

```
LOC   CODE        LINE

EEBB              *=$F13E
F13E              ;
F13E              ;****************************************
F13E              ;* GETIN -- GET CHARACTER FROM CHANNEL.
F13E              ;*       CHANNEL IS DETERMINED BY DFLTN.
F13E              ;* IF DEVICE IS 0, KEYBOARD QUEUE IS
F13E              ;* EXAMINED AND A CHARACTER REMOVED IF
F13E              ;* AVAILABLE.  IF QUEUE IS EMPTY, Z
F13E              ;* FLAG IS RETURNED SET.  DEVICES 1-31
F13E              ;* ADVANCE TO BASIN. THE CHARACTER IS
F13E              ;* RETURNED IN .A. IF ZERO, NULL CHAR.
F13E              ;****************************************
F13E              ;
F13E  A5 99       NGETIN LDA DFLTN       ;CHECK DEVICE
F140  D0 08              BNE L924        ;NOT KEYBOARD
F142  A5 C6              LDA NDX         ;QUEUE INDEX
F144  F0 0F              BEQ L944        ;NOTHING THERE, EXIT
F146  78                 SEI
F147  4C B4 E5           JMP $E5B4       ;REMOVE A CHAR
F14A  C9 02       L924   CMP #$02        ;RS-232?
F14C  D0 18              BNE L927        ;NO, USE BASIN
F14E  84 97       L926   STY XSAV        ;SAVE .Y, USED IN RS-232
F150  20 86 F0           JSR $F086
F153  A4 97              LDY XSAV        ;RESTORE .Y
F155  18          L944   CLC             ;GOOD RETURN
F156  60                 RTS
```

BASIN

Entry point: $FFCF

Function: Get a character from the current input device

Input parameters: None

Output parameters: .A holds character, CARRY clear

Registers used: .A

Error messages: None

Description: If the status from the last character read was ≠Ø (EOF), the character 13 (carriage return) is returned with CARRY clear. Otherwise one byte is read using the ACPTR routine.

```
LOC   CODE        LINE

F157              ;
F157              ;**************************************
F157              ;* BASIN-- INPUT CHARACTER FROM CHANNEL.
F157              ;*      BASIN DIFFERS FROM GETIN ON KEYBOARD
F157              ;* AND RS-232 ONLY. THE SCREEN EDITOR
F157              ;* MAKES READY AN ENTIRE LINE WHICH IS
F157              ;* PASSED CHARACTER BY CHARACTER UP
F157              ;* TO THE CARRIAGE RETURN. THE CHARACTER
F157              ;* IS RETURNED IN .A. ZERO FOR NULL CHAR
F157              ;* OTHER DEVICES ARE:
F157              ;*       0 --- KEYBOARD
F157              ;*       1 --- CASSETTE
F157              ;*       2 --- RS-232
F157              ;*       3 --- SCREEN
F157              ;*    4-31 --- SERIAL BUS
F157              ;**************************************
F157              ;
F157  A5 99       NBASIN LDA DFLTN        ;CHECK DEVICE
F159  D0 0B              BNE L927         ;NOT KEYBOARD
F15B              ;
F15B              ;INPUT FROM KEYBOARD
F15B              ;
F15B  A5 D3              LDA PNTR         ;SAVE CURRENT:
F15D  85 CA              STA LSTP         ;CURSOR COLUMN,
F15F  A5 D6              LDA TBLX
F161  85 C9              STA LSXP         ;LINE NUMBER
F163  4C 32 E6           JMP $E632        ;BLINK CURSOR UNTIL RETURN
F166              ;
F166  C9 03       L927   CMP #$03         ;SCREEN?
F168  D0 09              BNE L928         ;NO
F16A  85 D0              STA CRSW         ;FAKE CARRIAGE RETURN
F16C  A5 D5              LDA LNMX         ;ENDED:
F16E  85 C8              STA INDX         ;ON THIS LINE
F170  4C 32 E6           JMP $E632        ;PICK UP CHARACTERS
F173              ;
F173  B0 38       L928   BCS L939         ;DEVICES>3
F175  C9 02              CMP #$02         ;RS-232?
F177  F0 3F              BEQ $F1B8        ;YES
F179              ;-------------------------
F179              *=$F1AD
F1AD              ;
F1AD              ;INPUT FROM SERIAL BUS
F1AD              ;
F1AD  A5 90       L939   LDA STATUS       ;STATUS FROM LAST
F1AF  F0 04              BEQ L941         ;O.K.
F1B1  A9 0D       L932   LDA #$0D         ;BAD, ALL DONE
F1B3  18          L946   CLC              ;VALID DATA
F1B4  60          L945   RTS
F1B5              ;
F1B5  4C 13 EE    L941   JMP L865         ;GOOD, HANDSHAKE
F1B8              ;-------------------------
```

BSOUT

Entry point: $FFD2

Function: Output the character stored in .A to the current output device.

Input parameters: .A holds character

Output parameters: .A holds same character, CARRY clear

Registers used: None

Error messages: None

Description: This routine just jumps to the send buffered character to serial routine.

```
LOC   CODE         LINE

 F1B8               *=$F1CA
 F1CA               ;
 F1CA               ;***************************************
 F1CA               ;* BSOUT -- OUTPUT CHAR STORED IN .A TO
 F1CA               ;* CHANNEL DETERMINED BY VARIABLLE DFLTO:
 F1CA               ;*      0 --- INVALID
 F1CA               ;*      1 --- CASSETTE
 F1CA               ;*      2 --- RS-232
 F1CA               ;*      3 --- SCREEN
 F1CA               ;*  4-31 --- SERIAL BUS
 F1CA               ;***************************************
 F1CA               ;
 F1CA  48           NBSOUT PHA              ;PRESERVE .A
 F1CB  A5 9A               LDA DFLTO        ;CHECK DEVICE
 F1CD  C9 03               CMP #$03         ;SCREEN?
 F1CF  D0 04               BNE L933         ;NO
 F1D1  68                  PLA              ;YES, RESTORE .A
 F1D2  4C 16 E7            JMP $E716        ;PRINT TO SCREEN
 F1D5               ;
 F1D5  90 04        L933   BCC $F1DB        ;DEVICE 1 OR 2
 F1D7               ;
 F1D7               ;PRINT TO SERIAL BUS
 F1D7               ;
 F1D7  68                  PLA
 F1D8  4C DD ED            JMP L861
 F1DB               ;-----------------------
 F1DB               ;
 F1DB                      .LIB KSER3
```

CHKIN

Entry point: $FFC6

Function: Set a previously OPENed file for input.

Input parameters: .X holds the logical file number of the OPENed file.

Output parameters:
CARRY clear - OK
CARRY set - error, error number in .A

Registers used: .A, .X

Error messages:
File not open - if the logical file number in .X is not in the LFN table
Device not present - if bit 7 of ST is set, the device did not respond to the TALK command

Description: This routine first checks that the LFN in .X has a reference in the LFN table. If not, the message File not open is sent. The device referenced by the LFN is told to TALK and a secondary address is sent (if present). After sending the TALK secondary address, the device is shifted over to listener. If bit 7 of the STATUS byte (ST) is set, the message Device not present is sent.

```
LOC   CODE        LINE

 F1DB              *=$F20E
 F20E              ;
 F20E              ;***************************************
 F20E              ;* CHKIN -- OPEN CHANNEL FOR INPUT.
 F20E              ;*      THE NUMBER OF THE LOGICAL FILE TO
 F20E              ;* BE OPENED FOR INPUT IS PASSED IN .X.
 F20E              ;* CHKIN SEARCHES THE LOGICAL FILE TO
 F20E              ;* LOOK UP DEVICE AND COMMAND INFO.
 F20E              ;* ERRORS ARE REPORTED IF THE DEVICE WAS
 F20E              ;* NOT OPENED FOR INPUT, (E.G. CASSETTE
 F20E              ;* WRITE FILE), OR THE LOGICAL FILE HAS
 F20E              ;* NO REFERENCE IN THE TABLES. DEVICE 0,
 F20E              ;* (KEYBOARD), AND DEVICE 3 (SCREEN),
 F20E              ;* REQUIRE NO TABLE ENTRIES AND ARE
 F20E              ;* HANDLED SEPARATELY.
 F20E              ;***************************************
 F20E              ;
 F20E  20 0F F3    NCHKIN JSR L1000        ;FILE OPENED?
 F211  F0 03              BEQ L950         ;YES
 F213  4C 01 F7           JMP L1009        ;NO, FILE NOT OPEN
 F216  20 1F F3    L950   JSR L1002        ;GET FILE INFO
 F219  A5 BA              LDA FA
 F21B  F0 16              BEQ L963         ;KEYBOARD
 F21D              ;
 F21D              ;COULD BE SCREEN, RS-232, OR SERIAL
 F21D              ;
 F21D  C9 03              CMP #$03         ;SCREEN?
 F21F  F0 12              BEQ L963         ;YES, DONE
 F221  B0 14              BCS L961         ;SERIAL
 F223  C9 02              CMP #$02         ;RS-232?
 F225  D0 03              BNE L958         ;NO, MUST BE TAPE
 F227  4C 4D F0           JMP $F04D        ;RS-232
 F22A              ;
 F22A              ;CHECK FOR INPUT FILE ON TAPE
 F22A              ;
 F22A  A6 B9       L958   LDX SA           ;CHECK SECONDARY AD
 F22C  E0 60              CPX #$60         ;INPUT?
 F22E  F0 03              BEQ L963         ;YES
 F230  4C 0A F7           JMP L971         ;NO, NOT INPUT FILE
 F233  85 99       L963   STA DFLTN        ;SET INPUT
 F235  18                 CLC :GOOD RETURN
 F236  60                 RTS
 F237              ;
```

```
LOC   CODE        LINE

F237              ;A SERIAL DEVICE MUST TALK
F237              ;
F237  AA          L961    TAX             ;SAVE DEVICE #
F238  20 09 ED            JSR L836        ;TALK
F23B  A5 B9                LDA SA          ;SECOND?
F23D  10 06                BPL L962        ;YES, SEND IT
F23F  20 CC ED             JSR L970        ;NO, LET GO
F242  4C 48 F2             JMP L967
F245  20 C7 ED    L962    JSR L860        ;SEND TALK SA
F248  8A          L967    TXA
F249  24 90                BIT STATUS      ;DID IT LISTEN?
F24B  10 E6                BPL L963        ;YES
F24D  4C 07 F7             JMP L1026       ;DEVICE NOT PRESENT
```

CHKOUT

Entry point: $FFC9

Function: Set a previously OPENed file for output.

Input parameters: .X holds the logical file number of the OPENed file.

Output parameters:
CARRY clear - OK
CARRY set - error, error number in .A

Registers used: .A, .X

Error messages:
File not open - if the logical file number in .X is not in the LFN table
Device not present - if bit 7 of ST is set, the device did not respond to the LISTEN command

Description: This routine first checks that the LFN in .X has a reference in the LFN table. If not, the message File not open is sent. The device referenced by the LFN is told to LISTEN and a secondary address is sent (if present). If bit 7 of the STATUS byte (ST) is set, the message Device not present is sent.

```
LOC   CODE        LINE

F250              ;***************************************
F250              ;* CHKOUT -- OPEN CHANNEL FOR OUTPUT.
F250              ;*      THE NUMBER OF THE LOGICAL FILE TO
F250              ;* BE OPENED FOR OUTPUT IS PASSED IN .X.
F250              ;* CHKOUT SEARCHES THE LOGICAL FILE TO
F250              ;* LOOK UP DEVICE AND COMMAND INFO.
F250              ;* ERRORS ARE REPORTED IF THE DEVICE WAS
F250              ;* NOT OPENED FOR INPUT, (E.G. KEYBOARD)
F250              ;* OR THE LOGICAL FILE HAS NO REFERENCE
F250              ;* IN THE TABLES. DEVICE 3 (SCREEN)
F250              ;* REQUIRES NO TABLE ENTRY AND IS
F250              ;* HANDLED SEPARATELY.
F250              ;***************************************
```

```
LOC   CODE        LINE

F250              ;
F250  20 0F F3    NCKOUT JSR L1000        ;FILE IN TABLE;
F253  F0 03              BEQ L969         ;YES
F255  4C 01 F7           JMP L1009        ;NO, FILE NOT OPEN
F258  20 1F F3    L969   JSR L1002        ;GET TABLE INFO
F25B  A5 BA              LDA FA
F25D  D0 03              BNE L979         ;NOT KEYBOARD
F25F  4C 0D F7    L972   JMP L965         ;KEYBOARD, NOT OUTPUT FILE
F262              ;
F262              ;COULD BE SCREEN, SERIAL,
F262              ; CASSETTE, OR RS-232
F262              ;
F262  C9 03       L979   CMP #$03         ;SCREEN?
F264  F0 0F              BEQ L977         ;YES, DONE
F266  B0 11              BCS L975         ;NO, SERIAL
F268  C9 02              CMP #$02         ;RS-232?
F26A  D0 03              BNE L973         ;NO, MUST BE CASSETTE
F26C  4C E1 EF           JMP $EFE1        ;SET UP FOR RS-232
F26F              ;
F26F              ;CHECK FOR CASSETTE FILE TYPE
F26F              ;
F26F  A6 B9       L973   LDX SA
F271  E0 60              CPX #$60         ;INPUT FILE?
F273  F0 EA              BEQ L972         ;YES, ERROR
F275  85 9A       L977   STA DFLTO        ;SET OUTPUT
F277  18                 CLC              ;GOOD RETURN
F278  60                 RTS
F279              ;
F279              ;SERIAL DEVICES
F279              ;
F279  AA          L975   TAX              ;SAVE DEVICE #
F27A  20 0C ED           JSR L966         ;LISTEN
F27D  A5 B9              LDA SA           ;AND SECOND?
F27F  10 05              BPL L976         ;YES
F281  20 BE ED           JSR L983         ;NO, RELEASE LINES
F284  D0 03              BNE L981         ;ALWAYS
F286  20 B9 ED    L976   JSR L871         ;SEND LISTEN SA
F289  8A          L981   TXA
F28A  24 90              BIT STATUS       ;DID IT LISTEN?
F28C  10 E7              BPL L977         ;YES, FINISH
F28E  4C 07 F7           JMP L1026        ;NO, DEVICE NOT PRESENT
F291              .END
F291                     .LIB KSER4
```

CLOSE

Entry point: $FFC3

Function: Close a logical file.

Input parameters: .A holds the logical file number to close.

Output parameters: CARRY clear.

Registers used: .A, .Y, .X

Error messages: None.

Description: The LFN table is checked for the file to be closed. If the file is not open the routine exits, otherwise the device is told to listen and then unlisten and the file entry is removed from the table.

```
LOC   CODE         LINE


F291               ;
F291               ;****************************************
F291               ;* CLOSE -- CLOSE LOGICAL FILE.
F291               ;*      THE LOGICAL FILE NUMBER OF THE
F291               ;* FILE TO BE CLOSED IS PASSED IN .A.
F291               ;* KEYBOARD, SCREEN, AND FILES NOT OPEN
F291               ;* PASS STRAIGHT THROUGH. TAPE FILES
F291               ;* OPEN FOR WRITE ARE CLOSED BY DUMPING
F291               ;* THE LAST BUFFER AND CONDITIONALLY
F291               ;* WRITING AN END OF TAPE BLOCK. SERIAL
F291               ;* FILES ARE CLOSED BY SENDING A CLOSE
F291               ;* FILE COMMAND IF A SECONDARY ADDRESS
F291               ;* WAS SPECIFIED IN ITS OPEN COMMAND.
F291               ;****************************************
F291               ;
F291  20 14 F3     NCLOSE JSR L957          ;LOOK UP FILE
F294  F0 02               BEQ L982          ;FOUND
F296  18                  CLC               ;ELSE RETURN
F297  60                  RTS
F298  20 1F F3     L982   JSR L1002         ;GET FILE DATA
F29B  8A                  TXA               ;SAVE TABLE INDEX
F29C  48                  PHA
F29D  A5 BA               LDA FA            ;CHECK DEVICE #
F29F  F0 50               BEQ L987          ;KEYBOARD, DONE
F2A1  C9 03               CMP #$03          ;SCREEN?
F2A3  F0 4C               BEQ L987          ;YES, DONE
F2A5  B0 47               BCS L997          ;SERIAL
F2A7  C9 02               CMP #$02          ;RS-232?
F2A9  D0 1D               BNE $F2C8         ;NO, MUST BE TAPE
F2AB               ;--------------------------
F2AB               *=$F2EE
F2EE               ;CLOSE A SERIAL FILE
F2EE               ;
F2EE  20 42 F6     L997   JSR L1081
F2F1               ;
F2F1               ;REMOVE FILE ENTRIES FROM TABLES
F2F1               ;
F2F1  68           L987   PLA               ;GET TABLE INDEX
F2F2  AA           L986   TAX
F2F3  C6 98               DEC LDTND
F2F5  E4 98               CPX LDTND         ;IS IT AT END?
F2F7  F0 14               BEQ L989          ;YES, DONE
F2F9  A4 98               LDY LDTND         ;NO, SHIFT LAST ENTRY
F2FB  B9 59 02            LDA LAT,Y         ;INTO DELETED ENTRY'S
F2FE  9D 59 02            STA LAT,X         ;POSITION
F301  B9 63 02            LDA FAT,Y
F304  9D 63 02            STA FAT,X
F307  B9 6D 02            LDA SAT,Y
F30A  9D 6D 02            STA SAT,X
F30D  18           L989   CLC               ;GOOD EXIT
F30E  60                  RTS
F30F               ;FIND FILE ENTRY
F30F               ;
F30F  A9 00        L1000  LDA #$00
F311  85 90               STA STATUS
F313  8A                  TXA
F314  A6 98        L957   LDX LDTND
F316  CA           L984   DEX
F317  30 15               BMI L960
F319  DD 59 02            CMP LAT,X
F31C  D0 F8               BNE L984
F31E  60                  RTS
F31F               ;
F31F               ;FETCH TABLE ENTRIES
F31F               ;
F31F  BD 59 02     L1002  LDA LAT,X
F322  85 B8               STA LA
```

```
LOC   CODE        LINE

F324  BD 63 02            LDA FAT,X
F327  85 BA               STA FA
F329  BD 6D 02            LDA SAT,X
F32C  85 B9               STA SA
F32E  60          L960    RTS
F32F              .END
F32F                      .LIB KSER5
```

CLALL

Entry point: $FFE7

Function: Close all logical files.

Input parameters: None

Output parameters: None

Registers used: .A, .X

Error messages: None

Description: The number of files open is zeroed and the CLRCH routine is entered.

```
LOC   CODE        LINE

 F32F               ;
 F32F               ;****************************************
 F32F               ;* CLALL -- CLOSE ALL LOGICAL FILES.
 F32F               ;*       DELETES ALL TABLE ENTRIES AND
 F32F               ;* RESTORES DEFAULT I/O  CHANNELS AND
 F32F               ;* CLEARS SERIAL PORT DEVICES
 F32F               ;****************************************
 F32F               ;
 F32F  A9 00        NCLALL LDA #$00
 F331  85 98               STA LDTND       ;FORGET ALL FILES
```

CLRCH

Entry point: $FFCC

Function: Abort any serial I/O files and reset default I/O.

Input parameters: None

Output parameters: None

Registers used: .A, .X

Error messages: None

Description: The output device is checked and if it is serial, the command UNLISTEN is sent to it. The input device is then checked and if that is serial the command UNTALK is sent to it. The input device is then set to Ø (keyboard) and the output device is set to 3 (screen).

```
LOC   CODE        LINE

F333              ;
F333              ;****************************************
F333              ;* CLRCH -- CLEAR CHANNELS.
F333              ;*       UNLISTEN OR UNTALK SERIAL
F333              ;* DEVICES, BUT LEAVE OTHERS ALONE.
F333              ;* DEFAULT CHANNELS ARE RESTORED.
F333              ;****************************************
F333              ;
F333  A2 03       NCLRCH LDX #$03
F335  E4 9A              CPX DFLTO        ;OUTPUT CHANNEL SERIAL?
F337  B0 03              BCS L1001        ;NO
F339  20 FE ED           JSR L1006        ;YES, UNLISTEN
F33C  E4 99       L1001  CPX DFLTN        ;INPUT CHANNEL SERIAL?
F33E  B0 03              BCS L1003        ;NO
F340  20 EF ED           JSR L863         ;YES, UNTALK
F343  86 9A       L1003  STX DFLTO        ;OUTPUT CHANNEL=3
F345  A9 00              LDA #$00
F347  85 99              STA DFLTN        ;INPUT CHANNEL=0
F349  60                 RTS
F34A              .END
F34A                     .LIB KSER6
```

OPEN

Entry point: $FFCØ

Function: Open a logical file.

Input parameters:
$B7 – Length of text string to send with OPEN command (filename)
$B8 – Logical file number
$B9 – Secondary address
$BA – Device number
$BB/$BC – Pointer to filename

Output parameters:
CARRY clear – OK
CARRY set – error, error number in .A

Registers used: .A, .X, .Y

Error messages:
File open – if the file number in $B8 is equal to any entry in the LFN table
Too many files – if the LFN table already has 1Ø entries
Device not present – if the device in $BA did not respond to the LISTEN command

Description: The LFN table is checked to see if the file number already exists (file open), and if so exits with error. The number of files open is then checked for ten (too many files), and if so exits with error. Otherwise, the file entry is submitted to the file tables (with the secondary address ORed with $6Ø) and the number of files open incremented.

If there is no secondary address (>127), OPEN then exits. If there is no filename, OPEN exits. Otherwise, the device to be opened is told to LISTEN and the secondary address is sent. If bit 7 of ST is set, the routine exits with a device not present error. The filename is then sent one byte at a time and an UNLISTEN command is sent to the device.

```
LOC   CODE        LINE

 F34A             ;
 F34A             ;***************************************
 F34A             ;* OPEN  -- OPEN A FILE.
 F34A             ;*      CREATES AN ENTRY IN THE FILE
 F34A             ;* FILE TABLES CONSISTING OF LOGICAL
 F34A             ;* FILE NUMBER, DEVICE NUMBER, AND SEC
 F34A             ;* ADDRESS NUMBER.
 F34A             ;*      ROUTINES SETLFS & SETNAM SHOULD
 F34A             ;* BE USED FIRST.
 F34A             ;***************************************
 F34A             ;
 F34A  A6 B8      NOPEN  LDX LA           ;CHECK FILE #
 F34C  D0 03             BNE L1005       ;NOT KEYBOARD
 F34E  4C 0A F7          JMP L971        ;NOT INPUT FILE
 F351  20 0F F3   L1005  JSR L1000       ;ALREADY OPEN?
 F354  D0 03             BNE L1007       ;NO
 F356  4C FE F6          JMP L1011       ;YES, FILE OPEN
 F359  A6 98      L1007  LDX LDTND        ;END OF TABLE?
 F35B  E0 0A             CPX #$0A
 F35D  90 03             BCC L1008       ;NO
 F35F  4C F8 F6          JMP L1097       ;YES, TOO MANY FILES
 F362  E6 98      L1008  INC LDTND        ;NEW FILE
 F364  A5 B8             LDA LA
 F366  9D 59 02          STA LAT,X       ;STORE FILE #
 F369  A5 B9             LDA SA
 F36B  09 60             ORA #$60        ;MAKE SA SERIAL
 F36D  85 B9             STA SA
 F36F  9D 6D 02          STA SAT,X       ;STORE SA
 F372  A5 BA             LDA FA
 F374  9D 63 02          STA FAT,X       ;STORE DEVICE #
 F377             ;
 F377             ;PERFORM DEVICE SPECIFIC OPEN TASKS
 F377             ;
 F377  F0 5A             BEQ L1030       ;KEYBOARD, DONE
 F379  C9 03             CMP #$03        ;SCREEN?
 F37B  F0 56             BEQ L1030       ;YES, DONE
 F37D  90 05             BCC $F384       ;CASSETTE OR RS-232
 F37F  20 D5 F3          JSR L1021       ;OPEN SERIAL
 F382  90 4F             BCC L1030       ;ALWAYS, DONE
 F384             ;-------------------------
 F384             *=$F3D3
 F3D3  18         L1030  CLC
 F3D4  60         L1012  RTS              ;EXIT
 F3D5             ;
 F3D5             ;OPEN SERIAL
 F3D5             ;
 F3D5  A5 B9      L1021  LDA SA
 F3D7  30 FA             BMI L1030       ;NO SA, DONE
 F3D9  A4 B7             LDY FNLEN
 F3DB  F0 F6             BEQ L1030       ;NO FILENAME, DONE
```

```
LOC   CODE        LINE

F3DD  A9 00             LDA #$00
F3DF  85 90             STA STATUS
F3E1  A5 BA             LDA FA
F3E3  20 0C ED          JSR L966        ;DEVICE LA TO LISTEN
F3E6  A5 B9             LDA SA
F3E8  09 F0             ORA #$F0
F3EA  20 B9 ED          JSR L871
F3ED  A5 90             LDA STATUS      ;DEVICE THERE?
F3EF  10 05             BPL L1014       ;YES
F3F1  68                PLA             ;NO
F3F2  68                PLA
F3F3  4C 07 F7          JMP L1026       ;DEVICE NOT PRESENT
F3F6  A5 B7       L1014 LDA FNLEN
F3F8  F0 0C             BEQ L1033       ;NO NAME, DONE
F3FA              ;
F3FA              ;SEND FILE NAME
F3FA              ;
F3FA  A0 00             LDY #$00
F3FC  B1 BB       L1031 LDA (FNADR),Y
F3FE  20 DD ED          JSR L861
F401  C8                INY
F402  C4 B7             CPY FNLEN
F404  D0 F6             BNE L1031
F406  4C 54 F6    L1033 JMP L999         ;UNLISTEN AND RETURN
F409              ;-------------------------------
F409              .END
F409                    .LIB KSER7
```

LOAD/VERIFY

Entry point: $FFD5

Function: Load or verify a file from serial to RAM.

Input parameters:

$B7	-	Length of text string to send with OPEN command (filename)
$B8	-	Logical file number
$B9	-	Secondary address
$BA	-	Device number
$BB/$BC	-	Pointer to filename
.A	-	Load (Ø)/verify (≠Ø) flag
.Y/.X	-	Alternative load address (only if $B9=Ø)

Output parameters:

OK	-	CARRY clear .Y/.X end address
Error	-	CARRY set .A error number

Registers used: .A, .X, .Y

Error messages:

Missing filename - if length of filename is zero

File not found - if attempting to read the first byte gives a framing error

Break – if the stop key was pressed
Verify – if on verifying, the file does not match the memory contents

Description: The alternative load address is stored away. If the filename length is zero, a missing filename error is produced. Otherwise, the message 'searching for ...' is printed to the screen and the file is opened (with SA=$6Ø). The device is commanded to TALK and the first byte is read in and stored to the load address low. If bit 1 of ST is set (file not found), the file is closed and LOAD exits with error in .A. Another byte is read and stored in the load address high. If the original secondary address was zero, the load address is replaced by the alternative load address.

The message 'loading' is printed to the screen and each byte is read in until an end of file (bit 6 of ST) is encountered or the stop key is pressed (break). With each byte, it is either stored to memory or compared with memory and if different, bit 4 of ST is set. The address is bumped by 1 and the next byte handled.

When EOF has been found, the .X and .Y registers are loaded with the end address, CARRY is cleared and LOAD exits.

```
LOC   CODE        LINE

F409              *=$F49E
F49E              ;
F49E              ;****************************************
F49E              ;* LOAD RAM FUNCTION.
F49E              ;*      LOADS FROM CASSETTE OR SERIAL BUS
F49E              ;* DEVICES >=4 TO 31 AS DETERMINED BY
F49E              ;* CONTENTS OF VARIABLE FA. VERIFY FLAG
F49E              ;* IN .A.
F49E              ;*      ALT LOAD IF SA=0, NORMAL SA=1
F49E              ;*      .X, .Y LOAD ADDRESS IF SA=0
F49E              ;*      .A=0 PERFORMS LOAD,<>0 IS VERIFY.
F49E              ;* HIGH LOAD RETURN IN .X,.Y
F49E              ;* USE SETLFS & SETNAM BEFORE THIS ROUTINE
F49E              ;****************************************
F49E              ;
F49E  86 C3       L990    STX MEMUSS        ;LO ALT START
F4A0  84 C4               STY MEMUSS+1      ;HI ALT START
F4A2  6C 30 03            JMP (ILOAD)
F4A5  85 93       NLOAD   STA VERCK         ;STORE VERIFY FLAG
F4A7  A9 00               LDA #$00
F4A9  85 90               STA STATUS
F4AB  A5 BA               LDA FA            ;CHECK DEVICE #
F4AD  D0 03               BNE L1046
F4AF  4C 13 F7    L1241   JMP L1049         ;KEYBOARD, BAD DEVICE
F4B2  C9 03       L1046   CMP #$03          ;SCREEN?
F4B4  F0 F9               BEQ L1241         ;YES
F4B6  90 7B               BCC $F533         ;TAPE
F4B8              ;
F4B8              ;LOAD FROM SERIAL BUS DEVICES
F4B8              ;
F4B8  A4 B7               LDY FNLEN         ;MUST HAVE FILENAME
F4BA  D0 03               BNE L1045         ;O.K.
F4BC  4C 10 F7            JMP L974          ;MISSING FILENAME
F4BF  A6 B9       L1045   LDX SA
F4C1  20 AF F5            JSR L1062         ;'SEARCHING'
F4C4  A9 60               LDA #$60          ;SPECIAL LOAD COMMAND
F4C6  85 B9               STA SA
F4C8  20 D5 F3            JSR L1021         ;OPEN FILE
```

```
LOC   CODE        LINE

F4CB  A5 BA             LDA FA
F4CD  20 09 ED          JSR L836        ;TALK, ESTABLISH CHANNEL
F4D0  A5 B9             LDA SA
F4D2  20 C7 ED          JSR L860        ;TELL IT TO LOAD
F4D5  20 13 EE          JSR L865        ;GET FIRST BYTE
F4D8  85 AE             STA EAL
F4DA  A5 90             LDA STATUS      ;ERROR?
F4DC  4A                LSR A
F4DD  4A                LSR A
F4DE  B0 50             BCS L1058       ;FILE NOT FOUND
F4E0  20 13 EE          JSR L865
F4E3  85 AF             STA EAH
F4E5  8A                TXA             ;ORIG SA=0?
F4E6  D0 08             BNE L1048       ;NO
F4E8  A5 C3             LDA MEMUSS      ;YES, SET ALT
F4EA  85 AE             STA EAL         ; LOAD ADDRESS
F4EC  A5 C4             LDA MEMUSS+1
F4EE  85 AF             STA EAH
F4F0  20 D2 F5    L1048 JSR L1070       ;'LOADING'
F4F3  A9 FD       L1051 LDA #$FD        ;MASK OFF TIMEOUT
F4F5  25 90             AND STATUS
F4F7  85 90             STA STATUS
F4F9  20 E1 FF          JSR $FFE1       ;STOP KEY?
F4FC  D0 03             BNE L1055       ;NO
F4FE  4C 33 F6          JMP L1084       ;'BREAK'
F501  20 13 EE    L1055 JSR L865        ;GET BYTE
F504  AA                TAX
F505  A5 90             LDA STATUS      ;TIMEOUT?
F507  4A                LSR A
F508  4A                LSR A
F509  B0 E8             BCS L1051       ;YES, TRY AGAIN
F50B  8A                TXA
F50C  A4 93             LDY VERCK       ;VERIFY?
F50E  F0 0C             BEQ L1053       ;NO, LOAD IT
F510  A0 00             LDY #$00
F512  D1 AE             CMP (EAL),Y     ;VERIFY IT
F514  F0 08             BEQ L1056       ;O.K.
F516  A9 10             LDA #SPERR      ;NO, VERIFY ERROR
F518  20 1C FE          JSR $FE1C       ;UPDATE STATUS
F51B  2C                .BYT $2C        ;SKIP STORE
F51C  91 AE       L1053 STA (EAL),Y
F51E  E6 AE       L1056 INC EAL         ;INCREMENT STORE ADDR
F520  D0 02             BNE L1057
F522  E6 AF             INC EAH
F524  24 90       L1057 BIT STATUS      ;END OF INPUT?
F526  50 CB             BVC L1051       ;NO, CARRY ON
F528  20 EF ED          JSR L863        ;CLOSE CHANNEL
F52B  20 42 F6          JSR L1081       ;CLOSE FILE
F52E  90 79             BCC L1067       ;ALWAYS
F530  4C 04 F7    L1058 JMP L959        ;FILE NOT FOUND
F533                    ;-----------------------------
F533                    *=$F5A9
F5A9  18          L1067 CLC             ;GOOD EXIT
F5AA                    ;
F5AA                    ;SET UP END ADDRESS
F5AA                    ;
F5AA  A6 AE             LDX EAL
F5AC  A4 AF             LDY EAH
F5AE  60          L1059 RTS
F5AF                    ;
F5AF                    ;PRINT 'SEARCHING [FOR NAME]'
F5AF                    ;
F5AF  A5 9D       L1062 LDA MSGFLG      ;PRINT IT?
F5B1  10 1E             BPL L1071       ;NO
F5B3  A0 0C             LDY #$0C        ;'SEARCHING'
F5B5  20 2F F1          JSR $F12F
F5B8  A5 B7             LDA FNLEN
```

```
LOC   CODE        LINE

F5BA  F0 15             BEQ L1071
F5BC  A0 17             LDY #$17        ;'FOR'
F5BE  20 2F F1          JSR $F12F
F5C1                ;
F5C1                ;PRINT FILE NAME
F5C1                ;
F5C1  A4 B7         L1022  LDY FNLEN        ;NAME?
F5C3  F0 0C             BEQ L1071       ;NO, DONE
F5C5  A0 00             LDY #$00
F5C7  B1 BB         L1091  LDA (FNADR),Y
F5C9  20 D2 FF          JSR $FFD2
F5CC  C8                INY
F5CD  C4 B7             CPY FNLEN
F5CF  D0 F6             BNE L1091
F5D1  60            L1071  RTS
F5D2                ;
F5D2                ;PRINT LOADING/VERIFYING
F5D2                ;
F5D2  A0 49         L1070  LDY #$49         ;ASSUME 'LOADING'
F5D4  A5 93             LDA VERCK       ;CHECK FLAG
F5D6  F0 02             BEQ L1052       ;YES, LOADING
F5D8  A0 59             LDY #$59        ;'VERIFYING'
F5DA  4C 2B F1      L1052  JMP $F12B
F5DD                .END
F5DD                    .LIB KSER8
```

SAVE

Entry point: $FFD8

Function: SAVE a section of memory to serial device.

Input parameters:

$B7 - Length of text string to send with open command (filename)
$B8 - Logical file number
$B9 - Secondary address
$BA - Device number
$BB/$BC - Pointer to filename
.A - Pointer to zero page save address
.Y/.X - End of save address
(.A) - Page zero indirect start of save

Output parameters:

CARRY clear - OK
CARRY set - error, error number in .A

Registers used: .A, .X, .Y

Error messages:

Missing filename - if the length of the filename is zero
Break - if the stop key was pressed during SAVE

Description: The length of the filename is checked and if zero (missing filename), exits with error. The file is opened, the message 'saving ...' is printed

to the screen and the device is told to LISTEN. The save address (low followed by high) is sent to the device. The start address is compared with the end address and if reached the file is closed and the routine exits with CARRY clear.

One byte of the file is sent to the device and the stop key is tested. If the stop key was not pressed, the start address is bumped by 1 and the routine loops back to the address comparison. If the stop key was pressed, the file is closed and the routine exits with CARRY set.

```
LOC   CODE         LINE

F5DD               ;
F5DD               ;***************************************
F5DD               ;* SAVE MEMORY FUNCTION.
F5DD               ;*      SAVES TO CASSETTE OR SERIAL
F5DD               ;* DEVICES >=4 TO 31 AS SELECTED BY
F5DD               ;* VARIABLE FA.
F5DD               ;*      START OF SAVE IS INDIRECT AT .A
F5DD               ;* END OF SAVE IS .X, .Y
F5DD               ;* USE SETLFS & SETNAM BEFORE THIS ROUTINE
F5DD               ;***************************************
F5DD               ;
F5DD  86 AE        L1072  STX EAL
F5DF  84 AF               STY EAH
F5E1  AA                  TAX              ;SET UP START
F5E2  B5 00               LDA $00,X
F5E4  85 C1               STA STAL
F5E6  B5 01               LDA $01,X
F5E8  85 C2               STA STAH
F5EA  6C 32 03            JMP (ISAVE)
F5ED  A5 BA        NSAVE  LDA FA
F5EF  D0 03               BNE L1075
F5F1  4C 13 F7     L1242  JMP L1049        ;BAD DEVICE
F5F4  C9 03        L1075  CMP #$03         ;SERIAL?
F5F6  F0 F9               BEQ L1242        ;SCREEN, BAD DEVICE
F5F8  90 5F               BCC $F659        ;NO, TAPE
F5FA  A9 61               LDA #$61         ;YES
F5FC  85 B9               STA SA
F5FE  A4 B7               LDY FNLEN
F600  D0 03               BNE L1074
F602  4C 10 F7            JMP L974         ;MISSING FILE NAME
F605  20 D5 F3     L1074  JSR L1021         ;OPEN
F608  20 8F F6             JSR L1087        ;'SAVING'
F60B  A5 BA                LDA FA
F60D  20 0C ED             JSR L966         ;LISTEN
F610  A5 B9                LDA SA
F612  20 B9 ED             JSR L871         ;LISTEN SA
F615  A0 00                LDY #$00
F617  20 8E FB             JSR $FB8E
F61A  A5 AC                LDA SAL
F61C  20 DD ED             JSR L861
F61F  A5 AD                LDA SAH
F621  20 DD ED             JSR L861
F624  20 D1 FC     L1077  JSR $FCD1         ;COMPARE START TO END
F627  B0 16               BCS L1082        ;HAVE REACHED END
F629  B1 AC                LDA (SAL),Y
F62B  20 DD ED             JSR L861
F62E  20 E1 FF             JSR $FFE1        ;STOP KEY?
F631  D0 07               BNE L1054        ;NO
F633  20 42 F6     L1084  JSR L1081         ;YES, CLOSE
F636  A9 00                LDA #$00
F638  38                   SEC
F639  60                   RTS
F63A               ;
F63A  20 DB FC     L1054  JSR $FCDB         ;INCREMENT CURRENT ADDR
F63D  D0 E5               BNE L1077
```

```
LOC   CODE        LINE

F63F  20 FE ED    L1082  JSR L1006       ;UNLISTEN
F642  24 B9       L1081  BIT SA
F644  30 11              BMI L1034
F646  A5 BA              LDA FA
F648  20 0C ED           JSR L966        ;LISTEN
F64B  A5 B9              LDA SA
F64D  29 EF              AND #$EF
F64F  09 E0              ORA #$E0
F651  20 B9 ED           JSR L871        ;LISTEN SA
F654  20 FE ED    L999   JSR L1006       ;UNLISTEN
F657  18          L1034  CLC             ;GOOD EXIT
F658  60                 RTS
F659              ;-----------------------------
F659              *=$F68E
F68E  60          L1090  RTS
F68F              ;
F68F              ;PRINT 'SAVING [FILE NAME]'
F68F              ;
F68F  A5 9D       L1087  LDA MSGFLG       ;PRINT IT?
F691  10 FB              BPL L1090       ;NO
F693  A0 51              LDY #$51        ;'SAVING'
F695  20 2F F1           JSR $F12F
F698  4C C1 F5           JMP L1022       ;SEND FILENAME
F69B              .END
F69B                     .LIB KSER9
```

Error handler

Entry point:
$F6FB - (1) too many files
$F6FE - (2) file open
$F7Ø1 - (3) file not open
$F7Ø4 - (4) file not found
$F7Ø7 - (5) device not present
$F7ØA - (6) not input file
$F7ØD - (7) not output file
$F71Ø - (8) missing filename
$F713 - (9) bad device

Function: To flag an error and print it if output is enabled.

Input parameters: None

Output parameters: CARRY set, error number in .A

Registers used: .A, .X, .Y

Error message: I/O error #(number) - if bit 6 of MSGFLG is set

Description: At each entry point, the .A register is loaded with the value in brackets. The routine CLRCH is called and if bit 6 of MSGFLG (output enable) is clear, CARRY is set and .A holds the error number upon exit. If bit 6 is set, the message 'I/O error #' is printed to the screen and the number is converted to ASCII and printed. CARRY is set and .A is reloaded with the error number.

```
LOC   CODE        LINE

F69B              *=$F6FB
F6FB              ;**************************************
F6FB              ;* ERROR HANDLER.
F6FB              ;* PRINTS KERNAL ERROR MESSAGE IF BIT 6
F6FB              ;* OF MSGFLG IS SET. RETURNS WITH ERROR
F6FB              ;* # IN .A AND CARRY SET.
F6FB              ;**************************************
F6FB              ;
F6FB  A9 01       L1097  LDA #$01         ;TOO MANY FILES
F6FD  2C                 .BYT $2C
F6FE  A9 02       L1011  LDA #$02         ;FILE OPEN
F700  2C                 .BYT $2C
F701  A9 03       L1009  LDA #$03         ;FILE NOT OPEN
F703  2C                 .BYT $2C
F704  A9 04       L959   LDA #$04         ;FILE NOT FOUND
F706  2C                 .BYT $2C
F707  A9 05       L1026  LDA #$05         ;DEVICE NOT PRESENT
F709  2C                 .BYT $2C
F70A  A9 06       L971   LDA #$06         ;NOT INPUT FILE
F70C  2C                 .BYT $2C
F70D  A9 07       L965   LDA #$07         ;NOT OUTPUT FILE
F70F  2C                 .BYT $2C
F710  A9 08       L974   LDA #$08         ;MISSING FILE NAME
F712  2C                 .BYT $2C
F713  A9 09       L1049  LDA #$09         ;BAD DEVICE #
F715  48                 PHA             ;ERROR # ON STACK
F716  20 CC FF           JSR $FFCC       ;RESTORE I/O
F719  A0 00              LDY #$00
F71B  24 9D              BIT MSGFLG      ;PRINT ERROR?
F71D  50 0A              BVC L1018       ;NO
F71F  20 2F F1           JSR $F12F       ;PRINT 'I/O ERROR #'
F722  68                 PLA
F723  48                 PHA
F724  09 30              ORA #$30        ;MAKE ERROR # ASCII
F726  20 D2 FF           JSR $FFD2       ;PRINT IT
F729  68          L1018  PLA
F72A  38                 SEC
F72B  60                 RTS
F72C              ;------------------------------
F72C              .END
F72C                     .END
```

Symbol table

```
SYMBOL VALUE
 AUTODN   0292   BAD      0100   BASZPT   00FF   BAUDOF   0299
 BDF      0002   BDFH     0004   BITCI    00A8   BITNUM   0298
 BITTS    00B4   BLF      0001   BLNCT    00CD   BLNON    00CF
 BLNSW    00CC   BLUE     0006   BSOUR    0095   BSOUR1   00A4
 BUF      0200   BUFPT    00A6   BUFSZ    00C0   C3PO     0094
 CAS1     00C0   CBINV    0316   CBMCOL   D800   CBMSCN   0400
 CINV     0314   CKERR    0020   CMPO     00B0   CNTDN    00A5
 COLM     DC00   COLOR    0286   COUNT    00A5   CR       000D
 CRSW     00D0   D1CRA    DC0E   D1CRB    DC0F   D1DDRA   DC02
 D1DDRB   DC03   D1DFA    DC00   D1DFB    DC01   D1ICR    DC0D
 D1IODB   DC0C   D1TAH    DC05   D1TAL    DC04   D1TBH    DC07
 D1TBL    DC06   D1TOD1   DC08   D1TOD2   DC09   D1TOD3   DC0A
 D1TOD4   DC0B   D2CRA    DD0E   D2CRB    DD0F   D2DDRA   DD02
 D2DDRB   DD03   D2DFA    DD00   D2DFB    DD01   D2ICR    DD0D
 D2IODB   DD0C   D2TAH    DD05   D2TAL    DD04   D2TBH    DD07
 D2TBL    DD06   D2TOD1   DD08   D2TOD2   DD09   D2TOD3   DD0A
 D2TOD4   DD0B   DATA     00D7   DELAY    028C   DFLTN    0099
 DFLTO    009A   DIFF     00B5   DFSW     009C   EAH      00AF
 EAL      00AE   EOT      0005   FA       00BA   FAT      0263
 FIRT     00A4   FNADR    00BB   FNLEN    00B7   FREKZP   00FB
 FSBLK    00BE   GDBLN    00CE   GDCOL    0287   HIBASE   0288
```

SYMBOL	VALUE						
IBASIN	0324	IBSOUT	0326	ICHKIN	031E	ICKOUT	0320
ICLALL	032C	ICLOSE	031C	ICLRCH	0322	IGETIN	032A
ILOAD	0330	INBIT	00A7	INDX	00C8	INSRT	00DB
IOPEN	031A	IRQTMP	029F	ISAVE	0332	ISTOP	0328
KEYD	0277	KEYLOG	028F	KEYTAB	00F5	KOUNT	028B
L1000	F30F	L1001	F33C	L1002	F31F	L1003	F343
L1004	EE03	L1005	F351	L1006	EDFE	L1007	F359
L1008	F362	L1009	F701	L1011	F6FE	L1012	F3D4
L1014	F3F6	L1018	F729	L1021	F3D5	L1022	F5C1
L1026	F707	L1030	F3D3	L1031	F3FC	L1033	F406
L1034	F657	L1045	F4BF	L1046	F4B2	L1048	F4F0
L1049	F713	L1051	F4F3	L1052	F5DA	L1053	F51C
L1054	F63A	L1055	F501	L1056	F51E	L1057	F524
L1058	F530	L1059	F5AE	L1062	F5AF	L1067	F5A9
L1070	F5D2	L1071	F5D1	L1072	F5DD	L1074	F605
L1075	F5F4	L1077	F624	L1081	F642	L1082	F63F
L1084	F633	L1087	F68F	L1090	F68E	L1091	F5C7
L1097	F6FB	L1241	F4AF	L1242	F5F1	L836	ED09
L839	ED2E	L840	ED50	L841	EEA0	L842	ED36
L843	EE8E	L844	EE97	L845	EEB6	L846	EEB3
L847	EDB0	L848	ED66	L849	ED55	L850	ED5A
L851	ED7A	L852	EDB2	L853	ED7D	L854	EEA9
L855	ED9F	L856	EDAD	L858	EE06	L859	ED40
L860	EDC7	L861	EDDD	L862	EDEB	L863	EDEF
L864	ED20	L865	EE13	L866	EE20	L867	EE47
L868	EE3E	L869	EE5A	L870	EE56	L871	EDB9
L872	EE30	L873	EE67	L874	EE80	L875	EE85
L876	EE09	L924	F14A	L926	F14E	L927	F166
L928	F173	L932	F1B1	L933	F1D5	L939	F1AD
L941	F1B5	L943	EE1B	L944	F155	L945	F1B4
L946	F1B3	L949	EDE6	L950	F216	L957	F314
L958	F22A	L959	F704	L960	F32E	L961	F237
L962	F245	L963	F233	L965	F70D	L966	ED0C
L967	F248	L968	EDD6	L969	F258	L970	EDCC
L971	F70A	L972	F25F	L973	F26F	L974	F710
L975	F279	L976	F286	L977	F275	L979	F262
L980	ED11	L981	F289	L982	F298	L983	EDBE
L984	F316	L986	F2F2	L987	F2F1	L989	F30D
L990	F49E	L997	F2EE	L999	F654	LA	00B8
LAT	0259	LBERR	0008	LDTB1	00D9	LDTND	0098
LINTMP	00F2	LLEN	0028	LLEN2	0050	LNMX	00D5
LSTP	00CA	LSTSHF	028E	LSTX	00C5	LSXP	00C9
LTBLUE	000E	M26AJB	0295	M26CDR	0294	M26CTR	0293
MAXCHR	0050	MEMSIZ	0283	MEMSTR	0281	MEMUSS	00C3
MODE	0291	MSGFLG	009D	MYCH	00BF	NBASIN	F157
NBSOUT	F1CA	NCHKIN	F20E	NCKOUT	F250	NCLALL	F32F
NCLOSE	F291	NCLRCH	F333	NDX	00C6	NGETIN	F13E
NLINES	0019	NLOAD	F4A5	NMINV	0318	NOPEN	F34A
NSAVE	F5ED	NWRAP	0002	NXTBIT	00B5	OCHAR	00BD
PCNTR	00A3	PLF	0003	PNT	00D1	PNTR	00D3
PRP	00B6	PRTY	009B	PTR1	009E	PTR2	009F
QTSW	00D4	R2D2	00A3	RDFLG	00AA	RER	00A8
REZ	00A9	RIBUF	00F7	RIDATA	00AA	RIDBE	029B
RIDBS	029C	RINONE	00A9	RIPRTY	00AB	ROBUF	00F9
RODATA	00B6	RODBE	029E	RODBS	029D	ROPRTY	00BD
ROWS	DC01	RPTFLG	028A	RSSTAT	0297	RVS	00C7
SA	00B9	SAH	00AD	SAL	00AC	SAT	026D
SBERR	0004	SFDX	00CB	SHCNH	00AB	SHCNL	00A7
SHFLAG	028D	SIDREG	D400	SNSW1	00B4	SPERR	0010
STAH	00C2	STAL	00C1	STATUS	0090	STKEY	0091
SVXT	0092	SYNO	0096	T1	009E	T2	009F
TAPE1	00B2	TBLX	00D6	TBUFFR	033C	TEMP	00B1
TIME	00A0	TIMOUT	0285	TMP2	00C3	TMPC	009F
TMPO	00C1	USER	00F3	USRCMD	032E	VERCK	0093
VICREG	D000	XMAX	0289	XSAV	0097		

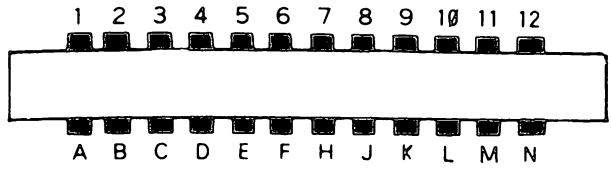
3.4 RS232 serial communications

The CBM 64 is able to communicate with peripheral devices, known as an RS232 I/O port. The name RS232 simply refers to an industry standard form of serial communication for computing devices. A serial I/O port can consist of as few as three lines, an output or transmit line, an input or receive line and a common ground line. The data is transmitted or received as a stream of pulses; a single byte becomes a string of eight pulses.

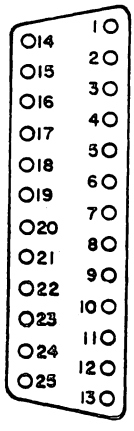
Although a serial port can have just three lines, other lines are frequently used to transfer control information. The 64 is able to receive and generate such control signals to implement a full 'X line' interface as well as the simple '3 line' interface. Whichever implementation is used all the lines are connected to I/O port B of CIA#2 (user port). The RS232 routines inside the 64 also use two other lines; PA2 on port A and FLAG which is connected to the NMI line. Normally an RS232 interface card will be used to connect between the user port and a standard RS232 connector. The card will also provide buffering and a higher drive voltage. For communications using the simple 3 line mode an interface card can easily be constructed using a couple of buffer/driver ICs. The RS232 line normally transmits data using a 12 volt signal, however, and providing cables are kept short it will work with a 5 volt signal. The standard RS232 connector is shown in Fig. 3.4. The function and pin assignment of each of these lines is as follows:

CIA line #	RS232 pin #	CIA pin #	Abv	EIA	In/ Out	Modes	Function
GND	1	A	GND	AA	---	1,2	Protective ground
FLAG	3	B	SIN	BB	In	1,2	Received data
PBØ	3	C	SIN	BB	In	1,2	Connected to FLAG
PB1	4	D	RTS	CA	Out	2	Request to send
PB2	2Ø	E	DTR	CD	Out	2	Data terminal ready
PB3	18	F	RI	CE	In	3	Ring indicator
PB4	8	H	DCD	CF	In	2	Received line signal
PB5	Not assigned						
PB6	5	K	CTS	CB	In	2	Clear to send
PB7	6	L	DSR	CC	In	2	Data set ready
PA2	2	M	SOUT	BA	Out	1,2	Transmitted data
GND	7	N	GND	AB	---	2,3	Signal ground

Modes:
1 Three line interface (note RTS and DTR are both held high during this mode)
2 X line interface
3 User only, not implemented in the CBM 64 code



PIN	TYPE	RS232 FUNCTION
A		
B	FLAG	┐
C	PB0	┴ Sin
D	PB1	— RTS
E	PB2	— DTR
F	PB3	— RI
H	PB4	— DCD
J		
K	PB6	— CTS
L	PB7	— DSR
M	PA2	— Sout
N	GND	— GND



PIN		
1	Protective Ground	AA
2	Transmitted Data	BA
3	Received Data	BB
4	Request To Send	CA
5	Clear To Send	CB
6	Data Set Ready	CC
7	Signal Ground	AB
8	Carrier Detect	CF
9	(not used)	
10	"	
11	"	
12	"	
13	"	
14	"	
15	"	
16	"	
17	"	
18	"	
19	"	
20	Data Terminal Ready	CD
21	(not used)	
22	"	
23	"	
24	"	
25	"	

Fig. 3.4. CBM 64 RS232 connector, pin allocations and E/A line coding.

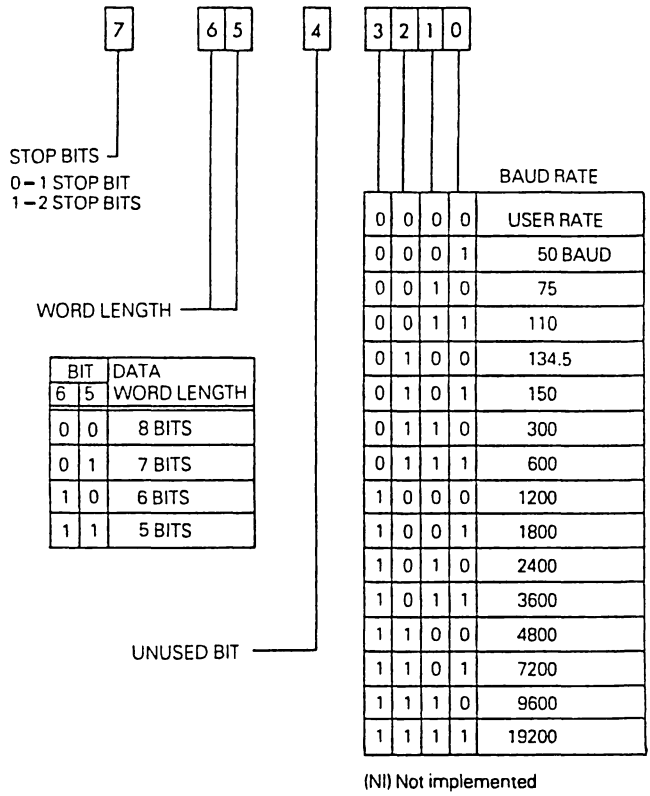
The implementation of the RS232 port on the 64 is very interesting since it involves the use of software (originally used on the VIC 20 with very few modifications for the 64) to emulate a hardware device (that was never used). This device was called the 6551 universal asynchronous receiver and transmitter or UART. Like the other I/O chips, it was intended that the 6551 functions were to be controlled by registers at specific memory locations. The software uses the same principle because when it was written for the VIC 20, Commodore

intended to replace the software with the 6551 when it became available, so there would be complete compatibility.

The pseudo registers are located in various parts of the variable storage area at the bottom of CBM 64 memory. Besides the registers, the RS232 routines require two 256 byte buffers; one for received data and one for data to be transmitted. The 512 bytes of memory occupied by these buffers are located at the top of available RAM memory, and the starting address of the two buffers is stored in four register bytes. The two most important registers are the control and command registers. These determine the exact operation of the RS232 port. They can be summarised as follows:

3.4.1 RS232 control register - Hex $Ø923 Decimal 659

The function of the control register (Fig. 3.5) is to set the speed of data transmission and reception and set the number of bits needed to transmit each character. The speed at which data is input or output is called the baud rate, and



BIT 6	BIT 5	DATA WORD LENGTH
0	0	8 BITS
0	1	7 BITS
1	0	6 BITS
1	1	5 BITS

3	2	1	0	BAUD RATE
0	0	0	0	USER RATE
0	0	0	1	50 BAUD
0	0	1	0	75
0	0	1	1	110
0	1	0	0	134.5
0	1	0	1	150
0	1	1	0	300
0	1	1	1	600
1	0	0	0	1200
1	0	0	1	1800
1	0	1	0	2400
1	0	1	1	3600
1	1	0	0	4800
1	1	0	1	7200
1	1	1	0	9600
1	1	1	1	19200

(NI) Not implemented

Fig. 3.5. Function of bits in the CBM 64 RS232 control register.

the value assigned to this is the number of bits per second. If the baud rate is set to 3ØØ baud, and each character is transmitted as the eight character bits plus one stop bit and one parity bit - a total of ten bits - then 3Ø characters will be transmitted every second. The selected baud rate depends on the specifications of the device communicating with the 64 via the RS232 port - check the manual

of the device before setting this value. Bits 5, 6 and 7 control the number of bits needed to transmit or receive data between the 64 and a peripheral. The number of bits per character plus the number of stop bits depends on the peripheral.

3.4.2 RS232 command register - Hex $Ø294 Decimal 66Ø

The command register (Fig. 3.6) controls the mode for data transmission and reception. Bit Ø sets the mode; a 3 line mode or an X line mode. Bit 4 sets the duplex mode as follows:

Full duplex - simultaneous transmission and reception of data
Half duplex - alternate transmission and reception of data

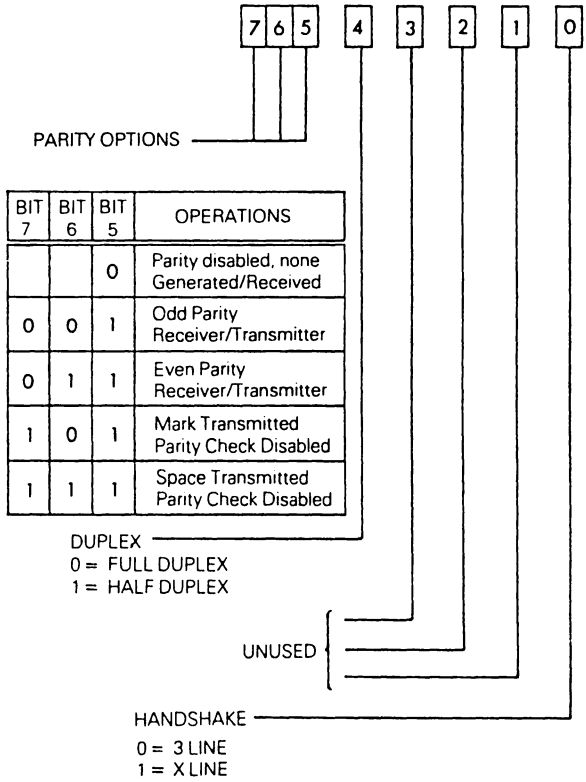


Fig. 3.6. Function of bits in the CBM 64 RS232 command register.

Bits 5, 6 and 7 determine the nature of the parity bit and whether the mark or space is transmitted. The parity bit is transmitted after the data bits and has an error checking function. The choice of whether the parity is disabled or set to odd or even depends on the communicating peripheral. The mark/space setting determines whether a logic '1' is transmitted as a zero voltage or a positive voltage.

3.4.3 RS232 status register - Hex $Ø297 Decimal 663

The function of each bit of the status register is shown in Fig. 3.7. The memory locations and pseudo registers of the RS232 routines are as follows:

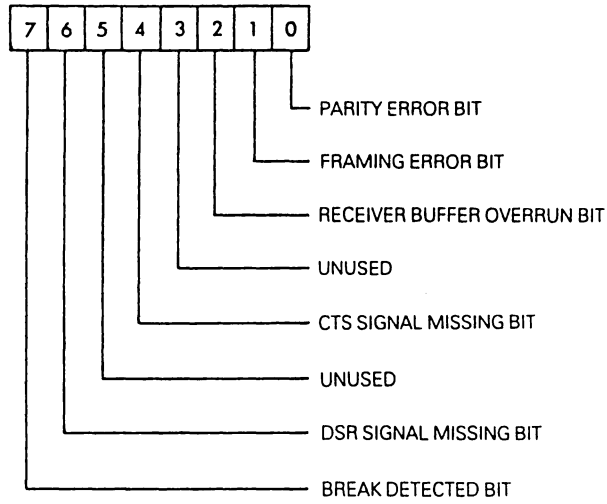


Fig. 3.7. Function of bits in the CBM 64 RS232 status register.

$A7 – receiver bit storage
$A8 – receiver bit count
$A9 – receiver flag start bit check
$AA – receiver byte buffer
$AB – receiver parity storage
$B4 – transmitter bit count
$B5 – transmitter next bit
$B6 – transmitter byte buffer
$BD – transmitter parity storage
$F7–$F8 – input buffer pointer
$F9–$FA – output buffer pointer
$Ø293 – RS232 control register
$Ø294 – RS232 command register
$Ø297 – RS232 status register
$Ø298 – number of bits to send/receive
$Ø299–$Ø29A – baud rate
$Ø29B – input buffer index to end
$Ø29C – input buffer index to start
$Ø29D – output buffer index to start
$Ø29E – output buffer index to end

3.4.4 RS232 system routine entry points

$EEB1 – entry for NMI continue routine
$EED7 – calculate parity
$EFØØ – count stop bits
$EFØ6 – entry to start of byte transmission

$EF13 – set up to send next byte
$EF2E – set errors
$EF4A – calculate number of bits to be sent
$EF59 – NMI routine to collect data into bytes
$EF63 – calculate parity
$EF69 – shift data bit in
$EF6E – have stop bit so store in buffer
$EF7E – enable to receive a byte
$EF9Ø – receiver start bit check
$EF97 – put data in buffer (at parity time)
$EFB3 – parity checking
$EFBC – check calculated parity
$EFC7 – errors reported
$EFE1 – output a file over RS232
$EFE9 – check for DSR and RTS
$EFF2 – check for active input
$EFF9 – wait for CTS to be off
$EFFE – turn on RTS
$FØØ6 – wait for CTS to go on
$FØ14 – buffer handler to output a character
$FØ28 – set up if necessary to output
$FØ4D – input a file over RS232
$FØ59 – check for DSR and not RTS
$FØ62 – wait for active output to be done
$FØ68 – turn off RTS
$FØ7Ø – wait for DCD to go high
$FØ77 – enable FLAG for RS232 input
$FØ7D – if not 3 line half then see if we need to turn on FLAG
$FØ86 – input a character buffer handler
$FØ9B – receiver always runs
$FØA4 – protect serial/cassette from RS232 NMIs

3.5 Using the RS232 port

3.5.1 Opening an RS232 channel

Basic syntax: OPEN lf,2,Ø,"(control register) (command register)"

The syntax coding is as follows:

lf – normal logical file ID (1–255). If lf>127 then line feed follows carriage return.
(control register) – an ASCII character equivalent to the required bit setting of the control register. *Example:* to set baud rate to 3ØØ and transmit 7 bit code use CHR$(6+32) – this sets bits 1, 2 and 5 to '1' and leaves the rest at 'Ø'.
(command register) – an ASCII character equivalent to the required bit setting of the command register. *Example:* to set the output to mark parity and full duplex use CHR$(32+128) – this sets bits 5 and 7 to '1' and leaves the rest at 'Ø'.

Entry point: $FFCØ

Notes on usage: Only one RS232 channel should be open at any time. Since the OPEN statement resets the buffer pointers, a second OPEN will destroy any data in the buffers set up in the first OPEN. The OPEN RS232 channel command should be used before any variable DIM statements; failure to do this will cause wiping of data. This is because the OPEN RS232 channel command performs an automatic CLR before allocating the 512 bytes at the top of memory used for the two RS232 buffers.

3.5.2 Receiving data from an RS232 channel

Basic syntax: GET #lf,(string variable)
lf – logical file ID used in OPEN RS232 channel command.

Entry points:
$FFC6 – set channel for input. Handles full X line implementation according to EIA standard RS232C interfaces. The RTS, CTS, and DCD lines are implemented when the CBM 64 is designated as a data terminal device.
$FFE4 – get character from buffer.

Notes on usage: Received data is put into the 64's 256 byte internal receiver buffer set up during the OPEN routine. Data input is under control of the 6526 timers and NMIs, and is performed in the background during the running of a Basic program. This is done by having the RS232 data input line connected to the FLAG handshake line, and input on FLAG will generate an NMI system interrupt. The use of NMI interrupts is the reason why the cassette and serial bus should not be used during RS232 data communications. The NMI will call the serial data input routines whenever data is present on the RS232 input. These routines will place the received data into the 256 byte receiver buffer located at the top of RAM memory. If the input data has a word width less than eight bits then all unused bits will be filled with zero.

The receiver buffer is organised as a first in first out – FIFO – buffer. The buffer removes the necessity for Basic to wait for data input before processing each byte of data. Instead the Basic program can take data from the buffer when it needs it rather than when it is presented. Basic accesses the buffer using the GET# command to transfer a single byte of data into a Basic variable. If there is no data in the buffer then the GET# command will return with a null character. If the buffer should overflow then all characters are lost. An overflow condition is indicated by bit 2 in the RS232 status register being set. An overflow condition will frequently result if an attempt is made to input data at fairly high data rates using Basic. This is because Basic is normally slow and the use of the GET# command with string concatenation will give rise to frequent garbage collects. Machine language routines are best used for data rates above the normal 300 baud.

3.5.3 Transmitting data to an RS232 channel

Basic syntax: CMD lf PRINT#lf,(variable list)
lf – logical file ID set up in the OPEN command.

Entry points:
$FFC9 – set channel for output. This handles X line handshaking for the

implementation of an EIA standard RS232 interface. The RTS, CTS, and DCD lines are implemented with the 64 as a data terminal.
$FFD2 – output character to channel.

Notes on usage: When either one of the two Basic commands is used data is first transferred from the assigned string or memory block to the 256 byte transmitter buffer. From here it is output to the RS232 channel using the format and baud rate assigned in the OPEN command. Data output is transparent to the operation of Basic since the timing is done by the 6526 timers and output of each byte initiated by an NMI system interrupt. As with data input on the RS232, the cassette or serial port should not be used during data transmission otherwise interrupt conflicts will occur. There is no carriage return delay implemented by the output channel, therefore a normal RS232 printer cannot correctly output the data unless some form of internal buffering or other hold-off is implemented by the printer. If a CTS handshake is implemented (in the X line mode) then the 64 buffer will fill, and output will not occur until transmission is allowed by an input on CTS.

3.5.4 Closing an RS232 data channel

Basic syntax: CLOSE lf
lf – logical file ID set up in the OPEN channel command.

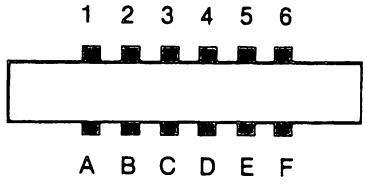
Entry point:
$FFC3 – close logical file

Notes on usage: Closing the RS232 file causes all the data in the buffers to be discarded, stops data transmitting or receiving , sets the RTS and SOUT lines high, and deallocates the memory area used for the RS232 buffers. Closing an RS232 file will also allow the cassette or serial ports to be used. Before closing the channel care should be taken to ensure that all data in the buffer is transmitted. This can be done by checking the status (ST variable) is=Ø and that bit Ø of the RS232 enable register at location 673 ($Ø2A1) is set to logic 1. If both are true then there is still data in the buffer.

Chapter Four
The Cassette Units

4.1 The cassette hardware

The CBM 64 has a single external cassette unit which is used for program and data storage. The cassette deck is connected to the CBM 64 by six lines – write, read, motor, sense and two power lines; ground and +5 volts. The connections are shown in Fig. 4.1. The cassette is controlled by I/O lines from the the CIA chip and the processor I/O register. The source of each of the cassette control lines is shown in Fig. 4.2. The cassette motor power supply lines are connected to the processor chip via a three transistor driver, used to boost the power and voltage, allowing the motor to be driven directly. The output to the motor is an



PIN #	TYPE
A-1	GND
B-2	+5V
C-3	CASSETTE MOTOR
D-4	CASSETTE READ
E-5	CASSETTE WRITE
F-6	CASSETTE SWITCH

Fig. 4.1. The allocation and function of pins on the cassette connector.

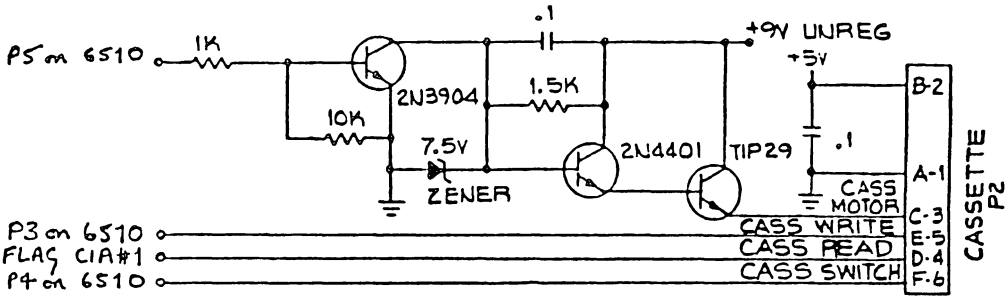


Fig. 4.2. The cassette circuit and its connection to the 6522 chips.

unregulated +9 volts at a power rating of up to 1ØØ mA. The cassette deck motor can be turned on and off by toggling line 5 of the processor I/O register:

```
POKE 1,PEEK(1) AND 191   turns the motor on
POKE 1,PEEK(1) OR 64     turns it off
```

Great care should be taken not to alter the status of bits 1 and 2 of location 1 when using this command, since these control the memory configuration of the machine. The sense line input, line 4 of the processor I/O register, is connected to a switch on the cassette deck which senses when the play, rewind or fast forward buttons have been pressed. The switch is only required to sense the pushing of the play button during a read or write to tape routine; this is done by a subroutine at $F82E. If either the rewind or fast forward button is pressed accidentally instead of the play button, the system will be unable to tell the difference and will act as if the play button has been pressed. For a similar reason during a record routine the record button must be pressed before the play button, since recording will start as soon as the sense switch is closed by pressing the play button.

The cassette read line is connected to the negative edge sensitive serial input line of CIA#1 and the cassette write line to line 3 of the processor I/O register. During a read operation the operating system uses the setting of the CIA#1 interrupt flag to detect transitions on the cassette read line. The functioning of the read and write lines is controlled entirely by the operating system, the only hardware required being signal amplification and pulse shaping circuitry. These circuits are contained on a small PC board within the cassette deck, their function being to give correct voltage and current to the record head and amplify the input from the read head to give a 5 volt square wave output, able to produce an interrupt on the FLAG or CB1 lines.

4.2 Cassette operation

In normal usage the cassette deck is assigned an I/O device number. The cassette is device number 1, and the number of the device currently being used is stored in location 186. The device number together with the logical file number and the secondary address is used when saving or retrieving data files from the cassette deck. The logical file number can be any number from 1 to 255 and is used to allow multiple files to be kept on the same device. It is of little use with cassette tape and is intended primarily for use with floppy disk units. It is usual to have the logical file number the same as the device number; the logical file number of the current file is stored in location 184. The secondary address is important since it determines the operational mode of the cassette; the current secondary address is stored in location 185, the normal default value being zero. If the secondary address is zero then the tape is opened for a 'read' operation, if it is set to 1 then it is opened for a 'write' operation, and if 2 then it is opened for a 'write' with an end of tape header being forced when the file is closed.

The CBM 64 operating system is configured to allow two different types of file to be stored on cassette: program files and data files. These names are rather

misleading, however, since a program can be stored as a data file and data can be stored as a program file. The difference between these two file types is not in their application but in the way the contents of the machine's memory are recorded. Instead of program and data files we must look upon them as binary and ASCII files.

4.3 Binary files

A binary file is usually used to store programs, since a binary file is created by the operating system to store the contents of memory between a starting location and an end location. It is called a binary file because it stores on tape the binary value in each memory location within the assigned memory area. Basic statements are stored in memory using tokens. The use of tokens means that Basic commands are not stored in the same manner as they are listed on the display or were entered on the keyboard. They are instead stored in memory in a partly encoded form. Being partly encoded, a binary file is a quicker and more efficient way of storing programs. Binary files are essential when saving and loading machine code programs.

The starting address from which a binary file will be saved is stored in locations 172 and 173. These locations are loaded by the SAVE routine with the memory location at which the SAVE will begin. Normally they will be set to Ø1 and Ø8, thereby pointing to the start of the Basic text area at 2Ø49. They can be altered by the SAVE routine to point to any location in memory. The end address of the area of memory to be saved is stored in locations 174 and 175. Normally when saving a Basic program these are set to the address of the double zero byte terminating link address. The end address can be altered to any desired location. To change either of these addresses one cannot use the normal SAVE routine since this automatically initialises these locations. Instead one must write a small machine code initialisation routine incorporating the desired operating system subroutines. By default a SAVE command will write a binary file and a LOAD command will read a binary file.

4.4 ASCII files

An ASCII file is normally used to store data but it can be used to store programs (see the MERGE procedure). The format is the same as that displayed on the screen or entered on the keyboard. ASCII files are created or read almost exclusively by instructions from within a Basic program. A binary file is created or read mostly by direct instructions, though the LOAD and SAVE instructions can be used within a program.

An ASCII file must first be opened with an OPEN statement. This specifies the logical file, device number, secondary address and filename. The operating system interprets these parameters and allows the user to read or write the file to the specified device. Data is written to an ASCII file on a particular device with a command to PRINT to the specified logical file number, and data is read by a READ from logical file command.

Whereas a binary file is loaded with the contents of successive memory locations, an ASCII file is loaded with a string of variables. Storing these would require the tape to be turned on and off repeatedly, storing a few bytes of data at a time. The CBM 64 overcomes this by having a 192 byte tape buffer into which all data to be written to or read from tape is loaded. Only when this buffer is full is the tape motor turned on. Data is stored on tape in blocks of 192 bytes, and since the motor is turned on and off between blocks a two second interval is left between blocks to allow the motor to accelerate and decelerate. The beginning of the 192 character buffer starts at address 828. The pointer to the start of the buffer is located at addresses 178 and 179. The number of characters in a buffer is stored in location 166. These locations can be used by the programmer to control the amount of space left in a data file. If, having opened a file on cassette, the command POKE 166,191 is executed, then the contents of the tape buffer even if empty are loaded onto the tape. If records are kept in multiples of 191 bytes we can very easily keep null or partially filled records allowing future data expansion.

4.5 Recording method

Whether the file being stored is binary or ASCII the recording method used is the same, involving an encoding method unique to Commodore and designed to ensure maximum reliability of recording and playback. Each byte of data or program is encoded by the operating system using pulses of three distinct audio frequencies. These are: long pulses with a frequency of 1488 Hz, medium pulses at 1953 Hz and short pulses at 284Ø Hz. All these pulses are square waves with a mark space ratio of 1:1. One cycle of a medium frequency is: 256 microseconds in the high state and 256 microseconds in the low state. The operating system takes about 9 milliseconds to record a byte of data consisting of the eight data bits, a word marker bit and an odd parity bit. The data bits are either ones or zeros and are encoded by a sequence of medium and short pulses: a '1' is one cycle of a medium length pulse followed by one cycle of a short length pulse, and 'Ø' is one cycle of a short length pulse followed by one cycle of a medium length pulse. Each bit consists of two square wave pulse cycles, one short and one medium, with a total duration of 864 microseconds. The waveform timing is shown in the diagram in Fig. 4.3.

The 'odd parity' bit is required for error checking and is encoded like the eight data bits using a long and short pulse. Its state is determined by the contents of the eight data bits. The word marker separates each byte of data and signals to the operating system the beginning of each byte. The word marker is encoded as one cycle of a long pulse followed by one cycle of a medium pulse (see Fig. 4.3).

Since a byte of data is recorded in just 8.96 milliseconds, a 192 byte block of data in an ASCII file should be recorded in just over 1.7 seconds. However, on timing such a recording we find it takes 5.7 seconds. There are two causes for this discrepancy in timing. Firstly, to reduce the possibility of audio dropouts the data is recorded twice. Secondly, a two second interrecord gap is left between each record of 192 bytes.

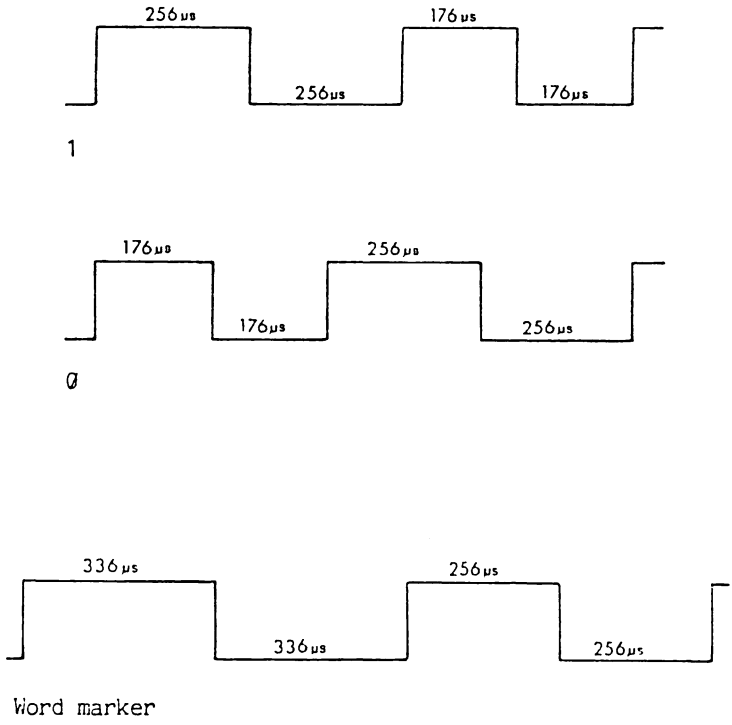


Fig. 4.3. Output waveforms to the cassette recorder.

The extensive use of error checking techniques is one reason why the tape system on the CBM 64 is slow but also quite reliable compared with that available on many other popular computers. There are two levels of error checking. The first divides the data into blocks of eight bytes and then computes a ninth byte, the checksum digit. The checksum is obtained by adding the eight data bytes together; the checksum is the least significant byte of the result. On reading the tape, if one bit in the eight bytes is dropped and a zero becomes a one or vice versa, the checksum can be used to detect this error. To do this the same procedure to calculate the check digit is performed, but the result will be different from that stored in byte nine – the check digit of that block computed when the tape was recorded. The second level of error checking involves recording each block of data twice. This allows errors detected by the check digit to be corrected during the second reading of the 192 byte data block. By recording the data twice a verification can be performed by comparing the contents of the two blocks; this will highlight the few errors not detected by the checksum.

The use of pulse sequences rather than two frequencies as in a standard FSK recording has a great advantage since it allows the operating system to compensate easily for variations in recording speed. Normally a hardware phase locked loop circuit would be used to lock the system onto the correct frequencies coming from the tape head. The CBM 64, however, uses software to perform this process. A ten second leader is written on the tape before recording of the data or program commences. This leader has two functions; first it allows the

tape motor to reach the correct speed, and secondly the sequence of short pulses written on the leader is used to synchronise the read routine timing to the timing on the tape. The operating system can thus produce a correction factor which allows a very wide variation in tape speed without affecting reading.

The system timing used to perform both reading and writing is very accurate, based as it is on the crystal controlled system clock and Timer 1 and Timer 2 of CIA#2. Interrecord gaps are used only in ASCII files and their function is to allow the tape motor time to decelerate after being turned off and accelerate to the correct speed when turned on prior to a block read or write. Each interrecord gap is approximately two seconds long and is recorded as a sequence of short pulses in the same manner as the ten second leader. There is also a gap between blocks. When the first block of 192 bytes is recorded it is followed by a block end marker which consists of one single long pulse followed by 5Ø+ cycles of short pulses. Then the second recording of the 192 block starts, which is identical to the first block.

The first record written on the tape after the ten second leader in both ASCII and binary files is a 192 character file header block. The file header contains the name of the file, the starting memory location, and the end location. In an ASCII file these addresses are the beginning and end of the tape buffer; in a binary file they point to the area of memory in which the program is to be stored.

The filename can be up to 187 bytes long. The length of the filename is stored in location 183. When read it is compared with the requested filename in the LOAD or OPEN command; if the name is the same the operating system will read the file, if different then it will search for the next ten second interfile gap and another header block. The filename is stored during a read or write operation in a block memory, the starting address of which is stored in locations 187 and 188. On completion of the operation these are reset to point to a location in the operating system. The starting location is normally set to the beginning of the user memory area, address 2Ø49, however it can be changed to point to any location - a method employed when recording programs in machine code using the monitor. The starting address is pointed to by the contents of locations 172 and 173. The end address is stored in locations 174 and 175. Normally this is the highest byte of memory occupied by the program, however it can be altered to point to any address providing it is greater than the start address.

4.6 Cassette operating system routines

The CBM 64 kernal contains a whole series of routines for handling data transfer between the processor and the cassette unit. The following sections describe these routines and how they can be used. These descriptions are accompanied by annotated source code listings of each routine (consult volume 1 of this series, *The Commodore 64 ROMs Revealed*, for the full kernal source code listing). The variable declaration file for these routines is to be found in Chapter 5.

Protect cassette/serial from RS232 NMI interrupts

Entry point: $FØA4

Function: This routine checks location $Ø2A1 to see if RS232 communications are enabled. If they are not then this location contains a zero and the routine exits to allow serial or cassette operation to commence. If RS232 communications are enabled then the routine goes into a loop waiting for the RS232 NMI interrupt to reset location $Ø2A1 to $Ø3, thereby signalling its completion. As soon as this happens the Timer A interrupt is disabled, the flag at $Ø2A1 is set to zero and the routine exits. The reason for this routine is to prevent an NMI interrupt from occurring during cassette or serial operation thereby causing data loss.

Input parameters: $Ø2A1 – if non zero then RS232 enabled

Output parameters: None

Registers used: .A is used but is pushed to the stack by the instruction at $FØA4 and then retrieved at the end of the routine by $FØBB.

Routine source code:

```
LOC   CODE        LINE

 DD10             *=$F0A4
 F0A4             ;
 F0A4             ;PROTECT SERIAL/CASSETTE FROM
 F0A4             ;RS-232 NMI'S
 F0A4             ;
 F0A4  48         L921   PHA              ;SAVE A
 F0A5  AD A1 02          LDA $02A1        ;RS232 ENABLES ?
 F0A8  F0 11             BEQ L923         ;NO
 F0AA  AD A1 02   L838   LDA $02A1
 F0AD  29 03             AND #$03
 F0AF  D0 F9             BNE L838
 F0B1  A9 10             LDA #$10         ;DISABLE FLAG
 F0B3  8D 0D DD          STA D2ICR
 F0B6  A9 00             LDA #$00
 F0B8  8D A1 02          STA $02A1
 F0BB  68         L923   PLA              ;ALL DONE
 F0BC  60                RTS
 F0BD             ;
```

Cassette error message output

Entry point:
$F12B – tests direct mode flag first
$F12F – displays message to screen

Function: This routine outputs a message to the screen concerning cassette

operation. The first entry point tests the contents of location $9D to see if the output is in direct or run mode. The second entry point performs the actual message output, the choice of message being determined by the value in the .Y index register. The messages used by this routine are stored in the area of memory immediately above this routine starting at $FØBD.

Input parameters:
.Y index register contains message number
$9D – direct mode flag; if the high bit of .A is set and the contents of location $9D are non zero, the required message is printed.

Output parameters: None

Routine source code:

```
LOC   CODE         LINE

 F0BD               ;ERROR MESSAGES
 F0BD               ;
 F0BD  0D           MS1     .BYT $D,'I/O ERROR ',$A3
 F0BE  49 2F
 F0C8  A3
 F0C9  0D           MS5     .BYT $D,'SEARCHING',$A0
 F0CA  53 45
 F0D3  A0
 F0D4  46 4F 52     MS6     .BYT 'FOR',$A0
 F0D7  A0
 F0D8  0D           MS7     .BYT $D,'PRESS PLAY ON TAP',$C5
 F0D9  50 52
 F0EA  C5
 F0EB  50 52        MS8     .BYT 'PRESS RECORD & PLAY ON TAP',$C5
 F105  C5
 F106  0D           MS10    .BYT $D,'LOADIN',$C7
 F107  4C 4F
 F10D  C7
 F10E  0D           MS11    .BYT $D,'SAVING',$A0
 F10F  53 41
 F115  A0
 F116  0D           MS21    .BYT $D,'VERIFYIN',$C7
 F117  56 45
 F11F  C7
 F120  0D           MS17    .BYT $D,'FOUND',$A0
 F121  46 4F
 F126  A0
 F127  0D           MS18    .BYT $D,'OK',$8D
 F128  4F 4B
 F12A  8D
 F12B               ;
 F12B               ;PRINT MESSAGE TO SCREEN ONLY IF
 F12B               ; OUTPUT ENABLED
 F12B               ;
 F12B  24 9D        L922    BIT MSGFLG      ;PRINTING MESSAGES?
 F12D  10 0D                BPL L925        ;NO
 F12F  B9 BD F0     L1073   LDA MS1,Y
 F132  08                   PHP
 F133  29 7F                AND #$7F
 F135  20 D2 FF             JSR $FFD2
 F138  C8                   INY
 F139  28                   PLP
 F13A  10 F3                BPL L1073
 F13C  18           L925    CLC
 F13D  60                   RTS
 F13E               .END
 F13E                       .LIB KTAPE1
```

Load RAM function

Entry point: $F49E

Function: This routine loads from cassette or a serial bus device (with a device number between 4 and 31 where this device number is stored in location $BA) into the memory starting at the LOAD address in the file if the secondary address is greater than Ø, or at the specified address if the secondary address is Ø.

Input parameters:
$BA - device number
$B9 - secondary address
.X - LOAD address lo if secondary address is zero
.Y - LOAD address hi if secondary address is zero
.A - if = Ø then load, ≠ Ø then verify

Output parameters:
.X - return high LOAD address hi
.Y - return high LOAD address lo

Routine source code:

```
LOC   CODE        LINE

F49E              *=$F49E
F49E              ;
F49E              ;****************************************
F49E              ;* LOAD RAM FUNCTION.
F49E              ;*      LOADS FROM CASSETTE OR SERIAL BUS
F49E              ;* DEVICES >=4 TO 31 AS DETERMINED BY
F49E              ;* CONTENTS OF VARIABLE FA. VERIFY FLAG
F49E              ;* IN .A.
F49E              ;*      ALT LOAD IF SA=0, NORMAL SA=1
F49E              ;*      .X, .Y LOAD ADDRESS IF SA=0
F49E              ;*      .A=0 PERFORMS LOAD,<>0 IS VERIFY.
F49E              ;* HIGH LOAD RETURN IN .X,.Y
F49E              ;* USE SETLFS & SETNAM BEFORE THIS ROUTINE
F49E              ;****************************************
F49E              ;
F49E  86 C3       L990    STX MEMUSS      ;LO ALT START
F4A0  84 C4               STY MEMUSS+1    ;HI ALT START
F4A2  6C 30 03            JMP (ILOAD)
F4A5  85 93       NLOAD   STA VERCK       ;STORE VERIFY FLAG
F4A7  A9 00               LDA #$00
F4A9  85 90               STA STATUS
F4AB  A5 BA               LDA FA          ;CHECK DEVICE #
F4AD  D0 03               BNE L1046
F4AF  4C 13 F7    L1241   JMP L1049       ;KEYBOARD, BAD DEVICE
F4B2  C9 03       L1046   CMP #$03        ;SCREEN?
F4B4  F0 F9               BEQ L1241       ;YES
F4B6  90 7B               BCC L1050       ;TAPE
F4B8              ;-----------------------------
F4B8              ;
F4B8              *=$F530
F530  4C 04 F7    L1038   JMP L959        ;FILE NOT FOUND
F533              ;
F533              ;*****  LOAD FROM TAPE
F533              ;
```

```
LOC   CODE        LINE
F533  4A          L1050  LSR A            ;TAPE?
F534  B0 03              BCS L1047        ;YES
F536  4C 13 F7           JMP L1049        ;NO, BAD DEVICE
F539  20 D0 F7    L1047  JSR L1104        ;SET TAPE POINTERS
F53C  B0 03              BCS L1060
F53E  4C 13 F7           JMP L1049        ;DEALLOCATED
F541  20 17 F8    L1060  JSR L938         ;'PRESS PLAY ON TAPE'
F544  B0 68              BCS L1059        ;STOP KEY?
F546  20 AF F5           JSR L1062        ;'SEARCHING'
F549  A5 B7       L1061  LDA FNLEN        ;NAME?
F54B  F0 09              BEQ L1066        ;NO, LOAD FIRST PROG
F54D  20 EA F7           JSR L1108        ;YES, FIND A FILE
F550  90 0B              BCC L1063        ;FOUND
F552  F0 5A              BEQ L1059        ;STOP KEY
F554  B0 DA              BCS L1058        ;NO, END OF TAPE
F556  20 2C F7    L1066  JSR L1098        ;FIND ANY HEADER
F559  F0 53              BEQ L1059        ;STOP KEY
F55B  B0 D3              BCS L1058        ;NO HEADER
F55D  A5 90       L1063  LDA STATUS
F55F  29 10              AND #SPERR       ;MUST HAVE GOT HEADER RIGHT
F561  38                 SEC
F562  D0 4A              BNE L1059        ;IS BAD
F564  E0 01              CPX #BLF         ;MOVEABLE?
F566  F0 11              BEQ L1068        ;YES
F568  E0 03              CPX #PLF         ;PROGRAM
F56A  D0 DD              BNE L1061        ;NO, TRY FOR NEXT
F56C  A0 01       L1064  LDY #$01         ;FIXED LOAD
F56E  B1 B2              LDA (TAPE1),Y    ;ADDRESS IN BUFFER
F570  85 C3              STA MEMUSS       ;IS LOAD ADDRESS
F572  C8                 INY
F573  B1 B2              LDA (TAPE1),Y
F575  85 C4              STA MEMUSS+1
F577  B0 04              BCS L1065
F579  A5 B9       L1068  LDA SA           ;MONITOR LOAD?
F57B  D0 EF              BNE L1064        ;YES, FIXED TYPE
F57D  A0 03       L1065  LDY #$03         ;TAPEA-TAPESTA
F57F  B1 B2              LDA (TAPE1),Y
F581  A0 01              LDY #$01
F583  F1 B2              SBC (TAPE1),Y
F585  AA                 TAX              ;LO TO .X
F586  A0 04              LDY #$04
F588  B1 B2              LDA (TAPE1),Y
F58A  A0 02              LDY #$02
F58C  F1 B2              SBC (TAPE1),Y
F58E  A8                 TAY              ;HI TO .Y
F58F  18                 CLC              ;EA=STA+(TAPEA-TAPESTA)
F590  8A                 TXA
F591  65 C3              ADC MEMUSS
F593  85 AE              STA EAL
F595  98                 TYA
F596  65 C4              ADC MEMUSS+1
F598  85 AF              STA EAH
F59A  A5 C3              LDA MEMUSS       ;SET UP START ADDRESS
F59C  85 C1              STA STAL
F59E  A5 C4              LDA MEMUSS+1
F5A0  85 C2              STA STAH
F5A2  20 D2 F5           JSR L1070        ;'LOADING'
F5A5  20 4A F8           JSR L940         ;LOAD TAPE BLOCK
F5A8  24                 .BYT $24         ;SKIP NEXT COMMAND
F5A9  18          L1067  CLC              ;GOOD EXIT
F5AA              ;
F5AA              ;SET UP END ADDRESS
F5AA              ;
F5AA  A6 AE              LDX EAL
F5AC  A4 AF              LDY EAH
F5AE  60          L1059  RTS
F5AF              ;
```

Print tape loading messages

Entry points:
$F5AF – print 'searching [for filename]'
$F5C1 – print filename
$F5D2 – print loading/verifying

Function: The function of these three routines is simply to display the appropriate messages on the screen when loading a program or file from tape.

Input parameters:
$9D – flag to indicate whether 'searching [for filename]' is printed; if high bit is set then message is printed
$B7 – filename length
$BB – filename address
$93 – loading/verifying flag; if = Ø then loading, otherwise verifying

Output parameters: None

Routine source code:

```
LOC   CODE         LINE

F5AF               ;PRINT 'SEARCHING FOR [NAME]'
F5AF               ;
F5AF  A5 9D        L1062  LDA MSGFLG       ;PRINT IT?
F5B1  10 1E                BPL L1071       ;NO
F5B3  A0 0C                LDY #MS5-MS1    ;'SEARCHING'
F5B5  20 2F F1             JSR L1073
F5B8  A5 B7                LDA FNLEN
F5BA  F0 15                BEQ L1071
F5BC  A0 17                LDY #MS6-MS1    ;'FOR'
F5BE  20 2F F1             JSR L1073
F5C1               ;
F5C1               ;PRINT FILENAME
F5C1               ;
F5C1  A4 B7        L1022  LDY FNLEN       ;NAME LENGTH
F5C3  F0 0C                BEQ L1071       ;NO NAME
F5C5  A0 00                LDY #$00
F5C7  B1 BB        L1091  LDA (FNADR),Y
F5C9  20 D2 FF             JSR $FFD2
F5CC  C8                   INY
F5CD  C4 B7                CPY FNLEN
F5CF  D0 F6                BNE L1091
F5D1  60           L1071  RTS
F5D2               ;
F5D2               ;PRINT LOADING/VERIFYING
F5D2               ;
F5D2  A0 49        L1070  LDY #MS10-MS1   ;ASSUME 'LOADING'
F5D4  A5 93                LDA VERCK       ;CHECK FLAG
F5D6  F0 02                BEQ L1052       ;YES, LOADING
F5D8  A0 59                LDY #MS21-MS1   ;'VERIFYING'
F5DA  4C 2B F1     L1052  JMP L922
F5DD               .END
F5DD                      .LIB KTAPE2
```

Save memory function

Entry point: $F5DD

Function: A specified block of memory is saved by this routine onto cassette or a serial device with a device number between 4 and 31. This routine must be preceded by the routine at $FFBA which sets logical first and secondary addresses and at $FFBD which sets up the filename.

Input parameters:
.A – indirect pointer to start of memory area to be saved
.X – end of SAVE lo
.Y – end of SAVE hi
$BA – device number

Output parameters: None

Routine source code:

```
LOC   CODE        LINE

 F5DD             ;
 F5DD             ;**************************************
 F5DD             ;* SAVE MEMORY FUNCTION.
 F5DD             ;*      SAVES TO CASSETTE OR SERIAL
 F5DD             ;* DEVICES >=4 TO 31 AS SELECTED BY
 F5DD             ;* VARIABLE FA.
 F5DD             ;*      START OF SAVE IS INDIRECT AT .A
 F5DD             ;* END OF SAVE IS .X, .Y
 F5DD             ;* USE SETLFS & SETNAM BEFORE THIS ROUTINE
 F5DD             ;**************************************
 F5DD             ;
 F5DD  86 AE      L1072  STX EAL          ;STORE END ADDRESS
 F5DF  84 AF             STY EAH
 F5E1  AA                TAX             ;SET UP START
 F5E2  B5 00             LDA $00,X
 F5E4  85 C1             STA STAL
 F5E6  B5 01             LDA $01,X
 F5E8  85 C2             STA STAH
 F5EA  6C 32 03          JMP (ISAVE)
 F5ED  A5 BA      NSAVE  LDA FA
 F5EF  D0 03             BNE L1075
 F5F1  4C 13 F7   L1242  JMP L1049       ;BAD DEVICE
 F5F4  C9 03      L1075  CMP #$03        ;SERIAL?
 F5F6  F0 F9             BEQ L1242       ;SCREEN, BAD DEVICE
 F5F8  99 5F             BCC L1085       ;NO, TAPE
 F5FA             ;-----------------------------
 F5FA             *=$F659
 F659             ;
 F659             ;******    TAPE SAVE
 F659             ;
 F659  4A         L1085  LSR A           ;RS-232?
 F65A  B0 03             BCS L1076       ;NO, MUST BE TAPE
 F65C  4C 13 F7          JMP L1049       ;BAD DEVICE
 F65F  20 D0 F7   L1076  JSR L1104       ;GET BUFFER ADDR
 F662  90 8D             BCC L1242       ;NOT ALLOCATED
 F664  20 38 F8          JSR L1114
 F667  B0 25             BCS L1090       ;STOP KEY
 F669  20 8F F6          JSR L1087       ;'SAVING'
```

```
LOC   CODE         LINE

F66C  A2 03                LDX #PLF         ;DECIDE TYPE TO SAVE
F66E  A5 B9                LDA SA           ;1-PLF, 0-BLF
F670  29 01                AND #$01
F672  D0 02                BNE L1086
F674  A2 01                LDX #BLF
F676  8A           L1086   TXA
F677  20 6A F7             JSR L1099        ;WRITE HEADER BLOCKS
F67A  B0 12                BCS L1090        ;STOP KEY
F67C  20 67 F8             JSR L952         ;WRITE PROGRAM BLOCKS
F67F  B0 0D                BCS L1090        ;STOP KEY
F681  A5 B9                LDA SA
F683  29 02                AND #$02         ;WRITE END OF TAPE?
F685  F0 06                BEQ L1088        ;NO
F687  A9 05                LDA #$05
F689  20 6A F7             JSR L1099        ;WRITE END TABLE BLOCKS
F68C  24                   .BYT $24         ;SKIP COMMAND
F68D  18           L1088   CLC
F68E  60           L1090   RTS
```

Print 'saving'

Entry point: $F68F

Function: Prints the message Saving [filename] on the screen. Note that this message can be output to another device such as a printer, but the following SAVE will give an error.

Input parameters: $9D – flag to indicate if message is to be printed; if high bit is not set then message is not printed.

Output parameters: None

Routine source code:

```
LOC   CODE         LINE

F68F               ;
F68F               ;PRINT 'SAVING [FILENAME]'
F68F               ;
F68F  A5 9D        L1087   LDA MSGFLG       ;PRINT IT?
F691  10 FB                BPL L1090        ;NO
F693  A0 51                LDY #MS11-MS1    ;'SAVING'
F695  20 2F F1             JSR L1073
F698  4C C1 F5             JMP L1022        ;SEND FILENAME
F69B               .END
F69B                       .LIB KTAPE3
```

Stop key servicing

Entry point: $F6ED

Function: This routine is included in this section because it is called by so many

of the other routines. The function of this routine is to check the stop key flag and if set then close any active I/O channels, flush the keyboard queue and return the machine to direct mode.

Input parameters: $91 - value of last keyboard row - contains 'stop' key

Output parameters:
Z flag - set if stop key depressed
.A - keys depressed from last keyboard row

Routine source code:

```
LOC   CODE        LINE

 F69B               *=$F6ED
 F6ED               ;
 F6ED               ;****************************************
 F6ED               ;* STOP -- CHECK STOP KEY FLAG AND
 F6ED               ;* RETURN Z FLAG SET IF FLAG TRUE.
 F6ED               ;* ALSO CLOSES ACTIVE CHANNELS AND
 F6ED               ;* FLUSHES KEYBOARD QUEUE.
 F6ED               ;* ALSO RETURNS KEY DOWNS FROM LAST
 F6ED               ;* KEYBOARD ROW IN .A.
 F6ED               ;*     SHOULD CALL UPDATE TIME BEFORE
 F6ED               ;* THIS.
 F6ED               ;****************************************
 F6ED               ;
 F6ED  A5 91        NSTOP  LDA STKEY        ;VALUE OF LAST ROW
 F6EF  C9 7F               CMP #$7F         ;STOP KEY POSITION
 F6F1  D0 07               BNE L1243        ;NOT DOWN
 F6F3  08                  PHP
 F6F4  20 CC FF            JSR $FFCC        ;CLEAR CHANNELS
 F6F7  85 C6               STA NDX          ;CLEAR KEY QUEUE
 F6F9  28                  PLP
 F6FA  60           L1243  RTS
```

Error handler

Entry points:
$F6FB - too many files
$F6FE - file open
$F7Ø1 - file not open
$F7Ø4 - file not found
$F7Ø7 - device not present
$F7ØA - not input file
$F7ØD - not output file
$F71Ø - missing filename
$F713 - illegal device number

Function: This will display a designated error message from a list of nine cassette and serial I/O related messages. The table of actual error message texts is stored in locations $A19E to $A225.

Input parameters: None

Output parameters: None

Routine source code:

```
LOC   CODE         LINE

F6FB               ;*****************************************
F6FB               ;* ERROR HANDLER.
F6FB               ;* PRINTS KERNAL ERROR MESSAGE IF BIT 6
F6FB               ;* OF MSGFLG IS SET. RETURNS WITH ERROR
F6FB               ;* # IN .A AND CARRY SET.
F6FB               ;*****************************************
F6FB               ;
F6FB  A9 01        L1097  LDA #$01         ;TOO MANY FILES
F6FD  2C                  .BYT $2C
F6FE  A9 02        L1011  LDA #$02         ;FILE OPEN
F700  2C                  .BYT $2C
F701  A9 03        L1009  LDA #$03         ;FILE NOT OPEN
F703  2C                  .BYT $2C
F704  A9 04        L959   LDA #$04         ;FILE NOT FOUND
F706  2C                  .BYT $2C
F707  A9 05        L1026  LDA #$05         ;DEVICE NOT PRESENT
F709  2C                  .BYT $2C
F70A  A9 06        L971   LDA #$06         ;NOT INPUT FILE
F70C  2C                  .BYT $2C
F70D  A9 07        L965   LDA #$07         ;NOT OUTPUT FILE
F70F  2C                  .BYT $2C
F710  A9 08        L974   LDA #$08         ;MISSING FILENAME
F712  2C                  .BYT $2C
F713  A9 09        L1049  LDA #$09         ;BAD DEVICE #
F715  48                  PHA              ;ERROR # ON STACK
F716  20 CC FF            JSR $FFCC        ;RESTORE I/O
F719  A0 00               LDY #MS1-MS1
F71B  24 9D               BIT MSGFLG       ;PRINT ERROR?
F71D  50 0A               BVC L1018        ;NO
F71F  20 2F F1            JSR L1073        ;PRINT 'I/O ERROR #'
F722  68                  PLA
F723  48                  PHA
F724  09 30               ORA #$30         ;MAKE ERROR # ASCII
F726  20 D2 FF            JSR $FFD2        ;PRINT IT
F729  68           L1018  PLA
F72A  38                  SEC
F72B  60                  RTS
F72C               .END
F72C                      .LIB KTAPE4
```

Find any tape header

Entry point: $F72C

Function: This routine reads the tape device until one of the following two block types is found: 'basic data file header' or 'basic load file'. The state of the carry flag indicates whether a header was found or not. Having found the header the message Found is displayed, followed by the filename from the header. A pause of 8.5 seconds is then generated before the routine exits to perform the rest of the load. This delay can be eliminated by pressing the CBM key.

Input parameters: None

Output parameters:
.A - Ø if stop key pressed
Carry flag - clear = header found; set = header not found

Routine source code:

```
LOC   CODE        LINE

F72C              ;
F72C              ;****************************************
F72C              ;* FIND ANY TAPE HEADER.
F72C              ;* READS TAPE DEVICE UNTIL ONE OF THE
F72C              ;* FOLLOWING BLOCK TYPES IS FOUND: BDFH--
F72C              ;* BASIC DATA FILE HEADER, BLF--BASIC
F72C              ;* LOAD FILE. FOR SUCCESS, CARRY IS
F72C              ;* CLEAR ON RETURN. FOR FAILURE, CARRY
F72C              ;* IS SET ON RETURN. IN ADDITION, .A IS
F72C              ;* 0 IF STOP KEY WAS PRESSED.
F72C              ;****************************************
F72C              ;
F72C  A5 93       L1098  LDA VERCK        ;SAVE OLD VERIFY
F72E  48                 PHA
F72F  20 41 F8           JSR L1029        ;READ TAPE BLOCK
F732  68                 PLA
F733  85 93              STA VERCK        ;RESTORE VERIFY
F735  B0 32              BCS L1101        ;READ TERMINATED
F737  A0 00              LDY #$00
F739  B1 B2              LDA (TAPE1),Y    ;GET HEADER TYPE
F73B  C9 05              CMP #EOT         ;END OF TAPE?
F73D  F0 2A              BEQ L1101        ;YES
F73F  C9 01              CMP #BLF         ;BASIC LOAD FILE?
F741  F0 08              BEQ L1027        ;YES
F743  C9 03              CMP #PLF         ;FIXED LOAD FILE?
F745  F0 04              BEQ L1027        ;YES
F747  C9 04              CMP #BDFH        ;BASIC DATA FILE?
F749  D0 E1              BNE L1098        ;NO, TRY AGAIN
F74B  AA          L1027  TAX              ;FILE TYPE IN .X
F74C  24 9D              BIT MSGFLG       ;PRINT MESSAGE?
F74E  10 17              BPL L1102        ;NO
F750  A0 63              LDY #MS17-MS1    ;'FOUND'
F752  20 2F F1           JSR L1073
F755  A0 05              LDY #$05
F757  B1 B2       L1100  LDA (TAPE1),Y    ;OUTPUT COMPLETE
F759  20 D2 FF           JSR $FFD2        ;FILENAME
F75C  C8                 INY
F75D  C0 15              CPY #$15
F75F  D0 F6              BNE L1100
F761  A5 A1              LDA TIME+1       ;WAIT FOR 8.5 SECONDS
F763  20 E0 E4           JSR $E4E0        ; OR FOR THE CBM KEY
F766  EA                 NOP
F767  18          L1102  CLC              ;SUCCESS
F768  88                 DEY
F769  60          L1101  RTS
```

Write tape header

Entry point: $F76A

Function: This routine first pushes the program start and end addresses onto the

stack and then blanks the tape buffer memory area and sets up a tape header with all the requisite information being stored in the correct position in the tape buffer. The tape buffer contents are then written to tape and the start and end addresses restored off the stack.

Input parameters: All tape header variables and filename

Output parameters: .A – tape SAVE error flag

Routine source code:

```
LOC   CODE        LINE

F76A              ;
F76A              ;****************************************
F76A              ;* WRITE TAPE HEADER
F76A              ;*     ERROR IF TAPE BUFFER DE-ALLOCATED
F76A              ;* CARRY CLEAR IF O.K.
F76A              ;****************************************
F76A              ;
F76A  85 9E       L1099  STA T1
F76C  20 D0 F7           JSR L1104        ;GET BUFFER ADDRESS
F76F  90 5E              BCC L1106        ;NOT ALLOCATED
F771  A5 C2              LDA STAH         ;PRESERVE START AND END
F773  48                 PHA              ; ADDRESSES
F774  A5 C1              LDA STAL
F776  48                 PHA
F777  A5 AF              LDA EAH
F779  48                 PHA
F77A  A5 AE              LDA EAL
F77C  48                 PHA
F77D  A0 BF              LDY #BUFSZ-1     ;BLANK TAPE BUFFER
F77F  A9 20              LDA #$20         ;SPACE CHARS
F781  91 B2       L998   STA (TAPE1),Y
F783  88                 DEY
F784  D0 FB              BNE L998
F786  A5 9E              LDA T1           ;BLOCK TYPE IN HEADER
F788  91 B2              STA (TAPE1),Y
F78A  C8                 INY
F78B  A5 C1              LDA STAL         ;START ADDRESS IN HEADER
F78D  91 B2              STA (TAPE1),Y
F78F  C8                 INY
F790  A5 C2              LDA STAH
F792  91 B2              STA (TAPE1),Y
F794  C8                 INY              ;END ADDRESS IN HEADER
F795  A5 AE              LDA EAL
F797  91 B2              STA (TAPE1),Y
F799  C8                 INY
F79A  A5 AF              LDA EAH
F79C  91 B2              STA (TAPE1),Y
F79E  C8                 INY              ;FILENAME IN HEADER
F79F  84 9F              STY T2
F7A1  A0 00              LDY #$00
F7A3  84 9E              STY T1
F7A5  A4 9E       L1105  LDY T1
F7A7  C4 B7              CPY FNLEN
F7A9  F0 0C              BEQ L1107
F7AB  B1 BB              LDA (FNADR),Y
F7AD  A4 9F              LDY T2
F7AF  91 B2              STA (TAPE1),Y
F7B1  E6 9E              INC T1
F7B3  E6 9F              INC T2
F7B5  D0 EE              BNE L1105
F7B7  20 D7 F7    L1107  JSR L995         ;SET UP START & END
F7BA  A9 69              LDA #$69         ;ADDR OF HEADER & SET
F7BC  85 AB              STA SHCNH        ; TIME FOR LEADER
```

```
LOC   CODE         LINE

 F7BE  20 6B F8           JSR L1089       ;WRITE FILE TO TAPE
 F7C1  A8                 TAY             ;SAVE ERROR CODE IN .Y
 F7C2  68                 PLA             ;RESTORE START & END
 F7C3  85 AE              STA EAL         ; ADDRESSES
 F7C5  68                 PLA
 F7C6  85 AF              STA EAH
 F7C8  68                 PLA
 F7C9  85 C1              STA STAL
 F7CB  68                 PLA
 F7CC  85 C2              STA STAH
 F7CE  98                 TYA             ;RESTORE ERROR CODE
 F7CF  60          L1106  RTS
```

Return buffer address

Entry point: $F7D7

Function: This routine is in two parts; the first tests if the tape buffer is allocated and the second calculates the start and end address pointers which are required by the SAVE routines.

Input parameters: None

Output parameters:
$C1 - start address lo
$C2 - start address hi
$AE - end address lo
$AF - end address hi

Routine source code:

```
LOC   CODE         LINE

 F7D0               ;
 F7D0               ;RETURN BUFFER ADDRESS
 F7D0               ;
 F7D0  A6 B2        L1104  LDX TAPE1
 F7D2  A4 B3               LDY TAPE1+1
 F7D4  C0 02               CPY #$02        ;ALLOCATED?
 F7D6  60                  RTS             ;CARRY CLEAR, DE-ALLOCATED
 F7D7  20 D0 F7    L995    JSR L1104       ;GET PTR TO CASSETTE
 F7DA  8A                  TXA
 F7DB  85 C1               STA STAL        ;SAVE START LOW
 F7DD  18                  CLC
 F7DE  69 C0               ADC #BUFSZ      ;COMPUTE POINTER TO END
 F7E0  85 AE               STA EAL         ;SAVE END LOW
 F7E2  98                  TYA
 F7E3  85 C2               STA STAH        ;SAVE START HI
 F7E5  69 00               ADC #$00        ;COMPUTE POINTER TO END
 F7E7  85 AF               STA EAH         ;SAVE END HIGH
 F7E9  60                  RTS
```

Find correct file on tape

Entry point: $F7EA

Function: This routine searches for a program header on tape. Having found a header the filename is compared with that specified (if the contents of location $B7 are zero then the first program encountered is loaded). If the program name in the header is not the same as that specified then the routine searches for the next header. It should be noted that this routine only compares the header filename for the number of characters in the filename specified in the LOAD/VERIFY command, thus if the filename Test is specified in the LOAD command but the header contains the filename Testing, then the routine will take this as a positive match and load Testing.

Input parameters: $B7 - length of current filename string

Output parameters: None

Routine source code:

```
LOC   CODE         LINE

 F7EA                ;***************************
 F7EA                ;* FIND CORRECT FILE ON TAPE
 F7EA                ;* IF FNLEN = 0 THEN USE
 F7EA                ;* FIRST HEADER FOUND
 F7EA                ;***************************
 F7EA                ;
 F7EA  20 2C F7      L1108  JSR L1698        ;FIND ANY HEADER
 F7ED  B0 1D                BCS L1111        ;FAILED
 F7EF  A0 05                LDY #$05         ;CHECK NAME
 F7F1  84 9F                STY T2           ;OFFSET TO HEADER
 F7F3  A0 00                LDY #$00
 F7F5  84 9E                STY T1           ;OFFSET TO NAME
 F7F7  C4 B7        L1024   CPY FNLEN        ;COMPARE THIS MANY
 F7F9  F0 10                BEQ L1112        ;DONE
 F7FB  B1 BB                LDA (FNADR),Y
 F7FD  A4 9F                LDY T2
 F7FF  D1 B2                CMP (TAPE1),Y
 F801  D0 E7                BNE L1108        ;WRONG FILENAME
 F803  E6 9E                INC T1
 F805  E6 9F                INC T2
 F807  A4 9E                LDY T1
 F809  D0 EC                BNE L1024        ;ALWAYS
 F80B  18           L1112   CLC              ;SUCCESS
 F80C  60           L1111   RTS
 F80D                .END
 F80D                .LIB K1APE5
```

Miscellaneous cassette support routines

Entry points:
$F8ØD - increase pointer in tape buffer
$F817 - wait for play switch
$F82E - test cassette switch
$F838 - check for record and play
$F841 - read header block

$F84A – read LOAD block entry

Routine source code:

```
LOC   CODE        LINE

F80D              ;INCREASE POINTER IN TAPE BUFFER
F80D              ;
F80D  20 D0 F7    L1110  JSR L1104       ;GET BUFFER ADDRESS
F810  E6 A6              INC BUFPT
F812  A4 A6              LDY BUFPT
F814  C0 C0              CPY #BUFSZ      ;CHECK END BUFFER
F816  60                 RTS
F817              ;
F817              ;WAIT FOR PLAY SWITCH
F817              ;
F817  20 2E F8    L938   JSR L1116
F81A  F0 1A              BEQ L1113
F81C  A0 1B              LDY #MS7-MS1    ;'PRESS PLAY...'
F81E  20 2F F1    L1020  JSR L1073
F821  20 D0 F8    L1117  JSR L1125       ;TEST STOP KEY
F824  20 2E F8           JSR L1116       ;TEST CASSETTE SWITCHES
F827  D0 F8              BNE L1117
F829  A0 6A              LDY #MS18-MS1   ;'OK'
F82B  4C 2F F1           JMP L1073
F82E              ;
F82E              ;TEST CASSETTE SWITCH
F82E              ;
F82E  A9 10       L1116  LDA #$10        ;CHECK PORT
F830  24 01              BIT $01         ;CLOSED?
F832  D0 02              BNE L1113       ;NO
F834  24 01              BIT $01         ;DEBOUNCE
F836  18          L1113  CLC             ;GOOD EXIT
F837  60                 RTS
F838              ;
F838              ;CHECK FOR RECORD & PLAY
F838              ;
F838  20 2E F8    L1114  JSR L1116
F83B  F0 F9              BEQ L1113
F83D  A0 2E              LDY #MS8-MS1    ;'PRESS RECORD...'
F83F  D0 DD              BNE L1020
F841              ;
F841              ;READ HEADER BLOCK
F841              ;
F841  A9 00       L1029  LDA #$00
F843  85 90              STA STATUS
F845  85 93              STA VERCK
F847  20 D7 F7           JSR L995
F84A              ;
F84A              ;READ LOAD BLOCK ENTRY
F84A              ;
F84A  20 17 F8    L940   JSR L938        ;'PRESS PLAY...'
F84D  B0 1F              BCS L1109       ;STOP KEY
F84F  78                 SEI
F850  A9 00              LDA #$00        ;CLEAR FLAGS
F852  85 AA              STA RDFLG
F854  85 B4              STA SNSW1
F856  85 B0              STA CMPO
F858  85 9E              STA PTR1
F85A  85 9F              STA PTR2
F85C  85 9C              STA DPSW
F85E  A9 90              LDA #$90        ;ENABLE FOR TAPE IRQ
F860  A2 0E              LDX #$0E        ;POINT IRQ VECTOR TO READ
F862  D0 11              BNE L1118       ;ALWAYS
```

Write memory

Entry point:
$F864 - write tape buffer
$F867 - write memory between start address and end address

Function: The first entry point sets up the addresses to SAVE the tape buffer. The second entry point is to the main tape write routine. This routine writes the contents of memory between the previously determined start and end addresses onto tape. This routine calls up several small routines located at $FBA6.

Input parameters:
$C1 - start address lo
$C2 - start address hi
$AE - end address lo
$AF - end address hi

Output parameters: None

Routine source code:

```
LOC   CODE        LINE

F864                ;
F864                ;****************************
F864                ;* WRITE TAPE BUFFER
F864                ;****************************
F864                ;
F864                ;SET UP TO SAVE TAPE BUFFER
F864                ;
F864  20 D7 F7      L1069  JSR L995         ;BUFFER
F867                ;*******************************
F867                ;WRITE MEMORY BETWEEN STAL,STAH
F867                ;AND EAL,EAH AS A BLOCK
F867                ;*******************************
F867  A9 14         L952_  LDA #$14         ;BETWEEN BLOCK SHORTS
F869  85 AB                STA SHCNH
F86B  20 38 F8      L1089  JSR L1114        ;'PRESS RECORD...'
F86E  B0 6C         L1109  BCS L1115        ;STOP KEY
F870  78                   SEI
F871  A9 82                LDA #$82         ;ENABLE T2 IRQ
F873  A2 08                LDX #$08         ;POINT IRQ VECTOR TO WRITE
F875                ;
F875                ;START TAPE OPERATION ENTRY POINT
F875                ;
F875  A0 7F         L1118  LDY #$7F         ;KILL UNWANTED IRQ
F877  8C 0D DC             STY D1ICR
F87A  8D 0D DC             STA D1ICR        ;ENABLE WANTED
F87D  AD 0E DC             LDA D1CRA
F880  09 19                ORA #$19
F882  8D 0F DC             STA D1CRB
F885  29 91                AND #$91
F887  8D A2 02             STA $02A2
F88A  20 A4 F0             JSR L921         ;WAIT FOR RS232
F88D  AD 11 D0             LDA VICREG+17    ;BLANK SCREEN
F890  29 EF                AND #$EF
F892  8D 11 D0             STA VICREG+17
F895  AD 14 03             LDA CINV         ;MOVE IRQ TO IRQ TEMP
F898  8D 9F 02             STA IRQTMP       ;FOR CASSETTE OPS
F89B  AD 15 03             LDA CINV+1
F89E  8D A0 02             STA IRQTMP+1
F8A1  20 BD FC             JSR L1195        ;CHANGE IRQ VECTOR
F8A4  A9 02                LDA #$02         ;FSBLK STARTS AT 2
F8A6  85 BE                STA FSBLK
F8A8  20 97 FB             JSR L1079        ;PREPARE LOCAL COUNTERS
```

```
LOC   CODE         LINE

F8AB  A5 01              LDA $01          ;TURN CASSETTE MOTOR ON
F8AD  29 1F              AND #$1F
F8AF  85 01              STA $01
F8B1  85 C0              STA CAS1         ;FLAG INTERNAL CONTROL
F8B3  A2 FF              LDX #$FF         ;DELAY BETWEEN BLOCKS
F8B5  A0 FF        L1119 LDY #$FF
F8B7  88           L1124 DEY
F8B8  D0 FD              BNE L1124
F8BA  CA                 DEX
F8BB  D0 F8              BNE L1119
F8BD               ;
F8BD               ; ENABLE TAPE IQR ROUTINES TO
F8BD               ;START WRITE OPERATION
F8BD  58                 CLI
F8BE  AD A0 02     L1123 LDA IRQTMP+1     ;CHECK FOR IRQ VECTOR
F8C1  CD 15 03           CMP CINV+1       ;POINTING AT WRITE ROUTINE
F8C4  18                 CLC
F8C5  F0 15              BEQ L1115        ;YES, RETURN
F8C7  20 D0 F8           JSR L1125        ;NO CHECK STOP
F8CA  20 BC F6           JSR $F6BC        ;UPDATE TIME
F8CD  4C BE F8           JMP L1123        ;STAY IN LOOP
F8D0  20 E1 FF     L1125 JSR $FFE1        ;TOP KEY DOWN?
F8D3  18                 CLC              ;ASSUME NOT
F8D4  D0 0B              BNE L1120        ;CORRECT ASSUMPTION
F8D6  20 93 FC           JSR L1192        ;STOP DOWN STOP TAPE
F8D9  38                 SEC              ;FAILED
F8DA  68                 PLA              ;BACK OR RTS
F8DB  68                 PLA
F8DC  A9 00        L1115 LDA #$00         ;DISABLE IRQTMP
F8DE  8D A0 02           STA IRQTMP+1
F8E1  60           L1120 RTS
```

Set up time out watch for next dipole

Entry point: $F8E2

Function: This routine is used to detect read errors by checking the timing of each pulse pair (dipole); if the pulses are too long then a time out error is assumed.

Input parameters: .X – time out constant for particular dipole

Output parameters: None

Routine source code:

```
LOC   CODE         LINE

F8E2               ;
F8E2               ;SET UP TIMEOUT WATCH FOR NEXT DIPOLE
F8E2               ;
F8E2  86 B1        L1126 STX TEMP         ;TIMEOUT CONSTANT
F8E4  A5 B0              LDA CMPO         ;CMPO*5
F8E6  0A                 ASL A
F8E7  0A                 ASL A
F8E8  18                 CLC
F8E9  65 B0              ADC CMPO
F8EB  18                 CLC
```

```
LOC   CODE         LINE

F8EC  65 B1                ADC TEMP        ;ADJUST LONG BYTE COUNT
F8EE  85 B1                STA TEMP
F8F0  A9 00                LDA #$00
F8F2  24 B0                BIT CMPO        ;CHECK CMPO..
F8F4  30 01                BMI L1146       ; MINUS, NO ADJUST
F8F6  2A                   ROL A           ; PLUS, ADJUST POS
F8F7  06 B1         L1146  ASL TEMP        ;MULTIPLY CORRECTED
F8F9  2A                   ROL A           ; VALUE BY 4
F8FA  06 B1                ASL TEMP
F8FC  2A                   ROL A
F8FD  AA                   TAX
F8FE  AD 06 DC      L1128  LDA D1TBL       ;WATCH OUT FOR ROLLOVER
F901  C9 16                CMP #$16        ;TIME FOR ROUTINE?
F903  90 F9                BCC L1128       ;TOO CLOSE SO WAIT
F905  65 B1                ADC TEMP        ;CALCULATE AND
F907  8D 04 DC             STA D1TAL       ; STORE ADJUSTED TIME COUNT
F90A  8A                   TXA
F90B  6D 07 DC             ADC D1TBH       ;ADJUST FOR HI TIME COUNT
F90E  8D 05 DC             STA D1TAH
F911  AD A2 02             LDA $02A2
F914  8D 0E DC             STA D1CRA
F917  8D A4 02             STA $02A4
F91A  AD 0D DC             LDA D1ICR
F91D  29 10                AND #$10
F91F  F0 09                BEQ L1129
F921  A9 F9                LDA #$F9
F923  48                   PHA
F924  A9 2A                LDA #$2A
F926  48                   PHA
F927  4C 43 FF             JMP $FF43
F92A  58            L1129  CLI
F92B  60                   RTS
F92C                .END
F92C                       .LIB KTAPE6
```

Cassette read subroutines

Entry point: $F92C

Function: This is the main routine which reads data from the tape. The bulk of the routine performs the timing of the incoming pulses in order to decode the pulse type and to give a software servo loop, which adjusts the timing of the pulses to the speed of the cassette deck. To understand the timing of the pulses see the waveform diagrams in Fig. 4.3 plus the documentation accompanying the source code listing.

Input parameters: None

Output parameters: $B6 – tape read error

Routine source code:

```
LOC   CODE         LINE

F92C                ;
F92C                ;****************************************
F92C                ;* CASSETTE READ SUBROUTINES
F92C                ;****************************************
```

```
LOC   CODE         LINE

F92C               ;
F92C               ;TAPE READ IRQ ROUTINE
F92C               ;
F92C  AE 07 DC     L1130  LDX D1TBH        ;GET TIME SINCE LAST IRQ
F92F  A0 FF               LDY #$FF         ;COMPUTE COUNTER DIFF
F931  98                  TYA
F932  ED 06 DC            SBC D1TBL
F935  EC 07 DC            CPX D1TBH        ;TIMER HIGH ROLLOVER?
F938  D0 F2               BNE L1130        ;YES, RECOMPUTE
F93A  86 B1               STX TEMP
F93C  AA                  TAX
F93D  8C 06 DC            STY D1TBL        ;RE-LOAD TIMER B
F940  8C 07 DC            STY D1TBH
F943  A9 19               LDA #$19
F945  8D 0F DC            STA D1CRB
F948  AD 0D DC            LDA D11CR
F94B  8D A3 02            STA $02A3
F94E  98                  TYA
F94F  E5 B1               SBC TEMP         ;CALCULATE HIGH
F951  86 B1               STX TEMP
F953  4A                  LSR A            ;MOVE 2 BITS FROM
F954  66 B1               ROR TEMP         ; HIGH TO TEMP
F956  4A                  LSR A
F957  66 B1               ROR TEMP
F959  A5 B0               LDA CMPO         ;CALC MIN PULSE VALUE
F95B  18                  CLC
F95C  69 3C               ADC #$3C
F95E  C5 B1               CMP TEMP         ;PULSE LESS THAN MIN?
F960  B0 4A               BCS L1141        ;YES, NOISE
F962  A6 9C               LDX DPSW         ;NO, LAST BIT?
F964  F0 03               BEQ L1132        ;NO, CONTINUE
F966  4C 60 FA            JMP L1154        ;YES, FINISH BYTE
F969               ;
F969  A6 A3        L1132  LDX PCNTR        ;9 BITS READ?
F96B  30 1B               BMI L1134        ;YES, GOTO ENDING
F96D  A2 00               LDX #$00         ;SET BIT VAL TO ZERO
F96F  69 30               ADC #$30         ;ADD UP TO HALF WAY BETWEEN
F971  65 B0               ADC CMPO         ; SHIRT PULSE AND SYNC PULSE
F973  C5 B1               CMP TEMP         ;SHORT?
F975  B0 1C               BCS L1139        ;YES
F977  E8                  INX              ;SET BIT VAL TO 1
F978  69 26               ADC #$26         ;MOVE TO MIDDLE OF HIGH
F97A  65 B0               ADC CMPO
F97C  C5 B1               CMP TEMP         ;1?
F97E  B0 17               BCS L1137        ;YES
F980  69 2C               ADC #$2C         ;MOVE TO LONGLONG
F982  65 B0               ADC CMPO
F984  C5 B1               CMP TEMP         ;LONGLONG?
F986  90 03               BCC L1136        ;GREATER THAN, ERROR
F988  4C 10 FA     L1134  JMP L1145        ;YES
F98B               ;
F98B  A5 B4        L1136  LDA SNSW1        ;NOT SYNCRONISED?
F98D  F0 1D               BEQ L1141        ;NO, ERROR
F98F  85 A8               STA RER          ;YES, FLAG RER
F991  D0 19               BNE L1141        ;ALWAYS
F993               ;
F993  E6 A9        L1139  INC REZ          ;COUNT REZ UP ON ZEROS
F995  B0 02               BCS L1138        ;ALWAYS
F997               ;
F997  C6 A9        L1137  DEC REZ          ;COUNT REZ DOWN ON ONES
F999  38           L1138  SEC              ;CALC ACTUAL VAL FOR COMPARE
F99A  E9 13               SBC #$13
F99C  E5 B1               SBC TEMP         ;SUBTRACT INPUT VAL
F99E  65 92               ADC SVXT         ; ADD DIFF TO TEMP STORE
F9A0  85 92               STA SVXT         ; USED TO ADJUST SOFT SERVO
F9A2  A5 A4               LDA FIRT         ;FLIP DIPOLE FLAG
F9A4  49 01               EOR #$01
```

```
LOC   CODE        LINE

F9A6  85 A4             STA FIRT
F9A8  F0 2B             BEQ L1143       ;SECOND HALF OF DIPOLE
F9AA  86 D7             STX DATA        ;FIRST HALF SO STORE VAL
F9AC                ;
F9AC  A5 B4         L1141  LDA SNSW1    ;NO BYTE START?
F9AE  F0 22             BEQ L1150       ;YES, RETURN
F9B0  AD A3 02          LDA $02A3       ;TIMER A IRQ'D?
F9B3  29 01             AND #$01
F9B5  D0 05             BNE L1133       ;YES
F9B7  AD A4 02          LDA $02A4
F9BA  D0 16             BNE L1150       ;NO, EXIT
F9BC  A9 00         L1133  LDA #$00     ;SET DIPOLE FLAG FOR FIRST HALF
F9BE  85 A4             STA FIRT
F9C0  8D A4 02          STA $02A4
F9C3  A5 A3             LDA PCNTR       ;WHERE IN BYTE
F9C5  10 30             BPL L1148       ; STILL DOING DATA
F9C7  30 BF             BMI L1134       ; PROCESS PARITY
F9C9                ;
F9C9  A2 A6         L1144  LDX #$A6     ;SETUP FOR LONGLONG
F9CB  20 E2 F8          JSR L1126
F9CE  A5 9B             LDA PRTY        ;EVEN PARITY?
F9D0  D0 B9             BNE L1136       ;NO, SET ERROR
F9D2  4C BC FE      L1150  JMP $FEBC    ;RESTORE REGS AND RTI
F9D5                ;
F9D5  A5 92         L1143  LDA SVXT     ;ADJUST SOFT SERVO?
F9D7  F0 07             BEQ L1149       ;NO
F9D9  30 03             BMI L1142       ;YES, MORE BASE TIME
F9DB  C6 B0             DEC CMPO        ;YES, LESS BASE TIME
F9DD  2C                .BYT $2C        ;SKIP NEXT
F9DE  E6 B0         L1142  INC CMPO
F9E0  A9 00         L1149  LDA #$00     ;CLEAR DIFF FLAG
F9E2  85 92             STA SVXT
F9E4  E4 D7             CPX DATA        ;CONSEC. LIKE VALS IN DIPOLE?
F9E6  D0 0F             BNE L1148       ;NO, PROCESS INFO
F9E8  8A                TXA             ;YES, CHECK VALS
F9E9  D0 A0             BNE L1136       ;ONES, ERROR
F9EB  A5 A9             LDA REZ         ;HOW MANY ZEROS?
F9ED  30 BD             BMI L1141       ; TOO MANY
F9EF  C9 10             CMP #$10        ; 16?
F9F1  90 B9             BCC L1141       ;NO, CONTINUE
F9F3  85 96             STA SYNO        ;YES, FLAG SYNO
F9F5  B0 B5             BCS L1141       ;ALWAYS
F9F7                ;
F9F7  8A            L1148  TXA          ;MOVE READ DATA TO .A
F9F8  45 9B             EOR PRTY        ;CALC PARITY
F9FA  85 9B             STA PRTY
F9FC  A5 B4             LDA SNSW1       ;REAL DATA?
F9FE  F0 D2             BEQ L1150       ;NO, FORGET
FA00  C6 A3             DEC PCNTR       ;DEC BIT COUNT
FA02  30 C5             BMI L1144       ;NEG, TIME FOR PARITY
FA04  46 D7             LSR DATA        ;SHIFT BIT FROM DATA
FA06  66 BF             ROR MYCH        ; INTO BYTE STORE
FA08  A2 DA             LDX #$DA        ;SETUP FOR NEXT DIPOLE
FA0A  20 E2 F8          JSR L1126
FA0D  4C BC FE          JMP $FEBC       ;RESTORE REGS AND RTI
FA10                ;
FA10                ;LONGLONG HANDLER
FA10                ;
FA10  A5 96         L1145  LDA SYNO     ;GOT BLOCK SYNC?
FA12  F0 04             BEQ L1140       ;NO
FA14  A5 B4             LDA SNSW1       ;HAD REAL BYTE?
FA16  F0 07             BEQ L1151       ;NO
FA18  A5 A3         L1140  LDA PCNTR    ;END OF BYTE?
FA1A  30 03             BMI L1151       ;YES
FA1C  4C 97 F9          JMP L1137       ;NO, TREAT AS LONG
FA1F                ;
FA1F  46 B1         L1151  LSR TEMP     ;ADJUST TIME OUT FOR
```

```
LOC   CODE        LINE

FA21  A9 93             LDA #$93        ; LONGLONG PULSE VAL
FA23  38                SEC
FA24  E5 B1             SBC TEMP
FA26  65 B0             ADC CMPO
FA28  0A                ASL A
FA29  AA                TAX             ;SET TIME OUT FOR LAST BIT
FA2A  20 E2 F8          JSR L1126
FA2D  E6 9C             INC DPSW        ;SET BIT THROW AWAY FLAG
FA2F  A5 B4             LDA SNSW1       ;BYTE SYNCRONISED?
FA31  D0 11             BNE L1152       ;YES, SKIP TO PASS CHAR
FA33  A5 96             LDA SYNO        ;THROW OUT DATA UNTIL SYNC
FA35  F0 26             BEQ L1155       ;NO SYNC
FA37  85 A8             STA RER         ;FLAG DATA AS ERROR
FA39  A9 00             LDA #$00        ;KILL 16 SYNC FLAG
FA3B  85 96             STA SYNO
FA3D  A9 81             LDA #$81        ;SETUP FOR TIMER B IRQ
FA3F  8D 0D DC          STA D1ICR
FA42  85 B4             STA SNSW1       ;FLAG WE HAVE BYTE SYNC
FA44                ;
FA44  A5 96         L1152  LDA SYNO     ;SAVE SYNO STATUS
FA46  85 B5             STA DIFF
FA48  F0 09             BEQ L1153       ;NO BLOCK SYNC
FA4A  A9 00             LDA #$00        ;TURN OFF BYTE SYNC SWITCH
FA4C  85 B4             STA SNSW1
FA4E  A9 01             LDA #$01        ;DISABLE TIMER B IRQ
FA50  8D 0D DC          STA D1ICR
FA53  A5 BF         L1153  LDA MYCH     ;PASS CHAR TO BYTE ROUTINE
FA55  85 BD             STA OCHAR
FA57  A5 A8             LDA RER         ;COMBINE ERROR VALS
FA59  05 A9             ORA REZ
FA5B  85 B6             STA PRP         ; AND SAVE IN PRP
FA5D  4C BC FE      L1155  JMP $FEBC    ;GET LAST BYTE
FA60                ;
FA60  20 97 FB      L1154  JSR L1079    ;FINISH BYTE, CLR FLAGS
FA63  85 9C             STA DPSW        ;GET BIT THROW AWAY FLAG
FA65  A2 DA             LDX #$DA        ;INIT FOR NEXT DIPOLE
FA67  20 E2 F8          JSR L1126
FA6A  A5 BE             LDA FSBLK       ;CHECK FOR LAST VAL
FA6C  F0 02             BEQ L1135
FA6E  85 A7             STA SHCNL
FA70                ;
FA70                ;****************************************
FA70                ;* BYTE HANDLER OF CASSETTE READ.
FA70                ;*     RER IS SET IF THE BYTE IS IN
FA70                ;* ERROR. REZ IS SET IF THE INTERRUPT
FA70                ;* PROGRAM IS READING ZEROS. RDFLG TELLS
FA70                ;* US WHAT WE ARE DOING. BIT 7 SAYS TO
FA70                ;* IGNORE BYTES UNTIL REZ IS SET, BIT 6
FA70                ;* SAYS TO LOAD THE BYTE. OTHERWISE
FA70                ;* RDFLG IS A COUNTDOWN AFTER SYNC. IF
FA70                ;* VERCK IS SET WE DO A COMPARE INSTEAD
FA70                ;* OF A STORE AND SET STATUS. FSBLK
FA70                ;* COUNTS THE TWO BLOCKS. PTR1 IS THE
FA70                ;* INDEX TO THE ERROR TABLE FOR PASS1.
FA70                ;* PTR2 IS THE INDEX TO THE CORRECTION
FA70                ;* TABLE FOR PASS2.
FA70                ;****************************************
FA70                ;
FA70  A9 0F         L1135  LDA #$0F
FA72  24 AA             BIT RDFLG       ;TEST FUNCTION MODE
FA74  10 17             BPL L1159       ;NOT WAITING FOR ZEROS
FA76  A5 B5             LDA DIFF        ;ZEROS YET?
FA78  D0 0C             BNE L1156       ;YES, WAIT FOR SYNC
FA7A  A6 BE             LDX FSBLK       ;PASS OVER?
FA7C  CA                DEX             ;ZERO, NO ERROR
FA7D  D0 0B             BNE L1158       ;NO
FA7F  A9 08             LDA #LBERR
```

```
LOC   CODE        LINE

FA81  20 1C FE            JSR $FE1C       ;YES, LONG BLOCK ERROR
FA84  D0 04               BNE L1158       ;ALWAYS
FA86  A9 00       L1156   LDA #$00
FA88  85 AA               STA RDFLG       ;NEW MODE, WAIT FOR SYNC
FA8A  4C BC FE    L1158   JMP $FEBC       ;EXIT, DONE
FA8D  70 31       L1159   BVS L1163       ;LOADING
FA8F  D0 18               BNE L1162       ;SYNCING
FA91  A5 B5               LDA DIFF        ;HAVE BLOCK SYNC?
FA93  D0 F5               BNE L1158       ;YES, EXIT
FA95  A5 B6               LDA PRP         ;FIRST BYTE IN ERROR?
FA97  D0 F1               BNE L1158       ;YES, EXIT
FA99  A5 A7               LDA SHCNL       ;MOVE FSBLK TO CARRY
FA9B  4A                  LSR A
FA9C  A5 BD               LDA OCHAR       ; SHOULD BE A HEADER COUNT CHAR
FA9E  30 03               BMI L1157       ;NEG, FIRST BLOCK DATA
FAA0  90 18               BCC L1161       ;EXPECTING FIRST BLOCK DATA
FAA2  18                  CLC
FAA3  B0 15       L1157   BCS L1161       ;EXPECTING 2ND BLOCK
FAA5  29 0F               AND #$0F        ;MASK OFF HIGH STORE HEADER
FAA7  85 AA               STA RDFLG       ; COUNT IN MODE FLAG
FAA9  C6 AA       L1162   DEC RDFLG       ;WAIT FOR REAL DATA
FAAB  D0 DD               BNE L1158       ; REAL
FAAD  A9 40               LDA #$40        ;NEXT UP IS REAL DATA
FAAF  85 AA               STA RDFLG       ; SET DATA MODE
FAB1  20 8E FB            JSR L1174       ;SETUP ADDR POINTERS
FAB4  A9 00               LDA #$00
FAB6  85 AB               STA SHCNH
FAB8  F0 D0               BEQ L1158       ;ALWAYS, EXIT
FABA  A9 80       L1161   LDA #$80        ;IGNORE BYTES MODE
FABC  85 AA               STA RDFLG
FABE  D0 CA               BNE L1158       ;ALWAYS
FAC0  A5 B5       L1163   LDA DIFF        ;END OF BLOCK?
FAC2  F0 0A               BEQ L1160       ;YES
FAC4  A9 04               LDA #S8ERR      ;SHORT BLOCK ERROR
FAC6  20 1C FE            JSR $FE1C
FAC9  A9 00               LDA #$00        ;FORCE RDFLG FOR ERROR
FACB  4C 4A FB            JMP L1167
FACE  20 D1 FC    L1160   JSR L1193       ;END OF STORE AREA?
FAD1  90 03               BCC L1164       ;NOT YET
FAD3  4C 48 FB            JMP L1172       ;YES
FAD6  A6 A7       L1164   LDX SHCNL        ;WHICH PASS?
FAD8  CA                  DEX
FAD9  F0 2D               BEQ L1169       ;SECOND
FADB  A5 93               LDA VERCK       ;LOAD OR VERIFY?
FADD  F0 0C               BEQ L1166       ;LOADING
FADF  A0 00               LDY #$00        ;VERIFYING
FAE1  A5 BD               LDA OCHAR
FAE3  D1 AC               CMP (SAL),Y     ;COMPARE
FAE5  F0 04               BEQ L1166       ;GOOD, CONTINUE
FAE7  A9 01               LDA #$01        ;BAD, FLAG
FAE9  85 B6               STA PRP         ; AS ERROR
FAEB              ;
FAEB              ;STORE BAD LOCATIONS FOR 2ND PASS RE-TRY
FAEB              ;
FAEB  A5 B6       L1166   LDA PRP         ;CHK FOR ERRORS
FAED  F0 4B               BEQ L1171       ;NONE
FAEF  A2 3D               LDX #$3D        ;MAX OF 30
FAF1  E4 9E               CPX PTR1        ;REACHED MAX?
FAF3  90 3E               BCC L1173       ;YES, FLAG 2ND PASS
FAF5  A6 9E               LDX PTR1        ;INDEX INTO BAD
FAF7  A5 AD               LDA SAH         ; AND STORE BAD LOC
FAF9  9D 01 01            STA BAD+1,X     ; IN BAD TABLE
FAFC  A5 AC               LDA SAL
FAFE  9D 00 01            STA BAD,X
FB01  E8                  INX             ;ADVANCE TO NEXT
FB02  E8                  INX
FB03  86 9E               STX PTR1
FB05  4C 3A FB            JMP L1171       ;STORE CHAR
```

```
LOC   CODE         LINE

FB08               ;
FB08               ;CHECK BAD TABLE FOR RE-TRY
FB08               ;
FB08  A6 9F        L1169  LDX PTR2         ;DONE ALL IN TABLE?
FB0A  E4 9E               CPX PTR1
FB0C  F0 35               BEQ L1170        ;YES
FB0E  A5 AC               LDA SAL          ;NEXT IN TABLE?
FB10  DD 00 01            CMP BAD,X
FB13  D0 2E               BNE L1170        ;NO
FB15  A5 AD               LDA SAH
FB17  DD 01 01            CMP BAD+1,X
FB1A  D0 27               BNE L1170        ;NO
FB1C  E6 9F               INC PTR2         ;FOUND NEXT ONE, ADVANCE
FB1E  E6 9F               INC PTR2
FB20  A5 93               LDA VERCK        ;LOAD OR VERIFY?
FB22  F0 0B               BEQ L1168        ;LOADING
FB24  A5 BD               LDA OCHAR        ;VERIFYING
FB26  A0 00               LDY #$00
FB28  D1 AC               CMP (SAL),Y
FB2A  F0 17               BEQ L1170        ;O.K.
FB2C  C8                  INY              ;.Y=1
FB2D  84 B6               STY PRP          ;FLAG IT AS AN ERROR
FB2F  A5 B6        L1168  LDA PRP          ;SECOND PASS ERROR?
FB31  F0 07               BEQ L1171        ;NO
FB33  A9 10        L1173  LDA #$PERR
FB35  20 1C FE            JSR $FE1C
FB38  D0 09               BNE L1170        ;ALWAYS
FB3A  A5 93        L1171  LDA VERCK        ;LOAD OR VERIFY?
FB3C  D0 05               BNE L1170        ;VERIFY
FB3E  A8                  TAY
FB3F  A5 BD               LDA OCHAR
FB41  91 AC               STA (SAL),Y      ;STORE CHARACTER
FB43  20 DB FC     L1170  JSR L1080        ;NEXT ADDRESS
FB46  D0 43               BNE L1177        ;ALWAYS
FB48               ;
FB48  A9 80        L1172  LDA #$80         ;SET SKIP NEXT DATA
FB4A  85 AA        L1167  STA RDFLG
FB4C  78                  SEI
FB4D  A2 01               LDX #$01
FB4F  8E 0D DC            STX D1ICR
FB52  AE 0D DC            LDX D1ICR
FB55  A6 BE               LDX FSBLK        ;DEC FSBLK FOR NEXT PASS
FB57  CA                  DEX
FB58  30 02               BMI L1165        ;DONE, FSBLK=0
FB5A  86 BE               STX FSBLK        ; ELSE, NEXT
FB5C  C6 A7        L1165  DEC SHCNL        ;DEC PASS CALC
FB5E  F0 08               BEQ L1175        ;ALL DONE
FB60  A5 9E               LDA PTR1         ;FIRST PASS ERRORS?
FB62  D0 27               BNE L1177        ;YES, CONTINUE
FB64  85 BE               STA FSBLK        ;CLEAR FSBLK IF NO ERRORS
FB66  F0 23               BEQ L1177        ;ALWAYS, EXIT
FB68               ;
FB68  20 93 FC     L1175  JSR L1192        ;READ IT ALL, EXIT
FB6B  20 8E FB             JSR L1174        ;RESTORE SAL & SAH
FB6E  A0 00               LDY #$00         ;SHCNH=0
FB70  84 AB               STY SHCNH        ; USED TO CALC PARITY BYTE
FB72               ;
FB72               ;COMPUTE PARITY BYTE
FB72               ;
FB72  B1 AC        L1176  LDA (SAL),Y      ;CALC BLOCK BCC
FB74  45 AB               EOR SHCNH
FB76  85 AB               STA SHCNH
FB78  20 DB FC            JSR L1080        ;BUMP ADDRESS
FB7B  20 D1 FC            JSR L1193        ;AT END?
FB7E  90 F2               BCC L1176        ;NOT YET
FB80  A5 AB               LDA SHCNH        ;BCC CHAR MATCH?
FB82  45 BD               EOR OCHAR
```

```
LOC   CODE          LINE

FB84  F0 05               BEQ L1177       ;YES, EXIT
FB86  A9 20               LDA #CKERR      ;CHKSUM ERROR
FB88  20 1C FE            JSR $FE1C
FB8B  4C BC FE      L1177 JMP $FEBC
FB8E                ;
FB8E  A5 C2         L1174 LDA STAH        ;RESTORE START ADDR
FB90  85 AD               STA SAH         ; TO POINTER SAH & SAL
FB92  A5 C1               LDA STAL
FB94  85 AC               STA SAL
FB96  60                  RTS
FB97                ;
FB97  A9 08         L1079 LDA #$08        ;SETUP FOR 8 BITS+PARITY
FB99  85 A3               STA PCNTR
FB9B  A9 00               LDA #$00        ;INITIALISE
FB9D  85 A4               STA FIRT        ; DIPOLE COUNTER
FB9F  85 A8               STA RER         ; ERROR FLAG
FBA1  85 9B               STA PRTY        ; PARITY BIT
FBA3  85 A9               STA REZ         ; ZERO COUNT
FBA5  60                  RTS             ;.A=0 ON RETURN
FBA6                .END
FBA6                      .LIB KTAPE7
```

Cassette write subroutines

Entry point: $FBA6

Function: These five routines are all required by the main write to tape routine at $F867.

Routine source code:

```
LOC   CODE          LINE

FBA6                ;
FBA6                ;****************************************
FBA6                ;* CASSETTE WRITE SUBROUTINES.
FBA6                ;*      FSBLK IS BLOCK COUNTER FOR RECORD
FBA6                ;*            = 0 SECOND DATA
FBA6                ;*            = 1 FIRST DATA
FBA6                ;*            = 2 FIRST HEADER
FBA6                ;****************************************
FBA6                ;
FBA6                ;TOGGLE WRITE BIT ACCORDING TO LSB
FBA6                ;IN OCHAR
FBA6                ;
FBA6  A5 BD         L1122 LDA OCHAR       ;BIT TO WRITE INTO CARRY
FBA8  4A                  LSR A
FBA9  A9 60               LDA #$60        ;ASSUME CARRY CLEAR (SHORT)
FBAB  90 02               BCC L1184       ;CORRECT
FBAD  A9 B0         L1185 LDA #$B0        ;SET LONG
FBAF  A2 00         L1184 LDX #$00        ;SET AND STORE TIME
FBB1  8D 06 DC      L1178 STA D1TBL       ;LO BYTE
FBB4  8E 07 DC            STX D1TBH       ;HI BYTE
FBB7  AD 0D DC            LDA D1ICR       ;CLEAR IRQ
FBBA  A9 19               LDA #$19
FBBC  8D 0F DC            STA D1CRB       ;FORCE LOAD & START TIMER
FBBF  A5 01               LDA $01         ;TOGGLE WRITE BIT
FBC1  49 08               EOR #$08
FBC3  85 01               STA $01
```

```
LOC   CODE        LINE

FBC5  29 08             AND #$08        ;LEAVE JUST WRITE BIT
FBC7  60                RTS
FBC8  38          L1181 SEC             ;FLAG PRP FOR END OF BLOCK
FBC9  66 B6             ROR PRP
FBCB  30 3C             BMI L1183       ;ALWAYS
FBCD              ;
FBCD              ;TAPE WRITE IRQ ENTRY
FBCD              ;
FBCD              ;
FBCD  A5 A8       WRTN  LDA REK         ;CHECK FOR ONE LONG
FBCF  D0 12             BNE L1191
FBD1  A9 10             LDA #$10        ;WRITE LONG BIT
FBD3  A2 01             LDX #$01
FBD5  20 B1 FB          JSR L1178
FBD8  D0 2F             BNE L1183
FBDA  E6 A8             INC REK
FBDC  A5 B6             LDA PRP         ;END OF BLOCK?
FBDE  10 29             BPL L1183       ;NO, CONTINUE
FBE0  4C 57 FC          JMP L1194       ;YES, FINISH OFF
FBE3              ;
FBE3  A5 A9       L1191 LDA REZ         ;CHECK FOR A ONE BIT
FBE5  D0 09             BNE L1180
FBE7  20 AD FB          JSR L1185
FBEA  D0 1D             BNE L1183
FBEC  E6 A9             INC REZ
FBEE  D0 19             BNE L1183
FBF0              ;
FBF0  20 A6 FB    L1180 JSR L1122       ;WRITE
FBF3  D0 14             BNE L1183       ;ON BIT LOW, EXIT
FBF5  A5 A4             LDA FIRT        ;FIRST OF DIPOLE?
FBF7  49 01             EOR #$01
FBF9  85 A4             STA FIRT
FBFB  F0 0F             BEQ L1179       ;DIPOLE DONE
FBFD  A5 BD             LDA OCHAR       ;FLIPS BIT FOR COMPLEMENTARY
FBFF  49 01             EOR #$01
FC01  85 BD             STA OCHAR
FC03  29 01             AND #$01        ;TOGGLE PARITY
FC05  45 9B             EOR PRTY-
FC07  85 9B             STA PRTY
FC09  4C BC FE    L1183 JMP $FEBC       ;RESTORE REGS AND RTI
FC0C              ;
FC0C  46 BD       L1179 LSR OCHAR       ;NEXT BIT
FC0E  C6 A3             DEC PCNTR       ;DEC COUNTER FOR # BITS
FC10  A5 A3             LDA PCNTR       ;8 BITS SENT?
FC12  F0 3A             BEQ L1190       ;YES, DO PARITY
FC14  10 F3             BPL L1183       ;NO, SEND REST
FC16              ;
FC16  20 97 FB    L1186 JSR L1079       ;CLEAN UP COUNTERS
FC19  58                CLI             ;ALLOW INTERRUPTS TO NEST
FC1A  A5 A5             LDA CNTDN       ;WRITING HEADER COUNTER?
FC1C  F0 12             BEQ L1189       ;NO
FC1E  A2 00             LDX #$00        ;WRITE HEADER COUNTERS
FC20  86 D7             STX DATA        ;CLEAR BCC
FC22  C6 A5             DEC CNTDN
FC24  A6 BE             LDX FSBLK       ;FIRST BLOCK HEADER?
FC26  E0 02             CPX #$02
FC28  D0 02             BNE L1196       ;NO
FC2A  09 80             ORA #$80        ;YES, MARK 1ST BLOCK HEADER
FC2C  85 BD       L1196 STA OCHAR       ;WRITE CHARS IN HEADER
FC2E  D0 D9             BNE L1183
FC30  20 D1 FC    L1189 JSR L1193       ;ADDR=END?
FC33  90 0A             BCC L1188       ;NOT YET
FC35  D0 91             BNE L1181       ;MARK END
FC37  E6 AD             INC SAH
FC39  A5 D7             LDA DATA        ;WRITE BCC
FC3B  85 BD             STA OCHAR
FC3D  B0 CA             BCS L1183       ;ALWAYS
```

```
LOC   CODE          LINE

FC3F                ;
FC3F  A0 00         L1188  LDY #$00         ;NEXT CHAR
FC41  B1 AC                LDA (SAL),Y
FC43  85 BD                STA OCHAR        ;STORE IN OUTPUT CHAR
FC45  45 D7                EOR DATA         ;UPDATE BCC
FC47  85 D7                STA DATA
FC49  20 DB FC             JSR L1080        ;BUMP ADDRESS
FC4C  D0 BB                BNE L1183        ;ALWAYS
FC4E                ;
FC4E  A5 9B         L1190  LDA PRTY         ;PARITY INTO OCHAR
FC50  49 01                EOR #$01
FC52  85 BD                STA OCHAR        ; FOR NEXT BIT
FC54  4C BC FE      L1187  JMP $FEBC        ;RESTORE REGS AND RTI
FC57                ;
FC57  C6 BE         L1194  DEC FSBLK        ;END?
FC59  D0 03                BNE L1182        ;BLOCK ONLY
FC5B  20 CA FC             JSR L1121        ;WRITE SO TURN OFF MOTOR
FC5E  A9 50         L1182  LDA #$50         ;PUT 80 CASSETTE
FC60  85 A7                STA SHCNL        ; SYNCS AT END
FC62  A2 08                LDX #$08
FC64  78                   SEI
FC65  20 BD FC             JSR L1195        ;SET VECTOR TO WRITE ZEROS
FC68  D0 EA                BNE L1187        ;ALWAYS
```

Tape IRQ

Entry point:
$FC6A – tape IRQ entry
$FCBD – change IRQ vectors

Function: The first of these two routines performs the main IRQ loop for both tape LOAD and SAVE. It should be noted that all SAVE and LOAD operations are performed under IRQ as a background program. The second routine is used to change the IRQ vectors for different tape read and write operations.

Routine source code:

```
LOC   CODE          LINE

FC6A                ;
FC6A                ; TAPE IRQ ENTRY FOR
FC6A                ;
FC6A  A9 78         WRTZ   LDA #$78         ;WRITING LEADING ZEROS
FC6C  20 AF FB             JSR L1184        ; FOR SYNC
FC6F  D0 E3                BNE L1187
FC71  C6 A7                DEC SHCNL        ;DONE WITH LOW SYNC?
FC73  D0 DF                BNE L1187        ;NO
FC75  20 97 FB             JSR L1079        ;YES, CLEAN UP COUNTERS
FC78  C6 AB                DEC SHCNH        ;DONE WITH SYNC?
FC7A  10 D8                BPL L1187        ;NO
FC7C  A2 0A                LDX #$0A         ;YES, VECTOR FOR DATA
FC7E  20 BD FC             JSR L1195
FC81  58                   CLI
FC82  E6 AB                INC SHCNH        ;ZERO SHCNH
FC84  A5 BE                LDA FSBLK        ;DONE?
FC86  F0 30                BEQ L1198        ;YES, SYSTEM RESTORE
```

```
LOC   CODE        LINE

FC88  20 8E FB          JSR L1174
FC8B  A2 09             LDX #$09        ;SETUP FOR HEADER COUNT
FC8D  86 A5             STX CNTDN
FC8F  86 B6             STX PRP
FC91  D0 83             BNE L1186       ;ALWAYS
FC93                    ;
FC93  08                L1192  PHP              ;CLEAN UP IRQ AND
FC94  78                       SEI              ; RESTORE PIA'S
FC95  AD 11 D0                 LDA VICREG+17    ;RESTORE SCREEN
FC98  09 10                    ORA #$10
FC9A  8D 11 D0                 STA VICREG+17
FC9D  20 CA FC                 JSR L1121        ;TURN OFF MOTOR
FCA0  A9 7F                    LDA #$7F         ;CLEAR INTERRUPTS
FCA2  8D 0D DC                 STA D1ICR
FCA5  20 DD FD                 JSR $FDDD        ;RESTORE KEYBOARD IRQ
FCA8  AD A0 02                 LDA IRQTMP+1     ;RESTORE KEYBOARD INTERRUPT VECTOR
FCAB  F0 09                    BEQ L1127        ;NO IRQ
FCAD  8D 15 03                 STA CINV+1
FCB0  AD 9F 02                 LDA IRQTMP
FCB3  8D 14 03                 STA CINV
FCB6  28                L1127  PLP
FCB7  60                       RTS
FCB8                    ;
FCB8  20 93 FC          L1198  JSR L1192        ;RESTORE SYSTEM IRQ
FCBB  F0 97                    BEQ L1187        ;CAME FOR TAPE IRQ SO RTI
FCBD                    ;****************************************
FCBD                    ;* SUBROUTINE TO CHANGE IRQ VECTORS.
FCBD                    ;* ON ENTRY, .X = 8 WRITE ZEROS TO TAPE
FCBD                    ;*              = 10 WRITE DATA TO TAPE
FCBD                    ;*              = 12 RESTORE TO KEYSCAN
FCBD                    ;*              = 14 READ DATA FROM TAPE
FCBD                    ;****************************************
FCBD                    ;
FCBD  BD 93 FD          L1195  LDA $FD93,X      ;MOVE IRQ VECTORS
FCC0  8D 14 03                 STA CINV         ; TO VECTOR TABLE
FCC3  BD 94 FD                 LDA $FD94,X
FCC6  8D 15 03                 STA CINV+1
FCC9  60                       RTS
FCCA                    ;
FCCA  A5 01             L1121  LDA $01          ;TURN OFF CASSETTE MOTOR
FCCC  09 20                    ORA #$20
FCCE  85 01                    STA $01
FCD0  60                       RTS
FCD1                    ;****************************************
FCD1                    ;* COMPARE START AND END OF LOAD/SAVE
FCD1                    ;* ADDRESSES. SUBROUTINE CALLED BY
FCD1                    ;* TAPE READ, SAVE, TAPE WRITE
FCD1                    ;****************************************
FCD1                    ;
FCD1  38                L1193  SEC
FCD2  A5 AC                    LDA SAL
FCD4  E5 AE                    SBC EAL
FCD6  A5 AD                    LDA SAH
FCD8  E5 AF                    SBC EAH
FCDA  60                       RTS
FCDB                    ;
FCDB                    ;BUMP ADDRESS POINTER SAL
FCDB                    ;
FCDB  E6 AC             L1080  INC SAL
FCDD  D0 02                    BNE L1083
FCDF  E6 AD                    INC SAH
FCE1  60                L1083  RTS
FCE2                    ;
FCE2                    ;---------------------------
FCE2                    *=$FD9B
FD9B                    ;
FD9B                    ; TAPE IRQ VECTORS
```

```
LOC   CODE        LINE

FD9B              ;
FD9B  6A FC             .WOR WRTZ       ;WRITE ZEROS TAPE
FD9D  CD FB             .WOR WRTN       ;WRITE NORMAL TAPE
FD9F  31 EA             .WOR $EA31      ;NORMAL IRQ
FDA1  2C F9             .WOR L1130      ;READ TAPE
FDA3              ;
FDA3              .END
FDA3                    .END
```

4.7 High speed tape operation

Virtually all Commodore 64 software currently being marketed uses some form of fast loader. These fast loaders are given names like: Turbo (this was the first fast loader available), Pavload, Flash Load, etc. The origin of these fast loader routines is rather obscure since many of the software houses use the same loader routines. In this section we give the source code for two fast loaders and their associated SAVE routine; these have been used on several software products of Zifra Software Ltd. under the name of ZITload and ZIFRAload.

A fast loader is a routine which replaces the existing LOAD and allows a program or data to be loaded from tape at about ten times the speed of a normal LOAD. This means that a tape can be as fast as a disk drive. A fast loader is achieved by simply changing the format of the pulse sequence which is stored onto the tape in order to allow a far greater density of information storage per inch of tape. In order to create a fast loader two programs are needed; a fast loader program which is a fairly short machine code routine loaded at the beginning of a LOAD operation and then auto run to LOAD the rest of the program and/or data which is stored in fast loader format. The second program which is required is a routine to SAVE a program in fast loader format, the fast SAVE.

The first major problem to be overcome in designing a fast loader is how each bit is stored on the tape. Each bit is stored on tape as a pulse which goes through a high-low transition (see Fig. 4.4). The length of the total pulse decides whether the bit is a 1 or Ø. A short pulse is a zero and a long pulse is a one. The bit is flagged in the interrupt register on the falling edge of the pulse.

The loader is a machine code program which runs with the interrupts disabled, sets a timer to between the two lengths, and when the timer runs out the interrupt register is checked to see if the pulse came in or not. If the falling edge of the pulse generates an interrupt before the timer runs out then the pulse was a zero, otherwise it was a one. The bits are then rotated into a byte storage until 8 bits have been read, thereby loading a full byte.

Before any bytes can be read and stored, the loader must set itself to be in sync with the bits on the tape. This is done by writing a string of zero bits with a single one bit at every byte interval. The routine then tries to align itself by recognising the value of the byte. An example of a header byte for aligning would be the value 64, hex $4Ø or in binary: Ø1ØØØØØØ. A series of these bytes is written as the header; only when this byte has been read in and recognised can the actual program can be read without risk of alignment errors.

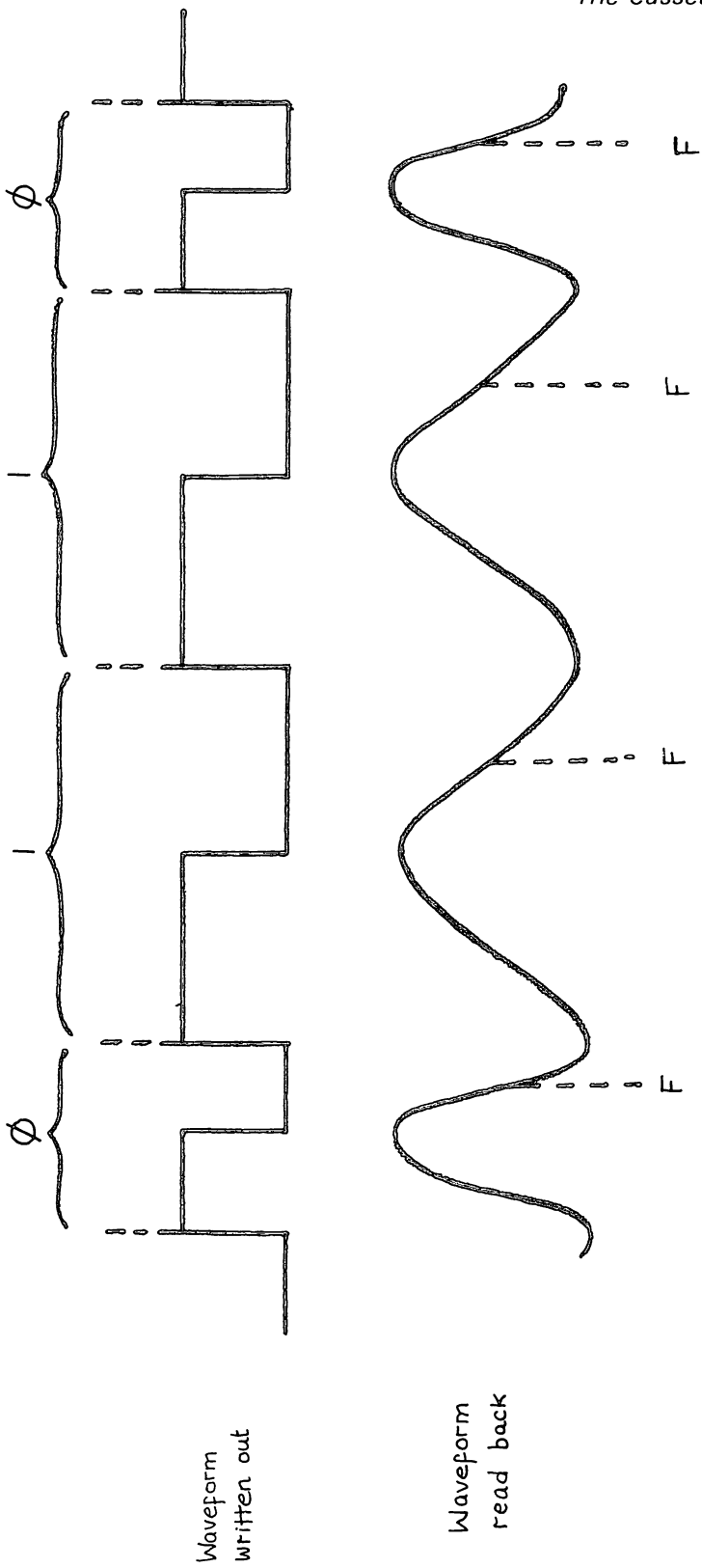


Fig. 4.4. High speed tape waveform.

The program is stored in different ways depending on how much protection it is desired to put in the program. The simplest way of formatting the file is to first SAVE the two byte load address followed by the two byte end address and then the actual file. The final byte following the end of the file is a checksum that was calculated by the SAVE routine and is also calculated during loading. If the two values are the same, the LOAD was successful. The routine for this form of fast loader is given in Program 5.

```
033C          !  FAST TAPE SAVE FOR THE 64.
033C          !*****************************
033C          !
033C          !THIS ROUTINE WILL SAVE A PROGRAM
033C          !TO TAPE SO THAT WHEN LOADED BACK
033C          !IT WILL LOAD FASTER THAN THE
033C          !1541 DISK DRIVE.
033C          !
033C          !AN OPTION FOR AUTO-RUN IS
033C          !INCLUDED.
033C          !
C000          *=$C000
C000 A90B               LDA #<SAVVEC          !CHANGE SAVE VECTOR
C002 8D3203             STA $0332             ! TO GO TO NEW
C005 A9C0               LDA #>SAVVEC          ! SAVE ROUTINE
C007 8D3303             STA $0333
C00A 60                 RTS
C00B          !
C00B 48       SAVVEC    PHA                   !SAVE OFF .A
C00C A5BA               LDA $BA               !GET DEVICE #
C00E C907               CMP #$07              !NUMBER 7?
C010 F004               BEQ TSAVE             !YES
C012 68                 PLA
C013 4CEDF5             JMP $F5ED             !DO NORMAL SAVE
C016          !
C016 A5B9     TSAVE     LDA $B9               !GET SEC. ADDR.
C018 8D29C2             STA RUNFLG            !FLAG FOR AUTO-RUN
C01B A00F               LDY #$0F
C01D A920               LDA #$20
C01F 99BCC1 LOOP1       STA FLNAME,Y          !BLANK FILENAME
C022 88                 DEY
C023 10FA               BPL LOOP1
C025 A4B7               LDY $B7               !GET FILENAME LENGTH
C027 C011               CPY #$11              !GREATER THAN 16?
C029 9002               BCC LOOP2             !NO
C02B A010               LDY #$10              !ONLY 1ST 16 CHARS
C02D 88       LOOP2     DEY
C02E 3008               BMI TSAVE1
C030 B1BB               LDA ($BB),Y           !GET FILENAME
C032 99BCC1             STA FLNAME,Y          !STORE IT
C035 4C2DC0             JMP LOOP2             !DO NEXT CHAR
C038          !
C038 A047     TSAVE1    LDY #$47
C03A B944C1 TSAVE2      LDA LOADER,Y          !GET LOADER BYTE
C03D 99BC02             STA $02BC,Y           !STORE IT TO SAVE
C040 88                 DEY
C041 10F7               BPL TSAVE2            !FOR ALL BYTES
C043 A901               LDA #$01
C045 AA                 TAX
C046 A8                 TAY
C047 20BAFF             JSR $FFBA             !SET FILE DETAILS
C04A A99E               LDA #$9E              !LENGTH OF FILENAME
C04C A2BC               LDX #<FLNAME          !FILENAME LO
C04E A0C1               LDY #>FLNAME          !FILENAME HI
C050 20BDFF             JSR $FFBD             !SET NAME DETAILS
C053 A900               LDA #$00              !STOP NAME FROM BEING
C055 859D               STA $9D               !PRINTED ON SAVE
C057 A902               LDA #$02
```

```
C059 85FC              STA $FC                 !SAVE START HI
C05B A9BC              LDA #$BC
C05D 85FB              STA $FB                 !SAVE START LO
C05F A9FB              LDA #$FB                !POINT TO START
C061 A204              LDX #$04                !SAVE END LO
C063 A003              LDY #$03                !SAVE END HI
C065 20D8FF            JSR $FFD8               !SAVE LOADER FILE
C068 A983              LDA #$83
C06A 8D0203            STA $0302               !RESET WARM START
C06D A9A4              LDA #$A4                ! VECTOR
C06F 8D0303            STA $0303
C072 A901              LDA #$01
C074 859D              STA $9D
C076 A000              LDY #$00
C078 A200              LDX #$00
C07A          !
C07A          !THE FAST SAVE ROUTINE
C07A          !STARTS HERE.
C07A          !
C07A 20CBC0            JSR WRTHDR              !WRITE ALIGNMENT BYTES
C07D A52B              LDA $2B                 !GET START LO
C07F 48                PHA
C080 20FAC0            JSR WRTBYT              !WRITE IT
C083 A52C              LDA $2C                 !GET START HI
C085 48                PHA
C086 20FAC0            JSR WRTBYT              !WRITE IT
C089 A52D              LDA $2D                 !GET END LO
C08B 20FAC0            JSR WRTBYT              !WRITE IT
C08E A52E              LDA $2E                 !GET END HI
C090 20FAC0            JSR WRTBYT              !WRITE IT
C093 84FB              STY $FB                 !ZERO CHECKSUM
C095 A42B              LDY $2B                 !GET PAGE OFFSET
C097 A900              LDA #$00
C099 852B              STA $2B                 !ZERO LO BYTE
C09B B12B    TSAVLOOP  LDA ($2B),Y             !GET A BYTE
C09D 20FAC0            JSR WRTBYT              !WRITE IT
C0A0 C8                INY
C0A1 D002              BNE TSAVE3
C0A3 E62C              INC $2C
C0A5 C42D    TSAVE3    CPY $2D                 !CHECK END OF SAVE
C0A7 A52C              LDA $2C
C0A9 E52E              SBC $2E
C0AB 90EE              BCC TSAVLOOP            !NOT YET
C0AD A5FB              LDA $FB                 !GET CHECKSUM
C0AF 20FAC0            JSR WRTBYT              !WRITE IT
C0B2 20EC1             JSR WRTBIT              !CLOSE OFF LAST BIT
C0B5 A91B              LDA #$1B
C0B7 8D11D0            STA $D011               !UNBLANK SCREEN
C0BA A937              LDA #$37
C0BC 8501              STA $01                 !STOP TAPE
C0BE 58                CLI                     !RESTART  IRQ
C0BF 68                PLA                     !GET START HI
C0C0 852C              STA $2C                 !STORE IT
C0C2 68                PLA                     !GET START LO
C0C3 852B              STA $2B                 !STORE IT
C0C5 2084FF            JSR $FF84               !RESET I/O
C0C8 4C74A4            JMP $A474               !EXIT TO 'READY.'
C0CB          !
C0CB A906    WRTHDR    LDA #$06                !BASIC ROM OUT &
C0CD 8501              STA $01                 ! START TAPE
C0CF A90B              LDA #$0B
C0D1 8D11D0            STA $D011               !BLANK SCREEN
C0D4 CA      HEADR1    DEX                     !PAUSE FOR TAPE
C0D5 D0FD              BNE HEADR1              ! TO GET TO FULL
C0D7 88                DEY                     ! SPEED
C0D8 D0FA              BNE HEADR1
C0DA 78                SEI                     !DISABLE IRQ
C0DB A9A0              LDA #$A0                !INITIAL TIMER
C0DD 8D04DD            STA $DD04               ! VALUE FOR DELAY
C0E0 A900              LDA #$00
```

```
C0E2 8D05DD             STA $DD05
C0E5 A919               LDA #$19
C0E7 8D0EDD             STA $DD0E           !START TIMER
C0EA A040               LDY #$40
C0EC A940   HEADR2      LDA #$40            !01000000 FOR
C0EE 20FAC0             JSR WRTBYT          !ALIGNMENT
C0F1 88                 DEY
C0F2 D0F8               BNE HEADR2          !WRITE 64 OF THEM
C0F4 A95A               LDA #$5A            !CHECK ALIGNMENT
C0F6 20FAC0             JSR WRTBYT          !WRITE IT
C0F9 60                 RTS
C0FA        !
C0FA 85BD   WRTBYT      STA $BD             !STORE BYTE
C0FC 45FB               EOR $FB             !CHECKSUM
C0FE 85FB               STA $FB
C100 A908               LDA #$08            !LOOP FOR 8 BITS
C102 85A3               STA $A3
C104 26BD   WBYTE1      ROL $BD             !BIT INTO CARRY
C106 200EC1             JSR WRTBIT          !WRITE THE BIT
C109 C6A3               DEC $A3
C10B D0F7               BNE WBYTE1          !DO NEXT BIT
C10D 60                 RTS
C10E        !
C10E A240   WRTBIT      LDX #$40            !ASSUME ZERO BIT
C110 9002               BCC WBIT1           !CORRECT ASSUMPTION
C112 A290               LDX #$90            !SET FOR ONE BIT
C114 8E04DD WBIT1       STX $DD04           !SET TIMER
C117 A900               LDA #$00
C119 8D05DD             STA $DD05
C11C A901               LDA #$01            !WAIT FOR TIMER
C11E 2C0DDD WBIT2       BIT $DD0D
C121 F0FB               BEQ WBIT2
C123 A501               LDA $01             !TOGGLE WRITE BIT
C125 4908               EOR #$08            ! IN 6510 REGISTER
C127 8501               STA $01
C129 EE20D0             INC $D020           !SHOW IT IS WORKING
C12C A919               LDA #$19
C12E 8D0EDD             STA $DD0E           !START TIMER
C131 A901               LDA #$01            !WAIT FOR TIMER
C133 2C0DDD WBIT3       BIT $DD0D
C136 F0FB               BEQ WBIT3
C138 A501               LDA $01             !TOGGLE WRITE BIT
C13A 4908               EOR #$08            ! IN 6510 REGISTER
C13C 8501               STA $01
C13E A919               LDA #$19
C140 8D0EDD             STA $DD0E           !START TIMER
C143 60                 RTS
C144        !
C144        !THE LOADER STARTS HERE
C144        !
C144 AD20D0 LOADER      LDA $D020
C147 85FE               STA $FE             !SAVE BORDER COLOUR
C149 A9A4               LDA #$A4            !RESET WARM START
C14B 8D0303             STA $0303           ! VECTOR
C14E A983               LDA #$83
C150 8D0203             STA $0302
C153 205103             JSR $0351           !FAST LOAD THE FILE
C156 A5FE               LDA $FE
C158 8D20D0             STA $D020           !RESTORE BORDER COLOUR
C15B A937               LDA #$37
C15D 8501               STA $01             !STOP THE TAPE
C15F 58                 CLI                 !RESTORE IRQ
C160 A91B               LDA #$1B
C162 8D11D0             STA $D011           !UNBLANK SCREEN
C165 2084FF             JSR $FF84           !RESET I/O
C168 A5FC               LDA $FC             !COMPARE CALCULATED TO
C16A C5FB               CMP $FB             ! LOADED CHECKSUM
C16C D015               BNE LODERR          !DIFFERENT..ERROR
C16E 2063A6             JSR $A663           !CLR
C171 ADDE03             LDA $03DE           !GET AUTO-RUN FLAG
```

```
C174 F00A              BEQ EXIT                !NO RUN
C176 208EA6            JSR $A68E               !SET CHARGET POINTER
C179 A900              LDA #$00
C17B 859D              STA $9D                 !FLAG RUN MODE
C17D 4CAEA7            JMP $A7AE               !RUN
C180          !
C180 6C0203 EXIT       JMP ($0302)             !WARM START
C183          !
C183 A21D   LODERR     LDX #$1D                !'?LOAD  ERROR'
C185 4C37A4            JMP $A437               !SEND ERROR
C188          !
C188 3BE3              WOR $E38B               !ERROR LINK
C18A BC02              WOR $02BC               !WARM START LINK
C18C          !
C18C 202020 FLNAME     TXT "                "
C19C          !
C19C          !16 SPACES
C19C          !
C19C          !*=$0351
C19C          !
C19C 208703            JSR $0387               !READ HEADER
C19F 20BA03            JSR $03BA               !READ A BYTE
C1A2 A8                TAY                     !LOAD LO
C1A3 A900              LDA #$00
C1A5 85C1              STA $C1
C1A7 20BA03            JSR $03BA               !READ A BYTE
C1AA 85C2              STA $C2                 !LOAD HI
C1AC 20BA03            JSR $03BA               !READ A BYTE
C1AF 852D              STA $2D                 !END LO
C1B1 20BA03            JSR $03BA               !READ A BYTE
C1B4 852E              STA $2E                 !END HI
C1B6 20BA03 TLOAD1     JSR $03BA               !READ A BYTE
C1B9 91C1              STA ($C1),Y             !STORE IT
C1BB 45FC              EOR $FC                 !CALCULATE CHECKSUM
C1BD 85FC              STA $FC
C1BF C8                INY
C1C0 D002              BNE TLOAD2
C1C2 E6C2              INC $C2
C1C4 C42D   TLOAD2     CPY $2D                 !CHECK END OF LOAD
C1C6 A5C2              LDA $C2
C1C8 E52E              SBC $2E
C1CA 90EA              BCC TLOAD1              !NOT YET
C1CC 20BA03            JSR $03BA               !READ CHECKSUM
C1CF 85FB              STA $FB
C1D1 60                RTS
C1D2          !
C1D2          !*=$0387
C1D2          !
C1D2 A907              LDA #$07
C1D4 8501              STA $01                 !START TAPE
C1D6 A90B              LDA #$0B
C1D8 8D11D0            STA $D011               !BLANK SCREEN
C1DB CA     RHEAD1     DEX                     !PAUSE FOR TAPE TO
C1DC D0FD              BNE RHEAD1              ! REACH FULL SPEED
C1DE 88                DEY
C1DF D0FA              BNE RHEAD1
C1E1 78                SEI                     !DISABLE IRQ
C1E2 84FC              STY $FC                 !ZERO CHECKSUM
C1E4 8C05DD            STY $DD05               !SET TIMER HI
C1E7 A9F8              LDA #$F8
C1E9 8D04DD            STA $DD04               !SET TIMER LO
C1EC A200              LDX #$00
C1EE 20C803 RHEAD2     JSR $03C8               !READ A BIT
C1F1 26BD              ROL $BD                 !INTO BYTE
C1F3 A5BD              LDA $BD
C1F5 C940              CMP #$40                !ALIGNED?
C1F7 D0F5              BNE RHEAD2              !NOT YET
C1F9 20BA03 RHEAD3     JSR $03BA               !READ A BYTE
C1FC C940              CMP #$40                !IS IT 64?
C1FE F0F9              BEQ RHEAD3              !YES
```

```
C200 C95A              CMP #$5A                !ALIGNMENT CHECK?
C202 D0EA              BNE RHEAD2              !NO
C204 60                RTS
C205          !
C205          !*=$03BA
C205          !
C205 A901              LDA #$01
C207 85BD              STA $BD
C209 20C803 GBYTE1     JSR $03C8               !READ A BIT
C20C 26BD              ROL $BD                 !INTO BYTE
C20E 90F9              BCC GBYTE1              !COMPLETE BYTE
C210 A5BD              LDA $BD
C212 60                RTS
C213          !
C213          !*=$03C8
C213          !
C213 A910              LDA #$10                !WAIT FOR BIT
C215 2C0DDC GBIT1      BIT $DC0D
C218 F0FB              BEQ GBIT1
C21A AD0DDD            LDA $DD0D               !GET BIT
C21D 48                PHA
C21E A919              LDA #$19
C220 8D0EDD            STA $DD0E               !START TIMER
C223 68                PLA
C224 EE20D0            INC $D020               !SHOW IT IS WORKING
C227 4A                LSR A                   !MOVE BIT INTO CARRY
C228 60                RTS
C229          !
C229          !*=$03DE
C229          !
C229 00       RUNFLG   BYT 0
```

Program 5.

Another type of LOAD, which uses the same saver but is slower, is the interrupt loader. This method has the advantage of being able to LOAD with the screen on and a foreground program running whilst the main program is loaded. Loaders of this type are: Novaload and Micro Load. The difference with this type of LOAD is that an interrupt is created when a pulse is read by the tape recorder, and the timer is checked to find out whether the pulse was a zero or a one. The whole LOAD is done in the background allowing a foreground program to play music, run a clock, etc. The foreground program must check at regular intervals to see if the loader has flagged for the end of load. The example of a background LOAD in Program 6 has only a foreground program that is waiting for the end of LOAD flag to be set.

```
033C          !  FAST TAPE SAVE FOR THE 64.
033C          !*****************************
033C          !
033C          !THIS ROUTINE WILL SAVE A PROGRAM
033C          !TO TAPE SO THAT WHEN LOADED BACK
033C          !IT WILL LOAD WITH THE SCREEN ON.
033C          !
C000          *=$C000
C000 A90B              LDA #<SAVVEC            !CHANGE SAVE VECTOR
C002 8D3203            STA $0332               ! TO GO TO NEW
C005 A9C0              LDA #>SAVVEC            ! SAVE ROUTINE
C007 8D3303            STA $0333
C00A 60                RTS
C00B          !
C00B 48       SAVVEC   PHA                     !SAVE OFF .A
C00C A5BA              LDA $BA                 !GET DEVICE #
C00E C907              CMP #$07                !NUMBER 7?
```

```
C010 F004            BEQ TSAVE              !YES
C012 68              PLA
C013 4CEDF5          JMP $F5ED              !DO NORMAL SAVE
C016          !
C016 A00E    TSAVE   LDY #$0E
C018 A920            LDA #$20
C01A 9999C1  LOOP1   STA FLNAME+1,Y         !BLANK FILENAME
C01D 88              DEY
C01E D0FA            BNE LOOP1
C020 A4B7            LDY $B7                !GET FILENAME LENGTH
C022 C00F            CPY #$0F               !GREATER THAN 14?
C024 9002            BCC LOOP2              !NO
C026 A00E            LDY #$0E               !ONLY 1ST 14 CHARS
C028 88      LOOP2   DEY
C029 3008            BMI TSAVE1
C02B B1BB            LDA ($BB),Y            !GET FILENAME
C02D 999AC1          STA FLNAME+2,Y         !STORE IT
C030 4C28C0          JMP LOOP2              !DO NEXT CHAR
C033          !
C033 A058    TSAVE1  LDY #$58
C035 B93FC1  TSAVE2  LDA LOADER,Y           !GET LOADER BYTE
C038 99AB02          STA $02AB,Y            !STORE IT TO SAVE
C03B 88              DEY
C03C 10F7            BPL TSAVE2             !FOR ALL BYTES
C03E A901            LDA #$01
C040 AA              TAX
C041 A8              TAY
C042 20BAFF          JSR $FFBA              !SET FILE DETAILS
C045 A9BB            LDA #$BB               !LENGTH OF FILENAME
C047 A298            LDX #<FLNAME           !FILENAME LO
C049 A0C1            LDY #>FLNAME           !FILENAME HI
C04B 20BDFF          JSR $FFBD              !SET NAME DETAILS
C04E A900            LDA #$00
C050 859D            STA $9D
C052 A902            LDA #$02
C054 85FC            STA $FC                !SAVE START HI
C056 A9AB            LDA #$AB
C058 85FB            STA $FB                !SAVE START LO
C05A A9FB            LDA #$FB               !POINT TO START
C05C A204            LDX #$04               !SAVE END LO
C05E A003            LDY #$03               !SAVE END HI
C060 20D8FF          JSR $FFD8              !SAVE LOADER FILE
C063 A983            LDA #$83
C065 8D0203          STA $0302              !RESET WARM START
C068 A9A4            LDA #$A4               ! VECTOR
C06A 8D0303          STA $0303
C06D A9FF            LDA #$FF
C06F 859D            STA $9D
C071 A200            LDX #$00
C073 A000            LDY #$00
C075          !
C075          !THE FAST SAVE ROUTINE
C075          !STARTS HERE.
C075          !
C075 20C6C0  SAVEIT  JSR WRTHDR             !WRITE ALIGNMENT BYTES
C078 A52B            LDA $2B                !GET START LO
C07A 48              PHA
C07B 20F5C0          JSR WRTBYT             !WRITE IT
C07E A52C            LDA $2C                !GET START HI
C080 48              PHA
C081 20F5C0          JSR WRTBYT             !WRITE IT
C084 A52D            LDA $2D                !GET END LO
C086 20F5C0          JSR WRTBYT             !WRITE IT
C089 A52E            LDA $2E                !GET END HI
C08B 20F5C0          JSR WRTBYT             !WRITE IT
C08E 84FB            STY $FB                !ZERO CHECKSUM
C090 A42B            LDY $2B                !GET PAGE OFFSET
C092 A900            LDA #$00
C094 852B            STA $2B                !ZERO LO BYTE
C096 B12B    TSAVLOOP LDA ($2B),Y           !GET A BYTE
```

```
C098 20F5C0            JSR WRTBYT              !WRITE IT
C09B C8                INY
C09C D002              BNE TSAVE3
C09E E62C              INC $2C
C0A0 C42D   TSAVE3     CPY $2D                 !CHECK END OF SAVE
C0A2 A52C              LDA $2C
C0A4 E52E              SBC $2E
C0A6 90EE              BCC TSAVLOOP            !NOT YET
C0A8 A5FB              LDA $FB                 !GET CHECKSUM
C0AA 20F5C0            JSR WRTBYT              !WRITE IT
C0AD 2009C1            JSR WRTBIT              !CLOSE OFF LAST BIT
C0B0 A91B              LDA #$1B
C0B2 8D11D0            STA $D011               !UNBLANK SCREEN
C0B5 A937              LDA #$37
C0B7 8501              STA $01                 !STOP TAPE
C0B9 58                CLI                     !RESTART  IRQ
C0BA 68                PLA                     !GET START HI
C0BB 852C              STA $2C                 !STORE IT
C0BD 68                PLA                     !GET START LO
C0BE 852B              STA $2B                 !STORE IT
C0C0 2084FF            JSR $FF84               !RESET I/O
C0C3 4C74A4            JMP $A474               !EXIT TO 'READY.'
C0C6           !
C0C6 A906   WRTHDR     LDA #$06                !BASIC ROM OUT &
C0C8 8501              STA $01                 ! START TAPE
C0CA A90B              LDA #$0B
C0CC 8D11D0            STA $D011               !BLANK SCREEN
C0CF CA     HEADR1     DEX                     !PAUSE FOR TAPE
C0D0 D0FD              BNE HEADR1              ! TO GET TO FULL
C0D2 88                DEY                     ! SPEED
C0D3 D0FA              BNE HEADR1
C0D5 78                SEI                     !DISABLE IRQ
C0D6 A9A0              LDA #$A0                !INITIAL TIMER
C0D8 8D04DD            STA $DD04               ! VALUE FOR DELAY
C0DB A900              LDA #$00
C0DD 8D05DD            STA $DD05
C0E0 A919              LDA #$19
C0E2 8D0EDD            STA $DD0E               !START TIMER
C0E5 A040              LDY #$40
C0E7 A940   HEADR2     LDA #$40                !01000000 FOR
C0E9 20F5C0            JSR WRTBYT              !ALIGNMENT
C0EC 88                DEY
C0ED D0F8              BNE HEADR2              !WRITE 64 OF THEM
C0EF A95A              LDA #$5A                !CHECK ALIGNMENT
C0F1 20F5C0            JSR WRTBYT              !WRITE IT
C0F4 60                RTS
C0F5           !
C0F5 85BD   WRTBYT     STA $BD                 !STORE BYTE
C0F7 45FB              EOR $FB                 !CHECKSUM
C0F9 85FB              STA $FB
C0FB A908              LDA #$08                !LOOP FOR 8 BITS
C0FD 85A3              STA $A3
C0FF 26BD   WBYTE1     ROL $BD                 !BIT INTO CARRY
C101 2009C1            JSR WRTBIT              !WRITE THE BIT
C104 C6A3              DEC $A3
C106 D0F7              BNE WBYTE1              !DO NEXT BIT
C108 60                RTS
C109           !
C109 A270   WRTBIT     LDX #$70                !ASSUME ZERO BIT
C10B 9002              BCC WBIT1               !CORRECT ASSUMPTION
C10D A2FF              LDX #$FF                !SET FOR ONE BIT
C10F 8E04DD WBIT1      STX $DD04               !SET TIMER
C112 A900              LDA #$00
C114 8D05DD            STA $DD05
C117 A901              LDA #$01                !WAIT FOR TIMER
C119 2C0DDD WBIT2      BIT $DD0D
C11C F0FB              BEQ WBIT2
C11E A501              LDA $01                 !TOGGLE WRITE BIT
C120 4908              EOR #$08                ! IN 6510 REGISTER
C122 8501              STA $01
```

```
C124 EE20D0             INC $D020               !SHOW IT IS WORKING
C127 A919               LDA #$19
C129 8D0EDD             STA $DD0E               !START TIMER
C12C A901               LDA #$01                !WAIT FOR TIMER
C12E 2C0DDD WBIT3       BIT $DD0D
C131 F0FB               BEQ WBIT3
C133 A501               LDA $01                 !TOGGLE WRITE BIT
C135 4908               EOR #$08                ! IN 6510 REGISTER
C137 8501               STA $01
C139 A919               LDA #$19
C13B 8D0EDD             STA $DD0E               !START TIMER
C13E 60                 RTS
C13F          !
C13F          !THE LOADER STARTS HERE
C13F          !
C13F A005     LOADER    LDY #$05
C141 A920               LDA #$20                !BLANK OUT 'READY.'
C143 995004 BLLOOP      STA $0450,Y
C146 88                 DEY
C147 10FA               BPL BLLOOP
C149 78                 SEI                     !DISABLE IRQ
C14A A905               LDA #$05
C14C 8501               STA $01                 !START TAPE
C14E A91F               LDA #$1F                !DISABLE KEYBOARD
C150 8D0DDD             STA $DD0D
C153 8D0DDC             STA $DC0D
C156 AD0DDD             LDA $DD0D
C159 AD0DDC             LDA $DC0D
C15C A968               LDA #$68                !SET TIMER
C15E 8D04DC             STA $DC04
C161 A903               LDA #$03
C163 8D05DC             STA $DC05
C166 A990               LDA #$90                !ENABLE TAPE IRQ
C168 8D0DDC             STA $DC0D
C16B A951               LDA #$51                !SET IRQ VECTOR
C16D 8DFEFF             STA $FFFE               ! TO POINT TO
C170 A903               LDA #$03                ! LOAD ROUTINE
C172 8DFFFF             STA $FFFF
C175 A977               LDA #$77                !SET NMI VECTOR
C177 8DFAFF             STA $FFFA               ! TO POINT TO
C17A A903               LDA #$03                ! AN RTI
C17C 8DFBFF             STA $FFFB
C17F A900               LDA #$00                !CLEAR LOADED FLAG
C181 8502               STA $02
C183 58                 CLI
C184 4CDD03             JMP $03DD               !WAIT FOR END OF LOAD
C187          !
C187          !*=$02F3
C187          !
C187 A983               LDA #$83                !RESET WARM START
C189 8D0203             STA $0302               ! VECTOR
C18C A9A4               LDA #$A4
C18E 8D0303             STA $0303
C191 4C84FF             JMP $FF84               !RESET I/O
C194 8BE3AB             WOR $E38B,$02AB
C198          !
C198 932A20 FLNAME      TXT "□*                 "
C1A8          !14 SPACES
C1A8 48                 PHA                     !IRQ ENTRY POINT
C1A9 98                 TYA
C1AA 48                 PHA
C1AB AD05DC             LDA $DC05               !GET TIMER HI BYTE
C1AE A019               LDY #$19                !RESTART TIMER
C1B0 8C0EDC             STY $DC0E
C1B3 4902               EOR #$02                !FLIP BIT 1
C1B5 4A                 LSR A                   ! AND SHIFT TO
C1B6 4A                 LSR A                   ! CARRY
C1B7 26A9               ROL $A9                 !MOVE BIT INTO
C1B9 A5A9               LDA $A9                 ! BYTE READ
C1BB 9002               BCC BITGOT              !WHEN BYTE READ
```

```
C1BD B00D              BCS EXIT                !NOT COMPLETE BYTE
C1BF C940    BITGOT    CMP #$40                !ALIGNMENT?
C1C1 D009              BNE EXIT                !NO
C1C3 A916              LDA #$16                !SET NEW ADDRESS
C1C5 8D6503            STA $0365
C1C8 A9FE    EX1       LDA #$FE                !GET READY FOR
C1CA 85A9              STA $A9                 ! A NEW BYTE
C1CC AD0DDC  EXIT      LDA $DC0D               !CLEAR IRQ
C1CF 68                PLA
C1D0 A8                TAY
C1D1 68                PLA
C1D2 40                RTI                     !EXIT IRQ
C1D3         !
C1D3 C940              CMP #$40                !MORE ALIGNMENT?
C1D5 F0F1              BEQ EX1                 !YES
C1D7 C95A              CMP #$5A                !FINAL CHECK?
C1D9 F007              BEQ BITGT2              !YES
C1DB A902              LDA #$02                !GO BACK TO
C1DD 8D6503            STA $0365               ! ALIGNMENT ROUTINE
C1E0 D0E6              BNE EX1
C1E2 A930    BITGT2    LDA #$30                !SET NEW ADDRESS
C1E4 8D6503            STA $0365               ! TO READ IN LOAD
C1E7 A900              LDA #$00                ! ADDRESSES. CLEAR
C1E9 85C1              STA $C1                 ! CHECKSUM
C1EB F0DB              BEQ EX1
C1ED         !
C1ED 85FB              STA $FB                 !STORE LOAD ADDRESS
C1EF EE9703            INC $0397               !INCREASE STORE
C1F2 AD9703            LDA $0397               ! UNTIL 4 BYTES
C1F5 C9FF              CMP #$FF
C1F7 D0CF              BNE EX1                 !NOT YET
C1F9 A943              LDA #$43                !STORE NEW ADDRESS
C1FB 8D6503            STA $0365               !FOR READING FILE
C1FE D0C8              BNE EX1
C200         !
C200 A000              LDY #$00
C202 91FB              STA ($FB),Y             !STORE A BYTE
C204 45C1              EOR $C1                 !CALCULATE CHECKSUM
C206 85C1              STA $C1
C208 EE00D8            INC $D800               !SHOW IT IS WORKING
C20B E6FB              INC $FB                 !INCREASE ADDRESS
C20D D002              BNE BITGT5
C20F E6FC              INC $FC
C211 A5FB    BITGT5    LDA $FB                 !END OF LOAD?
C213 C5FD              CMP $FD
C215 A5FC              LDA $FC
C217 E5FE              SBC $FE
C219 90AD              BCC EX1                 !NOT YET
C21B A965              LDA #$65                !NEW ADDRESS FOR
C21D 8D6503            STA $0365               !CHECKSUM
C220 D0A6              BNE EX1
C222         !
C222 85C2              STA $C2                 !STORE CHECKSUM
C224 A9FF              LDA #$FF                !FLAG END OF LOAD
C226 8502              STA $02
C228 A902              LDA #$02                !RESET BRANCH TO
C22A 8D6503            STA $0365               ! ALIGNMENT
C22D A9FB              LDA #$FB
C22F 8D9703            STA $0397
C232 D094              BNE EX1
C234         !
C234         !*=$03DD
C234         !
C234 A502    PAUSE     LDA $02                 !WAIT FOR FILE
C236 F0FC              BEQ PAUSE               ! TO BACKGROUND LOAD
C238 A900              LDA #$00
C23A 8502              STA $02
C23C A907              LDA #$07
C23E 8501              STA $01                 !RESET KERNAL ROM
C240 20F302            JSR $02F3
```

```
C243 2063A6          JSR $A663          !CLR
C246 A5C1            LDA $C1            !COMPARE CHECKSUMS
C248 C5C2            CMP $C2
C24A D003            BNE LODERR         !DIFFERENT..ERROR
C24C 4C74A4          JMP $A474          !GO TO 'READY.'
C24F          !
C24F A21D    LODERR  LDX #$1D           !'?LOAD  ERROR'
C251 4C37A4          JMP $A437          !SEND ERROR
```

Program 6.

4.7.1 Fast tape routines

Putting the theory into practice to create the fast loader routines is not difficult. The actual timing for the SAVE routine was not calculated from any theoretical formula but was obtained just by trial and error. The only guidelines were that the short pulse should be slightly shorter than half the long pulse, as the waveform of the pulse is evened out by the cassette hardware. The timing value used by the loader is just shorter than the time required before the long pulse reaches its falling edge.

There are two program listings in this section, one for each of the two types of LOAD. Each program will SAVE a Basic program to tape in its fast format and automatically put the fast loader routine into the filename where it is stored and, when loaded, will automatically start on the warm start vector. The routines are initialised by SYS(49152). A Basic program can be fast saved by using the SAVE command as normal but with a device number of 7, thus:

```
SAVE"PROGRAM",7
```

In addition the first kind of fast LOAD also makes use of the secondary address to auto run the program, thus:

```
SAVE"PROGRAM",7,1
```

will cause the program to auto run when loaded back. With both routines, when a program has been saved using one of these fast loader SAVE routines it is unnecessary to load anything before loading the program; it will load directly from the LOAD command.

An example of how fast these routines can be is shown by the following timing table. This was based on the time taken to load a 26.3K byte Basic program:

Method 1	:1 minute	
Disk	:1 minute	1Ø seconds
Method 2	:1 minute	25 seconds
Normal tape	:8 minutes	4Ø seconds

It should also be noted that the SAVE routines for the fast tape operation are considerably shorter than the normal tape routines which were analysed at the beginning of this chapter.

4.8 Causing programs to auto run from tape

The facility to have a program run automatically after completing its LOAD is a

nice feature to include, particularly if the program is intended for commercial sale. Adding this auto run feature to tape loaded programs is not difficult and considerably enhances a program's professionalism. Before saving a Basic program to tape, the secondary address is used to indicate whether the LOAD routine starts loading into the memory area from which it was saved, or starts loading at an address stored in the pointer to the start of Basic program storage variables. Thus if a program is saved with: SAVE"PROGRAM" it will commence loading wherever the pointer stored at $2B,$2C (decimal 43,44) indicates, regardless of where it was saved from. If, however, SAVE "PROGRAM",1,1 is used the LOAD routine will load the program into the same locations from which it was saved.

The use of the secondary address is thus the main principle required for auto running. To auto run a program a short machine code loader is required; this is loaded first, and on loading will then take control of the computer. The only way to make this happen is to write over one of the operating system vectors in page 3 of memory, the top end of the stack, or the 'Tape load IRQ' vector temporary storage at location $Ø29F/$Ø2AØ.

4.8.1 Page three vectors

There are plenty of vectors which can be used. The most commonly used is the Basic warm start vector (as in the fast load routines in the previous section). This is the easiest one to use since it can be set to point to the auto run routine in the vectors saved with the program, and then reset afterwards. In addition, use of this vector allows code to access the sprite 11 block.

Other vectors which can be used are:

Input vector	at $Ø324
Output vector	at $Ø326
Abort I/O vector	at $Ø32C

These three vectors will also cause control to be transferred to the routine after loading, but use of the sprite 11 block for code is impossible so the code must therefore be located in the filename. Problems can arise in using these vectors when saving, for example: the output vector is set up, as soon as the SAVE routine is called, and the computer will crash when it tries to print the message 'PRESS RECORD & PLAY ON TAPE'. The way to overcome this is to add a bit of code into the SAVE routine which is called before the vector is set up:

```
LDA #$ØØ
STA $9D        !disable the message 'saving'
JSR $F838      !wait for record and play
```

You can then set up the vector and save it.

4.8.2 The stack

A machine code program can be made to auto run by using the top 8 bytes of the stack. These locations are all set to a value of 2, and the machine code starts at location $Ø2Ø3. This method is not widely used, since it will only work on the majority of occasions when the machine is freshly powered up. There is one

advantage, however; if it does not auto run, there is less chance of the machine code being intact for prying eyes.

4.8.3 Tape IRQ save

With this vector you must have a SAVE routine which saves a program from one area of memory which will be loaded into another (see beginning of this section). All the auto run code must be located in the filename.

Having decided which vector to auto run and where to place the machine code loader, it is necessary to decide what the loader will do. The first function of any loader should be to get the kernal LOAD routine to stop printing messages. This will prevent the pause for CBM key when the next file is found. It may also be necessary to disable the RUN/STOP key (see next section). Other security methods that you can add into your loader are detailed in the next section of this chapter. Whichever vector is used to auto run, it must be reset to normal before running the main program. If page 3 vectors are used (IRQ save included), there are two ROM subroutines to use: $E453 for vectors from $Ø3ØØ to $Ø3ØB, or $FF8A for vectors between $Ø314 and $Ø333 (IRQ save changes $Ø314). The program can then be loaded. Depending on whether the program is in machine code or Basic, the auto run routine can either jump straight into the main program or cause the Basic program to run. Running a machine code program is straightforward, however there are several ways to initiate the running of a Basic program from a machine code routine:

a) Keyboard buffer

By storing the characters R, shift U, and carriage return into the keyboard buffer ($Ø277–$Ø28Ø) and setting the number of characters to 3 ($C6), the Basic program will then run by: JMP ($Ø3Ø2). The problem with this is that, to be on the safe side, the screen should first be cleared or there is a possibility of a syntax error occurring.

b) Basic ROM routines

The second, and best, way of running a Basic program is to use the routines in the ROM. The code to run a program this way is shorter than that for the keyboard buffer method. In both types, the end address from the LOAD must be stored into locations $2D and $2E. The code for running a Basic program using the ROM routines is as follows:

```
JSR $A65C       !perform 'CLR'
JSR $A68E       !reset charget pointers
JMP $A7AE       !execute the next statement
```

There is no need to store anything into the keyboard buffer or to clear the screen.

4.9 Tape security and anti piracy techniques

The greatest problem for anyone writing and/or selling commercial software is

illegal copying. This can lose the author a substantial proportion of the expected royalty. It has been estimated that often as many as two out of every three copies of a program in circulation are illegal pirate copies. The SAVE command makes pirating of unprotected programs so easy that it is essential to put some protection onto any commercial program. There is no absolutely secure way of protecting a piece of software on the 64. If someone has enough patience they can break any protection method and copy the program. Therefore, the main thing to concentrate on is making the job of breaking the protection as difficult or laborious as possible. The initial methods include disabling the RUN/STOP key, encoding the program before saving and decoding it on loading, etc.

To disable the RUN/STOP key is very simple:

```
        LDA #<STOP     !SET RUN/STOP VECTOR
        STA $Ø328      ! TO POINT TO NEW
        LDA #>STOP     ! ROUTINE
        STA $Ø329
        .
        .
STOP    LDA $91
        RTS
```

Another method of disabling the STOP key is by altering the low byte, but the above method is the only totally reliable way. This disables both the normal stop from a Basic program and the STOP/RESTORE combination. If the program is a machine code game, then it is better to just disable the NMI vector. This can be done by changing the vector at $Ø318 to point to an RTI instruction ($FEC1). The NMI vector does not have to be disabled; it could be of use in the actual program (see Chapter 6).

Encryption of the program is useful as it will stop a pirate from loading the main file without the auto run part. Encryption means that a special SAVE routine is used to encode a program which is then totally indecipherable. The loading then decodes it so that it can run properly. The best way of encoding and decoding is to use one of the arithmetic commands in the 651Ø instruction set. The most common and easiest to use is the EOR command. To do this take a key value, a number between Ø and 255, EOR it with a byte of the original code and store the result; this is the encrypted code. To restore the original code, simply take the stored encrypted code byte, EOR it with the key value and the original code is restored:

```
LDA STORE  !GET THE VALUE FROM MEMORY
EOR #$A1   !ENCODE IT
STA STORE  !STORE IT
```

This routine, when called the first time, will encode the byte. Call it a second time and the original value will be restored. Use the following routine to encode (or decode) a complete program where ($2B) is the start and ($2D) is the end plus 1:

```
        LDA $2B          !SET START ADDRESS
        STA $FB
        LDA $2C
        STA $FC
        LDY #$ØØ
LOOP    LDA ($FB),Y      !GET A BYTE
        EOR $FB          !ENCODE/DECODE IT
        STA ($FB),Y      !STORE IT
        INC $FB          !INCREMENT POINTER
        BNE CHECK
        INC $FC
CHECK   LDA $FB          !CHECK END OF
        CMP $2D          ! PROGRAM
        LDA $FC
        SBC $2E
        BCC LOOP         !NOT YET
        .
        .
```

It is not necessary to use location $FB for the EOR code, but whatever value is used it must be the same on encoding as it is on decoding. With the advent of fast tape formats, the need for this EOR encoding/decoding is nullified due to the fact that the high speed loader must be present to be able to load the main program.

Final security checks should be made on running the program to check certain locations for the presence of known values. Obvious locations are the cassette buffer (filename), device number (to check the last device used), etc.

4.9.1 Undocumented codes

All the previously mentioned methods can be displayed with the use of a monitor, and so with a little detective work they can be understood by someone intent on breaking the security. The use of some of the undocumented codes of the 65Ø2 within the program and its security makes the use of a monitor much harder. On all 65Ø2 microcomputers there are some instructions that don't appear in most documentation. These codes are therefore not included in any of the monitors available. The most useful of these codes are the multi-byte NOP instructions. These instructions have the same effect as the normal NOP with the exception that one or two bytes following are ignored. Using a two byte NOP before a three byte instruction with the byte to be ignored as, for example, $2Ø (JSR) or $4C (JMP) will result in the code looking like garbage upon disassembly. 2 byte NOPs:

$Ø4,$14,$34,$44,$54,$64,$74, and $F4

3 byte NOPs:

$ØC,$1C,$3C,$5C,$7C,$DC, and $FC

Three byte NOPs are useful since the next two bytes could contain a 2 byte

instruction which will read well with the rest of the code but is in fact ignored. For example, on assembly:

```
BYT $44,$4C     !2 BYTE NOP
JSR $FFD5       !LOAD FILE
BYT $3C         !3 BYTE NOP
LDX #$ØØ        !IGNORED
STX $2D         !STORE END LO
BYT $7C         !3 BYTE NOP
LDY #$ØØ        !IGNORED
STY $2E         !STORE END HI
BYT $74,$2Ø     !2 BYTE NOP
JMP $A474       !GOTO 'READY.'
```

actually does:

```
JSR $FFD5
STX $2D
STY $2E
JMP $A474
```

but on disassembly it gives:

```
.,  Ø33C 44          ???
.,  Ø33D 4C 2Ø D5    JMP $D52Ø
.,  Ø34Ø FF          ???
.,  Ø341 3C          ???
.,  Ø342 A2 ØØ       LDX #$ØØ
.,  Ø344 86 2D       STX $2D
.,  Ø346 7C          ???
.,  Ø347 AØ ØØ       LDY #$ØØ
.,  Ø349 84 2E       STY $2E
.,  Ø34B 74          ???
.,  Ø34C 2Ø 4C 74    JSR $744C
.,  Ø34F A4 xx       LDY $xx
```

The byte xx has nothing to do with the code.

The subject of program protection and security methods is one which can be gone into in great depth but unfortunately it would be inadvisable to give more information than has been included since a knowledge of how to protect a program will also tell the intending pirate how to break that protection. Readers interested in adding protection and security to their programs should write to Zifra Software Ltd., 40 Bowling Green Lane, London EC1. Zifra have considerable experience and expertise in security and protection methods for both tape and disk which have been used on Zifra products.

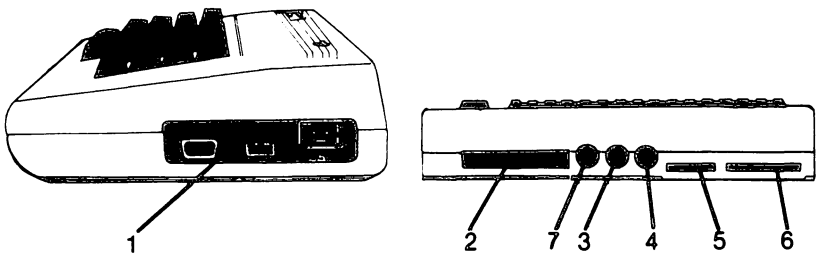
Chapter Five
The User Port

5.1 The I/O ports and the 6526

The CBM 64 communicates with peripheral devices via five integrated circuits. The most important of the five is the 651Ø microprocessor. This has a single eight line I/O port which is used principally to control memory bank switching but also some of the tape operations. The 6566 VIC chip controls the video display and has a light pen input. The sound output is generated by a 6581 SID chip, which also has four analog joystick inputs (see Fig. 5.1 for I/O connections on the CBM 64). The other two integrated circuits are 6526 complex interface adapters or CIAs, which are used to perform all the other I/O functions of the CBM 64. We can summarise the function of these two chips as follows:

Keyboard input
User port
Cassette deck
Serial I/O – used by the disk drive and printer
RS232 I/O – for printers, modems etc.
Joystick – simple switch type
IRQ timing for real time clock and keyboard

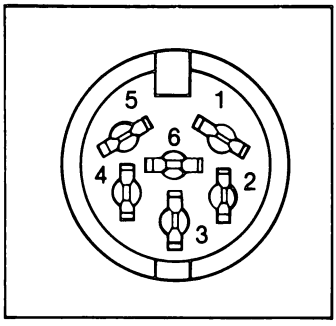
The two CIA chips which are used to control all these functions have between them just 32 programmable I/O lines and 8 handshake lines; many of these lines are thus used by more than one of the above functions.



1) Game I/O
2) Memory expansion
3) Audio and video
4) Serial I/O
5) Cassette
6) User port
7) Modulated TV output

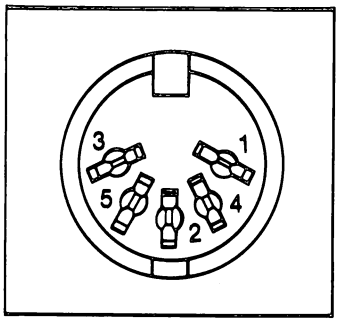
Fig. 5.1. The position of the different CBM 64 I/O outputs.

SERIAL I/O



PIN #	TYPE
1	SERIAL SRQ IN
2	GND
3	SERIAL ATN IN/OUT
4	SERIAL CLK IN/OUT
5	SERIAL DATA IN/OUT
6	NC

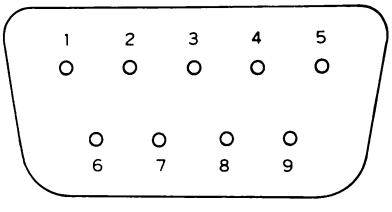
AUDIO/VIDEO



PIN #	TYPE
1	LUMINANCE
2	GND
3	AUDIO OUT
4	COMP VIDEO
5	AUDIO IN

GAME I/O

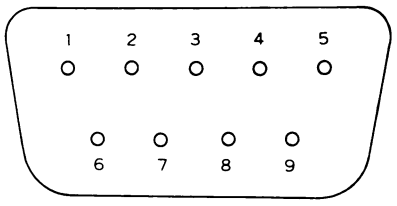
Port #1



PIN #	TYPE	NOTE
1	JOYØ	
2	JOY1	
3	JOY2	
4	JOY3	
5	POT Y	
6	LIGHT PEN/ BUTTON A	
7	+5V	MAX. 100mA
8	GND	
9	POT X	

Fig. 5.1. (contd.)

Port #2



PIN #	TYPE	NOTE
1	JOYØ	
2	JOY1	
3	JOY2	
4	JOY3	
5	POT Y	
6	BUTTON B	
7	+5V	MAX. 1ØØmA
8	GND	
9	POT X	

Fig. 5.1. (contd.)

An understanding of the two 6526 CIA interface chips is essential if all the features of the CBM 64 are to be used to the full, and a knowledge of these chips helps to explain some of the quirks of the system. The functioning of the chips is controlled by internal programmable registers, and there are 16 registers in each chip. These 32 registers (16 from each chip) are located in addressable memory space and are located at hex $DCØØ to $DDFF (decimal 563200 to 56831). They can thus be accessed from Basic using PEEK and POKE statements and from machine code using LDA and STA commands.

Of the 4Ø I/O lines output from the two CIA chips the user can directly connect equipment to, and control the functioning of or input from, 21 lines; the other 18 lines are used by the keyboard or memory bank select and are not therefore particularly usable; one line is not connected. All but two of the I/O lines on CIA#2 can be used, but only three of the lines on CIA#1. CIA#2 is thus used in all the examples in this section. The functions of each I/O line from the two CIA chips are shown in Fig. 5.2 and the electrical connections which allow the user to utilise some of the lines are shown in Fig. 5.3. Though these lines are all assigned particular functions the user is not confined to using a particular

PIN#	TYPE	NOTE	PIN#	TYPE	NOTE
1	GND		A	GND	
2	+5V	1ØØmA MAX.	B	$\overline{\text{FLAG}}$	
3	$\overline{\text{RESET}}$		C	PBØ	
4	CNT1		D	PB1	
5	SP1		E	PB2	
6	CNT2		F	PB3	
7	SP2		H	PB4	
8	$\overline{\text{PC2}}$		J	PB5	
9	SERIAL ATN IN		K	PB6	
1Ø	+9V AC	1ØØmA MAX.	L	PB7	
11	+9V AC		M	PA2	
12	GND		N	GND	

Fig. 5.2. The allocation and function of pins on the user port connector.

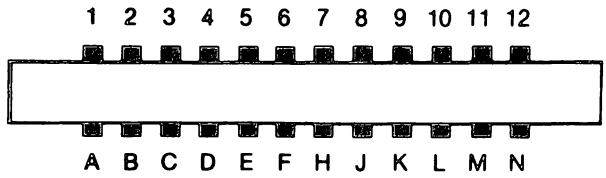


Fig. 5.3. User port edge connector line definition.

I/O line for the function designated for that line. This is because all the I/O lines are under software control and it is not until the routines within the operating system which utilise that line for a particular function are called that that line is used. This flexibility allows the redefinition of I/O line function and is one of the most useful features of the CBM 64.

The 6526 is a very complex chip with sixteen different addressable registers. Each bit within these registers has a specific function, either as an input or an output or to control the operation of the 6526. The registers are of six basic types; I/Ø, data direction, peripheral control, shift register, timers and timer control registers.

The 6526 can be functionally divided into two component parts. On one side are the connections to the processor; the processor interface. On the other side are the input/output lines; the peripheral interface. The main components of the processor interface are the eight bi-directional data lines. These are connected directly to the processor data bus and are used to transfer data between the CIA and the processor. As with any memory, the processor treats the 6526 as a sixteen byte block of memory. The direction of data transfer is controlled by the R/W line, the exact timing of a transfer being controlled by the $\phi 2$ clock line. The individual registers are addressed by the register select lines connected to the bottom address lines AØ–A3. The exact location of the 6526 within memory space is determined by decoding some of the address lines and connecting these to the chip select inputs. The registers of the 6526 will be accessed only if chip select CS is low. As with all the I/O chips the 6526 can generate a processor interrupt by pulling the IRQ line low. This occurs whenever an internal interrupt flag is set as a result of an input on one of the peripheral control lines.

The processor interface lines have seven basic functions which can be summarised as follows:

1) Phase two clock ($\phi 2$) – data transfers between the 6526 and the processor take place only when the $\phi 2$ clock is high. This clock also acts as a time base for the internal 6526 timers and shift register. On the CBM 64 the $\phi 2$ clock is derived from the 651Ø microprocessor chip which in turn is derived from the ϕØ clock produced by the VIC chip. The $\phi 2$ clock has a frequency of Ø.98 MHz on a PAL machine (UK version 64) and 1.Ø2 MHz on an NTSC (US version 64).
2) Chip select line (CS) – the chip select input is connected to the decoding circuitry connected to the PLA chip.
3) Register select lines (RSØ, RS1, RS2, RS3) – the four register select lines are connected to the processor address bus lines AØ – A3. This allows the register to select one of the sixteen registers in the 6526.

4) Read/write line (R/W) – the direction of data transfer between the 6526 and the processor is controlled by the R/W line. If R/W is high then a 'read' operation is performed and data is transferred from the 6526 onto the data bus. If R/W is low then a 'write' operation is performed and data currently on the data bus is loaded into the addressed register of the 6526.
5) Data bus (DBØ to DB7) – data is transferred between the processor and the 6526 via the eight bi-directional lines of the data bus. The internal data bus of the 6526 will only be connected to the processor data bus when the two chip select lines are enabled and the $\phi 2$ clock is high. The direction of data transfer will depend on the state of the R/W line and the register addressed on lines RSØ to RS3.
6) Reset (RES) – the reset line clears all the internal registers of the 6526 (except the timers and shift register) and sets them all at logic zero. The result is that all the interface lines are put in the input state, and timers, shift register and interrupts are all disabled. This is connected to the processor power up circuitry and is used only when the system is switched on (this line is accessible externally and since the system software can be changed its function could be modified).
7) Interrupt request (IRQ) – the interrupt request output from the 6526 is very important in the CBM 64. The IRQ line goes low whenever an internal interrupt flag is set and the corresponding interrupt enable flag is high. On CIA#2 the IRQ line is connected to the processor NMI interrupt line; the NMI line is also used to test the RESTORE key. On CIA#1 the IRQ line is connected to the processor IRQ line. The function of this line is to generate a regular 6Ø Hz interrupt which is used by the clock, I/O and keyboard routines; this interrupt is provided by Timer A in the CIA.

5.2 The peripheral interface lines

The peripheral interface lines on each 6526 CIA chip are divided into two I/O ports, each port having eight bi-directional I/O lines. The two ports share two handshaking and two serial control lines. The following is a brief description of the I/O buses and control lines of a 6526.

1) Peripheral ports A and B (PAØ – PA7) and (PBØ – PB7) – these ports consist of eight bi-directional lines each of which can be independently programmed under control of the data direction register to act as either an input or an output. The polarity of the lines defined as outputs is controlled by the contents of the output register. The internal control registers are used by the processor to control the modes of operation of the 6526. All lines represent a load of one standard TTL gate in the input mode and will drive two standard TTL loads in the output mode.
2) Handshaking lines ($\overline{\text{FLAG}}$, PC) – the $\overline{\text{FLAG}}$ peripheral control line acts as interrupt input, and PC as handshake output for peripheral port B. Each line controls an internal interrupt flag with a corresponding interrupt enable bit. The various modes of operation are controlled by the processor via the internal control registers of the 6526.

5.3 Operation of the I/O ports

Three registers are required to access each of the eight line peripheral ports; they are a data direction register, an output register and an input register. Each port has a data direction register for specifying whether each of the eight lines acts as either an input or an output. A zero in a bit of the data direction register causes the corresponding peripheral line to act as an input. A one causes the line to act as an output.

Example: Set lines Ø to 3 as inputs and 4 to 7 as outputs on port B of CIA#2.

I/O line number	Data direction	DDR contents if line = in	DDR contents for example
Ø	in	1	Ø
1	in	2	Ø
2	in	4	Ø
3	in	8	Ø
4	out	16	16
5	out	32	32
6	out	64	64
7	out	128	128
		Total for example -	24Ø

Command is POKE 56579, 24Ø

Each peripheral line is connected to an input register and an output register. When a line is programmed to act as an output the voltage on that line is controlled by the corresponding bit in the output register. A '1' in the output register causes the corresponding line to go high, and a 'Ø' causes it to go low.

Example: Output to port B of CIA#2 using the data direction set out in the previous example. Lines 4 and 7 are high and lines 5 and 6 are low.

I/O line number	Data direction of line	High or low	Value of line in I/O reg
Ø	in	-	-
1	in	-	-
2	in	-	-
3	in	-	-
4	out	high	16
5	out	low	Ø
6	out	low	Ø
7	out	high	128
		Total for example	144

Command is POKE 56577, 144

Reading one of the peripheral port registers causes the contents of the input register to be transferred onto the data bus. With input latching disabled the contents of the input registers will always reflect the data currently on all the peripheral port lines.

Example: Read the contents of the input lines of port B of CIA#2 set up in the example on data direction, and store the contents as variable A.

```
A = PEEK (56577) AND 15
```

The AND 15 masks off the lines used as outputs; they must be removed since the current state of the output lines is stored in the input register. AND commands can then be used to determine which lines are high and which are low.

5.3.1 Registers used in the operation of the I/O ports

Register 1 Parallel port A I/O register
CIA#1 - Hex $DCØØ decimal 5632Ø
CIA#2 - Hex $DDØØ decimal 56576

This register contains the contents of the input and output lines of port A of the 6526.

Register 2 Parallel port B I/O register with handshake control
CIA#1 - Hex $DCØ1 decimal 56321
CIA#2 - Hex $DDØ1 decimal 56577

This register contains the contents of the input and output lines of port B. It is identical to that of port A, except that this register has control over the handshake line PC. The PC line goes low for one clock cycle following either a read or write to the port B peripheral I/O register.

Register 3 Data direction register for port A
CIA#1 - Hex $DCØ2 decimal 56322
CIA#2 - Hex $DDØ2 decimal 56578

This register controls each of the eight lines on port A and determines whether they are acting as inputs or outputs. A one in any of the eight bits of this register sets the corresponding line into the output mode, and a zero puts it into the input mode.

Register 4 Data direction register for port B
CIA#1 - Hex $DCØ3 decimal 56323
CIA#2 - Hex $DDØ3 decimal 56579

This register controls each of the eight lines on port B and determines whether they are acting as inputs or as outputs. A one in any of the eight bits of this register sets the corresponding line into the output mode, and a zero puts it into the input mode.

5.3.2 Handshaking

The term handshaking is used to refer to signals which control or synchronise the transfer of data between the computer and another device. The 6526 has two handshaking lines for use on data transfers; the $\overline{\text{FLAG}}$ input and the PC output. The PC line is used to indicate that data is ready to be transmitted or received on port B. This is indicated by the PC line going low for one clock cycle following a

read or write of the port B data register. The $\overline{\text{FLAG}}$ line is an input which, on receiving a negative transition, will set the $\overline{\text{FLAG}}$ bit in the interrupt control register. The $\overline{\text{FLAG}}$ line can be used to detect the PC output from another 6526.

5.4 The interval timers and counters of the 6526

The 6526 has three internal interval timers (Timer A, Timer B, and TOD). One of these, TOD, is a 24 hour time of day clock. Timer A will also function as a counter of pulses input on one of the I/O lines. These timers are not only useful but are of vital importance to the operation of the CBM 64. It is these timers which are used to control the generation of the 6Ø Hz interrupt used to update the real time clock and scan the keyboard. They are also used to control the timing of I/O on the serial port, the RS232 port and the cassette. Since the CBM 64 interface uses two 6526 chips there are a total of six timers available for use by the system software. The timers are used in conjunction with the processor interrupts. The following table shows some of the functions of each timer plus the interrupt line affected:

CIA#1 IRQ interrupt

Timer A – System 6Ø Hz interrupt
Real time clock updating
Keyboard scanning
Cassette read/write timing
User programmable functions

Timer B – Cassette read/write timing
Serial port timing
User programmable functions

TOD – User programmable functions

Note that Timer A is used for both updating the kernal software's real time clock and cassette timing; for this reason the real time clock loses whenever the cassette is used.

CIA#2 NMI interrupt

Timer A – RS232 port I/O timing
User programmable functions

Timer B – RS232 port I/O timing
User programmable functions

TOD – User programmable

5.4.1 Timer A and Timer B

Each interval timer consists of two eight bit latches and a sixteen bit counter. Each timer occupies two of the 6526 registers; register numbers 5 to 8. Their locations in the CBM 64 are as follows:

Register 5	- Timer A low order byte	
	CIA#1 - Hex $DCØ4	decimal 56324
	CIA#2 - Hex $DDØ4	decimal 5658Ø
Register 6	- Timer A high order byte	
	CIA#1 - Hex $DCØ5	decimal 56325
	CIA#2 - Hex $DDØ5	decimal 56581
Register 7	- Timer B low order byte	
	CIA#1 - Hex $DCØ6	decimal 56326
	CIA#2 - Hex $DDØ6	decimal 56582
Register 8	- Timer B high order byte	
	CIA#1 - Hex $DCØ7	decimal 56327
	CIA#2 - Hex $DDØ7	decimal 56583

These registers are used to load values into the counters. After loading, the counter decrements at the system clock rate (Ø.98 MHz on PAL machines and 1.Ø2 MHz on NTSC). Thus if the counter is loaded with its maximum value (all sixteen bits = 1 or decimal 65535) it will be decremented to zero in .Ø669 seconds. Upon reaching zero, an interrupt flag is set and one of the two interrupt lines will go low and generate a processor interrupt. The timer will thus disable any further interrups until the interrupt servicing routine reads the interrupt control register of the 6526. In addition, the timer can be instructed to invert the output level on one of the peripheral I/O lines each time it 'times out'. The modes of operation are controlled by reading or writing to the four timer registers plus the two control registers and the interrupt register. The two timers A and B can be linked to create a single 32 bit counter which is capable of creating long delays. Program 7 demonstrates the operation of a 32 bit timer.

```
10 POKE56583,0:POKE56582,0
20 POKE56581,255:POKE56580,255
30 POKE56590,16+1:POKE56591,64+16+8+1
35 T1=TI
40 IF(PEEK(56589)AND2)<2THEN40
50 PRINT(TI-T1)/60
```

Program 7.

5.4.2 Time of day clock - TOD

This is a general purpose 24 hr am/pm timer with a 1 1Ø second resolution. This timer occupies four registers within the 6526. They are located and organised as follows in the CBM 64:

Reg #	CIA#1 location	CIA#2 location	Function
8	$DCØ8 - 56328	$DDØ8 - 56584	TOD 1/1Ø secs
9	$DCØ9 - 56329	$DDØ9 - 56585	TOD secs
1Ø	$DCØA - 5633Ø	$DDØA - 56586	TOD mins
11	$DCØB - 56331	$DDØB - 56587	TOD hours

Each of these registers stores its data as shown in the following table. It should be noted that the values are stored in BCD form rather than straight binary:

Register	Byte	7	6	5	4	3	2	1	Ø
8 - TOD 1/1Ø sec		Ø	Ø	Ø	Ø	T8	T4	T2	T1
9 - TOD seconds		Ø	shi4	shi2	shi1	slo8	slo4	slo2	slo1
1Ø - TOD minutes		Ø	mhi4	mhi2	mhi1	mlo8	mlo4	mlo2	mlo1
11 - TOD hours	PM flag		Ø	Ø	hhi1	hlo8	hlo4	hlo2	hlo1

shi, mhi and hhi are the decade portion of the respective second, minute or hour and slo, mlo and hlo are the unit portion.

The TOD clock is timed by a 5Ø or 6Ø Hz external clock pulse provided for the system interrupt timing (5Ø Hz is found on US machines and 6Ø Hz on UK machines). This external clock frequency must always be set to the correct value by setting the required bit in control register, .A bit 7, to Ø=6Ø Hz and 1=5Ø Hz. The TOD time registers can be preset by writing to them the required time values. This must, however, be done in the correct sequence. The TOD clock is stopped when a write is performed to the hours register. The clock will not start again until a write is performed to the 1/1Ø seconds register, thereby allowing accurate time setting.

When reading the contents of the TOD registers there is the problem of the register values changing whilst they are being read. This is overcome by latching all the register values on a read of the hours register. Whilst the values are latched the TOD clock will continue to count but will not affect the register values until the 1/1Ø seconds register is read; this disables the latches. Any of the registers (apart from hours) can be read without latching providing the problem of carry between registers is not important.

The TOD clock incorporates an alarm feature which causes an interrupt to be generated whenever the time reaches a preset value. The alarm is set by first setting bit 7 of control register .B to 1 and then writing the desired alarm time value into the four TOD registers. Having written the desired values into these registers, control register .B bit 7 should be reset to zero. Program 8 demonstrates the use of the TOD clock registers and the alarm feature.

```
Ø CIA=56576: REM CIA#2. FOR CIA#1, CIA=56320
1 POKECIA+14,PEEK(CIA+14)OR128
2 MO=Ø:GOSUB 1ØØØ SET TOD TIME
4 MO=1:GOSUB 1ØØØ SET TOD ALARM
5 PRINT"■□  :  :  .  M"
1Ø H=PEEK(CIA+11) :REM HOURS/AM OR PM
2Ø M=PEEK(CIA+1Ø) :REM MINUTES
3Ø S=PEEK(CIA+9)  :REM SECONDS
4Ø S1Ø=PEEK(CIA+8):REM 1/1Ø SECONDS
5Ø POKE1Ø24,((HAND112)/16)OR48
6Ø POKE1Ø25,(HAND15)OR48
7Ø POKE1Ø27,((MAND24Ø)/16)OR48
8Ø POKE1Ø28,(MAND15)OR48
9Ø POKE1Ø3Ø,((SAND24Ø)/16)OR48
```

```
100 POKE1031,(SAND15)OR48
110 POKE1033,S100R48
120 B8=16:IF(HAND128)<128 THEN B8=1
130 POKE1035,B8
140 IF PEEK(CIA+13)AND4=4THENPRINT"■■■ALARM":END
150 GOTO 10
997 REM
998 REM SET CLOCK OR TIME
999 REM
1000 IF MO=0 THEN PRINT"■■SET TIME:":POKECIA+15,PEEK(CIA+15)AND127:GOTO 1020
1010 PRINT"■■SET ALARM:":POKECIA+15,PEEK(CIA+15)OR128
1020 INPUT"HOURS";H:H=INT(H)
1030 IF H<1 OR H>12 THEN PRINT"■■":GOTO 1020
1040 PRINT"AM OR PM ?";
1050 GETA$:IFA$<>"A"ANDA$<>"P"THEN1050
1060 PRINTA$
1061 IF MO=1 THEN 1070
1065 IF H=12 AND A$="A" THEN A$="P":GOTO1070
1066 IF H=12 AND A$="P" THEN A$="A"
1070 B=128:IFA$="A"THENB=0
1080 POKECIA+11,B+INT(H/10)*16+H-INT(H/10)*10
1090 INPUT"MINUTES";M:M=INT(M)
1100 IF M<0 OR M>59 THEN PRINT"■■":GOTO1090
1110 POKECIA+10,INT(M/10)*16+M-INT(M/10)*10
1120 INPUT"SECONDS";S:S=INT(S)
1130 IF S<0 OR S>59 THEN PRINT"■■":GOTO1120
1140 POKECIA+9,INT(S/10)*16+S-INT(S/10)*10
1145 IF MO=1 THEN 1170
1150 PRINT"■■■PRESS ANY KEY TO START TIMER"
1160 GETA$:IFA$=""THEN1160
1170 POKECIA+8,0:RETURN
```

Program 8.

5.5 Serial data register (SDR)

One of the registers of the 6526, register 12, functions as a serial in/parallel out or parallel in/serial out shift register. The serial input or output from this register is connected to the SP pin on the chip and is designed to be used in conjunction with the CNT line to allow serial communications between 6526 chips. Data is clocked in or out of the shift register using either Timer A or the CNT pulses. In the input mode data is clocked in off the SP line on the rising edge of a clock pulse applied to the CNT line. Each pulse on the CNT line clocks in one bit of data, represented by the state of the SP line. After 8 CNT pulses the data in the shift register is transferred to the serial data register and an interrupt to the processor is generated.

In the output mode, data is loaded into the serial data register. Timer A is used to generate the timing rate at which data is clocked out. Timer A is first set into continuous running mode and data will be shifted out at half the timer underflow rate, the highest possible data rate being one quarter of the $\phi 2$ clock (245 KHz on a UK version of the 64 and 255 KHz on a US version). As soon as the data is written into the SDR transmission will commence, assuming that Timer A has already been set into continuous operation. Every time an underflow is generated by Timer A a CNT pulse is generated. A bit from the SDR data is shifted onto the SP line, becomes valid on the falling edge of the CNT pulse and remains valid until the next falling edge of a CNT pulse. After eight CNT pulses the entire contents of the SDR will have been transmitted on the SP line and an interrupt is then generated to indicate that data transmission

has been completed. On completion of transmission the CNT line will go high and the SP line will stay at the level of the last data bit transmitted. If a new byte of data is loaded into the SDR before the transmission of the previous byte has been completed, the 6526 will complete transmission of the current byte, and then instead of generating an interrupt, will carry on and transmit the second byte. In this manner continuous transmission can be achieved.

An important potential use for the serial line is in serial communications between computers and/or peripheral devices which also use the 6526. Program 9 shows how two or more CBM 64 computers can be connected via the CNT and SP lines, plus ground, to enable the transmission of programs and data between the two machines. This could easily be expanded to work with more machines.

```
0 REM RUN TO SEND FIRST
1 REM OR RUN70 TO RECEIVE FIRST
2 REM
5 INPUTA$:A$=A$+CHR$(13)
10 POKE56580,2:POKE56581,0
20 POKE56590,64+16+1
25 FORI=1TOLEN(A$)
26 J=ASC(MID$(A$,I,1))
30 POKE56588,J:PRINTCHR$(J);
50 IF (PEEK(56589)AND8)<8 THEN 50
60 NEXT:POKE56588,0
65 IF (PEEK(56589)AND8)<8 THEN 65
70 POKE 56590,PEEK(56590) AND (128+63)
80 POKE56588,0
90 IF (PEEK(56589)AND8)<8 THEN 90
100 I=PEEK(56588):IFI<>0THENPRINTCHR$(I);:GOTO90
110 GOTO5

10 POKE56579,1
20 POKE56326,255:POKE56327,255
30 POKE56335,32+16+1
40 PRINT"□"
50 PRINT"■"65535-(PEEK(56326)+PEEK(56327)*256)
60 FORI=0TO100:NEXT
70 GETA$:IFA$=""THEN70
80 POKE56577,1:POKE56577,0
90 GOTO 50


10 POKE56590,PEEK(56590)AND(128+63)
20 POKE56579,1
30 GETA$:IFA$=""THEN30
40 POKE56577,0:POKE56577,1
50 IF(PEEK(56589)AND8)<8THEN30
60 PRINTPEEK(56588):GOTO30
```

Program 9.

5.6 The interrupt control register (ICR)

The 6526 can generate interrupts in several different ways. There are altogether five sources of interrupts. The source of the interrupt is identified by examining which bit is set in the interrupt control register; this is register 13 of the 6526. The functions of the individual bits of this register are:

ICR bit #	Interrupt source
Ø	Underflow from Timer A
1	Underflow from Timer B
2	TOD clock alarm
3	Serial data register full/empty
4	Flag line input

Bits 5 and 6 are not used, while bit 7 is used to set or clear the ICR mask register.

The ICR, in fact, consists of two separate registers; the interrupt flag register which is read only and the interrupt mask register which is write only. When an interrupt occurs the corresponding bit in the interrupt flag register is set, providing it has previously been enabled by the mask register; an interrupt to the processor is also generated. The mask register is used to control which function or functions can create an interrupt. An interrupt will occur only when the corresponding mask register bit is set. When enabling an interrupt the mask register, with bit 7 = 1, is set by writing the appropriate bit pattern to register 13, the ICR. If, when writing to the ICR, bit 7 is cleared then all mask bits set to one will be cleared whilst all mask bits set to zero will remain in their previous state. Any interrupt which is enabled by the mask register will set bit 7 of the ICR flag register and thereby cause the IRQ pin to go low and generate an interrupt. The interrupt is cleared by reading the interrupt flag register. The interrupts on the CBM 64 are examined in greater detail in the Chapter 6.

5.7 The 6526 control registers (CRA and CRB)

The two control registers of the 6526 are used, as their names imply, to control the actual functioning and modes of the timers and the serial port. Each bit in the two registers has a separate control function; they can be summarised as follows:

Control register A

Bit	State	Function
Ø	Ø	start Timer A
	1	stop Timer A; in one shot mode this bit is reset on underflow
1	Ø	line PB6 functions normally as an I/O line
	1	output from Timer A appears on line PB6
2	Ø	pulse output on PB6 (only if bit 1 set)
	1	toggle output on PB6 (only if bit 1 set)
3	Ø	Timer A in continuous running mode
	1	Timer A in one shot mode

Control register A

Bit	State	Function
4	Ø	no effect
	1	forces the Timer A counter to be loaded from the Timer A latch
5	Ø	Timer A counts ϕ2 clock pulses
	1	Timer A counts positive transitions on the CNT line
6	Ø	SP line in input mode using external shift pulses on CNT line
	1	SP line in output mode. CNT sources shift pulses
7	Ø	TOD clock timing pulse at 6Ø Hz (use on US machines)
	1	TOD clock timing pulse at 5Ø Hz (use on UK machines)

Control Register B

Bit	State	Function
Ø	Ø	stop Timer B
	1	start Timer B; in one shot mode this bit is reset on underflow
1	Ø	normal I/O operation on the PB7 line
	1	output from Timer B appears on line PB7
2	Ø	pulse output on PB7 (only if bit 1 of CRB set)
	1	toggled output on PB7 (only if bit 1 of CRB set)
3	Ø	Timer B in continuous running mode
	1	Timer B in one shot mode
3	Ø	no effect
	1	forces the Timer B counter to be loaded from the Timer B latch
5,6		these two bits select one of four input modes for Timer B:

Bit 6	Bit 5	Mode
Ø	Ø	Timer B counts ϕ2 clock pulses
Ø	1	Timer B counts positive CNT transitions
1	Ø	Timer B counts Timer A underflow pulses
1	1	Timer B counts Timer A underflow pulses while the CNT line is high

7	Ø	writing to TOD registers will set TOD clock
	1	writing to TOD registers will set TOD alarm

5.8 Parallel interfacing

In some applications it is simply not possible to connect devices directly to the eight user port I/O lines. This is generally for one of two reasons. The first is that

the user port lines do not output enough power to drive the device; directly connecting the device to the user port could result in damage to the CIA chip. The second reason is that there are insufficient I/O lines for the application. The first type of problem can be overcome by using relays and opto-isolators; the second type by using multiplexing techniques to expand the available number of I/O lines.

The eight I/O lines from the CIA chip are in output mode only, capable of each driving the input of a single TTL chip. The simplest method of improving this drive capability is to put a buffer onto each output line; this will expand the drive capability of each line to 10 TTL chip inputs. This is adequate if the I/O lines are used just to control some TTL circuitry, but it is inadequate for controlling power devices such as motors, relays and lamps; for these a power driver circuit is needed. The simplest power driver circuit consists of a single transistor whose base is connected to the output of a buffer and whose outputs are connected on one side to the power supply and on the other to the device to be driven. It is, however, much easier to use one of the peripheral driver ICs like the SN75446. This chip is used in the circuit diagram in Fig. 5.4. The SN75446 is capable of driving devices requiring up to 50 volts and 400 mA. The circuit shows it driving two relays.

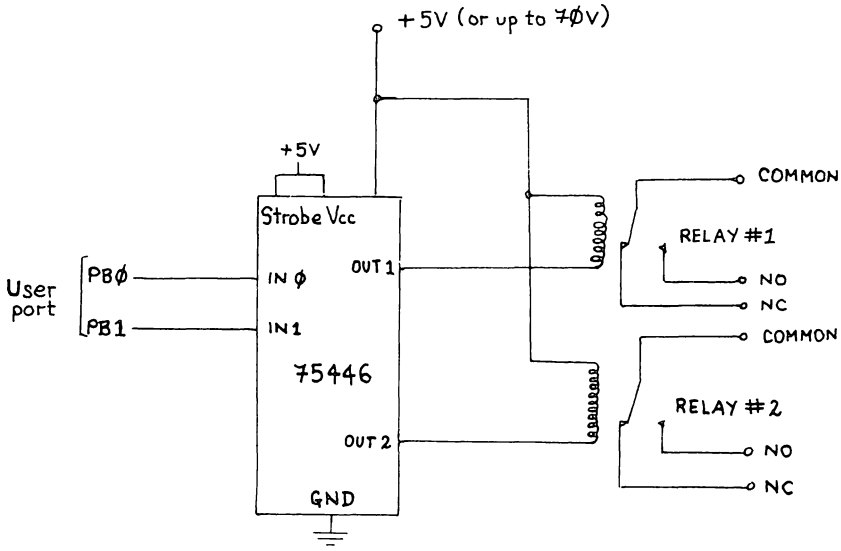


Fig. 5.4. Dual relay control circuit.

If there is any risk of a high voltage accidentally being present on one of the I/O lines it is advisable to protect the computer by using opto-isolators on lines. An opto-isolator simply consists of an optically coupled LED and photo transistor. An example of such a device which provides four separate opto-isolators which work on 5 volt lines is the ILQ74.

The most commonly needed I/O expansion is the requirement to test the state of a large number of input lines. This kind of I/O expansion is used when adding a special keyboard to the machine or testing switches in a security alarm system.

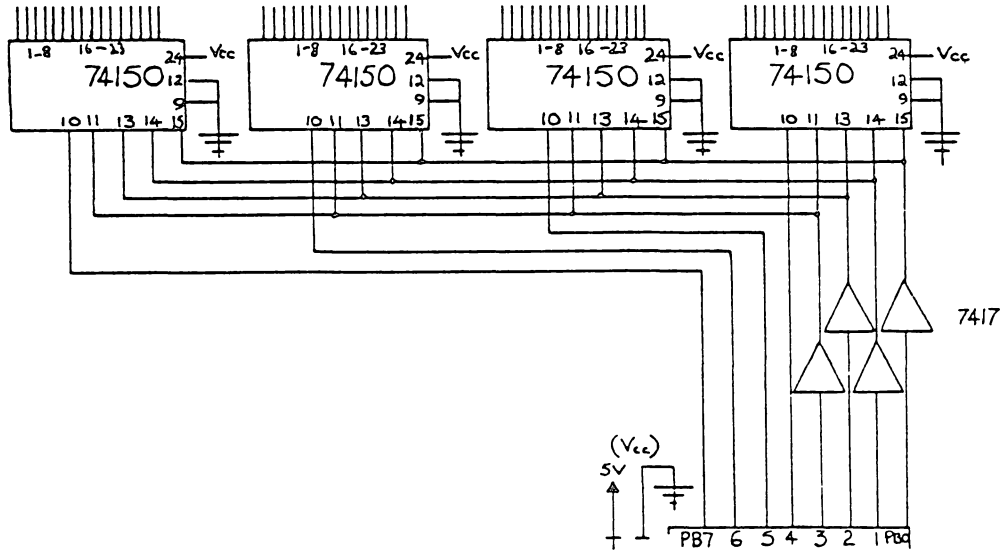


Fig. 5.5. I/O expansion circuit.

A circuit of this kind is shown in Fig. 5.5. It uses four 16 line to 4 line demultiplexers which convert the state of the 16 lines into a 4 bit binary value. This value is fed into four lines of the user port. The chip select line of each of the four demultiplexers is controlled by four output lines of the user port. Using this circuit the computer can scan the state of up to 64 input lines.

5.8.1 Parallel port application example

Program 10 is an example of how the parallel port can be used. This program is designed to allow disabled people to use a computer, both to write and use programs and to control various devices such as TV, radio, lamps etc. The program requires line Ø of the user port to be connected to a switch, the other side of which is connected to ground. The switch can be a simple microswitch usable with minimum finger pressure, or a suck/blow switch controllable by the user blowing into it. The other I/O lines are connected to devices which are to be controlled, and each line will require connection via a power driver circuit and relay, as in Fig. 5.4. A selection of possible applications is shown in the program.

```
6 PR=5:MC=6
10 DATA" LC  ","SENT ","DELC ","DELW ","     ","     ","     "," NL  "
20 DATA" UC  ","PARA ","SEND ","ESC  ","+VAR ","     ","     ","     "
30 DATA"TEXT ","PROG ","USER ","HELP ","-VAR ","     ","     ","DEL  "
100 DATA" SP  ",A,T,L,G,V," THE "
110 DATAE,I,S,U,Z,Q," AND "
120 DATAN,O,R,P,J,#," OF  "
130 DATAC,D,H,M,X,@," IS  "
140 DATAF,B,W,Y,K,',"  TO  "
150 DATA0,2,4,6,8,"  ","  IN  "
160 DATA1,3,5,7,9,!,"THAT "
170 DATA.,+,-,*,/,←,$
180 DATA",",?,=,%,(,),<
190 DATA&,↑,";",":",[,],>
200 DATA" ",A,T,L,G,V,THE
210 DATAE,I,S,U,Z,Q,AND
```

```
220 DATAN,O,R,P,J,#,OF
230 DATAC,D,H,M,X,@,IS
240 DATAF,B,W,Y,K,',TO
250 DATA0,2,4,6,8, ,IN
260 DATA1,3,5,7,9,!,THAT
270 DATA.,+,-,*,/,←,$
280 DATA",",?,=,%,(,),<
290 DATA&,↑,";",":",[,],>
400 DATA" SP  ",1,7,=," <>  ","GOTO "," ON  "
410 DATA0,2,6,",",>,"INPUT"," VAL "
420 DATA3,4,5,#,<,"POKE ","CHR$ "
430 DATA8,9,.," ''  "," <=  ","PEEK ","STR$ "
440 DATA),(,$,↑," >=  ","LEN  ","LEFT$"
450 DATA+,-,*,/," ","ASC  ","RGHT$"
460 DATA"LIST ","DATA ","IF   ","GOSUB"," DIM ","TRON ","MID$ "
470 DATA"RUN  ","CONT ","THEN ","RTRN ","STOP ","TROFF"," LOG "
480 DATA"READ ","INT  ","ABS  ","SGN  ","RND  ","SQR  ","EXP  "
490 DATA"PRINT"," FOR ","NEXT ","SIN  ","COS  ","TAN  ","     "
500 DATA" ",1,7,=,<>,GOTO,ON
510 DATA0,2,6,",",>,INPUT,VAL(
520 DATA3,4,5,#,<,POKE(,CHR$(
530 DATA8,9,.," ",<=,PEEK(,STR$(
540 DATA),(,$,↑,>=,LEN(,LEFT$(
550 DATA+,-,*,/,"",ASC(,RIGHT$(
560 DATALIST,DATA,IF,GOSUB,DIM,TRACEON,MID$(
570 DATARUN,CONT,THEN,RETURN,STOP,TRACEOFF,LOG(
580 DATAREAD,INT(,ABS(,SGN(,RND(,SQR(,EXP(
590 DATAPRINT,FOR,NEXT,SIN(,COS(,TAN(,""
1000 RESTORE
1010 DIMDF$(2,6),DA$(1,9,6),TA$(1,9,6),DV$(20),TV$(20)
1020 FORI=0TO2:FORJ=0TO6
1030 READDF$(I,J)
1040 NEXTJ:NEXTI
1050 FORI=0TO1
1060 FORJ=0TO9
1070 FORK=0TO6
1080 READDA$(I,J,K)
1090 IFLEN(DA$(I,J,K))=1THENDA$(I,J,K)="  "+DA$(I,J,K)+"  "
1100 NEXTK:NEXTJ
1110 FORJ=0TO9
1120 FORK=0TO6
1130 READTA$(I,J,K)
1140 NEXTK:NEXTJ
1150 NEXTI
1170 TA$(0,5,5)=CHR$(34)
1190 TA$(1,3,3)=CHR$(34)
1200 FORI=0TO20
1210 DV$(I)="     ":TV$(I)=""
1220 NEXTI
1700 UP=56577:UX=1
1710 VN=0:M=0:A$="":UC=1:ED=0:HP=0:TV=0:NY=0
1720 PD=70:PQ=50:FM=0
1730 GOSUB 20000
2000 PRINT"[illegible]*ADVICE";
2010 PRINT"[illegible]*HOME";
2020 PRINT"[illegible]";
2030 FORI=0TO9:PRINT"      ";
2040 FORJ=0TO6:PRINTDA$(M,I,J);
2050 NEXTJ:NEXTI
2055 PRINT
2060 PRINT"[illegible]";"[illegible]";"*VARIABLES";
2070 PRINT"[illegible]";
2080 FORI=0TO2:PRINT"      ";
2090 FORJ=0TO6:PRINTDV$(I*7+J);
2100 NEXTJ:NEXTI
2110 PRINT"[illegible]*FUNCTIONS";
2120 PRINT"[illegible]";
2130 FORI=0TO2:PRINT"      ";
2140 FORJ=0TO6:PRINTDF$(I,J);
2150 NEXTJ:NEXTI
```

```
2160 PRINT"■";A$;
3000 PRINT"■":PRINT
3005 IFHP=0GOTO3040
3010 PRINT"■■■■■■ADVICE ■SELECT ANY BOX FOR HELP■";
3020 HP=HP+1
3030 GOTO3200
3040 IFLEN(A$)+LEN(N$)+LEN(Y$)+LEN(Z$)<160GOTO3070
3050 PRINT"■■■■■■WARNING■PRINT STRING -- NOW!■";:GOTO3200
3070 FORI=1TOLEN(N$)
3080 NB$=MID$(N$,I,1)
3090 IFUC>0GOTO3130
3110 IFNB$<"A"ORNB$>"Z"GOTO3130
3120 NB$=CHR$(ASC(NB$)+128)
3130 A$=A$+NB$
3141 IFUC=2THENGOSUB20100
3142 IFUC=2THENUC=0
3143 NEXTI
3145 N$=""
3146 IFUC=3THENUC=2
3150 PRINT"■";A$;
3160 IFED=0GOTO3180
3170 PRINT"■";Y$;"■";Z$;
3180 PRINTFL$:FL$=""
3200 PRINT"■":PRINT:PRINT"■■■■■■■HOME■";
3205 IF(PEEK(UP)ANDUX)=0THEN3205
3210 IF(PEEK(UP)ANDUX)GOTO3210
3212 IFHP>0THEN3220
3213 IFED>0THEN3220
3214 IFNV>0THEN3220
3215 PRINT"■■■■■■ADVICE                                    ";
3220 PRINT"■■■■■■■HOME";
3230 PRINT"■■■■■■■";
3240 FORI=0TO15
3250 PRINT"■   > ■";
3260 FORJ=1TOPD:IF(PEEK(UP)ANDUX)GOTO3400
3265 NEXTJ
3270 PRINT"■■■■■■     ■■■■■■";
3280 PRINT"■";:IFI=9ORI=12THENPRINT"■";
3290 NEXTI
3310 GOTO3200
3400 IF(PEEK(UP)ANDUX)GOTO3400
3420 PRINT"■■■■■■     ";
3430 IFI>9GOTO3600
3440 FORJ=0TO6
3450 PRINT"■";DA$(M,I,J);"■";
3460 FORK=1TOPQ:IF(PEEK(UP)ANDUX)GOTO3490
3465 NEXTK
3470 PRINT"■■■■■■";DA$(M,I,J);
3480 NEXTJ
3485 PRINT"■■■■■■";DA$(M,I,J-1);:GOTO3200
3490 PRINT"■■■■■■";DA$(M,I,J);
3500 IFHP=2GOTO40000
3505 IF NV>0 GOTO7720
3510 N$=TA$(M,I,J):GOTO3000
3600 IFI>12GOTO3800
3610 II=I-10
3620 FORJ=0TO6:PRINT"■";DV$(II*7+J);"■";
3630 FORK=1TOPQ:IF(PEEK(UP)ANDUX)GOTO3670
3635 NEXTK
3650 PRINT"■■■■■■";DV$(II*7+J);
3660 NEXTJ
3665 PRINT"■■■■■■";DV$(II*7+J-1);:GOTO3200
3670 PRINT"■■■■■■";DV$(II*7+J);
3680 IFHP=2GOTO42000
3685 IF NV>0 GOTO7740
3690 N$=TV$(II*7+J):GOTO3000
3800 II=I-13
3810 FORJ=0TO6:PRINT"■";DF$(II,J);"■";
3830 FORK=1TOPQ:IF(PEEK(UP)ANDUX)GOTO3860
3835 NEXTK
```

```
3840 PRINT"■■■■■";DF$(II,J);
3850 NEXTJ
3855 PRINT"■■■■■";DF$(II,J-1);:GOTO3200
3860 PRINT"■■■■■";DF$(II,J);
3870 SS=(II*7+J)+1
3875 IF NV>0 GOTO7720
3880 IFHP=2GOTO44000
4000 IFSS>7GOTO4020
4010 ONSSGOTO4100,4300,4500,4700,4900,5100,5300
4020 IFSS>14GOTO4040
4030 ONSS-7GOTO5500,5700,5900,6100,6300,6500,6700
4040 ONSS-14GOTO6900,7100,7300,7500,7700,7900,8100
4100 REM SET TO LOWER CASE
4110 UC=0:GOSUB20100:GOTO3200
4300 REM BEGIN A SENTENCE
4310 UC=3:GOSUB20000:A$=A$+".    ":GOTO3000
4500 REM DELETE CHARACTER
4505 IFLEN(A$)=0GOTO3200
4510 IFLEN(A$)>1GOTO4530
4520 A$="":FL$=" ":GOTO3000
4530 A$=LEFT$(A$,LEN(A$)-1):FL$=" ":GOTO3000
4700 REM DELETE WORD
4701 IFLEN(A$)=0GOTO3000
4702 IFLEN(A$)=1GOTO4745
4705 FORI=LEN(A$)TO2STEP-1
4710 NB$=MID$(A$,I,1)
4720 IFNB$=" "GOTO4750
4730 A$=LEFT$(A$,I-1):FL$=FL$+" "
4740 NEXTI
4745 IFLEN(A$)=1ANDLEFT$(A$,1)<>" "THENGOSUB4800
4750 GOTO3000
4800 A$="":FL$=FL$+" ":RETURN
4900 REM NOT DEFINED
4910 GOTO3200
5100 REM NOT DEFINED
5110 GOTO3200
5300 REM CR-SENDCR/LF TO PRINTER
5310 OPENPR,PR
5320 PRINT#PR
5330 CLOSE PR
5340 GOTO3000
5500 REM SET TO UPPER CASE
5510 UC=1:GOSUB20000:GOTO3200
5700 REM PARAGRAPH
5710 OPENPR,PR
5720 GOSUB 21000:GOSUB 20900
5725 GOSUB 20000
5730 PRINT#PR:PRINT#PR:PRINT#PR
5740 A$="    "
5750 UC=3
5760 CLOSE PR
5770 GOTO3000
5900 REM PRINT CONTENTS OF A$
5910 OPEN PR,PR
5920 GOSUB21000:GOSUB20900
5930 A$=""
5940 CLOSEPR
5950 GOTO3000
6100 REM SEND LINE TO MICRO
6110 OPEN MC,MC
6120 PRINT#MC,A$
6125 GOSUB20900
6130 A$=""
6140 CLOSEMC
6150 GOTO3000
6300 REM ADD A MAKE A$ THE NEXT VARIABLE
6310 IF VN<21 THEN 6340
6320 PRINT"■■■■■■ADVICE - NO ROOM FOR NEW VARIABLE";
6330 GOTO3000
6335 IF A$=""THEN3000
```

```
6340 TV$(VN)=A$
6350 DV$(VN)=LEFT$(TV$(VN)+"      ",5)
6360 DV$(VN)=LEFT$(DV$(VN),4)
6365 DV$(VN)=DV$(VN)+CHR$(32)
6370 GOSUB22000
6380 VN=VN+1
6390 GOTO3000
6500 REM SEND ASCII 3 TO MICRO (BREAK-IN)
6510 OPEN MC,MC
6520 PRINT#MC,CHR$(3);CHR$(3);
6530 CLOSE MC
6540 GOTO3000
6700 REM UNDEFINED
6710 GOTO 3200
6900 REM TEXT MODE
6910 M=0:GOTO2000
7100 REM PROGRAM MODE
7110 M=1:UC=1:GOSUB20000:GOTO2000
7300 REM USER MODE
7310 GOTO30000
7500 REM HELP SUB-SYSTEM
7510 HP=1:GOTO3000
7700 REM DELETE VARIABLE
7701 IF VN>0 GOTO7710
7703 PRINT"ADVICE - NO VARIABLES TO REMOVE";
7705 GOTO3000
7710 PRINT"ADVICE - SELECT VARIABLE TO BE REMOVED";
7713 NV=1
7715 GOTO3000
7720 REM UNKNOWN VARIABLE
7725 PRINT"ADVICE - NO VARIABLE SELECTED!        ";
7730 NV=0
7735 GOTO3000
7740 REM DELETE SELECTED VARIABLE
7745 PRINT"ADVICE - O.K.                         ";
7750 FOR K=II*7+J TO 19
7755 DV$(K)=DV$(K+1)
7760 TV$(K)=TV$(K+1)
7762 NEXT K
7765 DV$(20)="     "
7770 TV$(20)=""
7780 GOSUB 22000
7785 NV=0
7790 VN=VN-1
7795 GOTO3000
7900 REM UNDEFINED
7910 GOTO3200
8100 REM DELETE BUFFER
8110 GOSUB20900:A$="":GOTO3000
10000 PRINT"ADVICE NO HELP IN THIS VERSION";
10005 HP=0
10010 GOTO3000
20000 PRINT" LC  ";
20010 PRINT" UC* ";
20020 DF$(1,0)=" UC* ":DF$(0,0)=" LC  "
20030 RETURN
20100 PRINT" LC* ";
20110 PRINT" UC  ";
20120 DF$(1,0)=" UC  ":DF$(0,0)=" LC* "
20130 RETURN
20900 PRINT"";
20910 FORL=1TO10
20920 PRINT"                    ";
20930 NEXT
20940 RETURN
21000 PRINT#PR,A$
21010 RETURN
22000 PRINT"";
22010 FORI=0TO2:PRINT"      ";
22020 FORJ=0TO6:PRINTDV$(I*7+J);
```

```
22030 NEXTJ:NEXTI
22040 RETURN
30000 REM USER FRAME
30010 PRINT"■ *** SELECT FUNCTION ***"
30020 PRINT
30030 PRINT"  T.V. ON"
30040 PRINT"  T.V. OFF"
30050 PRINT"  B.B.C. 1"
30060 PRINT"  B.B.C. 2"
30070 PRINT"  I.T.V."
30080 PRINT"  RADIO ON"
30090 PRINT"  RADIO OFF"
30100 PRINT"  LAMP ON"
30110 PRINT"  LAMP OFF"
30120 PRINT"  DOWN FASTER"
30130 PRINT"  DOWN SLOWER"
30140 PRINT"  ACROSS FASTER"
30150 PRINT"  ACROSS SLOWER"
30160 PRINT"  RETURN"
30170 PRINT"■■ *";
30180 IF(PEEK(UP)AND UX)=0 GOTO 30180
30190 IF(PEEK(UP)AND UX) GOTO 30190
30200 PRINT"■ ■";
30210 FOR I=1 TO 14
30220 PRINT"■*";
30230 FOR J=1 TO PD
30240 IF(PEEK(UP)AND UX) GOTO 30300
30250 NEXT J
30260 PRINT"■ ■";
30270 NEXT I
30280 PRINT"■ ";
30290 GOTO 30170
30300 PRINT"■ ";
30310 IF I>7 GOTO 30330
30320 ON I GOTO 30400,30500,30600,30700,30800,30900,31000
30330 ON I-7 GOTO 31100,31200,31300,31400,31500,31600,31700
30400 REM TURN TV ON
30410 POKE UP,PEEK(UP)AND 251
30420 GOTO 30600
30500 REM TURN TV OFF
30510 POKE UP,PEEK(UP)OR 4
30520 GOTO 30170
30600 REM BBC1
30610 POKE UP,PEEK(UP)OR 3
30620 GOTO30170
30700 REM BBC2
30710 POKE UP,(PEEK(UP)OR3)AND254
30720 GOTO30170
30800 REM ITV
30810 POKE UP,(PEEK(UP)OR3)AND253
30820 GOTO30170
30900 REM RADIO ON
30910 POKE UP,PEEK(UP)AND247
30920 GOTO30170
31000 REM RADIO OFF
31010 POKE UP,PEEK(UP)OR8
31020 GOTO30170
31100 REM LAMP ON
31110 POKE UP,PEEK(UP)AND239
31120 GOTO30170
31200 REM LAMP OFF
31210 POKE UP,PEEK(UP)OR16
31220 GOTO30170
31300 REM DOWN FASTER
31310 PD=PD-10:IF PD<30 THEN PD=30
31320 GOTO30170
31400 REM DOWN SLOWER
31410 PD=PD+10
31420 GOTO30170
31500 REM ACROSS FASTER
```

```
31510 PQ=PQ-10:IF PQ<30 THEN PQ=30
31520 GOTO30170
31600 REM ACROSS SLOWER
31610 PQ=PQ+10
31620 GOTO30170
31700 REM RETURN
31710 GOTO2000
40000 REM HELP WITH LETTERS
40010 GOSUB 20900
40020 PRINT"■BY SELECTING ´";DA$(M,I,J);
40030 IF LEN(TA$(M,I,J))=0THEN PRINT"´ NOTHING"
40040 IF LEN(TA$(M,I,J))=1THEN PRINT"´ THE CHARACTER ´";TA$(M,I,J);"´´"
40050 IF LEN(TA$(M,I,J))>1THEN PRINT"´ THE STRING ´";TA$(M,I,J);"´´"
40060 PRINT"□IS ADDED TO THE BUFFER."
40070 GOTO49000
42000 REM HELP WITH VARIABLES
42010 GOSUB 20900:PRINT"■";
42020 IF LEN(TV$(II*7+J))>0 THEN 42060
42030 PRINT"THIS VARIABLE (";II*7+J;") IS EMPTY;"
42040 PRINT"□SEE +VAR AND -VAR."
42050 GOTO49000
42060 PRINT"BY SELECTING VARIABLE ´";DV$(II*7+J);"´ THEN"
42070 PRINT"□´";TV$(II*7+J);"´ IS ADDED"
42080 PRINT"TO THE BUFFER."
42090 GOTO49000
44000 REM HELP WITH FUNCTIONS
44005 GOSUB 20900:PRINT"■";
44010 IF SS>7 GOTO 44030
44020 ON SS GOTO45000,45100,45200,45300,45400,45500,45600
44030 IF SS>14 GOTO 44050
44040 ON SS-7 GOTO 45700,45800,45900,46000,46100,46200,46300
44050 ON SS-14 GOTO 46400,46500,46600,46700,46800,46900,47000
45000 PRINT"■ LC  ■ FOLLOWING LETTERS WILL BE LOWER"
45010 PRINT"□CASE.  ALSO SEE ´ UC  ´."
45020 GOTO49000
45100 PRINT"■SENT ■ END OF SENTENCE, ADDS A FULL"
45110 PRINT"□STOP AND THREE SPACES TO THE BUFFER"
45120 PRINT"AND MAKES THE NEXT LETTER A CAPITAL."
45130 GOTO49000
45200 PRINT"■DELC ■ DELETES THE MOST RECENT"
45210 PRINT"□CHARACTER IN BUFFER."
45220 GOTO49000
45300 PRINT"■DELW ■ DELETES THE MOST RECENT WORD"
45310 PRINT"□IN THE BUFFER, NOT INCLUDING SPACES."
45320 GOTO49000
45400 PRINT"NOT DEFINED - CODE AT 4900"
45410 GOTO49000
45500 PRINT"NOT DEFINED - CODE AT 5100"
45510 GOTO49000
45600 PRINT"■ NL  ■ NEWLINE ON PRINTER, DOES NOT"
45610 PRINT"□AFFECT BUFFER."
45620 GOTO49000
45700 PRINT"■ UC  ■ FOLLOWING LETTERS WILL BE"
45710 PRINT"□UPPER CASE - ALSO SEE ´ LC  ´."
45720 GOTO49000
45800 PRINT"■PARA ■ END OF PARAGRAPH, PRINTS"
45810 PRINT"□BUFFER, THREE NEW LINES, AND SETS"
45820 PRINT"BUFFER TO THREE SPACES."
45830 GOTO49000
45900 PRINT"■SEND ■ PRINTS CONTENTS OF BUFFER,"
45910 PRINT"□ERASES BUFFER AND TAKES A NEWLINE."
45920 GOTO49000
46000 PRINT"■ESC  ■ SENDS BUFFER TO 2ND. MICRO,"
46010 PRINT"□AND ESCAPE CHARACTER."
46020 GOTO49000
46100 PRINT"■+VAR ■ SAVES THE CONTENTS OF THE BUFFER"
46110 PRINT"□IN THE NEXT FREE VARIABLE LOCATION."
46120 PRINT"SHOWS FIRST FOUR CHARACTERS."
46140 GOTO49000
46200 PRINT"■ ↑C  ■ SENDS CONTROL C (ASCII(3)) TO"
```

```
46210 PRINT"■THE 2ND. MICRO, ACTS AS A BREAK IN."
46220 GOTO49000
46300 PRINT"NOT DEFINED - CODE AT 6700"
46310 GOTO49000
46400 PRINT"■TEXT ■ GOTO TEXT MODE, DISPLAYS ASCII"
46410 PRINT"■CHARACTER SET AND A SELECTION OF"
46420 PRINT"FREQUENTLY USED WORDS."
46430 GOTO49000
46500 PRINT"■PROG ■ PROGRAMMING MODE, DISPLAYS CHAR-"
46510 PRINT"■ACTERS AND WORDS USED IN BASIC. SETS"
46520 PRINT"UC, VARIABLES MAY BE DEFINED IN TEXT."
46540 GOTO49000
46600 PRINT"■USER ■ USE TO CONTROL EXTERNAL"
46610 PRINT"■EQUIPMENT (T.V., RADIO ETC.) AND"
46620 PRINT"ALTER CURSOR SCAN SPEED."
46630 GOTO49000
46700 PRINT"■HELP ■ A HELP SYSTEM. USE AT FIRST FOR"
46710 PRINT"■GENERAL INFORMATION, THEN TO CHECK"
46720 PRINT"CONTENTS OF VARIABLES - HELP/VARIABLE."
46730 GOTO49000
46800 PRINT"■-VAR ■ REMOVES SELECTED VARIABLE AND"
46810 PRINT"■SHIFTS REMAINING ONES TO FILL SPACE."
46820 GOTO49000
46900 PRINT"NOT DEFINED - CODE AT 7900"
46910 GOTO49000
47000 PRINT"■DEL  ■ CLEARS BUFFER - NO OTHER EFFECT."
49000 PRINT"■■■■■■■ADVICE - ON/OFF TO RETURN              ";
49010 IF(PEEK(UP)AND UX)=0 GOTO 49010
49020 IF(PEEK(UP)AND UX) GOTO49020
49030 GOSUB 20900
49040 PRINT"■■■■■■■ADVICE - O.K.              ";
49050 HP=0
49060 GOTO 3000
```

Program 10.

5.9 Voice synthesis

Adding a voice synthesiser to the CBM 64 is both simple and cheap, and probably one of the easiest ways is to use the General Instrument SPØ256 speech processor chip. This IC is connected directly to the user port and its output is simply fed via an amplifier to the audio input line on the SID chip and thence to the monitor or TV speaker. This circuit is shown in Fig. 5.6.

The SPØ256 is an allophone speech generator which can be used to synthesise any English word by concatenating the individual speech sounds (phonemes) which comprise the word. Within this chip is a table of 64 different allophones and pauses; a full list of these is given in Table 5.1. These are accessed via the chip's six address lines. By having the user port connected directly to these six address lines we can generate any required allophone simply by outputting the correct address to these six lines. Normal speech contains between ten and twelve allophones per second, and consequently allophone synthesis is a very compact way of storing speech. The major advantage of allophone synthesis is that it can provide an unlimited vocabulary with fairly low storage requirements.

When using this circuit to generate speech it must be realised that the allophones do not necessarily correspond directly to the written letters and therefore a word must first be converted to its phonetic form. Thus because of

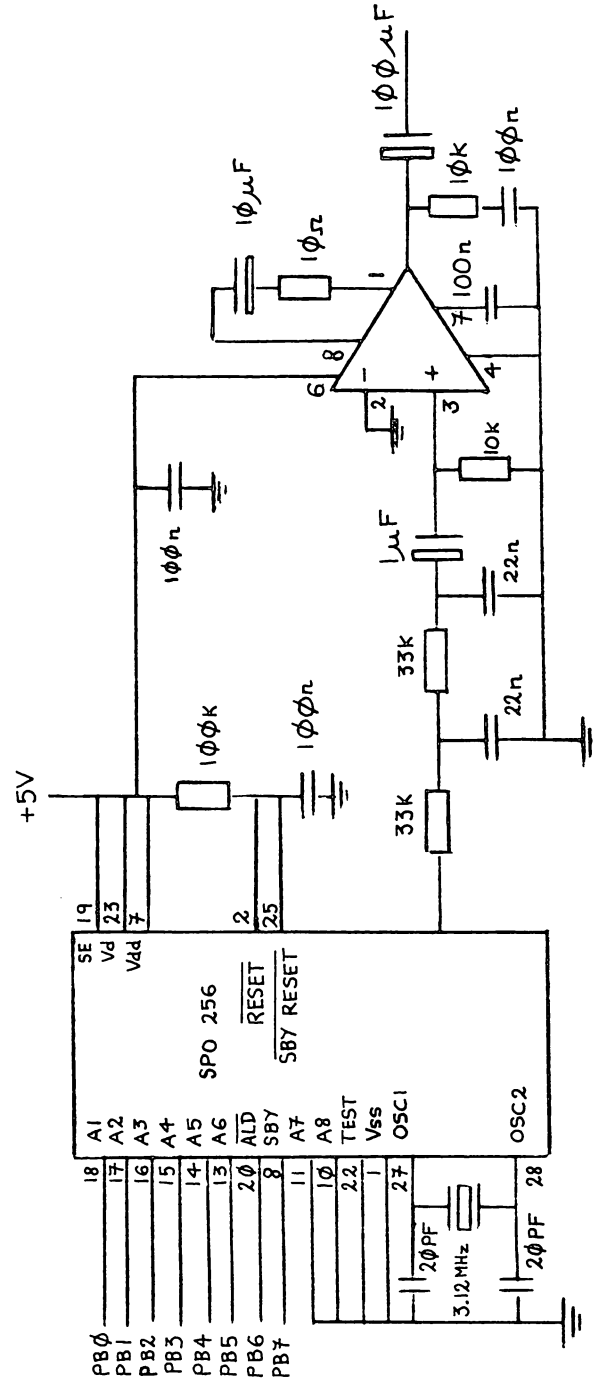


Fig. 5.6. Voice synthesiser circuit.

Table 5.1. Allophone address (Reproduced by courtesy of General Instruments).

Octal Address	Allophone	Sample Word	Duration	Octal Address	Allophone	Sample Word	Duration
000	PA1	PAUSE	10ms	040	/AW/	Out	250ms
001	PA2	PAUSE	30ms	041	/DD2/	Do	80ms
002	PA3	PAUSE	50ms	042	/GG3	Wig	120ms
003	PA4	PAUSE	100ms	043	/VV/	Vest	130ms
004	PA5	PAUSE	200ms	044	/GG1/	Guest	80ms
005	/OY/	Boy	290ms	045	/SH/	Ship	120ms
006	/AY/	Sky	170ms	046	/ZH/	Azure	130ms
007	/EH/	End	50ms	047	/RR2/	Brain	80ms
010	/KK3/	Comb	80ms	050	/FF/	Food	110ms
011	/PP/	Pow	150ms	051	/KK2/	Sky	140ms
012	/JH/	Dodge	100ms	052	/KK1/	Can't	120ms
013	/NN1/	Thin	170ms	053	/ZZ/	Zoo	150ms
014	/IH/	Sit	50ms	054	/NG	Anchor	200ms
015	/TT2/	To	100ms	055	/LL/	Lake	80ms
016	/RR1/	Rural	130ms	056	/WW/	Wool	140ms
017	/AX/	Succeed	50ms	057	/XR/	Repair	250ms
020	/MM/	Milk	180ms	060	/WH/	Whig	150ms
021	/TT1/	Part	80ms	061	/YY1/	Yes	90ms
022	/DH1/	They	140ms	062	/CH/	Church	150ms
023	/IY/	See	170ms	063	/ER1/	Fir	110ms
024	/EY/	Beige	200ms	064	/ER2/	Fir	210ms
025	/DD1/	Could	50ms	065	/OW/	Beau	170ms
026	/UW1/	To	60ms	066	/DH2/	They	180ms
027	/AO/	Aught	70ms	067	/SS/	Vest	60ms
030	/AA/	Hot	60ms	070	/NN2/	No	140ms
031	/YY2/	Yes	130ms	071	/HH2/	Hoe	130ms
032	/AE/	Hat	80ms	072	/OR/	Store	240ms
033	/HH1/	He	90ms	073	/AR/	Alarm	200ms
034	/BB1/	Business	40ms	074	/YR/	Clear	250ms
035	/TH/	Thin	130ms	075	/GG2/	Got	80ms
036	/UH/	Book	70ms	076	/EL/	Saddle	140ms
037	/UW2/	Food	170ms	077	/BB2/	Business	60ms

irregularities in spelling it is necessary to use the sounds of the word rather than the letters when dealing with speech allophones. A second problem is the segmentation of speech. This means that although we think of a spoken word as consisting of a sequence of separate sounds which correspond to a letter name, in fact speech sound is a continuously varying signal which cannot easily be broken into discrete units. This accounts for the occasional problems of intelligibility in allophone synthesised speech. A third problem is that the ear will perceive the same acoustic signal differently depending on the sounds which precede or follow it. Thus the initial p in 'pop' is different from the p in 'spy'. An attempt is made to overcome some of these problems by the design of the allophone sounds and by careful selection of allophones to describe a particular word.

The individual sounds of language are called phonemes. In each language these are slightly different. The SPØ256 is designed to give English phonemes. The phonemes can be divided into three different catagories; consonants, vowels, and speech sounds such as aspirants and pauses. Tables 5.2 to 5.6 show the consonant and vowel phonemes and how allophones can be used. Program 11 shows how to use the voice synthesis circuit and allophones from Basic.

```
1 REM ****************************
2 REM * SPEECH DATA TO USER PORT *
3 REM ****************************
4 REM
5 POKE54272+24,15
10 DD=56576
20 POKEDD+3,127
35 READD:IFD=-1THENEND
40 POKEDD+1,D OR64
50 POKEDD+1,D AND63
51 IFPEEK(DD+1)<128THEN51
60 GOTO 35
70 DATA42,59,45,3
80 DATA 3,39,12,50,59,21,3
85 DATA 3,26,11,33,3
90 DATA 3,11,12,41,3
91 DATA 3,46,52,41,3
93 DATA 40,58,3
100 DATA 43,12,40,39,26,3
110 DATA 12,11,40,58,16,20,37,15,11,3
120 DATA 13,7,42,56,53,45,53,10,19,3,-1
```

Program 11.

Table 5.2. Examples of spelling irregularities. (Reproduced by courtesy of General Instruments).

	Same sound represented by different letters	Different sounds represented by the same letter(s)
Vowels	meat feet Pete people penny	vein foreign deism deicer geisha
Consonants	**sh**ip ten**s**ion pre**c**ious na**t**ion	al**th**ough **gh**astly cou**gh**

Table 5.3. Consonant phonemes of English (Reproduced by courtesy of General Instruments).

		Labial[1]	Labio-Dental[2]	Inter-Dental[3]	Alveolar[4]	Palatal[5]	Velar[6]	Glottal[7]
Stops:	Voiceless Voiced	PP BB			TT DD		KK GG	
Fricatives:	Voiceless Voiced	WH	FF VV	TH DH	SS ZZ	SH ZH*		HH
Affricates:	Voiceless Voiced					CH JH		
Nasals:	Voiced	MM			NN		NG*	
Resonants:	Voiced	WW			RR, LL	YY		

*These do not occur in word-initial position in English.

1. Upper and Lower Lips Touch or Approximate
2. Upper Teeth and Lower Lip Touch
3. Tongue Between Teeth
4. Tip of Tongue Touches or Approximates Alveolar Ridge (just behind upper teeth)
5. Body of Tongue Approximates Palate (roof of mouth)
6. Body of Tongue Touches Velum (posterior portion of roof of mouth)
7. Glottis (opening between vocal cords)

Table 5.4. Vowel phonemes of English (Reproduced by courtesy of General Instruments).

	FRONT	CENTRAL	BACK
HIGH	YR IY IH*		UW# UH*#
MID	EY EH* XR	ER AX*	OW# OY#
LOW	AE*	AW# AY AR AA*	AO*# OR#

* SHORT VOWELS # ROUNDED VOWELS

Table 5.5. Examples of words made from allophones (Reproduced by courtesy of General Instruments).

DD2-AO-TT2-ER1	"daughter"
KK3-AX-LL-AY-DD1	"collide"
SS-SS-IH-SS-TT2-ER1	"sister"
KK1-LL-AW-NN1	"clown"
KK3-UH-KK1-IY	"cookie"
LL-EH-TT2-ER	"letter"
LL-IH-TT2-EL	"little"
AX-NG-KK3-EL	"uncle"
KK1-AX-MM-PP1-YY1-UW1-TT2-ER	"computer"
EH-KK1-SS-TT2-EH-EH-NN1-TT2	"extent"
TT2-UW2	"two"
AX-LL-AR-MM	"alarm"
SS-KK3-OR	"score"
FF-ER2	"fir"

Table 5.6. Guidelines for using the allophones (Reproduced by courtesy of General Instruments).

Silence	
PA1 (10ms)	before BB, DD, GG, and JH
PA2 (30ms)	before BB, DD, GG, and JH
PA3 (50ms)	before PP, TT, KK, and CH, and between words
PA4 (100ms)	between clauses and sentences
PA5 (200ms)	between clauses and sentences
Short Vowels	
*/IH/	sitting, stranded
*/EH/	extent, gentlemen
*/AE/	extract, acting
*/UH/	cookie, full
*/AO/	talking, song
*/AX/	lapel, instruct
*/AA/	pottery, cotton
Long Vowels	
/IY/	treat, people, penny
/EY/	great, statement, tray
/AY/	kite, sky, mighty
/OY/	noise, toy, voice
/UW1/	after clusters with YY: computer
/UW2	in monosyllabic words: two, food
/OW/	zone, close, snow
/AW/	sound, mouse, down

Table 5.6. Continued.

R-Colored Vowels	
/ER1/	letter, furniture, interrupt
/ER2/	monosyllables: bird, fern, burn
/OR/	fortune, adorn, store
/AR/	farm, alarm, garment
/YR/	hear, earring, irresponsible
/XR/	hair, declare, stare
Resonants	
/WW/	we, warrant, linguist
/RR1/	initial position: read, write, x-ray
/RR2/	initial clusters: brown, crane, grease
/LL/	like, hello, steel
/EL/	little, angle, gentlemen
/YY1/	clusters: cute, beauty, computer
/YY2/	initial position: yes, yarn, yo-yo
Voiced Fricatives	
/VV/	vest, prove, even
/DH1/	word-initial position: this, then, they
/DH2/	word-final and between vowels: bathe, bathing
/ZZ/	zoo, phase
/ZH/	beige, pleasure
Voiceless Fricatives	
*/FF/ */TH/ */SS/	These may be doubled for initial position and used singly in final position
/SH/	shirt, leash, nation
/HH1/	before front vowels: YR, IY, IH, EY, EH, XR, AE
/HH2/	before back vowels: UW, UH, OW, OY, AO, OR, AR
/WH/	white, whim, twenty
Voiced Stops	
/BB1/	final position: rib; between vowels: fibber; in clusters; bleed, brown
/BB2/	initial position before a vowel: beast
/DD1/	final position: played, end
/DD2/	initial position: down; clusters: drain
/GG1/	before high front vowels: YR, IY, IH, EY, EH, XR
/GG2/	before high back vowels: UW, UH, OW, OY, AX; and clusters: green, glue
/GG3/	before low vowels: AE, AW, AY, AR, AA, AO, OR, ER; in medial clusters: anger; and final position: peg
Voiceless Stops	
/PP/	pleasure, ample, trip
/TT1/	final clusters before SS: tests, its
/TT2/	all other positions: test, street
/KK1/	before front vowels: YR, IY, IH, EY, EH, XR, AY, AE, ER, AX; initial clusters: cute, clown, scream
/KK2/	final position: speak; final clusters: task
/KK3/	before back vowels: UW, UH, OW, OY, OR, AR, AO; initial clusters: crane, quick, clown, scream
Affricates	
/CH/	church, feature
/JH/	judge, injure
Nasal	
/MM/	milk, alarm, ample
/NN1/	before front and central vowels: YR, IY, IH, EY, EH, XR, AE, ER, AX, AW, AY, UW; final clusters: earn
/NN2/	before back vowels: UH, OW, OY, OR, AR, AA
/NG/	string, anger

*These allophones can be doubled.

5.10 Analog interfacing

In digital systems two voltage levels are used to represent data, with the binary digit Ø represented by a low voltage and binary 1 by a high voltage. Digital data is therefore represented by a series of pulses. Analog signals have an infinite range of voltage levels and are therefore continuous rather than having discrete units of information. The difference between the two types of waveform is shown in Fig. 5.7. The digital equivalent of an analog signal is generated by regularly sampling the waveform, and on each sample converting the measured voltage into a binary value using an analog to digital conversion circuit. The sampling of a waveform is shown in Fig. 5.8. For a computer to be able to create a smooth analog waveform it must at regular intervals output a binary value, which is converted to an analog voltage by a digital to analog conversion circuit. The digital synthesis of an analog waveform is shown in Fig. 5.9.

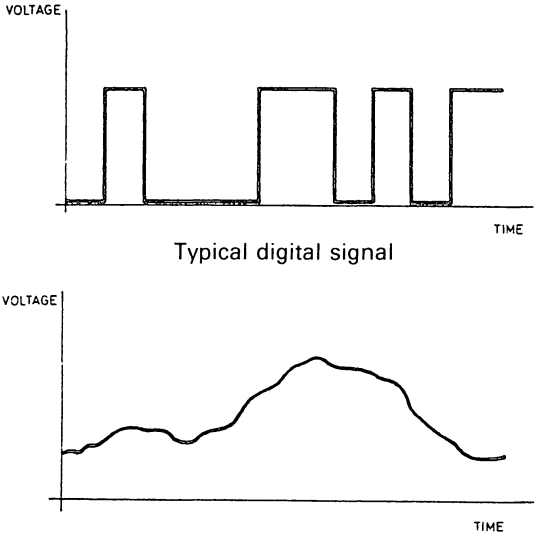


Fig. 5.7. Comparison of digital and analog waveforms (Reproduced by courtesy of *Practical Electronics*).

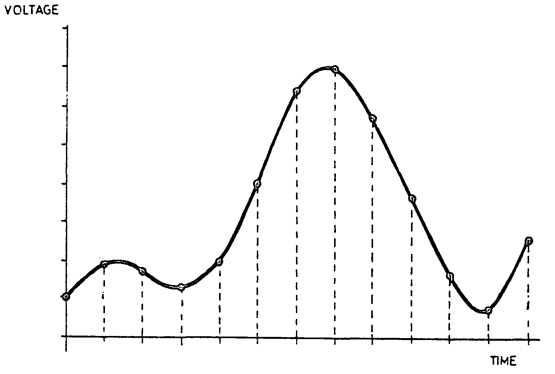


Fig. 5.8. Digital sampling of an analog waveform (Reproduced by courtesy of *Practical Electronics*).

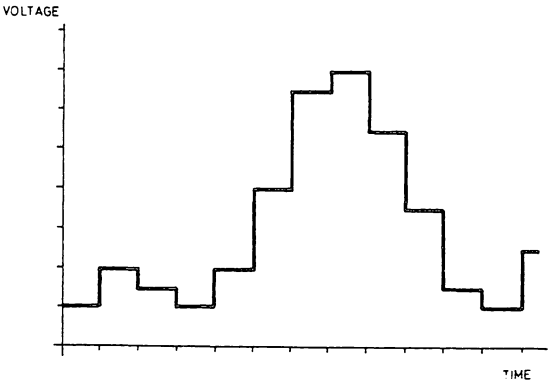


Fig. 5.9. Digital synthesis of an analog waveform (Reproduced by courtesy of *Practical Electronics*).

5.11 Digital to analog conversion

The circuit used to convert a digital signal to an analog signal is quite simple involving the use of a weighted resistor network. This most commonly takes the form of an R, 2R, 4R, 8R etc. ladder, such as the one shown in Fig. 5.10. In operation each successively lower weighted input produces an output voltage which is exactly half that produced by the preceding input. The voltages from each input are summed at the combined output and a voltage developed which is the analog representation of the binary digital value.

Although a digital to analog conversion circuit can be constructed easily from resistors it is simpler and often more accurate to use one of the many D to A converter ICs. An example of such a D to A IC is the ZN425E. This chip is an 8 bit dual mode A/D and D/A converter, incorporating a voltage reference, resistor network, input switches and an 8 bit binary counter. A block diagram and pin out for this IC is shown in Fig. 5.11. The 8 bit counter is used with an external comparator IC to facilitate analog to digital conversion. The logic

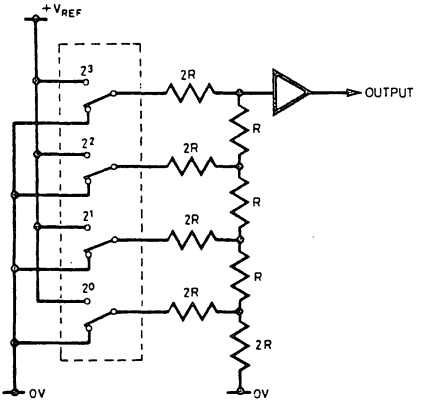


Fig. 5.10. Digital to analog converter using R-2R register network (Reproduced by courtesy of *Practical Electronics*).

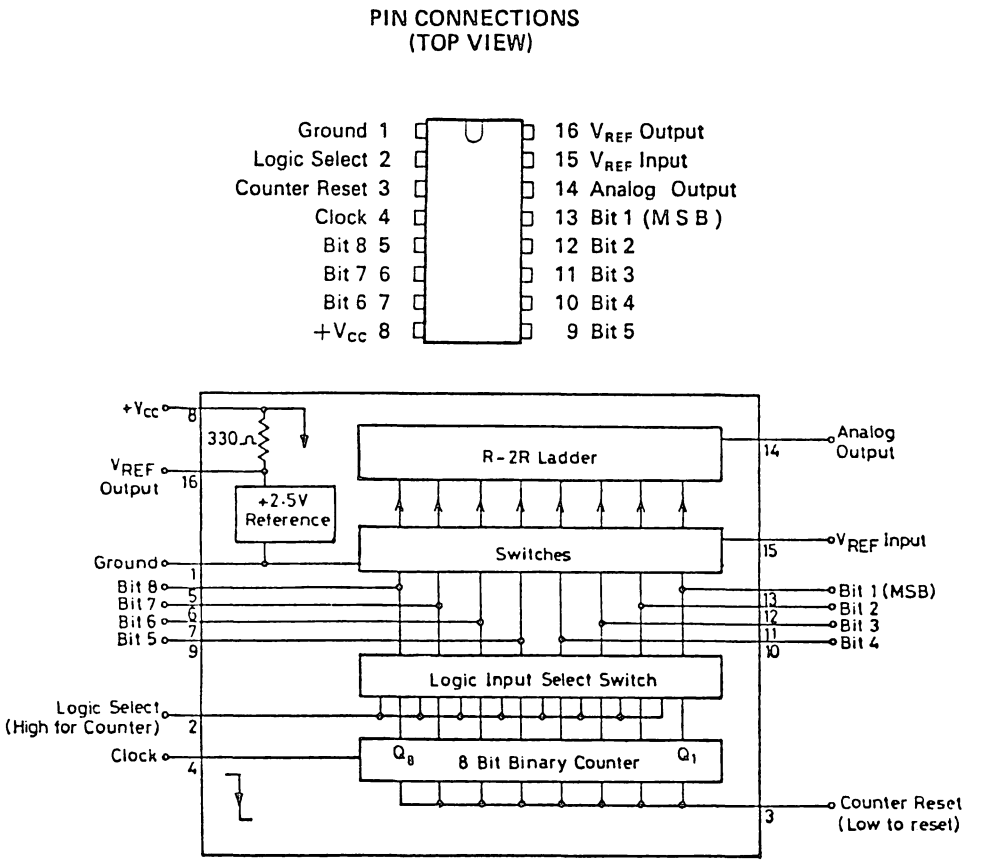


Fig. 5.11. Pin connections and block diagram for the A/D and D/A converter (Reproduced by courtesy of RS Components Limited).

select pin determines which function, A/D or D/A, is being used. The on-chip 2.5 volt reference signal ensures that the conversion is very accurate (Ø.2% accuracy). This chip is very easy to connect to the processor; the circuit diagram for connecting it is shown in Fig. 5.12. It should be noted that the output from this chip is a voltage ranging between Ø volts and 2.5 volts (an increase of 1 in the output to the D to A therefore gives a corresponding increase of approximately Ø.Ø1 volts). A buffer amplifier is necessary to change this voltage range, particularly if a positive to negative ranging voltage is desired, and calibrate the output.

The ability to generate an analog signal from the computer has many applications, probably the most obvious is in the generation of simple or complex analog waveforms. The technique for outputting a repeating waveform of frequency is quite simple. The fundamental requirement is a waveform table, usually one page (256 bytes) long. This table contains a sequence of precalculated values which define the waveform shape. By repeatedly outputting all the values in the table, in sequence, to the digital to analog converter a regular waveform is generated. The frequency of the waveform can be varied either by varying the delay between outputting each

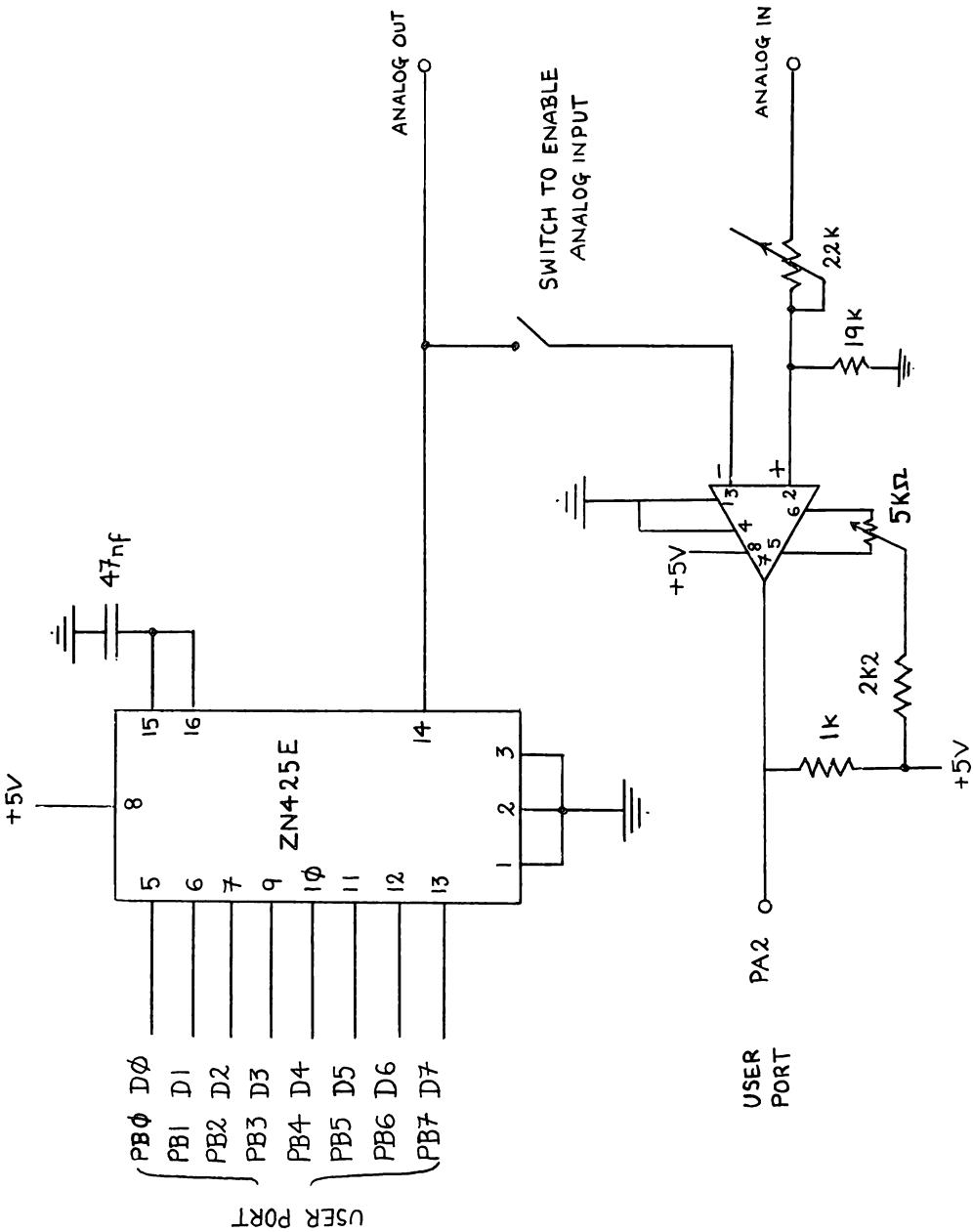


Fig. 5.12. Analog to digital and digital to analog conversion circuit.

```
LOC   CODE        LINE

C291              .LIB   FUNC.SIMPLE
C291              ; ROUTINE TO OUTPUT A FUMCTION
C291              ;TABLE OVER THE USER PORT TO A
C291              ;DIGITAL TO ANALOG CONVERTER.
C291              ;
C291              ; THE FREQUENCY IS CONTROLLED
C291              ;BY EITHER THE TIMER VALUE OR
C291              ;INCREASING/DECREASING THE
C291              ;SAMPLING VALUE.
C291              ;
C291  20 FD AE    FUNCTN JSR $AEFD        ;GET VALUE FOR
C294  20 8A AD           JSR $AD8A        ; TIMER A
C297  20 F7 B7           JSR $B7F7
C29A  A9 D1              LDA #<NMI        ;SET NMI VECTOR
C29C  8D 18 03           STA $0318
C29F  8D FA FF           STA $FFFA
C2A2  A9 C2              LDA #>NMI
C2A4  8D 19 03           STA $0319
C2A7  8D FB FF           STA $FFFB
C2AA  A5 14              LDA $14
C2AC  8D 04 DD           STA $DD04        ;STORE TIMER VALUE
C2AF  A5 15              LDA $15
C2B1  8D 05 DD           STA $DD05
C2B4  A9 FF              LDA #$FF
C2B6  8D 03 DD           STA $DD03        ;USER PORT TO OUTPUT
C2B9  A9 0F              LDA #$0F
C2BB  8D 18 D4           STA $D400+24     ;MAX SID VOLUME
C2BE  A9 00              LDA #$00
C2C0  8D 01 C3           STA FLAG         ;POINTER TO TABLE
C2C3  AD 0D DD           LDA $DD0D        ;CLEAR NMIS
C2C6  A9 81              LDA #$81         ;SET TIMER A NMI
C2C8  8D 0D DD           STA $DD0D
C2CB  A9 11              LDA #$11         ;START TIMER A
C2CD  8D 0E DD           STA $DD0E
C2D0  60                 RTS
C2D1              ;
C2D1  48          NMI    PHA              ;STORE REGISTERS
C2D2  8A                 TXA
C2D3  48                 PHA
C2D4  98                 TYA
C2D5  48                 PHA
C2D6  A9 01              LDA #$01         ;CAUSED BY TIMER A?
C2D8  2C 0D DD           BIT $DD0D
C2DB  D0 11              BNE SEND         ;YES
C2DD  A9 7F              LDA #$7F         ;CLEAR ENABLED NMIS
C2DF  8D 0D DD           STA $DD0D
C2E2  20 84 FF           JSR $FF84        ;RESET I/O
C2E5  20 8A FF           JSR $FF8A        ;RESET KERNAL
C2E8  68          NMEXIT PLA              ;PULL REGISTERS
C2E9  A8                 TAY
C2EA  68                 PLA
C2EB  AA                 TAX
C2EC  68                 PLA
C2ED  40                 RTI
C2EE              ;
C2EE  AE 01 C3    SEND   LDX FLAG         ;GET POINTER
C2F1  BD 13 C3           LDA TABLE,X      ;GET BYTE
C2F4  8D 01 DD           STA $DD01        ;SEND TO USER PORT
C2F7  8A                 TXA
C2F8  18                 CLC
C2F9  69 01       STORE  ADC #$01         ;ADD SAMPLING VALUE
C2FB  8D 01 C3           STA FLAG
C2FE  4C E8 C2           JMP NMEXIT       ;EXIT NMI
C301              ;
C301  00          FLAG   .BYT 0
```

```
LOC   CODE         LINE

C302               ;
C302  20 8A FF     DISAB  JSR $FF8A
C305  20 84 FF            JSR $FF84
C308  A9 FE               LDA #$FE
C30A  8D FB FF            STA $FFFB
C30D  A9 43               LDA #$43
C30F  8D FA FF            STA $FFFA
C312  60                  RTS
C313               ;
C313               TABLE  *=*+256
C413               .END
```

Symbol table

```
SYMBOL VALUE
 ALOOP1   C0A3   ATOD     C09C   CLRMEM   C203   CLRSCN   C26A
 DISAB    C302   DISPLY   C000   DIV8     C125   DONE     C1F0
 DOT      C0D1   ERROR    C013   EXIT     C0CD   FLAG     C301
 FUNCTN   C291   GRAPH    C1E1   GXY      C198   KERIN    C1D1
 KEROUT   C1C9   LOOP     C206   LOOP1    C26E   LOOP2    C0C3
 MUL320   C147   MUL8     C12E   NMEXIT   C2E8   NMI      C2D1
 NORM     C27E   OK       C018   PLOT1    C18A   PLOTIT   C181
 READ10   C060   RLOOP1   C06E   RLOOP2   C070   SEND     C2EE
 SETUP    C092   STORE    C2F9   TABLE    C313   TOP2X    C179
 TX       C1C7   XER      C0E1   XOK      C0E3   YND7OK   C123
 ZLOOP    C022   ZLOOP1   C03A   ZLOOP2   C042   ZPLOT    C04F
```

Program 12.

value or for higher frequencies by sampling the table rather than using every value, with the frequency being determined by the sampling step.

The machine code routine in Program 12 can be used to output a waveform using a predefined waveform table over a range of different frequencies, the frequency being controlled by the value stored in Timer A. This routine is designed such that the analog output is connected to the sound input of the SID chip so that the sound generated by the waveform can be heard. The Basic program in Program 13 is used in conjunction with Program 12 to create a waveform table, the waveform being created either from a mathematical function or drawn directly using either a joystick or the cursor keys. The resulting waveform is displayed on the screen using high resolution graphics. It should be noted that in order to obtain the graphics, the graphics routines in Program 14 should be present. These are integrated with the frequency generation routine so that they can both reside in memory together.

```
10 PRINT"□USE:"
20 PRINT"■     1 - JOYSTICK"
30 PRINT"■     2 - KEYBOARD"
40 PRINT"■     3 - FUNCTION"
50 GETA$:IFA$=""THEN50
60 A=VAL(A$):IFA<1ORA>3THEN50
90 T=49939:SYS49627
100 DIMT(255):FORI=0TO255:T(I)=127:POKET+I,127:SYS49537,I,T(I)-27:NEXT
110 ONAGOSUB1000,2000,3000
120 GETA$:IFA$=""THEN120
```

```
130 SYS49790
140 END
1000 REM
1010 REM INPUT WAVEFORM USING JOYSTICK
1020 REM
1030 X=0:Y=T(X)-27
1040 A=PEEK(56320):E=0:W=0:S=0:N=0
1050 IF (AAND16)=0 THEN RETURN
1060 IF (AAND8)=0 THEN E=1:GOTO1110
1070 IF (AAND4)=0 THEN W=-1:GOTO1110
1080 IF (AAND2)=0 THEN S=-1:GOTO1110
1090 IF (AAND1)=0 THEN N=1:GOTO1110
1100 GOTO 1040
1110 GOSUB 11100:GOTO1040
2000 REM
2010 REM INPUT WAVEFORM USING KEYBOARD
2020 REM
2030 X=0:Y=T(X)-27
2040 GETA$:E=0:W=0:S=0:N=0
2050 IF A$=CHR$(13) THEN RETURN
2060 IF A$="■" THEN E=1:GOTO 2110
2070 IF A$="■" THEN W=-1:GOTO 2110
2080 IF A$="■" THEN S=-1:GOTO 2110
2090 IF A$="■" THEN N=1:GOTO 2110
2100 GOTO 2040
2110 GOSUB 11100:GOTO2040
3000 REM
3010 REM PUT UP A WAVEFORM DEFINED IN
3020 REM FNF
3030 REM
3040 DEF FNF(Z)=128+(31-.122*Z)*SIN((Z*π/128)↑2)
3050 FORI=0TO255
3060 V=FNF(I):SYS49537,I,T(I)-27
3070 POKET+I,V:T(I)=V:SYS49537,I,T(I)-27
3080 NEXTI:RETURN
11100 IF E OR W THEN 11120
11110 IF(Y+S+N)<0THENRETURN
11111 IF (Y+S+N)>199 THEN RETURN
11112 SYS49537,X,Y:Y=Y+S+N
11115 T(X)=(Y+27):POKET+X,(Y+27):SYS49537,X,Y:RETURN
11120 X=(X+E+W)AND255:Y1=T(X)-27:SYS49537,X,Y1:SYS49537,X,Y
11130 T(X)=Y+27:POKET+X,Y+27:RETURN
```

Program 13.

```
LOC   CODE        LINE

0000              *=$C000
C000              .LIB   DIS.SIMPLE
C000  20 FD AE    DISPLY JSR $AEFD
C003  20 8A AD           JSR $AD8A        ;GET MEMORY ADDRESS
C006  20 F7 B7           JSR $B7F7        ; OF DISPLAY
C009  A5 15              LDA $15
C00B  C9 78              CMP #$78         ;LESS THAN BOTTOM?
C00D  90 04              BCC ERROR        ;YES
C00F  C9 A0              CMP #$A0         ;IN RANGE?
C011  90 05              BCC OK           ;YES
C013  A9 01       ERROR  LDA #$01         ;FLAG ERROR
C015  85 02              STA $02          ; AND EXIT
C017  60                 RTS
C018  A9 00       OK     LDA #$00         ;FLAG O.K.
C01A  85 02              STA $02
C01C  A9 00              LDA #$00         ;SET X COUNTER
C01E  85 FD              STA $FD
C020  85 FE              STA $FE
C022  A0 00       ZLOOP  LDY #$00
C024  B1 14              LDA ($14),Y      ;GET A VALUE
C026  20 4F C0           JSR ZPLOT        ;PLOT IT
C029  A5 14              LDA $14          ;INCREASE TABLE POINTER
C02B  18                 CLC              ;BY SAMPLING RATE
C02C  69 01              ADC #$01
```

```
LOC   CODE       LINE

C02E  85 14              STA $14
C030  A5 15              LDA $15
C032  69 00              ADC #$00
C034  C9 A0              CMP #$A0        ;WRAPAROUND?
C036  D0 02              BNE ZLOOP1      ;NO
C038  A9 78              LDA #$78
C03A  85 15       ZLOOP1 STA $15
C03C  E6 FD              INC $FD         ;INCREASE X
C03E  D0 02              BNE ZLOOP2      ; COORDINATE BY 1
C040  E6 FE              INC $FE
C042  A5 FE       ZLOOP2 LDA $FE
C044  C9 01              CMP #$01        ;DONE 320 POINTS?
C046  D0 DA              BNE ZLOOP       ;NOT YET
C048  A5 FD              LDA $FD
C04A  C9 40              CMP #$40
C04C  D0 D4              BNE ZLOOP       ;NO
C04E  60                 RTS             ;YES, EXIT
C04F                ;
C04F  85 5B       ZPLOT  STA $5B         ;STORE THE Y
C051  A9 00              LDA #$00        ; COORDINATE
C053  85 5C              STA $5C
C055  A5 FD              LDA $FD         ;STORE THE X
C057  85 59              STA $59         ; COORDINATE
C059  A5 FE              LDA $FE
C05B  85 5A              STA $5A
C05D  4C 84 C1           JMP PLOTIT+3    ;PLOT THE POINT
C060                .END
C060                .LIB   READ.SIMPLE
C060  78          READ10 SEI             ;DISABLE IRQ
C061  A9 0B              LDA #$0B        ;BLANK SCREEN
C063  8D 11 D0           STA $D011
C066  A9 00              LDA #$00        ;SET POINTER TO
C068  85 FD              STA $FD         ; START OF TABLE
C06A  A9 78              LDA #$78
C06C  85 FE              STA $FE
C06E  A2 01       RLOOP1 LDX #$01        ;SAMPLE RATE
C070  20 92 C0    RLOOP2 JSR SETUP       ;READ VALUE
C073  CA                 DEX
C074  D0 FA              BNE RLOOP2      ;IGNORE SAMPLE
C076  A0 00              LDY #$00
C078  91 FD              STA ($FD),Y     ;STORE THE VALUE
C07A  A9 01              LDA #$01        ;INCREASE TABLE
C07C  18                 CLC             ; POINTER BY 1
C07D  65 FD              ADC $FD
C07F  85 FD              STA $FD
C081  A5 FE              LDA $FE
C083  69 00              ADC #$00
C085  85 FE              STA $FE
C087  C9 A0              CMP #$A0        ;END OF TABLE?
C089  D0 E3              BNE RLOOP1      ;NO
C08B  A9 1B              LDA #$1B        ;RESTORE SCREEN
C08D  8D 11 D0           STA $D011
C090  58                 CLI             ;ENABLE IRQ
C091  60                 RTS
C092                ;
C092  A9 FF       SETUP  LDA #$FF        ;SET USER PORT
C094  8D 03 DD           STA $DD03       ; TO OUTPUT
C097  A9 FB              LDA #$FB        ;SET ONE INPUT LINE
C099  8D 02 DD           STA $DD02       ; (PA2)
C09C  A9 80       ATOD   LDA #$80        ;SET A TO D
C09E  8D 01 DD           STA $DD01       ;START VALUE
C0A1  85 61              STA $61
C0A3  AD 01 DD    ALOOP1 LDA $DD01       ;START MAIN LOOP
C0A6  05 61              ORA $61
C0A8  8D 01 DD           STA $DD01
C0AB  EA                 NOP
C0AC  EA                 NOP
C0AD  AD 00 DD           LDA $DD00       ;INPUT FROM
```

```
LOC   CODE        LINE

C0B0  6A                  ROR A           ; COMPARATOR INTO
C0B1  6A                  ROR A           ; CARRY
C0B2  6A                  ROR A
C0B3  B0 0E               BCS LOOP2       ;VALUE TOO SMALL
C0B5  A5 61               LDA $61         ;VALUE TOO LARGE
C0B7  4D 01 DD            EOR $DD01       ; TRY HALF VALUE
C0BA  8D 01 DD            STA $DD01
C0BD  46 61               LSR $61         ;DECREASE SEARCH STEP
C0BF  F0 0C               BEQ EXIT        ;COMPLETE
C0C1  10 E0               BPL ALOOP1      ;TRY AGAIN
C0C3  46 61       LOOP2   LSR $61         ;DECREASE SEARCH STEP
C0C5  EA                  NOP             ;ADJUST TIMING
C0C6  EA                  NOP
C0C7  EA                  NOP
C0C8  EA                  NOP
C0C9  A5 61               LDA $61
C0CB  D0 D6               BNE ALOOP1      ;TRY AGAIN
C0CD  AD 01 DD    EXIT    LDA $DD01       ;VALUE RETURNED IN
C0D0  60                  RTS             ; .A
C0D1              .END
C0D1              .LIB    DOT.SIMPLE
C0D1              ;
C0D1              ; ROUTINE TO CALCULATE LOCATION
C0D1              ;  AND BIT(S) FROM THE X AND Y
C0D1              ;  COORDINATES.
C0D1              ;
C0D1  A5 5A       DOT     LDA $5A         ; CHECK THAT X AND Y
C0D3  C9 00               CMP #$00        ; ARE WITHIN BOUNDS
C0D5  F0 0C               BEQ XOK
C0D7  C9 01               CMP #$01
C0D9  D0 06               BNE XER
C0DB  A5 59               LDA $59
C0DD  C9 40               CMP #$40
C0DF  90 02               BCC XOK
C0E1  38          XER     SEC             ; TOO LARGE EXIT
C0E2  60                  RTS
C0E3  A5 5C       XOK     LDA $5C
C0E5  D0 FA               BNE XER
C0E7  A5 5B               LDA $5B
C0E9  C9 C8               CMP #$C8
C0EB  B0 F4               BCS XER
C0ED  A9 C7               LDA #199
C0EF  38                  SEC
C0F0  E5 5B               SBC $5B
C0F2  85 5B               STA $5B
C0F4  A5 59               LDA $59         ;CALCULATE THE BIT TO
C0F6  29 07               AND #$07        ; BE PLOTTED AS
C0F8  85 5E               STA $5E         ; 7-(X AND Y)
C0FA  A9 07               LDA #$07
C0FC  38                  SEC
C0FD  E5 5E               SBC $5E
C0FF  AA                  TAX             ;CALCULATE 2↑$5E
C100  BD 79 C1            LDA TOP2X,X
C103  85 5E               STA $5E
C105              ;
C105              ;CALCULATE INT(Y/8)*320
C105              ;AND STORE IN $57
C105              ;
C105  A5 5B               LDA $5B
C107  4A                  LSR A
C108  4A                  LSR A
C109  4A                  LSR A
C10A  0A                  ASL A
C10B  AA                  TAX
C10C  BD 47 C1            LDA MUL320,X
C10F  85 57               STA $57
C111  BD 48 C1            LDA MUL320+1,X
```

```
LOC   CODE        LINE

C114  85 58             STA $58
C116              ;
C116              ;ADD Y AND 7 TO $57
C116              ;
C116  A5 5B             LDA $5B
C118  29 07             AND #$07
C11A  18                CLC
C11B  65 57             ADC $57
C11D  85 57             STA $57
C11F  90 02             BCC YND7OK
C121  E6 58             INC $58
C123              ;
C123              ;CALCULATE INT(X/8)
C123              ;
C123  A0 03       YND7OK LDY #$03
C125  46 5A       DIV8   LSR $5A
C127  66 59              ROR $59
C129  88                 DEY
C12A  D0 F9              BNE DIV8
C12C              ;
C12C              ;CALCULATE INT(X/8)*8
C12C              ;
C12C  A0 03              LDY #$03
C12E  06 59       MUL8   ASL $59
C130  26 5A              ROL $5A
C132  88                 DEY
C133  D0 F9              BNE MUL8
C135              ;
C135              ;ADD INT(X/8)*8 INTO $57
C135              ;
C135  A5 57              LDA $57
C137  18                 CLC
C138  65 59              ADC $59
C13A  85 57              STA $57
C13C  A5 58              LDA $58
C13E  65 5A              ADC $5A
C140              ;
C140              ;ADD $E000 INTO $57
C140              ;
C140  18                 CLC
C141  69 E0              ADC #$E0
C143  85 58              STA $58
C145  18                 CLC
C146  60                 RTS
C147  00 00       MUL320 .WOR 0,320,640,960,1280
C149  40 01
C14B  80 02
C14D  C0 03
C14F  00 05
C151  40 06              .WOR 1600,1920,2240,2560,2880
C153  80 07
C155  C0 08
C157  00 0A
C159  40 0B
C15B  80 0C              .WOR 3200,3520,3840,4160,4480
C15D  C0 0D
C15F  00 0F
C161  40 10
C163  80 11
C165  C0 12              .WOR 4800,5120,5440,5760,6080
C167  00 14
C169  40 15
C16B  80 16
C16D  C0 17
C16F  00 19              .WOR 6400,6720,7040,7360,7680
C171  40 1A
C173  80 1B
```

```
LOC   CODE        LINE

C175  C0 1C
C177  00 1E
C179  01          TOP2X  .BYT 1,2,4,8,16,32,64,128
C17A  02
C17B  04
C17C  08
C17D  10
C17E  20
C17F  40
C180  80
C181              .END
C181              .LIB   PLOT.SIMPLE
C181              ;
C181              ; ROUTINE TO PLOT A POINT
C181              ;
C181  20 98 C1    PLOTIT JSR GXY          ; GET X AND Y
C184  20 D1 C0           JSR DOT
C187  90 01              BCC PLOT1
C189  60                 RTS
C18A  20 C9 C1    PLOT1  JSR KEROUT       ;DISABLE IRQ
C18D  A0 00              LDY #$00
C18F  B1 57              LDA ($57),Y     ; OTHERWISE PLOT POINT
C191  45 5E              EOR $5E
C193  91 57              STA ($57),Y
C195  4C D1 C1           JMP KERIN
C198              ;
C198              ;GET X AND Y VALUE
C198              ;INTO $59 AND $5B
C198              ;
C198  20 FD AE    GXY    JSR $AEFD
C19B  20 8A AD           JSR $AD8A       ;GET X
C19E  20 BF B1           JSR $B1BF       ;FIX IT
C1A1  A6 65              LDX $65
C1A3  A4 64              LDY $64
C1A5  8E C7 C1           STX TX
C1A8  8C C8 C1           STY TX+1
C1AB  20 FD AE           JSR $AEFD       ;CHECK ','
C1AE  20 8A AD           JSR $AD8A       ;GET Y
C1B1  20 BF B1           JSR $B1BF       ;FIX IT
C1B4  A6 65              LDX $65
C1B6  A4 64              LDY $64
C1B8  86 5B              STX $5B
C1BA  84 5C              STY $5C
C1BC  AD C7 C1           LDA TX
C1BF  85 59              STA $59
C1C1  AD C8 C1           LDA TX+1
C1C4  85 5A              STA $5A
C1C6  60                 RTS
C1C7  00 00       TX     .WOR 0
C1C9              ;
C1C9              ;DISABLE KERNAL AND IRQ
C1C9              ;
C1C9  78          KEROUT SEI
C1CA  A5 01              LDA $01
C1CC  29 FD              AND #$FD        ;SWITCH OUT
C1CE  85 01              STA $01
C1D0  60                 RTS
C1D1              ;
C1D1              ;ENABLE KERNAL AND IRQ
C1D1              ;
C1D1  48          KERIN  PHA
C1D2  A5 01              LDA $01
C1D4  09 02              ORA #$02        ;SWITCH IN
C1D6  85 01              STA $01
C1D8  58                 CLI
C1D9  68                 PLA
C1DA  60                 RTS
C1DB              .END
```

```
LOC   CODE        LINE

C1DB              .LIB   MODE.SIMPLE
C1DB              ;
C1DB              ; ROUTINE TO SET UP HIRES SCREEN
C1DB              ;
C1DB  20 03 C2          JSR CLRMEM      ; CLEAR HIRES SCREEN
C1DE  20 6A C2          JSR CLRSCN      ; CLEAR VIDEO SCREEN
C1E1              ;
C1E1              ;GRAPH COMMAND ENTRY
C1E1              ;
C1E1  A9 3B       GRAPH LDA #$3B
C1E3  8D 11 D0          STA $D011       ; SELECT BIT MAP MODE
C1E6  A9 3D             LDA #$3D
C1E8  8D 18 D0          STA $D018       ; CHOOSE HIRES SCREEN
C1EB  A9 C8             LDA #$C8
C1ED  8D 16 D0          STA $D016       ; ELSE SET HIRES MODE
C1F0  AD 02 DD    DONE  LDA $DD02       ; SELECT BANK 2 FOR HIRES
C1F3  09 03             ORA #$03        ; SCREEN
C1F5  8D 02 DD          STA $DD02
C1F8  AD 00 DD          LDA $DD00
C1FB  29 FC             AND #$FC
C1FD  09 00             ORA #$00
C1FF  8D 00 DD          STA $DD00
C202  60                RTS
C203              ;
C203              ;CLG COMMAND ENTRY
C203              ;
C203  A0 00       CLRMEM LDY #$00       ; LOOP TO CLEAR HIRES
C205  98                TYA
C206  99 00 E0    LOOP  STA $E000,Y
C209  99 00 E1          STA $E100,Y
C20C  99 00 E2          STA $E200,Y
C20F  99 00 E3          STA $E300,Y
C212  99 00 E4          STA $E400,Y
C215  99 00 E5          STA $E500,Y
C218  99 00 E6          STA $E600,Y
C21B  99 00 E7          STA $E700,Y
C21E  99 00 E8          STA $E800,Y
C221  99 00 E9          STA $E900,Y
C224  99 00 EA          STA $EA00,Y
C227  99 00 EB          STA $EB00,Y
C22A  99 00 EC          STA $EC00,Y
C22D  99 00 ED          STA $ED00,Y
C230  99 00 EE          STA $EE00,Y
C233  99 00 EF          STA $EF00,Y
C236  99 00 F0          STA $F000,Y
C239  99 00 F1          STA $F100,Y
C23C  99 00 F2          STA $F200,Y
C23F  99 00 F3          STA $F300,Y
C242  99 00 F4          STA $F400,Y
C245  99 00 F5          STA $F500,Y
C248  99 00 F6          STA $F600,Y
C24B  99 00 F7          STA $F700,Y
C24E  99 00 F8          STA $F800,Y
C251  99 00 F9          STA $F900,Y
C254  99 00 FA          STA $FA00,Y
C257  99 00 FB          STA $FB00,Y
C25A  99 00 FC          STA $FC00,Y
C25D  99 00 FD          STA $FD00,Y
C260  99 00 FE          STA $FE00,Y
C263  99 F9 FE          STA $FEF9,Y
C266  88                DEY
C267  D0 9D             BNE LOOP
C269  60                RTS
C26A  A0 00       CLRSCN LDY #$00       ; LOOP TO CLEAR
C26C  A9 1B             LDA #$1B
C26E  99 00 CC    LOOP1 STA $CC00,Y
C271  99 00 CD          STA $CD00,Y
```

```
LOC   CODE        LINE

C274  99 00 CE          STA $CE00,Y
C277  99 00 CF          STA $CF00,Y
C27A  88                DEY
C27B  D0 F1             BNE LOOP1
C27D  60                RTS
C27E              .END
C27E              .LIB  NORM.SIMPLE
C27E              ;
C27E              ; ROUTINE TO RETURN TO NORMAL SCREEN
C27E              ;
C27E  AD 02 DD    NORM  LDA $DD02
C281  29 FC             AND #$FC
C283  8D 02 DD          STA $DD02       ; BACK TO BANK 0
C286  A9 1B             LDA #$1B
C288  8D 11 D0          STA $D011       ; BIT MAP MODE OFF
C28B  A9 15             LDA #$15
C28D  8D 18 D0          STA $D018       ; NORMAL SCREEN
C290  60                RTS
C291              .END
```

Program 14.

Another application for D to A converters involves using two converters, the output of each being connected to the X and Y inputs on an oscilloscope. This configuration can then be used to generate true vector graphics displays; the two D/A converters are switched by using the PA2 line. One of the D/A converters uses only 7 bits with the eighth bit used to control the Z axis or intensity control input on the scope. Alternatively the two D/A converters could be used to control two rotating mirrors for a laser display.

An extension of the waveform generation routine is a music generator. Such a routine is given in Program 15. This is a four voice sophisticated music synthesiser. The program uses four waveform tables, one for each voice. These are shown in Program 16, and their respective waveforms in Fig. 5.13. In addition to the waveform tables it also requires a score table; a sample score table is given in Program 17. It is divided into two sections; the main control table and the music table. It is in two sections for several reasons, the principal one being to allow it to be stored more compactly. The score is compacted by having sections of the score which are identical stored only once and then repeatedly called by the main control table. The control loop also allows the tempo and waveforms of each voice to be changed. This system may seem fairly complex but examination of Program 17 will show that it is fairly straightforward. This program is based on an original idea by Hal Chamberlin in his book *Musical Applications of Microprocessors* published by Hayden Books. These are the command codes used in the control and music tables:

Main control table commands

If byte is FF this specifies that the following byte contains a control code

If followed by Ø1 then the next byte contains tempo

If followed by Ø2 then the next four bytes specify the waveform for each voice, each byte being the msb of the start of the specified waveform table

If byte is not FF then each pair of bytes specify the hi, lo address of a pointer into the start of a section of the music table.

```
LOC   CODE        LINE

0000              USRPRT =$DD01          ;OUTPUT PORT
0000              DDR    =$DD03          ;DATA DIRECTION
0000              V1PT   =$40            ;FOUR VOICE WAVEFORM
0000              V2PT   =$45            ; POINTERS
0000              V3PT   =$48
0000              V4PT   =$4B
0000              INCPT  =$4E
0000              NOTES  =$50            ;POINTER TO MUSIC
0000              V1IN   =$52            ;FOUR VOICE INCREMENT
0000              V2IN   =$54            ; POINTERS
0000              V3IN   =$56
0000              V4IN   =$58
0000              DUR    =$5A            ;DURATION COUNTER
0000              INCA   =$5D            ;INITIAL INCPT
0000              TEMPO  =$5F            ;TEMPO VALUE
0000              *      =$0801
0801  0C 08               .WOR END        ;NEXT LINE POINTER
0803  0A 00               .WOR 10         ;LINE NUMBER 10
0805  9E                  .BYT $9E,'02062',0 ;SYS02062
0806  30 32
0808  00
080C  00 00       END     .WOR 0          ;END OF BASIC
080E              ;
080E              ;ENTRY
080E              ;
080E  78                  SEI             ;DISABLE IRQ
080F  A9 0B               LDA #$0B        ;DISABLE SCREEN DMA
0811  8D 11 D0            STA $D011
0814  D8                  CLD             ;DISABLE DECIMAL
0815  A9 0F               LDA #$0F        ;SET SID VOLUME
0817  8D 18 D4            STA $D418       ;  TO MAX
081A  A9 FF               LDA #$FF        ;SET USER PORT
081C  8D 03 DD            STA DDR         ;TO OUTPUT
081F  A2 00               LDX #$00
0821  B5 00       STORE   LDA $0000,X     ;SAVE OFF ZERO
0823  9D 00 C0            STA $C000,X     ;PAGE
0826  E8                  INX
0827  D0 F8               BNE STORE
0829  A2 00               LDX #$00        ;SET UP INCA TO
082B  A0 52               LDY #$52        ; POINT TO V1IN
082D  86 5E               STX INCA+1
082F  84 5D               STY INCA
0831  A0 0F               LDY #$0F        ;CONTROL TABLE STARTS
0833  86 FB               STX $FB
0835  84 FC               STY $FC
0837  86 41               STX V1PT+1      ;ZERO WAVEFORM
0839  86 46               STX V2PT+1      ; HIGH BYTES
083B  86 49               STX V3PT+1
083D  86 4C               STX V4PT+1
083F  86 4F               STX INCPT+1
0841  A0 00               LDY #$00
0843  B1 FB       LOOP    LDA ($FB),Y     ;GET CONTROL CODE
0845  C9 FF               CMP #$FF        ;PLAY CONTROL?
0847  F0 25               BEQ CNTROL      ;YES
0849  AA                  TAX             ;STORE AS HIGH BYTE
084A  C8                  INY             ; FOR MUSIC
084B  98                  TYA
084C  48                  PHA
084D  B1 FB               LDA ($FB),Y     ;GET LOW BYTE
084F  A8                  TAY
0850  20 98 08            JSR MUSIC       ;PLAY THE PIECE
0853  68                  PLA
0854  A8                  TAY
0855  C8         NEXT    INY             ;REPEAT UNTIL MUSIC
0856  D0 EB               BNE LOOP        ; COMPLETE
0858  A2 00       EXIT    LDX #$00
085A  BD 00 C0     RESTRE LDA $C000,X     ;COPY BACK TO
```

```
LOC   CODE        LINE

085D  95 00             STA $0000,X     ; ZERO PAGE
085F  E8                INX
0860  D0 F8             BNE RESTRE
0862  A9 00             LDA #$00        ;NO SID VOLUME
0864  8D 18 D4          STA $D418
0867  A9 1B             LDA #$1B        ;RESTORE SCREEN
0869  8D 11 D0          STA $D011
086C  58                CLI             ;START IRQ
086D  60                RTS             ;FINISHED
086E                ;
086E  C8          CNTROL INY            ;GET CONTROL NUMBER
086F  B1 FB             LDA ($FB),Y
0871  30 E5             BMI EXIT        ;END OF MUSIC
0873  C9 01             CMP #$01        ;IS VALUE 1?
0875  D0 07             BNE CONTR1      ;NO
0877  C8                INY
0878  B1 FB             LDA ($FB),Y     ;GET TEMPO
087A  85 5F             STA TEMPO
087C  D0 D7             BNE NEXT        ;TRY AGAIN
087E  C9 02       CONTR1 CMP #$02       ;IS CONTROL 2?
0880  D0 D6             BNE EXIT        ;NO EXIT PROG
0882  C8                INY
0883  B1 FB             LDA ($FB),Y     ;GET HI BYTE FOR
0885  85 42             STA V1PT+2      ; THE WAVEFORM
0887  C8                INY             ; POINTERS OF THE
0888  B1 FB             LDA ($FB),Y     ; FOUR VOICES
088A  85 47             STA V2PT+2
088C  C8                INY
088D  B1 FB             LDA ($FB),Y
088F  85 4A             STA V3PT+2
0891  C8                INY
0892  B1 FB             LDA ($FB),Y
0894  85 4D             STA V4PT+2
0896  D0 BD             BNE NEXT
0898                ;
0898  86 51       MUSIC  STX NOTES+1    ;STORE MUSIC TABLE
089A  84 50              STY NOTES      ; POINTERS
089C  A0 00       MUSIC1 LDY #$00       ;SET UP TO
089E  A5 5D              LDA INCA       ; TRANSLATE FOUR
08A0  85 4E              STA INCPT      ; VOICES INTO INCREMENTS
08A2  A9 7F              LDA #$7F       ;SET TO READ CONTROL
08A4  8D 00 DC           STA $DC00      ; KEY
08A7  AD 01 DC           LDA $DC01      ;GET ANY KEYS
08AA  C9 7F              CMP #$7F       ;STOP KEY?
08AC  D0 06              BNE MUSIC9     ;NO
08AE  68                 PLA            ;CLEAN UP STACK
08AF  68                 PLA
08B0  68                 PLA
08B1  4C 58 08           JMP EXIT       ;EXIT ROUTINE
08B4                ;
08B4  B1 50       MUSIC9 LDA (NOTES),Y  ;GET DURATION
08B6  F0 3E              BEQ ENDSNG     ;IF ZERO EXIT PHRASE
08B8  C9 01              CMP #$01       ;IF 1 GET NEXT SEGMENT
08BA  F0 2B              BEQ NXTSEG     ; OF PHRASE
08BC  85 5A              STA DUR        ;IS DURATION
08BE  E6 50       MUSIC2 INC NOTES      ;INCREMENT MUSIC
08C0  D0 02              BNE MUSIC3     ; POINTER
08C2  E6 51              INC NOTES+1
08C4  B1 50       MUSIC3 LDA (NOTES),Y  ;READ IN FOUR
08C6  AA                 TAX            ; VOICES AND STORE
08C7  BD 01 0A           LDA FRQTAB,X   ; IN VOICE INCREMENT
08CA  91 4E              STA (INCPT),Y  ; LOCATIONS
08CC  E6 4E              INC INCPT
08CE  BD 00 0A           LDA FRQTAB-1,X
08D1  91 4E              STA (INCPT),Y
08D3  E6 50              INC NOTES
08D5  D0 02              BNE MUSIC4
```

```
LOC   CODE        LINE

08D7  E6 51             INC NOTES+1
08D9  E6 4E       MUSIC4 INC INCPT       ;REPEAT FOR
08DB  A5 4E             LDA INCPT        ; OTHER VOICES
08DD  C9 5A             CMP #V4IN+2
08DF  D0 E3             BNE MUSIC3
08E1  20 F7 08          JSR PLAY         ;PLAY THE NOTES
08E4  4C 9C 08          JMP MUSIC1       ;DO NEXT LINE
08E7                    ;
08E7  C8          NXTSEG INY             ;GET POINTER TO
08E8  B1 50             LDA (NOTES),Y    ; NEW SEGMENT OF
08EA  48                PHA              ; MUSIC
08EB  C8                INY
08EC  B1 50             LDA (NOTES),Y
08EE  85 51             STA NOTES+1
08F0  68                PLA
08F1  85 50             STA NOTES
08F3  4C 9C 08          JMP MUSIC1
08F6                    ;
08F6  60          ENDSNG RTS             ;RETURN TO CONTROL LOOP
08F7                    ;
08F7  A0 00       PLAY   LDY #$00        ;PLAY THE NOTES
08F9  A6 5F             LDX TEMPO
08FB                    ;
08FB  18          PLAY1  CLC
08FC  B1 41             LDA (V1PT+1),Y   ;SUM WAVEFORMS OF
08FE  71 46             ADC (V2PT+1),Y   ; FOUR VOICES FOR
0900  71 49             ADC (V3PT+1),Y   ; OUTPUT
0902  71 4C             ADC (V4PT+1),Y
0904  8D 01 DD          STA USRPRT       ;OUTPUT VALUE
0907  A5 40             LDA V1PT         ;ADD INCREMENTS
0909  65 52             ADC V1IN         ; TO THE FOUR WAVE-
090B  85 40             STA V1PT         ; FORM TABLE POINTERS
090D  A5 41             LDA V1PT+1       ; VOICE 1
090F  65 53             ADC V1IN+1
0911  85 41             STA V1PT+1
0913  A5 45             LDA V2PT         ;       2
0915  65 54             ADC V2IN
0917  85 45             STA V2PT
0919  A5 46             LDA V2PT+1
091B  65 55             ADC V2IN+1
091D  85 46             STA V2PT+1
091F  A5 48             LDA V3PT         ;       3
0921  65 56             ADC V3IN
0923  85 48             STA V3PT
0925  A5 49             LDA V3PT+1
0927  65 57             ADC V3IN+1
0929  85 49             STA V3PT+1
092B  A5 4B             LDA V4PT         ;       4
092D  65 58             ADC V4IN
092F  85 4B             STA V4PT
0931  A5 4C             LDA V4PT+1
0933  65 59             ADC V4IN+1
0935  85 4C             STA V4PT+1
0937  CA                DEX
0938  D0 08             BNE TIMWAS       ;WASTE TIME
093A  C6 5A             DEC DUR          ;DECREMENT DURATION
093C  F0 0C             BEQ ENDNOT       ;IF DUR=0 THEN DO NEXT LINE
093E  A6 5F             LDX TEMPO
0940  D0 B9             BNE PLAY1
0942  D0 00       TIMWAS BNE *+2         ;WASTE A BIT OF
0944  D0 00             BNE *+2          ; TIME
0946  D0 00             BNE *+2
0948  D0 B1             BNE PLAY1
094A  60          ENDNOT RTS
094B                    ;
094B              FRQTAB =$0A01
094B                    .END
```

Symbol table

```
SYMBOL VALUE
 CNTROL   086E    CONTR1   087E    DDR      DD03    DUR      005A
 END      080C    ENDNOT   094A    ENDSNG   08F6    EXIT     0858
 FRQTAB   0A01    INCA     005D    INCPT    004E    LOOP     0843
 MUSIC    0898    MUSIC1   089C    MUSIC2   08BE    MUSIC3   08C4
 MUSIC4   08D9    MUSIC9   08B4    NEXT     0855    NOTES    0050
 NXTSEG   08E7    PLAY     08F7    PLAY1    08FB    RESTRE   085A
 STORE    0821    TEMPO    005F    TIMWAS   0942    USRPRT   DD01
 V1IN     0052    V1PT     0040    V2IN     0054    V2PT     0045
 V3IN     0056    V3PT     0048    V4IN     0058    V4PT     004B
```

Program 15.

Music data frequency tables

Bass frequency table

Hi-lo ØA7C to ØA93

```
.:0A00 00 00 01 E9 02 06 02 25'.......%
.:0A08 02 45 02 68 02 8C 02 B3'.E.....┤
.:0A10 02 DC 03 08 03 36 03 67'.▪...6..
.:0A18 03 9A 03 D1 04 0B 04 49'...◙...I
.:0A20 04 8A 04 CF 05 19 05 66'...┌....
.:0A28 05 B8 06 0F 06 6C 06 CD'.═.....\
.:0A30 07 35 07 A3 08 17 08 92'.5.¯....
.:0A38 09 15 09 9F 0A 31 0A CC'.....1.└
.:0A40 0B 71 0C 1F 0C D7 0D 98'.....o..
.:0A48 0E 6A 0F 45 10 2E 11 24'...E...$
.:0A50 12 29 13 3E 14 62 15 99'.).>....
.:0A58 16 E2 18 3E 19 AF 1B 36'...>.▬.6
.:0A60 1C D4 1E 8B 20 5C 22 48'.╘.. \"H
.:0A68 24 52 26 7B 28 C5 2B 31'$R&.(¯+1
.:0A70 2D C3 30 7C 33 5E 36 6C'-¬0.3↑6.
.:0A78 39 A8 3D 15 00 F4 01 03'9¨=.....
.:0A80 01 12 01 23 01 34 01 46'...#.4.F
.:0A88 01 5A 01 6D 01 84 01 9B'.Z.....
.:0A90 01 B3 01 CD 00 00 00 00'.┤.\....
```

Wraparound waveform table no 1

```
.:0B00 33 34 35 36 36 37 38 39'34566789
.:0B08 39 3A 3A 3B 3B 3B 3C 3C'9:::;;;<<
.:0B10 3C 3C 3C 3C 3C 3C 3C 3C'<<<<<<<<
.:0B18 3C 3C 3C 3B 3B 3B 3B 3B'<<<;;;;;
.:0B20 3A 3A 3A 3A 3A 3A 39 39'::::::99
.:0B28 39 39 39 39 39 39 39 39'99999999
.:0B30 3A 3A 3A 3A 3A 3B 3B 3B':::::;;;
.:0B38 3B 3C 3C 3C 3D 3D 3D 3D';<<<====
.:0B40 3E 3E 3E 3E 3F 3F 3F 3F'>>>>????
.:0B48 3F 3F 3F 3F 3F 3F 3F 3F'????????
.:0B50 3E 3E 3E 3D 3D 3C 3C 3B'>>>==<<;
.:0B58 3B 3A 39 38 38 37 36 35';:988765
.:0B60 34 33 32 31 30 2F 2E 2D'43210/.-
.:0B68 2C 2B 2A 29 28 27 26 25',+*)('&%
.:0B70 24 23 22 21 21 20 1F 1F'$#"!! ..
.:0B78 1E 1E 1D 1D 1D 1D 1C 1C'........
.:0B80 1C 1C 1D 1D 1D 1D 1D 1E'........
.:0B88 1E 1F 1F 20 20 21 21 22'...  !!"
.:0B90 23 23 24 24 25 26 26 27'##$$%&&'
.:0B98 28 28 29 29 29 2A 2A 2B'(())))**+
.:0BA0 2B 2B 2B 2B 2B 2B 2B 2A'+++++++*
.:0BA8 2A 2A 29 29 28 27 27 26'**))('&
.:0BB0 25 24 23 22 21 20 1F 1D'%$#"! ..
.:0BB8 1C 1B 19 18 17 15 14 13'........
.:0BC0 11 10 0F 0D 0C 0B 09 08'........
.:0BC8 07 06 05 04 03 03 02 01'........
.:0BD0 01 00 00 00 00 00 00 00'........
.:0BD8 00 00 01 01 01 02 03 04'........
.:0BE0 05 06 07 08 09 0B 0C 0D'........
.:0BE8 0F 10 12 13 15 16 18 1A'........
.:0BF0 1B 1D 1F 20 22 23 25 27'... "#%'
.:0BF8 28 2A 2B 2C 2E 2F 30 31'(*+,./01
```

Wraparound waveform table no 2

```
.:0C00 22 22 22 22 22 22 22 22'"""""""" 
.:0C08 22 21 20 20 1F 1F 1E 1D'"!  .... 
.:0C10 1D 1C 1C 1C 1C 1C 1B 1B'........ 
.:0C18 1B 1C 1C 1C 1D 1D 1E 1F'........ 
.:0C20 1F 20 20 21 21 22 25 25'.  !!"%% 
.:0C28 26 26 26 27 28 28 29 2A'&&&'(()* 
.:0C30 2A 2A 2C 2C 2E 2F 30 32'**,,./02 
.:0C38 32 34 34 37 38 39 3A 3A'244789:: 
.:0C40 3B 3C 3C 3D 3D 3D 3C 3C';<<===<< 
.:0C48 3B 3A 39 38 35 34 32 30';:985420 
.:0C50 2E 2B 29 27 25 21 20 1E'.+)'%! . 
.:0C58 1D 1C 1B 19 19 18 18 18'........ 
.:0C60 18 19 19 1B 1C 1D 1E 1F'........ 
.:0C68 20 21 22 22 25 25 26 26' !""%%&& 
.:0C70 26 26 25 25 25 22 21 21'&&%%%"!! 
.:0C78 20 1F 1E 1D 1C 1C 1B 19' ....... 
.:0C80 19 19 18 18 18 18 18 19'........ 
.:0C88 19 19 1B 1C 1C 1D 1E 1E'........ 
.:0C90 1E 1F 1F 20 20 20 20 20'...      
.:0C98 20 1F 1F 1F 1E 1E 1E 1D' ....... 
.:0CA0 1C 1C 1B 1B 19 18 18 17'........ 
.:0CA8 17 17 16 15 15 14 14 13'........ 
.:0CB0 13 12 10 0F 0E 0D 0C 0B'........ 
.:0CB8 0A 09 07 06 05 04 03 02'........ 
.:0CC0 01 01 00 00 00 00 00 00'........ 
.:0CC8 01 02 03 05 06 09 0B 0D'........ 
.:0CD0 0E 10 13 15 18 19 1C 1D'........ 
.:0CD8 1E 20 20 21 22 25 22 22'.  !"%"" 
.:0CE0 22 22 21 20 1F 1E 1E 1C'""! .... 
.:0CE8 1C 1B 19 18 17 17 17 17'........ 
.:0CF0 16 16 17 18 18 18 19 1B'........ 
.:0CF8 1B 1D 1D 1E 1F 20 21 21'..... !! 
```

Wraparound waveform table no 3

```
.:0D00 20 20 20 21 21 21 21 21'   !!!!! 
.:0D08 21 20 20 1F 1F 1E 1D 1C'!  ..... 
.:0D10 1B 1A 1A 19 18 18 17 17'........ 
.:0D18 17 17 18 19 1A 1B 1C 1E'........ 
.:0D20 1F 21 23 25 27 29 2A 2C'.!#%')*, 
.:0D28 2D 2E 2F 2F 2F 2F 2E 2D'-./////.- 
.:0D30 2C 2A 28 26 23 20 1E 1B',*(&# .. 
.:0D38 18 15 13 10 0E 0C 0B 0A'........ 
.:0D40 0A 0A 0A 0B 0C 0E 11 13'........ 
.:0D48 16 1A 1D 21 24 28 2B 2F'...!$(+/ 
.:0D50 32 34 37 38 3A 3A 3A 3A'2478:::: 
.:0D58 39 37 35 32 2F 2C 28 24'9752/,($ 
.:0D60 1F 1B 17 13 0F 0C 09 06'........ 
.:0D68 04 03 02 02 02 03 05 07'........ 
.:0D70 0A 0D 11 15 1A 1E 23 27'......#' 
.:0D78 2B 2F 33 36 39 3C 3D 3E'+/369<=> 
.:0D80 3E 3E 3D 3C 39 36 33 2F'>>=<963/ 
.:0D88 2B 27 23 1E 1A 15 11 0D'+'#..... 
.:0D90 0A 07 05 03 02 02 02 03'........ 
.:0D98 04 06 09 0C 0F 13 17 1B'........ 
.:0DA0 1F 24 28 2C 2F 32 35 37'.$(,/257 
.:0DA8 39 3A 3A 3A 3A 38 37 34'9::::874 
.:0DB0 32 2F 2B 28 24 21 1D 1A'2/+($!.. 
.:0DB8 16 13 11 0E 0C 0B 0A 0A'........ 
.:0DC0 0A 0A 0B 0C 0E 10 13 15'........ 
.:0DC8 18 1B 1E 20 23 26 28 2A'... #&(* 
.:0DD0 2C 2D 2E 2F 2F 2F 2F 2E',-./////. 
.:0DD8 2D 2C 2A 29 27 25 23 21'-,*)'%#! 
.:0DE0 1F 1E 1C 1B 1A 19 18 17'........ 
.:0DE8 17 17 17 18 18 19 1A 1A'........ 
.:0DF0 1B 1C 1D 1E 1F 1F 20 20'......   
.:0DF8 21 21 21 21 21 21 20 20'!!!!!!  
```

Wraparound waveform table no 4

```
.:0E00 20 20 20 20 20 20 20 20'
.:0E08 21 21 21 22 22 22 23 23'!!!"""##
.:0E10 24 25 25 26 26 27 28 28'$%%&&'((
.:0E18 29 2A 2B 2B 2C 2D 2E 2E')*++,-..
.:0E20 2F 30 31 32 32 33 34 34'/0122344
.:0E28 35 36 36 37 37 38 38 38'56677888
.:0E30 38 38 38 38 38 38 38 37'88888887
.:0E38 37 36 35 34 33 32 31 2F'7654321/
.:0E40 2E 2D 2B 29 27 26 24 22'.-+)'&$"
.:0E48 20 1E 1C 1A 18 16 15 13' .......
.:0E50 12 10 0F 0E 0D 0C 0C 0B'........
.:0E58 0B 0B 0C 0C 0D 0E 0F 11'........
.:0E60 13 14 16 18 1B 1D 1F 21'.......!
.:0E68 24 26 28 2A 2C 2D 2F 30'$&(*,-/0
.:0E70 30 31 31 31 30 2F 2E 2D'01110/.-
.:0E78 2B 29 27 24 22 20 1D 1B'+)'$" ..
.:0E80 19 17 15 13 12 11 11 11'........
.:0E88 11 12 13 14 16 18 1A 1C'........
.:0E90 1E 21 23 25 27 29 2A 2B'.!#%')*+
.:0E98 2C 2C 2C 2B 2A 29 27 25',,,+*)'%
.:0EA0 23 21 1E 1C 1A 18 17 16'#!......
.:0EA8 15 15 15 16 17 18 1A 1C'........
.:0EB0 1E 20 22 24 25 27 28 28'. "$%'((
.:0EB8 28 28 27 26 25 23 21 20'((&%#!
.:0EC0 1E 1C 1B 1A 19 18 18 19'........
.:0EC8 1A 1B 1C 1D 1F 21 22 23'.....!"#
.:0ED0 24 25 25 25 25 24 23 22'$%%%%$#"
.:0ED8 20 1F 1E 1D 1C 1B 1B 1B' .......
.:0EE0 1C 1C 1D 1E 1F 20 21 22'..... !"
.:0EE8 22 22 22 22 22 21 21 20'"""""!!
.:0EF0 1F 1F 1E 1E 1E 1E 1E 1E'........
.:0EF8 1F 1F 1F 20 20 20 20 20'...
```

Program 16.

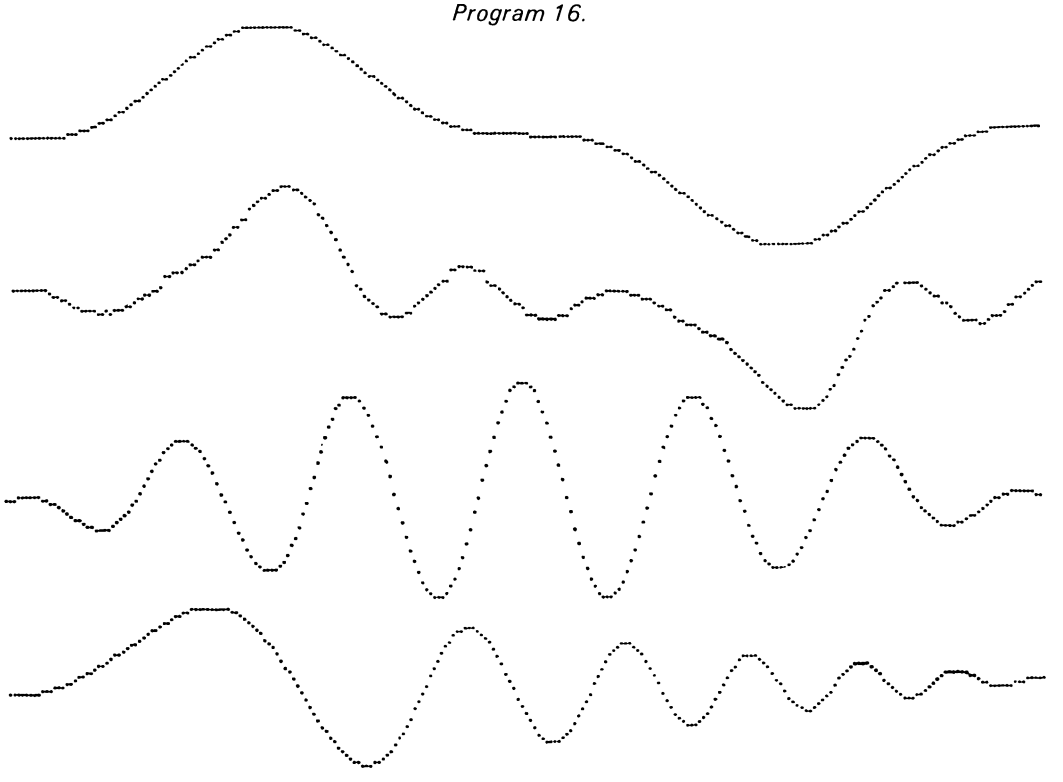


Fig. 5.13. Sample voice waveforms for music synthesis program.

Main control table
FF specifies control code
Followed by 1 = tempo as next byte
Followed by 2 = next 4 bytes are waveform table pointers
If not FF then hi-lo of pointer to following score table

```
.:0F00 FF 01 30 FF 02 0E 0E 0E'..0.....
.:0F08 0E 10 00 10 1A 10 00 10'........
.:0F10 1A 10 00 10 00 10 00 10'........
.:0F18 1A FF 02 0B 0C 0D 0E 10'........
.:0F20 20 10 8F 11 80 11 95 11' .......
.:0F28 AA 10 8F 11 E7 11 95 11'.......
.:0F30 FC 12 4D 13 1B 12 4D 13'..M...M.
.:0F38 94 10 8F 11 E7 11 95 14'........
.:0F40 AD 11 BE 10 8F 11 80 11'.......
.:0F48 95 14 AD 12 10 14 C2 10'.......
.:0F50 8F 11 80 11 95 16 71 16'......q.
.:0F58 DB 10 9E 11 80 11 95 16'+.......
.:0F60 71 16 FF FF FF 00 00 00'q.......
```

Music table
In groups of 5
Duration and 4 notes, 1 per voice
$\phi\phi$ = return to main control loop
$\phi 1$ = read next 2 bytes as pointer into this table lo-hi

```
.:1000 09 80 80 80 06 09 80 80'........
.:1008 84 0A 09 80 80 88 0E 25'.......%
.:1010 80 80 8A 10 20 00 00 00'.... ...
.:1018 00 00 60 00 00 00 00 00'..`.....
.:1020 34 48 30 22 10 0C 00 00'4H0"....
.:1028 00 00 14 4A 32 2C 14 0C'...J2,..
.:1030 00 00 00 00 34 4E 36 30'....4N60
.:1038 18 0C 00 00 00 00 14 52'.......R
.:1040 3A 32 1A 0C 00 00 00 00':2......
.:1048 34 54 3C 36 1E 0C 00 00'4T<6....
.:1050 00 00 14 52 3A 32 1A 0C'...R:2..
.:1058 00 00 00 00 34 4E 36 30'....4N60
.:1060 18 0C 00 00 00 00 14 4A'.......J
.:1068 32 2C 14 0C 00 00 00 00'2,......
.:1070 34 48 30 28 10 3C 00 00'4H0(.<..
.:1078 00 00 40 58 54 4E 48 20'..@XTNH
.:1080 00 00 00 00 40 00 00 10'....@...
.:1088 8A 20 00 00 00 00 00 20'. .....
.:1090 40 28 00 00 20 44 2C 00'@(.. D,.
.:1098 00 20 48 30 00 00 40 4A'. H0..@J
.:10A0 00 32 02 20 4A 40 3A 02'.2. J@:.
.:10A8 40 40 00 00 0A 20 40 3A'@@... @:
.:10B0 32 10 20 3A 00 22 1A 20'2. :."..
.:10B8 3A 00 22 00 20 3A 32 28':."..:2(
.:10C0 00 40 36 2C 26 08 20 32'.@6,&. 2
.:10C8 2C 26 08 40 30 24 00 06',&.@0$..
.:10D0 20 44 00 00 00 40 40 3A' D...@@:
.:10D8 2E 04 20 40 3C 30 06 20'.. @<0.
.:10E0 40 00 10 8A 20 40 28 00'@... @(.
.:10E8 00 20 44 2C 00 00 20 48'. D,.. H
.:10F0 30 00 00 20 4A 32 00 00'0.. J2..
.:10F8 20 4C 34 00 00 40 4E 36' L4..@N6
.:1100 00 10 20 4E 3C 40 10 40'.. N<@.@
.:1108 48 00 00 1E 20 48 3C 40'H... H<@
.:1110 1E 40 40 28 00 18 20 40'.@@(.. @
.:1118 3C 36 18 40 3C 30 28 10'<6.@<0(.
.:1120 20 36 30 28 10 40 32 00' 60(.@2.
```

```
.:1128 00 1A 20 32 28 22 1A 40',, 2("@
.:1130 32 00 00 14 20 32 28 22'2... 2("
.:1138 14 20 32 00 00 10 20 40'. 2... @
.:1140 28 00 10 20 44 2C 00 10'(.. D...
.:1148 20 48 30 00 0A 20 4A 32' H0.. J2
.:1150 00 0A 20 4E 36 00 0A 40'.. N6..@
.:1158 52 00 00 02 20 52 4A 40'R... RJ@
.:1160 02 40 4A 00 00 0A 20 4A'.@J... J
.:1168 40 3A 10 40 40 00 00 16'@:.@@...
.:1170 20 40 3A 32 16 40 3A 32' @:2.@:2
.:1178 28 16 20 32 32 28 16 00'(. 22(..
.:1180 40 3C 32 24 14 20 40 00'@<2$. @.
.:1188 28 14 40 44 00 2C 0C 20'(.@D.,.
.:1190 48 00 30 0A 00 40 4A 00'H.0..@J.
.:1198 32 06 20 4A 44 3E 06 40'2. JD>.@
.:11A0 48 00 30 06 20 44 3E 2C'H.0. D>,
.:11A8 06 00 40 40 28 10 8A 20'..@@(..
.:11B0 40 36 30 28 40 40 28 00'@60(@@(.
.:11B8 06 20 48 36 00 00 40 4E'. H6..@N
.:11C0 3E 14 8E 20 4E 3E 00 00'>.. N>..
.:11C8 40 4A 3E 36 06 20 44 3E'@J>6. D>
.:11D0 36 00 60 4E 40 36 18 60'6..N@6..
.:11D8 4E 3E 32 14 40 4E 3C 30'N>2.@N<0
.:11E0 10 20 00 00 00 00 00 40'. .....@
.:11E8 3C 00 24 14 20 3C 32 2C'<.$. <2,
.:11F0 14 40 44 00 2C 0C 20 44'.@D.,. D
.:11F8 32 2C 0A 00 40 40 00 28'2,..@@.(
.:1200 10 20 40 3C 30 28 40 40'. @<0(@@
.:1208 00 28 06 20 48 00 30 00'.(. H.0.
.:1210 40 4E 3C 36 10 20 4E 3C'@N<6. N<
.:1218 36 00 40 4A 3C 32 10 20'6.@J<2.
.:1220 48 3C 30 00 20 4A 40 3A'H<0. J@:
.:1228 1A 20 4A 40 3A 14 20 4A'. J@:. J
.:1230 40 3A 10 20 4A 40 3A 0C'@:. J@:.
.:1238 20 4A 40 3A 0A 20 4A 40' J@:. J@
.:1240 3A 06 40 4A 40 3A 02 20':.@J@:.
.:1248 00 00 00 00 00 34 32 00'.....42.
.:1250 00 1A 0C 00 00 00 00 20'.......
.:1258 32 00 00 1A 40 44 2C 24'2...@D,$
.:1260 0C 20 44 2C 24 1A 40 42'. D,$.@B
.:1268 2A 22 02 20 44 2C 24 1A'*". D,$.
.:1270 40 4E 2E 1E 0C 20 4E 3E'@N... N>
.:1278 36 1E 40 4A 2C 1E 02 20'6.@J,...
.:1280 44 2C 20 0E 40 46 2E 22'D, .@F."
.:1288 10 20 44 2C 20 00 40 46'. D, .@F
.:1290 2E 22 02 20 46 2E 22 00'." F.".
.:1298 20 46 2E 22 10 20 46 2E' F.". F.
.:12A0 24 10 20 46 2E 28 00 20'$. F.(.
.:12A8 46 2E 22 02 20 46 2E 1E'F.". F..
.:12B0 02 20 46 2E 1A 00 40 46'. F...@F
.:12B8 28 22 1A 20 44 2C 26 02'(". D,&.
.:12C0 60 46 28 1A 02 40 48 2A'.F(..@H*
.:12C8 22 1A 20 46 2E 28 02 60'". F.(..
.:12D0 48 2A 1A 02 40 4A 2C 24'H*..@J,$
.:12D8 0C 20 4A 32 00 1A 40 44'. J2..@D
.:12E0 2C 00 14 20 3C 00 24 0C',.. <.$.
.:12E8 40 32 00 1A 02 20 00 00'@2... ..
.:12F0 00 00 40 40 3A 32 02 20'..@@:2.
.:12F8 00 00 00 00 40 44 24 1A'....@D$.
.:1300 0C 20 44 24 2C 1A 40 42'. D$,.@B
.:1308 2A 22 02 20 44 2C 24 1A'*". D,$.
.:1310 40 4E 2E 1A 0C 20 4E 2E'@N... N.
.:1318 36 1A 00 40 4A 2C 1A 02'6..@J,..
.:1320 20 44 24 2C 1A 40 40 28' D$,.@@(
.:1328 22 1A 20 40 28 22 1A 40'". @(".@
.:1330 4A 32 00 10 20 4A 32 22'J2.. J2"
.:1338 10 20 4A 00 00 0A 20 4A'. J... J
.:1340 00 00 0C 20 4A 28 22 10'... J("
.:1348 40 4A 00 00 02 20 4A 28'@J... J(
.:1350 22 02 40 40 28 24 1E 20'".@@($.
```

```
.:1358 40 28 24 1E 40 4E 36 00'@($.@N6.
.:1360 10 20 4E 28 24 10 20 4E'. N($. N
.:1368 28 00 18 20 4E 28 00 1A'(.. N(..
.:1370 20 4E 28 24 1E 20 48 30' N($. H0
.:1378 24 10 20 44 2C 24 14 20'$. D,$.
.:1380 40 28 24 18 60 4A 28 22'@($..J("
.:1388 1A 60 4E 30 24 10 60 52'..N0$..R
.:1390 3A 28 02 00 40 4A 2C 20':(..@J,
.:1398 08 20 44 24 20 08 40 46'. D$ .@F
.:13A0 24 1E 06 20 46 2E 24 00'$.. F.$.
.:13A8 40 44 2C 24 16 20 46 2E'@D,$. F.
.:13B0 24 00 40 52 3A 2A 18 20'$.@R:*.
.:13B8 52 3A 2A 00 40 4E 36 2A'R:*.@N6*
.:13C0 0A 20 48 30 2A 0A 40 4A'. H0*.@J
.:13C8 32 00 0C 20 4A 32 2C 24'2.. J2,$
.:13D0 40 44 00 2C 02 20 4A 32'@D.,. J2
.:13D8 2C 00 40 46 2E 22 10 20',.@F."..
.:13E0 4A 32 22 00 40 4E 36 22'J2".@N6"
.:13E8 02 20 52 3A 22 00 20 54'. R:". T
.:13F0 3C 32 2C 20 54 32 2C 1E'<2, T2,.
.:13F8 20 54 32 2C 1A 20 54 32' T2,. T2
.:1400 2C 16 20 54 32 2C 14 20',. T2,.
.:1408 54 32 2C 10 20 00 00 00'T2,. ...
.:1410 0C 40 00 00 00 00 14 54'.@.....T
.:1418 4A 44 00 0C 00 00 00 00'JD......
.:1420 14 54 4A 44 00 0C 00 00'.TJD....
.:1428 00 00 14 54 4A 44 00 0C'...TJD..
.:1430 00 00 00 00 20 54 4A 44'.... TJD
.:1438 00 20 54 4E 44 24 20 54'. TND$ T
.:1440 4A 44 22 34 54 4A 44 20'JD"4TJD
.:1448 0C 00 00 20 08 14 54 4A'... ..TJ
.:1450 44 20 0C 00 00 20 08 20'D ... .
.:1458 56 4A 44 1E 20 56 4A 44'VJD. VJD
.:1460 1A 20 56 4A 44 16 34 56'. VJD.4V
.:1468 4A 44 14 0C 00 00 00 14'JD......
.:1470 14 56 4A 44 14 0C 00 00'.VJD....
.:1478 00 14 20 58 4E 48 10 40'.. XNH.@
.:1480 00 00 00 00 14 00 00 28'.......(
.:1488 10 0C 00 00 00 00 14 00'........
.:1490 00 28 10 0C 00 00 00 00'.(......
.:1498 14 00 00 28 10 0C 00 00'...(....
.:14A0 00 00 20 00 00 28 10 40'.. ..(.@
.:14A8 00 00 00 00 00 40 40 28'.....@@(
.:14B0 10 8A 20 40 36 30 28 40'.. @60(@
.:14B8 48 00 30 06 20 48 40 30'H.0. H@0
.:14C0 00 00 20 38 34 2E 08 20'.. 84..
.:14C8 38 34 2E 0C 20 38 34 2E'84.. 84.
.:14D0 10 40 00 00 00 12 20 38'.@.... 8
.:14D8 32 2A 12 40 00 00 00 08'2*.@....
.:14E0 20 38 32 2A 08 40 00 00' 82*.@..
.:14E8 00 02 20 38 32 2A 02 40'.. 82*.@
.:14F0 01 00 00 90 20 38 32 2A'.... 82*
.:14F8 8C 40 00 00 00 8A 20 38'.@.... 8
.:1500 34 28 0C 40 00 00 00 08'4(.@....
.:1508 20 3C 34 28 08 20 38 34' <4(. 84
.:1510 28 08 14 00 00 00 08 0C'(.......
.:1518 00 00 00 00 14 00 00 00'........
.:1520 0C 0C 00 00 00 00 14 00'........
.:1528 00 00 10 0C 00 00 00 00'........
.:1530 14 00 00 00 12 0C 00 00'........
.:1538 00 00 14 00 00 00 14 0C'........
.:1540 00 00 00 00 00 40 00 00'.....@...
.:1548 16 20 38 34 2E 16 40 00'. 84..@.
.:1550 00 00 10 20 38 34 2E 10'... 84..
.:1558 40 00 00 00 08 20 38 34'@.... 84
.:1560 2E 08 40 00 00 00 04 20'..@.... 
.:1568 38 34 2E 90 40 00 00 00'84..@...
.:1570 8C 20 38 32 2A 8C 14 3C'. 82*..<
.:1578 32 2A 8C 0C 00 00 00 8C'2*......
.:1580 14 00 32 2A 8C 0C 00 00'..2*....
```

```
.:1588 00 8C 14 3C 32 2A 8C 0C'...<2*..
.:1590 00 00 00 8C 20 38 32 2A'.... 82*
.:1598 8C 14 38 32 2A 08 0C 38'..82*..8
.:15A0 32 2A 00 14 38 32 2A 0C'2*..82*.
.:15A8 0C 38 32 2A 00 14 00 00'.82*....
.:15B0 00 10 0C 00 00 00 00 14'........
.:15B8 00 00 00 12 0C 00 00 00'........
.:15C0 00 14 00 00 00 16 0C 00'........
.:15C8 00 00 00 40 00 00 00 1A'...@....
.:15D0 20 38 32 2A 1A 40 00 00' 82*.@..
.:15D8 00 12 20 38 32 2A 12 40'.. 82*.@
.:15E0 00 00 00 08 20 38 32 2A'.... 82*
.:15E8 08 40 00 00 00 02 20 38'.@.... 8
.:15F0 32 2A 8C 40 00 00 00 04'2*.@....
.:15F8 20 3C 34 2A 04 40 00 00' <4*.@..
.:1600 00 0C 20 3C 34 2A 0C 40'.. <4*.@
.:1608 00 00 00 12 20 3C 34 2A'.... <4*
.:1610 12 40 00 00 00 10 20 3C'.@.... <
.:1618 34 2A 0C 40 00 00 00 08'4*.@....
.:1620 20 38 34 2E 08 40 00 00' 84..@..
.:1628 00 08 20 38 34 2E 10 40'.. 84..@
.:1630 00 00 00 16 20 36 2E 2A'.... 6.*
.:1638 16 40 00 00 00 12 20 36'.@.... 6
.:1640 2E 2A 0C 60 40 38 2E 16'.*..@8..
.:1648 14 46 40 38 08 0C 00 00'.F@8....
.:1650 00 00 14 46 40 38 08 0C'...F@8..
.:1658 00 00 00 00 14 46 40 38'.....F@8
.:1660 08 0C 00 00 00 00 40 48'......@H
.:1668 40 3C 10 20 00 00 00 00'@<. ....
.:1670 00 40 40 00 00 10 20 00'.@@... .
.:1678 00 00 00 40 4A 00 00 1A'...@J...
.:1680 20 00 00 00 00 40 40 00' ....@@.
.:1688 00 10 20 00 00 00 00 40'.. ....@
.:1690 4E 00 00 1E 20 00 00 00'N... ...
.:1698 00 40 40 00 00 10 20 00'.@@... .
.:16A0 00 00 00 40 52 00 00 22'...@R.."
.:16A8 20 00 00 00 00 C0 52 00' ....-R.
.:16B0 00 22 40 40 28 10 8A 20'."@@(.. 
.:16B8 40 36 30 28 40 48 00 30'@60(@H.0
.:16C0 06 20 48 40 36 30 40 4E'. H@60@N
.:16C8 3C 36 10 20 4E 3C 00 00'<6. N<..
.:16D0 40 4A 3C 32 10 20 48 40'@J<2. H@
.:16D8 3C 30 00 60 4A 40 3A 1A'<0.`J@:.
.:16E0 60 44 3E 32 20 40 48 40'`D>2 @H@
.:16E8 3C 1E 20 00 00 00 00 20'<. ....
.:16F0 40 3C 30 10 20 44 3C 30'@<0. D<0
.:16F8 10 20 48 3C 30 10 00 14'. H<0...
.:1700 4A 40 1A 02 0C 40 4A 00'J@...@J.
.:1708 00 14 40 4A 2C 14 0C 40'..@J,...@
.:1710 4A 00 00 14 40 4A 28 10'J...@J(.
.:1718 0C 40 4A 00 00 14 40 4A'.@J...@J
.:1720 24 0C 0C 40 4A 00 20 14'$..@J. .
.:1728 40 4A 22 0A 0C 40 4A 00'@J"..@J.
.:1730 00 14 40 4A 1E 06 0C 40'..@J...@
.:1738 4A 00 00 14 4E 46 1A 02'J...NF..
.:1740 0C 46 4E 00 00 14 46 4E'.FN...FN
.:1748 2C 14 0C 46 4E 00 00 14',..FN...
.:1750 46 4E 28 10 0C 46 4E 00'FN(..FN.
.:1758 00 14 46 4E 24 0C 0C 46'..FN$..F
.:1760 4E 00 00 14 46 4E 22 0A'N...FN".
.:1768 0C 46 4E 00 00 14 46 4E'.FN...FN
.:1770 1E 06 0C 46 4E 00 00 14'...FN...
.:1778 4A 52 1A 02 0C 4A 52 00'JR...JR.
.:1780 00 14 4A 52 2C 14 0C 4A'..JR,..J
.:1788 52 00 00 14 4A 52 28 10'R...JR(.
.:1790 0C 4A 52 00 00 14 4A 52'.JR...JR
.:1798 24 0C 0C 4A 52 00 00 14'$..JR...
.:17A0 4A 52 22 0A 0C 4A 52 00'JR"..JR.
.:17A8 00 14 4A 52 1E 06 0C 4A'..JR...J
.:17B0 52 00 00 14 4E 54 1A 02'R...NT..
```

```
.:17B8 0C 4E 54 00 00 14 4E 54'.NT...NT
.:17C0 2C 14 0C 4E 54 00 00 14',...NT...
.:17C8 4E 54 28 10 0C 4E 54 00'NT(..NT.
.:17D0 00 14 4E 54 24 0C 0C 4E'..NT$..N
.:17D8 54 00 00 14 4E 54 22 0A'T...NT".
.:17E0 0C 4E 54 00 00 14 4E 54'.NT...NT
.:17E8 1E 06 0C 4E 54 00 00 20'...NT..
.:17F0 52 58 1A 02 20 3A 00 00'RX.. :..
.:17F8 0A 20 40 00 00 10 20 4A'. @... J
.:1800 00 00 1A 20 40 00 00 10'... @...
.:1808 20 4A 00 00 1A 20 52 00' J... R.
.:1810 00 22 20 4A 00 00 1A 20'." J...
.:1818 52 00 00 22 20 58 00 00'R.." X..
.:1820 28 20 52 00 00 22 20 58'( R.." X
.:1828 00 00 28 30 62 58 52 32'..(..XR2
.:1830 20 00 00 00 00 20 00 00' .... ..
.:1838 10 3A 40 00 00 00 02 80'..@.....
.:1840 00 00 00 00 00 00 00 00'........
.
```

Program 17.

Music table commands

The bytes in this table are stored in groups of 5 bytes; these are a duration value and a note value for each of the four voices.

If the duration byte contains a ØØ then this specifies the end of the score segment and the program returns to the main control table.

If the duration byte contains a Ø1 then this specifies that the next two bytes contain a pointer to another section of the music table. This address is stored in lo, hi form.

5.12 Analog to digital conversion

The circuit used to convert an analog signal to a digital value is very simple. It involves the use of a voltage comparator IC and a digital to analog converter. The comparator has two inputs; one is the voltage to be measured and the other is a variable reference voltage. The comparator output will go high when the reference voltage is equal to or greater than the voltage being measured. If the reference voltage is generated by a D to A converter then it is a fairly simple matter to vary the converter output until it matches the input voltage. This point is detected by a change in the comparator output. Fig. 5.12 shows such a circuit.

Analog to digital conversion using the circuit in Fig. 5.12 relies heavily on software to find the correct D to A output value. This could be done simply by ramping up the output voltage from zero (using a simple increment loop) until the desired voltage is reached. This, however, would be very slow and could take up to 255 steps to find the match. A quicker technique, known as successive approximation, requires just eight loops. The successive approximation technique starts by setting the most significant bit (bit 8) to 1 and all other bits to zero. It then tests to see if the voltage resulting from this value is greater or smaller than the voltage to be measured. If it is larger then the msb is left set and if smaller then the msb is cleared. The routine then sets bit 7 to 1 leaving bit 8 in the state defined in the previous loop and all less significant bits set to zero. The same test is then performed to discover whether the resulting voltage value is

```
10 REM
20 REM  PROGRAM TO INPUT 10K VALUES
30 REM FROM AN A TO D CONVERTER AND THEN
40 REM DISPLAY 320 VALUES AT A TIME TO
50 REM A GRAPHICS SCREEN
60 REM
70 REM PROTECT MEMORY
80 REM
90 POKE52,120:POKE54,120:POKE56,120:CLR
100 REM
110 REM READ THE VALUES
120 REM
130 POKE 49263,1:SYS49248:REM 49263 IS SAMPLING VALUE
140 REM
150 REM GO INTO GRAPHICS MODE
160 REM
170 SYS49627
180 REM
190 REM LOOP TO DISPLAY 32 SCREENS FULL
200 REM
210 POKE 49197,1:FORI=0TO31:REM 49197 IS SAMPLING VALUE
220 SYS49152,I*320+30720
230 GETA$:IFA$=""THEN230
240 SYS49667:NEXT:SYS49790
```

Program 18.

greater or less than the input voltage to be measured. Depending on the result bit 7 is left set or cleared. This procedure is then repeated for all the other bit positions in the byte, with the result that only eight operations need be performed to obtain the required value. A successive approximation technique is shown in the first part of Program 13.

Program 18 is an example of one of the many applications to which an analog to digital conversion circuit can be applied. This program performs the function of a simple storage oscilloscope. This storage oscilloscope program is very short and written in Basic. It does, however, require that the machine code program in Program 13 is already loaded into memory. The program samples 1Ø24Ø values with a maximum sampling rate of approximately 25ØØ samples per second. This sampling rate can be varied to less than this by changing the contents of location 49263. The input waveform is then displayed in high resolution as 32 screens of information.

5.13 Expansion port

The expansion port is a 44 pin edge connector on the rear of the CBM 64. It gives access to most of the Commodore 64's internal signals. The port is designed to take two main types of device. The first are simple memory mapped devices such as ROMs or I/O chips like a 6526 (if you can get one) or a 6522. The second type of device is more interesting. These are less passive in that they can read or write direct to memory without going through the processor. The most common of these devices is the Commodore Z8Ø card. Using the DMA (direct memory access) line totally disables the 651Ø processor while the card is active.

5.13.1 Pin descriptions

Expansion port

44 pin double sided .1 edge connector socket. Labelled 1–22 (top) and A–Z (G,I,O and Q skipped)

Power connection (power out to boards)

Pins	
1,22,A,Z	Ground Ø V
2,3	+5 volts

Timing signals

Pins	*I/O*	
6	Out	Dot clock 8 MHz approx (varies with TV standard (PAL NTSC ..)
$\phi 2$	Out	$\phi 2$ Phase two clock

Bus control signals

Pins	*I/O*	
12	Out	BA system buses available from VIC chip
13	Input	$\overline{\text{DMA}}$ Direct memory access (gives expansion card control of system buses)
5	Input	R/$\overline{\text{W}}$ Read/write

Interrupts

Pins	*I/O*	
4	Input	$\overline{\text{IRQ}}$ Interrupt request
D	Input	$\overline{\text{NMI}}$ Non maskable interrupt

Memory mapping

Pins	*I/O*	
7	Out	$\overline{\text{I/O1}}$ Address decoded $DEØØ–$DEFF
1Ø	Out	$\overline{\text{I/O2}}$ Address decoded $DFØØ–$DFFF
11	Out	$\overline{\text{ROML}}$ Addr decoded $8ØØØ–$AØØØ
B	Out	$\overline{\text{ROMH}}$ Addr decoded $EØØØ–$FFFF
8	Input	$\overline{\text{GAME}}$ Expansion ROM at $AØØØ–$CØØØ (no Basic ROM)
9	Input	$\overline{\text{EXROM}}$ Exp ROM at $8ØØØ

Reset line

Pins	*I/O*	
C	Both	$\overline{\text{RES}}$ Reset everything

System buses

Pins	*I/O*	
14–21	Both	Data bus consisting of eight unbuffered lines with a maximum load of 1 TTL device. Line 14 is D7 and line 21 is DØ.
F–Y	Both	Address lines; these sixteen lines are unbuffered and have a maximum load of 1 TTL device. Line F is A15 and line Y is AØ.

5.13.2 ROM cartridge

The expansion port is set up to make ROM cartridges a simple direct connection. An expansion ROM for address $8ØØØ using a 2764 (8K by 8) is not too hard if you can obtain or make a board to fit the expansion port edge connector. Just connect the 13 address lines and 8 data lines. Then connect chip

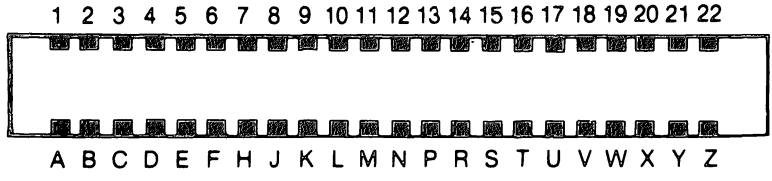
select to LROM and connect the 64's EXROM to ground. The 7464 pins Vpp, Vcc and PGM go to 5 V and Vss goes to ground.

5.13.3 I/O chips on the expansion port

Wiring up a 6526 or 6522 is similar but clock, interrupt and reset also have to be implemented. It is important to connect this type of chip to I/O1 or I/O2 and not to LROM or HROM.

Figure 5.14 shows 2764 and 6522 pin outs and appropriate expansion port connections.

MEMORY EXPANSION



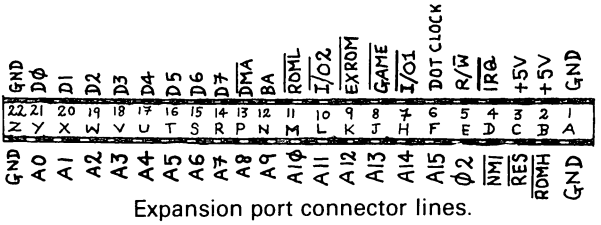
PIN #	TYPE
1	GND
2	+5V
3	+5V
4	$\overline{IRQ}$
5	R/$\overline{W}$
6	DOT CLOCK
7	I/$\overline{\phi 1}$
8	$\overline{GAME}$
9	$\overline{EXROM}$
1ϕ	I/$\overline{\phi 2}$
11	$\overline{ROML}$

PIN #	TYPE
12	$\overline{BA}$
13	$\overline{DMA}$
14	D7
15	D6
16	D5
17	D4
18	D3
19	D2
2ϕ	D1
21	Dϕ
22	GND

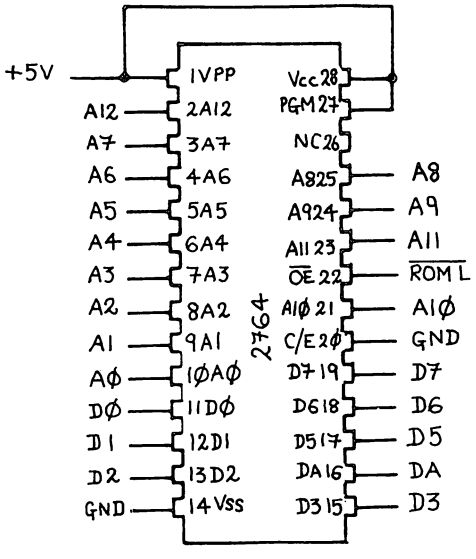
PIN #	TYPE
A	GND
B	$\overline{ROMH}$
C	$\overline{RESET}$
D	$\overline{NMI}$
E	$\phi 2$
F	A15
H	A14
J	A13
K	A12
L	A11
M	A1ϕ

PIN #	TYPE
N	A9
P	A8
R	A7
S	A6
T	A5
U	A4
V	A3
W	A2
X	A1
Y	Aϕ
Z	GND

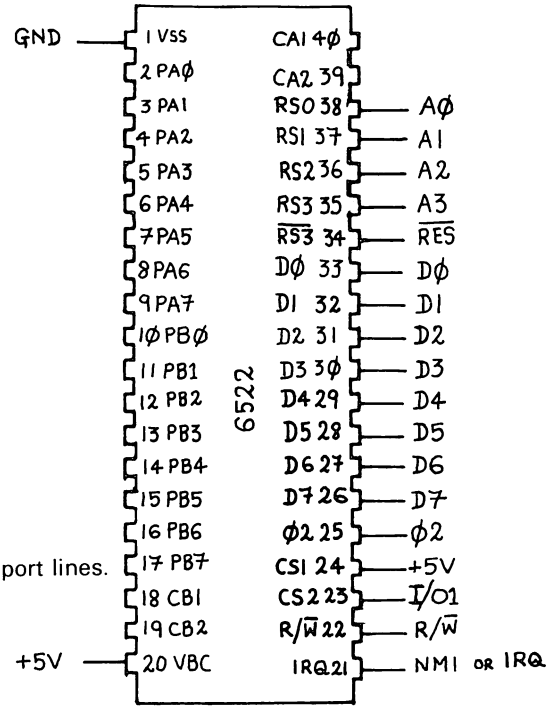
Fig. 5.14. The allocation and function of pins on the memory expansion connector.



Expansion port connector lines.



Connection of a 2764 EPROM to expansion port lines.



Connection of 6522 via I/O expansion connections.

Fig. 5.14. (contd.)

Chapter Six

Interrupts and Their Use

Interrupts are the signals used by peripheral devices, such as the CIA chips, to signal to the processor that they require servicing. This IRQ signal will then cause the processor to halt its current operation temporarily in order to service the interrupt generating device. Having completed this servicing the processor returns to the interrupted program.

6.1 Interrupt requests (IRQ)

The major implementation of IRQs in the Commodore 64's operating system is to scan and receive key presses from the keyboard. This IRQ runs on Timer A of CIA#1. The timer value is set up so that the keyboard is scanned every 1/6Øth of a second. IRQ interrupts can be disabled by setting bit 2 of the processor status register or by the use of the command SEI. To re-enable IRQ, reset bit 2 or use the CLI command. The SEI command is used by the disk operating system to prevent timing errors when accessing the disk.

The only other standard use of IRQs in the operating system of the Commodore 64 is in the tape I/O routines. Rather than just disabling IRQs, the tape system uses IRQs for reading from or writing to the tape. The tape system uses both Timer A and Timer B on CIA#1 for reading and writing. For more information on the tape routines, see Chapter 4.

6.2. Interrupt generating devices

6.2.1 The CIA chips

CIA#1 Register 14 ($DCØD)

Bit	7	Enable/disable (write), occurred (read)
	6	Not used
	5	Not used
	4	$\overline{\text{FLAG}}$ 1 line (cassette read)
	3	Serial data register
	2	TOD clock alarm
	1	Timer B
	Ø	Timer A

When reading bit 7 is used to determine whether an enabled IRQ on this chip occurred (if more than one device is connected to the IRQ line) i.e. if this bit was not set when the IRQ routine was caused, it must have been either the VIC chip or the expansion port. If bit 7 is set, bits Ø-4 will tell what caused the IRQ. It should be noted that when using IRQs, it is advisable to keep a separate record of the IRQs that are enabled, since their respective bits may be set but not necessarily enabled.

When writing, bit 7 is used to tell the CIA whether the lower bits are for disabling or enabling. If bit 7 is set, any other bits set are to enable an IRQ. If bit 7 is not set, any other bits set are to disable an IRQ.

1. Cassette read $\overline{\text{FLAG}}$ 1 line

This line is used by the cassette read routines and creates an IRQ when it is enabled. The tape flags an IRQ on this line when the pulse on the tape goes from high to low. An example of the use of this IRQ is shown in Chapter 4 (fast tape operation).

2. Serial data register (SDR)

The SDR is a serial input/output device of the 6526 CIA chip. When IRQ is enabled on this register, the IRQ will be caused either when the full byte has been read in (input) or when it has been sent out (output). When the IRQ occurs, either a new value to send must be put into the SDR or the byte contained in the SDR will be read and the SDR left to input the next byte. The SDR uses 2 lines on the user port. These lines are SP1 and CNT1, which together are used to send/receive data. When sending, each bit is set on SP and the CNT line is used to clock the bit using Timer A. An example use of the SDR can be found in Chapter 5.

3. TOD clock alarm

When the TOD clock alarm IRQ has been enabled (after setting TOD and the alarm) an IRQ occurs when the value in TOD becomes equal to the value set in the alarm. An example of how to use the TOD clock can be found in Chapter 5.

4. Timer B

Timer B can run in three different modes; as a straight timer, a count down on pulses from the CNT line of the user port, and a count down on Timer A running out. These three methods are outlined in Chapter 5. An IRQ will occur on Timer B in any of the three modes of operation when the value in Timer B clocks past zero.

5. Timer A

Timer A has only one mode of operation; as a straight timer. An IRQ on Timer A will occur when the value in Timer A clocks past zero. Note that with Timers A and B, the timer always decreases until it clocks past zero. Therefore, to time something, the timer should be set to the period and when it runs out the time is up. With CIA IRQs, the IRQ is cleared by reading register 14.

6.2.2 The VIC chip

The VIC chip is also connected to the IRQ line and VIC chip IRQs are controlled by registers 25 and 26 on the VIC chip.

VIC register 25 ($DØ19)
(Interrupt flag register)

Bit	7	Set on any enabled VIC IRQ occurring
	6–4	Not used
	3	Light pen (1=occurred)
	2	Sprite to sprite collision (1=occurred)
	1	Sprite to background collision (1=occurred)
	Ø	Raster compare (1=occurred)

VIC register 26 ($DØ1A)
(Interrupt enable mask)

Bit	7–4	Not used
	3	Light pen (1=enabled)
	2	Sprite to sprite collision (1=enabled)
	1	Sprite to background collision (1=enabled)
	Ø	Raster compare (1=enabled)

To enable IRQ, register 26 should be read and the bit to enable set and then written back to register 26. When the IRQ occurs, reading register 25 will tell you which VIC IRQ has occurred. To clear the IRQ, the corresponding bit to clear is written to register 25.

1. Light pen
The light pen IRQ occurs when the raster scan reaches the position of the light pen and the light pen values can then be read from registers 19 and 2Ø.

2. Sprite to sprite collision
Sprite to sprite collision IRQ occurs when any bit in the sprite to sprite collision register (3Ø – $DØ1E) is set.

3. Sprite to background collision
Sprite to background collision IRQ occurs when any bit in the sprite to background collision register (31 – $DØ1F) is set.

4. Raster compare
Raster compare IRQ occurs when the raster position being displayed becomes equal to the compare value written to registers 17 ($DØ11 high bit) and 18 ($DØ12).

6.2.3 The expansion port
IRQ can be caused by any I/O device connected to the Commodore 64 via the expansion port. There are two 'spare' areas for such I/O devices; they can either be addressed at $DEØØ or $DFØØ. See Chapter 5 for an example of adding a 6522 VIA chip to the Commodore 64 via the expansion port.

6.3 Non maskable interrupts (NMI)

NMIs are so named because they cannot be disabled by the SEI command. Normally the NMI routine is not called regularly like the IRQ routine. This is because NMI is only caused by 2 devices:

a) RS232 (user port $\overline{\text{FLAG}}$ sent low)
b) RESTORE key

There are five other ways of causing an NMI on the 64 that are not implemented in the software. These are Timers A and B, internal shift register, expansion port, and time of day clock on CIA#2. All NMIs except the RESTORE key and the expansion port are controlled by register 14 ($DDØD) on CIA#2. This register is used as a dual purpose write (enable/disable NMI) and read (to determine the source of NMI).

CIA#2 Register 14 ($DDØD)

Bit	7	Enable/disable (write), occurred (read)
	6	Not used
	5	Not used
	4	User port $\overline{\text{FLAG}}$ line RS232 data received)
	3	Shift register
	2	TOD clock alarm
	1	Timer B
	Ø	Timer A

When reading bit 7 is used to determine whether an enabled NMI on this chip has occurred (if more than one CIA chip is connected to the NMI line) i.e. if this bit was not set when the NMI routine was caused, the NMI must have been either the RESTORE key or expansion port. If bit 7 is set, bits Ø–4 will tell what caused the NMI. It should be noted that when using NMIs, it is advisable to keep a separate record of the NMIs that are enabled as their respective bits could be set but not enabled.

When writing, bit 7 is used to tell the CIA whether the lower bits are for disabling or enabling. If bit 7 is set, any other bits set are to enable an NMI. If bit 7 is not set, any other bits set are to disable an NMI.

6.4 Devices that cause NMI

1 User port $\overline{\text{FLAG}}$ line
This line is the one used by the RS232 routines and causes an NMI when it is enabled. The method of flagging an NMI on this line is to set the line to +5 V and then to ØV. This method is outlined in Program 19 which uses 1Ø lines on the user port to transfer a block of memory from one CBM 64 to another (8 data lines and 2 lines to flag the NMI on the other 64). When initialised, the NMI

```
C000          *=$C000
C000 A91F               LDA #<NMI               !SET NMI TO POINT
C002 8D1803             STA $0318               ! TO THE TRANSFER
C005 A9C0               LDA #>NMI               ! RECEIVE ROUTINE
C007 8D1903             STA $0319
C00A A9AE               LDA #<SAVWED            !SET SAVE TO POINT
C00C 8D3203             STA $0332               ! TO THE TRANSFER
C00F A9C0               LDA #>SAVWED            ! SEND ROUTINE
C011 8D3303             STA $0333
C014 A990               LDA #$90                !ENABLE USER
C016 8D0DDD             STA $DD0D               ! PORT NMI
C019 A904               LDA #$04                !RESET RECEIVE FLAG
C01B 8D70C0             STA FLAG
C01E 60                 RTS
C01F          !
C01F          !ROUTINE TO RECEIVE A FILE OVER
C01F          !THE USER PORT
C01F          !
C01F 48       NMI       PHA                     !PUSH OFF REGISTERS
C020 8A                 TXA
C021 48                 PHA
C022 98                 TYA
C023 48                 PHA
C024 A910               LDA #$10                !WAS NMI CAUSED BY
C026 2C0DDD             BIT $DD0D               ! THE USER PORT?
C029 D010               BNE LOADIT              !YES
C02B 20BCF6             JSR $F6BC               !NO, UPDATE CLOCK
C02E 20E1FF             JSR $FFE1               !TEST STOP KEY
C031 D037               BNE EXIT                !NOT DOWN
C033 A97F               LDA #$7F                !DISABLE USER
C035 8D0DDD             STA $DD0D               ! PORT NMI
C038 4C66FE             JMP $FE66               !DO NORMAL STOP/RESTORE
C03B          !
C03B A900     LOADIT    LDA #$00                !SET PORT TO INPUT
C03D 8D03DD             STA $DD03
C040 AD01DD             LDA $DD01               !GET INPUT BYTE
C043 EE20D0             INC $D020               !SHOW IT IS WORKING
C046 AE70C0             LDX FLAG                !READING FILE OR
C049 F009               BEQ STRFLE              ! LOAD ADDRESS?
C04B 95FA               STA $FA,X               !LOAD ADDRESS
C04D CA                 DEX                     !DECREASE FLAG
C04E 8E70C0             STX FLAG                !STORE IT
C051 4C6AC0             JMP EXIT                !EXIT NMI
C054          !
C054 A000     STRFLE    LDY #$00                !NOW READING FILE
C056 91FB               STA ($FB),Y             !STORE THE BYTE
C058 209FC0             JSR BUMP2               !INCREMENT AND TEST END
C05B 900D               BCC EXIT                !NOT YET
C05D A5FD               LDA $FD                 !SET PROGRAM END
C05F 852D               STA $2D                 ! POINTERS TO END
C061 A5FE               LDA $FE                 ! OF READ FILE
C063 852E               STA $2E
C065 A904               LDA #$04                !RESET LOADING FLAG
C067 8D70C0             STA FLAG
C06A          !
C06A 68       EXIT      PLA                     !RESTORE REGISTERS
C06B A8                 TAY                     ! AND EXIT NMI
C06C 68                 PLA
C06D AA                 TAX
C06E 68                 PLA
C06F 40                 RTI
C070          !
C070 04       FLAG      BYT 4
C071          !
C071          !ROUTINE TO SEND A FILE OVER THE
C071          ! USER PORT
C071          !
C071 AD70C0   SAVER     LDA FLAG                !IF RECEIVING,
C074 C904               CMP #$04                ! DON'T SEND
C076 D0F9               BNE SAVER
C078 A204               LDX #$04                !POINT TO SAVE
```

```
C07A B5AB   LOOP        LDA $AB,X                   !GET ADDRESS BYTE
C07C 20C2C0             JSR SBYTE                   !SEND THE BYTE
C07F CA                 DEX                         !DO NEXT?
C080 D0F8               BNE LOOP                    !YES
C082 A000               LDY #$00
C084 B1AC   LOOP1       LDA ($AC),Y                 !GET A FILE BYTE
C086 20C2C0             JSR SBYTE                   !SEND IT
C089 2090C0             JSR BUMP                    !INCREMENT AND TEST END
C08C 90F6               BCC LOOP1                   !NOT YET
C08E 18                 CLC                         !SAVED OK
C08F 60                 RTS                         !DONE
C090            !
C090 E6AC   BUMP        INC $AC                     !INCREMENT LO BYTE
C092 D002               BNE BUMP1
C094 E6AD               INC $AD                     !INCREMENT HI BYTE
C096 A5AC   BUMP1       LDA $AC                     !COMPARE SAVE
C098 C5AE               CMP $AE                     ! ADDRESS TO END
C09A A5AD               LDA $AD                     ! ADDRESS
C09C E5AF               SBC $AF
C09E 60                 RTS
C09F            !
C09F E6FB   BUMP2       INC $FB                     !INCREMENT LO BYTE
C0A1 D002               BNE BUMP3
C0A3 E6FC               INC $FC                     !INCREMENT HI BYTE
C0A5 A5FB   BUMP3       LDA $FB                     !COMPARE LOAD
C0A7 C5FD               CMP $FD                     ! ADDRESS WITH END
C0A9 A5FC               LDA $FC                     ! ADDRESS
C0AB E5FE               SBC $FE
C0AD 60                 RTS
C0AE            !
C0AE            !WEDGE INTO SAVE VECTOR
C0AE            !
C0AE A5BA   SAVWED      LDA $BA                     !TEST DEVICE #
C0B0 C907               CMP #$07                    !DEVICE 7?
C0B2 F003               BEQ SAVE1                   !YES, SEND OVER PORT
C0B4 4CEDF5             JMP $F5ED                   !NO, NORMAL SAVE
C0B7 A5C1   SAVE1       LDA $C1                     !SET SAVE START
C0B9 85AC               STA $AC                     ! ADDRESS FOR USER
C0BB A5C2               LDA $C2                     ! PORT SAVE
C0BD 85AD               STA $AD
C0BF 4C71C0             JMP SAVER                   !SEND FILE
C0C2            !
C0C2            !ROUTINE TO SEND 1 BYTE ACROSS
C0C2            ! THE USER PORT
C0C2            !
C0C2 48     SBYTE       PHA                         !SAVE OFF BYTE
C0C3 A9FF               LDA #$FF                    !SET PORT TO OUTPUT
C0C5 8D03DD             STA $DD03
C0C8 68                 PLA                         !GET BYTE
C0C9 8D01DD             STA $DD01                   !SEND TO PORT
C0CC AD02DD             LDA $DD02                   !SET LINE PA2
C0CF 0904               ORA #$04                    ! TO OUTPUT
C0D1 8D02DD             STA $DD02
C0D4 AD00DD             LDA $DD00                   !SEND PA2 HIGH
C0D7 0904               ORA #$04
C0D9 8D00DD             STA $DD00
C0DC 20F3C0             JSR DEL                     !PAUSE
C0DF AD00DD             LDA $DD00                   !SEND PA2 LOW
C0E2 29FB               AND #$FB                    !NMI HAS BEEN CAUSED
C0E4 8D00DD             STA $DD00                   ! ON RECEIVING MACHINE
C0E7 20F3C0             JSR DEL                     !PAUSE
C0EA A900               LDA #$0                     !SET USER PORT TO
C0EC 8D03DD             STA $DD03                   ! INPUT
C0EF EE20D0             INC $D020                   !SHOW IT IS WORKING
C0F2 60                 RTS
C0F3            !
C0F3 A910   DEL         LDA #$10                    !PAUSE FOR DATA
C0F5 E901   DE          SBC #$01                    !TO BE READ
C0F7 D0FC               BNE DE
C0F9 60                 RTS
```

Program 19.

vector is set to point to the receive routine and the SAVE vector is set to the send routine. When the user of one computer SAVEs a block of memory with device 7, the file is passed through to the other computer by setting a full byte onto the data lines and causing an NMI by setting the PA2 line hi then lo (PA2 is connected to $\overline{\text{FLAG}}$ both ways). The NMI routine then reads the byte from the port and either stores it as a load address or as part of the file.

To send a file, use SAVE"",7. Files are automatically received.

2. Serial data register
The NMI SDR has exactly the same operation as the IRQ SDR except that instead of lines CNT1 and SP1, lines CNT2 and SP2 are used. SDR use can be seen in Chapter 5.

3. TOD clock alarm
The NMI TOD clock alarm has exactly the same operation as the IRQ TOD clock alarm. An example of how to use the TOD clock can be found in Chapter 5.

4. Timer B
The NMI Timer B has exactly the same operation as the IRQ Timer B.

5. Timer A
The NMI Timer A has the same operation as the IRQ Timer A.

6. RESTORE key
The RESTORE key on the keyboard is connected directly to the NMI line and is not a true NMI. When RESTORE is pressed, the NMI routine is called and if the STOP key is also down, NMI will cause a restart of the computer. This is done by jumping to a routine pointed to by an indirection at $A00̸2: JMP ($A00̸2). If a cartridge ROM is in place (with the power-up bytes), JMP ($800̸2) is used instead.

7. Expansion port
Expansion port NMI has the same operation as expansion port IRQ except that IRQ occurs if the line is low, whereas NMI occurs *when* the line goes low.

6.5 The kernal vectors

There are a group of vectors in page three memory that are used for indirect jumps into some of the most useful kernal routines. These have been provided so that the machine code programmer can patch into them to change the operation of the computer. Each vector is a two byte low-high vector to the main machine code kernal routine and by changing its value, you may point it to your own routine.

The vectors are as follows:

Address	*Default*	*Use*
$Ø314	$EA31	Vector to the IRQ routine. This vector can be changed to point to your own IRQ routine for things such as screen scrolling etc.
$Ø316	$FE66	Vector for BRK instruction is changed by all monitors so that when a BRK is encountered, the computer jumps to the monitor.
$Ø318	$FE47	Vector to the NMI routine. Its major use is for the detection of the RESTORE key. Other methods are outlined in Chapter 5.
$Ø31A	$F34A	Vector to open file routine.
$Ø31C	$F291	Vector to close file routine.
$Ø31E	$F2ØE	Vector to set input device.
$Ø32Ø	$F25Ø	Vector to set output device.
$Ø322	$F333	Vector to restore I/O.
$Ø324	$F157	Vector to input. This routine is used in all peripheral input. It could be used for function keys etc.
$Ø326	$F1CA	Vector to output. This routine controls all output to the same devices as input (except keyboard).
$Ø328	$F6ED	Vector to test STOP routine. The most widely used patch is for disabling the STOP key.
$Ø32A	$F13E	Vector to get. This routine is used to get a single key from the keyboard buffer. The character received is not displayed but is just returned in register .A. The get key has the same operation as input from all devices except the keyboard where input inputs a line until carriage return is pressed.
$Ø32C	$F32F	Vector to abort I/O.
$Ø32E	$FE66	Unused vector. This vector can be used by your own routines.
$Ø33Ø	$F4A5	Vector to load routine. This vector is jumped to after the load parameters have been set up.
$Ø332	$F5ED	Vector to save routine. An example of a patch into this vector can be seen in Chapter 4 and in Program 19 in this chapter.

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A knowledge of the Commodore 64 kernal software and the hardware with which it interacts is essential for programmers wishing to make full use of the machine's capabilities. The kernal software provides the interface between the user, the BASIC interpreter and the electronics – and a thorough knowledge of its functioning gives the programmer a wealth of ideas and methods for interesting programming techniques.

This book gives the programmer a unique insight into the operation of the Commodore 64 plus a wide variety of very useful hints on subjects as diverse as reconfiguring the keyboard and anti tape-copying security. The book also covers the user port and the addition of external circuitry to it.

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Richard Franklin and Carl Graham are programmers with Zifra Software Ltd and together with Nick Hampshire have written some of the software included in this book.

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