1. Introduction

- Model of A Communication System
- Communication Channels
- Classification of Communications
- Mathematical Models for Communication Channels
- What Shall We Learn in This Course?

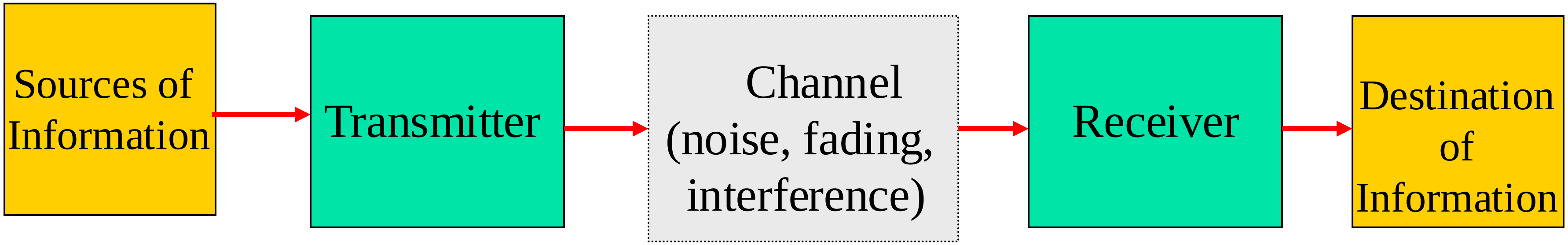
Basic Terms

System: An integrated structure of hardware devices (e.g., electronic circuits, antennas, fiber optics, computer processors) and software algorithms (e.g., digital signal processing algorithms, network protocols) designed to achieve a specified function.

Communication: The transfer of information from one "point" to another point (in space and/or time). This process involves electronic transmitting / receiving / processing of information.

Analog communication: Information is encoded as an analog signal (i.e., a continuous-amplitude continuous-time waveform over time).

Digital communication: Information is encoded as a digital signal (i.e., a discrete-time sequence of finite-alphabet symbols).



Model of a communication system

- Transmitter: Converts the above electronic signal into a form suitable for analog transmission through the propagation channel.
- Receiver: Performs the inverse of the transmitter operations in order to recover the original message signal.
- Channel: Transmission medium.

Communication Channels

Channel: The propagation medium (analog in nature) linking the transmitter and the receiver.

Channel types:

- wire-line channels:
  - copper wire telephone line and coaxial cable
  - fiber-optics cable
- wireless channels:
  - cellular wireless radiowave communication (landmobile or satellite)
  - indoor infrared optical communication
  - underwater acoustical communication
  - visible light communication
- storage channels: storage and retrieval systems (tape, CD, DVD, …)

Channel impairments:

As the transmitted signal travels through this analog medium, the signal degrades in various ways:

- additive (thermal) noise
- multiplicative noise (Rayleigh fading or signal attenuation)
- time-delayed multipath (intersymbol interference)

Thermal noise is produced at the receiver front end (as a result of the thermally excited random motion of free electrons in a conducting medium, such as a resistor.)

Classification of Communications

To classify the communications based on the format of the information to be sent:

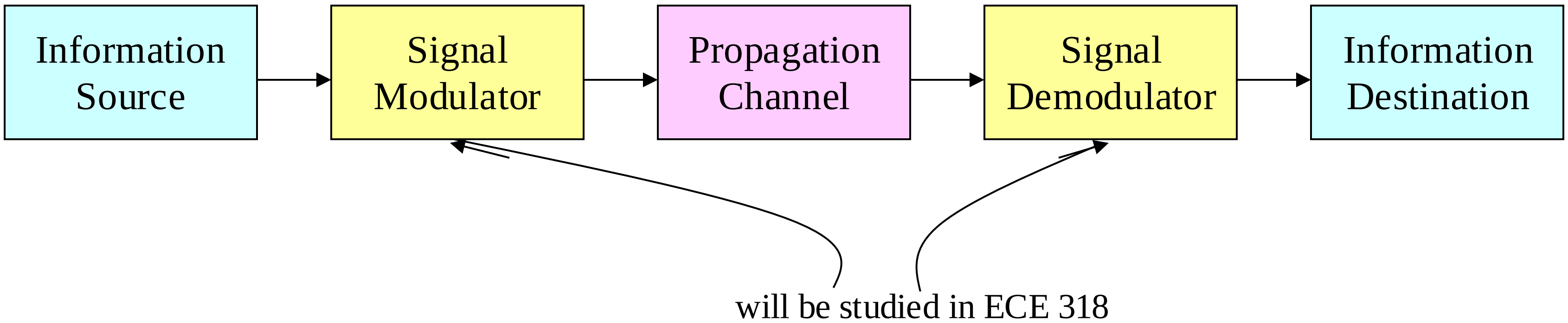
Analog communication system:
The information to be transmitted is in form of an analog signal.

Digital communication system :
The message signal to be transmitted is in digital form consisting of discrete symbols (both amplitude and time take on discrete values)

To classify the communication based on the characteristics of the channel.

Wireline communication:
wireline channels
Wireless communication:
wireless channels (mobile and fixed).

Analog Communication Systems

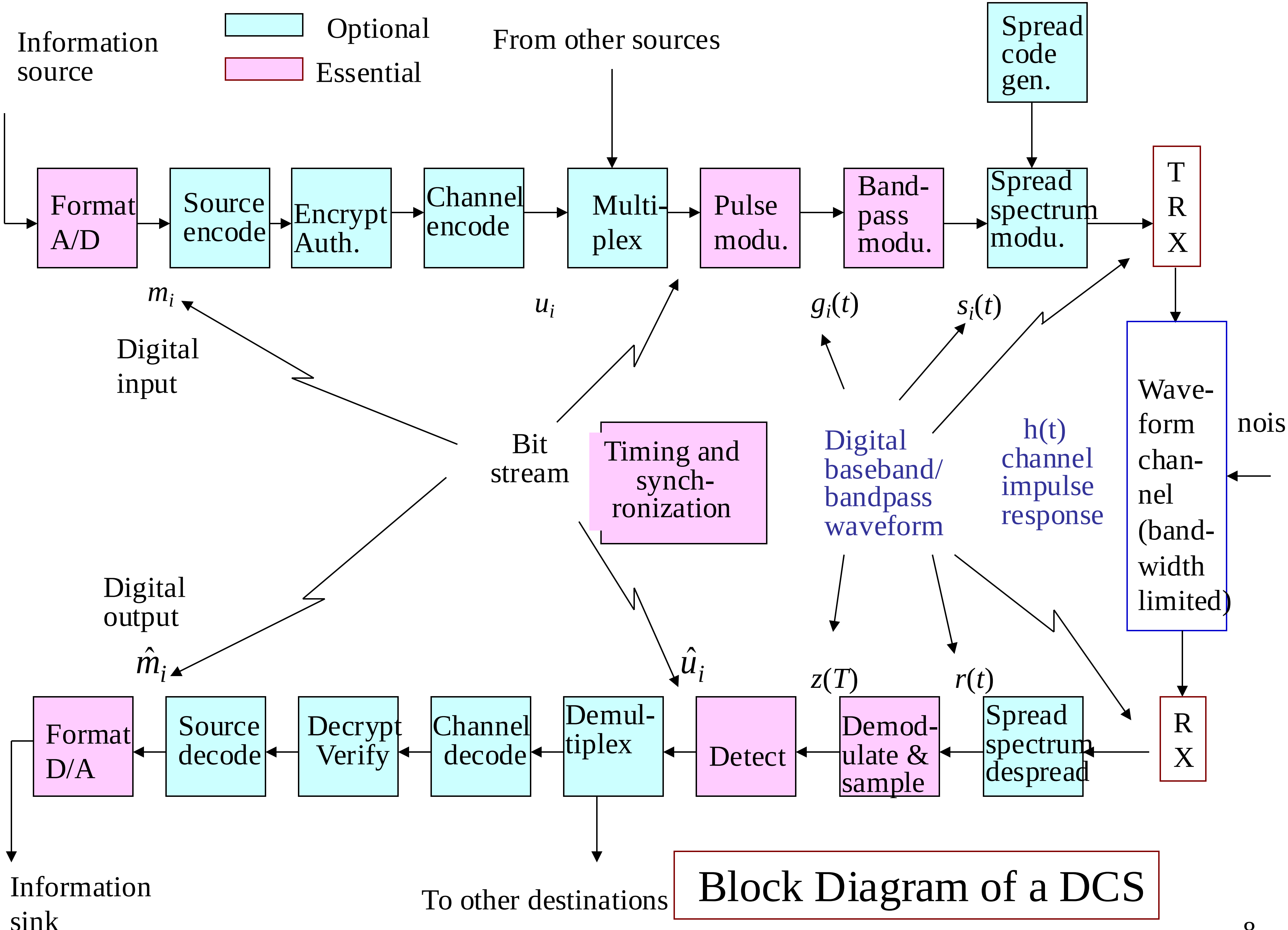


- Analog signals may be transmitted directly via carrier modulation over the propagation channel and to be carrier-demodulated at the receiver.
- Despite a general trend towards digital communications, analog communication systems remain widely used, especially in audio broadcasting.

Digital Communication Systems

An analog (i.e., continuous-amplitude continuous-time) information-signal may be converted into a discrete-time discrete-amplitude digital signals by time-sampling and amplitude-quantization. The resulting digitized information signal will be modulated back into an analog waveform for propagation through the channel (ECE 414, ECE 611). The following figure is a typical block diagram of a digital communication system.

Block Diagram of a DCS



Format: transforms the source information into bits (A/D converter if it is analog).

Channel encode/decode: add redundancy, in a controlled manner, to message symbols and the decoder can use this redundancy to detect and correct errors.

Source encode/decode: remove redundancy existing in the source information so that it can be represented efficiently.

Modulation, demodulation/detection: generate signal waveform which is suitable for transmission over the channel.

Encrypt/Decrypt: protect privacy of the information Authentication/Verify: provide integrity checking for origin of the information source (this block can be placed after any block before modulation).

Spread spectrum modulation/Despread: an additional level of modulation beyond pulse modulation and bandpass modulation. The transmitted signal is much wider than and independent of the bandwidth of the information to be transmitted.

Timing and synchronization: a clock signal, is involved in the control of almost every blocks.

Digital Versus Analog Performance Criteria

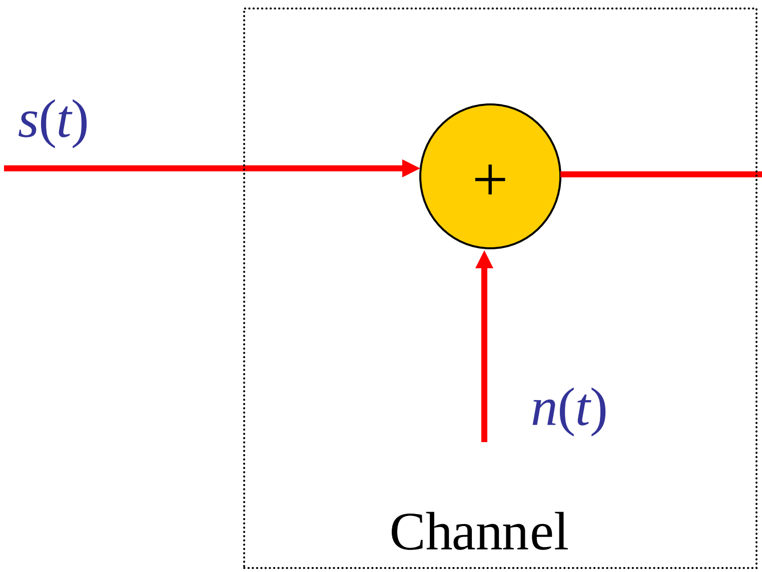
Analog: Fidelity criterion such as signal-to-noise ratio, % distortion, or expected mean square error (MSE) between the transmitted and received waveforms.

Digital: The probability of incorrectly detecting a digit or a packet of symbols, i.e., the probability of error P_e

Mathematical Models for Communication Channels

1. The Additive White Gaussian Noise (AWGN) Channel

The transmitted signal $s(t)$ is corrupted by an additive white Gaussian noise process $n(t)$ (one of the simplified mathematical models for various physical communications channels including wired channels and some radio channels)



$r(t) = s(t) + n(t)$

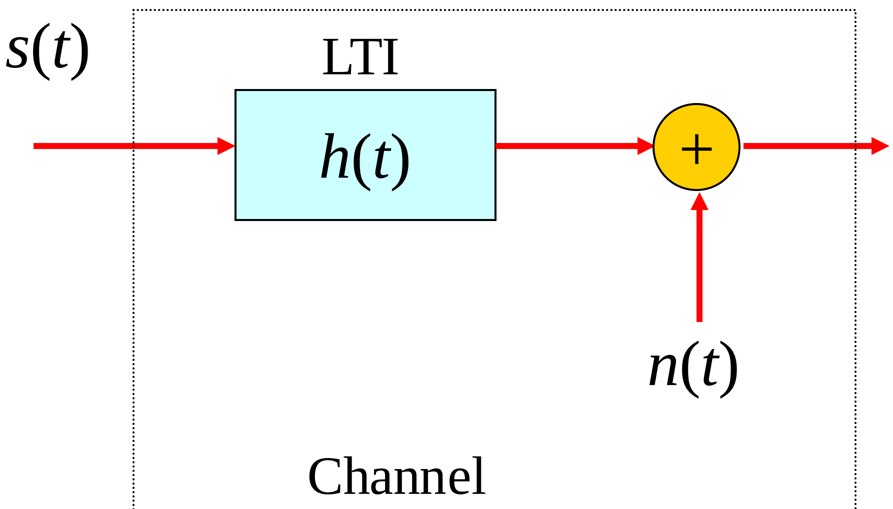
For an AWGN process $n(t)$:

- The power spectral density (psd) is constant, $N_0/2$, as a function of frequency (i.e., white noise).
- For any time instant t, the probability density function (pdf) of $n(t)$ follows a Gaussian distribution.

A white Gaussian noise is uncorrelated and hence independent: $E[n(0)n(t)]=N_0/2\ \delta(t)$

2. The Linear Time Invariant Filter Channel

In general, a wired (and some fixed wireless) channel can be modeled as a linear time invariant (LTI) system, which can be mathematically described by the impulse response of the system.



$$r(t) = (s * h)(t) + n(t)$$
$$= \int_{-\infty}^{\infty} s(t-\tau)h(\tau)d\tau + n(t)$$

The LTI filter channel with an AWGN

The Relationship Between Information Rate, Bandwidth and Noise

The most important question associated with a communication channel is the maximum rate at which it can *reliably* transfer information.

A signal that doesn't change doesn't carry information!
Information can be carried by the values and the rate of the changes.

Nyquist's Discovery: Analogue signals passing through physical channels may not change arbitrarily fast. The rate at which a signal may change is determined by its bandwidth. A signal of bandwidth W may change at a maximum rate of $2W$. If each change takes one of M different values, then, the maximum information rate is $2W \log_2 (M)$ bits/s (without consideration of noise, i.e., we can increase M indefinitely).

Claude Shannon's Discovery: Established the following fundamental limits for communication systems. Given a transmitted power constraint P, a bandwidth W, and an additive white Gaussian noise (AWGN) channel with bilateral power spectral density (psd) of $N_0/2$, then the channel capacity is given by $C=W \log_2(1+P/WN_0)$ bits/s, where P/WN_0 is the signal-to-noise ratio or SNR.

bit=*b*inary *i*nformation uni*t*. If we take the natural logarithm instead of $\log_2$, then the information is measured by *nats*=*na*tural uni*ts*.

Claude Elwood Shannon

Born: 30 April 1916 in Gaylord, Michigan, USA
Died: 24 Feb 2001 in Medford, Massachusetts, USA

His seminal work "*A Mathematical Theory of Communication*" in the *Bell System Technical Journal* (1948) founded the subject of information theory (based on probability theory): measure of information, mathematical model of communication channels, capacity limit, existence of codes that approach the capacity). Within fifty years, (discovery of Turbo codes and the re-discovery of LDPC codes) the goal of achieving the Shannon capacity was reached, from an engineering viewpoint (i.e., error rates of 10^{-6} achievable within a fraction of a dB of the Shannon limit).

What Shall We Learn in This Course?

To learn to design a communication system that is:

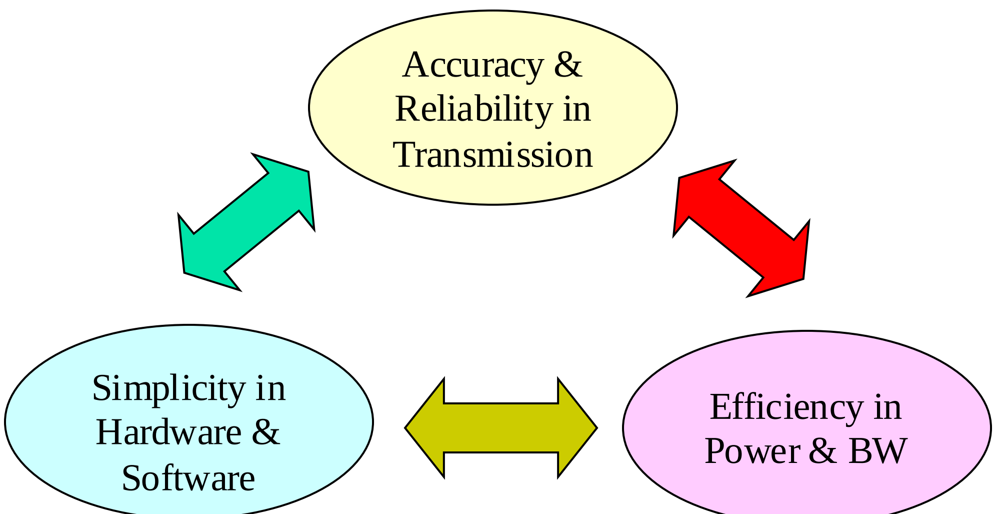
(1) Reliable:

information message received ≅ information message sent,

$\Rightarrow$ high fidelity, low probability of system outage.

(2) Efficient in frequency spectrum & transmission power.

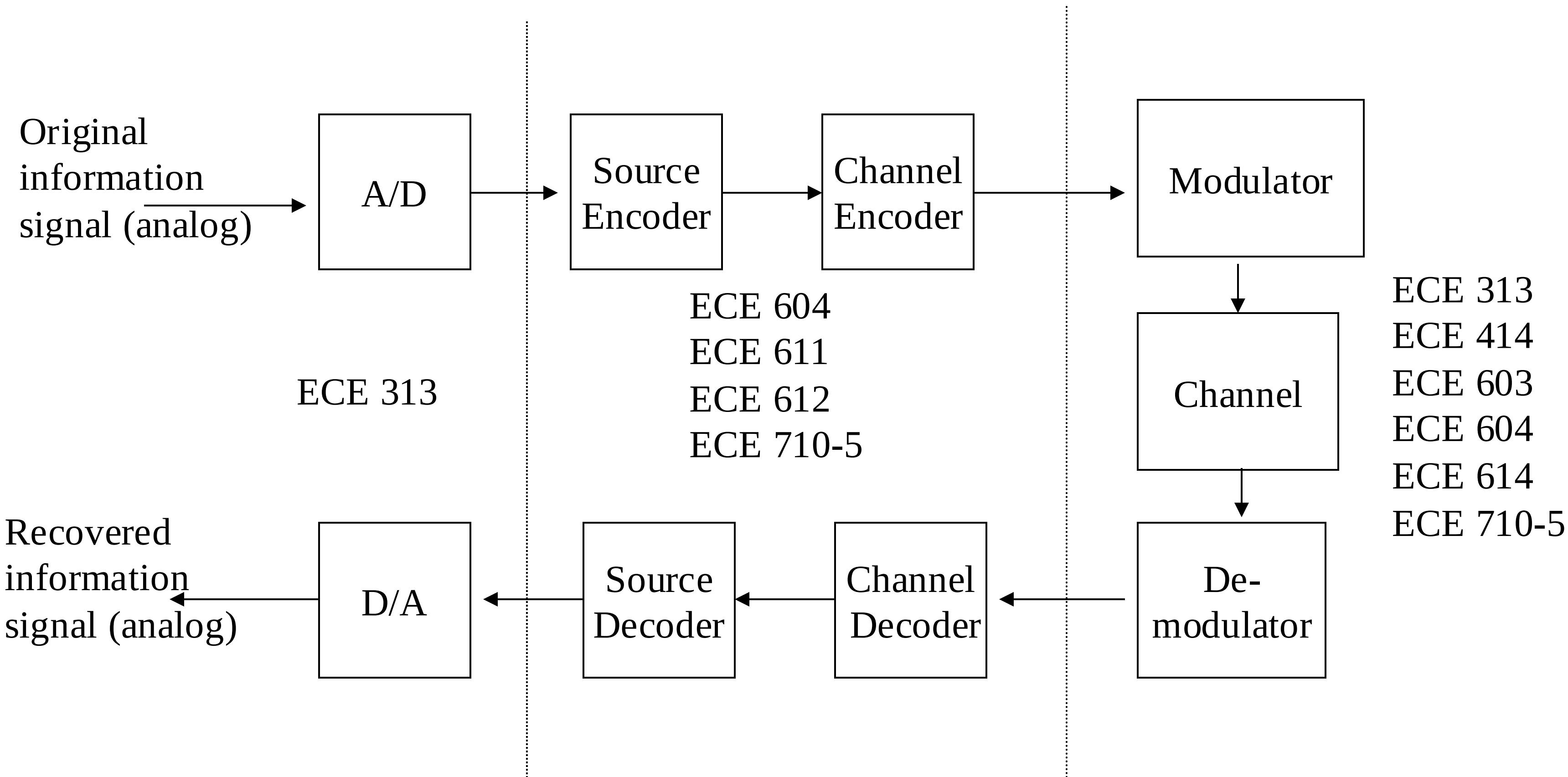
(3) Simple (thus economical) in transmitter/receiver hardware/software.



To achieve the above objectives through studying:

- Principles of AM / FM / PM analog communication (Chapters 3 & 4 & 6)
- Basic digital coding & modulation: (Chapter 7 & 8)
- Underline signal processing (Chapters 2 & 5)
- Selected topics (ISI channels, OFDM, Chapters 10, 11)

Digital Communications Related Courses in ECE



In an <u>ideal</u> system, the recovered signal will be exactly the same as the original one.

Some Related Courses

- ECE313: Digital Signal Processing
- ECE414: Wireless Communication
- ECE603: Statistical Signal Processing
- ECE604: Stochastic Processes
- ECE611: Advanced Digital Communications
- ECE612: Information Theory
- ECE614: Communications over Fading Channels
- ECE710: Coding Theory