6502 inside®

Tower of Eightness Reference Manual.

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Chapter 0. Introduction to the Tower of Eightness.

Welcome

You are now the proud owner of one of the most trailing edge pieces of technology. This sophisticated, versatile, and very capable engineering tool/toy is built for those with a need to play around, make and learn unimpeded by modern technologies closed-off and locked down architectures.

The Tower of Eightness has despite its trailing edge tech, enough capability to run an office, teach the basics of robotics, play games etc. The power is within you to make it do great things. Everything is documented where possible in order to make it the tinkerers heaven. There is just one thing I ask of you. When you make something beautiful, *share it!*

A Guided tour

First, let's learn the pieces. The main unit consists of a 3D printed modular case which houses the backplane, of which there are versions with and without the W65C02S6-TPG14 Central Processing Unit and system clock generator. The W65C02S6-TPG14 is the beating heart of the system, and it can be considered to be its brain.

Then there is the memory card. On this card is 96 Kibibytes of RAM in three banks of 16 Kibibytes by 2 pages wide. At the top of memory space are two pages of ROM each also of 16 Kibibytes. This is where TowerOS, TowerBASIC and TowerTAPE FS live. This card is an essential without which the computer will not operate. It is recommended that this sits in the top slot if one intends to make frequent changes to the ROM.

Next up is the GPIO card. You need at least one of these to use TowerTAPE FS, SPI or I^{2}C facilities. The first one should always be at $C020 base address.

Either an ACIA card or a dual ACIA card (recommended) is needed to provide one or more serial ports. All keyboard input is initially routed through the first serial port and on systems' that don't have some form of VDU output, this is how one sees the computers output.

In most cases you'll want a video output with some form of graphics, for this there is the ANSI video output card. With this, you'll be able to enjoy 80 columns output, a full PCDOS character set and some limited graphics capability. This card outputs either PAL or NTSC timed monochrome composite synch video.

Do you want to make some noise!!? Good, there's a soundcard based on the AY-3-8912A sound chip for that. It has a single stereo 3.5mm jack with line level output on it.

How about printing? For that there is the Centronics and Tower Peripheral Bus card. The printer port is especially useful. The Tower Peripheral Bus hardware is all there, but the firmware is a work in progress.

There is an up-and-coming much faster solid state storage card, this will operate with far greater reliability and speed than tape.

Getting Up and Running

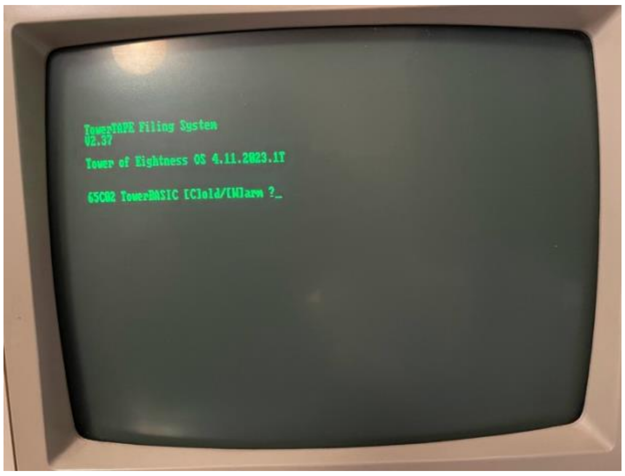
Firstly, we need power. On the back is a 2.1mm power jack that accepts anything from 8 to 12VDC positive tip with at least 1A. Whilst the computer itself doesn't use all that, peripherals and future upgrades *might*. Plug that in but don't switch the computer on just yet.

Now, connect the ACIA port 1 to either a terminal/terminal emulator *or* the PS2 keyboard interface with the appropriate lead. For connecting to the keyboard interface, use the supplied SC1-K1 serial cable. It only fits one way round. For use with the terminal/terminal emulator you will need to make up a custom cable using the data in one of the ACIA adapter chapters. If using the PS2 to Keyboard adapter, you will need to supply power to that also. See the PS2 to Keyboard Adapter User Guide for further guidance there. We now have a way to type commands into the computer and if using it with a terminal, also see the output.

It is strongly recommended that you use the ANSI card with a composite capable display device. This wat you can enjoy its extra benefits. The output on that card is a single yellow RCA jack. This outputs either 50 or 60Hz monochrome video compatible with many modern television sets that support PAL or NTSC.

Should you wish to use TowerTAPE FS then you should now use a short and I do mean *short* 20-way ribbon cable to connect port B of the first GPIO card to the tape and joystick interface. This also supplies power to the tape and joystick interface, so you won't need yet another power supply.

These are considered the base options for the Tower of Eightness. Some might say sound is a base option, but that very much depends on your point of view. Now we can flip the power switch!



```
TowerTAPE Filing System
V2.37

Tower of Eightness OS 4.11.2023.1T

65C02 TowerBASIC [C]old/[W]arm ?_
```

Figure 1 ToE Boot-screen

When starting from power-up you must always choose [C]old by pressing C. You will then be prompted to enter an amount of memory. For now just press [ENTER] and let the computer decide. This will drop you into TowerBASIC.

Let the adventure begin!

Let's get stuck in shall we? Good, TowerBASIC is a close fork of EhBASIC, it is therefore derived from EhBASIC, and due respect should be paid to its original and *late* author Lee Davidson. It is free to use but not copyright free. He would hate to see people abusing the spirit and intention of his work, so please don't. Now with that out of the way, BASICs of this type have a few things in common.

First, there are keywords such as **PRINT**, **IF** and **LET** which will appear throughout this manual as they do here. Take the following example for instance: -

```
10 PRINT "Hello world!"¶
20 GOTO 10¶
```

Typing this and then **RUN¶** tells the computer to print Hello world! repeatedly down the screen. To stop it doing so press escape or [Control]C, from now on shown ^C.

The numbers at the start of each line tell the computer where to put them in relation to each other, and each line is followed in numerical order. If you type a new line in with the same number, it replaces any existing one of the same line number with the new line. Try changing the message in the quotes on line 10 and see what happens!

Where you see **PRINT** that command prints whatever is between the quotes.

Line 20 does something different. It is an instruction to start running commands from the number following the **GOTO** command. In this simple form it must be followed by a line number that *must* exist or the computer will stop running your program with an **Undefined statement Error.**

Congratulations, you've just run your first program!

It would be a shame to have to type in an entire program consisting of many many lines of carefully crafted code, so connect your Tower of Eightness up to a tape recorder and whenever you have created something you'd rather not loose, just find a good spot on a tape, press record and type **SAVE** "<filename>"¶

When the computer has done saving you'll be greeted by the **Ready** prompt and be able to continue on with your day. Getting your program back is as simple as finding the right spot and typing **LOAD** "<optional filename>"¶, and playing the tape back. It may take a while to find the sweet spot on your tape recorders volume dial to get reliable loading of saved programs. Please refer to the chapter on the Tape and Joystick Interface for a fuller understanding.

Variables and Math

So, computers are often insulted as being overgrown calculators, and whilst this is not true, they definitely owe their roots to the efforts of mathematicians and engineers.

The Tower of Eightness is quite capable of performing calculations with great speed and ease. Just to give you a taste, let's explore this a little.

Let us consider the following program: -

```
10 LET a=4
20 LET b=3
30 PRINT a*b
```

Upon being RUN this program produces the result 12. Nothing remarkable you might say, but the devil is in the detail for computers don't work in human numbers (decimal), they work in binary (noughts and ones, also known as base 2).

Line 10 assigns the variable 'a' with the value 4, whenever the computer then needs to use that number, you can use 'a' instead. In fact, you can change the contents of a whenever you like and even assign it the results of a previous calculation. The computer is taking an equation, in this case a times b and **`PRINT`**ing the result.

Line 20 is doing the same for the variable b, but not b=3.

Line 30 both performs the calculation and prints the result for the user to see.

For the Tower of Eightness, this was a trivial calculation that took such a short time I bet you didn't even perceive it. The computer has a good selection of operators.

It can add (+), subtract (-), multiply (*), divide (/), raise to a power (^) and much, much more. The TowerBASIC Reference Manual gives a full list of operators and functions to assist the programmer in making use of the computers calculating capability.

There are also string variables, and *arrays* of variables can exist as well.

Any variable name that ends in s '$' symbol is a *string* variable. Strings are any number of characters one after another and can have some limited operations after them. We shall just briefly touch upon them here. To know more, refer to the TowerBASIC Reference Manual.

```
N$="<Yourname>"
PRINT "Hello ";N$;". It's jolly nice to meet you!"
```

Using the PRINT Command

You've seen PRINT in use already, but did you know, it can do *more?* In fact, when properly used, it can do most of what you might want to do with the Tower of Eightness display. Its purpose is more fully realised when you know the PC-DOS character set and special *control codes* that give it the ability to draw pixels, double height, double width, bold or otherwise characters sets and even change the number of columns on the screen.

PRINT can exist on its own to move down the screen by one line:-

```
10 PRINT “MENU”
20 PRINT
30 PRINT “Spam and eggs”
40 PRINT “Spam and chips”
50 PRINT “Spam, spam, spam, wonderful Spam!!”
```

PRINT can print multiple things together!

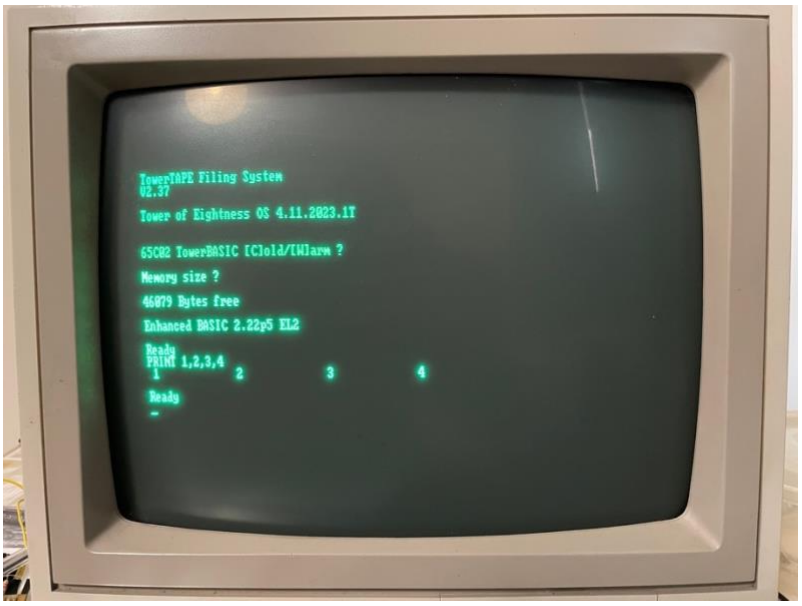
```
10 LET a=9
20 PRINT “The square root of”;a;” is”;SQR(a)
```

which yields the result of ‘**The square root of 9 is 3**’ when run. We’ve also just encountered a function **SQR()** which *returns* the square root of whatever is in the parentheses. There are many such functions.

One such function especially useful with **PRINT** is **CHR$()**. It takes a number from 0 to 255 and passes the result as a single character. If you look at the PC-DOS character set, listed at the back of this manual, you will see that each and every character has a unique number associated with it, and better yet, there’s also a whole bunch of fancy symbols to play with as well! A word of caution though, it is quite possible to get the screen in a terrible mess whilst exploring this, so don’t forget that if you press the reset button and choose [W]arm start, you’ll have a nice readable display to call home again.

PRINT can also produce columnated figures. Try the following: -

PRINT 1,2,3,4



```
TowerTAPE Filing System
V2.37

Tower of Eightness OS 4.11.2023.1T

65C02 TowerBASIC [C]old/[W]arm ?

Memory size ?

46079 Bytes free

Enhanced BASIC 2.22p5 EL2

Ready
PRINT 1,2,3,4
 1         2          3          4

Ready
_
```

Figure 2 Tabulated printing in TowerBASIC.

As you can see from the above image, there are fixed tabs where the numbers appear. This is useful for making your information sit more readably and presentably.

There are a couple of useful functions for moving whatever you print along too. Following the print statement or after a ‘,’ or ‘;’ within the **`PRINT`** statement, you can include either a **`SPC(x)`** or **`TAB(x)`** function where x is a positive numeric value.

`SPC(x)` works by moving the print position x characters along, but **`TAB(x)`** attempts to get to column x so long as that column hasn’t already been passed.

Finally, if you end your print statement with a semicolon, a carriage return is not issued. That is to say that the next thing starts *immediately* after the last print.

Chapter 1. The Zero Page.

Tower of Eightness Zero Page Usage

LAB_WARM	$00	BASIC warm start entry point
Wrmjpl	$01	BASIC warm start vector jump low byte
Wrmjph	$02	BASIC warm start vector jump high byte
Usrjmp	$0A	USR function JMP address
Usrjpl	$0B	USR function JMP vector low byte
Usrjph	$0C	USR function JMP vector high byte
Nullct	$0D	nulls output after each line
TPos	$0E	BASIC terminal position byte
TWidth	$0F	BASIC terminal width byte
Iclim	$10	Input column limit
Itempl	$11	Temporary integer low byte
Itemph	$12	Temporary integer high byte
nums_1	$11	Number to bin/hex string convert MSB
nums_2	$12	Number to bin/hex string convert
nums_3	$13	Number to bin/hex string convert LSB
Srchc	$5B	Search character
Temp3	$5B	Temp byte used in number routines
Scnquo	$5C	Scan-between-quotes flag
Asrch	$5C	Alt search character
XOAw_l	$5B	eXclusive OR, OR and word low byte
XOAw_h	$5C	eXclusive OR, OR and AND word high byte
Ibptr	$5D	Input buffer pointer
Dimcnt	$5D	# of dimensions
Tindx	$5D	Token index
Defdim	$5E	Default DIM flag
Dtypef	$5F	Data type flag, $FF=string, $00=numeric
Oquote	$60	Open quote flag (b7) (Flag: DATA scan; LIST quote; memory)
Gclctd	$60	Garbage collected flag
Sufnxf	$61	Subscript/FNX flag, 1xxx xxx = FN(0xxx xxx)
Imode	$62	Input mode flag, $00=INPUT, $80=READ
Cflag	$63	Comparison evaluation flag
TabSiz	$64	TAB step size (was input flag)
next_s	$65	Next descriptor stack address

These two bytes form a word pointer to the item currently on top of the descriptor stack.

last_s	$66	Last descriptor stack address low byte
last_sh	$67	Last descriptor stack address high byte (always $00)
des_sk	$68	Descriptor stack start address (temp strings)

	$70	End of descriptor stack
ut1_pl	$71	Utility pointer 1 low byte
ut1_ph	$72	Utility pointer 1 high byte
ut2_pl	$73	Utility pointer 2 low byte
ut2_ph	$74	Utility pointer 2 high byte
Temp_2	$71	Temp byte for block move
FACt_1	$75	FAC temp mantissa1
FACt_2	$76	FAC temp mantissa2
FACt_3	$77	FAC temp mantissa3
dims_l	$76	Array dimension size low byte
dims_h	$77	Array dimension size high byte
TempB	$78	Temp page 0 byte
Smeml	$79	Start of mem low byte (Start-of-Basic)
Smemh	$80	Start of mem high byte (Start-of-Basic)
Svarl	$7B	Start of vars low byte (Start-of-Variables)
Svarh	$7C	Start of vars high byte (Start-of-Variables)
Sarryl	$7D	Var mem end low byte (Start-of-Arrays)
Sarryh	$7E	Var mem end high byte (Start-of-Arrays)
Earryl	$7F	Array mem end low byte (End-of-Arrays)
Earryh	$80	Array mem end high byte (End-of-Arrays)
Sstorl	$81	String storage low byte (String storage (moving down))
Sstorh	$82	String storage high byte (String storage (moving down))
Sutill	$83	String utility ptr low byte
Sutilh	$84	String utility ptr high byte
Ememl	$85	End of mem low byte (Limit-of-memory)
Ememh	$86	End of mem high byte (Limit-of-memory)
Clinel	$87	Current line low byte (Basic line number)
Clineh	$88	Current line high byte (Basic line number)
Blinel	$89	Break line low byte (Previous Basic line number)
Blineh	$8A	Break line high byte (Previous Basic line number)
Cpntrl	$8B	Continue pointer low byte
Cpntrh	$8C	Continue pointer high byte
Dlinel	$8D	Current DATA line low byte
Dlineh	$8E	Current DATA line high byte
Dptrl	$8F	DATA pointer low byte
Dptrh	$90	DATA pointer high byte
Rdptrl	$91	Read pointer low byte
Rdptrh	$92	Read pointer high byte
Varnm1	$93	Current var name 1st byte

Varnm2	$94	Current var name 2nd byte
Cvaral	$95	Current var address low byte
Cvarah	$96	Current var address high byte
Frnxtl	$97	Var pointer for FOR/NEXT low byte
Frnxth	$98	Var pointer for FOR/NEXT high byte
Tidx1	$97	Temp line index
Lvarpl	$97	Let var pointer low byte
Lvarph	$98	Let var pointer high byte
Prstk	$99	Precedence stacked flag
comp_f	$9B	compare function flag, bits 0,1 and 2 used Bit 2 set if > Bit 1 set if = Bit 0 set if <
func_l	$9C	Function pointer low byte
func_h	$9D	Function pointer high byte
garb_l	$9C	Garbage collection working pointer low byte
garb_h	$9D	Garbage collection working pointer high byte
des_2l	$9E	String descriptor_2 pointer low byte
des_2h	$9F	String descriptor_2 pointer high byte
g_step	$A0	Garbage collect step size
Fnxjmp	$A1	Jump vector for functions
Fnxjpl	$A2	Functions jump vector low byte
Fnxjph	$A3	Functions jump vector high byte
g_indx	$A2	Garbage collect temp index
FAC2_r	$A3	FAC2 rounding byte
Adatal	$A4	Array data pointer low byte
Adatah	$A5	Array data pointer high byte
Nbendl	$A4	New block end pointer low byte
Nbendh	$A5	New block end pointer high byte
Obendl	$A6	Old block end pointer low byte
Obendh	$A7	Old block end pointer high byte
Numexp	$A8	String to float number exponent count
Expcnt	$A9	String to float exponent count

Numbit	$A8	Bit count for array element calculations
Numdpf	$AA	String to float decimal point flag
Expneg	$AB	String to float eval exponent -ve flag
Astrtl	$AA	Array start pointer low byte
Astrth	$AB	Array start pointer high byte
Histrl	$AA	Highest string low byte
Histrh	$AB	Highest string high byte
Baslnl	$AA	BASIC search line pointer low byte
Baslnh	$AB	BASIC search line pointer high byte
Fvar_l	$AA	Find/found variable pointer low byte
Fvar_h	$AB	Find/found variable pointer high byte
Ostrtl	$AA	Old block start pointer low byte
Ostrth	$AB	Old block start pointer high byte
Vrschl	$AA	Variable search pointer low byte
Vrschh	$AB	Variable search pointer high byte
FAC1_e	$AC	FAC1 exponent
FAC1_1	$AD	FAC1 mantissa1
FAC1_2	$AE	FAC1 mantissa2
FAC1_3	$AF	FAC1 mantissa3
FAC1_s	$B0	FAC1 sign (b7)
str_ln	$AC	String length
str_pl	$AD	String pointer low byte
str_ph	$AE	String pointer high byte
des_pl	$AE	String descriptor pointer low byte
des_ph	$AF	String descriptor pointer high byte
mids_l	$AF	MID$ string temp length byte
negnum	$B1	String to float eval -ve flag
numcon	$B1	Series evaluation constant count
FAC1_o	$B2	FAC1 overflow byte
FAC2_e	$B3	FAC2 exponent
FAC2_1	$B4	FAC2 mantissa1
FAC2_2	$B5	FAC2 mantissa2
FAC2_3	$B6	FAC2 mantissa3
FAC2_s	$B7	FAC2 sign (b7)
FAC_sc	$B8	FAC sign comparison, Acc#1 vs #2
FAC1_r	$B9	FAC1 rounding byte

ssptr_l	$B8	String start pointer low byte
ssptr_h	$B9	String start pointer high byte
sdescr	$B8	String descriptor pointer
csidx	$BA	Line crunch save index
Asptl	$BA	Array size/pointer low byte
Aspth	$BB	Array size/pointer high byte
Btmpl	$BA	BASIC pointer temp low byte
Btmph	$BB	BASIC pointer temp low byte
Cptrl	$BA	BASIC pointer temp low byte
Cptrh	$BB	BASIC pointer temp low byte
Sendl	$BA	BASIC pointer temp low byte
Sendh	$BB	BASIC pointer temp low byte
LAB_IGBY	$BC	Get next BASIC byte subroutine
LAB_GBYT	$C2	Get current BASIC byte subroutine
Bpntrl	$C3	BASIC execute (get byte) pointer low byte
Bpntrh	$C4	BASIC execute (get byte) pointer high byte
	$D7	end of get BASIC char subroutine
Rbyte4	$D8	Extra PRNG byte
Rbyte1	$D9	Most significant PRNG byte
Rbyte2	$DA	Middle PRNG byte
Rbyte3	$DB	Least significant PRNG byte
	$DC	unused
	$DD	unused
	$DE	unused
	$DF	unused
	$E0	unused
	$E1	unused
	$E2	TPB card temporary location
	$E3	TPB card temporary location
	$E4	TAPE temporary location
	$E5	TAPE_BlockLo
	$E6	TAPE_BlockHi
	$E7	TOE_MemptrLo low byte general purpose pointer
	$E8	TOE_MemptrHi high byte general purpose pointer
	$E9	unused
	$EA	unused
	$EB	unused
	$EC	unused
	$ED	unused
	$EE	unused

Decss	$EF	Number to decimal string start
Decssp1	$F0	Number to decimal string start
	$FF	Decimal string end

Chapter 2. OS Memory Map.

TowerBASIC Non-Zero Page Memory

Operating systems memory is necessary, or the OS would not work. Some benefit to the user is afforded by the clear documentation of this memory below.

$200	ccflag	Control-C flag. 0=Enabled, 1=Disabled.
$201	ccbyte	Control-C character. One may define whatever one chooses, but with great power comes great RESETs!
$202	ccnull	Timeout time for the Control-C character.
$203-$204	VEC_CC	Control-C check vector.
$205-$206	VEC_IN	TowerBASIC Input vector.
$207-$208	VEC_OUT	TowerBASIC output vector.
$209-$20A	VEC_LD	TowerBASIC LOAD vector.
$20B-$20C	VEC_SV	TowerBASIC SAVE vector.
$20D-£20E	VEC_VERIFY	TowerBASIC VERIFY vector.

THE Next two vectors (Greyed out) are no longer in use.

$F9F3-$F9F4	IRQ_vec	Interrupt ReQuest vector. (Currently patched out, see Chapter 12, The IRQ Sub-System.)
$20F-$210	NMI_vec	Non Maskable Interrupt vector.

ToE Monitor Top Level Component Memory

$5E0	os_outsel	Output stream selection bitfield. See table at end of chapter.
$5E1	os_infilt	Input stream filter selection bitfield. See table at end of chapter.
$5E2	os_insel	This variable contains an input stream selection bit. The bitfield allows you to select which source you want to use, with invalid selections causing a return to ACIA1.

ToE ACIA Configuration Variables

$5E3	ACIA1_cfg_cmd	The load values for configuring ACIA1's command register upon initialisation.
$5E4	ACIA1_cfg_ctrl	The load values for configuring the ACIA1's control register upon initialisation.
$5E5	ACIA2_cfg_cmd	The load values for configuring ACIA2's command register upon initialisation.
$5E6	ACIA2_cfg_ctrl	The load values for configuring ACIA2's command register upon initialisation.

ToE I2C Engine Variables

$5D0	I2C Status	Stores the status of the I2C engine including the ACK/NAK bit.
$5D1	I2C_Byte	This is the data register for the I2C engine.

Tower Peripheral Bus Memory Locations

$5F2	TPB_curr_dev	TPB Currently selected device ID.
$5F3	TPB_dev_type	TPB device type.
$5F4	TPB_last_read	Last read byte from the TPB bus.
$5F5	TPB_BUS_status	Status word for the TPB bus. Subject to change.
$5F6	TPB_BUS_tries	Bus device counter, this ensures fewer hangs.
$5F7	TPB_BUS_lim	Bus countdown timer limit. (Reload value).
$5F8	TPB_BUS_lenlo	Low byte of the length of the block in or out.
$5F9	TPB_BUS_lenhi	High byte of the length of the block in or out.
$5FA	TPB_BUS_stlo	Low byte of the start of the block in or out.
$5FB	TPB_BUS_sthi	High byte of the start of the block in or out.
$5FC	TPB_BUS_blk_type	Type of block transfer. See Table below.
$600	TPB_Dev_table	Device descriptor table.
$610-$6FF	TPB_BUS_IO_buff	Buffer for IO operations on the TPB bus.
$700-$7FF	TPB_BUFFER	Buffer for TPB block operations.

TowerTAPE Filing System Memory.

$900-$901	V_TAPE_BlockSize	Size of block to transfer to or from tape.
$902	TAPE_Temp2	Temporary memory location for TFS internals.
$903	TAPE_Temp3	Temporary memory location for TFS internals.
$904	TAPE_Temp4	Temporary memory location for TFS internals.
$905	TAPE_LineUptime	Number of passes the tape system superloop has made since the tape line rose.
$906	TAPE_Demod_Status	Demodulated bit status.
$907	TAPE_Demod_Last	Previous demodulated bit status.
$908	TAPE_StartDet	Start bit detection status.
$909	TAPE_RX_Status	Receive engine status bitfield.
$90A	TAPE_BitsToDecode	Down counter of remaining bits to decode.
$90B	TAPE_ByteReceived	Last byte received by the TFS.
$90C	TAPE_Sample_Position	Countdown timer for bit engine sample synchronization.

$90D	TAPE_BlockIn_Status	Status register for the F_TAPE_BlockIn function.
$90E-929	TAPE_Header_Buffer	This is where the tape header information is stored for use when **SAVE**ing and **LOAD**ing.
$92A	TAPE_CS_AccLo	Tape checksum accumulator low byte.
$92B	TAPE_CS_AccHi	Tape checksum accumulator high byte.
$92C	V_TAPE_Phasetime	Tape phase time variable.

The following variables are allocated for future upgrades to the tape system and ignored for now.

$92D	V_TAPE_Sample_Offset	Sample offset variable. This determines how far into a bit the sample is taken.
$92E	V_TAPE_Bitlength	How many bits in a word stored on tape.
$92F	V_TAPE_bitcycles	Number of cycles of the super-loop to a bit.
$930	V_TAPE_Verify_Status	Stores the verify status bits used by the TAPE_VERIFY_vec ($FF7E)
$931-$942	V_TAPE_Fname_Buffer	Working file name buffer. Stores the null terminated file name specified in **LOAD**, **SAVE** and **VERIFY** commands.
$943	V_TAPE_LOADSAVE_Type	Temporary store of what file type is being worked on by the TAPE file system.
$944-$945	V_TAPE_Address_Buff	Temporary store of the starting address being worked on by the TAPE file system.
$946-$947	V_TAPE_Size_Buff	Temporary store of how big the file being worked on is.
$948	V_TAPE_Config	TowerTAPE Filing system configuration word.
$949-$94B	TAPE_KBD_vec	This stores a JMP, and the address of the routine needed to check for break to BASIC. This is set whenever a block read operation occurs. The user must change this whenever the input stream is changed and a call is made to F_TAPE_GetByte. This is done by calling F_TAPE_SetKbd_vec ($FFBA)

AY Soundcard V2 Memory Locations

$A00	AY_Reg	Register to write to
$A01-$A02	AY_Data	Contents to be transferred between the system and the AY-3-8912A when calling AY_Userwrite_vec ($FFD5),

		AY_Userwrite_16_vec ($FFCF), AY_Userread_vec ($FFD8) or AY_Userread_16_vec ($FFD2).
$A03	AY_Mask	Contains the shadow copy of the enable bits for the AY-3-8912A sound channels.
$A04	AY_Channel	Contains a shadow copy of the channel specified in the BASIC command **SOUND**.
$A05-$A06	AY_Period	Contains a shadow copy of the period specified in the BASIC command **SOUND**.
$A07	AY_Volume	Contains a shadow copy of the volume specified in the BASIC command **SOUND**.
$A08-$A09	AY_Envelope_Period	Contains a shadow copy of the envelope period specified in the BASIC command **ENVELOPE**.
$A0C	AY_Envelope_Mode	Contains a shadow copy of the envelope mode specified in the TowerBASIC command **ENVELOPE**.

IRQ Handler Subsystem Locations

$A20-$A2F	IRQH_CallList	Table of 8 addresses for the IRQ Handlers
$A30-$A31	IRQH_CallReg	Address being worked on by set or clear calls.
$A32	IRQH_ClaimsList	bitfield showing which IRQ's claimed an interrupt. LSb is IRQ0, MSb is IRQ7
$A33	IRQH_MaskByte	Selection switch for interrupts. 1 means on and the order is LSb for IRQ0 through MSb for IRQ7.
$A34	IRQH_WorkingMask	Used internally when enumerating IRQs.
$A35	IRQH_CurrentEntry	Convenience variable informing IRQs etc which IRQ is currently being handled.
$A36-$A46	IRQH_Command_Table	16-byte table consisting of a parameter followed by the command code. Ordered by ascending IRQ number.

Countdown Timer IRQ Locations

$A4A-$A4B	CTR_V	Counter. This is the countdown timer's present value, decremented each GPIO card Timer 1 IRQ.
$A4C-$A4D	CTR_RELOAD_VAL_V	Counter reload value. Reloads only if CTR_Reload_En bit (b0) of CTR_Options ($A52) is set.

$A4E-$A4F	CTR_PERIOD_V	Counter period. This is determined to be counted down by one every PHI2 clock and after reaching 0 triggers an interrupt that decrements the CTR_V ($A4A-$A4B). Caution, Do not set this extremely low or your computer may become unresponsive.
$A50-$A51	CTR_External_vec	Contains the address of any call you wish to service upon CTR_V reaching 0. Load this before enabling it which is done by setting CTR_vec_En bit (b1) of CTR_Options ($A52)
$A52	CTR_Options	Bitfield containing flag bits controlling behaviour of the Countdown timer.

System Vector Locations

$FF60	TOE_PrintStr_vec	Prints a null terminated string to the currently selected outputs.
$FF63	TAPE_Leader_vec	Generates a tape leader signal.
$FF66	TAPE_BlockOut_vec	Transmits a block of bytes.
$FF69	TAPE_ByteOut_vec	Transmits a byte.
$FF6C	TAPE_BlockIn_vec	Reads a block of bytes from tape.
$FF6F	TAPE_ByteIn_vec	Reads a byte from tape.
$FF72	TAPE_init_vec	Initialises the tape system.
$FF75	TAPE_CAT_vec	Continually scans the tape, outputting the filename and type of any found files.
$FF78	TAPE_SAVE_BASIC_vec	**`SAVE`**s a program to tape.
$FF7B	TAPE_LOAD_BASIC_vec	**`LOAD`**s a program from tape.
$FF7E	TAPE_F_TAPE_VERIFY_BASIC	**`VERIFY`**s a program in memory against what is stored on tape. Can be accessed from TowerBASIC using the **`VERIFY`** command.
$FF90	ANSI_init_vec	Initialises the ANSI card.
$FF93	ANSI_write_vec	Writes whatever is in the accumulator to the ANSI card.
$FF96	TPB_init_vec	Initialises the Tower Peripheral Bus card.
$FF99	TPB_LPT_write_vec	Writes the contents of A to the Centronics port.
$FF9C	TPB_tx_byte_vec	Writes a byte to the tower peripheral bus.
$FF9F	TPB_block_vec	Writes a block of bytes to the tower peripheral bus.
$FFA2	TPB_ATN_handler_vec	Processes ATN signals generated by TPB peripherals.
$FFA5	TPB_rx_byte_vec	Reads a byte from the TPB bus.
$FFA8	TPB_rx_block_vec	Reads a block from the TPB bus.

$FFAB	TPB_Dev_Presence_vec	Checks for the presence of a given device on the bus.
$FFAE	TPB_Req_Dev_Type_vec	Requests the device report its device type.
$FFB1	TPB_dev_select_vec	Selects a device on the TPB. A device must not respond unless selected.
$FFB4	TPB_Ctrl_Block_Wr_vec	Writes to a devices control block.
$FFB7	TPB_Ctrl_Block_Rd_vec	Reads a devices control block.
$FFCF	AY_Userwrite_16_vec	Writes to the specified AY register and its consecutive register.
$FFD2	AY_Userread_16_vec	Reads from the specified AY register and its consecutive register.
$FFD5	AY_Userwrite_vec	Writes to the specified AY register.
$FFD8	AY_Userread_vec	Reads from the specified AY register.
$FFDB	IRQH_Handler_Init_vec	Initialises the IRQ Handler sub-system.
$FFDE	IRQH_SetIRQ_vec	Atomically sets an IRQ address in the handler table.
$FFE1	IRQH_ClrIRQ_vec	Atomically clears an IRQ to the null IRQ handler in the specified handler table.
$FFE4	IRQH_SystemReport_vec	Returns the IRQ Handler subsystem version and base address of the handler data structure.
$FFE7	INIT_COUNTDOWN_IRQ	Initialises the countdown timer IRQ.

CPU Vectors (CPU hard-wired)

$FFFA	NMI_vec	Non-Maskable-Interrupt vector.
$FFFC	RES_vec	Reset vector. This is the reset vector. The CPU takes the address here as it's start point.
$FFFE	IRQ_vec	Interrupt request vector. IRQ's jump from here.

System Soft-Switches

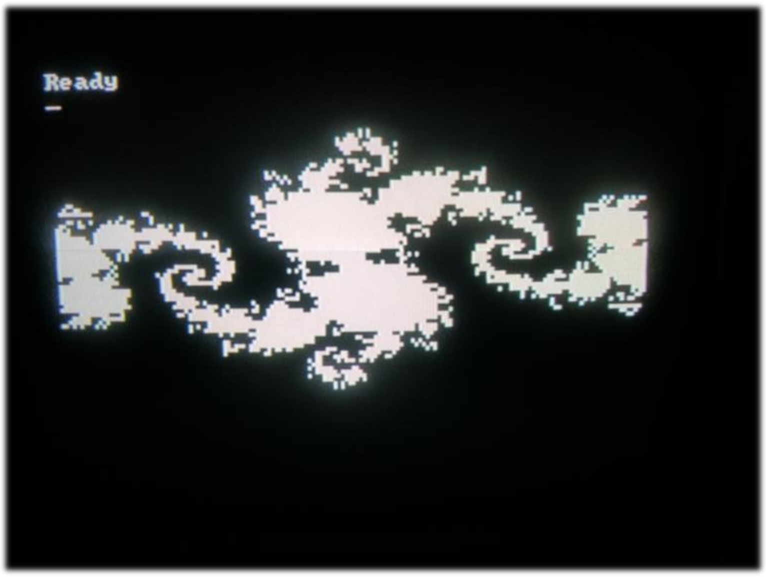
System soft switches are bits stored within system variables that control characteristics of the system such as output streams and input filtering. This section is likely to grow with revision changes.

os_outsel ($5E0)								
Bit	7	6	5	4	3	2	1	0
Function	Reserved for future uses.				ACIA2	TPB LPT	ANSI	ACIA1

os_infilt ($5E1)								
Bit	7	6	5	4	3	2	1	0
Function	Reserved for future uses.						ACIA2 LF Filter	ACIA1 LF Filter.

os_insel ($5E2)								
Bit	7	6	5	4	3	2	1	0
Function	Reserved for future uses.				ACIA2	Reserved		ACIA1

Chapter 3. The ANSI Card.


```
Ready
_
```

ANSI Card Description

ANSI stands for American National Standards Institute, and in this case, we're dealing with ANSI terminal output.

Each character is put into the card's internal memory by means of addressing the W65C22S-TPG14 versatile interface adapter on the ANSI card. This card must be set to base address C000-C00F by setting the selector wheel to 0 if one wants to access it via the TowerOS, a second ANSI card could be installed but you must drive it yourself as no OS support is given. To read or set the cards address, just use the number on the wheel as the most significant digit of a two-digit hexadecimal number and add the nIOSEL base address to it.

Refer to the Western Design Center datasheet for operation of the VIA, something which cannot be understated in its importance on the ToE as it is extensively utilised on several add-on cards.

The Avail line is connected to PA6 and indicates the cards availability for use. PA7 is the acknowledge line and flips upon receipt of any byte placed upon port B.

Therefore, the relevant addresses are as per the below table.

Address	ANSI Function
0	Output byte (Output Register B)
1	PA7 = Ack, PA6 = Avail, PA5-0 not used. (Output Register A)
2	Data Direction Register B. Should be set to $FF
3	Data Direction Register A. Should be set to $40

To write directly to the ANSI processor, one checks the Ack bit and current Avail bit are matching, only changing the content of the data byte when they do. Then, one flips the Avail line. When the ANSI processor has accepted it, both the Ack and Avail lines will match. One can go about one's merry way but may not change the contents without first checking for agreement.

The nIRQ line of the VIA is *not* connected to the system bus. If one wishes to use the VIA internal hardware to generate an interrupt, one must use a Schottky diode to wire-or to the appropriate interrupt line. There is nothing stopping one from using the internal timers however, you would just need to poll the registers in software.

Access to the ANSI card through the TowerOS is the recommended method and the following functions below are how this is achieved.

ANSI_init_vec Call Address: $FF90

Calling this address initialises the ANSI card registers. Normally you won't need this as TowerOS does this on start-up.

ANSI_write_vec Call Address: $FF93

The contents of the Accumulator is written to the ANSI card. Note that if the ANSI card is still busy, this will function will block until it has completed. There is no timeout, error condition, or filters.

System Soft switch Control

The system soft switch for this card is in os_outsel ($5E0) and is bit 1. Setting this bit causes the system to send output to the ANSI card and is on by default unless you use the ACIA build of the ToE ROM.

Controlling the Display

To control the display, one sends control codes which cause the video processor to update the display contents. There is a full set of ASCII characters including extended PC DOS characters and some limited graphics.

Other effects include doubling the width, height of the characters, and whether it is bold.

To control the character width, height and whether it is bold, one sends a character control attribute $18 (24) followed by a byte containing the following bitfield:

Character Control Attribute $18 (24) and bitfield of following byte							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Graphics	Spare	Spare	Spare	Spare	Double Height	Bold	80 Columns

Positioning the Cursor

Issuing control code $0E (14) (set column) or $0F (15) (set row) followed by the desired position achieves this goal. TowerBASIC Also has the **`LOCATE`** command which sets both x and y position.

Redefining the Cursor

Control code $02 (2) followed by the ASCII character desired defines the cursor. If the cursor is set to 0 then it is turned off. Leaving the cursor over a graphical area causes the undesirable effect of making graphical area to flash.

Accessing the PC DOS Characters (0 (0) – $1F (31))

To use these extra characters, send $1A (26) first, this causes the next character to be displayed as the specified PC DOS character.

Simple Graphics

The pixel resolution is 160 across by 100, the origin of which is top left at 0,0 up to 159,99 in the bottom right.

One may issue a SetPixel command $5 (5) or ClearPixel $6 (6) command followed by x then y. TowerBASIC also has the **`PLOT`** command to set or clear a pixel.

Please note that there is currently no way to read back what you have on the screen so you will need to keep track of the salient details.

Writing a Pixel Pattern Directly

Internally, each character cell can be loaded with a 2 by 4 pattern by first sending $80 (128), then the bit pattern is defined by the bit position of the character cell.

TowerBASIC commands for graphics

There are three commands currently implemented that assist in the use of the ANSI card.

```
CLS
```

This clears the screen to a useable state.

```
LOCATE x,y
```

Sets the print cursor to position x, y.

```
PLOT m,x,y
```

If m is 1 then this sets a pixel at x,y pixel position, but if m is 0 then it clears that pixel.

Video Control Codes

$01 (01)	Cursor home	*(Standard ASCII)*
$02 (02)	Define cursor character (2nd byte is the cursor character, or 0 to turn off)	
$03 (03)	Cursor blinking	
$04 (04)	Cursor solid	
$05 (05)	Set graphics pixel (next two bytes = x,y)	
$06 (06)	Reset graphics pixel (next two bytes = x,y)	
$08 (08)	Backspace	*(Standard ASCII)*
$09 (09)	Tab	*(Standard ASCII)*
$0A (10)	Linefeed	*(Standard ASCII)*
$0C (12)	Clear screen	*(Standard ASCII)*
$0D (13)	Carriage return	*(Standard ASCII)*
$0E (14)	Set column 0 to 79 (2nd byte is the column number) or 0 to 39 for a 40 char line	
$0F (15)	Set row 0 to 24 (2nd byte is the row number)	
$10 (16)	Delete start of line	
$11 (17)	Delete to end of line	
$12 (18)	Delete to start of screen	
$13 (19)	Delete to end of screen	
$14 (20)	Scroll up	
$15 (21)	Scroll down	
$16 (22)	Scroll left	
$17 (23)	Scroll right	
$18 (24)	Set font attribute for the current line	
$1A (26)	Treat next byte as a character (to allow PC DOS char codes 1 to 31 to be displayed on screen)	
$1B (27)	ESC - reserved for ANSI sequences	
$1C (28)	Cursor right	
$1D (29)	Cursor Left	
$1E (30)	Cursor up	
$1F (31)	Cursor down	
$20 (32) to…		
$7E (126)	Standard ASCII codes	
$7F (127)	Delete	
$80 (128) to…		
$FF (255)	PC (DOS) extended characters	

Chapter 4. The Single ACIA Card.

Single ACIA Card Description

Serial communications are provided to permit headless usage, for serial terminals, modems, and many other devices to be connected to the Tower of Eightness. Most notably is keyboard input, the PS2 to Serial interface being the easiest way to control the ToE. Without some way to communicate with the ToE it would be useless and so this is one of the essential interfaces. The default port setting is 9600 baud, 1 start bit, 1 stop bit, no parity and RTS/CTS hardware handshaking.

The 65C51-4P or equivalent Asynchronous Communications Interface Adapter which ACIA stands for, bridges the gap between the system bus and RS232 serial. This card provides a 9 pin RS232 port at the correct signalling levels.

Mark is -Ve and Space is +Ve. Serial data always starts with a start bit, 5 to 8 data bits depending on the setting and at least one stop bits at a regular rate known as the bitrate. The bit rate is not the baud rate as can be realised by considering that the start bit and stop bits take up time also, therefore the baud rate is less than the bitrate by necessity.

Provided below is the pinout of the serial IO DB9 connector which is wired as Data Terminal Equipment. The only handshaking lines provided however are Request-To-Send and Clear-To-Send.

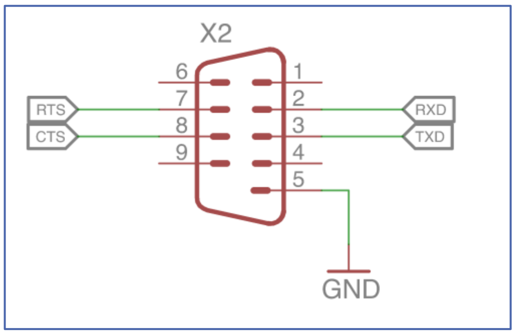


Figure 1

Setting the IO Address

To set the IO address one moves jumpers on JP3 to either closed or open positions. Open is a 1 and closed is a 0. There are six of them and they form the top six bits of the IO address offset from nIOSEL which is at $C000. This card occupies four locations in IO address space. The default base address and the one the Tower OS will use is at $C010 meaning that all the jumpers should be set to CCOCCC from back edge to front.

The least significant bit is nearest the bus connector and the most significant furthest away. Whatever binary value is jumpered, just multiply it by four and add the nIOSEL base address.

It is possible to add several ACIA cards, and even mix with dual ACIA cards. but they must not share IO addresses with anything else and at least *one* must be at $C010 as it receives the keyboard input.

System Soft switch Control

The system soft switch for output to this card is in os_outsel ($5E0) and is bit 0. Setting this bit causes the system to send output to the ACIA card and is off by default unless you use the ACIA build of the ToE ROM.

There is also a system soft switch for input filtering, which is os_infilt ($5E1). Bit 0 when set to 1 (default is set) strips out linefeed characters ($A).

ToE ACIA Configuration Variables

$5E3	ACIA1_cfg_cmd	The load values for configuring ACIA1's command register upon initialisation.
$5E4	ACIA1_cfg_ctrl	The load values for configuring the ACIA1's control register upon initialisation.

The following variables are only applicable if a second ACIA is present at $C014.

$5E5	ACIA2_cfg_cmd	The load values for configuring ACIA2's command register upon initialisation.
$5E6	ACIA2_cfg_ctrl	The load values for configuring ACIA2's command register upon initialisation.

ACIA Vectors

TowerOS provides the following vectors for direct access to the ACIAs but the ACIA2 vectors are only relevant if you have a second ACIA at $C014.

ACIA_INI_SYS_vec ($FF42)	Initialises the ACIA system to default values. 8N9600 for both ports.
ACIA1_init_vec ($FF45)	Initialises ACIA1 to the values in ACIA1_cfg_ctrl ($5E4) and ACIA1_cfg_cmd ($5E3) system variables. Changing these variables and re-initialising the ACIA can changes the settings.
ACIA2_init_vec ($FF48)	Initialises ACIA2 to the values in ACIA2_cfg_ctrl ($5E6) and ACIA2_cfg_cmd ($5E5) system variables. Changing these variables and re-initialising the ACIA can changes the settings.
ACIA1out_vec ($FF4B)	Waits until ACIA1's transmit buffer is empty then puts the contents of the accumulator into the transmit buffer.
ACIA2out_vec ($FF4E)	Waits until ACIA2's transmit buffer is empty then puts the contents of the accumulator into the transmit buffer.

Chapter 5. The Dual ACIA Card.

Dual ACIA Card Description

Serial communications are provided to permit headless usage, for serial terminals, modems, and many other devices to be connected to the Tower of Eightness. Most notably is keyboard input, the PS2 to Serial interface being the easiest way to control the ToE. Without some way to communicate with the ToE it would be useless and so this is one of the essential interfaces. The default port setting is 9600 baud, 1 start bit, 1 stop bit, no parity and RTS/CTS hardware handshaking.

The 65C51-4P or equivalent Asynchronous Communications Interface Adapter which ACIA stands for, bridges the gap between the system bus and RS232 serial. This card provides a 9 pin RS232 port at the correct signalling levels.

Mark is -Ve and Space is +Ve. Serial data always starts with a start bit, 5 to 8 data bits depending on the setting and at least one stop bits at a regular rate known as the bitrate. The bit rate is not the baud rate as can be realised by considering that the start bit and stop bits take up time also, therefore the baud rate is less than the bitrate by necessity.

Provided below is the pinout of the serial IO DB9 connectors which are wired as Data Terminal Equipment. The only handshaking lines provided however are Request-To-Send and Clear-To-Send.

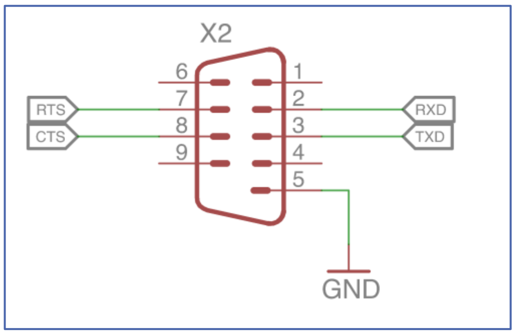


Figure 1

Setting the IO Address

To set the IO address one sets the DIP switches to the appropriate binary address. There are six of them and they form the top six bits of the IO address offset from nIOSEL which is at $C000. This card occupies two sets of four locations in IO address space. The default base address and the one the Tower OS will use for primary input is at $C010 meaning that the appropriate DIP switch setting is 00100. The second ACIA port should be set to $C014 with the DIP switches set to 00101.

The least significant bit is nearest the bus connector and the most significant furthest away. Whatever binary value is jumpered, just multiply it by four and add the nIOSEL base address.

It is possible to add several ACIA cards, but they must not share IO addresses with anything else and at least *one* must be at $C010 as it receives keystrokes upon start up.

System Soft switch Control

The system soft switches for output to this card are in os_outsel ($5E0). Bit 0 controls the primary ACIA and bit 3 controls the secondary ACIA. Setting these bits causes the system to send output to the selected ACIA and ACIA 1 is on off default unless you use the ACIA build of the ToE ROM.

There are also system soft switches for input filtering, which are in os_infilt ($5E1). Bit 0 when set to 1 (default is set) strips out linefeed characters ($A) on ACIA 1 and bit 1 (on by default) filters ACIA 2 in the same manner.

ToE ACIA Configuration Variables

$5E3	ACIA1_cfg_cmd	The load values for configuring ACIA1's command register upon initialisation.
$5E4	ACIA1_cfg_ctrl	The load values for configuring the ACIA1's control register upon initialisation.
$5E5	ACIA2_cfg_cmd	The load values for configuring ACIA2's command register upon initialisation.
$5E6	ACIA2_cfg_ctrl	The load values for configuring ACIA2's command register upon initialisation.

ACIA Vectors

TowerOS provides the following vectors for direct access to the ACIAs.

ACIA_INI_SYS_vec ($FF42)	Initialises the ACIA system to default values. 8N9600 for both ports.
ACIA1_init_vec ($FF45)	Initialises ACIA1 to the values in ACIA1_cfg_ctrl ($5E4) and ACIA1_cfg_cmd ($5E3) system variables. Changing these variables and re-initialising the ACIA can changes the settings.
ACIA2_init_vec ($FF48)	Initialises ACIA2 to the values in ACIA2_cfg_ctrl ($5E6) and ACIA2_cfg_cmd ($5E5) system variables. Changing these variables and re-initialising the ACIA can changes the settings.
ACIA1out_vec ($FF4B)	Waits until ACIA1's transmit buffer is empty then puts the contents of the accumulator into the transmit buffer.
ACIA2out_vec ($FF4E)	Waits until ACIA2's transmit buffer is empty then puts the contents of the accumulator into the transmit buffer.
ACIA1in_vec ($FF51)	Checks ACIA1's input buffer for received data and if present loads it into the accumulator. If

	no data is present, then the accumulator is set to 0. The carry flag is set if successful, otherwise it is cleared.
ACIA2in_vec ($FF54)	Checks ACIA2's input buffer for received data and if present loads it into the accumulator. If no data is present, then the accumulator is set to 0. The carry flag is set if successful, otherwise it is cleared.

Chapter 6. The GPIO Card.

GPIO Card Description

This card is basically both ports, complete with CA1, CA2, BA1 and BA2 broken out into two identical sockets. The IRQ line is also connected to assist the programmer with its use.

For those wishing to attach an external peripheral, be it home-made or otherwise, the GPIO card implements not one, but two BBC Micro equivalent user ports. Port B is notably however, used for the cassette and joystick interface and if used for other things may clash with other things. This is true only of this card if it is mapped into a base address of $C040.

General Configuration

To set its address, one set the jumpers in accordance with the upper nybble of the lower byte of its address and then adds on the nIOSEL offset which is $C000.

Placing the card on a flat surface with the bus connector to the left, moving a jumper to the left represents a binary 0 and to the right is binary 1. CID1 is the least significant bit and CID4 is the most significant bit so the default from CID1 to 4 is left, left, right, left.

Usage

There are only calls to use port B with the cassette interface and port A with I^{2}C and SPI. To use these, please read the chapter entitled Cassette and Joystick Interface for the cassette, or the chapters on I^{2}C and SPI. The pins for I^{2}C and SPI are not configured until their respective engines are initialised. To take full advantage of this card one needs to write directly to the registers of its VIA chip and so one is directed to the WDC65C22S6-TPG14 datasheet. This is especially important with regards to the VIAs electrical specification as exceeding those may lead to damage to the card and even in some cases the ToE itself.

The some of the pins of the VIA have special features specific to that pin and internal to the VIAs are timers, counters, handshake lines, pulse generators etc.

Pinout

Port A. Base address offset 1, Data Direction Register Offset 3.

19	17	15	13	11	9	7	5	3	1
0V	0V	0V	0V	0V	0V	0V	0V	+5V	+5V
20	18	16	14	12	10	8	6	4	2
PA7	PA6	PA5	PA4	PA3	PA2	PA1	PA0	CA2	CA1

Port B. Base address offset 0, Data Direction Register Offset 2.

19	17	15	13	11	9	7	5	3	1
0V	0V	0V	0V	0V	0V	0V	0V	+5V	+5V
20	18	16	14	12	10	8	6	4	2
PB7	PB6	PB5	PB4	PB3	PB2	PB1	PB0	CB2	CB1

Be aware that neither of these ports is hot pluggable or protected by any kind of static, or out of specification protection except for the VIAs internal diodes. Also, there is no fuse or other kind of current limiting on the 5V lines. It is up to the user to ensure that the bus is not abused.

Chapter 7. The AY-3-8912A Sound Card V2.

"Music speaks what cannot be expressed,
sooths the mind and gives it rest,
heals the heart and makes it whole,
and flows from heaven to the soul."

AY Soundcard Description

From the above prose, you might gather that this is a *sound card* and so it is that you may, with minimal skill produce at least some beeps and squarks. With great skill the chip this sound card is based on has produced some very joyous tunes rejoiced by many a kid of the 80's.

The Tower of Eightness has a maximum clock speed primarily limited by its peripheral set. As the processor has a design limit of 14MHz and the backplane is good for perhaps 10MHz, only cards that can handle the system clock frequency and do not unduly load the bus may operate correctly as part of the system. One such device to limit the system speed is the AY-3-8912A sound chip which here is clocked locally at 1.842MHz. To that end, this card isolates the sound chip from the main system bus to permit maximum system operating speed. This isolation is achieved by the use of an on card W65C22S VIA chip.

This VIA is mapped into $C0E0 to $C0EF by convention, thereby allowing programs to directly drive it for maximum performance. This is necessary as sound is popular for games amongst other things.

The nIRQ line is connected so that one may use interrupts.

Port B (Offset 0) is connected to the data lines of the AY-3-8912A, and Port A (Offset 1) is used for control lines. PA0 is connected to BC1 whilst PA1 is connected to BDIR. BC2 is tied high therefore creating a simplified bus for the AY chip.

PA0 and PA1 should be set as outputs and their logic should be driven as listed below.

It is important to note that there is currently no logic protection to prevent bus contention between the AY and the VIA chip and the onus is on the programmer to maintain harmony and protect the logic from stressful conditions. More advanced logic will be brought forward at a later date but for now this is all that is required. This has been done with the Oric-1 and Oric Atmos computers and many of those have survived more than 30 years so this is a proven adequate solution.

When BDIR is low, the AY bus is readied for output of its internal registers, and when high it is ready to receive from the bus.

BC1 should remain low until Port A is configured as an input with BDIR low or an output with appropriate data on it and BDIR high. BC1 should be strobed to make the transfer.

The following table should clarify this: -

Table of Bus States

BC1	BDIR	State
0	0	Inactive.
1	0	Read from AY. The AY selected register is on the data lines.
0	1	Write to AY. The data lines are transferred to the AY
1	1	Latch Address. Write register address to AY from data lines.

For the full AY-3-8912A hardware specification, refer to the Microchip datasheet.

Configuration

The only configuration that can be done to this card is to set its base address offset by means of the provided jumpers. The four jumpers are arranged such that the least significant bit is nearest the VIA and the most significant nearest the edge of the card. These jumpers form a binary address that is the most significant four bits of the offset from nIOSEL. Leave the base address at $C0E0 unless this is an additional sound card since software is being targeted at the above agreed address and firmware is being written to use it too.

Usage from TowerBASIC

There are two commands to make sounds and music on the AY, **SOUND** and **ENVELOPE**.

SOUND takes the form below.

SOUND channel, period, volume

where channel is 0 to 6. 0 through 2 are the sound channels A, B and C whilst 3 through 5 is using the same output channels but for noise.

For tones, period is any value from 0 to 4095 with the period being calculated as being 1.842MHz/16/period.

Volume is fixed between 0-15 or if 16 used, it is defined by the **ENVELOPE** period and mode.

ENVELOPE defines the period and modulation mode of any waveform set to volume 16. The envelope period is in the range of 0-65535 and is calculated as 1.842MHz/256/period. It is unfortunate that the AY contains only one envelope generator and that this affects all sound channels so set equally. If you need to control a sound channels envelope with a differing mode or something more exotic, wouldn't go far wrong with an interrupt in assembly language, though this negates the use of TowerBASIC whilst the interrupt is in use and consumes further resources.

ENVELOPE period, mode

Here is an example which plays a bell sound at about C5 (523.25Hz).

```
10 SOUND 1, 220,16
20 ENVELOPE 24000,0
```

The Mode Parameter.

The mode parameter is a bitfield containing four bits that control the envelope generator of the AY.

Mode parameter							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
				Continue	Attack	Alternate	Hold

Hold (bit 0) when set, limits the envelope generator to one cycle when set, the value at the end of the cycle being held at the end of the cycle.

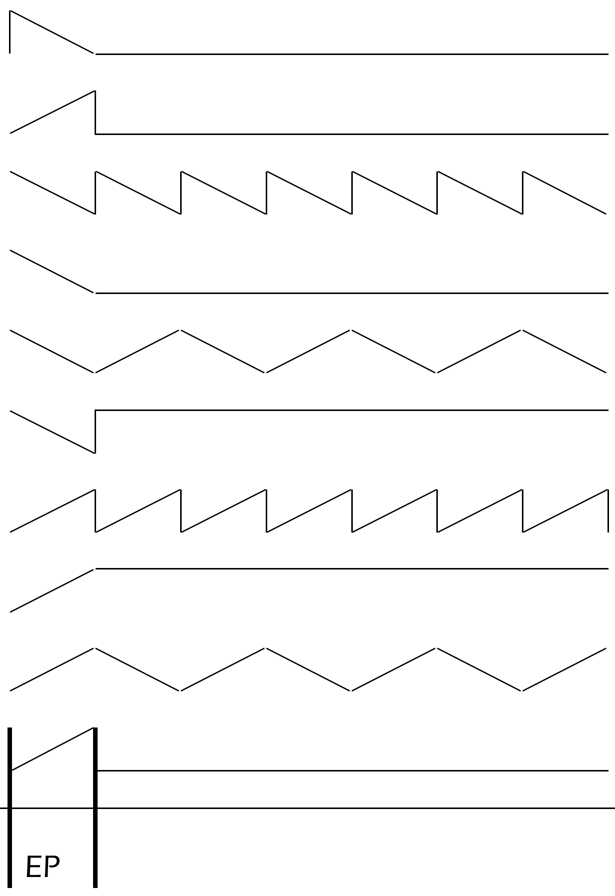
Alternate (bit 1) when set, causes the envelope generator to reverse the direction of its cycle when it reaches its end. It thus produces an up-down effect.

Attack (bit 2) when set, causes the envelope generator to count up, and when clear causes it to count down, producing a decay.

Continue (bit 3) when set, causes the cycle pattern to be defined by the hold bit, but when clear causes the counter to reset to 0 after one cycle.

Envelope Table.

Envelope Shape/Cycle Operation				
Mode bits (AY reg 13)				
B3	B2	B1	B0	
Continue	Attack	Alternate	hold	Graphic Representation of Envelope Generator Output.
0	0	X	X	
0	1	X	X	
1	0	0	0	
1	0	0	1	
1	0	1	0	
1	0	1	1	
1	1	0	0	
1	1	0	1	
1	1	1	0	
1	1	1	1	



EP is the envelope period (duration of one cycle).

The envelope period is limited to 16 different logarithmic values and as such the envelope has significant jumps at the higher volume levels. Luckily, human hearing is also logarithmic.

Register Writes to the AY

To write directly to an AY register one simply pokes the appropriate register address to AY_Reg ($A00) and data to AY_Data ($A01-$A02) and calls the appropriate function call. It is of course possible to drive the AY by directly controlling the W65C22 on the AY card this in fact necessary if you change its address or add a second card. It should be noted that it is far quicker to make these calls than it is to POKE the registers directly, and quicker (and easier) still for many use cases to use the provided TowerBASIC commands. Below is a list of currently implemented function call vectors.

List of AY function call vectors

AY_Userwrite_16_vec ($FFCF)	Takes a 16-bit word and puts it in the registers specified by AY_Reg ($A00) and the consecutive register.
AY_Userread_16_vec ($FFD2)	Fetches a 16-bit word from the registers specified by AY_Reg ($A00) and the consecutive register and places it in AY_Data ($A01-$A02).
AY_Userwrite_vec ($FFD5)	Takes a byte at AY_Data ($A01) and puts it in the register specified by AY_Reg ($A00).
AY_Userread_vec ($FFD8)	Fetches a byte from the register specified by AY_Reg ($A00) and places it in AY_Data ($A01, low byte). The high byte is not overwritten.
AY_Init_vec ($FFCC)	Calling this initialises the AY-3-8912A and its associated VIA.

AY System Memory Locations

AY_Reg ($A00)	Pointer to the AY register to be either written to or read from.
AY_Data ($A01-$A02)	Used for transferring data to the above pointed register(s). $A01 contains the low byte and $A02 the high one. Used by the AY user read and write functions provided to make the users' usage easier.
AY_Mask ($A03)	Holds a shadow copy of which channels are selected.
AY_Channel ($A04)	The retrieved copy of the channel specified by the TowerBASIC command **SOUND**.
AY_Period ($A05-$A06)	The retrieved copy of the period parameter of either of TowerBASICs **SOUND** or **ENVELOPE** commands.
AY_Volume ($A07)	The retrieved copy of the volume specified by the TowerBASIC command **SOUND**.
AY_Envelope_Period ($A08-$A09)	The retrieved copy of the period specified by the TowerBASIC command **ENVELOPE**.

AY_Envelope_Mode ($A0A)	The retrieved copy of the envelope mode specified by the TowerBASIC command **`ENVELOPE`**.

Chapter 8. The Tape & Joystick Interface.

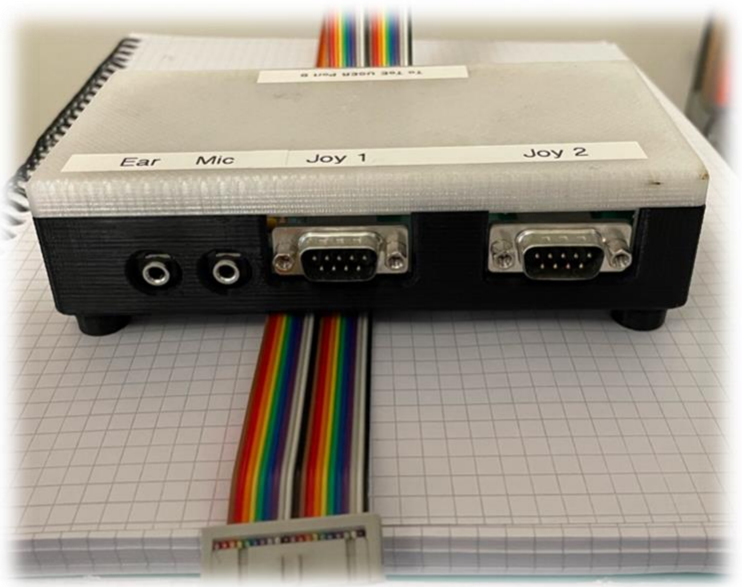


Figure 3. Tape and Joystick Interface Version 2.

Tape and Joystick Interface Description

Tape loading, saving and dual Atari style joystick interface are supplied using this interface. It is designed to be connected to a GPIO port and the TowerOS provides support for it through Port B of the GPIO card mapped to the base address of $C040.

One should keep bits 0 and 7 of DDRB $C042 set when using it as these are used to drive the tape output and select which joystick will be read.

The interface is driven by modulating bit 7 to generate a tape signal for **SAVE** operations. Conversely, bit 6 is used to monitor the state of the audio coming in for **LOAD** operations.

The tape signal coming in is cleaned up by a biased Schmitt trigger buffer amplifier and fed back to the VIA on pin 6.

The TowerOS provides several system vectors that can be called and has extensive memory locations associated with this interface which will need to be used to make the most of it and are documented later.

To use the joystick interface, one either clears bit 0, selecting joystick port 1 (left) or set it, selecting joystick port 2 (right). The state of the joystick can then be read on Port B bits 1 through 5.

An example fire button read would go something like this: -

```
10 F = NOT(BITTST($C040,5))
```

The observant amongst you will already have noticed the **NOT** in that little snippet of TowerBASIC. That is because the joystick ports supply negative logic. A 0 means that switch is pressed.

One should *never* make the joystick bits outputs as that would prevent access to *both* joysticks on the affected bits. It won't however, break anything.

Below is a table of bits associated with the joystick port: -

Tape and Joystick Bit Usage

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Tape Out	Tape In	Fire	Right	Left	Down	Up	JS Select

Tape Support in TowerOS

TowerOS supports loading and saving of TowerBASIC from simple **`LOAD`** and **`SAVE`** commands, but for the advanced user there are system calls and memory locations associated. It should be noted that when you see **`XXXX XXXX`** that means that the file is at address **`XXXX`** hexadecimal and is **`XXXX`** hexadecimal long in that order. Leading zeros are left in to keep the output of '**`CAT`**' neat and regular.

To load an TowerBASIC program simply type '**`LOAD`** `"<optional filename>"¶`' and play the cassette. Specifying the file name ensures that *only* that file will be loaded, and the quotes may not be omitted. If the first character of the filename is '**`!`**' then it will automatically run upon successful load. This feature can be disabled by clearing the TAPE_AutoRUN_En bit (b1) of V_TAPE_Config ($948). Breaking out of a **`LOAD`** can be achieved by pressing ^C.

Under normal circumstances, the display will tell you '**`Searching`**...' whilst it is looking for a header, '**`Found BASIC: XXXX XXXX`** `"<Filename>"`' when it finds the specified file and '**`Loading`**...' whilst it is loading and '**`Ready`**' when it has completed loading. Not giving a file name causes it to load the *first* file it finds. Should the load encounter an error, you will get the message '**`Tape Loading Error.`**'.

To save an TowerBASIC program one types '**`SAVE`** `"<filename>"¶`' whilst the cassette is recording. You must include a filename of between 1 and 16 characters in length when saving a file. No checks are made for what those characters are except that a null is used to terminate the string in TowerTAPE FS, so avoid this and other unfortunate characters where possible. *Remember, the name you use when saving is the name that will be used to load your program.* If it is too awkward, you may be making a rod for your own back, though clever tricks are also possible this way.

The system will tell you it is '**`Saving XXXX XXXX`** `"<Filename>"`' and when done will drop you to the **`Ready`** prompt. Adding a '**`!`**' to the start of your chosen filename prompts the system to run it when loaded back. This applies to both TowerBASIC programs and binaries. To make a binary execute, ensure your code can run at the location you are loading it to and that it will execute from the first byte. This means that if you load to address xx, it will execute from address xx.

Given the nature of cassette storage, errors are a concern and to ensure the integrity of the saved file, the '**`VERIFY`** `"<optional filename>"¶`' command is included. This will operate very much like the **`LOAD`** `""` command, but instead reports on the consistency of the **`SAVE`**d content with that in RAM, breaking with the **`VERIFY Error`** the moment it encounters a byte that either can't be read or does not match with the one in memory. This step whilst optional, should not be ignored. Many people have been reduced to tears over lost files.

When one gives a specific file name to **LOAD** or **VERIFY**, the system ignores any files that do not match the name given or of another file type.

If you should receive an error message, then remedial action will be required. The following error messages and their meanings are listed below.

- Header error. Retrying.
    - This means loading error has occurred with the header. TowerTAPE filing system lets you know so you can rewind to the start and try again or escape back to TowerBASIC if you give up.
- Tape loading error.
    - This means loading error has occurred with the file block. TowerTAPE filing system drops you back into the TowerBASIC Ready prompt letting you know of the failure.
- Verify Error.
    - Receiving this indicates that there is something wrong with the program stored on the cassette and that it will need to be re-done. Consider the quality of the equipment and media in use if this becomes too much of a nuisance.
- Filename Too Long
    - Filenames must be no longer than 16 characters and must be present when saving a file.

Listing the Contents of Cassette.

'**CAT¶**'

Starts the catalogue system, printing each file and its type as it is found. This command needs to be escaped by pressing ^C to return control to the system but does not cause a warm start or print upon return. This is so that it may be used from within a program without interrupting flow and it is therefore advised that you provide for this otherwise you may need to perform a restart of the system.

CAT displays '**Searching**…' followed by the line '**Found BASIC: XXXX XXXX** "<Filename>"' for each filename found.

Binary File Handling.

To save binary data one does as per the following example: -

'**SAVE** "<filename>" **$A000, $100¶**'

This would save $100 bytes of data starting at address $A000. If your filename begins with an ! then execution will commence at the load address unless the TAPE_AutoEXEC_En bit (b2) of V_TAPE_Config ($948) is cleared or ^C is used to break and return to immediate mode. To load in binary data, one must specify a load address as in the below example: -

Loading is accomplished as follows: -

'**LOAD** "<optional filename>" **$A000¶**'

And to verify the integrity of the data saved: -

'**VERIFY** "<optional filename>" **$A000¶**'

Note that there is no comma separating the address from the filename, it is not needed. One does have to specify the load address at present, as there is currently no other way to indicate that the binary file should be loaded at other than its original address. This feature may be subject to change.

Pressing ^C whilst verifying will break into immediate mode.

List of TowerTAPE Filing System Calls

$FF63	TAPE_Leader_vec
$FF66	TAPE_BlockOut_vec
$FF69	TAPE_ByteOut_vec
$FF6C	TAPE_BlockIn_vec
$FF6F	TAPE_ByteIn_vec
$FF72	TAPE_init_vec
$FF75	TAPE_CAT_vec
$FF78	TAPE_SAVE_BASIC_vec (to be used from TowerBASIC)
$FF7B	TAPE_LOAD_BASIC_vec (to be used from TowerBASIC)
$FFBA	F_TAPE_Setkbd_vec

$FF63 TAPE_Leader_vec

Calling this vector causes the generation of a leader tone.

$FF66 TAPE_BlockOut_vec

This is the vector call address for F_TAPE_BlockOut. V_TAPE_BlockSize ($900) contains the number of bytes to write and TAPE_BlockLo ($E5) and TAPE_BlockHi($E6) contain the block pointer.

This function returns having modified TAPE_BlockLo ($E5) and TAPE_BlockHi ($E6).

$FF69 TAPE_ByteOut_vec

Whatever byte is in the accumulator when this function is called is output.

$FF6C TAPE_BlockIn_vec

Calls to this function require parameters to be loaded into specific memory locations. point to the start of the block to be read. V_TAPE_BlockSize ($900-$901) specifies how many bytes will be read and TAPE_BlockLo ($E5) and TAPE_BlockHi ($E6) contain the write pointer used by this function. No additional information is read.

This function drops through before completion if any character is received from the ACIA card or an overrun error occurs and the state of the engine upon exit is reported in **TAPE_BlockIn_Status** ($90D)

This function returns having modified TAPE_BlockLo ($E5) and TAPE_BlockHi ($E6) which it uses these incrementally point to the byte it is writing to memory at any given moment.

$FF6F TAPE_ByteIn_vec

Attempts to read a byte from the tape and return it in **TAPE_ByteReceived** ($90B). If a byte is received from the ACIA whilst it is in progress or if an overrun error occurs this function will exit reporting its status in **TAPE_RX_Status** ($909).

$FF72 TAPE_init_vec

Initialises the TowerTAPE filing system. This is called by TowerOS on bootup and only needs to be called if the TowerTAPE filing system needs to be re-initialised.

$FF75 TAPE_CAT_vec

Starts the tape system cataloguing routine. Can be called from Assembly language or by using the TowerBASIC keyword CAT.

$FF78 TAPE_SAVE_BASIC_vec

Causes the TowerBASIC program or specified memory range (as a binary file) to be saved. This should not be called from anywhere except TowerBASIC as it is carefully designed to work as part of TowerBASIC.

$FF7B TAPE_LOAD_BASIC_vec

Causes the attempted loading of an TowerBASIC program or binary file from tape. This should not be called from anywhere except TowerBASIC as it is carefully designed to work as part of TowerBASIC.

$FF7E TAPE_VERIFY_BASIC_vec

Causes the attempted verification of an TowerBASIC program or binary stored on tape. This should not be called from anywhere except TowerBASIC as it is carefully designed to work as part of TowerBASIC.

$FFBA F_TAPE_Setkbd_vec

Sets up the vector for checking the keyboard input during any block read operation. This means it is called upon **`LOAD`**, **`VERIFY`** and **`CAT`** operations.

TowerTAPE Filing System, System Variables

Below is a list of system variables with their associated address and size. These were grabbed direct from a spreadsheet which is also available.

System Variable	*Address*	*Number of Bytes*
TAPE_BlockLo	$E5	1
TAPE_BlockHi	$E6	1
V_TAPE_BlockSize	$900	2
TAPE_temp2	$902	1
TAPE_temp3	$903	1
TAPE_temp4	$904	1
TAPE_LineUptime	$905	1
TAPE_Demod_Status	$906	1
TAPE_Demod_Last	$907	1
TAPE_StartDet	$908	1
TAPE_RX_Status	$909	1
TAPE_BitsToDecode	$90A	1
TAPE_ByteReceived	$90B	1
TAPE_Sample_Position	$90C	1
TAPE_BlockIn_Status	$90D	1

TAPE_Header_Buffer $90E 28

TAPE_HeaderID	$90E	4
TAPE_FileType	$912	1
TAPE_FileSizeLo	$913	1
TAPE_FileSizeHi	$914	1
TAPE_LoadAddrLo	$915	1
TAPE_LoadAddrHi	$916	1
TAPE_FileName	$917-927	17
TAPE_ChecksumLo	$928	1
TAPE_ChecksumHi	$929	1

Remainder of TowerTAPE System Variables

TAPE_CS_AccLo	$92A	1
TAPE_CS_AccHi	$92B	1
V_TAPE_Phasetime	$92C	1
V_TAPE_Sample_Offset	$92D	1
V_TAPE_Bitlength	$92E	1
V_TAPE_bitcycles	$92F	1
V_TAPE_Verify_Status	$930	1
V_TAPE_Fname_Buffer	$931-$942	17
V_TAPE_LOADSAVE_Type	$943	1
V_TAPE_Address_Buff	$944-$945	2
V_TAPE_Size_Buff	$946-$947	2
V_TAPE_Config	$948	1
TAPE_KBD_vec	$949-$94B	3

V_TAPE_Config has at present two bits for controlling the file system, with only TAPE_AutoRUN_En for controlling execution of BASIC programs and TAPE_AutoEXEC_En for binaries. ParityOn is planned for implementation at time of modulation scheme amendment.

V_TAPE_Config Bit Usage ($948)

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Function						TAPE_AutoEXEC_En	TAPE_AutoRUN_En	ParityOn
Default	0	0	0	0	0	0	1	0

TowerTAPE File Modulation Scheme

Each byte is encoded a series of bursts of carrier. A presence of carrier signifies a 1 and an absence a 0. Each burst of carrier is 16 cycles at 4KHz.

Each byte is structured as follows: -

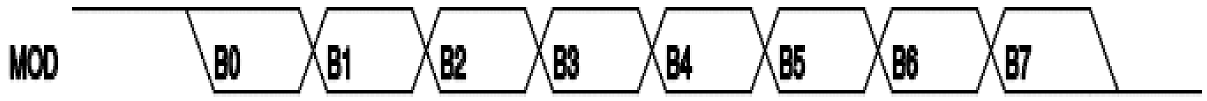


Figure 4 Bit Order for Tape Byte

Chapter 9. The V2 Memory Board.

Memory Bank Structure on the ToE

The ToE organises its memory into four groups of two banks of memory of 16 kibibytes each. Each bank group has a selection bit associated with it in a write only register located at address $C0FF. Writes to this register should be handled with great care as to not inadvertently page out something you are using at that time. Since many things you might need are located in the bottom and top banks, these are most likely to be of use to the machine code programmer and unlikely to be of use to anyone programming in TowerBASIC. The banks with the best outcome to the user of TowerBASIC are the middle ones as they can be excluded from use by TowerBASIC at boot time or by careful reconfiguration later.

This register is initialised to 0 at reset placing the lower half of each memory IC into view. For now, the upper four bits should be set to 0 whenever writing to this register as this is reserved for later expansion.

Banks 0 through 2 are RAM and bank 3 is the ToEs ROM containing TowerOS and TowerBASIC.

Although bank 3 consists of 32 kibibytes of space, the address range $C000 to $C0FF is put aside for memory mapped hardware and is inaccessible. This constitutes a loss of just half a kibibyte. In a system with 96 kibibytes of RAM and 32 kibibytes of ROM. A small price to pay for such a generous and fully decoded IO space!

Jumper Selection

There are two jumpers on this card, the one nearest the bus connector (JP4), is to allow the use of 27 series 16K EPROMs and should be set 1-2 (back) for 27 series, or 2-3 (front) for 28C256 EEPROMs.

The other jumper (JP5) is a write protect. One cannot state enough that this should be left write protected under normal circumstances to avoid crashes and corruption of the ROM. Position 1-2 (back) is write-protected and 2-3 (front) allows writes to occur.

Firmware Update Guidance

To write to the EEPROM, one must use a bootloader as write times are somewhat in excess of normal access times and the data lines contain write status information whilst a write is being attempted. The CPU would attempt to execute this status information as instructions if code was being executed from the ROM at this time!!

Inadvertent writes will not cause a crash when write protect is on.

Chapter 10. The CPU Card (V2).

CPU Card V2 Description

Central to the Tower of Eightness is its processor. The WDC65C02-TPG14 processor is a CMOS microprocessor with an eight-bit wide data bus and a sixteen-bit wide address bus. It executes single byte opcodes at typically two to three processor cycles per instruction and does this at up to 14MHz. The Tower bus being a backplane for various unknown addons has required the CPU to be limited to 4MHz and so the on-board oscillator produces 4, 2 or 1MHz as selected by a set of jumpers.

As can be seen from Figure 3, the board has four positions on a header labelled 1 through 4 alongside some text informing one of the available speeds. Connecting across jumper position 1 will give 1MHz operation, 2 will give 2MHz, and 3 will give 4MHz from the divider circuit. Position four is for connecting an external clock to the system bus and *must* not be shorted or the clock line will be tied to ground!

The recommended position is as fast as your hardware will allow. Most of the time this is 4MHz. There is also a header which provides LED output for the status of the IRQ and NMI lines to assist the programmer with interrupts. For the assembly language programmer or the hardware developer, the WDC65C02 datasheet is a must read and is included. For the TowerBASIC user, it is usually enough to know how fast this processor is running.

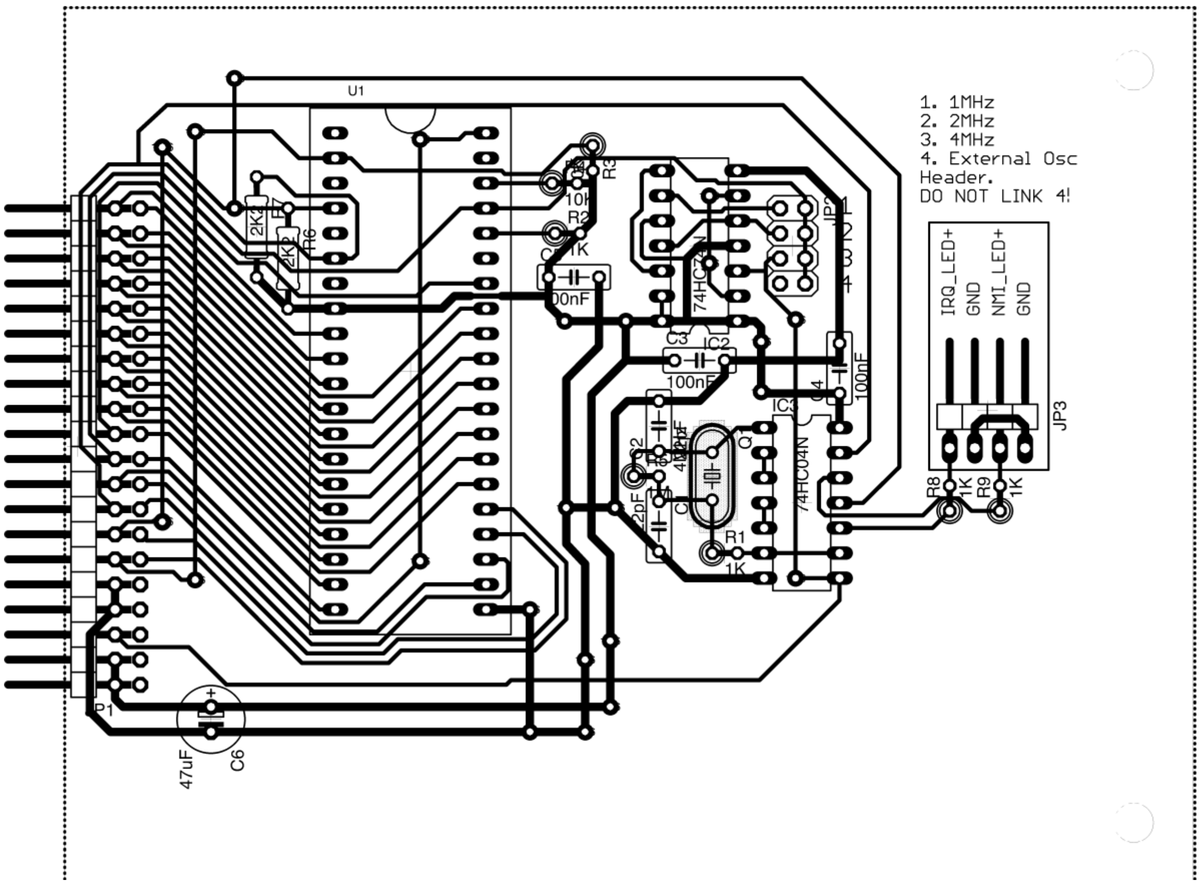


Figure 3

Chapter 11. Tower 8 Card & CPU Backplane.

CPU Backplane Description

As the system grew, the original backplanes became a little *constraining* and so was born the 8-slot integrated CPU backplane. On the backplane there are 8 TowerBUS slots, one W65C02S6-TPG14 CPU, one clock generator (which can be disabled), IRQ and NMI lights header, reset header, power input terminals and the logic to decode bank selection and IO page selection. This does not handle sideways bank selection, that is done by the memory card.

It should be noted that the 8 slot and CPU backplane needs either the extension piece with two extra joining bars *or* the larger modular case sections. Both the new motherboard and the older 7 slot one can use the same endcaps, joining bars and power supply module.

TowerBUS Pinout and Specification

There are 40 pins in two rows of 20. Each pin is assigned a signal except for the 5V and ground pins which are assigned in pairs.

Each signal pin is compatible with 74HC series logic and there is no buffering so be mindful of fanout, taking note of the W65C22S6-TPG14 datasheet for the CPU bus pins and the Lattice GAL22V10D-7LP datasheet for the bank selection pins. The power supply is rated at 1.4A but the supplied fuse is an F1A M205. Do not exceed 1.4A even with a bigger fuse fitted.

TowerBUS Pinout

Top row LH Side	nIOSEL	nBANK3	nBANJ2	nBANK1	nBANK0	A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1
Pin No.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Bottom Row LH Side	VCC	VCC	OSC	GND	GND	RDY	IRQB	NMIB	RESB	PHI2	RWB	D7	D6	D5	D4	D3	D2	D1	D0	A0

Table of Pins/Signals

1	nIOSEL	Signals to hardware that the IO address range is being selected.
2	VCC	+5V power output. Tied to pin 4.
3	nBANK3	Signals to the hardware that memory bank 3 is being selected.
4	VCC	+5V power output. Tied to pin 3.
5	nBANK2	Signals to the hardware that memory bank 2 is being selected.
6	OSC	This is the 4MHz oscillator output for the system.
7	nBANK1	Signals to the hardware that memory bank 1 is being selected.
8	GND	Return path to ground. Tied to pin 10.
9	nBANK0	Signals to the hardware that memory bank 0 is being selected.
10	GND	Return path to ground. Tied to pin 8.
11	A15	Address line 15 from the CPU.
12	RDY	Ready pin for use arbitrating the bus usage of the CPU.
13	A14	Address line 14 from the CPU.
14	IRQB	Interrupt request signal used by hardware to interrupt the CPU.
15	A13	Address line 13 from the CPU.
16	NMIB	Non-Maskable interrupt request signal used by the hardware to interrupt the CPU.
17	A12	Address line 12 from the CPU.
18	RESB	Reset line. Briefly pulled low by the reset circuit on the PSU board and optionally by external hardware.
19	A11	Address line 11 from the CPU.
20	PHI2	Processor clock generator, used extensively around the system to provide synchronisation of various hardware connected to the TowerBUS. This is the rate at which the CPU operates and is set by jumpers.
21	A10	Address line 10 from the CPU.
22	RWB	Signals that the CPU is reading the bus when high, writing when low. Must be used in conjunction with a means of ensuring processor timing requirements are met.
23	A9	Address line 9 from the CPU.
24	D7	Data bit 7 of the TowerBUS.
25	A8	Address line 8 from the CPU.
26	D6	Data bit 7 of the TowerBUS.
27	A7	Address line 7 from the CPU.
28	D5	Data bit 5 of the TowerBUS.
29	A6	Address line 6 from the CPU.
30	D4	Data bit 4 of the TowerBUS.
31	A5	Address line 5 from the CPU.
32	D3	Data bit 3 of the TowerBUS.
33	A4	Address line 4 from the CPU.
34	D2	Data bit 2 of the TowerBUS.

35	A3	Address line 3 from the CPU.
36	D1	Data bit 1 of the TowerBUS.
37	A2	Address line 2 from the CPU.
38	D0	Data bit 0 of the TowerBUS.
39	A1	Address line 1 from the CPU.
40	A0	Address line 0 from the CPU.

Chapter 12. Tower Peripheral Bus & Centronics Interface.

Tower Peripheral Bus and Centronics Card Description

This card provides both multi-drop serial communications (Tower Peripheral Bus) and Centronics printer support. The TPB bus *in particular*, has very complex behaviour and many function calls. This bus is a work-in-progress at present, but the hardware is functional. This card has a base address of $C020 and uses up-to $C02F.

The Centronics Port

This is modelled after the BBC micro implementation and may serve to output any characters as the user wishes via the OUTP_V, or more directly via either the vectored system call TPB_LPT_write_vec ($FF99) or by direct hardware access, though this is discouraged. To use TPB_LPT_write_vec, place the character to be written into the accumulator and call TPB_LPT_write_vec. This presently a blocking call and if the printer hangs the Centronics bus in a way you can't clear printer-side, you will have to perform a warm start.

To direct your output stream to also go to the LPT port, one usually sets os_outsel ($5E0) bit 2 to 1, everything then also going to the Centronics port. Clearing bit 2 stops this.

Centronics Port Pinout													
Top	NC	NC	NC	ACK	PD7	PD6	PD5	PD4	PD3	PD2	PD1	PD0	STROBE
	25	23	21	19	17	15	13	11	9	7	5	3	1
Bottom	26	24	22	20	18	16	14	12	10	8	6	4	2
	NC	GND	GND	GND	GND	GND	GND	GND	GND	GND	GND	GND	GND

Chapter 13. The IRQ Handler Sub-system.

IRQ Handler Sub-System Description

Interrupts make it easier to handle outside events such as incoming serial data, timing, and software exceptions. The ToE's processor furnishes only rudimentary interrupt handling, and this sub-system is provided to flexibly manage multiple interrupts. The way this is achieved is by use of a table of eight vectors processed one by one, using a bitfield to select which one's are active. Initially, the table is populated with a null handler such that if one of its entries is inadvertently enabled, it is handled gracefully, rather than crashing the system.

The means by which one sets or clears an interrupt vector are by the provision of atomic calls which retain the interrupt handling state as much as possible so that other interrupts are delayed as little as possible.

IRQ System Call Vectors

$FFDB	IRQH_Handler_Init_vec
$FFDE	IRQH_SetIRQ_vec
$FFE1	IRQH_ClrIRQ_vec
$FFE4	IRQH_SystemReport_vec

$FFDB IRQH_Handler_Init_vec

Calling this vector clears the interrupt vector table and resets the IRQ Handler sub-system. It may be that individual interrupt vectors get a reset vector table too, but this is not a given yet.

$FFDE IRQH_SetIRQ_vec

Atomically transfers an interrupt's vector from **IRQ_CallReg** to the table location specified in A. Locations available are 0 through 7 with 0 being handled first, subsequent locations being handled in sequential order. Note that this does not affect whether the interrupt vector is selected or not. It is the users' responsibility to manage this themselves.

$FFE1 IRQH_ClrIRQ_vec

Atomically transfers the null vector to the table location specified in the accumulator. Locations available are 0 through 7 with 0 being handled first, subsequent locations being handled in sequential order. Note that this does not affect whether the interrupt vector is selected or not. It is the users' responsibility to manage this themselves.

$FFE4 IRQH_SystemReport_vec

Calling this returns the base address of the IRQ handler table, including all variables. This is done so that the table location does not need to be known in advance. Given that this data structure is very likely to change, this will prevent breakage of code written for the ToE.

Upon return, X will contain **IRQH_Table_Base** low byte, Y will contain its high byte, and A will contain the IRQ handler version.

IRQH_Table_Base Structure

Offset	Name	Purpose
$0-$15	IRQH_CallList	Eight consecutive little-endian call addresses for the users' IRQ device handlers.
$16-$17	IRQH_CallReg	Intermediate register for atomically transferring addresses to the call list above.
$18	IRQH_ClaimsList	Bitfield showing which interrupts claimed and thus serviced an interrupt.
$19	IRQH_MaskByte	Bitfield for selecting which interrupts are to be serviced in the event of the IRQ vector being invoked.
$20	IRQH_WorkingMask	Internal variable, this walks from the LSb to the MSb and is used for various parts of the process. Do not write to this variable.
$21-$31	IRQH_CMD_Table	Table of IRQ Commands and parameter values.

Command Codes

Each IRQ has an associated parameter and command code byte entry in the IRQH_CMD_Table. These are sorted as follows. First is the parameter, followed by the command code.

Each IRQ must check on entry and before claiming IRQ for the following commands:

0.	IRQH_Service_CMD	Instructs the IRQ that service is required.
1.	IRQH_Shutdown_CMD	The IRQ must perform an orderly shutdown.
2.	IRQH_Reset_CMD	The IRQ must reset to an initial state.

Further commands may be implemented by the user but values below 8 are presently reserved for future upgrades.

Starting an IRQ Service

Starting and IRQ consists of writing it's address to the IRQH_CallReg ($A30-$A31), Loading the accumulator with our chosen IRQH_CallList location (0-7), calling IRQH_SetIRQ_vec to load it atomically and then calling our IRQ's initialisation routine.

The IRQ initialisation routine should handle starting of the IRQ as necessary. To return the IRQ vector to the system, there is a separate call IRQH_ClrIRQ_vec ($FFE1).

Servicing an IRQ

IRQ's running through the IRQ Handler must check upon entry, their associated command entry, pointed to by IRQH_CMD_Table + the X index register. The IRQ must process at least the minimum system command codes listed above. Parameters for the minimum set are not required.

Each time the IRQ is called, it must check that the hardware associated with it has generated an interrupt, set the appropriate claim bit in IRQH_ClaimsList ($A32) by ORing IRQH_WorkingMask ($A34) into it and clear the hardware IRQ signal so as not to cause nuisance IRQ calls and system hangs. IRQ's not generated by the associated hardware must not cause undue resource wastage or set the claim bit.

Exit from the IRQ routine is by RTS not RTI. This is so that other IRQ routine's may check their associated hardware and commands before the handler hands control back to the system.

Stopping an IRQ

Sending the IRQH_Shutdown_CMD (1) to the IRQ will cause the IRQ to stop. This does not remove it from the IRQH_CallList but does allow the IRQ the chance to stop in an appropriate manner. Alternatively, an atomic call may be created to do the same.

A stopped IRQ may be re-started at any time by either calling its initialisation routine or if appropriate, setting its associated bit in IRQH_MaskByte ($A33).

Removing an IRQ Service from the IRQH_CallList ($A20-$A30)

One must have first stopped the IRQ, then the accumulator must be loaded with the correct table entry. This is followed by calling IRQH_ClrIRQ_vec, which handles this atomically. After clearing, the table contains a safe dummy entry that points to a function that does nothing but ensure the IRQH_ClaimsList is correct before returning control to the IRQ handler.

Chapter 14. The Countdown IRQ Handler Sub-system.

Countdown IRQ Subsystem Description

This provides a countdown timer with programmable count rate. A GPIO card or other hardware containing a W65C22 must be installed with its W65C22 base address at $C020 for this to work as it relies on the W65C22's Timer 1 to generate a regular stream of interrupts. This 6522 is chosen as it provides cassette storage signals and is normally expected to be present at this base address.

The IRQ is configured at start-up in prime position at IRQH_CallList ($A20) position 0.

There is only one vector associated with the countdown timer, INIT_COUNTDOWN_IRQ_vec ($FFE7). Calling this with its IRQ mask bit in the accumulator (1 unless the user moves the IRQ to a less prime location) initialises the countdown timer, which will update the countdown variable each count until it reaches 0, after which it shuts down.

It is possible to alter the IRQ reload value mid countdown, but one must either set the interrupt mask bit before updating or adverse effects may occur.

There are system variables and flags which must be set before initialising the countdown timer. These are listed in the table below. One fortunately only needs to setup the variables used. There is no point in initialising a vector for instance if one only needs the countdown variable.

System Variables for the Countdown IRQ

($A4A-$A4B)	CTR_V	Counts down from its initial value until zero is reached, after which if CTR_Reload_En (b0) of CTR_Options ($A52) is set it reloads and repeats, otherwise the IRQ disables itself.
($A4C-$A4D)	CTR_RELOAD_VAL_V	Reloads if CTR_Reload_En (b0) of CTR_Options ($A52) is set.
($A4E-$A4F)	CTR_PERIOD_V	The reload value used upon initialisation. Changing this alters the IRQ rate. Caution is advised that setting this at or close to zero will cause the system to become unresponsive since it will use up all available CPU time.
($A50-$A51)	CTR_External_vec	Contains the address of any routine you wish to call upon CTR_V reaching 0. To use this vector, first load your address, then set CTR_vec_En (b1) of CTR_Options ($A52).
($A52)	CTR_Options	Bitfield containing the configuration options for the countdown timer.

Countdown Timer Initialisation Code Example with Reload and Vector.

```
10 DOKE $85,$AFFF: CLEAR : REM Make space for our timed
service
20 LOAD “!ServiceCode” $B000 : REM Load self-initialising
service code
30 :
40 DOKE $A4A,$1000 : REM Setup count
50 DOKE $A4C,$1000 : REM Setup reload
60 DOKE $A4E,39999 : REM Setup period for 40000 PHI2’s per
count.
70 DOKE $A50,$B100 : REM Setup vector for service code
80 POKE $A52,%11 : REM Setup for reload and service.
90 CALL $FFE7 : REM Initialise Countdown Timer IRQ
```

The TowerBASIC folder contain this example code alongside the binary generator program that goes with this. If run successfully, you should get a rising and falling tone from the AY V2 soundcard.

Chapter 15. The I2C-Bus Engine Sub-system.

I2C Engine General Description

This I2C-bus engine is provided such that those who are sufficiently experienced in such things can have a multitude of I2C-bus devices operated from the computer with lower effort. Whilst it is not the fastest implementation by far, it still affords a huge range of possibilities, from ADCs and DACs to digital IO expanders, digital pots, sensors, programmable oscillators, tuners and memories both volatile and non-volatile just to name a few. It should therefore be a very useful addition.

The I^2C-bus is implemented by software alone and only requires a GPIO card mapped to $CO40 such that it can use port A. Pin PA0 is SDA (Serial Data) and pin PA1 is SCL (Serial CLock).

Data is transmitted at somewhat below the I^2C-bus standard speed specification of 100KHz and depends on both the system clock and interrupt load. Timings are thus slightly irregular but perfectly useable.

There are calls to Initialise the I2C-Subsystem, send a (re)start, send a stop, output a byte and input a byte at present. Soon to implemented are calls to send an I2C 7-bit address with the relevant read or write bit set.

Before using the I^2C subsystem, one needs to initialise it by calling I2C_Init_vec ($FF81).

There are vectors for Start, Stop, Out and In. A start may be sent as a re-start.

The user circuit must provide suitable pull-ups as these lines are driven as open-drain to facilitate multiple I^2C slave devices.

For a fuller understanding of the I^2C-bus and protocol, one should read documents such as NXP's UM10204 I^2C-bus specification and user manual.

TowerBASIC Commands for I2C communications

`I2C_INIT` is provided to setup the I^2C-bus engine and pins. It should be used *before* any other I^2C commands.

`I2C_START` sends the start (S) condition on the bus.

`I2C_STOP` sends the stop (P) condition on the bus, freeing it.

`I2C_OUT()` is used to transmit a byte to the I^2C-bus. The returned byte has ACK (0)/NAK (1) returned in bit 0 and if the bus times out then bit 1 will be set. To send a device address, it should be in the top seven bits with bit 0 being the read/not write bit.

`I2C_IN()` reads a byte from the I^2C-bus and sends either an ACK (0) or NAK (1) which the user passes to the function.

List of I^{2}C-Bus Subsystem Variables

I2C_Status ($5D0)	I^{2}C Subsystem status register. There is an associated bitfield for this.
I2C_Byte ($5D1)	The byte to be transmitted or which has just been received.
I2C_Timeout_V ($5D1-$5D2)	Contains the timeout counter variable. This is used to reload an internal counter which the I^{2}C subsystem uses to determine how long to wait before giving up. Used to prevent hangs in the event the slave device does not respond.

I2C_Status ($5D0) Bitfield

Bits 7-4	Not used.
Bit 3	I2C_STA_Master. Currently, the I^{2}C engine is always the master. This bit is presently ignored.
Bit 2	I2C_STA_Rd_nWr. Determines whether the I^{2}C-bus is sending a Read or Write to the slave device. Currently not implemented.
Bit 1	I2C_STA_Timeout. Indicates whether the I^{2}C-bus engine timed out in its last operation.
Bit 0	I2C_STA_NAK. Used to signal to the slave either an ACKnowledge or negative ACKnowledge at the end of a byte transmission.

I2C-Subsystem Calls

I2C_Init_vec ($FF81)	Calling this initialises the I^{2}C-bus engine including the IO pins SDA (PA0) and SCL (PA1).
I2C_Start_vec ($FF84)	Sends a start condition to the slave.
I2C_Stop_vec ($FF87)	Sends a stop condition to the slave.
I2C_Out_vec ($FF8A)	Transmits the byte placed in I2C_Byte ($5D1). The I2C_STA_NAK (bit 0) is copied from I2C_Status ($5D1) also and should the device have timed out, the I2C_STA_Timeout (bit 1) will also be set.
I2C_In_Vec ($FF8D)	Reads a byte from the slave device, placing it in I2C_Byte ($5D1).

Chapter 16. The SPI Sub-system.

SPI Subsystem Description

Some peripherals one might attach require that they be interfaced using an interfacing standard called Serial Peripheral Interface. This is an interface that transfers data serially, transferring one bit in and on bit out, synchronised by a clock signal. There can be multiple devices sharing an SPI bus, as long as each device has its own select pin. In many cases, this is called slave select, shortened to SS, but it is also often called Chip Select. The assertion level of one's SPI devices can be both negative and positive logic on both the clock and selection pins, but not the data pins. Normally, SPI devices accept data starting with the MSb in words of 8 bits.

The SPI engine implemented here always transmits MSb first in 8-bit words but drives the SS (device select) pin and SCK (shift clock) in either positive or negative logic. The SPI engine can also support all three SPI modes.

The SPI engine operates on the following named pins: -

MOSI (Master Out, Slave In).	Data is sent to the slave on this pin.
MISO (Master In Slave Out).	Data is received from the slave on this pin.
SCK (Shift ClocK).	This signal provided the clock edge for each bit.
SS (Slave Select).	Provides a means of selecting the appropriate device.

It is possible to specify which pin to use for MOSI (Master Out, Slave In), MISO (Master In, Slave Out), SCK (Shift ClocK) and SS (Slave Select). By changing the settings, one can use multiple devices on the same SPI bus. The SPI bus only operates on Port A of the primary GPIO card at a base address of $C040 for now, however.

Because all these pins are being driven directly from GPIO port A, which also provides the I2C port on pins PA0 and PA1, if you intend on using both, you will have to take care. Also, these pins are 5V CMOS IO pins and not all SPI devices will be logic level compatible. It is beyond the scope of this manual to explain the intricacies of bridging differing logic families.

SPI speeds achieved on this bus are software and processor clock limited and if you require faster speeds, a hand crafted driver or hardware assistance will be required.

TowerBASIC SPI Support.

There is a command supporting SPI and a function, **`SPI_INIT`** which takes 6 parameters sets up the SPI Engine and pins, and **`SPI-XFER(`**data out**`)`** which exchanges data over SPI.

Example:-

```
10 SPI_INIT 1,7,6,5,4,0
20 br=SPI_XFER($20)
30 PRINT br
```

In the above example the SPI engine is initialised to SPI mode 1, MOSI on PA7, MISO on PA6, SCK on PA5, SS on PA4 and SS is active low in that order.

Next is the numeric variable 'br' receiving the byte returned by **`SPI_XFER`** which also transmits $20 to the SPI slave device. The return value is then printed.

Below are the command details:-

`SPI_INIT` *mode, MOSI, MISO, SCK, SS, ss_active_state*
ret_value=**`SPI_XFER(`** *byte_to_send* **`)`**

Checks are made to prevent one setting the same pin for two or more functions, that the mode is valid and that the slave select pin active state is correct otherwise this command will generate a function call error. The checks on **`SPI_XFER`** are minimal however for performance reasons and for the fact that there is only one argument. This does however predispose one to thinking that the fault is with the system and not the users' code. 256 would therefore be sent as 0 as this causes a roll-over.

Using the SPI engine

There is a data structure called SPI_Struct. SPI Struct starts at $400 and its fields are listed in the table below.

SPI_Struct ($400-$408)			
Field name	Function	Address	Default values.
SPI_In	Byte received	$400	0
SPI_Out	Byte to be sent	$401	0
SPI Mode	See table below	$402	0
SPI_SS_Pin	The bit is set is SS	$403	0b00100000
SPI_SS_Act	1=Active Low, 0=High	$404	1
SPI_MOSI_Pin	The bit set is MOSI	$405	0b00001000
SPI_MISO_Pin	The bit set is MISO	$406	0b00010000
SPI_SCK_Pin	The bit set is SCK	$407	0b00000100
SPI_Temp	Internally used	$408	xx. Not for user

Calling SPI_Struct_Init_vec ($FF57) prefills SPI_Struct ($400-$408) with default values.

To transfer over SPI, configure the engine by loading sane values into SPI_Struct ($400-$408) and call SPI_Init_vec ($FF5A) to get everything ready. Then load SPI_Out ($401) before each transfer and call SPI_Xfer_vec ($FF5D) to make the transfer. Upon return, SPI_In ($400) should contain any returned byte. One can transfer as many bytes as one desires without reconfiguring the engine, or even change the SS pin to use a different SPI device. It is not recommended to change the SS pin active level between devices.

List of SPI Function Calls

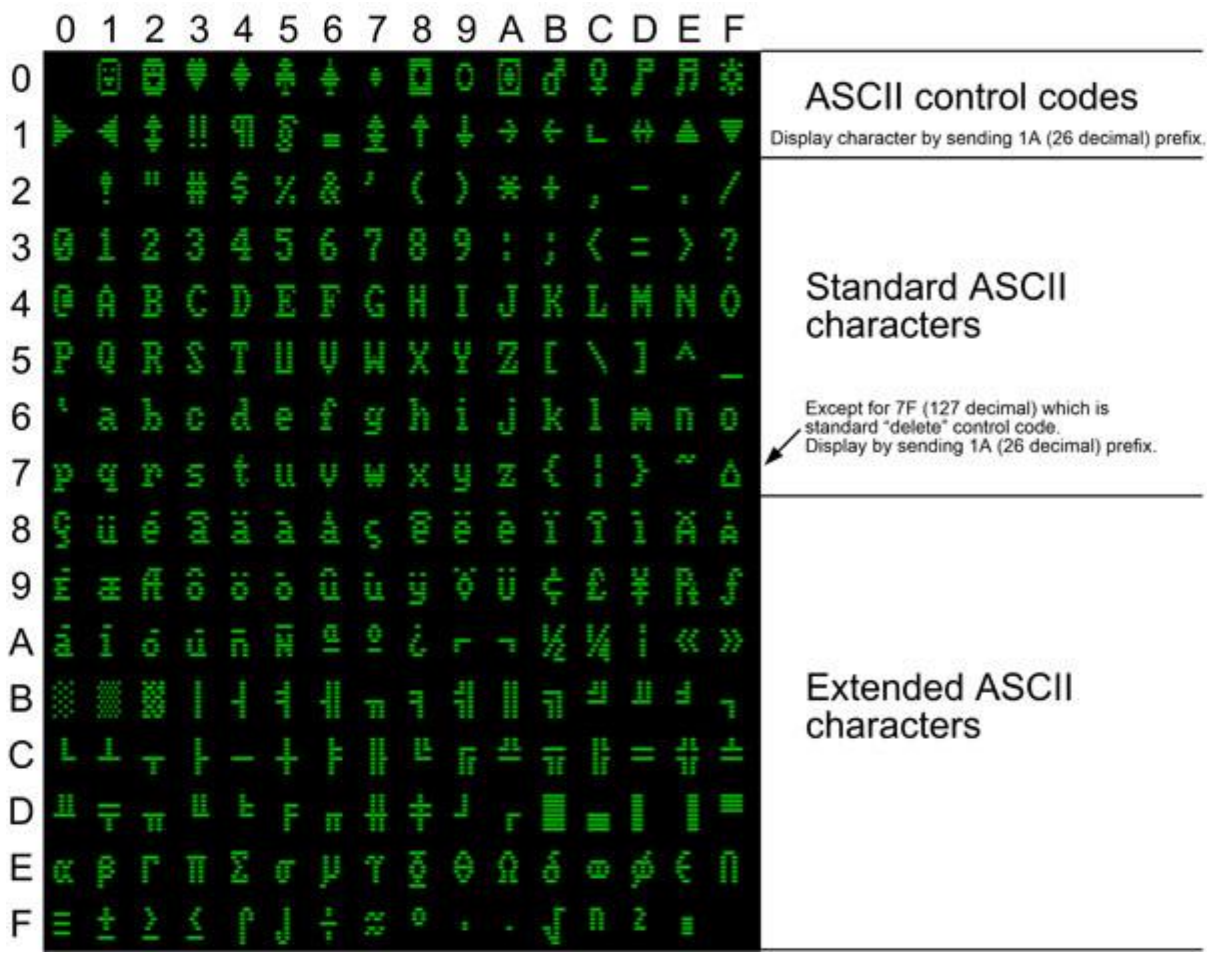
SPI_Struct_Init_vec ($FF57)	Initialises SPI_Struct ($400-$408) with sensible safe values useful to a wide range of SPI slaves.
SPI_Init_vec ($FF5A)	Initialises the SPI engine and pins ready for transmissions.
SPI_Xfer_vec ($FF5D)	Transfers one byte into SPI_In ($400) and one byte out from SPI_Out ($401).

Table of SPI Modes		
Mode 0	CPHA0, CPOL0	Positive clock, transfer on leading edge of clock.
Mode 1	CPHA1, CPOL0	Positive clock, transfer on trailing edge of clock.
Mode 2	CPHA0, CPOL1	Negative clock, transfer on leading edge of clock.
Mode 3	CPHA1, CPOL1	Negative clock, transfer on trailing edge of clock.

Appendices

Appendix A. PC-DOS Character Set

The row gives the most significant digit and the column the least. This chart is in hexadecimal.



	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0		☺	☻	♥	♦	♣	♠	•	◘	○	◙	♂	♀	♪	♫	☼
1	►	◄	↕	‼	¶	§	▬	↨	↑	↓	→	←	∟	↔	▲	▼
2		!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
3	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
4	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
5	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
6	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
7	p	q	r	s	t	u	v	w	x	y	z	{	¦	}	~	⌂
8	Ç	ü	é	â	ä	à	å	ç	ê	ë	è	ï	î	ì	Ä	Å
9	É	æ	Æ	ô	ö	ò	û	ù	ÿ	Ö	Ü	¢	£	¥	₧	ƒ
A	á	í	ó	ú	ñ	Ñ	ª	º	¿	⌐	¬	½	¼	¡	«	»
B	░	▒	▓	│	┤	╡	╢	╖	╕	╣	║	╗	╝	╜	╛	┐
C	└	┴	┬	├	─	┼	╞	╟	╚	╔	╩	╦	╠	═	╬	╧
D	╨	╤	╥	╙	╘	╒	╓	╫	╪	┘	┌	█	▄	▌	▐	▀
E	α	ß	Γ	π	Σ	σ	µ	τ	Φ	Θ	Ω	δ	∞	φ	ε	∩
F	≡	±	≥	≤	⌠	⌡	÷	≈	°	∙	·	√	ⁿ	²	■	

ASCII control codes
Display character by sending 1A (26 decimal) prefix.

Standard ASCII characters

Except for 7F (127 decimal) which is standard "delete" control code.
Display by sending 1A (26 decimal) prefix.

Extended ASCII characters

Appendix B. Display Layout

80 Column Mode (Text)							
Row 0, Col 0	...	...	...	...	...	...	...Row 0, Col 79
...	...	...	...	...	...	...	
...	...	...	...	...	...	...	
Row 24,0	...	...	...	...	...	...	...Row 24, Col 79

40 Column Mode (Text)							
Row 0, Col 0	...	...	...	...	...	...	...Row 0, Col 39
...	...	...	...	...	...	...	
...	...	...	...	...	...	...	
Row 24,0	...	...	...	...	...	...	...Row 24, Col 39

Graphics (Bloxel Graphics)							
X0,Y0	...	...	...	...	...	...	...X159,Y0
...	...	...	...	...	...	...	
...	...	...	...	...	...	...	
X0,Y99	...	...	...	...	...	...	...X159,Y99

Appendix C. Video Control Codes

$01 (01)	Cursor home	*(Standard ASCII)*
$02 (02)	Define cursor character (2nd byte is the cursor character, or 0 to turn off)	
$03 (03)	Cursor blinking	
$04 (04)	Cursor solid	
$05 (05)	Set graphics pixel (next two bytes = x,y)	
$06 (06)	Reset graphics pixel (next two bytes = x,y)	
$08 (08)	Backspace	*(Standard ASCII)*
$09 (09)	Tab	*(Standard ASCII)*
$0A (10)	Linefeed	*(Standard ASCII)*
$0C (12)	Clear screen	*(Standard ASCII)*
$0D (13)	Carriage return	*(Standard ASCII)*
$0E (14)	Set column 0 to 79 (2nd byte is the column number) or 0 to 39 for a 40 char line	
$0F (15)	Set row 0 to 24 (2nd byte is the row number)	
$10 (16)	Delete start of line	
$11 (17)	Delete to end of line	
$12 (18)	Delete to start of screen	
$13 (19)	Delete to end of screen	
$14 (20)	Scroll up	
$15 (21)	Scroll down	
$16 (22)	Scroll left	
$17 (23)	Scroll right	
$18 (24)	Set font attribute for the current line	
$1A (26)	Treat next byte as a character (to allow PC DOS char codes 1 to 31 to be displayed on screen)	
$1B (27)	ESC - reserved for ANSI sequences	
$1C (28)	Cursor right	
$1D (29)	Cursor Left	
$1E (30)	Cursor up	
$1F (31)	Cursor down	
$20 (32) to… $7E (126)	Standard ASCII codes	
$7F (127)	Delete	
$80 (128) to… $FF (255)	PC (DOS) extended characters	

Appendix D. Character Control Bits

Character Control Attribute $18 (24) and bitfield of following byte							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Graphics	Spare	Spare	Spare	Spare	Double Height	Bold	80 Columns

Appendix E. ANSI Card Register Table

	ANSI Function
0	Output byte (Output Register B)
1	PA7 = Ack, PA6 = Avail, PA5-0 not used. (Output Register A)
2	Data Direction Register B. Should be set to $FF
3	Data Direction Register A. Should be set to $40

It should be noted that should one change the direction registers to incorrect values, there will be contention between the ANSI processor and the W65C22S6-TPG14. This not only will prevent the ANSI card from functioning but will result in increased pin currents. Try to keep the IO directions set correctly wherever possible.

Appendix F. Tower of Eightness Memory Overview

Bank Structure and IOMAP oveview.

	Page 0	Page 1
Bank 3 $C000-$FFFF	TowerOS, BASIC and FS	TowerOS, BASIC and FS
Bank 2 $8000-$BFFF	RAM. Ramtop is normally at the top of this page.	RAM
Bank 1 $4000-$7FFF	RAM	RAM
Bank 0 $0000-$3FFF	RAM. Pages 0 & 1 are special. Take care when switching	RAM. Pages 0 & 1 are special. Take care when switching

IO Page $C000-$C0FF
$C0FF - Bank Select
$C0E0-$C0EF AY Soundcard
$C060-$C0FE Uncommitted.
$C050-$C05F GPIO Card 2 (if present)
$C040-$C04F GPIO Card 1
$C030-$C03F Uncommitted
$C020-$C02F TPB/Centronics Card
$C014-$C017 ACIA 2 (If present)
$C010-$C013 ACIA 1
$C000-$C00F ANSI Card

The below register selects which page is in any given bank. This register is write-only and if you don't keep track of it, you might find yourself in the wrong place in memory.

Bank Select Register Bitfield ($C0FF)

Bit	B7	B6	B5	B4	B3	B2	B1	B0
Default	0	0	0	0	0	0	0	0
	Reserved. Keep at 0.				Bank 3 Page 1 Select (EEPROM)	Bank 2 Page 1 Select	Bank 1 Page 1 Select	Bank 0 Page 1 Select (Warning CPU Page 0 & 1 included)

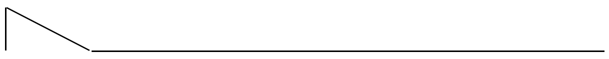
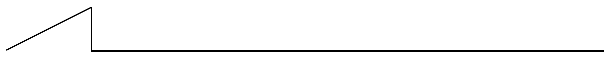
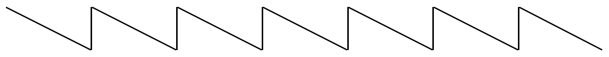
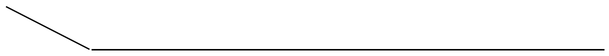
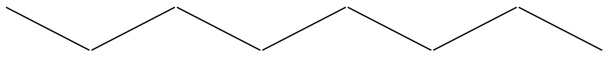
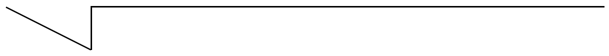
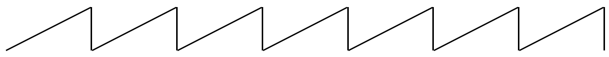
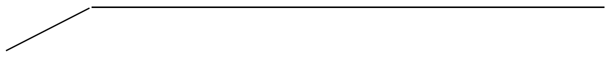
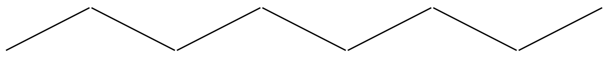
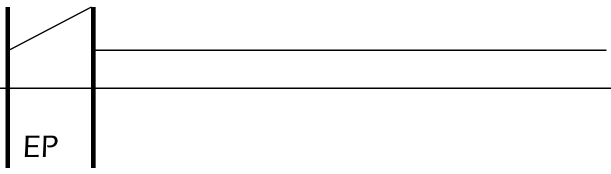
Appendix G. AY Hardware Details

AY-3-8912A Register Map

Reg	Bit	B7	B6	B5	B4	B3	B2	B1	B0
R0	Channel A Tone Period	8-Bit fine tune A.							
R1						4-Bit coarse tune A.			
R2	Channel B Tone Period	8-Bit fine tune B.							
R3						4-Bit coarse tune B.			
R4	Channel C Tone Period	8-Bit fine tune C.							
R5						4-Bit coarse tune C.			
R6	Noise Period				5-Bit Period control.				
R7	nEnable	nIOB	nIOA	nNOISE Ch C	nNOISE Ch B	nNOISE Ch A	nTONE Ch C	nTONE Ch B	nTONE Ch A
R8	Channel A Amplitude				M	L3	L2	L1	L0
R9	Channel B Amplitude				M	L3	L2	L1	L0
R10	Channel C Amplitude				M	L3	L2	L1	L0
R11	Envelope Period	8-Bit Fine Tune Envelope							
R12		8-Bit Coarse Tune Envelope							
R13	Envelope Shape/Cycle					Continue	Attack	Alternate	Hold
R14	I/O Port A Data Store	8-Bit parallel I/O on Port A. Not connected to anything.							
R15	I/O Port B Data Store	8-Bit parallel I/O on Port B. Pins not available on AY-3-8912A							

Table of Bus States

BC1	BDIR	State
0	0	Inactive.
1	0	Read from AY. The AY selected register is on the data lines.
0	1	Write to AY. The data lines are transferred to the AY
1	1	Latch Address. Write register address to AY from data lines.

Envelope Shape/Cycle Operation				
Mode bits (AY reg 13)				
B3	B2	B1	B0	
Continue	Attack	Alternate	hold	Graphic Representation of Envelope Generator Output.
0	0	X	X	
0	1	X	X	
1	0	0	0	
1	0	0	1	
1	0	1	0	
1	0	1	1	
1	1	0	0	
1	1	0	1	
1	1	1	0	
1	1	1	1	

EP is the envelope period (duration of one cycle).

NOTE: - The AY clock from which all periods is generated is 1.842MHz.

Appendix H. Pinouts

TowerBUS Pinout

Top row LH Side	nIOSEL	nBANK3	nBANK2	nBANK1	nBANK0	A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1
Pin No.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Bottom Row LH Side	VCC	VCC	OSC	GND	GND	RDY	IRQB	NMIB	RESB	PHI2	RWB	D7	D6	D5	D4	D3	D2	D1	D0	A0

Centronics Port Pinout

Top	NC	NC	NC	ACK	PD7	PD6	PD5	PD4	PD3	PD2	PD1	PD0	STROBE
	25	23	21	19	17	15	13	11	9	7	5	3	1
Bottom	26	24	22	20	18	16	14	12	10	8	6	4	2
	NC	GND	GND	GND	GND	GND	GND	GND	GND	GND	GND	GND	GND

GPIO Card Port Pinouts

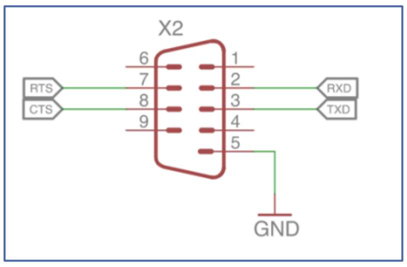
Port A. Base address offset 1, Data Direction Register Offset 3.

19	17	15	13	11	9	7	5	3	1
0V	0V	0V	0V	0V	0V	0V	0V	+5V	+5V
20	18	16	14	12	10	8	6	4	2
PA7	PA6	PA5	PA4	PA3	PA2	PA1	PA0	CA2	CA1

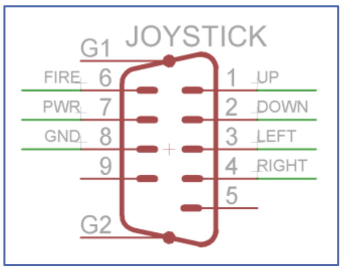
Port B. Base address offset 0, Data Direction Register Offset 2.

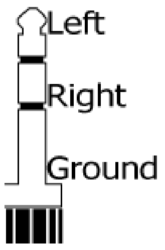
19	17	15	13	11	9	7	5	3	1
0V	0V	0V	0V	0V	0V	0V	0V	+5V	+5V
20	18	16	14	12	10	8	6	4	2
PB7	PB6	PB5	PB4	PB3	PB2	PB1	PB0	CB2	CB1

ACIA Port Pinout



Joystick Port Pinout



AY Soundcard Output Jack Pinout		
	Tip	Left Audio Out
	Ring	Right Audio Out
	Sleeve	Ground

Appendix I. W65C02 Instruction List

Mnemonic	Operation # Immediate ~ NOT ^ AND v OR xv XOR	a	(a,x)	a,x	a,y	(a)	A	#	i	r	s	zp	(zp,x)	zp,x	zp,y	(zp)	(zp),y	Processor Status Register (P)							
																		7	6	5	4	3	2	1	0
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	N	V	1	1	D	I	Z	C
ADC	A+M+C→A	6D		7D	79			69				65	61	75		72	71	N	V					Z	C
AND	A^M→A	2D		3D	39			29				25	21	35		32	31	N						Z	
ASL	C←7..0←0	0E		1E			0A					06		16				N						Z	M_7
BBR0	Branch on b0 reset							0F																	
BBR1	Branch on b1 reset							1F																	
BBR2	Branch on b2 reset							2F																	
BBR3	Branch on b3 reset							3F																	
BBR4	Branch on b4 reset							4F																	
BBR5	Branch on b5 reset							5F																	
BBR6	Branch on b6 reset							6F																	
BBR7	Branch on b7 reset							7F																	
BBS0	Branch on b0 set							8F																	
BBS1	Branch on b1 set							9F																	
BBS2	Branch on b2 set							AF																	
BBS3	Branch on b3 set							BF																	
BBS4	Branch on b4 set							CF																	
BBS5	Branch on b5 set							DF																	
BBS6	Branch on b6 set							EF																	
BBS7	Branch on b7 set							FF																	
BCC	Branch on C=0							90																	
BCS	Branch on C=1							B0																	
BEQ	Branch if Z=1							F0																	
BIT	A^M	2C		3C				89		24		34						M_7	M_6					Z	
BMI	Branch if N=1							30																	
BNE	Branch if Z=0							D0																	
BPL	Branch if N=0							10																	
BRA	Branch Always							80																	
BRK	Break								00												1	0	1		
BVC	Branch if V=0							50																	
BVS	Branch if V=1							70																	
CLC	0→C						18																		0
CLD	0→D						D8															0			
CLI	0→I						58																0		
CLV	0→V						B8												0						
CMP	A-M	CD		DD	D9			C9				C5	C1	D5		D2	D1	N						Z	C
CPX	X-M	EC						E0				E4						N						Z	C
CPY	Y-M	CC						C0				C4						N						Z	C
DEC	Decrement	CE		DE			3A					C6		D6				N						Z	
DEX	X-1→X								CA									N						Z	
DEY	Y-1→Y								88									N						Z	
EOR	A⊻M→A	4D		5D	59			49				45	41	55		52	51	N						Z	
INC	Increment	EE		FE			1A					E6		F6				N						Z	
INX	X+1→X								E8									N						Z	
INY	Y+1→Y								C8									N						Z	
JMP	Jump to location	4C	7C			6C																			
JSR	Jump to subroutine	20																							
LDA	M→A	AD		BD	B9			A9				A5	A1	B5		B2	B1	N						Z	
LDX	M→X	AE			BE			A2				A6			B6			N						Z	
LDY	M→Y	AC		BC				A0				A4		B4				N						Z	
LSR	0→7..0→C	4E		5E			4A					46		56				0						Z	M_0
NOP	No Operation								EA																
ORA	A∨M→A	0D		1D	19			09				05	01	15		12	11	N						Z	

Mnemonic	Operation # Immediate ~ NOT ^ AND v OR xv XOR	a	(a,x)	a,x	a,y	(a)	A	#	i	r	s	zp	(zp,x)	zp,x	zp,y	(zp)	(zp),y	Processor Status Register (P)							
																		7	6	5	4	3	2	1	0
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	N	V	1	1	D	I	Z	C
PHA	A→Ms, S-1→S										48							N						Z	
PHP	P→Ms, S-1→S										08														
PHX	X→Ms, S-1→S										DA														
PHY	Y→Ms, S-1→S										5A														
PLA	S+1→S. Ms→A										68							N						Z	
PLP	S+1→S. Ms→P										28							N	V		B	D	I	Z	C
PLX	S+1→S. Ms→X										FA							N						Z	
PLY	S+1→S. Ms→Y										7A							N						Z	
RMB0	Reset Memory b0											07													
RMB1	Reset Memory b1											17													
RMB2	Reset Memory b2											27													
RMB3	Reset Memory b3											37													
RMB4	Reset Memory b4											47													
RMB5	Reset Memory b5											57													
RMB6	Reset Memory b6											67													
RMB7	Reset Memory b7											77													
ROL	C←7..0←C	2E		3E			2A					26		36				N						Z	M_7
ROR	C→7..0→C	6E		7E			6A					66		76				N						Z	M_0
RTI	Return from Interrupt										40							N	V			D	I	Z	C
RTS	Return from Subroutine										60														
SBC	A-M-(-C) →A	ED		FD	F9			E9				E5	E1	F5		F2	F1	N	V					Z	C
SEC	1→C								38																1
SED	1→D								F8													1			
SEI	1→I								78														1		
SMB0	Set Memory b0											87													
SMB1	Set Memory b1											97													
SMB2	Set Memory b2											A7													
SMB3	Set Memory b3											B7													
SMB4	Set Memory b4											C7													
SMB5	Set Memory b5											D7													
SMB6	Set Memory b6											E7													
SMB7	Set Memory b7											F7													
STA	A→M	8D		9D	99							85	81	95		92	91								
STP	Stop (1→PHI2)								DB																
STX	X→M	8E										86			96										
STY	Y→M	8C										84		94											
STZ	00→M	9C		9E								64		74											
TAX	A→X								AA									N						Z	
TAY	A→Y								A8									N						Z	
TRB	~A^M→M											14												Z	
TSB	A∨M→M											04												Z	
TSX	S→X								BA									N						Z	
TXA	X→A								8A									N						Z	
TXS	X→S								9A																
TYA	Y→A								98									N						Z	
WAI	0→RDY								CB																

Appendix J. Alphabetic List of TowerBASIC Commands.

BITCLR <addr>,<b>

Clears bit b of address addr. Valid bit numbers are 0..7 with the LSb being 0. Values outside that range will result in a Function Call Error.

BITSET <addr>,<b>

Sets bit b of address addr. Valid bit numbers are 0..7 with the LSb being 0. Values outside that range will result in a Function Call Error.

CALL <addr>

Calls a user routine at address addr. No values are passed or returned making this faster than USR().

CAT

Reads file headers off the tape, displaying type, start, length and Filename. You must ^C break out of this to continue or press reset.

CLEAR

Erases all variables and functions and resets **`FOR`** .. **`NEXT`**, **`GOSUB`** .. **`RETURN`** and **`DO`** .. **`LOOP`** states.

CLS [<b>]

CLS without an attribute clears the display to the currently selected text attributes. If you are printing to a terminal or printer, it will perform a form-feed. If you specify an attribute between 0 and 255 the new attribute is set and the screen cleared to the new value. Any value outside this range will result in a Function call error.

CONT

Continues program execution after a ^C break has been typed, a **`STOP`** has been encountered or a null input was given to an **`INPUT`** request.

DATA [{r|$}[,{r|$}]...]

Defines one or more constants. Real constants are held as strings in program memory and can be read as numeric values or string values. String constants may contain spaces but if they need ti contain commas, then they must be enclosed in quotes.

DEC <var>,[<var>]...

Decrements one or more variables. The variables listed will have their values decremented by 1. Trying to decrement a string variable will generate a Type Mismatch error.

DEF FN <name>(<var>)=<statement>

Defines <statement> as function <name>. <name> can be any valid numeric variable name of one or more characters. <var> must be a simple variable and is used to pass a numeric argument into the function.

Note that the value of <var> will be unchanged if it is used in the function so <var> should be considered a local variable name.

DIM <var[$](i1[,i2[,in]...])...

Dimensions arrays. Creates arrays of either numeric or string variables. The arrays can have one or more dimensions. The lower limit of any array is always zero and the upper limit is i. If you do not explicitly dimension an array then its number of dimensions will be set when you first access it and the upper bound will be set to 10 for each dimension.

DO

Marks the beginning of a **`DO`** .. **`LOOP`**. This command can be nested like **`GOSUB`** .. **`RETURN`** and **`FOR`** .. **`NEXT`** loops. No parameters are taken.

DOKE <addr,w>

Writes word <w> to address <addr> in memory. The least significant byte comes at <addr> and the most at <addr>+1. If you should write to $FFFF then the most significant byte will be written to address $0000.

ELSE

See **`IF`**.

END

Terminates program execution and returns the user to immediate mode. **END** may be placed anywhere in a program and there may be any number of **END** statements including none.

CONT may be used to resume program execution from the following statement.

ENVELOPE <period>,<mode>

Takes the period value followed by the envelope mode value in that order. This, depending on the mode, may cause the AY-3-8912A to generate or alter the character of the sound generated.

See also: **SOUND**.

FN <name>(<expression>)

See **DEF**.

FOR <var>=<expression> TO <expression> [STEP <expression>]

Assigns a variable <var> to a loop counter, optionally setting a start value, the end value and **STEP** size. If the **STEP** expression is omitted then a default **STEP** size of +1 is assumed.

GET <var[$]>

Gets a character from the currently selected input stream. If there is no character then var will be set to 0 and var$ will return a null string "". GET does not halt and execution will continue.

GOSUB <n>

Calls a subroutine at line <n>. Program execution is diverted to line <n> but the calling point is remembered. Upon encountering a RETURN statement program execution will continue with the statement following the GOSUB. If line <n> does not exist then execution will stop with an error.

GOTO <n>

Continues execution from line <n>. If line <n> does not exist then execution will stop with an error.

I2C_INIT

Initialises the I2C engine and sets up the pins SDA (PA0) and SCL (PA1) on port A of the first GPIO card which must be at address $C040.

I2C_START

Sends a start condition (S) over the I^{2}C-Bus.

I2C_STOP

Sends a stop condition (P) over the I^{2}C-Bus.

IF <expression> {GOTO <n> [THEN <n|statement}>} [ELSE<{n|statement}>]

Evaluates <expression>. If the result is non-zero, then the GOTO or statement after the THEN is executed. If the result is zero, then execution resumes from the following line or after the ELSE is executed.

INC <var>[,var]...

Increments one ore more variables. The variables listed have their values incremented by one.

INPUT [“$”;]<var>[,<var>]...

Get a variable, or list of variables from the currently selected input stream. If there is no prompt string then a “?” will be output first. If there are more variables in the list then a “??” will be output until enough values have been entered.

There are two possible messages that may appear during the execution of an **`INPUT`** statement:

Extra Ignored

The user has attempted to enter more values than are required. The program will continue but the extra data will be discarded.

Redo from start

A string was entered when a number was expected. The reverse never happens as numbers are considered valid strings.

LET <var>=<expression>

Assigns to <var> the value of <expression>. Both <var> and <expression> must be of the same data type. The **LET** command is optional and just <var>=<expression> is also valid.

LIST [n1][-n2]

Lists all or part of the program held in memory. if n1 is specified then listing begins with line n1 and continues up to and including n2 if included. If n2 is not included, then listing continues to the end. If neither is included, then the whole program is listed. Listing is output to the currently selected output stream(s).

LOAD <expression$> [<expression>]

Takes <expression$> as the filename for loading. If <expression$> is null "" then it will load the first file of the correct type it encounters. If <expression> is not present then TowerBASIC is assumed, otherwise <expression> is used as the load address of a binary file to be loaded.

If the first character of the file is a "!" then the file is automatically executed upon load unless the relevant bit is cleared in V_TAPE_Config. Execution of binary files begins at the load address with TowerBASIC at extension level 4.

LOCATE <expr1>,<expr2>

Positions the text cursor at <expr1> columns across by <expr2> rows down. Subsequent output will appear from there. This command has little or no meaning for printers and some terminal software.

LOOP [{UNTIL|WHILE} <expression>]

On its own, the loop will repeat forever. When WHILE is used the loop will continue as long as <expression> is true before each pass. When UNTIL is used, the loop will execute at least once as the <expression is evaluated at the end of each pass.

NEW

Erases the current program and all of its variables from memory.

NEXT [var[,var]...]

Increments, or decrements a loop variable and checks for the terminating condition. If the terminating condition has been reached then execution continues with the next command, else execution continues with the command after the FOR assignment.

The list of variables is handed left to right.

NOT <expression>

returns the bitwise NOT of <expression>.

NULL <n>

Sets the number of null characters printed by TowerBASIC after every carriage return. <n> may be between 0 and 255.

ON <expression> {GOTO|GOSUB} <n>[,n]...

The integer value of <expression> is calculated and then used to address the nth number after the GOTO or GOSUB executed thereafter. Valid results for <expression> are 0...255 and any result outside this range will generate a Function call error.

PLOT <expr1>,<expr2>,<expr3>

The first expression, if even, causes plot to clear a pixel, but if odd, set a pixel. <expr2> is the x co-ordinate with 0 at the left. <expr3> is the y co-ordinate with 0 at the top.

With the ANSI card, the x co-ordinate should be in the range of 0..159 and the y co-ordinate should be in the range of 0..99. Values outside that range have undefined visual results.

POKE <addr,b>

Writes byte value <b` to address <addr>.

PRINT [<expression>][;|,}[expression]...[{;|,}]

Outputs the value of expression. If the list of expressions to be output does not end with a comma or semicolon, then a carriage return and linefeed are output after the values.

Expressions on the line can be separated by a semicolon, in which case the next expression will follow immediately, or by a comma, which will cause the next expression to be advanced to the next tab stop before continuing to print. If nothing follows the PRINT statement, then a carriage return and linefeed are printed.

READ <var>[,<var>]...

Reads values from **`DATA`** statements and assigns them to the listed variables. Trying to read a string into a numeric variable will cause a Syntax error.

Also see **`RESTORE`**.

REM

Everything on the line following this command is ignored including colons. Used normally for inserting comments into the program.

RESTORE [n]

Resets the DATA pointer. If <n> is specified then the pointer is reset to the beginning of that line, else it will be reset to the beginning of the program. If <n> is specified but does not exist, then an error will be generated.

RETURN

Returns execution to the next statement after the last **`GOSUB`** was encountered. If there are no more **`GOSUB`**s to return from then a RETURN without GOSUB error will be generated.

RUN [n]

Begins execution of the program currently in memory at the lowest numbered line unless a line number is specified in which case execution starts from that line. All variables, **`FOR`** .. **`NEXT`**, **`GOSUB`** .. **`RETURN`** and **`DO`** .. **`LOOP`** states are cleared, and the data pointer is set to the program start.

SAVE <expression$> [<addr>,<size>]

If there is only the string expression, then it saves the current TowerBASIC program. If there are also the two numeric expressions <addr> and <size> then it saves a binary file, the contents of which are the memory starting at <addr> and <size> bytes long.

If the filename in <expression$. is longer than 16 characters then a Filename too long error will be generated.

SOUND <channel>, <period>, <volume>

Tells the AY-3-8912 to play a tone of <period> on <channel> at volume <volume>. The AY will remain in that state until programmed otherwise.

Volume of 16 indicates to the AY that one wishes to use the envelope generator to control the volume.

SPC(<expression>)

Prints <expression> spaces. This command is only valid in a print statement.

SPI_INIT <mode>,<MOSI_P>,<MISO_P>,<SCK_P>,<SS_P>,<SS_act>

Initialises the SPI engine on port A of the first GPIO card, which must be set to a base address of $C040. <mode> is the SPI mode, each of the _P's are values between 0 and 7 and no pin _P must overlap. <SS_act> represents the active state of <SS_P>.

If any of the parameters is out of range, or a pin should overlap a Function call error will be generated.

STEP

Sets the step size in a `FOR` .. `NEXT` loop. See `FOR`.

SWAP <var[$]>,<var[$]>

Swaps two variables. The two variables will have their values exchanged. Both must be of the same type or a Type mismatch will occur. Either or both variables can be array elements.

TAB(<expression>)

Sets the cursor position to <expression> by printing spaces. If the cursor is already beyond that point, then the cursor will be left where it is. This command is only valid in a **`PRINT`** statement.

THEN

See **`IF`**.

TO

Sets the range in a **`FOR`** .. **`NEXT`** loop. See **`FOR`**.

UNTIL

See **`DO`** and **`LOOP`**.

VERIFY <filename$> [<addr>]

Compares the contents of <filename$> with memory. If <addr> is included then it will compare binary information, otherwise it will compare TowerBASIC. If the contents of memory and tape do not match then a Verify Error is generated, otherwise it reports Verified OK. If <filename$> is a null string, then it compares the first file of the correct type it finds.

WAIT <addr>,b1>[,b2]

Pauses program execution until the contents of memory at location <addr> exclusive ORed with <b2> and ANDed with <b1> is non-zero. If <b2> is not defined, then it is assumed to be zero. Note, both <b1> and <b2> must be byte values.

WHILE

See **`DO`** and **`LOOP`**.

WIDTH {b1|,b2|b1,b2}

Sets the terminal width and TAB spacing. b1 is the terminal width and b2 is the **`TAB`** spacing. The default is 80 and 14. If width is set to zero then it is assumed to be infinite, or from 16 to 255.

The **`TAB`** size is from 2 to width minus 1, or 127, whichever is smaller.

Appendix K. List of Functions

ABS(<expression>)

Returns the absolute value <expression>.

ASC(<expression$>)

Returns the ASCII value of the first character of the expression. If <expression$> is null "" then a Function call error is generated.

ATN(<expression>)

Returns in radians, the arctangent of <expression>.

BIN$(<expression>[,b])

Returns <expression> as a binary string. If b is omitted or zero then leading zeros are stripped and is of variable length. If b is set, permissible values range from 1 to 24, then a string of length b will be returned. The result is always unsigned and calling this function with expression > 2^24-1 or b>24 will cause a Function call error.

BITTST(<addr>,<b>)

Tests bit b of address addr. Valid bit numbers are from 0, the least significant bit, to 7, the most significant bit. Returns zero if the bit was a zero, or -1 if the bit was a 1.

CHR$(b)

Takes the ASCII value b and returns a single character string with that character.

COS(<expression>)

Returns the cosine of the angle <expression> radians.

DEEK(<addr>)

Returns the word of value <addr> and <addr>+1 as a positive integer in the range of 0..65535. <addr> holds the low byte.

EXP(<expression>)

Returns e^<expression>. Natural antilog.

FRE(<expression>)

Returns the amount of free program memory. The value of expression is ignored and can be anything.

HEX$(<expression>[,b])

Returns <expression> as a hexadecimal string. If b is omitted or zero, then leading zeros are removed and is of variable length. If b is set, permissible values ranging from 0 to 6, then a string of length b will be returned. The result is always unsigned and calling this function with expression > 2^24-1 or b>6 will cause a Function call error.

I2C_IN(<b>)

Receives a byte on the I^2C-Bus and transmits an ACK (b=0), or a NAK (b=1).

I2C_OUT(<b>)

Transmits byte b on the I^2C-Bus and returns either an ACK (result=0), or a NAK (result=1).

INT(<expression>)

Returns the integer of <expression>

LCASE$(<expression$>)

Returns <expression$> with all the alpha characters in lower case.

LEFT$(<expression$,b>)

Returns the leftmost b characters of <expression$>.

LEN(<expression$>)

Returns the length of <expression$>.

LOG(<expression>)

Returns the base e (natural) logarithm of <expression>.

MAX((<expression>[,<expression]...)

Returns the maximum value from the list of numeric expressions. There must be at least one expression, but the limit is dictated by the line length.

MID$(<expression$,b1>[,b2])

Returns the substring of <expression$>, starting at b1 and of length b2. The leftmost character is at position 1. If b2 is omitted then all of the string from b1 to the end are returned.

MIN(<expression>[,<expression>]...)

Returns the minimum value from the list of numeric expressions. There must be at least one expression, but the limit is dictated by the line length.

PEEK(<addr>)

Returns the byte stored at the address <addr>.

PI

Returns the value of pi as 3.14159274, which is the closest floating-point value.

POS(<expression>)

returns the position of the cursor on the terminal line. The value of the expression is ignored.

RIGHT$(<expression$,b>)

Returns the rightmost b characters of <expression$>.

RND(<expression>)

Returns a pseudo-random number in the range of 0 to 1. If <expression> is non-zero then it will be use as the seed for the returned pseudo-random number, otherwise the next number in the sequence will be returned.

SADD(<{var$|var$()}>)

Returns the address of var$ or var$(). This returns the pointer to the actual string in memory and not its descriptor. If you want the pointer to the descriptor instead, then use **`VARPTR`** instead.

SGN(<expression>)

Returns the sign of <expression>. If the sign is positive, it returns 1, if it is 0 then it returns 0, if negative it then returns -1.

SIN(<expression>)

Returns the sine of the angle <expression> radians.

SPI_XFER(<b>)

Transmits b over SPI whilst simultaneously returning the received byte.

SQR(<expression>)

Returns the square root of <expression>.

STR$(<expression>)

Returns the result of <expression> as a string.

TAN(<expression>)

Returns the tangent of the angle <expression> radians.

TWOPI

Returns the value of 2*pi as 6.28318548 (closest floating-point value).

UCASE$(<expression$>)

Returns <expression$> with all alpha characters in upper case.

USR(<expression>)

Takes the value of <expression> and places it in FAC1 and then calls the user routine pointed to by the vector at address $000B. What the user routine does with this is entirely up to the user, even being safely ignored if so desired. The routine after the user does an RTS, takes the contents of FAC1 and returns that. It can be either numeric or a string value.

VAL(<expression$>)

Returns the value of <expression$>. <expression$> must contain a number and VAL will not work with anything else.

VARPTR(<var[$]>)

Returns a pointer to the variable memory space. If the variable is numeric, or numeric array element, then **`VARPTR`** returns the pointer to the packed value of that variable in memory. If that variable is a string, or a string array element, then **`VARPTR`** returns a pointer to the descriptor for that string. If you want the pointer to the string itself use **`SADD`** instead.

Appendix L. List of Error Messages.

Array bounds Error

An attempt was made to access an element of an array outside its bounding dimensions.

Break

^C was pressed.

Can't continue Error

Execution can't continue because either the program execution ended because of an error, `NEW` or `CLEAR` were executed, or the program has since been edited.

Divide by zero Error

The right-hand side of an expression A/B was zero.

Double dimension Error

An attempt was made to dimension an array which has already been dimensioned. This could be because it has already been accessed, causing it to be dimensioned by default.

Extra ignored (INPUT warning)

The user has attempted to enter more values than were required at the INPUT prompt. The extra is thrown away and execution continues.

Filename too Long

The <filename$> expression of a LOAD, SAVE or VERIFY command was greater than 16 characters in length.

Function call Error

Some parameter of a function was outside its limits. Example: POKEing a value of less than 0 or greater than 255.

Header Error. Retrying.

This warning is for a LOAD, CAT, or VERIFY header read, and this warning appears if it detects an error in the header, giving you the chance to rewind the tape and try again.

Illegal direct Error

An attempt was made to execute a command or function in direct mode (from the command line) which is disallowed in that mode. INPUT and DEF are such examples.

LOOP without DO Error

`LOOP` has been encountered with no matching **`DO`**.

NEXT without FOR Error

`NEXT` has been encountered and no matching **`FOR`** could be found.

Out of DATA Error

A READ has tried to read data past the last item. Usually because you either mistyped the DATA lines, miscounted the DATA, RESTOREd to the wrong place, or just plain forgot to RESTORE.

Out of memory Error

Anything that uses memory can cause this error. Consider how you pack your data, be terse in your style and throw out what isn't needed. Using arrays with sparse data is especially wasteful, and using an array of numbers when you only need integers is very inefficient. You could lower the top of ram by DOKEing $85,Ram_top, then Executing a CLEAR. This would allow you to store values as integers directly into RAM with a little creative thinking.

Overflow Error

The result of a calculation has overflowed the numerical range of TowerBASIC. The range that can be stored is plus or minus 1.7014117+E38. A full description of floating point numbers and their special characteristics and hazards is beyond the scope of this manual.

Redo from start

This is a warning from the INPUT command that you have entered something that was not numeric when it is expecting a number.

RETURN without GOSUB Error

A RETURN was encountered when no matching GOSUB.

String too complex Error

A string expression has caused an overflow on the descriptor stack. Try splitting the expression into smaller pieces.

String too long Error

Strings can be from 0 to 255 characters long. Any more and this error will occur.

Syntax Error

Just about anything else wrong. Misspelled KEYWORDS, missing arguments etc.

Tape loading Error.

Whilst loading, an error with the data was detected. Don't forget to back-up anything you might consider precious (yes you at the back there!).

Type mismatch Error

An attempt was made to assign a numeric value to a string variable, a string value to a numeric variable or a value of one type was returned when a value of the other type was expected or an attempt at a relational operation between a string and a number was made.

Undefined function Error

FN <var> was called but not found.

Undefined statement Error

Either a **GOTO**, **GOSUB**, **RUN** or **RESTORE** was attempted to a line that doesn't exist, or the line referenced in an **ON** <expression> doesn't exist.

Verify Error.

When comparing the contents of memory with that of the file, the VERIFY command detected either a discrepancy in the data on tape, or the tape filing system reported a framing error.