104 DSP

16-bit

DSP Engine and DSP Libraries

Class Objective

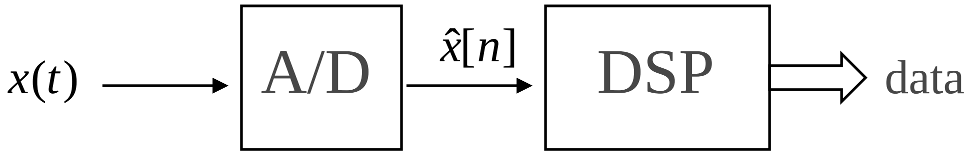
- **When you finish this class you will:**
  - Be familiar with dsPIC DSP features
  - Be familiar with using dsPIC DSP library and tools

Agenda

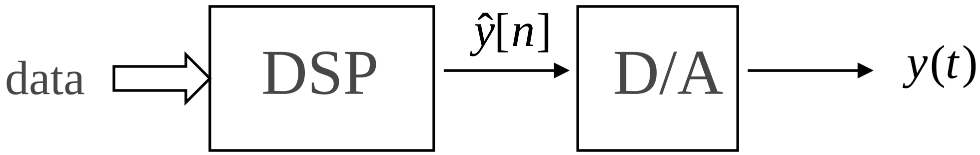
- **Why DSP**
- **dsPIC Support for DSP**
  - dsPIC DSP architecture
  - dsPIC DSP Tools and Libraries

Why DSP

DSP Systems



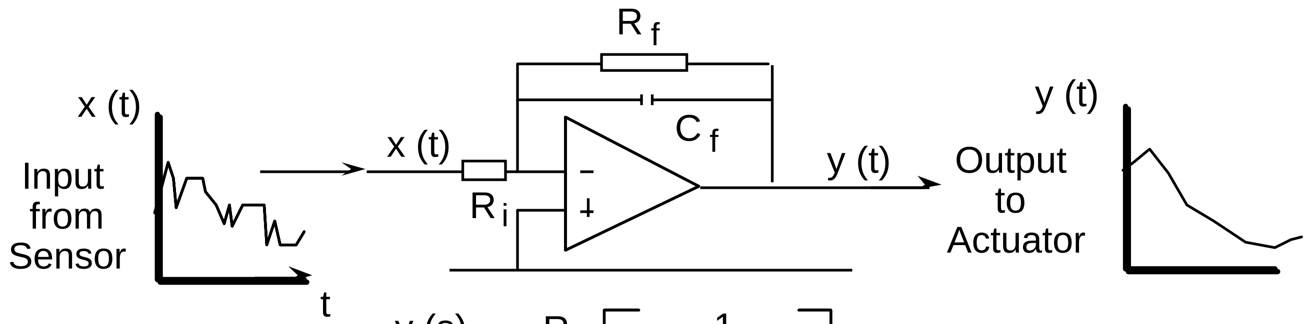
Analysis (Receiver / Encoder)



Synthesis (Transmitter / Decoder)

Signal Conditioning/Control

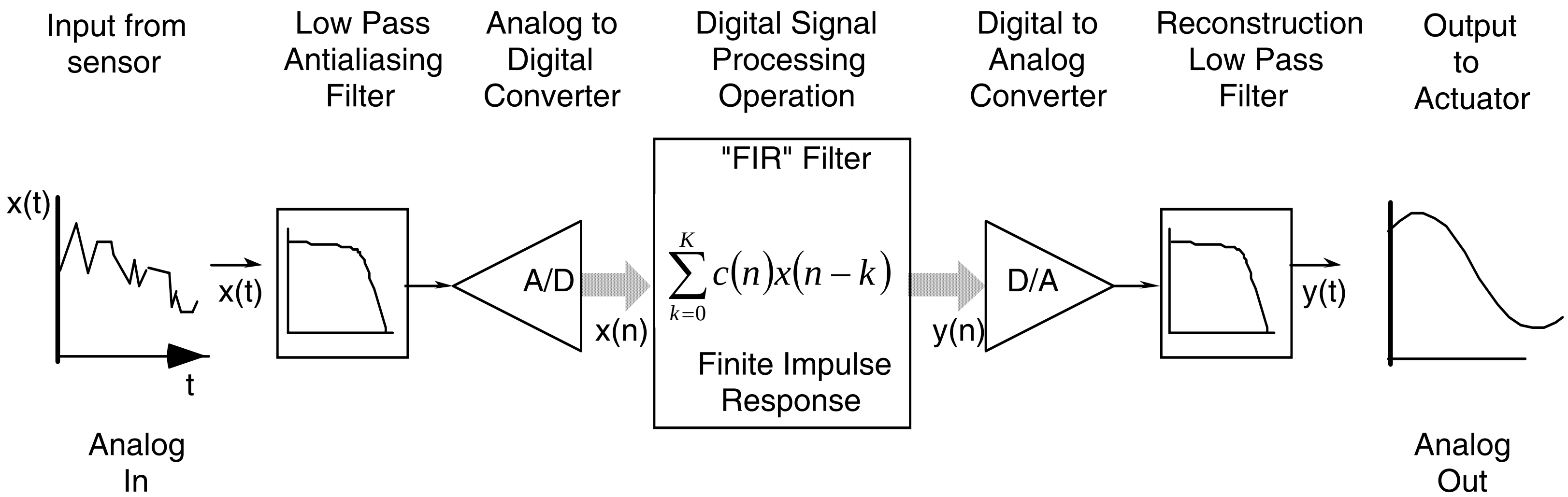
Analog Control Systems



$$\frac{y(s)}{x(s)} = -\frac{R_f}{R_i}\left[\frac{1}{1 + jwR_fC_f}\right]$$

- Drawbacks:
  - Low noise immunity
  - Little flexibility
  - Requires adjustments
  - Critical component specification, especially for high order filters
- Filter characteristics change with
  - Temperature
  - Component aging
  - Power supply variation

Digital Control Systems



- Some key advantages of digital filtering:
  - Less affected by noise
  - Lower power consumption
  - Programmable systems
  - Minimal effect of drift in characteristics with age

FIR Filters: Definition

- **The input-output relation of a FIR filter is given by**

$$y[n] = \sum_{k=0}^{T-1} b_k x[n-k]$$

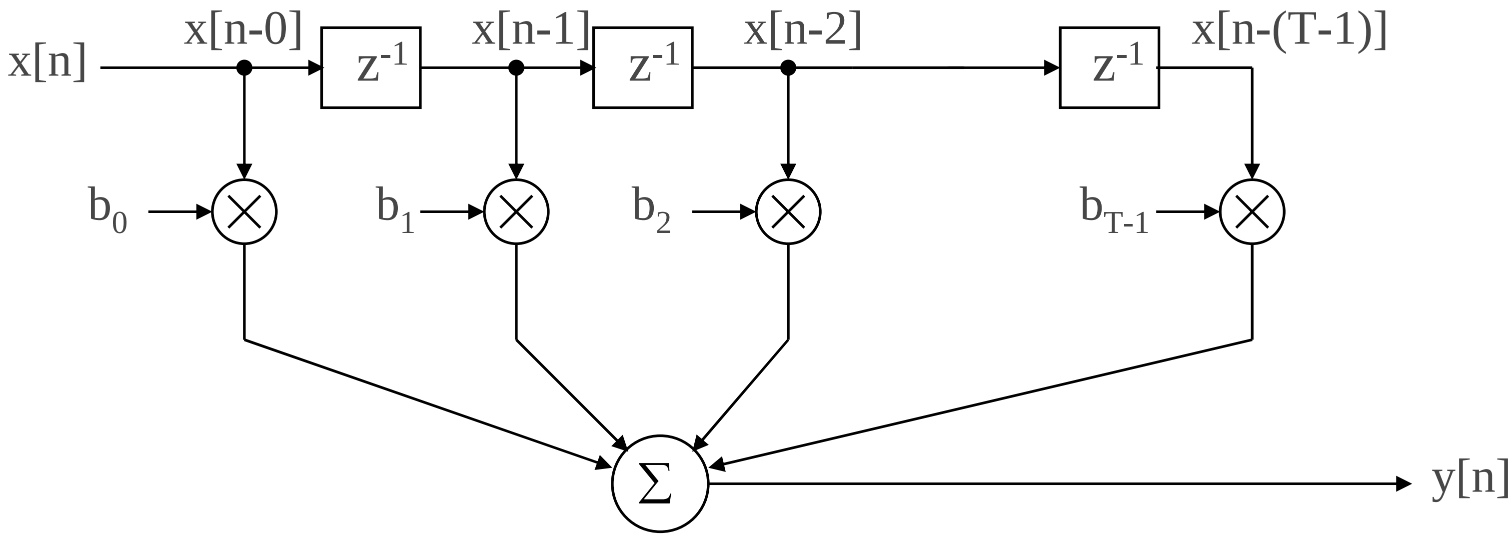
where:

T = filter length (# of taps)

b_k = the k^{th} coefficient of the filter

FIR Filters: Structure

- **FIR filter tapped delay line form**
  - z^{-1} refers to a unit sample delay



DSP Architecture

dsPIC support for Filters

- DSP Library Support
- Dual Harvard Architecture
- MAC instructions with data prefetch
- Modulo Addressing
- Loop control - DO and REPEAT instructions

C-callable fixed point FIR from MPLAB

Description:	`FIR` applies an FIR filter to the sequence of source samples, places the results in the sequence of destination samples, and updates the delay values.
Include:	`dsp.h`
Prototype:	see below

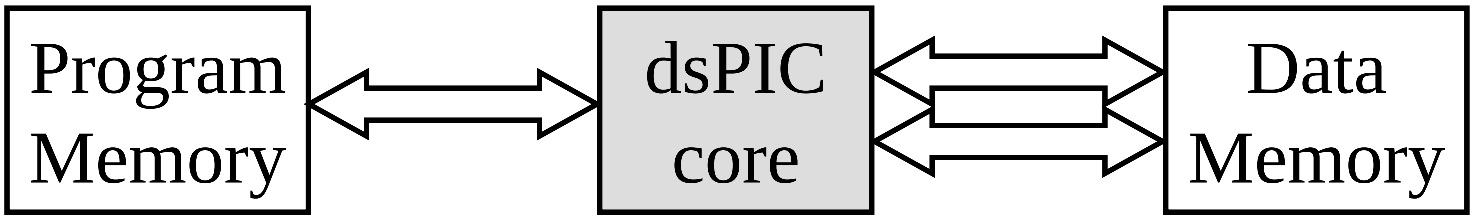
```
extern fractional* FIR (
   int numSamps,
   fractional* dstSamps,
   fractional* srcSamps,
   FIRStruct* filter
);
```

Arguments:

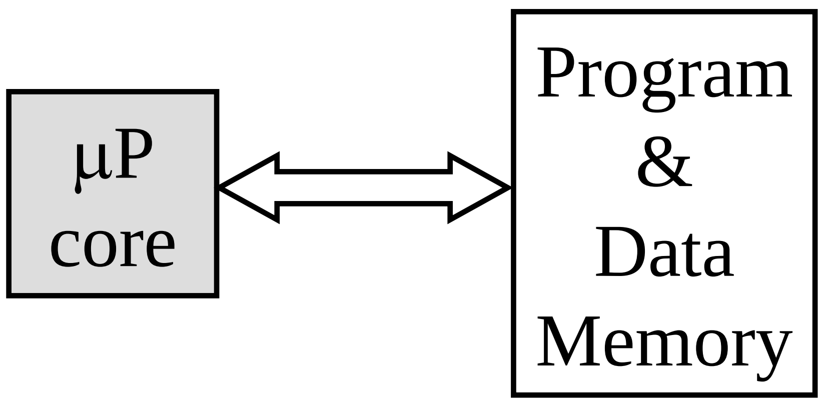
numSamps	number of input samples to filter (also N)
dstSamps	pointer to destination samples (also y)
srcSamps	pointer to source samples (also x)
filter	pointer to `FIRStruct` filter structure

Return Value: Pointer to base address of destination samples.

dsPIC vs. Microprocessor Architectures



Dual Harvard Architecture



Von Neumman Architecture

MAC and dual parallel reads

MAC

Multiply and Accumulate

Syntax:	{label:}	MAC	Wm*Wn, Acc	{,[Wx], Wxd}	{,[Wy], Wyd}	{,AWB}

Operation: (Acc(A or B)) + (Wm) * (Wn) → Acc(A or B)
([Wx]) → Wxd; (Wx) + kx → Wx
([Wy]) → Wyd; (Wy) + ky → Wy
(Acc(B or A)) rounded → AWB

Description: Multiply the contents of two working registers, optionally prefetch operands in preparation for another `MAC` type instruction and optionally store the unspecified accumulator results. The 32-bit result of the signed multiply is sign-extended to 40 bits and added to the specified accumulator.

Words: 1

Cycles: 1

One clock cycle, One program word!

Example 1: `MAC W4*W5, A, [W8]+=6, W4, [W10]+=2, W5`

MAC and dual parallel reads

MAC W4*W5, A, [W8]+=2, W4, [W10]-=6, W5, W13

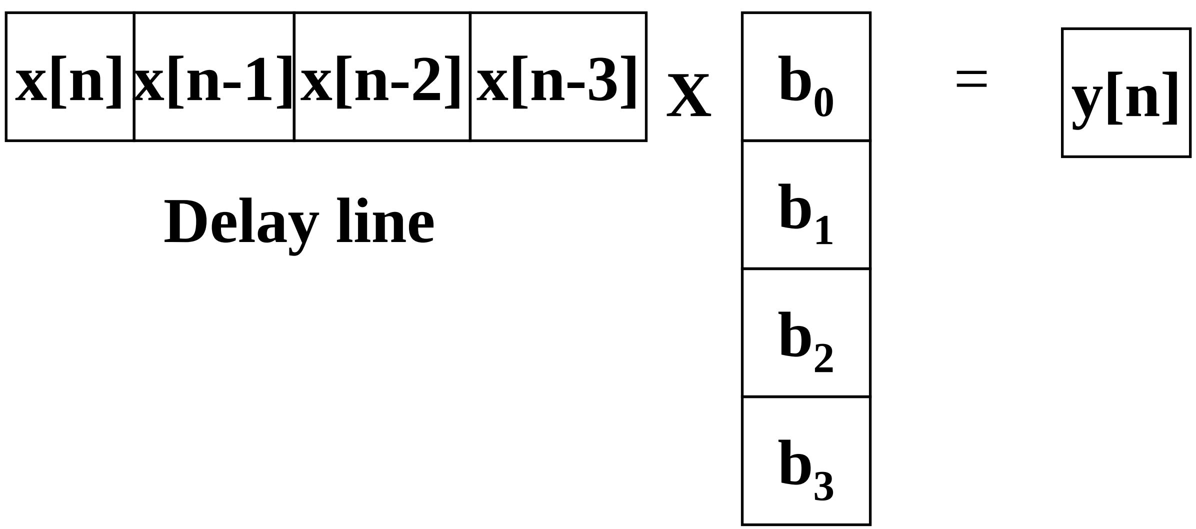
- Source operand registers: W4*W5
- Destination accumulator: A
- X prefetch source: [W8]+=2
- X prefetch destination: W4
- Y prefetch source: [W10]-=6
- Y prefetch destination: W5
- Other Acc. Write-back destination: W13

Modulo or “Circular” Addressing

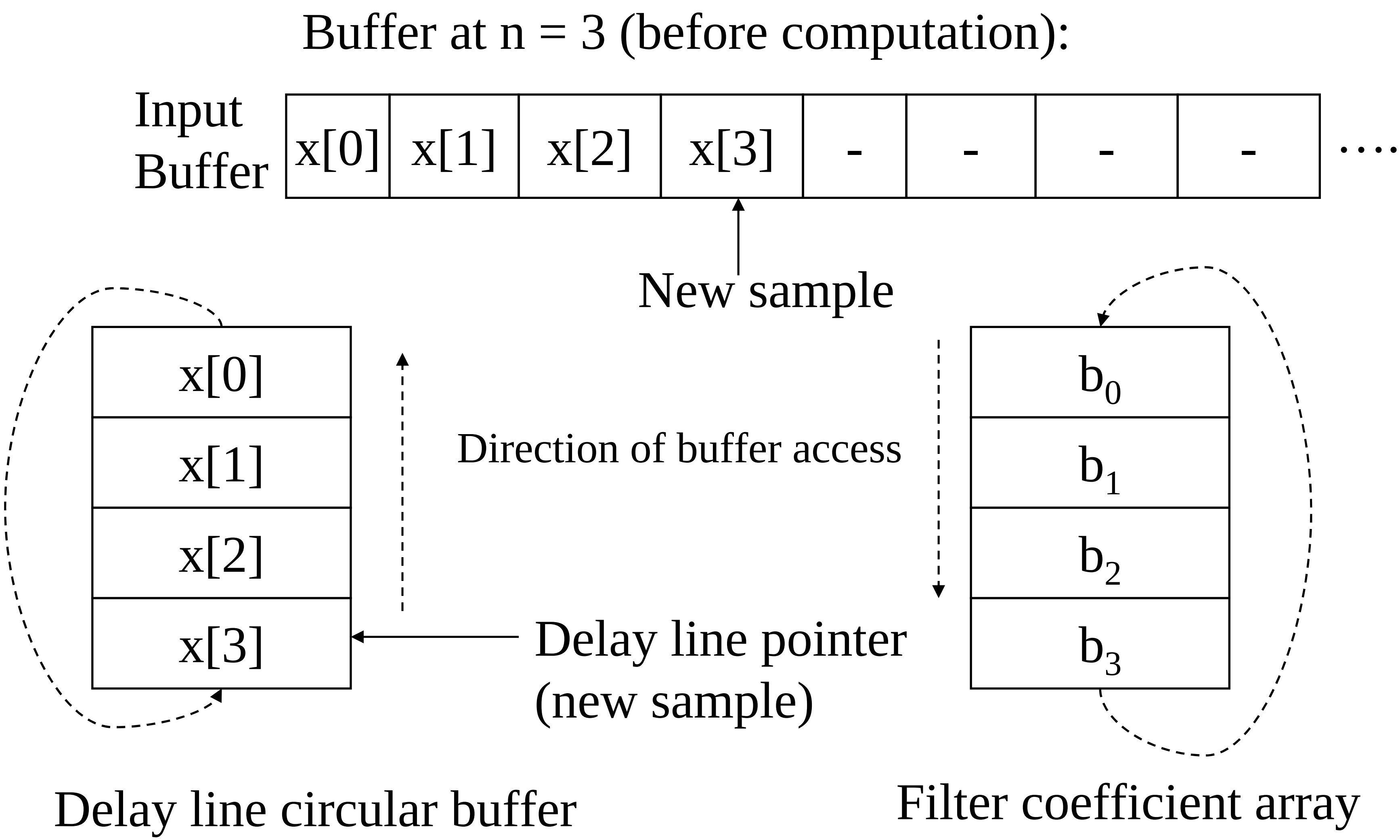
- Eliminates the software overhead associated with effective address (EA) correction
- Data address boundary checks are performed in hardware
- May be used with any instruction that utilizes indirect addressing

Modulo: FIR Filter Example

- Single Sample FIR Filter Operation (4 taps)
- Vector Dot Product of…
  - Input Delay Line
  - Coefficient Array



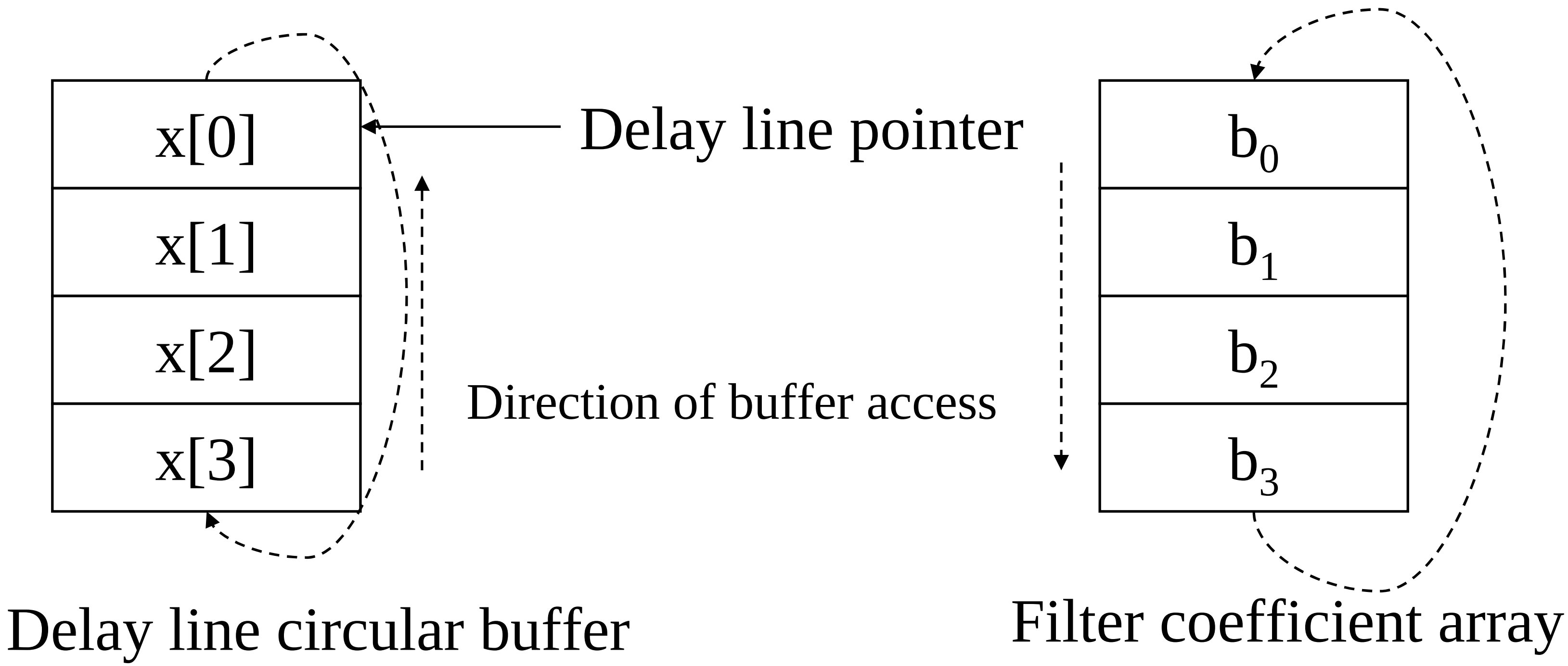
Modulo: FIR Filter Example



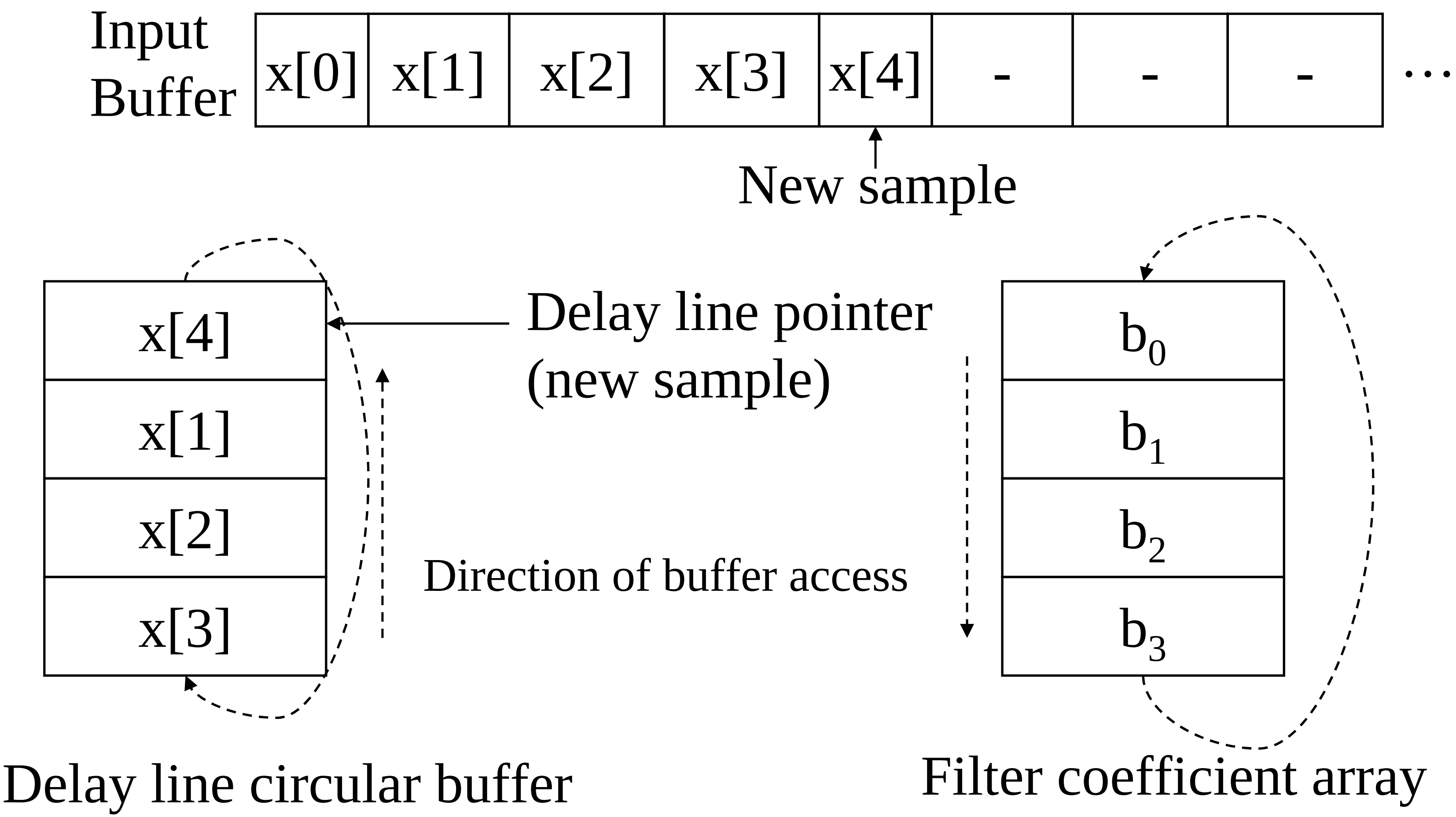
Modulo: FIR Filter Example

FIR output for n = 3:

$$y[3] = x[3]*b_0+x[2]*b_1+x[1]*b_2+x[0]*b_3$$



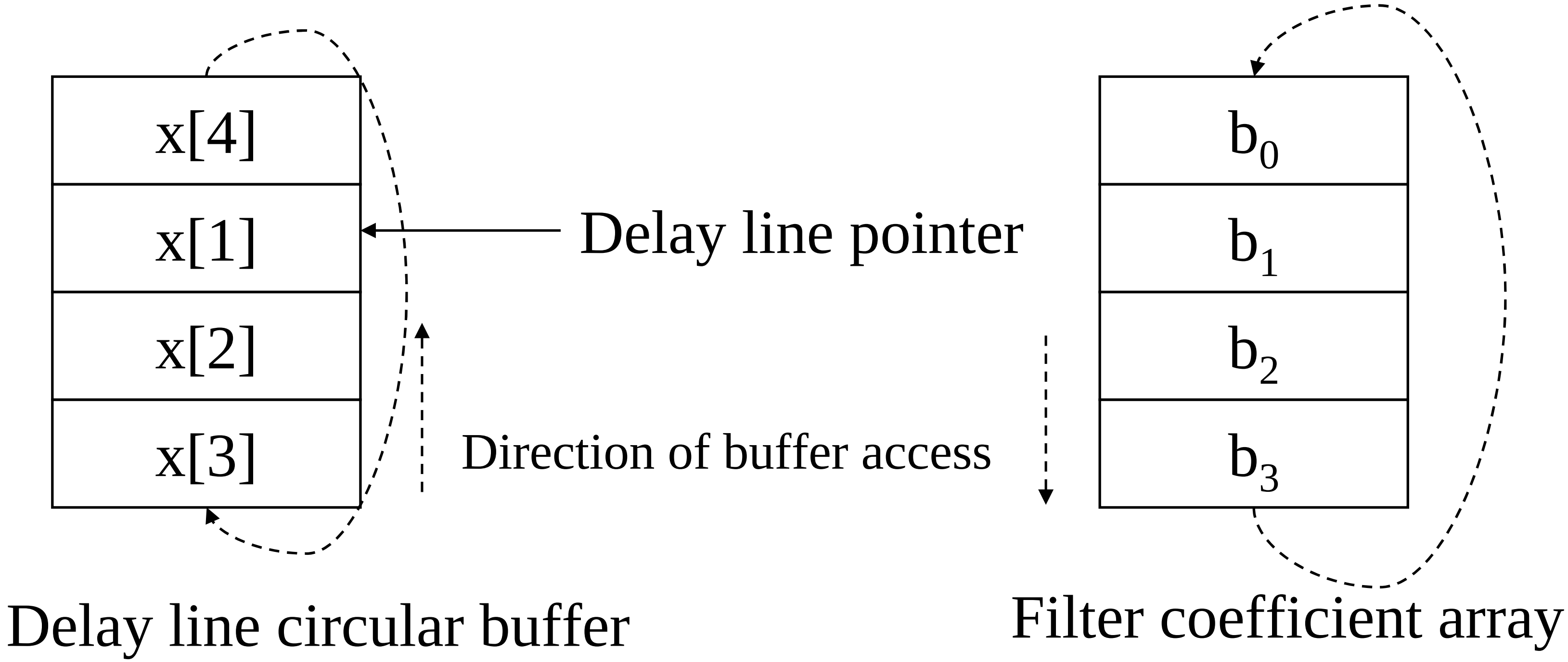
Modulo: FIR Filter Example



Modulo: FIR Filter Example

FIR output for n = 4:

$y[4] = x[4]*b_0+x[3]*b_1+x[2]*b_2+x[1]*b_3$



Zero Overhead Looping

- Two Instructions
  - **REPEAT** for single instruction loops
  - **DO** for multiple instruction loops
- Interruptable
- STATUS register indicates when looping is active

REPEAT Examples

- REPEAT #200
  MOV [W0--], [W1]++

- REPEAT W8
  CLR [W5]++

- REPEAT #0x20
  ADD A, [W3++]

Nested DO Example

```
        DO    LOOP1, #0x100
        MOV   [W0], W1
        AND   #0x3FF, W1
        DO    LOOP2, #0x8
        BTG   W1, #0x9
LOOP2:  IOR   W1, [W2]++, [W3]++
LOOP1:  MOV   W1, [W0]++
```

4 Lines (dsPIC) vs. 31 Lines (16-bit MCU)

dsPIC

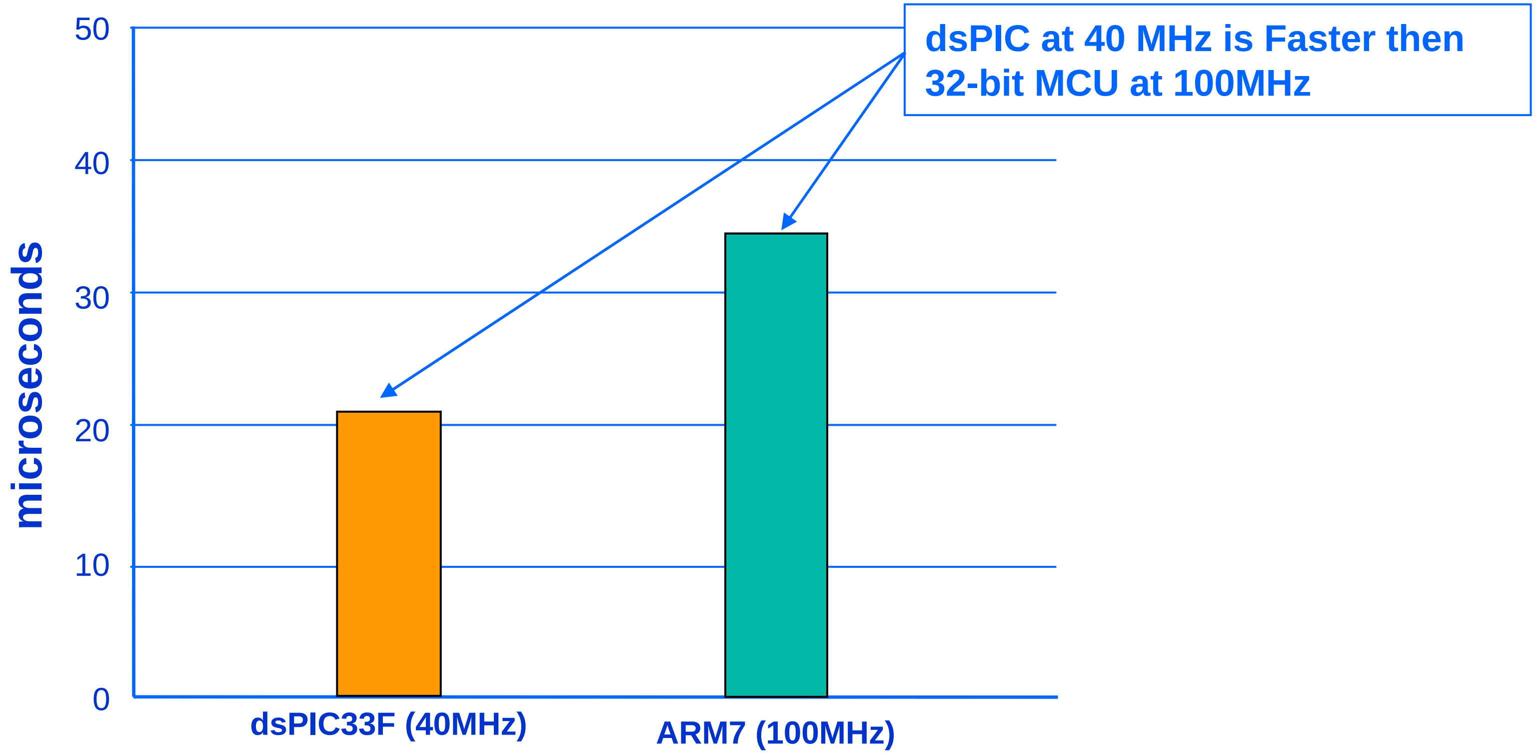
```
repeat  w4
mac     w5*w6,a,[w8]+=2,w5,[w10]+=2,w6
mac     w5*w6,a,[w8]+=2,w5,[w10],w6
mac     w5*w6,a
```

16-bit MCU

```
do_again1:
        mov   R6,[R5]    ;Get next x(n-I)
        mov   R7,[R12+]  ;Get next FIR filter coeff-a(i)
        mul   R6,R7      ;Form product a(I)*x(n-I)
        jmpr  cc_NV,copyl              ;Test for only 16 bit result
        mov   R9,MDH     ;Move high portion of MD
copy1:
        mov   R6,MDL     ;Move low portion of MD
        add   R11,R6     ;acc. Product terms in R10 and R11
        addc  R10,R9
        sub   R5,#2      ;Point to a next item in x(n-I)
        cmp   R5,R13     ;Chk if ptr falls out of circ buffer table
        jmp   cc_NN,leap1              ;If still in table keep going otherwise
                                       ;adj. Ptr. To top of table
        mov   R4,R2
        shl   R4,#1
        add   R5,R4      ;adj. Ptr to top of table
leap1:
        add   R1,#1h     ;Determine if all taps computed
        cmp   R1,R2
        jmp   cc_NZ,do_again1
        mov   R4,#curr_ptr
        mov   R5,[R4]
        add   R5,#2h     ;Inc. ptr. Into circ. Buffer
        mov   R3,R2
        shl              R3,#1
        sub              R3,#2
        mov              R6,R13
        add              R6,R3
        cmp              R5,R6         ;Does curr_ptr exceed top of table?
        jmpr             cc_NZ,leap3
        mov              R5,R13        ;Back to beginning of table
leap3:
        cmp              R10,#0h
        jmpr             cc_Z,leap2
```

DSP Benchmark

- **BDTI's Real Block FIR Filter Benchmark**
  - Execution time (lower is better)

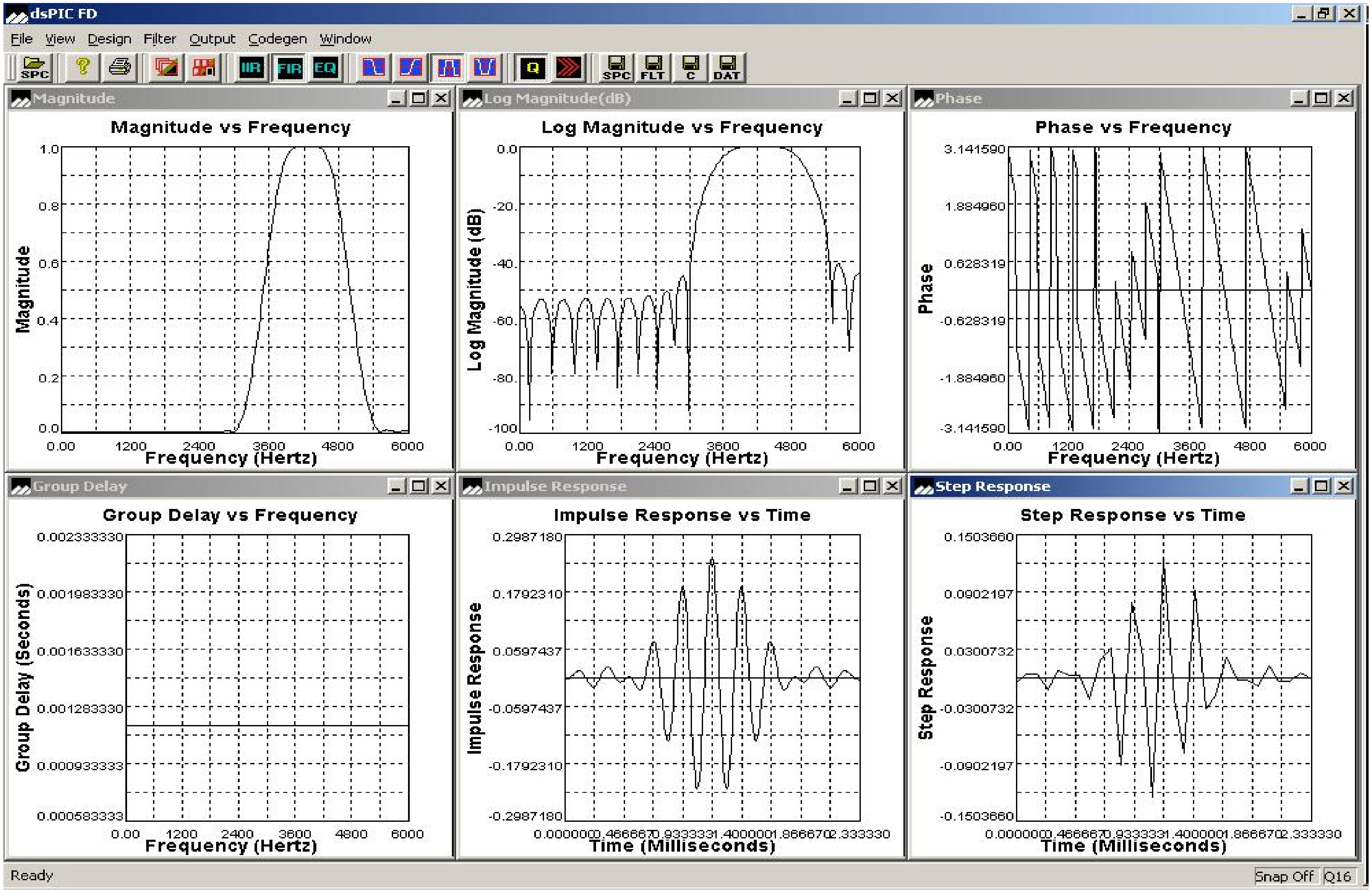


DSP Tools

dsPIC® Digital Filter Design

- **Graphically design all types of digital filters**
  - Low-pass, high-pass
  - Band-pass, band-stop
- **Digital filter algorithm kernels are provided for:**
  - FIR—Finite Impulse Response
  - IIR—Infinite Impulse Response
- **Designing coefficients to control the filter response is the tricky part**
  - You can do the math or use this tool!!
- **Quickly observe filters response**
- **Generated code and coefficients fully compatible with MPLAB® C30 C Compiler language tools**

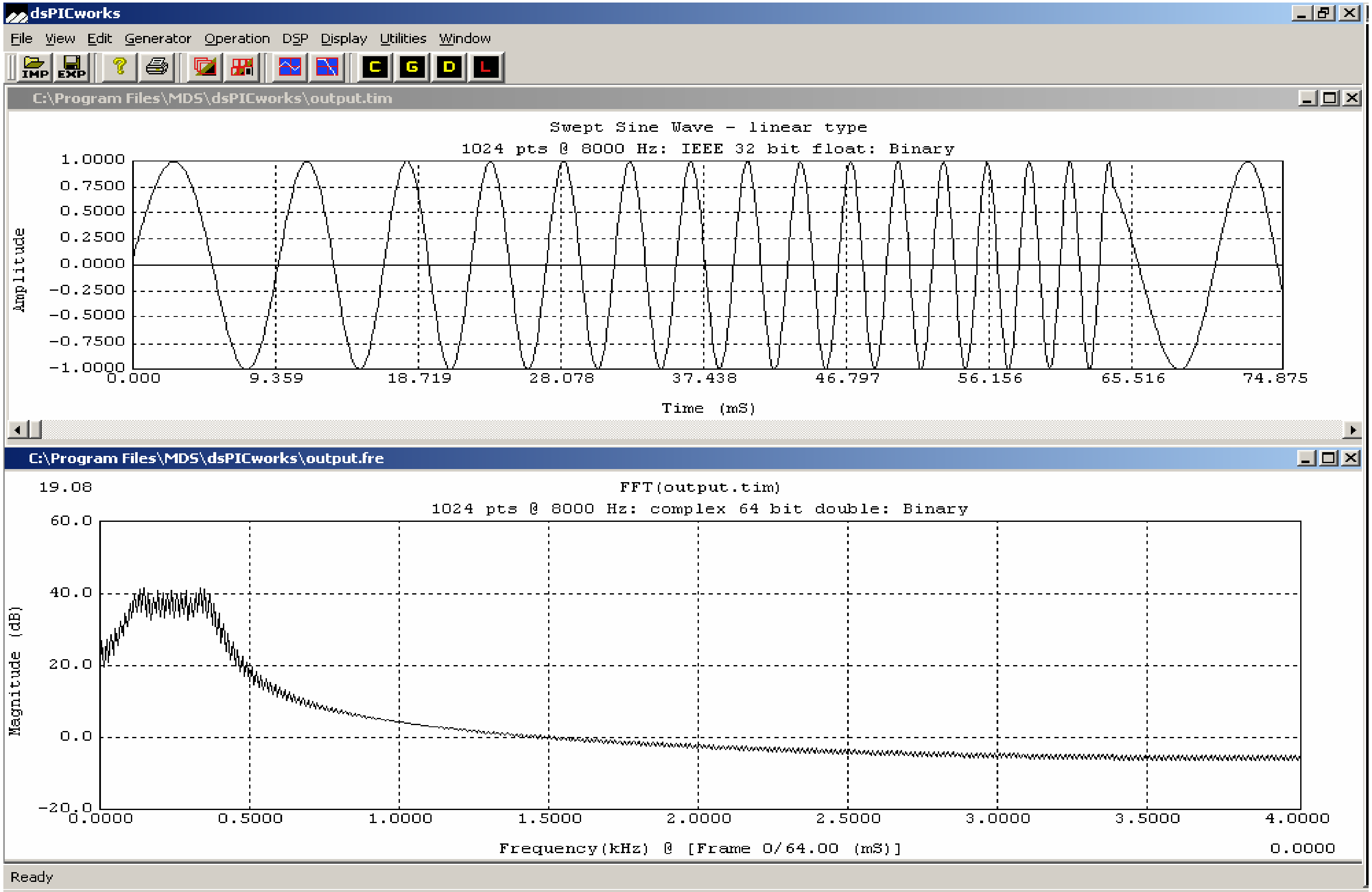
dsPIC® Digital Filter Design



dsPICWorks™ Data Analysis and DSP Software

- **Graphical signal analysis and generation tool**
  - Create waveforms and process them
  - Signal generation
    - **SIN, square, swept SIN, triangular, etc...**
  - Signal operations
    - **Add, Flip and Shift, Multiply, etc...**
  - DSP operations
    - **Filtering, correlation, FFT, LPC analysis, etc...**
- **Designed especially for the dsPIC30F**
  - Import/export data with MPLAB® compatible files
  - Processes filter files saved from dsPIC® Digital Filter Design

dsPICWorks™ Data Analysis



Lab 1

Using DSP Tools and Libraries

Lab 1 – Using DSP

- **Goals**
  - Learn DSP tools and Libraries
- **Lab**
  - Implement signal filtering using FIR fitler

DSP Related Libraries

Math Library

- **Supports all of <MATH.H> from ANSI "C"**
  - Trigonometric Functions
  - Exponent and Log Functions
  - Power, Square Root, Floor(不大于的最大整数), Ceiling(不小于的最小整数), etc.
- **IEEE-754 Compliant**
- **Optimized for code size, developed in Assembly**
- **Supports 2 data types**
  - 32-bit floating point
  - 64-bit double
- **Benefits any application which uses floats/doubles**
- **C and assembly callable**

DSP Library

- **Libraries for your DSP requirements**
- **Collection of 49 of the most common DSP functions**
  - Vector and Matrix Functions
    - **Add, Subtract, Multiply, Max, Min**
    - **Convolution, Correlation, Power, etc...**
  - Filter Functions—block and single sample processing
    - **FIR, IIR, Adaptive LMS(自适应LMS算法), Lattice(格型算法） and more**
  - Transform Functions
    - **FFT, Inverse FFT, Discrete Cosine Transform(离散余弦变换)**
  - Window Functions
    - **Bartlett, Blackman, Hamming, Hanning, Kaiser**
- **Most functions are hand coded in assembly language**
  - Fast execution time, C and assembly callable

Embedded Modem Library

- **Software Modem (soft-modem) Support**
  - Replacing external modem chip with software!
- **Benefits**
  - Single-chip integrated solution (up to 14.4 kbps)
  - Quick dialup and connection times
    - **Perfect for small transactions on analog phone line**
- **Application Examples**
  - Home automation, remote access, security systems
  - POS applications, web-enabled devices
  - Tele-metering, remote upgrades
- **Library supplied with full DTMF Generation/Detection modules**

Soft-Modem Resource Summary

- **dsPIC30F implementation leaves room for other tasks...**

ITU-T Specification	Bit Rate (bps)	RAM (Bytes)	Program Memory (Kbytes)	MIPS
V.32bis	14400	3600	36	15
V.32	9600	3200	31	12
V.22bis	2400	1700	22	7
V.23	600/1200	1000	15	4.5
V.21	300	1000	13	4.5
V.42 (Error Corr.)	na	2000	14	1.5

FREE

Includes DTMF Library

Speech Coding Library

- **Performs speech compression / decompression**
- **Encoder - 16:1 compression ratio**
  - Speech input: 8 KHz, 16-bit mono
  - Encoded output: 8kbps data stream
- **Decoder**
  - Decoder input: 8 kbps data stream
  - Speech output: 8 KHz, 16-bit mono
- **Based on Speex**
  - Open source technology
  - Numerous PC plug-ins / apps readily available
  - www.speex.org
- **Includes PC Utility for making “playback” files**

Speech Coding Library How may it be used?

- **By any application with voice communication**
- **Benefits**
  - Reduces communication bandwidth
  - Reduces storage requirements
- **Sample Applications**
  - Digital radios / walkie-talkies
  - Answering machines / voice recorders
  - Playback-only systems
    - **Security Systems (building evacuation)**
    - **Museum Guides**
    - **Application Voice Prompts**

Speech Coding Library Resource Requirements

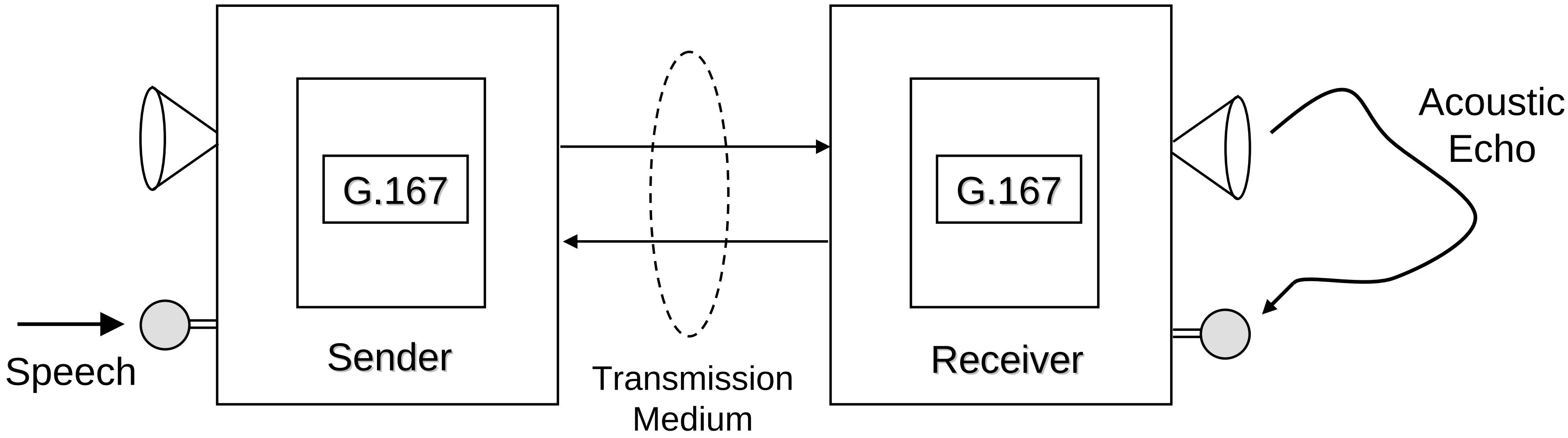
- **Small Decoder footprint / Encoder is RAM intensive**

	Encoder	Decoder
MIPs	19	3
RAM	5.4 KB	3.2 KB
Flash	33 KB	15 KB

- **2 analog interfaces supported**
  - **Silicon Labs Si-3000 Codec**
  - **Alternate interface for cost-sensitive applications**
    - **ADC for microphone input**
    - **Output compare for speaker output**
    - **Sample circuits provided in User's Guide**

Acoustic Echo Cancellation Library

- **Provides 'far-end' echo cancellation**
  - Speaker output is picked up by the local microphone and transmitted back to the sender
- **Features**
  - G.167-compliant algorithm (up to 64 msec)
  - Supports full-duplex operation



Acoustic Echo Cancellation Library

- **G.167 CPU Resources**

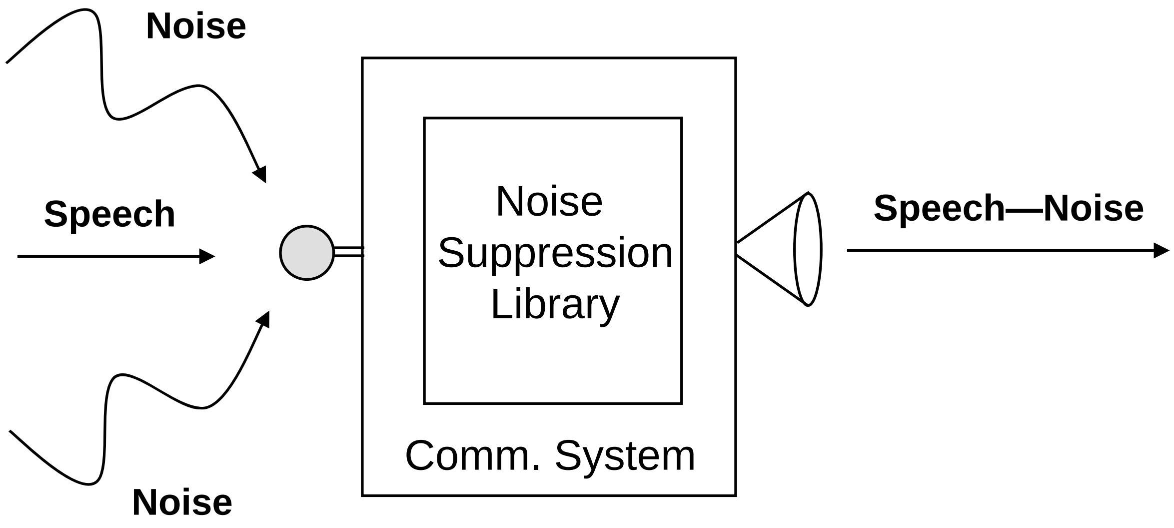
Echo Delay	RAM (KB)	Program Memory (KB)	MIPS
16 msec	4.6*	6	7.5
32 msec	5.4*	6	10.5
64 msec	7.7*	6	16.5

* Includes up to 2KB for CODEC and UART buffers and *A*/*U*-law compression

- **Target Applications**
  - Speakerphone
  - Hands-free car phone
  - Intercom
  - Emergency alarm units

Noise Suppression Library

- **Removes extraneous noise picked up by microphone**
  - Voice activity detector differentiates noise and speech
  - Noise reduction filters adjust every 10 ms during periods of speech inactivity (uses FFT analysis)
  - Speech is continuously filtered, reducing noise



Noise Suppression Library

- **Noise Suppression CPU Resources**
  - 3.3 MIPS
  - 5 Kbytes Flash memory
  - 2 Kbytes RAM
    - **Includes up to 1 Kbyte for buffering Codec data**
- **Target Applications**
  - Front end for any voice based system
    - **Headsets**
    - **Hands-free telephone**
    - **Intercom**
    - **Speech recognition**
    - **Speech coding**

Embedded Encryption Libraries

- **dsPIC30F Symmetric Key Library**
  - Message Digests: SHA-1, MD5
  - Symmetric Key Encryption: T-DES, AES
  - Deterministic Random Bit Generator: ANSI X9.82
- **dsPIC30F Asymmetric Key Library**
  - Signing and Verification: RSA, DSA
  - Public Key Encryption: RSA
  - Key Agreement Protocol: Diffie-Hellman
  - Big Integer Arithmetic Package

Embedded Encryption Applications

- **Secure Web Transactions**
  - Secure web access (SSL/TLS)
  - E-mail (S/MIME), secure XML transactions, and Virtual Private Networks (IPsec)
- **Smart Card Readers**
- **PDAs and other mobile devices**
- **Secure communications between a dsPIC® DSC application and personal computers**
  - Trusted Computing Group (TCG)
  - Microsoft® Next Generation Secure Computing Base (NGSCB)

Summary

- We learned advantages of dsPIC DSP architecture
- We learned DSP tools and libraries available for dsPIC

References

- dsPIC30 & dsPIC33 Datasheet
- dsPICDEM1.1 User’s Guide
- MPLAB® IDE
- C30 Compiler
- ICD2 In Circuit Debugger

All Done!

Thank you all for attending

Please remember the evaluation sheets

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