You are to write and submit a microprogram to interpret the following target machine instruction set on the data-flow path given in the figure using the microprogramming tool "AMISS".

AMISS is run at the command line on Grace while in the directory where your microprogram memory control file "cmemory", and test program “memory” reside as follows:

`~meseec/AMISS/CPU -d`

You are required to e-mail your fully-commented "cmemory", "memory" files containing the machine instruction programs that you have used to test your control microprogram to:

“meseec@rit.edu”

Target Machine & Instruction Set Architecture

The target Accumulator-based machine has a datapath width of eight bits. However, the memory address bus width is sixteen bits (can access 65536 memory bytes).

There are three types of instructions:

1. **Inherent instructions**: One-byte instructions, just the Opcode byte.
2. **Immediate instructions**: Two-byte instructions. The instruction Opcode byte is followed by one additional byte of immediate data.
3. **Memory reference instructions**: three-byte instructions. The instruction Opcode byte is followed by two bytes of address information. The high-order byte of the address appears in the byte memory location immediately following the Opcode byte.
• The condition code bits or flags are "N" for negative, "Z" for zero, "V" for overflow, and "C" for carry.

• Condition code settings are "0" for cleared, "1" for set, "-" for no change, and "x" for possible change.

Inherent Instructions: One Byte Only

<table>
<thead>
<tr>
<th>Opcode</th>
<th>Condition Codes:</th>
<th>NZVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>00001111 - NOP - No operation</td>
<td>- - - -</td>
<td></td>
</tr>
<tr>
<td>00011111 - HALT - Halt the machine</td>
<td>- - - -</td>
<td></td>
</tr>
<tr>
<td>00101111 - CLA - Clear the accumulator</td>
<td>0100</td>
<td></td>
</tr>
<tr>
<td>00111111 - CMA - 1’s complement the accumulator</td>
<td>xx00</td>
<td></td>
</tr>
<tr>
<td>01001111 - INCA - Increment the accumulator by one</td>
<td>xx0x</td>
<td></td>
</tr>
<tr>
<td>01011111 - DECA - Decrement the accumulator by one</td>
<td>xx0x</td>
<td></td>
</tr>
<tr>
<td>01101111 - RET - Return from subroutine</td>
<td>- - - -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(post incrementing SP)</td>
<td></td>
</tr>
<tr>
<td>01111111 - ROLCA - Circular shift Carry bit &amp; Acc left 1 bit</td>
<td>xx0x</td>
<td></td>
</tr>
<tr>
<td>10001111 - CLC - Clear Carry Flag bit</td>
<td>- - 0</td>
<td></td>
</tr>
<tr>
<td>10011111 - STC - Set Carry Flag bit</td>
<td>- - 1</td>
<td></td>
</tr>
</tbody>
</table>

Store and Branch Instructions: Two additional address bytes

<table>
<thead>
<tr>
<th>Opcode</th>
<th>Condition Code:</th>
<th>NZVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>00001z00 - STA - Store accumulator (use STAin for indirect)</td>
<td>- - - -</td>
<td></td>
</tr>
<tr>
<td>00011z00 - JMP - Unconditional branch</td>
<td>- - - -</td>
<td></td>
</tr>
<tr>
<td>00101z00 - JEQ - Branch if equal to zero (Z=1)</td>
<td>- - - -</td>
<td></td>
</tr>
<tr>
<td>00111z00 - JCS - Branch if carry (C=1)</td>
<td>- - - -</td>
<td></td>
</tr>
<tr>
<td>01001z00 - JLT - branch if negative (N=1)</td>
<td>- - - -</td>
<td></td>
</tr>
<tr>
<td>01011z00 - JVS - branch if overflow (V=1)</td>
<td>- - - -</td>
<td></td>
</tr>
<tr>
<td>01101z00 - JSR - jump to subroutine</td>
<td>- - - -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(push PC on stack - predecrement SP)</td>
<td></td>
</tr>
</tbody>
</table>
Other Instructions: One or two additional bytes

<table>
<thead>
<tr>
<th>Opcode</th>
<th>Condition Codes:</th>
<th>NZVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000yz01 - LDA - Load Acc (use LDAim for immediate)</td>
<td>xx00</td>
<td></td>
</tr>
<tr>
<td>0001yz01 - ORA - Inclusive OR to Accumulator</td>
<td>xx00</td>
<td></td>
</tr>
<tr>
<td>0010yz01 - EOR - Exclusive OR to Accumulator</td>
<td>xx00</td>
<td></td>
</tr>
<tr>
<td>0011yz01 - AND - Logical AND to Accumulator</td>
<td>xx00</td>
<td></td>
</tr>
<tr>
<td>0100yz01 - ADD - Add to Accumulator</td>
<td>xxxx</td>
<td></td>
</tr>
<tr>
<td>0101yz01 - SUBA - Subtract from Accumulator</td>
<td>xxxx</td>
<td></td>
</tr>
<tr>
<td>0110yz01 - LDS - Load stack pointer SP with 16-bit value</td>
<td>----</td>
<td></td>
</tr>
</tbody>
</table>

• Where the "y" bit is set to indicate that an immediate operand follows the opcode (add “im” to instruction name).
• The "z" bit is set to indicate that indirect addressing is to be performed through the location specified by the two bytes following the opcode (add “indir” to instruction name).
• Note that it is not allowed to have both the "y" bit and the "z" bit to be set simultaneously for these instructions.
• In addition to submitting your "cmemory" and "memory" files by e-mail, you should submit a written report with the following items:

(1) A brief description of your approach to the assignment, and the features of your solution.
(2) Dependent RTN statements for all the instructions implemented.
(3) The resulting CPI for the different instruction types.
(4) A statement of any relevant problems or difficulties encountered during the assignment.
(5) A listing of your fully-commented "cmemory" and "memory" files as e-mailed.
(6) A description of testing procedures used and observations.
(7) Any additional remarks or conclusions you deem noteworthy of mention.
### Inherent Instructions Opcodes

<table>
<thead>
<tr>
<th>Binary</th>
<th>Hex</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOP</td>
<td>0f</td>
</tr>
<tr>
<td>HALT</td>
<td>1f</td>
</tr>
<tr>
<td>CLA</td>
<td>2f</td>
</tr>
<tr>
<td>CMA</td>
<td>3f</td>
</tr>
<tr>
<td>INCA</td>
<td>4f</td>
</tr>
<tr>
<td>DECA</td>
<td>5f</td>
</tr>
<tr>
<td>RET</td>
<td>6f</td>
</tr>
<tr>
<td>ROLCA</td>
<td>7f</td>
</tr>
<tr>
<td>CLC</td>
<td>8f</td>
</tr>
<tr>
<td>STC</td>
<td>9f</td>
</tr>
</tbody>
</table>

### Store and Branch Instructions Opcodes

<table>
<thead>
<tr>
<th>Binary</th>
<th>Hex (Direct z=0)</th>
<th>Hex (Indirect z=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STA</td>
<td>00001z00</td>
<td>08</td>
</tr>
<tr>
<td>JMP</td>
<td>00011z00</td>
<td>18</td>
</tr>
<tr>
<td>JEQ</td>
<td>00101z00</td>
<td>28</td>
</tr>
<tr>
<td>JCS</td>
<td>00111z00</td>
<td>38</td>
</tr>
<tr>
<td>JLT</td>
<td>01001z00</td>
<td>48</td>
</tr>
<tr>
<td>JVS</td>
<td>01011z00</td>
<td>58</td>
</tr>
<tr>
<td>JSR</td>
<td>01101z00</td>
<td>68</td>
</tr>
</tbody>
</table>

### Other Instructions Opcodes

<table>
<thead>
<tr>
<th>Binary</th>
<th>Hex Direct y = z =0</th>
<th>Indirect y=0 z=1</th>
<th>Immediate y=1 z=0</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDA</td>
<td>0000yz01</td>
<td>01</td>
<td>05</td>
</tr>
<tr>
<td>ORA</td>
<td>0001yz01</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>EOR</td>
<td>0010yz01</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>AND</td>
<td>0011yz01</td>
<td>31</td>
<td>35</td>
</tr>
<tr>
<td>ADD</td>
<td>0100yz01</td>
<td>41</td>
<td>45</td>
</tr>
<tr>
<td>SUBA</td>
<td>0101yz01</td>
<td>51</td>
<td>55</td>
</tr>
<tr>
<td>LDS</td>
<td>0110yz01</td>
<td>61</td>
<td>65</td>
</tr>
</tbody>
</table>
Test Memory Files (also posted online as separate text files)

memory.inherent

;  test file for Microprogramming Project
;
0f     ;NOP
4f     ;INCA
4f     ;INCA
4f     ;INCA
5f     ;DECA
2f     ;CLA
5f     ;DECA from 00
4f     ;INCA
3f     ;CMA
2f     ;CLA
4f     ;INCA
9f     ;STC
7f     ;ROLCA
9f     ;STC
8f     ;CLC
1f     ;HALT

;  should do nothing for first instruction,
;  then increment accumulator by 3,
;  then decrement it by 1,
;  then clear accumulator,
;  then decrement by 1 resulting in FF in ACC and N=1,V=0,
;  then increment by 1 to 00 with Z,V=0
;  then ones-complement accumulator to get FF and C=0,V=0
;  then clear accumulator,
;  then increment to 1,
;  then set carry bit to 1
;  then roll carry and accumulator from 1 00000001 to 0 00000011
;  then set carry bit,
;  then clear carry bit,
;  then HALT execution
Test Memory Files (also posted online as separate text files)
memory.otherbranches

; test file for Microprogramming Project
; test branch and store instructions
; - specifically test JEQ, JEQind, JCS, JCSind, JLT, JLTind
4f  ;01: INCA (00)
2f  ;02: CLA (01)
28 00 06 ;03: JEQ 0006 (02-04)
4f  ;04: INCA - filler (should not execute) (05)
5f  ;05: DECA - should jump here from line 03 (06)
28 00 0c ;06: JEQ 000c (07-09)
4f  ;07: INCA - should be executed, no jump (0a)
2c 00 0f ;08: JEQind 000f (0b-0d)
4f  ;09: INCA - filler (should not be executed) (0e)
00 12 ;10: address to jump to from line 08 (0f-10)
4f  ;11: INCA - filler (should not be executed) (11)
5f  ;12: DECA - should jump here from line 08 (12)
2c 00 0f ;13: JEQind 000f (13-15)
4f  ;14: INCA - should be executed, no jump (16)
9f  ;15: STC (17)
38 00 1c ;16: JCS 001c (18-1a)
4f  ;17: INCA - filler (should not be executed) (1b)
8f  ;18: CLC - should jump here from line 16 (1c)
38 00 1c ;19: JCS 001c (1d-1f)
9f  ;20: STC - should be executed, no jump (20)
3c 00 24 ;21: JCSind 0024 (21-23)
00 27 ;22: address to jump to from line 21 (24-25)
4f  ;23: INCA - should not be executed (26)
8f  ;24: CLC (27)
3c 00 24 ;25: JCSind 0024 (28-2a)
5f  ;26: DECA - should be executed, no jump (2b)
48 00 30 ;27: JLT 0030 (2c-2e)
5f  ;28: DECA - filler (2f)
4f  ;29: INCA - should jump here from line 27 (30)
48 00 30 ;30: JLT 0030 (31-33)
5f  ;31: DECA - should be executed, no jump (34)
4c 00 38 ;32: JLTind 0038 (35-37)
00 3b ;33: address to jump to from line 32 (38-39)
5f  ;34: DECA - filler (3a)
4f  ;35: INCA - should jump here from line 32 (3b)
4c 00 38 ;36: JLTind 0038 (3c-3e)
1f  ;37: HALT, no jump (3f)

; program should execute as follows:
; increment accumulator by one to 1
; clear the accumulator
; jump to address 6, line 5
; decrement accumulator to FF
; jump NOT taken, accumulator incremented to 0
; jump to address 12, line 12
; decrement accumulator to FF
; jump NOT taken, accumulator incremented to 0
; set the carry bit
; jump to address 1C, line 18
; clear the carry bit
; jump NOT taken, set the carry bit
; jump to address 27, line 24
; clear the carry bit
; jump NOT taken, decrement accumulator to FF
; jump to address 30, line 29
; increment accumulator to 0
; jump NOT taken, decrement accumulator to FF
; jump to address 3b, line 35
; increment accumulator to 0
; jump NOT taken, program HALTed
Test Memory Files (also posted online as separate text files)
memory.otherslogical

; test file for Microprogramming Project
;
; test LDA, LDAimm, LDAind, ORA, ORAimm, ORAind, EOR, EORimm, EORind, AND, ANDimm, ANDind,
; ADD, ADDimm, ADDind, SUBA, SUBAimm, SUBAind, LDS, LDSimm, LDSind, JVS, JVSind

01 00 06 ;01: LDA 0006 (00-02)
18 00 07 ;02: JMP 0007 (03-05)
69 ;03: value to load into accumulator (06)
05 00 0d ;04: LDAind 000d (07-09)
18 00 10 ;05: JMP 0010 (0a-0c)
00 0f ;06: address of value to load into accumulator (0d-0e)
aa ;07: value to load into accumulator (0f)
09 bc ;08: LDAimm bc (10-11)
11 00 18 ;09: ORA 0018 (12-14)
18 00 19 ;10: JMP 0019 (15-17)
ab ;11: value to OR with accumulator (18)
15 00 1f ;12: ORAind 001f (19-1b)
18 00 22 ;13: JMP 0022 (1c-1e)
00 21 ;14: address of value to OR with accumulator (1f-20)
ec ;15: value to OR with the accumulator (21)
19 3b ;16: ORAimm 3b (22-23)
21 00 2a ;17: EOR 002a (24-26)
18 00 2b ;18: JMP 002b (27-29)
24 ;19: value to EOR with accumulator (2a)
25 00 31 ;20: EORind 0031 (2b-2d)
18 00 34 ;21: JMP 0034 (2e-30)
00 33 ;22: address of value to EOR with accumulator (31-32)
98 ;23: value to EOR with accumulator (33)
29 fe ;24: EORimm fe (34-35)
31 00 3c ;25: AND 003c (36-38)
18 00 3d ;26: JMP 003d (39-3b)
aa ;27: value to AND with accumulator (3c)
35 00 43 ;28: ANDind 0043 (3d-3f)
18 00 46 ;29: JMP 0046 (40-42)
00 45 ;30: address of value to AND with accumulator (43-44)
37 ;31: value to AND with accumulator (45)
39 94 ;32: ANDimm 94 (46-47)
1f ;33: HALT (48)

;program should execute as follows:
; load accumulator with 69
; jump to address 7, line 4
; load accumulator with aa
; jump to address 10, line 8
; load accumulator with bc
; OR accumulator with ab, ab or bc = bf
; jump to address 19, line 12
; OR accumulator with ec, bf or ec = ff
; jump to address 22, line 16
; OR accumulator with 3b, ff or 3b = ff
; EOR accumulator with 24, ff xor 24 = db
; jump to address 2b, line 20
; EOR accumulator with 98, db xor 98 = 43
; jump to address 34, line 24
; EOR accumulator with fe, 43 xor fe = bd
; AND accumulator with aa, bd and aa = a8
; jump to address 3d, line 28
; AND accumulator with 37, a8 and 37 = 20
; jump to address 46, line 32
; AND accumulator with 94, 20 and 94 = 00
; end program with HALT
Test Memory Files (also posted online as separate text files)

memory.othersmath

; test file for Microprogramming Project
;
; test ADD, ADDimm, ADDind, SUBA, SUBAimm, SUBAind, LDS, LDSimm, LDSind

41 00 06 ;01: ADD 0006 (00-02)
18 00 07 ;02: JMP 0007 (03-05)
5a ;03: value to add to accumulator (06)
45 00 0d ;04: ADDind 000d (07-09)
18 00 10 ;05: JMP 0010 (0a-0c)
00 0f ;06: address of value to add to accumulator (0d-0e)
24 ;07: value to add to accumulator (0f)
49 33 ;08: ADDimm 33 (10-11)
51 00 18 ;09: SUBA 0018 (12-14)
18 00 19 ;10: JMP 0019 (15-17)
13 ;11: value to subtract from accumulator (18)
55 00 1f ;12: SUBAind 001f (19-1b)
1c 00 22 ;13: JMP 0022 (1c-1e)
00 21 ;14: address of value to subtract from accumulator (1f-20)
8f ;15: value to subtract from accumulator (21)
59 25 ;16: SUBAimm 25 (22-23)
61 00 2a ;17: LDS 002a (24-26)
18 00 2c ;18: JMP 002c (27-29)
aa 69 ;19: value to load into stack pointer (2a-2b)
65 00 32 ;20: LDSind 0032 (2c-2e)
18 00 36 ;21: JMP 0036 (2f-31)
00 34 ;22: address of value to load into SP (32-33)
69 aa ;23: value to load into stack pointer (34-35)
69 ab cd ;24: LDSimm abcd (36-38)
1f ;25: HALT (39)

; program should execute as follows:
; add 5a to 0 in accumulator
; jump to address 7, line 4
; add 24 to accumulator, 5a + 24 = 7e
; jump to address 10, line 8
; add 33 to accumulator, 7e + 33 = b1
; subtract 13 from accumulator, b1 - 13 = 9e
; jump to address 19, line 12
; subtract 8f from accumulator, 9e - 8f = f
; jump to address 22, line 16
; subtract 25 from accumulator, f - 25 = -EA
; load aa into SPHi, 69 into SPLo
; jump to address 40, line 28
; load 69 into SPHi, aa into SPLo
; jump to address 4a, line 32
; load ab into SPHi, cd into SPLo
; end program with HALT
Test Memory Files (also posted online as separate text files)
memory.storebranch

; test file for Microprogramming Project
;
; test branch and store instructions
; specifically test STA,STAind,JMP,JMPind,JSR,JSRind,and RET

4f ;01: INCA (00)
4f ;02: INCA (01)
08 0f 01 ;03: STA 0f01 (02-04)
4f ;04: INCA (05)
0c 00 0d ;05: STAind 000d (06-08)
18 00 0f ;06: JMP 000f (09-0b)
4f ;07: INCA - filler (should not execute) (0c)
0f 05 ;08: address to store at from line 5 (0d-0e)
5f ;09: DECA - should jump here from line 6 (0f)
1c 00 13 ;10: JMPind 0013 (10-12)
00 16 ;11: address to jump to from line 10 (13-14)
4f ;12: INCA - filler (should not execute) (15)
5f ;13: DECA - should jump here from line 10 (16)
68 00 1e ;14: JSR 001e (17-19)
6c 00 20 ;15: JSRind 0020 - should return here from RET on line 18 (1a-1c)
1f ;16: HALT - end of program - returns from line 22 (1d)
3f ;17: CMA - should jump here from line 14 (1e)
6f ;18: RET - should return to line 15 (1f)
00 23 ;19: address to jump to from line 15 (20-21)
4f ;20: INCA - FILLER (should not execute) (22)
2f ;21: CLA - should jump here from line 15 (23)
6f ;22: RET - should return to line 16 (24)

;execution should be as follows -
; increment accumulator twice to 2
; store the accumulator at the address 0f01
; increment accumulator to 3
; store accumulator at address 0f05
; jump to address 000F, which is line 9 above
; decrement accumulator to 2
; jump to address at address 0013 which is 0016, or line 13
; decrement accumulator to 1
; jump to subroutine at address 001e, line 17
; do one's complement of accumulator
; return from subroutine to address 1a, line 15
; jump to subroutine at the address that is at address 0020,
;    which is 0023, line 21
; clear the accumulator
; return from subroutine to address 1d, line 16
; end program with HALT
The Datapath

- **ISA Registers:**
  - Program Counter (PC) 16 bits implemented in datapath by two 8-bit registers: PCHi, PCLo
  - Accumulator (ACC) 8-bit register.
  - Flags Register (FLGS) 8-bit register, low four bits are the flags: NZVC
  - Stack Pointer (SP) 16-bit register implemented in datapath by two 8-bit registers: SPHi, SPLo

- **Memory Details**
  - A single main memory used for instructions and data. 16-bit address.
  - Memory Address High Register (MAH) must be loaded first for both reads and writes.
  - For memory writes the MW (Memory Write) register must be loaded with the byte to be stored.
  - Reading from and writing to memory is triggered by loading MAL (Memory Address Low) register using ALUDEST microinstruction field options.
  - Memory read/write operations take two clock cycles from the start of a memory read or write.

- **Temporary Datapath/Microprogram Registers:**
  - The following 8-bit registers can be used by the control microprogram to store temporary values as needed and are not visible to the ISA or user programs: T, U, B, XLo, Xhi

- **The ALU Output Shifter:**
  - Combinational logic shifter that can shift the ALU output one position left or right and also manipulate the most significant bit of the ALU output (L-bit) before shifting in a single cycle.

- **Constant Value (Const):** Shown as a possible input to the ALU is 5-bit value that can be specified by a microinstruction field (field H).
# The Control Microinstruction Format

<table>
<thead>
<tr>
<th>Bit</th>
<th>Field</th>
<th>Name</th>
<th>Operations</th>
</tr>
</thead>
</table>
| 0   | A     | MEMDEST               | 00 - NOP  (See Note 2)  
01 - MD  
10 - MD and MALow  
11 - MD and MALow and IR |
|     | B     | LCNTRL                | 00 - Leave L alone  
01 - Clear L  
10 - Set L  
11 - L = Carry Out of ALU |
| 2   | C     | SHFTNTRL              | 00 - No Shift  
01 - Shift Right  
10 - Shift Left  
11 - Not Used |
| 4   | D     | ALUCTRL               | 0000 - X  
0001 - Y  
0010 - X plus Y  
0011 - X plus Y plus 1  
0100 - X and Y  
0101 - X or Y  
0110 - X xor Y  
0111 - not Y  
1000 - X plus 1  
1001 - Y plus 1  
1010 - X and 1  
1011 - Y and 1  
1100 - Y plus not X plus 1  
1101 - not X  
1110 - minus 1  
1111 - 0 |
| 6   | E     | YSOURCE               | 0000 - none  
0001 - ACC  
0010 - PCLo  
0011 - SPLo  
0100 - B  
0101 - FLAGS  
0110 - XHi  
0111 - XLo  
1000 - PCHi  
1001 - SPHi  
1010 - unused  
1011 - unused  
1100 - unused  
1101 - unused  
1110 - unused  
1111 - unused |
| 10  | F     | XSOURCE               | 0000 - ACC  
001 - MD  
010 - CONST  (Constant Field from Microinstruction)  
011 - External Data (not used here)  
100 - T  
101 - MALo  
110 - MAHi  
111 - U |
| 14  | G     | ALUDEST                | 0000 - none  
0001 - ACC  
0010 - PCLo  
0011 - SPLo  
0100 - B  
0101 - FLAGS  
0110 - XHi  
0111 - XLo  
1000 - PCHi  
1001 - SPHi  
1010 - MAHi  
1011 - MALo, Read (Starts Memory Read)  
1100 - T  
1101 - MALo, Write (Starts Memory Write)  
1110 - U  
1111 - MW |
| 21  | H     | CONST                 | Unsigned 5-bit constant for XSOURCE |
| 26  | I     | LOADFLGS              | When 1 loads FLAGS from internal ALU flags NBIT, ZBIT, VBIT, CBIT |
### The Control Microinstruction Format (Continued)

<table>
<thead>
<tr>
<th>Bit</th>
<th>Field</th>
<th>Name</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>J</td>
<td>TEST</td>
<td>00 - Branch on NBIT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>01 - Branch on ZBIT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 - Branch on VBIT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11 - Branch on CBIT</td>
</tr>
<tr>
<td>28</td>
<td>K</td>
<td>INTRENAB</td>
<td>Not Used, always put 0 in this field</td>
</tr>
<tr>
<td>29</td>
<td>L</td>
<td>ADDRF</td>
<td>9-bit address field of Next microinstruction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>bit 30: Most Significant Bit of Address</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(See Note 1)</td>
</tr>
<tr>
<td>30</td>
<td>M</td>
<td>COND</td>
<td>Determines Type of Next Microinstruction Address</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(See note 1)</td>
</tr>
<tr>
<td>31</td>
<td>N</td>
<td>OPCODE</td>
<td>Opcode: Format of Microinstruction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Only one format used here, always put 0 in this field.</td>
</tr>
</tbody>
</table>

#### Micrinstruction Fields Notes:

**Note 1:**

If COND = 00 then MPC (next microinstruction address) = ADDRF (i.e bits 30-38) as given.

If COND = 01 Then MPC (next microinstruction address) is determined by bits 30-37 of ADDRF along with the particular test bit specified by TEST field from the ALU replacing the least significant bit of 38 of ADDRF (i.e two way branch on the condition bit tested).

If COND = 10 Then MPC (next microinstruction address) by bits 30-34 (five most significant bits of ADDRF) along with the 4 most significant bits of IR (instruction register) replacing the low 4 bits 35-38 of ADDRF (I.e 16-way branch on the 4 most significant bits of IR).

If COND = 11 Then MPC (next microinstruction address) by bits 30-34 (five most significant bits of ADDRF) along with the 4 least significant bits of IR (instruction register) replacing the low 4 bits 35-38 of ADDRF (I.e 16-way branch on the 4 least significant bits of IR).

**Note 2:** The Memory destination from the memory bus MBUS (memory data bus) is as follows:

- When the MEMDEST field is not 00, MD is loaded from MBUS.
- When the field is 10 (2 decimal) MD and MALo registers are loaded from MBUS.
- When the field is 11 (3 decimal) MD, MALo and IR registers are loaded from MBUS.

**Note 3:** For every microinstruction field, use the decimal value of the binary field values specified above, as shown in the sample microprogram start segment on the next page.

**Note 4:** A microinstruction with each field filled with 999 will halt execution.
Sample Microprogram Start Segment

;A - MEMDEST
;| B - LCNTRL
;| | C - SHFTCNTRL
;| | | D - ALUCNTRL
;| | | | E - YSRCE
;| | | | | F - XSRCE
;| | | | | | G - ALUDEST
;| | | | | | | H - CONST
;| | | | | | | | I - LDFLG
;| | | | | | | | | J - TEST
;| | | | | | | | | | K - INTRNE
;| | | | | | | | | | | L - ADDR
;| | | | | | | | | | | | M - COND
;| | | | | | | | | | | | | N - OPCODE
;| | | | | | | | | | | | | | ADDRESS COMMENT
|
0 0 0 15 0 0 8 0 0 0 0 1 0 0 0 000 :PCHI <- 0
0 0 0 15 0 0 2 0 0 0 0 2 0 0 0 001 :PCLO <- 0
0 0 0 13 0 2 9 0 0 0 0 3 0 0 0 002 :SPHI <- FF
0 0 0 13 0 2 3 0 0 0 0 4 0 0 0 003 :SPLO <- FF
0 0 0 15 0 0 1 0 0 0 0 5 0 0 0 004 :ACC <- 0
0 0 0 1 8 0 10 0 0 0 0 6 0 0 0 005 :MAHI <- PCHI
0 0 0 1 2 0 11 0 0 0 0 7 0 0 0 006 :MALO <- PCLO START FETCH
0 0 0 9 2 0 2 0 0 3 0 8 1 0 0 007 :PCLO += 1 (ALSO WAIT CYCLE)
3 0 0 0 0 0 0 0 0 0 0 10 0 0 0 008 :IR <- M
3 0 0 9 8 0 8 0 0 0 0 10 0 0 0 009 :IR <- M, PCHI+=1

;END FETCH, START DECODE
0 0 0 0 0 0 0 0 0 0 0 16 3 0 0 10 :START DECODE
0 0 0 0 0 0 0 0 0 0 0 16 0 0 0 011 :NO-OP
0 0 0 0 0 0 0 0 0 0 0 16 0 0 0 012 :NO-OP
0 0 0 0 0 0 0 0 0 0 0 16 0 0 0 013 :NO-OP
0 0 0 0 0 0 0 0 0 0 0 16 0 0 0 014 :NO-OP
0 0 0 0 0 0 0 0 0 0 0 16 0 0 0 015 :NO-OP

;BEGIN FIRST STAGE DECODE, 16-WAY BRANCH ON LOWER HALF OF OPCODE BYTE
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 016 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 144 0 0 0 017 :NO-OP DIRECT OTHER
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 018 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 019 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 020 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 021 :NO-OP INDIRECT OTHER
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 022 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 023 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 024 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 025 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 026 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 027 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 028 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 029 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 030 :NO-OP ERROR HALT
0 0 0 0 0 0 0 0 0 0 0 349 0 0 0 031 :NO-OP INHERNET

;END FIRST STAGE DECODE, BEGIN SECOND STAGE
;
999 999 999 999 999 999 999 999 999 999 999 999 999 999; 349: HALT