AD NUMBER: AD0896847

LIMITATION CHANGES

TO:

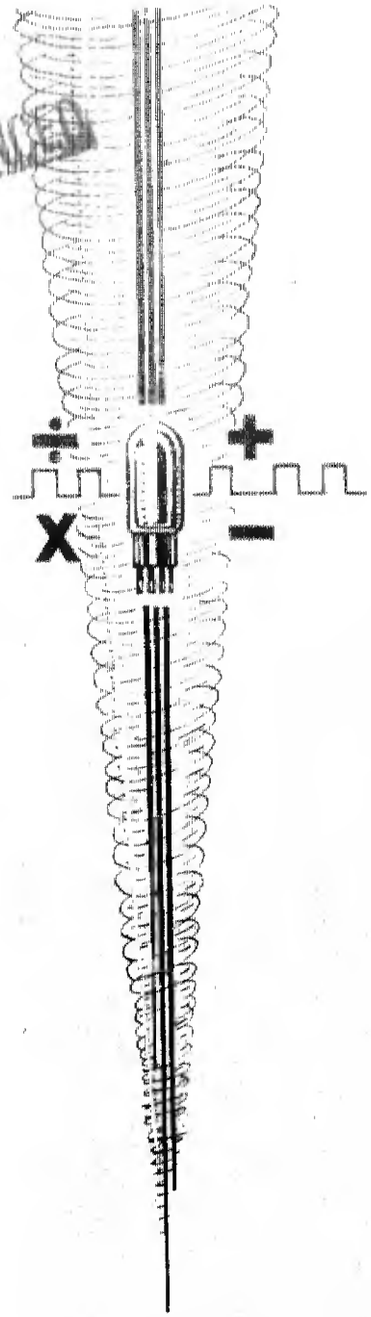
Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 4 Sep 1947 Other requests shall be referred to the Office of Naval Research, Washington, DC 20360.

AUTHORITY

ONR ltr dtd 9 Nov 1977



PROJECT
WHIRLWIND

Contract N5ori60

SUMMARY REPORT NO. 2
VOLUME 6

REPORT R-127

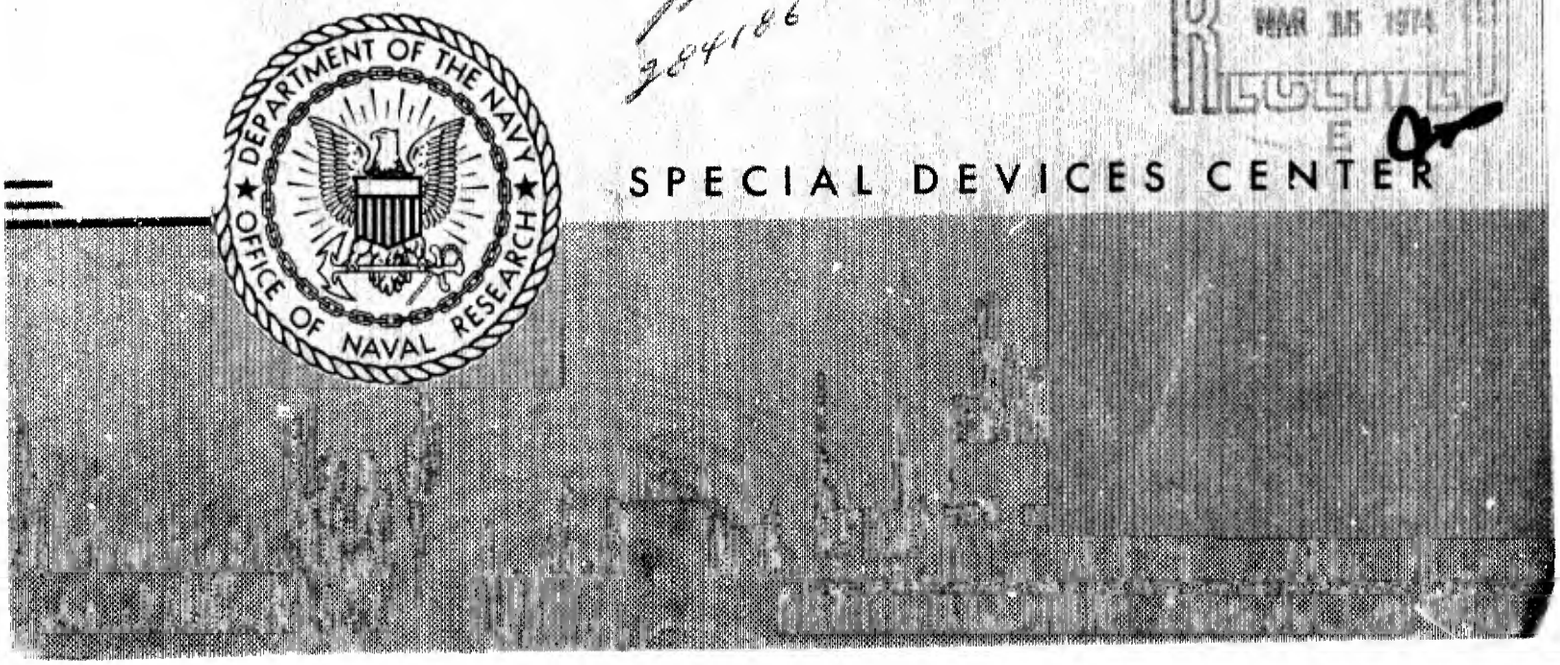
WHIRLWIND I COMPUTER BLOCK DIAGRAMS

VOLUME 2 OF 2 VOLUMES

SERVOMECHANISMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 4, 1947

SPECIAL DEVICES CENTER



PROJECT WHIRLWIND.

(DEVICE 24-X-3)

REPORT R-127

WHIRLWIND I COMPUTER BLOCK DIAGRAMS,

VOLUME 2 OF 2 VOLUMES

Submitted to the

SPECIAL DEVICES CENTER

OFFICE OF NAVAL RESEARCH

Under Contract N5ori60

Report by

R. R. Everett & F. E. Swain

SERVOMECHANISMS LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cambridge 39, Massachusetts

MIT-
Project DIC-6345

September 4, 1947

78 p.

FOREWORD

This report is a description of the Whirlwind electronic digital computers under development at the Servomechanisms Laboratory of M. I. T. for the Office of Naval Research. The arithmetic nature and the physical nature of the computers are covered briefly, and the block diagrams for the prototype computer WWI are discussed in some detail.

The report consists of two volumes: Volume 1 contains the text and Volume 2 the drawings.

LIST OF DRAWINGS

Figure Number	Drawing Number	Title
1	A-30339	General Block Diagram
2	A-30445	Store Result
3	A-30440	Origin of Orders
4	A-30441	Setup Order
5	A-30442	Read Out Order
6	A-30443	Setup Operation
7	A-30444	Perform Operation
8	A-30446	Subprogram
9	A-30454	Electronic Switch
10	A-30452	Time Pulse Distributor
11	A-30453	Control
12	A-30400	Decimal Addition
13	A-30401	Binary Addition
14	A-30402	A Binary Adder
15	A-30417	Negative Numbers
16	A-30410	Subtraction Using 9's Complements
17	A-30403	Decimal Multiplication
18	A-30355	Binary Notation
19	A-30409	Binary Multiplication
20	A-30404	Modified Binary Multiplication
21	A-30447	Multiplication I
22	A-30448	Multiplication II
23	A-30449	Multiplication III
24	A-30450	Multiplication IV
25	A-30451	Multiplication V
26	A-30406	Rounding Off
27	A-30683	Decimal Division
28	A-30686	Binary Division
29	C-37072	Arithmetic Element
30	A-30433	Accumulator
31	A-30432	Accumulator
32	A-30685	Shift and Carry
33	A-30684	Shift Left
34	C-37099	Clear and Add
35	C-37100	Add
36	A-30682	Arithmetic Check
37	C-37101	Clear and Subtract
38	C-37102	Subtract
39	C-37103	Multiply and Roundoff
40	C-37104	Divide
41	C-37105	Transfer to Storage
42	C-37106	Shift Right
43	C-37107	Shift Left
44	C-37108	Conditional Program
45	C-37109	Special Add
46	C-37071	System Block Diagram
47	B-37073	Control Functions
48	B-37070	Bus Connections

LIST OF DRAWINGS

Figure Number	Drawing Number	Title
49	B–37098	Control
50	B–37058	Master Clock
51	B–37062	Program Counter
52	B–37067	Program Register
53	B–37066	Control Switch
54	C–37077	Operation Matrix I
55	C–37078	Operation Matrix II
56	B–37076	Time Pulse Distributor Control
57	B–37068	Pulse Distributor
58	B–37075	Program Timing Matrix
59	C–37064	Storage Chassis Arrangement
60	B–37057	Flip-flop Storage Section
61	B–37060	Storage Output Section
62	B–37061	Flip-flop Storage Control
63	C–37072	Arithmetic Element
64	B–37056	Section of A-Register
65	C–37063	Accumulator Sections
66	C–37096	Accumulator Sections
67	B–37069	B-Register Sections
68	B–37097	B-Register Sections
69	B–37074	Step Counter
70	B–37065	Check Register
71	A–30874	Program Timing
72	B–37080	Timing for Add
73	B–37081	Timing for Clear and Add
74	B–37082	Timing for Subtract
75	B–37083	Timing for Clear and Subtract
76	B–37084	Timing for Multiply and Roundoff
77	B–37085	Timing for Multiply and Hold Full Product
78	B–37094	Timing for Divide
79	B–37086	Timing for Transfer to Storage
80	B–37088	Timing for Shift Right
81	B–37089	Timing for Shift Left
82	B–37090	Timing for Subprogram
83	B–37091	Timing for Conditional Program
84	B–37092	Timing for Transfer Digits
85	B–37093	Timing for Special Add
86	B–37087	Timing for Store & Display
87	B–37001	Parallel Digit Computer Codes

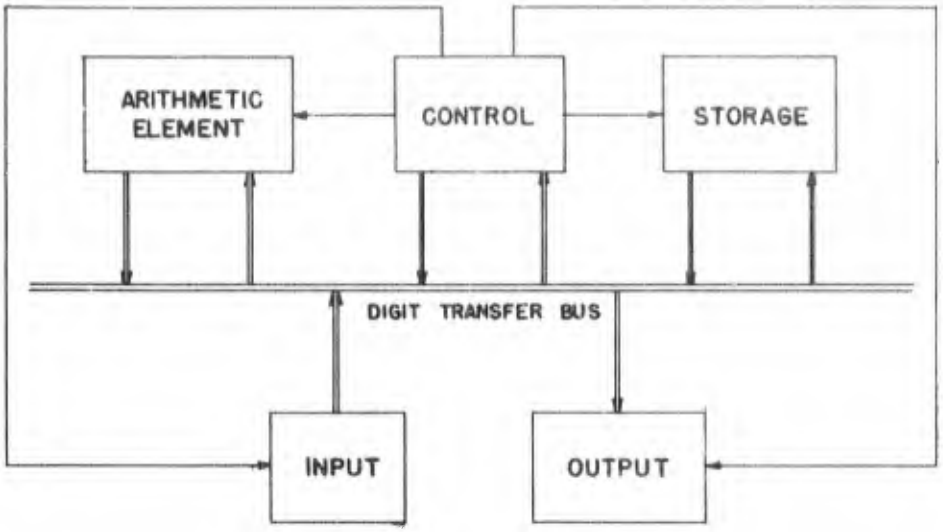


Figure 1

GENERAL BLOCK DIAGRAM

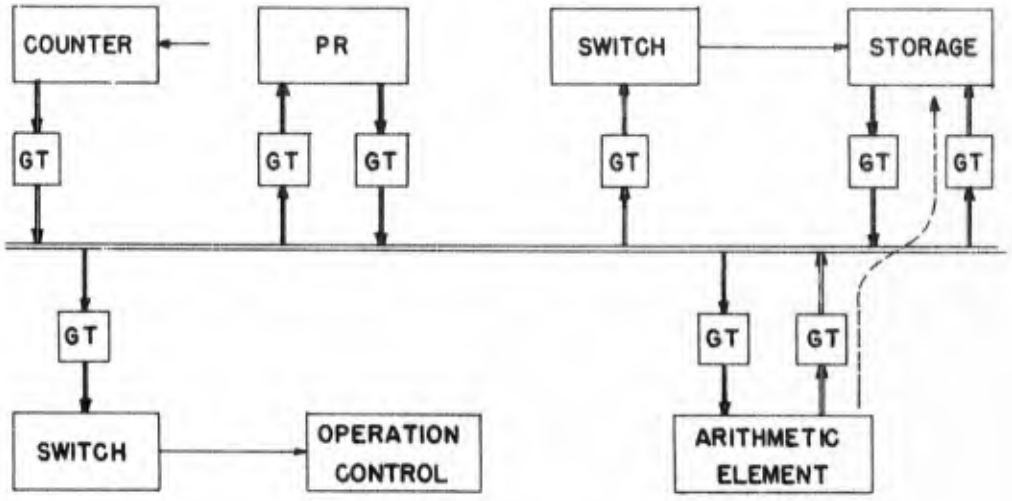


Figure 2

STORE RESULT

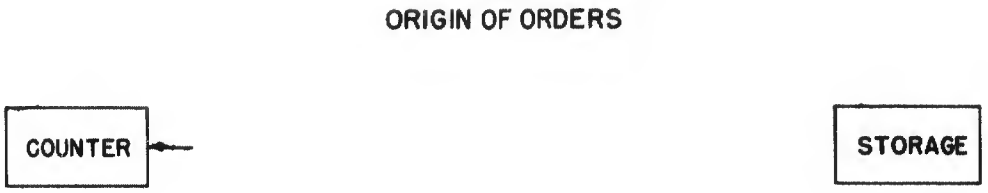


Figure 3
ORIGIN OF ORDERS

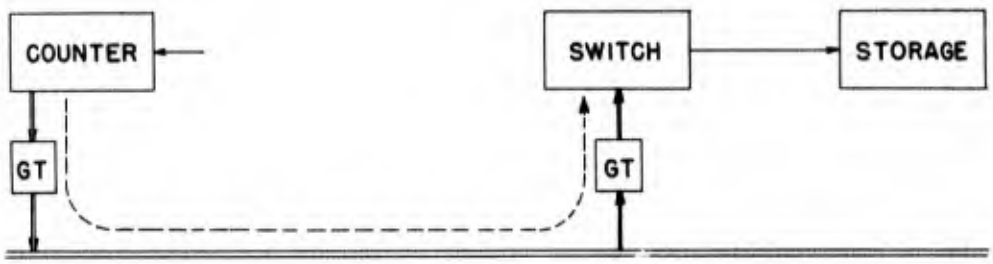


Figure 4
SETUP ORDER

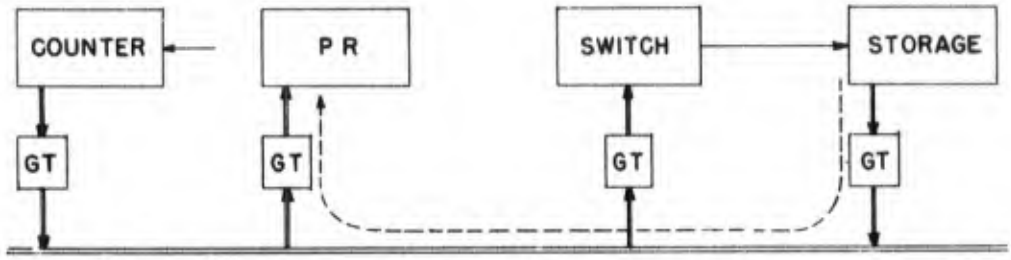


Figure 5
READ OUT ORDER

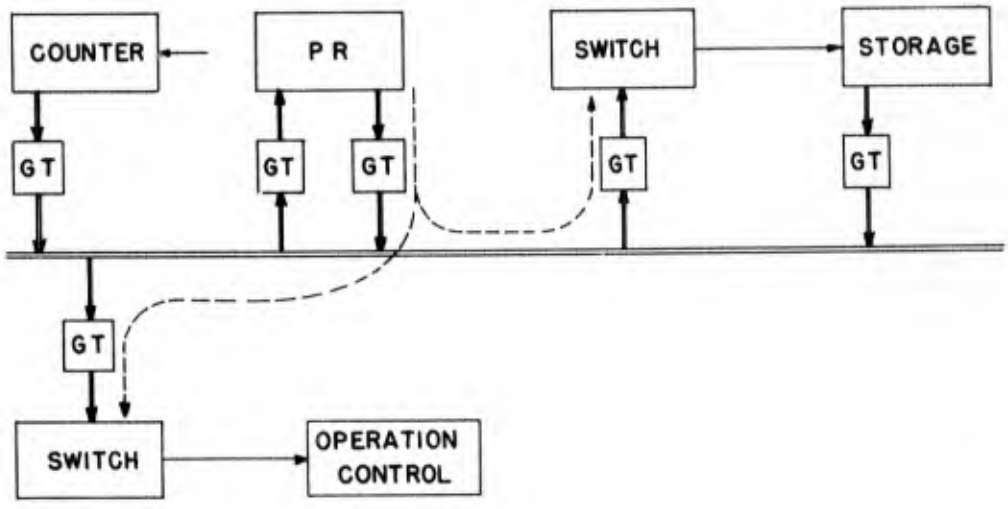


Figure 6
SETUP OPERATION

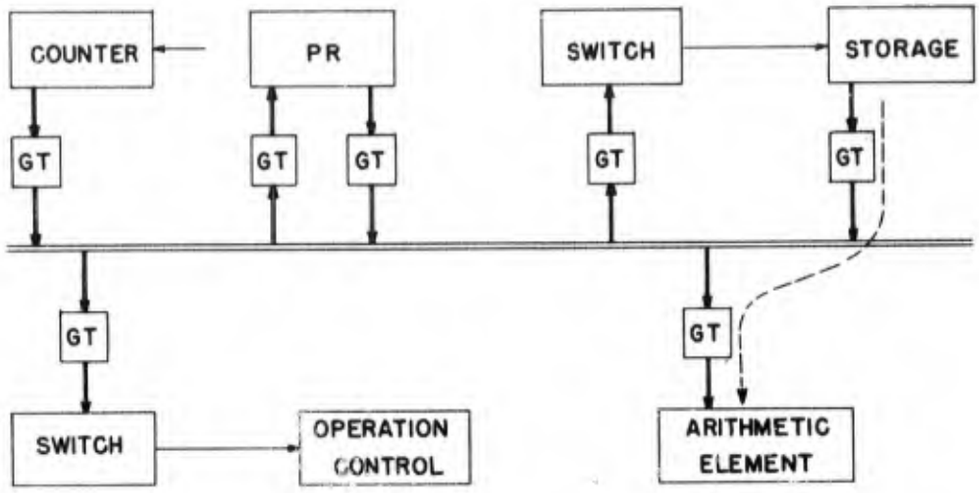


Figure 7

PERFORM OPERATION

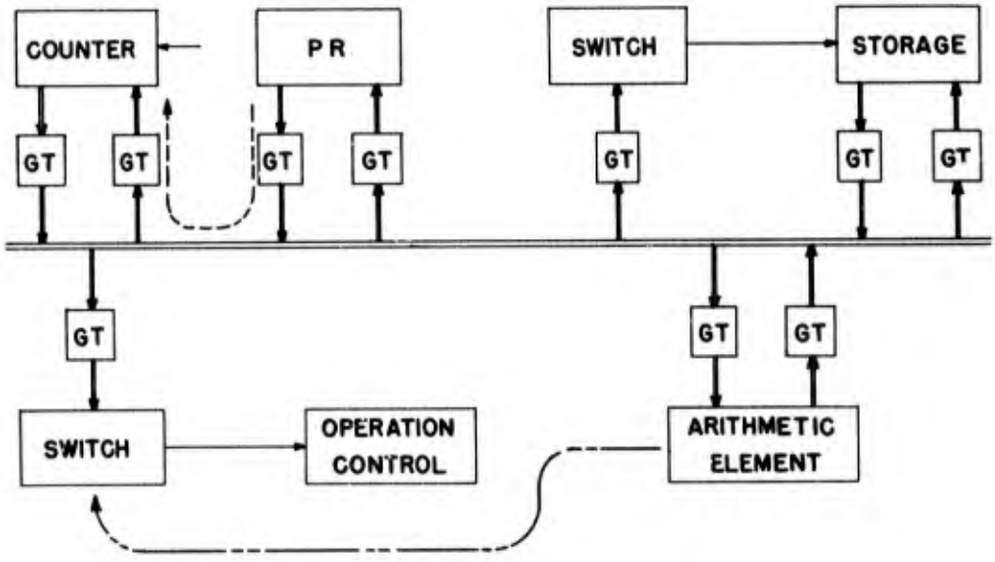


Figure 8

SUBPROGRAM

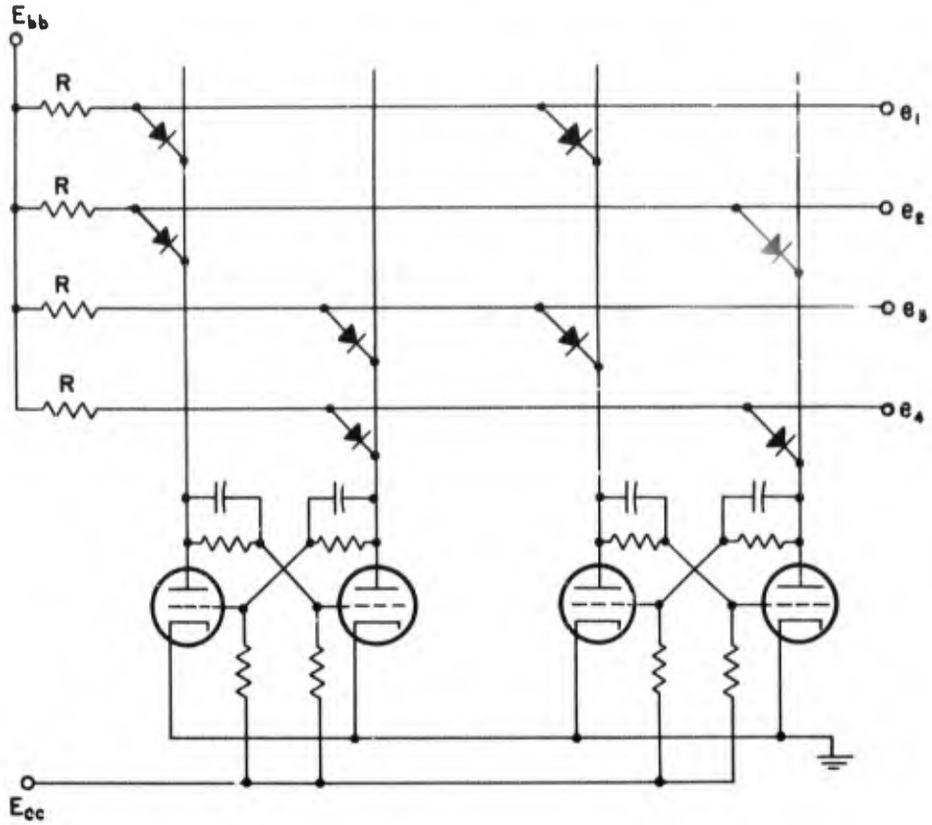


Figure 9

ELECTRONIC SWITCH

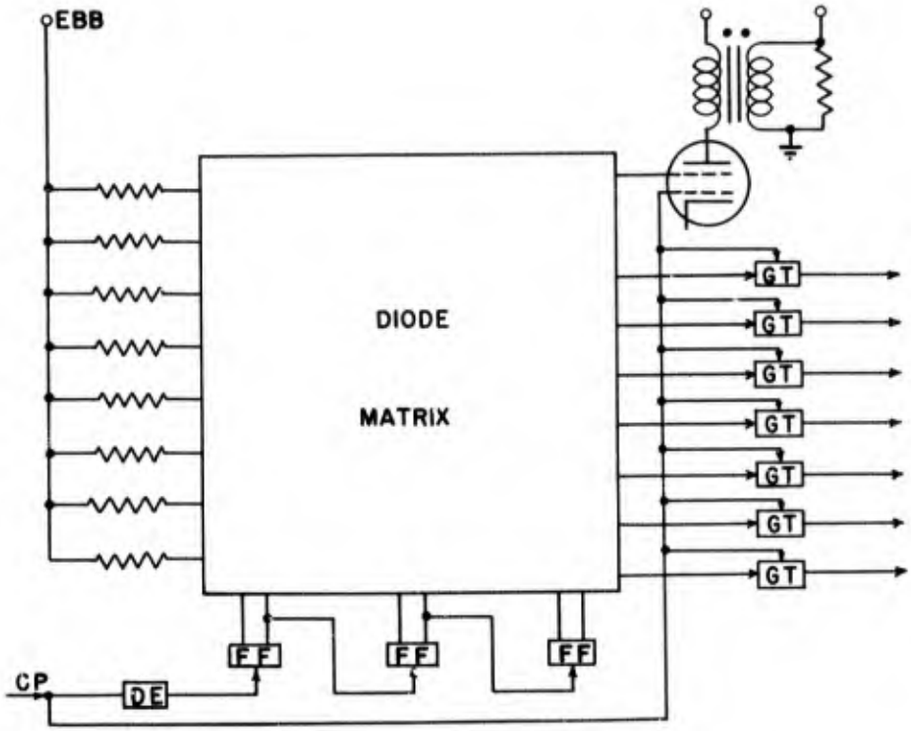


Figure 10

TIME PULSE DISTRIBUTOR

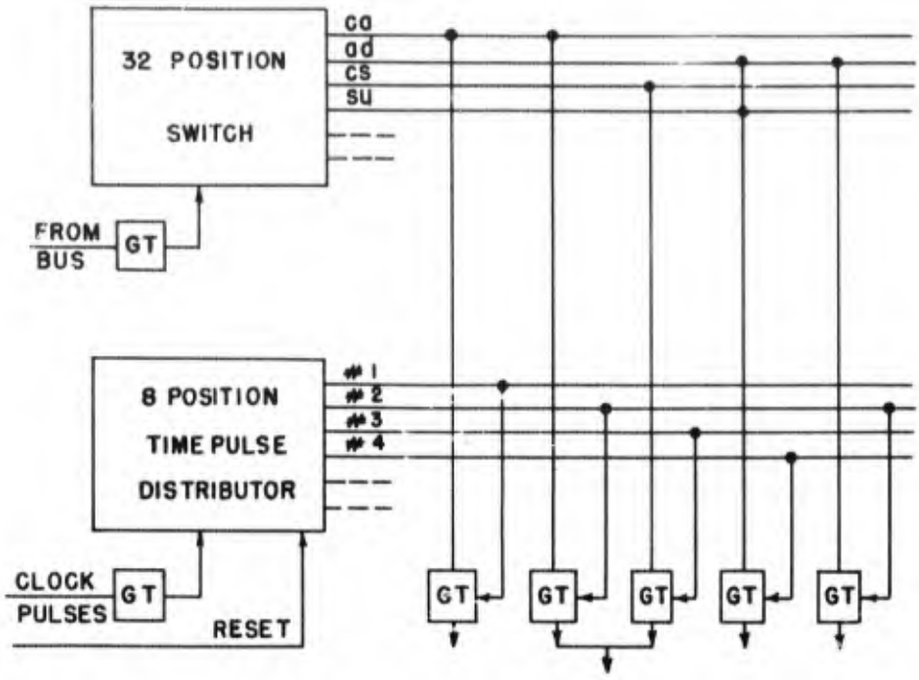


Figure 11

CONTROL

```
 3546
 1371
 ----
   1
 4817
   +1
 ----
 4917
```

Figure 12

DECIMAL ADDITION

```
 11011010
 10110110
 ---------
 01101100
  1  1  1
 ---------
 10100100
    1  1
 ---------
 10000000
    1  1
 ---------
 11001000
```

Figure 13
BINARY ADDITION

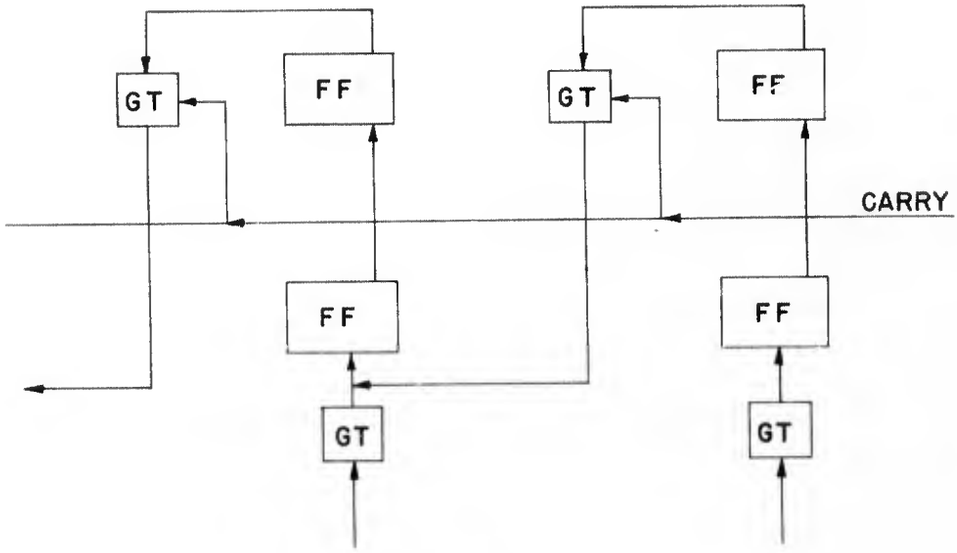


Figure 14
A BINARY ADDER

	DECIMAL	BINARY
POSITIVE NUMBER	223	11011111
NEGATIVE "	- 223	- 11011111
10's COMPLEMENT	1|777	1|00100001
9's "	1|776	1|00100000

Figure 15

NEGATIVE NUMBERS

BINARY			DECIMAL
+010110110	$= N_1$		- 182
-011010010	$= -N_2$		- -210
			- 28
010110110	$= N_1$		
100101101	$= 2^n - N_2 - 1$		
111100011	$= 2^n - (N_2 - N_1) - 1$		
-000011100	$= N_1 - N_2$		- -28
010110110	$= N_1$		- 182
-010010010	$= N_2$		- -146
			+ 36
010110110	$= N_1$		
101101101	$= 2^n - N_2 - 1$		
1000100011	$= N_1 - N_2 + 2^n - 1$		
END AROUND CARRY +1			
000100100	$= N_1 - N_2$		- + 36

Figure 16

SUBTRACTION USING 9'S COMPLEMENTS

```
  356   MULTIPLICAND
  627   MULTIPLIER
 -----
   42
   35
  21
 -----
 2492   PARTIAL PRODUCT
   12
  10
   6
 -----
 9612   PARTIAL PRODUCT
   36
  30
 18
-----
223212   PRODUCT
```

Figure 17

DECIMAL MULTIPLICATION

REPRESENTS POWERS OF 2

MULTIPLICATION TABLE:

1 X 1 = 1
1 X 0 = 0
0 X 0 = 0

ADDITION:

1 + 1 = 10
1 + 0 = 1
0 + 0 = 0

BINARY COLUMNS $\approx 3\frac{1}{3}$ X DECIMAL COLUMNS

ONLY DIGITS 1 AND 0 REQUIRED IN EQUIPMENT

Figure 18

BINARY NOTATION

```
  10110   MULTIPLICAND      22
  10011   MULTIPLIER        19
 -----                     ----
  10110                     198
 10110                      22
-------                   ----
 1000010  PARTIAL PRODUCT   418
00000
-------
 1000010  PARTIAL PRODUCT
00000
-------
 01000010 PARTIAL PRODUCT
10110
-------
110100010  = 418 PRODUCT
```

Figure- 19

BINARY MULTIPLICATION

```
          10110   MULTIPLICAND
STEP 1    10011   MULTIPLIER
          10110   PARTIAL PRODUCT
          ---------------------
          10110   MULTIPLICAND
           1001   SHIFTED MULTIPLIER
STEP 2    10110   SHIFTED PARTIAL PRODUCT
          10110
          -------
          1000010 PARTIAL PRODUCT
          ---------------------
          10110   MULTIPLICAND
            100   SHIFTED MULTIPLIER
STEP 3    1000010 SHIFTED PARTIAL PRODUCT
          00000
          -------
          1000010 PARTIAL PRODUCT
          ---------------------
          10110   MULTIPLICAND
             10   SHIFTED MULTIPLIER
STEP 4    1000010 SHIFTED PARTIAL PRODUCT
          00000
          -------
          01000010 PARTIAL PRODUCT
          ---------------------
          10110   MULTIPLICAND
              1   SHIFTED MULTIPLIER
STEP 5    01000010 SHIFTED PARTIAL
          10110          PRODUCT
          -------
          110100010 PRODUCT
```

Figure 20

MODIFIED BINARY MULTIPLICATION

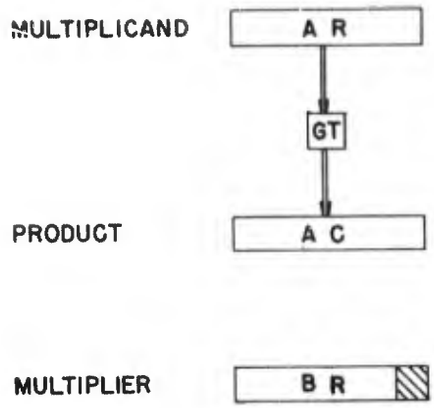


Figure 21

MULTIPLICATION I

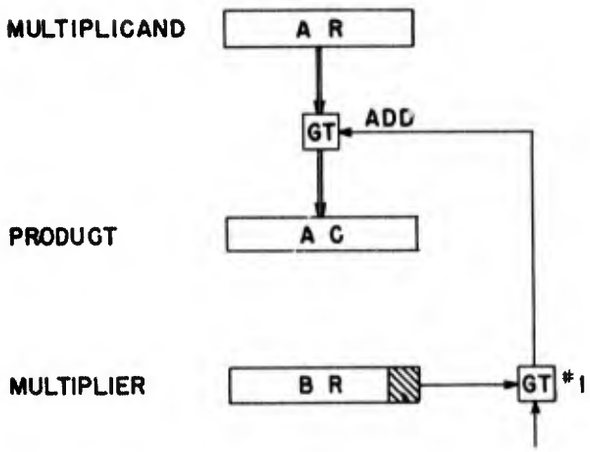


Figure 22

MULTIPLICATION II

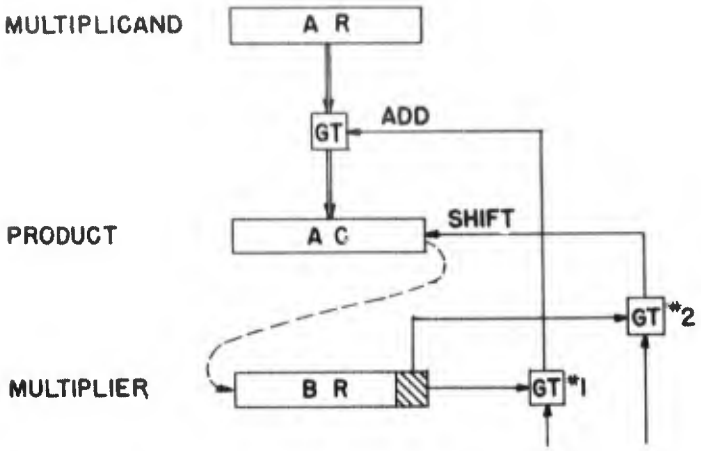


Figure 23
MULTIPLICATION III

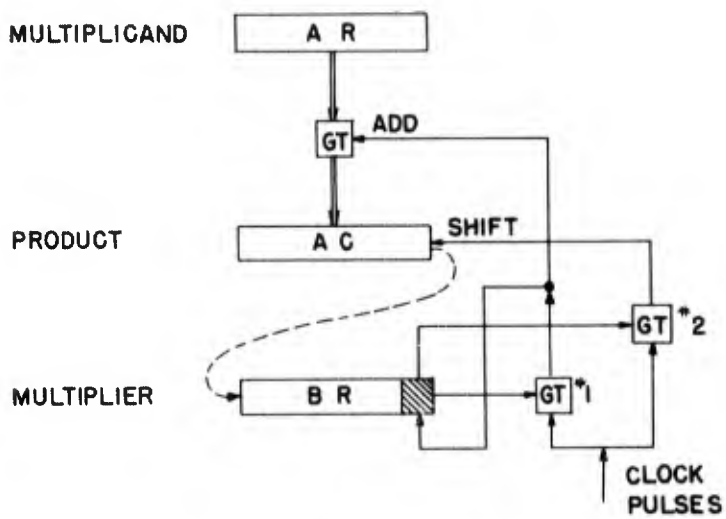


Figure 24
MULTIPLICATION IV

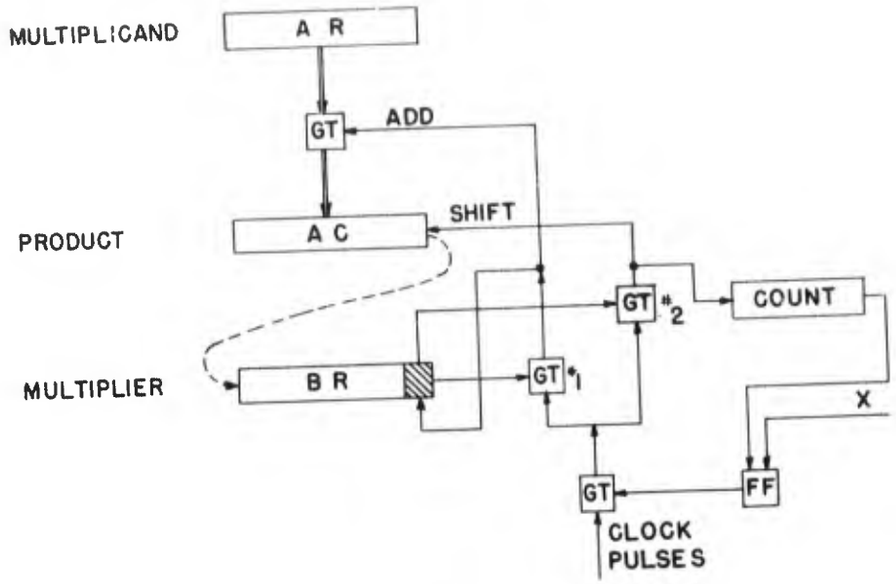


Figure 25
MULTIPLICATION V

DECIMAL

1734	6148
	5
1735	1

173	46148
	5
173	9

BINARY

11010	1010
	1
11011	

1101	01010
	1
1101	1

Figure 26
ROUNDING OFF

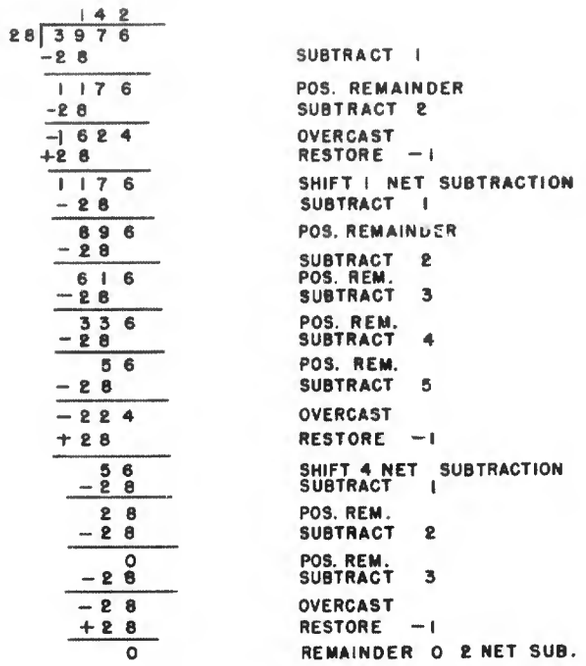


Figure 27

DECIMAL DIVISION

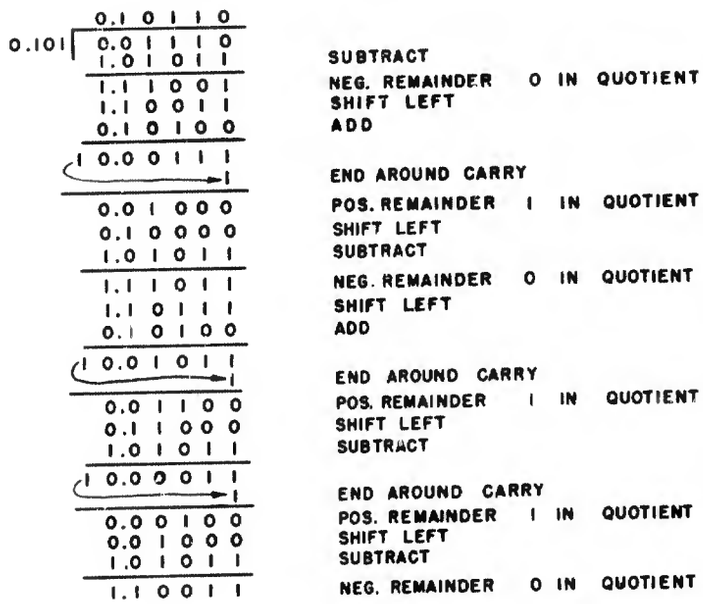


Figure 28

BINARY DIVISION

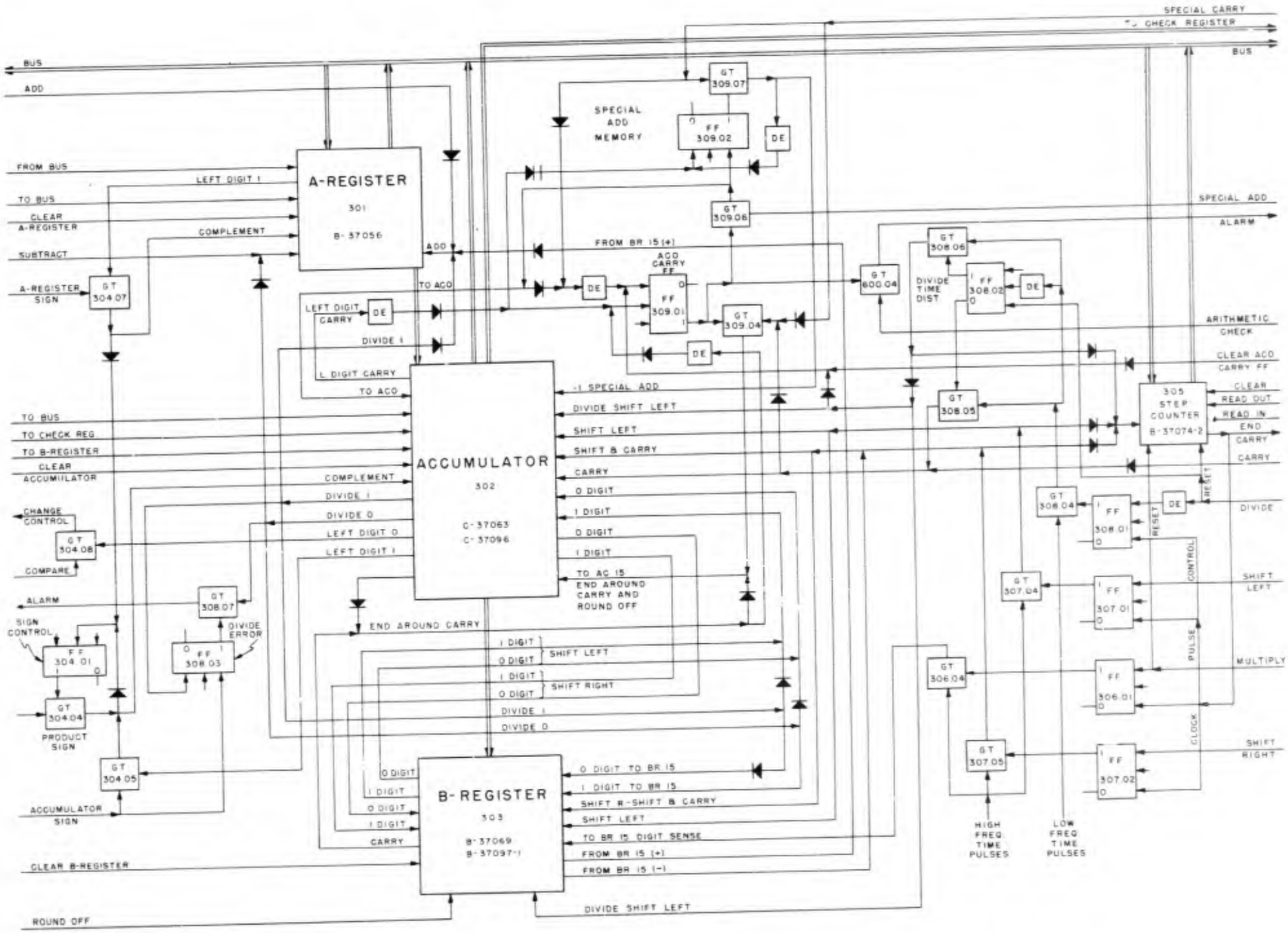


Figure 29

ARITHMETIC ELEMENT

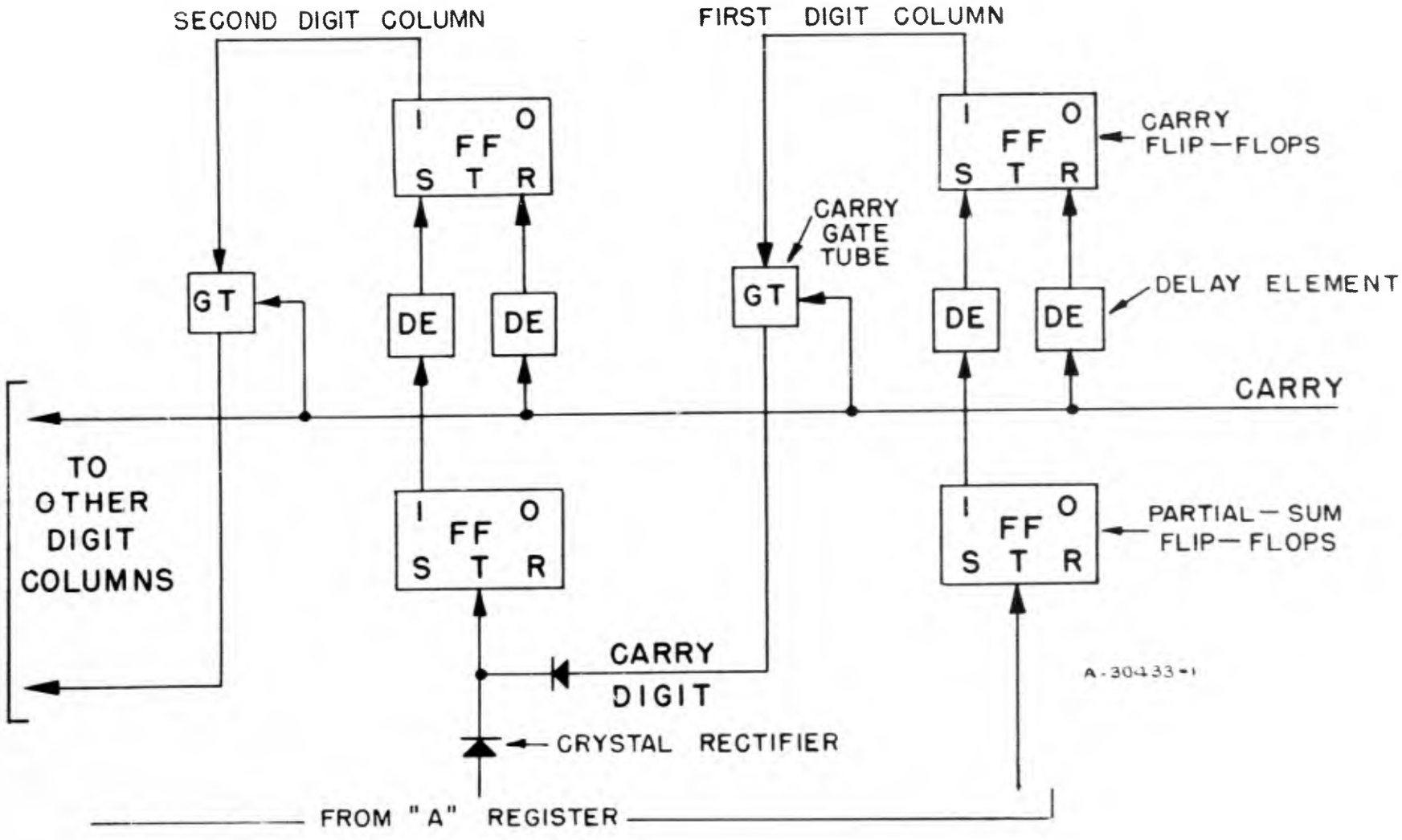


Figure 30

ACCUMULATOR

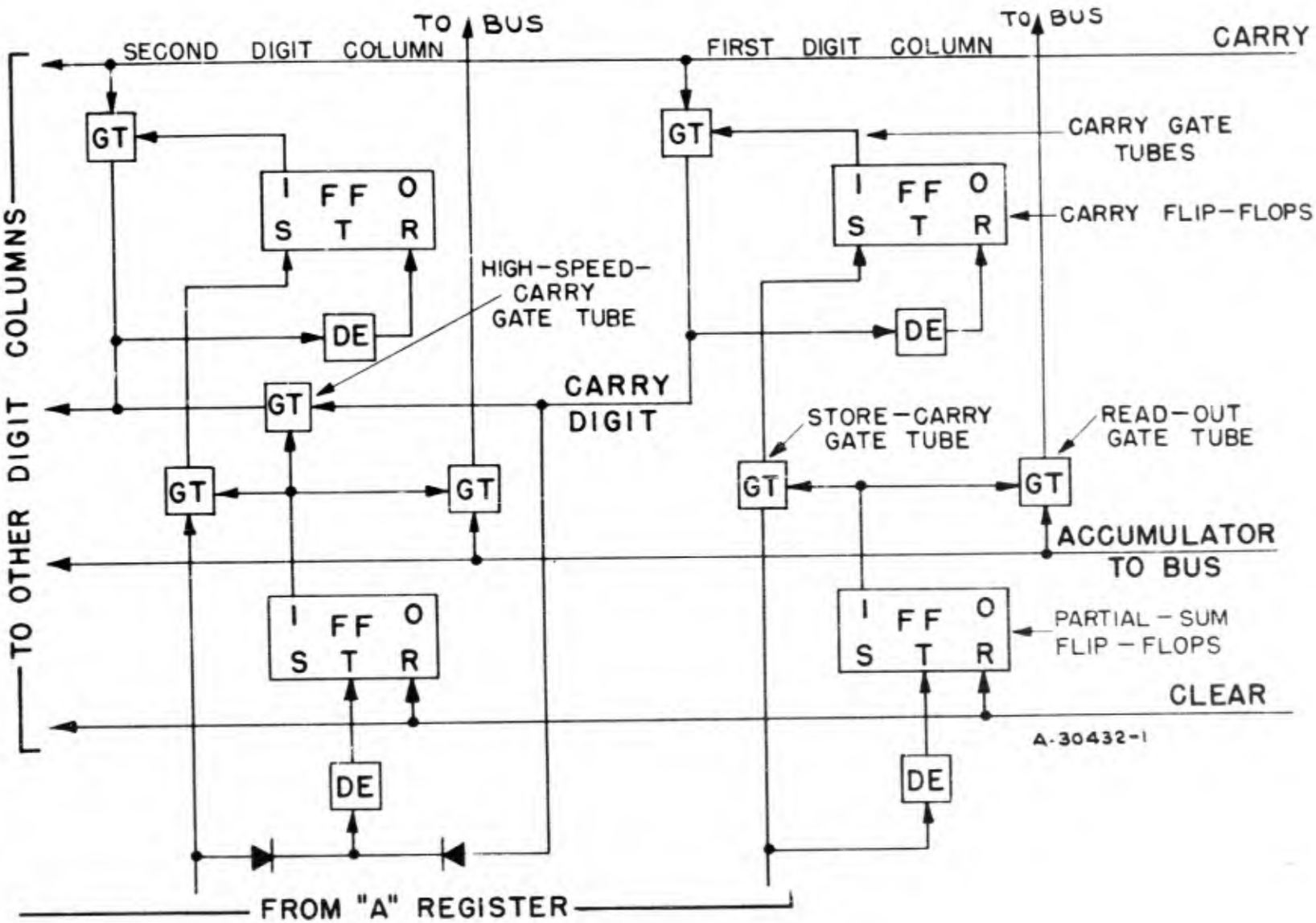


Figure 31
ACCUMULATOR

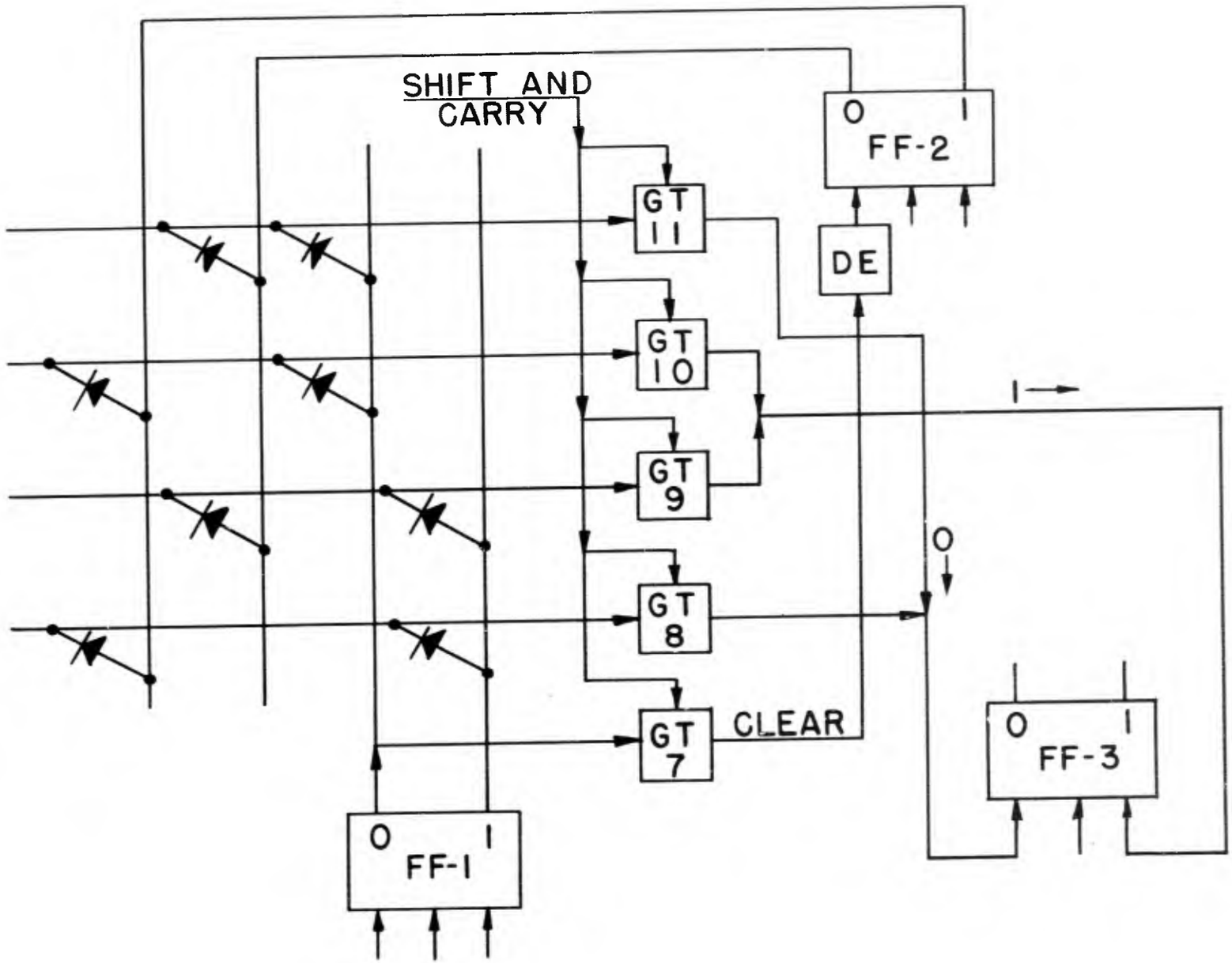


Figure 32
SHIFT AND CARRY

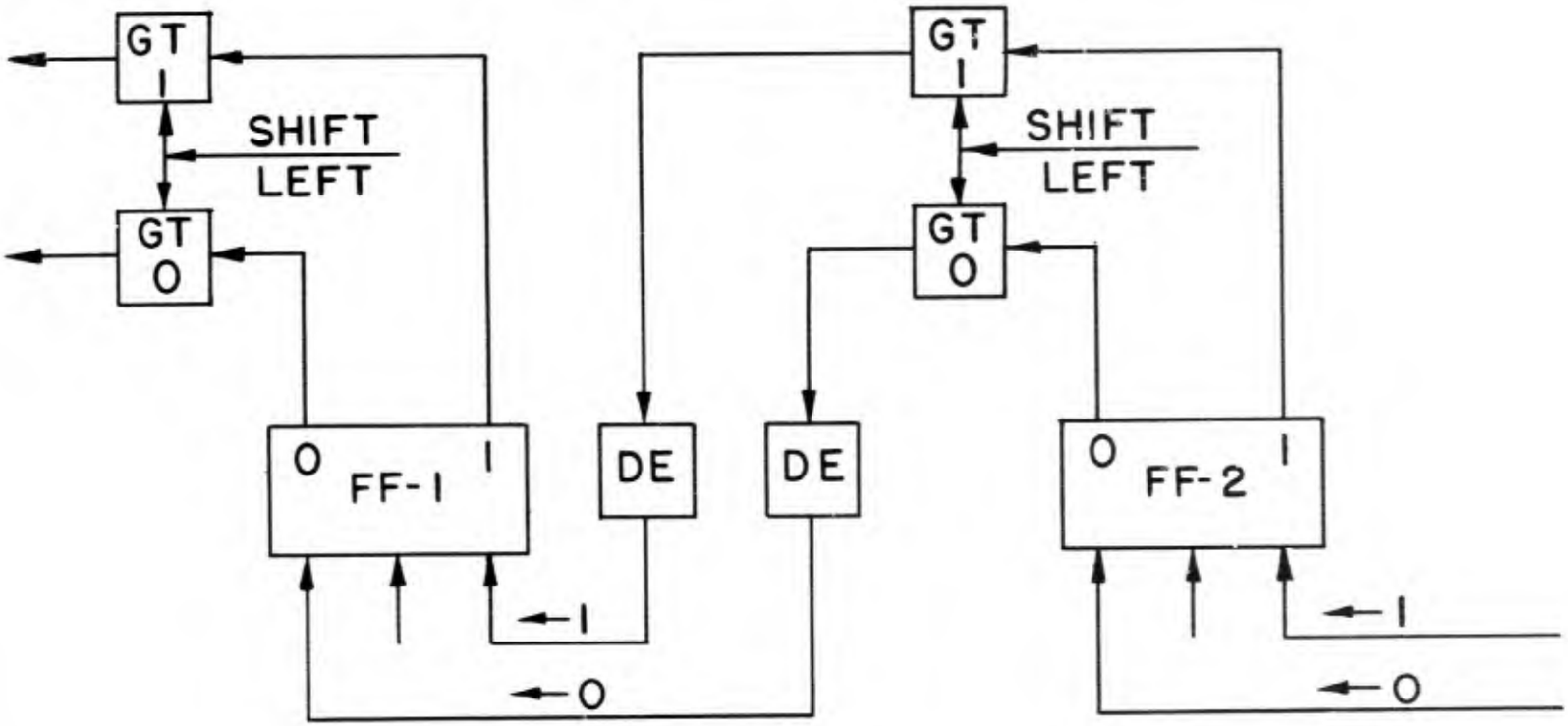


Figure 33
SHIFT LEFT

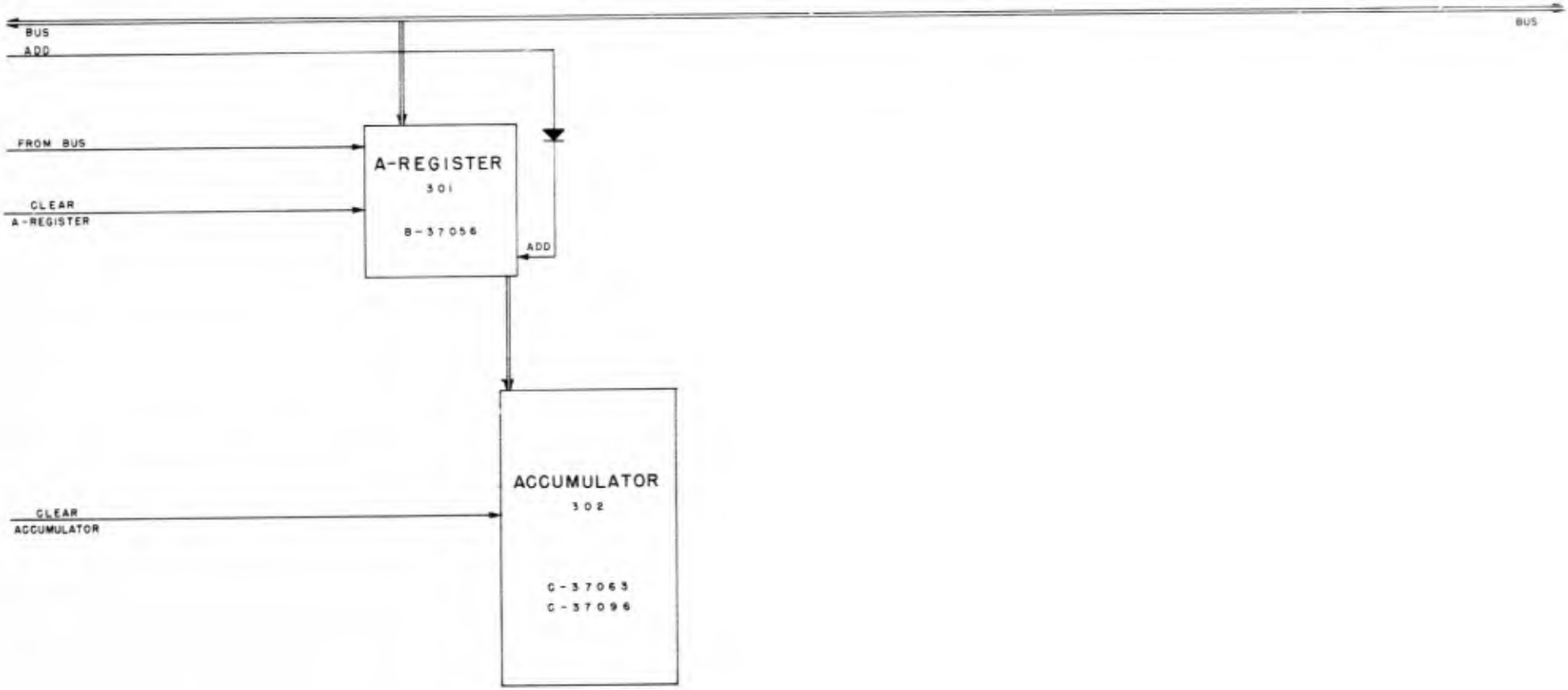


Figure 34
CLEAR AND ADD

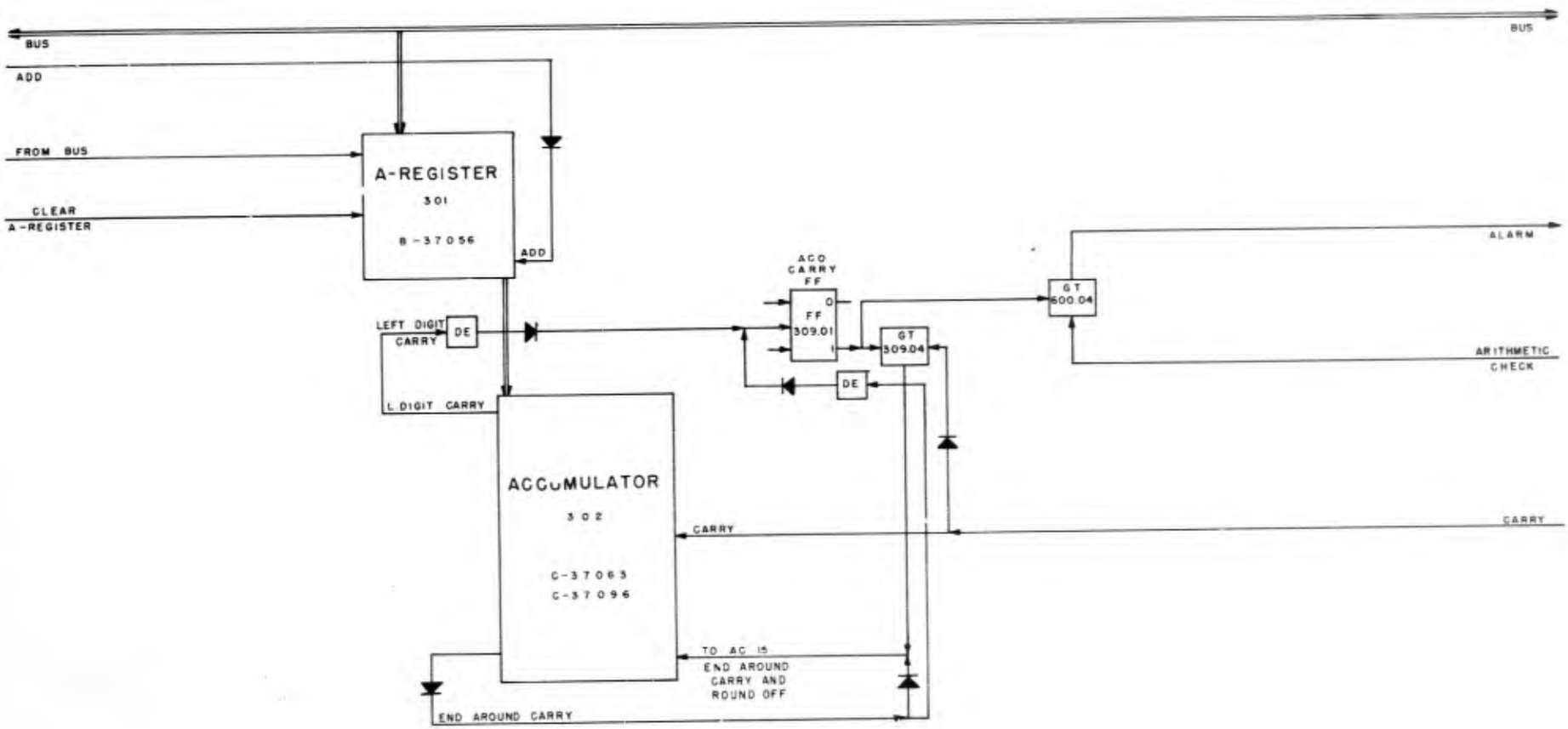


Figure 35
ADD

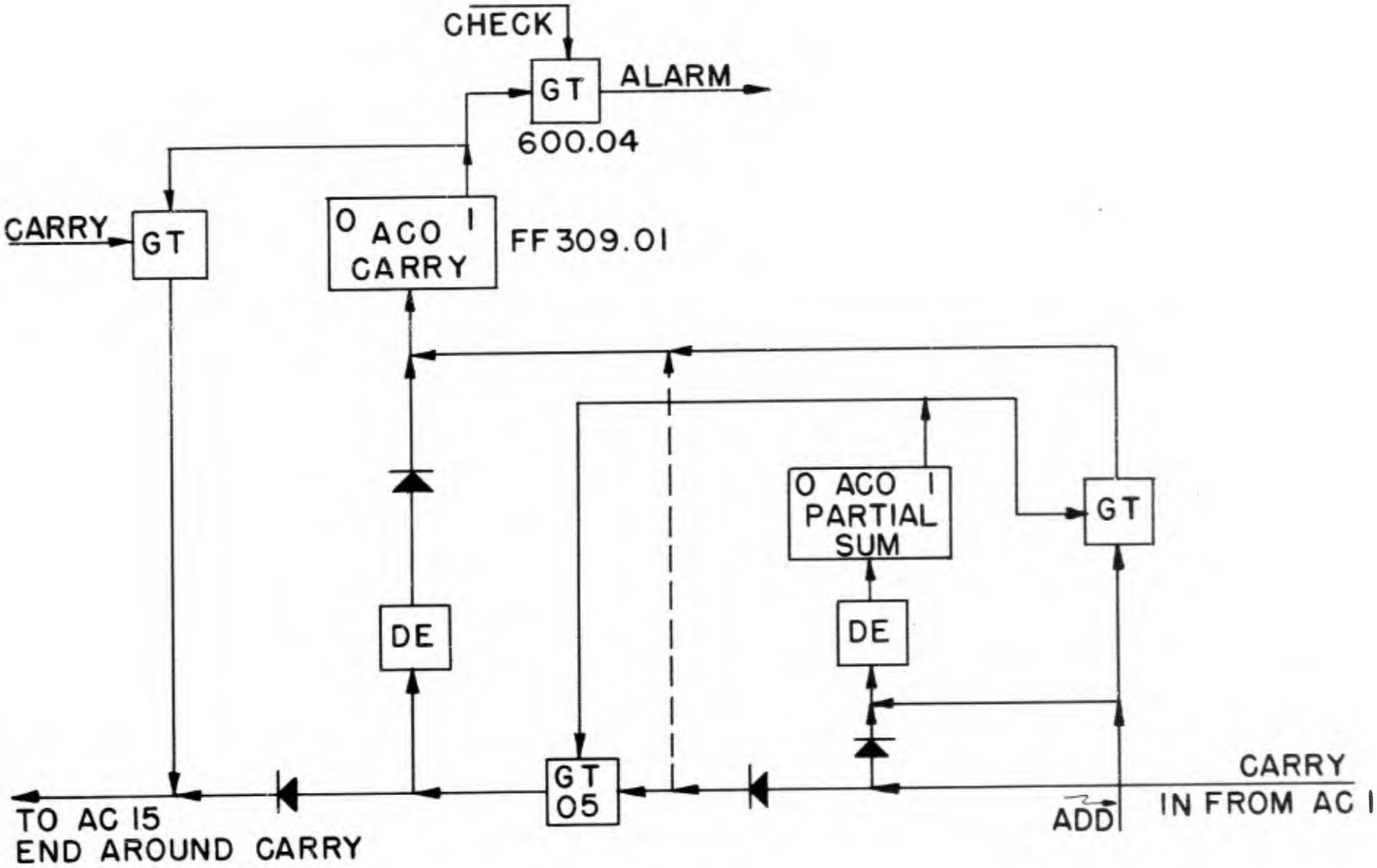


Figure 36
ARITHMETIC CHECK

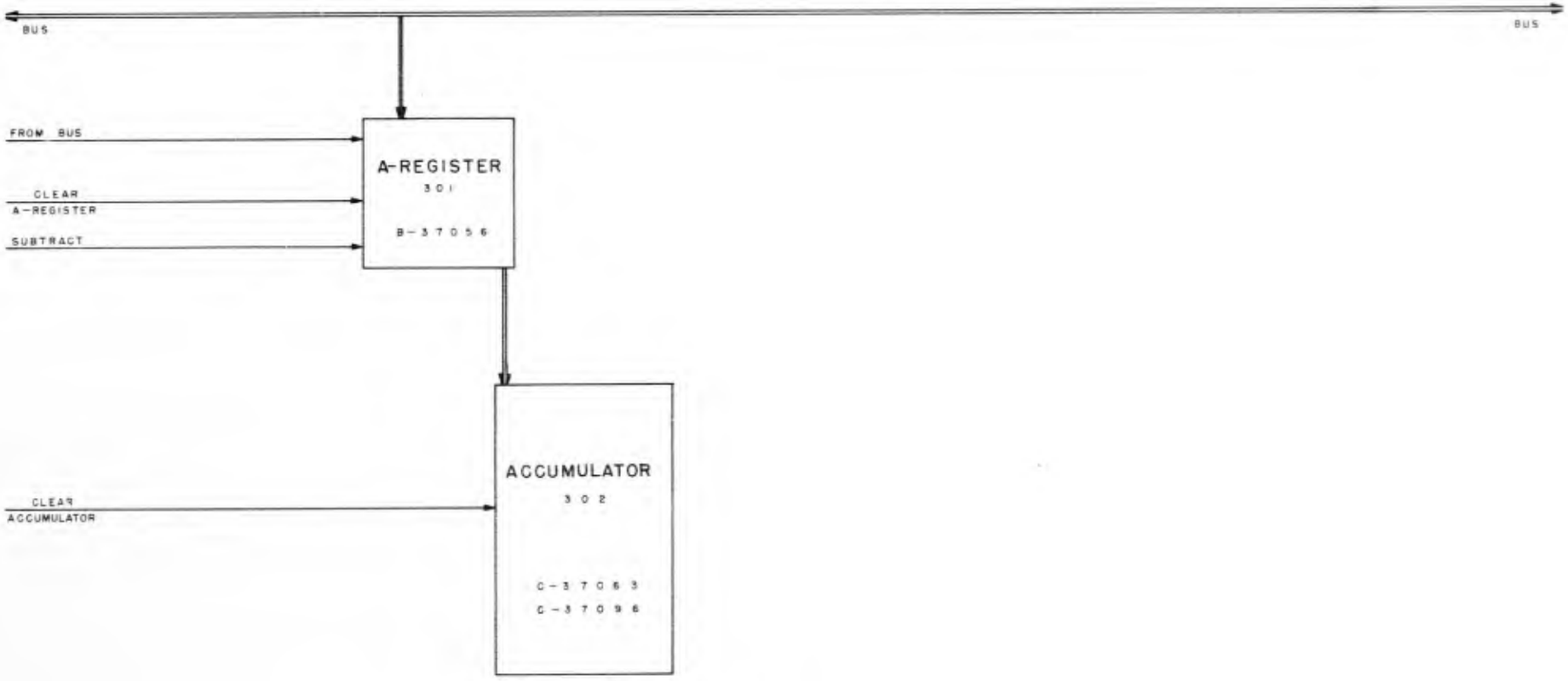


Figure 37

CLEAR AND SUBTRACT

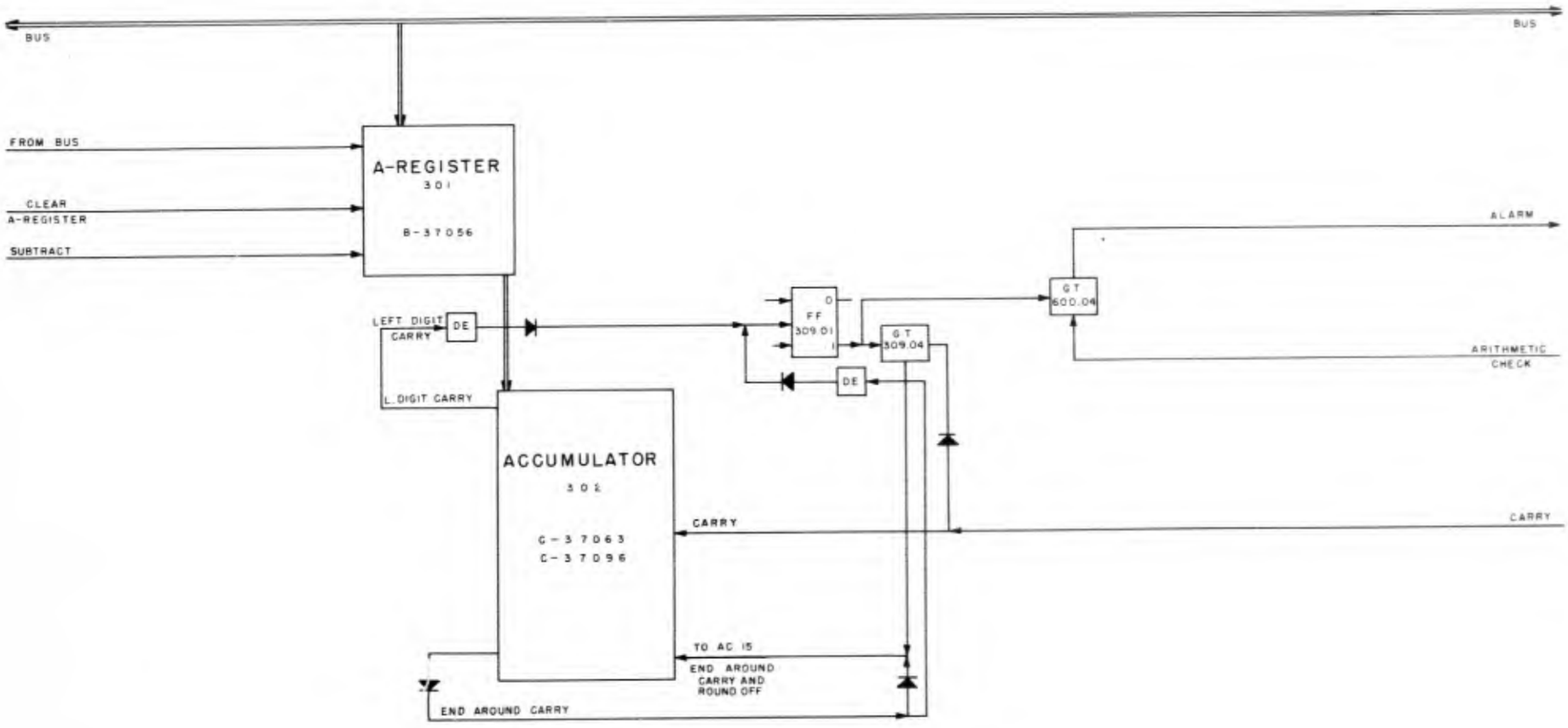


Figure 38
SUBTRACT

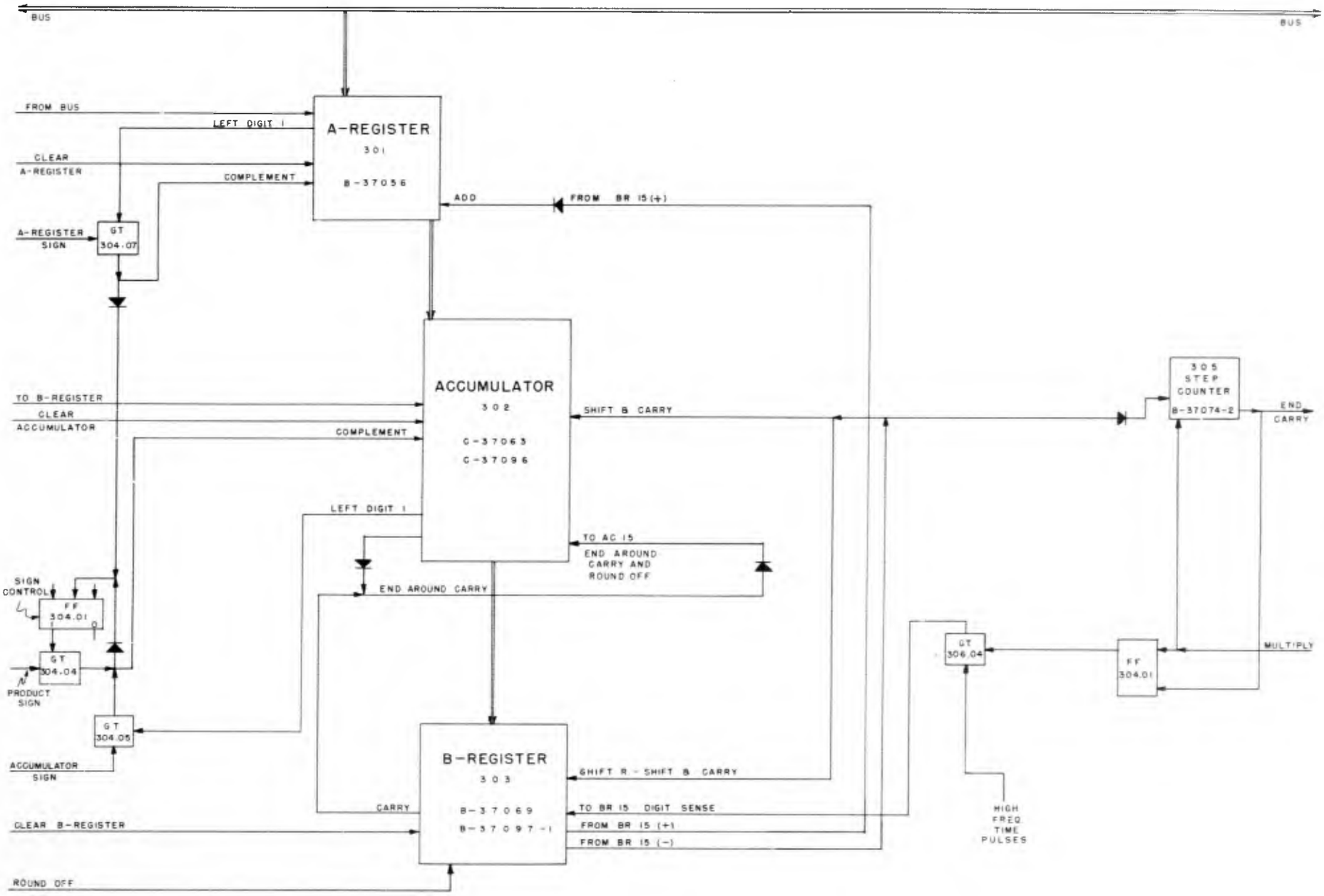


Figure 39

MULTIPLY AND ROUNDOFF

MULTIPLY AND HOLD FULL PRODUCT

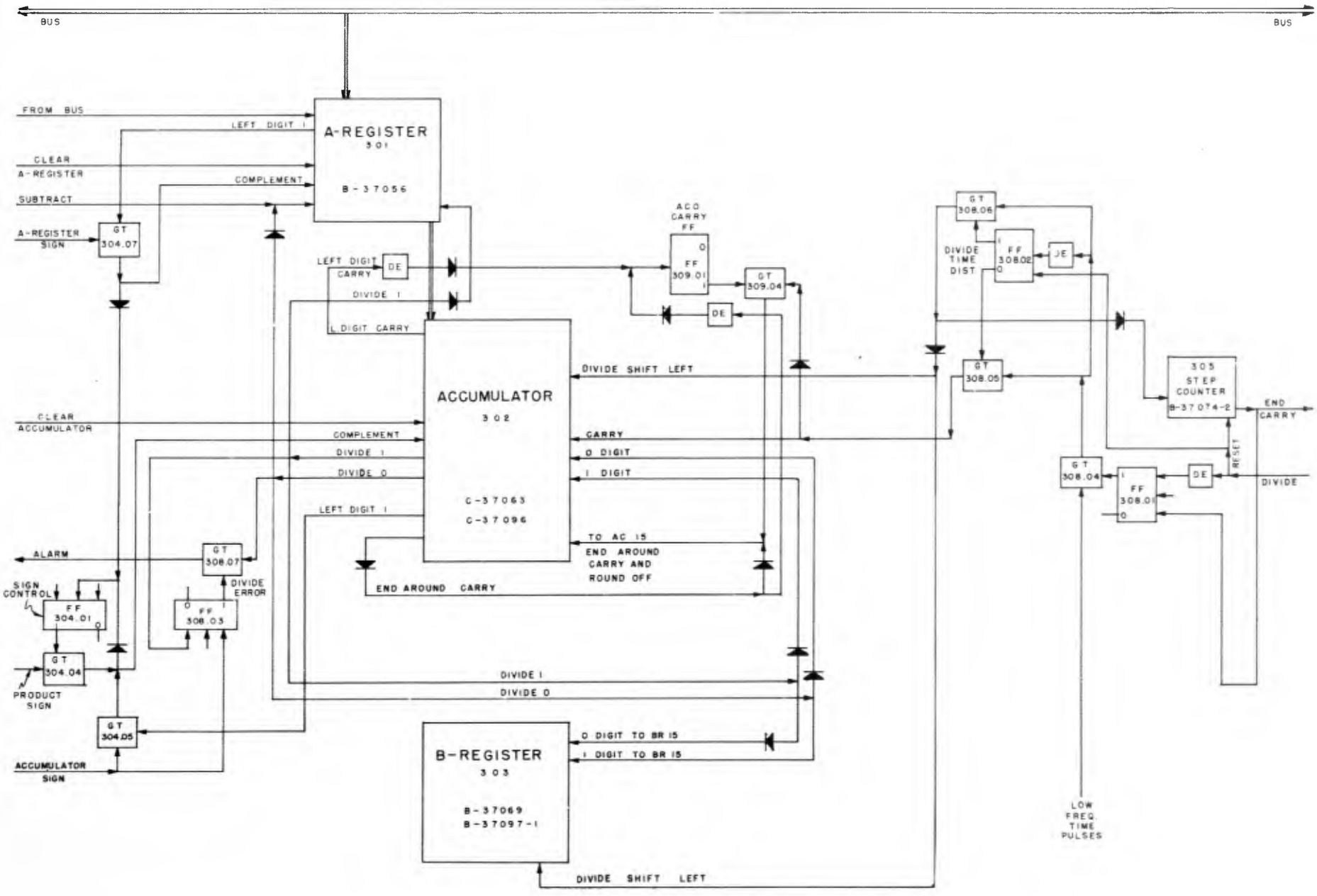


Figure 40

DIVIDE

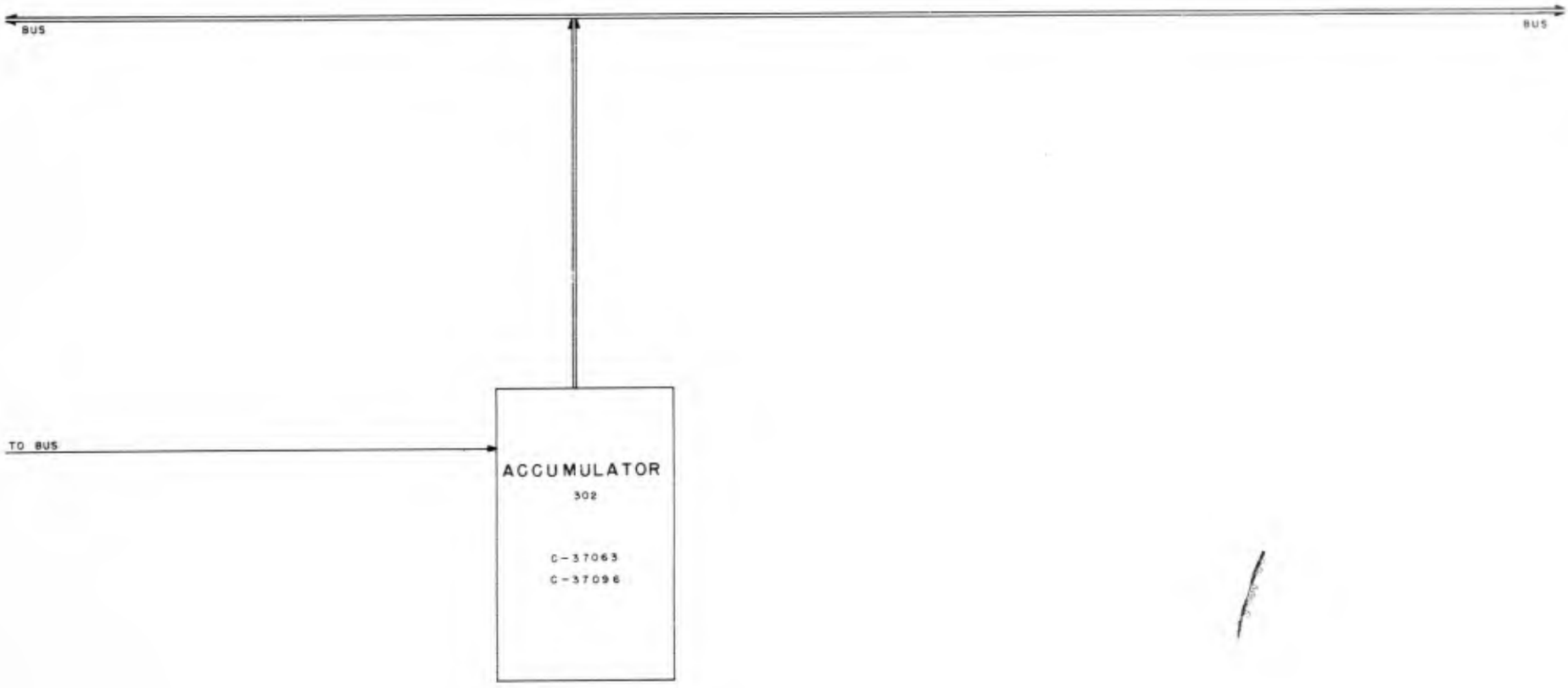


Figure 41

TRANSFER TO STORAGE

TRANSFER DIGITS

STORE AND DISPLAY

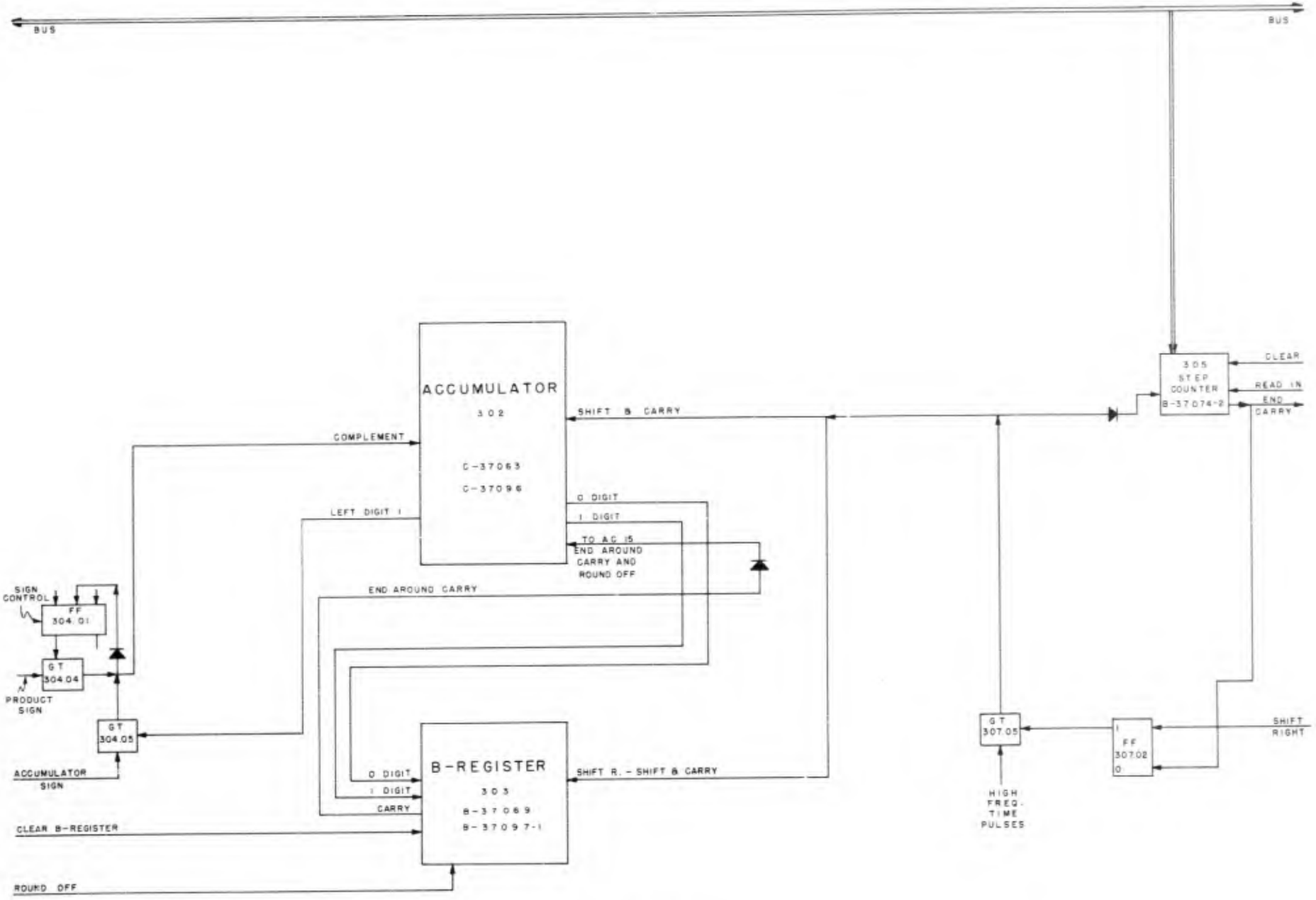


Figure 42

SHIFT RIGHT

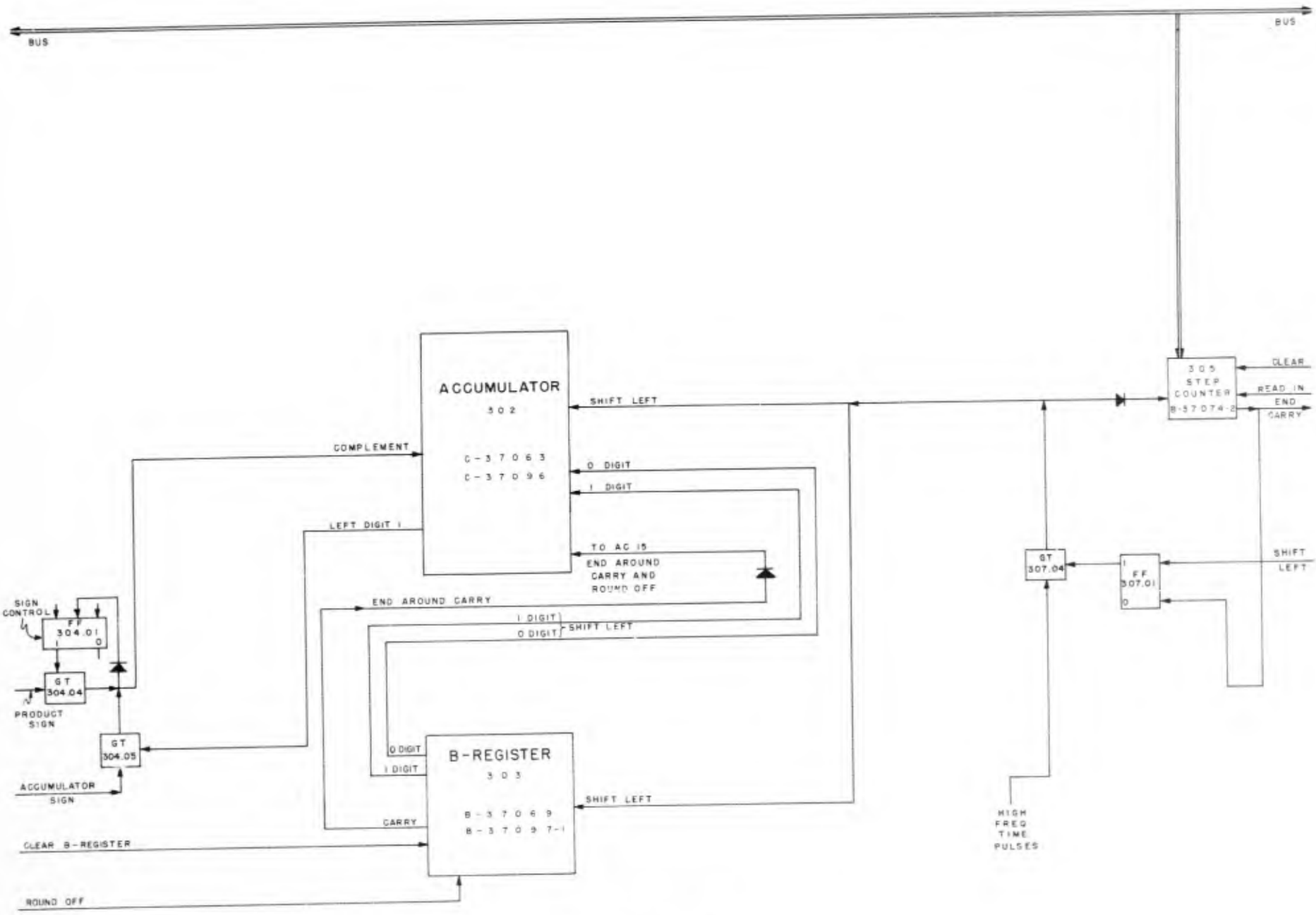


Figure 43

SHIFT LEFT

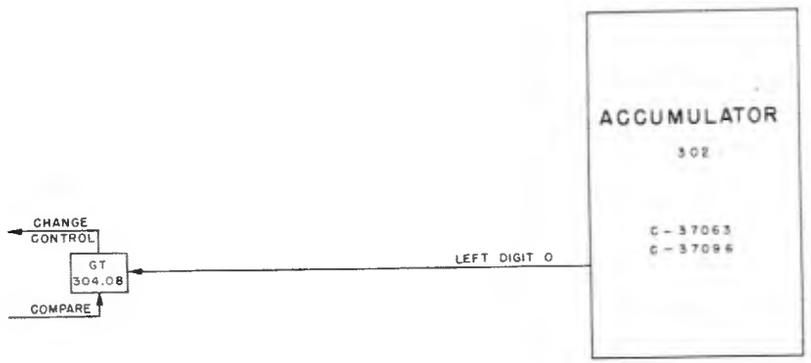


Figure 44
CONDITIONAL PROGRAM

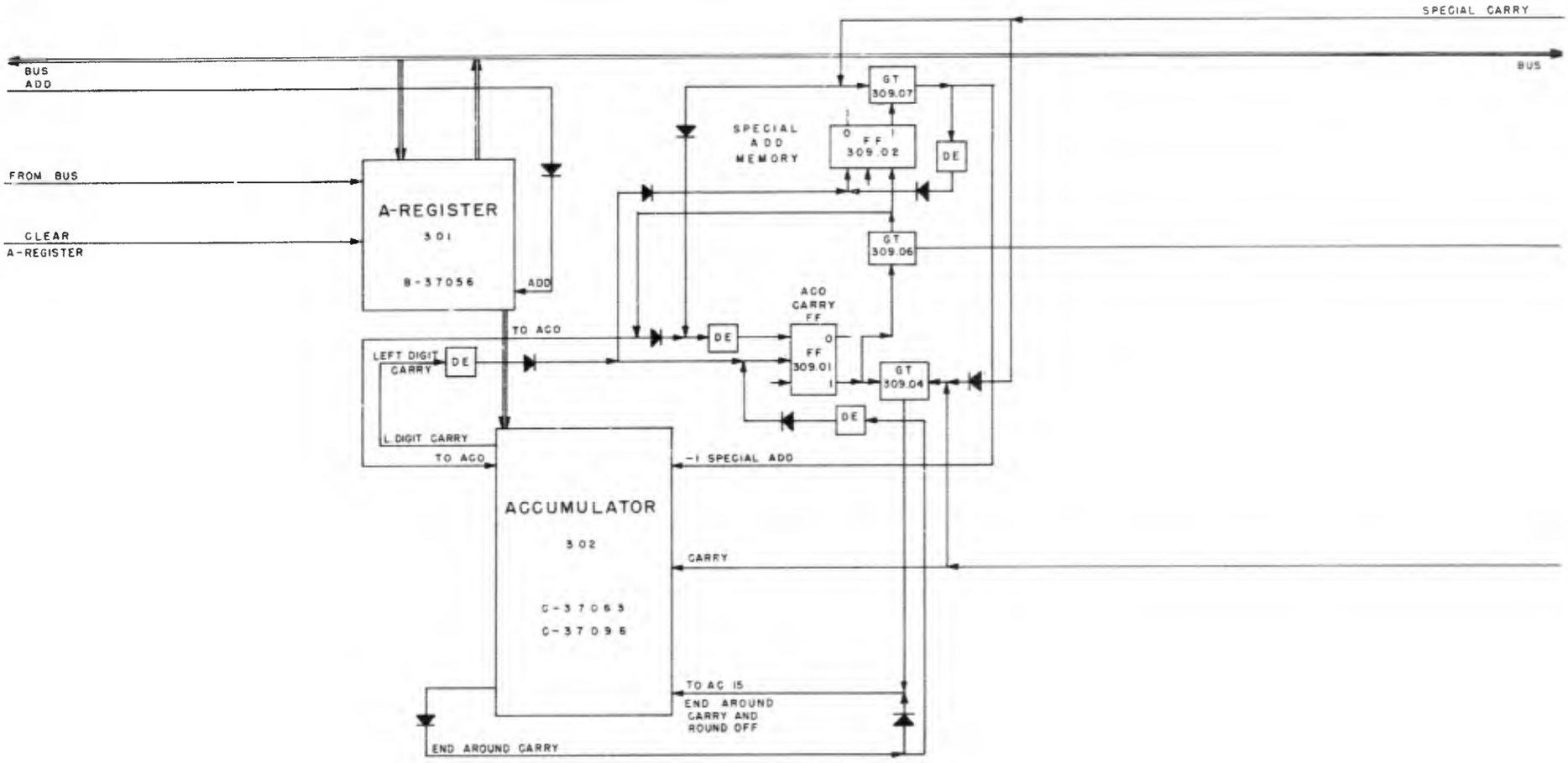


Figure 45
SPECIAL ADD

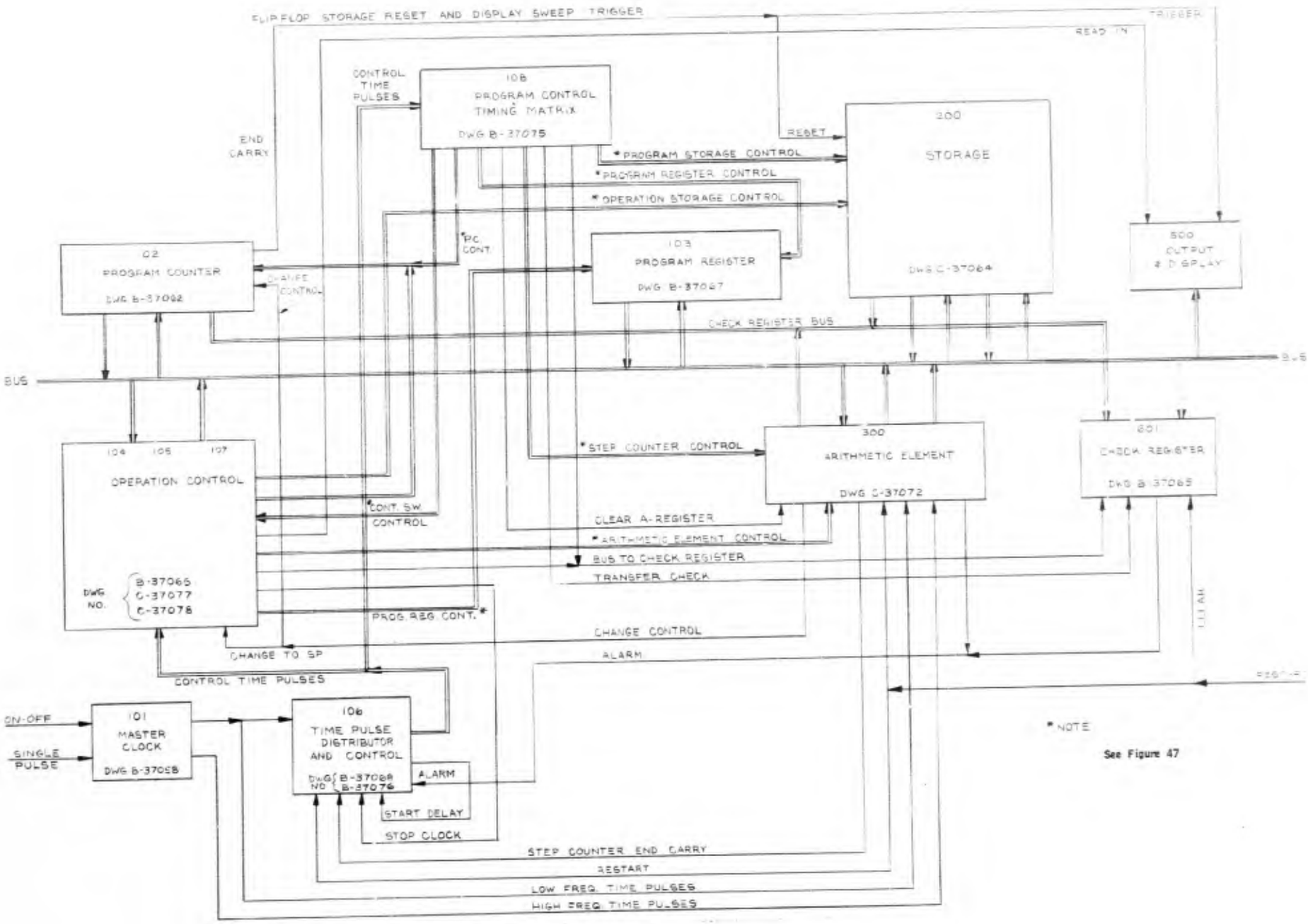


Figure 46

SYSTEM BLOCK DIAGRAM

ARITHMETIC ELEMENT CONTROL

1.	Bus to A-Register	GT 301.01
2.	A-Register to Bus	GT 301.02
3.	Subtract: A-Register to Accum.	GT 301.04
4.	Add: A-Register to Accumulator	GT 301.05
5.	Accumulator to Bus	GT 302.02
6.	Accumulator to Check Register	GT 302.03
7.	Accumulator to B-Register	GT 302.04
8.	Carry	GT 302.20
9.	Roundoff	GT 303.08
10.	Product Sign	GT 304.04
11.	Accumulator Sign	GT 304.05
12.	A-Register Sign	GT 304.07
13.	Compare	GT 304.08
14.	Multiply	FF 306.01
15.	Shift Left	FF 307.01
16.	Shift Right	FF 307.02
17.	Divide	FF 308.01
18.	Special Add	GT 309.06
19.	Arithmetic Check	GT 600.04
20.	Clear Accumulator	
21.	Clear B-Register	
22.	Special Carry	

PROGRAM COUNTER CONTROL

1.	In from Bus	GT 102.01
2.	Out to Bus	GT 102.02
3.	Out to Check Register	GT 102.03
4.	Add Pulse	
5.	Clear	

PROGRAM REGISTER CONTROL

1.	In from Bus	GT 103.01
2.	Out to Bus	GT 103.02
3.	Clear	

CONTROL SWITCH CONTROL

1.	In from Bus	GT 104.01
2.	Out to Bus	GT 104.02
3.	Clear	

STEP COUNTER CONTROL

1.	In from Bus	GT 305.01
2.	Out to Bus	GT 305.02
3.	Clear	

PROGRAM STORAGE CONTROL

1.	Bus to Storage Switch	GT 201.01
2.	Storage Switch to Bus	GT 201.02
3.	Storage Readout	GT 203.02
4.	Storage Switch Clear	
5.	Storage to Check Register	GT 203.03

OPERATION STORAGE CONTROL

1.	In from Bus	GT 203.01
2.	Storage Readout	GT 203.02
3.	Out to Check Register	GT 203.03
4.	Storage Clear	

NOTE: See Figure 46

Figure 47

CONTROL FUNCTIONS

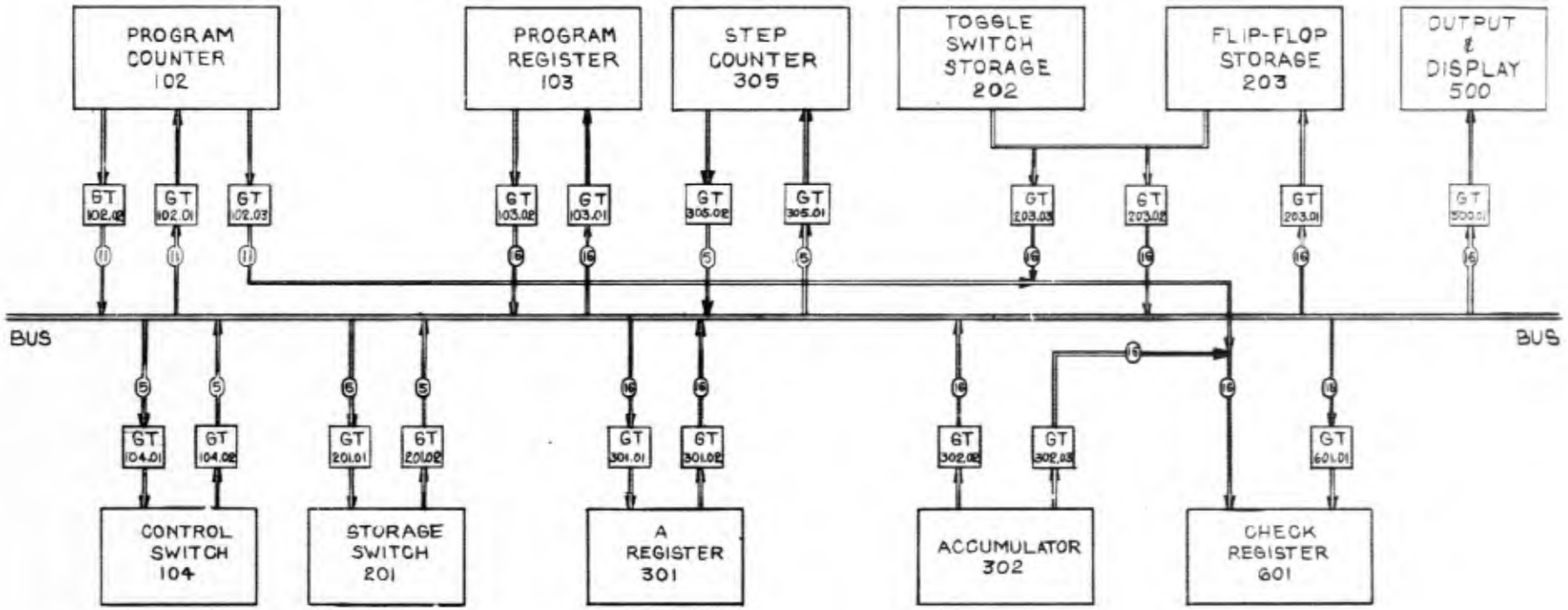


Figure 48

BUS CONNECTIONS

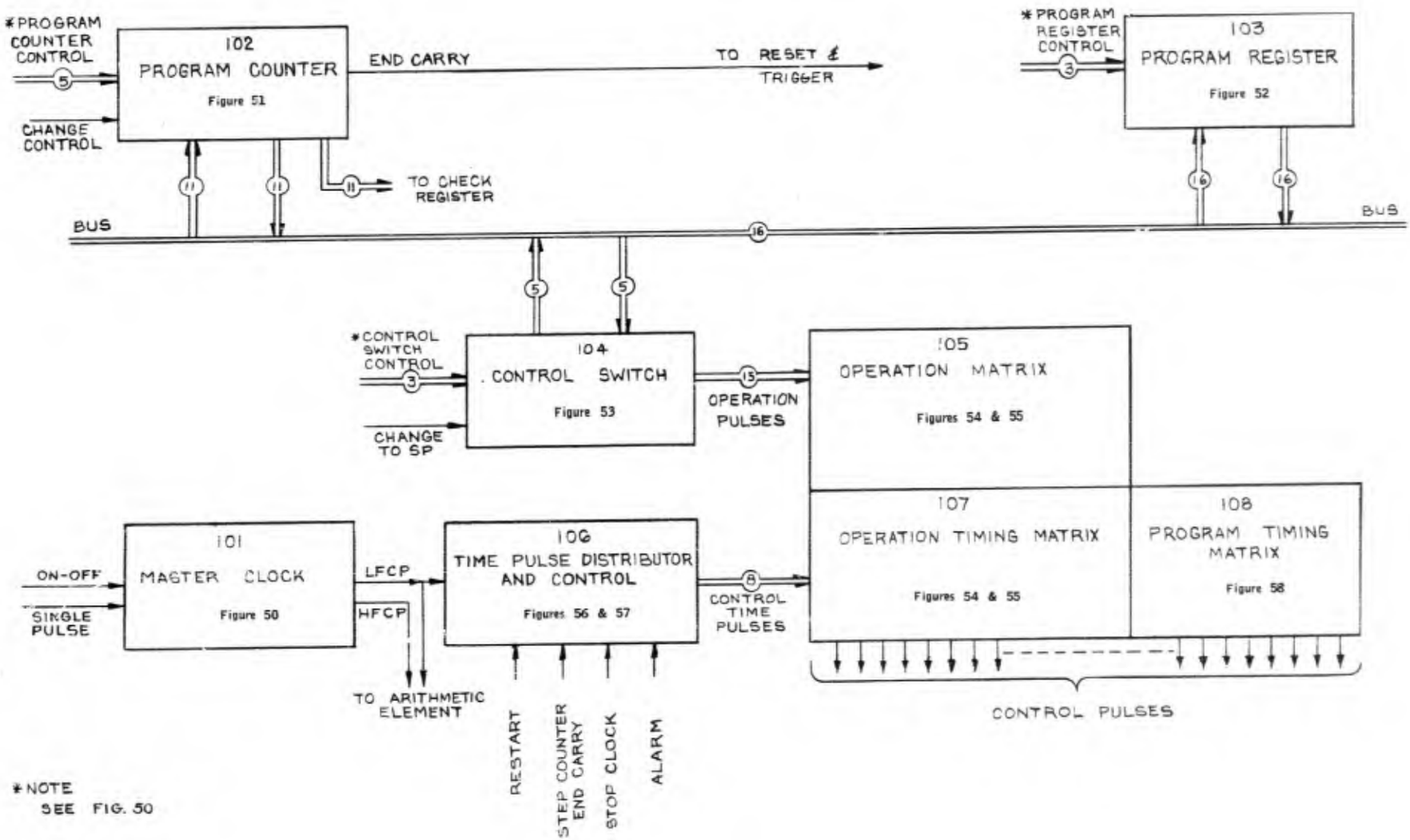


Figure 49

CONTROL

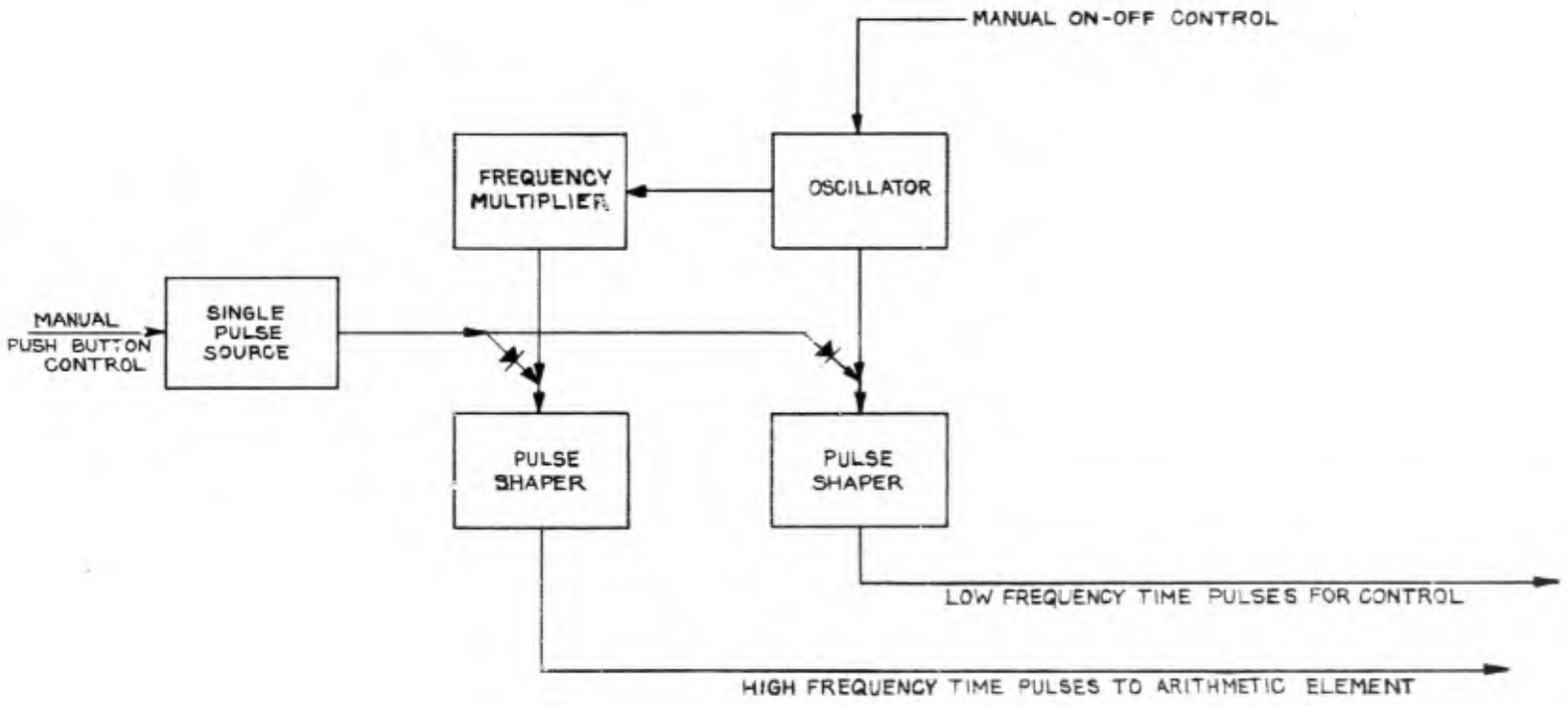


Figure 50
MASTER CLOCK

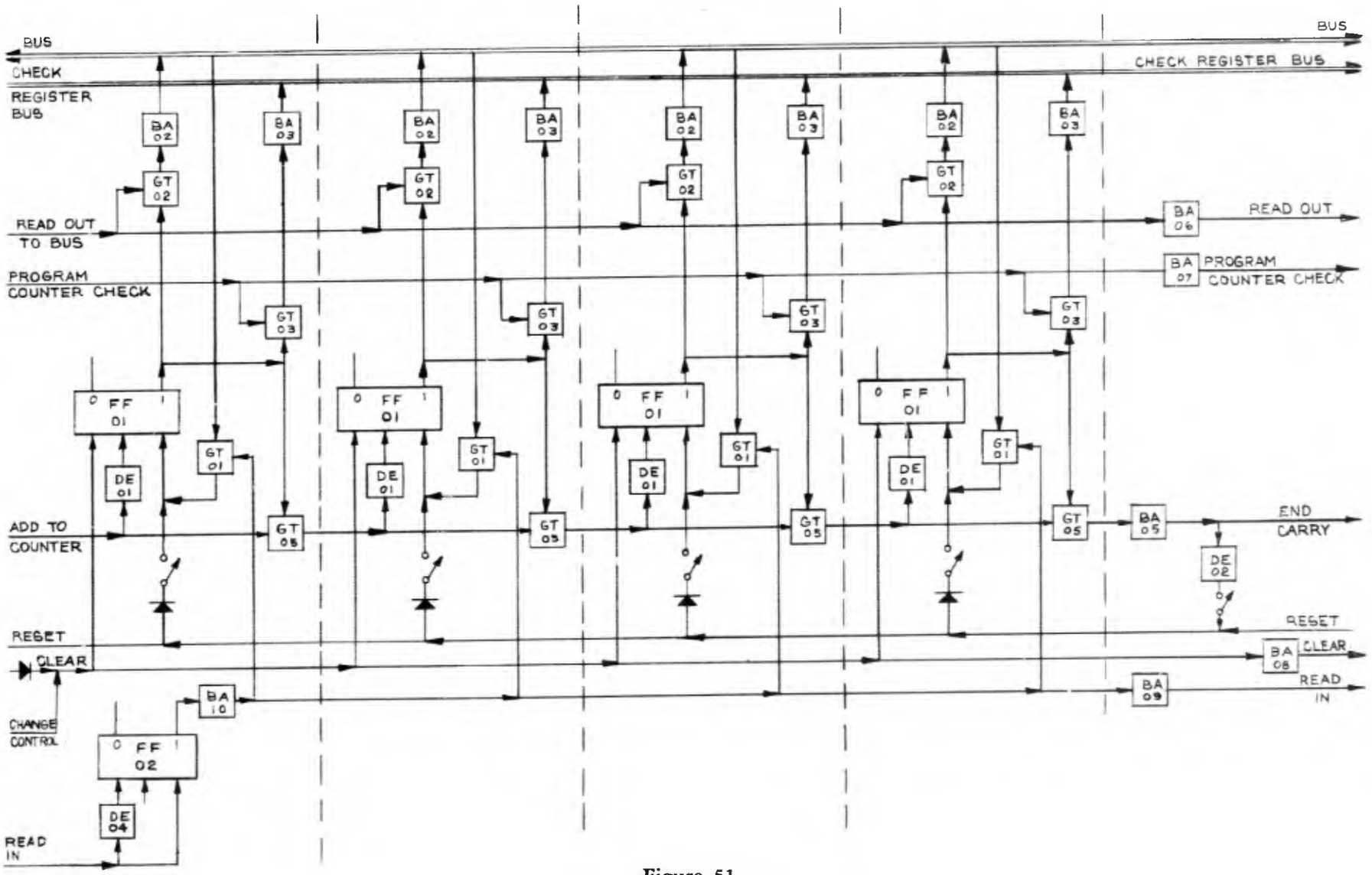


Figure 51

PROGRAM COUNTER

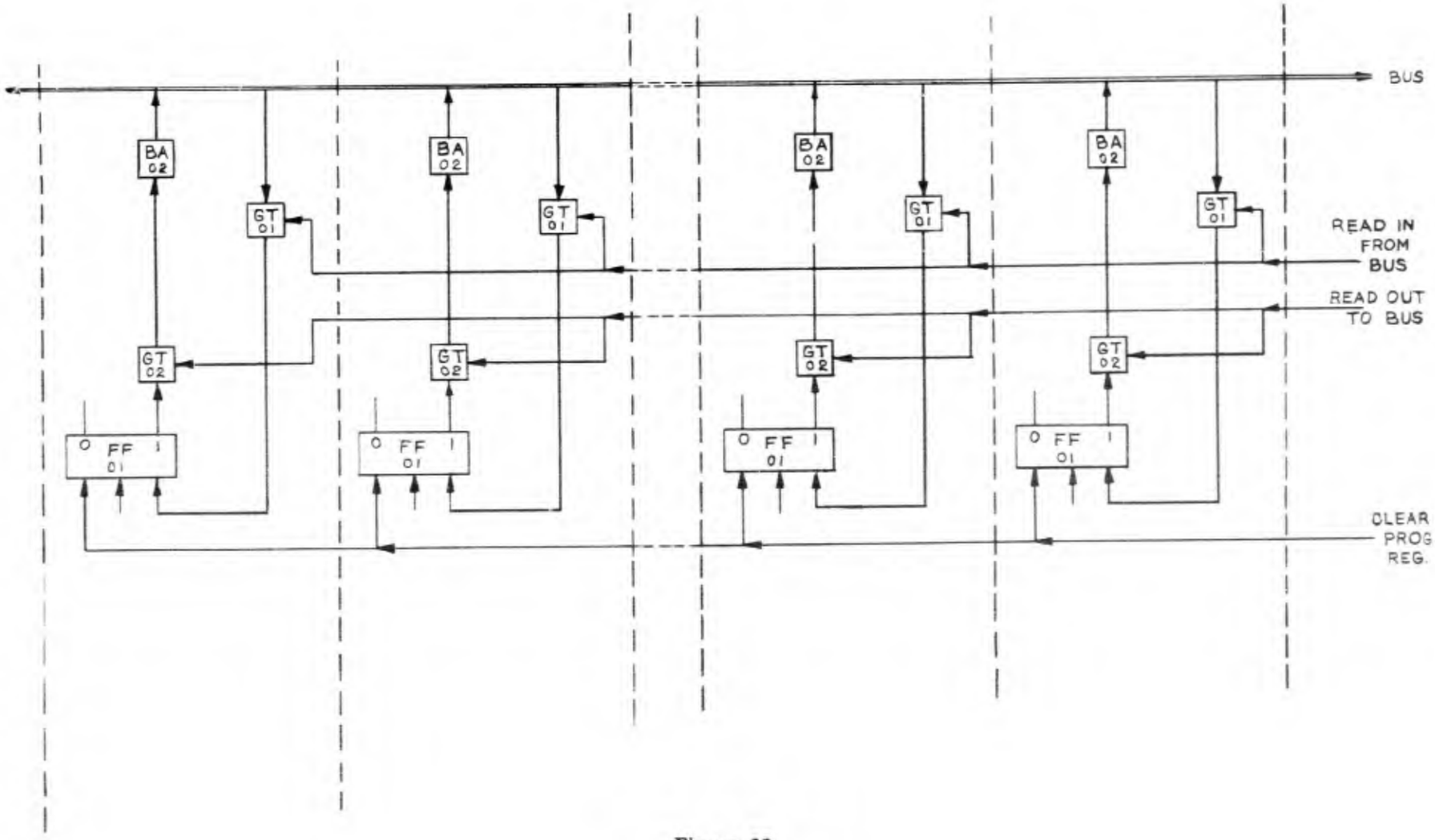


Figure 52

PROGRAM REGISTER

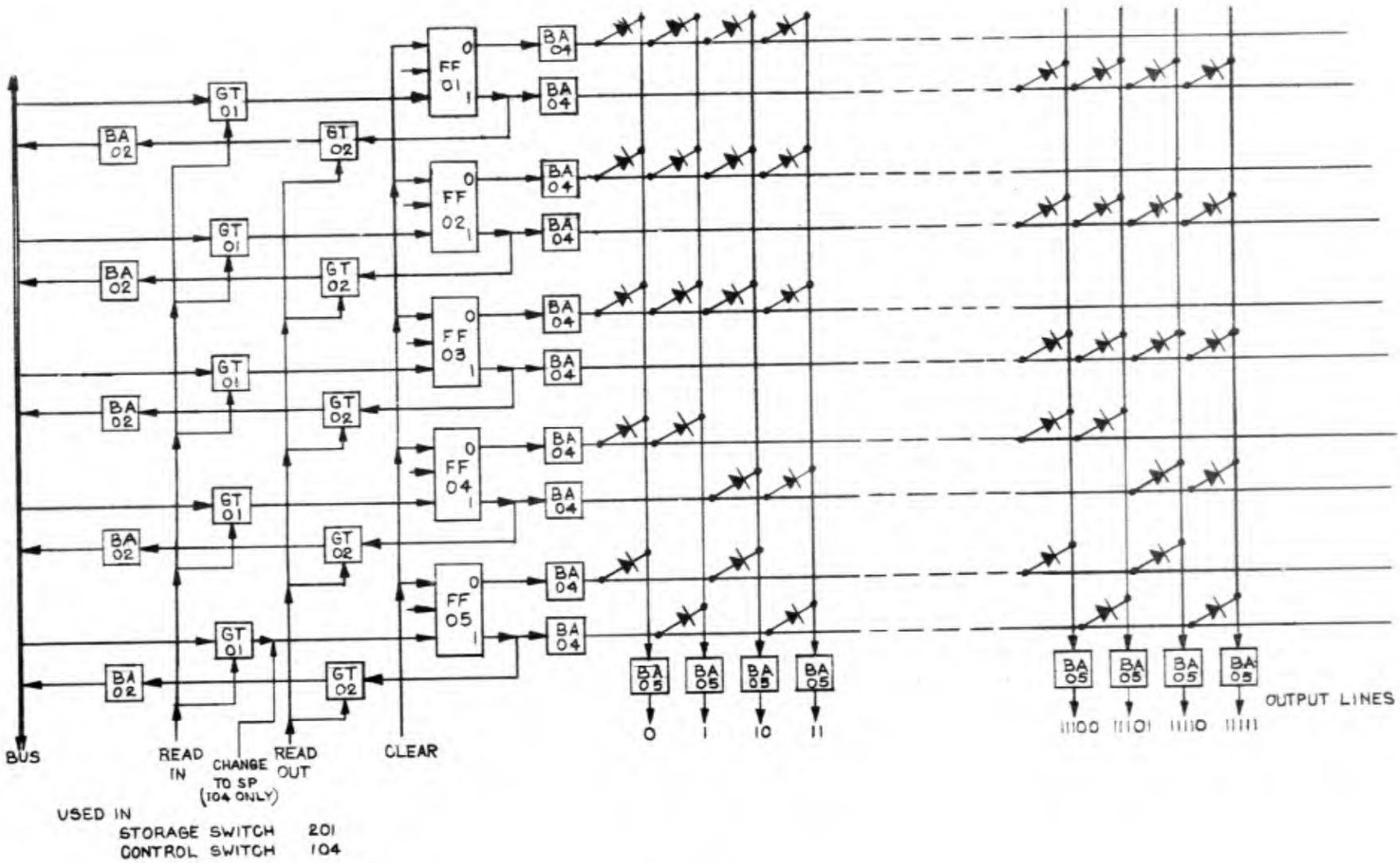


Figure 53
CONTROL SWITCH

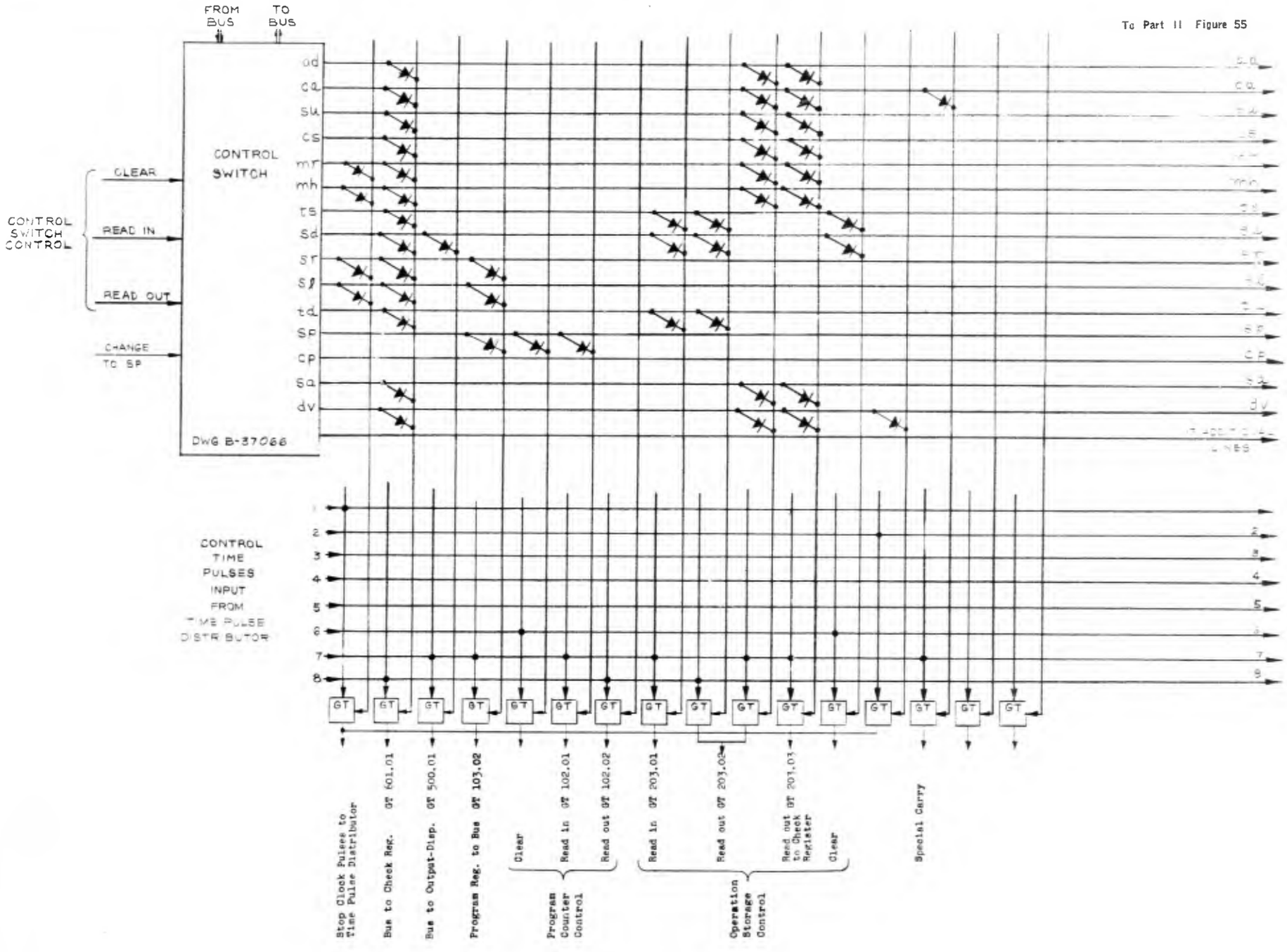


Figure 54

OPERATION MATRIX I

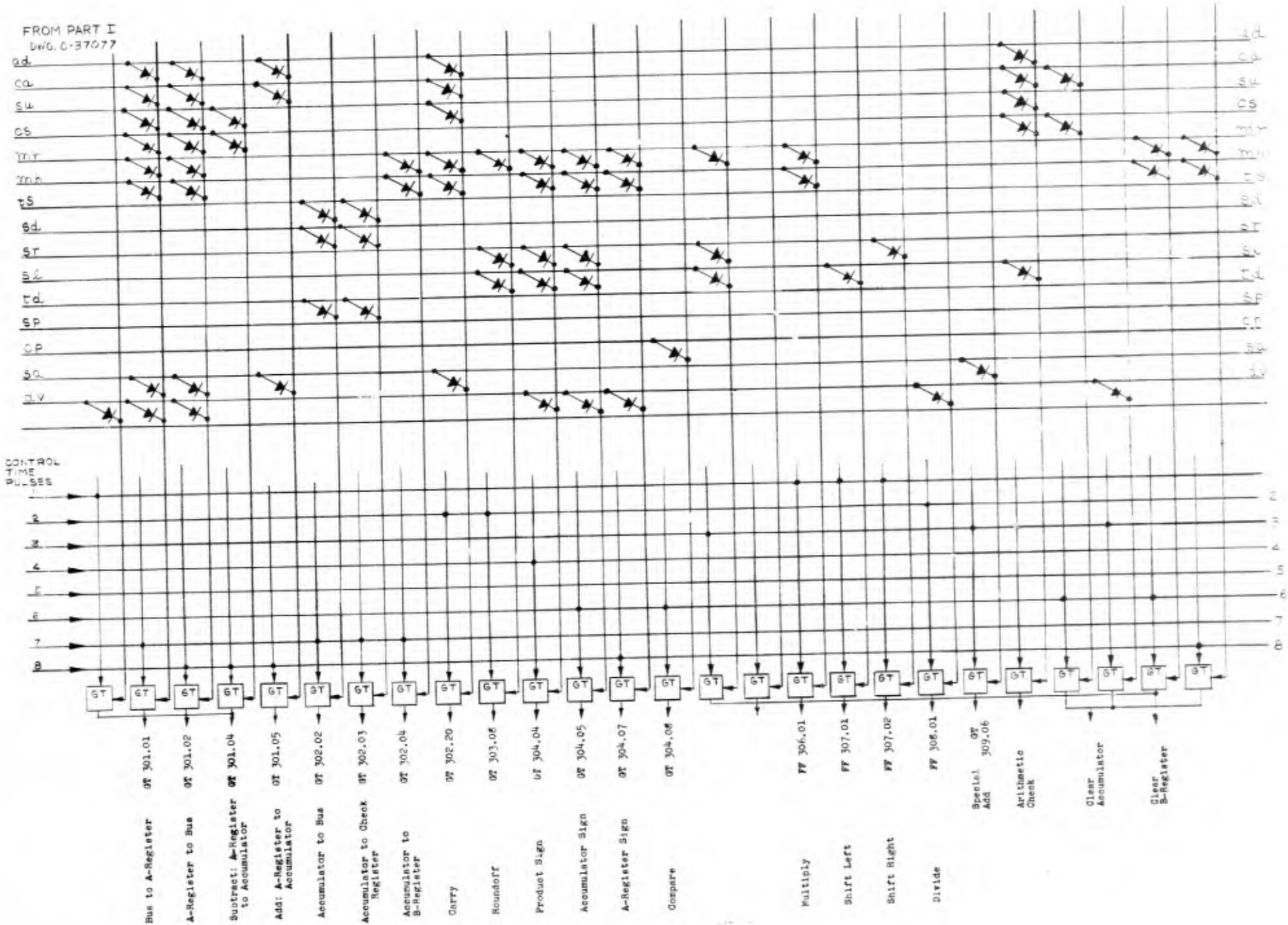


Figure 55

OPERATION MATRIX II

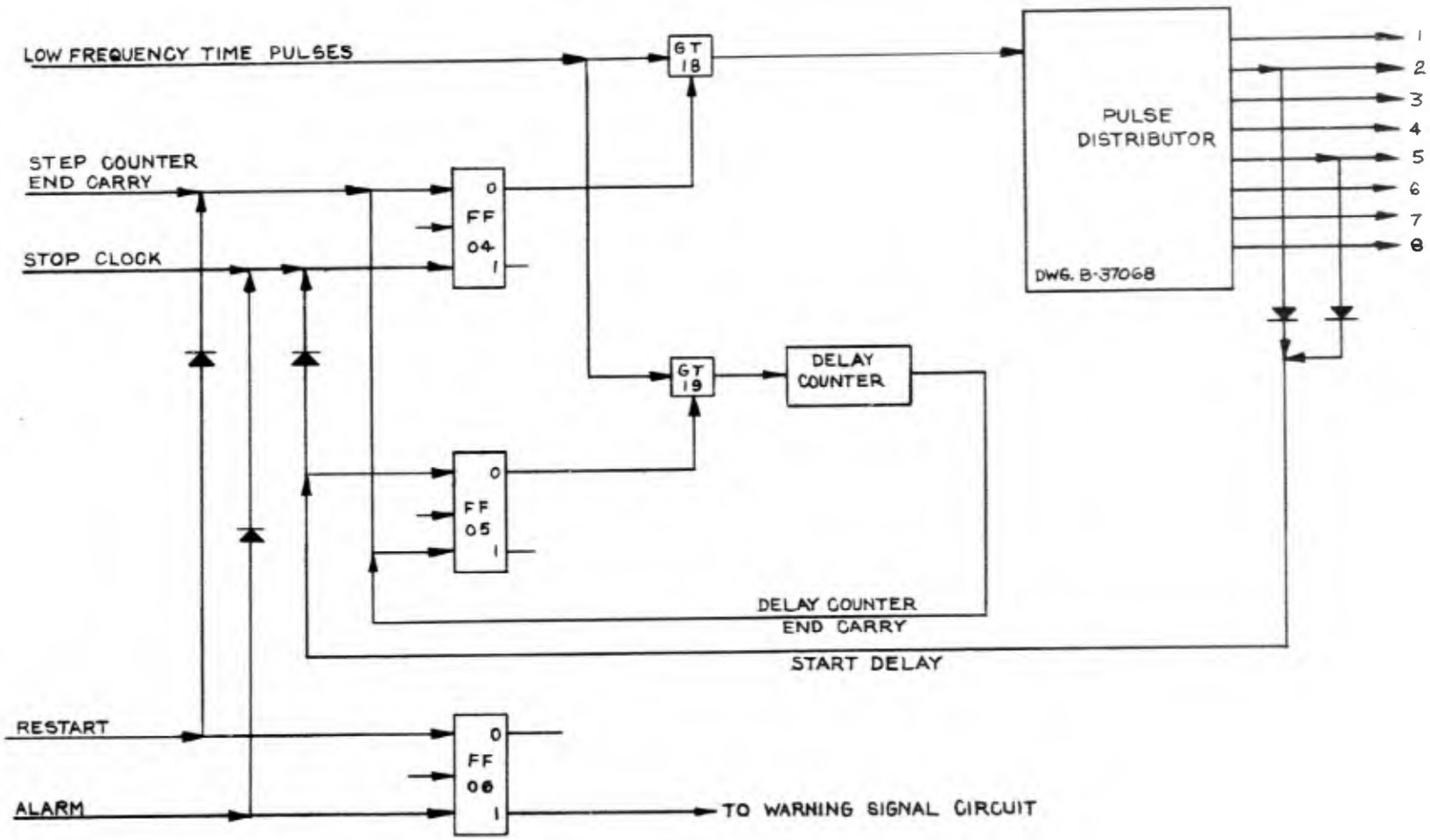


Figure 56

TIME PULSE DISTRIBUTOR CONTROL

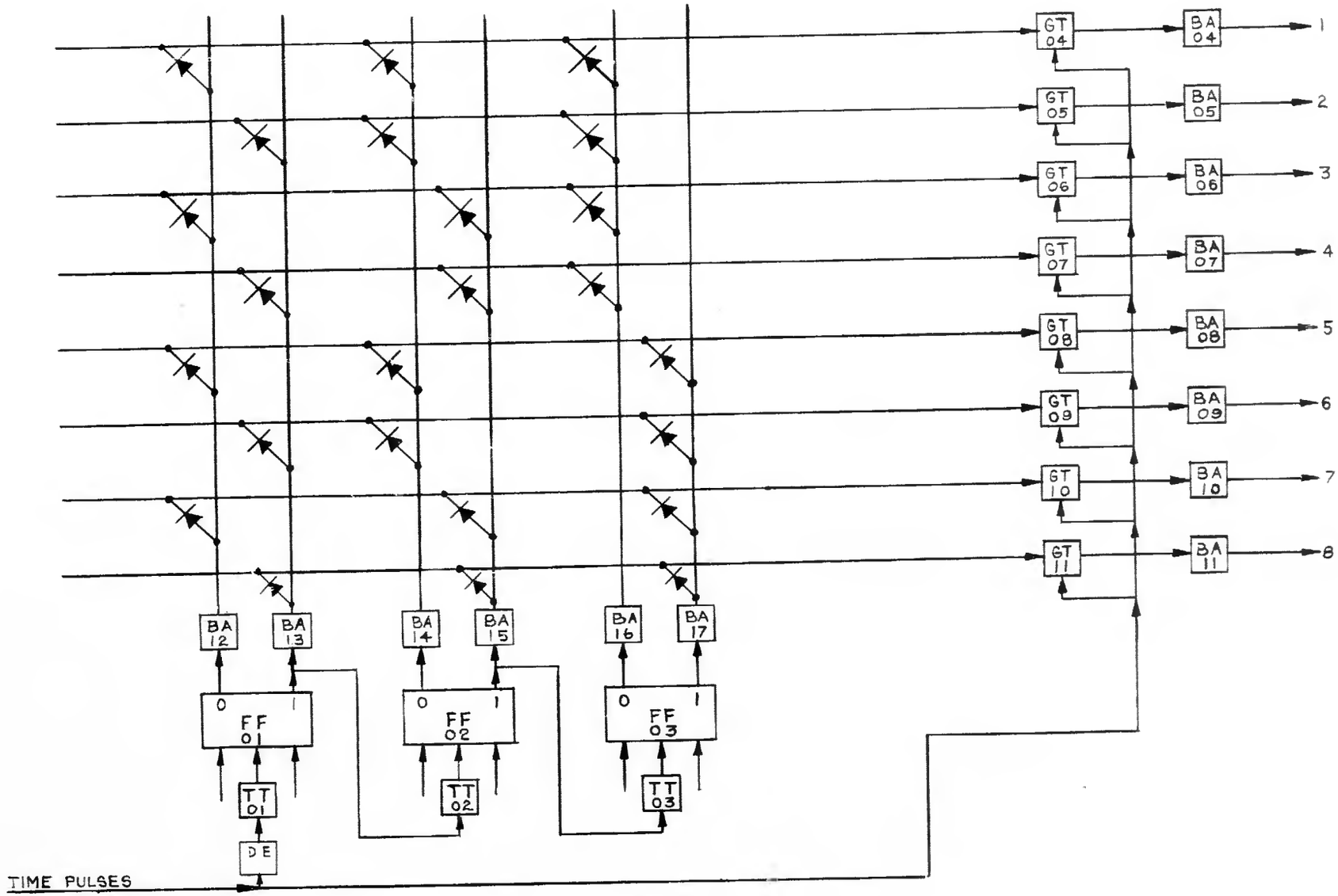


Figure 57

PULSE DISTRIBUTOR

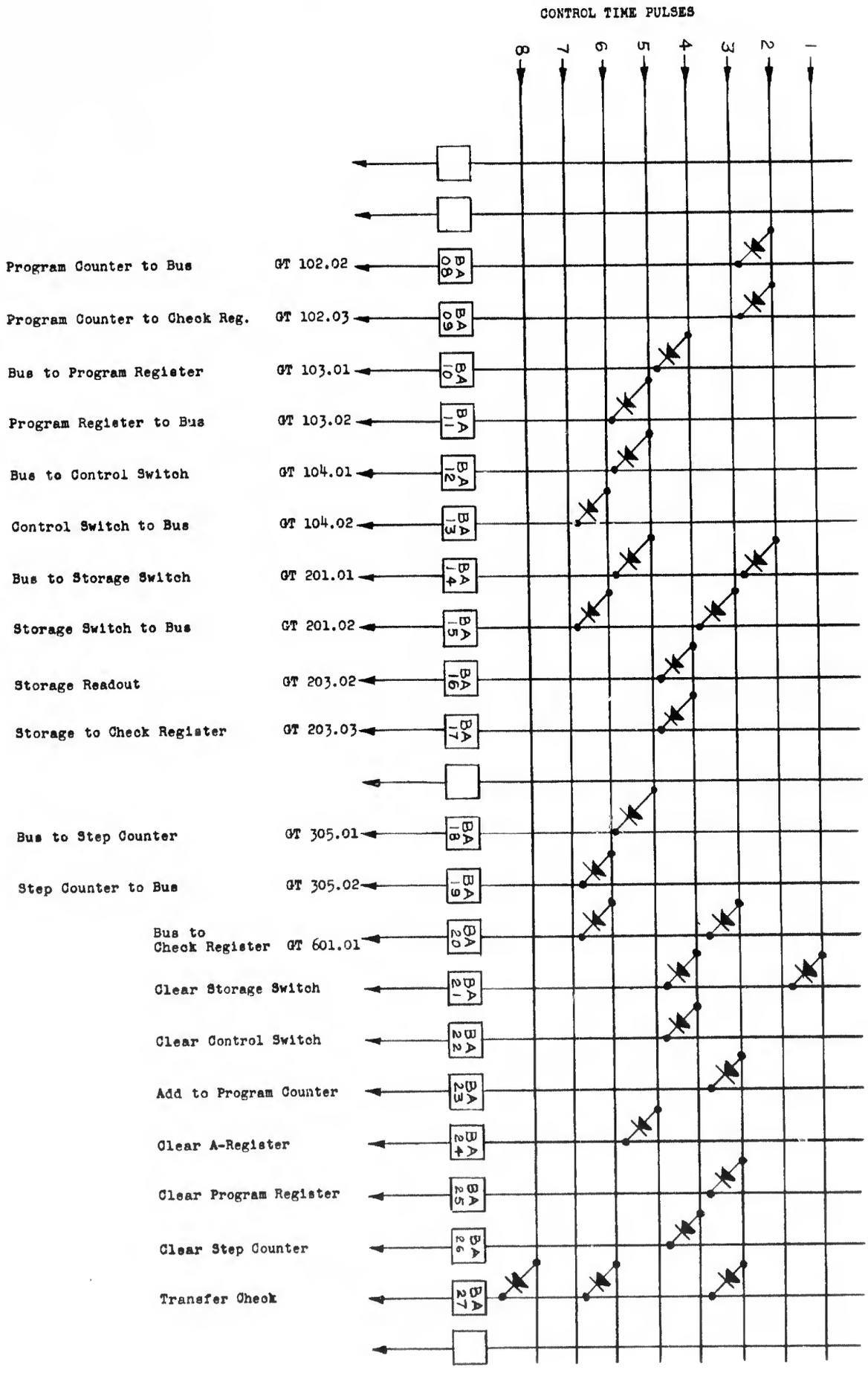


Figure 58

PROGRAM TIMING MATRIX

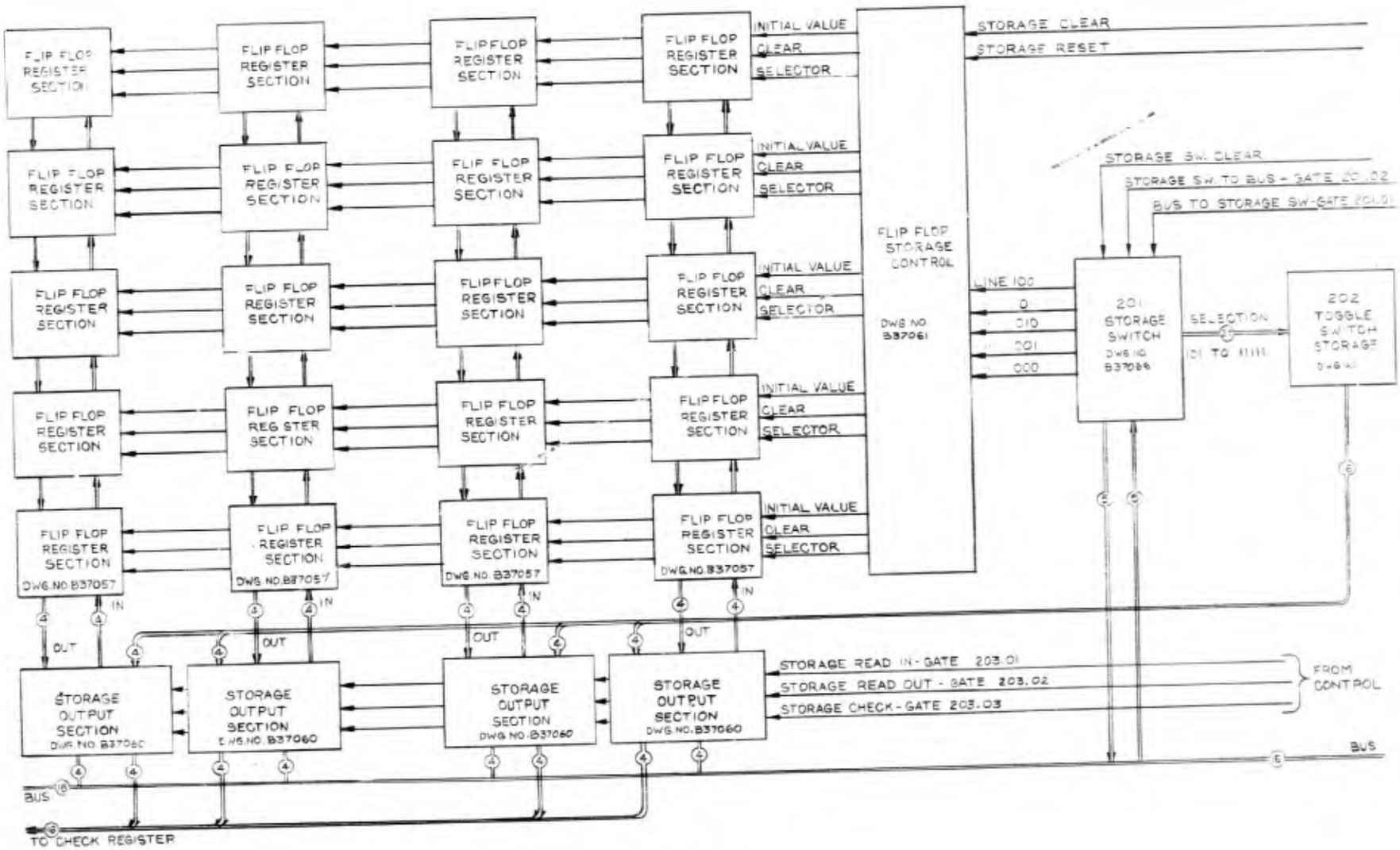


Figure 59

STORAGE CHASSIS ARRANGEMENT

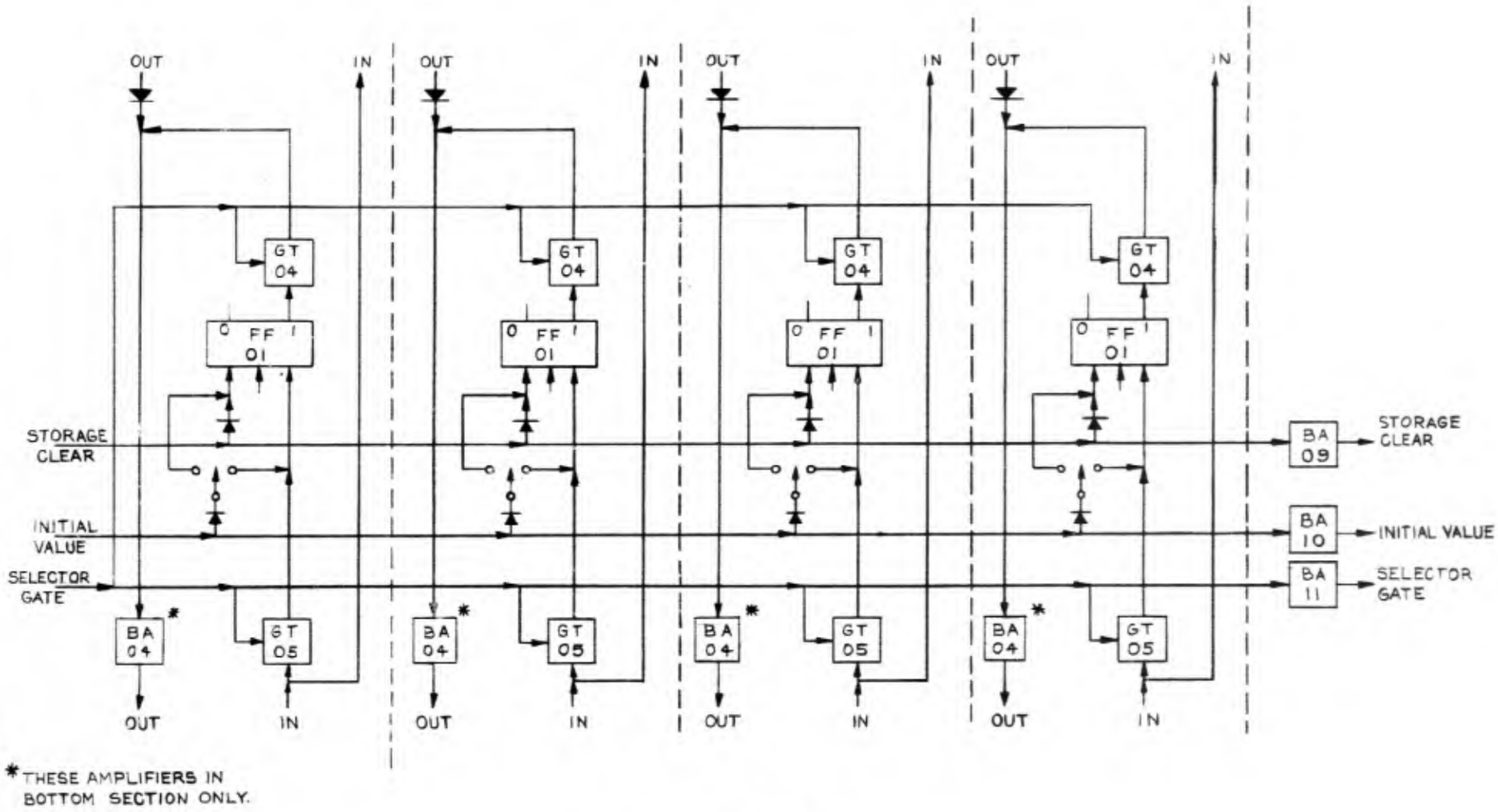


Figure 60

FLIP-FLOP STORAGE SECTION

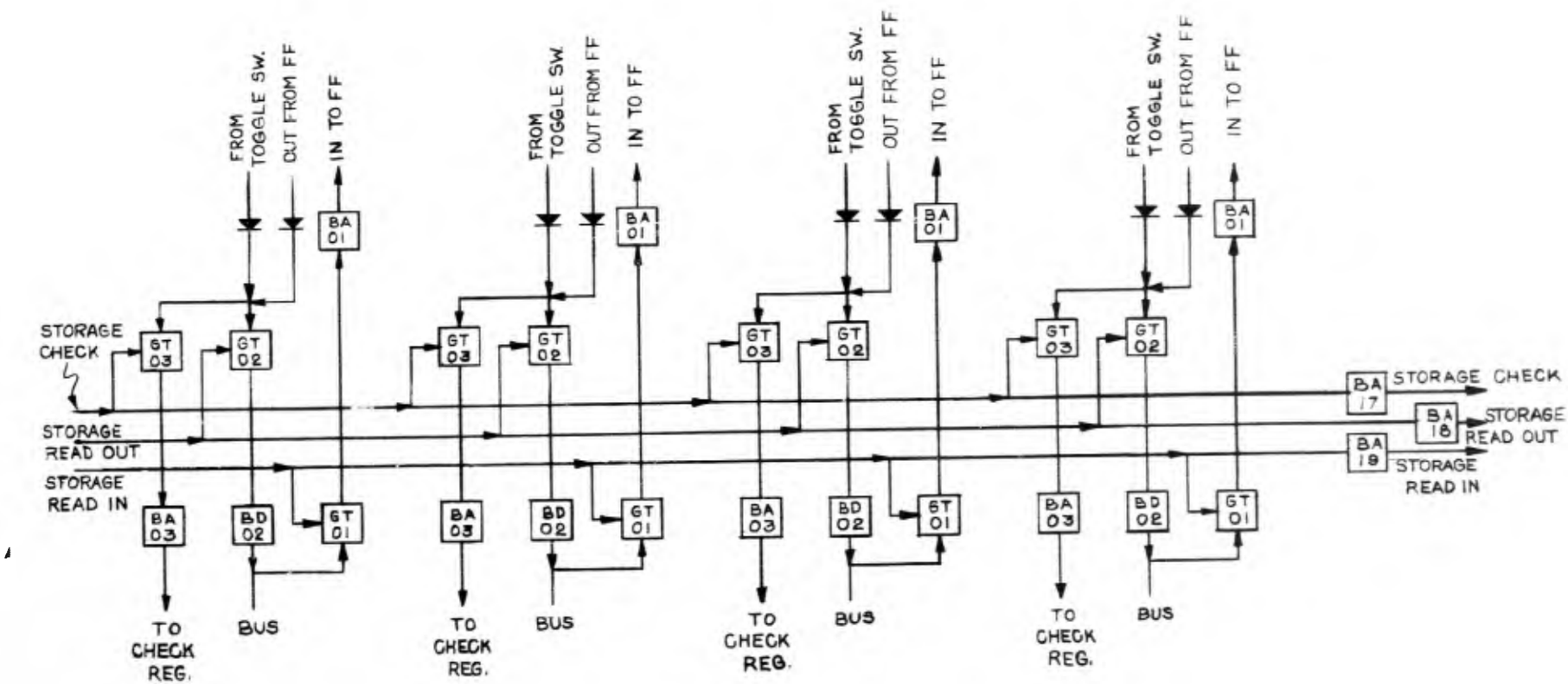


Figure 61

STORAGE OUTPUT SECTION

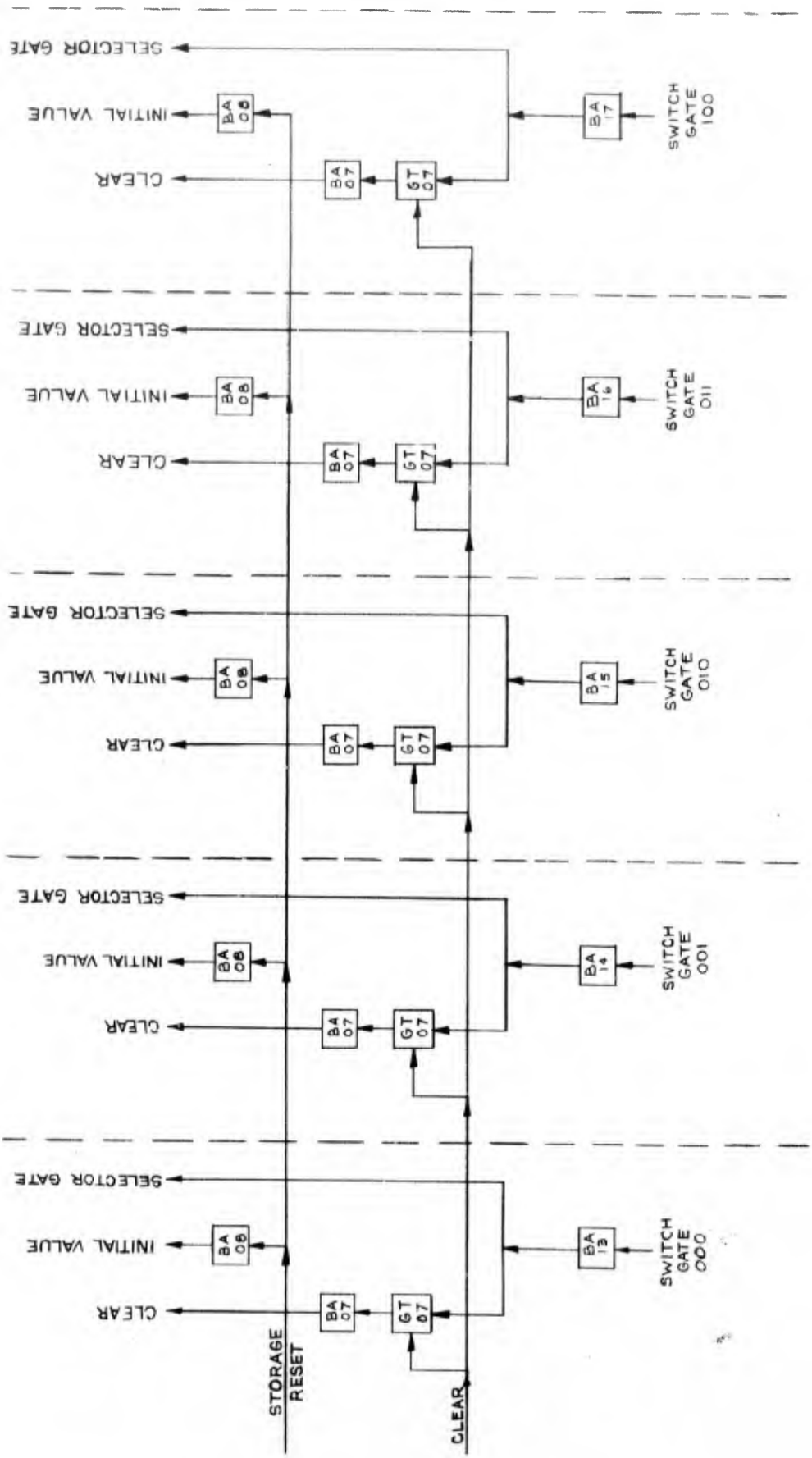


Figure 62

FLIP-FLOP STORAGE CONTROL

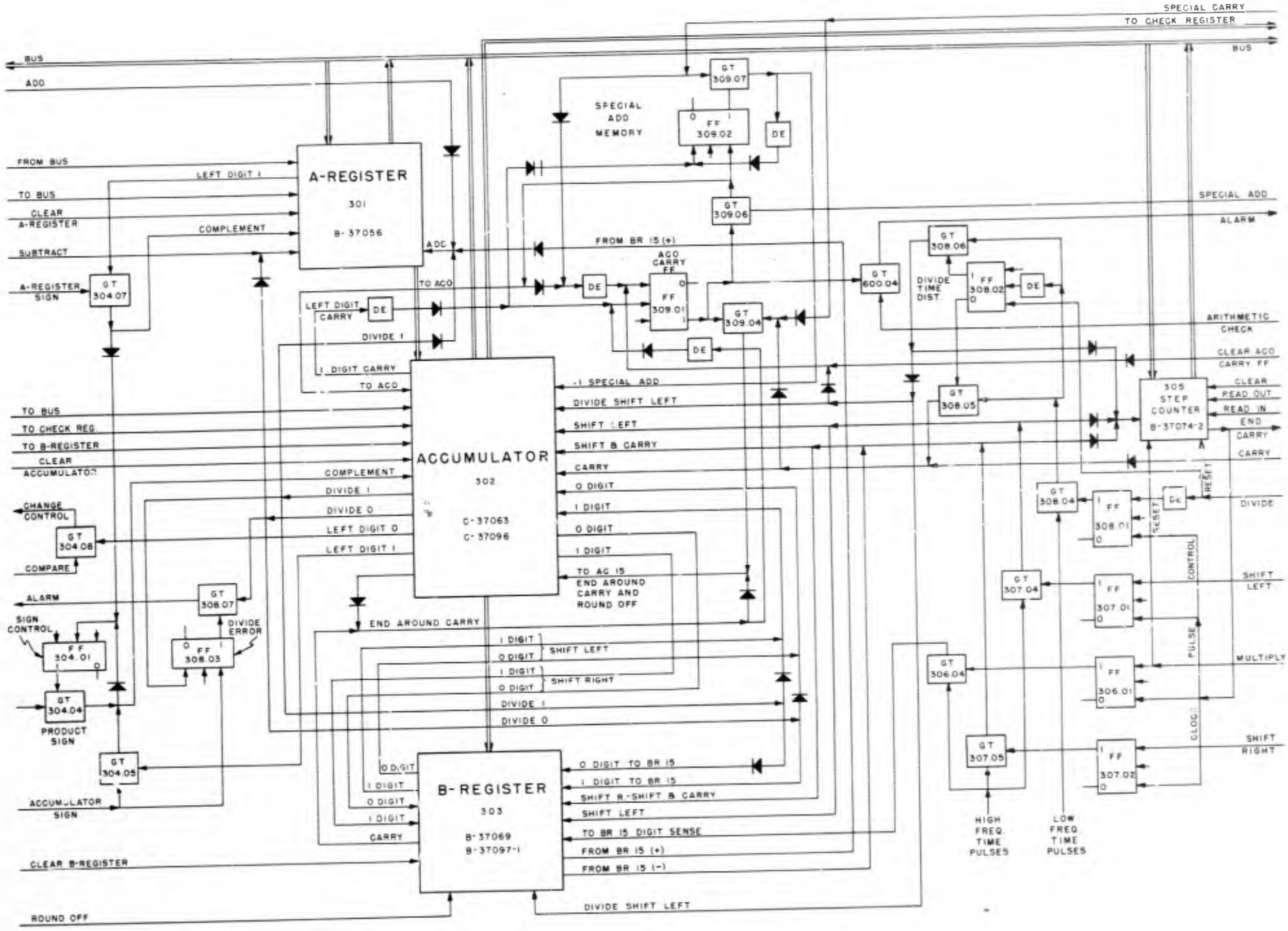


Figure 63

ARITHMETIC ELEMENT

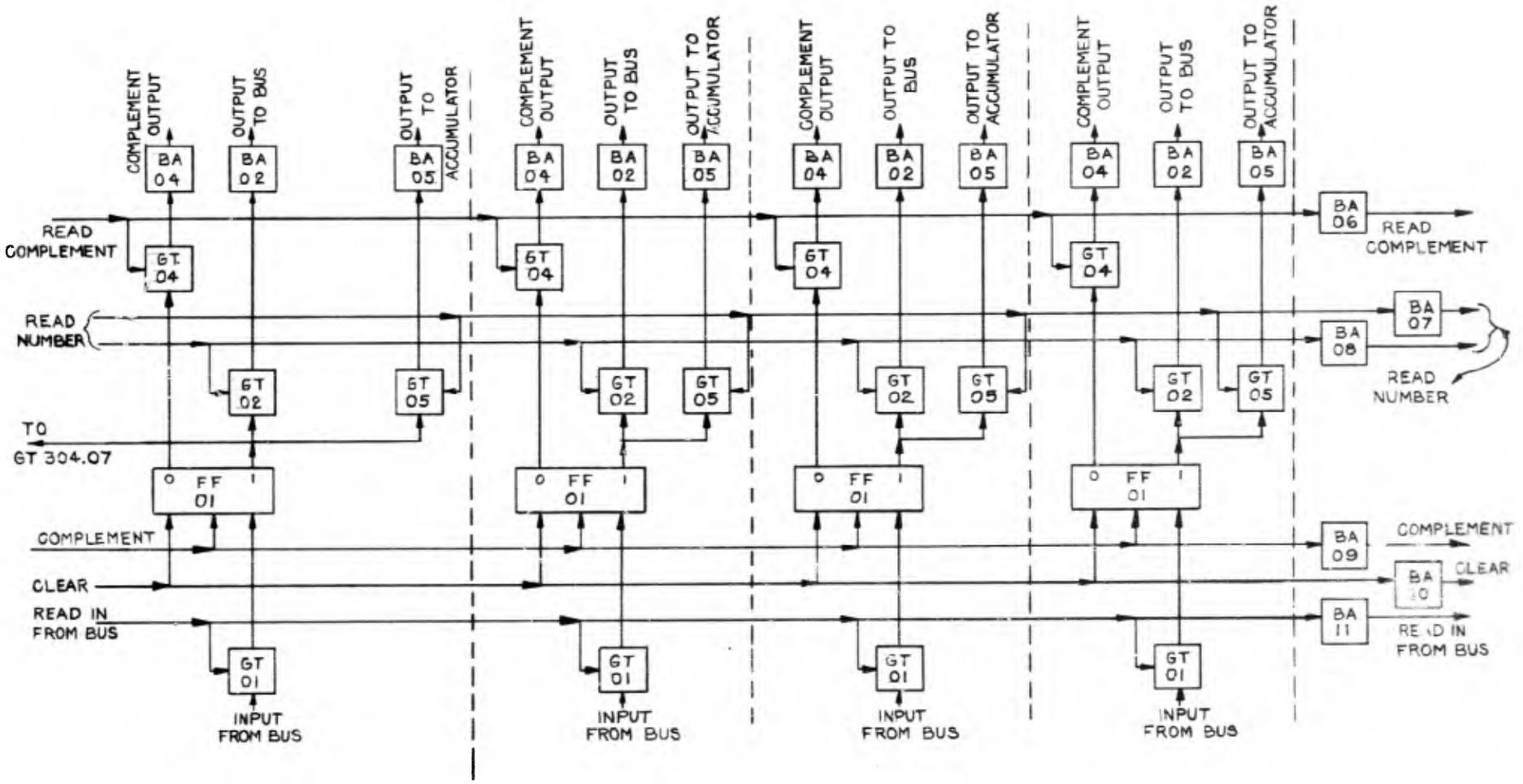


Figure 64

SECTION OF A-REGISTER

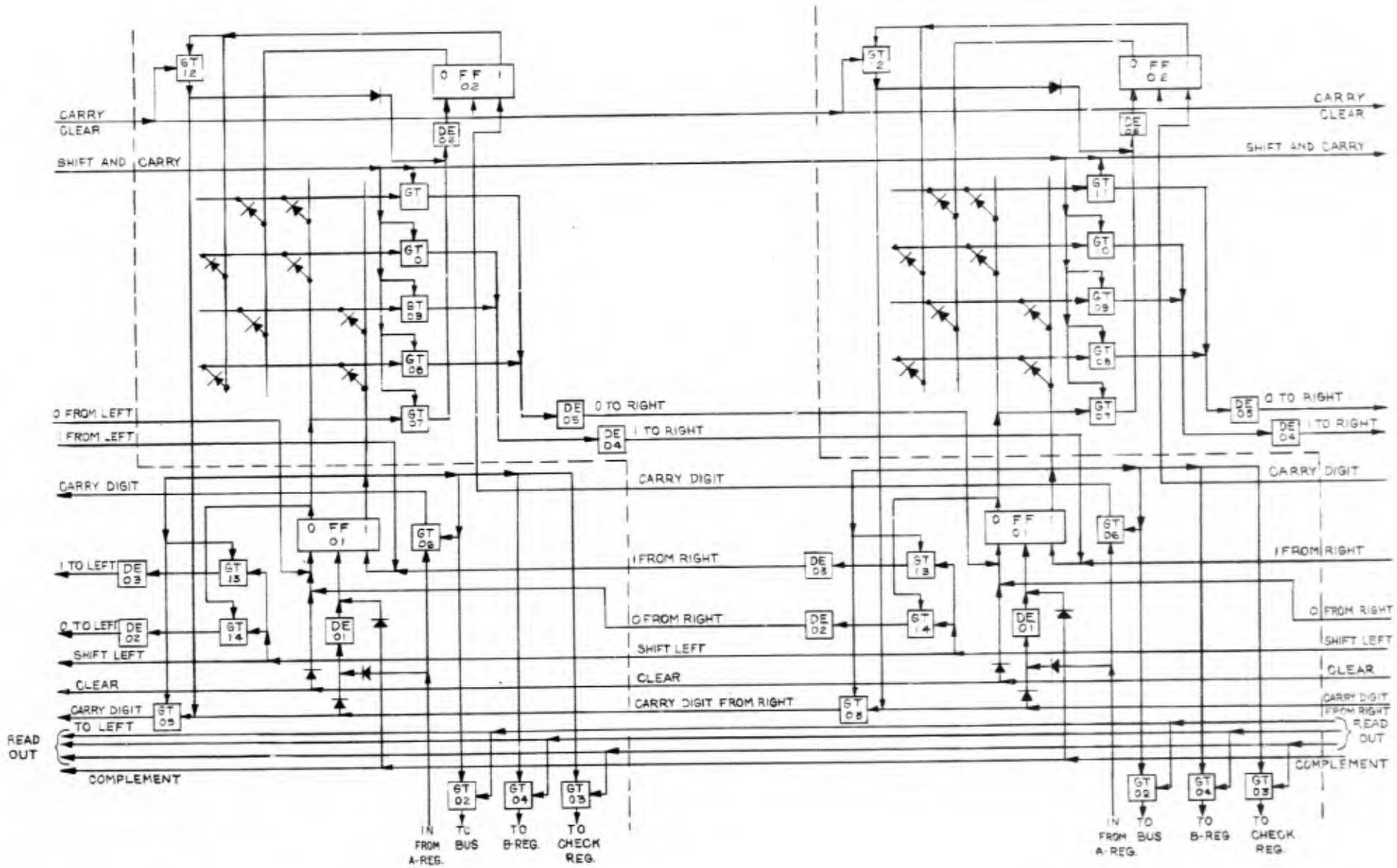


Figure 65

ACCUMULATOR SECTIONS

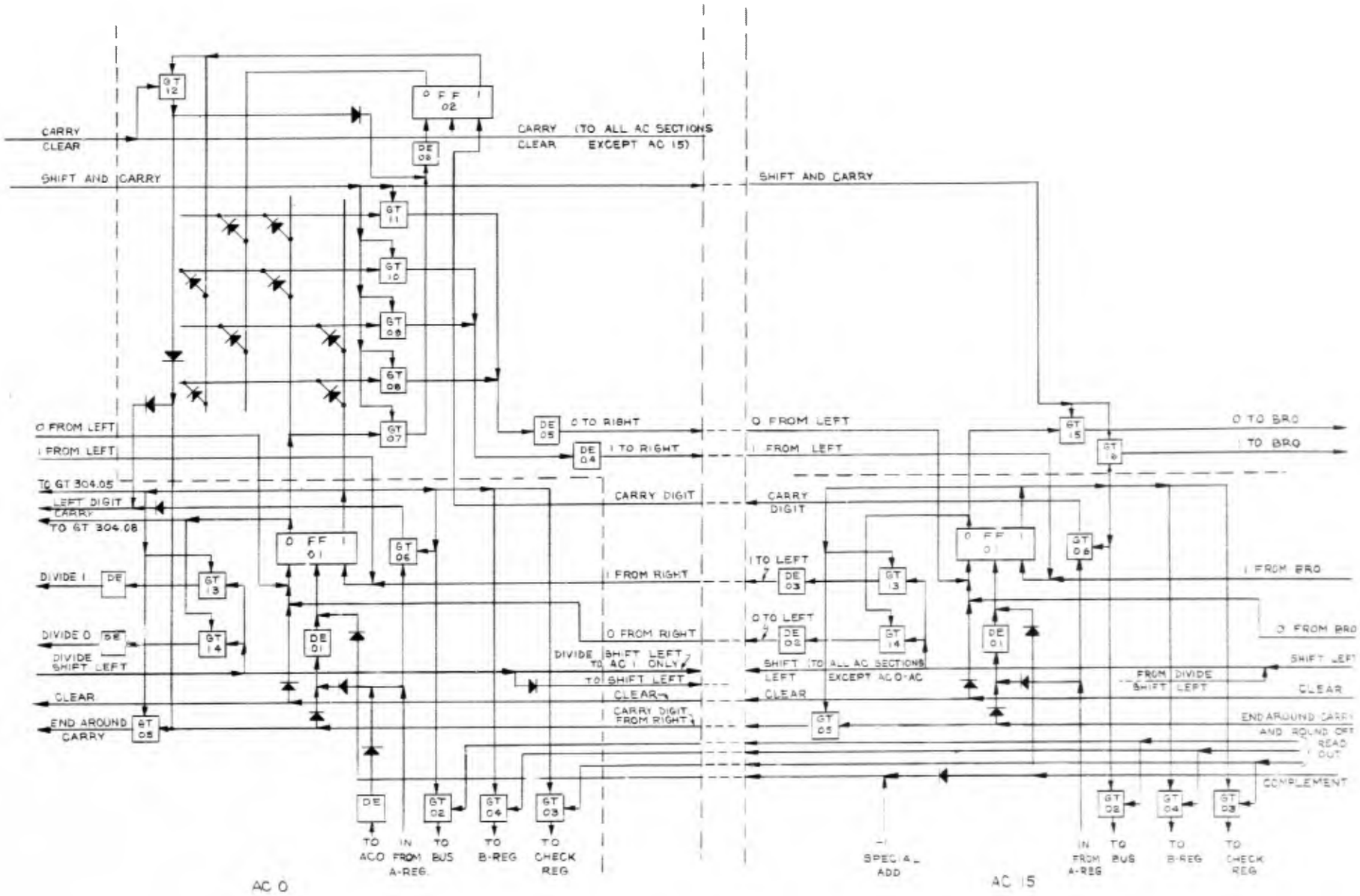


Figure 66

ACCUMULATOR SECTIONS AC0-AC15

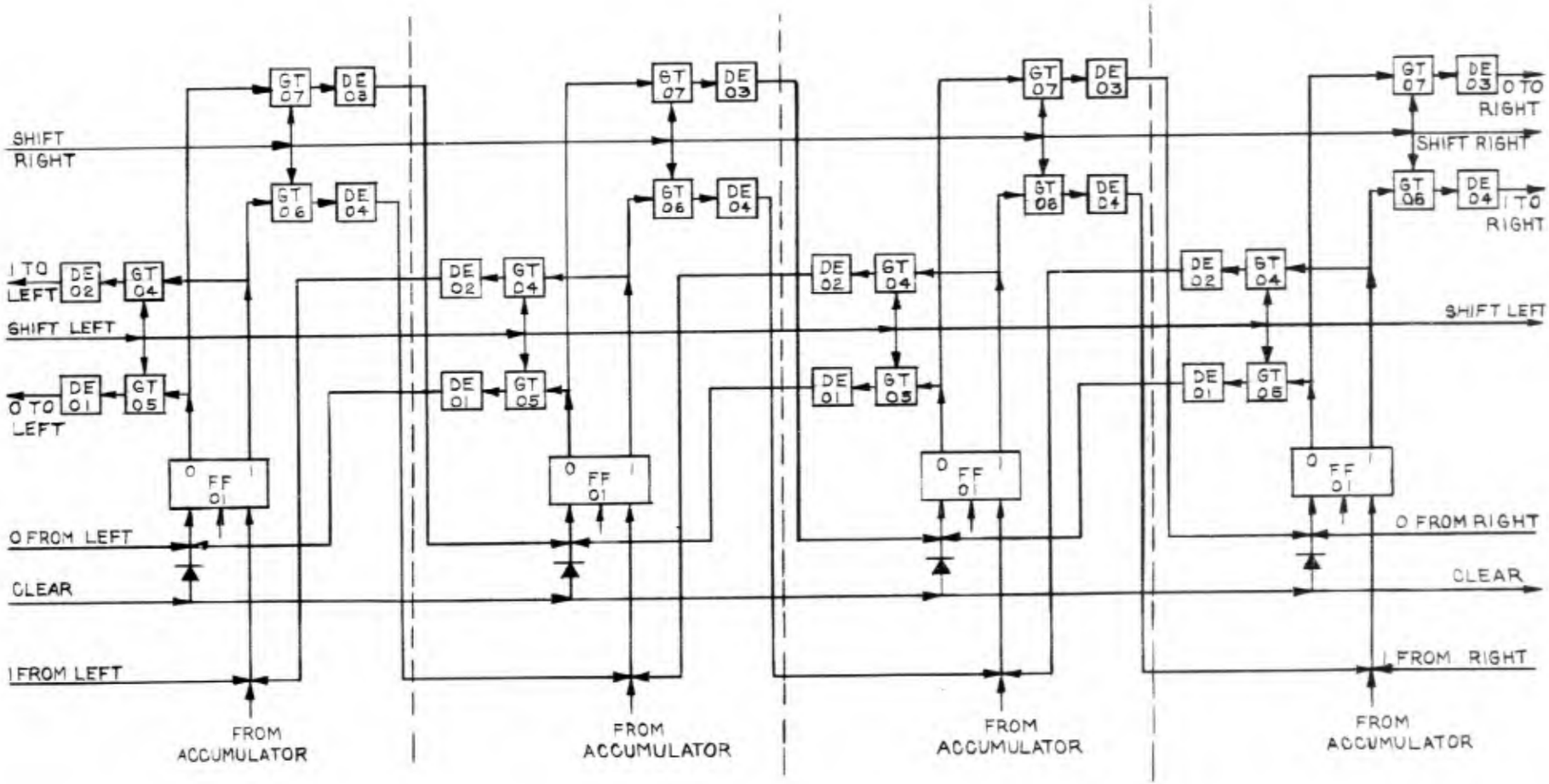


Figure 67

B-REGISTER SECTIONS

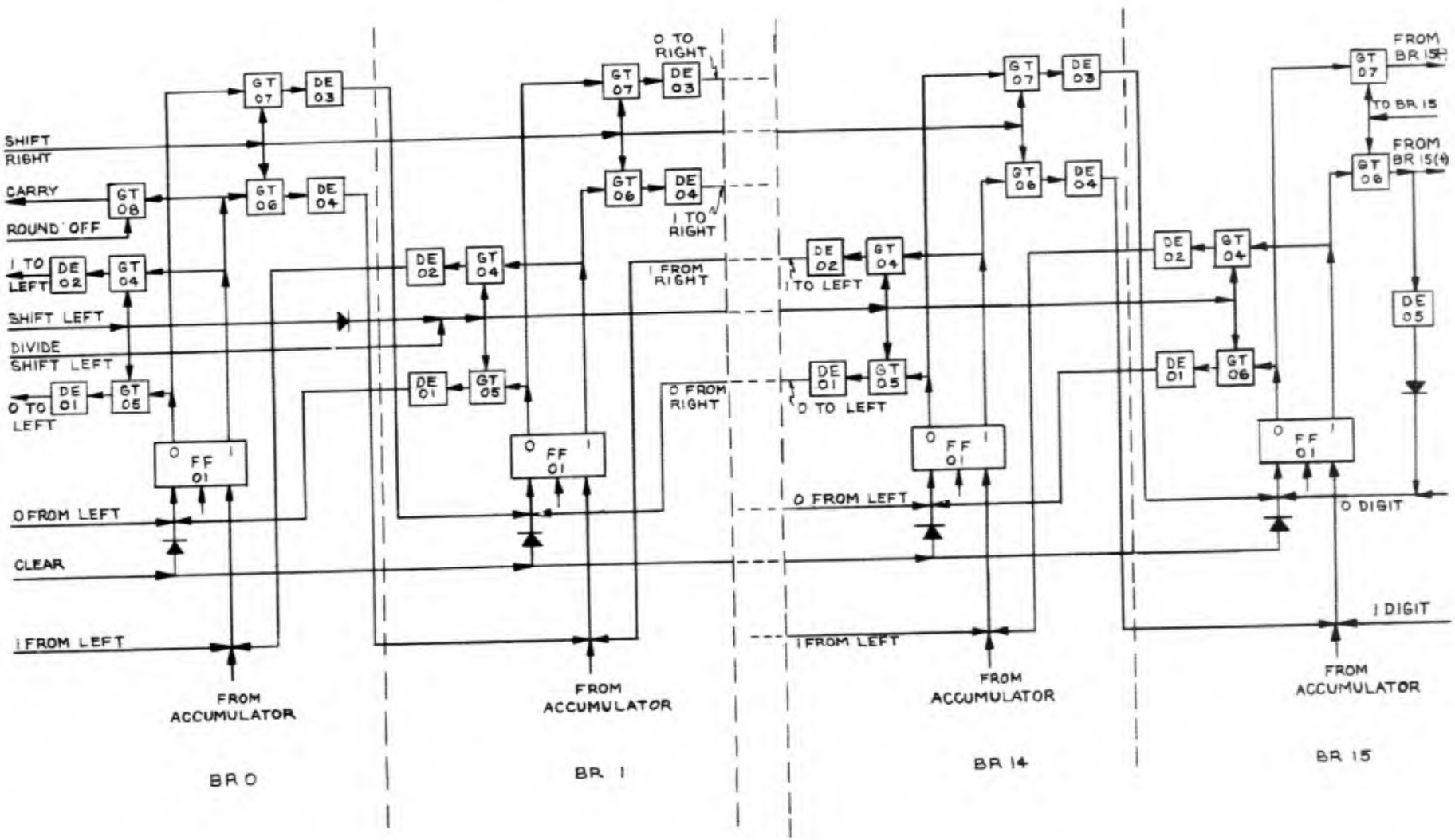


Figure 68

B-REGISTER SECTIONS BR 0, 1, 14, 15

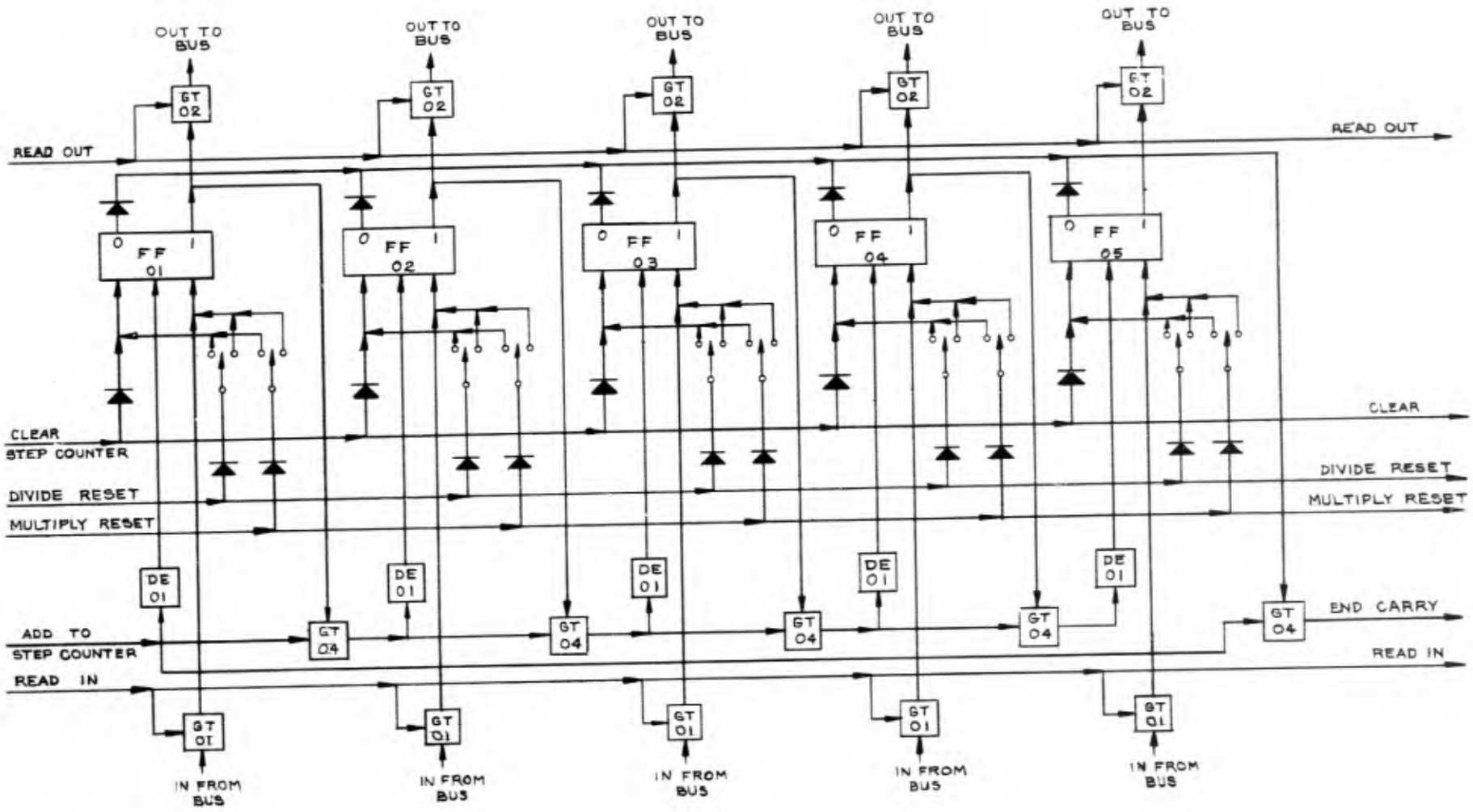


Figure 69

STEP COUNTER

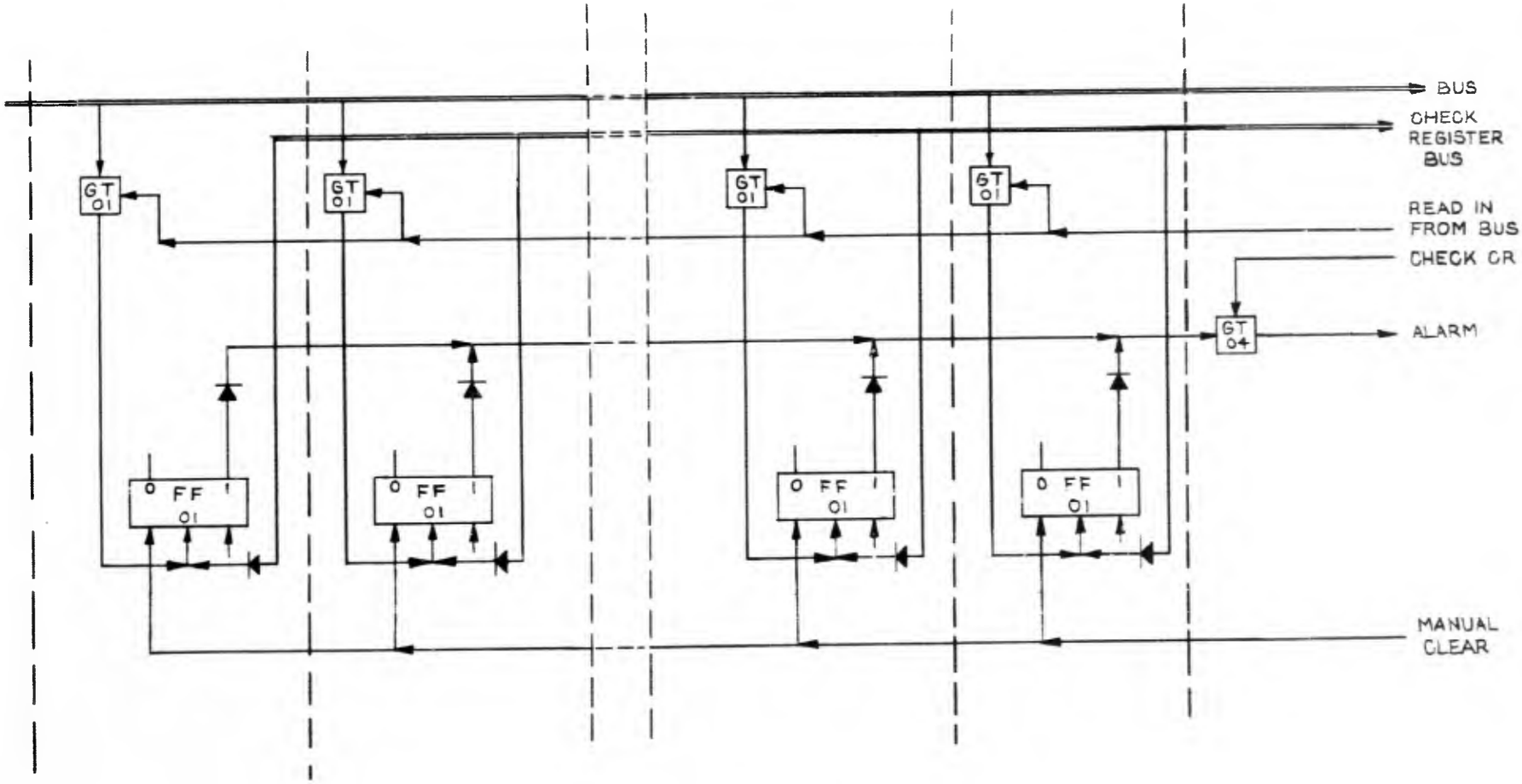


Figure 70
CHECK REGISTER

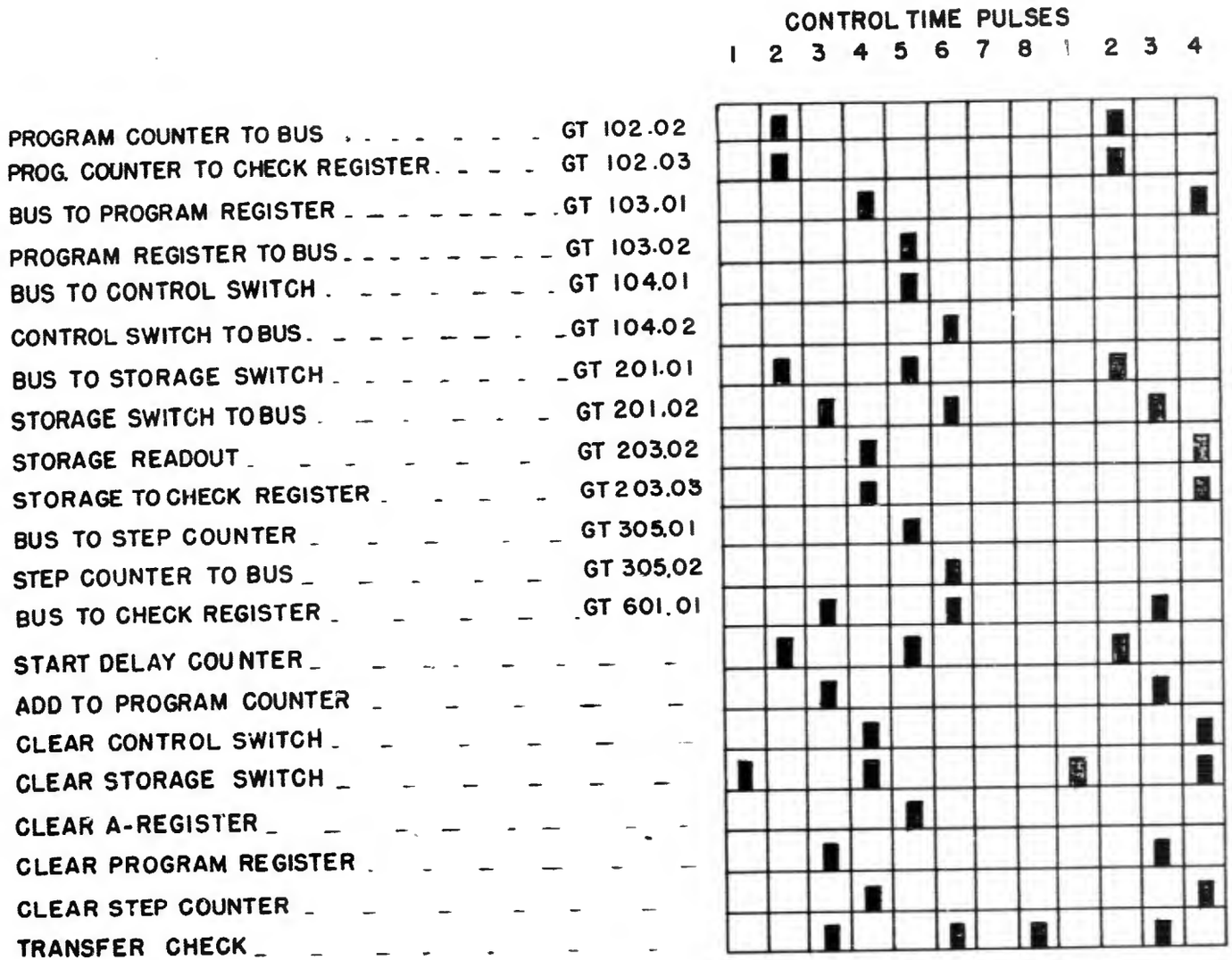


Figure 71

PROGRAM TIMING

OPERATION: ADD ad

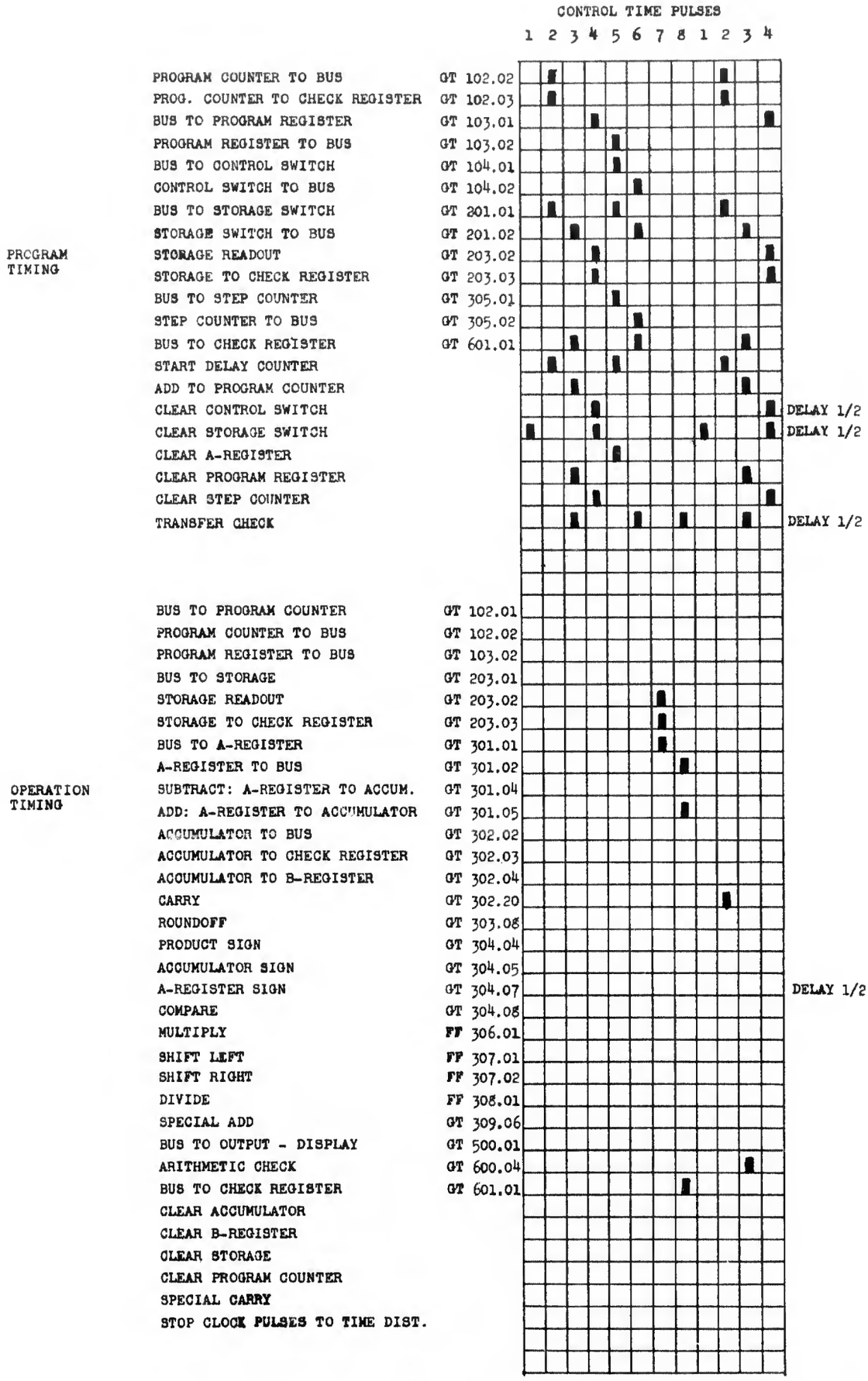


Figure 72

TIMING FOR ADD

OPERATION: CLEAR AND ADD ca

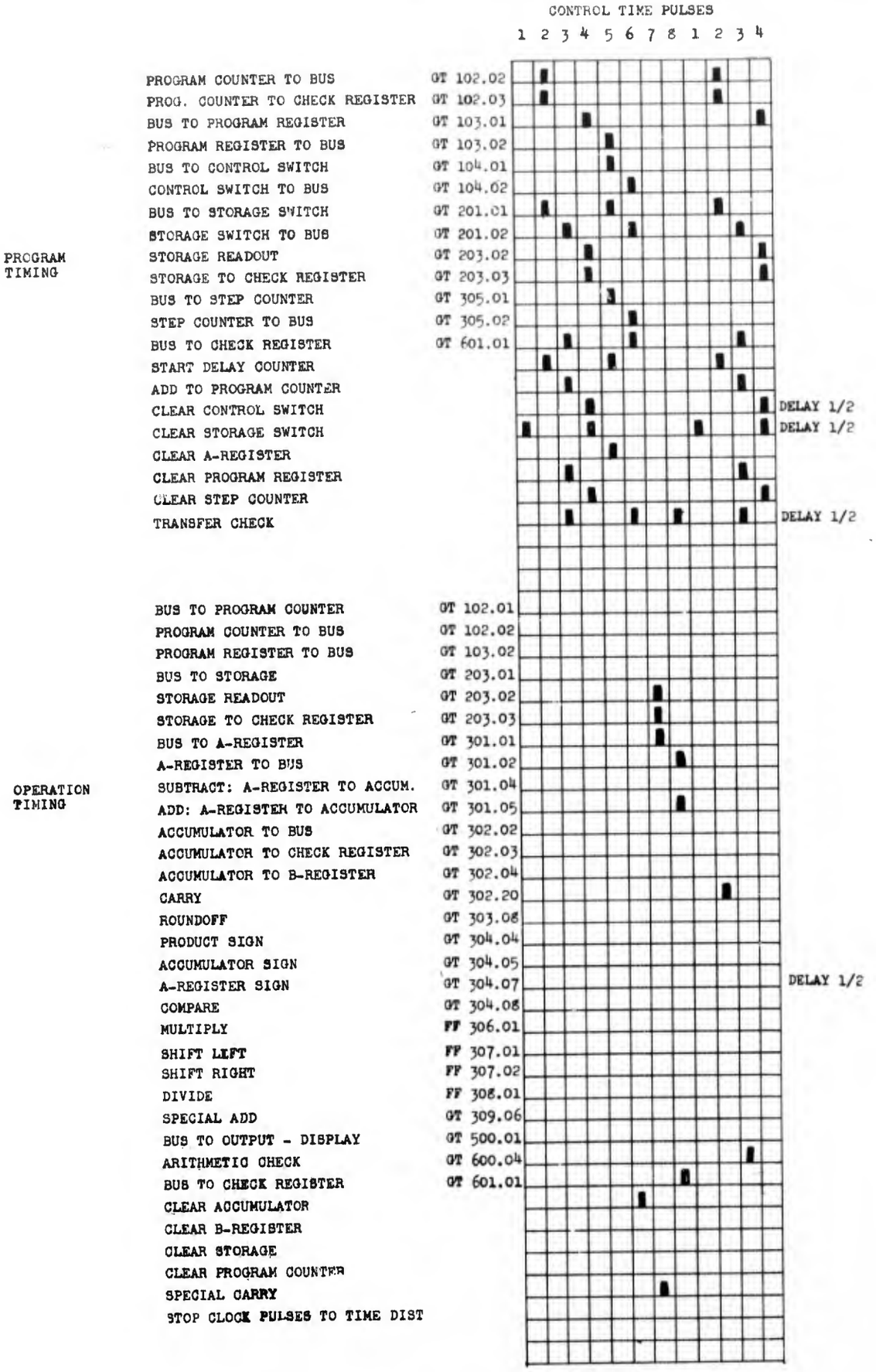


Figure 73

TIMING FOR CLEAR AND ADD

OPERATION: SUBTRACT su

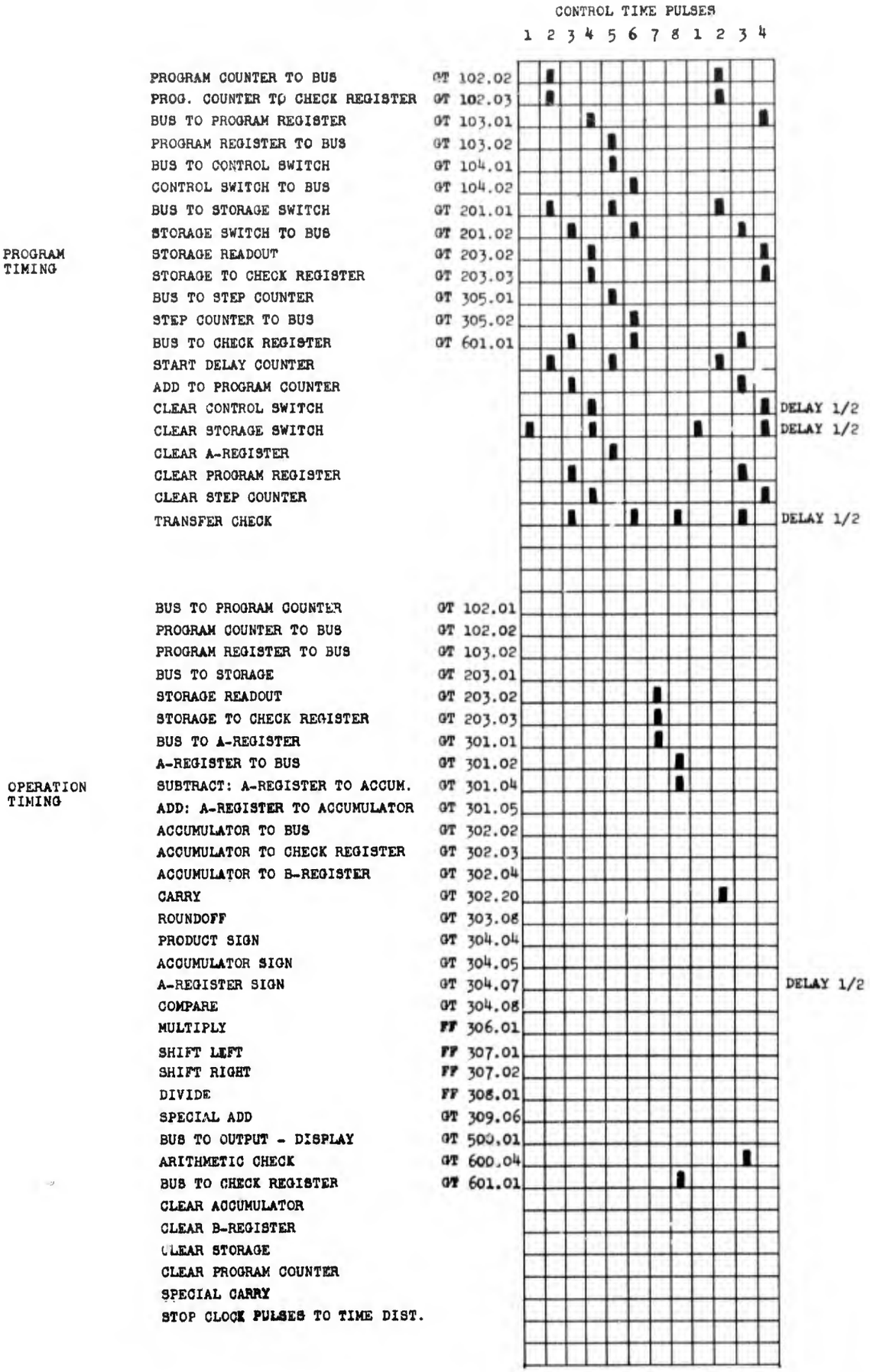


Figure 74

TIMING FOR SUBTRACT

OPERATION: CLEAR AND SUBTRACT cs

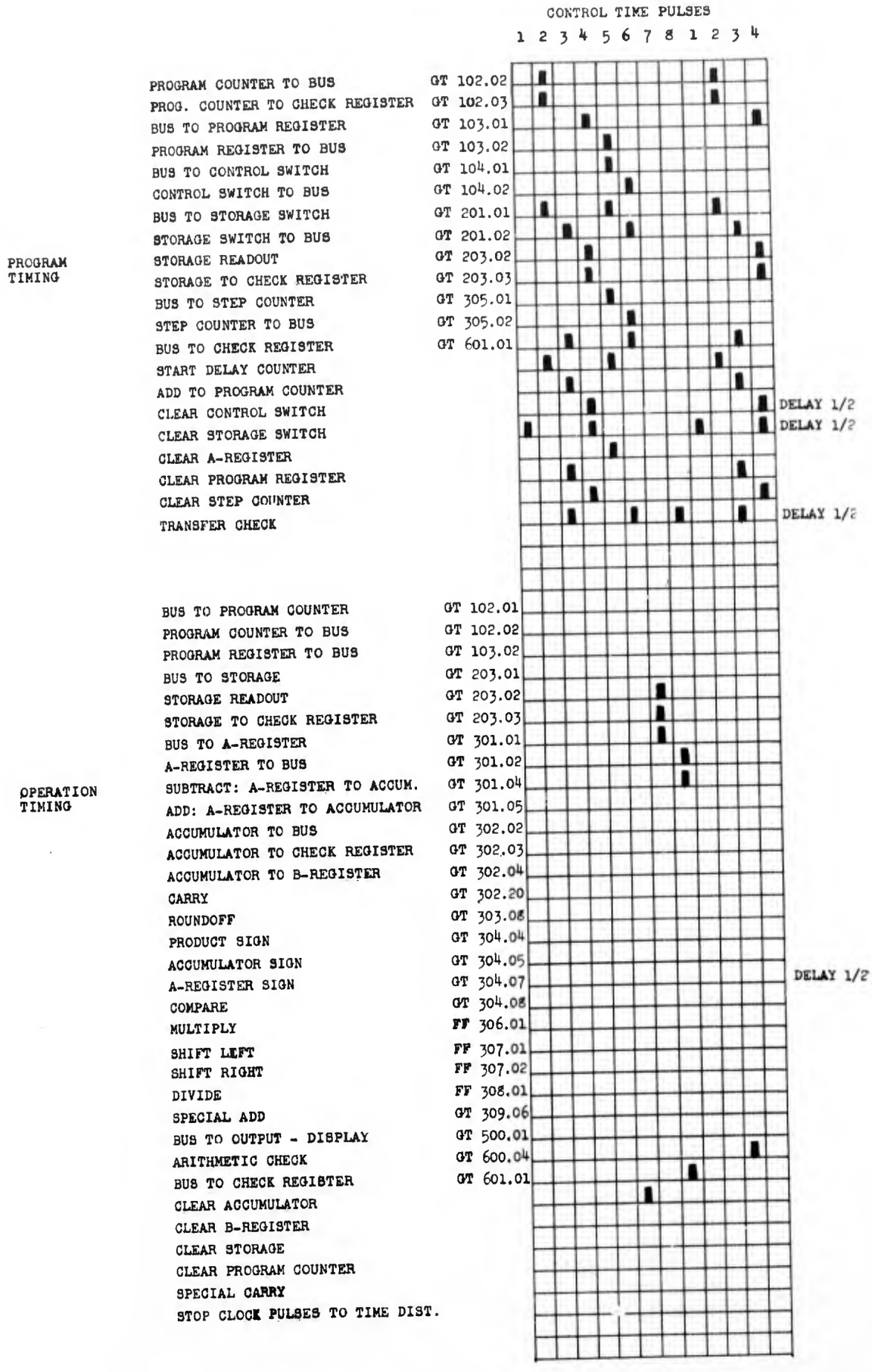


Figure 75

TIMING FOR CLEAR AND SUBTRACT

OPERATION: MULTIPLY AND ROUNDOFF mr

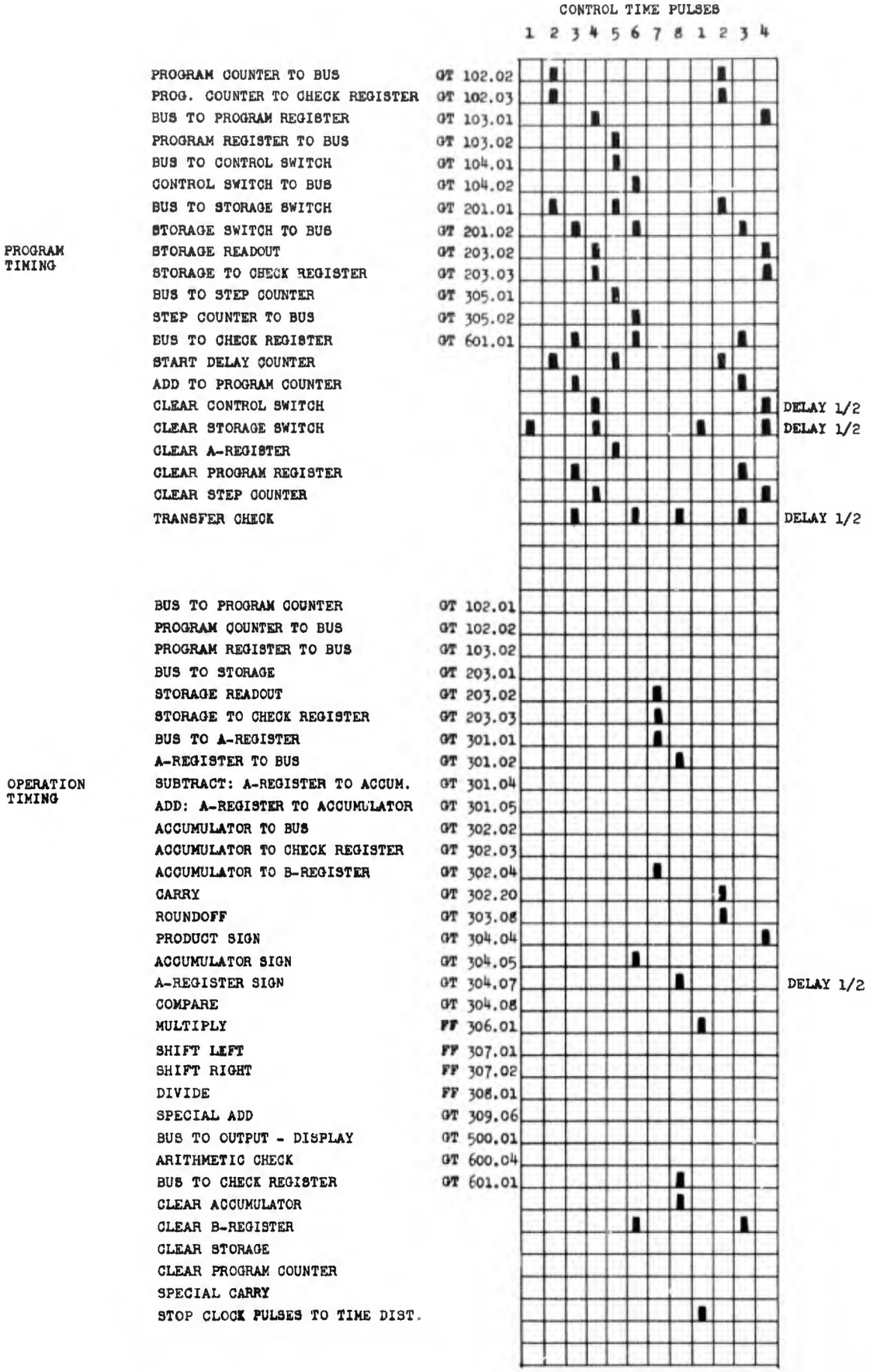


Figure 76

TIMING FOR MULTIPLY AND ROUNDOFF

OPERATION: MULTIPLY AND HOLD FULL PRODUCT mh

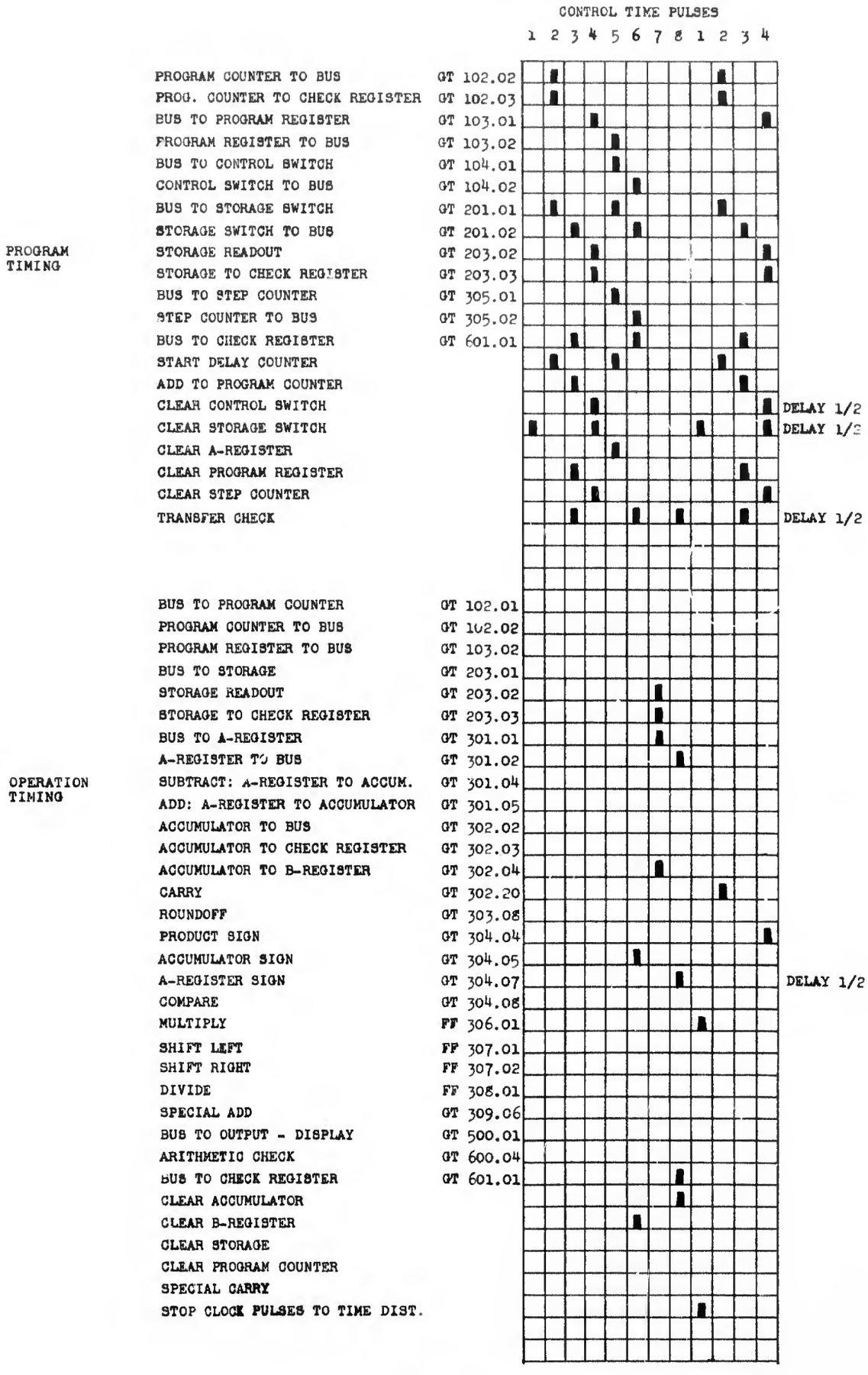


Figure 77

TIMING FOR MULTIPLY AND HOLD FULL PRODUCT

OPERATION: DIVIDE dv

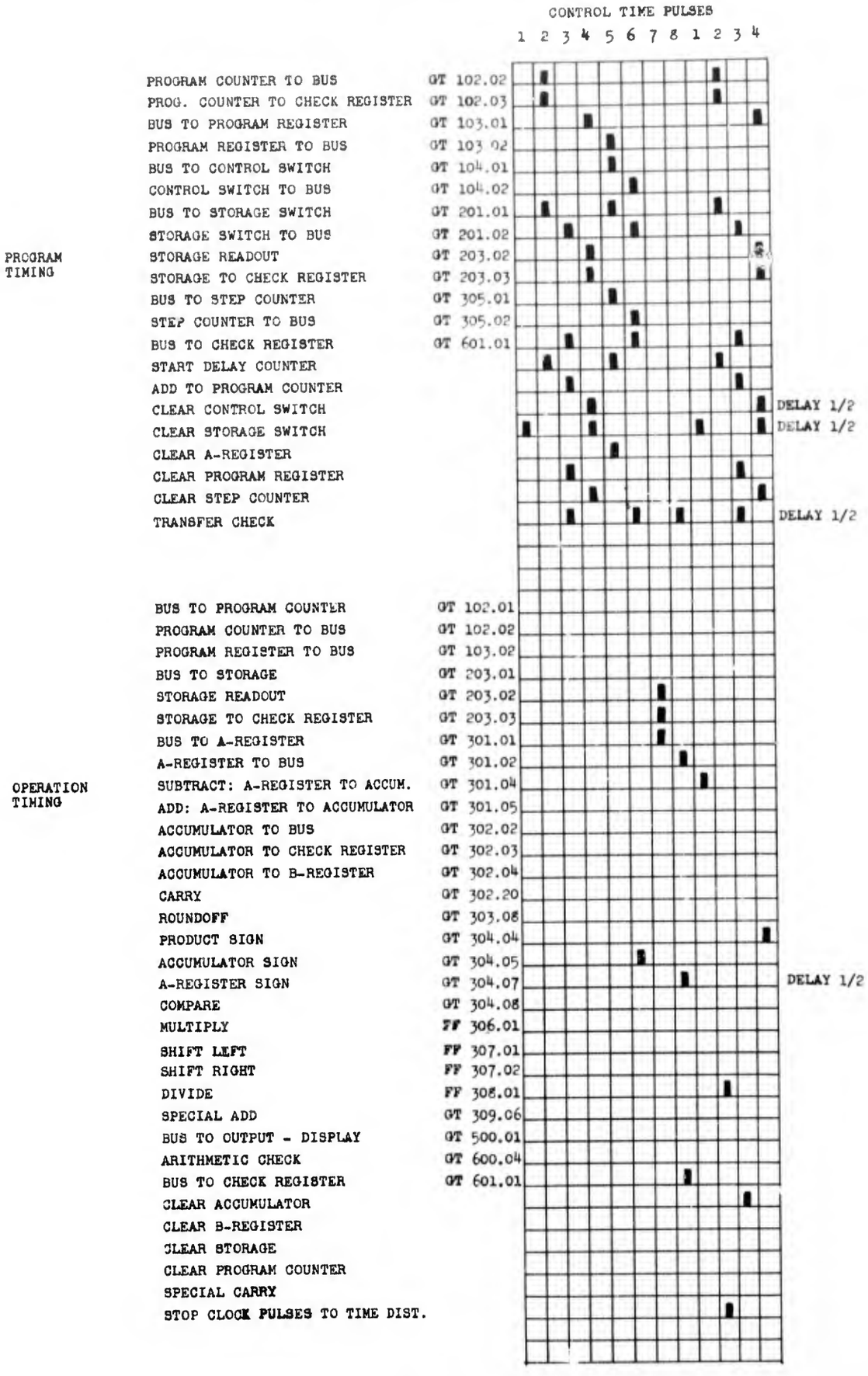


Figure 78

TIMING FOR DIVIDE

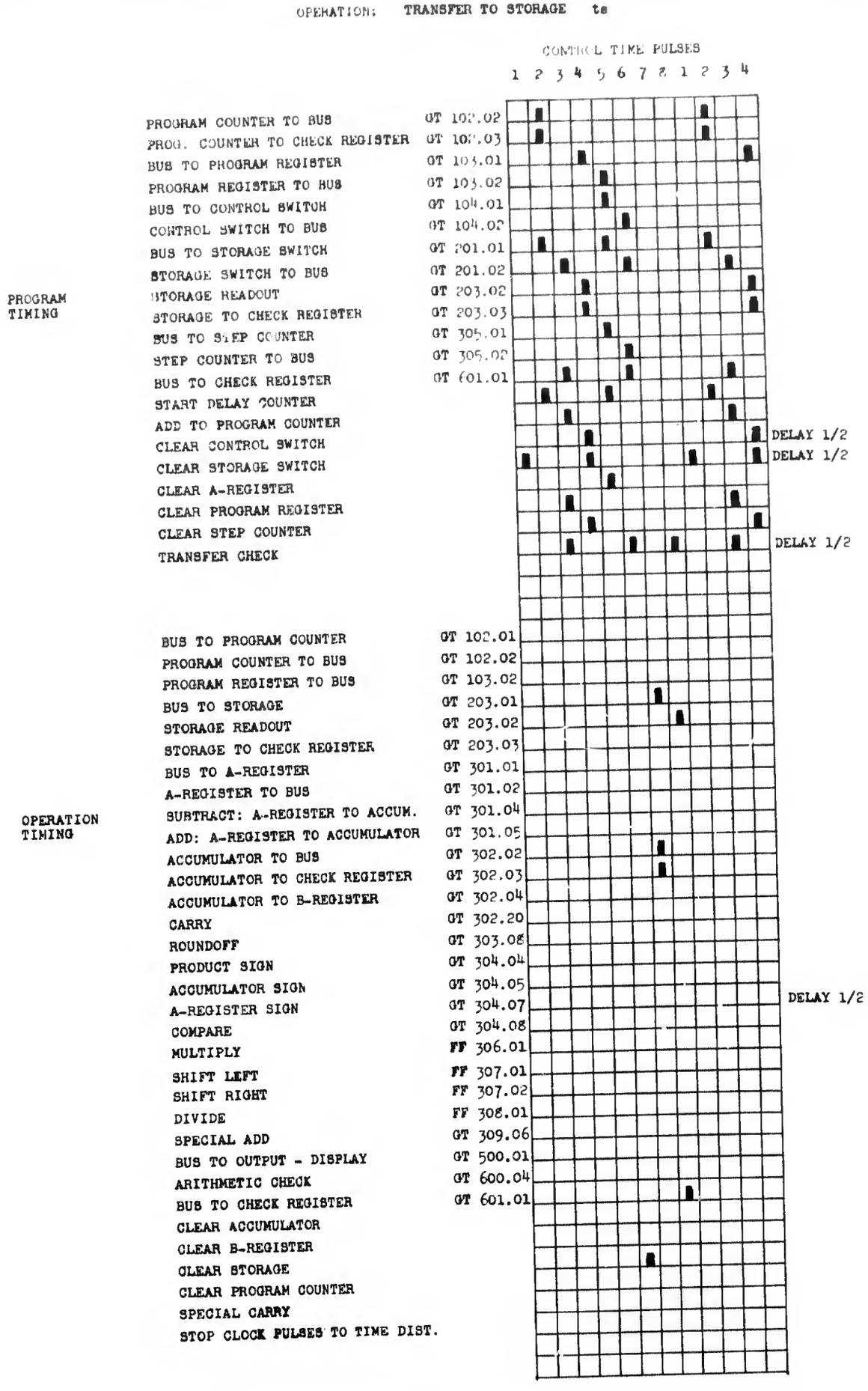


Figure 79

TIMING FOR TRANSFER TO STORAGE

OPERATION: SHIFT RIGHT sr

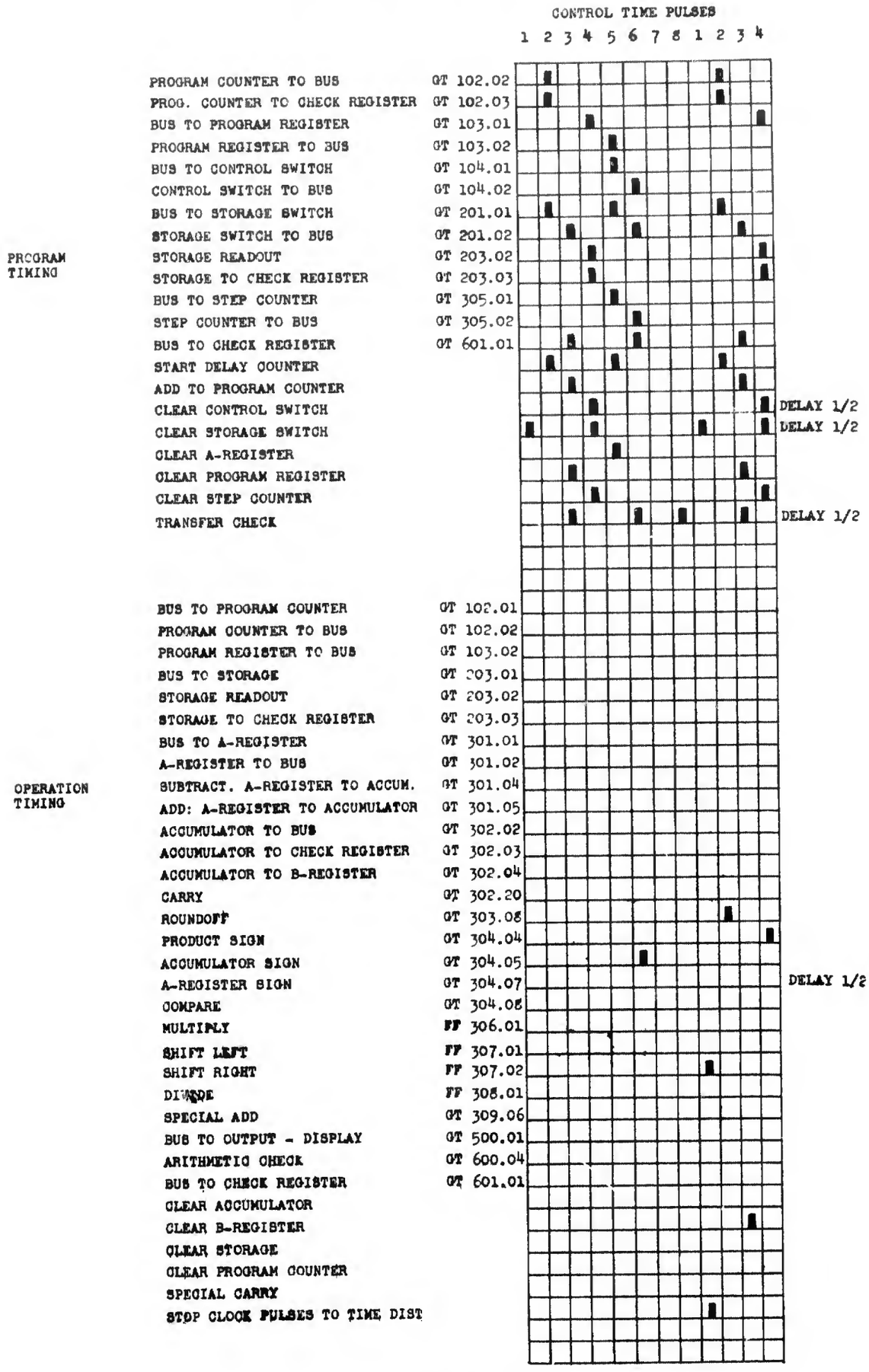


Figure 80

TIMING FOR SHIFT RIGHT

OPERATION: SHIFT LEFT s1

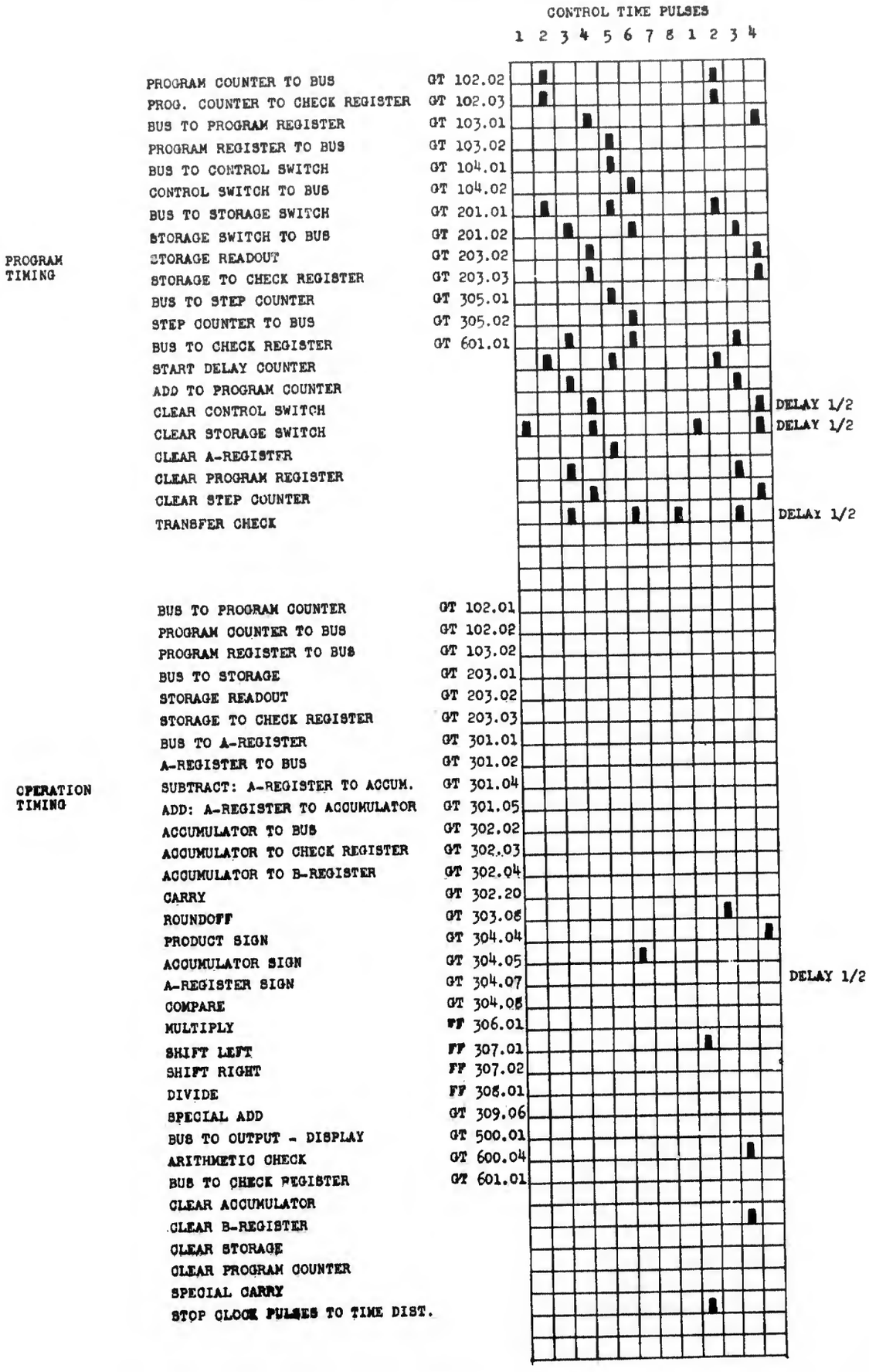


Figure 81

TIMING FOR SHIFT LEFT

OPERATION: SUBPROGRAM sp

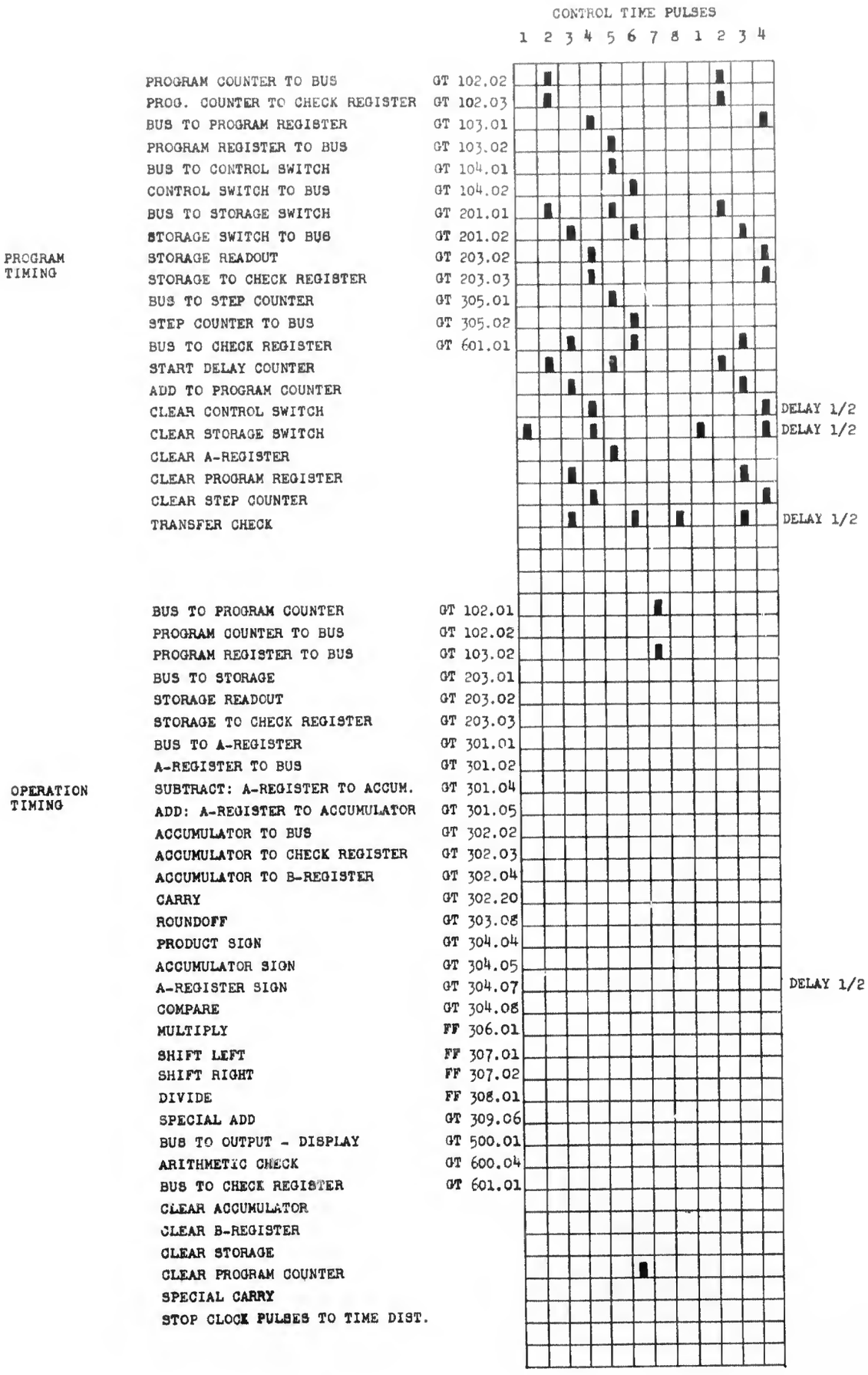


Figure 82

TIMING FOR SUBPROGRAM

OPERATION: COMPARE op

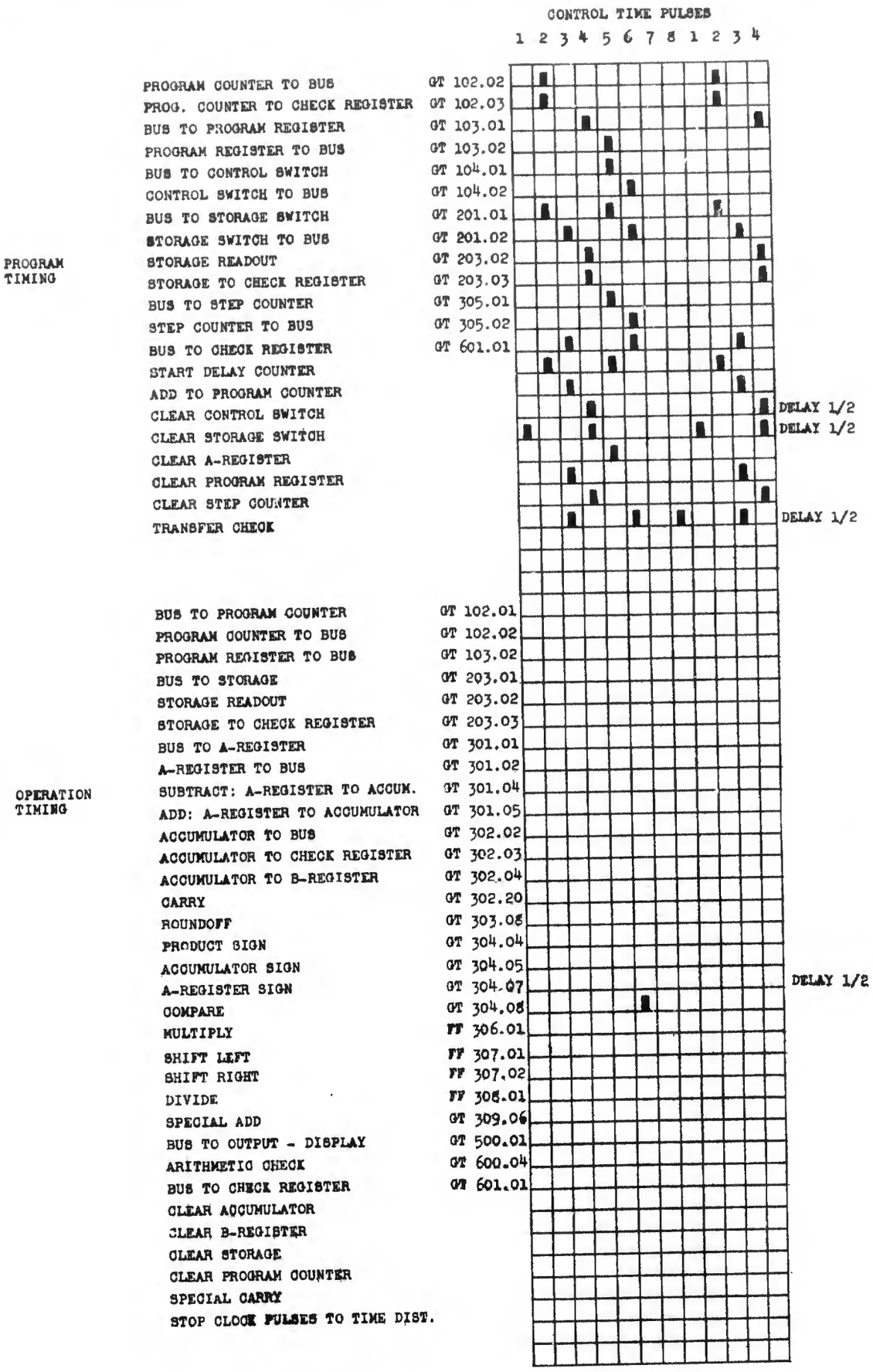


Figure 83

TIMING FOR CONDITIONAL PROGRAM

OPERATION: TRANSFER DIGITS td

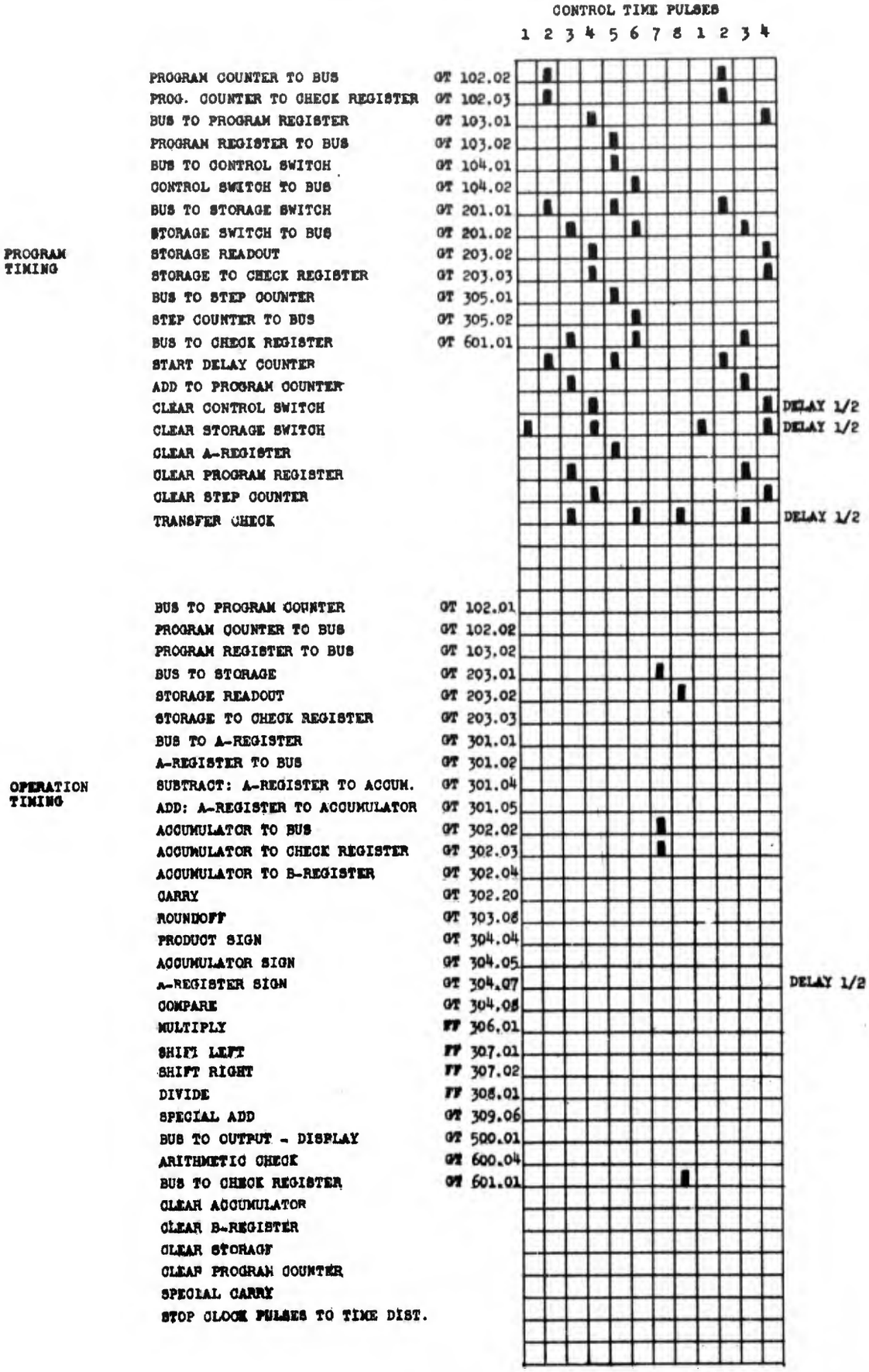


Figure 84

TIMING FOR TRANSFER DIGITS

OPERATION: SPECIAL ADD ss

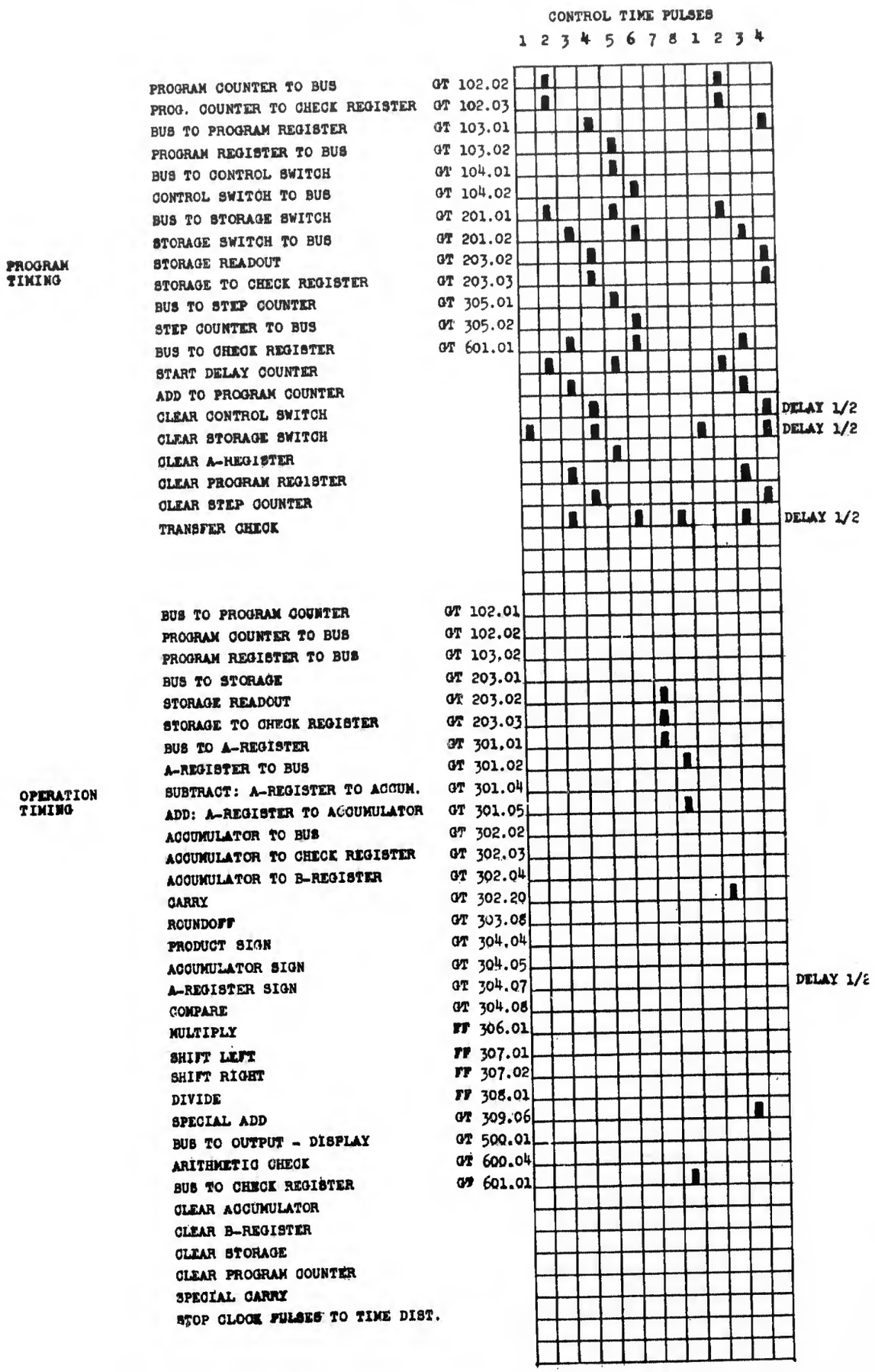


Figure 85

TIMING FOR SPECIAL ADD

OPERATION: STORE AND DISPLAY sd

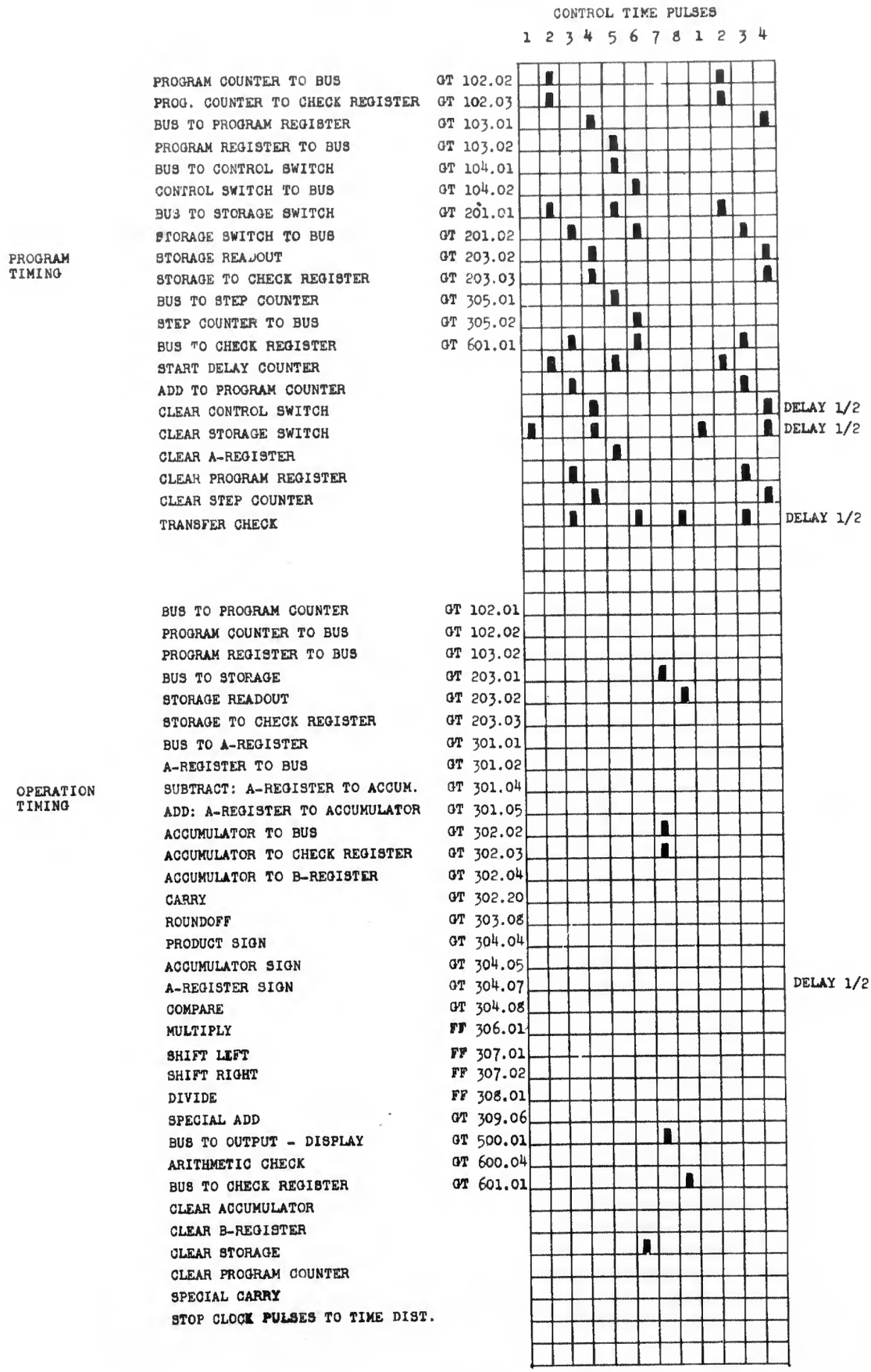


Figure 86

TIMING FOR STORE AND DISPLAY

UNIT CODE NUMBERS

100 Control

- 101 Master Clock
- 102 Program Counter
- 103 Program Register
- 104 Control Switch
- 105 Operation Matrix
- 106 Time Pulse Distributor
- 107 Operation Timing Matrix
- 108 Program Timing Matrix
- 109 Repeat Switch - (Removed from System)

200 Storage

- 201 Switch
- 202 Toggle Switch Storage
- 203 Flip Flop Stroage

300 Arithmetic Element

- 301 A-Register
- 302 Accumulator
- 303 B-Register
- 304 Sign Control
- 305 Step Counter
- 306 Multiply
- 307 Shift
- 308 Divide

400 Input

500 Output

600 Checking

- 601 Check Register

LETTER SYMBOLS

AC	Accumulator
BA	Buffer Amplifier
BC	Binary Coder
BD	Bus Driver
DE	Delay Element
ES	Electronic Switch
FD	Frequency Divider
FF	Flip Flop
GT	Gate Tube Circuit
IC	Intensity Control Circuit
PF	Pulse Forming Circuit
ST	Storage Tube
TG	Trigger Pulse Generator
TP	Timing Pulse Generator
TT	Trigger Tube

DRAWING SYMBOLS

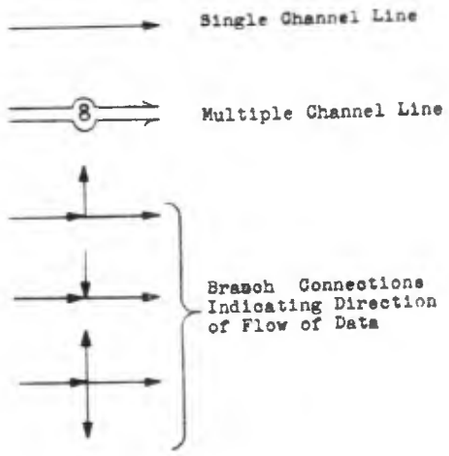


Figure 87

PARALLEL DIGIT COMPUTER CODES