11095 SPH

G.726A and G.711

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UNIVERSITY OF MICROCHIP U OF M MASTERs 2007

Agenda

- **Speech Coding Overview**
- **Speech Coding Solutions**
- **G726A**
  - Basic Idea into working of the Algorithm
  - Data Structures and Library API
  - LAB #1 and #2
    - With **ADC/PWM PICtail™ Plus** Daughter Board
    - With **dsSPEAK™** Speech Processing Reference Design Board
- **G711**
  - Basic Idea into working of the Algorithm
  - Data Structures and Library API
  - LAB #3
    - with **ADC/PWM PICtail Plus** Daughter Board

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Learning Objective

When you finish this class you will:

- **Understand features of G711 and G726A speech processing solutions**
- **Look at some common applications**
- **Learn how to use the software functions and demos**

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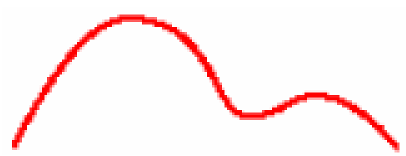
Speech Coding Overview

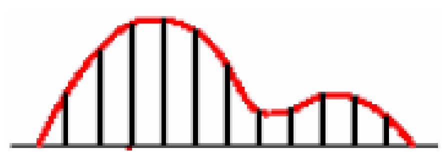
- **Data compression – speech**
- **Standard PCM encoding of analog signals**
  - 8 KHz sampling rate – 8-16 bits/sample
  - Requires 64-128 Kbps

Analog Signal



Upto 4000 Hz

Sampled Signal



Upto 8000 Hz

Digital Word

10111000

8-bit PCM word

8 bits x 8000 samples = 64 Kbps

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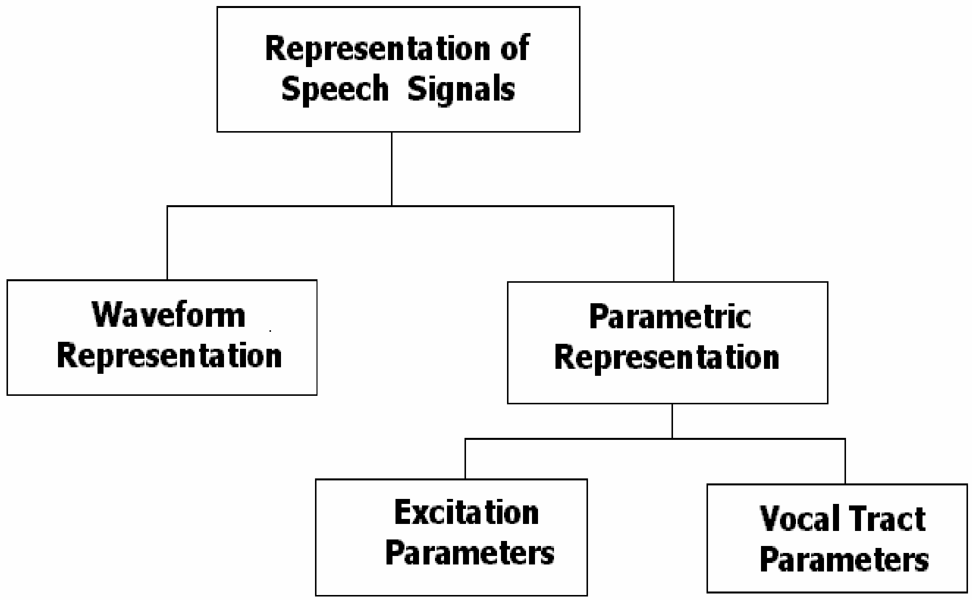
Representation of Speech Signal



- **Waveform representations** are concerned with simply preserving the wave shape of the analog speech.
- **Parametric representations** are concerned with representing the speech signal as the output of a model for speech production

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Waveform Coders

- Waveform coders encode the shape of the waveform
- Faithful reconstruction of the time-domain waveform
- Non-speech specific coders, represent nonspeech sounds (music, background noise).
- Operate at medium-rates
- Examples: PCM,DPCM,ADPCM, Mu/A law

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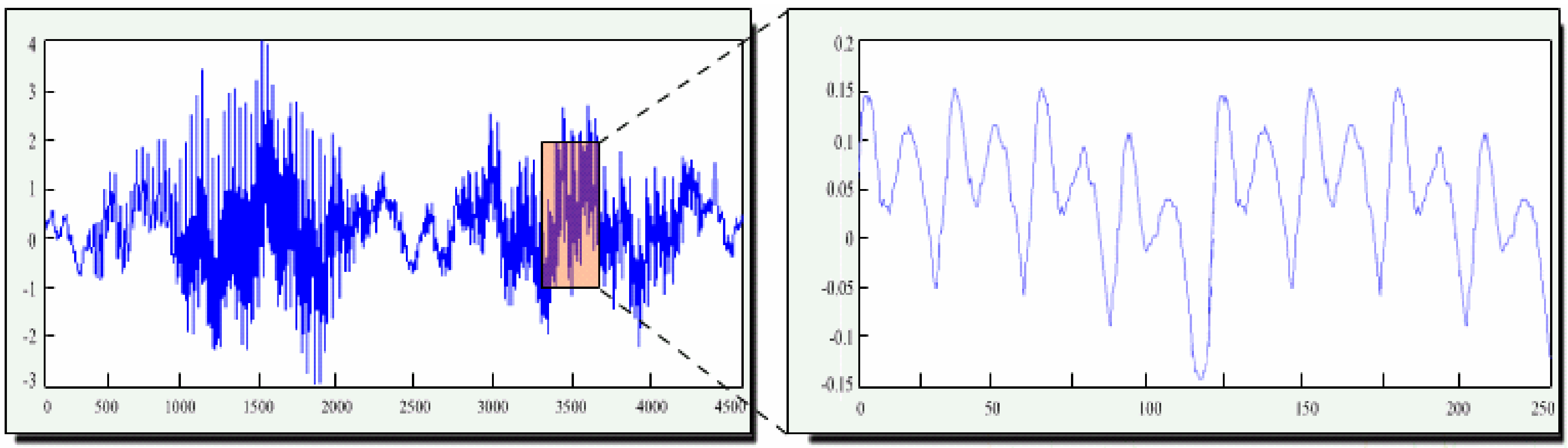
Parametric Coders



- Speech specific Coders (VOCODERS)
- Speech though random, consists of quasi-stationary signals (Voiced Sounds)
- Parameters of the voiced portion sent instead of the whole waveform
- Compression rates as low as 4 Kbps have been achieved
- Examples: CELP, ACELP

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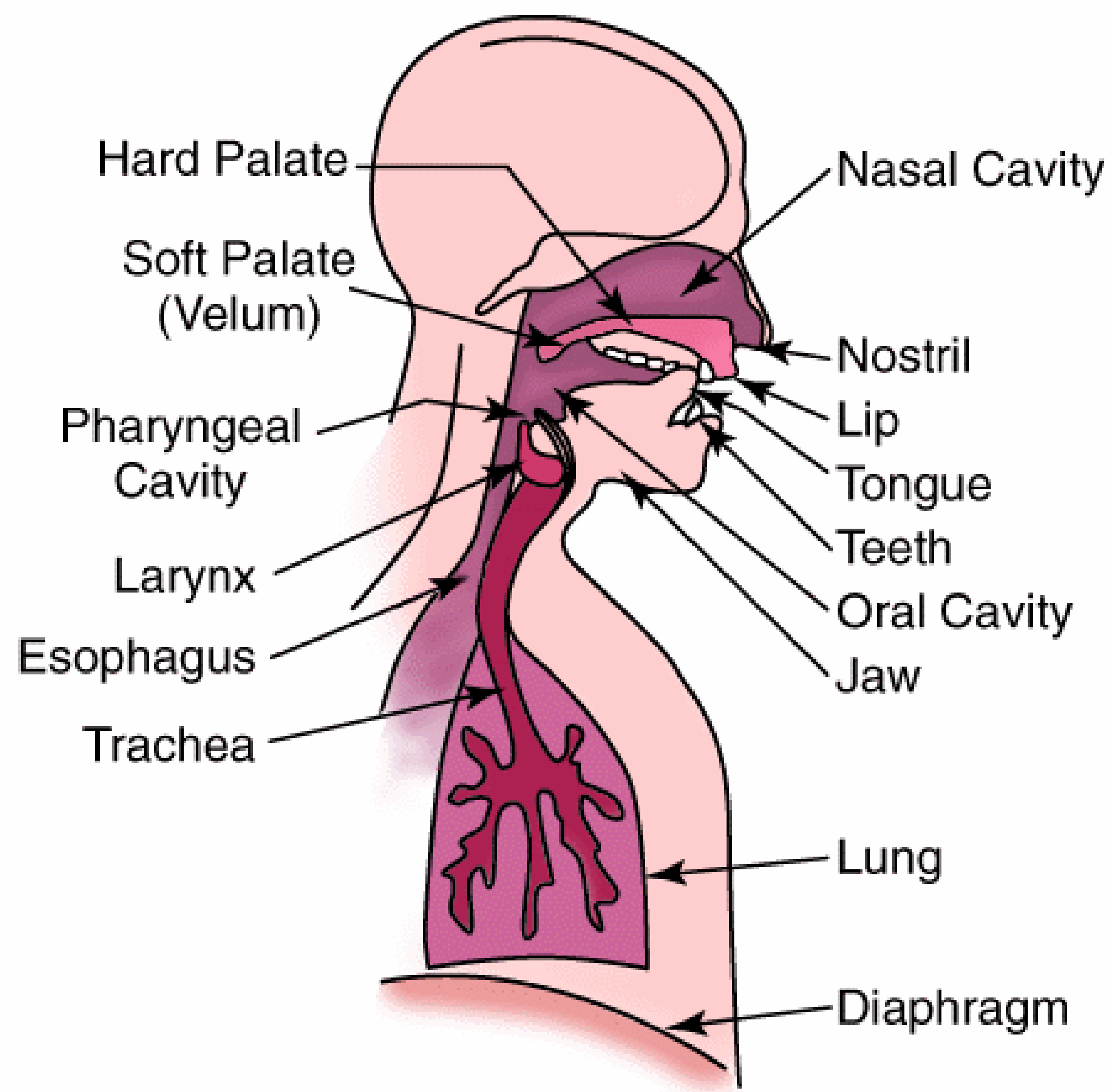
Know Your Vocal Apparatus



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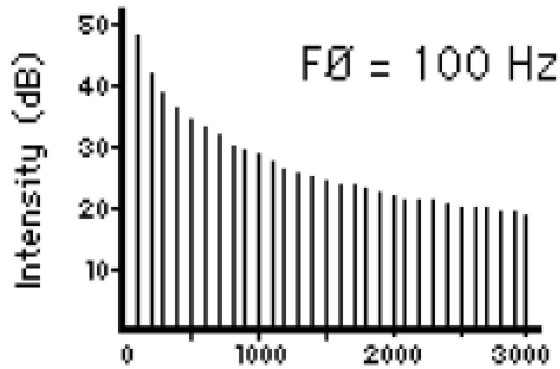
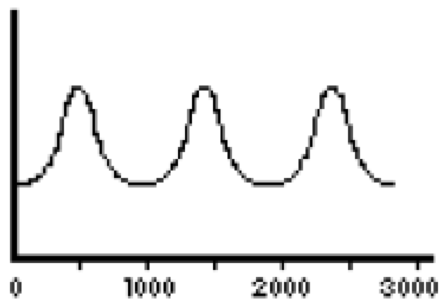
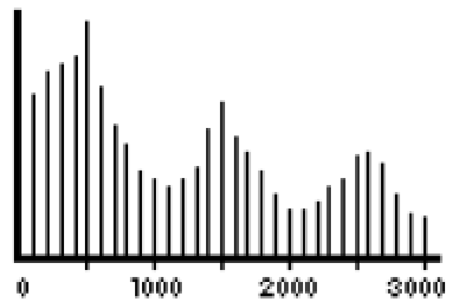
Know Your Vocal Apparatus



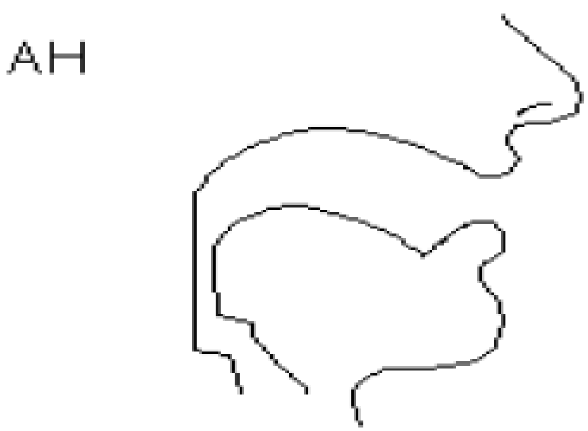
Source spectrum

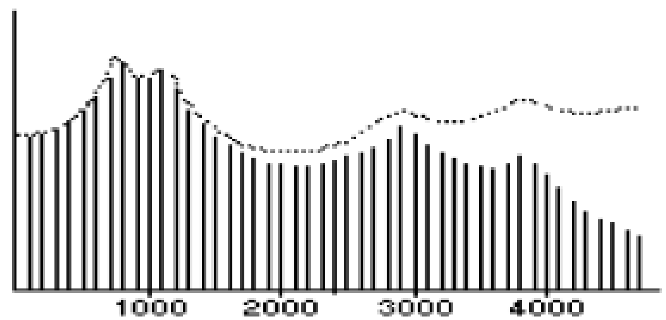


Filter Function



Output Spectrum





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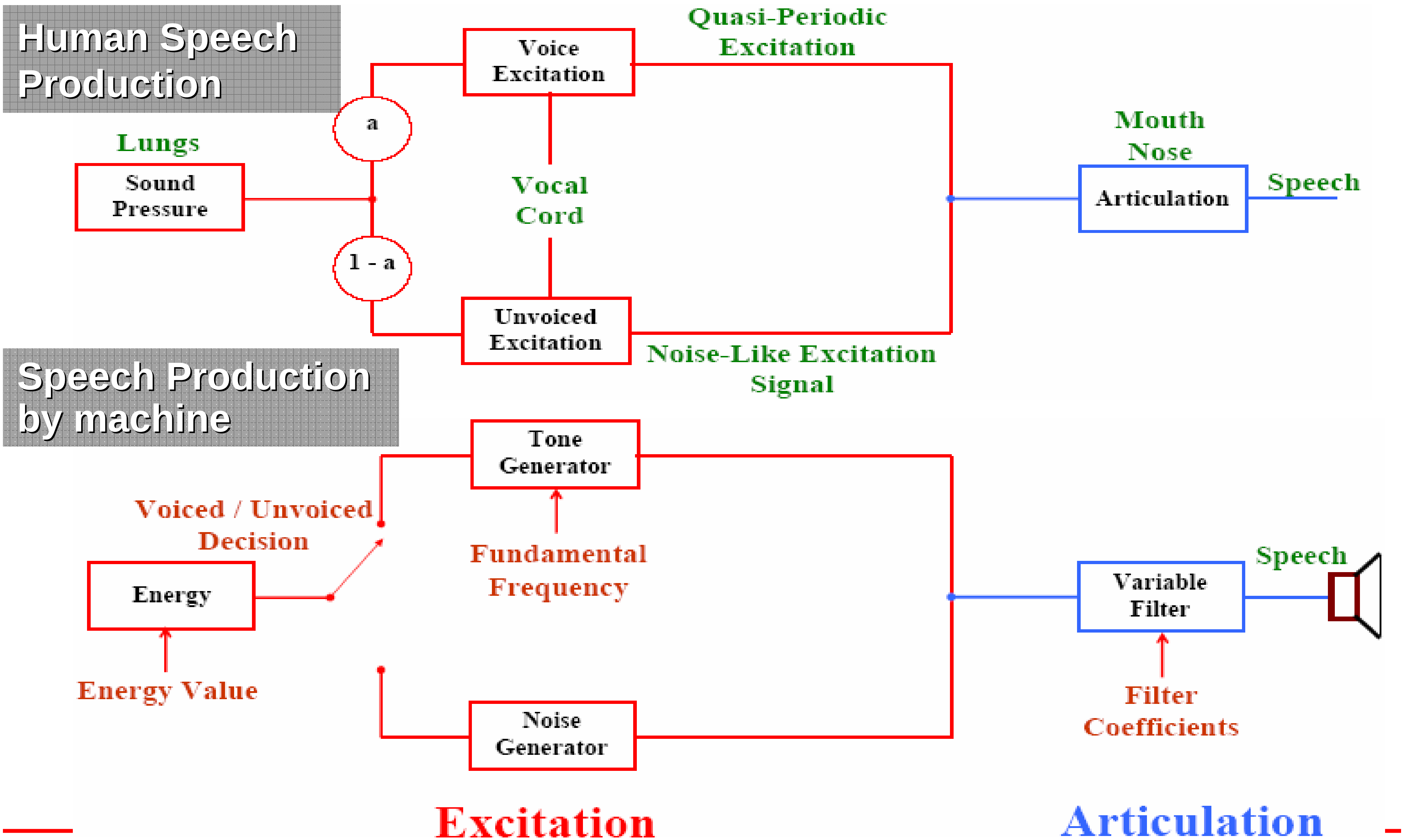
Model Based Coders



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Speech Coding Solutions

- **Speech Compression (**Encoding**)**
  - Reduce amount of data required to represent a speech signal, thus reducing communication or storage requirements
- **Speech Decompression (**Decoding**)**
  - Reconstruct original speech signal from compressed data
- **Suite of speech coding solutions**
  - Speex, G.726A, G.711
  - G.711 also supports PIC24H/PIC24F

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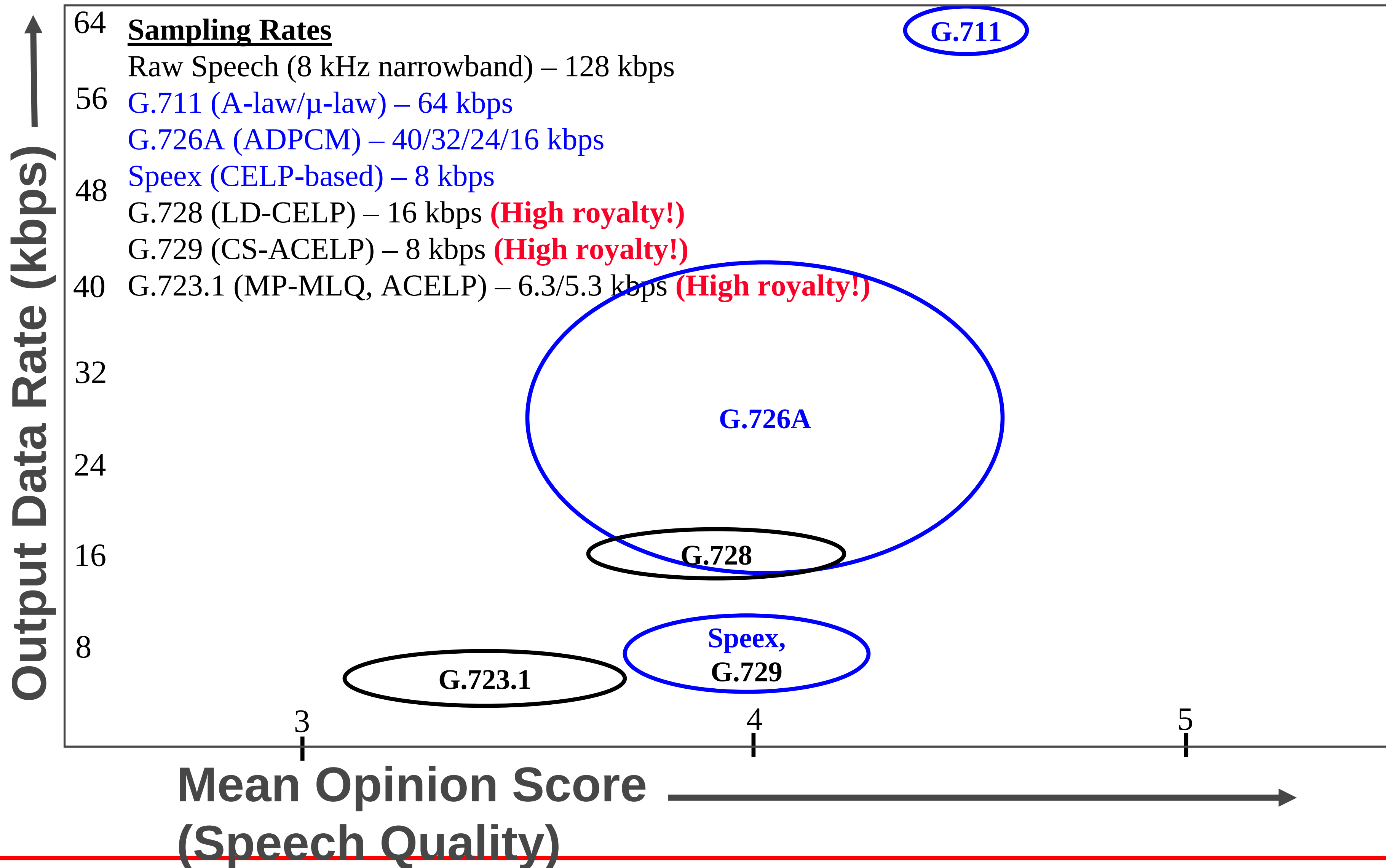
Speech Coding Solutions



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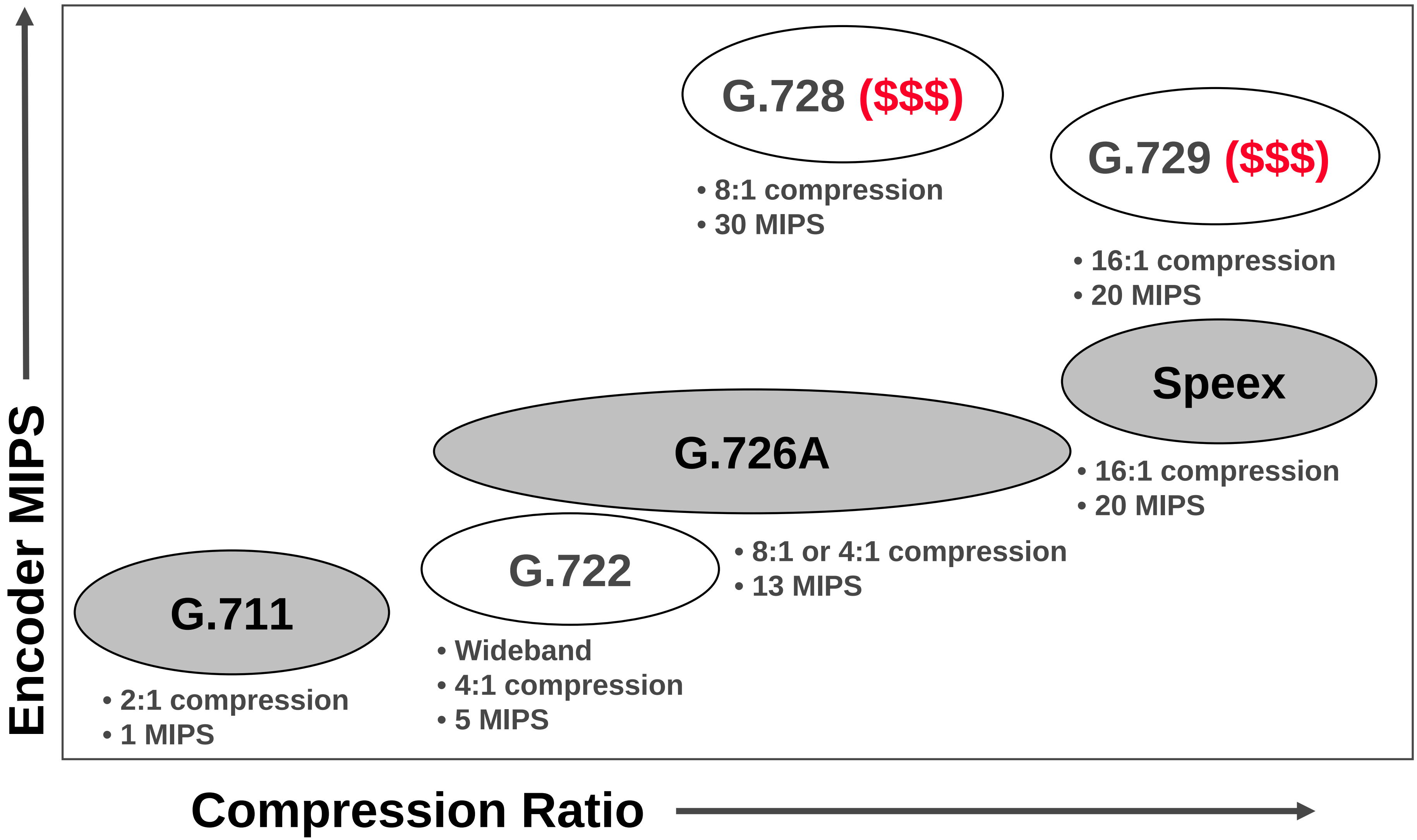
Speech Coding Solutions



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Why use dsPIC® DSC for Speech Processing?

- **High processor speed (40 MIPS)**
- **DSP instructions, bit manipulation and data shifting**
- **Fast, deterministic interrupts**
- **Peripherals**
  - Codec interface (DCI)
  - ADC and PWM for alternative low-cost speech I/O interfaces
  - Serial Peripheral Interface (SPI) to transmit and receive compressed data

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Speech Coding Solutions Resource Requirements

	G.711	G.726A	Speex
MIPS	1	13	20
Flash (KB)	3.5	6	30
RAM (KB)	3.5	4	7

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Speech Coding Benefits and Applications

- **Benefits**
  - Reduces communication bandwidth
  - Reduces storage requirements
- **Sample Applications**
  - Communication Systems (full-duplex)
    - Digital radios and walkie-talkies
    - Voice-over-IP phones
  - Record-and-Playback Systems (half-duplex)
    - Answering machines and voice recorders
  - Playback-only Systems (simplex)
    - Toys, security systems (building evacuation), museum guides

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How to Obtain the Libraries?

- **Order from *buy.microchip.com***
  - 3-tiered Library Pricing for each library
    - **$2500 for 5,000 unit license**
    - **$4950 for 25,000 unit license**
    - **$9750 for 100,000 unit license**
  - Free Evaluation License, full-feature package
  - G.711 library is Free

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Speech Coding Solution #1

G.726A Speech Coding Library

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Overview

- **Based on Adaptive Differential Pulse Code Modulation (ADPCM)**
  - ITU-T standard, but no royalties!!
  - Similar to G.726, but no G.711 needed
  - Very popular for medium data rates
- **Mean Opinion Score (MOS):**
  - 4.5 (40 kbps)
  - 4.4 (32 kbps)
  - 4.1 (24 kbps)
  - 3.4 (16 kbps)

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Differential PCM

- **Motivation:**
  - The motivation is that the differenced signal has a smaller amplitude swing compared with the original signal
  - Reduces data by encoding a difference signal instead of input signal
  - The difference is obtained by subtracting the estimate (Prediction) of the Input signal from the Input Signal

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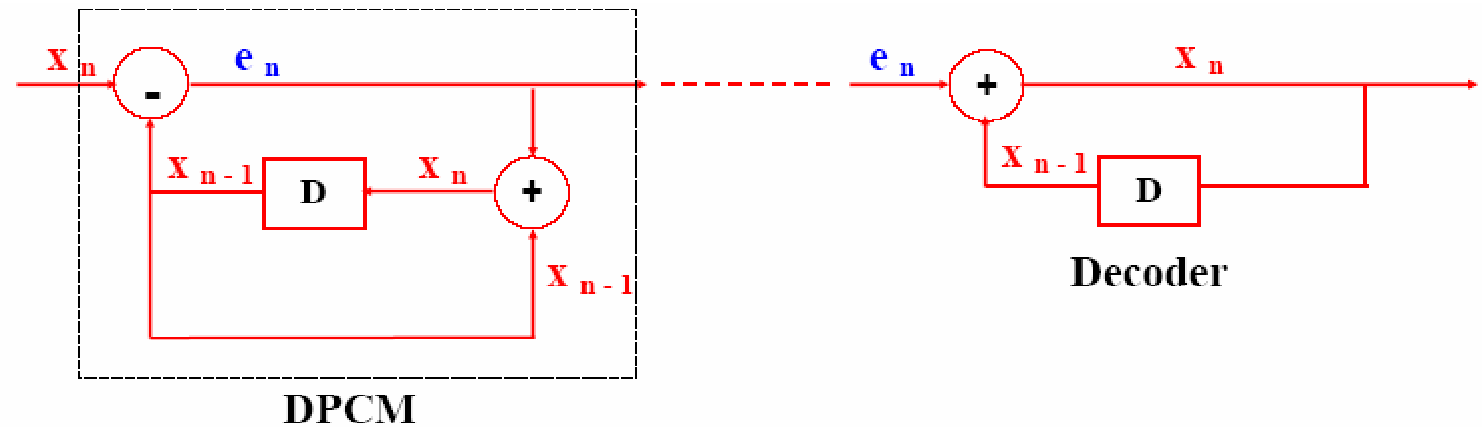
First Order Prediction



- **Encoding**

$$x_1\ x_2\ \ldots\ \ldots\ x_N \longrightarrow e_1\ e_2\ \ldots\ \ldots\ e_N$$

$$e_1 = x_1 \qquad e_n = x_n - x_{n-1}, \qquad n=2,\ldots,N$$

- **Decoding**

$$e_1\ e_2\ \ldots\ \ldots\ e_N \longrightarrow x_1\ x_2\ \ldots\ \ldots\ x_N$$

$$x_1 = e_1 \qquad x_n = e_n + x_{n-1}, \qquad n=2,\ldots,N$$

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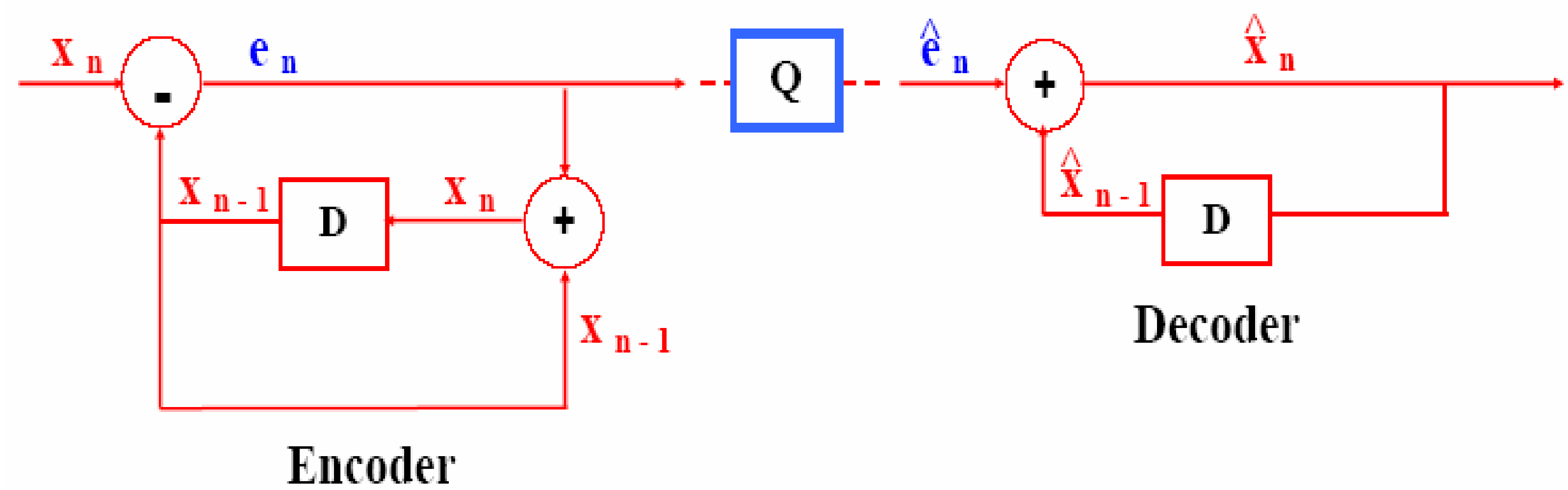
Prediction Meets Quantization

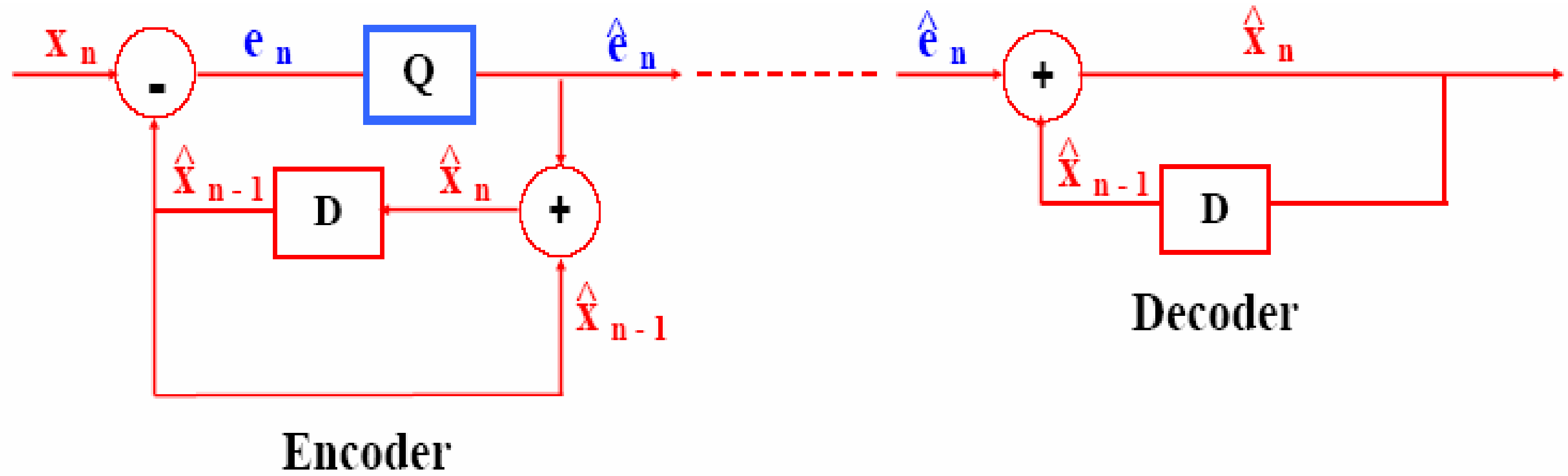
- **Open-Loop DPCM**



  - Quantization is located outside the DPCM loop
  - Prediction is based on the past unquantized sample

Prediction Meets Quantization

- **Closed-Loop DPCM**



X_n, e_n: unquantized samples and prediction residues

$\hat{X}_n$, $\hat{e}_n$: decoded samples and quantized prediction residues

- Quantization is located inside the DPCM loop
- Prediction is based on the past decoded sample

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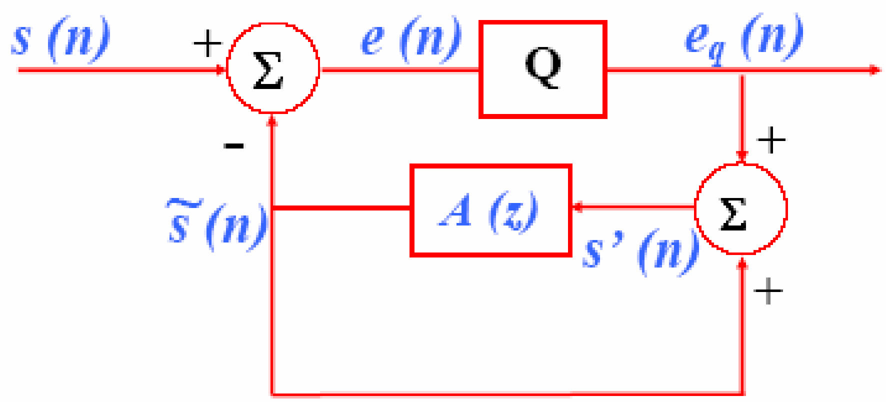
DPCM Encoder



Encoder

$$A(z) = \sum_{i=1}^{P} a_i Z^{-i}$$

Digital Filter operating as a Linear Filter

$$\check{S}(n) = \sum_{i=1}^{P} a_i S'(n-i)$$

Current Sample is predicted by a linear combination of 'P' past samples

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G.726A Algorithm

- **Feedback-based ADPCM technique**
- **Two Adaptive Predictor Structures used**
  - Sixth order section that models Zeros
  - Second order section that models Poles
- **Adaptive Quantizer used**
  - 31, 15, 7 or 4 quantization levels (5, 4, 3 or 2 bits per sample)
  - Standardized lookup table

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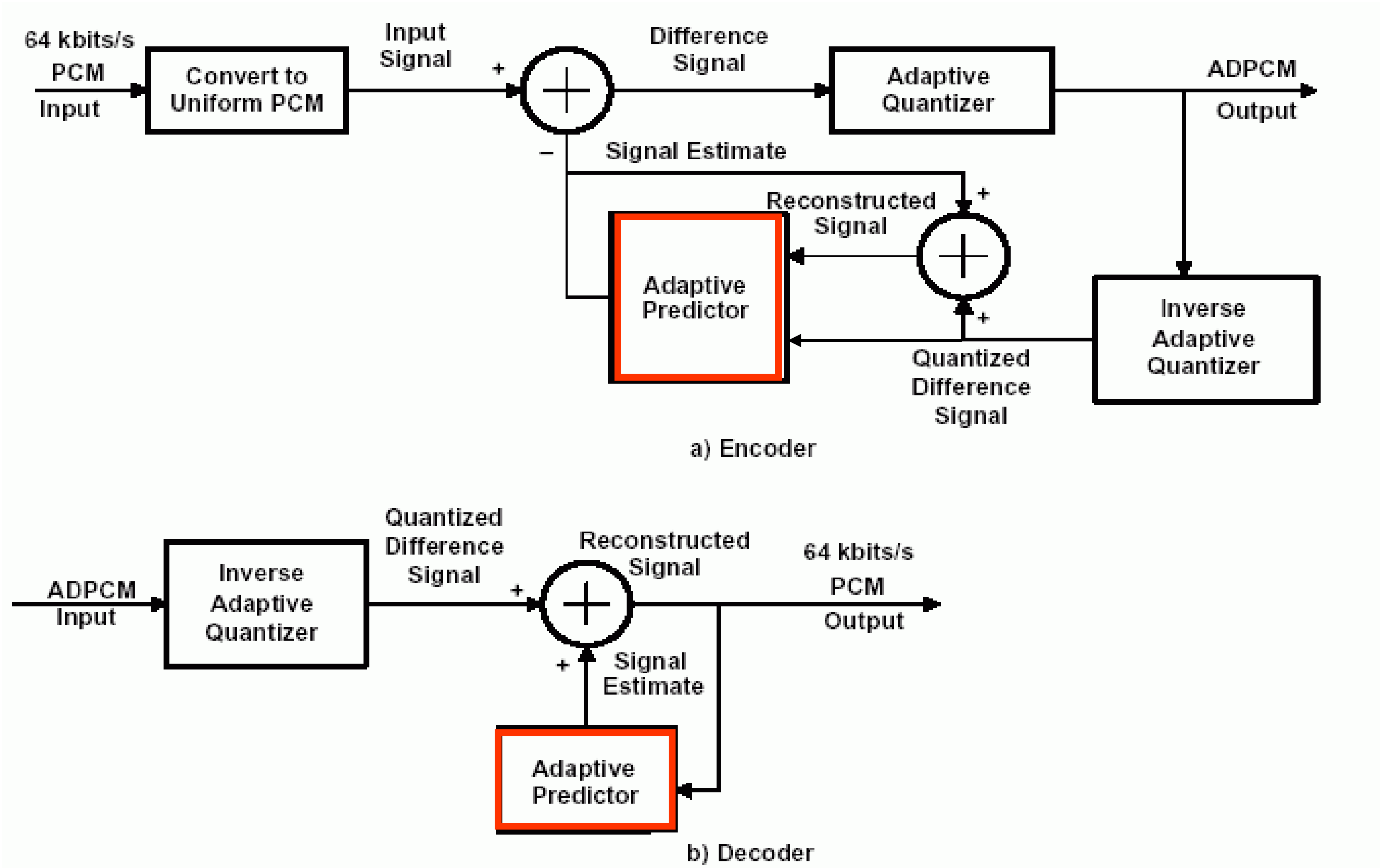
ADPCM (G726A)



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G.726A Speech Coding Library Overview

- **Encoder**
  - Compression ratio: 3.2:1, 4:1, 5.33:1 or 8:1
  - Speech input: 8 kHz, 16-bit mono
  - Encoded output: 40/32/24/16 kbps
- **Decoder**
  - Decoder input: 40/32/24/16 kbps
  - Speech output: 8 kHz, 16-bit mono

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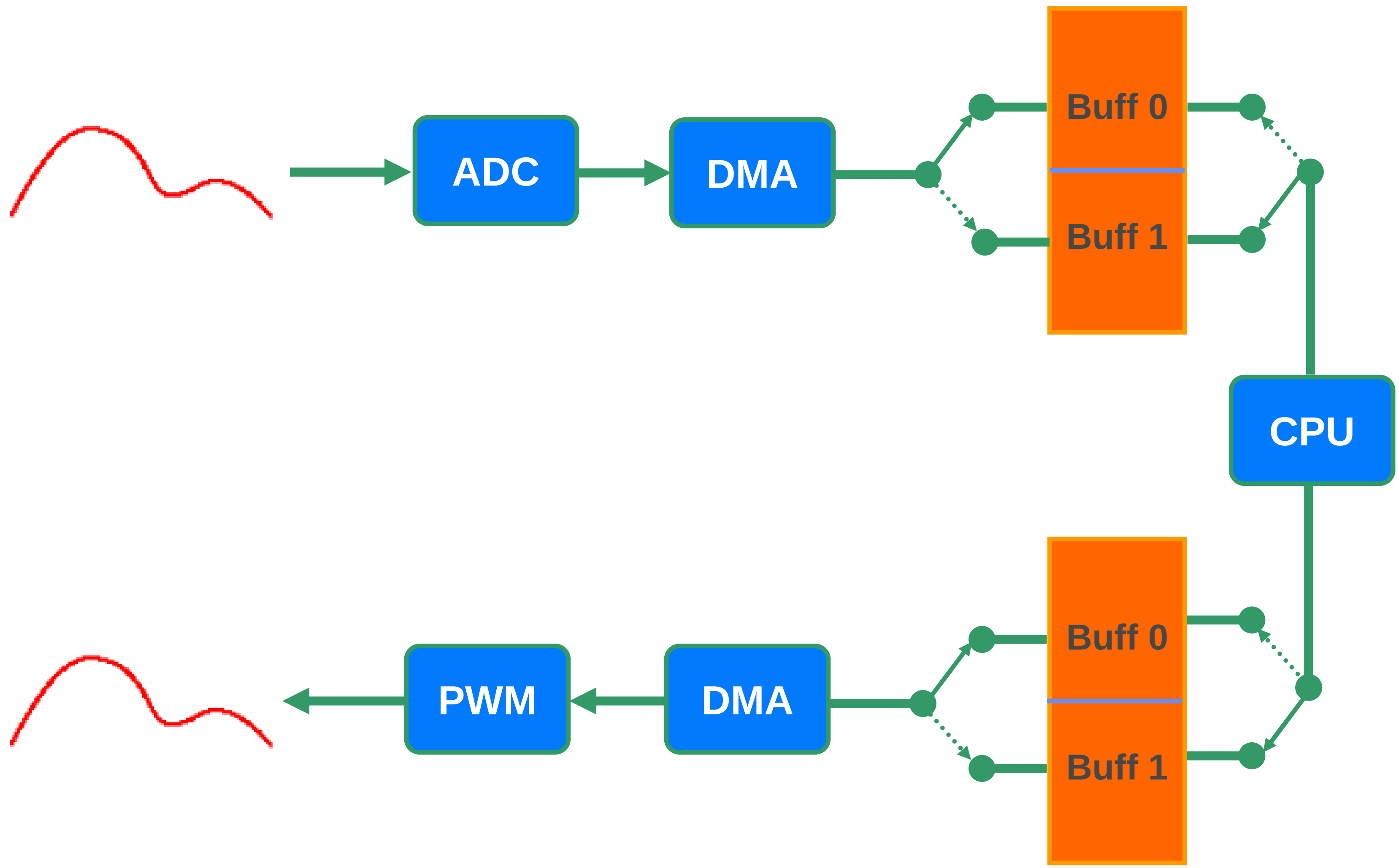
Loopback with ADC/PWM



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Data Structures

- Structure "*sADCChannelHandle*" contains user-defined speech buffer pointers and synchronization flags

sADCChannelHandle Structure:

```
– typedef struct sADCChannelHandle {
        int * buffer1;
        int * buffer2;
        volatile int bufferIndicator;
        volatile int isReadBusy;
  } ADCChannelHandle;
```

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Encoder Data Buffers

- **Encoder Data Buffer usage**

Buffer	Frame 0 (32 msec)	Frame 1 (32 msec)	Frame 2 (32 msec)	Frame 3 (32 msec)
Buffer1	Filled by DMA	Processed by library	Filled by DMA	Processed by library
Buffer2	Idle	Filled by DMA	Processed by library	Filled by DMA

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Alternate Sampling Interface

- **On-chip ADC**
  - Reduces system cost
  - 12-bit dynamic range
  - Good intelligibility

- **Initialization**
  - ***ADCChannelInit ( )***
    - **Initializes** DMA0 **,**12-bit ADC **&** Timer3 **modules.**
    - ***ADCChannelInit*** *(ADCChannelHandle * pHandle,int * pBufferInDMA);*

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Alternate Sampling Interface (*cont….)*

- *ADCChannelStart( )*
  - **Enables the** ADC**,** DMA0 **and** Timer3 **modules.**
  - ***ADCChannelStart*** *(ADCChannelHandle * pHandle);*
  - *AD1CON1bits.ADON = 0x01;* //Enable A/D //converter module

- **Synchronization**

  - *ADCChannelIsBusy ( )*
    - Polls the *isReadBusy* flag to check if a new frame is available
    - ***ADCChannelIsBusy(****ADCChannelHandle * pHandle****);***

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G726A Encoder API

- The G726A Encoder is initialized by calling the *G726_encoder_init()* function with the desired input bit-rate and the address of the instantiation of *G726_state* structure.

```
G726_state  encoder_state;

G726_encoder_init ( &encoder_state, codecdata.rate );
```

- Speech Encoding is performed by the *G726_encode( )* function.

```
G726_encode( codecdata.sampleOpBuffer,
             codecdata.sampleEncodeIpBuffer,
             slen, codecdata.rate, &encoder_state );
```

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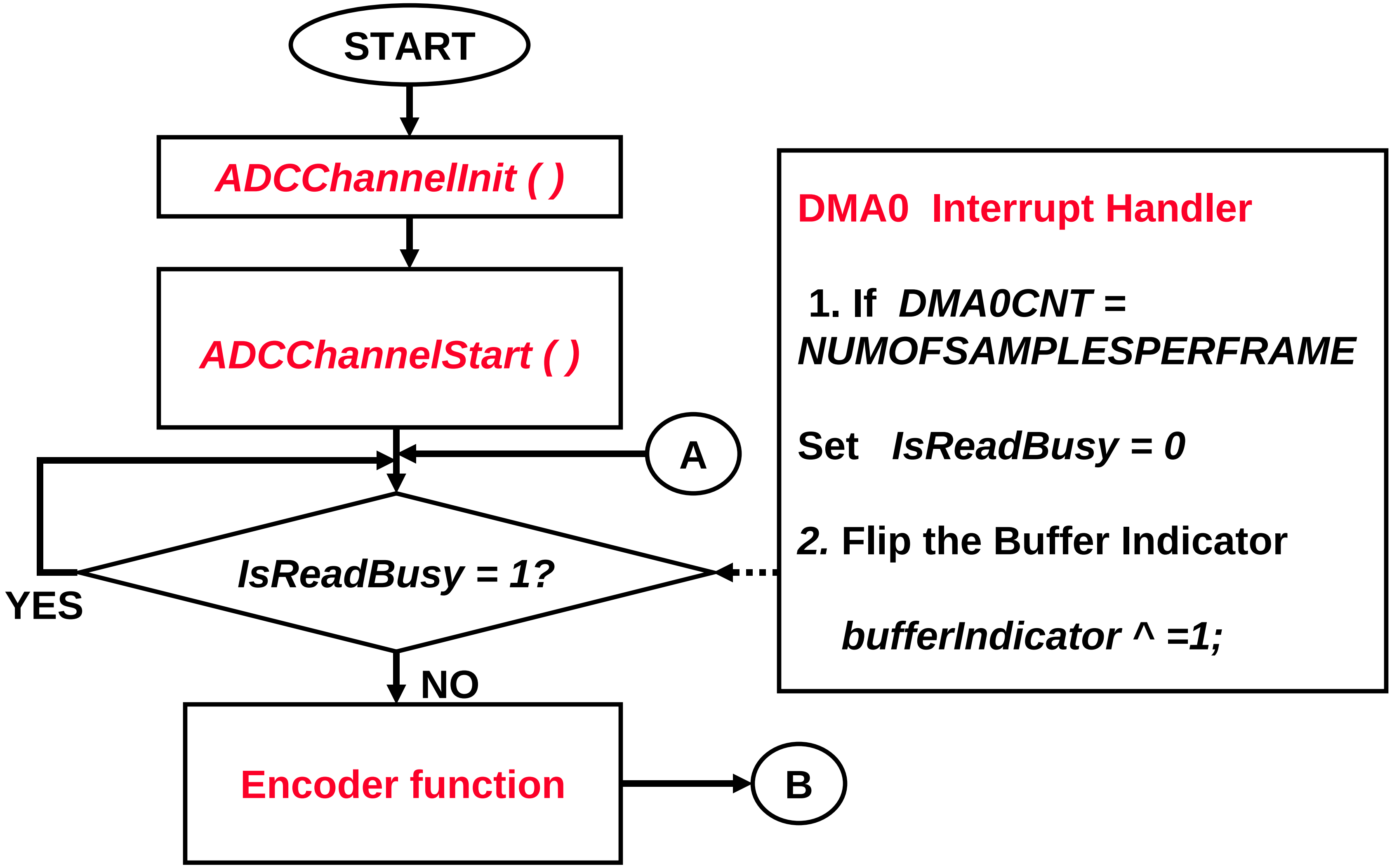
Encoder Application Flowchart



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Data Structures

- Structure "*sOCPWMHandle*" contains user-defined speech buffer pointers and synchronization flags

sOCPWMHandle Structure:

```
typedef struct sOCPWMHandle {
        int * buffer1;
        int * buffer2;
        volatile int bufferIndicator;
        volatile int isWriteBusy;
}OCPWMHandle;
```

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Alternate Playback Interface

- **On-chip Output Compare**
  - Reduces system cost
  - Pulse-Width Modulation (PWM) mode

- **Intialization**
  - ***OCPWMInit( )***
    - Initializes **DMA1** and **Timer2** module.
    - ***void OCPWMInit(****OCPWMHandle * pHandle,int * pBufferInDMA****);***

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Alternate Playback Interface (*cont….)*

- *OCPWMStart( )*
  - Enables **DMA1**, **Output compare** and **Timer2** module.
  - ***void OCPWMStart(****OCPWMHandle * pHandle****);***
  - ***OC1CON= OCCON_WORD;*** ***/* Turn module on */***

- **Synchronization**
  - *OCPWMIsBusy ( )*
    - Polls the *isWriteBusy* flag to check if a new frame is available
    - ***OCPWMIsBusy(****OCPWMHandle * pHandle****);***

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G726A Decoder API

- The G726A Decoder is initialized by calling the *G726_decoder_init()* function with the desired input bit-rate and the address of the instantiation of *G726_state* structure.

  G726_state *decoder_state**;***

  G726_decoder_init (*&decoder_state, codecdata.rate* ***);***

- *G726_decode( )* function is called to perform decoding.

  G726_decode (*codecdata.sampleEncodeOpBuffer,*
  codecdata.sampleDecodeIpBuffer,
  slen, codecdata.rate,&decoder_state ***);***

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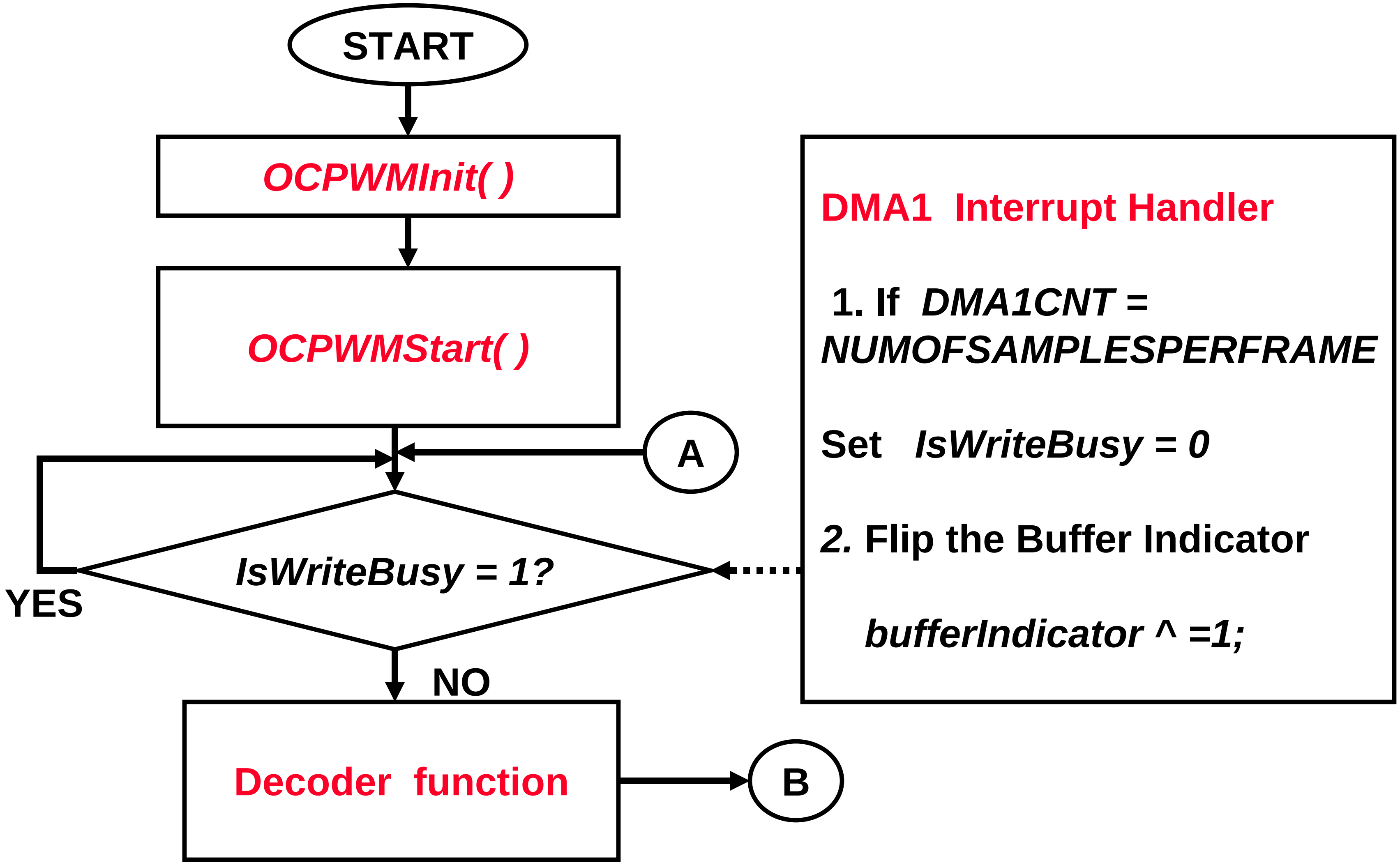
Decoder Application Flowchart



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Hands-on LAB #1

Loopback with ADC/PWM using G.726A

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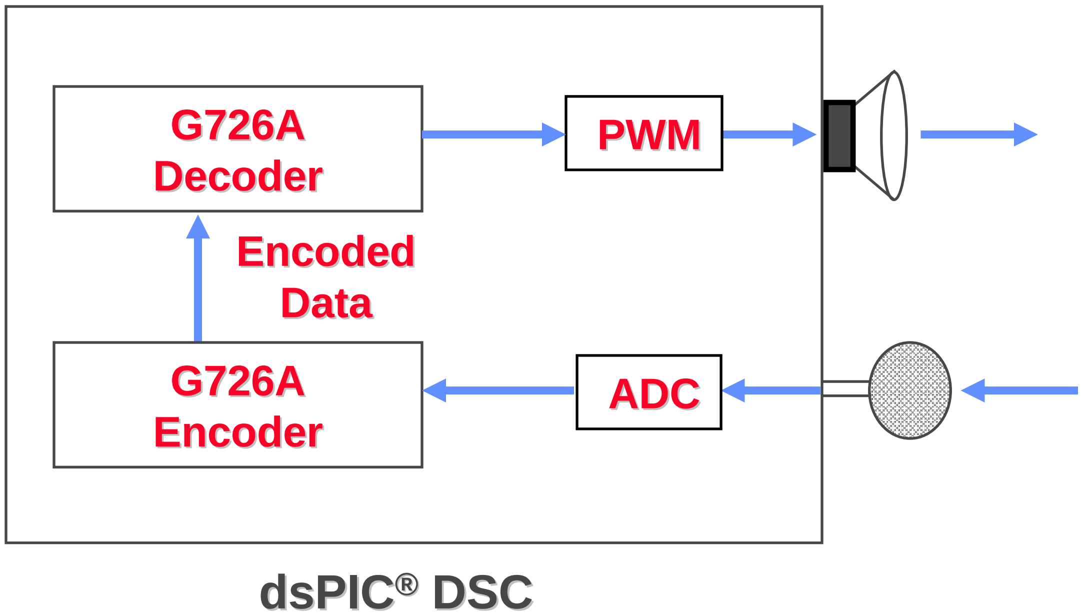
G726A Loopback Demo with ADC/PWM



- **Microphone input:**
  – ADC
- **Speaker output:**
  – PWM

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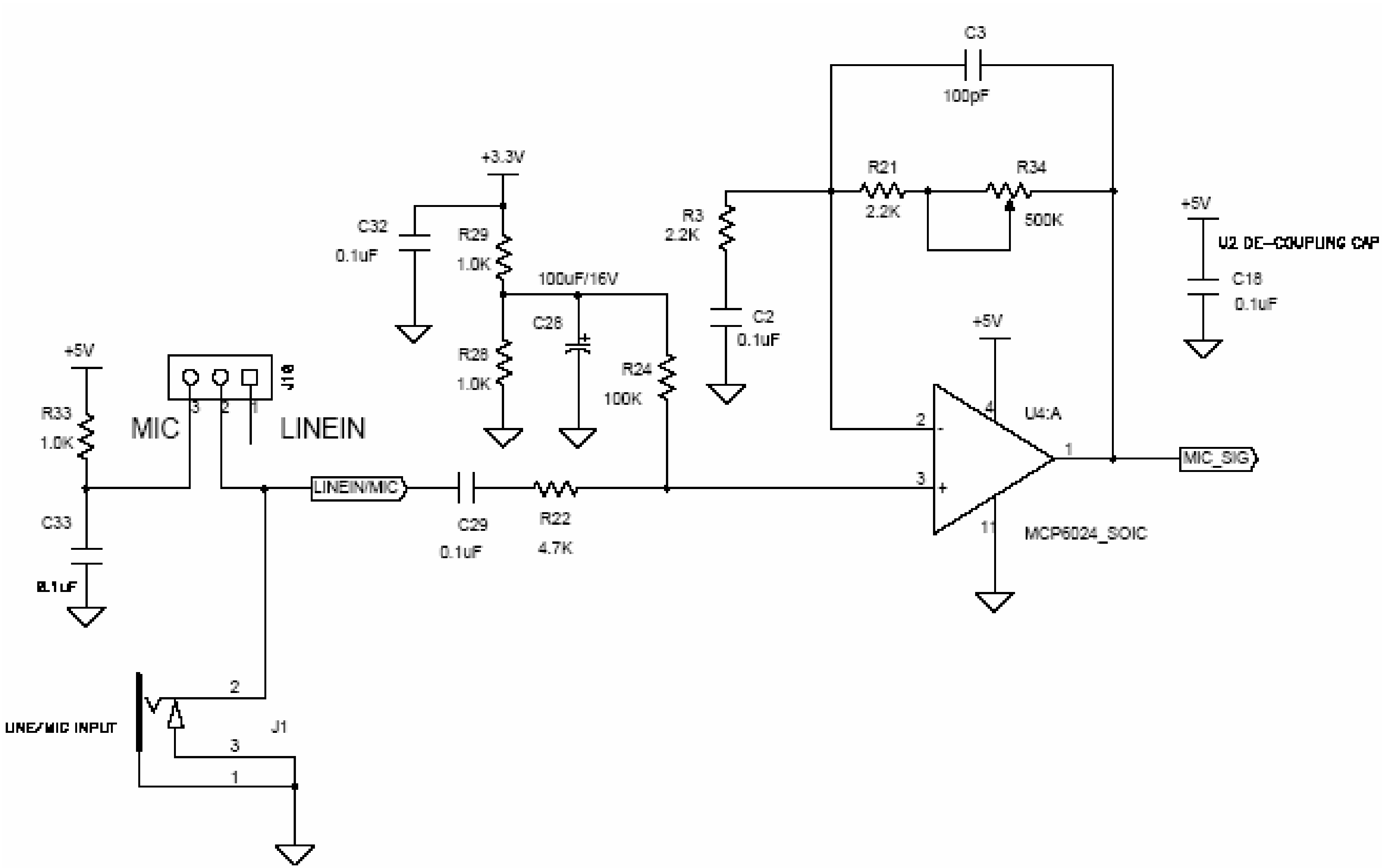
MIC/Line PRE-AMP



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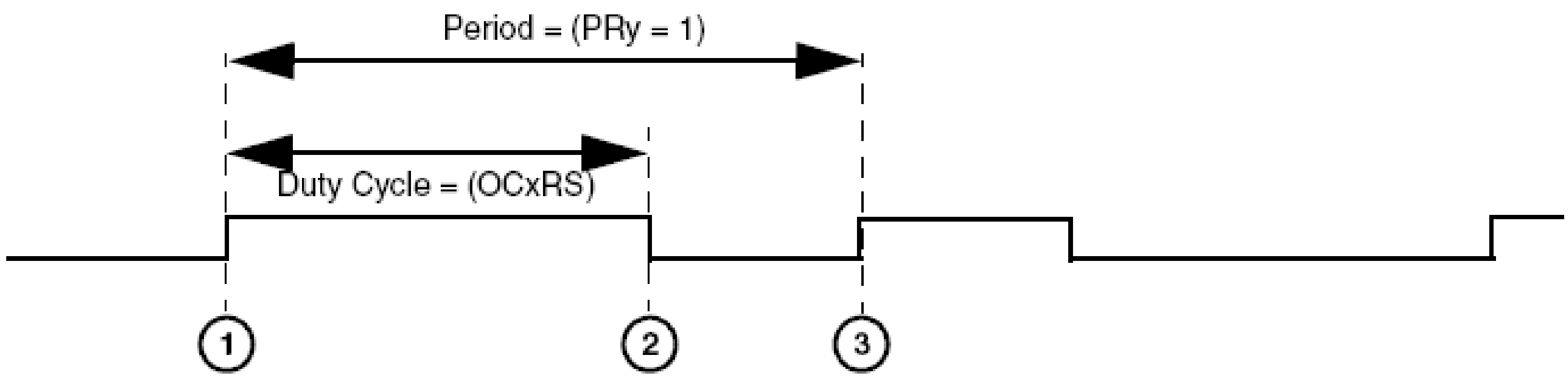
PWM Timing Diagram



1. Timer is cleared and new duty cycle value is loaded from OCxRS into OCxR.
2. Timer value equals value in the OCxR register, OCx pin is driven low.
3. Timer overflow, value from OCxRS is loaded into OCxR, OCx pin driven high. TyIF interrupt flag is asserted.

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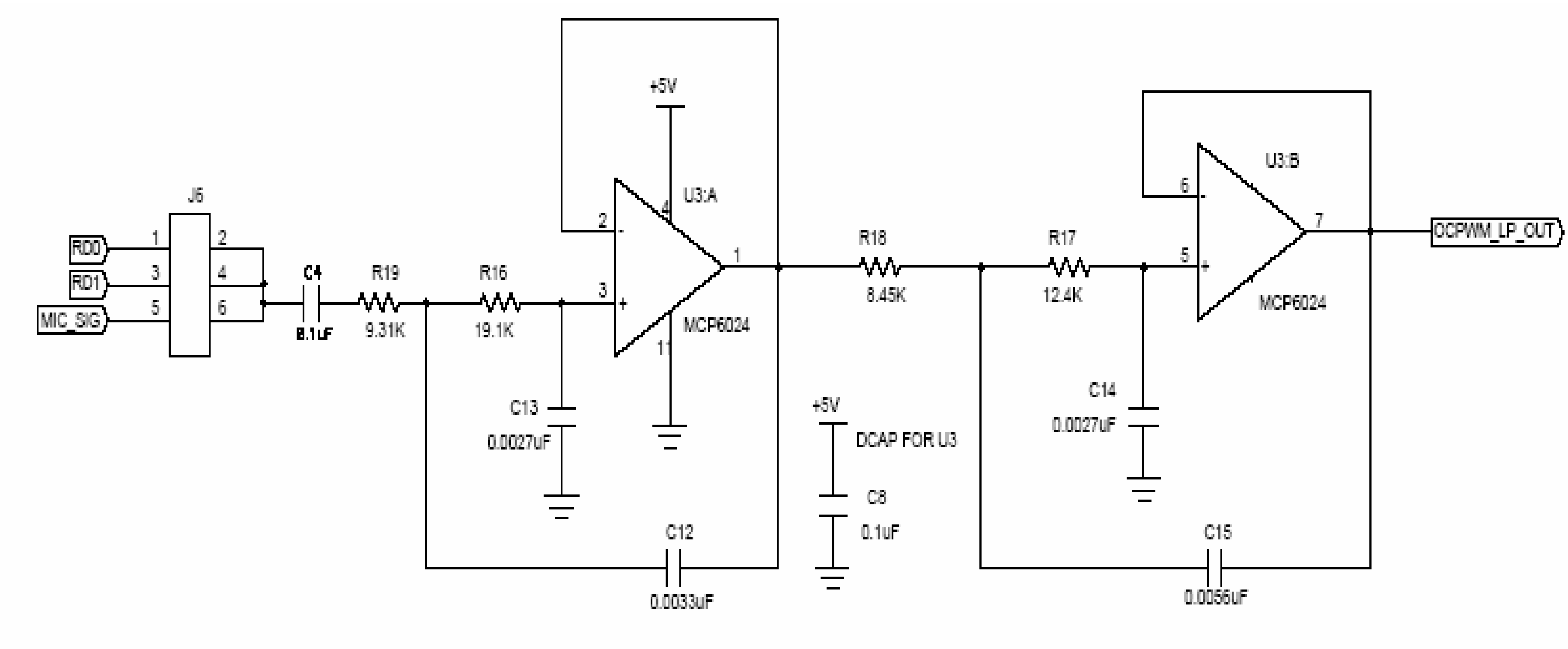
OC PWM Filter



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Hands-on LAB #2

Loopback with dsSPEAK™ Speech Processing Reference Design Using G.726A

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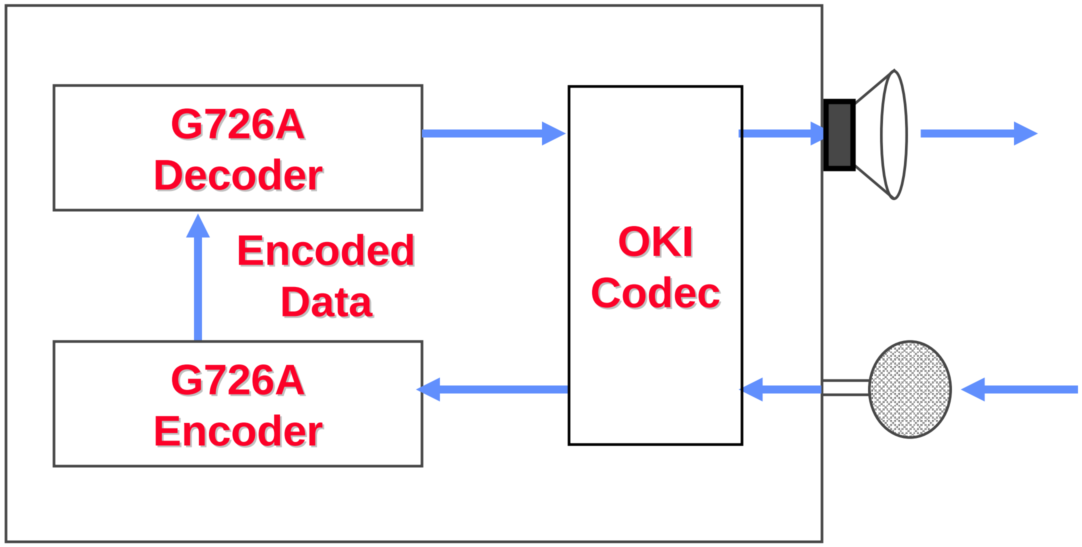
G726A Loopback Demo with dsSPEAK™ Speech Processing Reference Design



dsPIC® DSC

- **Microphone input:**
  - OKI codec (via DCI)
- **Speaker output:**
  - OKI codec (via DCI)

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Features of dsSPEAK™ Speech Processing Reference Design

- 16-bit dual channel voice band codec
  (OKI MSM7704-01)
- On board voice band filters
- 5 W audio amplifier for external speaker
- Full duplex audio channel for connecting external audio signal

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Speech Coding Solution #2

G.711 Speech Coding Library

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Overview

- **Based on A-law and µ-law companding**
  - ITU-T standard, but no royalties!!
  - Standard method for telephony: A-law for Europe, µ-law for USA
  - Can interface with A-law/µ-law codecs
- **MOS: 4.3 – 4.5**

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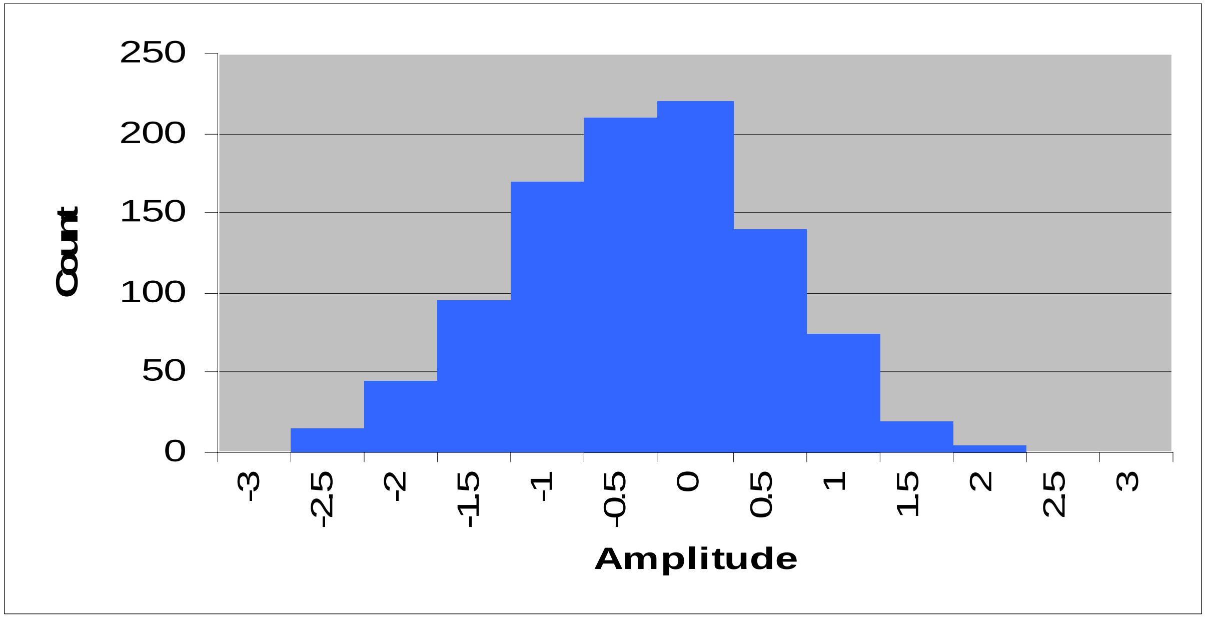
G.711

- **Motivation**
  - **Speech signals have the characteristic that small-amplitude samples occur more frequently than large-amplitude ones**
  - **The Amplitude Distribution is non-uniform**



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G.711

- **Basic idea:** assign smaller quantization step size for small-amplitude regions and larger quantization step size for large-amplitude regions

- **Two types of nonlinear compressing functions**
  - **Mu-law** adopted by North American telecommunications systems
  - **A-law** adopted by European telecommunications systems

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G.711 Suite - Alaw

- **A-law Equation**

$sign(x) * A |x| / (1 + ln(A)), \quad for\ 0 < |x| < 1/A$

$sign(x) * (1+ln(A |x|)) / (1+ln(A)), \quad when\ 1/A \le |x| \le 1$

Typical value for A is ***87.56***

Note: *A-law is a combination of logarithmic curve for large amplitudes and linear curve for small amplitudes.*

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G.711 Suite - µlaw

- **µ-law Equation**

  *sign(x) * ln(1 + µ|x|) / ln(1 + (µ))*

  Typical value for ***µ*** is ***256***

  Note: *µ-law is not exactly logarithmic or linear in any range*

  *but is approximately linear for small amplitudes and logarithmic for large amplitudes***.**

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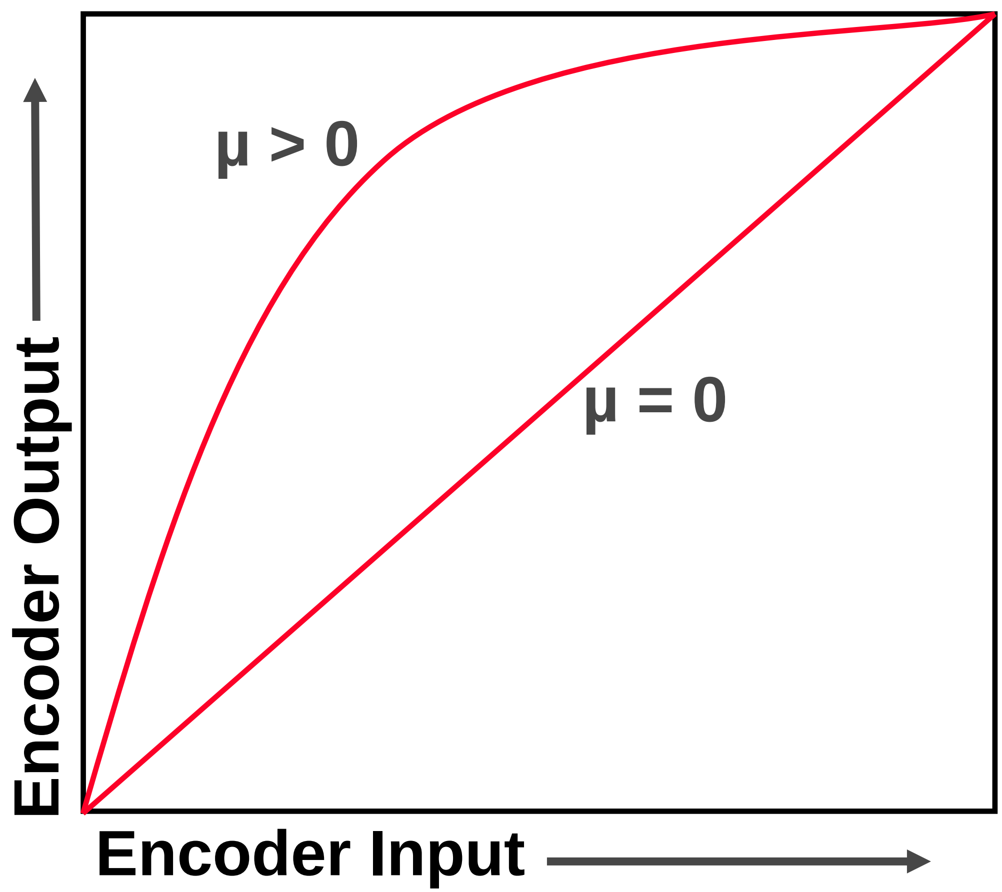
G.711 Algorithm



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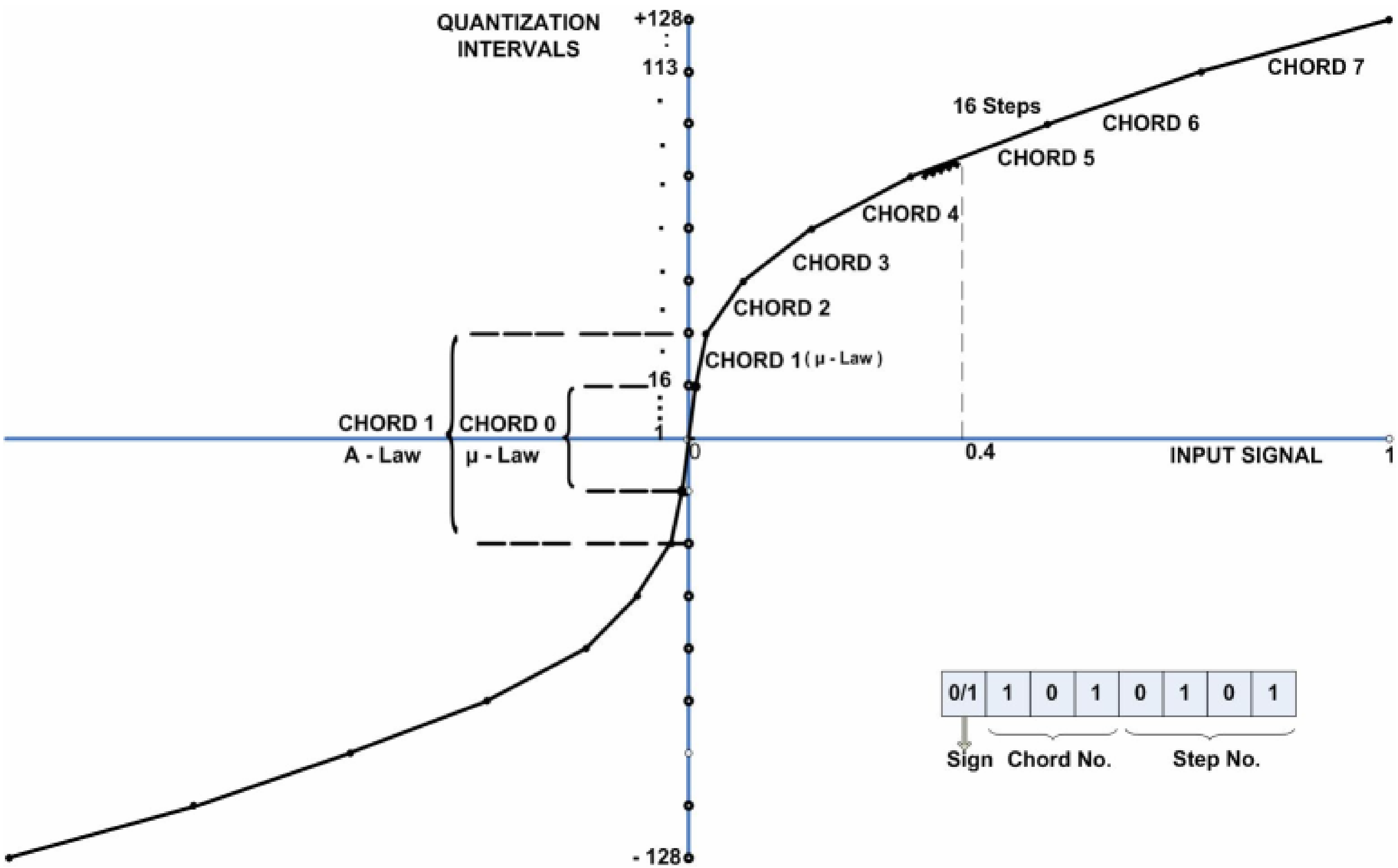
Piece-wise linear approximation



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Piece-wise linear approximation

- **μ-law** and **A law** use 8 linear segments on either side of analog zero
- **μ law** consists of 15 segment with two inner most segments with identical slope
- **A-law** Consists of 13 segments with four innermost segments having identical slope

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G.711 Speech Coding Library

- **Encoder – 2:1 compression ratio**
  - Speech input: 8 kHz, 16-bit mono
  - Encoded output: 64 kbps
- **Decoder**
  - Decoder input: 64 kbps
  - Speech output: 8 kHz, 16-bit mono

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Alternate Playback Interface

- **Intialization**
  - *OCPWMInit( )*
    - Initializes **Timer2** module.
    - ***OCPWMInit*** *();*
  - *OCPWMStart( )*
    - Enables **Output compare** and **Timer2** module.
    - ***OCPWMStart( );***

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Alternate Playback Interface

- **Synchronization**
  - ***OCPWMIIsBusy ( )***
    - Polls the *isWriteBusy* flag to check if a new frame is available
    - ***OCPWMIsBusy( );***

G.711 Library API

- **A-law API**

  Encode:

  G711Lin2Alaw(*int * input, char * output, int size****)***

  Decode:

  G711Alaw2Lin(*char * input, int * output, int size****)***

- **Mu-law API**

  Encode:

  G711Lin2Ulaw(*int * input, char * output, int size****)***

  Decode:

  G711Ulaw2Lin(*char * input, int * output, int size****)***

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Hands-on LAB #3

Playback with PWM using G.711

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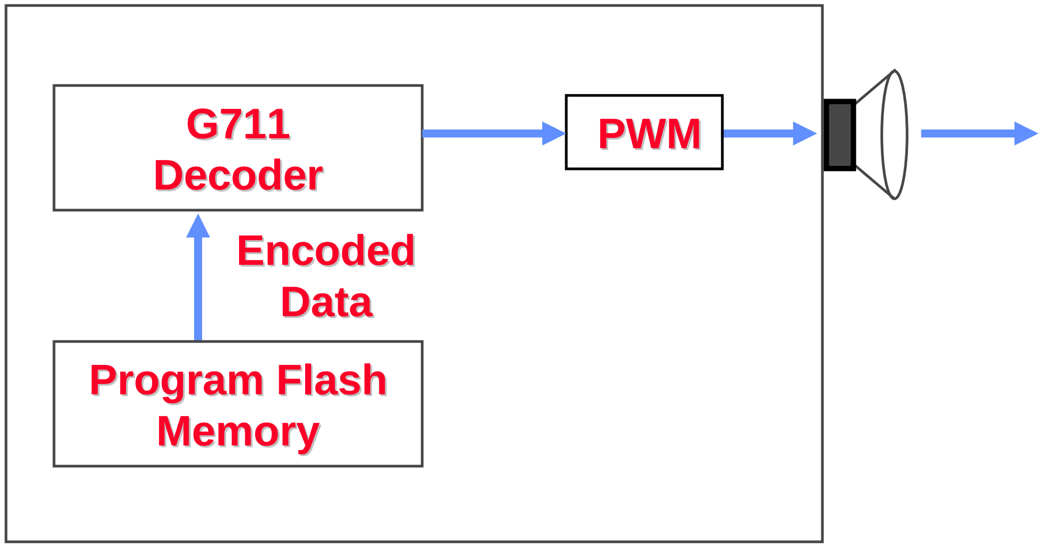
Playback Demo PWM



dsPIC® DSC

- **Decoder input memory source:**
  - Program Flash Memory
- **Speaker output:**
  - PWM

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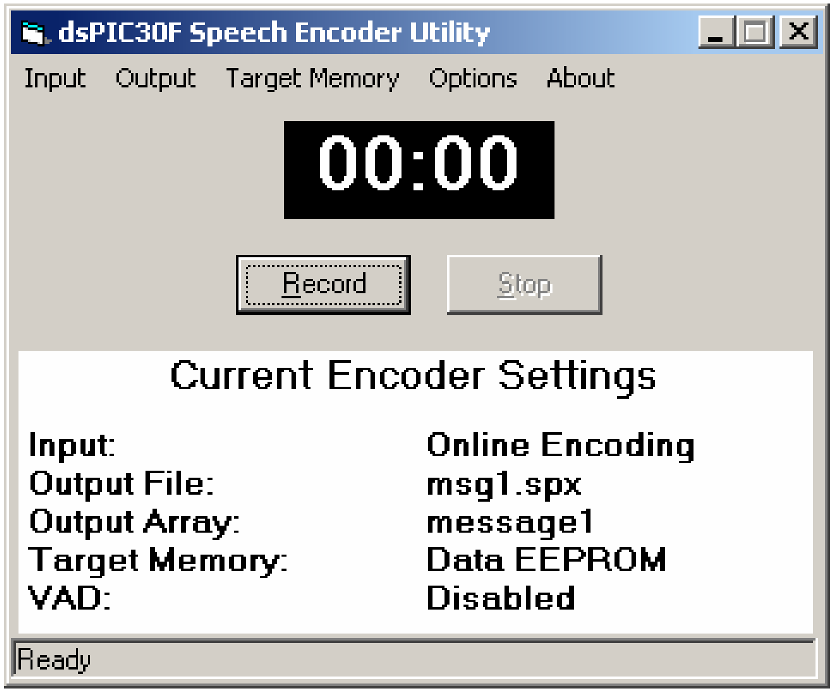
Speech Encoding Utility

- Used mainly for making “playback” files
- Generates an encoded data file from PC microphone (live input) or WAV file
- User links encoded file into application project



- **Target memory for storing encoded speech array**
  - Program Flash
  - Data EEPROM
  - External Flash
  - RAM

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Summary

- dsPIC® DSC Speech Processing libraries provide computationally efficient software solutions for a wide range of speech and telephony applications
- Self-contained software packages with pre-compiled library functions and demo application
- Easy-to-use Application Programming Interface for integration into user application

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Dev Tools used in this class

- **Development Boards**
- **G726A Loopback demo with ADC/PWM**
  – Explorer 16 Board (DM240001)
  – Audio PICtail™ Plus Daughter Board (AC164129)
- **G726A Loopback demo with dsSPEAK™ Speech Processing Reference Design**
  – dsSPEAK Speech Processing Reference Design Board (DM300025)
- **G711 Playback demo with ADC/PWM**
  – Explorer 16 Board (DM240001)
  – Audio PICtail Plus Daughter Board (AC164129)
- **Development Tools**
  – MPLAB® ICD 2 In-Circuit Debugger **OR**
  – MPLAB REAL ICE™ In-Circuit Emulator

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