Appendix C BENCHMARK PROGRAMS

C-1 INTRODUCTION

The following benchmarks illustrate the source code syntax and programming techniques for the DSP56300 Core. The assembly language source is organized into 6 columns as shown below.

Label	Opcode	Operands	X Bus Data	Y Bus Data	Comment
FIR	MAC	X0,Y0,A	X:(R0)+,X0	Y:(R4)+,Y0	;Do each tap

The Label column is used for program entry points and end of loop indication. The Opcode column indicates the Data ALU, Address ALU or Program Controller operation to be performed. The Operands column specifies the operands to be used by the opcode. The X Bus Data specifies an optional data transfer over the X Bus and the addressing mode to be used. The Y Bus Data specifies an optional data transfer over the Y Bus and the addressing mode to be used. The Comment column is used for documentation purposes and does not affect the assembled code. The Opcode column must always be included in the source code.

C-2 SET OF BENCHMARKS

C-2.1 Real Multiply

$$c = a \times b$$

Label	Opcode	Operands	X Bus Data	Y Bus Data	Comment	Prog wrds	Clock Cycles
	move		x:(r0),x0	y:(r4),y0	;	1	1
	mpyr	x0,y0,a			;	1	1
	move		a,x:(r1)		;	1	2 i’lock
					Totals	3	4

C-2.2 N Real Multiplies

$$c(i) = a(i) \times b(i) \qquad i = 1, 2, \ldots, N$$

Memory map:

pointer	X mem	Y mem
r0	a(i)	
r4		b(i)
r1	c(i)	

						Prog wrds	Clock Cycles
	move	#AADDR,r0					
	move	#BADDR,r4					
	move	#CADDR,r1					
	move		x:(r0)+,x0	y:(r4)+,y0	;	1	1
	mpyr	x0,y0,a	x:(r0)+,x0	y:(r4)+,y0	;	1	1
	do	#N-1,end			;	2	5
	mpyr	x0,y0,a	a,x:(r1)+	y:(r4)+,y0	;	1	1
	move		x:(r0)+,x0		;	1	1
end					;		
	move		a,x:(r1)+		;	1	1
					Totals	7	2N+8

C-2.3 Real Update

$$d = c + a \times b$$

					Prog wrds	Clock Cycles
move	#AADDR,r0					
move	#BADDR,r4					
move	#CADDR,r1					
move	#DADDR,r2					
move		x:(r0),x0	y:(r4),y0	;	1	1
move		x:(r1),a		;	1	1
macr	x0,y0,a			;	1	1
move		a,x:(r2)		;	1	2 i'lock
				Totals	4	5

C-2.4 N Real Updates

$$d(i) = c(i) + a(i) \times b(i) \qquad i = 1, 2, \ldots, N$$

Memory map:

pointer	X mem	Y mem
r0	a(i)	
r4		b(i)
r1	c(i)	
r5		d(i)

```
                                                              Prog    Clock
                                                              wrds    Cycles
      move    #AADDR,r0
      move    #BADDR,r4
      move    #CADDR,r1
      move    #DADDR,r5
      move                x:(r0)+,x0   y:(r4)+,y0   ;         1       1
      move                x:(r1)+,a                 ;         1       1
      move                x:(r1)+,b                 ;         1       1
      do      #N/2,end                              ;         2       5
      macr    x0,y0,a     x:(r0)+,x1   y:(r4)+,y1   ;         1       1
      macr    x1,y1,b     x:(r0)+,x0   y:(r4)+,y0   ;         1       1
      move    x:(r1)+,a   a,y:(r5)+                 ;         1       1
      move    x:(r1)+,b   b,y:(r5)+                 ;         1       1
end
                                                    Totals    9       2N+8
```

C-2.5 Real Correlation Or Convolution (FIR Filter)

$$c(n) = \sum_{i=0}^{N-1} [a(i) \times b(n-i)]$$

Memory map:

pointer	X mem	Y mem
r0	a(i)	
r4		b(i)

					Prog wrds	Clock Cycles
move	#AADDR,r0					
move	#BADDR,r4			;		
move	#N-1,m4			;		
move	m4,m0			;		
movep	y:input,y:(r4)			;	1	2
clr	a	x:(r0)+,x0	y:(r4)-,y0	;	1	1
rep	#N-1			;	1	5
mac	x0,y0,a	x:(r0)+,x0	y:(r4)-,y0	;	1	1
macr	x0,y0,a		(r4)+	;	1	1
movep	a,y:output			;	1	2 i'lock
				Totals	6	N+14

Memory map:

pointer	X mem	Y mem
r0	a(i)	
r1	b(i)	

					Prog wrds	Clock Cycles
	move	#AADDR,r0				
	move	#BADDR,r1		;		
	move	#N-1,m1		;		
	move	m1,m0		;		
	movep	y:input,x:(r1)		;	1	2
	clr	a	x:(r0)+,x1	;	1	1
	do	#N-1,end		;	2	5
	move		x:(r1)-,x0	;	1	1
	mac	x0,x1,a	x:(r0)+,x1	;	1	1
end				;		
	move		x:(r1)-,x0	;	1	1
	macr	x0,x1,a	(r1)+	;	1	1
	movep	a,y:output		;	1	2 i'lock
				Totals	9	2N+10

C-2.6 Real * Complex Correlation Or Convolution (FIR Filter)

$$cr(n) = jci(n) = \sum_{i=0}^{N-1} [(ar(i) + jai(i)) \times b(n-i)]$$

$$cr(n) = \sum_{i=0}^{N-1} ar(i) \times b(n-i) \qquad ci(n) = \sum_{i=0}^{N-1} ai(i) \times b(n-i)$$

Memory map:

pointer	X mem	Y mem
r0	ar(i)	ai(i)
r4	b(i)	
r1	cr(n)	ci(n)

```
                                                      Prog   Clock
                                                      wrds   Cycles
        move    #AADDR,r0                         ;
        move    #BADDR,r4                         ;
        move    #CADDR,r1                         ;
        move    #N-1,m4                           ;
        move    m4,m0                             ;
        movep   y:input,x:(r4)                    ;   1      2
        clr     a        x:(r0),x0                ;   1      1
        clr     b        x:(r4)-,x1  y:(r0)+,y0   ;   1      1
        do      #N-1,end                          ;   2      5
        mac     x0,x1,a  x:(r0),x0                ;   1      1
        mac     y0,x1,b  x:(r4)-,x1  y:(r0)+,y0   ;   1      1
end
        macr    x0,x1,a                           ;   1      1
        macr    y0,x1,b  (r4)+                    ;   1      1
        move             a,x:(r1)                 ;   1      1
        move                         b,y:(r1)     ;   1      1
                                            Totals    11     2N+11
```

C-2.7 Complex Multiply

$$cr + jci = (ar + jai) \times (br + jbi)$$

$$cr = ar \times br - ai \times bi \qquad ci = ar \times bi + ai \times br$$

Memory map:

pointer	X mem	Y mem
r0	ar	ai
r4	br	bi
r1	cr	ci

					Prog wrds	Clock Cycles
move	#AADDR,r0					
move	#BADDR,r4					
move	#CADDR,r1					
move		x:(r0),x1	y:(r4),y0	;	1	1
mpy	y0,x1,b	x:(r4),x0	y:(r0),y1	;	1	1
macr	x0,y1,b			;	1	1
mpy	x0,x1,a			;	1	1
macr	-y0,y1,a		b,y:(r1)	;	1	1
move		a,x:(r1)		;	1	2 i'lock
				Totals	6	7

C-2.8 N Complex Multiplies

$$cr(i) + jci(i) = (ar(i) + jai(i)) \times (br(i) + jbi(i)) \qquad i = 1, 2, \ldots, N$$

$$cr(i) = ar(i) \times br(i) - ai(i) \times bi(i)$$

$$ci(i) = ar(i) \times bi(i) + ai(i) \times br(i)$$

Memory map:

pointer	X mem	Y mem
r0	ar(i)	ai(i)
r4	br(i)	bi(i)
r5	cr(i)	ci(i)

```
                                                                Prog   Clock
                                                                wrds   Cycles
        move    #AADDR,r0                                  ;
        move    #BADDR,r4                                  ;
        move    #CADDR-1,r5                                ;
        move                x:(r0),x1     y:(r4),y0        ;    1      1
        move                x:(r5),a                       ;    1      1
        do      #N,end                                     ;    2      5
        mpy     y0,x1,b     x:(r4)+,x0    y:(r0)+,y1       ;    1      1
        macr    x0,y1,b     a,x:(r5)+                      ;    1      1
        mpy     -y0,y1,a                  y:(r4),y0        ;    1      1
        macr    x0,x1,a     x:(r0),x1     b,y:(r5)         ;    1      1
end
        move    a,x:(r5)                                   ;    1      2 i'lock
                                                           Totals 9    4N+9
```

C-2.9 Complex Update

$$dr + jdi = (cr + jci) + (ar + jai) \times (br + jbi)$$

$$dr = cr + ar \times br - ai \times bi \qquad di = ci + ar \times bi + ai \times br$$

Memory map:

pointer	X mem	Y mem
r0	ar	ai
r4	br	bi
r1	cr	ci
r2	dr	di

```
                                                                Prog   Clock
                                                                wrds   Cycles
        move    #AADDR,r0
        move    #BADDR,r4
        move    #CADDR,r1
        move    #DADDR,r2
        move                              y:(r1),b         ;    1      1
        move                x:(r0),x1     y:(r4),y0        ;    1      1
        mac     y0,x1,b     x:(r4),x0     y:(r0),y1        ;    1      1
        macr    x0,y1,b     x:(r1),a                       ;    1      1
        mac     x0,x1,a                                    ;    1      1
        macr    -y0,y1,a                  b,y:(r2)         ;    1      1
        move                a,x:(r2)                       ;    1      2 i'lock
                                                           Totals 7    8
```

C-2.10 N Complex Updates

$$dr(i) + jdi(i) = (cr(i) + jci(i)) + (ar(i) + jai(i)) \times (br(i) + jbi(i))$$
$$dr(i) = cr(i) + ar(i) \times br(i) - ai(i) \times bi(i)$$
$$di(i) = ci(i) + ar(i) \times bi(i) + ai(i) \times br(i)$$
$$i = 1, 2, \ldots, N$$

Memory map:

pointer	X mem	Y mem
r0	ar(i) ; ai(i)	
r4		br(i) ; bi(i)
r1	cr(i) ; ci(i)	
r5		dr(i) ; di(i)

```
                                                               Prog   Clock
                                                               wrds   Cycles
        move   #AADDR,r0                            ;
        move   #BADDR,r4                            ;
        move   #CADDR,r1                            ;
        move   #DADDR-1,r5                          ;
        move                x:(r0)+,x1  y:(r4)+,y0  ;          1      1
        move                x:(r1)+,b   y:(r5),a    ;          1      1
        do     #N,end       ;25                     ;          2      5
        mac    y0,x1,b      x:(r0)+,x0  y:(r4)+,y1  ;          1      1
        macr   -x0,y1,b     x:(r1)+,a   a,y:(r5)+   ;          1      1
        mac    x0,y0,a      x:(r1)+,b   b,y:(r5)+   ;          1      2 i'lock
        macr   x1,y1,a      x:(r0)+,x1  y:(r4)+,y0  ;          1      1
end
        move                            a,y:(r5)+   ;          1      2 i'lock
                                                    Totals     9      5N+9
```

Memory map:

pointer	X mem	Y mem
r0	ar(i)	ai(i)
r4	br(i)	bi(i)
r1	cr(i)	ci(i)
r5	dr(i)	di(i)

						Prog wrds	Clock Cycles
	move	#AADDR,r0			;		
	move	#BADDR,r4			;		
	move	#CADDR,r1			;		
	move	#DADDR-1,r5			;		
	move		x:(r5),a		;	1	1
	move		x:(r0),x1	y:(r4),y0	;	1	1
	move		x:(r4)+,x0	y:(r1),b	;	1	1
	do	#N,end			;	2	5
	mac	y0,x1,b	a,x:(r5)+	y:(r0)+,y1	;	1	1
	macr	x0,y1,b	x:(r1)+,a		;	1	1
	mac	-y0,y1,a	y:(r4),y0		;	1	1
	macr	x0,x1,a	x:(r0),x1	b,y:(r5)	;	1	1
	move		x:(r4)+,x0	y:(r1),b	;	1	1
end							
	move		a,x:(r5)		;	1	1
					Totals	11	5N+9

C-2.11 Complex Correlation Or Convolution (FIR Filter)

$$cr(n) + jci(n) = \sum_{i=0}^{N-1} [(ar(i) + jai(i)) \times (br(n-i) + jbi(n-i))]$$

$$cr(n) = \sum_{i=0}^{N-1} [ar(i) \times br(n-i) - ai(i) \times bi(n-i)]$$

$$ci(n) = \sum_{i=0}^{N-1} [ar(i) \times bi(n-i) + ai(i) \times br(n-i)]$$

Memory map:

pointer	X mem	Y mem
r0	ar(i)	ai(i)
r4	br(i)	bi(i)
r1	cr(i)	ci(i)

```
                                                          Prog   Clock
                                                          wrds   Cycles
        move    #AADDR,r0                          ;
        move    #BADDR,r4                          ;
        move    #CADDR,r1
        move    #N-1,m4
        move    #m4,m0
        movep   y:input,x:(r4)                            1      2
        movep   y:input,y:(r4)                            1      2
        clr     a                                  ;      1      1
        clr     b          x:(r0),x1   y:(r4),y0   ;      1      1
        do      #N-1,end                           ;      2      5
        mac     y0,x1,b    x:(r4)-,x0  y:(r0)+,y1  ;      1      1
        mac     x0,y1,b                            ;      1      1
        mac     x0,x1,a                            ;      1      1
        mac     -y0,y1,a   x:(r0),x1   y:(r4),y0   ;      1      1
end
        mac     y0,x1,b    x:(r4),x0   y:(r0)+,y1  ;      1      1
        macr    x0,y1,b                            ;      1      1
        mac     x0,x1,a                            ;      1      1
        macr    -y0,y1,a                           ;      1      1
        move                           b,y:(r1)    ;      1      1
        move               a,x:(r1)                ;      1      1
                                                   Totals 16     4N+13
```

C-2.12 Nth Order Power Series (Real)

$$c = \sum_{i=0}^{N-1} [a(i) \times b^i]$$

Memory map:

pointer	X mem	Y mem
r0	a(i)	
r4		b
r1	c	

						Prog wrds	Clock Cycles
	move	#AADDR,r0			;		
	move	#BADDR,r4					
	move	#CADDR,r1					
	move		x:(r0)+,a		;	1	1
	move			y:(r4),x0		1	1
	mpyr	x0,x0,b	x:(r0)+,y0		;	1	1
	move			b,y1	;	1	2 i'lock
	do	#N-1,end			;	2	5
	mac	y0,x0,a	x:(r0)+,y0		;	1	1
	mpyr	x0,y1,b	b,x0		;	1	1
end							
	macr	y0,x0,a			;	1	1
	move		a,x:(r1)		;	1	2 i'lock
					Totals	10	2N+11

C-2.13 2nd Order Real Biquad IIR Filter

$$w(n)/2 = x(n)/2 - (a1)/2 \times w(n-1) - (a2)/2 \times w(n-2)$$
$$y(n)/2 = w(n)/2 + (b1)/2 \times w(n-1) + (b2)/2 \times w(n-2)$$

Memory map:

pointer	X mem	Y mem
r0	w(n-2), w(n-1)	
r4		a2/2, a1/2, b2/2, b1/2

						Prog wrds	Clock Cycles
ori	#$08,mr			;			
move	#AADDR,r0			;			
move	#BADDR,r4			;			
move	#1,m0						
move	#3,m4						
movep	y:input,a			;		1	1
rnd	a	x:(r0)+,x0	y:(r4)+,y0	;		1	1
mac	-y0,x0,a	x:(r0)-,x1	y:(r4)+,y0	;		1	1
mac	-y0,x1,a	x1,x:(r0)+	y:(r4)+,y0	;		1	1
mac	y0,x0,a	a,x:(r0)	y:(r4),y0	;		1	2 i'lock
macr	y0,x1,a			;		1	1
movep	a,y:output			;		1	2 i'lock
				Totals		7	9

C-2.14 N Cascaded Real Biquad IIR Filter

$$w(n)/2 = x(n)/2 - (a1)/2 \times w(n-1) - (a2)/2 \times w(n-2)$$
$$y(n)/2 = w(n)/2 + (b1)/2 \times w(n-1) + (b2)/2 \times w(n-2)$$

Memory map:

pointer	X mem	Y mem
r0	w(n-2)1, w(n-1)1, w(n-2)2, ...	
r4		(a2/2)1, (a1/2)1, (b2/2)1, (b1/2)1, (a2/2)2, ...

						Prog wrds	Clock Cycles
	ori	#$08,mr			;		
	move	#AADDR,r0			;		
	move	#BADDR,r4			;		
	move	#(2N-1),m0			;		
	move	#(4N-1),m4			;		
	move		x:(r0)+,x0	y:(r4)+,y0	;	1	1
	movep	y:input,a			;	1	1
	do	#N,end			;	2	5
	mac	-y0,x0,a	x:(r0)-,x1	y:(r4)+,y0	;	1	1
	mac	-y0,x1,a	x1,x:(r0)+	y:(r4)+,y0	;	1	1
	mac	y0,x0,a	a,x:(r0)+	y:(r4)+,y0	;	1	2 i’lock
	mac	y0,x1,a	x:(r0)+,x0	y:(r4)+,y0	;	1	1
end							
	rnd	a			;	1	1
	movep	a,y:output			;	1	2 i'lock
					Totals	10	5N+10

C-2.15 N Radix-2 FFT Butterflies (DIT, in-place algorithm)

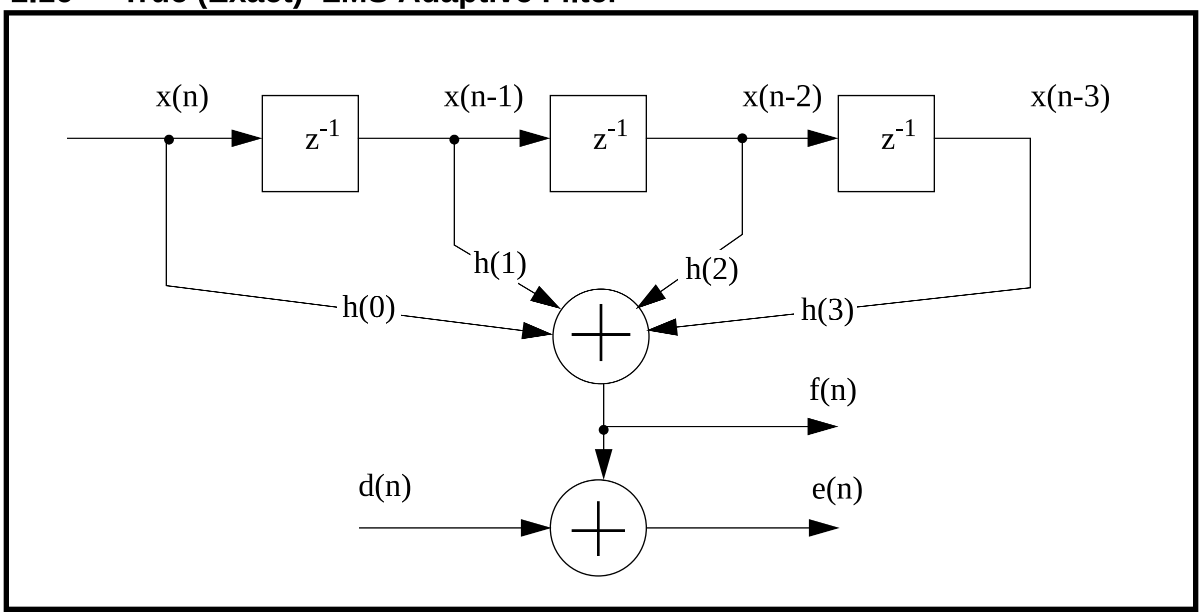
$$ar' = ar + cr \times br - ci \times bi \qquad br' = ar - cr \times br + ci \times bi = 2 \times ar - ar'$$
$$ai' = ai + ci \times br + cr \times bi \qquad bi' = ai - ci \times br - cr \times bi = 2 \times ai - ai'$$

Memory map:

pointer	X mem	Y mem
r0	ar(i)	ai(i)
r1	br(i)	bi(i)
r6	cr(i)	ci(i)
r4	ar’(i)	ai’(i)
r5	br’(i)	bi’(i)

					Prog wrds	Clock Cycles
	move	#AADDR,r0			;		
	move	#BADDR,r1			;		
	move	#CADDR,r6			;		
	move	#ATADDR,r4			;		
	move	#BTADDR-1,r5			;		
	move		x:(r1),x1	y:(r6),y0	;	1	1
	move		x:(r5),a	y:(r0),b		1	1
	do	#N,end			;	2	5
	mac	y0,x1,b	x:(r6)+n,x0	y:(r1)+,y1	;	1	1
	macr	x0,y1,b	a,x:(r5)+	y:(r0),a	;	1	1
	subl	b,a			;	1	1
	move		x:(r0),b	b,y:(r4)	;	1	1
	mac	x0,x1,b	x:(r0)+,a	a,y:(r5)	;	1	1
	macr	-y0,y1,b	x:(r1),x1	y:(r6),y0	;	1	1
	subl	b,a	b,x:(r4)+	y:(r0),b	;	1	2 i'lock
end							
	move		a,x:(r5)+		;	1	2 i'lock
					Totals	12	8N+9

C-2.16 True (Exact) LMS Adaptive Filter



Notation and symbols:

x(n)	-	Input sample at time n.
d(n)	-	Desired signal at time n.
f(n)	-	FIR filter output at time n.
H(n)	-	Filter coefficient vector at time n. H={h0,h1,h2,h3}
X(n)	-	Filter state variable vector at time N, X={x(n),x(n-1),x(n-2),x(n-3)}.
u	-	Adaptation gain.
NTAPS	-	Number of coefficient taps in the filter. For this example, ntaps=4.

System equations:

True LMS Algorithm	Delayed LMS Algorithm
e(n)=d(n)-H(n)X(n)	e(n)=d(n)-H(n)X(n)
H(n+1)=H(n)+uX(n)e(n)	H(n+1)=H(n)+uX(n-1)e(n-1)

LMS Algorithm:

True LMS Algorithm	Delayed LMS Algorithm
Get input sample	Get input sample
Save input sample	Save input sample
Do FIR	Do FIR
Get d(n), find e(n)	Update coefficients
Update coefficients	Get d(n), find e(n)
Output f(n)	Output f(n)
Shift vector X	Shift vector X

Memory map:

pointer	X mem	Y mem
r0	x(n), x(n-1), x(n-2), x(n-3)	
r4, r5		h(0), h(1), h(2), h(3)

```
                                                                Prog   Clock
                                                                wrds   Cycles
         move    #-2,n0                                 ;
         move    n0,n4
         move    #NTAPS-1,m0                            ;
         move    m0,m4                                  ;
         move    m0,m5                                  ;
         move    #AADDR+NTAPS-1,r0                      ;
         move    #BADDR,r4                              ;
         move    r4,r5                                  ;
_getsmp
         movep   y:input,x0                  ;get input sample  1      1
         clr     a         x0,x:(r0)+   y:(r4)+,y0      ;save   1      1
                                                        ;X(n), get h0
         rep     #NTAPS-1                               ;do fir 1      5
                                                        ;do taps
         mac     x0,y0,b   x:(r0)+,x0   y:(r4)+,y0      ;       1      1
                                                        ;last tap
         macr    x0,y0,b                                ;       1      1
;Get d(n), subtract fir output, multiply by "u",
;put the result in y1.
;This section is application dependent.
         move    x:(r0)+,x0  y:(r4)+,a                          1      1
         movep   b,y:output  ;output fir if desired             1      1
         move                y:(r4)+,b                          1      1
         do      #NTAPS/2,cup                           ;       2      5
         macr    x0,x1,a   x:(r0)+,x0   y:(r4)+,y0      ;       1      1
         macr    x0,x1,b   x:(r0)+,x0   y:(r4)+,y1      ;       1      1
         tfr     y0,a                   a,y:(r5)+               1      1
         tfr     y0,b                   b,y:(r5)+               1      1
cup
         move              x:(r0)+n0,x0 y:(r4)+n4,y0    ;       1      1
;continue looping (jmp _getsmp)
                                                        Total   15     3N+16
```

C-2.17 Delayed LMS Adaptive Filter

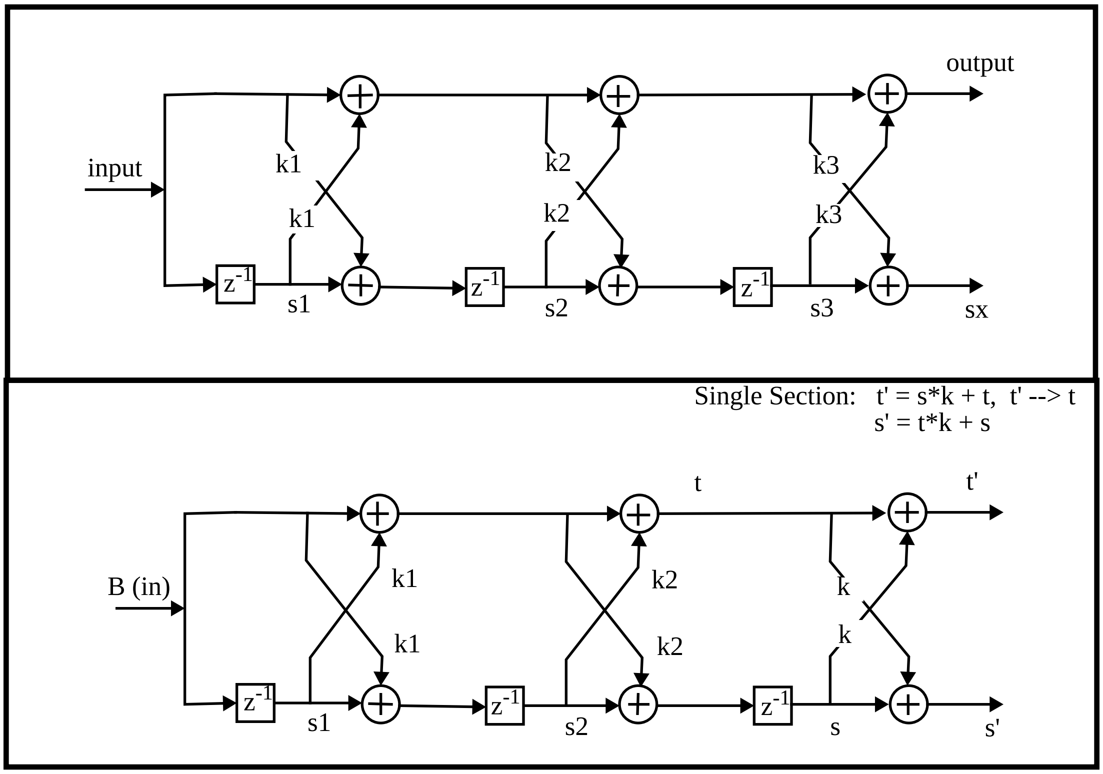
- error signal is in y1
- FIR sum in a = a + h(k)old*x(n-k)
- h(k)new in b = h(k)old + error*x(n-k-1)

Memory map:

pointer	X mem	Y mem
r0	x(n), x(n-1), x(n-2), x(n-3), x(n-4)	
r5, r4		dummy, h(0), h(1), h(2), h(3)

```
                                                          Prog  Clock
                                                          wrds  Cycles
      move    #STATE,r0                  ;start of X
      move    #2,n0                      ;used for pointer update
      move    #NTAPS,m0                  ;number of filter taps
      move    #COEF+1,r4                 ;start of H
      move    m0,m4                      ;number of filter taps
      move    #COEF,r5                   ;start of H-1
      move    m4,m5                      ;number of filter taps
      movep   y:input,a                  ;get input sample        1     1
      move    a,x:(r0)                   ;save input sample       1     1
      clr     a            x:(r0)+,x0    ;x0<-x(n)                1     1
      move                 x:(r0)+,x1    y:(r4)+,y0               1     1
                                         ;x1<-x(n-1); y0<-h(0)
      do      #TAPS/2,lms                          ;              2     5
      ;a<-h(0)*x(n) b<-h(0) Y<-dummy
      mac     x0,y0,a      y0,b          b,y:(r5)+                1     2 i'lock
      ;b<-H(0)=h(0)+e*x(n-1), x0<-x(n-2), y0<-h(1)
      macr    x1,y1,b      x:(r0)+,x0    y:(r4)+,y0    ;          1     1
      ;a<-a+h(1)*x(n-1); b<-h(1); Y(0)<-H(0)
      mac     x1,y0,a      y0,b          b,y:(r5)+     ;          1     2 i'lock
      ;b<-H(1)=h(1)+e*x(n-2); x1<-x(n-3); y0<-h(2)
      macr    x0,y1,b      x:(r0)+,x1    y:(r4)+,y0    ;          1     1
lms
      movep   a,y:output                                          1     1
      move    b,y:(r5)+                  ;Y<-last coef            1     1
      move    (r0)-n0                    ;update pointer          1     1
                                                   Totals         13    3N+12
```

C-2.18 FIR Lattice Filter

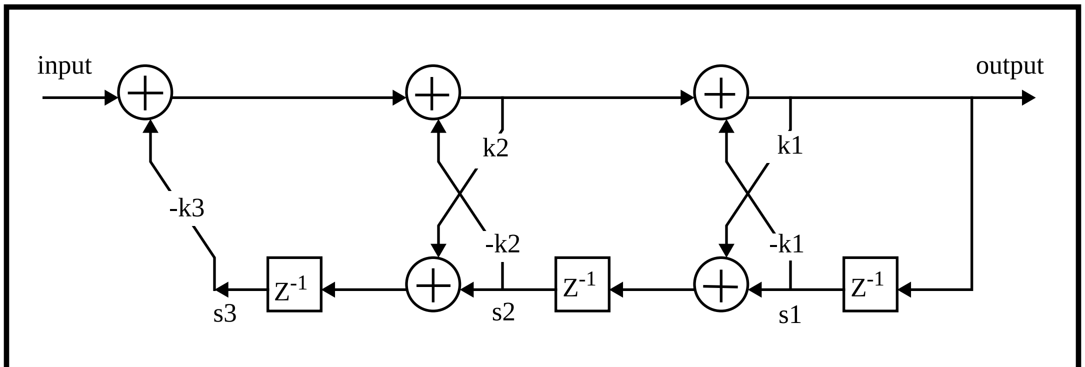


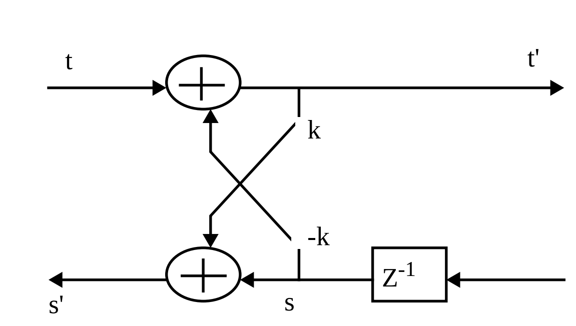
Memory map:

pointer	X mem	Y mem
r0	s1, s2, s3, sx	
r4		k1, k2, k3

```
                                                                      Prog  Clock
                                                                      wrds  cycles
        move    #S,r0                         ;point to s
        move    #N,m0                         ;N=number of k coefficients
        move    #K,r4                         ;point to k coefficients
        move     #N-1,m4                      ;mod for k's
        movep   y:datin,b                     ;get input                  1     1
        move     b,a                          ;save first state           1     1
        move                x:(r0),x0  y:(r4)+,y0  ;get s, get k          1     1
        do      #N,_elat                           ;                      2     5
        macr    x0,y0,b                b,y1        ;s*k+t,copy t for mul  1     1
        tfr     x0,a        a,x:(r0)+              ;save s', copy next s  1     1
        macr    y1,y0,a     x:(r0),x0  y:(r4)+,y0  ;t*k+s, get s, get k   1     1
_elat
        move                a,x:(r0)+   y:(r4)-,y0 ;adj r4,dummy load     1     1
        movep   b,y:datout                         ;output sample         1     1
                                                   Totals                 10    3N+10
```

C-2.19 All Pole IIR Lattice Filter





Single section:

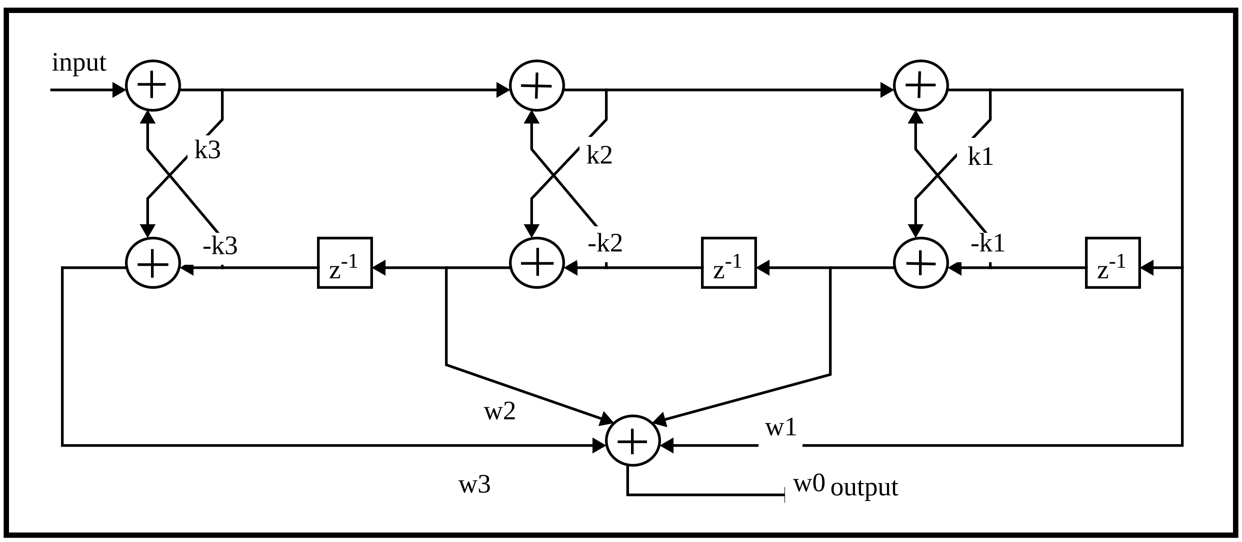
```
t' = t - k*s
s' = s + k*t'
t' --> t
```

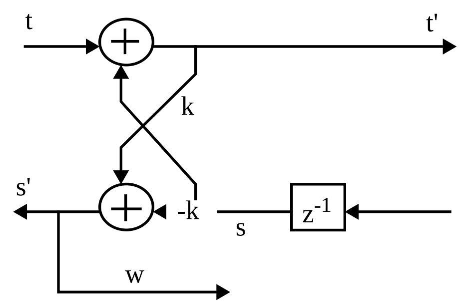
Memory map:

pointer	X mem	Y mem
r0	k3, k2, k1	
r4		s3, s2, s1

```
                                                                  Prog   Clock
                                                                  wrds   Cycles
        move    #k+N-1,r0                         ;point to k
        move    #N-1,m0                           ;number of k's-1
        move    #STATE,r4               ;point to filter states
        move    m0,m4                             ;mod for states
        move    #1,n4                             ;
        movep   y:datin,a               y:(r4)+,b ;get input          1      1
        move              x:(r0)-,x0    y:(r4)+,y0 ;get s, get k      1      1
        macr    -x0,y0,a  x:(r0)-,x0    y:(r4),y0  ;s*k+t             1      1
        do      #N-1,_endlat                       ;do sections       2      5
        macr    -x0,y0,a                y:(r4)+,y1 ;                  1      1
        tfr     y1,b      a,x1          b,y:(r4)   ;                  1      2 i'lock
        macr    x1,x0,b   x:(r0)-,x0    y:(r4),y0                     1      1
_endlat
        movep   a,y:datout                                            1      1
        move              x:(r0)+,x0    y:(r4)+,r0 ;output sample     1      1
        move    b,y:(r4)+                          ;save s'           1      1
;save last s', update r4
        move              a,y:(r4)                                    1      1
                                                   Totals             12     4N+8
```

C-2.20 General Lattice Filter





Single section:

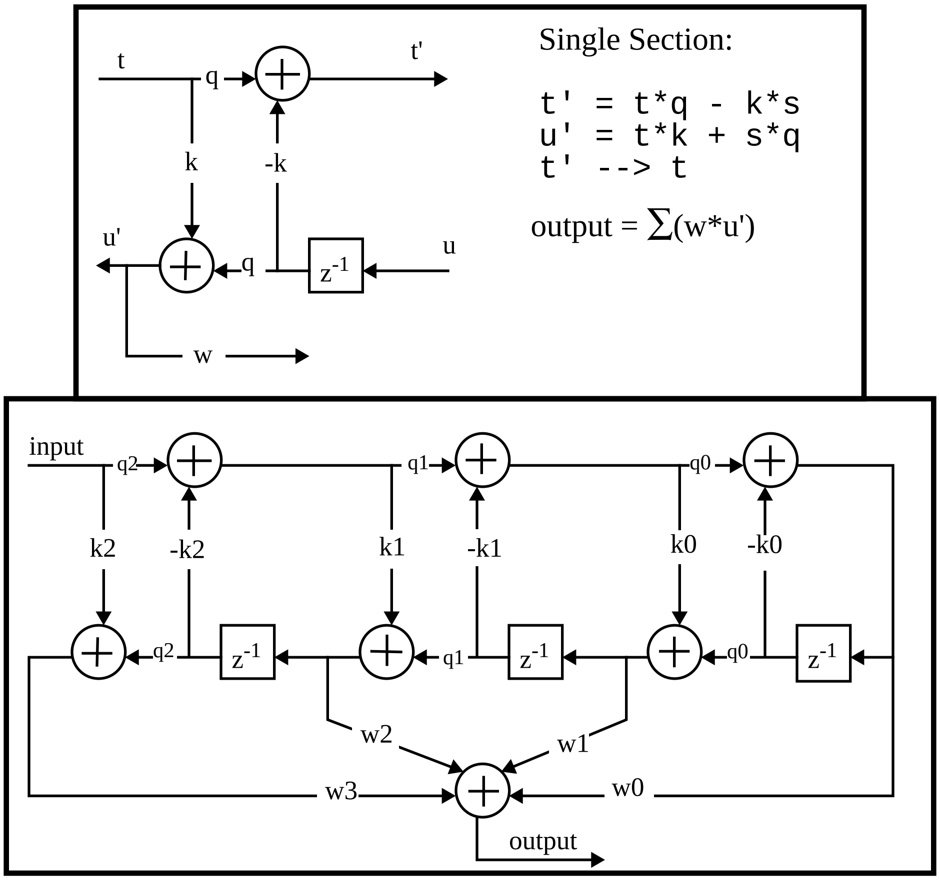
$t' = t - k*s$
$s' = s + k*t'$
$t' \rightarrow t$
$output = \sum(w*s')$

Memory map:

pointer	X mem	Y mem
r0	k3, k2, k1, w3, w2, w1, w0	
r4		s4, s3, s2, s1

```
                                                                        Prog   Clock
                                                                        wrds   Cycles
        move     #K,r0                          ;point to coefficients
        move    #2*N,m0                         ;mod 2*(# of k's)+1
        move    #STATE,r4                       ;point to filter states
        move    #-2,n4
        move    #N,m4                           ;mod on filter states
        movep   y:datin,a                       ;get input                   1      1
        move                 x:(r0)+,x0  y:(r4)-,y0                          1      1
        do      #N,_endlat                                                   2      5
        macr     -x0,y0,a                                    ;               1      1
        tfr     y0,b         a,x1        b,y:(r4)+n4         ;               1      2 i'lock
        macr    x1,x0,b      x:(r0)+,x0  y:(r4)-,y0          ;               1      1
_endlat
        move                             b,y:(r4)+           ;save s'        1      2 i'lock
        clr     a                        a,y:(r4)+           ;save last s', update r4   1   1
        move                             y:(r4)+,y0                          1      1
        rep     #N                                           ;               1      5
        mac     x0,y0,a      x:(r0)+,x0  y:(r4)+,y0          ;s*w+out, get s, get w   1   1
        macr    x0,y0,a                                      ;last mac       1      1
        movep   a,y:datout                                   ;output sample  1      2 i'lock
                                                             Totals          14     5N+19
```

C-2.21 Normalized Lattice Filter



Memory map:

pointer	X mem	Y mem
r0	q2, k2, q1, k1, q0, k0, w3, w2, w1, w0	
r4		sx, s2, s1, s0

```
                                                            Prog  Clock
                                                            wrds  Cycles
    move    #COEF,r0                          ;point to coefficients
    move    #3*N,m0                           ;mod on coefficients
    move    #STATE+1,r4                       ;point to state variables
    move    #N,m4                             ;mod on filter states
    movep   y:datin,y0                        ;get input sample    1     1
    move               x:(r0)+,x1             ;get q in the table  1     1
    do      #N,_elat                                               2     5
    mpy     x1,y0,a    x:(r0)+,x0  y:(r4),y1  ;q*t,get k,get s     1     1
    macr    -x0,y1,a               b,y:(r4)+  ;q*t-k*s,save new s  1     1
```

	mpy	x0,y0,b			;k*t	1	1
	macr	x1,y1,b	x:(r0)+,x1	a,y0	;k*t+q*s,get next q,set t'	1	1
_elat							
	move	b,y:(r4)+			;save second last state	1	2 i'lock
	move	a,y:(r4)+			;save last state	1	1
	clr	a		y:(r4)+,y0	;clear a, get first state	1	1
	rep	#N				1	5
	mac	x1,y0,a	x:(r0)+,x1	y:(r4)+,y0	;fir taps	1	1
	macr	x1,y0,a	(r4)+		; round, adj pointer	1	1
	movep	a,y:datout			;output sample	1	2 i'lock
					Total	15	5N+19

C-2.22 [1x3][3x3] Matrix Multiplication

						Prog wrds	Clock Cycles
_init							
	move	#MAT_A,r0			;point to A matrix		
	move	#MAT_B,r4			;point to B matrix		
	move	#MAT_X,r1			;output X matrix		
	move	#2,m0			;mod 3		
	move	#8,m4			;mod 9		
	move	m0,m1			;mod 3		
_start							
	move	x:(r0)+,x0	y:(r4)+,y0			1	1
	mpy	x0,y0,a	x:(r0)+,x0	y:(r4)+,y0		1	1
	mac	x0,y0,a	x:(r0)+,x0	y:(r4)+,y0		1	1
	macr	x0,y0,a	x:(r0)+,x0	y:(r4)+,y0		1	1
	mpy	x0,y0,b	x:(r0)+,x0	y:(r4)+,y0		1	1
	move			a,y:(r1)+		1	1
	mac	x0,y0,b	x:(r0)+,x0	y:(r4)+,y0		1	1
	macr	x0,y0,b	x:(r0)+,x0	y:(r4)+,y0		1	1
	mpy	x0,y0,a	x:(r0)+,x0	y:(r4)+,y0		1	1
	move			b,y:(r1)+		1	1
	mac	x0,y0,a	x:(r0)+,x0	y:(r4)+,y0		1	1
	macr	x0,y0,a				1	1
	move			a,y:(r1)+		1	2 i’lock
_end							
					Totals	13	14

C-2.23 N Point 3x3 2-D FIR Convolution

The two dimensional FIR uses a [3x3] coefficient mask:

c(1,1) c(1,2) c(1,3)

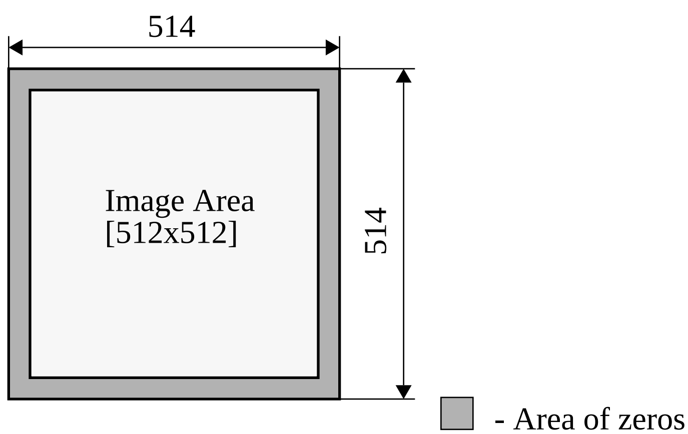
c(2,1) c(2,2) c(2,3)

c(3,1) c(3,2) c(3,3)

stored in Y memory in the order:

c(1,1), c(1,2), c(1,3), c(2,1), c(2,2), c(2,3), c(3,1), c(3,2), c(3,3).

The image is an array of 512x512 pixels. To provide boundary conditions for the FIR filtering, the image is surrounded by a set of zeros such that the image is actually stored as a 514x514 array. i.e.



The image (with boundary) is stored in row major storage. The first element of the array image(,) is image(1,1) followed by image(1,2). The last element of the first row is image(1,514) followed by the beginning of the next column image(2,1). These are stored sequentially in the array "im" in X memory:

Image(1,1) maps to index 0, image(1,514) maps to index 513;

Image(2,1) maps to index 514 (row major storage).

Although many other implementations are possible, this is a realistic type of image environment where the actual size of the image may not be an exact power of 2. Other possibilities include storing a 512x512 image but computing only a 511x511 result, computing a 512x512 result without boundary conditions but throwing away the pixels on the border, etc.

Memory map:

r0	-->	image(n,m)
		image(n,m+1)
		image(n,m+2)

r1	-->	image(n+514,m) image(n+514,m+1) image(n+514,m+2)
r2	-->	image(n+2*514,m) image(n+2*514,m+2) image(n+2*514,m+3)
r4	-->	FIR coefficients
r5	-->	output image

```
                                                                         Prog   Clock
                                                                         wrds   Cycles
        move    #MASK,r4                                ;point to coeffi-
                                                        cients
        move    #8,m4                                   ;mod 9
        move    #IMAGE,r0                               ;top boundary
        move    #IMAGE+514,r1                           ;left of first pixel
;left of first pixel 2nd row
        move    #IMAGE+2*514,r2                         ;
;adjust. for end of row
        move    #2,n1                                   ;
        move    n1,n2                                   ;
        move    #IMAGEOUT,r5                            ;output image
;first element, c(1,1)
        move                    x:(r0)+,x0  y:(r4)+,y0  ;               1      1
        do      #512,row                                ;               2      5
        do      #512,col                                ;               2      5
        mpy     x0,y0,a         x:(r0)+,x0  y:(r4)+,y0  ;c(1,2)         1      1
        mac     x0,y0,a         x:(r0)-,x0  y:(r4)+,y0  ;c(1,3)         1      1
        mac     x0,y0,a         x:(r1)+,x0  y:(r4)+,y0  ;c(2,1)         1      1
        mac     x0,y0,a         x:(r1)+,x0  y:(r4)+,y0  ;c(2,2)         1      1
        mac     x0,y0,a         x:(r1)-,x0  y:(r4)+,y0  ;c(2,3)         1      1
        mac     x0,y0,a         x:(r2)+,x0  y:(r4)+,y0  ;c(3,1)         1      1
        mac     x0,y0,a         x:(r2)+,x0  y:(r4)+,y0  ;c(3,2)         1      1
        mac     x0,y0,a         x:(r2)-,x0  y:(r4)+,y0  ;c(3,3)         1      1
;preload, get c(1,1)
        macr    x0,y0,a         x:(r0)+,x0  y:(r4)+,y0  ;               1      1
;output image sample
        move                                a,y:(r5)+   ;               1      2 i'lock
col
; adjust pointers for frame boundary
;adj r0,r5 w/dummy loads
```

move	x:(r0)+,x0	y:(r5)+,y1	;	1	1
;adj r1,r5 w/dummy loads					
move	x:(r1)+n1,x0	y:(r5)+,y1	;	1	1
;adj r2 (dummy load y1), preload x0 for next pass					
move	x:(r0)+,x0		;	1	1
move		y:(r2)+n2,y1	;	1	1
row					
		Total	19 (prog. words)	$11N^2+8N+7$ (clock cycles)	

C-2.24 Parsing data stream

This routine implements parsing of data stream for MPEG audio.
The data stream, composed by concatenated words of variable length, is allocated in consecutive memory words. The words lengths reside in another memory buffer.
The routine extracts words from data stream according to their length.
Two consecutive words are read from the stream buffer and are concatenated in the accumulator. Using bit offset and the specified length, a field of variable length can be extracted. The decision whether to load a new memory word into the accumulator from the stream is determined when bit offset overflow to the LSP of the accumulator.

The following describes the pointers and registers used by the routine:

- r0 - pointer to the buffer in X memory containing the variable length stream.
- r5 - pointer to buffer in Y memory where the length of each field is stored.
- r4 - pointer to a location that stores the "bits offset", number of bits left to be consumed. 48 initially.
- r3 - pointer to a location storing the constant 24.
- r1 - used as temporary storage (no need to initialize).
- y1 - stores the length of the field to be extracted.
- x0 - stores 24.

Memory map:

pointer	X mem	Y mem
r0	stream buffer	
r5		length buffer
r4		"bits offset"
r3	‘24‘	

```
init_              ;this is the initialization code
          move     #stream_buffer,r0
          move     #length_buffer,r5
          move     #bits_offset,r4
          move     #boundary,r3
          move     #>48,b
          move     #>24,x0
          move                    x0,x:(r3)       b,y:(r4)

                                                                    Prog    Clock
                                                                    wrds    Cycles
Get_bits
                   ;bring length of next field and '24'
          move                    x:(r3),x0       y:(r5)+,y1        1       1
                   ;bring word for parsing and "bits offset"
          move                    x:(r0)+,a       y:(r4),b          1       1
                   ;bring next word for parsing, point back to first word
          move                    x:(r0)-,a0                        1       1
                   ;calculate new "bits offset", r1 points to current word
          sub      y1,b           r0,r1                             1       1
                   ;save "bits offset" in x1
          move     b,x1                                             1       2
                   ;merge width and offset
          merge    y1,b                                             1       1
                   ;extract the field according to b, place it in a
          extract  b1,a,a                                           1       1
                   ;restore "bits offset", r0 points to next word
          tfr      x1,b           (r0)+                             1       1
                   ;compare "bits offset" to 24, extracted word to a1
          cmp      x0,b           a0,a                              1       1
                   ;if "bits offset" is less or equal 24 another word is
                   needed - update "bits offset" and point to next word
          add      x0,b           ifle                              1       1
          tgt                     r1,r0                             1       1
                   ;save "bits field" in memory
          move                    b1,y:(r4)                         1       1
                                                        Totals      12      13
```

C-2.25 Creating data stream

This routine implements creation of data stream for MPEG audio.
Words of variable length are concatenated and stored in consecutive memory words.
The words for generating the stream are allocated in a memory buffer, and are aligned to

the right. The words lengths reside in another memory buffer.
The word and its length are loaded for insertion. A word is read from the stream buffer into the accumulator. Using a bit offset and the specified length, a field of variable length is inserted into the accumulator. The accumulator is stored back containing the new concatenated field. The decision whether to read a new word from the stream is determined when bit offset overflow to the LSP of the accumulator.

The following describes the pointers and registers used by the routine:

- r0 - pointer to a buffer in X memory, containing the variable length codes. The code is right aligned at each location.
- r2 - pointer to a buffer in X memory containing the stream generated.
- r4 - pointer to a buffer in Y memory where the actual length of each field is stored.
- r3 - pointer to a location that stores the "bits offset", number of bits left to be consumed. 48 initially.
- r5 - pointer to a location storing the constant 24.
- r1 - used as temporary storage (no need to initialize).
- x0 - stores the current word to be inserted
- y1 - stores the length of the code brought in x0.
- y0 - stores 24.

Memory map:

pointer	X mem	Y mem
r0	data buffer	
r2	stream buffer	
r4		length buffer
r3		"bits offset"
r5		24

```
init_                  ;this is the initialization code
         move     #data_buffer,r0
```

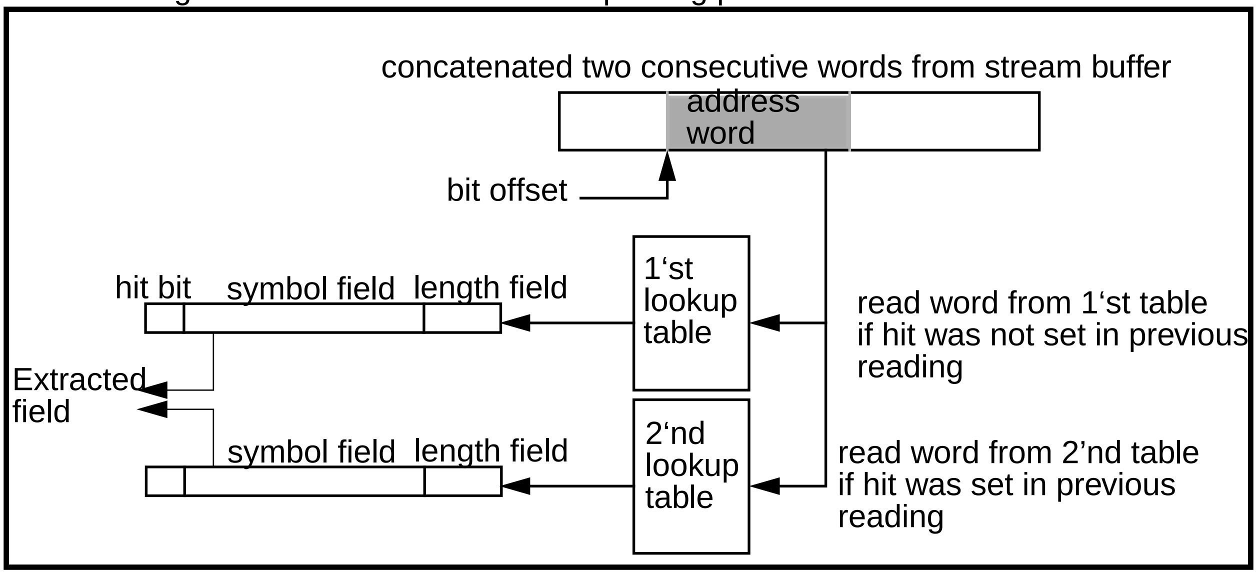
```
        move    #stream_buffer,r2
        move    #length_buffer,r4
        move    #bits_offset,r3
        move    #boundary,r5
        move    #>48,b
        move    #>24,y0
        move                b,x:(r3)     y0,y:(r5)
```

					Prog wrds	Clock Cycles
Put_bits						
		;bring code and its length				
	move		x:(r0)+,x0	y:(r4)+,y1	1	1
		;bring "bits offset" and ‘24‘				
	move		x:(r3),b	y:(r5),y0	1	1
		;calculate new "bits offset", bring current word from stream buffer				
	sub	y1,b	x:(r2),a		1	1
		;save "bits offset" in x1				
	move	b,x1			1	2
		;merge width and offset				
	merge	y1,b			1	1
		;insert the field according to b, place it in a				
	insert	b1,x0,a			1	1
		;restore "bits offset", r1 points to current word				
	tfr	x1,b	r2,r1		1	1
		;compare "bits offset " to 24, send new word to stream buffer				
	cmp	y0,b	a1,x:(r2)+		1	1
		;send a0 to next location in stream buffer in case of crossing boundary				
	move		a0,x:(r2)		1	2
		;if "bits offset" is less or equal 24 then update "bits offset " and point to the next word in stream buffer				
	add	y0,b	ifle		1	1
	tgt		r1,r2		1	1
		;save "bits offset" in memory				
	move		b1,y:(r4)		1	1
				Totals	12	14

C-2.26 Parsing Hoffman code data stream

This routine implements the parsing of Hoffman code data stream.

The routine extracts a bit field from the stream. Two consecutive words are brought to the accumulator from the stream buffer. An address word is extracted using a bit offset and a field length. The field length is determined by the number of bits needed by the address of the two Hoffman code lookup tables. A word is loaded from the first lookup table. If the hit bit in the word is not set then a field of variable length is extracted. The length of the extracted field is specified in the length field in the word. The bit offset is updated according to the length of the extracted word.
If the hit bit in the word is set then a new address word is read from the stream. A word is brought from the second lookup table. The bit field is extracted according to the same guidelines.
The following flow chart demonstrates the parsing process:



Thek following describes the pointers and registers used by the routine:

- r0 - pointer to the buffer in X memory containing the stream.
- r1 - used as temporary storage (no need to initialize).
- r3 - pointer to buffer in Y memory where the extracted fields are stored.
- r5 - pointer to a location that stores the "bits offset", number of bits left to be consumed. 48 initially.
- r2 - pointer to the right table.
- r6 - pointer to the first lookup table.
- r7 - pointer to the second lookup table.
- r4 - pointer to constants.

Memory map:

pointer	X mem	Y mem
r0	stream buffer	
r3	extracted data buffer	

pointer	X mem	Y mem
r5		"bits offset"
r4		#no.1 address bus length
		#no.2 mask word for length field
		#no.3 merged width and offset
		‘24‘
r6	first lookup table	
r7	second lookup table	

```
init_                   ;this is the initialization code
            move        #stream_buffer,r0
            move        #data_buffer,r3
            move        #bits_offset,r5
            move        #constants,r4
            move        #first_table,r2
            move        #first_table,r6
            move        #second_table,r7
                        ;move constants to memory
            move        #>48,b
            move        b,y:(r5)
            move        #>3,n4
            move        #n0_1,y1
            move        y1,y:(r4)+
            move        #n0_2,y1
            move        y1,y:(r4)+
            move        #n0_3,y1
            move        y1,y:(r4)+
            move        #>24,y1
            move        y1,y:(r4)-n4


                                                                  Prog     Clock
                                                                  wrds     Cycles
Get_bits
                        ;bring word from stream, and "bits-offset"
            move                       x:(r0)+,a      y:(r5)+,b   1        1
                        ;bring next word from stream, and address length
            move                                      y:(r4)+,y0  1        1
```

```
move                     x:(r0)-,a0                    1     1
        ;calculate new "bits offset", and save old one in x1
sub     y0,b             b,x1                          1     1
        ;merge width and offset
merge   y0,b                                           1     1
        ;extract the field according to b, place it in a
extract b1,a,a                                         1     1
        ;move address to n2
move                     a0,n2                         1     1
        ;bring mask for length field in tookup table words
move                     y:(r4)+,y1                    1     1
        ;bring the merged offset and length for extactionf
move                     y:(r4)+,x0                    1     1
        ;r1 points to current address for extracted field
move                     r3,r1                         1     1
        ;bring word from lookup table
move                     x:(r2+n2),a                   1     1
        ;extract the field according to x0, place it in b
extract x0,a,b                                         1     1
        ;test if hit bit is set, r2 points s first lookup table
tst     a                r6,r2                         1     1
        ; if hit bit is set, r2 points second lookup table, a holds
        address length
tmi     y0,a             r7,r2                         1     1
        ;restore "bit offset" , send extracted field to memory
tfr     x1,b             b0,x:(r3)+                    1     1
        ; if hit bit is set, restore r3
tmi                      r1,r3                         1     1
        ;mask length field , save pointer to current stream
        word
and     y1,a             r0,r1                         1     1
        ;calculate new "bits offset", y1 holds ’24’
sub     a,b              y:(r4)-n4,y1                  1     1
        ;compare "bits offset " to 24, update steam pointer
cmp     y1,b             (r0)+                         1     1
        ;if "bits offset" is less or equal 24 another word is
        needed - update "bits offset " and point to next word
add     y1,b             ifle                          1     1
tgt                      r1,r0                         1     1
        ;save "bits field" in memory
move                     b1,y:(r5)                     1     1
                                            Totals     22    22
```

C-3 BENCHMARK OVERVIEW

Benchmark	Program Length in Words	Program Length in Clock Cycles	Sample Rate or Execution Time for 50MHz Clock Cycle	Sample Rate or Execution Time for 60MHz Clock Cycle
Real Multiply on page 3	3	4	80 ns	67 ns
N Real Multiplies on page 3	7	2N+8	40N+160ns	33.3N+133 ns
Real Update on page 4	4	5	100 ns	83 ns
N Real Updates on page 4	9	2N+8	40N+160 ns	33.3N+133.6ns
Real Correlation Or Convolution (FIR Filter) on page 5	6	N+14	50/(N+14) MHz	60/(N+14) MHz
Real * Complex Correlation Or Convolution (FIR Filter) on page 7	9	2N+10	25/(N+5) MHz	30/(N+5) MHz
Complex Multiply on page 7	6	7	140 ns	117 ns
N Complex Multiplies on page 8	9	5N+9	80N+180 ns	66.7N+150.3ns
Complex Update on page 9	7	8	160 ns	133 ns
N Complex Updates on page 10	9	4N+9	80N+180 ns	66.7N+150.3ns
Complex Correlation Or Convolution (FIR Filter) on page 11	16	4N+13	25/(2N+5.5) MHz	30/(2N+5.5) MHz
Nth Order Power Series (Real) on page 12	10	2N+11	40N+220 ns	33.3N+183.7ns
2nd Order Real Biquad IIR Filter on page 13	7	9	180 ns	150.3 ns
N Cascaded Real Biquad IIR Filter on page 14	10	5N+10	10/(N+2) MHz	12/(N+2) MHz
N Radix-2 FFT Butterflies (DIT, in-place algorithm) on page 15	12	8N+9	160N+180 ns	133.6N+150.3 ns
True (Exact) LMS Adaptive Filter on page 16	15	3N+16	50/(3N+17) MHz	60/(3N+17) MHz
Delayed LMS Adaptive Filter on page 18	13	3N+12	50/(3N+12) MHz	60/(3N+12) MHz

Benchmark	Program Length in Words	Program Length in Clock Cycles	Sample Rate or Execution Time for 50MHz Clock Cycle	Sample Rate or Execution Time for 60MHz Clock Cycle
FIR Lattice Filter on page 20	10	3N+10	50/(3N+10) MHz	60/(3N+10) MHz
All Pole IIR Lattice Filter on page 21	12	4N+8	25/(2N+4) MHz	30/(2N+4) MHz
General Lattice Filter on page 22	14	5N+19	50/(5N+19) MHz	60/(5N+19) MHz
Normalized Lattice Filter on page 24	15	5N+19	50/(5N+19) MHz	60/(5N+19) MHz
[1x3][3x3] Matrix Multiplication on page 25	13	14	280 ns	233.8 ns
N Point 3x3 2-D FIR Convolution on page 25	19	$11N^2+8N+7$	$50/(11N^2+8N+7)$ MHz	$60/(11N^2+8N+7)$ MHz