Using MMX™ Instructions to Implement a Modem Baseband Canceler

Information for Developers and ISVs

From Intel® Developer Services
www.intel.com/IDS

March 1996

Information in this document is provided in connection with Intel® products. No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted by this document. Except as provided in Intel's Terms and Conditions of Sale for such products, Intel assumes no liability whatsoever, and Intel disclaims any express or implied warranty, relating to sale and/or use of Intel products including liability or warranties relating to fitness for a particular purpose, merchantability, or infringement of any patent, copyright or other intellectual property right. Intel products are not intended for use in medical, life saving, or life sustaining applications. Intel may make changes to specifications and product descriptions at any time, without notice.

Note: Please be aware that the software programming article below is posted as a public service and may no longer be supported by Intel.

Copyright © Intel Corporation 2004
* Other names and brands may be claimed as the property of others.
CONTENTS

1.0. INTRODUCTION
2.0. OVERVIEW
3.0. MMX TECHNOLOGY BASEBAND ECHO CANCELER IMPLEMENTATION
   3.1. The Complex FIR
   3.2. Calculation of New Received Signal
   3.3. Adaptation of Filter Coefficients
4.0. POSSIBLE IMPROVEMENTS FOR THE MMX™ TECHNOLOGY VERSION
1.0. INTRODUCTION

The media extension to the Intel Architecture (IA) instruction set includes single instruction, multi-data (SIMD) instructions. This application note presents an implementation of a common modem algorithm that takes advantage of these new instructions. Specifically, the baseband echo canceler function, \texttt{ecmmx}, demonstrates how the \texttt{PMADDWD} instruction can be used to perform complex FIR calculations efficiently and how use of the \texttt{PUNPCKL} and \texttt{PUNPCKH} instructions allow the adaptation of several filter coefficients at a time within a single loop.

2.0. OVERVIEW

There are two sources of echo in a modem. The near end (NE) echo signal is a combination of the reflection of the transmitted signal due to the impedance mismatches of the lines at the hybrid transformer on the modem board and the mismatches at the Public Switch Telephone Network (PSTN). The far end echo signal is a combination of the reflection of the transmitted signal due to impedance mismatches of the lines at the far end hybrid transformer on the receiving modem board and the mismatches at the far end of the PSTN (Figure 1). The near end echo has a much larger amplitude than the far end echo. The algorithm is the same for both the near end and far end echo cancelers. The difference is in the amount of delay in the buffer that holds the transmitted data used in the filter calculation, the delay is longer for the far end.

![Figure 1. Source of Echo in a Modem](image)

The baseband echo canceler is an adaptive filter that effectively cancels out the near and far end echoes allowing the transmitted signal from the remote modem to arrive more cleanly at the receiver. The echo canceler can adapt because it knows the characteristics of its transmitted signal which appears in the echoes and can therefore subtract it out from the combined signal made up of the received signal and the echoes.
3.0. MMX TECHNOLOGY BASEBAND ECHO CANCELER IMPLEMENTATION

The MMX technology version of the baseband echo canceler consists of four parts:

1. The imaginary and real filter output is calculated for each sample.
2. The output of the filter is subtracted off the complex received signal and stored as the clean received signal and used as the complex error signal for the adaptation.
3. The real coefficients are adapted for the given filter.
4. The imaginary coefficients are adapted for the given filter.

Figure 2. Basic Block of Echo Canceler Algorithm

Figure 2 shows the core operation performed by the code presented in this paper. The code loops three times to process each received baud that arrives at the modem because each baud is represented by three complex samples stored in the $x_I$ and $x_Q$ arrays. As a result, there are three pairs of complex filters that need to be calculated in the MMX technology version of the baseband echo canceler.

The data and received signal arrays, $txdata_I$, $txdata_Q$, $x_I$, and $x_Q$, are all 16-bit signed fixed point fractions. The coefficients, $h_I$ and $h_Q$, are represented as 32-bit signed fixed point fractions but are stored as two 16-bit value arrays, $h_{IH}$ and $h_{IL}$ for the real coefficients and $h_{QH}$ and $h_{QL}$ for the imaginary coefficients. This is done because the higher 16 bits of the coefficients are used in the filter calculation while all 32 bits are used in the adaptation of the coefficients. These coefficients start out initialized as 0. The 'I' notation on the array names indicates the real part of the complex value and the 'Q' notation indicates the imaginary part. The $h_I$ arrays are stored in memory as $[h_{IH0} h_{IH1} h_{IH2}]$ and $[h_{IL0} h_{IL1} h_{IL2}]$ where each of the subscripts denotes one of the three complex filters while the $h_Q$ arrays are stored as $[h_{QH0} h_{QH1} h_{QH2}]$ and $[h_{QL0} h_{QL1} h_{QL2}]$. Each filter is the same length which must be a multiple of 8 in this implementation.

3.1. The Complex FIR

The formula used to calculate the complex FIR output is as follows:

$$ y[k] = \sum txdata[n] h[n-k] \text{ for } n = 0 \text{ to length of the filters} $$

where $txdata$ is the transmitted data and $h$ are the filter coefficients.
The formula for the calculation of the real output and imaginary output were derived as follows:

\[ y_I[k] + i \cdot y_Q[k] = S \left[(txdata_I[n] + itxdata_Q[n]) \cdot (h_I[nk] + ih_Q[nk])\right] \]

**Real filter output:**

\[ y_I[k] = S \left[(txdata_I[n] \cdot h_I[nk]) \cdot (txdata_Q[n] \cdot h_Q[nk])\right] \]

**Imaginary filter output:**

\[ y_Q[k] = S \left[(txdata_Q[n] \cdot h_I[nk] + (txdata_I[n] \cdot h_Q[nk]))\right] \]

By using the `PMADDWD` instruction the filter loop can be performed quite efficiently. In each loop iteration it is possible to calculate two of the multiply/add and subtract operations for the real filter output calculation and two multiply and add operations for the imaginary filter output calculations. Only the high order 16-bits of the coefficients are used in this calculation. The following figure shows how the filter is performed. Register MM0 is used as the accumulator for the real filter output while MM1 is used for the imaginary filter output.

**Figure 3. Register Usage in a Filter Calculation**

There are a few initial conditions set before the complex FIR loop is entered. Register MM4 is preloaded with the first four values in the `txdata_I` array and the accumulator registers are cleared. These instructions are done so that the loop of the FIR filter can be paired efficiently. As a result of this instruction reordering, after the loop is complete MM5 and MM6 must be subtracted from MM0 and added to MM1 respectively.
Using MMX™ Instructions to Implement a Modem Baseband Canceler
March 1996

Example 1. FIR Calculation

; Complex FIR Loop
FIRLoop:
    pmaddwd mm4, [ecx+edi] ; Compute txdataI*hIH value
    psubd mm0, mm5 ; Accumulate real filter sum
    movq mm5, [ebx+edi] ; Read in txdataQ values
    padd mm1, mm6 ; Accumulate imag. filter sum
    pmaddwd mm7, [edx+edi] ; Compute txdataQ*hQH value
    movq mm6, mm5 ; Copy txdataQ value from mm5
    pmaddwd mm5, [edx+edi] ; Compute txdataQ*hQH value
    padd mm0, mm4 ; Accumulate real filter sum
    movq mm4, [eax+edi+8] Load next set of txdataI to be used
    pmaddwd mm6, [ecx+edi] ; Compute txdataQ*hIH value
    padd mm1, mm7 ; Accumulate imag. filter sum
    movq mm7, mm4 ; Copy txdataI value from mm4
    add edi, 8 ; Increase data pointer by 8 bytes
    sub esi, 4 ; Decrement counter value
    jg FIRLoop ; If no more filter taps then done with loop

    psbdr mm0, mm5 ; Final accumulate for real filter
    padd mm1, mm6 ; Final accumulate for imag filter

; End of Loop for FIR

To get the final result of the real filter MM0 is then copied into MM2 and shifted right by 32 bits and added back to MM0. The imaginary result mm1 is copied to MM3 and shifted right by 32 bits and added back to MM1. These values are then scaled to 16-bit values so the new received signal can be calculated.

3.2. Calculation of New Received Signal

The values of the received data, both real and imaginary are then read into a register and the filtered echo signal is subtracted from them.

\[ x_{I_{new}} = x_{I_{received}} y_I \text{ where } y_I \text{ is the real filtered value} \]
\[ x_{Q_{new}} = x_{Q_{received}} y_Q \text{ where } y_Q \text{ is the imaginary filtered value} \]

These new \( x_I \) and \( x_Q \) are stored back into memory and are also used as the error signal used to adapt the coefficients of the filters (see Figure 2).

3.3. Adaptation of Filter Coefficients

The are two loops that take care of the filter coefficient adaptation. First, the real coefficients are adapted and then the imaginary coefficients are calculated in the second loop. This is done because the technique used did not leave enough MMX registers to accomplish both adaptations within one loop. The error signals were stored in the way they were see(see figure 4) so that for every loop iteration four coefficients could be adapted at a time. The following equations were used for adaptation:

\[ h_{new} = h_{old} + m e d^* \]

where \( m = \text{adaptation step size} \) (0.125 in this code), \( e = \text{error signal} \) (\( x_{I_{new}} \) and \( x_{Q_{new}} \) in this code), and \( d^* = \text{the conjugate of the transmitted data} \) (txdata in this code).

Expanding out the above equation provides the individual equations used in the adaptation loops.

\[ h_{I_{new}} + i h_{Q_{new}} = h_{I_{old}} + i h_{Q_{old}} + m (x_{I_{new}} + i x_{Q_{new}})(txdataI \text{ txdataQ}) \]
Using MMX™ Instructions to Implement a Modem Baseband Canceler

March 1996

\[ h_{\text{new}} = h_{\text{old}} + m \left( txdataI \times x_{\text{new}} \right) + \left( txdataQ \times x_{\text{Qnew}} \right) \]

\[ h_{\text{Qnew}} = h_{\text{Qold}} + m \left( txdataI \times x_{\text{Qnew}} \right) + \left( txdataQ \times x_{\text{new}} \right) \]

In the above equations notice that for the adaptation of the filter coefficients the error values, \( x_{\text{new}} \) and \( x_{\text{Qnew}} \), must be multiplied by each data value, \( txdataI \) or \( txdataQ \), associated with the coefficient being adapted. For example, to adapt the first coefficient \( h[0] \) (full 32-bit value) the error value \( x_{\text{new}} \) would be multiplied with \( txdataI[0] \) and value \( x_{\text{Qnew}} \) would be multiplied with \( txdataQ[0] \) and they would be added together. By storing the complex error signals interleaved with zeroes, multiple adaptation of coefficients can occur in the adaptation loops.

**Figure 4. Storage of Complex Error Signal**

<table>
<thead>
<tr>
<th>real_diff1</th>
<th>real error ( x_{\text{Inew}} )</th>
<th>0x0000</th>
<th>real error ( x_{\text{Inew}} )</th>
<th>0x0000</th>
</tr>
</thead>
<tbody>
<tr>
<td>real_diff2</td>
<td>0x0000</td>
<td>real error ( x_{\text{Inew}} )</td>
<td>0x0000</td>
<td>real error ( x_{\text{Inew}} )</td>
</tr>
<tr>
<td>imag_diff1</td>
<td>imag. error ( x_{\text{Qnew}} )</td>
<td>0x0000</td>
<td>imag. error ( x_{\text{Qnew}} )</td>
<td>0x0000</td>
</tr>
<tr>
<td>imag_diff2</td>
<td>0x0000</td>
<td>imag. error ( x_{\text{Qnew}} )</td>
<td>0x0000</td>
<td>imag. error ( x_{\text{Qnew}} )</td>
</tr>
</tbody>
</table>

For example, by using `real_diff1`, the PMADDWD instruction, and the \( txdataI \) value and adding it to the result of using `imag_diff1`, the PMADDWD instruction, and the \( txdataQ \) value to the second and fourth coefficients could be adapted (see Figure 5). After the PADDD instruction is performed the data then only needs to be shifted by three bits to the right, which equates to a multiplication of \( \mu \) equal to 0.125, and it is ready to be added to the previous 32-bit coefficient for adaptation (see Figure 6). Similarly, `real_diff2` and `imag_diff2` are used to calculate the adaptation for the first and third coefficient. The adaptation equation is described in further detail in the next section.

**Figure 5. How Complex Error Signal is Used to Calculate Adaptation**

\[
\text{mm0:} \quad \begin{bmatrix}
\text{real_diff1} \\
\text{imag_diff1}
\end{bmatrix}
\]

\[
\text{mm0:} \quad \begin{bmatrix}
\text{txdataI[3]} \\
\text{txdataI[1]} \\
\text{txdataI[0]}
\end{bmatrix}
\]

\[
\text{mm0:} \quad \begin{bmatrix}
\text{txdataI[3]} \times x_{\text{Inew}} \\
\text{txdataI[1]} \times x_{\text{Inew}} \\
\text{txdataI[0]}
\end{bmatrix}
\]

\[
\text{mm1:} \quad \begin{bmatrix}
\text{txdataQ[3]} \\
\text{txdataQ[1]} \\
\text{txdataQ[0]}
\end{bmatrix}
\]

\[
\text{mm1:} \quad \begin{bmatrix}
\text{txdataQ[3]} \times x_{\text{Qnew}} \\
\text{txdataQ[1]} \times x_{\text{Qnew}} \\
\text{txdataQ[0]}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\text{txdataI[3]} \times x_{\text{Inew}} \\
\text{txdataI[1]} \times x_{\text{Inew}} \\
\text{txdataI[0]}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\text{txdataQ[3]} \times x_{\text{Qnew}} \\
\text{txdataQ[1]} \times x_{\text{Qnew}} \\
\text{txdataQ[0]}
\end{bmatrix}
\]

\[
\text{PADDD mm0, mm1}
\]
Figure 6 shows in more detail how the adaptation of the first two real coefficients is done. These same instructions are used in the adaptation loops to accomplish the adaptation of the next six real coefficients. The same instructions are used in the adaptation of the imaginary coefficients.

Since the coefficients are 32-bits but are stored in an array of high 16-bit coefficients and an array of low 16-bit coefficients, unpacking and shifting operations must be used to manipulate the data properly to get the correct outcome of the equation for filter coefficient adaptation. The PUNPCKHWD, PUNPCKLWD, and PSRAD are used to accomplish the adaptation but since they all use the MM shifter unit they cannot be paired with each other. Each of the loops were unrolled once so that pairing could be improved. So now in each loop iteration eight coefficients are adapted. The value of $\mu$ was chosen as a fixed value of 0.125 which is just a shift of three bits to the right. After the new coefficients are generated they must be unpacked into their high and low 16-bit values before they are stored back into memory.
Figure 6. Sample Calculation of Adaptation of Real Filter Coefficients

Using MMX™ Instructions to Implement a Modem Baseband Canceler

March 1996
4.0. POSSIBLE IMPROVEMENTS FOR THE MMX™ TECHNOLOGY VERSION

It may be possible to reduce the number of cycles that the echo canceler code performs by making adjustments in how the data arrays are passed into the function to reduce the number of misaligned data accesses. For example, currently the transmit data, \texttt{txdataI} and \texttt{txdataQ}, are passed into the function as sequential arrays and the way the filters operate on them causes misaligned accesses three out of four times because the pointer to these arrays is incremented by two bytes for every filter output calculation. Perhaps four copies of the data could be passed in for each the real and imaginary data, each copy being a shifted version of the original array, thus preventing misaligned accesses if the algorithm was thought out with the data in this structure. The overhead of making these multiple copies would be amortized by the fact that the same \texttt{txdata} is used many times as the FIR and adaptation loops execute.

\textit{Figure 7. How to Store Data to Avoid Data Misalignment}

During the calculation of the first filter output, the arrays starting with the \texttt{txdataI[0]} and \texttt{txdataQ[0]} elements would be used. The next filter output would be calculated using the arrays starting with \texttt{txdataI[1]} and \texttt{txdataQ[1]}, the next using \texttt{txdataI[2]} and \texttt{txdataQ[2]}, and the next using \texttt{txdataI[3]} and \texttt{txdataQ[3]}. The next iteration the pointer to the array could be incremented by 8 bytes and the first arrays could be used for the next calculation.

An even better way, to avoid the problem of having to have eight pointers to the various arrays is to arrange two arrays as described in Figure 8. This way there are only two pointer values that have to be stored and the same amount of memory is used to store the arrays.

\textit{Figure 8. Another Method to Store Data While Avoiding Data Misalignment}

\begin{align*}
\text{tl} &= \text{txdataI} \\
\text{tQ} &= \text{txdataQ}
\end{align*}
Using MMX™ Instructions to Implement a Modem Baseband Canceler

March 1996

;* Description:
;*    This file is an example of one way to implement a baseband echo canceler
;*    in MMX technology and will serve as an instructional example.
;* Assumptions:
;*    1. The number of coefficients in the filters is a multiple of 8.
;*    2. The number of baud being processed is a multiple of four.
;*    3. The arrays passed into this routine are ordered in a specific way
described later.

;* title   EchoCancelerMMX
.
.model flat, c

; Local Variable Declarations
;   1. Filt_Num  - keeps track of which of the three filter is being
                  performed
;   2. Baud_Count - number of baud being processed in this block
;   3. Rx_real   - address where real received data is stored in memory
;   4. Rx_imag   - address where imaginary received data is stored in memory
;   5. dword_mask- word mask used with MMX register
;   6. real_diff1- used to store the real error signal in this format
;                  error | 0x0000 | error | 0x0000
;   7. real_diff2- used to store the real error signal in this format
;                  0x0000 | error | 0x0000 | error
;   8. imag_diff1- used to store the imaginary error signal in this format
;                  error | 0x0000 | error | 0x0000
;   9. imag_diff2- used to store the imaginary error signal in this format
;                  0x0000 | error | 0x0000 | error

; In the comments for the code the dI array notation indicates the txdataI array
; while the dQ array notation indicates the txdataQ array that are passed in.
; First real set of coefficients start at hIH[0] and go to hIH[n-1] where n is the
; length of the filter and filter #2's coefficients start at hIH[n] and got to
; hIH[2n-1] and filter #3's coefficients start at hIH[2n] and got to hIH[3n-1].
; This is the way hQH array is set up and hIL array and hQL array.

.code
EchoCancelerMMX    PROC C uses ebx ecx edx esi edi,
txdataI:PTR WORD, txdataQ:PTR WORD, xI:PTR WORD, xQ:PTR WORD, 
hIH:PTR WORD, hQH:PTR WORD, hIL:PTR WORD, hQL:PTR WORD, 
h_Leng:DWORD, x_Leng:DWORD
LOCAL Filt_Num:DWORD
LOCAL Baud_Count:DWORD
LOCAL Rx_real:DWORD
LOCAL Rx_imag:DWORD
LOCAL dword_mask:DWORD
LOCAL real_diff1[2]:DWORD
LOCAL real_diff2[2]:DWORD
LOCAL imag_diff1[2]:DWORD
LOCAL imag_diff2[2]:DWORD
mov   Filt_Num, 0000H
mov   esi, xI
mov   dword_mask, 0FFFFH
mov   eax, txdataI
mov   ebx, txdataQ
mov   ecx, hIH
Using MMX™ Instructions to Implement a Modem Baseband Canceler

March 1996

mov esi, xQ
mov edx, hQH
mov Rx_imag, esi
mov esi, x_Leng
mov edi, 0 ; edi = address incrementer for input data
mov Baud_Count, esi ; esi = filter length

; This section of code is where the complex FIR is calculated. Before entering
; the loop mm4 is preloaded with first 4 real elements from data array so that
; better pairing can be accomplished. The accumulators mm0 and mm1 are also
; initialized to 0.

FilterLoop:
    pxor mm0, mm0
    pxor mm1, mm1
    sub ecx, edi ; adjust pointer to hIH
    sub edx, edi ; adjust pointer to hQH
    mov esi, h_Leng ; esi = filter length
    pxor mm6, mm6
    pxor mm5, mm5
    mov ebx, txdataQ
    movq mm7, mm4

; Complex FIR Loop
FIRLoop:
    pmaddwd mm4, [ecx+edi] ; mm4 =
        dI[1]*hIH[1] + dI[0]*hIH[0]
    psubd mm0, mm5
        ; mm0 -= mm5 (hQH * dQ)
    movq mm5, [ebx+edi]
        ; mm5 =
    padd mm1, mm6
        ; mm1 += mm6 (hIH * dQ)
    pmaddwd mm7, [edi+edi] ; mm7 =
        dI[1]*hQH[1] + dI[0]*hQH[0]
    movq mm6, mm5
        ; mm6 =
    pmaddwd mm5, [edi+edi]
        ; mm5 =
    padd mm0, mm4
        ; mm0 += mm4 (hIH * dI)
    movq mm4, [eax+edi+8]
        ; mm4 =
    pmaddwd mm6, [ecx+edi]
        ; mm6 =
    padd mm1, mm7
        ; mm1 += mm7 (hQH * dI)
    movq mm7, mm4
        ; mm7 =
    add edi, 8 ; increase data pointer by 8 bytes
    sub esi, 4 ; decrement counter value
    jc FIRLoop ; if >0 then do loop again

; End of Loop for FIR
psubd mm0, mm5
    ; mm0 -= mm5 (hQH * dQ)
padd mm1, mm6
    ; mm1 += mm6 (hIH * dQ)

; Here the final complex result of the filter is calculated by copying mm0,
; shifting the copied value 32-bits to the right and adding it back to mm0.
; The same thing is done for the imaginary result in mm1.
; mm0 = yI = (hIH[3,2] * dI[3,2]) + (hQH[3,2] * dQ[3,2])
; | (hIH[1,0] * dI[1,0]) + (hQH[1,0] * dQ[1,0])
; mm1 = yQ = (hIH[3,2] * dQ[3,2]) + (hQH[3,2] * dI[3,2])
; | (hIH[1,0] * dQ[1,0]) + (hQH[1,0] * dI[1,0])
movq mm2, mm0
Using MMX™ Instructions to Implement a Modem Baseband Canceler

March 1996

movq mm3, mm1
movdt mm4, dword_mask
psrlq mm0, 32 ; mm0 = 0x00000000

psrlq mm1, 32 ; mm1 = 0x00000000

paddd mm0, mm2 ; mm0 = single real output of filter

mov eax, Rx_Real

paddd mm1, mm3 ; mm1 = single imaginary output of filter

This section of code reads in the complex received values and subtracts off the
; filtered value. Then it stores the new received value back into memory and
; stores it back in variables real_diff1, real_diff2, imag_diff1, and imag_diff2
; to be used later in adaptation.

mov ebx, Rx_Imag

psrld mm0, 14 ; adjust output value to lowest 16 bits of mm0
; YI & introduce gain of 2
; xxxx | xxxx | xxxx | YI

mov mm2, [eax]

psrld mm1, 14 ; adjust output value to lowest 16 bits of mm1
; YQ & introduce gain of 2
; xxxx | xxxx | xxxx | YQ

mov mm3, [ebx]

psubw mm2, mm0

psubw mm3, mm1

pand mm2, mm4

movq mm7, mm2 ; mm7 = 0x0000 | 0x0000 | 0x0000 | xI

movq mm6, mm2 ; mm6 = 0x0000 | 0x0000 | 0x0000 | xI

psllq mm7, 32 ; mm7 = 0x0000 | xI | 0x0000 | 0x0000

movdf ecx, mm2

por mm6, mm7 ; mm6 = 0x0000 | xI | 0x0000 | xI

mov WORD PTR [eax], cx

mov mm7, mm6 ; mm7 = 0x0000 | xI | 0x0000 | xI

add eax, 2

mov mm4, mm3 ; mm5 = 0x0000 | 0x0000 | 0x0000 | xQ

mov Rx_Real, eax

mov mm5, mm3 ; mm5 = 0x0000 | 0x0000 | 0x0000 | xQ

movdf edx, mm3

psllq mm6, 16 ; mm6 = xI | 0x0000 | xI | 0x0000

mov WORD PTR[ebx], dx

add ebx, 2

movq real_diff1, mm6

psllq mm5, 32 ; mm5 = 0x0000 | xQ | 0x0000 | 0x0000

movq real_diff2, mm7

por mm4, mm5 ; mm4 = 0x0000 | xQ | 0x0000 | xQ

mov Rx_Imag, ebx

mov mm5, mm4 ; mm5 = 0x0000 | xQ | 0x0000 | xQ

psllq mm4, 16 ; mm4 = xQ | 0x0000 | xQ | 0x0000

mov ecx, hIH

; Here the base address for the filter coefficients to be adapted is calculated.
; Since the coefficients are stored [hIH0 hIH1 hIH2] and [hIL0 hIL1 hIL2] the
; pointer to the coefficients needs to be adjusted if it is your first iteration
; and hIH0 hIL0 needs to be pointed to, or the second iteration where hIH1 hIL1( =
; (hIH0 hIL0) + 2 * length of filter) needs to be pointed to, or the third
; iteration where hIH2 hIL2( = (hIH0 hIL0) + 4 * length of filter) needs to be
; pointed to.

mov edx, hIL ; load edx with base address of low 16-bits

mov ebx, Filt_Num ; of real filter coefficients

mov eax, h_Leng ; h_Leng = offset needed to point to correct

mov esi, h_Leng ; set of coefficients to be adapted

movq imag_diff1, mm4 ; store imag. error for adaptation

movq imag_diff2, mm5
Using MMX™ Instructions to Implement a Modem Baseband Canceler

March 1996

dec ebx ; determine which filter is being done this
jg real_adapt2 ; time through loop
jl real_adapt

real_adapt1:
    shl eax, 1
    jmp do_real_adapt
real_adapt2:
    shl eax, 2
    jmp do_real_adapt
real_adapt:
    mov eax, 0
do_real_adapt:
    add ecx, eax ; point to correct set of coefficients to
    add edx, eax ; adapt
    sub edi, esi
    mov eax, txdataI
    sub edi, esi
    mov ebx, txdataQ
    sub ecx, edi
    sub edx, edi

; This section of code performs the loop that calculates the real coefficient
; adaptation.
; real hnew = real hold + mu * (real error * real data + imag error * imag data)
; mu = 0.125 (shift right by 3 bits)
; real data = txdataI = dI in comments
; real error = xI
; imag data = txdataQ = dQ in comments
; imag error = xQ

; Adaptation loop for real coefficients

Adapt_Real:
    movq mm7, real_diff2 ; mm7 = 0x0000 | xI | 0x0000 | xI
    movq mm0, mm6 ; mm0 = xI | 0x0000 | xI | 0x0000
    pmaddwd mm0, [eax+edi] ; mm0 = xI * dI[3] | xI * dI[1]
    movq mm2, mm4 ; mm2 = xQ | 0x0000 | xQ | 0x0000
    pmaddwd mm2, [ebx+edi] ; mm2 = xQ * dQ[3] | xQ * dQ[1]
    pmaddwd mm1, mm7 ; mm1 = 0x0000 | xI | 0x0000 | xI
    pmaddwd mm1, [eax+edi] ; mm1 = xI * dI[2] | xI * dI[0]
    pmaddwd mm3, mm5 ; mm3 = 0x0000 | xQ | 0x0000 | xQ
    pmaddwd mm3, [ebx+edi] ; mm3 = xQ * dQ[2] | xQ * dQ[0]
    pmaddwd mm6, [eax+edi+8] ; mm6 = xI * dI[7] | xI * dI[5]
    pmaddwd mm4, [ebx+edi+8] ; mm4 = xQ * dQ[7] | xQ * dQ[5]
    psrad mm0, 3 ; multiply by mu(0.125)
    pmaddwd mm7, [eax+edi+8] ; mm7 = xI * dI[6] | xI * dI[4]
    pmaddwd mm1, mm3 ; mm1 = xI * dI[2] + xQ * dQ[2] | xI * dI[0] + xQ * dQ[0]
    pmaddwd mm5, [ebx+edi+8] ; mm5 = xQ * dQ[6] | xQ * dQ[4]
    psrad mm1, 3 ; multiply by mu(0.125)

    movq mm2, mm0 ; mm2 = mu*(xI * dI[3] + xQ * dQ[3])
    movq mm3, mm1 ; mm3 = mu*(xI * dI[2] + xQ * dQ[2])
    punpcklqdq mm1, mm2 ; mm1 = mu*(xI * dI[1] + xQ * dQ[1])
    punpckhdq mm3, mm0 ; mm3 = mu*(xI * dI[3] xQ * dQ[3])

    xI * dI[1] + xQ * dQ[1])
    xI * dI[0] + xQ * dQ[0])

    xI * dI[0] + xQ * dQ[0])
    xI * dI[2] + xQ * dQ[2])

    xI * dI[2] + xQ * dQ[2])
    xI * dI[2] + xQ * dQ[2])

    xI * dI[0] + xQ * dQ[0])
    xI * dI[0] + xQ * dQ[0])

    xI * dI[0] + xQ * dQ[0])
    xI * dI[2] + xQ * dQ[2])

    xI * dI[2] + xQ * dQ[2])
    xI * dI[2] + xQ * dQ[2])
movq mm4, mm6 ; mm4 = μ * (xI*dI[7] + xQ*dQ[7])

punpcklwd mm2, [ecx+edi] ; mm2 = hIH[1] | hIL[1] | hIH[0] | hIL[0]

movq mm5, mm7 ; mm5 = μ * (xI*dI[6] + xQ*dQ[6])

paddd mm0, mm3 ; mm0 = hnew[3,2] = hold[3,2] + μ * error*D

punpckldq mm7, mm4 ; mm7 = μ * (xI*dI[5] + xQ*dQ[5])

paddd mm1, mm2 ; mm1 = hnew[1,0] = hold[1,0] + μ * error*D
                ; = hIH[1] | hIL[1] | hIH[0] | hIL[0]

punpckhdq mm5, mm6 ; mm5 = μ * (xI*dI[7] + xQ*dQ[7])


movq mm2, mm0 ; mm2 = hnew[3,2] = hold[3,2] + μ * error*D


psrlq mm2, 32 ; mm2 = 0x0000 | 0x0000 | hIH[3] | hIL[3]


movq mm3, mm1 ; mm3 = hnew[1,0] = hold[1,0] + μ * error*D


padd mm6, mm5 ; mm6 = hnew[7,6] = hold[7,6] + μ * error*D


psrlq mm3, 32 ; mm3 = 0x0000 | 0x0000 | hIH[1] | hIL[1]

padd mm7, mm4 ; mm7 = hnew[5,4] = hold[5,4] + μ * error*D

punpckldq mm2, mm0 ; mm2 = hIH[2] | hIH[1] | hIH[0] | hIL[0]

movq mm5, mm7 ; mm5 = hnew[5,4] = hold[5,4] + μ * error*D


movq [ecx+edi], mm3 ; store new hIHs back into memory

movq [edx+edi], mm1 ; store new hILs back into memory

sub esi, 8

jg Adapt_Real

movq mm7, real_diff2 ; mm7 = 0x0000 | xQ | 0x0000 | xQ

movq mm6, real_diff1 ; store new hILs back into memory

movq mm0, mm1

movq mm5, imag_diff1


movq mm1, mm6

movq mm5, imag_diff2

punpckldq mm7, mm1 ; mm7 = 0x0000 | xQ | 0x0000 | xQ

movq mm6, real_diff1

movq mm0, mm1

movq mm5, [ecx+edi+8], mm7 ; store new hIHs back into memory

movq mm0, mm6

movq mm5, [ecx+edi+8], mm0 ; store new hIHs back into memory

add edi, 16

sub esi, 8

jg Adapt_Real

movq mm7, real_diff2 ; mm7 = 0x0000 | xI | 0x0000 | xI

; Here the base address for the imag.filter coefficients to be adapted is calculated.

; Since the coefficients are stored [hQH0 hQH1 hQH2] and [hQL0 hQL1 hQL2] the
; pointer to the coefficients needs to be adjusted if it is your first iteration
; and hQH0 hQL0 needs to be pointed to, or the second iteration where hQH1 hQL1 =
; (hQH0 hQL0) + 2 * length of filter) needs to be pointed to, or the third
Using MMX™ Instructions to Implement a Modem Baseband Canceler

March 1996

; iteration where H2H2 HQL2 ( = (H0H0 HQL0) + 4 * length of filter) needs to be
; pointed to.
mov ecx, hQH
mov edx, hQL
; load edx with base address of low 16-bits
; of imaginary filter coefficients
mov ebx, Filt_Num
; h_Leng = offset needed to point to correct
mov eax, h_Leng
; set of coefficients to be adapted
mov esi, h_Leng
dec ebx
jg imag_adapt2
jl imag_adapt
imag_adapt1:
    shl eax, 1
    jmp do_imag_adapt
imag_adapt2:
    shl eax, 2
    jmp do_imag_adapt
imag_adapt:
    mov eax, 0
    do_imag_adapt:
    add ecx, eax ; point to correct set of coefficients to
    add edx, eax ; adapt
    sub edi, esi
    mov eax, txdataI
    sub edi, esi
    mov ebx, txdataQ
    sub edi, esi
    mov ebx, txdataQ
    sub ecx, edi
    sub edx, edi

; This section of code performs the loop that calculates the imaginary coefficient
; adaptation.
; imag hnew = imag hold + mu * (imag error * real data - real error * imag data)
; mu = 0.125 (shift right by 3 bits)
; real data = txdataI = dI in comments
; real error = xI
; imag data = txdataQ = dQ in comments
; imag error = xQ
; Adaptation loop for imaginary coefficients
Adapt_Imag:
movq mm4, imag_diff2 ; mm7 = xQ | 0x0000 | xQ | 0x0000
movq mm3, mm5 ; mm3 = 0x0000 | xQ | 0x0000 | xQ
pmaddwd mm3, [eax+edi] ; mm3 = xQ * dI[2] | xQ * dI[0]
movq mm1, mm7 ; mm1 = 0x0000 | xI | 0x0000 | xI
pmaddwd mm1, [ebx+edi] ; mm1 = xI * dQ[2] | xI * dQ[0]
movq mm0, mm6 ; mm0 = xI | 0x0000 | xI | 0x0000
pmaddwd mm0, [ebx+edi] ; mm0 = xI * dQ[3] | xI * dQ[1]
movq mm2, mm4 ; mm2 = xQ | 0x0000 | xQ | 0x0000
pmaddwd mm2, [eax+edi] ; mm2 = xQ * dI[3] | xQ * dI[1]
pmadwd mm6, [ebx+edi+8] ; mm6 = xI * dI[7] | xI * dI[5]
psubd mm3, mm1 ; mm3 = xQ * dI[2] - xI * dQ[2] | xQ * dI[0] - xI * dQ[0]
pmadwd mm4, [eax+edi+8] ; mm4 = xQ * dI[7] | xQ * dI[5]
pshrd mm3, 3 ; multiply by mu(0.125)
pmadwd mm7, [ebx+edi+8] ; mm7 = xI * dQ[6] | xI * dQ[4]
psubd mm2, mm0 ; mm2 = xQ * dI[3] - xI * dQ[3] | xQ * dI[1] - xI * dQ[1]
pmadwd mm5, [eax+edi+8] ; mm5 = xQ * dI[6] | xQ * dI[4]
pshrd mm2, 3 ; multiply by mu(0.125)

movq mm0, mm2 ; mm0 = mu * (xQ * dI[3] - xI * dQ[3] | xQ * dI[1] - xI * dQ[1])
movq mm1, mm3 ; mm1 = mu * (xQ * dI[2] - xI * dQ[2] | xQ * dI[0] - xI * dQ[0])
punpckldq mm1, mm2 ; mm1 = mu * (xQ * dI[1] - xI * dQ[1] | xQ * dI[0] - xI * dQ[0])
Using MMX™ Instructions to Implement a Modem Baseband Canceler

March 1996

punpckhdq mm3, mm0 ; mm3 = mu*(xQ*dI[3] - xI*dQ[3]) | xQ*dI[2]

xI*dQ[2])

movq mm0, [edx+edi] ; mm0 = hQL[3] | hQL[2] | hQL[1] | hQL[0]
psradb mm4, 3 ; multiply by mu(0.125)
movq mm2, mm0 ; mm2 = hQL[3] | hQL[2] | hQL[1] | hQL[0]
psradb mm5, 3 ; multiply by mu(0.125)
punpckhwd mm0, [ecx+edi] ; mm0 = hQL[3] | hQL[2] | hQL[1] | hQL[0]
movq mm6, mm4 ; mm6 = mu*(xQ*dI[7] - xI*dQ[7]) | xQ*dI[5]

xI*dQ[5])

movq mm7, mm5 ; mm7 = mu*(xQ*dI[6] - xI*dQ[6]) | xQ*dI[4]

xI*dQ[4])
padd mm0, mm3 ; mm0 = hnew[3,2] = hold[3,2] + mu*error*D
punpckldq mm7, mm4 ; mm7 = hQL[3] | hQL[2] | hQL[1] | hQL[0]
padd mm2, mm1 ; mm2 = hnew[1,0] = hold[1,0] + mu*error*D
punpckhdq mm5, mm6 ; mm5 = hQL[3] | hQL[2] | hQL[1] | hQL[0]

xI*dQ[4])
movq mm1, mm0 ; mm1 = hnew[3,2] = hold[3,2] + mu*error*D
psrlq mm1, 32 ; mm1 = 0x0000 | 0x0000 | hQL[3] | hQL[2]
movq mm3, mm2 ; mm3 = hnew[1,0] = hold[1,0] + mu*error*D
padd mm6, mm5 ; mm6 = hnew[7,6] = hold[7,6] + mu*error*D
psrlq mm3, 32 ; mm3 = 0x0000 | 0x0000 | hQL[1] | hQL[0]
padd mm4, mm7 ; mm4 = hnew[1,0] = hold[1,0] + mu*error*D
punpckldq mm1, mm0 ; mm1 = hQL[2] | hQL[1] | hQL[0] | hQL[3]
movq mm7, mm6 ; mm7 = hnew[7,6] = hold[7,6] + mu*error*D
movq mm5, mm4 ; mm5 = hnew[5,4] = hold[5,4] + mu*error*D
punpckldq mm3, mm2 ; mm3 = hQL[0] | hQL[1] | hQL[2] | hQL[3]
punpcklwd mm0, mm1 ; mm0 = hQL[3] | hQL[2] | hQL[1] | hQL[0]
movq mm2, mm3 ; mm2 = hQL[1] | hQL[0] | hQL[1] | hQL[0]
punpckldq mm5, mm4 ; mm5 = hQL[1] | hQL[0] | hQL[1] | hQL[0]
movq mm0, mm5 ; mm5 = hQL[3] | hQL[2] | hQL[1] | hQL[0]
movq mm5, imag_diff2 ; mm5 = 0x0000 | xI | 0x0000 | xI
movq mm1, mm6 ; mm6 = xQ | 0x0000 | xQ | 0x0000
movq mm7, real_diff2 ; mm7 = 0x0000 | xQ | 0x0000 | xQ
Using MMX™ Instructions to Implement a Modem Baseband Canceler

March 1996

movq [edx+edi+8], mm0 ; store new hQLs back into memory
movq [ecx+edi+8], mm4 ; store new hQHs back into memory
add edi, 16
sub esi, 8
jg Adapt_Imag

; This section of code determines which of the three filters is to be done next
mov esi, h_Leng
mov ecx, hIH
mov edx, hQH
sub edi, esi
mov ebx, Filt_Num
sub edi, esi
dec ebx
je filter2
jg filter0

filter1: ; iteration = 1
mov esi, h_Leng ; esi = h_Leng
inc ebx
shl esi, 1 ; esi = 2*hLeng
inc ebx ; Filt_Num = 1
mov Filt_Num, ebx ; Filt_Num = 1 for next time
add ecx, esi ; ecx = hIH + 2*h_Leng
add edx, esi ; edx = hQH + 2*h_Leng
jmp FilterLoop

filter2: ; iteration = 2
mov esi, h_Leng ; esi = h_Leng
inc ebx
shl esi, 2 ; esi = 4*hLeng
inc ebx ; Filt_Num = 2
mov Filt_Num, ebx ; Filt_Num = 2 for next time
add ecx, esi ; ecx = hIH + 4*h_Leng
add edx, esi ; edx = hQH + 4*h_Leng
jmp FilterLoop

filter0: ; iteration = 0
dec ebx ; Filt_Num = 0
mov esi, Baud_Count
mov Filt_Num, ebx ; Filt_Num = 0 for next time
add edi, 2

; Check to see if block of baud has been processed. If so then ecmmx is done!
; If not continue computation.
dec ebx ; Filt_Num = 0
mov Baud_Count, esi
jne FilterLoop

emms ; empty floating point stack

ret

EchoCancelerMMX EndP
END