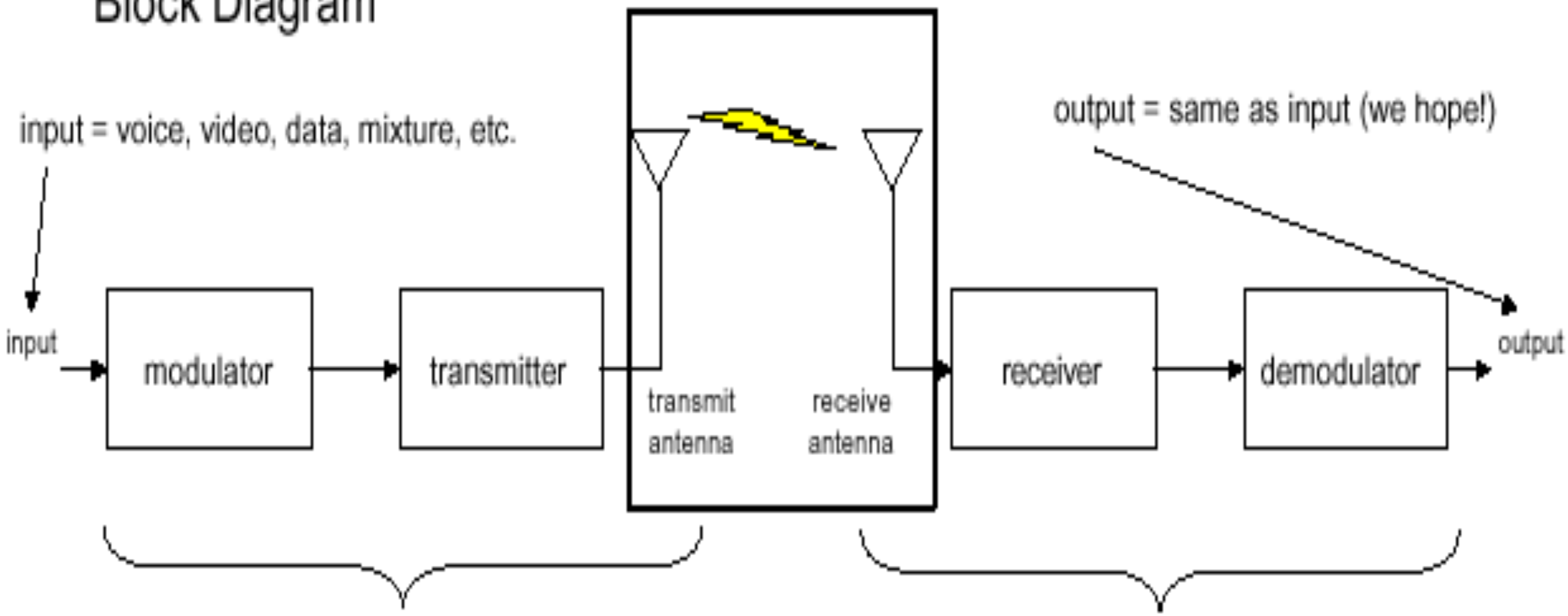
Fundementals of digital RF systems

By: Dr.Mohab Mangoud

Basic Wireless Communications System

Block Diagram



Basic Components:
❶ antenna
❷ transmitter
❸ modulator

Basic Components:
❶ antenna
❷ receiver
❸ demodulator

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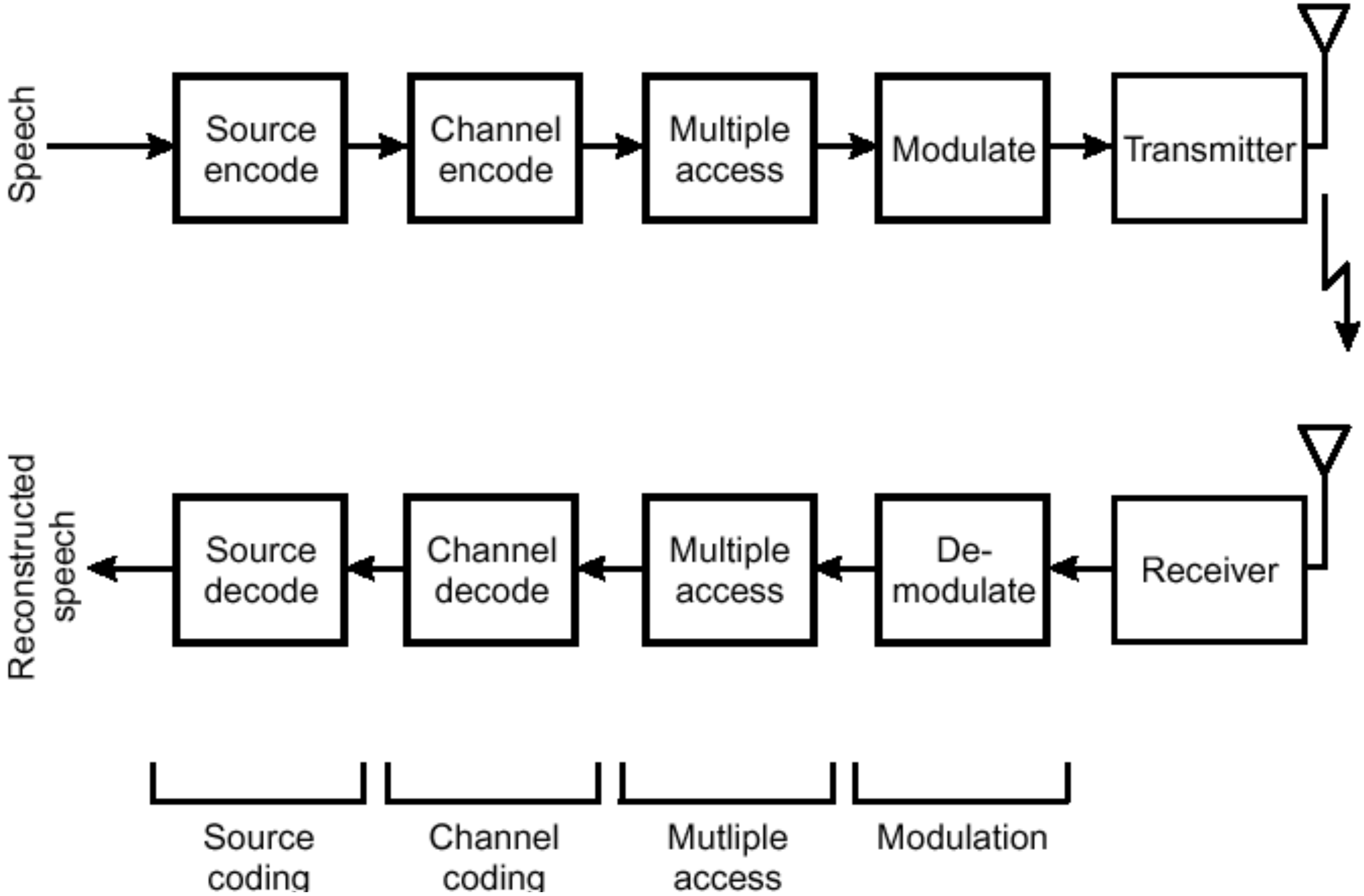

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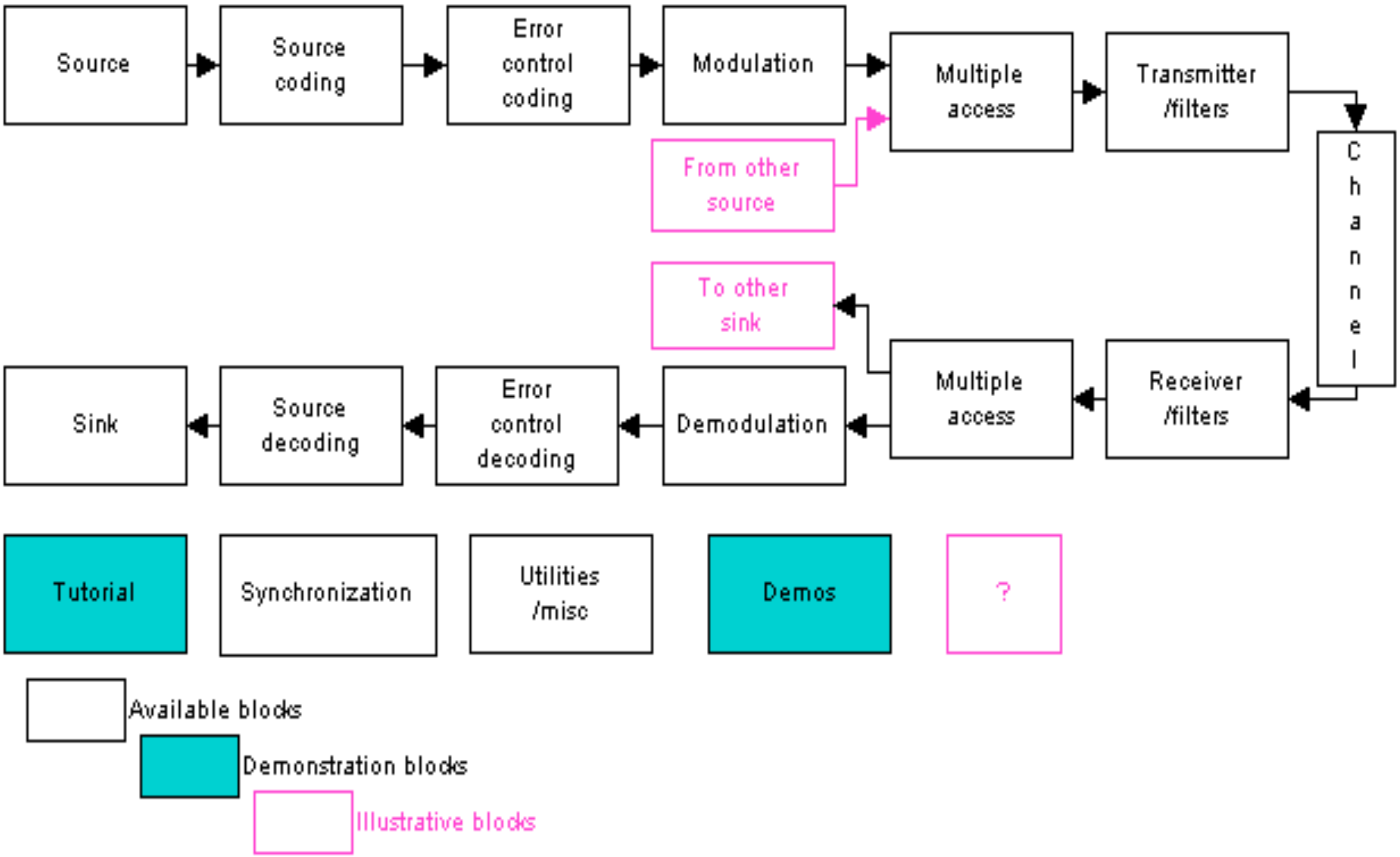
COMMUNICATIONS TOOLBOX SIMULINK BLOCK LIBRARY



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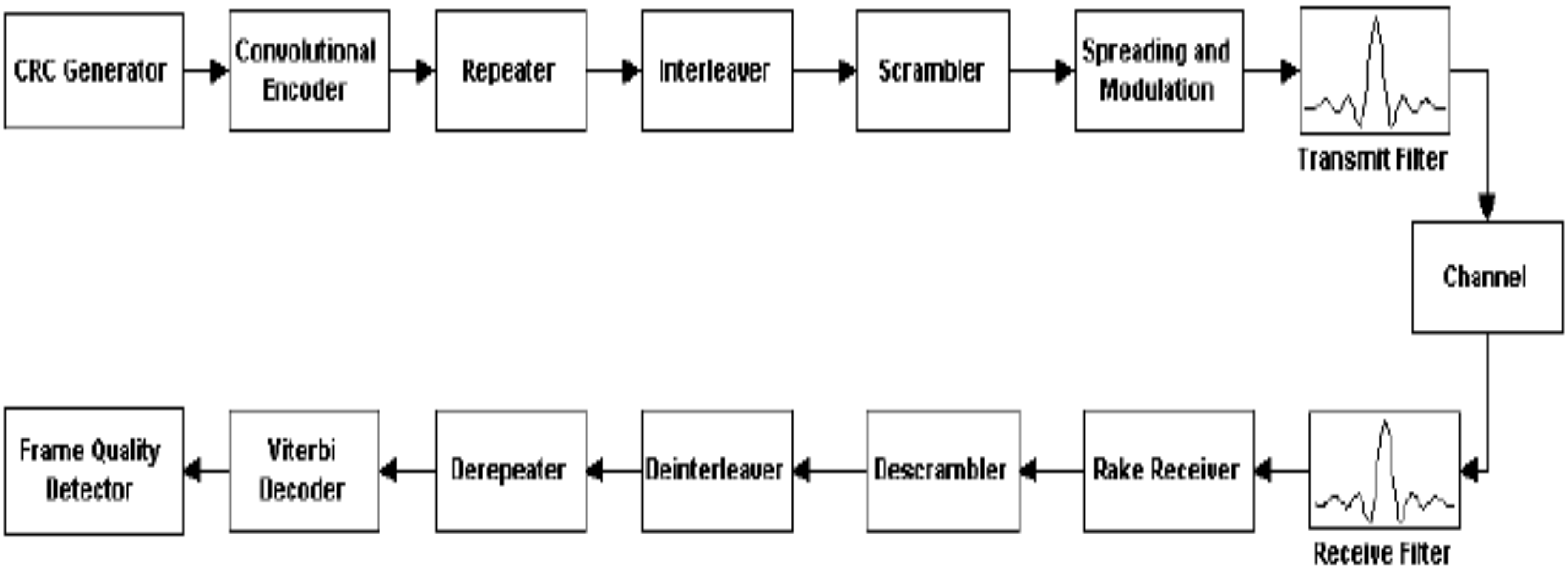

IS-95A Forward Channel Diagram

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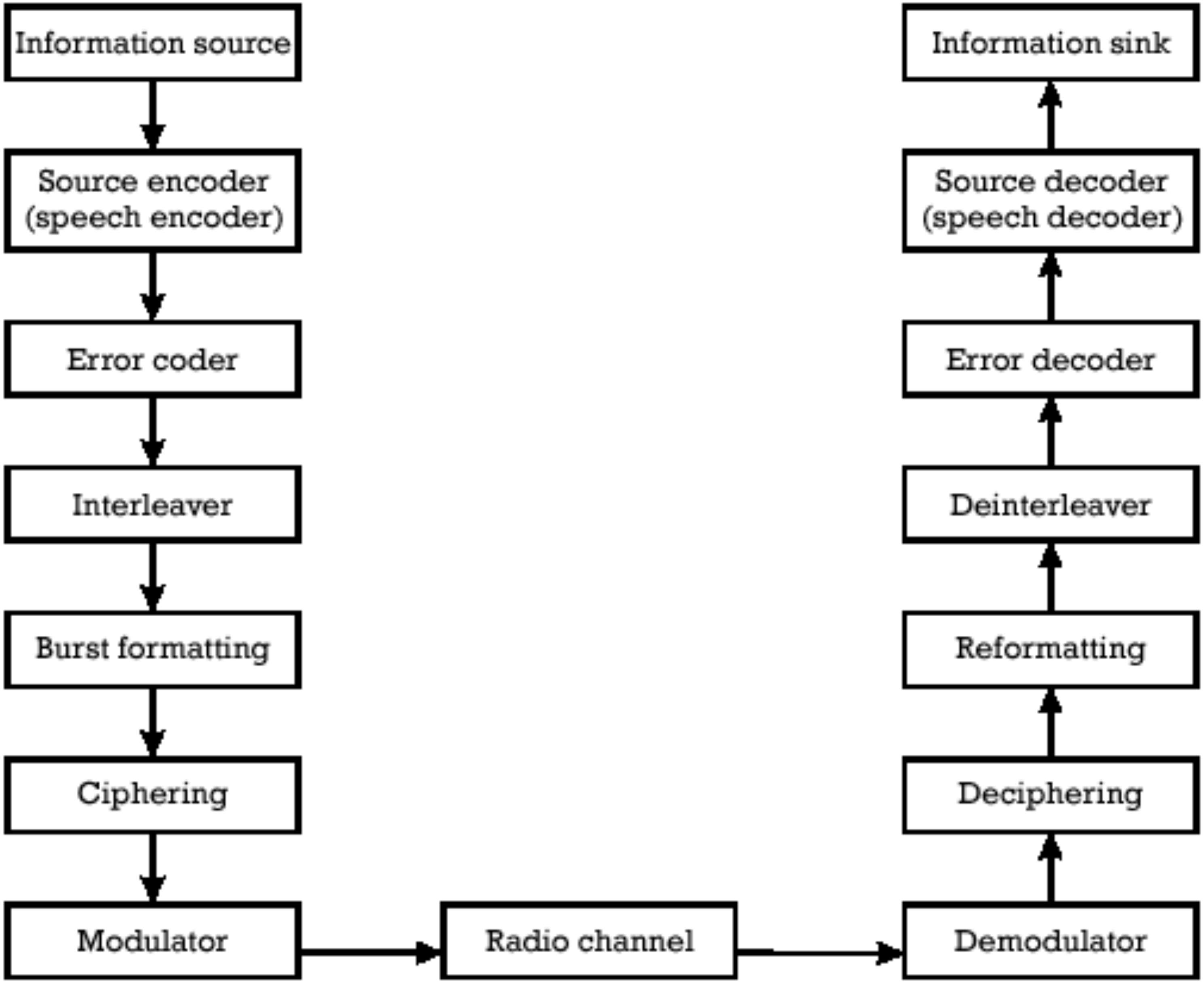

Figure 2.14 Block diagram of a radio system.

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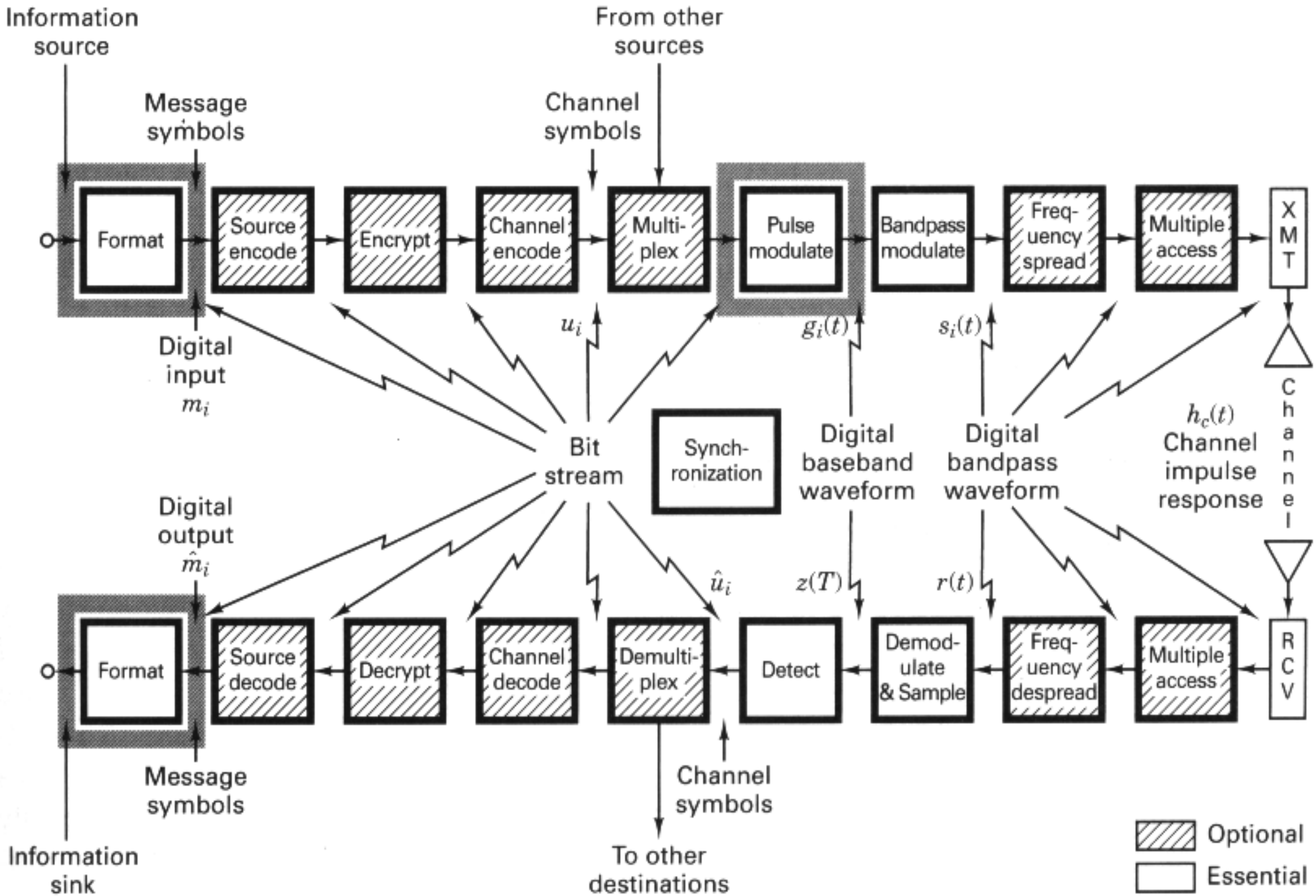


Information source
Message symbols
Channel symbols
From other sources
Format
Source encode
Encrypt
Channel encode
Multi-plex
Pulse modulate
Bandpass modulate
Freq-uency spread
Multiple access
XMT
Digital input
m_i
u_i
$g_i(t)$
$s_i(t)$
Bit stream
Synch-ronization
Digital baseband waveform
Digital bandpass waveform
$h_c(t)$
Channel impulse response
Channel
Digital output
$\hat{m}_i$
$\hat{u}_i$
$z(T)$
$r(t)$
Format
Source decode
Decrypt
Channel decode
Demulti-plex
Detect
Demod-ulate & Sample
Freq-uency despread
Multiple access
RCV
Information sink
Message symbols
To other destinations
Channel symbols
Optional
Essential

FORMATTING / SOURCE CODING

- CHARACTER CODING
- SAMPLING
- QUANTIZATION
- PULSE CODE MODULATION (PCM)
- PARTIAL RESPONSE CODING

- DIFFERENTIAL PCM
- DELTA MODULATION (DM)
- CONTINUOUS VARIABLE SLOPE DM (CVSD)
- LINEAR PREDICTIVE CODING (LPC)
- HUFFMAN CODING

COHERENT

- PHASE SHIFT KEYING (PSK)
- FREQUENCY SHIFT KEYING (FSK)
- AMPLITUDE SHIFT KEYING (ASK)
- HYBRIDS
- OFFSET Q'PSK (OQPSK)
- MINIMUM SHIFT KEYING (MSK)

NONCOHERENT

- DIFFERENTIAL PHASE SHIFT KEYING (DPSK)
- FREQUENCY SHIFT KEYING (FSK)
- AMPLITUDE SHIFT KEYING (ASK)
- HYBRIDS

CHANNEL CODING

WAVEFORM

- M-ARY SIGNALING
- ORTHOGONAL
- BIORTHOGONAL
- TRANSORTHOGONAL

STRUCTURED SEQUENCES

- BLOCK
- CONVOLUTIONAL

MULTIPLEXING / MULTIPLE ACCESS

- FREQUENCY DIVISION (FDM/FDMA)
- TIME DIVISION (TDM/TDMA)
- CODE DIVISION (CDM/CDMA)
- SPACE DIVISION (SDMA)
- POLARIZATION DIVISION (PDMA)

SPREADING

- DIRECT SEQUENCING (DS)
- FREQUENCY HOPPING (FH)
- TIME HOPPING
- HYBRIDS

ENCRYPTION

- BLCCK
- DATA-STREAM

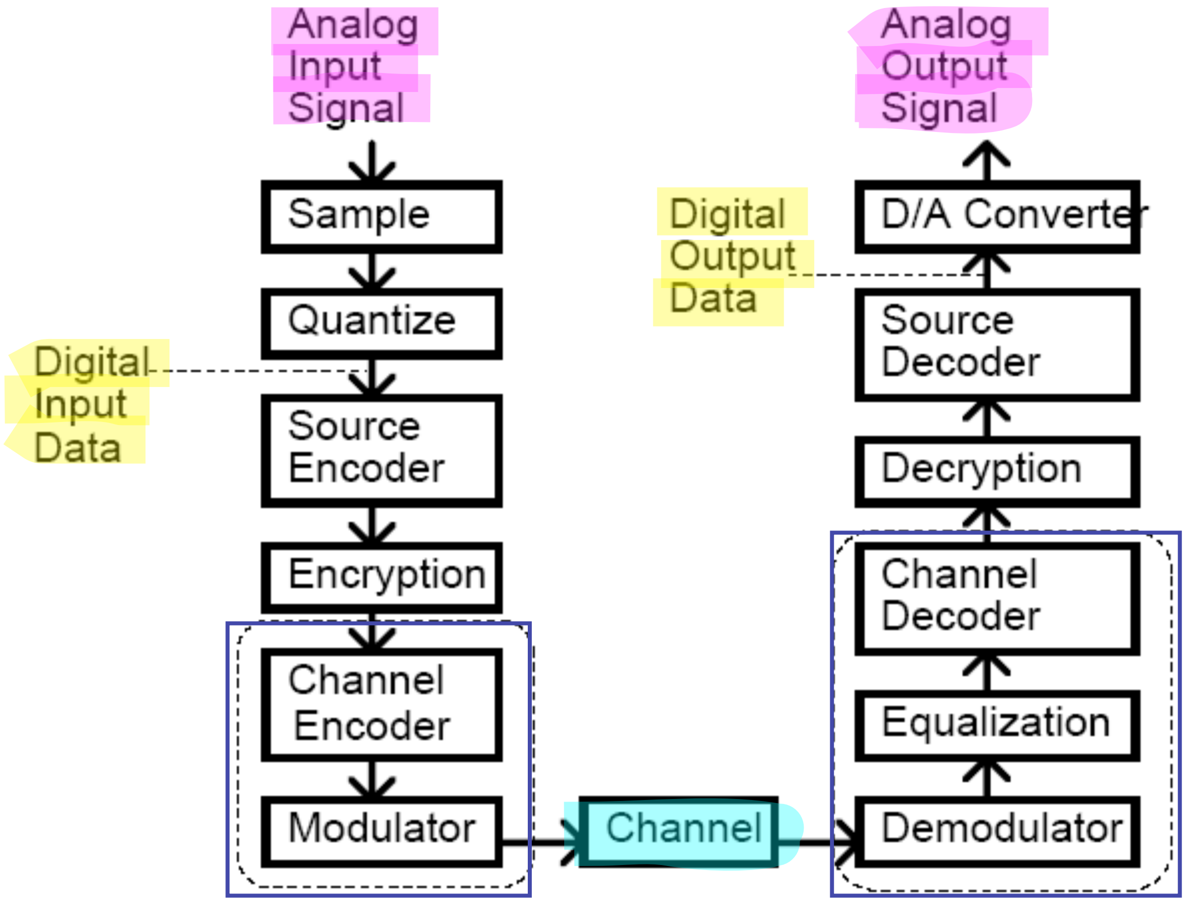
SYNCHRONIZATION

- CARRIER SYNCHRONIZATION
- SYMBOL SYNCHRONIZATION
- FRAME SYNCHRONIZATION
- NETWORK SYNCHRONIZATION

Why *digital* communications?

- Any noise introduces distortion to an analog signal. Since a digital receiver need only distinguish between two waveforms it is possible to exactly recover digital information.
- Many signal processing techniques are available to improve system performance: source coding, channel (error-correction) coding, equalization, encryption
- Digital ICs are inexpensive to manufacture. A single chip can be mass produced at low cost, no mater how complex
- Digital communications allows integration of voice, video, and data on a single system
- Digital communication systems provide a better tradeoff of bandwidth efficiency and energy efficiency than analog

Block Diagram of Typical Digital Communications System



Sampling

- Sampling makes signal discrete in time
- Sampling Theorem says that a band-limited signal can be sampled without introducing distortion
- Baseband sampling theorem
  - $f_s \geq 2B$
    - B - absolute bandwidth

Quantization

- Quantizer makes signal discrete in amplitude
- Unlike sampling, quantization introduces some distortion
- Data rate out of quantizer dependent on sampling rate and number of quantization levels
- Good quantizers are able to use few bits and introduce small distortion

Source Coding

- Quantization – method of converting analog message to digital message
- Digital Source coding (compression) – method of removing the redundancy from the digital data
  - e.g., Huffman coding
- Analog source coding – combination of quantization and compression
  - Takes advantage of the redundant information in the analog source
  - e.g., vocoders

Encryption

- Encryption techniques can ensure data privacy
- Encryption is what we think of when we think of spies and secret decoder rings - Communications engineers use the word "coding" for other ideas
- Very good "public key" encryption algorithms exist - this worries the folks at NSA
- We will not talk about encryption in detail

Channel Encoder

- Provides protection against transmission errors by selectively inserting redundant data
- Note that quantizer and source encoder work to squeeze out redundant information. The channel encoder inserts redundant information in a very selective manner to protect against transmission errors
- Also called Forward Error Correction (FEC) coding
- Error correction coding plays an important role in digital communications, especially spread spectrum systems

Modulator

- Converts digital data to a continuous waveform suitable for transmission over channel - usually a sinusoidal wave
- Information is transmitted by varying one or more parameters of waveform:
  - Amplitude
  - Phase
  - Frequency
- Although we modulate a high frequency sinusoid, we will study the modulation in terms of complex baseband (using a signal space approach)

Examples of Modulation

- Amplitude Shift Keying (ASK) or On/Off Keying (OOK):

$$1 \Rightarrow A\cos\left(2\pi f_c t\right)$$
$$0 \Rightarrow 0$$

- Frequency Shift Keying (FSK):

$$1 \Rightarrow A\cos\left(2\pi f_1 t\right)$$
$$0 \Rightarrow A\cos\left(2\pi f_0 t\right)$$

- Phase Shift Keying (PSK):

$$1 \Rightarrow A\cos(2\pi f_c t)$$
$$0 \Rightarrow A\cos(2\pi f_c t + \pi) = -A\cos(2\pi f_c t)$$

Channel

- Carries signal - could be a telephone wire, free space
- Presents distorted signal to demodulator. Effects include attenuation, noise, fading.
- Fading is very important - studied in Cellular and Personal Communications class
  - Rayleigh fading
  - Ricean fading
  - Log-normal "shadowing"
- We will *usually* assume a very simple channel - additive Gaussian noise (AWGN)

Classical vs. Modern Wireless Systems

The attributes of a classical digital communications system:

- ➔ AWGN channel (Additive signal and noise, Gaussian noise, infinite bandwidth)
- ➔ System performance is` typically noise limited.
- ➔ Receiver structure is simple (matched filter is optimum).
- ➔ Relative motion between transmitter and receiver is not important and is usually ignored.
- ➔ Path loss is the enemy of system performance since increased path loss reduces received signal power and therefore capacity.

$$C = B\log_2\left(1+\frac{S}{N}\right) = B\log_2\left(1+\frac{S}{N_o B}\right)$$

Classical vs. Modern Wireless Systems

The attributes of a modern wireless system:

- ➔ Channel is time dispersive due to fading (multipath).
- ➔ System performance is typically limited by interference rather than by noise.
- ➔ Optimal receiver structure is typically complex. For Example:
  - ➔ Rake receivers to mitigate mutipath
  - ➔ Maximum sequence estimation
- ➔ Path loss is our friend since path loss supports frequency reuse. Frequency reuse in turn gives rise to a cellular architecture.