Spread Spectrum Communications

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Syllabus

Review of noise and fading channels models

Introduction to Spread Spectrum (SS) Communications:

Concept and definitions of SS communications as compared with conventional types of communications, Origin of SS communications, Implementations of SS communications, Spreading Sequences, Orthogonal and Semi-orthogonal sequences.

PN Sequences: Pseudo-noise (PN) sequences generation and its properties (balance, run and correlation properties).

M-sequences: Generation of m-sequence using shift registers (Fibonacci and Galois feedback generators), characteristics of m-sequence (near balance, correlation and security etc.), polynomial representation of m-sequences.

Syllabus

Gold Sequences: Why Gold codes, generation of Gold codes, finding preferred pair of m-sequences, correlation properties of Gold sequences.

Orthogonal Sequences: Walsh Codes, Motivation, Generation and its properties, application of Walsh Codes, Variable length orthogonal codes (motivation, generation and properties).

Spread Spectrum Communication Systems:

Fundamental of Spread Spectrum:: Concept of Spectrum and Bandwidth, Definition of SS Signals, Types of SS signals, Benefits of SS techniques.

Analysis of SS Systems: Direct Sequence SS systems, Frequency-Hopped SS systems, Synchronization of SS communication system (Acquisition and Tracking)

Syllabus

Application of Spread Spectrum: Anti-jamming, Ranging, multipath suppression, code-division multiple access, recent commercial applications.

CDMA Systems: Introduction to 2G/3G standards, CDMA 2000 Systems & Architecture, WCDMA System and Architecture.

Recommended Books:

- R. Petersons, R. Ziemer "Introduction to Spread Spectrum Communications", Prentice-Hall 1995.
- R. C. Dixon, "Spread Spectrum System with Commercial Applications", 4th ed. Wiley 2000.
- Andrew J. Viterbi, "CDMA Principles of Spread spectrum Communication", Adison-Wiley, 2004.

Tentative Teaching Plan

Sr. #	Topic	No. of Lectures
1	Introduction to the subject, Review of noise and fading channels models	2
2	Concept and definitions of SS communications	2
3	Origin of SS communications	2
4	Implementations of SS communications	2
5	Spreading Sequences, Orthogonal and Semi-orthogonal sequences	2
6	PN Sequences: Pseudo-noise (PN) sequences generation and its properties (balance, run and correlation properties).	2
7	M-sequences: Generation of m-sequence using shift registers (Fibonacci and Galois feedback generators)	2
8	Characteristics of m-sequence (near balance, correlation and security etc.)	2
9	Polynomial representation of m-sequences	2
10	Gold Sequences: Why Gold codes, generation of Gold codes,	2
11	Finding preferred pair of m-sequences, correlation properties of Gold sequences. Test – 01	2
12	Orthogonal Sequences: Walsh Codes, Motivation, Generation and its properties	2
13	Application of Walsh Codes, Variable length orthogonal codes (motivation, generation and properties).	2

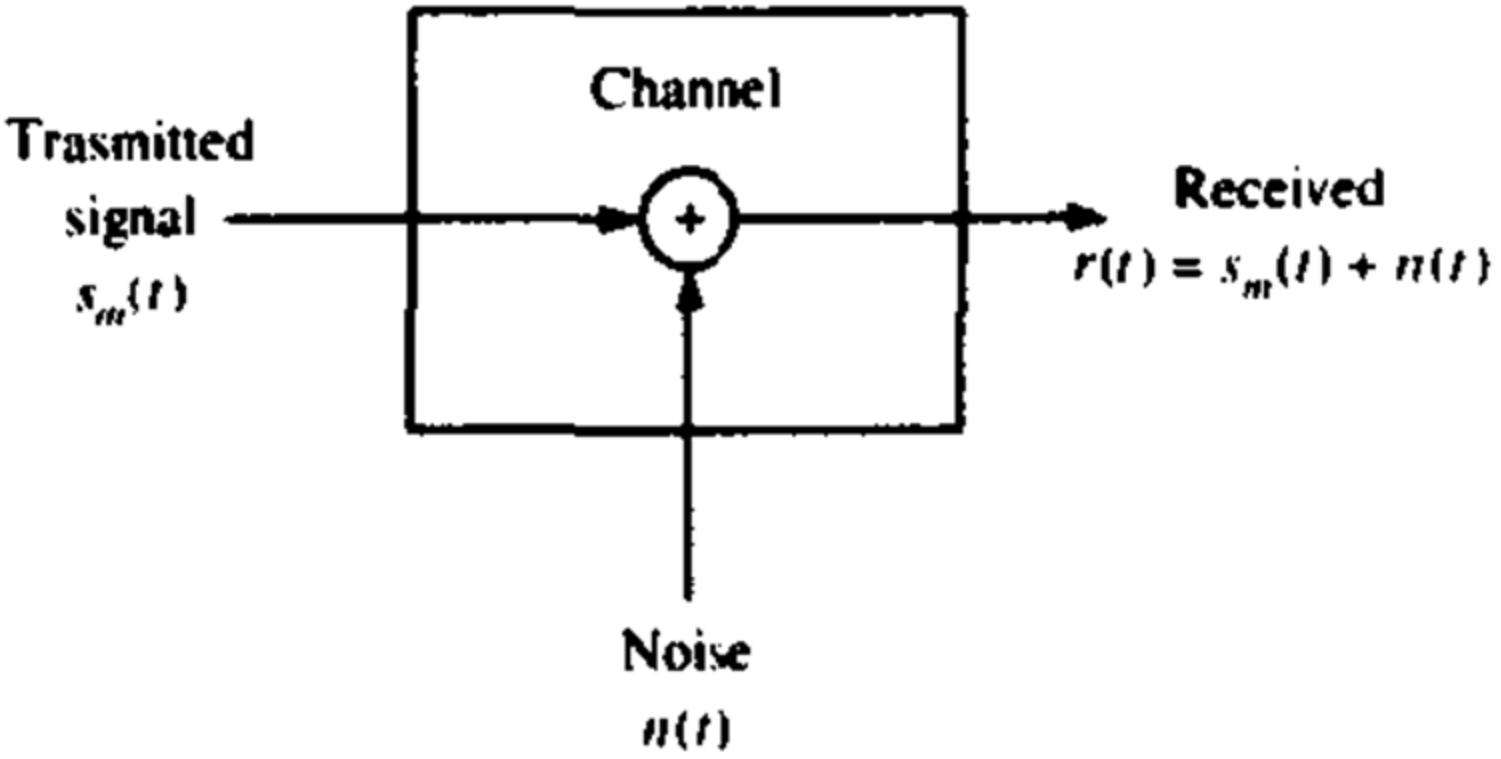
Tentative Teaching Plan

Sr. #	Topic	No. of Lectures
14	Fundamental of Spread Spectrum: Concept of Spectrum and Bandwidth	2
15	Definition of SS Signals, Types of SS signals	2
16	Benefits of SS techniques	2
17	Analysis of SS Systems: Direct Sequence SS systems	2
18	Frequency-Hopped SS systems. Test – 02	2
19	Synchronization of SS communication system (Acquisition and Tracking)	2
20	Application of Spread Spectrum: Anti-jamming, Ranging	2
21	Multipath suppression	2
22	Code-Division Multiple Access	2
23	Recent Commercial Applications	2
24	CDMA Systems: Introduction to 2G/3G standards	2
25	CDMA 2000 Systems & Architecture, Test – 03	2
26	WCDMA System and Architecture	2
	Total lectures	52

Some Definitions / Concepts-AWGN

- Additive White Gaussian Noise (AWGN) is a basic noise model to reproduce the effects due to random processes occurring in nature.
- Additive because it is added to any noise that might be intrinsic to the information system.
- White refers to idea that it has uniform power across the frequency band for the information system. It is an analogy to the color white which has uniform emissions at all frequencies in the visible spectrum.
- Gaussian because it has a normal distribution in the time domain with an average time domain value of zero.

Some Definitions / Concepts-AWGN



Some Definitions / Concepts-AWGN

- Wideband noise comes from many natural sources, such as:
  - The thermal vibrations of atoms in conductors (referred to as thermal noise or Johnson-Nyquist noise),
  - Shot noise (also known as photon noise)-comes into the system because of photo-detection process.
  - Black body radiation from the earth and other warm objects, and from celestial sources such as the Sun.
- The central limit theorem of probability theory indicates that the summation of many random processes will tend to have distribution called Gaussian or Normal.

Some Definitions / Concepts-Random processes

- Stochastic or Random Process
- A mathematical model is used to describe a physical phenomenon.
- Two types of mathematical models are:
- **Deterministic process:**
- A model is said to be deterministic if there is no uncertainty about its time-dependent behavior at any instant of time.
- **Stochastic process:**
- In real world problems, the use of deterministic model is inappropriate because the physical phenomenon of interest involves too many unknown factors.

Some Definitions / Concepts-Random processes

- So we speak of a model in probabilistic terms.
- Such a model is said to be stochastic or random.
- Consider for example, a radio communication system. The received signal in such a system usually consists of
  - an information bearing signal component,
  - a random interference component,
  - and a channel noise.
- The information bearing signal component may represent, for example, a voice signal that, typically consists of randomly spaced bursts of energy of random duration.

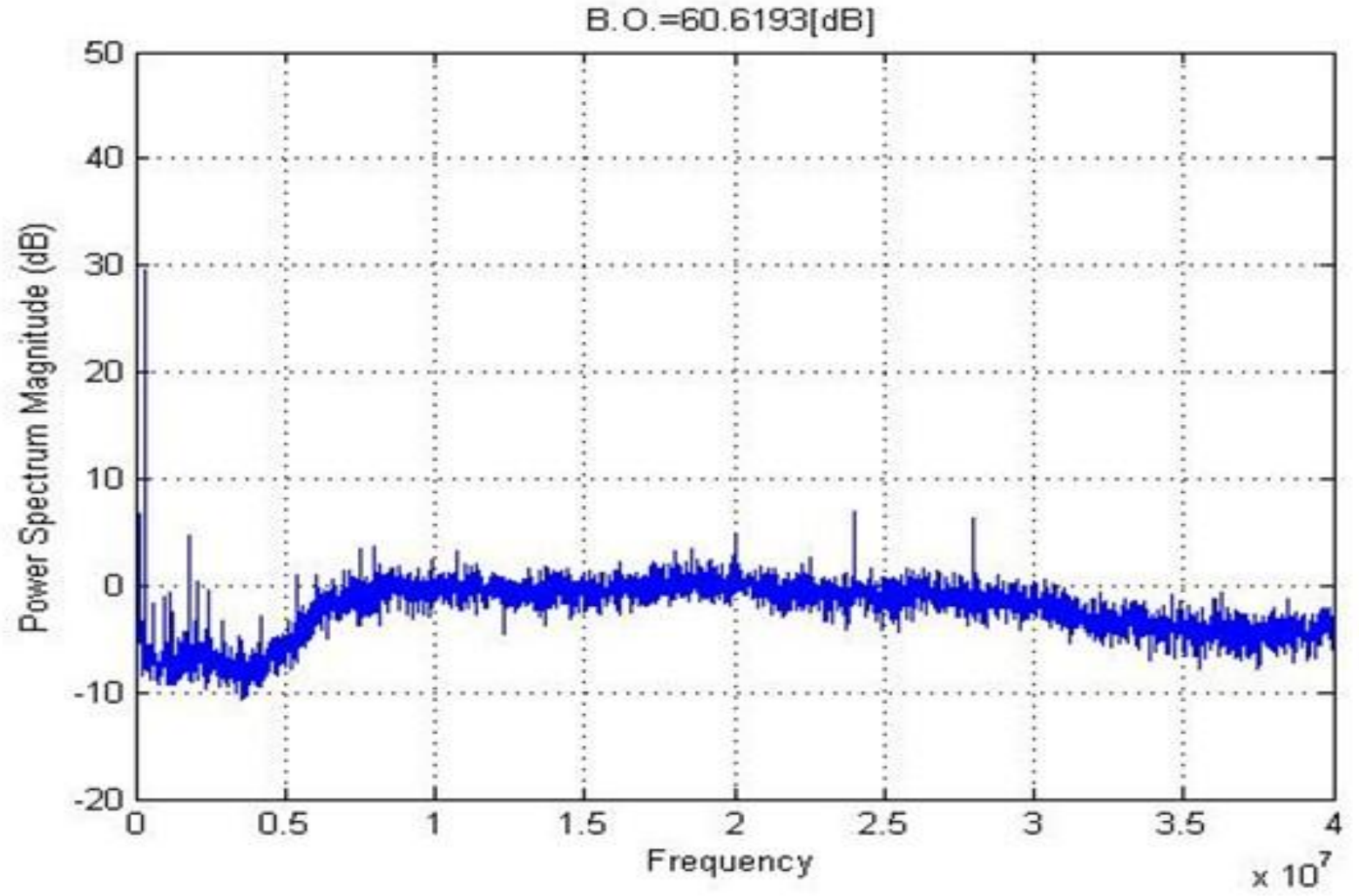
Some Definitions / Concepts-Random processes

- The interference component may represent spurious electromagnetic waves produced by other communication systems operating in the vicinity of the radio receiver.
- A major source of channel noise is thermal noise, which is caused by the random motion of the electrons in the conductors and devices at the front end of the receiver.
- We thus find the received signal is random in nature.
- Although it is not possible to predict the exact value of the signal in advance, it is possible to describe the signal in terms of statistical parameters such as average power and power spectral density.

Some Definitions / Concepts-PSD

- **Power spectral density (psd)**
- Spectrum of a signal shows how much power is contained in each of its harmonic or spectral components or the frequency spectrum of the signal.
- Power spectral density (PSD) describes how the power of a signal or time series is distributed over the different frequencies.
- A plot of the frequency components on the x-axis and attendant Power in that frequency on the y-axis is called the Power Spectrum of the signal. Its units are watts per Hertz.

Some Definitions / Concepts-PSD

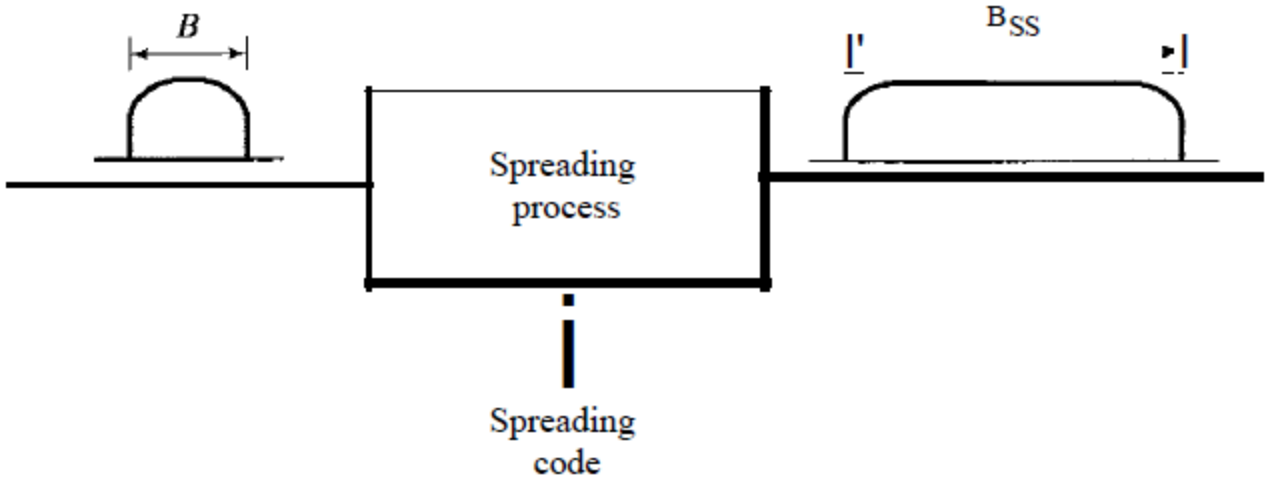


Why Spread Spectrum?

- Spread spectrum modulation refers to any modulation scheme that produces a spectrum for the transmitted signal much wider than the bandwidth of the information being transmitted independently of the information-bearing signal.
- Why wasteful modulation be done?
- Reasons are:
- To provide some degree of resistance to interference and jamming (called *jam resistance-JR*);
- To provide a means for masking the transmitted signal in the background noise in order to lower the probability of intercept by an adversary (called *low probability of intercept-LPI*);
- To provide resistance to signal interference from multiple transmission paths (i.e. *multipath*);

Why Spread Spectrum?

- To permit the access of a common communication channel by more than one user (called *multiple access*);
- To provide a means for measuring range, or distance between two points.



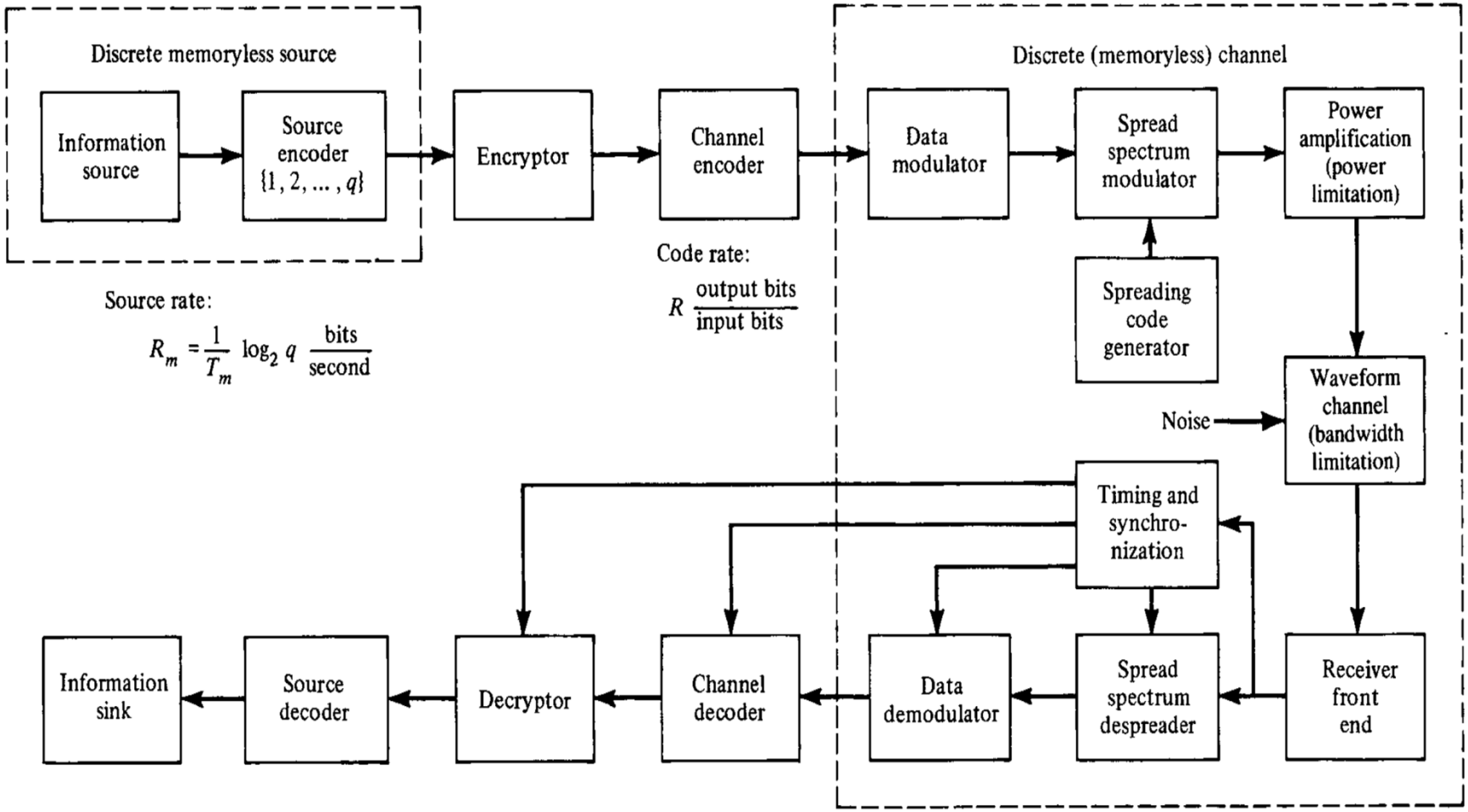
Why Spread Spectrum?

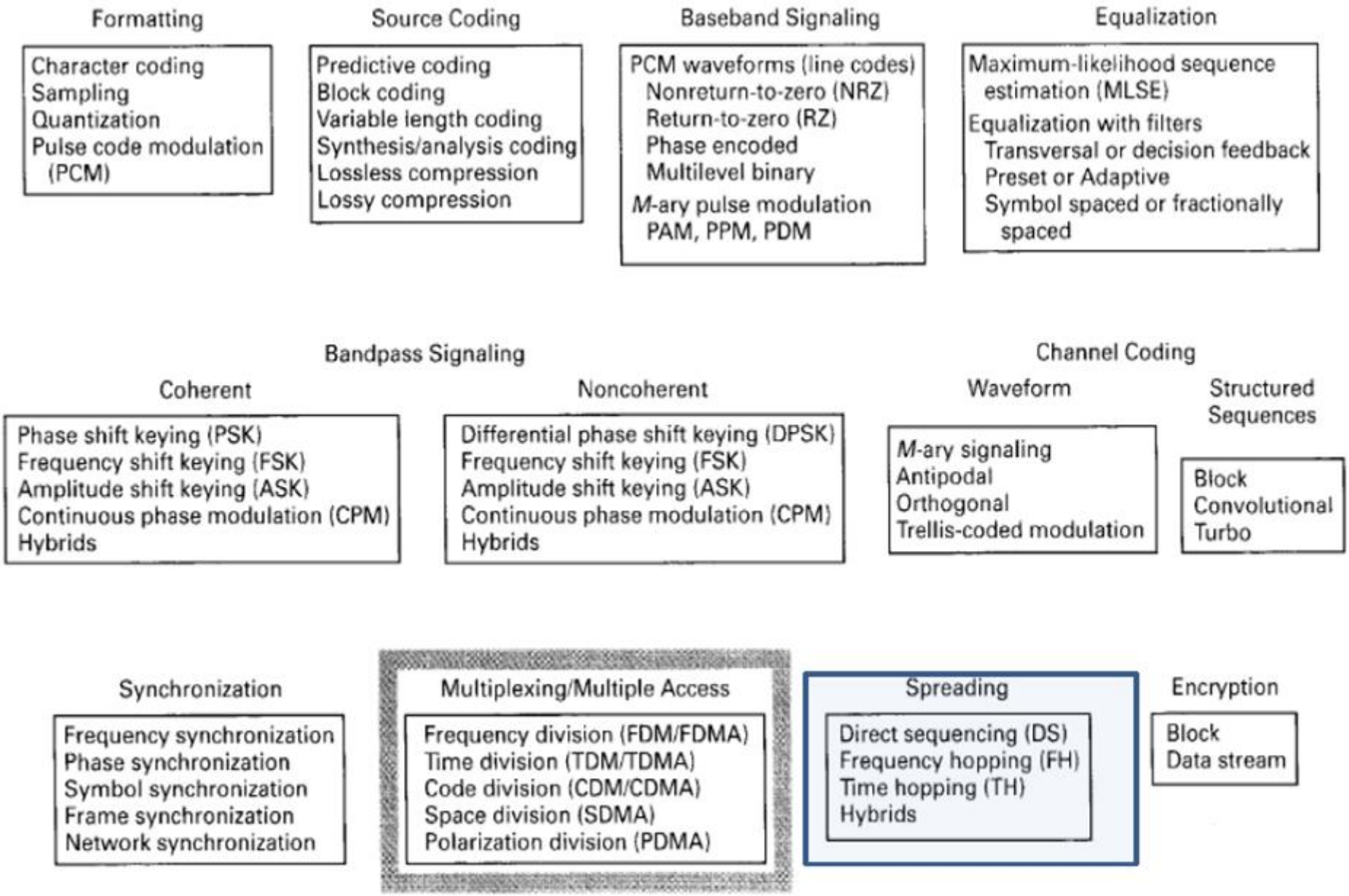
- Spread-spectrum communications technology was first described on paper by an actress and a musician!
- In 1941 Hollywood actress Hedy Lamarr and pianist George Antheil described a secure radio link to control torpedoes. They received U.S. Patent #2.292.387.
- The technology was not taken seriously at that time by the U.S. Army and was forgotten until the 1980s, when it became active. Since then the technology has become increasingly popular for applications that involve radio links in hostile environments.

Applications of Spread Spectrum

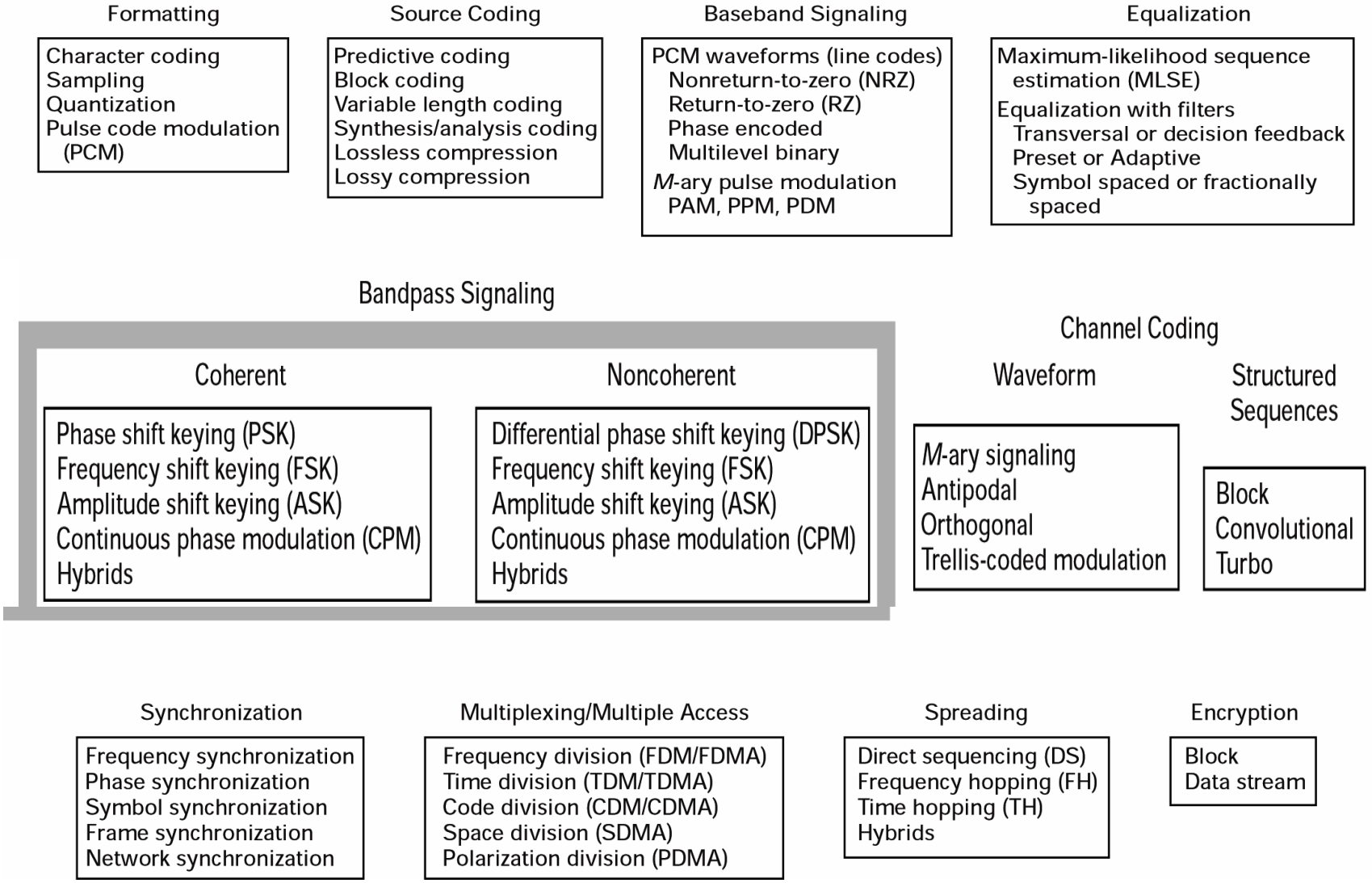
- Applications of SS Communications:
  - Military Communications
  - Multiple-Access Satellite Communications
  - CDMA (Code-Division Multiple-Access) Mobile Communications
  - Global Positioning System (GPS)

Digital Communication




Formatting
Character coding
Sampling
Quantization
Pulse code modulation (PCM)
Source Coding
Predictive coding
Block coding
Variable length coding
Synthesis/analysis coding
Lossless compression
Lossy compression
Baseband Signaling
PCM waveforms (line codes)
Nonreturn-to-zero (NRZ)
Return-to-zero (RZ)
Phase encoded
Multilevel binary
M-ary pulse modulation
PAM, PPM, PDM
Equalization
Maximum-likelihood sequence estimation (MLSE)
Equalization with filters
Transversal or decision feedback
Preset or Adaptive
Symbol spaced or fractionally spaced
Bandpass Signaling
Coherent
Phase shift keying (PSK)
Frequency shift keying (FSK)
Amplitude shift keying (ASK)
Continuous phase modulation (CPM)
Hybrids
Noncoherent
Differential phase shift keying (DPSK)
Frequency shift keying (FSK)
Amplitude shift keying (ASK)
Continuous phase modulation (CPM)
Hybrids
Channel Coding
Waveform
M-ary signaling
Antipodal
Orthogonal
Trellis-coded modulation
Structured Sequences
Block
Convolutional
Turbo
Synchronization
Frequency synchronization
Phase synchronization
Symbol synchronization
Frame synchronization
Network synchronization
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 (TH)
Hybrids
Encryption
Block
Data stream

Digital Communication



Digital Communication-Basic Terminology

- ***Formatting*** transforms the source information into bits.
- ***Modulation*** is the process by which message symbols or channel symbols are converted to waveforms (line codes) that are compatible with the requirements of transmission channel.
- ***Baseband*** refers to a signal whose spectrum extends from (or near) dc up to some finite value, usually less than few megahertz.
- ***Bandpass*** is used to indicate that the baseband waveform $g_i(t)$ is frequency translated by a carrier wave to a frequency that is much larger than the spectral content of $g_i(t)$.
  - Bandpass modulation is required whenever the transmission medium will not support propagation of pulse-like waveform such as RF transmission. For such cases, the medium requires a bandpass waveforms $s_i(t)$.

Digital Communication-Basic Terminology

- ***Equalization*** can be described as a filtering option that is used in or after the demodulator to reverse any degrading effects on the signal that were caused by the channel.
  - An equalizer is implemented to compensate for (i.e., remove or diminish) any signal distortion caused by a non-ideal channel impulse response $h_c(t)$.
- ***Demodulation*** is defined as recovery of a waveform (baseband pulse), and detection is defined as decision-making regarding the digital meaning of that waveform.
- **Demodulation** is typically accomplished with signal attributes (particularly phase), the process is termed ***coherent;*** when phase information is not used, the process is termed ***non-coherent***.

Digital Communication-Basic Terminology

- ***Source coding*** produces Analog-to-digital (A/D) conversion (for Analog sources) and removes redundant (unneeded) information.
- Information is encoded in different formats like a picture can be encoded in JPEG or MPEG, etc.
- A typical DCS would either use the source coding option (for both digitizing and compressing the source information), or it would use the simpler formatting transformation (for digitizing alone).
- ***Encryption*** prevents unauthorized users from understanding messages and from injecting false messages into the system.

Digital Communication-Basic Terminology

- **Symbol** (digital message)- A symbol is a group of k bits considered as a unit. We refer to this unit as a message symbol m_i.
- ***Data rate-*** This quantity in bits per second is given by $R=k/T=(1/T)\log_2 M$ bits/s, where k bits identify a symbol from an $M=2^k$ symbol alphabet, and T is the k-bit symbol duration.
- **Signal to Noise Ratio (SNR)-** The figure of merit for analog communication system is a fidelity criterion, such as SNR, percent distortion, or expected mean-square error between the transmitted and received waveforms. A figure for digital communication system is the probability of incorrectly detecting a digit, or the probability of error, P_E.

Digital Communication

- **Channel coding**
- Information is transmitted through channels (e.g. Wires, optical fibres and even air)
- Channels are noisy and we do not receive what was transmitted
- So channel coding can be defined as:

  "Class of signal transformations designed to improve communication performance by enabling the transmitted signals to better withstand channel distortions such as noise, interference, and fading."

Digital Communication-Basic Terminology

- ***Channel coding***, for a given data rate, can reduce the probability of error, PE, or reduce the required signal-to-noise ratio to achieve a desired PE at the expense of transmission bandwidth or decoder complexity.
- Channel coding can be divided into two major classes:
    1. Waveform coding by signal design
    2. Structured sequences by adding redundancy
- **Waveform coding-** Deals with transforming waveform into "better waveform" robust to channel distortion hence improving detector performance.

Digital Communication

- Examples of Waveform coding
  1. Antipodal signaling
  2. Orthogonal signaling
  3. Bi-orthogonal signaling
  4. M-ary signaling
  5. Trellis-coded modulation (TCM)

Digital Communication-Basic Terminology

- **Structured sequences** involve the use of redundant bits to determine whether or not an error has occurred due to noise on the channel.
- One of these techniques, known as **automatic repeat request (ARQ)**, simply recognizes the occurrence of an error and requests that the sender retransmit the message.
- Other techniques, known as **forward error correction (FEC)**, are capable of automatically correcting the errors (within specified limits).

Digital Communication

- **Examples of structured sequences**
  - Linear codes
    - Hamming codes
    - BCH codes
    - Cyclic codes
    - Reed-Solomon codes
  - Non-Linear codes
    - Convolution codes
    - Turbo codes

Digital Communication

•The " standard" components that would appear in most communication systems include:

1. The source, source coder;
2. Data modulator;
3. Power amplification (and antenna if radio propagation channel);
4. Receiver including receiving antenna (if radio propagation channel);
5. Timing and synchronization;
6. Data demodulator;
7. Information sink, source decoder;

Digital Communication

•The " non-standard" components are:

1. Encryptor;
2. Channel encoder;
3. Spread-spectrum modulator;
4. Spread-spectrum despreader;
5. Channel decoder
6. Decryptor;

• Items 2-5 will be standard components in a spread spectrum communications system.