

ARCHITECTURE, PACKAGING  
AND APPLICATIONS OF THE FIRST  
ELECTRONIC HOME COMPUTER:

ECHO-IV  
ELECTRONIC COMPUTING HOME OPERATOR  
1966-1975

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JAY SUTHERLAND

20 FEBRUARY 1997

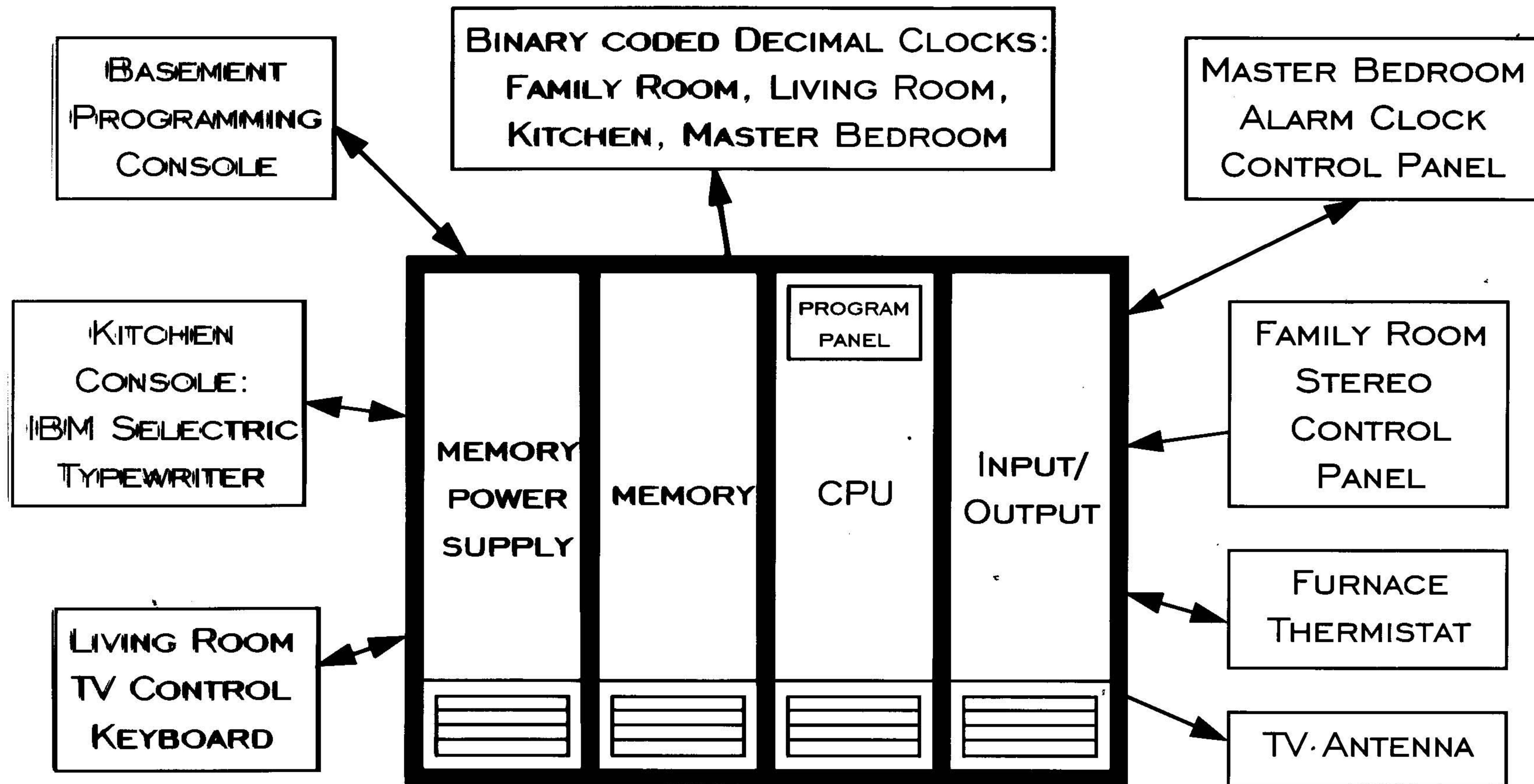
# EARLY HISTORY OF ELECTRONIC HOME COMPUTERS

- AMATEUR COMPUTER SOCIETY (ACS) FOUNDED MAY 1966 (70 MEMBERS BY END OF YEAR)
- SURVEY RESULTS FROM JANUARY 1968 ACS NEWSLETTER REPORTED ONLY TWO WORKING HOME COMPUTERS
  - ECHO-IV ELECTRONIC HOME COMPUTER (JIM SUTHERLAND)
  - EL-65 PROGRAMMABLE DESKTOP CALCULATOR (HANS ELLENBERGER)
- ECHO-IV RECOGNIZED AS FIRST ELECTRONIC HOME COMPUTER (OPERATIONAL APRIL 14, 1966) BY
  - IEEE ANNALS OF COMPUTING HISTORY (FALL 1994)
  - THE COMPUTER MUSEUM, BOSTON, MA (FALL/WINTER 1985 REPORT)

## ECHO-IV BEGINNINGS

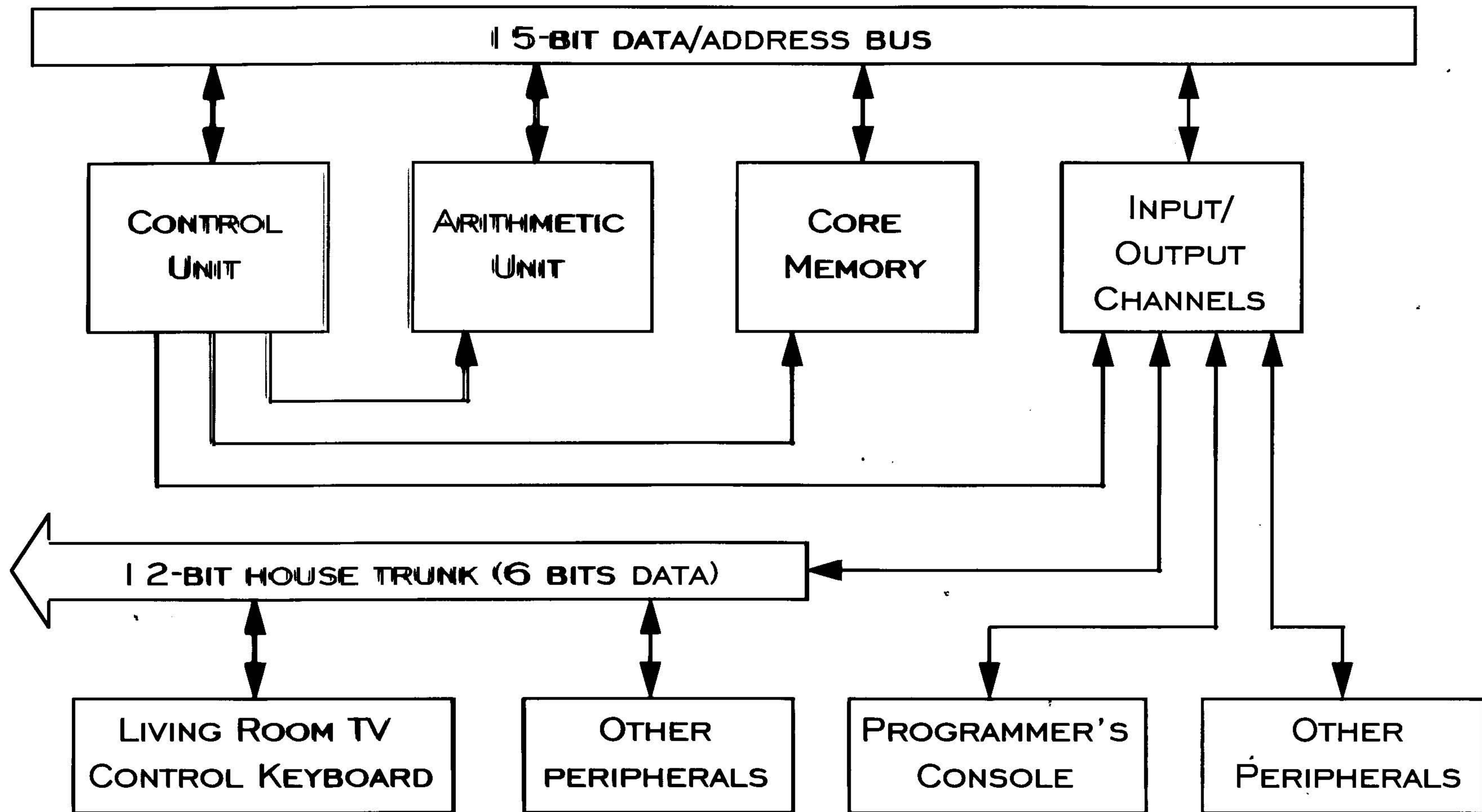
- **1959:** WESTINGHOUSE PURCHASES AMPEX CORE MEMORY FOR US IN THEIR PRODAC-X PROCESS CONTROL COMPUTER PROTOTYPE
- **1961:** PRODAC-X'S ARE DELIVERED TO CUSTOMERS FOR ON SITE TESTS AND OPERATION
- **1965:** PRODAC-X IS UPGRADED, WITH ALL PARTS RETURNED TO WESTINGHOUSE IN PITTSBURGH, PA
- **1965:** WESTINGHOUSE LOANS CORE MEMORY UNIT, POWER SUPPLIES AND PC CARDS TO JIM SUTHERLAND FOR EXPERIMENTAL USE
- **1966:** ECHO-IV DESIGNED, BUILT, AND IN OPERATION AT HOME

# ECHO-IV SYSTEM DIAGRAM

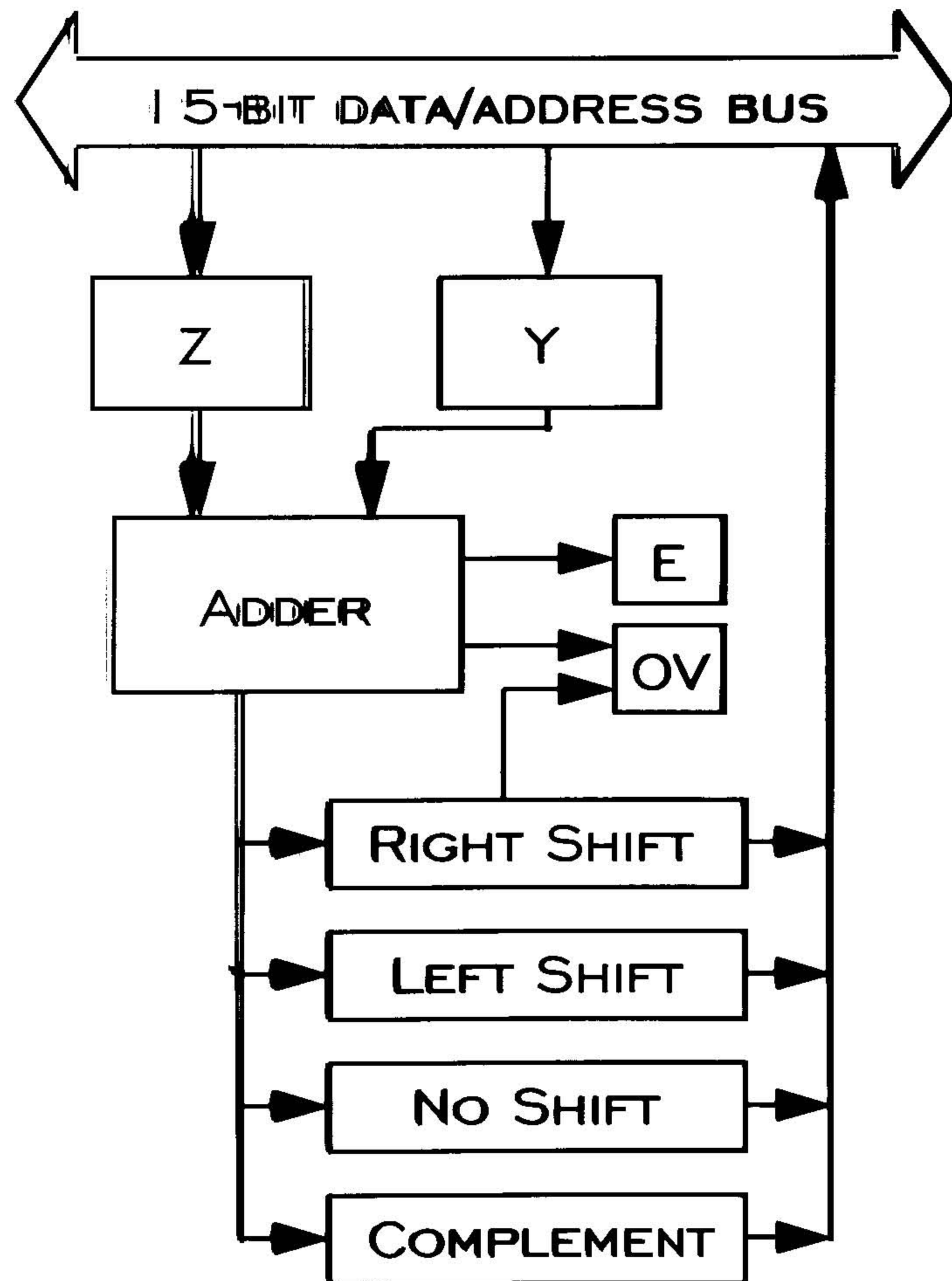


MAIN BASEMENT CABINET: 6' HIGH, 7' WIDE, 1.5' DEEP

# ECHO-IV BLOCK DIAGRAM



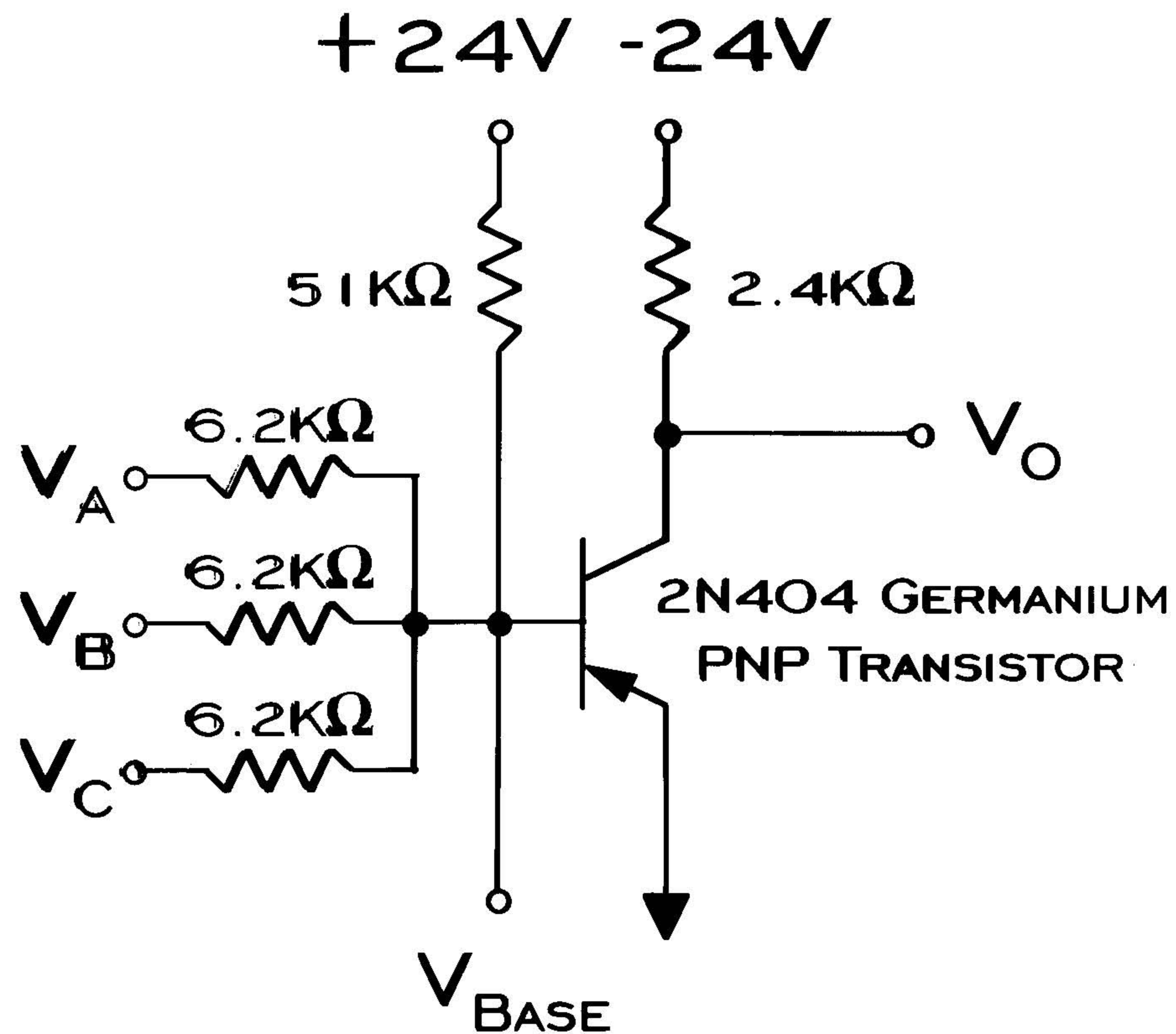
# ARITHMETIC UNIT



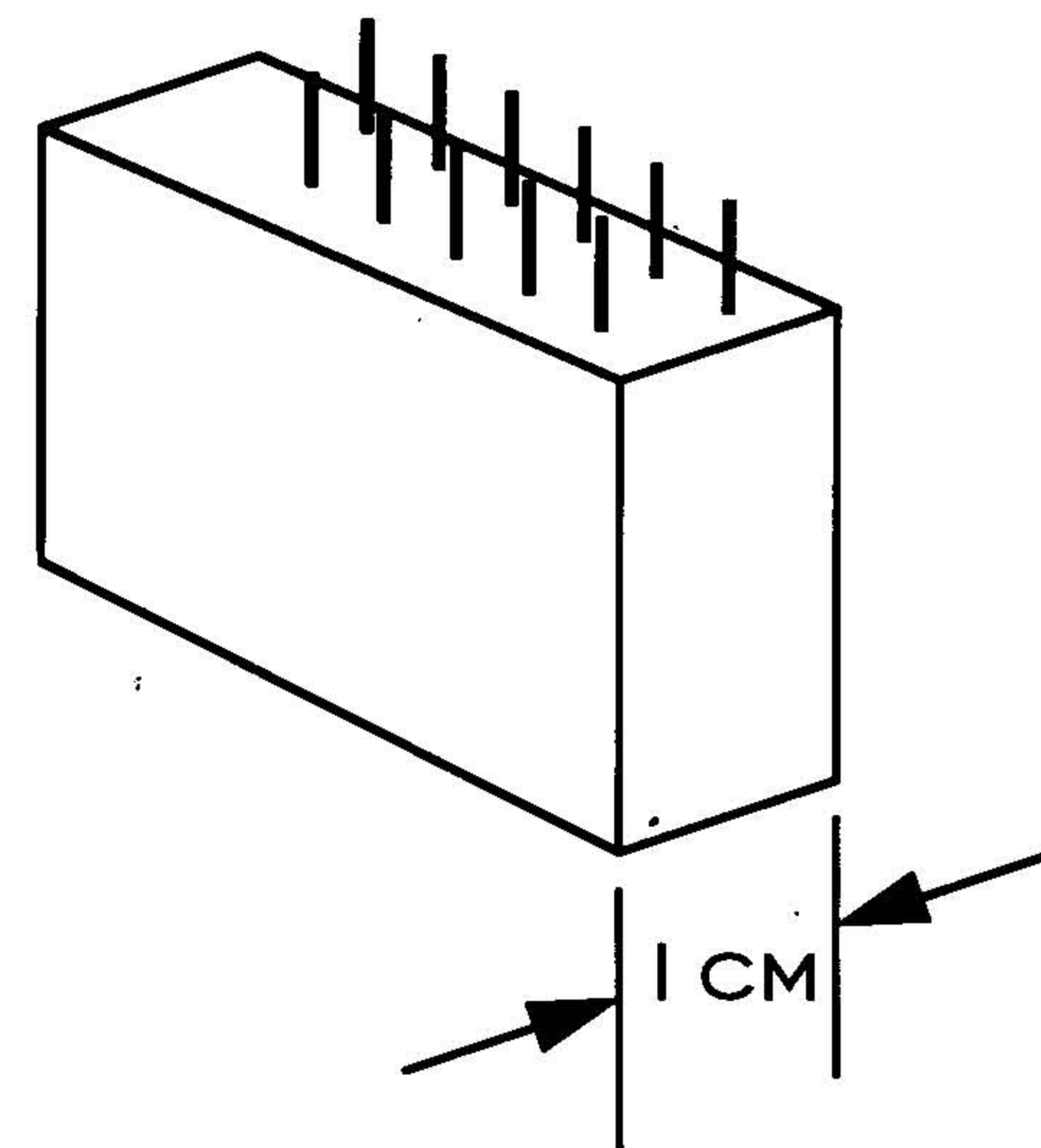
- 216  $\mu$ S CYCLE TIME
- ADDER PERFORMS:
  - ONES COMPLIMENT ADD
  - EXCLUSIVE OR OPERATION
  - AND OPERATION
  - INCREMENTATION OF PROGRAM COUNTER REGISTER P
- ENDAROUND CARRY (E) DESIGNATOR SET IF CARRY OUT OF ADDER BIT 14 OCCURS DURING ADD
- OVERFLOW (OV) DESIGNATOR SET IF
  - BIT 0 OF REGISTER A EQUALS "1" BEFORE RIGHT SHIFT
  - SIGN OF SUM IS DIFFERENT THAN SIGN OF LIKE-SIGNED INPUTS

# RESISTOR TRANSISTOR LOGIC

## NOR GATES



- SWITCHING TIME: 3-4  $\mu s$
- GATE INPUTS: 3-6
- OUTPUT FANOUT: 4
- EACH NOR GATE TRANSISTOR IS ENCAPSULATED WITH ALL ASSOCIATED RESISTORS IN A SINGLE PACKAGE

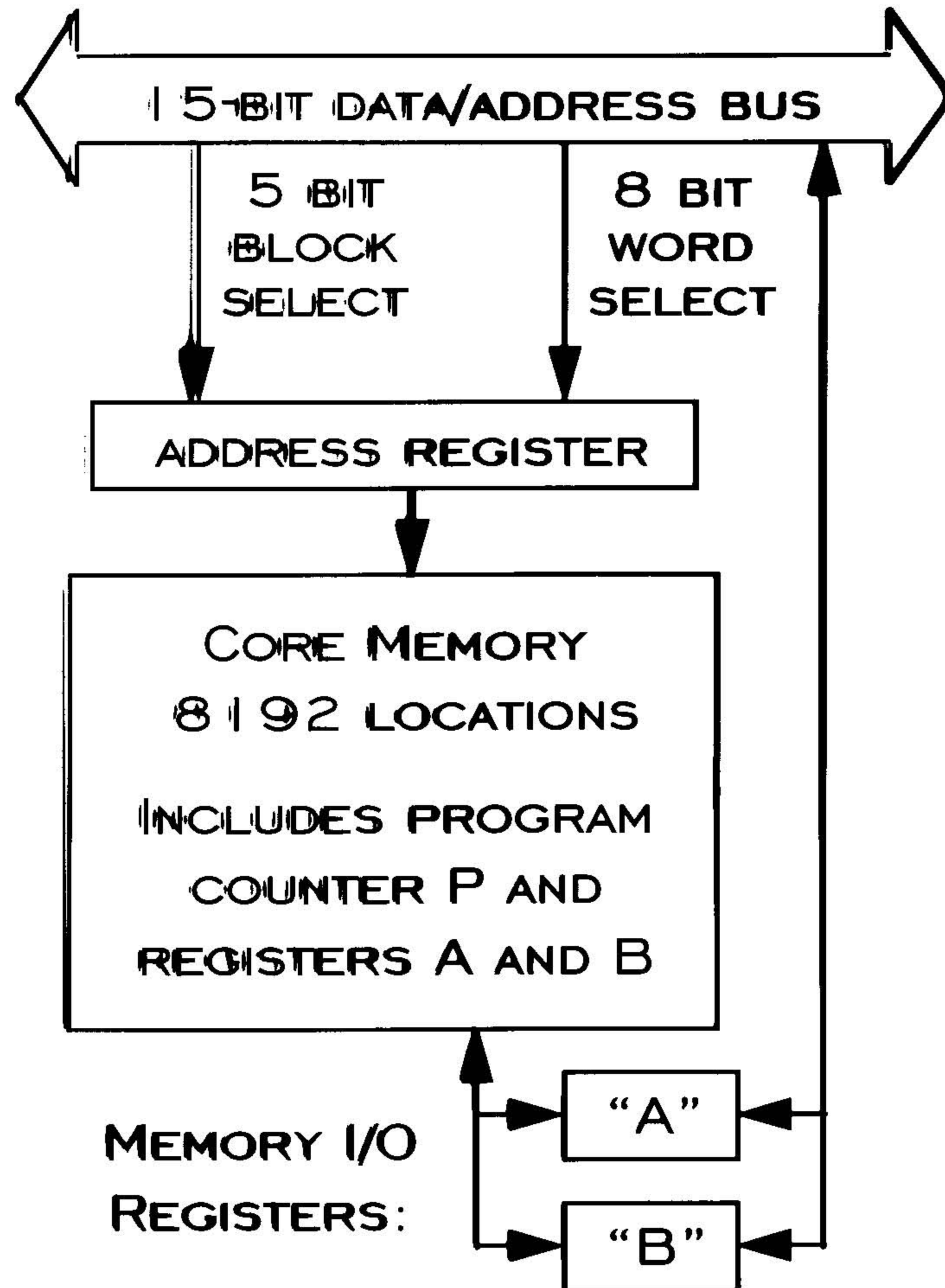


# PACKAGING PROBLEMS & SOLUTIONS

- **INTERMITTANT FAILURE OF LOGIC GATES**
  - DUE TO DESIGN OF ENCAPULATED LOGIC GATE CIRCUIT BOARD
  - NOTCHES IN CIRCUIT BOARD EDGE WERE INTENDED TO ELIMINATE A DRILLING STEP DURING MANUFACTURE
  - SOLDER JOINTS BETWEEN CIRCUIT BOARD CONDUCTORS AND RESISTOR LEADS FAILED DUE TO THERMAL CYCLING
  - WESTINGHOUSE DISCONTINUED THE NOTCHED CIRCUIT BOARD DESIGN DUE TO EXCESSIVE FIELD FAILURES, AND REPLACED IT WITH A DRILLED CIRCUIT BOARD VERSION
  
- **SOLUTIONS**
  - “LOBOTOMIZE” LOGIC GATES AND RESOLDER CONNECTIONS
  - TRACE FAILURES BY ADDING A PROGRAM COUNTER TRAP TO HALT COMPUTER AT SPECIFIC ADDRESSES

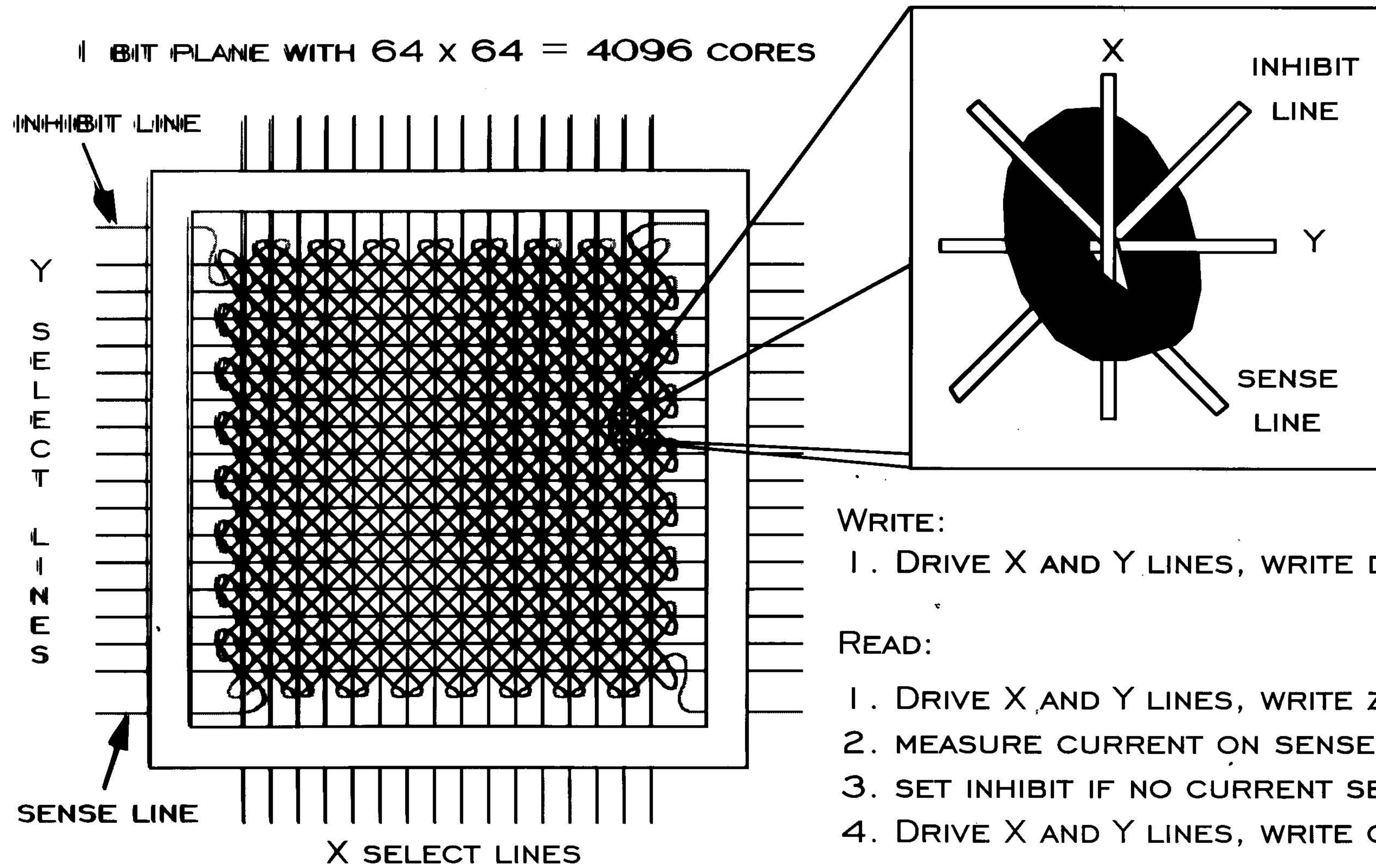


# MEMORY UNIT



- **AMPEX 4096-RQ-30A CORE MEMORY**
  - ORIGINALLY 4096 LOCATIONS WITH 30-BIT WORDS
  - ORGANIZED AS 8192 LOCATIONS OF 15-BIT WORDS
  - 32 BLOCKS OF 256 WORDS EACH
  - 6 μS MEMORY CYCLE TIME
  - ORIGINAL COST IN 1959: \$49,000
  
- **PACKAGING**
  - CORE MEMORY AND ASSOCIATED CONTROL LOGIC FILLED ONE ECHO-IV CABINET (6'x1.75'x1.5')
  - REQUIRED 17 DIFFERENT POWER SUPPLIES, FILLING MOST OF ECHO-IV POWER SUPPLY CABINET

# CORE MEMORY OPERATION



**WRITE:**

1. DRIVE X AND Y LINES, WRITE DATA

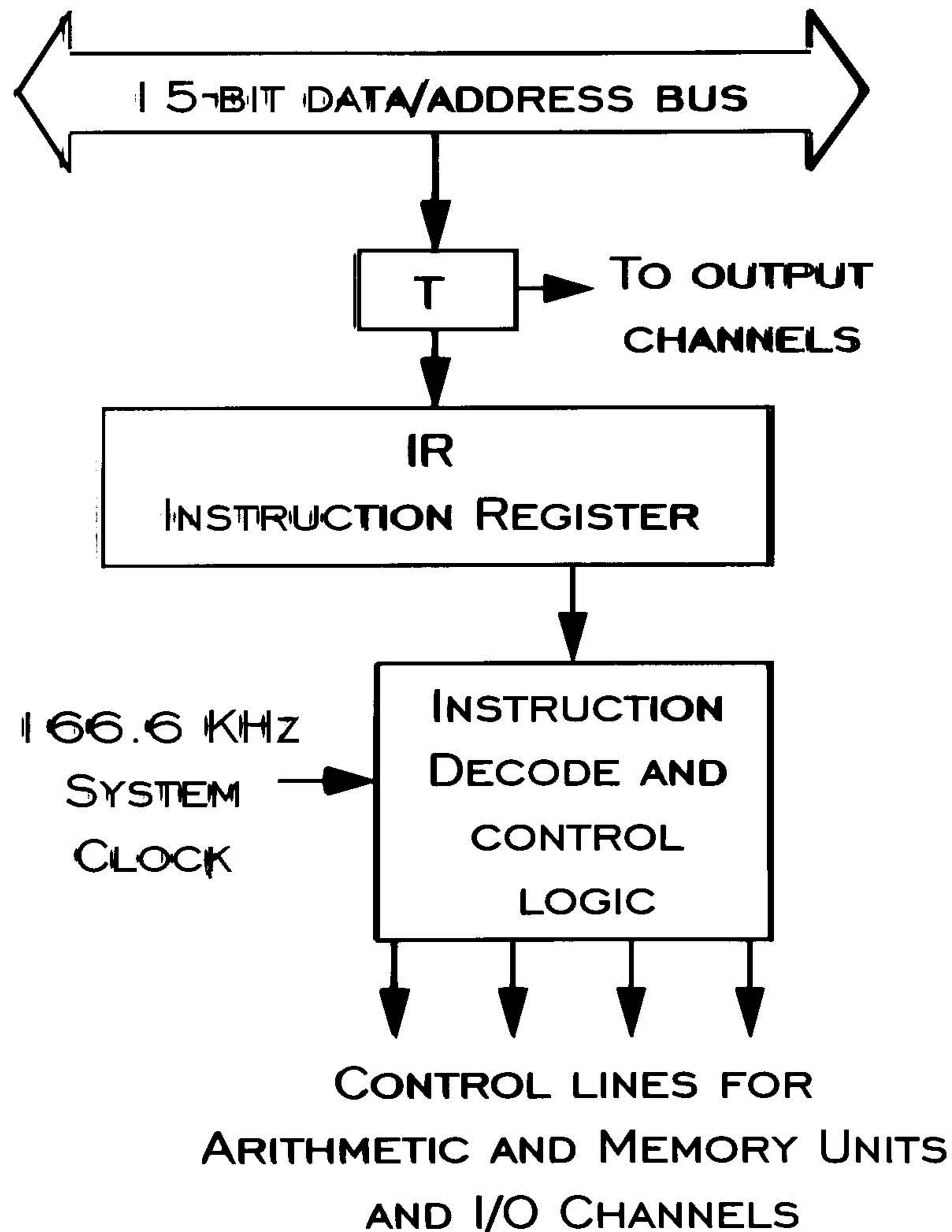
**READ:**

1. DRIVE X AND Y LINES, WRITE ZERO
2. MEASURE CURRENT ON SENSE LINE
3. SET INHIBIT IF NO CURRENT SENSED
4. DRIVE X AND Y LINES, WRITE ONE

# ASSIGNED CORE MEMORY LOCATIONS: BLOCK "ZERO"

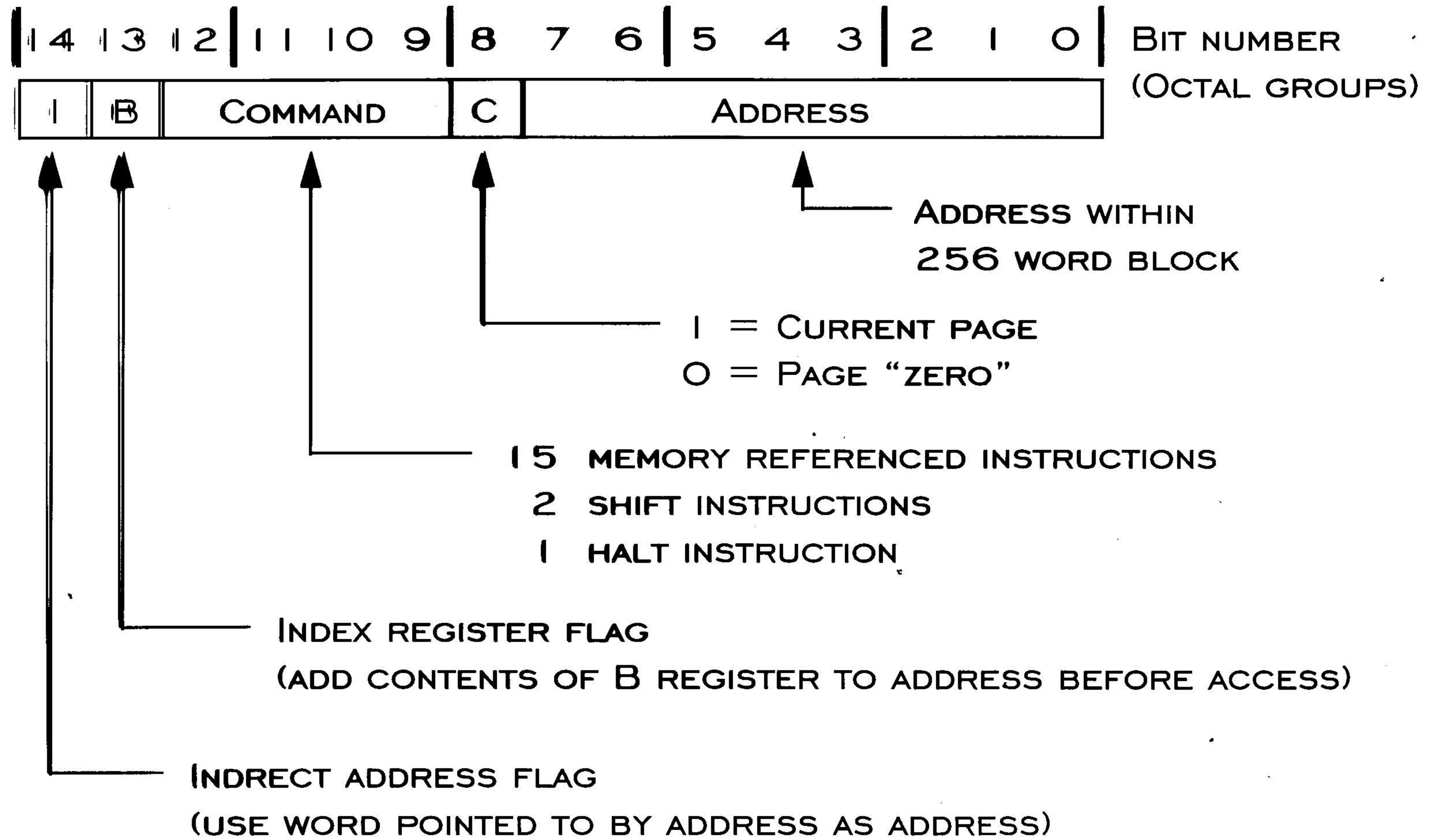
<u>ADDRESS</u>	<u>CONTENTS</u>
00000 <sub>8</sub>	P PROGRAM COUNTER
00001 <sub>8</sub>	ZERO CONSTANT
00002 <sub>8</sub>	B INDEX REGISTER
00003 <sub>8</sub>	A ACCUMULATOR
00004 <sub>8</sub>	INTERRUPTED PROGRAM RETURN ADDRESS
00005 <sub>8</sub>	START OF INTERRUPT HANDLER
00277 <sub>8</sub>	END OF INTERRUPT HANDLER
00300 <sub>8</sub>	START OF CONSTANTS TABLES
00377 <sub>8</sub>	END OF BLOCK "ZERO"

# CONTROL UNIT



- CONTROL UNIT INSTRUCTION CYCLE STEPS
  - PROGRAM COUNTER INCREMENT
  - INSTRUCTION FETCH
  - OPTIONAL ADDRESS INDIRECTION
  - OPTIONAL ADDRESS INDEXING USING B
  - EXECUTE INSTRUCTION
- INSTRUCTION SET
  - 18 INSTRUCTIONS
  - RISC APPROACH BY DEFAULT
- CONTROL UNIT TIMING
  - 12 CLOCK PERIODS PER STEP:  
STEP TIME = 72  $\mu$ s
  - 3 TO 5 STEPS PER INSTRUCTION:  
INSTRUCTION TIME = 216-360  $\mu$ s
  - 0.0028 TO 0.0046 MIPS

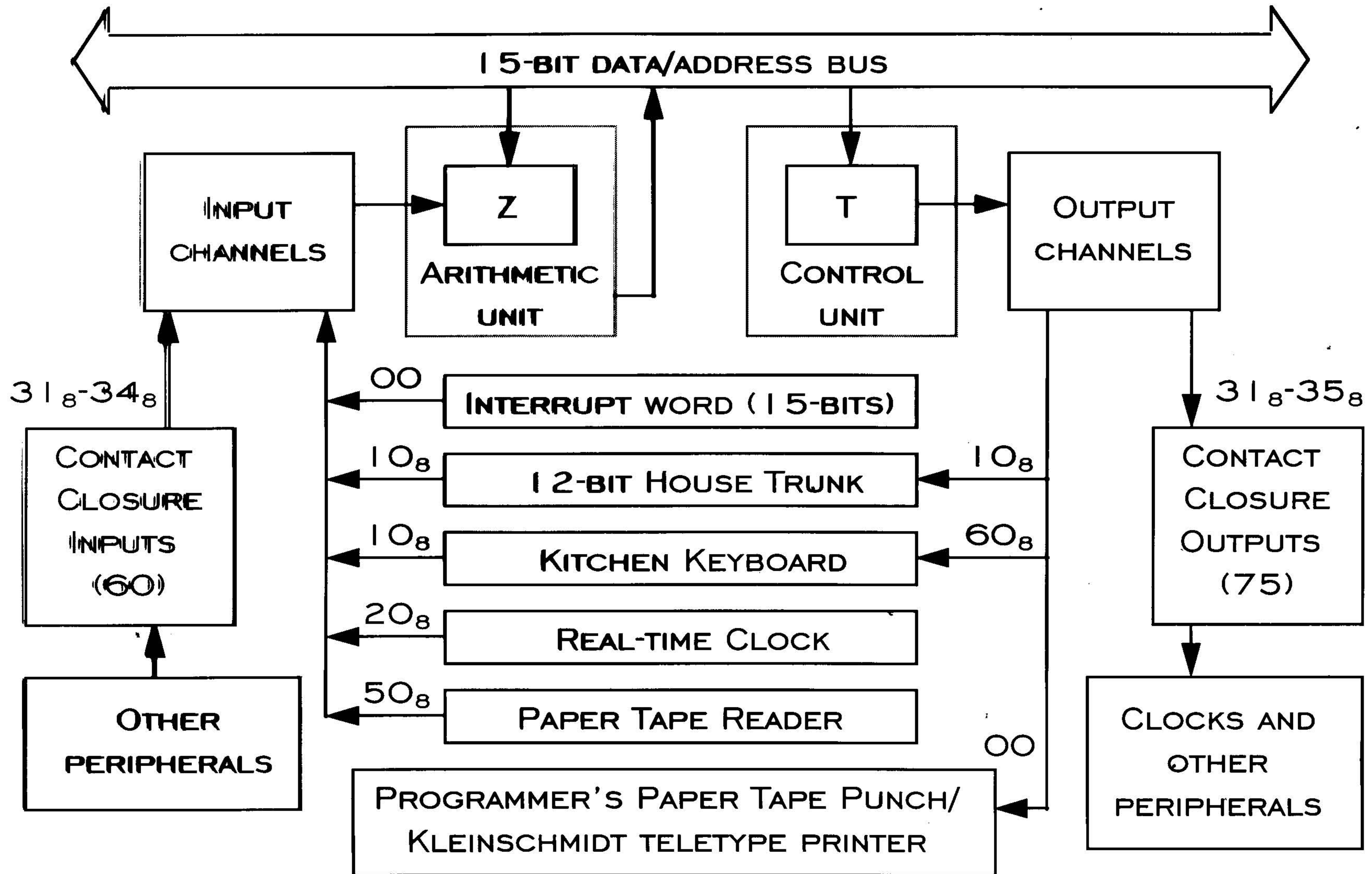
# INSTRUCTION FORMAT



# INSTRUCTION SET

<u>CODE</u>	<u>MNEMONIC</u>	<u>DEFINITION</u>
01	JMP	JUMP TO $Y + 1$
02	JOV	JUMP TO $Y + 1$ IF OV FLAG = 1
03	COM	COMPLEMENT Y
04	DCS	DECREMENT Y AND SKIP NEXT INST IF $Y = -1$ AFTER DECR.
05	SIP	STORE $P + 1$ IN Y
06	ENB	STORE Y IN B
07	ENA	STORE Y IN A
$10_8$	OUT	OUTPUT FROM A TO SPECIFIED CHANNEL
$11_8$	INP	INPUT TO A FROM SPECIFIED CHANNEL
$12_8$	JAN	JUMP TO $Y + 1$ IF REGISTER A BIT 14 = 1
$13_8$	JAZ	JUMP TO $Y + 1$ IF A = POSITIVE ZERO
$14_8$	STA	STORE A IN Y
$15_8$	ADD	STORE A PLUS Y IN A
$16_8$	EOR	STORE A XOR Y IN A
$17_8$	AND	STORE A AND B IN A
$00000_8$	HLT	HALT
$40000_8$	LSH	LEFT SHIFT A, BIT 14 REPLACES BIT 00
$00400_8$	RSH	RIGHT SHIFT A, BIT 00 ENTERS OV FLAG

# INPUT/OUTPUT CHANNELS



# PROGRAMMING

- **WRITE AND EDIT PROGRAMS ON PAPER FORMS**
  - TWO-PASS MANUAL COMPILE
- **INITIAL PROGRAMMING VIA FRONT PANEL CONSOLE**
  - LAMPS DISPLAY CONTENTS OF REGISTERS AND MEMORY LOCATIONS
  - CONDUCTIVE STYLUS PERMITS SETTING/RESETTING OF BITS
  - PUSHBUTTONS TO RUN AND HALT COMPUTER
- **PROGRAMMER'S CONSOLE**
  - PROGRAMS KEYED IN AT KEYBOARD USING OCTAL CODES
  - PROGRAMS COULD BE READ FROM OR WRITTEN TO PAPER TAPE
- **PAPER TAPE EDITOR**



# APPLICATIONS

- **PROGRAMMER'S CONSOLE I/O**

- OCTAL PROGRAM INPUT FROM CONSOLE KEYBOARD
- OCTAL DUMP TO KLEINSCHMIDT TELETYPE
- LOAD AND STORE PROGRAMS AND DATA ON PAPER TAPE

- **KITCHEN CONSOLE WORD-PROCESSING**

- DOCUMENTS TYPED ON IBM 735 SELECTRIC TYPEWRITER WERE STORED IN MEMORY AND AVAILABLE FOR REPRINTING LATER
- DOCUMENTS COULD BE SAVED ON PAPER TAPE, READ IN LATER, AND PORTED DIRECTLY TO THE KITCHEN CONSOLE
- FORMATTING CHANGES AND PAGE NUMBERS COULD BE AUTOMATICALLY ADDED TO PRINTED DOCUMENTS
- IN 1975, ECHO-IV WAS USED TO FORMAT A 516-PAGE BOOK ON ANALYSIS OF POST-REVOLUTIONARY WAR LAND GRANT SURVEYS

# PACKAGING PROBLEMS & SOLUTIONS

- **EXCESSIVE POWER REQUIREMENTS**

- LOGIC GATES AND I/O CHANNELS: 1 KW (24V AT ~40A)
- CORE MEMORY AND ASSOCIATED POWER SUPPLIES: 2KW

- **SOLUTIONS:**

- AUTOMATICALLY TURN COMPUTER ON/OFF ON DEMAND
- LINK COMPUTER TO REAL-TIME CLOCK, TURN ON ONCE PER HOUR TO DO PERIODIC HOUSEKEEPING TASKS
- ADD ACTIVATION BUTTONS AT PROGRAMMER'S CONSOLE AND KITCHEN CONSOLE TO POWER UP COMPUTER ON DEMAND

# INTERRUPT PROCESSING

- **PROCESSOR INTERRUPTED 60 TIMES/SECOND BY REAL-TIME CLOCK**

- 30 TIMES/SECOND: CHECK FOR PAPER TAPE READER OR PUNCH INTERRUPT
- 15 TIMES/SECOND: CHECK FOR KITCHEN CONSOLE SERVICE INTERRUPT OR CHANGE IN REAL-TIME CLOCK LEAST SIGNIFICANT BIT (SECONDS)
- 7.5 TIMES/SECOND: CHECK FOR PROGRAMMER'S CONSOLE TELETYPE INTERRUPT
- 7.5 TIMES/SECOND: CHECK FOR KEYPAD INPUT FROM PROGRAMMER'S CONSOLE, TV CONSOLE, OR MASTER BEDROOM CONSOLE

# APPLICATIONS

- **BCD CLOCK DRIVER**

- UPDATED HOUR FIELD EVERY HOUR, AND INCREMENTED DAY FIELD IF NECESSARY

- **ALARM CLOCK**

- CONTROL PANEL IN MASTER BEDROOM SET UNIQUE ALARM TIME (IN BCD) FOR EACH DAY OF THE WEEK

- **STEREO SYSTEM POWER**

- COMPUTER ACTIVATED AND DEACTIVATED HOUSE STEREO SYSTEM

# APPLICATIONS

- **TV CONTROL**

- KEYPAD IN LIVING ROOM CHANGED CHANNELS ON LIVING ROOM TELEVISION, AND REPOSITIONED ROOF ANTENNA FOR OPTIMUM SIGNAL
- TV BLACKOUT PROGRAM DISABLED TV ON SCHOOL NIGHTS

- **MUSIC/TONE GENERATOR**

- SPEAKER BUILT INTO COMPUTER WAS PROGRAMMED TO PLAY SONGS

- **PROBLEM SOLVING PROGRAMS**

- CALCULATION OF  $2^N$  FOR  $0 \leq N \leq 400$
- CALCULATION OF SOLUTION TO "INSTANT INSANITY" COLOR CUBE PUZZLE

# MAGAZINE & NEWSPAPER ARTICLES

<u>DATE</u>	<u>MAGAZINE</u>	<u>PAGE</u>
DEC 1966	HOUSE & GARDEN	30
DEC 1966	FAMILY WEEKLY	2
MAR 1967	EE: THE ELECTRONIC ENGINEER	36
JAN 1968	AMATEUR COMP. SOC. NEWSLETTER	4
APR 1968	POPULAR MECHANICS	77
FEB 1970	COMPUTERWORLD	12
MAR 1970	DATAMATION	150
FEB 1971	SCIENCE & MECHANICS	66
JAN 1972	COMPUTERS & AUTOMATION	20
JUL 1978	BYTE	64
NOV 1984	CREATIVE COMPUTING	10
FALL 1985	THE COMPUTER MUSEUM REPORT	18
FALL 1994	IEEE ANNALS OF COMPUTING HISTORY	59

## ASSOCIATED PRESS NEWS RELEASE ARTICLES

JAN 1970	123 NEWSPAPERS	77,000,000 CIRC.
JUN 1970	95 NEWSPAPERS	60,000,000 CIRC.

## TODAY

- **ECHO-IV RESIDES AT THE COMPUTER MUSEUM IN BOSTON, MA**
  - DONATED TO THE MUSEUM IN 1984
  - WILL BE MOVED TO A WEST-COAST VERSION OF THE COMPUTER MUSEUM IN SAN JOSE, CA, OPENING LATER THIS YEAR
- **MY PARENTS LIVE IN MONROEVILLE, PA**
  - MY DAD RETIRED FROM WESTINGHOUSE IN 1994 AFTER 38 YEARS OF SERVICE AND 25 PATENT AWARDS
  - HE STILL TAKES ON HUGE COMPUTER PROJECTS JUST FOR FUN