DIGITAL SIGNAL PROCESSING(DSP)

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Learning Objectives

- Why process signals digitally?
- Definition of a real-time application.
- Why use Digital Signal Processing processors?
- What are the typical DSP algorithms?
- Parameters to consider when choosing a DSP processor.
- Programmable vs ASIC DSP.
- Texas Instruments' TMS320 family.

Introduction to DSP

- Definition:
  - ***DSP*** – Digital Signal Processing/Processor
  - It refers to:
    - Theoretical signal processing by digital means
    - Specialized hardware (processor) that can process signals in real-time

Introduction to DSP

- ***DSP's*** process signals
- ***Signal*** – a ***detectable physical quantity*** or impulse (as a voltage, current, or magnetic field strength) by which messages or ***information*** can be transmitted

Introduction to DSP’s

- Signal Characteristics:
  - Signals are Physical Quantities
  - Signals are Measurable
  - Signals are Analog
  - Signals Contain Information.

- Examples:

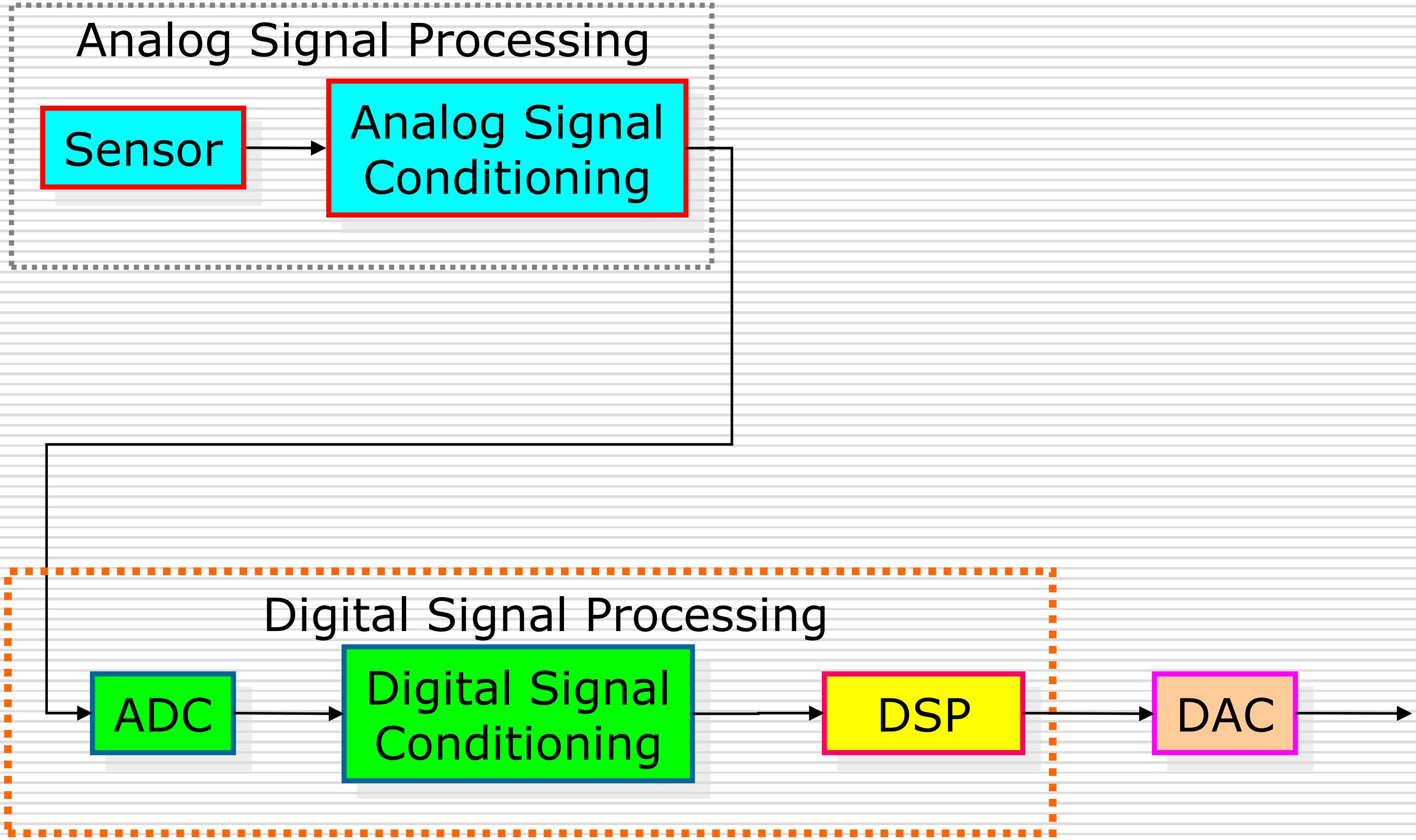
Temperature	[^{o}C]
Pressure	[Newtons/m^2] or [Pa]
Mass	[kg]
Speed	[m/s]
Acceleration	[m/s^2]
Torque	[Newton*m]
Voltage	[Volts]
Current	[Amps]
Power	[Watts]

- In this class, analog signals are electrical.
  - Sensors: are devices that convert other physical quantities (temperature, pressure, etc.) to electrical signals.

Introduction to DSPs

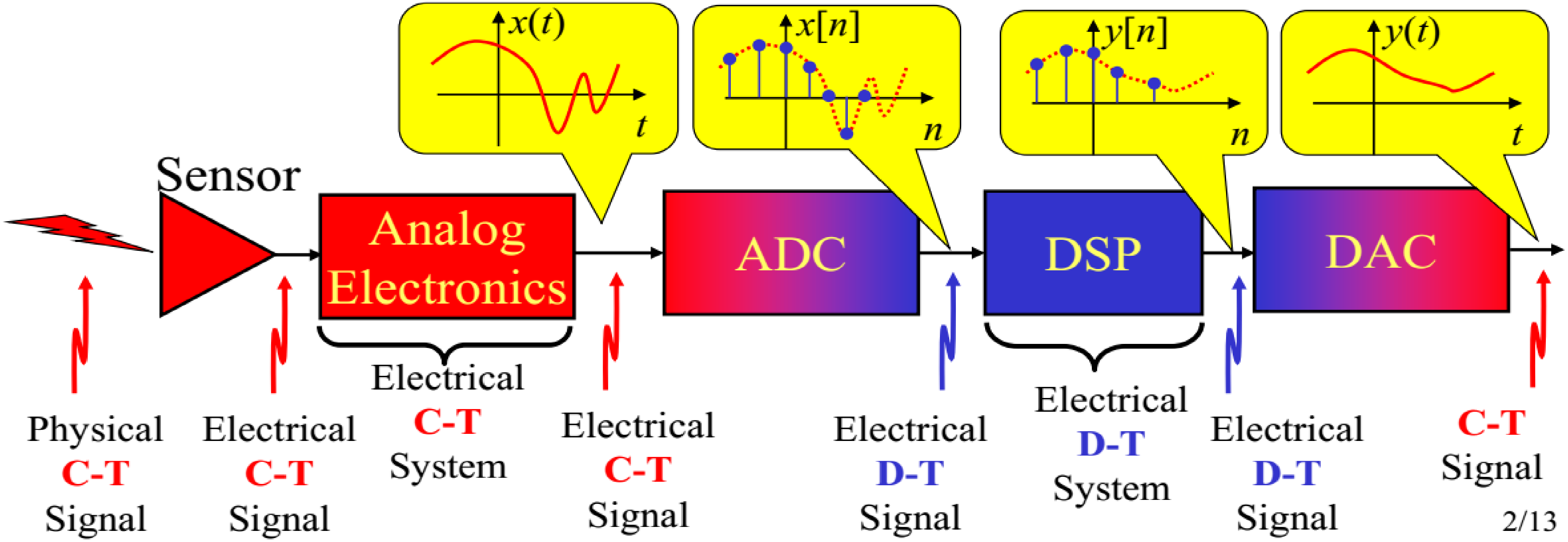
- DSP process digital signals:
  - Analog-to-Digital Converter (ADC)
    - Binary representation of the analog signal
  - Digital-to-Analog Converter (DAC)
    - Digital representation of the signal is converted to continuous analog signal.
- ***Analog ⇔ Continuous***

Typical Architecture of a DSP System



DSP Scenario

- Modern systems generally…
  - get a **continuous-time signal** from a sensor
  - a **cont.-time system** modifies the signal
  - an "analog-to-digital converter" (ADC or A-to-D) sample the signal to create a **discrete-time signal** … a "stream of numbers"
  - A **discrete-time system** to do the processing
  - and then (if desired) convert back to analog (not shown here)



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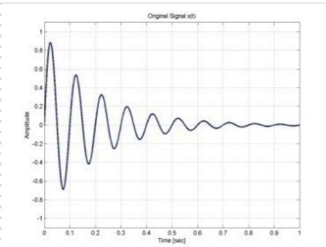
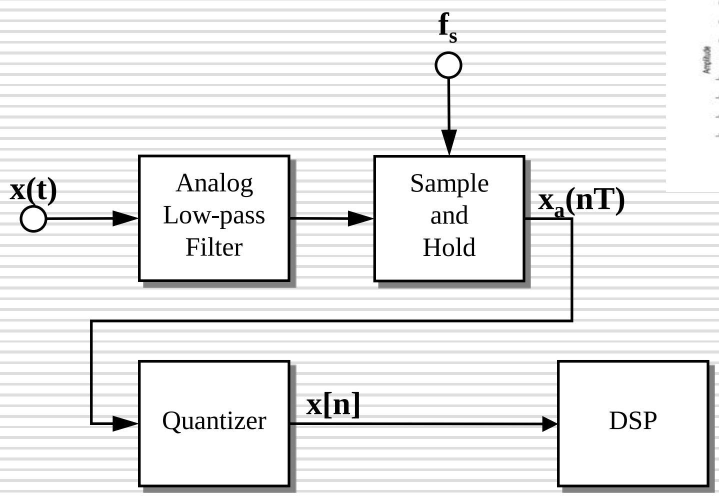
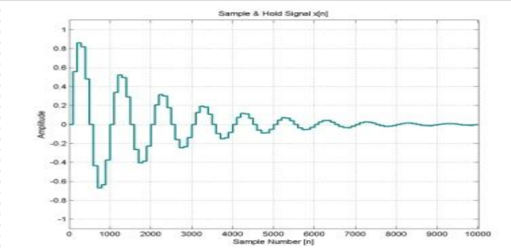
ADC

a) Continuous Signal

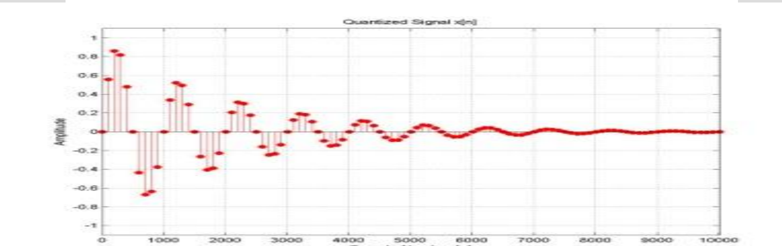




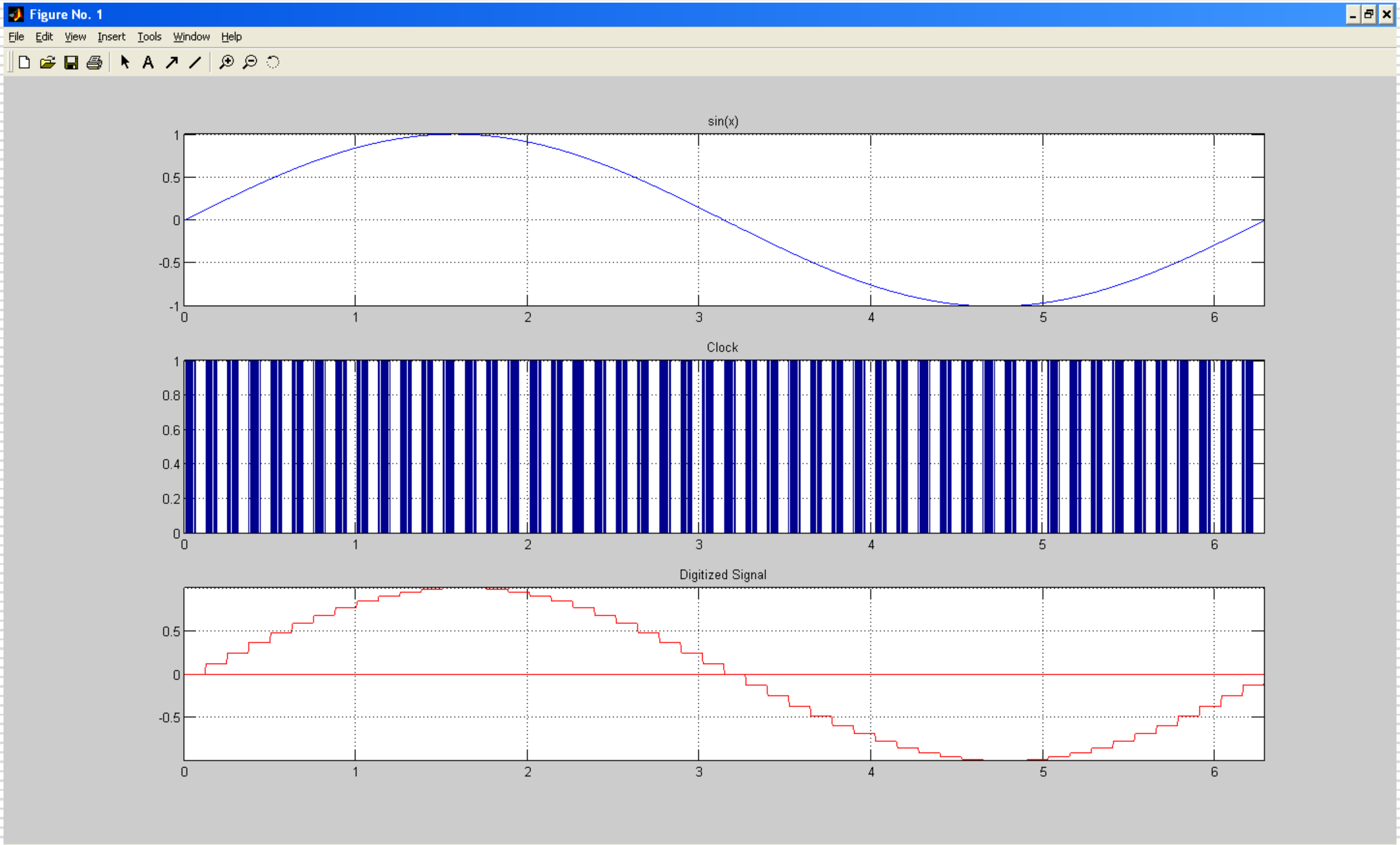
b) Amplitude Quantized Signal



c) Amplitude & Time Quantized – Digital Signal



Example of ADC

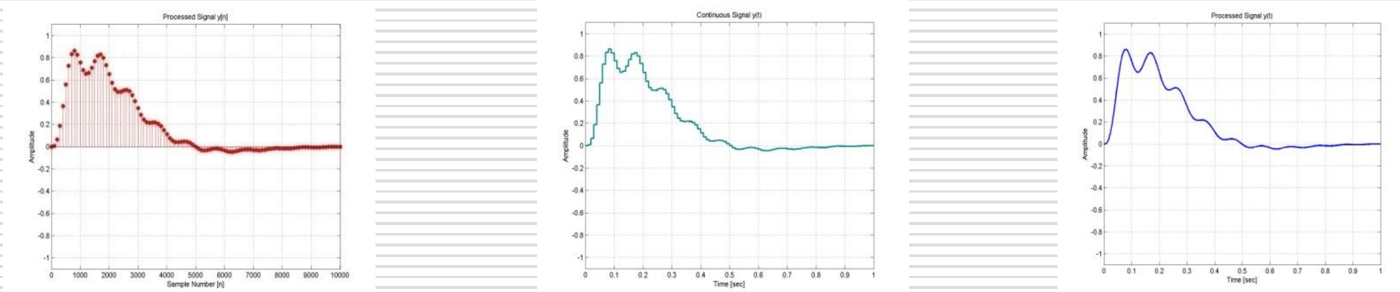


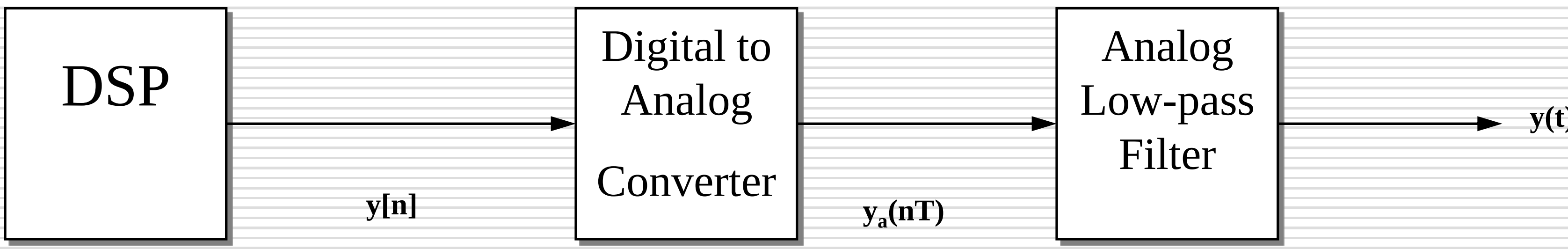
DAC

a) Digital Output Signal

b) Analog Signal

c) Continuous Low-pass filtered Signal





Why Processing Signals?

- ***Extraction of Information***
  - Amplitude
  - Phase
  - Frequency
  - Spectral Content
- ***Transform the Signal***
  - FDMA (Frequency Division Multiple Access)
  - TDMA (Time Division Multiple Access)
  - CDMA (Code Division Multiple Access)
- ***Compress Data***
  - ADPCM (Adaptive Differential Pulse Code Modulation)
  - CELP (Code Excited Linear Prediction)
  - MPEG (Moving Picture Experts Group)
  - HDTV (High Definition TV)
- ***Generate Feedback Control Signal***
  - Robotics (ASIMOV)
  - Vehicle Manufacturing
  - Process Control
- ***Extraction of Signal in Noise***
  - Filtering
  - Autocorrelation
  - Convolution
- ***Store Signals in Digital Format for Analysis***
  - FFT
  - …

Digital Telephone Communication System Example:

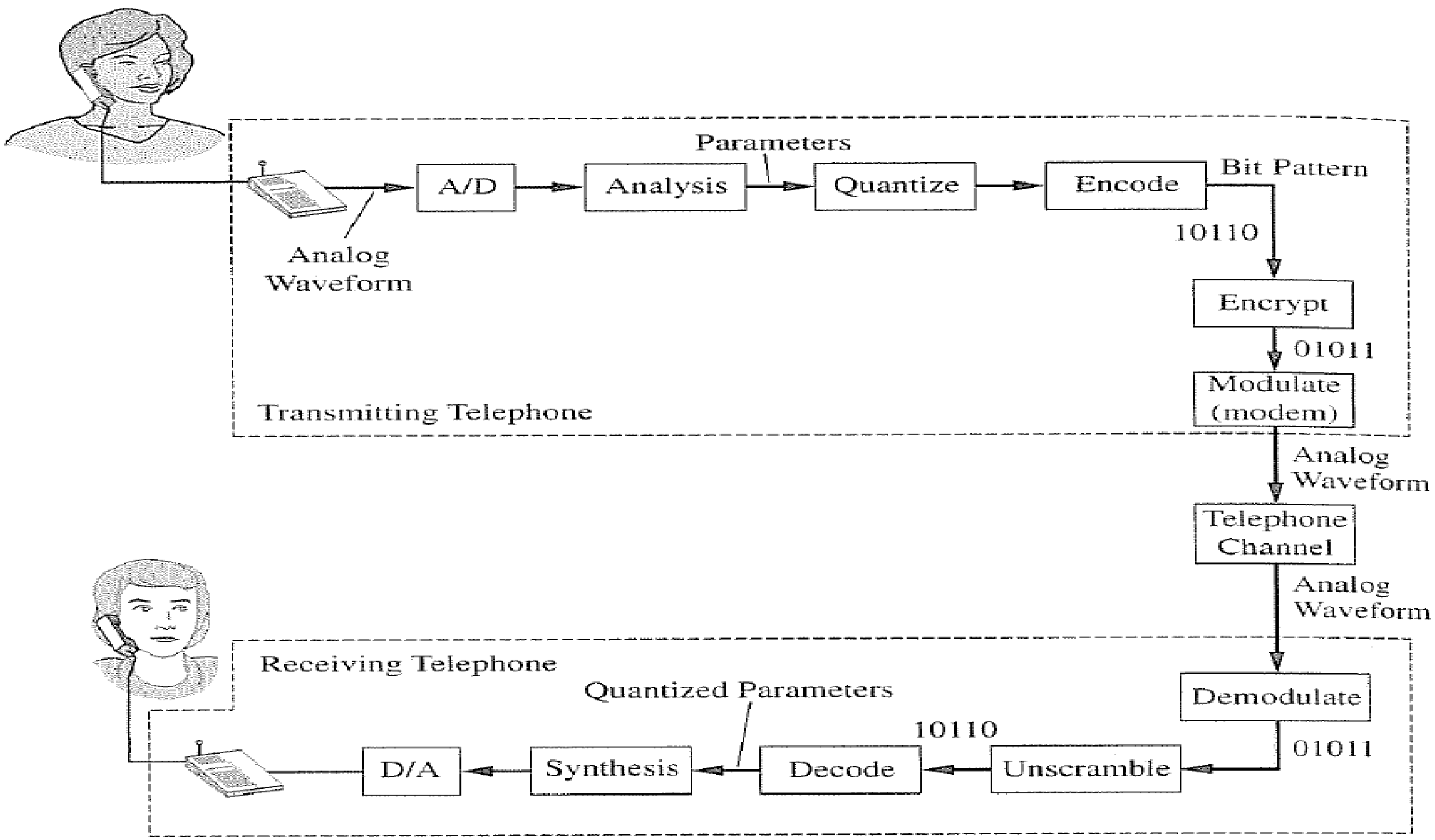


Figure 12.1 An example digital telephone communication system.

Analog vs. Digital Implementations

Analog

- Cons:
  - Approximate Filter Coefficients
    - Only standard components available
  - Environment Temperature dependent
  - Less accurate
  - Can be used only for designed purpose
- Pros:
  - Operate in real-time

Digital (DSP)

- Cons:
  - Real-time operation is dependent on the speed of processor and the complexity of problem at hand.
- Pros:
  - Accurate Filter implementation to desired precision
  - Operation independent on the environment.
  - Flexible
    - DSP’s can be reprogrammed.

Why go digital?

- Digital signal processing techniques are now so powerful that sometimes it is extremely difficult, if not impossible, for analogue signal processing to achieve similar performance.
- Examples:
  - FIR filter with linear phase.
  - Adaptive filters.

Why go digital?

- Analogue signal processing is achieved by using analogue components such as:
  - Resistors.
  - Capacitors.
  - Inductors.
- The inherent tolerances associated with these components, temperature, voltage changes and mechanical vibrations can dramatically affect the effectiveness of the analogue circuitry.

Why go digital?

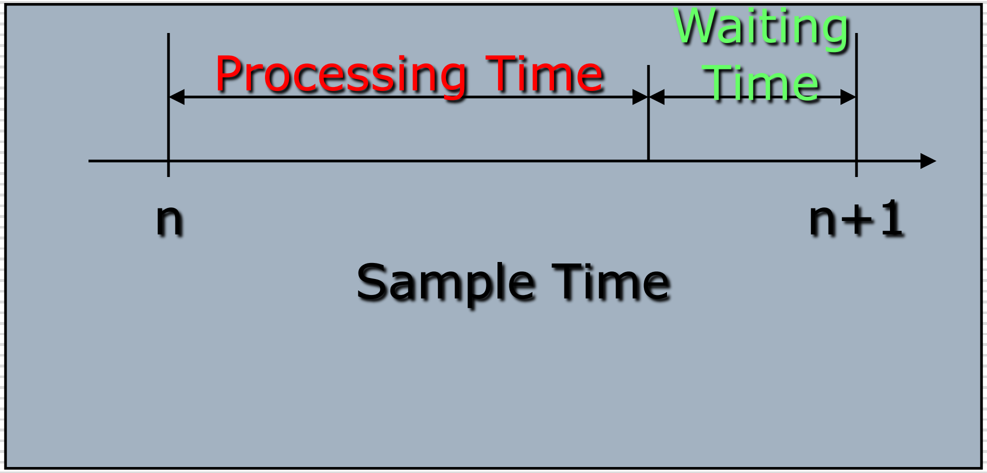
- With DSP it is easy to:
  - Change applications.
  - Correct applications.
  - Update applications.
- Additionally DSP reduces:
  - Noise susceptibility.
  - Chip count.
  - Development time.
  - Cost.
  - Power consumption.

Real-time processing

- DSP processors have to perform tasks in real-time, so how do we define real-time?
- The definition of real-time depends on the application.
- Example: a 100-tap FIR filter is performed in real-time if the DSP can perform and complete the following operation between two samples:

$$\boxed{y(n) = \sum_{k=0}^{99} a(k)x(n-k)}$$

Real-time processing



- We can say that we have a real-time application if:
  - Waiting Time ≥ 0

Why do we need DSP processors?

- Why not use a General Purpose Processor (GPP) such as a Pentium instead of a DSP processor?
  - What is the power consumption of a Pentium and a DSP processor?
  - What is the cost of a Pentium and a DSP processor?

Why do we need DSP processors?

- Use a DSP processor when the following are required:
  - Cost saving.
  - Smaller size.
  - Low power consumption.
  - Processing of many “high” frequency signals in real-time.
- Use a GPP processor when the following are required:
  - Large memory.
  - Advanced operating systems.

What are the typical DSP algorithms?

- The Sum of Products (SOP) is the key element in most DSP algorithms:

Algorithm	Equation
Finite Impulse Response Filter	$y(n) = \sum_{k=0}^{M} a_k \, x(n-k)$
Infinite Impulse Response Filter	$y(n) = \sum_{k=0}^{M} a_k \, x(n-k) + \sum_{k=1}^{N} b_k \, y(n-k)$
Convolution	$y(n) = \sum_{k=0}^{N} x(k) h(n-k)$
Discrete Fourier Transform	$X(k) = \sum_{n=0}^{N-1} x(n) \exp[-j(2\pi / N) nk]$
Discrete Cosine Transform	$F(u) = \sum_{x=0}^{N-1} c(u).f(x).\cos\left[\frac{\pi}{2N} u(2x+1)\right]$

Hardware vs. Microcode multiplication

- DSP processors are optimised to perform multiplication and addition operations.
- Multiplication and addition are done in hardware and in one cycle.
- Example: 4-bit multiply (unsigned).

```
        Hardware              Microcode

             1011                  1011
           x 1110                x 1110
        ---------             ---------
        10011010                   0000      Cycle 1
                                  1011.      Cycle 2
                                 1011..      Cycle 3
                                1011...      Cycle 4
                              ---------
                               10011010    Cycle 5
```

Parameters to consider when choosing a DSP processor

Parameter	TMS320C6211 (@150MHz)	TMS320C6711 (@150MHz)
Arithmetic format	32-bit	32-bit
Extended floating point	N/A	64-bit
Extended Arithmetic	40-bit	40-bit
Performance (peak)	1200MIPS	1200MFLOPS
Number of hardware multipliers	2 (16 x 16-bit) with 32-bit result	2 (32 x 32-bit) with 32 or 64-bit result
Number of registers	32	32
Internal L1 program memory cache	32K	32K
Internal L1 data memory cache	32K	32K
Internal L2 cache	512K	512K

Parameters to consider when choosing a DSP processor

Parameter	TMS320C6211 (@150MHz)	TMS320C6711 (@150MHz)
I/O bandwidth: Serial Ports (number/speed)	2 x 75Mbps	2 x 75Mbps
DMA channels	16	16
Multiprocessor support	Not inherent	Not inherent
Supply voltage	3.3V I/O, 1.8V Core	3.3V I/O, 1.8V Core
Power management	Yes	Yes
On-chip timers (number/width)	2 x 32-bit	2 x 32-bit
Cost	US$ 21.54	US$ 21.54
Package	256 Pin BGA	256 Pin BGA
External memory interface controller	Yes	Yes
JTAG	Yes	Yes

Floating vs. Fixed point processors

- Applications which require:
  - High precision.
  - Wide dynamic range.
  - High signal-to-noise ratio.
  - Ease of use.

  Need a floating point processor.
- Drawback of floating point processors:
  - Higher power consumption.
  - Can be more expensive.
  - Can be slower than fixed-point counterparts and larger in size.

Floating vs. Fixed point processors

- It is the application that dictates which device and platform to use in order to achieve optimum performance at a low cost.
- For educational purposes, use the floating-point device (C6713) as it can support both fixed and floating point operations.

General Purpose DSP vs. DSP in ASIC

- Application Specific Integrated Circuits (ASICs) are semiconductors designed for dedicated functions.
- The advantages and disadvantages of using ASICs are listed below:

Advantages	Disadvantages
• High throughput • Lower silicon area • Lower power consumption • Improved reliability • Reduction in system noise • Low overall system cost	• High investment cost • Less flexibility • Long time from design to market

Texas Instruments' TMS320 family

- Different families and sub-families exist to support different markets.

C2000	C5000	C6000
Lowest Cost	**Efficiency**	**Performance & Best Ease-of-Use**
Control Systems • Motor Control • Storage • Digital Ctrl Systems	Best MIPS per Watt / Dollar / Size • Wireless phones • Internet audio players • Digital still cameras • Modems • Telephony • VoIP	• Multi Channel and Multi Function App's • Comm Infrastructure • Wireless Base-stations • DSL • Imaging • Multi-media Servers • Video

TMS320C64x:

- TMS320C64x: The C64x fixed-point DSPs offer the industry's highest level of performance to address the demands of the digital age.
- At clock rates of up to 1 GHz, C64x DSPs can process information at rates up to 8000 MIPS with costs as low as $19.95. In addition to a high clock rate, C64x DSPs can do more work each cycle with built-in extensions.
- These extensions include new instructions to accelerate performance in key application areas such as digital communications infrastructure and video and image processing

TMS320C62x:

- TMS320C62x: These first-generation fixed-point DSPs represent breakthrough technology that enables new equipments and energizes existing implementations for multi-channel, multi-function applications, such as ……

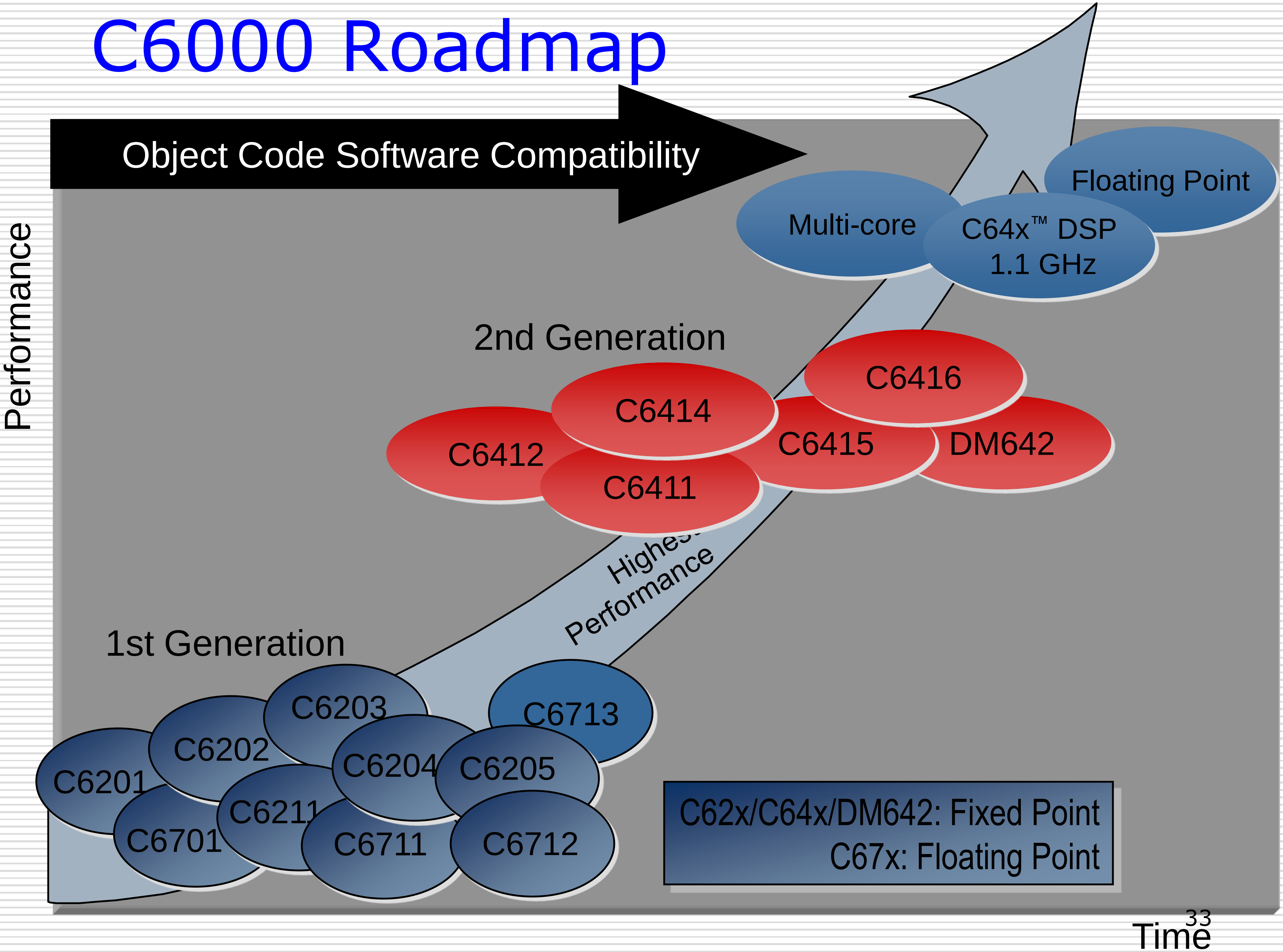
  wireless base stations, remote access servers (RAS), digital subscriber loop (xDSL) systems, personalized home security systems, advanced imaging/biometrics, industrial scanners, precision instrumentation and multi-channel telephony systems.

TMS320C67x:

- TMS320C67x: For designers of high-precision applications, C67x floating-point DSPs offer the speed, precision, power savings and dynamic range to meet a wide variety of design needs.

- These dynamic DSPs are the ideal solution for demanding applications like audio, medical imaging, instrumentation and automotive.

C6000 Roadmap



Thanks!