## - MC9S12 Assembler Directives

- A Summary of MC9S12 Instructions
- Disassembly of MC9S12 op codes
- Number of cycles and time taken to execute an MC9S12 program
- A label is a name assigned to the address of the location counter where the label is defined
- Use of assembler directives
- A summary of MC9S12 instruction
- How to disassemble an MC9S12 instruction sequence

Summary of HCS12 addressing modes
ADDRESSING MODES

| Name |  | Example | Op Code | Effective <br> Address |
| :---: | :---: | :---: | :---: | :---: |
| INH | Inherent | ABA | 1806 | None |
| IMM | Immediate | LDAA \#\$35 | 8635 | $\mathrm{PC}+1$ |
| DIR | Direct | LDAA \$35 | 9635 | 0x0035 |
| EXT | Extended | LDAA \$2035 | B6 2035 | 0×2035 |
| IDX <br> IDX1 <br> IDX2 | Indexed | LDAA 3, x LDAA $30, \mathrm{x}$ LDAA $300, \mathrm{X}$ | $\begin{array}{llll} \text { A6 } & 03 & & \\ \text { A } 6 & \text { E0 } & 13 & \\ \text { A6 } & \text { E2 } & 01 & \text { 2C } \end{array}$ | $\begin{aligned} & x+3 \\ & x+30 \\ & x+300 \end{aligned}$ |
| IDX | Indexed <br> Postincrement | LDAA 3, $\mathrm{X}+$ | A 632 | $\mathrm{X} \quad(\mathrm{X}+3 \rightarrow \mathrm{x})$ |
| IDX | Indexed Preincrement | LDAA 3, +X | A6 22\| | $\mathrm{x}+3 \mathrm{l}$ (x+3 $\rightarrow$ x) |
| IDX | Indexed <br> Postdecrement | LDAA 3, $\mathrm{X}-$ | A 6 3D | $\mathrm{X} \quad(\mathrm{X}-3 \rightarrow \mathrm{X})$ |
| IDX | Indexed Predecrement | LDAA 3,-X | A 6 2D | $\mathrm{X}-3 \quad(\mathrm{X}-3 \rightarrow \mathrm{x})$ |
| REL | Relative | BRA \$1050 <br> LBRA \$1F00 | $\begin{array}{ll} 20 & 23 \\ 18 & 20 \end{array} \quad \mathrm{EE} \quad \mathrm{CF}$ | $\begin{aligned} & P C+2+\text { Offset } \\ & P C+4+\text { Offset } \end{aligned}$ |

A few instructions have two effective addresses:

- MOVB \#\$AA,\$1C00 Move byte 0xAA (IMM) to address \$1C00 (EXT)
- MOVW 0,X,0,Y Move word from address pointed to by X (IDX) to address pointed to by Y (IDX)

A few instructions have three effective addresses:

- BRSET FOO, \#\$03,LABEL Branch to LABEL (REL) if bits \#\$03 (IMM) of variable FOO (EXT) are set.

Using $X$ and $Y$ as Pointers

- Registers X and Y are often used to point to data.
- To initialize pointer use


## ldx \#table

not

## Idx table

- For example, the following loads the address of table (\$1000) into X; i.e., X will point to table:
ldx \#table ; Address of table $\Rightarrow X$
The following puts the first two bytes of table (\$0C7A) into X . X will not point to table:

```
Idx table ; First two bytes of table }=>
```

- To step through table, need to increment pointer after use


## Idaa 0,x

inx
or

## Idaa 1,x+



$$
\begin{array}{lll} 
& \text { org } & \$ 900 \\
\text { table: } & \begin{array}{l}
\text { dc.b } \\
\text { dc.b }
\end{array} & 12,122,-43,0 \\
& \mathrm{a}^{\prime}, \mathrm{b}^{\prime},{ }^{\prime} \mathrm{c}^{\prime},{ }^{\prime} \mathrm{d}^{\prime}
\end{array}
$$

Which branch instruction should you use?
Branch if A>B
Is $0 \mathrm{xFF}>0 \mathrm{x} 00$ ?

If unsigned, $0 x F F=255$ and $0 x 00=0$,
so $0 \mathrm{xFF}>0 \mathrm{x} 00$
If signed, $0 \times \mathrm{xF}=-1$ and $0 \mathrm{x} 00=0$,

$$
\text { so } 0 x F F<0 x 00
$$

Using unsigned numbers: BHI (checks C bit of CCR )
Using signed numbers: BGT (checks $V$ bit of CCR)
For unsigned numbers, use branch instructions which check C bit
For signed numbers, use branch instructions which check V bit

Hand Assembling a Program
To hand-assemble a program, do the following:

1. Start with the org statement, which shows where the first byte of the program will go into memory.
(e.g., org $\mathbf{\$ 2 0 0 0}$ will put the first instruction at address $\mathbf{\$ 2 0 0 0}$.)
2. Look at the first instruction. Determine the addressing mode used. (e.g., Idab \#10 uses IMM mode.)
3. Look up the instruction in the MC9S12 S12CPUV2 Reference Manual, find the appropriate Addressing Mode, and the Object Code for that addressing mode.
(e.g., Idab IMM has object code C6 ii.)

- Table A. 1 of the S12CPUV2 Reference Manual has a concise summary of the instructions, addressing modes, op-codes, and cycles.

4. Put in the object code for the instruction, and put in the appropriate operand. Be careful to convert decimal operands to hex operands if necessary.
(e.g., Idab \#10 becomes C6 0A.)
5. Add the number of bytes of this instruction to the address of the instruction to determine the address of the next instruction.
(e.g., $\mathbf{\$ 2 0 0 0} \mathbf{+ 2} \mathbf{=} \mathbf{\$ 2 0 0 2}$ will be the starting address of the next instruction.)
org \$2000
ldab \#10
loop: clra
dbne b,loop
swi

Table A-1. Instruction Set Summary (Sheet 7 of 14)

| Source Form | Operation | Addr. Mode | $\begin{gathered} \text { Machine } \\ \text { Coding (hex) } \end{gathered}$ | HCS12 | M58HC12 | SXHI | NZVC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| LEGT M13 | Long Branch I Greater Than $\left.\left[\begin{array}{l}\mathrm{Z} \\ \mathrm{Z}\end{array} \mathrm{N} \oplus \mathrm{V}\right)=0\right]$ (slgnad) | REL | 182 Eqg IT | OWD/ORO ${ }^{1}$ | OPVD/ONO ${ }^{1}$ | ---- | ---- |
| LEH relt 6 | Long Branch I Higher (f $\mathrm{C}+\mathrm{Z}=$ o ) (unsigned) | REL | $18 \quad 22 \mathrm{qq} \mathrm{Ir}$ | OWD/ORO ${ }^{1}$ | OVED/ORO ${ }^{1}$ | ---- | ---- |
| LEHS for 13 | Long Branch 1 Higher or Same [f $\mathrm{C}=\mathrm{O}$ ) (unsigned) seme function as LBCC | REL | 1824 qq Ir | OWD/000 ${ }^{1}$ | ODVD/ONO ${ }^{\text {P }}$ | ---- | ---- |
| LELE fal 15 | Long Branch 1 Less Than or Equal <br>  | REL | 182 Fqq rr | OWP/OPO ${ }^{1}$ | ODED/ODO ${ }^{1}$ | ---- | ---- |
| LELO re' 16 | Long Branch It Lowes (f) C - 1) (unsigned) same furction as LBCS | REL | 1825 qq Ir | OWD/ODO ${ }^{1}$ | OVED/ODO ${ }^{\text {d }}$ | ---- | -- |
| LELS [9116 | Long Branch 1 Lower or Same [f $\mathrm{C}+\mathrm{Z}=1$ ) (unslgned) | REL | $18 \quad 23 \mathrm{qq} \mathrm{Ir}$ | OWD/ODO ${ }^{1}$ | ODPD/ODO ${ }^{1}$ | ---- | ---- |
| LBLT refl6 | Long Branch il Less Than [f $\mathrm{N} \oplus \mathrm{V}=1$ ) (signed] | REL | $18 \mathrm{2d}$ qq rr | OWD/000 ${ }^{1}$ | ODVP/ODO ${ }^{1}$ | ---- | -- |
| LEM relf 6 | Long Branch I M Mius (fiN = 1) | REL | $18 \mathrm{2B} \mathrm{qq} \mathrm{Ir}$ | OFPD/001 ${ }^{1}$ | OPDP/ODO | - | - |
| LENE g16 | Long Eranch i Not Equal (1 $\mathrm{Z}=0$ ) | REL | 1826 qq Ir | OFPD/000 ${ }^{1}$ | OPVP/ODO ${ }^{\text {a }}$ | ---- | -- |
| LEPL \% ${ }^{\text {P15 }}$ | Long Branch 1 Pus (f $\mathrm{N}=0$ ) | REL | 182 Aqq Ir | OFPD/ODO ${ }^{1}$ | OPDP/ODO ${ }^{\text {a }}$ | - | - |
| LERA mal 16 | Long Branch AlwEys (f 1m) | REL | 1820 qq rr | Cow | ODVD | ---- | - |
| LERN relf6 | Long Branch Never (filo) | REL | 1821 qq rr | 000 | ODO | ---- | ---- |
| LEVC 015 | Long Branch 1 Overfiow Bt Clear (f V-0) | REL | 182 g qq Ir | OFP/ $/ 0.0{ }^{1}$ | OPVD/ODO ${ }^{1}$ | - | - |
| LEVS rel 16 | Long Eranch I Overfiow Bt Set (\% V = 1) | REL | 1829 qq rr | Omp/cio ${ }^{1}$ | OPVP/ODO ${ }^{2}$ | -- | ---- |
| LDAA topr 9 <br> LDAA qpBa <br> LDAA qrife <br> LDAA qMOD $x y s p$ <br> LDAA qpo9. ysp <br> LDAA quafig.ysp <br> LDAA [D,ysp] <br> LDAA [quaf $6 . y s p$ ] | $\mid \mathrm{M}) \neq \mathrm{A}$ <br> Loed Accurnulator A | IMM DIR EXT IDX IDX1 IDX2 $[D, I D X]$ [IDXZ] |  | D rDI rDO rDI rDO IrDD IIIrDI IIPIDI | D rID rOD rID rDD ITDD $\operatorname{ITITID}$ IIDRID | ---- | $\triangle \triangle 0-$ |
| LDAB soprg <br> LDAB quBa <br> LDAB qifice <br> LDA日 q000 $x y s$ <br> LDAB qu99.ysp <br> LDAB quat 6 ysp <br> LDA日 [D,ysp] <br> LDAB [pori $6 y s p$ ] | $\left\lvert\, \begin{aligned} & \mathrm{V}) \Rightarrow \mathrm{B} \\ & \text { Loed Accurulator B } \end{aligned}\right.$ | IMM DIR EXT IDX IDX1 IDX2 $[D, I D X]$ $[I D X Z]$ |  | I rDI rDO rDI rDO ITPD IIfrDI IIDrDI | D rID rOD rID rDO ITDD IITIID IIDRID | ---- | $\triangle \triangle 0$ - |
|  | $\begin{aligned} & \mathrm{M}(\mathrm{M}+1) \Rightarrow \mathrm{A} \cdot \mathrm{~B} \\ & \text { Loed Doubla Accumulator } \mathrm{D}(\mathrm{~A} B) \end{aligned}$ | IMM DIR EXT DX IDX1 IDX2 $[D, I D X]$ $[I D X Z]$ |  |  |  | ---- | $\triangle \triangle 0$ - |


| LDS apria | $(\mathrm{M} M+1) \Rightarrow \mathrm{SP}$ | IVM | CF 11 kk | DO | OD | --- | $\triangle \triangle 0-$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| LDS qrila | Loed Stack Pointer | DIA | De di | RDE | PID |  |  |
| LDS qriba |  | EXT | FF th 11 | H20 | RLD |  |  |
| LDS 9000 y ysp |  | 1DX | EF xb | RDE | M10 |  |  |
| LDS pon9yys |  | IDX1 | EF xb it | Pro | 300 |  |  |
| LDS quat 6 ysp |  | IDX2 | EF xb ac [1 | IFOD | E3D2 |  |  |
| LDS [D, yspp] |  | [D, IDX] | $\text { EF } \mathrm{xb}$ | SITRDI | E1E301 |  |  |
| LDS [ 0 ¢rxi6.ysp]] |  | [1DXZ] | EF xb act It | E1PMDI | TIESID |  |  |
| LDX appia | $(\mathrm{M} M+1) \Rightarrow \mathrm{X}$ | IVM | CE 11 kx | DO | CD | ---- | $\triangle \triangle 0-$ |
| LDX ¢0.39 | Load Indax Aegister X | DIA | DE dd | HDE |  |  |  |
| LDX qpr18a |  | EXT | FE ht 11 | PRO | BLD |  |  |
| LDX POOD y ysp |  | DX | EE xb | RDP | R10 |  |  |
| LDX apagyysp |  | IDX1 | ER ED 21 | 1850 | 3 BDO |  |  |
| LDX quat $6 . y \leq p$ |  | IDX2 | EP xb ad f1 | IEOD | S300 |  |  |
| LDXX [D,ysp] |  | [D, IDX] | EE Eb | ITIMDI | TIERAD |  |  |
| LDX [0pryis,ysp] |  | [IDXZ] | EE xb ac ft | SIPSD | ETVITD |  |  |

Table A－1．Instruction Set Summary（Sheet 3 of 14）

| Source Form | Operation | Addr． <br> Mode | $\begin{aligned} & \text { Machine } \\ & \text { Coding (rex) } \end{aligned}$ | HCS12 | M63HC12 | SXHI | NZVC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| BLS meg | Eranch 1 Lower or Same （f $\mathrm{C}+\mathrm{Z}=1$ ）（unsigned） | REL | 23 Ir | DW／D ${ }^{1}$ | DW／D ${ }^{1}$ | －－－－－ | －－－－ |
| BLT mg | Brarch i Less Than ［ $\mathrm{f} \mathrm{N} \oplus \mathrm{V}=1$ ）（ slgned ］ | REL | 2 DIT | DWP／D | NWP／D ${ }^{2}$ | －－－－ | －－－－ |
| BMI 918 | Eranch I Minus（iN＝1） | REL | 2 BrI | VWP／D ${ }^{1}$ | VW／D ${ }^{2}$ | －－－－－ | －－－－－ |
| ENE Reg | Eranch 1 Not Equal（if $\mathrm{z}=0$ ） | REL | 26 II | DW／ $\mathrm{D}^{1}$ | DW／D ${ }^{2}$ | －－－－ | －－ |
| BPL me9 | Erarch If Plis（ $\mathrm{IN}=0$ ） | REL | 2A II | DWP／D ${ }^{\text {a }}$ | DWF／D ${ }^{2}$ | －－－－ | －－ |
| BRARER | Erarch Always［ 11 －1） | REL | 20 II | DW | DVD | －－－－ | －－ |
|  | $\begin{aligned} & \text { Erarch it }(M) \text { • }(\mathrm{mr})=0 \\ & (\mathrm{f} \text { Al Selected Bt }(5) \text { Clear }) \end{aligned}$ | DIR EXT IDX IDX1 IDX2 |  | $\begin{array}{\|l} \hline r W D \\ \text { rIDVD } \\ \text { rWp } \\ \text { rIDWD } \\ \text { DrIDVD } \end{array}$ | $\begin{array}{r} \text { rDVD } \\ \text { repDD } \\ \text { rDVD } \\ \text { reEDVD } \\ \text { frDe } \end{array}$ | －－－－ | －－－－ |
| BRN ralg | Brarch Never（if 1 － 0 ） | REL | 21 II | D | D | －－－－ | － |
|  | Branch I（ $(\mathrm{V}) \cdot(\mathrm{mm})=0$ （t Al Selected Bt（3）Set） | DIA EXT IDX IDX1 IDX2 | 4E dd mn II <br> 1E Mh 11 mm Ir <br> 樶 xb mir IT <br> 呎 xb If mm IT <br> 㫙 xb Qe If mm IT | $\begin{array}{\|l} \hline r W D \\ \text { rIPVD } \\ \text { rWP } \\ \text { rIDPD } \\ \text { DrIDVD } \end{array}$ | $\begin{array}{r} \text { rDVD } \\ \text { revVD } \\ \text { rDVD } \\ \text { rfepVD } \\ \text { frDEEDVD } \end{array}$ | －－－－ | －－－－ |
| BSET qurg，mskg <br> BSET qritie，mskg <br> BSET qOOD $x y$ sp mskg <br> BSET q009，ysp，mskg <br> BSET quar $6 . y s p$ mskg | $\begin{aligned} & (\mathrm{M})+(\mathrm{mm}) \Rightarrow \mathrm{M} \\ & \text { See: } \mathrm{B}=(\mathrm{s}) \text { in Memory } \end{aligned}$ | $\begin{aligned} & \hline \mathrm{DIR} \\ & \mathrm{EXT} \\ & \mathrm{IDX} \\ & \mathrm{IDX1} \\ & \operatorname{IDX2} \end{aligned}$ |  | $\begin{aligned} & \text { rNWO } \\ & \text { rNWD } \\ & \text { rNWO } \\ & \text { rNVD } \\ & \text { rrDWDO } \end{aligned}$ | IDON IDNN INON IDWD ITDWCD | －－－－ | $\triangle \triangle 0$－ |
| BSR mg | $\begin{aligned} & \left.[S P)-2 \Rightarrow S_{P} ; \text { RTN }_{4} \mathrm{RTN}_{\mathrm{L}} \Rightarrow \mathrm{M}_{(3 P}\right)_{(S P+1)} \\ & \text { Subrouthe address } \Rightarrow \mathrm{PC} \\ & \text { Branch to Subrouthe } \end{aligned}$ | REL | 07 II | SDPV | DPDS | －－－ | －－－－ |
| BVCres | Eranch 1 Overflow Bt Ciear（ P V－ 0 ） | REL | 28 IF | DWV／D ${ }^{\text {a }}$ | WW／D ${ }^{2}$ | － | －－－－ |
| BVS reg | Eranch 1 Overflow Bt Set（in $\mathrm{V}=1$ ） | REL | 29 II | DWP／D ${ }^{\text {d }}$ | DWP／D ${ }^{2}$ | －－－－－ | －－－－ |
| CALL opice，page <br> CALL opro ysp，page <br> CALL opx 9 yspp，page <br> CALL opr 15xysp，page <br> CAll［D，yss］ <br> CALL［porf 6 xsp］ |  | $\begin{gathered} \hline E X T \\ I D X \\ I D X 1 \\ I D X 2 \\ {[D, I D X]} \\ {[1 D X Z]} \end{gathered}$ | 4A Hh 11 pg 4 B xb pg 4 B xb fI pg 4 B xb ac fI pg 4 B xb 4 B xb ac ft | gnSaDVD <br> gn3sDVD <br> gnSaDVP <br> fgnSamp <br> fIIgnSappp <br> fIIgnSappp |  | －－－－ | － |
| CBA | （A）－（B） Compare B．at accuruators | NH | 1817 | 00 | 00 | －－－－ | $\triangle \Delta \Delta \Delta$ |
| CLC | $\begin{aligned} & 0 \Rightarrow \mathrm{C} \\ & \text { Translagto } \text { ANDCC } \pm \text { \&FE } \end{aligned}$ | IVM | 10 FE | D | － | －－－－ | －－－0 |
| CL |  | IVM | 10 ZF | D | D | －－－0 | －－－－ |
| CLR qifice <br> CLR 9000 xjsp <br> CLR qua9，ysp <br> CLR porisuysp <br> CLR Dysp <br> CLR［porifysp］ <br> CLAA <br> CLRB | $0 \Rightarrow \mathrm{M}$ Clear Memory Locabon <br>   <br>   <br> $0 \Rightarrow \mathrm{~A}$ Clear Accurnulator A <br> $0 \Rightarrow \mathrm{~B}$ Clear Accurnulator B | EXT IDX IDX1 IDX2 ［D，IDX］ $[I D X Z$ NH NH |  | DwO Dw DWO DwD DIIU DIDU 0 $D$ | WOD Dw DWO DWD DIEDw DIDPw 0 0 | －－－ | 0100 |
| CLV | $0 \Rightarrow V$ <br> Transtasto ANDCC $45 F D$ | IVM | 10 FD | D | D | －－－－ | －－0－ |
| Note 1．PPPAP indcatas tris instuction takes three cycies to refil fre instuction queua if the branch is taken and one program fetch cycie if the branch is not taken． |  |  |  |  |  |  |  |
|  | $(\mathrm{A})-(\mathrm{M})$ <br> Compare Accurulator A with Marory | IMM <br> DIA <br> EXT <br> IDX <br> IDX1 <br> $[D X 2$ <br> $[D, I D X]$ <br> $[D X Z]$ |  | $D$ IDI rDO IDI IDO ITDD IIITDI IIDrDI |  | －－－－ | $\triangle \Delta \Delta \Delta$ |

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Table A-1. Instruction Set Summary (Sheet 4 of 14)

| Source Form | Operation | Addr. Mode | $\begin{aligned} & \text { Machine } \\ & \text { Coding (nex) } \end{aligned}$ | HCS12 | M6aHC12 | SXHI | NZVC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\begin{aligned} & {[\mathrm{B})-(\mathrm{M}]} \\ & \text { Corpare Accurnulator B wth Memory } \end{aligned}$ | IMM DIR EXT IDX IDX1 IDX2 $[D, I D X]$ $[I D X Z]$ |  | ICSIR IDI rDO rDI rDO ITDD IIITDI IIDIDI | $D$ <br> $r \pm D$ <br> $r C D$ <br> $r I D$ <br> $r D O$ <br> TrDD <br> TITrID <br> TIDrID | ----- | $\triangle \Delta \Delta \Delta$ |
| CON oprite CON opno_ysp CON opn9,ysp CON opri6. $x y s p$ CON $0, y y s p]$ CON [quif $6 y s p]$ CONA CONB | (V) $\Rightarrow \mathrm{M}$ equinelert D \$FF $-(\mathrm{M}) \Rightarrow \mathrm{M}$ 1s Complenent Memory Location <br> $(\bar{A}) \rightarrow A$ <br> Complerent Accuruator A <br> $(\mathrm{B}) \Rightarrow \mathrm{B}$ <br> Complement Accuruator $B$ | EXT IDX IDX1 IDX2 $[\mathrm{D,IDX]}$ $[I D X Z]$ NH NH | 71 xh 11  <br> 61 xb   <br> 61 xb If  <br> 61 xb aa If <br> 61 xb   <br> 61 xb ac ft <br> 41    <br> 51    | $\begin{aligned} & \hline \text { rNW0 } \\ & \text { rNv } \\ & \text { rDW0 } \\ & \text { IrDWD } \\ & \text { IIIrDw } \\ & \text { IIDrDw } \\ & 0 \\ & 0 \end{aligned}$ |  | ---- | A 401 |
|  | $\begin{aligned} & (\mathrm{A} \cdot \mathrm{~B})-(\mathrm{M}+\mathrm{M}+1) \\ & \text { Compare } \mathrm{D} \text { to Mamory (16-Bt) } \end{aligned}$ | IMM DIA EXT IDX IDX1 IDX2 $[D, I D X]$ $[I D X Z]$ | $B C$ 11 kk <br> $9 C$ $d 1$  <br> $B C$ zh 11 <br> $A C$ $x b$  <br> $A C$ $x b$ $2 f$ <br> $A C$ $x b$ $a 0$ <br> $A C$ $x b$  <br> $A C$ $x b$ $a c$ | DO RDI RDO FDI HDO IROD IIIPDI IIDRDI |  | ---- | $\triangle \Delta \Delta \Delta$ |
|  | $\begin{aligned} & (\mathrm{SP})-(\mathrm{M} \mathrm{~N}+1) \\ & \text { Corpare SP to Manory (16-Bt) } \end{aligned}$ | INM DIR EXT DX IDX1 IDX2 $[D, I D X]$ $[I D X Z]$ |  |  | $C D$ <br> RID <br> ROD <br> RID <br> RDD <br> EMDD <br> TITMAD <br> TIMAPD | ---- | $\triangle \Delta \Delta \Delta$ |
|  | $\begin{aligned} & (X)-(M M+1) \\ & \text { Compere } X \text { to Merary }(16-\mathrm{Bt}) \end{aligned}$ | IMM DIR EXT IDX IDX1 IDX2 $[D, 1 D X]$ $[I D X Z]$ |  | DO RDI RDO RDI RDO IFPD ITIMRI IIDMDI |  | ---- | $\triangle \Delta \Delta \Delta$ |
|  | $\begin{aligned} & (\mathrm{Y})-(\mathrm{MM}+1) \\ & \text { Compare Y tD Menary (16-日t) } \end{aligned}$ | INM DIR EXT DX IDX1 IDX2 $[D, I D X]$ $[I D X Z]$ |  |  | $C D$ <br> RID <br> ROD <br> RID <br> RDD <br> EMDD <br> TITKPD <br> TIDMAD | ---- | $\triangle \Delta \Delta \Delta$ |
| DAA | Aduas Sum to BCD Decinal Adust Accumulator A | NH | $18 \quad 07$ | Oro | 010 | -- | $\Delta \Delta ? \Delta$ |
| DEEQ abdiys, re9 |  | REL (9-5t) | 04 1b IT | $\begin{aligned} & \text { VW (branch) } \\ & \text { VDO (no } \\ & \text { branch) } \end{aligned}$ | DND | -- | ---- |
| DENE abdys, ral9 |  | $\begin{aligned} & \text { REL } \\ & (9-b t) \end{aligned}$ | 04 1b IT | $\begin{aligned} & \text { VW (branch) } \\ & \text { DVO (no } \\ & \text { branch) } \end{aligned}$ | DND | --- | --- |


| Souroe Form | Operation | $\begin{array}{c\|} \hline \text { Addrece } \\ \text { Mode } \end{array}$ | Msohling Coding (Hex) | Aooece Datall | SXHINZVC |
| :---: | :---: | :---: | :---: | :---: | :---: |
| STY ocr8a <br> STY ocri6a <br> STY ocroD_xyapp <br> STY oorr9, xyapoc <br> STY oorr16,xyappc <br> STY [D,xysppd] <br> STY [oprx $16, x y s p p d]$ | 3tore Y $\left(\gamma_{1+}-\gamma_{L}\right) \Rightarrow M C M+1$ |  | sDdd <br> 7nhh 11 <br> 6D xb <br> ED xb ff <br> 6Dxbenff <br> 6D Xb <br> 6Dxbonff |  | - - - - ${ }^{\text {a }}$ |
| SUBA\#oprSI <br> SUEA oprks <br> SUEA opri6s <br> SUBA opmo_xympa <br> SUBA opne9,xyspoc <br> SUBA oprif $6, x y$ gpp <br> SUEA [D, xyappc] <br> SUBA [oprri6, ryspoc]] | $\begin{aligned} & \text { Subtract fom } A \\ & (A)-M)=A \\ & \text { or }(A)-m m \Rightarrow A \end{aligned}$ |  |  |  |  |
| SU 5 E \#oprsi <br> SUeB oprss <br> suab opri6s <br> SUSB opro_ xyspoc <br> SUSB opn9, xy appc <br> SUEB opxif, rysppc <br> SUSB [D, xуappc] <br> SUaB [opry 16 , ryzpoc] | $\begin{aligned} & \text { Subtract fom } \mathrm{B} \\ & \text { (B)-M) } \mathrm{M}) \mathrm{B} \\ & \text { or }(\mathrm{B})-\mathrm{mm} \Rightarrow \mathrm{~B} \end{aligned}$ | DMM <br> DIR <br> EXT <br> DX <br> DX1 <br> DX2 <br> DJI <br> DDX] <br> DOX2] <br> DM |  |  |  |
| SUED *oprisi <br> SUED oprBa <br> SUED opri6a <br> SUSD opro_xysppc <br> SUED opms, xysppc <br> SUED oprri6,xysppc <br> SUED [D_ryzppc] <br> SUSD [oprri6,xyzppc] | Subtract from D $(A \cdot B)-(M) M+1)=A \cdot B$ or $(A B)-i m m=A \cdot B$ |  |  |  |  |
| SWI | Software interrupt (SP)-2 $\rightarrow$ SP <br> RTN $N_{H}:$ RTN $_{L} \Rightarrow M_{\mathrm{gp}} \mathrm{M}_{\mathrm{gP}}+1$ | NH | ${ }^{3}$ | vaparvarp* |  |
| "The CPU also uses vapasmasp for hardware interrupts and unimplemented opcode traps. |  |  |  |  |  |
| TAB | Tranzfer $\mathrm{A} 00 \mathrm{~B} ;(\mathrm{A})=\mathrm{B}$ | NH | 1808 | - | - -H- ${ }^{\text {a }}$ |
| TAP | Transfer Ato CCR; (A) $=$ CCR Assembled as TFRA, OCR | NH | 11702 | P |  |
| TBA | Transfer Bto $\mathrm{A} ;(\mathrm{B})=\mathrm{A}$ | NH | 1808 | - | - - - - ${ }^{\text {a }}$ |
| TBEQ abctrysprel9 | $\begin{aligned} & \text { Teat and branch if equas to } 0 \\ & \text { if (courter) }=0 \text {, then (PC) } 12 \text { tre) } P \mathrm{FC} \end{aligned}$ | $\begin{array}{\|l\|} \hline \mathrm{REL} \\ (9-\mathrm{bI}) \end{array}$ | 041 brr | $\begin{aligned} & \text { Wov (branch) } \\ & \text { wo (no branch) } \end{aligned}$ | - - - - - - |
| TBL opnos_ryspoc | Table lookup and interpolate, 8 -bt $(M)+[1 B) \times(M+1)-(M) D] S A$ | DX | 1830xb | cutets |  |
| TBNE aboxyzp,rel9 | Teat and branch If not equal to 0 If (counter) 0 , then (PC) $+2+$ rel $\Rightarrow \mathrm{PC}$ | $\begin{aligned} & \mathrm{REL} \\ & (9-\mathrm{bR}) \end{aligned}$ | 041 lrr | PVy (branch) <br> PDO (no branch) | W-H-T- |
| TFR abcotrysp, abcorysp | Transfer fom regleterto register $(r 1) \Rightarrow \mathrm{r} 2 \mathrm{r} 1$ and r 2 same alze $\$ 00:(\mathrm{r} 1) \Rightarrow \mathrm{r} 2 \mathrm{r} 1-9-\mathrm{b} / \mathrm{t}, \mathrm{r} 2=16-\mathrm{b} / \mathrm{t}$ $\left(\mathrm{ri}_{1}\right)=r 2 \mathrm{r} 1=15-\mathrm{blt}, \mathrm{r} 2-3-\mathrm{blt}$ | NH | mi ab | P |  |
| TPASame as TFR CCR,A | Transfer CCR to $A ;(C C R)=A$ | NH | 11720 | P | W-H-N-H-6 |

## DBNE

Operation (counter) $-1 \Rightarrow$ counter
If (counter) not $=0$, then $(\mathrm{PC})+\$ 0003+\mathrm{rel} \Rightarrow \mathrm{PC}$
Subtracts one from the counter register A, B, D, X, Y, or SP. Branches to a relative destination if the counter register does not reach zero. Rel is a 9-bit two's complement offset for branching forward or backward in memory. Branching range is $\$ 100$ to $\$ 0 \mathrm{FF}$ $(-256$ to +255$)$ from the address following the last byte of object code in the instruction.
CCR
Effects


Code and
CPU
Cycles

| Source Form | Address <br> Mode | Machine <br> Code (Hex) | CPU Cycles |
| :--- | :--- | :--- | :--- |
| DENE abdxysp, rel9 | REL <br> (9-blt) | 04 lb rr | PPP (branch) <br> PPO (no branch) |


| Loop Primitive Postbyte (1b) Coding |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| Source Form | Postbyte ${ }^{1}$ | Object Code | Counter Register | Offset |
| DBNE A. rel9 DBNE B, rel9 DENE D, re/9 DBNE X, rel9 DENE Y, rel9 DBNE SP, re/9 | $0010 \times 000$ <br> $0010 \times 001$ <br> $0010 \times 100$ <br> $0010 \times 101$ <br> $0010 \times 110$ <br> $0010 \times 111$ | 0420 Ir <br> 0421 Ir <br> 0424 Ir <br> 0425 rr <br> 0426 II <br> 0427 II | A B D $X$ $Y$ S SP | Posilive |
| DBNE A, rel9 DENE B, re/9 DBNE D, rel9 DENE X, rel9 DENE Y, re/9 DENE SP, rel9 | 0011 X000 <br> $0011 \times 001$ <br> $0011 \times 100$ <br> $0011 \times 101$ <br> 0011 X110 <br> 0011 X111 | 0430 rr <br> 0431 rr <br> 0434 rr <br> 0435 rr <br> 0436 rr <br> 0437 rr | A B D X Y SP | Negative |

NOTES:

1. Bits $7: 6: 5$ select DBEQ or DBNE; bit 4 is the offset slgn bit: bit 3 is not used; bits 2:1:0 select the counter register.

MC9S12 Cycles

- MC9S12 works on 48 MHz clock
- A processor cycle takes 2 clock cycles - $\mathbf{P}$ clock is 24 MHz
- Each processor cycle takes $41.7 \mathbf{n s}(1 / 24 \mu \mathrm{~s})$ to execute
- An instruction takes from $\mathbf{1}$ to $\mathbf{1 2}$ processor cycles to execute
- You can determine how many cycles an instruction takes by looking up the CPU cycles for that instruction in the Reference Manual.
- For example, LDAA using the IMM addressing mode shows one CPU cycle (of type P ).
- LDAA using the EXT addressing mode shows three CPU cycles (of type rPO). - Section 6.6 of the S12CPUV2 Reference Manual explains what the HCS12 is doing during each of the different types of CPU cycles.

| 2000 |  |  | org \$2000 | ; Inst | Mode Cycles |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 2000 | C6 0A |  | ldab \#10 | ; LDAB | (IMM) 1 |
| 2002 | 87 | loop: | clra | ; CLRA | (INH) 1 |
| 2003 | 0431 FC |  | dbne b,loop | ; DBNE | (REL) 3 |
| 2006 | 3F |  | swi | ; SWI | 9 |

The program executes the ldab \#10 instruction once (which takes one cycle). It then goes through the loop 10 times (which has two instructions, one with one cycle and one with three cycles), and finishes with the swi instruction (which takes 9 cycles).

Total number of cycles:
$1+10 \times(1+3)+9=50$

50 cycles $=50 \times 41.7 \mathrm{~ns} /$ cycle $=2.08 \mu \mathrm{~s}$

## LDAB



## Assembler Directives

- In order to write an assembly language program it is necessary to use assembler directives.
- These are not instructions which the HC 12 executes but are directives to the assembler program about such things as where to put code and data into memory.
- We will use only a few of these directives. (Note: In the following table, [ ] means an optional argument.) Here are the ones we will need:

| Directive Name | Description | Example |
| :---: | :--- | :--- |
| equ | Give a value to a symbol | len: equ 100 |
| org | Set starting value of location counter <br> where code or data will go | org \$1000 |
| dc.b | Allocate and initialize storage for 8-bit <br> variables. <br> Place the bytes in successive memory <br> locations | var: dc.b 2,18 <br> name: dc.b "Jane" |
| dc.w | Allocate and initialize storage for 16-bit <br> variables. <br> Place the bytes in successive memory <br> locations | var: dc.w \$ABCD |
| ds.b | Allocate specified number of 8-bit <br> storage places | Table: ds.b 10 |
| ds.w | Allocate specified number of 16-bit <br> storage spaces | table: ds.w 50 |
| dcb.b | Fill memory with a given value <br> The first value is the number of bytes to <br> fill. <br> The second number is the value to put <br> into memory | init_data: dc.b 100,0 |

Using labels in assembly programs
A label is defined by a name followed by a colon as the first thing on a line. When the label is referred to in the program, it has the numerical value of the location counter when the label was defined.

Here is a code fragment using labels and the assembler directives dc and ds:

```
    org $2000
table1:dc.b $23,$17,$f2,$a3,$56
table2: ds.b 5
var: dc.w $43af
```

The CodeWarrior assembler produces a listing file (.lst). Here is the listing file from the assembler:

Freescale HC12-Assembler
(c) Copyright Freescale 1987-2009

| Abs. | Rel. | Loc | Obj. code | Source line |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |
| 1 | 1 |  |  |  | org | \$2000 |
| 2 | 2 a 0020002317 F2A3 |  |  | table1: | dc.b | \$23,\$1 |
| 3 | 3 a 0 | 005 |  | table2: | ds.b | 5 |
| 4 | 4 a 00 | 00A 43 |  | var: | dc.w | \$43af |

Note that table1 is a name with the value of $\$ 2000$, the value of the location counter defined in the org directive. Five bytes of data are defined by the dc.b directive, so the location counter is increased from \$2000 to \$2005.

Note that table2 is a name with the value of $\$ 2005$. Five bytes of data are set aside for table2 by the ds.b 5 directive. The as 12 assembler initialized these five bytes of data to all zeros. var is a name with the value of $\$ 200$ a, the first location after table2.

## HC12 Instructions

1. Data Transfer and Manipulation Instructions - instructions which move and manipulate data (S12CPUV2 Reference Manual, Sections 5.3, 5.4, and 5.5).

- Load and Store - load copy of memory contents into a register; store copy of register contents into memory.

LDAA \$2000 ; Copy contents of addr \$2000 into A
STD 0,X ; Copy contents of D to addrs X and X+1

- Transfer - copy contents of one register to another.

TBA ; Copy B to A
TFR X,Y ; Copy X to Y

- Exhange - exchange contents of two registers.

XGDX ; Exchange contents of D and X
EXG A,B ; Exchange contents of A and B

- Move - copy contents of one memory location to another.

MOVB $\$ 2000, \$ 20 \mathrm{~A} 0$; Copy byte at $\$ 2000$ to $\$ 20 \mathrm{~A} 0$
MOVW 2,X+,2,Y+ ; Copy two bytes from address held ; in X to address held in Y ; Add 2 to X and Y
2. Arithmetic Instructions - addition, subtraction, multiplication, divison (S12CPUV2

Reference Manual, Sections 5.6, 5.8 and 5.12).
ABA ; Add B to A; results in A
SUBD \$20A1; Subtract contents of \$20A1 from D
INX ; Increment X by 1
MUL ; Multiply A by B; results in D
3. Logic and Bit Instructions - perform logical operations (S12CPUV2 Reference

Manual, Sections 5.9, 5.10, 5.11, 5.13 and 5.14).

- Logic Instructions

ANDA $\$ 2000$; Logical AND of A with contents of $\$ 2000$
EORB 2,X ; Exclusive OR B with contents of address (X+2)

- Clear, Complement and Negate Instructions

NEG -2,X ; Negate ( 2 's comp) contents of address (X-2)
CLRA ; Clear Acc A

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- Bit manipulate and test instructions - work with one bit of a register or memory.

BITA \#\$08 ; Check to see if Bit 3 of A is set
BSET \$0002,\#\$18 ; Set bits 3 and 4 of address \$002

- Shift and rotate instructions
$\begin{array}{ll}\text { LSLA } & \text {; Logical shift left A } \\ \text { ASR \$1000 } & \text {; Arithmetic shift right value at address \$1000 }\end{array}$

4. Compare and test instructions - test contents of a register or memory (to see if zero, negative, etc.), or compare contents of a register to memory (to see if bigger than, etc.) (S12CPUV2 Reference Manual, Section 5.9).

TSTA ; (A)-0 -- set flags accordingly
CPX \#\$8000 ; (X) - \$8000 -- set flags accordingly
5. Jump and Branch Instructions - Change flow of program (e.g., goto, it-then-else, switch-case) (S12CPUV2 Reference Manual, Sections 5.19, 5.20 and 5.21).

JMP L1 ; Start executing code at address label L1
BEQ L2 ; If Z bit set, go to label L2
DBNE X,L3 ; Decrement X; if X not 0 then goto L3
BRCLR \$1A,\#\$80,L4 ; If bit 7 of addr \$1A clear, go to label L4
JSR sub1 ; Jump to subroutine sub1
RTS ; Return from subroutine
6. Interrupt Instructions - Initiate or terminate an interrupt call (S12CPUV2 Reference Manual, Section 5.22).

- Interrupt instructions

SWI ; Initiate software interrupt
RTI ; Return from interrupt
7. Index Manipulation Instructions - Put address into X, Y or SP, manipulate X, Y or SP (S12CPUV2 Reference Manual, Section 5.23).

ABX ; Add (B) to (X)
LEAX 5,Y ; Put address ( Y ) + 5 into X
8. Condition Code Instructions - change bits in Condition Code Register (S12CPUV2 Reference Manual, Section 5.26).

ANDCC \#\$f0 ; Clear N, Z, C and V bits of CCR
SEV ; Set V bit of CCR
9. Stacking Instructions - push data onto and pull data off of stack (S12CPUV2

Reference Manual, Section 5.24).
PSHA ; Push contents of A onto stack
PULX ; Pull two top bytes of stack, put into X
10. Stop and Wait Instructions - put MC9S12 into low power mode (S12CPUV2 Reference Manual, Section 5.27).

STOP ; Put into lowest power mode
WAI ; Put into low power mode until next interrupt
11. Null Instructions

NOP ; No operation
BRN ; Branch never
12. Instructions we won't discuss or use - BCD arithmetic, fuzzy logic, minimum and maximum, multiply-accumulate, table interpolation (S12CPUV2 Reference Manual, Sections 5.7, 5.16, 5.17, and 5.18).

## Disassembly of an HC12 Program

- It is sometimes useful to be able to convert HC12 op codes into mnemonics.

For example, consider the hex code:
ADDR DATA
1000 C6 05 CE 2000 E6 0118060435 EE 3F

- To determine the instructions, use Table A-2 of the HCS12 Core Users Guide.
- If the first byte of the instruction is anything other than \$18, use Sheet 1 of Table A.2. From this table, determine the number of bytes of the instruction and the addressing mode. For example, \$C6 is a two-byte instruction, the mnemonic is LDAB, and it uses the IMM addressing mode. Thus, the two bytes C6 05 is the op code for the instruction LDAB \#\$05.
- If the first byte is $\mathbf{\$ 1 8}$, use Sheet 2 of Table A.2, and do the same thing. For example, $\mathbf{1 8 0 6}$ is a two byte instruction, the mnemonic is ABA, and it uses the INH addressing mode, so there is no operand. Thus, the two bytes $\mathbf{1 8} \mathbf{0 6}$ is the op code for the instruction ABA.
- Indexed addressing mode is fairly complicated to disassemble. You need to use Table A. 3 to determine the operand. For example, the op code \$E6 indicates LDAB indexed, and may use two to four bytes (one to three bytes in addition to the op code). The postbyte 01 indicates that the operand is 0,1 , which is 5 -bit constant offset, which takes only one additional byte. All 5-bit constant offset, pre and post increment and decrement, and register offset instructions use one additional byte. All 9-bit constant offset instructions use two additional bytes, with the second byte holding 8 bits of the 9 bit offset. (The 9th bit is a direction bit, which is held in the first postbyte.) All 16-bit constant offset instructions use three postbytes, with the 2nd and 3rd holding the 16-bit unsigned offset.
- Transfer (TFR) and exchange (EXG) instructions all have the op code \$B7. Use Table A. 5 to determine whether it is TFR or an EXG, and to determine which registers are being used. If the most significant bit of the postbyte is $\mathbf{0}$, the instruction is a transfer instruction.
- Loop instructions (Decrement and Branch, Increment and Branch, and Test and Branch) all have the op code $\mathbf{\$ 0 4}$. To determine which instruction the op code $\mathbf{\$ 0 4}$ implies, and whether the branch is positive (forward) or negative (backward), use Table A.6. For example, in the sequence $\mathbf{0 4} 35$ EE, the 04 indicates a loop
instruction. The 35 indicates it is a DBNE $\mathbf{X}$ instruction (decrement register $\mathbf{X}$ and branch if result is not equal to zero), and the direction is backward (negative). The $\mathbf{E E}$ indicates a branch of -18 bytes.
- Use up all the bytes for one instruction, then go on to the next instruction.

| C6 05 | $\Rightarrow$ LDAA \#\$05 | two-byte LDAA, IMM addressing mode |
| :---: | :---: | :---: |
| CE 2000 | $\Rightarrow$ LDX \#\$2000 | three-byte LDX, IMM addressing mode |
| E6 01 | $\Rightarrow$ LDAB 1,X | two to four-byte LDAB, IDX addressing mode. Operand $01=>1, \mathrm{X}$, a 5 b constant offset which uses only one postbyte |
| 1806 | $\Rightarrow \mathrm{ABA}$ | two-byte ABA, INH addressing mode |
| 0435 EE | $\Rightarrow$ DBNE $\mathrm{X},(-18)$ | three-byte loop instruction |
| 3F | $\Rightarrow$ SWI | Postbyte 35 indicates DBNE X, negative one-byte SWI, INH addressing mode |

Table A-2. CPU12 Opcode Map (Sheet 1 of 2)

| $\mathrm{BGND}^{+5}$ | ${ }^{10} \text { ANDCC }^{1}$ | $20$ | PULX | ${ }^{40}{ }^{\text {NEGA }}$ | ${ }^{50}{ }^{\text {NEGB }}$ | $\mathrm{NEG}^{3-6}$ | ${ }^{70}{ }_{\text {NEG }}{ }^{4}$ | ${ }^{80}{ }^{1}$ | ${ }^{90} \text { SUBA }{ }^{3}$ |  | ${ }^{0}{ }^{\prime}{ }^{3-6}$ | $\begin{aligned} & \text { BO } \\ & \text { SUBA } \end{aligned}$ | $\begin{gathered} \text { CO } \\ \text { SUBB } \end{gathered}$ | $\mathrm{SUBB}^{3}$ | $E^{E 0}{ }^{3-8}$ | $\mathrm{FO}_{\text {SUBB }}{ }^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| IH | IM | RL | IH | 1 H | IH | ID 2.4 | EX 3 | IM 2 | DI 2 |  | D 2-4 | EX 3 | IM 2 | DI 2 | ID $2-4$ | EX |
| ${ }^{01} \text { MEM }^{5}$ | ${ }^{11} \text { EDIV }{ }^{11}$ | ${ }^{21} \mathrm{BRN}^{1}$ | ${ }^{31}{ }_{\text {PULY }}{ }^{3}$ | $\mathrm{COMA}^{1}$ | $\mathrm{COMB}^{1}$ | $\mathrm{COM}^{3-6}$ | ${ }^{71} \text { COM }^{4}$ | ${ }^{81} \mathrm{CMPA}^{1}$ | ${ }^{91} \mathrm{CMPA}^{3}$ |  | $\mathrm{CM}^{31}{ }^{3-6}$ | ${ }^{B 1} \mathrm{CMPA}^{3}$ | $\mathrm{Cl}_{\mathrm{CMPB}}{ }^{1}$ | $\mathrm{CMPB}^{3}$ | $\begin{array}{cc} \mathrm{E}_{1} & 3-6 \\ \mathrm{CMPB} \end{array}$ | $\mathrm{CMPB}^{3}$ |
| $1 \mathrm{H}^{\prime}$ | IH | RL | IH | IH | H | ID | EX 3 | M | DI 2 |  | D $\quad 2-4$ | EX 3 | IM | DI 2 | ID $2-4$ | EX |
| ${ }^{02} \text { INY }$ | ${ }^{12} \mathrm{MUL}^{\ddagger}$ | ${ }^{22} \mathrm{BHI}^{3 / 1}$ | ${ }^{32} \text { PULA }{ }^{3}$ | ${ }^{42}{ }^{1 N C A}$ | ${ }^{52} \quad 1$ | $\mathrm{INC}^{3-8}$ | $\begin{array}{\|l\|} \hline 72 \end{array}$ | $82$ | $\mathrm{SBCA}^{32}$ |  | $\mathrm{SBCA}^{3-6}$ | $\mathrm{SBCA}^{3}$ | $\begin{aligned} & \mathrm{C} 2 \\ & \mathrm{SBCB} \end{aligned}$ | $\mathrm{SBCB}^{3}$ | $\begin{array}{cc} \mathrm{E} 2 & 3-6 \\ \mathrm{SBCB} \end{array}$ | $\begin{gathered} \mathrm{F} 2 \\ \mathrm{SBCB} \end{gathered}$ |
| 1 H | 1 H | RL 2 | IH | 1 H | IH | ID $2-4$ | EX | M | DI |  | D 2-4 | EX 3 | IM | DI 2 | ID 2-4 | EX |
| ${ }^{03} \mathrm{DEY}$ | ${ }^{13} \text { EMUL }{ }^{3}$ | ${ }^{23} \text { BLS }^{3 / 1}$ | ${ }^{33} \text { PULB }^{3}$ | $\mathrm{DECA}^{1}$ | ${ }^{53} \mathrm{DECB}^{1}$ | $\mathrm{DEC}^{33}$ | ${ }^{73} \text { DEC }^{4}$ | ${ }^{83} \text { SUBD }^{2}$ | ${ }^{93} \text { SUBD }{ }^{3}$ |  | $\begin{aligned} & \text { A3 }{ }^{3-6} \\ & \text { SUBD } \end{aligned}$ | ${ }^{\text {B3 }} \mathrm{SUBD}^{3}$ | ${ }_{\mathrm{ADDD}}$ | $\mathrm{ADCD}^{3}$ | $\begin{array}{cc} \mathrm{E}_{3} & 3-6 \\ \mathrm{ADDD} \end{array}$ | $\mathrm{FB}_{\mathrm{ADDD}}{ }^{3}$ |
|  | 1 H | RL 2 | IH | 1 H | IH | ID $2-4$ | EX 3 | 1 M | DI 2 |  | D 2-4 | EX 3 | IM | DI 2 | ID 2-4 | EX |
| $04 \text { loop }^{*}$ | ${ }^{14}{ }^{\text {ORCC }}{ }^{1}$ | ${ }^{24} \mathrm{BCC}^{3 / 1}$ | ${ }^{34} \mathrm{PSHX}^{2}$ | ${ }^{44} \operatorname{LSRA}^{1}$ | ${ }^{54} \text { LSRB }^{1}$ | $\mathrm{LSR}^{3-6}$ | ${ }^{74} \text { LSR }^{4}$ | ${ }^{84}{ }^{\text {ANDA }}$ | ${ }^{94}{ }_{\text {ANDA }}{ }^{3}$ |  | $\begin{aligned} & \text { A4 }{ }^{3-6} \\ & \text { ANDA } \end{aligned}$ | ${ }^{\mathrm{B} 4} \mathrm{ANDA}^{3}$ | $\mathrm{C4}$ | $\mathrm{ANDBB}^{3}$ | $\begin{array}{cc} \mathrm{E}_{4} & 3-8 \\ \text { ANDB } \end{array}$ | ANDB |
| RL 3 | 1 M | RL | IH | IH | H | ID 2.4 | EX 3 | IM | DI 2 |  | D 2-4 | EX 3 | IM | DI 2 | ID 2-4 | EX |
| ${ }^{05} \mathrm{JMP}^{3-8}$ | ${ }^{15} \mathrm{JSR}^{4 \cdot 7}$ | ${ }^{25} \mathrm{BCS}^{3 / 1}$ | ${ }^{35} \mathrm{PSHY}^{2}$ | ${ }^{45} \text { ROLA }{ }^{1}$ | ${ }^{55} \text { ROLB }^{1}$ | $\begin{gathered} 65 \mathrm{ROL}^{3-6} \end{gathered}$ | $75 \quad 4$ | $\begin{gathered} 85 \\ \text { BITA } \end{gathered}$ | ${ }^{95} \text { BITA }{ }^{3}$ |  | $\mathrm{BITA}^{3-6}$ | $\begin{array}{\|l\|} \hline \text { B5 } \\ \text { BITA } \end{array}$ | $\begin{gathered} \text { C5 } \\ \text { BITB } \end{gathered}$ | $\text { BITB }^{3}$ | $\begin{array}{cc} \text { E5 }^{3-6} \\ \text { BITB }^{3-1} \end{array}$ | $\mathrm{FB}_{\text {BITB }}{ }^{3}$ |
| ID $\quad 2-4$ | ID $\quad 2-4$ | RL 2 | IH | 1 H | IH | ID $2-4$ | EX 3 | 1 M | DI |  | D $2-4$ | EX 3 | IM | DI 2 | ID 2-4 | EX 3 |
| ${ }^{06} \mathrm{JMP}^{3}$ | ${ }^{16}{ }^{\text {JSR }}{ }^{4}$ | ${ }^{28} \mathrm{BNE}^{3 / 1}$ | ${ }^{36} \mathrm{PSHA}^{2}$ | ${ }^{46} \mathrm{RORA}^{1}$ | ${ }^{56} \mathrm{RORB}^{1}$ | ${ }^{66} \mathrm{ROR}^{3-6}$ | ${ }^{76} \mathrm{ROR}^{4}$ | ${ }^{86}{ }^{\text {LDAA }}{ }^{1}$ | ${ }^{96} \text { LDAA }^{3}$ |  | $\mathrm{LDAA}^{3-6}$ | ${ }_{\text {LDAA }}{ }^{3}$ | C6 | $\mathrm{LDAB}^{3}$ | $\mathrm{EDAB}^{3-6}$ | ${ }_{\text {LDAB }}{ }^{3}$ |
| EX | EX | RL 2 | IH | IH | IH | ID $\quad 2-4$ | EX 3 | IM 2 | DI 2 |  | D 2-4 | EX 3 | IM | DI 2 | ID 2-4 | EX |
| ${ }^{07} \text { BSR }^{4}$ | ${ }^{17}{ }_{\text {JSR }}$ | $\begin{gathered} 27 \\ \mathrm{BEQ}^{3 / 1} \end{gathered}$ | ${ }^{37} \mathrm{PSHB}^{2}$ | ${ }^{47}{ }_{\text {ASRA }}{ }^{1}$ | ${ }^{57} \text { ASRB }^{1}$ | $\begin{gathered} 67 \\ A S R^{3-6} \end{gathered}$ | ${ }^{77} \text { ASR }{ }^{4}$ | ${ }^{87} \text { CLRA }$ | ${ }^{97} \text { TSTA }$ |  | ${ }^{\text {A7 }}{ }^{\text {NOP }}{ }^{1}$ | $\begin{array}{\|l\|l\|} \hline \text { B7 } & 1 \\ \text { TFR/EXG } \end{array}$ | $\stackrel{C 7}{C L R B}$ | ${ }^{\mathrm{D} 7} \mathrm{TSTB}^{1}$ | $\mathrm{EF}^{\mathrm{TST}}{ }^{3-6}$ | ${ }_{\text {F7 }}^{\text {TST }}{ }^{3}$ |
| RL | DI | RL 2 | IH | 1 H | IH | ID 2.4 | EX 3 | IH | IH |  | H | $1 \mathrm{H} \quad 2$ | IH | H 1 | ID 2-4 | EX |
| ${ }^{08}{ }_{\text {INX }}{ }^{1}$ | ${ }^{18} \text { Page 2 }{ }^{-1}$ | ${ }^{28} \mathrm{BVC}^{3 / 1}$ | ${ }^{38} \text { PULC }^{3}$ | ${ }^{48} \text { ASLA }{ }^{1}$ | ${ }^{58}{ }_{\text {ASLB }}{ }^{1}$ | ${ }^{68} \mathrm{ASL}^{3-8}$ | ${ }^{78} \text { ASL }$ | $88$ | ${ }^{98} \text { EORA }^{3}$ |  | $\begin{aligned} & \text { A8 }{ }^{3-6} \\ & \text { EORA } \end{aligned}$ | ${ }^{\text {B8 }} \text { EORA }{ }^{3}$ | $\stackrel{C 8}{\mathrm{E}} \mathrm{EORB}$ | $\mathrm{EORB}^{3}$ | $\begin{array}{cc} E_{8} & 3-8 \\ \text { EORB } \end{array}$ | $\mathrm{FORB}^{3}$ |
| 1 H | - - | RL 2 | IH | $1 \mathrm{H} \quad 1$ | IH | ID $2-4$ | EX 3 | M 2 | DI 2 |  | D 2-4 | EX 3 | 1 M | DI 2 | ID 2-4 | EX |
| $0^{09}{ }^{1}$ | $\begin{array}{\|l\|l\|} \hline 19 \\ \text { LEAY } \end{array}$ | ${ }^{29} \mathrm{BVS}^{3 / 1}$ |  |  | ${ }^{59}{ }_{\text {ASLD }}{ }^{1}$ | $\begin{array}{cc}  \\ \hline 69 & \ddagger 2-4 \\ \mathrm{CL}^{\prime} \end{array}$ |  | ${ }^{89}$ | 99 ADCA ${ }^{3}$ |  | $\mathrm{ADCA}^{3-6}$ | B9 ADCA ${ }^{3}$ | C9 ADCB | D9 ADCB ${ }^{3}$ | $\begin{array}{cc} E 9 & 3-6 \\ A D C B \end{array}$ | $\mathrm{F9}_{\text {ADCB }}{ }^{3}$ |
| IH | ID $2-4$ | RL 2 | IH | 1 H | IH | $10 \quad 2-4$ | EX | IM | Di 2 |  | D 2-4 | EX 3 | IM | DI | ID $2-4$ | EX |
| $\mathrm{OA}_{\mathrm{RTC}}{ }^{\ddagger 7}$ | ${ }^{1 A} \text { LEAX }^{2}$ | ${ }^{2 A \mathrm{BPL}^{3 / 1}}$ | ${ }^{3 A} \text { PULD }^{3}$ | $\mathrm{CALL}^{\ddagger 7}$ | ${ }^{5 \text { A }} \text { STAA }^{2}$ | $\begin{gathered} \text { 6A } \\ \text { STAA } \\ \hline 2-4 \end{gathered}$ | ${ }^{7 A} \text { STAA }^{3}$ | $\begin{array}{\|c\|} \hline 8 \mathrm{~A} \\ \hline \end{array}$ | $\text { OA ORAA }{ }^{3}$ |  | $\mathrm{AA}^{\mathrm{OARAA}}$ | ${ }^{\text {BA }}{ }^{2 R A A}{ }^{3}$ | ${ }^{\text {CA }} \text { ORAB }^{1}$ | $\mathrm{ORAB}^{3}$ | $\begin{array}{c\|} \hline \text { EA }{ }^{3-6} \\ \text { ORAB } \end{array}$ | $\mathrm{FA}_{\mathrm{ORAB}}{ }^{3}$ |
| IH | ID $\quad 2-4$ | RL 2 | IH | EX 4 | DI | ID $\quad 2-4$ | EX 3 | 1 M | DI 2 |  | D 2-4 | EX 3 | IM | D 2 | ID 2-4 | EX |
| ${ }^{0 B} \mathrm{RTI}^{\dagger 8}$ | ${ }^{1 B} \text { LEAS }^{2}$ | $2 \mathrm{~B} \quad 3 / 1$ | ${ }^{3 \mathrm{BS}} \mathrm{PSD}^{2}$ | $\begin{gathered} \hline \text { 4B } \pm 7-10 \\ \text { CALL } \end{gathered}$ | $\mathrm{STAB}^{2}$ | $\begin{gathered} \hline \text { 6B } \quad \ddagger 2-4 \\ \text { STAB } \end{gathered}$ |  | ${ }^{8 \mathrm{ADDA}}{ }^{1}$ | ${ }_{\mathrm{ADDA}}{ }^{3}$ |  | $\mathrm{AB}^{3-6}{ }^{3-6}$ | $\mathrm{BB}_{\mathrm{ADDA}}{ }^{3}$ | $\mathrm{CB}$ | $\mathrm{ADDB}^{3}$ | $\begin{array}{cc} \mathrm{EB}^{3-6} \\ \mathrm{ADDB} \end{array}$ | $\underset{\mathrm{ADDB}}{ }{ }^{3}$ |
| IH | ID $2-4$ | RL | IH | ID 2-5 | DI | ID $\quad 2-4$ | EX | M | DI |  | D $2-4$ | EX 3 | IM | DI 2 | ID 2-4 | EX |
| $\begin{array}{\|l\|} \hline 0 \mathrm{OCET} \\ \hline{ }^{\text {BSET }} \\ \hline \end{array}$ | ${ }^{1 \mathrm{C}} \mathrm{BSET}^{4}$ | ${ }^{2 C_{B G E}}{ }^{3 / 1}$ | $\begin{array}{\|cc\|} \hline 3 C_{\text {wavr }} & \ddagger+5 \\ \hline \end{array}$ | ${ }^{4 \mathrm{CSET}}{ }^{4}$ | ${ }^{5 \mathrm{C}_{\mathrm{STD}}}$ | $\mathrm{CBTD}_{\mathrm{ST}}^{\ddagger 2-4}$ | ${ }^{7 \mathrm{C}_{\text {STD }}}{ }^{3}$ | ${ }^{8 C} \mathrm{CPD}^{2}$ | ${ }^{9 C} \mathrm{CPD}^{3}$ |  | $\mathrm{ACPD}^{3-6}$ | ${ }^{\mathrm{BC}} \mathrm{CPD}$ | $\overline{\mathrm{CC}}$ | $\mathrm{LDD}^{3}$ | $\mathrm{ECD}^{3-6}$ | $\stackrel{C}{\mathrm{~F}} \mathrm{LDD}$ |
| ID $3-5$ | EX | RL 2 | SP | DI 3 | DI 2 | ID 2.4 | EX 3 | 1 M | DI 2 |  | D $2-4$ | EX 3 | IM | DI 2 | ID $2-4$ | EX |
| $\begin{array}{\|cc\|} \hline 0 D & 4-6 \\ \text { BCLR } \end{array}$ | ${ }^{1 D} \text { BCLR }^{4}$ | ${ }_{\mathrm{BLT}}{ }^{3 / 1}$ |  | ${ }^{4 D}{ }_{B C L R}{ }^{4}$ |  | $\begin{gathered} \text { 6D } \\ \mathrm{STY}^{\ddagger 2-4} \end{gathered}$ |  |  |  |  | $P Y^{3-6}$ | ${ }^{\text {BD }} \mathrm{CPY}$ | CD | $\overline{\mathrm{LD}}$ | $\mathrm{ED}_{\mathrm{LDY}}{ }^{3-6}$ | FD ${ }^{3}$ |
| ID 3-5 | EX | RL 2 | IH | DI | DI | ID $\quad 2.4$ | EX 3 | 1 M | DI |  | D 2-4 | EX 3 | 1 M | DI 2 | ID 2-4 | EX |
| $\begin{array}{\|c\|} \hline 0 E \\ \text { BRSET } \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline 1 \mathrm{E} \\ \mathrm{BRSET}^{5} \end{array}$ | ${ }^{2 E_{B G T}}{ }^{3 / 1}$ | ${ }^{3 E_{\text {WAI }}}{ }^{\ddagger \dagger 7}$ | $\begin{array}{cc} 4 \mathrm{EESSET} \end{array}$ | ${ }^{5 E_{S T X}}{ }^{2}$ | $\mathrm{SE}_{\mathrm{STX}}^{\ddagger 2-4}$ | $7 \mathrm{E}_{\text {cTV }}{ }^{3}$ | ${ }^{8 E} \mathrm{CPX}^{2}$ | ${ }^{9 E} \mathrm{CPX}{ }^{3}$ |  | $\mathrm{CPE}^{3-6}$ | $\mathrm{BE}_{\mathrm{CPX}}{ }^{3}$ | CE | $\mathrm{LDX}^{3}$ | $E E X^{3-6}$ | $\mathrm{FE}_{\mathrm{LDX}}{ }^{3}$ |
| ID $\quad 4-6$ | EX 5 | RL 2 | IH | DI 4 | DI | ID 2.4 | EX 3 | M | DI 2 |  | D $2-4$ | EX 3 | IM | DI 2 | ID $2-4$ | EX |
| $\begin{array}{\|cc\|} \hline 0 \mathrm{FF} & \ddagger 4-6 \\ \text { BRCLR } \end{array}$ | $\begin{array}{\|l\|} \hline 1 \mathrm{~F} \\ \text { BRCLR } \\ \hline \end{array}$ | ${ }^{2 F_{B L E}}{ }^{3 / 1}$ | ${ }^{3 F} \mathrm{SW}$ | $\begin{aligned} & \hline 4 \mathrm{~F} \\ & \text { BRCLR }^{4} \end{aligned}$ | ${ }^{5 \mathrm{~F}} \text { STS }$ | $\begin{gathered} 6 \mathrm{~F} \\ \mathrm{STS} \end{gathered}$ |  | ${ }^{8 F^{C P S}}{ }^{2}$ | ${ }^{9 F_{C P S}}{ }^{3}$ |  | $\mathrm{CPS}^{3-6}$ | ${ }^{\text {BF }} \mathrm{CPS}$ | $\overline{\text { CFS }}$ | LDS | $\operatorname{LDS}^{3-6}$ | $\operatorname{LDS}^{3}$ |
| ID $\quad 4-6$ | EX | RL 2 | IH | DI 4 | DI | $10 \quad 2.4$ | EX 3 | M | DI 2 |  | D 2-4 | EX 3 | IM 3 | DI 2 | $10 \quad 2-4$ | EX |

Key to Table A-2


Table A-2. CPU12 Opcode Map (Sheet 2 of 2)

| $\mathrm{MOWW}^{4}$ | ${ }^{10} \text { IDIV }^{12}$ | ${ }^{20} \text { LBRA }{ }^{4}$ | ${ }^{30} \text { TRAP }^{10}$ | $\operatorname{TRAP}^{10}$ | ${ }^{50} \text { TRAP }^{10}$ | ${ }^{60} \operatorname{TRAP}^{10}$ | ${ }^{70} \operatorname{TRAP}^{10}$ | ${ }^{80} \operatorname{TRAP}^{10}$ | ${ }^{90} \operatorname{TRAP}^{10}$ | $\mathrm{ADAP}^{10}$ | $\mathrm{BRAP}^{10}$ | $\mathrm{CO}_{\mathrm{TRAP}}{ }^{10}$ | ${ }^{D 0} \text { TRAP }^{10}$ | $\mathrm{ERAP}^{10}$ | $\begin{array}{c\|} \hline \text { FO }{ }^{10} \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| IM-ID | IH 2 | RL 4 | IH 2 | IH 2 | IH 2 | H 2 | IH 2 | H 2 | $1 \mathrm{H} \quad 2$ | IH 2 | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | IH 2 |
| $\begin{aligned} & 01 \\ & \text { MOVW }^{5} \end{aligned}$ | ${ }^{11} \text { FDIV }^{12}$ | ${ }^{21} \text { LBRN }^{3}$ | ${ }^{31} \text { TRAP }^{10}$ | ${ }^{41} \text { TRAP }^{10}$ | ${ }^{51} \operatorname{TRAP}^{10}$ | ${ }^{61} \operatorname{TRAP}^{10}$ | ${ }^{71} \text { TRAP }^{10}$ | ${ }^{81} \operatorname{TRAP}^{10}$ | ${ }^{91} \text { TRAP }^{10}$ | $\mathrm{A1}_{\mathrm{TR} A P}{ }^{10}$ | $\mathrm{BRAP}^{10}$ | ${ }^{C 1} \text { TRAP }^{10}$ | $\mathrm{DRAP}^{10}$ | $\mathrm{E}^{\mathrm{TRAP}}{ }^{10}$ | $\begin{aligned} & \text { F1 } \text { TRAP }^{10} \end{aligned}$ |
| EX-ID | $1 \mathrm{H} \quad 2$ | RL 4 | $1 \mathrm{H} \quad 2$ | H 2 | IH 2 | IH 2 | IH 2 | H 2 | IH | IH 2 | IH | $1 \mathrm{H} \quad 2$ | IH 2 | IH | H 2 |
| $\text { MOWw }^{5}$ | $\begin{array}{l\|} \hline 12 \\ \text { EMACS } \\ \hline \end{array}$ | $\mathrm{LBHI}^{4 / 3}$ | $\mathrm{TRAP}^{32}$ | ${ }^{42} \operatorname{TRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | ${ }^{72} \text { TRAP }^{10}$ | ${ }^{82} \operatorname{TRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | $\mathrm{ARAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{CD}_{\mathrm{TRAP}}{ }^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{E}_{2} \mathrm{TRAP}^{10}$ | ${ }^{F 2} \text { TRAP }^{10}$ |
| ID-ID | SP 4 | RL 4 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | IH 2 | H 2 | $1 \mathrm{H} \quad 2$ | $\mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | H 2 |
| $\text { MOWW }^{53}$ | ${ }^{13} \text { EMULS }{ }^{3}$ | ${ }^{23}{ }^{\text {LBLS }}$ | ${ }^{33} \text { TRAP }^{10}$ | $\operatorname{TRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | ${ }^{63} \operatorname{TRAP}^{10}$ | ${ }^{73} \text { TRAP }^{10}$ | ${ }^{83} \text { TRAP }^{10}$ | ${ }^{93} \text { TRAP }^{10}$ | $\operatorname{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | $\mathrm{DRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | ${ }^{F 3} \text { TRAP }^{10}$ |
| IM-EX 6 | IH | RL 4 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | IH 2 | IH 2 | H 2 | IH | IH 2 | $1 \mathrm{H} \quad 2$ | IH | IH 2 | $1 \mathrm{H} \quad 2$ | IH |
| $\mathrm{MONW}^{6}$ | $\begin{array}{\|c\|} \hline 14 \\ { }^{14} \text { EDIVS }^{12} \\ \hline \end{array}$ | $\begin{array}{\|cc\|} \hline 24 & 4 / 3 \\ \hline \text { LBCC } \end{array}$ | $\text { TRAP }^{34}$ | $\operatorname{TRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | ${ }^{64} \operatorname{TRAP}^{10}$ | ${ }^{74} \text { TRAP }^{10}$ | ${ }^{84} \operatorname{TRAP}^{10}$ | ${ }^{94} \text { TRAP }^{10}$ | $\mathrm{ARAP}^{10}$ | $\operatorname{TRAP}^{10}$ | $\operatorname{CA}^{\operatorname{TRAP}}{ }^{10}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{ERAP}^{10}$ | $\mathrm{FA}_{\mathrm{TRAP}}{ }^{10}$ |
| EX-EX 6 | $1 \mathrm{H} \quad 2$ | RL 4 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 |
| $\text { MOWW }^{5}$ | ${ }^{15} \text { IDIVS }^{12}$ | $\mathrm{LBCS}^{25}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | ${ }^{55} \text { TRAP }^{10}$ | $\mathrm{TRAP}^{10}$ | ${ }^{75} \text { TRAP }^{10}$ | ${ }^{85} \mathrm{TRAP}^{10}$ | ${ }^{95} \operatorname{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | $\begin{aligned} & \text { F5 }{ }^{10}{ }^{10} \\ & \hline \end{aligned}$ |
| ID-EX 5 | $1 \mathrm{H} \quad 2$ | RL 4 | $1 \mathrm{H} \quad 2$ | IH 2 | IH 2 | H 2 | IH 2 | H 2 | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | H 2 |
| ${ }_{A B A}{ }^{2}$ | ${ }^{16} S B A^{2}$ | $\begin{gathered} \text { LBNE } \end{gathered}$ | ${ }^{36} \text { TRAP }^{10}$ | $\operatorname{TRAP}^{10}$ | $\text { TRAP }^{10}$ | ${ }^{68} \operatorname{TRAP}^{10}$ | ${ }^{78} \text { TRAP }^{10}$ | ${ }^{86} \text { TRAP }{ }^{10}$ | ${ }^{96} \text { TRAP }^{10}$ | $\mathrm{ARAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\begin{aligned} & \text { C6 } \operatorname{TRAP}^{10} \end{aligned}$ | $\mathrm{DR}^{\mathrm{TR} A P^{10}}$ | $\operatorname{ERAP}^{10}$ | $\begin{aligned} & \text { F6 }{ }^{\text {TRAP }}{ }^{10} \\ & \hline \end{aligned}$ |
| $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | RL 4 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 |
| ${ }^{07} \text { DAA }^{3}$ | ${ }^{17} \mathrm{CBA}^{2}$ | $\begin{array}{\|c\|} \hline 27 \\ \hline \text { LBEQ } \end{array}$ | ${ }^{37} \text { TRAP }^{10}$ | $\mathrm{TRAP}^{47}$ | ${ }^{57} \operatorname{TRAP}^{10}$ | ${ }^{67} \text { TRAP }^{10}$ | $\begin{gathered} 77 \\ \text { TRAP }^{10} \end{gathered}$ | ${ }^{87} \text { TRAP }^{10}$ | ${ }^{97} \operatorname{TRAP}^{10}$ | $\mathrm{AR}_{\mathrm{TRAP}}{ }^{10}$ | ${ }^{\mathrm{B7}} \mathrm{TRAP}^{10}$ | $\mathrm{CRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{ERAP}^{10}$ | $\begin{array}{\|l\|} \hline F 7 \\ \text { TRAP }^{10} \end{array}$ |
| $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | RL 4 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | H 2 |
| ${ }^{08} \text { MOVB }^{4}$ | $\begin{array}{\|c\|} \hline 18 \\ \text { MAXA }^{4-7} \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline 28 \\ \hline L B V C^{4 / 3} \\ \hline \end{array}$ | ${ }^{38} \text { TRAP }^{10}$ | ${ }^{48} \operatorname{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | ${ }^{78} \operatorname{TRAP}^{10}$ | ${ }^{88} \operatorname{TRAP}^{10}$ | ${ }^{98} \operatorname{TRAP}^{10}$ | $\mathrm{ARAP}^{10}$ | ${ }^{B 8} \operatorname{TRAP}^{10}$ | $\mathrm{CR}^{\mathrm{TR} A P^{10}}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{ERAP}^{10}$ | $\begin{aligned} & \text { F8 }{ }^{10}{ }^{10} \\ & \hline \end{aligned}$ |
| IM-ID 4 | ID 3-5 | RL $\quad 4$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 |
| ${ }_{\text {MOVB }}{ }^{5}$ | $\mathrm{MINA}^{4-7}$ | $\begin{array}{\|c\|} \hline 29 \quad 4 / 3 \\ \hline \text { LBVS } \end{array}$ | $\text { TRAP }^{10}$ | $\operatorname{TRAP}^{10}$ | $\operatorname{TRAP}^{10}$ | ${ }^{69} \operatorname{TRAP}^{10}$ | ${ }^{79} \text { TRAP }^{10}$ | ${ }^{89} \text { TRAP }{ }^{10}$ | $\operatorname{TRAP}^{10}$ | $\mathrm{ARAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{CRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{Eg}_{\text {TRAP }}{ }^{10}$ | ${ }^{F 9} \text { TRAP }^{10}$ |
| EX-ID 5 | ID $\quad 3-5$ | RL 4 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | H 2 |
| $\mathrm{MOVB}^{5}$ | $\begin{aligned} & \text { 1A }{ }^{4-7} \\ & \text { EMAXD } \end{aligned}$ | $\begin{array}{\|c\|} \hline 2 \mathrm{~A} \quad \mathrm{LBPL}^{4 / 3} \\ \hline \end{array}$ | ${ }_{R_{E V}{ }^{\dagger 3 n}}$ | $\operatorname{TRAP}^{10}$ | $\begin{gathered} 5 A^{10} \\ \text { RRAP }^{10} \end{gathered}$ | $\mathrm{TRAP}^{10}$ | ${ }^{7 A} \text { TRAP }^{10}$ | ${ }^{8 A} \text { TRAP }^{10}$ | ${ }^{9 A} \text { TRAP }^{10}$ | $\mathrm{ARAP}^{10}$ | $\begin{array}{\|c\|} \hline \text { BA } \operatorname{TRAP}^{10} \end{array}$ | $\begin{aligned} & \text { CA } \operatorname{TRAP}^{10} \end{aligned}$ | $\begin{gathered} \mathrm{DA} \\ \operatorname{TRAP} \end{gathered}$ | $\operatorname{TRAP}^{10}$ | $\begin{gathered} \text { FA }{ }^{\text {TRAP }}{ }^{10} \\ \hline \end{gathered}$ |
| ID-ID 4 | ID 3-5 | RL 4 | SP 2 | IH 2 | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H}^{2} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 |
| $\mathrm{OB}_{\mathrm{MOVB}}{ }^{4}$ | $\begin{array}{ll} \hline 1 \mathrm{~B} & 4-7 \\ \mathrm{EMIND} \end{array}$ | $\begin{array}{\|c\|} \hline 2 \mathrm{BBMI} \\ \hline \end{array}$ | $\begin{gathered} 3 \mathrm{~B}+5 \mathrm{n} / 3 \mathrm{n} \\ \mathrm{REVW} \end{gathered}$ | ${ }^{4 \mathrm{~B}} \mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{5 \mathrm{~B}}{ }^{10}$ | ${ }^{6 B} \operatorname{TRAP}^{10}$ | $\begin{gathered} 7 \mathrm{BE} \mathrm{TRAP}^{10} \\ \hline \end{gathered}$ | $\begin{gathered} 8 \mathrm{~B} \quad 10 \\ \text { TRAP }^{10} \end{gathered}$ | ${ }^{9 B} \operatorname{TRAP}^{10}$ | $\begin{aligned} & \text { AB }{ }^{10}{ }^{10} \end{aligned}$ | $\mathrm{BBAP}^{10}$ | $\begin{aligned} & \text { CB }{ }^{10}{ }^{10} \end{aligned}$ | $\begin{gathered} \mathrm{DB} \mathrm{TRAP}^{10} \end{gathered}$ | $\operatorname{EBAP}^{10}$ | $\begin{array}{\|l\|} \hline F B \\ T_{R A P}^{10} \end{array}$ |
| IM-EX 5 | ID 3 3-5 | RL 4 | SP 2 | IH 2 | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 |
| $\stackrel{O C}{M O V B}{ }^{6}$ | $\begin{gathered} \text { 1C }{ }_{\text {MAXM }}{ }^{4-7} \end{gathered}$ | $\begin{array}{\|cc\|} \hline 2 \mathrm{C} & 4 / 3 \\ \hline \text { LBGE } \end{array}$ | $\mathrm{WAV}^{\mathbf{3 C}} \underset{\mathrm{WAV}^{ \pm 78}}{ }$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | ${ }^{6 C} \operatorname{TRAP}^{10}$ | ${ }^{7 \mathrm{TC}} \mathrm{TRAP}^{10}$ | ${ }^{8 C} \text { TRAP }^{10}$ | ${ }^{9 C} \text { TRAP }^{10}$ | $\mathrm{AC}_{\mathrm{TRAP}}{ }^{10}$ | $\mathrm{BRAP}^{10}$ | $\begin{aligned} & \text { CC }{ }^{10} \\ & \operatorname{TRAP}^{10} \end{aligned}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{ERAP}^{10}$ | $\begin{aligned} & \text { FC } \mathrm{TRAP}^{10} \end{aligned}$ |
| EX-EX 6 | ID 3-5 | RL 4 | SP 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{IH}^{2}$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 |
| $\begin{gathered} \text { ODOVB } \\ \text { M } \end{gathered}$ | $\begin{gathered} 10 \text { D4-7 } \\ \text { MINM } \end{gathered}$ | $\mathrm{LBLT}^{2 \mathrm{~L}}$ | $\mathrm{TBL}^{\ddagger 6}$ | $\operatorname{TRAP}^{10}$ | ${ }^{50} \text { TRAP }^{10}$ | ${ }^{6 D} \operatorname{TRAP}^{10}$ | $\begin{gathered} 70 \\ \text { TRAP }^{10} \end{gathered}$ | ${ }^{8 D} \text { TRAP }^{10}$ | ${ }^{9 D} \operatorname{TRAP}^{10}$ | $\begin{aligned} & \text { AD }{ }^{\text {TRAP }}{ }^{10} 1 \end{aligned}$ | $\mathrm{TRAP}^{10}$ | $\begin{gathered} \text { CD } \operatorname{TRAP}^{10} \end{gathered}$ | $\frac{\mathrm{DD}}{\mathrm{TRAP}}{ }^{10}$ | $\begin{aligned} & \operatorname{ED} \operatorname{TRAP}^{10} \end{aligned}$ | $\begin{aligned} & \text { FD }{ }^{10}{ }^{10} \\ & \hline \end{aligned}$ |
| ID-EX 5 | ID $\quad 3-5$ | RL $\quad 4$ | D 3 | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | H 2 | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | H 2 |
| $E_{T A B}{ }^{2}$ | $\begin{aligned} & 1 \mathrm{E} \quad 4-7 \\ & \mathrm{EMAXM} \end{aligned}$ | $\mathrm{LEGT}^{4 / 3}$ | $\text { STOP }{ }^{\ddagger 8}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $9 \mathrm{TRAP}^{10}$ | $\mathrm{AE}_{\mathrm{TRAP}}{ }^{10}$ | $\mathrm{TRAP}^{10}$ | $\begin{aligned} & \text { CE } \operatorname{TRAP}^{10} \end{aligned}$ | $\text { DE } \mathrm{TRAP}^{10}$ | $\operatorname{EEAP}^{10}$ | $\begin{gathered} \text { FE }{ }^{10} \\ \text { TRAP } \end{gathered}$ |
| $1 \mathrm{H} \quad 2$ | ID 3-5 | RL 4 | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | $1 \mathrm{H} \quad 2$ | IH 2 |
| ${ }^{0 F_{T B A}}{ }^{2}$ | $\begin{gathered} 1 \mathrm{~F} \\ \text { EMINM } \end{gathered}$ | ${ }^{2 F} \text { LBLE }^{4 / 3}$ | ${ }_{E_{\text {ETBL }}}{ }^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | ${ }^{8 F} \text { TRAP }^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{ARAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\mathrm{TRAP}^{10}$ | $\operatorname{EFAP}^{10}$ | $\begin{aligned} & \text { FF } \text { TRAP }^{10} \\ & \hline \end{aligned}$ |
| $1 \mathrm{H} \quad 2$ | ID 3-5 | RL 4 | ID 3 | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | $1 \mathrm{H} \quad 2$ | IH 2 | IH | H 2 |

Table A-3. Indexed Addressing Mode Postbyte Encoding (xb)

| $\int_{5 b}^{\infty} \begin{gathered} 0 . X \\ 50 \text { const } \end{gathered}$ | $\left\lvert\, \begin{aligned} & 10 \\ & 5 b \text { const } \\ & \text {-16 } x \end{aligned}\right.$ | $\begin{array}{\|c} 20 \\ \text { pre-inc } \\ 1 .+X \\ \hline \end{array}$ | $\begin{array}{rr} 30 & 1, X_{+} \\ \text {post-inc } \end{array}$ | $0, Y$ 5b const | $\begin{aligned} & 50 \\ & -16, Y \\ & 5 b \text { const } \end{aligned}$ | $\begin{array}{cc} 60 \\ & 1,+Y \\ \text { pre-inc } \end{array}$ | $\begin{array}{\|r\|} \hline 70 \\ 1, Y_{+} \\ \text {post-inc } \end{array}$ | $\begin{array}{cc} 80 \\ 0, S P \\ 5 b \text { const } \end{array}$ | $\begin{aligned} & 90 \\ & -16, S P \\ & 5 b \text { const } \end{aligned}$ | $\begin{array}{\|l\|} A_{0} \\ \text { 1,+SP } \\ \text { pre-inc } \end{array}$ | $\left\lvert\, \begin{gathered} 80 \\ \text { 1.SP+ } \\ \text { post-inc } \end{gathered}\right.$ | $\begin{array}{\|c\|} \hline 0, P C \\ 5 \mathrm{~b} \text { const } \end{array}$ | $\left\lvert\, \begin{aligned} & \mathrm{DO} \\ & -16, \mathrm{PC} \\ & 5 \mathrm{~b} \text { const } \end{aligned}\right.$ | $\begin{array}{\|ll} E 0 & \\ \hline & n, X \\ 9 b & \text { const } \end{array}$ | $\begin{array}{\|cc} \text { FO } \\ \text { n,SP } \\ & \text { gb const } \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{array}{\|cc} \hline 01 & 1, X \\ 5 b & \\ & \\ \hline \end{array}$ | $\begin{aligned} & 11-15, X \\ & 5 b \text { const } \end{aligned}$ | $\begin{array}{\|l\|l\|} \hline 2,+X \\ \text { pre-inc } \end{array}$ | $\begin{array}{\|r\|} \hline 31 \\ 2, X_{+} \\ \text {post-inc } \\ \hline \end{array}$ | 1,Y 5b const | $\begin{aligned} & 51-15, Y \\ & 5 b \text { const } \end{aligned}$ | $\begin{array}{\|c\|} \hline 2,+Y \\ { }^{61} \\ \text { pre-inc } \end{array}$ | ${ }^{71}{ }_{2, Y+}{ }^{2, Y}$ | 1,SP 5b const | $\begin{array}{\|l} 91 \\ -15, S P \\ 5 b \text { const } \end{array}$ | $\begin{aligned} & \text { A1 } \begin{array}{l} 2,+S P \\ \text { pre-inc } \end{array} \end{aligned}$ | $\begin{aligned} & \mathrm{Bi}_{2}{ }_{2, \mathrm{SP}+} \\ & \text { post-inc } \end{aligned}$ | 1,PC 5b const | $\begin{array}{\|l} \mathrm{D} 1 \\ -15, \mathrm{PC} \\ 5 \mathrm{~b} \text { const } \end{array}$ | $\begin{array}{ll} E 1 & -n, X \\ 9 b \text { const } \end{array}$ | $\begin{aligned} & \mathrm{F} 1 \\ & -\mathrm{n}, \mathrm{SP} \\ & 9 \mathrm{~b} \text { const } \end{aligned}$ |
| $\begin{aligned} & 02 \\ & 2, \mathrm{X} \\ & 5 \mathrm{~b} \text { const } \\ & \hline \end{aligned}$ | $\begin{array}{\|c\|} \hline 12 \\ 5 b \text { const } \\ \hline \end{array}$ | $\begin{array}{\|l\|l} 22 & 3 .+x \\ \text { pre-inc } \end{array}$ | $\begin{array}{\|r\|} 32 \\ 3, \mathrm{X}+ \\ \text { post-inc } \end{array}$ | 2,Y <br> 5b const | $\begin{array}{\|l} 52 \\ 5 b \text { const } \\ \hline \end{array}$ | $\begin{array}{\|l\|} \hline 62 \\ { }_{3,+Y} \\ \text { pre-inc } \end{array}$ | $\begin{array}{\|r} 72 \\ 3, Y_{+} \\ \text {post-inc } \end{array}$ | 2,SP <br> 5b const | $\begin{array}{\|l\|} \hline 92 \\ -14, S P \\ 5 b \text { const } \\ \hline \end{array}$ | $\begin{aligned} & \text { A2 }{ }_{3,+S P} \\ & \text { pre-inc } \end{aligned}$ | $\begin{aligned} & \text { B2 } \\ & \text { 3,SP+ } \\ & \text { post-inc } \end{aligned}$ | 2,PC <br> 5b const | $\begin{array}{\|l} \hline \mathrm{D} 2 \\ -14, \mathrm{PC} \\ 5 \mathrm{~b} \text { const } \end{array}$ | $\begin{array}{\|l\|} \hline E 2 n \\ \\ 16 \mathrm{~b}, \mathrm{X} \text { const } \\ \hline \end{array}$ | $\begin{array}{\|l\|} \hline F 2{ }_{n} \mathrm{SP} \\ 16 \mathrm{~b} \text { const } \end{array}$ |
| $\begin{gathered} 03 \\ 3, \mathrm{X} \\ 5 \mathrm{~b} \text { const } \\ \hline \end{gathered}$ | $\begin{aligned} & 13 \\ & 5 b \text { const } \end{aligned}$ | ${ }^{23} 4,+X$ | ${ }^{33} 4, \mathrm{X}_{+}$ | 3,Y 5b const | $\begin{aligned} & 53 \\ & 5 b \text { const } \\ & 53, Y \end{aligned}$ | $\begin{array}{\|l\|l\|} \hline 63 & 4,+Y \\ \text { pre-inc } \end{array}$ | ${ }^{73}{ }_{4, Y_{+}} \text {post-inc }$ | 3,SP 5b const | $\begin{aligned} & 93 \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{aligned} & \text { A3 }{ }_{4,+S P} \\ & \text { pre-inc } \end{aligned}$ | $\begin{array}{\|l} \mathrm{B3}_{4, \mathrm{SP}+} \\ \text { post-inc } \end{array}$ | 3,PC 5b const | $\begin{aligned} & \mathrm{D3} 3 \\ & -13, \mathrm{PC} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{aligned} & E 3{ }_{[n, \mathrm{X}]} \\ & 16 \mathrm{~b} \text { indr } \end{aligned}$ | $\begin{aligned} & \mathrm{F} 3 \\ & 10 \mathrm{n}, \mathrm{SP}] \\ & 18 \mathrm{indr} \end{aligned}$ |
| ${ }^{04} 4, \mathrm{x}$ | 14 <br> $-12, \mathrm{X}$ <br> $5 b$ const | $\begin{aligned} & 54 .+\mathrm{x} \\ & \text { pre-ine } \end{aligned}$ | $\begin{array}{r} 34 \\ 5, \mathrm{X}+ \\ \text { post-inc } \end{array}$ | 4,Y 5b const | $\begin{array}{ll} 54 & \\ 5 b & -12, Y \\ 5 \mathrm{const} \end{array}$ | $\left.\right\|_{5,+Y} ^{64}{ }^{64} \text { pre-inc }$ | $\begin{array}{\|c} 74 \\ 5, Y_{+} \\ \text {post-inc } \end{array}$ | 4,SP <br> 5b const | $\begin{aligned} & 94 \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{aligned} & \text { A4 }{ }_{5,+S P} \\ & \text { pre-inc } \end{aligned}$ | $\begin{aligned} & 84 \\ & 5, \mathrm{SP}+ \\ & \text { post-inc } \end{aligned}$ | $\begin{aligned} & \text { C4 } \\ & \text { 4,PC } \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{aligned} & \mathrm{D} 4 \\ & -12, \mathrm{PC} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|l\|} \mathrm{E4} \mathrm{~A}, \mathrm{X} \\ \text { A offset } \end{array}$ | F4 A,SP A offset |
| 5.X 5b const | $-11, X$ $5 b$ const | $\left.\right\|_{\text {8, +X }} ^{25}$ | ${ }^{35}{ }_{6, \mathrm{X}_{+}} \text {post-inc }$ | 5,Y 5b const | $\begin{aligned} & 55 \\ & -11, Y \\ & 5 b \text { const } \end{aligned}$ | $\begin{array}{\|c\|} 65 \\ \text { Bre-inc } \end{array}$ | $\begin{array}{\|c} 75 \\ 6, Y+ \\ \text { post-inc } \end{array}$ | 5,SP 5b const | $\begin{aligned} & 95 \\ & -11, S P \\ & 5 b \text { const } \end{aligned}$ | $\begin{aligned} & \text { A5 } \\ & \text { 6,+SP } \\ & \text { pre-inc } \end{aligned}$ | $\begin{aligned} & 85 \\ & \text { 6.SP+ } \\ & \text { post-inc } \end{aligned}$ | 5.PC 5b cons | $\begin{aligned} & \text { D5 } \\ & \text {-11,PC } \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|l\|} \hline E 5 \\ B, X \\ B \text { offset } \end{array}$ | B,SP B offset |
| $\begin{array}{\|cc} 06, x \\ 5 b & 6 . X \\ 5 \text { const } \end{array}$ | $\begin{aligned} & 16 \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{ll} 28 \\ 7,+X \\ \text { pre-inc } \end{array}$ | $\begin{array}{rr} 36 \\ 7, X_{+} \\ \text {post-inc } \end{array}$ | 6,Y 5b const | $\int_{56}^{56}-10, Y \text { const }$ | $\begin{array}{\|rr} 66 \\ \hline & 7 .+Y \\ \text { pre-inc } \end{array}$ | ${ }^{76} 7, \mathrm{Y}_{+}+$ |  | $\begin{aligned} & 96 \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|l} \hline \text { A6 } \\ 7,+ \text { SP } \\ \text { pre-inc } \end{array}$ | $\begin{aligned} & 86 \\ & \text { 7.SP }+ \\ & \text { post-inc } \end{aligned}$ | $\begin{aligned} & \hline \text { C6 } \\ & 5 \mathrm{~B}, \mathrm{PC} \\ & 5 \mathrm{const} \end{aligned}$ | $\begin{aligned} & \text { D6 } \\ & -10, \mathrm{PC} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|l\|} \hline \text { E6 } \\ \text { D.X } \\ \text { D offset } \end{array}$ | $\begin{array}{\|c\|} \hline \text { F6 } \\ \text { D.SP } \\ \text { D offset } \end{array}$ |
| 7.X $5 b$ const | $-8, \mathrm{X}$ 5 b const | $\begin{array}{\|l\|} \hline 27 \\ \text { pre-inc } \\ 8 .+X \\ \hline \end{array}$ | $\begin{array}{\|r\|} \hline 37 \\ 8, \mathrm{X}_{+} \\ \text {post-inc } \end{array}$ | 7,Y 5b const | -9. Y <br> 5b const | $\begin{array}{\|l\|} \hline 67 \\ 8,+Y \\ \text { pre-inc } \\ \hline \end{array}$ | $\begin{array}{\|l\|} \hline 77 \\ 8, Y_{+} \\ \text {post-inc } \end{array}$ | 7,SP 5b cons | $\begin{aligned} & 97 \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{aligned} & \text { A7 } \\ & \text { 8,+SP } \\ & \text { pre-inc } \end{aligned}$ | $\begin{aligned} & 87 \\ & \text { 8,SP+ } \\ & \text { post-inc } \end{aligned}$ | 7.PC 5b const | $\begin{aligned} & \mathrm{D7} \\ & 5 \mathrm{-9,PC} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | [D.X] D indirect | [D,SP] <br> D indirect |
| $\begin{array}{\|cc\|} \hline 08 \\ 8, X \\ 5 \mathrm{~b} \text { const } \\ \hline \end{array}$ | $\begin{array}{\|cc} 18 \\ & -8, \mathrm{X} \\ 5 \mathrm{~b} \text { const } \end{array}$ | $\left.\right\|^{28} 88 .-\mathrm{x}$ | $\begin{array}{\|c\|} \hline 38 \\ 8, X- \\ \text { post-dec } \\ \hline \end{array}$ | 8,Y 5b const | $\begin{array}{ll} 58 & \\ \hline \text {-8, } \mathrm{Y} \\ 5 \mathrm{const} \end{array}$ | $\begin{array}{\|r\|} \hline 68 \\ 8,-Y \\ \text { pre-dec } \end{array}$ | $\begin{array}{\|c\|} \hline 78 \\ 8, Y- \\ \text { post-dec } \\ \hline \end{array}$ | 8,SP 5b const | $\begin{aligned} & 98 \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|l\|} \hline \text { A8 } \\ \text { 8.-SP } \\ \text { pre-dec } \end{array}$ | $\begin{aligned} & 88 \\ & 8, S P- \\ & \text { post-dec } \end{aligned}$ | $\begin{aligned} & \mathrm{C} 8 \\ & 5 \mathrm{~b} \text { 8.PC } \\ & 5 \mathrm{c} \text { const } \end{aligned}$ | $\begin{array}{\|l\|} \hline \text { D8 } \\ 5 \mathrm{Bb} \text { - } \mathrm{Ponst} \\ \hline \end{array}$ | $\begin{array}{\|cc} \hline \text { E8 } & \\ & \text { n,Y } \\ \hline 9 b \text { const } \\ \hline \end{array}$ | $\begin{aligned} & \hline \begin{array}{l} \text { n,PC } \\ \text { n const } \end{array} \\ & \hline \end{aligned}$ |
| $\begin{array}{cc} \hline 09 & 9 . x \\ 5 b \text { const } \end{array}$ | $\begin{array}{cc} 19 & -7, X \\ 5 \mathrm{~b} \text { const } \end{array}$ | $\begin{array}{\|l\|} \hline 29 \\ 7,-\mathrm{X} \\ \text { pre-dec } \end{array}$ | $\begin{array}{\|c\|} \hline 39 \\ 7 . X- \\ \text { post-dec } \end{array}$ | 9,Y 5b const | $\int_{50}^{50}-7, Y$ | $\begin{array}{\|cc\|} \hline 69,-Y \\ \text { pre-dec } \end{array}$ | $\begin{array}{\|l\|} \hline 79 \\ 7, Y- \\ \text { post-dec } \end{array}$ | 9,SP 5b const | $\begin{aligned} & 98-7, \mathrm{SP} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{aligned} & \text { A9 } \\ & 7,-\mathrm{SP} \\ & \text { pre-dec } \end{aligned}$ | $\begin{aligned} & \text { B9 } \\ & \text { 7,SP- } \\ & \text { post-dec } \end{aligned}$ | 9,PC 5b const | $\begin{array}{\|l} \hline \text { D9 } \\ 5 \mathrm{~b} \text { const } \end{array}$ | $\begin{aligned} & \text { E9 } \\ & 9 \mathrm{n} \text { const } \end{aligned}$ | $\begin{array}{\|l\|} \hline \text { F9 } \\ \text {-n, PC } \\ 9 \mathrm{~b} \text { const } \end{array}$ |
| $\begin{aligned} & \hline \text { OA } 10, \mathrm{X} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{aligned} & 1 \mathrm{~A} \\ & 5 \mathrm{~b} \text { const } \mathrm{X} \\ & \hline \end{aligned}$ | ${ }^{2 A} 6,-x$ | $\begin{array}{\|c\|} \hline 3 \mathrm{~A} \\ 6, \mathrm{X}- \\ \text { post-dec } \end{array}$ | 4A $10, Y$ 5b const | $\begin{aligned} & 5 \mathrm{~A} \\ & 5 \mathrm{~b} \text { const } \mathrm{Y} \\ & \hline \end{aligned}$ | $\begin{array}{\|c\|} 6 A-Y \\ \text { pre-dec } \end{array}$ | $\begin{aligned} & 7 \mathrm{AA} \\ & \begin{array}{c} 6, Y- \\ \text { post-dec } \end{array} \end{aligned}$ | ${ }^{8 \mathrm{~A}} 10 . \mathrm{SP}$ 5b const | $\begin{aligned} & 9 \mathrm{~A} \\ & 5 \mathrm{~b} \text { const } \\ & 5 \mathrm{SP} \end{aligned}$ | $\begin{array}{\|l\|} \hline \text { AA } \\ \text { 6.-SP } \\ \text { pre-dec } \end{array}$ | $\begin{aligned} & \text { BA } \\ & \text { 6.SP- } \\ & \text { post-dec } \end{aligned}$ | $\begin{aligned} & \text { CA } \\ & \text { 10,PC } \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|l} \hline \text { DA } \\ -6, \mathrm{PC} \\ 5 \mathrm{~b} \text { const } \end{array}$ | $\begin{aligned} & \text { EA } \quad \text { n, } Y \\ & 16 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|l\|} \hline F A \\ \\ 10 \mathrm{n}, \mathrm{PC} \text { const } \\ \hline \end{array}$ |
| $\begin{aligned} & 08 \\ & \text { 11,X } \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|c\|} \hline 1 \mathrm{~B} \\ \text { 5b const } \\ \hline \end{array}$ | $\left\lvert\, \begin{aligned} & 28 \\ & { }_{5}^{28}-\mathrm{x} \\ & \text { pre-dec } \end{aligned}\right.$ | ${\underset{c}{5 . X-}}_{\text {post-dec }}^{3 \mathrm{~B}}$ | $\begin{array}{ll} 48 \\ 11, Y \\ 5 b \\ 50 n s t \end{array}$ | $\begin{array}{\|l\|} \hline 5 \mathrm{~B} \\ \text { 5b const } \\ \hline \end{array}$ | $\begin{array}{\|c\|} 6 B-Y \\ \text { pre-dec } \end{array}$ | $\left\lvert\, \begin{aligned} & 7 \mathrm{~B} \\ & \text { post- } \mathrm{Y}-\mathrm{dec} \end{aligned}\right.$ | $\begin{aligned} & 8 \mathrm{~B} \\ & 11, \mathrm{SP} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{aligned} & 9 \mathrm{~B} \\ & 5 \mathrm{E} \text { const } \\ & 5 \mathrm{~s} \text { con } \end{aligned}$ | $\begin{array}{\|l} \hline \text { AB } \\ \text { 5,-SP } \\ \text { pre-dec } \end{array}$ | $\begin{aligned} & \text { BB } \\ & \text { 5,SP- } \\ & \text { post-dec } \end{aligned}$ | $\begin{array}{\|l} \hline \mathrm{CB} \\ \\ 5 \mathrm{~b} \text { const } \end{array}$ | $\begin{aligned} & \mathrm{DB} \\ & \quad-5, \mathrm{PC} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | [ $\mathrm{n}, \mathrm{Y}$ ] 16 b indr | $\begin{array}{\|l} \hline \text { FB } \\ {[\mathrm{n}, \mathrm{PC}]} \\ 16 \mathrm{~b} \text { indr } \end{array}$ |
| 12, X 5b const | $\begin{aligned} & 1 \mathrm{C} \\ & 5 \mathrm{~b} \text { const } \mathrm{X} \\ & \hline \end{aligned}$ | $\begin{array}{\|l\|} \hline 2 \mathrm{C} \\ \text { 4,-X } \\ \text { pre-dec } \end{array}$ | $\left\lvert\, \begin{array}{\|c\|} \hline 3 C_{4, X-} \\ \text { post-dec } \end{array}\right.$ | 12. Y 5b const | $\begin{aligned} & 5 \mathrm{C} \\ & 5 \mathrm{~b} \text { const } \mathrm{Y} \end{aligned}$ | $\begin{aligned} & 6 \mathrm{E},-\mathrm{Y} \\ & \text { pre-dec } \end{aligned}$ | 4, Y-post-dec | 12,SP 5 b const | $\left[\begin{array}{r} -4, S P \\ 5 b \text { const } \end{array}\right.$ | $\begin{array}{\|l} \hline \mathrm{AC} \\ 4,-\mathrm{SP} \\ \text { pre-dec } \end{array}$ | $\begin{array}{\|l\|} \hline \text { BC } \\ \text { 4,SP- } \\ \text { post-dec } \end{array}$ | 12,PC 5b const | $\begin{aligned} & D C \\ & 5 \mathrm{~b}, \mathrm{PC} \\ & 5 \mathrm{const} \end{aligned}$ | A. $Y$ A offset | A.PC A offset |
| $\begin{aligned} & 0013, x \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|c} \hline 1 \mathrm{D} \\ 5 \mathrm{c}-\mathrm{x} \\ 5 \mathrm{~b} \text { const } \end{array}$ | $\mathrm{m}_{3,-\mathrm{x}}^{\mathrm{pre-dec}}$ | $\begin{array}{\|c} 3 D \\ 3, X- \\ \text { post-dec } \end{array}$ | $\begin{aligned} & 4 \mathrm{D} \\ & 13, Y \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\left\{\begin{array}{l} 5 D-3, Y \\ 5 \mathrm{~b} \text { const } \end{array}\right.$ | $\begin{array}{\|c\|} \hline 60-Y \\ \text { pre-dec } \end{array}$ | $\begin{gathered} 7 \mathrm{D} \\ 3, Y- \\ \text { post-dec } \end{gathered}$ | 13.SP 5b const | $\begin{aligned} & 9 \mathrm{D} \\ & -3, \mathrm{SP} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{aligned} & \text { AD } \\ & \text { 3,-SP } \\ & \text { pre-dec } \end{aligned}$ | $\begin{array}{\|l} \hline \text { BD } \\ 3, S P- \\ \text { post-dec } \end{array}$ | $\begin{array}{\|l\|} \hline \mathrm{CD} \\ 13, \mathrm{PC} \\ 5 \mathrm{~b} \text { const } \\ \hline \end{array}$ | $\begin{array}{\|l\|} \hline \mathrm{DD} \\ -3, P C \\ 5 b \text { const } \\ \hline \end{array}$ | $\begin{array}{\|l\|} \hline \text { ED } \\ \text { B.Y } \\ \text { B offset } \end{array}$ | $\begin{array}{\|c\|} \hline \text { FD } \\ \text { B,PC } \\ \text { B offset } \end{array}$ |
| $\begin{aligned} & 0 \mathrm{E} \\ & 14, X \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{gathered} 1 \mathrm{E} \\ 5 \mathrm{~b} \text { const } \mathrm{X} \end{gathered}$ | ${ }_{2 \mathrm{E},-\mathrm{X}}^{\mathrm{pre-dec}}$ | $\left\lvert\, \begin{aligned} & 3 \mathrm{E}_{2, \mathrm{X}} \\ & \text { post-dec } \end{aligned}\right.$ | $\begin{aligned} & 4 \mathrm{E} \\ & \text { 14,Y } \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{aligned} & 5 \mathrm{E} \\ & -2, Y \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|l\|} 6 E_{2,-Y} \\ \text { pre-dec } \end{array}$ | $\begin{array}{\|l\|} \hline 7 \mathrm{E}_{2, \mathrm{Y}} \\ \text { post-dec } \end{array}$ | $8_{14, S P}$ $5 \mathrm{~b} \text { const }$ | $\begin{aligned} & 9 \mathrm{E} \\ & -2, \mathrm{SP} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|c\|} \hline \text { AE } \\ 2,-S P \\ \text { pre-dec } \end{array}$ | $\begin{array}{\|l\|} \hline \text { BE } \\ 2, S P- \\ \text { post-dec } \\ \hline \end{array}$ | $\begin{aligned} & \mathrm{CE} \\ & 14, \mathrm{PC} \\ & 5 \mathrm{~b} \text { const } \end{aligned}$ | $\begin{array}{\|l\|} \hline \mathrm{DE} \\ -2, \mathrm{PC} \\ 5 \mathrm{~b} \text { const } \end{array}$ | $\begin{array}{\|c\|c} \text { EE } & \text { D,Y } \\ \text { D offset } \end{array}$ | $\begin{array}{\|c\|} \text { FE } \\ \text { D.PC } \\ \text { Doffiset } \end{array}$ |
| $\begin{aligned} & \text { OF } \\ & \text { 15,X } \\ & \text { 5b const } \end{aligned}$ | $\begin{array}{\|l\|} \hline 1 \mathrm{~F} \\ \text { } \\ \text { 5b const } \mathrm{X} \end{array}$ | $\int_{\text {1.-X }}^{2 F}{ }^{2 F}$ | $\begin{aligned} & \text { 3F } \\ & 1, X- \\ & \text { post-dec } \end{aligned}$ | 15, Y 5b const | $\begin{aligned} & 5 \mathrm{~F} \\ & 5 \mathrm{l} \text { const } \mathrm{Y} \\ & 5 \end{aligned}$ | $\begin{array}{\|l\|} \hline 6 F_{1,-Y} \\ \text { pre-dec } \end{array}$ | $\begin{array}{\|l\|} \hline 7 \mathrm{FF} \\ \text { 1,Y- } \\ \text { post-dec } \end{array}$ | 15.SP <br> $5 b$ const | $\left\lvert\, \begin{aligned} & 9 \mathrm{~F} \\ & 5 \mathrm{~b} \text { const } \end{aligned}\right.$ | $\begin{aligned} & \text { AF } \\ & \text { 1,-SP } \\ & \text { pre-dec } \end{aligned}$ | $\begin{array}{\|l\|} \hline \text { BF } \\ \text { 1,SP- } \\ \text { post-dec } \\ \hline \end{array}$ | 15.PC 5b const | $\begin{array}{\|l\|} \hline \mathrm{DF} \\ -1, P \mathrm{P} \\ 5 \mathrm{~b} \text { const } \\ \hline \end{array}$ | [D,Y] D indirect | $\begin{aligned} & \left\lvert\, \begin{array}{l} \text { FF } \\ \text { [D.PC] } \\ \mathrm{D} \text { indirect } \end{array}\right. \end{aligned}$ |

Key to Table A-3


Table A-5. Transfer and Exchange Postbyte Encoding

| TRANSFERS |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| LS | MS $\Rightarrow$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 0 |  | $\mathrm{A} \Rightarrow \mathrm{A}$ | $\mathrm{B} \Rightarrow \mathrm{A}$ | $\mathrm{CCR} \Rightarrow \mathrm{A}$ | TMP3 ${ }_{L} \Rightarrow \mathrm{~A}$ | $\mathrm{B} \Rightarrow \mathrm{A}$ | $\mathrm{X}_{\mathrm{L}} \Rightarrow \mathrm{A}$ | $Y_{L} \Rightarrow A$ | $\mathrm{SP}_{\mathrm{L}} \Rightarrow \mathrm{A}$ |
| 1 |  | $\mathrm{A} \Rightarrow \mathrm{B}$ | $\mathrm{B} \Rightarrow \mathrm{B}$ | $\mathrm{CCR} \Rightarrow \mathrm{B}$ | TMP3 ${ }_{L} \Rightarrow \mathrm{~B}$ | $B \Rightarrow B$ | $\mathrm{X}_{\mathrm{L}} \Rightarrow \mathrm{B}$ | $Y_{L} \Rightarrow B$ | $\mathrm{SP}_{\mathrm{L}} \Rightarrow \mathrm{B}$ |
| 2 |  | $\mathrm{A} \Rightarrow \mathrm{CCR}$ | $\mathrm{B} \Rightarrow \mathrm{CCR}$ | $\mathrm{CCR} \Rightarrow \mathrm{CCR}$ | TMP3 ${ }_{\text {L }} \Rightarrow \mathrm{CCR}$ | $\mathrm{B} \Rightarrow \mathrm{CCR}$ | $\mathrm{X}_{\mathrm{L}} \Rightarrow \mathrm{CCR}$ | $Y_{L} \Rightarrow C C R$ | $\mathrm{SP}_{\mathrm{L}} \Rightarrow \mathrm{CCR}$ |
| 3 |  | sex:A $\Rightarrow$ TMP2 | sex: $B=$ TMP2 | sex:CCR $\Rightarrow$ TMP2 | TMP3 $\Rightarrow$ TMP2 | $\mathrm{D} \Rightarrow$ TMP2 | $\mathrm{x} \Rightarrow$ TMP2 | $\mathrm{Y} \Rightarrow$ TMP2 | $\mathrm{SP} \Rightarrow \mathrm{TMP2}$ |
| 4 |  | $\begin{aligned} & \text { sex:A } \Rightarrow D \\ & \text { SEXA,D } \end{aligned}$ | $\begin{aligned} & \operatorname{sex}: B \Rightarrow D \\ & \text { SEX } B, D \end{aligned}$ | $\begin{aligned} & \text { sex:CCR } \Rightarrow D \\ & \text { SEX CCR,D } \end{aligned}$ | TMP3 $\Rightarrow$ D | $D \Rightarrow D$ | $x \Rightarrow D$ | $Y \Rightarrow D$ | SP $\Rightarrow$ D |
| 5 |  | $\begin{aligned} & \operatorname{sex}: A \Rightarrow X \\ & S E X A, X \end{aligned}$ | $\begin{gathered} \hline \operatorname{sex}: B \Rightarrow X \\ \text { SEX } B, X \end{gathered}$ | $\begin{aligned} & \hline \text { sex:CCR } \Rightarrow X \\ & \text { SEX CCR,X } \end{aligned}$ | TMP3 $\Rightarrow$ X | $D \Rightarrow x$ | $x \Rightarrow x$ | $Y \Rightarrow X$ | SP $\Rightarrow$ X |
| 6 |  | $\begin{aligned} & \text { sex:A } \Rightarrow Y \\ & \text { SEXA,Y } \end{aligned}$ | $\begin{gathered} \operatorname{sex}: B \Rightarrow Y \\ \text { SEXB,Y } \end{gathered}$ | $\begin{aligned} & \text { sex:CCR } \Rightarrow Y \\ & \text { SEXCCR, } Y \end{aligned}$ | TMP3 $\Rightarrow$ Y | $D \Rightarrow Y$ | $X \Rightarrow Y$ | $Y \Rightarrow Y$ | SP $\Rightarrow \mathrm{Y}$ |
| 7 |  | $\begin{aligned} & \operatorname{sex}: A \Rightarrow S P \\ & \operatorname{SEX} A, S P \end{aligned}$ | $\begin{gathered} \operatorname{sex}: B \Rightarrow S P \\ S E X B, S P \end{gathered}$ | $\begin{gathered} \text { sex:CCR } \Rightarrow \text { SP } \\ \text { SEX CCR,SP } \end{gathered}$ | TMP3 $\Rightarrow \mathrm{SP}$ | $D \Rightarrow S P$ | $\mathrm{X} \Rightarrow \mathrm{SP}$ | $Y \Rightarrow$ SP | $\mathrm{SP} \Rightarrow \mathrm{SP}$ |
| EXCHANGES |  |  |  |  |  |  |  |  |  |
| $\Downarrow$ LS | MS $\Rightarrow$ | 8 | 9 | A | B | C | D | E | F |
| 0 |  | $A \Leftrightarrow A$ | $B \Leftrightarrow A$ | $C C R \Leftrightarrow A$ | $\begin{gathered} \mathrm{TMP} 3_{\mathrm{L}} \Rightarrow \mathrm{~A} \\ \$ 00: \mathrm{A} \stackrel{\mathrm{TMP3}}{ } \end{gathered}$ | $\begin{aligned} & B \Rightarrow A \\ & A \Rightarrow B \end{aligned}$ | $\begin{gathered} x_{L} \Rightarrow A \\ \$ 00: A \Rightarrow x \end{gathered}$ | $\begin{gathered} Y_{L} \Rightarrow A \\ \$ 00: A \Rightarrow Y \end{gathered}$ | $\begin{aligned} S P_{L} & \Rightarrow \mathrm{~A} \\ \$ 00: \mathrm{A} & \Rightarrow \mathrm{SP} \end{aligned}$ |
| 1 |  | $A \Leftrightarrow B$ | $B \Leftrightarrow B$ | $C C R \Leftrightarrow B$ | $\begin{gathered} \mathrm{TMP3}_{\mathrm{L}} \Rightarrow \mathrm{~B} \\ \mathrm{SFF}: \mathrm{B} \Rightarrow \mathrm{TMP3} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{B} \Rightarrow \mathrm{~B} \\ \$ \mathrm{FF} \Rightarrow \mathrm{~A} \end{gathered}$ | $\begin{gathered} x_{L} \Rightarrow B \\ \text { SFF:B } \Rightarrow x \end{gathered}$ | $\begin{gathered} Y_{L} \neq B \\ \text { SFF:B } \Rightarrow Y \end{gathered}$ | $\begin{aligned} S P_{\mathrm{L}} & \Rightarrow \mathrm{~B} \\ \mathrm{SFF}: \mathrm{B} & \Rightarrow \mathrm{SP} \end{aligned}$ |
| 2 |  | $A \Leftrightarrow C C R$ | $\mathrm{B} \Leftrightarrow \mathrm{CCR}$ | $C C R \Leftrightarrow C C R$ | $\begin{array}{\|c\|} \hline \mathrm{TMP}_{\mathrm{L}} \Rightarrow \mathrm{CCR} \\ \text { SFF:CCR } \Rightarrow \mathrm{TMP3} 3 \\ \hline \end{array}$ |  | $\begin{array}{c\|} \mathrm{x}_{\mathrm{L}} \Rightarrow \mathrm{CCR} \\ \text { SFF:CCR } \Rightarrow \mathrm{x} \end{array}$ | $\begin{array}{\|c\|} \hline Y_{L} \Rightarrow C C R \\ \text { SFF:CCR } \Rightarrow Y \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline \mathrm{SP} \mathrm{~L}_{\mathrm{L}} \Rightarrow \mathrm{CCR} \\ \text { SFF:CCR } \Rightarrow \mathrm{SP} \end{array}$ |
| 3 |  | $\begin{gathered} \hline \mathrm{SOO}: \mathrm{A} \Rightarrow \mathrm{TMP2} \\ \mathrm{TMP2}{ }_{\mathrm{L}} \Rightarrow \mathrm{~A} \\ \hline \end{gathered}$ | $\begin{gathered} \$ 00: B \Rightarrow \mathrm{TMP2} \\ \mathrm{TMP} 2_{\mathrm{L}} \Rightarrow \mathrm{~B} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{SOO:CCR} \Rightarrow \mathrm{TMP2} \\ \mathrm{TMP}_{2} \Rightarrow \mathrm{CCR} \\ \hline \end{gathered}$ | TMP3 $\Leftrightarrow$ TMP2 | $D \Leftrightarrow T M P 2$ | X $\quad$ TMP2 | $Y$ Y TMP2 | $\mathrm{SP} \Leftrightarrow \mathrm{TMP2}$ |
| 4 |  | \$00:A $\Rightarrow \mathrm{D}$ | \$00: $\mathrm{B} \Rightarrow \mathrm{D}$ | $\begin{gathered} \$ 00: C C R \Rightarrow D \\ B \Rightarrow C C R \end{gathered}$ | TMP3 $\Leftrightarrow$ D | $D \Leftrightarrow D$ | $\mathrm{X} \Leftrightarrow \mathrm{D}$ | $Y \Leftrightarrow D$ | $\mathrm{SP} \Leftrightarrow \mathrm{D}$ |
| 5 |  | $\begin{gathered} \text { S00:A } \Rightarrow X \\ x_{L} \Rightarrow A \end{gathered}$ | $\begin{gathered} s 00: B \Rightarrow X \\ X_{L} \Rightarrow B \end{gathered}$ | $\begin{gathered} \$ 00: C C R \Rightarrow x \\ x_{L} \Rightarrow C C R \end{gathered}$ | TMP3 ${ }^{\text {c }}$ ( | $D \Leftrightarrow X$ | $X \Leftrightarrow X$ | $Y \Leftrightarrow X$ | SP $\Leftrightarrow \mathrm{X}$ |
| 6 |  | $\begin{gathered} \$ 00: A \Rightarrow Y \\ Y_{L} \Rightarrow A \end{gathered}$ | $\begin{gathered} S 00: B \Rightarrow Y \\ Y_{L} \Rightarrow B \end{gathered}$ | $\begin{gathered} \$ 00: C C R \Rightarrow Y \\ Y_{L} \Rightarrow C C R \end{gathered}$ | TMP3 $¢ \mathrm{Y}$ | $D \Leftrightarrow Y$ | $X \Leftrightarrow Y$ | $Y \Leftrightarrow Y$ | $\mathrm{SP} \Leftrightarrow \mathrm{Y}$ |
| 7 |  | $\begin{gathered} \$ 00: A \Rightarrow S P \\ S P_{L} \Rightarrow A \end{gathered}$ | $\begin{gathered} \$ 00: B \Rightarrow S P \\ S P_{\mathrm{L}} \Rightarrow \mathrm{~B} \end{gathered}$ | $\begin{gathered} \mathrm{SOO:CCR} \Rightarrow \mathrm{SP} \\ \mathrm{SP} \Rightarrow \mathrm{C} \Rightarrow \mathrm{CCR} \end{gathered}$ | $T M P 3 \Leftrightarrow$ SP | $D \Leftrightarrow S P$ | $\mathrm{X} \Leftrightarrow \mathrm{SP}$ | $Y \Leftrightarrow S P$ | $\mathrm{SP} \Leftrightarrow \mathrm{SP}$ |

TMP2 and TMP3 registers are for factory use only.

Table A-6. Loop Primitive Postbyte Encoding (lb)

| $\begin{array}{\|c\|} \hline \infty \\ \hline \text { DBEQ } \\ (+) \end{array}$ | $\begin{array}{\|c} \hline \text { DBEQ } \\ \hline \\ \hline \end{array}$ | ${ }^{20} \mathrm{DENE}^{\mathrm{A}}$ <br> (+) | ${ }^{30}$ DBNE A (-) | ${ }^{40}{ }^{\text {TBEQ }}{ }^{A}$ <br> ( + ) | ${ }^{50}$ TBEQ $^{\text {A }}$ - | ${ }^{60}$ TBNE ${ }^{\text {A }}$ <br> ( + ) | $\begin{array}{\|c\|c\|} \hline 70 \\ \hline \end{array}$ | $\begin{array}{\|c\|c\|} \hline 30 \\ \hline \text { IBEQ } \\ (+) \end{array}$ |  | ${ }^{A D}{ }^{\text {IBNE }} \mathrm{A}$ $(+)$ | ${ }_{\text {IBNE }}{ }^{\text {A }}$ (H) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{array}{\|c\|} \hline 01 \\ \text { DBEQ } \\ (+) \end{array}$ | $\begin{array}{\|c\|c\|} \hline 11 \\ \text { DBEQ } \\ (-) \end{array}$ | ${ }^{21}{ }^{21} \mathrm{DBNE}^{\mathrm{B}}$ $(+)$ | $\begin{array}{\|c\|} \hline 31 \\ \hline \\ \hline \end{array}$ | $$ | $\begin{array}{\|c\|} \hline 51 \\ \hline \text { TBEQ } \\ (-) \\ \hline \end{array}$ | ${ }^{61} \mathrm{TBNE}^{\mathrm{B}}$ $(t)$ | $\begin{array}{\|c\|} \hline 71 \\ \hline \\ \hline \end{array}$ | $$ | $\begin{array}{\|c\|c\|} \hline 21 \\ \hline \end{array}$ | $\mathrm{A}_{\text {IBNE }} \mathrm{B}$ <br> ( + | $\begin{gathered} \text { Bi IBNE } \\ (H) \\ \hline \end{gathered}$ |
| 02 | 12 | 22 | 32 | 42 | 52 | 62 |  |  |  |  |  |
| 03 | 13 | 23 | 33 | 43 | 53 | 63 | ${ }^{73}$ | 83 | $\underbrace{3}$ | A3 |  |
| 04 DBEQ <br> $(+)^{\text {D }}$ | $\begin{array}{\|c\|} \hline 14 \\ \text { DBEQ }^{\text {D }} \\ (-) \end{array}$ | $\underset{\substack{\text { DENE } \\(+)}}{24}$ | $\begin{array}{\|c\|} \hline 34 \\ \mathrm{DBNE}^{34} \\ (-) \end{array}$ | $\begin{array}{\|c\|} \hline 44 \\ \hline \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline 54 \\ \text { TBEQ } \\ (-) \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline 64 \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline 74 \\ \hline \text { TBNE } \\ (H) \\ \hline \end{array}$ |  | $\begin{array}{\|c\|} \hline 94 \\ \hline 1 \mathrm{IBEQ} \\ (-) \\ \hline \end{array}$ | $\begin{aligned} & \text { A4 }{ }^{\text {IBNE }} \\ & \hline \end{aligned}$ <br> ( + ) | $\begin{gathered} \mathrm{BA}^{\mathrm{B4}} \mathrm{IBNE} \\ (-) \\ \hline \end{gathered}$ |
| $\begin{gathered} \hline 05 \\ \hline \text { DBEQ } \\ (t) \\ \hline \end{gathered}$ | $\begin{gathered} \hline 15 \text { DBEQ }^{1} \quad \mathrm{X} \\ \hline \end{gathered}$ | $\begin{gathered} 25 \\ \text { DENE }^{1} \\ (+) \end{gathered}$ |  | $\begin{array}{\|c\|} \hline 45 \\ \hline \text { TBEQ } \\ (t) \\ \hline \end{array}$ |  | ${ }^{65} \text { TBNE }{ }^{X}$ <br> ( + | $\begin{gathered} \hline 75 \\ \hline \text { TBNE } \\ (H) \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline 85 \\ \hline 1 \mathrm{IBEQ} \\ (+) \end{array}$ | $\begin{array}{\|c\|} \hline \infty \\ \hline 1 \mathrm{IBEQ} \\ (-) \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline \text { A5 IBNE } \\ (+) \\ \hline \end{array}$ |  |
|  | $\begin{array}{\|c\|} \hline 16 \\ \text { DBEQ }^{16} \\ (H) \\ \hline \end{array}$ |  | $\underset{\substack{\text { DBNE } \\(-)}}{{ }^{36}}$ | $\begin{gathered} \hline 46 \text { TBEQ }^{(t)} \\ \hline \end{gathered}$ | $\underset{\substack{\text { TBEQ } \\(-)}}{ }{ }^{\mathrm{SE}}$ |  | $\begin{array}{\|c\|} \hline \text { T6 } \\ \text { TBNE } \\ (H) \\ \hline \end{array}$ |  | $\begin{array}{\|c\|} \hline \mathrm{P}_{\text {IBEQ }} \mathrm{Y} \\ (H) \\ \hline \end{array}$ | AE ${ }^{Y}$ (+) |  |
| $\begin{array}{\|c} \hline 07 \\ \hline \text { DBEQ } \\ (+) \\ \hline \end{array}$ | $\begin{gathered} \hline 17{ }^{17} \text { SP }^{\text {DBEQ }} \\ (-) \\ \hline \end{gathered}$ | $\underset{\substack{27 \\ \text { DENE } \\(+)}}{ }$ | $\underset{\substack{\text { DBNE } \\(-)}}{\text { SP }}$ | $\begin{array}{\|c\|} \hline 47 \\ \hline \text { TBEQ } \\ (t) \\ \hline \end{array}$ | $57{ }_{\substack{\text { TBEQ } \\ (-)}}{ }^{\text {SP }}$ | $\begin{array}{\|c\|} \hline 67 \\ \hline \text { TBNE } \\ (+) \\ \hline \end{array}$ | $\underset{\substack{77 \\ \text { TBNE } \\(H)}}{ }$ | $\begin{gathered} \hline 87 \mathrm{SPEQ} \\ (+) \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline 97 \\ \hline 1 \mathrm{IBEQ} \\ (-) \\ \hline \end{array}$ |  | $\begin{gathered} \mathrm{Br}^{\mathrm{B7}} \mathrm{SP} \\ \mathrm{IBNE} \\ (-) \\ \hline \end{gathered}$ |

Key to Table A-6


Table A-7. Branch/Complementary Branch

| Branch |  |  |  | Complementary Branch |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Test | Mnemonic | Opcode | Boolean | Test | Mnemonic | Opcode | Comment |
| r $\quad$ m | BGT | 2 E | $\mathrm{Z}+(\mathrm{N} \oplus \mathrm{V})=0$ | r ¢ m | BLE | 2 F | Signed |
| ram | BGE | 2C | $\mathrm{N} \oplus \mathrm{V}=0$ | $\mathrm{r}<\mathrm{m}$ | BLT | 2D | Signed |
| $\mathrm{r}=\mathrm{m}$ | BEQ | 27 | $\mathrm{Z}=1$ | r ¢ m | BNE | 26 | Signed |
| $r \leq m$ | BLE | 2 F | $\mathrm{Z}+(\mathrm{N} \oplus \mathrm{V})=1$ | r>m | BGT | 2E | Signed |
| $r<m$ | BLT | 2D | $\mathrm{N} \oplus \mathrm{V}=1$ | r 2 m | BGE | 2 C | Signed |
| r $\times \mathrm{m}$ | BHI | 22 | $\mathrm{C}+\mathrm{Z}=0$ | $\mathrm{r} \leq \mathrm{m}$ | BLS | 23 | Unsigned |
| rem | BHS/BCC | 24 | $\mathrm{C}=0$ | $\mathrm{r}<\mathrm{m}$ | BLO/BCS | 25 | Unsigned |
| $\mathrm{r}=\mathrm{m}$ | BEQ | 27 | $Z=1$ | r ¢ m | BNE | 26 | Unsigned |
| r mm | BLS | 23 | $C+Z=1$ | r>m | BHI | 22 | Unsigned |
| $\mathrm{r}<\mathrm{m}$ | BLOVBCS | 25 | $\mathrm{C}=1$ | r 2 m | BHS/BCC | 24 | Unsigned |
| Carry | BCS | 25 | $\mathrm{C}=1$ | No Carry | BCC | 24 | Simple |
| Negative | BMI | 2B | $\mathrm{N}=1$ | Plus | BPL | 2A | Simple |
| Overflow | BVS | 29 | $\mathrm{V}=1$ | No Overflow | BVC | 28 | Simple |
| $\mathrm{r}=0$ | BEQ | 27 | $Z=1$ | $r \neq 0$ | BNE | 26 | Simple |
| Always | BRA | 20 | - | Never | BRN | 21 | Unconditional |

