User's manual

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PART 1

CHAPTER 1: AN INTRODUCTION TO THE BINARY NUMBER SYSTEM

1.1 BINARY NUMBERS:

NUMBERS IN EVERY DAY USE ARE WRITTEN IN THE DECIMAL SYSTEM, THAT IS, TO THE NUMBER BASE 1Ø. A POSITIONAL NOTATION IS USED REPRESENTING ONE '1ØØ's; TWO '1Ø's & EIGHT '1's AS THE SYMBOL 128. THE RIGHTMOST (i.e. LEAST SIGNIFICANT) DIGIT IS IN THE "UNITS" COLUMN, THE 2 IN THE "TENS" COLUMN, THE 1 IN THE "HUNDREDS" COLUMN, AND THE VALUE OF THE SYMBOL '128' IS EVALUATED AS 1x1ØØ+2x1Ø + 8x1 = 128. SIMILARLY '1Ø24' IS EVALUATED AS 1x1ØØØ + Øx1ØØ + 2x1Ø + 4x1 = 1Ø24, WHICH IS MORE CONVENIENTLY WRITTEN AS $1 \times 10^3 + 0 \times 10^2 + 2 \times 10^1 \; 4 \times 10^0 = 1024$, USING THE MATHEMATICAL SHORTHAND FOR $1000 = 10 \times 10 \times 10 = 10^3$, AND THE CONVENTION "ANY NUMBER TO THE POWER ZERO IS 1" TO GIVE A CONSISTENT METHOD OF EVALUATING SUCH SYMBOLS.

SO 1Ø24

CAN BE WRITTEN IN COLUMNS

3	2	1	Ø
1	Ø	2	4

AND EVALUATED AS $1 \times 10^3 + 0 \times 10^2 + 2 \times 10^1 + 4 \times 10^0$

TO THE BASE 1Ø.

TO THE BASE 8, 1Ø24 WOULD MEAN $1 \times 8^3 + 0 \times 8^2 + 2 \times 8^1 + 4 \times 8^0$ WHICH IS THE DECIMAL NUMBER 532.

TO THE BASE 16, 1Ø24 WOULD MEAN $1 \times 16^3 + 0 \times 16^2 + 2 \times 16^1 + 4 \times 16^0$ WHICH IS THE DECIMAL NUMBER 4132.

TO DISTINGUISH THE BASE TO WHICH A NUMBER IS WRITTEN WE'LL WRITE ITS' BASE AFTER IT AS A SUBSCRIPT: 1024_{10} AND NOW WE CAN WRITE

$1024_8 = 532_{10}$

$1024_{16} = 4132_{10}$

$10000000_2 = 128_{10}$

JUST AS BASE TEN HAS THE NAME 'DECIMAL', BASE SIXTEEN HAS THE NAME 'HEXADECIMAL', BASE EIGHT HAS THE NAME 'OCTAL' AND BASE TWO 'BINARY'. THESE FOUR BASES ARE IN COMMON USE WITH MODERN COMPUTERS, ESPECIALLY HEXADECIMAL (HEX) AND BINARY. CONVERSION BETWEEN BINARY, OCTAL & HEX NUMBERS IS VERY SIMPLE. SINCE THEY ARE ALL POWERS OF TWO, NUMBERS JUST NEED DIVIDING UP:–

$10000000_2 = |1000||0000|_{16} = 80_{16}$

$= |010||000||000|_8 = 200_8$

– EACH HEX DIGIT IS FOUR BINARY DIGITS (BITS) & EACH OCTAL DIGIT IS 3 BITS.

OCTAL DIGITS ARE Ø, 1, 2, 3, 4, 5, 6, 7.

HEX DIGITS ARE Ø, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F A....F ARE USED INSTEAD OF 1Ø....15 TO ALLOW UNRESTRICTED USE OF THE POSITIONAL SYSTEM.

CONVERSION TABLE

HEX	DECIMAL	OCTAL	BINARY
Ø	Ø	Ø	Ø
1	1	1	1
2	2	2	1Ø
3	3	3	11
4	4	4	1ØØ
5	5	5	1Ø1
6	6	6	11Ø
7	7	7	111
8	8	1Ø	1ØØØ
9	9	11	1ØØ1
A	1Ø	12	1Ø1Ø
B	11	13	1Ø11
C	12	14	11ØØ
D	13	15	11Ø1
E	14	16	111Ø
F	15	17	1111
1Ø	16	2Ø	1ØØØØ
2Ø	32	4Ø	1ØØØØØ
4Ø	64	1ØØ	1ØØØØØØ
64	1ØØ	144	11ØØ1ØØ
8Ø	128	2ØØ	1ØØØØØØØ
1ØØ	256	4ØØ	1ØØØØØØØØ

THE ACORN MICROPROCESSOR IS DESIGNED TO DEAL WITH 8 BITS AT A TIME. THE COLLECTION OF 8 BITS IS GIVEN THE SPECIAL NAME 'BYTE', AND IS NORMALLY WRITTEN IN HEXADECIMAL OR BINARY. A BYTE THUS IS Ø....FF_{16}; Ø....11111111_2 OR Ø....255_{10}. THE MICROPROCESSOR CAN CARRY OUT LOGICAL AND ARITHMETICAL MANIPULATIONS ON BYTES.

1.2 LOGICAL MANIPULATIONS

THE MICROPROCESSOR CAN IMMEDIATELY CARRY OUT THE LOGICAL AND, EXCLUSIVE - OR & OR FUNCTIONS ON ALL 8 BITS SIMULTANEOUSLY, USING THE FOLLOWING TRUTH TABLES FOR EACH BIT (SYMBOL 'b')

AND (∧)

b_1	b_2	result
Ø	Ø	Ø
Ø	1	Ø
1	Ø	Ø
1	1	1

EXCLUSIVE - OR (∀)

b_1	b_2	result
Ø	Ø	Ø
Ø	1	1
1	Ø	1
1	1	Ø

OR (∨)

b_1	b_2	result
Ø	Ø	Ø
Ø	1	1
1	Ø	1
1	1	1

EXAMPLE

OPERANDS

ØØ1111ØØ		ØØ1111ØØ		ØØ1111ØØ
Ø1Ø11Ø1Ø	AND	Ø1Ø11Ø1Ø	E-OR	Ø1Ø11Ø1Ø OR
————	(OPERATOR)	————		————
ØØØ11ØØØ	RESULT	Ø11ØØ11Ø		Ø111111Ø

1.3 ARITHMETIC MANIPULATIONS

BINARY ADDITION
WITH CARRY OUTPUT

b_1	b_2	SUM	CARRY
Ø	Ø	Ø	Ø
Ø	1	1	Ø
1	Ø	1	Ø
1	1	Ø	1

BINARY ADDITION WITH CARRY FROM RIGHT

b_1	b_2	INPUT CARRY	SUM	OUTPUT CARRY TO LEFT
Ø	Ø	Ø	Ø	Ø
Ø	1	Ø	1	Ø
1	Ø	Ø	1	Ø
1	1	Ø	Ø	1
Ø	Ø	1	1	Ø
Ø	1	1	Ø	1
1	Ø	1	Ø	1
1	1	1	1	1

EXAMPLE:	ØØ1111ØØ	3C$_{16}$	6Ø$_{10}$
	Ø1Ø11Ø1Ø+	5A$_{16}$ +	9Ø$_{10}$ +
	1ØØ1Ø11Ø	96$_{16}$	15Ø$_{10}$

IN ORDER TO MAKE LONGER ADDITIONS EASIER TO PROGRAM, THE MICROPROCESSOR HAS A CARRY BIT (FLAG). AT THE START OF AN ADDITION THIS IS TREATED AS THE INPUT CARRY, AND AT THE END IT RECEIVES THE CARRY OUT FROM THE SUM AT BIT 7: ASSUMING WE HAVE A CARRY INPUT:

	11ØØØØ11		C3$_{16}$	195$_{10}$
	1Ø1ØØ1Ø1	CARRY IN	A5$_{16}$	165$_{10}$
	[1] +		1$_{16}$ +	1$_{10}$+
CARRY OUT [1]	Ø11Ø1ØØ1		169$_{16}$	361$_{10}$

SUBSTRACTION OPERATES IN A SIMILAR MANNER, EXCEPT THAT THE CARRY (OR BORROW) FLAG OPERATES UPSIDE DOWN: A Ø CARRY FLAG IS TREATED AS REPRESENTING A BORROW FROM THE PREVIOUS STAGE:

	11111111	FF$_{16}$	255$_{10}$
	ØØØØØØØØ	ØØ$_{16}$	ØØØ$_{10}$
	Ø	Ø$_{16}$	Ø$_{10}$
[1]	1111111Ø	1FE$_{16}$	51Ø$_{10}$

NOT QUITE THE RESULTS ONE MIGHT HAVE WISHED FOR! (SUPERFICIALLY THIS OCCURS BECAUSE OF THE HARDWARE IMPLEMENTATION OF SUBTRACTION A SUBTRACTION, (P–Q), IS REGARDED BY THE MICRO-PROCESSOR AS THE EQUIVALENT (P+(–Q)), BECAUSE THERE IS A SIMPLE WAY TO GENERATE THE NEGATIVE OF A NUMBER.

THE 'ONES-COMPLEMENT' OF A BINARY NUMBER IS SIMPLY GENERATED BY EXCHANGING 'Ø's & '1's:

'1's	ØØØØ11ØØ$_2$	ØC$_{16}$	12$_{10}$
COMPLEMENT	1111ØØ11$_2$	F3$_{16}$	243$_{10}$

IF THIS ONE'S-COMPLEMENT IS TO BE THE NEGATIVE OF A NUMBER, WE SHOULD GET Ø ON ADDITION:

ØØØØ11ØØ$_2$	ØC$_{16}$	12$_{10}$
1111ØØ11$_2$ +	F3$_{16}$ +	243$_{10}$ +
11111111$_2$	FF$_{16}$	255$_{10}$

WHICH DOESN'T HAPPEN .... UNTIL WE ADD AN EXTRA 1:

ØØØØ11ØØ$_2$	ØC$_{16}$	12$_{10}$	
1111ØØ11$_2$	F3$_{16}$	243$_{10}$	
1$_2$ +	1$_{16}$ +	1$_{10}$	16
1 ØØØØØØØØ$_2$	1ØØ$_{16}$	256$_{10}$	

AND THEN TREAT THE OUTPUT CARRY AS INDICATING THE ABSENCE OF A BORROW FROM THE HIGHER ORDERS.

THE NUMBER (ONE'S-COMPLEMENT + 1) IS CALLED THE TWO'S-COMPLEMENT OF A NUMBER:

BINARY	HEXADECIMAL	DECIMAL
ØØØØØØØ1$_2$	Ø1$_{16}$	+1$_{10}$
ØØØØØØØØ$_2$	ØØ$_{16}$	+Ø$_{10}$ or −Ø$_{10}$
11111111$_2$	FF$_{16}$	−1$_{10}$
111111Ø2	FE$_{16}$	−2$_{10}$
:	:	:
1111Ø1ØØ$_2$	F4$_{16}$	−12$_{10}$
1ØØØØØØØ$_2$	8Ø$_{16}$	−128$_{10}$
Ø1111111$_2$	7F$_{16}$	+127$_{10}$

SO A BYTE CAN BE TREATED AS A 'SIGNED BINARY NUMBER' IN THE RANGE +127..... Ø..... −128, OR AS A BINARY NUMBER IN THE RANGE Ø.....+255. NOW THE SUBTRACTION ABOVE SHOULD BE CLEAR : INTERNALLY, THE MICRO-PROCESSOR ONE'S-COMPLEMENTS ONE OF THE NUMBERS AND THEN EXECUTES A NORMAL ADDITON WITH CARRY.

1.4 BINARY CODED DECIMAL (BCD) ARITHMETIC

99$_{16}$ LOOKS VERY LIKE 99$_{10}$ THEY BEHAVE THE SAME WAY AS THEY ARE MOVED AROUND AND UNDERGO LOGICAL OPERATIONS SINCE THEY ARE WRITTEN THE SAME WAY. THE BINARY REPRESENTATION OF 99$_{10}$ WOULD NORMALLY BE Ø11ØØØ11$_2$, AND OF 99$_{16}$ IT WOULD BE 1ØØ11ØØ1$_1$. WE NOW DEFINE THE BINARY CODED DECIMAL VERSION OF 99$_{10}$ AS BEING THE BINARY REPRESENTATION OF THE DECIMAL DIGITS IN THE ORIGINAL POSITIONAL NOTATION, MAKING THE DIFFERENCE BETWEEN THE BINARY REPRESENTATIONS OF 99$_{16}$ & 99$_{10}$ A MATTER OF SUPSCRIPTS:

99$_{16}$ = 1ØØ11ØØ1$_2$

99$_{10}$ = 1ØØ11ØØ1 B.C.D.

THE B.C.D. AND BINARY NUMBERS DIFFER IN HANDLING ONLY IN ARITHMETIC:

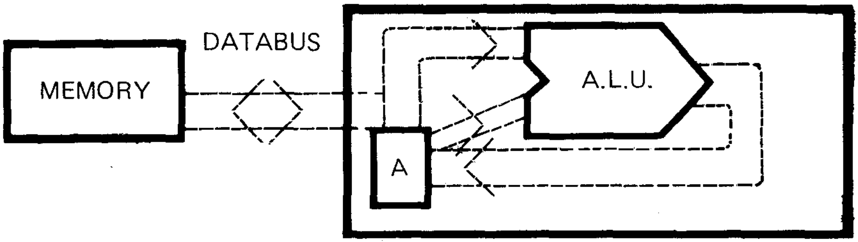
79$_{16}$			79$_{10}$	
22$_{16}$	+	BUT	22$_{10}$	+
9B$_{16}$			1Ø1$_{10}$	

THE MICROPROCESSOR CAN BE 'TOLD' WHICH TYPE OF ARITHMETIC TO CARRY OUT, BY SETTING (PUTTING A ONE INTO) OR CLEARING (PUTTING A ZERO INTO) AN INTERNAL BIT, THE 'DECIMAL MODE' FLAG.

CHAPTER 2: WELCOME TO THE MACHINE

2.1 HOW ACORN'S MICROPROCESSOR WORKS

TO CARRY OUT THE ABOVE OPERATIONS THE MICROPROCESSOR HAS AN INTERNAL ARITHMETIC LOGIC UNIT (A.L.U.) WHOSE OUTPUT IS SENT TO AN INTERNAL REGISTER OF ONE BYTE LENGTH CALLED THE ACCUMULATOR 'A', THIS REGISTER ALSO ACTS AS ONE OF THE OPERANDS; THE OTHER BEING DRAWN FROM THE MEMORY EXTERNAL TO THE μPROCESSOR, WHICH IS CONNECTED TO THE μP BY 8 LINES CALLED THE DATABUS:



DATA CAN BE TRANSFERRED ALONG THE DATABUS IN EITHER DIRECTION, THIS DIRECTION IS CHOSEN BY THE, μP AND INDICATED TO THE EXTERNAL UNITS BY A SINGLE 'R/W' LINE : WHEN HIGH, '1' , THE μP IS RECEIVING DATA FROM THE MEMORY, 'READING'; WHEN LOW, 'Ø', THE μP IS SENDING DATA TO THE MEMORY, 'WRITING'. ALL INFORMATION USED BY THE μP TRAVELS ALONG THE DATABUS, INCLUDING THE INSTRUCTIONS. SO THAT THE μP KNOWS WHERE ITS INSTRUCTIONS ARE IT HAS A TWO BYTE (16_{10} BIT) REGISTER CALLED THE PROGRAM COUNTER, 'PC', WHICH POINTS AT THE INSTRUCTIONS BEING EXECUTED. THE MEMORY CAN BE VIEWED AS A BOOK OF 256 PAGES, THE PARTICULAR PAGE BEING DECIDED BY THE MOST SIGNIFICANT 8 BITS (BITS 15–8) OF THE 16 BIT ADDRESS, EACH PAGE CONTAINING 256 BYTES, THE PARTICULAR BYTE BEING DECIDED BY THE LEAST SIGNIFICANT 8 BITS (BITS 7–Ø) OF THE 16 BIT ADDRESS.

IN THE KIT, PAGES FE_{16} & FF_{16} ARE OCCUPIED BY A NON-ERASEABLE PROGRAM TO INTERFACE BETWEEN THE MICROPROCESSOR AND THE KEYBOARD & DISPLAY UNIT. TO START THE μP IN THIS PROGRAM (AT THE CORRECT PLACE) THERE IS A RESET BUTTON WHICH INITIALIZES THE PROGRAM COUNTER. IN PAGE $ØØ_{16}$ THERE IS SOME ALTERABLE MEMORY, OF WHICH THE BOTTOM $1F_{16}$ BYTES ARE GIVEN SPECIAL USES BY THE FE_{16} & FF_{16} MONITOR PROGRAM, SO UNLESS PRESSED FOR SPACE, IT'S BEST TO STAY OUT OF THEM.

2.2 THE MONITOR COMMANDS M,↑,↓

THE FIRST FEATURE OF THE MONITOR IS THE MEMORY INSPECT & MODIFY CONTROL SWITCH ON, AND PRESS THE RESET BUTTON:

MODE	ADDRESS		DATA
.	....	.	..

THEN PRESS THE MODIFY KEY, M. THIS GETS YOU INTO THE MEMORY INSPECTION AND MODIFY MODE. THE MODE INDICATOR SHOWS 'A' FOR ALTER. THIS FIRST PHASE OF 'A' ALLOWS YOU TO CHOOSE ANY ADDRESS IN MEMORY.

A. XXXX .

APPEARS ON THE DISPLAY, WHERE X REPRESENTS ANY OF THE 16 HEX CARACTERS SIGNIFYING THE ADDRESS.NOW PRESS THE KEYS F, E, Ø, Ø (IF YOU MAKE A MISTAKE, E.G. PRESSED F, D, JUST START OFF FROM THE F AGAIN). AS EACH KEY IS PRESSED THE INFORMATION ON THE DISPLAY SHIFTS TO THE LEFT:

A. XXXF .
A. XXFE .
A. XFEØ .
A. FEØØ .

AND SO YOU END UP WITH FEØØ ON THE DISPLAY. PRESS ANY OF THE EIGHT COMMAND KEYS (IT DOES NOT MATTER WHICH) AND YOU CAN INSPECT THE CONTENTS OF THIS MEMORY ADDRESS. THIS IS PHASE TWO OF MODE 'A' AND ALLOWS YOU TO INSPECT AND ALTER THE DATA OF THE MEMORY ADDRESS CHOSEN IN PHASE ONE.

A. FEØØ . AØ

THIS IS THE INFORMATION STORED AT THE VERY BEGINNING OF THE MONITOR. IF YOU PRESS THE ↑ KEY

A. FEØ1 . Ø6

UP WE GO. NATURALLY THE ↓ KEY BRINGS BACK

A. FEØØ . AØ

AND EITHER KEY MAY BE USED ANY NUMBER OF TIMES IN SUCCESSION. NOW, IF, WITHOUT TURNING OFF, YOU PRESS RESET

. ...

AND THEN M

A. FEØØ .

THE SYSTEM HAS REMEMBERED THE ADDRESS YOU WERE USING (WHICH DOESN'T HAVE TO BE FEØØ) TO INSPECT MEMORY NOW ENTER THE ADDRESS ØØ3Ø AND TERMINATE WITH ANY COMMAND KEY

A. ØØ3Ø . XX

ØØ3Ø IS AN ADDRESS IN THE ALTERABLE SECTION OF THE MEMORY. PRESSING DIGIT KEYS NOW WILL CAUSE THE INFORMATION IN ØØ3Ø TO CHANGE (WHAT HAPPENS AT FEØØ?? TRY IT! YOU CANNOT WRITE INTO THE MONITOR PROM, (i.e. THE PROGRAMMABLE READ ONLY MEMORY). PRESS Ø, 1.

A. ØØ3Ø . Ø1

PRESS 2,3

A. ØØ3Ø . 23

AS BEFORE INFORMATION IS SHIFTED IN UNTIL TERMINATED BY ANY COMMAND KEY. BUT, UNLIKE THE ADDRESS FETCHING PHASE, THE COMMAND KEY WILL BE EXECUTED. USEFUL TERMINATORS ARE THE M, ↑ & ↓ KEYS. PRESS ↑.

A. ØØ31 . XX

PRESS 4,5

A. ØØ31 . 45

PRESS ↓

A. ØØ3Ø . 23

& ↑ AGAIN

A ØØ31 . 45

YOU CAN GO UP AND DOWN INSPECTING & MODIFYING THE MEMORY CONTENTS IF THERE IS NO ALTERABLE MEMORY (E.G. A PROM) AT A PARTICULAR ADDRESS, THE INFORMATION WILL NOT CHANGE. TO CLOSE THIS SECTION WE'LL MAKE THE MONITOR DO A LITTLE TRICK. M,Ø,Ø,Ø,E, k (k ≡ ANY COMMAND KEY)

PRESS 1,6. (IF YOU GET BORED, YOU CAN GO THE OTHER WAY BY 1,7) (ESCAPE BY RESET). THE MONITOR SCANS THROUGH ALL MEMORY SUCCESSIVELY SHOWING ITS CONTENTS (DATA). WHERE THERE IS NO MEMORY AT ALL YOU WILL PROBABLY SEE THE FIRST TWO ADDRESS DIGITS.

2.3 AT LAST, A PROGRAM

2.3.1 ASSEMBLY LANGUAGE, MACHINE LANGUAGE, THE INSTRUCTIONS LOAD, STORE AND JUMP

A PROGRAM IS THE NAME FOR A SET OF STORED COMMANDS THAT THE MICROPROCESSOR WILL EXECUTE. THESE ARE STORED IN BINARY, SINCE THAT'S ALL THAT ANYTHING CAN BE STORED IN, (ENTERED BY YOU IN HEX) AND ARE INDISTINGUISHABLE FROM ANYTHING ELSE. IF IT GETS THE CHANCE THE μP (MICROPROCESSOR) WILL BUSY ITSELF TREATING INFORMATION WHICH YOU MEANT AS DATA AS A PROGRAM. IT PROBABLY WON'T BE DOING ANYTHING INTELLIGENT AND WILL HAVE TO BE SUMMONED BACK WITH THE RESET KEY. SOME SORT OF TRANSLATION BETWEEN THE STORED BINARY/HEX AND YOU IS NEEDED. 1Ø1Ø11Ø1$_2$ MEANS A GREAT DEAL TO THE μP BUT LITTLE TO YOU. IT ACTUALLY MEANS "LOAD THE ACCUMULATOR WITH THE CONTENTS OF THE MEMORY ADDRESS DEFINED BY THE FOLLOWING TWO BYTES, OF WHICH THE FIRST IS THE LEAST SIGNIFICANT ADDRESS". THIS IS A LITTLE LONG FOR WRITING STRAIGHT INTO A PROGRAM AND IS USUALLY ABBREVIATED TO LDA ABS, OR JUST LDA.ABSOLUTE MEANS ANYWHERE IN THE 64K. THE 6502 CAN ADDRESS 64K OF MEMORY WHICH IS DIVIDED INTO PAGES 256 BYTES LONG THE FIRST PAGE IS CALLED ZERO PAGE. LOCATIONS IN ZERO PAGE CAN BE ADDRESSED BY JUST ONE BYTE. THERE ARE SPECIAL INSTRUCTIONS TO DO THIS. AT THE END OF THE MANUAL THERE IS A LIST OF ALL THESE MNEMONICS WITH THEIR HEX EQUIVALENTS IN APPENDIX B. SO IF WE WROTE THE PROGRAM IN MNEMOMICS IT WOULD LOOK LIKE.

```
LDA FE ØØ
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AND WE WOULD TRANSLATE IT FOR THE μP AS THE THREE BYTES

```
AD    LOAD ABSOLUTE
ØØ    LOWER BYTE OF ADDRESS
FE    HIGH BYTE OF ADDRESS
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WHICH WOULD CAUSE THE μP TO PUT AØ (THE DATA STORED IN FEØØ) IN ITS ACCUMULATOR (REMEMBER USING THE MONITOR TO LOOK AT FEØØ?). THE TRANSLATION PROCESS IS CALLED ASSEMBLING AND COMPUTER PROGRAMS WHICH DO IT ARE CALLED ASSEMBLERS. A RESIDENT ASSEMBLER IS ONE THAT RUNS (OPERATES) ON THE SAME MACHINE THAT IT ASSEMBLES FOR; A CROSS ASSEMBLER RUNS ON A DIFFERENT MACHINE. THE MNEMONICS LDA, STA etc ARE OFTEN CALLED ASSEMBLY LANGUAGE, THE GENERATED BINARY IS CALLED MACHINE CODE.
WE CAN LOAD THE ACCUMULATOR IN TEN OTHER WAYS; HERE ARE TWO OF THEM.

INSTRUCTION LENGTH IN BYTES	TYPE	HEX	MNEMONIC	EXECUTION TIME,µS	BRIEF EXPLANATION
2	1	A9	LDA #	2	PUT THE NEXT BYTE IN ACCUMULATOR. "LOAD IMMEDIATE'.
2	2	A5	LDA Ƶ	3	SHORTENED FORM OF LOAD ABS ØØXX 'LOAD ZERO PAGE'.
3	3	AD	LDA	4	LOAD A ABSOLUTE.

THE FIRST OF THESE INSTRUCTIONS IS VERY IMPORTANT. IF WE KNOW THAT WE WANT AØ IN THE ACCUMULATOR THEN IT IS WASTEFUL TO FIND A MEMORY LOCATION WHICH HAPPENS TO CONTAIN IT, SINCE TWO BYTES ARE NEEDED (GENERALLY) TO SPECIFY WHERE IT IS AND SO WE IMPLY, BY THE IMMEDIATE INSTRUCTION, WHERE IT IS & ACTUALLY ENTER IT IN THE PROGRAM. THERE ARE COMPLEMENTARY STORE ACCUMULATOR 'STA' INSTRUCTIONS TO LDA Ƶ AND LDA.

BYTES	TYPE	HEX	MNEMONIC	TIME µS	
2	2	85	STA Ƶ	2	STORE A ZERO PAGE (IN THE FIRST 256 BYTES)
3	3	8D	STA	3	STORE A ABSOLUTE (ANYWHERE IN MEMORY)

WE CAN ALSO LOAD THE PROGRAM COUNTER. THE PROGRAM COUNTER IS AN INTERNAL REGISTER THAT POINTS TO THE NEXT LINE OF THE PROGRAM. THE MNEMONIC FOR THIS IS NOT LDPC BECAUSE WHEN THE P.C. IS LOADED WITH A NEW VALUE IT GIVES THE MICROPROCESSOR A DIFFERENT PLACE TO LOOK FOR INSTRUCTIONS: THE PROGRAM JUMPS. SO 'LOAD P.C. WITH NEXT TWO BYTES' (LDPC   ) IS JMP, THIS IS REFERRED TO AS JUMP ABSOLUTE SINCE THE PROGRAM JUMPS TO A NEW ABSOLUTE ADDRESS. SO IF WE ARE NOT IN THE MONITOR AND WANT TO BE, JMP FFØ4 WILL ENTER THE MONITOR. NOW WHAT HAPPENS IF THE FOLLOWING PROGRAM IS RUN?

```
LDA       FEØØ
STA   Ƶ    2Ø
JMP       FFØ4
```

THE FIRST INSTRUCTION GETS THE CONTENTS OF FEØØ, AND PUTS IT IN THE ACCUMULATOR. THE SECOND STORES THE ACCUMULATOR IN LOCATION ØØ2Ø.THE FIRST TWO Ø'S REFER TO ZERO PAGE AND ARE ASSUMED BY THE PROCESSOR IN THE ZERO PAGE MODE. THE THIRD GETS BACK TO THE MONITOR, SO THAT YOU CAN INSPECT LOCATION 2Ø. THIS READS AS.

```
ØØ3Ø     AD (OPCODE)      LDA FEØØ
ØØ31     ØØ (DATA)
ØØ32     FE (DATA)
ØØ33     85 (OPCODE)      STA Ƶ 2Ø
ØØ34     2Ø (DATA)
ØØ35     4C (OPCODE)      JMP FFØ4
ØØ36     Ø4 (DATA)
ØØ37     FF (DATA)
```

THE ADDRESS ØØ3Ø IS THE STARTING ADDRESS OF THE PROGRAM. THIS PARTICULAR PROGRAM WILL WORK WITH ANY STARTING ADDRESS – IT IS SAID TO BE 'POSITION INDEPENDENT' OR 'RELOCATABLE' – BUT OTHER PROGRAMS MAY NOT. IF YOU ARE NEW TO THE GAME, IT WILL BE EASIER IF YOU ENTER PROGRAMS AT THE STARTING ADDRESS SHOWN IN THE MANUAL.

2.3.2 ENTERING A PROGRAM, THE GO COMMAND

TO ENTER THIS PROGRAM, WE'LL GO THROUGH IT STEP BY STEP.

I ENTER THE STARTING ADDRESS: PRESS M,Ø.Ø,3,Ø, k

II ENTER A BYTE OF DATA A,D

III USE THE ↑ KEY TO TERMINATE DATA ENTRY AND STEP UP
– CONTINUE WITH Ø,Ø,↑,F,E,↑,8,5,↑,2,Ø,↑,4,C,↑,Ø,4,↑,F,F

IV CHECK THAT THE PROGRAM IS ENTERED CORRECTLY BY, E.G, USING ↓ TO GO BACK DOWN THROUGH IT.
– REMEMBER THAT MISTAKES AT KEY ENTRY (E.G. PRESSED 8,6) MAY BE CORRECTED BY CONTINUING (PRESS 8,5) –

NOW THAT THE PROGRAM IS LOADED PRESS ONLY ONCE THE 'GO' (G) KEY

K. XXXX .

APPEARS THE K (F.) REMINDS YOU OF TWO THINGS: I THIS IS A DIFFERENT STORED ADDRESS TO THE A. ADDRESS. II YOU CAN'T GO BACK! (UNLESS YOU EITHER PRESS RESET OR ENTER ADDRESS FFØ4, THE MONITOR ENTRY ADDRESS, AND GO) THE NEXT COMMAND KEY YOU PRESS WILL CAUSE THE µP TO DO A KAMI-KAZE DIVE TO THE ADDRESS SHOWN, SO ITS AS WELL TO GET IT RIGHT!! ENTER Ø,Ø,3,Ø

K. ØØ3Ø .

AND PRESS ANY COMMAND KEY. NOTHING HAPPENED? WELL IT DID, REALLY. IT JUST HAPPENED VERY QUICKLY:

PROGRAM		EXECUTION TIMES, µS
LDA	FEØØ	4
STA Z	2Ø	3
JMP	FFØ4	3
		TOTAL $1Ø_{10}$ µS

IT TOOK TEN MILLIONTHS OF A SECOND TO HAPPEN. WE'RE NOW BACK IN THE MONITOR. PRESSING ANY DIGIT KEY WILL CAUSE THE (BY NOW) FAMILIAR DOTS TO REAPPEAR. PRESS M,Ø,Ø,2,Ø k :

A. ØØ2Ø . AØ

WHICH CHECKS THAT THE PROGRAM ACTUALLY DID WORK. YOU COULD CHANGE ØØ2Ø AND RUN THE PROGRAM AGAIN BY THE KEYS

F, F, G, G, M, M

WHICH SUCCESSIVELY PUT FF IN ØØ2Ø, RUN THE PROGRAM AND RE-EXAMINE

LOCATION ØØ2Ø. A LOT QUICKER FOR YOU THE SECOND TIME, WASN'T IT? THIS IS BECAUSE M & G REMEMBER WHAT THEY WERE POINTING AT. LET'S MAKE THE PROGRAM BETTER. AT THE MOMENT WE HAVE NO IDEA IF IT RAN, AND WE DON'T KNOW IF IT RAN CORRECTLY UNTIL WE LOOK AT ØØ2Ø. IF THE PROGRAM WROTE OUT THE BYTE ON THE DISPLAY AS WELL AS STORING IT IN ØØ2Ø, WE'D KNOW THAT IT HAD ALL HAPPENED. INSIDE THE ACORN MONITOR PROGRAM IS A SET OF INSTRUCTIONS TO WRITE A BYTE ONTO THE TWO RIGHT HAND DISPLAY DIGITS. THIS PROGRAM IS LOCATED AT FE6Ø AND EXPECTS THE BYTE TO BE DISPLAYED TO BE IN THE ACCUMULATOR, WHICH IT IS. THE PROGRAM DESTROYS THIS BYTE AS IT PUTS IT ONTO THE DISPLAY SO WE MUST PUT IT IN ØØ2Ø BEFORE USING THE PROGRAM.

2.3.3 INSTRUCTIONS JMP, JSR

IF WE SIMPLY WENT JMP FE6Ø THIS WOULD CORRECTLY EXECUTE THE PROGRAM BUT WE WOULD BE LEFT IN THE MIDDLE OF THE MONITOR SOME-WHERE SINCE THE PROGRAM DOES NOT HAVE AN ADDRESS TO JUMP BACK TO. WE CAN GIVE IT SUCH AN ADDRESS WITH THE INSTRUCTION JSR (OPCODE 2Ø HEX) THIS IS EXACTLY LIKE A JUMP BUT IT SAVES THE PROGRAM COUNTER BEFORE JUMPING. THEN THE SINGLE BYTE INSTRUCTION RTS (OPCODE 6Ø HEX) RESTORES THE PROGRAM COUNTER AND WE GET BACK AGAIN. JSR IS "JUMP TO SUBROUTINE" AND RTS IS "RETURN FROM SUBROUTINE". THE PROGRAM AT FE6Ø HAS AN RTS ATTACHED AT ITS END, AND SO CAN TRANSFER CONTROL BACK TO THE PROGRAM WHICH CALLED IT. OUR NEW PROGRAM IS 3 BYTES LONGER:

ØØ3Ø	AD	LDA FEØØ
ØØ31	ØØ	
ØØ32	FE	
ØØ33	85	STA Ƶ 2Ø
ØØ34	2Ø	
ØØ35	2Ø	JSR FE6Ø
ØØ36	6Ø	
ØØ37	FE	
ØØ38	4C	JMP FFØ4
ØØ39	Ø4	
ØØ3A	FF	

AND WE WILL HAVE TO ENTER 6 BYTES FROM ØØ35 TO ØØ3A WITH M,Ø,Ø,3,5, k , 2,Ø, ↑,6,D,↑,F,E,↑,4,C,↑,Ø,4,↑,F,F. WE HAVEN'T CHANGED THE START OF THE PROGRAM SO G, G WILL RUN IT.

K. ØØ3Ø . AØ

APPEARS MEANING THAT ØØ2Ø HAS AGAIN HAD AØ WRITTEN INTO IT. INSTEAD OF STORING THINGS IN ØØ2Ø, LET'S USE ITS INFORMATION AS PART OF A LOGICAL OPERATION.

2.3.4 THE LOGIC INSTRUCTIONS 'ORA', 'AND', 'EOR'.

IF WE PUT $6Ø_{16}$ IN LOCATION ØØ2Ø (M,Ø,Ø,2,Ø, k, ,6,Ø : YOU SHOULD KNOW BY NOW) AND ALTER THE STA Ƶ INSTRUCTION AT ØØ33 TO, SAY, ORA Ƶ (OPCODE Ø5 HEX) (THE PROGRAM READS

```
LDA   FEØØ
ORA   Ƶ 2Ø
JSR   FE6Ø
JMP   FFØ4)
```

WE HAVE A PROGRAM THAT DISPLAYS THE LOGICAL 'OR' BETWEEN THE CONTENTS OF FEØØ (AØ) AND ØØ2Ø, (6Ø). THE HEX FOR ORA Ƶ IS Ø5 AND IT CARRIES OUT A LOGICAL 'OR' BETWEEN THE ACCUMULATOR AND THE SPECIFIED LOCATION IN Ƶ PAGE. M,Ø,Ø,3,3, k Ø,5 IS THE MODIFICATION TO THE PROGRAM, THEN SINCE WE STILL START AT ØØ3Ø, G,G RUNS IT :

K. ØØ3Ø . EØ

THE OPERATION WAS 'OR' :

AØ		1Ø1ØØØØØ	
6Ø	or	Ø11ØØØØØ	or
EØ		111ØØØØØ	

TRY CHANGING ØØ2Ø TO 4Ø AND RUNNING THE PROGRAM AGAIN IS THE ANSWER WHAT YOU EXPECTED?

WE CAN CHANGE ØØ33 TO MAKE THE PROGRAM DO LOGICAL 'AND' OR 'EXCLUSIVE – OR'. THE MNEMONICS AND OPCODES ARE:

AND	Ƶ	25_{16}	LOGICAL AND ACCUMULATOR AND Ƶ PAGE MEMORY
EOR	Ƶ	45_{16}	LOGICAL EXCLUSIVE–OR ACCUMULATOR AND Ƶ PAGE MEMORY

AND THE PROGRAMS WOULD READ

```
LDA FEØØ        &      LDA  FEØØ
AND Ƶ 2Ø               EOR  Ƶ 2Ø
JSR  FE6Ø              JSR  FE6Ø
JMP  FFØ4              JMP  FFØ4
```

BY NOW YOU MUST BE GETTING TIRED OF THE AØ IN FEØØ SO WE'LL CHANGE THE PROGRAM TO READ

```
LDA  Ƶ 21
EOR  Ƶ 2Ø
JSR  FE6Ø
JMP  FFØ4
```

THE SPACE TAKEN UP BY LDA Ƶ 21 IS ONE BYTE LESS THAN THAT USED BY LDA FEØØ. WE COULD SIMPLY WRITE THE NEW TWO BYTES IN AT LOCATIONS ØØ31 & ØØ32 AND CHANGE THE GO ADDRESS TO ØØ31. THIS IS VERY SIMPLE HERE SINCE THAT IS ALL WE HAVE TO DO. BUT IF THERE WERE MANY REFERENCES TO ØØ3Ø AS THE START OF THIS PROGRAM IT WOULD TAKE A LONG TIME TO FIND AND CHANGE THEM ALL, AND IF WE DIDN'T CHANGE THEM ALL SOMETHING WOULD GO WRONG. WE CAN'T MOVE THE REST OF THE PROGRAM DOWN ONE BYTE: SOMETHING MIGHT BE REFERRING TO IT. THE PROBLEM ARISES BECAUSE LDA Ƶ IS SHORTER THAN LDA. WE COULD SIMPLY USE LDA WITH A ZERO PAGE ADDRESS BUT THIS TAKES A WHOLE µS

LONGER THAN LDA Ƶ! THE SOLUTION IS TO USE LDA Ƶ AND TO INCORPORATE AN EXTRA BYTE IN ØØ3Ø AS PADDING. THIS MUST BE A SINGLE-BYTE INSTRUCTION, THAT DOES NOTHING TO AFFECT THE PROGRAM, AND ONE IS SPECIFICALLY PROVIDED

```
            NOP          EA           "NO OPERATION"
```

THE PROGRAM READS

```
ØØ3Ø EA              NOP
ØØ31 A5 21           LDA Ƶ 21
ØØ33 45 2Ø           EOR Ƶ 2Ø
ØØ35 26 6Ø FE        JSR FE6Ø
ØØ38 4C Ø4 FF        JMP FFØ4
```

–NOTICE THE MORE COMPACT MODE OF WRITING IT DOWN. THIS IS MORE CONSISTENT WITH THE WAY MNEMONICS ARE WRITTEN. IT IS EXACTLY EQUIVALENT TO

```
ØØ3Ø EA              NOP
ØØ31 A5              LDA Ƶ 21
ØØ32 21
ØØ33 45              EOR Ƶ 2Ø
ØØ34 2Ø
ØØ35 2Ø              JSR FE6Ø
ØØ36 6Ø
ØØ37 FE
ØØ38 4C              JMP FFØ4
ØØ39 Ø4
ØØ3A FF
```

AND IT WILL BE USED THROUGHOUT THE REST OF THE MANUAL:
THIS PROGRAM TAKES THE CONTENTS OF (WHICH MAY BE WRITTEN BY PUTTING BRACKETS AROUND THE PARTICULAR ADDRESS) ØØ2Ø & ØØ21 AND PRESENTS THEIR LOGICAL EXCLUSIVE – OR ON THE DISPLAY. APART FROM THEIR LOGICAL FUNCTIONS, THESE OPERATORS ARE OFTEN USED TO MANIPULATE SINGLE BITS. FOR INSTANCE ORA #Ø1 WOULD SET BIT Ø OF THE ACCUMULATOR, AND # FE WOULD CLEAR IT AND EOR #Ø1 WOULD COMPLENT IT, ALL WITHOUT AFFECTING ANY OTHER BITS IN THE ACCUMULATOR.

2.3.5 ARITHMETIC INSTRUCTIONS 'ADC', 'SEC', 'CLC'.

FROM LOGIC OPERATIONS WE PROGRESS AGAIN TO ARITHMETIC. LOOKING AT ORA Ƶ, EOR Ƶ, AND Ƶ WOULD LEAD ONE TO ASSUME THE EXISTENCE OF ADD Ƶ. WELL, THERE ISN'T ONE, THERE'S ONLY ADC Ƶ.

BYTES:			
2	ADC Ƶ	65	"ADD WITH CARRY, ZERO PAGE"
1	SEC	38	"SET CARRY FLAG"
1	CLC	18	"CLEAR CARRY FLAG"

THIS IS MOST UNUSUAL AND A TRAP FOR UNWARY PROGRAMMERS, ESPECIALLY THOSE USED TO μPs WHICH POSSESS AN ADD INSTRUCTION: THE CARRY FLAG MUST BE CLEARED BEFORE AN ADC (OR IT MUST BE IN A KNOWN STATE E.G.

```
{ SEC          ≡     { CLC
{ ADC #ØØ            { ADC #Ø1 OR
```

'UNEXPECTED' ANSWERS WILL APPEAR. WHEN THE μP LEAVES THE MONITOR USING THE GO ROUTINE THE CARRY FLAG IS SET: FAILURE TO CLEAR IT BEFORE AN ADC RESULTS IN AN ANSWER 1 GREATER THAN EXPECTED.

ANOTHER TRAP FOR THOSE USED TO DIFFERENT μPs IS THE DECIMAL FLAG. INSTEAD OF A SINGLE "DECIMAL ADJUST" INSTRUCTION TO ADJUST THE RESULT OF BINARY ARITHMETIC ON B.C.D. NUMBERS TO B.C.D. THERE ARE TWO INSTRUCTIONS

BYTES:			
1	SED	F8	"SET DECIMAL MODE"
1	CLD	D8	"CLEAR DECIMAL MODE"

WHICH INSTRUCT THE PROCESSOR TO DO AUTOMATICALLY (OR NOT DO) THE ADJUSTMENT AFTER ARITHMETIC OPERATIONS. THIS RESULTS IN SHORTER, FASTER PROGRAMS FOR HANDLING B.C.D. ARITHMETIC ..... WHICH, MERELY BY CHANGING THE DECIMAL MODE FLAG, WILL HANDLE BINARY ARITHMETIC

IN ORDER TO FULLY UTILISE THE μP's POWER THE MONITOR SUBROUTINES FOR FETCHING KEYS & OUTPUTTING DATA TO THE DISPLAY HAVE BEEN WRITTEN WITHOUT ARITHMETIC SO THEY MAY BE CALLED WITH THE DECIMAL FLAG SET OR CLEARED & THEY WILL NOT AFFECT IT.

SO LET'S DO A DECIMAL ADDITION;

```
ØØ2F    F8         SED
ØØ3Ø    18         CLC
ØØ31    A5 21      LDA Ƶ 21
ØØ33    65 2Ø      ADC Ƶ 2Ø
ØØ35    2Ø 6Ø FE   JSR FE6Ø
ØØ38    4CØ4 FF    JMP FFØ4
```

OUR STANDARD PROGRAM HAS BEEN EXTENDED BACKWARDS BY ONE BYTE, THE SED INSTRUCTION. THIS SHOULD BE INCLUDED (BY ,Ø,Ø,2,F,4) THE FIRST TIME THE PROGRAM IS RUN, BUT MAY BE OMMITTED (K,Ø,Ø,3,Ø,4) ON SUBSEQUENT RUNS. THIS LITTLE PROGRAM WILL TELL US THAT 22 + 11 = 33, IT WILL SAY THAT 35 + 26 = 61 AND THAT 5Ø + 51 = Ø1 WHOOPS!

THE PROGRAM AT FE6Ø ONLY DEALS WITH PUTTING THE BYTE IN THE ACCUMULATOR ON THE DISPLAY. IT PAYS NO ATTENTION TO THE CARRY FLAG, INDEED IT CHANGES THE STATE OF THE CARRY FLAG ITSELF, SO THAT WE CAN'T IMMEDIATELY CALL FE6Ø, HAVE IT WRITE ON THE DISPLAY & RETURN THEN WRITE OUT THE STATE OF THE CARRY SOMEHOW.WHAT WE NEED IS:

I SAVE THE CARRY FLAG

II USE FE6Ø

III GET THE CARRY FLAG BACK & WRITE IT OUT SOMEHOW

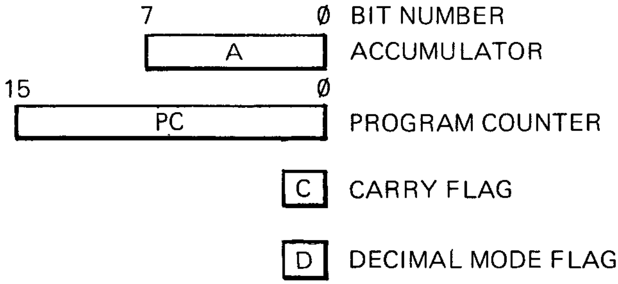
A FRENZIED SEARCH THROUGH THE MNEMONICS REVEALS THAT THERE ARE NO MNEMONICS LIKE LDC (LOAD C) OR STC (STORE C)

A CLOSER LOOK AT THE MICROPROCESSOR IS REQUIRED.

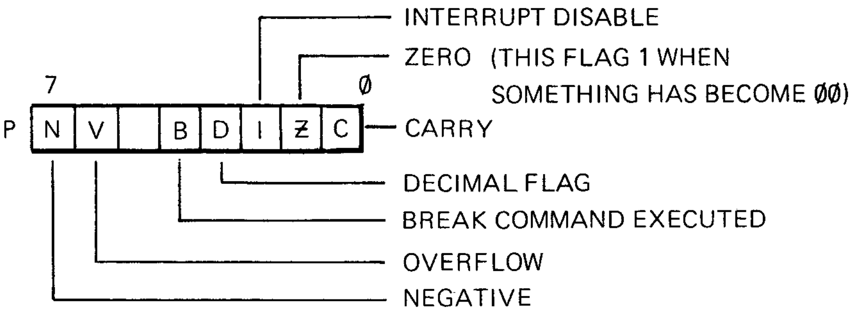
CHAPTER 3: INSIDE THE 65Ø2

SO FAR THE PROCESSOR'S INTERNAL WORKINGS ARE

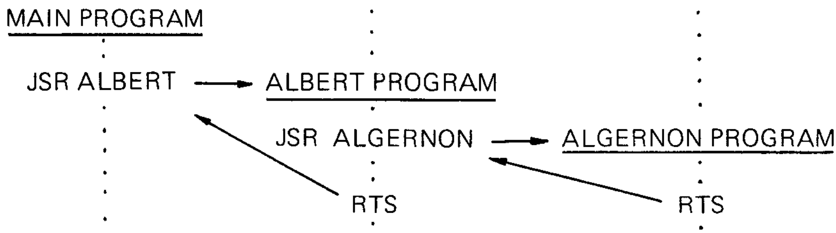
3.1 THE ACCUMULATOR, PROGRAM COUNTER, STATUS REGISTER



THE CARRY & DECIMAL MODE FLAGS HAVE BEEN TREATED SEPARATELY TO DATE. THEY ARE ACTUALLY MEMBERS OF A SPECIAL REGISTER CALLED THE PROCESSOR STATUS REGISTER,P.



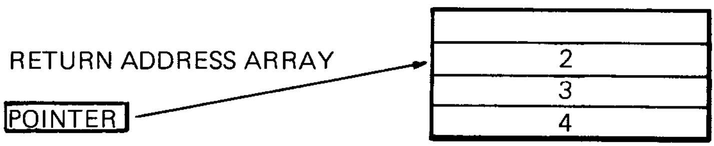
CAN WE, THEN, USE LDP & STP? NO, THEY DON'T EXIST EITHER.(FUME). IN ORDER TO SOLVE THIS PROBLEM WE MUST INTRODUCE THE STACK.
DID YOU WONDER JUST WHAT HAPPENED TO PC DURING A JSR? YOU WERE TOLD THAT IT WAS 'SAVED'. WHERE? HOW? IT WOULD BE TERRIBLE TO HAVE TO SPECIFY WHERE IT HAD TO BE STORED. WHAT'S NEEDED IS SOME PLACE WHERE IT CAN BE PUT DOWN AND PICKED UP AGAIN. IT WOULD BE GOOD TO ALLOW NESTED SUBROUTINES:



WE CAN'T JUST SAY THAT PC IS TO BE SAVED IN LOCATION, SAY, L & M – WE WOULDN'T GET BACK FROM ALBERT SINCE THE CALL TO ALGERNON WOULD HAVE DESTROYED THE NECESSARY INFORMATION IN L & M. (IT IS WORTH NOTING HERE THAT L & M COULD BE "CALLED" –2 "CALLED" –1. THEN A CALL TO ALBERT AS A SUBROUTINE WOULD STORE THE RETURN ADDRESS JUST BEFORE THE START OF ALBERT ALLOWING NESTED SUBROUTINES AS ABOVE. A PROBLEM IS THAT THIS DOES NOT WORK WITH READ ONLY MEMORY, LIKE THE MONITOR).

3.2 THE STACK POINTER

WE NEED SOMETHING WHICH WILL DECIDE WHAT L & M ARE TO BE, DEPENDING ON WHICH SUBROUTINE WE ARE IN AN OBVIOUS CHOICE IS TO USE AN ARRAY OF MEMORY LOCATIONS, AND A VARIABLE WHICH POINTS TO THE CURRENT LOCATION OF L & M EACH TIME WE DO A JSR WE STEP UP THE POINTER & EACH TIME WE DO AN RTS WE STEP IT DOWN.

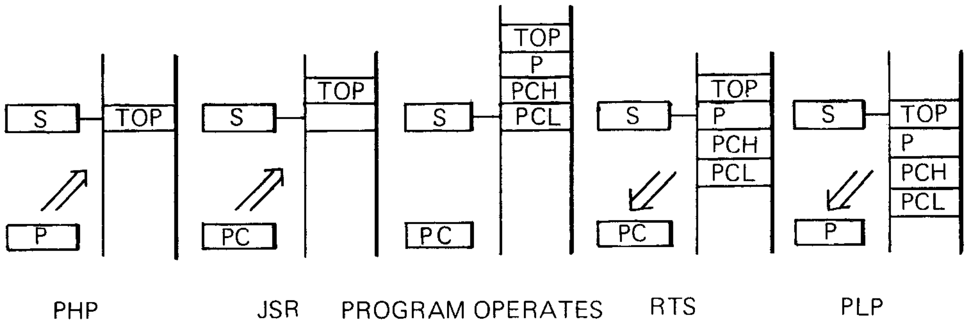


WITH ACORN WE'LL NEED TWO BYTES FOR EACH RETURN ADDRESS. THIS IS NO TROUBLE, WE JUST INCREMENT & DECREMENT THE POINTER TWICE. THE WHOLE PROCESS IS CARRIED OUT BY THE PROCESSOR AUTOMATICALLY ON EACH JSR & RTS, THE POINTER IS CALLED THE STACK POINTER AND IS A SPECIAL 8 BIT REGISTER INSIDE THE PROCESSOR. THE ARRAY IS USUALLY CALLED A STACK SINCE IT CAN ALSO BE USED TO STORE THINGS OTHER THAN RETURN ADDRESSES. THE ACTUAL STACK RUNS FROM Ø1FF DOWN TO Ø1ØØ, AND IT STARTS AT THE TOP: AN EMPTY STACK HAS STACK POINTER AT FF. A BYTE IS PUT ON THE STACK AND THE POINTER IS DECREMENTED TO POINT AT THE NEXT LOCATION; THE POINTER IS INCREMENTED AND A BYTE LOADED FROM THE STACK IN THE REVERSE OPERATION. NO CHECK IS MADE FOR THE ØØ TO FF DECREMENT INDICATING AN OVERFLOWED STACK, SO PROGRAMS THAT REQUIRE MORE THAN 256 BYTES OF STACK SPACE WILL MYSTERIOUSLY FAIL. SINCE THIS IS 128 CONSECUTIVE JSR'S, THE PROBLEM WON'T BE ENCOUNTERED VERY OFTEN. . .

NOW THE PROCESSOR STATUS REGISTER CAN BE PUSHED ONTO THE STACK:

```
        PLP        28          "PULL P"
        PHP        Ø8          "PUSH P"
```
AND SO WE MAY SAVE IT BEFORE A SUBROUTINE CALL AND RECOVER IT AFTERWARDS

```
        PHP
        JSR . . . .
        PLP
```
THE SEQUENCE OF STACK OPERATIONS IS



SO WE HAVE NOW MANAGED TO SAVE THE CARRY FLAG, USE FE6Ø, AND REGAIN THE CARRY FLAG. WE WISH TO WRITE IT OUT, SO IT WOULD HAVE BEEN BETTER TO WRITE.

```
        PHP
        JSR FE6Ø
        PLA           PULL BYTE FROM STACK INTO A
```
SINCE THIS GIVES THE CARRY FLAG IN A, AS THE LEAST SIGNIFICANT BIT, TO GET RID OF THE REST OF THE BITS OF THE RECOVERED STATUS REGISTER, WE CAN SIMPLY AND # Ø1. NOW A CONTAINS Ø OR 1 DEPENDING ON THE CARRY FROM ORIGINAL SUM. OUR PROGRAM NOW IS

```
        SED                 SET UP FOR DECIMAL ADD
        CLC
        LDA Ƶ 21            DO IT
        ADC Ƶ 2Ø
        PHP                 SAVE CARRY
        JSR FE6Ø            WRITE OUT TWO DIGITS
                            ON DISPLAYS 6 & 7

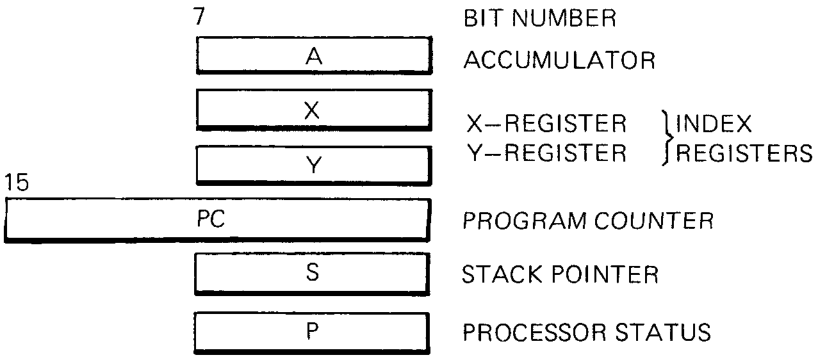
        PLA
        AND #Ø1              A = Ø (NO CARRY FROM SUM)
                                OR A = 1 (CARRY FROM SUM)
```

NOW ALL WE NEED TO DO IS WRITE OUT THE ACCUMULATOR ON DISPLAY NO.5. THE WAY WE WROTE OUT THE FIRST TWO DIGITS OF THE RESULT WAS TO USE A MONITOR SUBROUTINE WHICH DID JUST THAT. YOU'VE PROBABLY NOTICED THAT THE MONITOR ONLY PUTS A DOT ON DISPLAY 5 (THE 3RD

FROM THE RIGHT) AND SUSPECT THAT IT CAN'T PUT ANYTHING ELSE THERE. THIS IS TRUE, BUT IT DOESN'T MEAN THAT THERE ISN'T A MONITOR SUBROUTINE THAT CAN DO THE JOB. SUCH A SUBROUTINE LIVES AT FE7A. IT IS DESIGNED TO PUT THE LOWEST FOUR BITS OF THE ACCUMULATOR ONTO ANY OF THE DISPLAYS, AS A READABLE CHARACTER. THIS IS JUST WHAT WE NEED – BUT HOW DO WE TELL THE SUBROUTINE WHICH DISPLAY TO USE?

3.3 THE INTERNAL REGISTERS X ANDY.

WELL, BACK TO THE μP. THIS IS WHAT IT LOOKS LIKE INSIDE



TWO NEWCOMERS, YOU'LL NOTICE! X & Y ARE 'INDEX REGISTERS', THEY WILL BE DEALT WITH MORE THOROUGHLY IN A FEW MORE PAGES, BUT WHAT MATTERS NOW IS THE USE FE7A MAKES OF THEM:

I FE7A NEITHER CARES ABOUT, NOR CHANGES X

II FE7A DOESN'T CHANGE Y, BUT THE DISPLAY IT PUTS A ONTO IS CONTROLLED BY Y THAT IS, THE LOWER 4 BITS OF A ARE TRANSFORMED INTO THE CORRECT SEQUENCE OF BITS TO REPRESENT THEIR HEXADECIMAL CHARACTER AS IT SHOULD APPEAR ON THE 7 SEGMENT DISPLAY. THEN THIS IS STORED IN MEMORY TO AWAIT THE SUBROUTINE WHICH ACTUALLY PUTS THINGS ON DISPLAY.

ALTHOUGH FE7A MAKES NO RESTRICTIONS ON THE SIZE OF Y, THE MONITOR SUBROUTINE WHICH DISPLAYS THEM ONLY KNOWS ABOUT THE FIRST 8 (NUMBERED, OF COURSE, Ø–7) OF THEM, IN LINE WITH THE ACTUAL DISPLAY HARDWARE. DISPLAY Ø IS THE LEFTMOST, DISPLAY 7 IS THE RIGHTMOST.

TO KEEP THE MONITOR AS EFFICIENT AS POSSIBLE THE SUBROUTINE AT FE6Ø USES FE7A. IT FOLLOWS THAT IT MUST HAVE LOADED Y WITH 7 & 6, AND SINCE FE7A DOESN'T CHANGE Y, Y IS STILL SET TO THE LAST USED OF THESE WHICH IS 6. SO, INSTEAD OF USING

```
        LDY #Ø5     AØ  Ø5     "LOAD Y WITH THE NEXT BYTE" (Ø5 HERE)
```

WE CAN USE

```
        DEY         88         "DECREMENT (IN HEXADECIMAL) Y BY
                               ONE"
```

TO SET Y TO 5, THUS SAVING A WHOLE BYTE! (BUT NO TIME, THE TWO INSTRUCTIONS ARE EXECUTED IN THE SAME TIME, 2μS). THE COMPLETE PROGRAM IS

```
ØØ2F F8          SED
ØØ3Ø 18          CLC
ØØ31 A5 21       LDA Z 21
ØØ33 65 2Ø       ADC Z 2Ø
ØØ35 Ø8          PHP
ØØ36 2Ø 6Ø FE    JSR FE6Ø
ØØ39 68          PLA
ØØ3A 29 Ø1       AND # Ø1
ØØ3C 88          DEY
ØØ3D 2Ø 7A FE    JSR FE7A
ØØ4Ø 4C Ø4 FF    JMP FFØ4
```

AND SO, AT LAST, WE FIND THE ANSWER TO $5Ø_{10}$ + $5Ø_{10}$ IS

K.   ØØ2F   1ØØ

PERHAPS WE SHOULD HAVE CLEARED THE DISPLAY? OR MADE IT SHOW THE NUMBERS TO BE ADDED TOGETHER? OR ACTUALLY FETCHED THE TWO NUMBERS USING KEYBOARD AND DISPLAY LIKE THE MONITOR DOES? OR SOME COMBINATION OF THESE?

3.4 MAKING OUR PROGRAM 'FRIENDLY'

USING THE MONITOR SUBROUTINE AT FE88 IT IS EASY TO DO THE THIRD OPTION. FE88 IS THE ROUTINE WHICH FETCHES 4 DIGIT NUMBERS, TERMINATED BY ANY COMMAND KEY, INTO THE TWO BYTES IN ZERO PAGE X & X + 1 [i.e. IF X CONTAINS 2Ø, INTO ØØ2Ø (LOW BYTE = RH PAIR OF NUMBERS) & ØØ21] JUST WHAT WE NEED!

```
ØØ2A     F8          SED
ØØ2B     A2 2Ø       LDX# 2Ø
ØØ2D     2Ø 88 FE    JSR FE 88
ØØ3Ø     18          CLC
ØØ31     A5 21       LDA Z 21
ØØ33     65 2Ø       ADC Z 2Ø
ØØ35     Ø8          PHP
ØØ36     2Ø 6Ø FE    JSR FE6Ø
ØØ39     68          PLA
ØØ3A     29 Ø1       AND #Ø1
ØØ3C     88          DEY
ØØ3D     2Ø 7A FE    JSR FE7A
ØØ4Ø     4C Ø4 FF    JMP FFØ4
```

ONCE AGAIN THE PROGRAM HAS BEEN EXTENDED BACKWARDS SINCE THE GREATER PART OF IT HAS ALREADY BEEN ENTERED (UNLESS YOU'VE SWITCHED OFF AND LOST IT ALL)
RUNNING THIS PROGRAME (GØ,Ø,2,A, k) PRODUCES

K.   5Ø5Ø . (ON THE ASSUMPTION THAT ØØ2Ø & ØØ21 STILL CONTAIN THE 5Ø'S ADDED TOGETHER AS BEFORE)

YOU SHOULD ENTER THE TWO PAIRS OF NUMBERS YOU WISH ADDED TOGETHER AS IF THEY FORMED AN ADDRESS. TERMINATING YOUR ENTRY WITH k INSTANTLY PRODUCES THE RESULT

K. 5Ø5Ø 1ØØ

LOOKING BACK OVER THE PROGRAM, AND EXAMINING THE MONITOR LISTING,WILLREVEAL THAT IT TOOK AD$_{16}$ (OR 173$_{10}$) BYTES OF CODE TO ACHIEVE THIS. THE ACTUAL OPERATION USED 6 BYTES OF CODE (SED; CLC; LDA Z; ADC Z) WHILE THE OTHER 167$_{10}$ ARE THERE 'MERELY' TO DISPLAY THE RESULT& FETCH THE INFORMATION NEATLY(THE CODE CALCULATIONS DO NOT CONSIDER THE 16$_{10}$ BYTES OF CHARACTER FONT OR THE 11$_{10}$ BYTES OF TEMPORARY STORAGE ALSO USED)

CHAPTER 4: THE REMAINDER OF THE INSTRUCTION SET

4.1 BRANCHES

THINKING ABOUT THE FE88 PROGRAM, YOU SHOULD REALIZE THAT IT DOES SOMETHING OF THE FORM

FETCH NEXT KEY
IF KEY IS A COMMAND KEY THEN RETURN

THIS IS A CONDITIONAL TRANSFER OF CONTROL AND REPRESENTS SOME NEW INSTRUCTIONS AND A DIFFERENT WAY OF CHANGING THE PROGRAM COUNTER. AN OPERATION LIKE ADC DOES MORE THAN ADDING TWO BYTES AND THE CARRY FLAG TOGETHER AND OUTPUTTING A CARRY. IT ALSO SETS SOME OF THE OTHER FLAGS IN P:

THE Ƶ FLAG IS SET IF THE RESULTING BYTE WAS ZERO
THE V FLAG IS SET IF THERE WAS A 2'S COMPLEMENT OVERFLOW
THE N FLAG IS SET IF THE RESULT WAS A NEGATIVE 2'S COMPLEMENT NUMBER – I.E. BECOMES BIT 7 OF THE RESULT.

THESE FLAGS ARE ABLE TO CAUSE CONDITIONAL TRANSFER BY USING THE APPROPRIATE ONE OF THE EIGHT 'BRANCH' INSTRUCTIONS. THE MECHANISM EMPLOYED IS TO PERFORM A 2'S COMPLEMENT ADD BETWEEN THE PROGRAM COUNTER AND THE SECOND BYTE OF THE BRANCH INSTRUCTION THUS PERMITTING THE TRANSFER TO BE –128. . . +127 BYTES FROM THE NEXT INSTRUCTION. THIS IS CALLED 'RELATIVE ADDRESSING' AND IS A POSITION INDEPENDENT METHOD OF TRANSFER, THE EIGHT BRANCH INSTRUCTIONS ARE ASSOCIATED TWO TO EACH OF THE C, Ƶ, V & N FLAGS, ONE OF WHICH BRANCHES IF THE FLAG IS SET, THE OTHER BRANCHES IF IT IS CLEAR.

TO CLARIFY THIS LET'S LOOK AT AN EXAMPLE:

```
* + Ø       BCS Ø3      "BRANCH IF CARRY SET"
* + 2       SEC         SET CARRY
* + 3       BCS Ø1
* + 5       CLC         CLEAR CARRY
* + 6       . . . . .
```

(THE ARROWS ARE PUT IN FOR CLARITY)

WE'LL NEED TO CONSIDER THIS PROGRAM BOTH WITH THE CARRY SET & WITH IT CLEAR

I CARRY IS CLEAR

INSTRUCTION I DOES NOT TRANSFER CONTROL SO WE DO INSTRUCTION II, SEC, NOW INSTRUCTION III TRANSFERS CONTROL SINCE THE CARRY IS NOW SET. Ø1 IS ADDED TO THE PC (= * + 5) TO GIVE* + 6 AS THE ADDRESS OF THE NEXT INSTRUCTION.

II CARRY IS SET

INSTRUCTION I TRANSFERS CONTROL. Ø3 IS ADDED TO THE PC (= * + 2) TO GIVE * + 5 AS THE ADDRESS OF THE NEXT INSTRUCTION, INSTRUCTION IV. CLC.

SO IF THE CARRY WAS CLEAR IT IS SET; IF IT WAS SET IT IS CLEARED, SO THE PROGRAM COMPLEMENTS THE CARRY (THERE ARE QUICKER METHODS, INDEED IT CAN BE DONE WITH 3 INSTRUCTIONS IN 4 BYTES).

AND WE CAN GO BACKWARDS:

```
* + Ø      BCS    Ø3     BRANCH IF CARRY SET
* + 2      SEC           SET CARRY
* + 3      BCS    FB     BRANCH IF CARRY SET
* + 5      CLC           CLEAR CARRY
* + 6      . . . .
```

IF THE CARRY IS SET THE PROGRAM IS AS BEFORE IF IT IS CLEARED WE SET IT & BRANCH FB

(2's COMPLEMENT ADD   * + 5
                          FB +
                        * + Ø)

—BACK TO THE BEGINNING. A RATHER COMPLICATED WAY OF CLEARING THE CARRY.

MOST OF THE NON-BRANCH INSTRUCTIONS WILL CHANGE SOME OF THESE 4 TESTABLE FLAGS, USUALLY THE N & Ƶ FLAGS SINCE THEY CONSTANTLY MONITOR THE STATUS OF OPERANDS SO BRANCHES WILL APPEAR RATHER FREQUENTLY IN PROGRAMS.

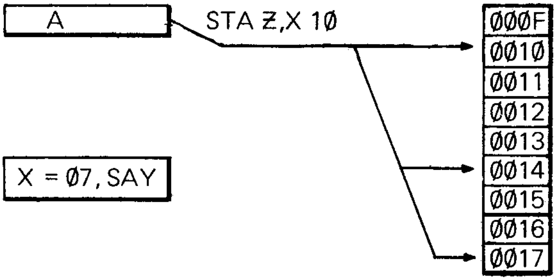
4.2 INDEXING

IF YOU WISHED TO CLEAR (SET EACH BYTE TO Ø) A PATCH OF MEMORY, e.g. THE MEMORY USED TO STORE THE DATA WHICH IS TO BE OUTPUT TO THE DISPLAYS, WHICH IS FROM ØØ1Ø TO ØØ17, YOU MIGHT THINK

```
LDA# ØØ     LOAD ACCUMULATOR IMMEDIATE WITH ØØ
STA Ƶ 1Ø    STORE ACCUMULATOR IN ADDRESS ØØ1Ø
STA Ƶ 11    STORE ACCUMULATOR IN ADDRESS ØØ11
STA Ƶ 12    STORE ACCUMULATOR IN ADDRESS ØØ12
   :
STA Ƶ 17    STORE ACCUMULATOR IN ADDRESS ØØ17
```

IS NECESSARY. THIS LOOKS SUFFICIENTLY REGULAR THAT THE COMPUTER SHOULD BE ABLE TO DOT IT. THIS IS WHERE THE INDEX REGISTERS REAPPEAR. WE CAN STORE THE ACCUMULATOR INDEXED BY EITHER INDEX REGISTER

```
STA Ƶ,X      95     "STORE A INDEXED BY X IN ZERO
                     PAGE"
STA Ƶ,X 1Ø
```



A IS STORED IN 17 WHICH IS 1Ø THE "BASE ADDRESS" +Ø7 THE "INDEX"

IF WE DO

```
A2 Ø7        LDX # Ø7
95 1Ø        STA Ƶ,X 1Ø
```

THE STORE IS TO LOCATION 17 (=1Ø + X). THE ADDITION IS STRAIGHT-FORWARD BINARY, TRUNCATED TO A LOCATION IN ZERO PAGE SO

```
             LDX #  FF
             STA Ƶ,X 1Ø
```

STORES IN LOCATION ØF

WE ALSO HAVE

```
             STA, X     9D          "STORE A INDEXED BY X"
             STA, Y     99          "STORE A INDEXED BY Y"
```

(BUT NO STA Ƶ, Y) WHICH DO NOT NEED TO TRUNCATE THE ADDITION THEY EXPECT A TWO BYTE ADDRESS SO

```
             LDX # FF
             STA, X ØØ1Ø
```

STORES IN LOCATION Ø1ØF

NOW

```
             DEX        CA          "DECREMENT (IN HEX) X BY ONE"
```

SETS THE Ƶ FLAG IF X IS ZERO, & THE N FLAG EQUAL TO BIT 7 OF X.

```
             BPL        1Ø          "BRANCH IF PLUS"
```

TAKES THE BRANCH IF THE N FLAG IS CLEAR I.E. IS SAYING 'NOT NEGATIVE' I.E. PLUS. IT'S EASY TO SEE THAT THE COMBINATION

```
             DEX    <--+
             BPL FD ---+
```

DECREMENTS X ONCE, AND, IF THE RESULT WAS POSITIVE (I.E. IN THE RANGE Ø – 7F) IT TAKES THE BRANCH AND DECREMENTS X AGAIN. . . . AND AGAIN UNTIL IT REACHES A NON-POSITIVE NUMBER, WHICH WILL BE FF, WHEN IT DOESN'T TAKE THE BRANCH. IF WE START AT 7 AND EACH TIME AROUND THE LOOP CLEAR THE RELEVANT DISPLAY:

CODE	LABEL	MNEMONICS	COMMENT
A9 ØØ		LDA # ØØ	LOAD ACCUMULATOR IMMEDIATE
A2 Ø7		LDX # Ø7	LOAD X IMMEDIATE
95 1Ø	LOOP:	STA Ƶ, X 1Ø ←	STORE X IN ZERO PAGE INDEXED BY X
CA		DEX	DECREMENT X BY ONE
1Ø FB		BPL LOOP →	BRANCH IF PLUS TO "LOOP"

SO WE CAN WRITE A VERY SHORT PROGRAM TO CLEAR THE DISPLAY. BY MAKING THE LOOP SLIGHTLY LARGER (WITH THE SAME LENGTH OF PROGRAM)

```
ØØ6Ø A2 Ø7              LDX #Ø7
ØØ62 B5 48        LOOP: LDA Ƶ, X 48
ØØ64 95 1Ø              STA Ƶ,X 1Ø
ØØ66 CA                 DEX
ØØ67 1Ø F9              BPL LOOP
ØØ69 4C Ø4 FF           JMP FFØ4
```

WE CAN, INSTEAD OF CLEARING THE DISPLAY, CAUSE A BLOCK OF MEMORY, ØØ48 – ØØ4F, TO BE TRANSFERRED TO THE DISPLAY. THE PROGRAM IS POSITION INDEPENDENT SO YOU CAN WRITE IT INTO MEMORY ANYWHERE. . . EXCEPT LOCATIONS ØØ1Ø – ØØ17. IF YOU PUT THE PROGRAM IN ØØ48 . . . . IT WILL FUNCTION PERFECTLY BUT YOU WON'T BE ABLE TO CHANGE THE DATA WHICH IS MOVED, SINCE THIS IS THE PROGRAM. YOU CAN TRY THE PROGRAM USING THIS DATA

```
ØØ48      ØØ 77 58 5C 5Ø 54 ØØ ØØ
```

OR YOU COULD CONSTRUCT YOUR OWN DATA, USING APPENDIX A.
THE INDEXING MECHANISM SHOWN ABOVE IS ONLY CAPABLE OF DEALING WITH 256 (CONSECUTIVE) BYTES, STARTING AT A GIVEN ADDRESS. THUS

```
A9 ØØ              LDA #ØØ          LOAD A IMMEDIATE WITH "ØØ"
A8                 TAY              TRANSFER A TO Y
18           LOOP: CLC              CLEAR CARRY
79 ØØ FE           ADC, Y FEØØ      ADD WITH CARRY INDEXED BY Y
C8                 INY              INCREMENT Y
DØ F9              BNE LOOP         BRANCH IF NOT EQUAL
2Ø 6Ø FE           JSR  FE6Ø        JUMP SUBROUTINE
4C Ø4 FF           JMP FFØ4         JUMP
```

COMPUTES THE LOWEST BYTE OF THE 256 BYTE ADDITION. (NOTE THAT, SINCE Y IS ZERO WHEN YOU LEAVE THE MONITOR BY THE GO FUNCTION, THE INITIALISATION OF A & Y CAN BE ACCOMPLISHED BY TYA INSTEAD OF LDA #ØØ, TAY) HOW COULD THIS BE DONE FOR ALL 65536 MEMORY BYTES? CLEARLY IT IS POSSIBLE TO HAVE AN ADC, Y FOR EACH PAGE:

```
98                 TYA
18           LOOP: CLC
79 ØØ ØØ           ADC, Y ØØØØ   }
18                 CLC           }        CLC
79 ØØ FF           ADC, Y Ø1ØØ   }   256  ADC, Y INSTRUCTION PAIRS
:                  :             }
18                 CLC           }
79 ØØ FF           ADC, Y FFØØ   }
C8                 INY`
FØ Ø3              BEQ END
4C ? ?             JMP LOOP
2Ø 6Ø FE END       JSR FE6Ø
4C Ø4 FF           JMP FFØ4
```

IN ORDER TO SHORTEN THIS PROGRAM WE WILL INTRODUCE THE CONCEPT OF "INDIRECTION".

4.3.INDIRECTION:

YOU'LL NOTICE THAT THE PROGRAM IS NOT POSITION INDEPENDENT: THE ADDRESS OF THE CLC INSTRUCTION MUST BE WRITTEN INTO THE PROGRAM. THIS IS ANOTHER DISADVANTAGE OF THIS METHOD: (THERE IS AN ADVANTAGE: THIS PROGRAM IS VERY FAST, TAKING ONLY 6µS PER BYTE). THE INSTRUCTION REQUIRED MUST HAVE A 16 BIT UNFIXED ADDRESS AND THIS CAN ONLY GO IN ONE PLACE : MEMORY. A LIMITATION IS THAT GENERALLY IT CAN ONLY BE IN ZERO PAGE MEMORY. THE CONCEPT IS KNOWN AS INDIRECTION. THE MOST DIRECT VERSION OF THIS IS THE INDIRECT JUMP.

6C Ø2 ØØ   JMP (ØØØ2)

THIS IS THE ONE VERSION OF INDIRECTION THAT DOESN'T NEED TO REFER TO ZERO PAGE MEMORY. WHAT HAPPENS IS THIS:

TIME, µS	ADDRESS BUS	DATA BUS	R/W	
Ø	PC	6C	1	JUMP INDIRECT
1	PC+1	Ø2	1	
2	PC+2	ØØ	1	
3	ØØØ2	V	1	LOWER BYTE
4	ØØØ3	U	1	HIGHER BYTE
5	UV	OPCODE	1	OLD 6C COMPLETED

THE MONITOR USES A JUMP INDIRECT FOR THE GO FUNCTION, HAVING BUILT THE ADDRESS IN ØØØ2 & ØØØ3 : A JUMP INDIRECT VIA ØØØ2 & ØØØ3, ASSUMING THAT THESE LOCATIONS HAVEN'T BEEN ALTERED, WILL THUS RETURN TO THE START OF THE PROGRAM – WITHOUT KNOWING WHERE IT HAD BEEN ENTERED INTO MEMORY AT THE TIME OF WRITING.

INDIRECT JUMP

```
MAIN PROGRAM   ZERO PAGE
                    :
JMP  (ØØØ2)         :
               12        ØØØ2
               34   :    ØØØ3
                            4
                  ROUTINE
               XX        1234
               XX        1235
               XX        1236
               " "         "
```

WELL, THAT WAS SIMPLE INDIRECTION. NOW WE'LL MOVE ONTO THE MORE COMPLICATED MODES OF INDIRECTION. HAVING FETCHED THE ADDRESS OUT OF MEMORY WITH THE INDIRECTION STAGE, WE CAN INDEX IT. THIS IS CALLED POST-INDEXED INDIRECTION. WITH THE 65XX SERIES OF MICRO-PROCESSORS YOU MAY ONLY

I INDEX IN THIS MODE WITH THE Y INDEX REGISTER
II USE ZERO PAGE MEMORY

TIME, μS	ADDRESS BUS	DATA BUS	R/W	
Ø	PC	B1	1	LDA (I),Y
1	PC+1	I	1	
2	ØØI	J	1	
3	ØØI+1	K	1	
4	KJ+Y	DATA	1	(AN EXTRA μS IS NEEDED IF J+Y
5	PC+2	OPCODE	1	RESULTS IN A CARRY)

THIS IS THE MODE OF ADDRESSING NEEDED TO SOLVE THE 65536 BYTE ADDITION PROBLEM. MEANWHILE WHAT ABOUT THE X REGISTER AND INDIRECTION? HERE WE HAVE PRE-INDEXED INDIRECTION

TIME, μS	ADDRESS BUS	DATA BUS	R/W	
Ø	PC	A1	1	LDA (I,X)
1	PC+1	I	1	
2	ØØI	DATA, DISCARDED	1	
3	ØØI+X	J	1	NO CARRY TO HIGH ORDER BYTE
4	ØØI+X+1	K	1	
5	KJ	DATA	1	PUT I N A
6	PC+2	OP CODE	1	

THIS IS THE OPPOSITE TO POST-INDEXED ... HERE THE INDEXING SWITCHES BETWEEN DIFFERENT INDIRECTION LOCATIONS. THE EFFECTS OF THESE TWO INDEXING MODES ARE ONLY THE SAME IN THE TRIVIAL CASE OF ZERO INDEXES. HERE IS THE SOLUTION TO THE 65536 BYTE ADDITION:

```
98                  TYA             -ZERO Y & A
85 2Ø               STA Z 2Ø       }
85 21               STA Z 21       } SET UP INDIRECT LOCATIONS
18         LOOP     CLC
71 2Ø               ADC (2Ø), Y
C8                  INY
DØ FA               BNE LOOP
E6 21               INC Z 21
DØ F6               BNE LOOP
2Ø 6Ø FE            JSR FE6Ø
4C Ø4 FF            JMP FFØ4
```

THE PROGRAM IS, ONCE AGAIN, POSITION INDEPENDENT. IT IS, AS IMPLIED IN THE FIRST SOLUTION, SLOW : 12μS PER BYTE. THIS IS MAINLY DUE TO THE SMALL SIZE OF THE LOOP : THE 3μS 'NEARLY ALWAYS TAKEN' BRANCH IS TAKING A DISPROPORTIONATE AMOUNT OF TIME, IN THE FIRST SOLUTION THE EQUIVALENT 5μS BRANCH AND JUMP COMBINATION OCCURS ONLY EVERY 256 BYTES AND IS THUS IGNORED IN THE TIME CALCULATIONS. THE INSTRUCTION INC Z 21 HAS AN OBVIOUS FUNCTION : INCREMENT (IN HEXADECIMAL) LOCATION ØØ21. IT ACTS JUST LIKE INX OR INY – BUT IT TAKES 5μS INSTEAD OF 2μS.

4.4 READ-MODIFY WRITE INSTRUCTIONS

THERE ARE COMPANION INSTRUCTIONS TO INC Z THAT CAN DIRECTLY ALTER MEMORY CONTENTS, THESE ARE CALLED READ-MODIFY-WRITE INSTRUCTIONS, THE NEXT OF WHICH IS THE OBVIOUS DEC INSTRUCTION.

THE OTHER FOUR ARE NEW, THEY ARE SHIFTS AND ROTATES. LET'S USE ASL AS AN EXAMPLE

```
ØØ7Ø   A9 55      LDA #55     LOAD A IMMEDIATE WITH 55
  72   ØA         ASLA        ARITHMETIC SHIFT LEFT
  73   2Ø 6Ø FE   JSR FE6Ø    JUMP TO SUBROUTINE
  76   4C Ø4 FF   JMP FFØ4    JUMP
```

THE RESULT OF RUNNING THIS PROGRAM IS AA ON THE DISPLAY. EACH BIT IN THE ACCUMULATOR HAS BEEN SHIFTED ONE BIT LEFT.

```
              C           A
BEFORE       [1]        [Ø1Ø1Ø1Ø1]
AFTER        [Ø] <----  [1Ø1Ø1Ø1Ø] <---- Ø
```

ROLA, ROTATE LEFT ACCUMULATOR, (2A) WILL HAVE THE SAME EFFECT, EXCEPT THAT THE RIGHT INPUT Ø IS REPLACED BY C, IN THIS CASE 1, SO THE RESULT IS AB.

LSRA,LOGICAL SHIFT RIGHT ACCUMULATOR (4A)

```
              C
BEFORE       [1]    Ø   [Ø1Ø1Ø1Ø1]        -2A
AFTER        [1]    --> [1Ø1Ø1Ø1Ø]
```

RORA, ROTATE RIGHT ACCUMULATOR (6A) WILL REPLACE THE LEFT INPUT Ø WITH C TO GIVE AA

ALL THESE INSTRUCTIONS MAY BE USED DIRECTLY ON MEMORY LIKE INC Ƶ.

4.5 MISCELLANEOUS REMAINING INSTRUCTIONS

THERE ARE A FEW INSTRUCTIONS LEFT, WHICH WILL HAVE TO BE DEALT WITH PIECE-MEAL:

BRK ØØ : THE MICROPROCESSOR HAS TWO INTERRUPTS, AS EXPLAINED IN THE HARDWARE SECTION, AND THE INSTRUCTION SIMULATES AN IRQ, FIRST SETTING THE B FLAG IN THE STATUS REGISTER. THE RETURN AFTER A BREAK WILL BE AT THE NEXT BUT ONE BYTE

BIT 2C : A COMBINATION OF TWO INSTRUCTIONS

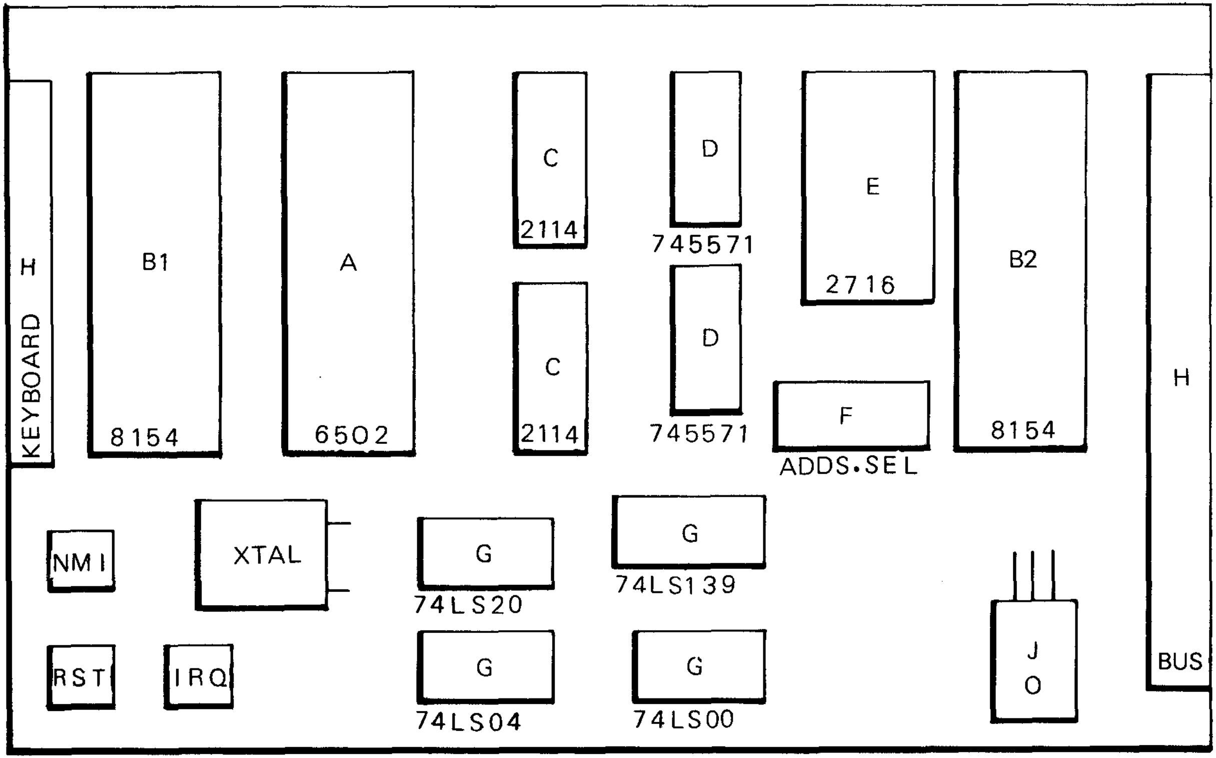
- I READ MEMORY BITS 6 & 7 INTO THE OVERFLOW & NEGATIVE FLAGS
- II LOGICAL AND ACCUMULATOR AND MEMORY, A ZERO RESULT SETTING THE Ƶ FLAG. THE RESULT IS NOT LOADED INTO THE ACCUMULATOR. THE INSTRUCTION IS USUALLY USED TO TEST THE STATUS OF PERIPHERAL DEVICES, WITHOUT UPSETTING A,X OR Y.

RTI, RTS 4Ø, 6Ø BOTH INSTRUCTIONS PULL THE PROGRAM COUNTER FROM THE STACK, RTI FIRST PULLS THE PROCESSOR STATUS FROM THE STACK.

CHAPTER 5: ACORN HARDWARE

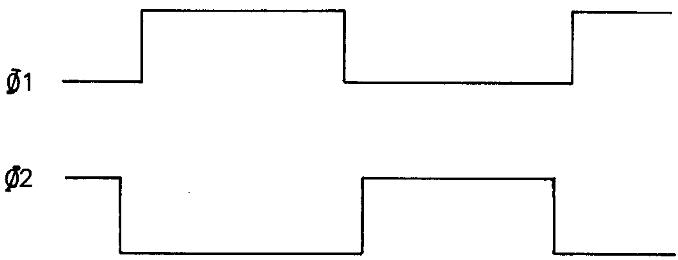
5.1 CHIP LAYOUT AND BUS

BEFORE PLUNGING DEEPER INTO SOFTWARE WE'LL TAKE A REST AND LOOK AT THE HARDWARE. WE'LL START WITH THE CPU BOARD


H
KEYBOARD
B1
8154
A
6502
C
2114
C
2114
D
745571
D
745571
E
2716
F
ADDS.SEL
B2
8154
H
BUS
NMI
RST
IRQ
XTAL
G
74LS20
G
74LS04
G
74LS139
G
74LS00
J
O

SECTION 5.1

THE OBVIOUS IMPORTANT DEVICE HERE IS A, THE MICROPROCESSOR. THIS IS WHERE A,X,Y,P,S,PC LIVE. FROM HERE COME THE COMMANDS TO RUN EVERYTHING ELSE. THERE ARE TWO PRIMARY BUSSES, CONSISTING OF PARALLEL PATHS OF BINARY DATA, THE BIGGEST BUS IS THE ADDRESS BUS. THIS CONSISTS OF 16 LINES TO TRANSFER THE ADDRESS GENERATED BY THE PROCESSOR TO THE ADDRESS INPUTS OF ALL OTHER SYSTEM CHIPS. THIS BUS IS UNIDIRECTIONAL : ONLY THE PROCESSOR (IN A NORMAL SYSTEM) GENERATES ADDRESSES, AND IT HAS 2^{16} STATES (=65536,) THE SECOND BUS IS THE DATA BUS. THIS IS 8 BI-DIRECTIONAL LINES, ALLOWING A SINGLE WORD/BYTE TO BE TRANSFERRED EITHER FROM THE PROCESSOR TO MEMORY – A WRITE, OR FROM MEMORY TO PROCESSOR – A READ. THE REMAINING BUS IS THE CONTROL BUS, ITS MEMBERS HAVE NO PARTICULAR RELATIONSHIP WITH EACH OTHER, BUT THEY ARE ALL SUPERVISORY SIGNALS FOR THE SYSTEM. THE FIRST CONTROL SIGNAL IS THE R/W LINE. THIS SPECIFIES THE TYPE OF DATA TRANSFER THAT THE PROCESSOR WISHES TO MAKE: WHEN THE R/W LINE IS HIGH (LOGIC ONE; > 2.4 V DC) THE PROCESSOR IS READING WHEN THE R/W LINE IS LOW (LOGIC ZERO < Ø.8 V DC) THE PROCESSOR IS WRITING,THE NEXT CONTROL LINES ARE THE SYSTEM CLOCK, WHICH CONTROLS THE TIMING OF ALL DATA TRANSFERS. THE PROCESSOR, WITH HELP FROM 1/6 OF A TTL IC, GENERATES THE SYTEM CLOCK AS TWO NON-OVERLAPPING SQUARE WAVES, PHASE ONE (Ø1) & PHASE TWO (Ø2)



DURING Ø1 THE ADDRESS BUS AND THE R/W LINE CHANGE, AT THE END OF, OR DURING, Ø2 THE DATA IS TRANSFERRED. OTHER CONTROL SIGNALS ALSO CHANGE AT TIMES SPECIFIED WITH RESPECT TO THE SYSTEM CLOCK, E.G. THE SYNC SIGNAL : THIS GOES HIGH DURING Ø1 WHEN THE PROCESSOR IS FETCHING AN INSTRUCTION, AND RETURNS LOW WITH THE TRAILING EDGE OF Ø2.

5.2 RESET. INTERRUPT REQUEST AND NON-MASKABLE INTERRUPT

ANOTHER CONTROL LINE IS RESET. THIS IS GENERATED BY SUITABLE HARDWARE (IN THE ACORNTHE CORNER SWITCH ON THE CPU BOARD, AND THE RESET SWITCH ON THEKEYBOARD,) ANDCAUSES ALL PARTS OF THE SYSTEM TO BE RESET TO A SAFE, KNOWN STATE. IN THE PROCESSOR'S CASE RESET INITIALIZES THE PROGRAM COUNTER TO THE CONTENTS OF ADDRESSES FFFC AND FFFD WHICH, FOR ACORN, CONTAIN THE ADDRESS FEF3. EXECUTION OF THE ACORN MONITOR STARTS THERE. PERIPHERAL DEVICES SHOULD BE SET TO THEIR LEAST DANGEROUS STATE BY RESET, E.G. REMOVE INTERRUPT CAPABILITY, SET ALL PROGRAMMABLE INPUT/OUTPUT LINES TO INPUTS.

THE TWO PUSH BUTTONS ON THE CPU BOARD ON EITHER SIDE OF THE RESET BUTTON ARE INTERRUPT BUTTONS. THE IDEA OF AN INTERRUPT IS TO PULL THE PROCESSOR AWAY FROM IT'S CURRENT TASK, LET IT BRIEFLY DO SOMETHING IMPORTANT AND THEN RETURN TO IT'S TASK AS IF NOTHING HAD HAPPENED. THE 65Ø2 HAS TWO DISTINCT INTERRUPT CAPABILITIES

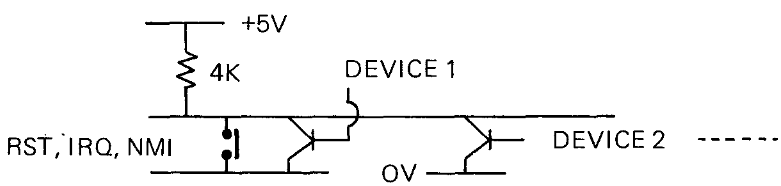
IRQ

WITH AN INTERRUPT REQUEST, IRQ, THE PROCESSOR HAS THE OPTION OF IGNORING IT. AN IRQ IS ONLY GRANTED IF THE FLAG I (INTERRUPT DISABLE) IN THE PROCESSOR STATUS REGISTER IS Ø. THE PROCESSOR THEN PUSHES PC & P & THEN SETS I TO 1. (THE STATE OF THE IRQ LINE IS CHECKED BETWEEN INSTRUCTIONS . . . IF IT REMAINS LOW,WE DON'T WANT ANOTHER INTERRUPT). THEN THE PROCESSOR LOADS PC FROM LOCATIONS FFFE & FFFF AND CONTINUES. NOTE THAT AN RTI RETURNS THE ORIGINAL P, WHICH HAD THE I FLAG Ø.

NMI

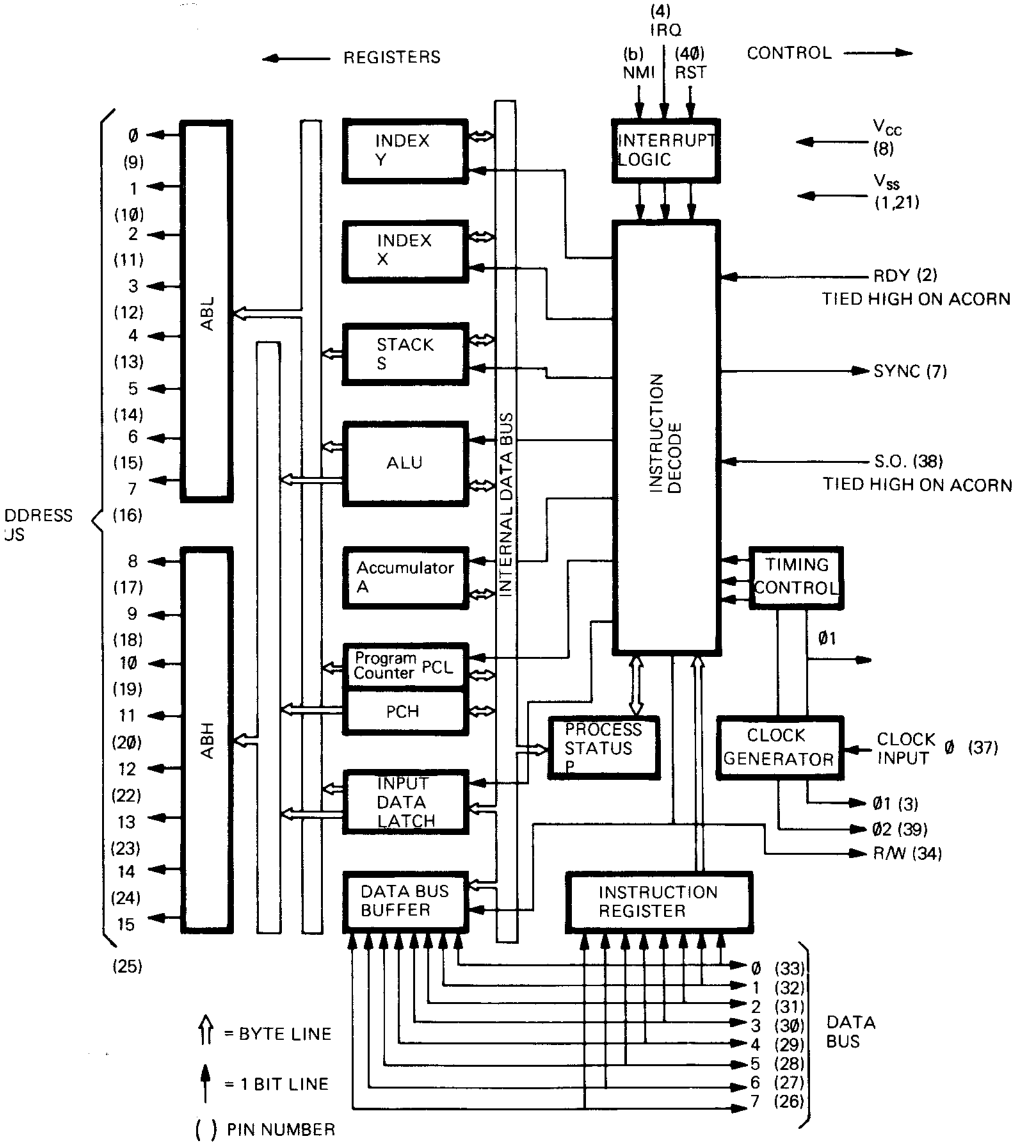
WITH A NON-MASKABLE INTERRUPT, NMI, THE PROCESSOR HAS NO OPTIONS; WHEN THE LINE HAS BEEN LOW FOR AT LEAST TWO CLOCK CYCLES, THE PROCESSOR WILL FINISH ITS CURRENT INSTRUCTION, SAVE ITS STATUS & PC, SET I HIGH AND FETCH A NEW PC FROM FFFA & FFFB. TO AVOID RECOGNISING ANOTHER INTERRUPT NMI IS EDGE-SENSITIVE: NO FURTHER INTERRUPTS ARE RECOGNISED UNTIL NMI HAS RETURNED HIGH. SINCE NMI SETS I HIGH, IRQ WILL NOT SUCCEED DURING THE NORMAL OPERATION OF AN NMI PROGRAM, BUT NMI WILL BE ABLE TO TAKE CONTROL DURING EXECUTION OF AN IRQ PROGRAM; IT HAS A HIGHER PRIORITY.

IRQ, NMI, & RESET ARE OPEN-COLLECTOR LINES ON THE CPU BOARD: MANY INTERRUPTING/RESETTING DEVICES MAY BE CONNECTED.



TO DECIDE WHICH DEVICE CAUSED AN INTERRUPT THE PROCESSOR CHECKS A STATUS REGISTER OF EACH DEVICE, USING THE BIT INSTRUCTION TO TEST BIT 7 OF THE DEVICE. AFTER EXECUTING THE PROGRAM REQUIRED FOR A PARTICULAR DEVICE THE PROCESSOR RESETS THE DEVICE'S INTERRUPT BEFORE EXECUTING ITS RTI. IF THE INTERRUPT LINE IS STILL LOW (IRQ) OR MAKES ANOTHER NMI THE WHOLE THING IS REPEATED. THIS PRIORITIES THE INTERRUPTS IN SOFTWARE.

5.3 65Ø2 INTERNAL ARCHITECTURE

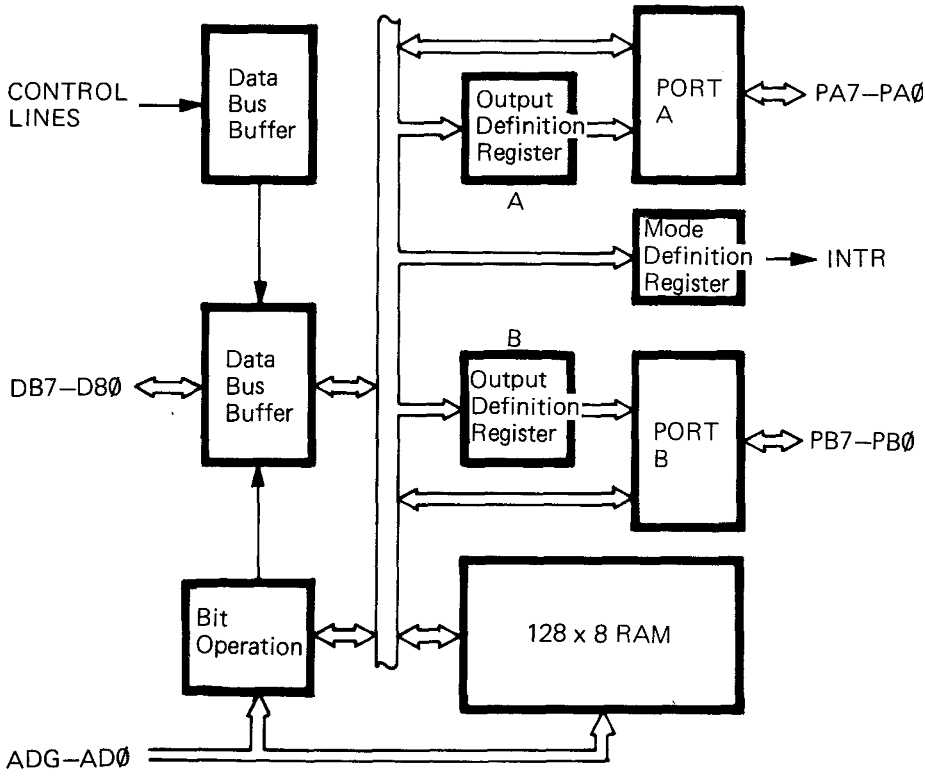


5.4 PROMS, EPROM, RAM, RAM I/O

THE NEXT THINGS CONNECTED TO THE CPU ARE DEVICES D. THESE ARE PROMS: PROGRAMMABLE READ ONLY MEMORYS. EACH CONTAINS 512 X 4 BITS OF INFORMATION WHICH HAS BEEN FIXED AS HALF OF THE ACORN MONITOR. SHORT OF CATASTROPHIC DESTRUCTION THERE IS NO WAY TO MAKE A 'HIGH' PART OF THE MEMORY 'LOW', BUT 'LOW' PARTS CAN BE PROGRAMMED 'HIGH' BY PASSING EXCESS CURRENT THROUGH A FUSE AND DESTROYING IT. IN NORMAL ACORN OPERATION THESE TWO DEVICES WILL BE ENABLED BY ANY ADDRESS IN THE RANGE F8ØØ TO FFFF: THEY THUS OCCUR IN THE MEMORY FOUR SEPARATE TIMES, MORE ON THIS ANON.
AKIN TO D, IS DEVICE E. THIS IS NOT PART OF THE KIT, BUT IS INTENDED TO BE A 2Ø48 X 8 EPROM: ERASEABLE PROGRAMMABLE READ ONLY MEMORY. LIKE THE PROM, THE EPROM CAN BE PROGRAMMED ALTHOUGH FUSES ARE NOT BLOWN BUT CHARGE IS STORED ON THE GATE OF A FIELD EFFECT TRANSISTOR (F.E.T.). THIS CHARGE CAN ONLY LEAK AWAY SLOWLY – ABOUT TEN YEARS, UNLESS THE GATE IS EXPOSED TO ULTRA-VIOLET LIGHT WHICH HAS ENOUGH ENERGY TO SET THE DEVICE BACK TO IT'S STANDBY STATE. (IF YOU MAKE ONE PROGRAM MISTAKE THE WHOLE DEVICE MUST BE ERASED TO ALLOW YOU TO CORRECT THE MISTAKE. STILL, IT'S BETTER THAN NOT BEING ABLE TO CORRECT A MISTAKE AS WITH THE PROM). AN ENABLE SIGNAL IS PROVIDED BETWEEN FØØØ & F7FF FOR THIS DEVICE, OR ELSE IT MAY BE PROGRAMMED WITH A LARGER MONITOR AND ENABLED BY THE F8ØØ – FFFF SIGNAL. SMALLER (1Ø24 X 8 or 512 X 8) EPROMS MAY ALSO BE FITTED IN SOCKET E, BUT THESE OLDER DEVICES USUALLY REQUIRE ADDITIONAL POWER SUPPLIES, AND TWO MODIFICATIONS TO THE CIRCUIT BOARD ARE REQUIRED TO ALLOW THIS.
THE LAST TYPE OF MEMORY ON THE CPU BOARD IS TYPE C. THIS IS A STATIC READ/WRITE MEMORY: INFORMATION CAN BE CREATED AND DESTROYED BY THE MICROPROCESSOR ITSELF, BUT ALL IS LOST WHEN THE POWER IS REMOVED. TOGETHER WITH THE DYNAMIC VERSION, THIS TYPE OF DEVICE HAS RECEIVED THE NAME RANDOM ACCESS MEMORY R.A.M., ALTHOUGH THEY ARE NO MORE RANDOM THAN P.R.O.M.S. OR E.P.R.O.M.S. DEVICES C ARE 1Ø24 X 4 RAMS, TWO ARE REQUIRED LIKE THE TWO PROMS TO BUILD UP A WHOLE BYTE, AND THEY ARE ENABLED BY ADDRESSES IN THE RANGE ØØØØ TO Ø3FF. THEY THUS CONTAIN ZERO PAGE & PAGE 1, THE STACK PAGE, AS WELL AS TWO FURTHER PAGES.
THE ENABLE SIGNALS FOR ALL I.C.S. ON THE CPU BOARD ARE PROVIDED BY THE LOGIC I.C.'S G. THESE I.C.S. DECODE CERTAIN RANGES OF ADDRESSES FROM THE ADDRESS BUS BY RECOGNISING A PATTERN ON HIGH ADDRESS LINES, E.G. FOR THE SIGNAL TO THE TWO RAM'S THE TOP 6 (A15–A1Ø) ADDRESS LINES MUST BE LOW (LOGIC ZERO).THE SIGNALS ARE ALL BROUGHT TO THE SOCKET F, WHERE LINKS CAN BE MADE (OR A D.I.L. HEADER USED) TO TAKE THE ENABLE SIGNALS AWAY TO THE CHOSEN DEVICES THUS MANY DIFFERENT SYSTEM CONFIGURATIONS CAN BE USED, FROM JUST THE TWO P.R.O.M.S AND DEVICE B1, THROUGH TO BOTH C'S, B2 & E OR ANY COMBINATION.

DEVICES B HAVE TWO FUNCTIONS. IN THE FIRST PLACE EACH CONTAINS A 128 X 8 RAM, BRINGING THE CPU BOARD UP TO 128Ø BYTES OF R.A.M. SECONDLY EACH HAS THE FACILITIES FOR MAKING TWO WORDS OF MEMORY

(16 BITS) APPEAR IN A USABLE FORM FOR THE OUTSIDE WORLD. THE ACORN MONITOR USES DEVICE B1 TO CONTROL THE DISPLAY, CASSETTE INTERFACE AND KEYBOARD.
EACH ONE OF THE 16 LINES MAY BE PROGRAMMED TO BE AN INPUT OR AN



8154 RAM I/0

OUTPUT DEPENDING ON THE STATE OF INTERNAL CONTROL REGISTERS. ONLY A GENERAL DESCRIPTION OF THE DEVICE IS GIVEN HERE, IN ADDITION TO THE FOLLOWING FUNCTIONS PORT A MAY BE SET TO OPERATE IN A VARIETY OF DIFFERENT HANDSHAKING TRANSFER MODES BY USE OF THE MODE DEFINITION REGISTER. IT SHOULD BE NOTED THAT THESE MODES REQUIRE CONNECTION OF INTERRUPT AND THAT THE INS8154 INTERRUPT LINE IS THE INVERSE OF THAT REQUIRED BY THE PROCESSOR.

THE 16 LINES ARE, AS YOU MIGHT EXPECT, DIVIDED INTO TWO SEPERATE BYTE SECTIONS A & B. A & B BOTH HAVE AN "OUTPUT DEFINITION REGISTER" ASSOCIATED WITH THEM. EACH BIT IN THE O.D.R. DEFINES THE ASSOCIATED BIT IN THE 'PORT' AS EITHER AN INPUT (Ø) OR AN OUPUT (1). THUS, IN THE MONITOR WE WRITE FF TO THE SEGMENT O.D.R. TO USE ALL IT'S LINES AS OUTPUTS, AND 'DISPLAY' WRITES Ø7 TO THE DIGIT DRIVE O.D.R. TO HAVE 3 OUTPUTS AND 5 INPUTS.

NOT ONLY MAY WE READ/WRITE TO THE OUTPUT PORT USING THE PARALLEL READ & WRITE OPERATIONS, BUT WE MAY ALSO READ/WRITE SINGLE BITS:

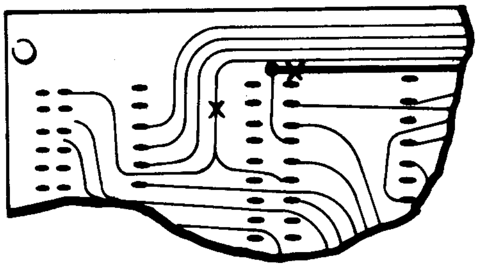
OPERATION			ADDRESS LOW	R/W
SET	BIT Ø	PORT A	1Ø	W
SET	BIT 7	PORT A	17	W
CLEAR	BIT Ø	PORT A	ØØ	W
CLEAR	BIT 7	PORT A	Ø7	W
READ	BIT Ø	PORT A	ØØ or 1Ø	R
READ	BIT 7	PORT A	Ø7 or 17	R
SET	BIT 1	PORT B	19	W
SET	BIT 6	PORT B	1E	W
CLEAR	BIT 2	PORT B	ØA	W
CLEAR	BIT 5	PORT B	ØD	W
READ	BIT 4	PORT B	ØC or 1C	R
	PORT A		2Ø	R or W
	PORT B		21	R or W
	O.D.R.A.		22	W
	O.D.R.B.		23	W

IF YOU READ A SINGLE BIT IT WILL END UP IN BIT 7 OF A BYTE, THUS THE BIT INSTRUCTION WILL ASSIGN IT TO THE TESTABLE N FLAG.

THE INS8154 ALSO CONTAINS A USEFUL 128 BYTES OF RAM. THIS IS CONTINUOUS FROM (ADDRESS LOW) 8Ø TO FF.

DEVICE B1 IS ENABLED FOR ADDRESS HIGH OF ØE, DEVICE B2 IS AT Ø9.

ALSO ON THE CPU BOARD IS A 5V REGULATOR. THIS PROVIDES THE REGULATED +5V POWER SUPPLY USED BY ALLTHE I.C.S. ON THE BOARD, AND THE KEYBOARD/INTERFACE BOARD WHEN CONNECTED. IF THE 27Ø4 OR 27Ø8 TYPE OF E.P.R.O.M. IS EMPLOYED IN SOCKET E, EXTRA +12 & –5 V POWER SUPPLY LINES ARE REQUIRED, AND TWO TRACKS ON THE P.C.B. NEED CUTTING.



THE TWO CUTS ARE ON THE REAR OF THE MPU BOARD IN THE TOP LEFT HAND CORNER. X's MARK THE SPOTS

(THERE IS NO PROVISION FOR ON-BOARD REGULATORS FOR THESE TWO EXTRA SUPPLIES).
OF COURSE, THE 2716 EPROM NEEDS NO EXTRA SUPPLY LINES, AND IS THE DEVICE THAT THE P.C.B. WAS DESIGNED FOR, IT PLUGS STRAIGHT INTO SOCKET E.
THE CONNECTOR H CARRIES THE ADDRESS BUS, THE DATA BUS, THE CONTROL BUS, POWER SUPPLY LINES AND THE 16 INPUT/OUTPUT LINES FROM B2. THIS WILL PLUG INTO A BACKPLANE WHICH TAKES THE BUSSES TO OTHER ACORN CARDS.

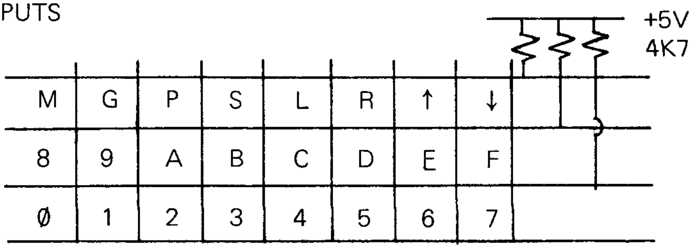
5.5 THE KEYBOARD AND TAPE INTERFACE

AT THE OTHER END OF THE BOARD, CONNECTOR I CARRIES ALL 16 I/O LINES FROM DEVICE B1, AS WELL AS OV, +5V, Ø2 & RESET LINES. WITH THE INTELLIGENT ACORN MONITOR AND THE KEYBOARD BOARD, THE I/O LINES ARE DEDICATED AS FOLLOWS

B1 PORT	BØ-7	OUTPUTS	SEGMENT DRIVES
	AØ-2	OUTPUTS	BINARY ENCODED DIGIT DRIVES
	A3-5	INPUTS	KEYBOARD ROW INPUTS
	A6	OUTPUT	FROM COMPUTER TO CASSETTE
	A7	INPUT	FROM CASSETTE TO COMPUTER

—A COMMENT FOR THOSE INTERESTED: ALTHOUGH THE KEYBOARD ONLY CONSISTS OF 24 KEYS AT PRESENT, IT IS POSSIBLE, WITH A PRIORITY ENCODER ON THE ROW INPUTS, TO USE UP TO 56 KEYS. THE DISPLAY SUBROUTINE WILL COPE CORRECTLY WITH THE UNKNOWN KEYS, EXCEPT THAT, AT THE POINT, OUTPUT, IT THROWS AWAY A SIGNIFICANT BIT OF INFORMATION. HOWEVER, THE ACTUAL KEY VALUE HAS BEEN STORED IN LOCATION ØØØF AND SO CAN BE RECOVERED. THE UNKNOWN KEYS WILL NOT AFFECT THE MONITOR ITSELF, SINCE AT THE POINT SEARCH MORE ITS OF INFORMATION IS THROWN AWAY, LEAVING THE MONITOR WITH A CHOICE OF EIGHT VALUES.

THE SUBROUTINE DISPLAY RUNS THE DISPLAY IN A MULTIPLEXED MANNER, AT THE SAME TIME STROBING AND DEBOUNCING THE MATRIXED KEYBOARD ON THE KEYBOARD BOARD. EACH OF THE EIGHT COLUMNS OF THE 8 X 3 KEYBOARD IS DRIVEN BY ONE OF THE EIGHT DIGIT DRIVER LINES, THE THREE ROW LINES ARE CONNECTED TO DEVICE B1, AND THEY ARE PULLED TO LOGIC ONE BY THE 4K7 RESISTORS. IN CONJUNCTION WITH ITS COLUMN BEING DRIVEN LOW, A CLOSED KEY PRODUCES A LOW ON ONE OF THE ROW INPUTS



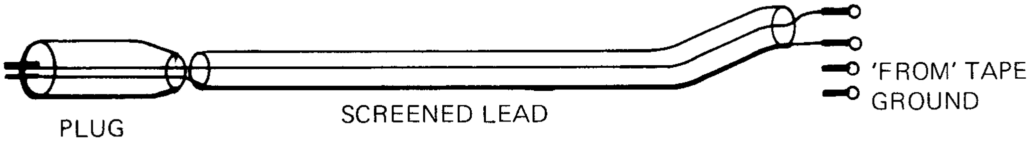
ALL THE INTERFACE BETWEEN THE MICROPROCESSOR AND THE KEYBOARD AND DISPLAY IS THUS ACCOMPLISHED BY ONE OCTAL DECODER/DRIVER AND THREE RESISTORS. THE REST OF THE CIRCUITRY ON THE INTERFACE BOARD ALLOWS PROGRAMS TO BE RECORDED ON CASSETTE AT THIRTY BYTES PER SECOND, THE INTERFACE IS SLIGHTLY MORE COMPLICATED THAN THE SINGLE I.C. AND THREE RESISTORS USED ABOVE, IT HAS TWO TASKS.

I CONVERT THE SERIAL STREAM OF INFORMATION PRODUCED BY PUTBYTE INTO TONES SUITABLE FOR AN UNMODIFIED CASSETTE RECORDER TO RECORD. THE FREQUENCIES USED ARE 24Ø3.8 HZ FOR A LOGIC ONE AND 12Ø1.9 HZ FOR A LOGIC ZERO. THE FREQUENCIES ARE PRODUCED BY DIVIDING Ø2, WHICH IS CRYSTAL CONTROLLED AT 1 MHZ, BY 416 OR 832.

II CONVERT THE PLAYED BACK FREQUENCIES INTO A STREAM OF BINARY INFORMATION. THE PLAYBACK IS 'AMPLIFIED' INTO A SQUARE WAVE, AND ITS PERIOD IS COMPARED WITH THE PERIOD OF A REFERENCE DIGITAL MONOSTABLE ON THE CIRCUIT BOARD

BECAUSE OF THE AMPLIFICATION STAGE, THE OUTPUT FROM A TAPE RECORDER'S 'LINE' OUTPUT, OR THE 'EAR' JACK SOCKET, SHOULD PERFORM SATISFACTORILY EVEN AT MODEST VOLUME LEVEL. HOWEVER THE COMPUTER OUTPUT IS AT QUITE HIGH LEVEL AND SHOULD BE ATTENUATED FOR THE TAPE RECORDER. TO PREVENT NOISE PICK-UP THIS SHOULD BE

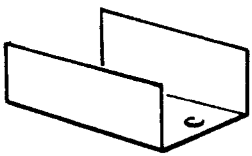
DONE IN THE PLUG CONNECTING TO THE RECORDER



BEST RECORDING RESULTS WITH A LEVEL OF ABOUT TWO-THIRDS MAXIMUM LEVEL. THE VERY CHEAPEST TAPE RECORDERS SOMETIMES USE A DC. ERASE SYSTEM, AND SUBSTANTIALLY POORER RESULTS MAY OCCUR ON RECORDING OVER AN ALREADY RECORDED SECTION OF TAPE. HIGH FREQUENCY RESPONSE IS AT A PREMIUM IN THIS APPLICATION, THE TAPE RECORDER'S HEADS SHOULD BE CLEANED FREQUENTLY, AND, PREFERABLY, DEMAGNETISED EVERY 8–1Ø HOURS. LOW QUALITY TAPES SHOULD BE AVOIDED SINCE THEY OFTEN CAUSE VERY FAST BUILD UP OF DIRT ON THE HEADS. THE SPEED OF THE REPLAYED DATA SHOULD NOT DEVIATE BEYOND ±5% OF THE RECORDED SPEED, SO DON'T USE BATTERIES FOR POWER, (OR C12Ø CASSETTES SINCE THE THINNER, HEAVIER TAPE OFTEN GETS STUCK). CLEAN THE EXPOSED CAPSTAN AND PRESSURE WHEEL WHEN YOU CLEAN THE HEADS: A HEAD CLEANING TAPE MAY NOT MANAGE TO REMOVE OXIDE BUILD-UP FROM THE MECHANISM.

5.6 POWER SUPPLY

THE TWO BOARDS ARE SUPPLIED BY THE 5V REGULATOR ON THE CPU BOARD. IF ALL THE I.C.S. ARE IN PLACE ON THE CPU BOARD, THEN AT LEAST 6ØØ MA IS REQUIRED. PROPER REGULATION IS ENSURED BY NEVER LETTING THE INPUT UNREGULATED SUPPLY DROP BELOW +7V. WHILE THE REGULATOR IS PERFECTLY HAPPY WITH +27V INPUT, IT WILL NEED TO DISSIPATE 13.2W AND WILL GET EXTREMELY HOT. . . AND TURN ITSELF OFF DUE TO THERMAL OVERLOAD, LOSING YOUR NICE PROGRAM IN THE R.A.M. UNLESS AN ADDITIONAL HEAT SINK IS USED, +12V SHOULD BE REGARDED AS AN ABSOLUTE MAXIMUM UNREGULATED INPUT, THE REGULATOR WILL NOT GET SO HOT AS TO TURN ITSELF OFF, BUT YOU MIGHT RECEIVE A BURN IF YOU TOUCH IT.



ADDITIONAL HEATSINK

CHAPTER 6: FIRMWARE
6.1 TAPE STORE AND LOAD

IN THE SOFTWARE SECTION WE USED SOME OF THE FUNCTIONS OF THE ACORN MONITOR TO WRITE AND EXECUTE SOME SIMPLE PROGRAMS WHICH DEMONSTRATED FEATURES OF THE MICROPROCESSOR AND PROGRAMMING. THE MONITOR IS MORE POWERFUL THAN DEMONSTRATED IN THAT SECTION, AND HERE WE'LL EXAMINE IT MORE CLOSELY, AND GIVE A COMPLETE LISTING OF IT. AFTER THE M, G, ↑ AND ↓ KEYS, THE MOST USEFUL KEYS WILL PROBABLY BE S AND L. THESE ENABLE YOU TO STORE AND LOAD PROGRAMS OF ANY SIZE USING CASSETTE TAPE OR A SIMILAR RECORDING MEDIUM. LET'S ASSUME WE WISH TO CREATE A TAPE VERSION OF THE DUCK-SHOOT GAME. THIS WILL HAVE BEEN ENTERED IN MEMORY FROM ADDRESS, SAY, Ø2ØØ TO ADDRESS Ø23F INCLUSIVE. AFTER TESTING THAT THE PROGRAM ACTUALLY DOES WORK, PRESS THE S KEY.

F.   XXXX   .

THE MONITOR IS PROMPTING YOU TO ENTER THE ADDRESS FROM WHICH YOU WANT TO RECORD. THE DISPLAYED ADDRESS IS EITHER GARBAGE OR THE LAST END ADDRESS USED. ENTER THE ADDRESS, TERMINATING WITH ANY COMMAND KEY

F.   Ø2ØØ   .

–   XXXX   .

THE MONITOR IS NOW PROMPTING YOU TO ENTER THE END ADDRESS. THIS IS THE ADDRESS OF THE LAST BYTE IN YOUR PROGRAM + 1. THE DISPLAYED ADDRESS IS EITHER GARBAGE OR THE LAST END ADDRESS USED. ENTER THE ADDRESS, BUT DON'T TERMINATE IT YET

–   Ø24Ø   .

THE SYSTEM IS NOW READY TO SERIALLY OUTPUT THAT SECTION OF MEMORY. YOU SHOULD RECORD A BRIEF VERBAL DESCRIPTION OF THE PROGRAM – "DUCKSHOOT" – AND ALSO THE ADDRESSES (OR ADDRESS OF START AND LENGTH) WHICH THE PROGRAM USES. KEEP A LIST OF WHICH PROGRAMS ARE STORED ON EACH TAPE. NOW CONNECT IN THE COMPUTER AND START RECORDING. AFTER A FEW SECONDS, PRESS ANY COMMAND KEY TO TERMINATE THE ADDRESS ENTRY. THE DISPLAY WILL GO BLANK, WHILE THE PROCESSOR DEVOTES ITSELF TO SENDING THE INFORMATION TO THE TAPE. WHEN THE DISPLAY

–   Ø24Ø   .

REAPPEARS, YOU MAY STOP THE TAPE-RECORDER: THE RECORDING IS COMPLETE, AND YOU ARE BACK AT FFØ4. ANY HEX KEY HERE WILL BRING BACK THE MONITOR'S DOTS, OR YOU MAY JUST START USING THE MONITOR. THE RECORDING PROCEEDS AT 3Ø BYTES PER SECOND, THIS PROGRAM, AT 68 BYTES (PROGRAM LENGTH + 4 BYTES OF ADDRESS INFORMATION) TOOK ONLY TWO SECONDS TO RECORD.

TO LOAD A PROGRAM FROM THE TAPE YOU SHOULD BE IN A SITUATION WHERE MONITOR COMMANDS ARE ACCEPTED, NOT WHERE YOU ARE ALLOWED ANY KEY TO TERMINATE AN ADDRESS ENTRY. PLAY THE TAPE, AND, WHEN THE 24Ø3.8 HZ LEADER IS HEARD, PRESS THE L KEY. THE DISPLAY WILL BE BLANK UNTIL DATA IS ENCOUNTERED ON TAPE, WHEN EACH BYTE ENTERED WILL BE DISPLAYED AS A SYMBOL ON THE LEFTMOST DIGIT. WHEN THE LAST BYTE HAS BEEN READ THE PREVIOUS DISPLAY WILL RETURN – YOU'RE AT FFØ4 AGAIN. THE ADDRESSES INTO WHICH THE PROGRAM IS LOADED WILL BE THOSE WITH WHICH IT WAS STORED ON TAPE, BUT YOU MAY WISH TO DELIBERATELY AVOID THIS. JUST USING THE MONITOR, THE BEST THAT CAN BE DONE IS TO TREAT THE ENTIRE RECORDING AS DATA AND LOAD ENOUGH OF IT TO FIT BETWEEN TWO ADDRESSES: THE FIRST FOUR BYTES LOADED WILL THUS BE THE ORIGINAL ADDRESSES THE PROCEDURE IS

I SET ADDRESSES ØØØ8 & ØØØ9 TO THE LOW & HIGH BYTE OF THE ADDRESS INTO WHICH YOU WISH TO PUT THE FIRST BYTE.
II SET ADDRESSES ØØØA & ØØØB TO THE LOW & HIGH BYTE OF THE LAST ADDRESS +1 INTO WHICH YOU WANT THE DATA TO BE LOADED.
III SET UP THE GO ADDRESS OF FF8A, START THE PLAYBACK, WHEN YOU HEAR THE 24Ø3.8 HZ LEADER, PRESS ANY KEY TO GO. LOADING WILL OCCUR BETWEEN THE ADDRESSES SPECIFIED.

THE ABOVE PROCEDURE MAY NOT BE SATISFACTORY: IT LOADS THE PROGRAM'S ADDRESSES AS DATA, AND DESTROYS THE DATA IN REGISTERS Ø AND 1 (A & X AFTER A BREAKPOINT) BETTER METHODS ARE GIVEN IN THE SYSTEM SECTION OF THE APPLICATION PROGRAMS

THE LAST COMMENT ON LOAD FROM TAPE IS THAT IT IS POSSIBLE TO CREATE A PROGRAM ON TAPE THAT WILL, WHEN LOADED, SEIZE CONTROL AND EXECUTE ITSELF. THIS IS IDEAL FOR, SAY, A BASIC INTERPRETER: YOU JUST HAVE TO LOAD IT, AND IT AUTOMATICALLY SETS ITSELF RUNNING AND PROMPTS <u>READY</u>. THE IDEA IS TO LOAD THE PROGRAM INTO THE MONITOR'S ZERO PAGE REGISTERS, LOADING THE PROGRAM START ADDRESS INTO <u>GAP</u> AND THE GO KEY (11) INTO <u>REPEAT</u>. CARE MUST BE TAKEN WHEN YOU LOAD INTO <u>FAP</u> AND <u>TAP</u>: YOU MUST BE SURE TO LOAD WHAT'S ALREADY THERE, OR SOMETHING SENSIBLE!

6.2 THE BREAKPOINT AND RESTORE COMMAND

THE FINAL TWO MONITOR FUNCTIONS ARE EMBODIED BY THE KEYS R AND P. YOU MAY ALREADY HAVE DISCOVERED THAT PRESSING R IS DISASTROUS, AND THAT P IS LIKE M, BUT WITH A PENCHANT FOR INSERTING ØØ INTO THE ADDRESS SPECIFIED. WITH THESE KEYS YOU ARE EXPECTED TO DEBUG (A BUG IS ANY SMALL MISTAKE PREVENTING A PROGRAM FROM FUNCTIONING) YOUR PROGRAMS. THE P KEY ALLOWS YOU TO INSERT THE BREAK INSTRUCTION ON TOP OF AN INSTRUCTION AT A POINT WHERE YOU SUSPECT SOMETHING SUSPICIOUS IS HAPPENING, SAY Ø2ØØ:

P.   Ø2ØØ   .

AFTER THE ADDRESS IS SET UP, THEN ANY KEY WILL CHANGE THE STATE OF IT'S CONTENTS: IF NOT A BREAK, A BREAK IS INSERTED, THE ORIGINAL DATA IS SAVED IN LOCATION ØØ18. IF A BREAK, THEN THE CONTENTS OF ØØ18 ARE INSERTED. THE RESULTING STATE OF THE LOCATION IS DISPLAYED

P.　　　Ø2ØØ　　　.　　　ØØ-

WE ARE NOW BACK AT FFØ4. BUT ↑ & ↓ NOW OPERATE ON THE P ADDRESS. CONTENTS OF A LOCATION MAY BE CHANGED AS IF THIS WERE M. PRESSING P TWICE WILL INSERT A BREAKPOINT (ONLY A SINGLE LOCATION'S BACK-UP COPY IS RETAINED) AND SEND YOU BACK TO FFØ4. THE M KEY WILL RETURN IT'S MEMORY ADDRESS WHEN PRESSED

NOW THE PROGRAM IS SITTING THERE WITH A BREAK AT Ø2ØØ. EXECUTION OF THIS BREAK WILL CAUSE AN IRQ AND CONTROL IS TRANSFERRED TO THE ADDRESS IN LOCATION ØØIE & ØØ1F: FOR DIAGNOSTICS THIS ADDRESS SHOULD BE FFB3 (THE B3 IN ØØIE & THE FF IN ØØIF) ALSO THE PROGRAM COUNTER REQUIRES RESETTING AFTER A BREAK. THE AMOUNT BY WHICH THIS IS DONE, Ø2, SHOULD BE STORED IN LOCATION ØØIB NOW EXECUTING THE BREAK CAUSES THE STATUS OF THE PROCESSOR TO BE DISPLAYED IN THE FOLLOWING FORM

FIRST DISPLAY SET : | A | X | Y | P | (HEX PAIRS OF DATA IN EACH)

SECOND DISPLAY SET: | PC | SP | (TWO BYTES EACH, SECOND SET DISPLAYED AFTER ANY KEY IS PRESSED).

THIS PROGRAM

```
Ø2ØØ    78      SEI          -SET INTERRUPT DISABLE
Ø2Ø1    B8      CLV          -CLEAR OVERFLOW
Ø2Ø2    18      CLC          -CLEAR CARRY
Ø2Ø3    F8      SED          -SET DECIMAL MODE
Ø2Ø4    A9 11   LDA #11      11
Ø2Ø6    A2 FF   LDX #FF
Ø2Ø8    AØ33    LDY #33      33
Ø2ØA    9A      TXS          -INITIALISE STACK
Ø2ØB    A2 22   LDX #22      22
Ø2ØD    ØØ      BRK
Ø2ØE
```

CAUSES　　1 1 2 2 3 3 3 C　　FOR THE FIRST DISPLAY SET AND

Ø 2 Ø D Ø 1 F C　　FOR THE SECOND SET.

THE ACTIVE FLAGS ARE THE DECIMAL AND INTERRUPT DISABLE FLAGS, (THE 2 PART OF THE STATUS REGISTER'S 2C IS AN UNUSED FLAG), THE PROGRAM WAS STOPPED AT LOCATION Ø2ØD WITH AN EMPTY STACK (THREE BYTES, PCH, PCL, P, WERE AUTOMATICALLY STACKED BY THE BRK INSTRUCTION). YOU MAY NOW CONTINUE TO WRITE (OR CORRECT) THE PROGRAM, USING THE MONITOR AS USUAL (BUT AVOID PRESSING THE RESET KEY SINCE THE STACKED PCH, PCL & P WILL BE DESTROYED) PRESSING THE R KEY WILL RETURN YOU TO Ø2ØD TO TRY CONTINUING THE PROGRAM,

WITH THE COMPLETE PROCESSOR STATUS RECOVERED. THUS, IF WE FINISH THE PROGRAM

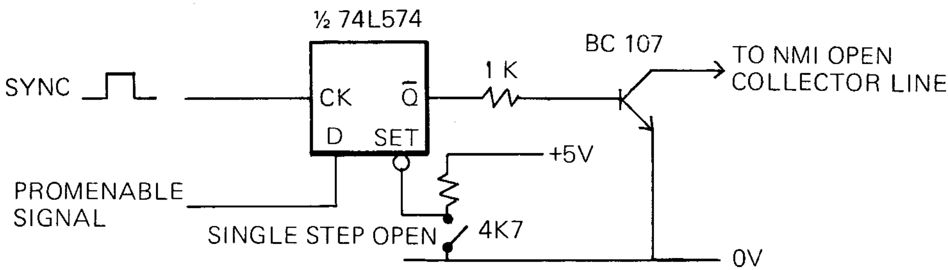
```
Ø2ØD      69 19       ADC #19
Ø2ØF      2Ø 6Ø FE    JSR RDHEXTD
Ø212      4C Ø4 FF    JMP RESTART
Ø215
```

AND PRESS R, THE DISPLAYED ANSWER WILL BE ~~03~~ 30

6.3 THE SINGLE STEPPING FACILITY

A MORE INTERESTING USE OF THE ROUTINE BREAK AT FFB3 IS IF YOU GENERATE GENERATE A NMI EVERY OPCODE FETCHED NOT IN THE MONITOR, AS DISCUSSED DISCUSSED IN THE HARDWARE SECTION THE SYNC PULSE ISSUED DURING AN OPCODE FETCH IS LESS THAN 1 CYCLE LONG, WHILE NMI REQUIRES AT LEAST 2 CYCLES. A LATCH IS REQUIRED TO STRETCH THE SYNC SIGNAL

The single step mode will work if the 1k base resistor of the BC107 is connected to Q and not $\bar{Q}$. The chip used is a 74LS74.



AND IT ALSO ONLY PROVIDES AN NMI WHEN NOT IN THE MONITOR. BEFORE EXECUTING A PROGRAM SET THE NMI VECTOR (LOCATIONS ØØ1C & ØØ1D) TO BREAK (FFB3) THE PROGRAM COUNTER RECALCULATION, IN ØØ1B, SHOULD BE ØØ. EACH INSTRUCTION EXECUTED CAUSES THE MONITOR TO DISPLAY THE STATUS OF THE PROCESSOR, PRESSING R CAUSES THE NEXT INSTRUCTION TO BE EXECUTED. YOU MAY USE THE MONITOR TO ALTER A,X,Y (LOCATIONS) ØØØA, B & C) OR P (AT STACK POINTER + 1), BEFORE THE NEXT STEP. IT IS INADVISABLE TO CHANGE PC (STACK POINTER +2 & +3), BUT THIS CAN BE DONE AS WELL. THE SINGLE STEP EXECUTION CAN BE STOPPED IN TWO WAYS

I GROUND NMI LINE/GROUND THE SET INPUT OF THE D FLIP-FLOP

II POINT THE NMI VECTOR AT AN RTI INSTRCTION, SAY THE ONE AT FFID (EXECUTION OF A PROGRAM WILL BE SLOWED DOWN BY A FACTOR OF 5 OR SO DUE TO THE PERSISTENT NMI'S.)

AN IMPORTANT NOTE: THE BREAK ROUTINE SETS THE REPEAT LOCATION TO FF, SO THAT IT, AND THE MONITOR, MAY SAFELY USE THE DISPLAY ROUTINE. IF YOU NEED TO USE SINGLE SCANS AND BREAKS TO THE BREAK ROUTINE, SOME INGENUITY WILL BE REQUIRED, OR SOME DEDICATED BUTTON PUSHING.

NOW THE COMPLETE MONITOR LISTING. THIS IS WRITTEN TO FIT IN THE TWO 512 X 4 PROMS.

ACORN MONITOR

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
FE ØØ	AØ Ø6	QUAD	LDY #Ø6	DISPLAY THE 4 BYTES AT X–3,X–2, X–1 & X IN THAT ORDER ON THE DISPLAY
FE Ø2	B5 ØØ	STILL	LDA ƵX ØØ	– GET THE BYTE POINTED TO BY X
Ø4	2Ø 6F FE		JSR DHEXTD	– USE DOUBLE HEX TO DISPLAY ROUTINE
Ø7	CA		DEX	– NEXT X
Ø8	88		DEY	– NEXT Y POSITION
Ø9	88		DEY	
ØA	1Ø F6		BPL STILL	– FALL AUTO DISPLAY WHEN FINISHED –Y POSITION & ALSO LOOP COUNTER
FE ØC	86 1A	DISPLAY	STX Ƶ TX	– SAVE X!!!!
FE ØE	A2 Ø7	RESCAN	LDX #Ø7	– SCAN 8 DIGITS, NO MATTER WHAT
1Ø	8E 22 ØE		STX 1 ADDR	– SET UP DATA DIRECTION REGISTER
FE 13	AØ ØØ	SCAN	LDY #ØØ	– CLEAR Y FOR LATER USE
15	B5 1Ø		LDA Ƶ,X D	– GET DISPLAY DATA FROM THE ZERO PAGE MEMORY
17	8D 21 ØE		STA 1PIB	– & PUT IT ONTO SEGMENTS
1A	8E 2Ø ØE		STX 1PIA	– SET DIGIT DRIVE ON AND THE KEY COLUMNS
1D	AD 2Ø ØE		LDA 1PIA	– GET KEY DIGIT BACK
2Ø	29 3F		AND #3F	– REMOVE SURPLUS TOP BITS
22	24 ØF		BIT Ƶ EXEC	– CHECK STATUS = 'I' MEANS NOT PROCESSING A KEY
24	1Ø 18		BPL BUTTON	– BUT Ø MEANS THAT WE ARE
26	7Ø ØA		BVS DELAY	– THUS CAN BE BLOWN TO AN ESCAPE FROM THE DISPLAY ROUTINE ALTOGETHER ON STATUS CØ AT THE MOMENT IT IGNORES KEYS IF GIVEN THIS STATUS
28	C9 38		CMP #38	– CHECK FOR ALL 1'S ROW INPUT FROM KEYBOARD = SET COPY IOF SO
2A	BØ Ø6		BCS DELAY	– IF ALL 1's THEN NO KEY HAS BEEN PRESSED
2C	86 19		STX Ƶ COL	– STORE THE PRESSED KEY'S COLUMN INFORMATION
2E	A9 4Ø		LDA #4Ø	– SET STATUS TO "WE ARE PROCESSING A KEY"
FE 3Ø	85 ØF	KEY CLEAR	STA Ƶ ECEC	
FE 32	88	DELAY	DEY	– Y WAS ZERO SO HERE IS A 256X5μS DELAY
33	DØ FD		BNE DELAY	– Y WILL BE ZERO ON EXIT
35	CA		DEX	
FE 36	1Ø DB		BPL SCAN	– IF X WAS STILL TVE, CONTINUE THIS SCAN
38	A5 ØE		LDA Ƶ REPEAT	– IF WE SHOULD CONTINUE SCANNING THEN TOP BIT IS SET
3A	3Ø D2		BMI RESCAN	– CONTINUE SCANNING
3C	1Ø 14		BPL OUTPUT	– IF TOP BIT IS ZERO, THEN USE THIS DATA AS THE KEY ITSELF

```
FE3E   E4  19        BUTTON    CPX Ƶ COL       – ARE WE ON THE SAME KEY'S
                                                 COLUMN?
  4Ø   DØ  FØ                  BNE DELAY       – NO
  42   C9  38                  CMP #38         – HAS A KEY ACTUALLY BEEN
                                                 PRESSED?
  44   9Ø  Ø4                  BCC PRESSED     – YES
  46   A9  8Ø                  LDA #8Ø         – NO, THEN CLEAR THE EXECUTION
                                                 STATUS – THE KEY HAS BEEN
                                                 PRESSED & RELEASED
  48   DØ  E6                  BNE KEYCLEAR    – ALWAYS BRANCH
FE4A   C5  ØF        PRESSED   CMP Ƶ EXEC      – A KEY HAS BEEN PRESSED
  4C   FØ  E4                  BEQ DELAY       – BUT IT HAS ALREADY BEEN
                                                 EXECUTED
  4E   85  ØF                  STA Ƶ EXEC      – SET IT AS BEING EXECUTED
  5Ø   49  38                  EOR #38         – JIGGERY POKERY TO ENCODE THE
                                                 ROW INPUTS TO BINARY
FE52   29  1F        OUTPUT    AND #IF         – ALSO ENSURE THE KEY IN REPEAT
                                                 WAS OF REASONABLE SIZE
  54   C9  1Ø                  CMP #1Ø         – A HEX KEY OR NOT? CARRY CLEAR
                                                 IF HEX
  56   85  ØD                  STA Ƶ KEY       – PUT THE KEY IN A TEMP LOCATION
                                                 FOR FURTHER USE (BY "MODIFY")
  58   A6  1A                  LDX Ƶ TX        – RETRIEVE X
  5A   82  21  ØE              STY 1PIB        – TURN THE SEGMENT DRIVES OFF
  5D   6Ø                      RTS             – AND RETURN
FE5E   AØ  ØØ        MHEXTD    LDA (ØØ, X)     – MEMORY HEX TO DISPLAY = GET A
                                                 BYTE FROM MEMORY
FE6Ø   AØ  Ø6        RDHEXTD   LDY #Ø6         – RIGHT (OF DISPLAY) DOUBLE HEX
                                                 TO DISPLAY : SET Y TO RIGHT OF
                                                 DISPLAY
  62   DØ  ØB                  BNE DHEXTD      – AND USE DHEXTD
FE64   AØ  Ø3        QHEXTD1   LDY #Ø3         – QUAD HEX TO DISPLAY 1: SET Y
                                                 TO USE POSNS 1,2,3 & 4
FE66   B5  ØØ        QHEXTD2   LDA Ƶ,Y ØØ        2: USE ANY Y: GET THE DATA
  68   2Ø  6F  FE              JSR DHEXTD      – AND USE DHEXTD
  68   88                      DEY
FE6C   88                      DEY             – HAVING DECREMENTED THE
                                                 POSITION
  6D   B5  Ø1                  LDA Ƶ, X Ø1     – GET THE HIGH BYTE OF THE DATA
                                                 & USE DHEXTD
FE6F   C8            DHEXTD    INY             – DOUBLE HEX TO DISPLAY : FIRST
                                                 HEX ON RIGHTEST POSITION
  7Ø   48                      PHA             – SAVE A
  71   2Ø  7A  FE              JSR HEXTD       – USE HEX TO DISPLAY
  74   88                      DEY             – GET Y BACK TO CORRECT
                                                 POSITION
  75   68                      PLA             – RETRIEVE A
  76   4A                      LSR A
  77   4A                      LSR A
  78   4A                      LSR A
  79   4A                      LSR A           – ORIENTATED FOR OTHER HEX
                                                 DIGIT
FE7A   84  1A        HEXTD     STY Ƶ TY        – HEX TO DISPLAY = SAVE Y
  7C   29  ØF                  AND #ØF         – REMOVE SURPLUS BITS FROM A
  7E   A8                      TAY             – & PUT IT IN 7
  7F   B9  EA  FF              LDA, Y FONT     – GET THE 7 SEGMENT FORM
  82   A4  1A                  LDY Ƶ TY        – RETRIEVE Y
  84   99  1Ø  ØØ              STA, Y D        – AND POSITION THE 7 SEG FORM ON
                                                 THE DISPLAY
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```
E 87    6Ø                      RTS
FE 88   2Ø  64  FE  QDATFE7     JSR QHEXTD1      – QUAD DATA FETCH – DISPLAY OLD
                                                   DATA
   8B   2Ø  ØC  FE              JSR DISPLAY      – GET KEY
   8E   BØ  2Ø                  BCS RETURN       – NON HEX RETURN
   9Ø   AØ  Ø4                  LDY #Ø4          – LOOP COUNTER
   92   ØA                      ASL A
   93   ØA                      ASL A
   94   ØA                      ASL A
   95   ØA                      ASL A            – DIGIT IN A IN CORRECT PLACE
FE 96   ØA          SHIFTIN     ASL A            – MULTI SHIFT TO GET DIGIT INTO
                                                   MEMORY
FE 97   36  ØØ                  ROL Ƶ,X ØØ       – INDEXED
   99   36  Ø1                  ROL Ƶ,X Ø1
   9B   88                      DEY
   9C   DØ  F8                  BNE SHIFTIN      – KEEP SHIFTING IN
   9E   FØ  E8                  BEQ QDATFET      – GO AND DO IT ALL AGAIN
FE AØ   F6  Ø6      COM 16      INC Ƶ,X Ø6       – INCREMENT & COMPARE 16 BIT
                                                   NOS – INCREMENT LOWER
   A2   DØ  Ø2                  BNE NOINC        – NO HIGH INCREMENT
   A4   F6  Ø7                  INC Ƶ,X Ø7
FE A6   B5  Ø6      UDINC       LDA Ƶ,X Ø6       – LOW BYTE EQUALITY TEST
   A8   D5  Ø7                  CMP Ƶ,X Ø8
   AA   DØ  Ø4                  BNE RETURN       – NO NEED TO DO HIGH BYTE
   AC   B5  Ø7                  LDA Ƶ,X Ø7       – HIGH BYTE EQUALITY TEST
   AE   D5  Ø9                  CMP Ƶ,X Ø9
FE BØ   6Ø          RETURN      RTS
FE B1   AØ  4Ø      PUTBYTE     LDY #4Ø          – PUT BYTE TO TAPE – CONFIGURE
                                                   I/O PORT
   B3   8C  22  ØE              STY 1ADDR
   B6   AØ  Ø7                  LDY #Ø7          – LOOP COUNTER
   B8   8C  2Ø  ØE              STY 1PIA         – AND SEND THE START BIT
   BB   6A                      ROR A
   BC   6A                      ROR A            – BACK A UP A COUPLE OF BITS
FE BD   2Ø  CD  FE  AGAIN       JSR WAIT         – WAIT TO SEND OUT RESET BIT
   CØ   6A                      ROR A            – SENDING ORDER IS BIT Ø→BIT 7
   G1   8D  2Ø  ØE              STA 1PIA         – SEND BIT
   C4   88                      DEY
   C5   1Ø  F6                  BNE AGAIN        – KEEP GOING
   C7   2Ø  CD  FE              JSR WAIT         – WAIT FOR THAT BIT TO END
   CA   8C  2Ø  ØE              STY 1PIA         – SEND STOP BIT : Y IS FF
FE CD   2Ø  DØ  FE  WAIT        JSR ½ WAIT       – 3ØØ BAND WAITING TIME – IN TWO
                                                   PARTS
FEDØ    84  1A      ½ WAIT      STY Ƶ TY         – ½ THE WAITING TIME – SAVE Y
   D2   AØ  48                  LDY #48          – 72 X 5µS DELAY
   D4   88          WAIT 1      DEY              – PART ONE OF THE WAIT
   D5   DØ  FD                  BNE WAIT 1
   DY   88          WAIT 2      DEY              – Y WAS ZERO ON ENTRY – 256 x 5µS
                                                   DELAY
   D8   DØ  FD                  BNE WAIT 2
   DA   A4  1A                  LDY Ƶ TY         – RETRIEVE Y
   DC   6Ø                      RTS
FE DD   AØ  Ø8      GETBYTE     LDY #Ø8          – GET BYTE FROM TAPE – LOAD
                                                   COUNTER
FE DF   2C  2Ø  ØE  START       BIT 1PIA         – WAIT FOR 1 →Ø TRANSISITON –
                                                   A START BIT
   E2   3Ø  FB                  BMI START
   E4   2Ø  DØ  FE              JSR ½ WAIT       – WAIT HALF THE TIME, SO
                                                   SAMPLING IN THE CENTRE
FE E7   2Ø  CD  FE  INPUT       JSR WAIT         – FULL WAIT TIME BETWEEN
                                                   SAMPLES
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```
   EA    ØE  2Ø  ØE              ASL 1PIA             – GET SAMPLE AUTO CARRY
   ED    6A                      ROR A                – AND AUTO A
   EE    88                      DEY
   EF    DØ  F6                  BNE INPUT            – KEEP GOING
 FE F1   FØ  DA                  BEQ WAIT             – USE WAIT TO GET OUT ONTO THE
                                                        THE SHOP BIT HIGH
 FE F3   A2  FF      RESET       LDX #FF              – MAIN PROGRAM
   F5    QA                      TXS                  – INITIALIZE STACK
   F6    8E  23  ØE              STX 1BDDR            – AND B DATA DIRECTION REGISTER
   F9    86  ØE                  STX Ƶ REPEAT         – MULTI-SCAN DISPLAY MODE
 FE FB   AØ  8Ø      INIT        LDY #8Ø              – THE FAMILIAR DOT ON THE
                                                        DISPLAY
   FD    A2  Ø9                  LDX #Ø9              – ALL EIGHT DISPLAYS AND
                                                        INITIALIZE EXEC
   FF    94  ØE                  STY Ƶ, X REPEAT      – Y USED FOR AMUSEMENT
 FFØ1    CA                      DEX
 FF Ø2   DØ  FB                  BNE ROUND            – X ZERO ON EXIT, SO UP & DOWN
                                                        IMMEDIATELY VALID
 FF Ø4   2Ø  ØC  FE  RESTART     JSR DISPLAY          – MARK RETURN TO MONITOR POINT
                                                        DISPLAY DISPLAY & GET KEY
 FF Ø7   9Ø  F2      RE-ENTER    BCC INIT             – HEX KEY GETS THE DOTS BACK
 FF Ø9   29  Ø7      SEARCH      AND #Ø7              – REMOVE ANY STRAY BITS
                                                        (EFFECTIVELY SUBTRACT 1Ø)
   ØB    C9  Ø4                  CMP #Ø4
   ØD    9Ø  25                  BCC FETADD           – KEYS OF VALUE LESS THAN 4
                                                        NEED AN ADDRESS
   ØF    FØ  6F                  BEQ LOAD             – KEY 4 IS THE LOAD KEY
   11    C9  Ø6                  CMP #Ø6
   13    FØ  Ø9                  BEQ "UP"             – KEY 6 IS UP
   15    BØ  ØF                  BCS "DOWN"           – & KEY 7 IS DOWN
 FF 17   A5  ØA      "RETURN"    LDA Ƶ RØ             – MUST BE KEY 5 – GET A BACK
   19    A6  ØB                  LDX Ƶ R1             – GET X BACK
   1B    A4  ØC                  LDY Ƶ R2             – GET Y BACK
   1D    4Ø                      RTI                  – GET P & PC BACK & CONTINUE
                                                        FROM WHERE YOU WERE
 FF 1E   F6  ØØ      "UP"        INC Ƶ,X ØØ           – 16 BIT INDEXED INCREMENT
   2Ø    DØ  ØC                  BNE ENTERM
   22    F6  Ø1                  INC Ƶ,X Ø1
   24    BØ  Ø8                  BCS ENTERM           – A BRANCH ALWAYS : THE CARRY
                                                        WAS SET BY THE FF11 COMPARE
 FF 26   B5  ØØ      "DOWN"      LDA Ƶ,X ØØ           – 16 BIT INDEXED DECREMENT
   28    DØ  Ø2                  BNE NODEC
   2A    D6  Ø1                  DEC Ƶ,X Ø1
 FF 2C   D6  ØØ      NODEC       DEC Ƶ,X ØØ
 FF 2E   2Ø  64  FF  ENTERM      JSR QHEXTD1          – NOW DISPLAY THE VALUE
   31    4C  45  FF              JMP "MODIFY"         – AND GET INTO THE MODIFY
                                                        SECTION
 FF 34   84  16      FETADD      STY Ƶ D+6            – CLEAR DISPLAYS 6
   36    84  17                  STY Ƶ D+7              & 7 – Y WAS ZERO ON EXIT FROM
                                                        DISPLAY
   38    ØA                      ASL A                – DOUBLE A
 FF 39   AA                      TAX                  – THE ZERO PAGE ADDRESSES MAP,
                                                        GAP, PAP & FAP
   3A    49  F7                  EOR #F7              – FIX UP DIGIT Ø COMMAND SYMBOL
   3C    85  1Ø                  STA Ƶ D
   3E    2Ø  88  FE              JSR QDATFET          – FETCH THE ADDRESS, AUTO MAP,
                                                        GAP, PAP OR FAP
   41    EØ  Ø2                  CPX #Ø2              – CHECK X TO FIND OUT WHICH
                                                        COMMAND WE'RE DOING
   43    BØ  15                  BCS NI               – MUST BE 2, 4 OR 6 – AS Ø IS
```

```
FF45  2Ø  5E  FE  "MODIFY"  JSR MHEXTD       — DISPLAY THE MEMORY
  48  2Ø  ØC  FE            JSR DISPLAY      — AND GET KEY
  4B  BØ  BC                BCS SEARCH       — IF NOT HEX DO OVER
  4D  A1  ØØ                LDA (ØØ, X)      — HEX SO GET OLD INFO
  4F  ØA                    ASL A
  5Ø  ØA                    ASL A
  51  ØA                    ASL A
  52  ØA                    ASL A            — MOVED ALONG
  53  Ø5  19                ORA Ƶ KEY        — AND PUT IN NEW INFO
  55  81  ØØ                STA (ØØ, X)      — AND PUT IT BACK
  57  4C  45  FF            JMP "MODIFY"     — THEN KEEP DOING IT
FF5A  DØ  Ø3      N1        BNE N2           — MUST BE 4 OR 6 AS 2 IS
FF5C  6C  Ø2  ØØ  "GO"      JMP (GAP)        — THE VERY SIMPLE GO
FF5F  EØ  Ø4      N2        CPX #Ø4          — IS IT 4 OR 6?
  61  FØ  36                BEQ POINT        — WELL IT'S NOT 4
  63  A2  Ø8      "STORE"   LDX #Ø8          — SO IT MUST BE 6 – X NOW POINTS
                                               TO TAP
  65  86  1Ø                STX Ƶ D          — GIVE PROMPT
  67  2Ø  88  FE            JSR QDATFET      — AND GET 2ND STORE INFO
FF6A  A2  Ø4                LDX #Ø4          — LOOP COUNT
FF6C  B5  Ø5                LDA Ƶ,X Ø5       — SEND ADDRESSES TO TAPE
  6E  2Ø  B1  FE            JSR PUTBYTE
  71  CA                    DEX
FF72  DØ  F8                BNE ADDRESS      — X NEATLY ZEROED ON EXIT
FF74  A1  Ø6      DATAS     LDA (Ø6, X)      — DATA SEND – GET INFO FROM
                                               MEMORY
  76  2Ø  31  FE            JSR PUTBYTE      — AND SEND IT TO TAPE
  79  2Ø  AØ  FE            JSR COM16        — SEE IF PRINTED
  7C  DØ  F6                BNE DATAS        — NO
  7E  FØ  2A                BEQ WAYOUT       — YES
FF8Ø  A2  Ø4      "LOAD"    LDX #Ø4
FF82  2Ø  DD  FE  ADDRSL    JSR GETBYTE      — RESCUE ADDRESSES FROM TAPE
  85  95  Ø5                STA Ƶ,X Ø5       — PUT THEM IN FAP & TAP, THOUGH
                                               IT COULD BE ELSEWHERE
  87  CA                    DEX
  88  DØ  F8                BNE ADDRSL       — X NEATLY SERVED AGAIN
FF8A  2Ø  DD  FE  DATAL     JSR GETBYTE      — GET DATA FROM TAPE
  8D  81  Ø6                STA (Ø6, X)      — AND STORE IT IN MEMORY
  8F  8D  21  ØE            STA 1PIB         — AND ON THE DISPLAY SO IT CAN BE
                                               SEEN
  92  2Ø  AØ  FE            JSR COM16        — SEE IF FINISHED
  95  DØ  F3                BNE DATAL        — NO
  97  FØ  11                BEQ WAYOUT       — YES
FF99  A1  ØØ      "POINT"   LDA (ØØ, X)      — SET/CLEAR BREAK POINT – GET
                                               DATA FROM ADDRESSED MEMORY
  9B  FØ  Ø6                BEQ SET          — IF ZERO BREAK POINT HAS
                                               ALREADY BEEN SET = MUST CLEAR
                                               IT
  9D  85  18                STA Ƶ P          — NOT ZERO SO SAVE THE
                                               INFORMATION
  9F  A9  ØØ                LDA #ØØ          — AND PUT IN A BREAK POINT
  A1  FØ  Ø2                BEQ OUT
FFA3  A5  18      SET       LDA Ƶ P          — WAS SET SO GET OLD
                                               INFORMATION BACK
FFA5  81  ØØ      OUT       STA (ØØ, X)      — INSERT BREAK POINT OR OLD
                                               INFORMATION
  A7  2Ø  5E  FE            JSR MHEXTD       — NOW READ IT OUT AGAIN TO
                                               REVEAL ROM
FFAA  4C  Ø4  FF  WAYOUT    JMP RESTART      — GO BACK & DO IT ALL OVER AGAIN
FFAD  6C  1C  ØØ  NMI       JMP (USERNMI)    — INDIRECTION ON NMI
FFBØ  6C  1E  ØØ  IRQ       JMP (USERIRQ)    — INDIRECTION ON IRQ
```

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FF B3   85  ØA            BREAK    STA Ƶ RØ       – WHEN THE IRQ/BREAK VECTOR
                                                    POINTS HERE THEN DISPLAY
                                                    DISPLAY EVERYTHING – SAVE A

  B5    86  ØB                     STX Ƶ R1       – SAVE X
  B7    84  ØC                     STY Ƶ R2       – SAVE Y
  B9    68                         PLA            – GET P OFF STACK
  BA    48                         PHA            – PUT IT BACK FOR FUTURE USE
  BB    85  ØD                     STA Ƶ R3       – STORE Q IN REGISTER 3
  BD    A2  ØD                     LDX #R3        – SET X TO POINT AT REGISTERS
                                                    3→Ø FOR QUAD
  BF    A9  FF                     LDA # FF       – KILL POSSIBILITY OF DISPLAY
                                                    BEING ON SINGLE SCAN
  C1    85  ØE                     STA Ƶ REPEAT
  C3    2Ø  ØØ  FE                 JSR QUAD       – USE QUAD TO WRITE OUT A X Y P

  C6    BA                         TSX            – GET STACK POINTER
  C7    86  13                     STX Ƶ R7
  C9    C8                         INY            – Y ZERO SINE QUAD ENDED WITH
                                                    DISPLAY SO THIS FORMS Ø1
  CA    84  12                     STY Ƶ R6
  CC    D8                         CLD            – CLEAR DECIMAL MODE FOR BINARY
                                                    SUBTRACT – DOESN'T AFFECT
                                                    USER SINCE P IS STACKED
  CD    BD  Ø2  Ø1                 LDA, X Ø1Ø2    – GET PCL OFF STACK
  DØ    38                         SEC
  D1    E5  1F                     SBC Ƶ RECAL    – CORRECT IT BY AMOUNT IN RECAL
  D3    9D  Ø2  Ø1                 STA, X Ø1Ø2    – PUT IT BACK ON STACK
  D6    85  11                     STA Ƶ R5       – AND STORE IT FOR QUAD
  D8    BD  Ø3  Ø1                 LDA, X Ø1Ø3    – PCH OFF STACK
  DB    E9  ØØ                     SBC #ØØ        – REST OF TWO BYTE SUBTRACTION
  DD    9D  Ø3  Ø1                 STA, X Ø1Ø3    – PUT IT BACK ON STACK
  EØ    85  1Ø                     STA Ƶ R4       – AND STORE IT FOR QUAD
  E2    A2  13                     LDX #R7        – POINT X AT THESE REGISTERS –
                                                    QUAD WILL DESTROY THEM
  E4    2Ø  ØØ  FE                 JSR QUAD       – QUAD WRITES OUT PC SP
FF E7   4C  Ø7  FF                 JMP RE-ENTER   – AND THE WHOLE SHEBARG STARTS
                                                    OVER AGAIN
FF EA   3F  Ø6  5B  4F FONT        'Ø' '1' '2' '3' – 7 SEGMENT FORMS OF THE HEX
                                                    DIGITS
  EE    66  6D  7D  Ø7             '4' '5' '6' '7'
  F2    7F  6F  77  7C             '8' '9' 'A' 'b'
  F6    58  5E  79  71             'c' 'd' 'E' 'F'
FF FA   AD  FF            NMIVEC   NMI            – POINT TO THE ADDED INDIRECTION
FF FC   F3  FE            RSTVEC   RESET          – POINT TO THE RESET ENTRY POINT
FF FE   BØ  FF            IRQVEC   IRQ            – POINT TO THE ADDED INDIRECTION
```

PART 2
APPLICATION PROGRAMS

MATHEMATICAL

1. SQUARE ROOT (HEX. OR DECIMAL)
2. DIVIDE (HEX. OR DECIMAL)
3. SINGLE BYTE MULTIPLY
4. DOUBLE BYTE MULTIPLY

SYSTEM

1. DECIMAL TO HEX.
2. HEX. TO DECIMAL
3. BRANCH OFFSET CALCULATOR
4. RELOCATOR
5. TAPE USE PROGRAMS
6. SCROLL

GAMES

1. NIM
2. DUCK SHOOT

MISCELLANEOUS

1. COUNTER
2. KEYBOARD COUNTER ROUTINE
3. METRONOME
4. EIGHT QUEENS PROBLEM

GENERAL

THESE APPLICATIONS PROGRAMS ARE INTENDED TO DEMONSTRATE SOME OF THE CAPABILITIES OF THE SYSTEM AND OF THE PROCESSOR. THEY HAVE BEEN DESIGNED FOR CLARITY AND SIMPLICITY AND IN MANY CASES ARE NOT OPTIMAL EITHER IN TERMS OF LENGTH OF PROGRAM OR OF EXECUTION TIME. THEY ARE INTENDED SIMPLY TO GIVE YOU A FEEL FOR THE SYSTEM AND SOMEWHERE TO START OFF FROM.

ALL PROGRAMS MARKED RELOCATABLE CAN BE ENTERED ANYWHERE IN AVAILABLE MEMORY, SUBJECT TO NOT IMPINGING IN VARIABLE STORAGE SPACE FOR EITHER THE PROGRAM OR MONITOR AND NOT USING SPACE NEEDED BY THE STACK. (FOR STACK USAGE SEE RELEVANT SECTIONS OF PART 1 OF THIS MANUAL.)

AS FAR AS HAS PROVED POSSIBLE THE CONVENTION OF A XX ØØØØ XX PROMPT FOR THE FIRST NUMBER TO BE ENTERED AND XX 1111 XX FOR THE SECOND HAS BEEN OBSERVED IN THESE PROGRAMS. AFTER ENTERING A NUMBER CHECK THAT IT IS CORRECT AND THEN PRESS A CONTROL KEY (ANY ONE WILL DO) TO PROGRESS THROUGH THE PROGRAM.

YOU SHOULD NOW BE READY TO TYPE IN THE PROGRAMS AND RUN THEM, BOTH TO ASSURE YOURSELF THAT THE SYSTEM IS OPERABLE AND TO FAMILIARISE YOURSELF WITH ITS OPERATION.

THROUGHOUT THESE NOTES X INDICATES AN UNDEFINED/UNIMPORTANT CHARACTER.

MOST OF THE PROGRAMS WERE WRITTEN BY MARK I'ANSON, THANK YOU MARK I.

MATHEMATICAL PROGRAMS

ALL THESE ROUTINES RESET THEMSELVES WHEN A CONTROL KEY IS PRESSED AFTER THE NUMBER HAS BEEN OBTAINED. THEY MAY ALL BE USED AS SUB

ROUTINES BY ENTERING THE SECTION OF PROGRAM FROM THE TITLE LABEL (E.G. DIVIDE) TO THE RESULT LABEL AND SUBSTITUTING THE LINE

60 RESULT RTS .

ALL ARE RELOCATABLE.

SYSTEM PROGRAMS

THESE PROGRAMS ARE ALL SHORT ROUTINES WHICH CAN PROVE USEFUL TIME SAVERS AT THE DEVELOPMENT AND INPUT STAGES OF PROGRAM WRITING.
IT MAY BE FOUND USEFUL TO KEEP COPIES OF THEM ON TAPE AND TO HAVE THEM IN THE ACORN AND BESIDE YOU WHILE DEVELOPING PROGRAMS.
BRANCH CALCULATIONS IN PARTICULAR ARE A FERTILE SOURCE OF ERRORS AND TIME WASTING IN ANY HAND ASSEMBLED PROGRAM.
THE RELOCATOR WILL MOVE PROGRAMS AROUND MEMORY FOR YOU. A GODSEND TO ANYONE WHO FINDS THEMSELVES WITH THE NEED TO REENTER LARGE CHUNKS OF CODE MANUALLY.

MISCELLANEOUS

THIS IS A SELECTION OF PROGRAMS AND ROUTINES INCLUDED BECAUSE THEY ARE INTERESTING, ELEGANT OR IMPORTANT. THEY SHOW SOME OF OF THE THINGS THAT CAN BE DONE WITH THE SYSTEM, WHICH MAY BE MORE THAN YOU IMAGINE. WE HAVE, FOR INSTANCE, RUN A CHESS GAME IN THE 1K SYSTEM.
IN PARTICULAR THE METRONOME AND COUNTER PROGRAMS ARE INTENDED TO DEMONSTRATE SOME OF THE USES OF THE KEYBOARD. IN ORDER TO UNDERSTAND WHAT IS GOING ON WITH THESE PROGRAMS YOU WOULD BE WELL ADVISED TO STUDY THE MONITOR LISTING AND PART 1 OF THIS MANUAL.

MATHEMATICAL

THE SQUARE ROOT PROGRAM WILL CALCULATE EITHER DECIMAL OR HEXA-DECIMAL SQUARE ROOTS ACCORDING AS CLD (FOR HEX) OR SED (FOR DECIMAL) IS ENTERED AS THE FIRST LINE. IN EITHER CASE THE PROMPT WILL BE XX0000XX . THE SQUARE SHOULD BE ENTERED, A CONTROL KEY PRESSED AND THE ROOT WILL APPEAR ON THE DISPLAY.
THE PROGRAM IS BASED ON THE EQUALITY

$$((N+1)*(N+1))-(N*N)=(2*N)+1$$

AND SUCCESIVELY SUBTRACTS 1,3,7,9 ETC. FROM THE SQUARE. WHEN THE RESULT OF A SUBTRACTION GOES NEGATIVE THE NUMBER OF SUBTRACTIONS DONE TO DATE IS THE ROOT.

HEX/DEC SQ ROOT. **RELOCATABLE**

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
0200	F8 OR D8		SED (OR CLD)	– SET DECIMAL (BINARY) OPERATING
0201	84 21		STY Z SQH	– CLEAR SQUARE TO PROMPT
0203	84 20		STY Z SQL	
0205	A2 20		LDX #SQL	
0207	20 88 FE		JSR QDATFET	– FETCH THE NO. WHOSE ROOT IS TO BE FOUND
020A	84 24		STY Z SUBH	– CLEAR HIGH PART OF SUBTRACTING NO.
020C	84 22		STY Z ROOT	– CLEAR ROOT
020E	C8		INY	

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø20F	84 23		STY Ƶ SUBL	– SUBTRACT ØØØ1 AT START
Ø211	A4 2Ø		LDY Ƶ SQL	– USE Y & X AS DOUBLE SIZED ACCUMULATOR
Ø213	A6 21		LDX Ƶ SQH	
Ø215	38	NXTSUB	SEC	
Ø216	98		TYA	
Ø217	E5 23		SBC Ƶ SUBL	
Ø219	A8		TAY	– SUBTRACT SUB FROM X & Y
Ø21A	8A		TXA	
Ø21B	E5 24		SBC Ƶ SUBH	
Ø21D	AA		TAX	
Ø21E	9Ø 14		BCC RESULT	– IF NEGATIVE THEN STOP
Ø22Ø	A9 ØØ		LDA # ØØ	– NOT FINISHED YET. INCREMENT ROOT
Ø222	65 22		ADC Ƶ ROOT	
Ø224	85 22		STA Ƶ ROOT	
Ø226	A5 23		LDA Ƶ SUBL	– INCREMENT SUB
Ø228	69 Ø2		ADC #Ø2	
Ø22A	85 23		STA Ƶ SUBL	
Ø22C	A5 24		LDA Ƶ SUBH	
Ø22E	69 ØØ		ADC #ØØ	
Ø23Ø	85 24		STA Ƶ SUBH	
Ø232	9Ø E1		BCC NXTSUB	– THERE CAN BE NO CARRY: BRANCH ALWAYS
Ø234	A5 22	RESULT	LDA Ƶ ROOT	
Ø236	2Ø 6Ø FE		JSR DHEXTD	– DISPLAY ANSWER
Ø239	4C Ø4 FF		JMP RESTART	
Ø24B				

THE DIVIDE ROUTINE WILL CALCULATE THE INTEGER RESULT AND REMAINDER OF A FOUR DIGIT NUMBER DIVIDED BY A TWO DIGIT NUMBER. BY ENTERING CLD (FOR HEX.) OR SED (FOR DECIMAL) EITHER BASE MAY BE USED, SINCE IT WORKS BY SUBTRACTING THE DIVISOR SUCCESSIVELY FROM THE DIVIDEND. THE ROUTINE PROMPTS WITH XXØØØØXX FOR THE DIVIDEND AND THEN XXXX11XX FOR THE DIVISOR. THE ANSWER WILL APPEAR IN THE FORM ABCD.EF WHERE ABCD IS THE INTEGER RESULT AND EF IS THE REMAINDER.

DIVIDER

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø2ØØ	D8 OR F8		CLD OR SED	– BINARY (DECIMAL) OPERATION
Ø2Ø1	84 2Ø		STY Ƶ 2Ø DIVIDED	– CLEAR DIVIDEND – PROMPT FOR NUMBER
Ø2Ø3	84 21		STY Ƶ 21	
Ø2Ø5	A9 11		LDA #11	– PROMPT FOR SECOND NUMBER
Ø2Ø7	85 22		STA Ƶ 22 DIVISOR	
Ø2Ø9	A2 2Ø		LDX #2Ø	
Ø2ØB	2Ø 88 FE		JSR QDATFET	– FETCH DIVIDEND
Ø2ØE	A2 22		LDX #22	
Ø21Ø	2Ø 88 FE		JSR QDATFET	– FETCH DIVISOR
Ø213	84 24		STY Ƶ 24 RESULT	– CLEAR RESULT
Ø215	84 25		STY Ƶ 25	

```
ADDR   HEX          LABEL      INSTRUCTION        COMMENTS
       CODE
Ø217   A4  2Ø                  LDY Ƶ 2Ø           – USE Y & X AS DOUBLE
                                                    ACCUMULATOR
Ø219   A6  21                  LDX Ƶ 21
Ø21B   38                      SUB SEC         ┐
Ø21C   98                      TYA             │
Ø21D   E5  22                  SBC Ƶ 22        │
Ø21F   A8                      TAY             ├  – SUBTRACT THE DIVISOR
Ø22Ø   8A                      TXA             │
Ø221   E9  ØØ                  SBC #ØØ         │
Ø223   AA                      TAX             ┘
Ø224   9Ø  1Ø                  BCC RESULT         – IF NEGATIVE THEN FINISHED
Ø226   84  23                  STY Ƶ 23           – ELSE UPDATE THE REMAINDER
Ø228   A5  24                  LDA Ƶ 24        ┐
Ø22A   69  ØØ                  ADC #ØØ         │
Ø22C   85  24                  STA Ƶ 24        ├  – AND ADD ONE TO THE RESULT
Ø22E   A5  25                  LDA Ƶ 25        │    (CARRY WAS SET ON INPUT).
Ø23Ø   69  ØØ                  ADC #ØØ         │
Ø232   85  25                  STA Ƶ 25        ┘
Ø234   9Ø  E5                  BCC SUB            – NO CARRY IS POSSIBLE (USUALLY)
Ø236   A2  24       RESULT     LDX #24
Ø238   2Ø  64  FE              JSR QHEXTDI        – DISPLAY RESULT
Ø23B   A5  23                  LDA Ƶ 23
Ø23D   2Ø  6Ø  FE              JSR RDHEXTD        – AND REMAINDER
Ø24Ø   4C  Ø4  FF              JMP RESTART
Ø242
```

THE TWO MULTIPLY ROUTINES ARE FOR SINGLE AND DOUBLE BYTE BINARY MULTIPLICATION. THE FIRST PROMPTS XXØØ11XX AND THE TWO NUMBERS TO BE MULTIPLIED SHOULD BE ENTERED SEQUENTIALLY. (E.G. 1234 WOULD GIVE 12 X 34). THE SECOND PROMPTS XXØØØØXX FOLLOWED BY XX1111XX FOR THE TWO NUMBERS. ANSWERS ARE, AS USUAL, DISPLAYED AFTER A CONTROL KEY HAS BEEN PRESSED.
BOTH ARE BASED ON AN EQUIVALENT TO THE NORMAL METHOD OF LONG MULTIPLICATION.

E.G.

```
         11Ø1Ø
         ØØ11Ø
    ØØØØØØØØØØ     – (Ø X 2^4) X 11010
     ØØØØØØØØØ     – (Ø X 2^3) X 11010
       11Ø1ØØØ     – (1 X 2^2) X 11010
        11Ø1ØØ     – (1 X 2)   X 11010
        ØØØØØØ     – (Ø X 2^0) X 11010
      1ØØ111ØØ
```

SINGLE BYTE MULTIPLY

```
ADDR   HEX          LABEL      INSTRUCTION        COMMENTS
       CODE
Ø2ØØ   D8                      CLD
Ø2Ø2   84  2Ø                  STY Ƶ 2Ø           – SET UP PROMPT FOR ZERO –
                                                    MULTIPLIER
Ø2Ø4   A9  11                  LDA #11
Ø2Ø6   85  21                  STA Ƶ 21           – PROMPT FOR FIRST – MULTIPLICAND
```

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø2Ø8	A2 2Ø		LDX #2Ø	
Ø2ØA	2Ø 88 FE		JSR QDATFET	– FETCH THE NUMBERS
Ø2ØD	98		TYA	– CLEARS A
Ø2ØE	AØ Ø8		LDY #Ø8	– LOOP COUNTER
Ø21Ø	66 2Ø	LOOP	ROR Ƶ 2Ø	– SHIFT MULIPLIER (AND HIGH BYTE OF RESULT)
Ø212	9Ø Ø3		BCC NAD	– NO ADD IF NO BIT
Ø214	18		CLC	
Ø215	65 21		ADC Ƶ 21	– ADD MULTIPLICAND INTO LOW BYTE OF RESULT
Ø217	6A	NAD	ROR A	– AND SHIFT LOW BYTE OF RESULT
Ø218	88		DEY	
Ø219	DØ F5		BNE LOOP	
Ø213	85 21		STA Ƶ 21	– PUT IN LOW BYTE
Ø21D	66 2Ø		ROR Ƶ 2Ø	– FINAL JUSTIFICATION SHIFT
Ø21F	2Ø 64 FE		JSR QHEXTD	– DISPLAY ANSWER
Ø222	2Ø 64 FF		JMP RESTART	
Ø224				

DOUBLE BYTE MULTIPLY

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø2ØØ	D8		CLD	– BINARY ONLY
Ø2Ø1	84 2Ø		STY Ƶ 2Ø MPIER	– FORM PROMPT FOR THE ZERO INPUT
Ø2Ø3	84 21		STY Ƶ 21	
Ø2Ø5	A9 11		LDA #11	
Ø2Ø7	85 22		STA Ƶ 22 MPICAND	– FORM PROMPT FOR THE FIRST INPUT
Ø2Ø9	85 23		STA Ƶ 23	
Ø2ØB	A2 2Ø		LDX #2Ø	
Ø2ØD	2Ø 88 FE		JSR QDATFET	– FETCH ZERO INPUT
Ø21Ø	A2 22		LDX #22	
Ø212	2Ø 88 FE		JSR QDATFET	– AND FIRST INPUT
Ø215	84 24		STY Ƶ 24	– CLEAR WORKING SPACE
Ø277	84 25		STY Ƶ 25	
Ø219	AØ 1Ø		LDY #1Ø	– LOOP COUNT INITIALISATION
Ø21B	66 23	LOOP	ROR Ƶ 23	– TWO BYTE SHIFT RIGHT
Ø21D	66 22		ROR Ƶ 22	
Ø21F	9Ø ØD		BCC NAD	– NO ADD IF THE O/P BIT ISN'T A ONE
Ø221	18		CLC	
Ø222	A5 2Ø		LDA Ƶ 2Ø	– TWO BYTE ADD
Ø224	65 24		ADC Ƶ 24	
Ø226	85 24		STA Ƶ 24	
Ø228	A5 21		LDA Ƶ 21	
Ø22A	65 25		ADC Ƶ 25	
Ø22C	85 25		STA Ƶ 25	– NO CARRY OUT OF THE ADD
Ø22E	66 25	NAD	ROR Ƶ 25	– SHIFT AGAIN
Ø23Ø	66 24		ROR Ƶ 24	
Ø232	88		DEY	
Ø233	DØ E6		BNE LOOP	– GO ROUND LOOP 16 TIMES
Ø235	66 23		ROR Ƶ 23	– FINAL SHIFT ON RESULT
Ø237	66 22		ROR Ƶ 22	
Ø239	AØ Ø6		LDY #Ø6	– SET UP POSITION
Ø23B	2Ø 66 FE		JSR QHEXTD2	– X ALREADY POINTING AT CORRECT LOCATIONS – PUT 4 HEX OUT
Ø23E	AØ Ø2		LDY #Ø2	– NEXT POSITION

```
ADDR   HEX         LABEL     INSTRUCTION      COMMENTS
       CODE
Ø24Ø   A2  24                LDX #24          – SET UP X
Ø242   2Ø  66  FE            JSR QHEXTD2      – PUT NEXT 4 OUT
Ø245   4C  Ø4  FF            JMP RESTART      – DISPLAY RESULT
Ø247
```

SYSTEM

THE DECIMAL TO HEX CONVERTER WILL PROMPT WITH ØXXXX FOR THE FIRST DIGIT OF THE 5 DIGIT DECIMAL NUMBER. THEN XØØØØ. FOR THE LAST FOUR DIGITS OF THE DECIMAL NUMBER. CLEARLY ANYTHING OVER 65535 WILL GIVE THE REMAINDER WHEN DIVIDED BY 1ØØØØ HEX. TO ENTER THIS NUMBER YOU WOULD KEY 6, CONTROL KEY, 5535, CONTROL KEY, AND FFFF WILL APPEAR ON THE DISPLAY (AFTER A SLIGHT DELAY!)
THE PROGRAM WORKS BY A PROCESS OF DECREMENTING THE DECIMAL NUMBER AND THEN INCREMENTING THE HEX. NUMBER.

DEC→HEX

```
Ø2ØØ   98                    TYA              – CLEAR A
Ø2Ø1   85  2Ø                STA Ƶ DECL       – CLEAR NO
Ø2Ø3   85  21                STA Ƶ DECH
Ø2Ø5   A2  2Ø                LDX #DECC
Ø2Ø7   85  22      AGAIN     STA Ƶ DECVH      }
Ø2Ø9   2Ø  7A  FE            JSR HEXTD        } – FETCH THE FIRST DIGIT
Ø2ØC   2Ø  ØC  FE            JSR DISPLAY      }
Ø2ØF   9Ø  F6                BCC AGAIN        }
Ø211   2Ø  88  FE            JSR QDATFET      – AND THEN THE LAST FOUR DIGITS
Ø214   F8                    SED              – DECIMAL MODE
Ø215   84  1Ø                STY Ƶ D          – CLEAR LEFT DISPLAY
Ø217   A6  21                LDX Ƶ DECH       – X & Y AS DOUBLE ACCUMULATOR
Ø219   98                    TYA
Ø21A   85  21                STA Ƶ DECH       – CLEAR AREA FOR RESULT
Ø21C   A4  2Ø                LDY Ƶ DECL
Ø21E   85  2Ø                STA Ƶ DECL
Ø22Ø   38          NEXT      SEC              }
Ø221   98          ALSO      TYA              }
Ø222   E9  Ø1                SBC #Ø1          } – DO A DECIMAL SUBTRACT, DOUBLE
                                              }   BYTE
Ø224   A8                    TAY              }
Ø225   8A                    TXA              }
Ø226   E9  ØØ                SBC #ØØ          }
Ø228   AA                    TAX
Ø229   BØ  Ø4                BCS NODEC
Ø22B   C6  22                DEC Z DECVH      – LAST OF THE DECIMAL SUBTRACT,
                                                TO DO 5 DIGITS
Ø22D   3Ø  Ø9                BMI RESULT       – IF MINUS THEN FINISHED
Ø22F   E6  2Ø      NODEC     INC Ƶ DECL       – DOUBLE HEX INCREMENT
Ø231   DØ  ED                BNE NEXT
Ø233   E6  21                INC Ƶ DECH
Ø235   38                    SEC              } – CREATE BRANCH ALWAYS, BUT
Ø236   BØ  E9                BCS ALSO         }   DON'T BOTHER TO SET THE CARRY
                                                  TWICE
Ø238   A2  2Ø      RESULT    LDX #2Ø
Ø23A   2Ø  64  FE            JSR QHEXTD       – DISPLAY RESULT
Ø23D   4C  Ø4  FF            JMP RESTART
Ø23F
```

THE HEXADECIMAL TO DECIMAL CONVERTER PROMPTS WITH XXØØØØXX AND AFTER A CONTROL KEY IS PRESSED WILL PROVIDE AN ANSWER IN THE FORM ????????, AFTER A WAIT!
THE PROGRAM WORKS BY DECREMENTING THE HEX. NUMBER AND INCREMENTING THE DECIMAL NUMBER UNTIL THE HEX. NUMBER REACHES ZERO.
THIS PROGRAM, LIKE THE DECIMAL TO HEX. CONVERTER, WHICH USES VIRTUALLY THE SAME METHOD, ILLUSTRATES THE USE OF THE DECIMAL MODE, AN IMPORTANT FACET OF THIS PROCESSOR.
THEY ALSO PROVIDE AN EXCELLENT DEMONSTRATION OF THE TRADEOFF FREQUENTLY FOUND BETWEEN PROGRAM LENGTH AND SIMPLICITY, AND PROGRAM EXECUTION TIME. THE METHOD USED IS BOTH SHORT AND SIMPLE, BUT CAN TAKE UP TO THREE SECONDS FOR SOME CALCULATIONS. A MUCH LONGER AND MORE COMPLEX (RELATIVELY) PROGRAM COULD HAVE BEEN WRITTEN BASED ON ABCD = A(16*16*16)+B(16*16)+C(16)+D AND WOULD HAVE BEEN VIRTUALLY INSTANTANEOUS.

HEX → DEC

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø2ØØ	84 2Ø		STY Ƶ HEXL	– SET UP ZERO PROMPT
Ø2Ø2	84 21		STY Ƶ HEXH	–
Ø2Ø4	A2 2Ø		LDX #HEXL	
Ø2Ø6	2Ø 88 FE		JSR Q DATFET	– AND FETCH THE DATA
Ø2Ø9	F8		SED	– DECIMAL MODE
Ø2ØA	A2 ØØ		LDX #ØØ	– SET X & Y & DECOUT TO ZERO
Ø2ØC	86 22		STX Ƶ DECOUT	
Ø2ØE	A5 2Ø	DECRHEX	LDA Ƶ HEXL	– TEST FOR ZERO, THEN DECREMENT
Ø21Ø	DØ Ø6		BNE NODEL	
Ø212	A5 21		LDA Ƶ HEXH	
Ø214	FØ 13		BEQ DEAD	– IF HEX NO. IS ZERO, THEN FINISHED
Ø216	C6 21		DEC Ƶ HEXH	
Ø218	C6 2Ø	NODEC	DEC Ƶ HEXL	
Ø21A	18		CLC	
Ø21B	98		TYA	
Ø21C	69 Ø1		ADC #Ø1	
Ø21E	A8		TAY	
Ø21F	8A		TXA	ADD 1 TO THE DECIMAL NUMBER,
Ø22Ø	69 ØØ		ADC #ØØ	USING X & Y AS TWO BYTE
Ø222	AA		TAX	ACCUMULATOR
Ø223	9Ø E9		BCC DECRHEX	
Ø225	E6 22		INC Ƶ DECOUT	
Ø227	BØ E5		BCS DECRHEX	
Ø229	84 2Ø	DEAD	STY Ƶ HEXL	– FINISHED, SO STORE X & Y
Ø22B	86 21		STX Ƶ HEXH	
Ø22D	A2 2Ø		LDX #HEXL	
Ø22F	2Ø 64 FE		JSR QHEXTD1	– DISPLAY 4 DIGITS
Ø232	88		DEY	
Ø233	A5 22		LDA Ƶ DECOUT	
Ø235	2Ø 7A FE		JSR HEXTD	– DISPLAY 5 DIGIT
Ø238	4C Ø4 FF		JMP RESTART	
Ø23A				

THE OFFSET CALCULATOR CALCULATES THE OFFSET TO BE ENTERED AS THE SECOND BYTE OF A BRANCH INSTRUCTION. IT WILL PROMPT WITH XX0000XX AND YOU SHOULD ENTER THE ADDRESS OF THE BRANCH INSTRUCTION. AFTER A CONTROL KEY IT WILL PROMPT AGAIN WITH XX1111XX AND YOU SHOULD ENTER THE ADDRESS YOU WISH TO BRANCH TO. THE REPLY WILL BE EITHER "OFFSET XX" WHERE XX IS THE VALUE TO BE ENTERED, OR "TOO FAR" IF THAT IS THE CASE. A CONTROL KEY RESTARTS THE SEQUENCE.

OFFSET CALCULATOR **NOT RELOCATABLE**

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
0200	D8		CLD	
0201	A9 02	AGAIN	LDA #02	
0203	85 21		STA MESSH	– INITIALIZE MESSAGE POINTER
0205	84 22		STY FROMH	– SET UP PROMPT
0207	84 23		STY FROML	
0209	A2 22		LDX #FROML	
020B	20 88 FE		JSR QDATFET	– FETCH FIRST ADDRESS
020E	A9 11		LDA #11	– SET UP 2ND PROMPT
0210	85 24		STA TOL	
0212	85 25		STA TOH	
0214	A2 24		LDX #TOL	
0216	20 88 FE		JSR QDATFET	– FETCH SECOND ADDRESS
0219	A5 22		LDA FROML	– OFFSET TO MAKE OVERLENGTH EASY
021B	E9 7E		SBC #7E	– CARRY KNOWN SET BY QDATFET
021D	85 22		STA FROML	
021F	B0 03		BCS HSUB	– DON'T SET THE CARRY AGAIN!
0221	C6 23		DEC FROMH	
0223	38		SEC	
0224	A5 24	HSUB	LDA TOL	– CALCULATE THE LENGTH
0226	E5 22		SBC FROML	
0228	AA		TAX	
0229	A5 25		LDA TOH	
022B	E5 23		SBC FROMH	
022D	D0 0E		BNE TOOFAR	
022F	A9 51		LDA #51	
0231	20 44 02		JSR MESSAGE	– PRINT OUT
0232	8A		TXA	
0235	49 80		EOR #80	– COMPLEMENT TOP BIT BECAUSE OF THE OFFSET APPLIED
0236	20 60 FE		JSR RDHEXTD	– PRINT OUT ANSWER, OVER WRITING THE
0239	4C 04 FF		JMP RESTART	– FINISHED
023C	A9 57	TOOFAR	LDA #57	– WHOOPS
023E	20 44 02		JSR MESSAGE	– TELL THE PROGRAMMER THAT IT'S WRONG
0241	4C 01 02		JMP AGAIN	– AND GET IT DONE AGAIN
0244	85 20	MESSAGE	STA MESSL	– MESSAGE DESCRIBED BY A
0246	A0 07		LDY #07	– EIGHT BYTES OF DATA TO DISPLAY
0248	B1 20	LOOP	LDA (MESSL), Y	– FETCH THEM
024A	99 10 00		STA D, Y	
024D	88		DEY	
024E	10 F8		BPL LOOP	
0250	60		RTS	
0251	5C 71 71			– THE DATA
0254	ED 79 78			
0257	78 5C 5C			

```
Ø25A    ØØ  71  77
Ø25D    5Ø  ØØ
Ø25F
```

THE RELOCATOR FIRST FETCHES THE THREE ADDRESSES IT REQUIRES, THE ADDRESSES OF THE START & END OF THE MEMORY SECTION TO BE MOVED, AND THE ADDRESS OF THE START OF THE AREA TO WHICH THE MOVE IS TO TAKE PLACE. THE PROMPTS ARE F., & **t** RESPECTIVELY. AFTER TERMINATING THE LAST ADDRESS, THE MOVE TAKES PLACE. MOVES UP BY LESS THAN THE LENGTH OF THE MATERIAL TO BE USED WILL NOT BE SUCCESSFUL (I.E. **t – F** ., IF POSITIVE, SHOULD BE GREATER THAN **–t**)

RELOCATOR

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø2ØØ	A2 F1		LDX #F1	
Ø2Ø2	86 1Ø		STX Ƶ D	– SET UP FROM PROMPT F.
Ø2Ø4	A2 2Ø		LDX #2Ø	
Ø2Ø6	2Ø 88 FE		JSR QDATFET	– AND GET ADDRESS
Ø2Ø9	A2 46		LDX #46	
Ø2ØB	86 1Ø		STX Ƶ D	– SET UP END PROMPT
Ø2ØD	A2 22		LDX #22	
Ø2ØF	2Ø 88 FE		JSR QDATFET	– AND GET SECOND ADDRESS – MOVE THE DATA BETWEEN THESE ADDRESSES
Ø212	A2 78		LDX #78	
Ø214	86 1Ø		STX Ƶ D	– SET UP TO PROMPT
Ø216	A2 24		LDX #24	
Ø218	2Ø 88 FE		JSR QDATFET	– AND GET BASE ADDRESS – MOVE TO HERE & SUCCESSIVE LOCATIONS
Ø21B	A2 1A		LDX #1A	
Ø21D	A1 Ø6	MOVE	LDA (Ø6,X)	– DO THE MOVE
Ø21F	91 24		STA (24,Y)	
Ø221	C8		INY	– INCREMENT THE TO ADDRESS
Ø222	DØ Ø2		BNE NOINC	
Ø224	E6 25		INC Ƶ 25	
Ø226	2Ø AØ FE	NOINC	JSR COM16	– USE COM16 TO DO THE LIMIT TEST
Ø229	DØ F2		BNE MOVE	
Ø22B	4C Ø4 FF		JMP RESTART	
Ø22D				

THE FIRST PROGRAM, TEST, IS TRIVIAL: IT JUST SENDS A PARTICULAR BYTE TO TAPE REPETETIVELY. IT MUST BE STOPPED BY RESET. RECORD A FEW MINUTES OF THIS, THEN LOAD IT USING LOAD. DEVIATIONS FROM THE STATIONARY PATTERN ARE EASY TO SEE. THE SECOND PROGRAM, RETAG, IS RELOCATABLE. IT ACTS JUST LIKE THE MONITOR'S STORE ROUTINE, EXCEPT THAT IT ASKS FOR AN EXTRA ADDRESS. THE DATA WHICH IS STORED IS THAT STARTING AT THIS LAST ADDRESS, IT PRETENDS TO BE SITUATED BETWEEN THE FIRST TWO ADDRESSES. INCORPORATE THE REQUIRED STATE OF ZERO PAGE REGISTERS IN FRONT OF YOUR DATA, THEN 'LOAD AND AUTO RUN' PROGRAMS MAY BE CREATED.

TAPE PROGRAMS **NOT RELOCATABLE**

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø2ØØ	A9 55	TEST	LDA #55	– THE TEST BYTE
Ø2Ø2	2Ø B1 FE		JSR PUTBYTE	– SEND IT
Ø2Ø5	4C ØØ Ø2		JMP TEST	– KEEP SENDING IT
Ø2Ø8	A9 F1	RETAG	LDA #F1	– F. PROMPT
Ø2ØA	85 1Ø		STA D	
Ø2ØC	A2 Ø6		LDX #Ø6	
Ø2ØE	2Ø 88 FE		JSR QDATFET	– FIRST ADDRESS
Ø211	A2 Ø8		LDX #Ø8	
Ø213	86 1Ø		STX D	– PROMPT
Ø215	2Ø 88 FE		JSR QDATFET	– SECOND ADDRESS
Ø218	A9 46		LDA #46	– PROMPT
Ø21A	85 1Ø		STA D	
Ø21C	A2 2Ø		LDX #2Ø	
Ø21E	2Ø 88 FE		JSR QDATFE7	– LAST ADDRESS: ACTUAL DATA START
Ø221	A2 Ø4		LDX #Ø4	
Ø223	B5 Ø5	ADRSS	LDA Ƶ,X Ø5	– SEND FAKE ADDRESSES
Ø225	2Ø B1 FE		JSR PUTBYTE	
Ø228	CA		DEX	
Ø229	DØ F8		BNE ADDRSS	
Ø22B	AØ ØØ	DATAS	LDY #ØØ	
Ø22D	B1 2Ø		LDA (2Ø),Y	– PROPER DATA
Ø22F	E6 2Ø		INC 2Ø	– INCREMENT PROPER DATA COUNTER
Ø231	DØ Ø2		BNE NOINC	
Ø233	E6 21		INC 21	
Ø235	2Ø B1 FE	NOI1NC	JSR PUTBYTE	– SEND DATA
Ø238	2Ø AØ FE		JSR COM16	– CHECK FAKE ADDRESSES FOR END
Ø23B	DØ EE		BNE DATAS	
Ø23D	4C Ø4 FF		JMP RESTART	
Ø24Ø				

THE SCROLL PROGRAM SHIFTS THE WHOLE DISPLAY ONE LEFT, AND ENTERS THE NEW INFORMATION, IN A, ON THE FAR RIGHT.

SCROLL

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø2ØØ	A2 ØØ		LDX #ØØ	– MUST GO FORWARDS
Ø2Ø2	B4 11	LOOP	LDY ƵX D + 1	– PICK-UP DATA ON RIGHT
Ø2Ø4	94 1Ø		STY ƵX D	– & MOVE IT ONE LEFT
Ø2Ø6	E8		INX	

```
ADDR   HEX      LABEL      INSTRUCTION      COMMENTS
       CODE
Ø2Ø7   EØ  Ø7              CPX #Ø7
Ø2Ø9   DØ  F7              BNE LOOP         – KEEP GOING
Ø2ØB   85  17              STA Ƶ D + 7      – NEW DATA
Ø2ØD   6Ø                  RTS.
Ø2ØE
```

GAMES PROGRAMS
1

NIM IS A TRADITIONAL GAME IN WHICH THE PLAYERS ALTERNATIVELY REMOVE STICKS, OR COINS, OR WHATEVER FROM ONE OF SEVERAL STACKS. THE ONLY RULES ARE THAT YOU MUST TAKE AT LEAST ONE PIECE PER MOVE AND THAT YOU CAN ONLY REMOVE PIECES FROM ONE STACK PER MOVE. THERE IS A WELL-DEFINED STRATEGY FOR OPTIMAL PLAY BUT THIS DOES NOT GUARANTEE A WIN UNLESS THE OPPONENT MAKES A MISTAKE OR THE INITIAL SITUATION IS AGAINST HIM. THE COMPUTER PLAYS WELL BUT, WITH LUCK, CAN BE BEATEN. THE WINNER IS THE PLAYER WHO REMOVES THE LAST PIECE

IN THIS VERSION OF THE GAME THERE ARE FOUR STACKS OF FROM Ø–F PIECES. YOU MUST ENTER THE SIZE OF YOUR STACKS IN MEMORY LOCATIONS 2Ø–23 BEFORE STARTING THE GAME. THE GAME STARTS AT ~~ØØ2F~~ AND YOUR MOVE OR ~~Ø18Ø~~ AND THE COMPUTER'S MOVE. ON RUNNING, THE DISPLAY WILL SHOW A· B C D WHERE A,B,C,D ARE THE CONTENTS OF THE STACKS. ANY CONTROL KEY WILL MOVE THE POINTER (FULL STOP) AROUND THE STACKS. WHEN IT POINTS TO THE STACK FROM WHICH YOU WISH TO REMOVE PIECES PRESS THE KEY CORRESPONDING TO THE NUMBER YOU WISH TO REMOVE. ZERO IS ILLEGAL AND WILL NOT BE ALLOWED. IF YOU SUBTRACT MORE PIECES THAN ARE IN THE STACK THE GAME WILL GET VERY CONFUSED.

AFTER REMOVAL OF PIECES THE DISPLAY WILL SHOW THE CURRENT SITUATION AND THE COMPUTER WILL MAKE ITS MOVE.

CONTINUE UNTIL SOMEONE (SOMETHING?) WINS.

YOU MIGHT LIKE TO TRY AND WRITE SUBROUTINES TO PRINT MESSAGES ON THE DISPLAY IN THE EVENT OF EITHER A HUMAN OR COMPUTER VICTORY. A CHECK WOULD HAVE TO BE INSERTED TO DECIDE A COMPUTER WIN BUT THE JUMP FOR A HUMAN WIN IS ALREADY THERE UNDER THE MNEMONIC JMP MESSAGE, THOUGH THE CODE IN FACT JUMPS TO THE HUMAN MOVE.

NIM   NOT RELOCATABLE

```
                                                – CLEAR DECIMAL
Ø2ØØ  2Ø  99  Ø2  HUMMOV    JSR DSPGAP          – DISPLAY STACKS
Ø2Ø3  B5  11      SHIFTPT   LDƵX D + 1          – SET DECIMAL POINT ON
Ø2Ø5  Ø9  8Ø                ORA #8Ø
Ø2Ø7  95  11                STAƵX D + 1
Ø2Ø9  2Ø  ØC  FE  CHEAT     JSR DISPLAY         – WAIT FOR INPUT
Ø2ØC  9Ø  1Ø                BCC MINUS
Ø2ØE  B5  11                LDAƵX D + 1         – REMOVE CURRENT DECIMAL POINT
```

ADDR	HEX CODE			LABEL	INSTRUCTION	COMMENTS
Ø21Ø	29	7F			AND #7F	
Ø212	95	11			STAƵX D + 1	
Ø214	E8				INX	– MOVE FORWARD
Ø215	E8				INX	
Ø216	EØ	Ø7			CPX #Ø7	– END OF STACKS?
Ø218	9Ø	E9			BCC SHIFTPT	
Ø21A	A2	ØØ			LDX #ØØ	
Ø21C	FØ	E5			BEQ SHIFTPT	
Ø21E	A8			MINUS	TAY	
Ø21F	FØ	E8			BEQ CHEAT	– PREVENT ZERO FROM BEING USED
Ø221	8A				TXA	
Ø222	4A				LSRA	– ADDRESS OF REQUIRED STACK
Ø223	AA				TAX	
Ø224	38				SEC	
Ø225	B5	2Ø			LDAƵX STACK	– DO THE PLAYER'S MOVE
Ø227	E5	ØD			SBC KEY	
Ø229	95	2Ø			STAƵX STACK	
Ø22B	2Ø	99	Ø2	COMMOV	JSR DSPGAP	– SHOW STACKS
Ø22E	84	ØE			STY REPEAT	
Ø23Ø	A2	ØØ			LDX #ØØ	
Ø232	2Ø	ØC	FE	WAIT	JSR DISPLAY	– THINKING TIME
Ø235	CA				DEX	
Ø236	DØ	FA			BNE WAIT	
Ø238	CA				DEX	
Ø239	86	ØE			STX REPEAT	– CLEAR REPEAT STATUS
Ø23B	AØ	Ø3			LDY #Ø3	
Ø23D	A2	Ø3		NEXTS	LDX #Ø3	– TRANSFER STACK TO POSS
Ø23F	B5	2Ø		BLOCK	LDAƵX STACK	– POSS REPRESENTS THE POSSIBLE COMPUTER
Ø241	95	24			STAƵX POSS	– MOVES
Ø243	CA				DEX	
Ø244	1Ø	F9			BPL BLOCK	
Ø246	A2	Ø3		ONEOFF	LDX #Ø3	– TRANSFER POSS TO ANAL
Ø248	B5	24		BRICK	LDA2X POSS	– ANAL REPRESENTS THE MOVE BEING
Ø24A	95	28			STA2X ANAL	– ANALYSED
Ø24C	CA				DEX	
Ø24D	1Ø	F9			BPL BRICK	
Ø24F	A2	Ø3			LDX #Ø3	
Ø251	B9	24	ØØ		LDA, Y POSS	
Ø254	38				SEC	
Ø255	E9	~~ØØ~~ Ø1			SBC #Ø1	
Ø257	99	24	ØØ		STA, Y POSS	– POSS CONTAINS POSSIBLE MOVE
Ø25A	99	28	ØØ		STA, Y ANAL	– ANAL CONTAINS POSSIBLE MOVE
Ø25D	BØ	12			BCS CHECK	
Ø25F	88				DEY	
Ø26Ø	1Ø	DB			BPL NEXTS	– TRY ALL STACKS
Ø262	B5	2Ø		TRY	LDAƵX STACK	– CHECK IF STACK EMPTY
Ø264	FØ	Ø5			BEQ EMPTY	
Ø266	D6	2Ø			DECƵX STACK	– MAKE DESPERATE MOVE
Ø268	4C	ØØ	Ø2		JMP HUMMOV	
Ø26B	CA			EMPTY	DEX	
Ø26C	1Ø	F4			BPL TRY	
Ø26E	4C	Ø4	FF		JMP RESTART	– LOST.
Ø271	A9	Ø4		CHECK	LDA #Ø4	
Ø273	85	1F			STA COUNT	
Ø275	A9	ØØ		CONT	LDA #ØØ	– EVALUATE MOVE
Ø277	46	28			LSR ANAL	
Ø279	2A				ROLA	
Ø27A	46	29			LSR ANAL + 1	

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø27C	69 ØØ		ADC #ØØ	
Ø27E	46 2A		LSR ANAL + 2	
Ø28Ø	69 ØØ		ADC #ØØ	
Ø282	46 2B		LSR ANAL + 3	
Ø284	69 ØØ		ADC #ØØ	
Ø286	4A		LSRA	
Ø287	BØ BF		BCS ONEOFF	– NOT A GOOD MOVE
Ø289	C6 1F		DEC COUNT	
Ø28B	DØ E8		BNE CONT	– KEEP CHECKING THE MOVE
Ø28D	A2 Ø3		LDX #Ø3	– GOOD MOVE, TRANSFER TO ACTUAL STACKS
Ø28F	B5 24	BAT	LDAƵX POSS	
Ø291	95 2Ø		STAƵX STACK	
Ø293	CA		DEX	
Ø294	1Ø F9		BPL BAT	
Ø296	4C ØØ Ø2		JMP HUMMOV	– OPPONENT.
Ø299	A9 ØØ	DSPGAP	LDA #ØØ	
Ø29B	A2 Ø7		LDX #Ø7	
Ø29D	95 1Ø	CLEAR	STAƵX D	– CLEAR THE DISPLAY FIRST
Ø29F	CA		DEX	
Ø2AØ	1Ø FB		BPL CLEAR	
Ø2A2	D8		CLD	– CLEAR DECIMAL MODE
Ø2A3	A2 Ø4		LDX #Ø4	– DISPLAY STACKS
Ø2A5	AØ ~~Ø1~~ 07		LDY #Ø1	
Ø2A7	B5 1F	AROUND	LDAƵX STACK –1	
Ø2A9	2Ø 7A FE		JSR HEXTD	
Ø2AC	~~C8~~ 88		INY	
Ø2AD	~~C8~~ 88		INY	
Ø2AE	CA		DEX	
Ø2AF	DØ F6		BNE AROUND	
Ø2B1	~~6Ø~~ A0 1F		RTS	
~~Ø2B2~~				
02B3	60			

2

THE DUCKSHOOT GAME IS A SPEED TEST: YOU HAVE TO SHOOT THE FLYING DUCKS. THEY SUCCESSIVELY ENTER FROM THE RIGHT AND FLY TOWARDS THE LEFT AT A SET SPEED. YOU SHOOT A DUCK BY PRESSING ITS CURRENT POSITION ON THE KEYBOARD. THE LEFT MOST DISPLAY IS Ø, THE RIGHTMOST DISPLAY IS 7. WHEN A DUCK IS HIT IT DIES. THE GAME MAY BE RESTARTED WITH ANY HEX DIGIT KEY

DUCK SHOOT

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø2ØØ	A9 1F	BEGIN	LDA #1F	– SINGLE SCAN DISPLAY ROUTINE
Ø2Ø2	85 ØE		STA Ƶ ØE	
Ø2Ø4	A9 ØØ		LDA #ØØ	– CLEAR THE DISPLAY
Ø2Ø6	A2 Ø7		LDX #Ø7	
Ø2Ø8	86 2Ø		STX Ƶ 2Ø	
Ø2ØA	95 1Ø	CLEAR	STA Ƶ X 1Ø	
Ø2ØC	CA		DEX	
Ø2ØD	1Ø FB		BPL CLEAR	
Ø2ØF	A9 ØØ	REMOVE	LDA #ØØ	– TAKE THE OLD DUCK OFF
Ø211	A6 2Ø		LDX Ƶ 2Ø	

ADDR	HEX CODE			LABEL	INSTRUCTION	COMMENTS
Ø213	95	1Ø			STA Ƶ X 1Ø	
Ø215	A9	61		INSERT	LDA #DUCK	PUT NEW DUCK ON
Ø217	CA				DEX	IN NEW POSITION
Ø218	1Ø	Ø2			BPL OLDX	BUT NOT OVER THE END OF THE DISPLAY
Ø21A	A2	Ø7			LDX #Ø7	
Ø21C	95	1Ø		OLDX	STA Ƶ X 1Ø	
Ø21E	86	2Ø			STX Ƶ 2Ø	
Ø22Ø	A2	ØE			LDX #TIME	DISPLAY INTERVAL IS SET BY THE BYTE LOADED INTO X
Ø222	2Ø	ØC	FE	WAIT	JSR DISPLAY	
Ø225	C5	2Ø			CMP Ƶ 2Ø	HIT?
Ø227	FØ	Ø5			BEQ H1T	
Ø229	CA				DEX	
Ø22A	DØ	F6			BNE WAIT	
Ø22C	FØ	E1			BEQ REMOVE	FINISHED WAIT TIME
Ø22E	A9	1C		HIT	LDA #DEAD DUCK	PUT IN A DEAD DUCK
Ø23Ø	A6	2Ø			LDX Ƶ 2Ø	
Ø232	95	1Ø			STA Ƶ X 1Ø	
Ø234	A9	FF			LDA #FF	
Ø236	85	ØE			STX Ƶ ØE	
Ø238	2Ø	ØC	FE		JSR DISPLAY	TEST FOR CONTINUATION
Ø23B	9Ø	C3			BCC BEGIN	
Ø23D	4C	Ø4	FF		JMP RESTART	OR BACK TO THE MONITOR
Ø23F						

MISCELLANEOUS

1

THE COUNTER PROGRAM COULD BE USED AS A SUBROUTINE IN A LONGER PROGRAM WHEN "JSR INCR" AND "JSR DECR" WOULD INCREMENT OR DECREMENT THE DISPLAY. IF THE PROGRAM APPENDED IS ALSO ENTERED THE DISPLAY WILL INCREASE OR DECREASE RAPIDLY IF "UP" OF "DOWN" KEYS ARE DEPRESSED. THIS WILL BE STOPPED BY ANY HEX KEY. IT WILL INCREMENT BY THE INDICATED AMOUNT IF KEYS 1–F ARE DEPRESSED AND WILL IGNORE ALL OTHER KEYS.

YOU SHOULD PARTICULARLY NOTICE THAT A JSR DISPLAY RETURNS WITH THE CARRY BIT CLEAR AND THE ACCUMULATOR HOLDING THE VALUE OF THE KEY PRESSED FOR THE NUMERICAL KEYS, AND THE CARRY BIT SET AND THE VALUES Ø–7 IN THE ACCUMULATOR FOR THE CONTROL KEYS. IF MEMORY LOCATION ØE, WHICH IS DEDICATED TO THE MONITOR AND SHOULD NOT NORMALLY BE USED IN PROGRAMS, HAS THE MOST SIGNIFICANT BIT CLEAR THEN JSR DISPLAY WILL SCAN ONLY ONCE, IF IT IS SET IT WILL WAIT FOR A KEY TO BE DEPRESSED BEFORE RETURNING TO THE PROGRAM. IT IS A GOOD IDEA TO LOAD IT WITH 'IF' IF YOU WISH TO USE THIS FACILITY AS OTHER VALUES MAY CAUSE YOU DIFFERENT PROBLEMS. AGAIN SEE THE REST OF THIS MANUAL IF YOU REALLY WISH TO UNDERSTAND THE PROCESS.

COUNTER KEYBOARD

```
ADDR  HEX          LABEL     INSTRUCTION      COMMENTS
      CODE
                                              – START OF ØØ1C
ØØ1D  2Ø  ØC  FE   DISP      JSR DISPLAY      – LOOK FOR KEY
ØØ2Ø  9Ø  ØA                 BCC CHANGE       – CHECK IF CONTROL KEY CARRY
                                                SET IF SO
ØØ22  C9  Ø7                 CMP #´Ø7
ØØ24  FØ  1F                 BEQ DOWN
ØØ26  C9  Ø6                 CMP # Ø6
ØØ28  FØ  11                 BEQ UP
ØØ2A  DØ  F1                 BNE DISP
ØØ2C  C9  ØØ       CHANGE    CMP # ØØ
ØØ2E  85  19                 STA COUNT
ØØ3Ø  FØ  ED       MORE      BEQ DISP      }
ØØ32  2Ø  6Ø  ØØ             JSR INCR      }
ØØ35  C6  19                 DEC COUNT     }  INCREMENT NO OF TIME OF TEY
ØØ37  1Ø  F7                 BPL MORE      }
ØØ39  3Ø  E2                 BMI DISP      }
ØØ3B  2Ø  6Ø  ØØ   UP        JSR INCR      }
ØØ3E  2Ø  45  ØØ             JSR ZOOM      }
ØØN                                        }
ØØ41  DØ  CF                 BNE DISP      }  RAPID INCREMENT
ØØ43  FØ  F6                 BEQ UP        }
ØØ45  2Ø  69  ØØ   DOWN      JSR DECR      }
ØØ48  2Ø  4F  ØØ             JSR ZOOM      }
ØØ4B  DØ  D9                 BNE DISP      }  RAPID INCREMENT
ØØ4D  FØ  F6                 BEQ DOWN      }
ØØ4F  A9  1F       ZOOM      LDA #1F
ØØ51  85  ØE                 STA ØE           SET FOR ONE SCAN ONLY
ØØ53  2Ø  ØC  FE             JSR DISPLAY
ØØ56  9Ø  Ø3                 BCC STOP         CHECK IF KEY DEPRESSED CLEAR
                                              IF ONE IS
ØØ58  A9  ØØ                 LDA # ØØ
ØØ5A  6Ø                     RTS
ØØ5B  A9  FF                 LDA # FF         RESET SO THAT JSR DISPLAY
                                              WAITS FOR INPUT
ØØ5D  A9  FF                 LDA # FF
ØØ5D  85  ØE                 STA ØE
ØØ5F  6Ø                     RTS
```

COUNTER SUBROUTINE

```
ADDR  HEX          LABEL     INSTRUCTION      COMMENTS
      CODE

ØØ6Ø  F6  1A       INCR      INC CNTL
ØØ62  DØ  ØD                 BNE UPDATE
ØØ64  E6  1B                 INC CNTH
ØØ66  38                     SEC
ØØ67  BØ  Ø8                 BCS UPDATE
ØØ69  A5  1A       DECR      LDA CNTL
ØØ63  DØ  Ø2                 BNE NOT
ØØ6D  C6  1B                 DEC CNTH
ØØ6F  C6  1A       NOT       DEC CNTL
ØØ71  A2  1A       UPDATE    LDX #IE
ØØ73  2Ø  64  FE             JSR QHEXTD1
ØØ76  6Ø                     RTS
```

3

THE METRONOME PRODUCES A PULSE AT THE TAPE OUTPUT PIN, PA6, WITH A REGULAR PERIOD. THE "UP" AND "DOWN" KEYS WILL INCREASE AND DECREASE THE PERIOD RESPECTIVELY. WITH SUITABLE ADDITIONAL CIRCUITRY THIS COULD DRIVE A LOUDSPEAKER OR A 'STROBE' LIGHT. IN FACT A SMALL SOUND CAN BE OBTAINED BY SIMPLY CONNECTING A LOUD-SPEAKER ACROSS THE TAPE OUTPUT AND EARTH PINS.
THE CONSTANTS USED AT PRESENT MEAN THAT THE PULSE IS OF 1/3ØØ SEC. AND THE DELAY BETWEEN PULSES CAN BE VARIED FROM 1/2Ø SEC. TO ABOUT 13 SECS. YOU CAN DEFINE THE PERIOD BEFORE STARTING THE PROGRAM BY PUTTING THE REQUIRED VALUE INTO MEMORY LOCATION ØØ2Ø. 2Ø WILL GIVE ABOUT 1 SEC BETWEEN PULSES, AND ANYTHING ELSE PROPORTIONATELY MORE OR LESS. ONCE THE PROGRAM IS RUNNING THE 'UP' AND 'DOWN' KEYS WILL INCREMENT AND DECREMENT THE PERIOD BY ABOUT 1/2Ø SEC EACH TIME THEY ARE PRESSED. THEY ALSO RESET THE CYCLE. THIS FACILITY COULD USEFULLY BE USED FOR FINE TUNING BUT WOULD BE TEDIOUS FOR LARGE CHANGES OF PERIOD.

METRONOME

ADDR	HEX CODE	LABEL	INSTRUCTION	COMMENTS
Ø2ØØ	A9 1F		LDA #1F	
Ø2Ø2	85 ØE		STA REPEAT	– SET DISPLAY TO SINGLE SCAN
Ø2Ø4	A9 4Ø	PULSE	LDA #4Ø	
Ø2Ø6	8D 22 ØE		STA 1ADDR	– DEFINE PA6 AS OUTPUT
Ø2Ø9	8D 16 ØE		STA SET PIA6	– USE INS8154 SET BIT MODE
Ø2ØC	2Ø CD FE		JSR WAIT	– USE THE 3ØØ BAND WAIT
Ø2ØF	8D Ø6 ØE		STA CLR PIA6	– USE IN58154 CLEAR BIT MODE
Ø212	A6 2Ø		LDXZ PERIOD	
Ø214	2Ø ØC FE	DELZ	JSR DISPLAY	– LOOK AT KEYBOARD
Ø217	C9 16		CMP #16	– UP KEY?
Ø219	DØ Ø4		BNE DOWN	– NO
Ø21B	E6 2Ø		INCZ PERIOD	– INCREASE PERIOD
Ø21D	BØ E5		BCS PULSE	– CARRY WAS SET BY THE COMPARE: ALWAYS
Ø21F	C9 17	DOWN	CMP #17	– DOWN KEY?
Ø221	DØ Ø4		BNE DELI	– NO
Ø223	C6 2Ø		DECZ PERIOD	– DECREASE PERIOD
Ø225	BØ DD		BCS PULSE	– CARRY WAS SET BY THE COMPARE: ALWAYS
Ø227	AØ ØC	DELI	LDY #ØC	– CYCLE TIME OF µ½Ø SEC.
Ø229	2Ø CD FE	DELJ	JSR WAIT	
Ø22C	88		DEY	
Ø22D	1Ø FA		BPL DELJ	
Ø22F	CA		DEX	
Ø23Ø	DØ E2		BNE DEL2	
Ø232	FØ DØ		BEQ PULSE	– END OF THIS PERIOD SO PULSE
Ø234				

4

THE EIGHT QUEENS PROBLEM IS TO FIND THE NUMBER OF WAYS IN WHICH EIGHT QUEENS MAY BE PLACED ON A CHESS BOARD WITHOUT ATTACKING EACH OTHER. THE PROGRAM FINDS 92 WAYS SINCE IT COUNTS ROTATIONS AND REFLECTIONS, ALL POSSIBLE POSITIONS ARE TRIED AS SOLUTIONS IN THIS HIGH SPEED RECURSIVE (I.E. IS DEFINED IN TERMS OF ITSELF)

PROGRAM. THE STRATEGY OF THE PROGRAM IS NOT OBVIOUS, AND IS LEFT AS AN EXERCISE TO THE READER. A SMALL PRIZE WILL REWARD THE SUBMISSION OF A SHORTER, FASTER PROGRAM; NOTE THAT WORKSPACE REQUIREMENTS CONTRIBUTE TO THE LENGTH!

8 QUEENS PROGRAM

```
Ø2ØØ  F8             MAIN     SED
Ø2Ø1  A2  2Ø                  LDX #2Ø
Ø2Ø3  84  1F                  STY COUNT      – CLEAR COUNT
Ø2Ø5  84  2Ø                  STY ROW        – CLEAR ROW OCCUPIED
Ø2Ø7  84  29                  STY LEFT       – CLEAR LEFT DIAGONAL ATTACKS
Ø2Ø9  84  32                  STY RIGHT      – CLEAR RIGHT DIAGONAL ATTACKS
Ø2ØB  2Ø  16  Ø2              JSR TRY        – FIND THE NO OF WAYS
Ø2ØE  A5  1F                  LDA COUNT
Ø21Ø  2Ø  6Ø  FE              JSR RDHEXTD    – DISPLAY ANSWER
Ø213  4C  Ø4  FF              JMP RESTART
Ø216  B5  ØØ         TRY      LDAƵX ØØ       – FINISHED YET?
Ø218  C9  FF                  CMP #FF
Ø21A  DØ  Ø7                  BNE CONTINUE
Ø21C  A5  1F                  LDA COUNT      – FINISHED, SO INCREMENT COUNT
Ø21E  69  ØØ                  ADC #ØØ
Ø22Ø  85  1F                  STA COUNT
Ø222  6Ø             FINISH   RTS
Ø223  15  Ø9                  ORAƵX Ø9       – CURRENT LEFT
Ø225  15  12                  ORAƵX 12       – CURRENT RIGHT
Ø227  A8             LOOP     TAY
Ø228  49  FF                  EOR #FF
Ø22A  FØ  F6                  BEQ FINISH     – NO CHANCE
Ø22C  95  1B                  STAƵX 1B       – CURRENT POSSIBLE PLACE
Ø22E  C8                      INY
Ø22F  98                      TAY
Ø23Ø  35  1B                  ANDƵX 1B
Ø232  A8                      TYAY
Ø233  15  ØØ                  CRAƵX ØØ
Ø235  95  Ø1                  STAƵX Ø1       – NEW ROW
Ø237  98                      TYA
Ø238  15  Ø9                  ORAƵX Ø9
Ø23A  ØA                      ASLA
Ø23B  95  ØA                  STAƵX ØA       – NEW LEFT ATTACK
Ø23D  98                      TYA
Ø23E  15  12                  ORAƵX 12
Ø24Ø  4A                      LSRA
Ø241  95  13                  STAƵX 13       – NEW RIGHT ATTACK
Ø243  E8                      INX
Ø244  2Ø  16  Ø2              JSR TRY
Ø247  CA                      DEX
Ø248  B5  Ø1                  LDAƵX Ø1
Ø24A  49  FF                  EOR #FF
Ø24C  35  1B                  ANDƵX 1B
Ø24E  49  FF                  EOR #FF
Ø25Ø  4C  27  Ø2              JMP LOOP
Ø253
```

APPENDIX A
64 CHARACTER ASCII ON ACORN'S 7 SEGMENT DISPLAY

ASCII CODE	DISPLAY	CHARACTER	HEX	ASCII CODE	DISPLAY	CHARACTER	HEX
Ø		@	5F	2Ø			ØØ
1		A	77	21		!	86
2		B	7C	22		"	22
3		C	58	23		#	63
4		D	5E	24		£	3B
5		E	79	25		%	2D
6		F	71	26		&	7B
7		G	3D	27		'	Ø2
8		H	34	28		(	B9
9		I	Ø5	29		)	8F
A		J	ØD	2A		*	76
B		K	75	2B		+	42
C		L	38	2C		,	Ø4
D		M	37	2D		–	4Ø
E		N	54	2E		.	8Ø
F		0	5C	2F		/	52
1Ø		P	73	3Ø		Ø	3F
11		Q	67	31		1	Ø6
12		R	5Ø	32		2	5B
13		S	ED	33		3	4F
14		T	78	34		4	66
15		U	9C	35		5	6D
16		V	1C	36		6	7D
17		W	7E	37		7	Ø7
18		X	49	38		8	7F
19		Y	6E	39		9	6F
1A		Ƶ	BD	3A		:	82
1B		[	39	3B		;	84
1C		\	64	3C		⟨	46
1D		]	ØF	3D		=	48
1E		Λ	23	3E		⟩	7Ø
1F		–	Ø8	3F		?	D3

APPENDIX B INSTRUCTION SET

I ACCUMULATOR REFERENCE: ACCUMULATOR, OPERATION, MEMORY → ACCUMULATOR

MNEMONIC	VERBAL	ADDRESSING MODE	IMMED	ZERO	Z,X	ABSOLUTE	A,X	A,Y	(I,X)	(I),Y	
		FLAGS IN P AFFECTED	2 2	2 3	2 4	3 4	3 4+	3 4+	2 6	2 5+	BYTES CYCLES = SPEED μS
ADC	ADD WITH CARRY	NZCV	69	65	75	6D	7D	79	61	71	A + M + C → A
AND	LOGICAL AND	NZ	29	25	35	2D	3D	39	21	31	A → M → A
CMP	LOGICAL COMPARE	NZC	C9	C5	D5	CD	DD	D9	C1	D1	A – M
EOR	LOGICAL EXCLUSIVE OR	NZ	49	45	55	4D	5D	59	41	51	A V M → A
LDA	LOAD ACCUMULATOR	NZ	A9	A5	B5	AD	BD	B9	A1	B1	M → A
ORA	LOGICAL OR	NZ	Ø9	Ø5	15	ØD	1D	19	Ø1	11	A V M → A
SBC	SUBTRACT WITH BORROW/CARRY	NZCV	E9	E5	F5	ED	FD	F9	E1	F1	A – M + C → A
STA	STORE ACCUMULATOR		–	85	95	8D	9D	99	81	91	A → M

II RELATIVE: RELATIVE ADDRESSING MODE

2 BYTES 2+† CYCLES

MNEMONIC	VERBAL		
BCC	BRANCH IF CARRY CLEAR	9Ø	BRANCH IF C = Ø
BCS	BRANCH IF CARRY SET	BØ	C = 1
BEQ	BRANCH IF EQUAL (TO ZERO)	FØ	Ƶ = 1
BMI	BRANCH IF MINUS	3Ø	N = 1
BNE	BRANCH IF NOT EQUAL	DØ	Ƶ = Ø
BPL	BRANCH IF PLUS	1Ø	N = Ø
BVC	BRANCH IF OVERFLOW CLEAR	5Ø	V = Ø
BVS	BRANCH IF OVERFLOW SET	7Ø	V = 1

III IMPLIED. SINGLE BYTE WITH NO ADDRESS MODE

MNEMORIC	VERBAL	FLAGS		TIME		
ASLA	ARITHMETIC SHIFT LEFT A	NZC	ØA	2	C ← [A] ← Ø BINARY X 2	ALSO KNOWN AS ACCUMULATOR ADDRESS MODE
BRK	BREAK	B	ØØ	7	1 → B then on IRQ	ALSO KNOWN AS 'SOFTWARE INTERRUPT'
CLC	CLEAR CARRY FLAG	C	18	2	Ø → C	
CLD	CLEAR DECIMAL MODE	D	D8	2	Ø → D	– OPERATE IN BINARY ARITH.
CLI	CLEAR INTERRUPT DISABLE	I	58	2	Ø → I	– ALLOWS INTERRUPTS
CLV	CLEAR OVERFLOW	V	B8	2	Ø → V	
DEX	BINARY DEC X	NZ	CA	2	X – 1 → X	
DEY	BINARY DEC Y	NZ	88	2	Y – 1 → Y	
INX	BINARY INC X	NZ	E8	2	X + 1 → X	
INY	BINARY INC Y	NZ	C8	2	Y + 1 → Y	
LSRA	LOGICAL SHIFT RIGHT A	NZC	4A	2	Ø → [A] → C (Ø→N) BINARY ÷ 2	– ACCUMULATOR ADDRESSING
NOP	NO OPERATION		EA	2		
PHA	PUSH A		48	3	A → Ø1ØØ + S ; S – 1 → S	
PHP	PUSH PROCESSOR STATUS		Ø8	3	P → Ø1ØØ + S ; S – 1 → S	
PLA	PULL A	NZ	68	4	S + 1 → S Ø1ØØ + S → A	
PLP	PULL PROCESSOR STATUS	ALL	28	4	S + 1 → S Ø1ØØ + S → P	
ROLA	ROTATE LEFT A	NZC	2A	2	C ← [A] ← C	–'ACCUMULATOR ADDRESSING'
RORA	ROTATE RIGHT A	NZC	6A	2	C → [A] → C	–'ACCUMULATOR ADDRESSING'
RTI	RETURN FROM INTERRUPT	ALL	4Ø	6	S + 1 → S Ø1ØØ + S → P S + 1 → S Ø1ØØ + S → PCL S + 1 → S Ø1ØØ + S → PCH	– RTI executes the opcode obtained by pulling PC, but RTS steps PC to PC+1 and executes that opcode.
RTS	RETURN FROM SUBROUTINE		6Ø	6	S + 1 → S Ø1ØØ + S → PCL S + 1 → S Ø1ØØ + S → PCH	–OPPORTUNITY FOR A PHP ON ENTRY & AN RTI ON EXIT
TAX	TRANSFER A TO X	NZ	AA	2	A → X	
TAY	TRANSFER A TO Y	NZ	A8	2	A → Y	
TSX	TRANSFER S TO X	NZ	BA	2	S → X	
TXA	TRANSFER X TO A	NZ	8A	2	X → A	
TXS	TRANSFER X TO S	NZ	9A	2	X → S	
TYA	TRANSFER Y TO A	NZ	98	2	Y → A	

IV REGISTERS OTHER THAN ACCUMULATOR

MNEMONIC	VERBAL	FLAGS	ADDRESSING MODE	IMMED	ZERO	Z,X	Z,Y	ABSOLUTE	A,X	A,Y	INDIRECT	
				2 2	2 3	2 4	2 4	3 4	3 4+	3 4+	3 5	BYTES TIME
BIT	LOGICAL AND WITH MASK AND TEST BITS	NƵV		—	24	—	—	2C	—	—	—	A ∧ M → Ƶ, M_6 → V, M_7 → N
CPX	COMPARE X	NƵC		EØ	E4	—	—	EC	—	—	—	X – M
CPY	COMPARE Y	NƵC		CØ	C4	—	—	CC	—	—	—	Y – M
JMP	JUMP	—		—	—	—	—	4C	—	—	6C	M → PCL M + 1 → PCH
LDX	LOAD X REGISTER	NƵ		A2	A6	—	B6	AE	—	BE	—	M → X
LDY	LOAD Y REGISTER	NƵ		AØ	A4	B4	—	AC	BC	—	—	M → Y
STX	STORE X REGISTER			—	86	—	96	8E	—	—	—	X → M
STY	STORE Y REGISTER			—	84	94	—	8C	—	—	—	Y → M

V READ — MODIFY — WRITE

MNEMONIC	VERBAL	FLAGS	ADDRESSING MODE	ZERO	Ƶ,X	ABS	A,X	
				2 5	2 6	3 6	3 7	BYTES TIME
ASL	ARITHMETIC SHIFT LEFT	NƵC		Ø6	16	ØE	1E	C ← [A] ← Ø
DEC	BINARY DECREMENT	NƵ		C6	D6	CE	DE	M – 1 → M
INC	BINARY INCREMENT	NƵ		E6	F6	EE	FE	M + 1 → M
LSR	LOGICAL SHIFT RIGHT	NƵC		46	56	4E	5E	C Ø→ [M] (Ø → N)
ROL	ROTATE LEFT	NƵC		26	36	2E	3E	C ← [M]
ROR	ROTATE RIGHT	NƵC		66	76	6E	7E	C → [M]

+ : EXTRA CYCLE IF OPERATION INVOLVES PAGE CROSSING
+†: + Ø IF NO BRANCH; + 1 IF BRANCH; + 2 IF BRANCH & CROSS PAGE

ST DIGIT

2ND DIGIT

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	
0	BRK.	ORD (I,X)				ORA ZERO	ASL ZERO		PHP	ORA IMMED	ASLA			ORA ASOLUTE	ASL ABSOLUTE		0
1	BPL	ORD (I),Y				ORD Z,X	ASL Z,X		CLC	ORA A,Y				ORA A,X	ASL A,X		1
2		AND (I,X)			BIT ZERO	AND ZERO	ROL ZERO		PLP	AND IMMED	ROLA		BIT ABSOLUTE	AND ABSOLUTE	ROL ABSOLUTE		2
3	BMI	AND (I),Y				AND Z,X	ROL Z,X			AND A,Y				AND A,X	ROL A,X		3
4	RTI	EOR (I,X)				EOR ZERO	LSR ZERO		PHA	EOR IMMED			JMP ABSOLUTE	EOR ABSOLUTE	LSR ABSOLUTE		4
5	BVC	EOR (I),Y				EOR Z,X	LSR Z,X		CLI	EOR A,Y	LSRA			EOR A,X	LSR A,X		5
6	RTS	ADC (I,X)				ADC ZERO	FOR ZERO		PLA	ADC IMMED	RORA		JMP INDIRECT	ADC ABS	ROR ABSOLUTE		6
7	BVS	ADC (I),Y				ADC Z,X	ROR Z,X			ADC A,Y				ADC A,X	ROR A,X		7
8		STA (I,X)			STY ZERO	STA ZERO	STX ZERO		DEY	STA A,Y	TXA		STY ABSOLUTE	STA ABSOLUTE	STX ABSOLUTE		8
9	BCC	STA (I),Y			STY Z,X	STA Z,X	STX Z,Y		TYA		TXS			STA A,X			9
A	LDY IMMED	LDA (I,X)	LDX IMMED		LDY ZERO	LDA ZERO	LDX ZERO		TAY	LDA IMMED	TAX		LDY ABSOLUTE	LDA ABSOLUTE	LDX ABSOLUTE		A
B	BCS	LDA (I),Y			LDY Z,X	LDA Z,X	LDX Z,Y		CLV	LDA A,Y	TSX		LDY A,X	LDA A,X	LDX A,Y		B
C	CPY IMMED	CMP (I,X)			CPY ZERO	CMP ZERO	DEC ZERO		INY	CMP IMMED	DEX		CPY ABSOLUTE	CMP ABSOLUTE	DEC ABSOLUTE		C
D	BNE	CMP (I),Y				CMP Z,X	DEC Z,X		CLD	CMP A,Y				CMP A,X	DEC A,X		D
E	CPX IMMED	SBC (I,X)			CPX ZERO	SBC ZERO	INC ZERO		INX	SBC IMMED	NOP		CPX ABSOLUTE	SBC ABSOLUTE	INC ABSOLUTE		E
F	BEQ	SBC (I),Y				SBC Z,X	INC Z,X			SBC A,Y				SBC A,X	INC A,X		F
	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	

DISSASSEMBLY CHART

APPENDIX C HEXADECIMAL TO DECIMAL

1st DIGIT / 2nd DIGIT

	Ø	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
Ø	Ø	1	2	3	4	5	6	7	8	9	1Ø	11	12	13	14	15
1	16	17	18	19	2Ø	21	22	23	24	25	26	27	28	29	3Ø	31
2	32	33	34	35	36	37	38	39	4Ø	41	42	43	44	45	46	47
3	48	49	5Ø	51	52	53	54	55	56	57	58	59	6Ø	61	62	63
4	64	65	66	67	68	69	7Ø	71	72	73	74	75	76	77	78	79
5	80	81	82	83	84	85	86	87	88	89	9Ø	91	92	93	94	95
6	96	97	98	99	1ØØ	1Ø1	1Ø2	1Ø3	1Ø4	1Ø5	1Ø6	1Ø7	1Ø8	1Ø9	11Ø	111
7	112	113	114	115	116	117	118	119	12Ø	121	122	123	124	125	126	127
8	128	129	13Ø	131	132	133	134	135	136	137	138	139	14Ø	141	142	143
9	144	145	146	147	148	149	15Ø	151	152	153	154	155	156	157	158	159
A	16Ø	161	162	163	164	165	166	167	168	169	17Ø	171	172	173	174	175
B	176	177	178	179	18Ø	181	182	183	184	185	186	187	188	189	19Ø	191
C	192	193	194	195	196	197	198	199	2ØØ	2Ø1	2Ø2	2Ø3	2Ø4	2Ø5	2Ø6	2Ø7
D	2Ø8	2Ø9	21Ø	211	212	213	214	215	216	217	218	219	22Ø	221	222	223
E	224	225	226	227	228	229	23Ø	231	232	233	234	235	236	237	238	239
F	24Ø	241	242	243	244	245	246	247	248	249	25Ø	251	252	253	254	255

HEX	DEC
1ØØ	256
2ØØ	512
4ØØ	1Ø24
8ØØ	2Ø48
1ØØØ	4Ø96
2ØØØ	8192
4ØØØ	16384
8ØØØ	32768
1ØØØØ	65536

APPENDIX D ACORN MONITOR ADDRESS INFORMATION

ADDRESS	LABEL	COMMENT
ØØØØ,ØØØ1	MAP	LOW AND HIGH BYTES OF THE M ADDRESS
ØØØ2,ØØØ3	GAP	LOW AND HIGH BYTES OF THE GO ADDRESS
ØØØ4,ØØØ5	PAP	LOW AND HIGH BYTES OF THE BREAKPOINT ADDRESS
ØØØ6,ØØØ7	FAP	LOW AND HIGH BYTES OF THE TAPE FROM ADDRESS
ØØØ8,ØØØ9	TAP	LOW AND HIGH BYTES OF THE TAPE TO ADDRESS
ØØØA	RØ	REGISTER Ø: CONTAINS A AFTER BREAK.
ØØØB	R1	REGISTER 1: CONTAINS X AFTER BREAK.
ØØØC	R2	REGISTER 2: CONTAINS Y AFTER BREAK.
ØØØD	R3, KEY	REGISTER 3: TEMPORARILY P AFTER BREAK, CONTAINS LAST PRESSED KEY FOR DISPLAY
ØØØE	REPEAT	MSB=1 SETS REPEATEDLY SCANNED DISPLAY, OTHERWISE SINGLE SCAN.
ØØØF	EXEC	EXECUTION STATUS OF THE KEY PROCESSING ROUTINE

ØØ1Ø	D,R4	BASE ADDRESS OF THE EIGHT DISPLAYED MEMORY LOCATIONS, REGISTER 4: TEMPORARILY PCH AFTER BREAK.
ØØ11	R5	REGISTER 5: TEMPORARILY PCL AFTER BREAK
ØØ12	R6	REGISTER 6: TEMPORARILY Ø1 AFTER BREAK
ØØ13	R7	REGISTER 7: TEMPORARILY S AFTER BREAK.
ØØ14-ØØ17		LAST 4 DISPLAYED MEMORY LOCATIONS.
ØØ18	P	SINGLE LEVEL OF STORAGE FOR PREVIOUS DATA AT BREAK POINTS.
ØØ19	COL	COLUMN OF KEY CURRENTLY BEING PROCESSED
ØØ1A	TX,TY	TEMPORARY STORAGE FOR X (IN DISPLAY) OR Y (VARIOUS PLACES).
ØØ1C,ØØ1D	USERNMI	ADDRESS OF USER'S NMI PROGRAM
ØØ1E,ØØ1F	USERIRQ	ADDRESS OF USER'S IRQ PROGRAM
ØØ1B	RECAL	CONTAINS PC RECALCULATION FACTOR FOR BREAK
FEØØ	QUAD	DISPLAY X–3,X–2,X–1,X ON THE DISPLAY; THEN ↓
FEØC	DISPLAY	STROBE KEYBOARD, MULTIPLEX DISPLAY, RETURN WITH KEY INFORMATION
FE5E	MHEXTD	DISPLAY A MEMORY BYTE ON RIGHT OF DISPLAY
FE6Ø	RDHEXTD	DISPLAY A ON RIGHT OF DISPLAY
FE64	QHEXTD1	DISPLAY X & X+1 ON DISPLAYS 1,2,3 & 4
FE66	QHEXTD2	DISPLAY X & X+1 ON DISPLAYS Y–2,Y–1, Y & Y+1
FE6F	DHEXTD	DISPLAY A ON DISPLAYS Y & Y+1
FE7A	HEXTD	DISPLAY BOTTOM 4 BITS OF A ON DISPLAY Y
FE88	QDATFET	FETCH AN ADDRESS INTO LOCATIONS X & X+1
FEAØ	COM16	INCREMENT & COMPARE TWO 16 BIT NOS X+6,X+7 & X+8,X+9
FEA6	NOINC	COMPARE X+6,X+7 & X+8,X+9 FOR EQUALITY
FEB1	PUTBYTE	A TO TAPE, DO 1 START & 1 STOP BITS, NO PARITY
FECD	WAIT	WAIT FOR CASSETTE TIMING
FEDØ	½ WAIT	HALT THE WAIT
FEDD	GETBYTE	TAPE TO A, WAIT FOR START BIT, CENTRE TIMING
FEF3	RESET	ENTRY TO MONITOR
FFØ4	RESTART	RE-ENTRY TO RUNNING MONITOR
FFB3	BREAK	ENTRY TO MONITOR FROM BRK INSTRUCTION, DISPLAY CPU
FFEA	FONT	SEVEN SEGMENT PICTURES OF THE HEX DIGITS
ØØIF	RECAL	CONTAINS PC RECALCULATION FACTOR FOR BREAK

GLOSSARY

- ACCUMULATOR: 8-BIT CENTRAL REGISTER IN THE MICROPROCESSOR. MOST INFORMATION HAS TO GO THROUGH IT.
- ADDRESS: 16 BIT POINTER TO A MEMORY LOCATION. THE 6502 MICRO-PROCESSOR CAN ADDRESS 65, 536 SUCH LOCATIONS (WHICH IS 2^{16}).
- ARITHMETIC LOGIC UNIT (A.L.U.): A SECTION OF THE MICROPROCESSOR WHICH CARRIES OUT ARITHMETIC (ADDITION, SUBTRACTION, INCREMENT, DECREMENT & COMPARE) AND LOGIC ("AND", "EOR", "OR", & BIT SHIFTS) MANIPULATIONS. THIS IS THE ONLY PART OF THE MICROPROCESSOR WHICH ALTERS DATA.
- COMMAND: THE MONITOR FUNCTIONS M,G,P,R,L,S,↑,↓.
- DATA: INFORMATION FOR THE PROCESSOR THAT DOES NOT HAVE TO BE TRANSLATED. e.g. "AD" AS DATA ACTUALLY MEANS $10x16+13x1 = 173_{10}$ WHEREAS THE INSTRUCTION "AD" GETS TRANSLATED INTO THE OPERATION "LOAD ACCUMULATOR ABSOLUTE".
- EPROM: ERASABLE PROGRAMMABLE READ ONLY MEMORY. THIS TYPE OF MEMORY IS LIKE A PROM, BUT CAN AGAIN BE ERASED BY EXPOSING THE CHIP TO ULTRAVIOLET LIGHT.
- FLAGS: ONE BIT INTERNAL REGISTERS. ALL SEVEN FLAGS CAN ALSO BE TREATED AS SEPARATE BITS OF THE P REGISTER (PROCESSOR STATUS).
- INDEX REGISTER: A REGISTER WHICH CAN BE USED TO MODIFY AN ADDRESS (USED IN REFERRING TO DATA) BY BEING ADDED TO IT, THUS ACCESSING A CERTAIN ELEMENT OF A TABLE. THE 6502 HAS TWO INDEX REGISTERS CALLED X & Y.
- INSTRUCTION: A FUNCTION OF THE MICROPROCESSOR LIKE LOAD AND STORE.
- I/0: INPUT/OUTPUT. THIS CHIP ALLOWS YOU TO COMMUNICATE WITH THE OUTSIDE WORLD. IN THE ACORN THE I/0 CHIP HAS 16 PROGRAMMABLE LINES WHICH CAN EITHER BE OUTPUTS OR INPUTS. IT ALSO HAS 128 BYTES OF RAM.
- IRQ: INTERRUPT REQUEST. IF FLAG I (INTERRUPT DISABLE) IS CLEAR AND A REQUEST IS MADE THE PROCESSOR WILL ATTEND TO IT AFTER SETTING FLAG I AND STORING THE PROGRAM COUNTER AND STATUS REGISTER.
- JUMP: THE PROGRAM COUNTER IS LOADED WITH A NEW ADDRESS. THE EXECUTION OF THE PROGRAM, WHICH IS NORMALLY USING CONSECUTIVE ADDRESSES, CONTINUES (JUMPS) AT THIS NEW ADDRESS.
- LOAD: TRANSFERS THE DATA OF A MEMORY LOCATION TO AN INTERNAL REGISTER.
- MNEMONIC: SUGGESTIVE ABBREVIATION OF AN INSTRUCTION e.g. THE INSTRUCTION "LOAD ACCUMULATOR ABSOLUTE" HAS THE MNEMONIC "LDA".
- NMI: NON MASKABLE INTERRUPT WHEN THE NON MASKABLE INTERRUPT IS ACTIVATED THE PROCESS WILL SET FLAG I, STORE AWAY ITS PROGRAM COUNTER AND STATUS REGISTER AND THEN IMMEDIATELY ATTEND TO THE INTERRUPT. THERE IS NO WAY OF PREVENTING THIS INTERRUPT. IT HAS PRIORITY OVER IRQ.
- OPCODE: HEXADECIMAL REPRESENTATION OF AN INSTRUCTION. e.g. THE INSTRUCTION "LOAD ACCUMULATOR ABSOLUTE" HAS THE MNEMONIC "LDA" AND THE OPCODE "AD".

- PROGRAM COUNTER: 16 BIT REGISTER WHICH CONTAINS THE ADDRESS OF THE INSTRUCTION BEING EXECUTED. DURING EXECUTION THE PROGRAM COUNTER IS STEPPED UP TO POINT AT THE NEXT INSTRUCTION.
- PROM: PROGRAMMABLE READ ONLY MEMORY. THIS TYPE OF MEMORY ARRIVES BLANK. IT CAN BE PROGRAMMED BY THE USER WITH THE HELP OF A SPECIAL PROM BLOWER. ONCE THIS PROGRAM HAS BEEN PUT IN, IT CANNOT BE CHANGED.
- RAM: RANDOM ACCESS MEMORY. THIS IS THE STANDARD READ/WRITE MEMORY. DATA (AND PROGRAMS) ARE LOST WHEN THE POWER IS SWITCHED OFF.
- REGISTER: STORAGE LOCATION IN THE MICROPROCESSOR ITSELF. THERE ARE INTERNAL REGISTERS A, X, Y, PC, S, P.
- ROM: READ ONLY MEMORY. THIS IS MEMORY THAT HAS A PROGRAM PUT IN DURING PRODUCTION. THIS PROGRAM CANNOT EVER BE CHANGED, IT CAN ONLY BE READ.
- STORE: TRANSFERS DATA FROM AN INTERNAL REGISTER TO MEMORY.
- XTAL: THE CRYSTAL IN THE ACORN OSCILLIATES AT 1 MHZ. i.e. ONE MILLION TIMES A SECOND. IT DOES THIS WITH GREAT ACCURACY. SO YOU CAN BUILD A CLOCK FROM YOUR ACORN.

ACORN COMPUTER
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