Digital Communications

— Lecture 01 —
Introduction

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Outline of the Course

- Introduction
- Signal-Space Representation
- On-Off Keying
- M-ary Digital Memoryless Communications over AWGN Channel
- Popular Modulation Formats
- Bounds on SER and BER
- PSD of Digitally-Modulated Signals
- Comparison of Digital-Modulation Schemes
- Complex-Valued Modulation
- Communications over Bandlimited Channels
- Wireless Channels
- Performance over Fading Channels and Diversity Techniques

Communication System (1/3)

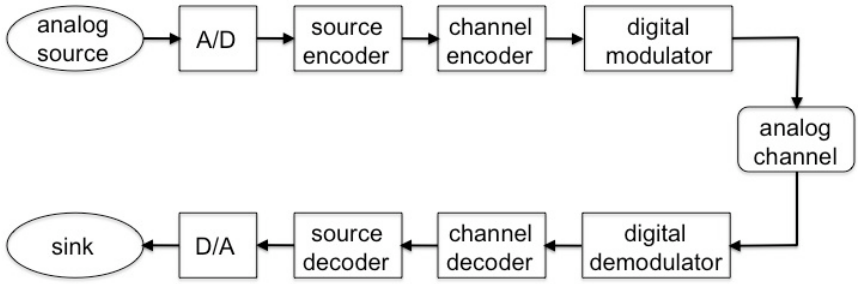
Block diagram of a point-to-point communication system, also denoted Single-Input Single-Output (SISO) communication system

- Source: source of the information message
- Sink: destination of the information message
- Channel: physical medium linking the source to the sink
- TX & RX: make reliable communications possible (to be designed)

Each block is a "virtual" system including different functionalities depending on the focus of the designer

Communication System (2/3)

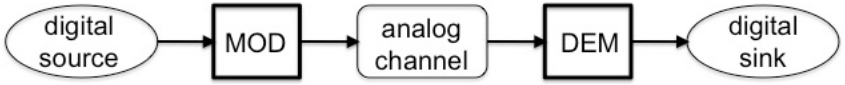
Detailed block diagram of a SISO communication system



We will focus on MODEM design

Communication System (3/3)

Block diagram of the equivalent communication system



- Digital Source:
  - produces symbols from a finite alphabet with constant rate
  - is assumed stationary and memoryless
- Digital Sink:
  - accepts symbols from a finite alphabet with (same) constant rate
- Analog Channel:
  - supports analog signals (waveforms)
  - has infinite bandwidth
  - is noisy
- MOD & DEM: to be designed

Notation (1/2)

- $\mathcal{U} = \{\ldots, u_0, u_1, \ldots, u_k, u_{k+1} \ldots\}$ is the message to be transmitted
- $u_k \in \mathcal{A}$ is the symbol transmitted at discrete time k
- $\mathcal{A} = \{a_1, \ldots, a_M\}$ is the symbol alphabet
- $\Pi = \{p_1, \ldots, p_M\}$ is the symbol probability distribution
  $p_m = \Pr(u_k = a_m)$ stationary memoryless digital source
  $p_m \geq 0, \quad \sum_{m=1}^{M} p_m = 1$
- M is cardinality of the alphabet (constellation size)
- T is the symbol time and $1/T$ is the symbol frequency
- $R = \frac{\log_2(M)}{T}$ is the transmission bit-rate
- $\{s_1(t), \ldots, s_M(t)\}, \ t \in [0, T)$ is the set of transmitted waveforms, also denoted signals

$$u_k = a_m \ \rightarrow \ s_m(t - kT)$$

$$z(t; \mathcal{U}) = \sum_{k=-\infty}^{+\infty} s(t - kT; u_k)$$

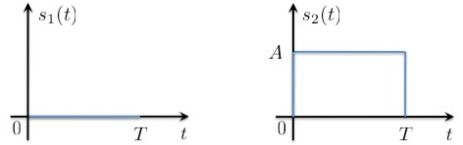
Notation (2/2)

- $\mu_x(t) = \mathbb{E}\{x(t)\}$
  mean of a stochastic process
- $R_x(t, s) = \mathbb{E}\{x(t)x^*(s)\}$
  Auto-Correlation Function (ACF) of a stochastic process
- $P_x(f) = \mathcal{F}\left\{\lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{+T/2} R_x(t, t-\tau)dt\right\}(\tau \rightarrow f)$
  Power Spectral Density (PSD) of a stochastic process

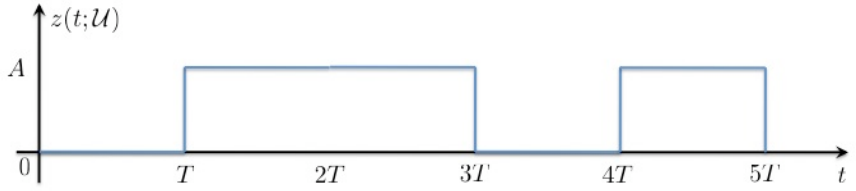
On-Off Modulation

- $M = 2$ binary modulation
- $\mathcal{A} = \{a_1, a_2\} = \{0, 1\}$
- $s_1(t) = 0, \quad s_2(t) = p(t)$

e.g. $p(t) = A \ \text{rect}\left(\frac{t - T/2}{T}\right)$

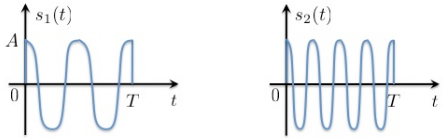


e.g. $\mathcal{U} = \{a_1, a_2, a_2, a_1, a_2\}$

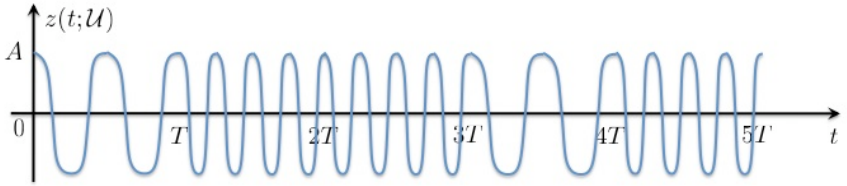


Binary FSK

- $M = 2$ binary modulation
- $\mathcal{A} = \{a_1, a_2\} = \{0, 1\}$
- $s_1(t) = A\cos(2\pi f_1 t)\text{rect}\left(\frac{t-T/2}{T}\right)$, $s_2(t) = A\cos(2\pi f_2 t)\text{rect}\left(\frac{t-T/2}{T}\right)$



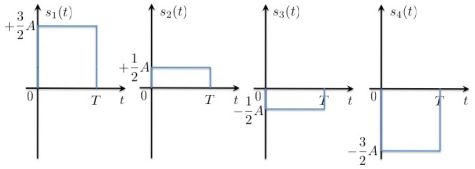
e.g. $\mathcal{U} = \{a_1, a_2, a_2, a_1, a_2\}$



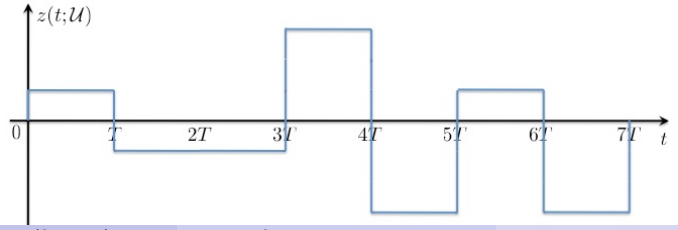
Multilevel Modulation (ASK)

- $M = 4$ quaternary modulation
- $\mathcal{A} = \{a_1, a_2, a_3, a_4\} = \{00, 01, 10, 11\}$
- $s_1(t) = (+3/2)p(t)$, $s_2(t) = (+1/2)p(t)$
  $s_3(t) = (-1/2)p(t)$, $s_4(t) = (-3/2)p(t)$

e.g. $p(t) = A\ \text{rect}\left(\frac{t-T/2}{T}\right)$

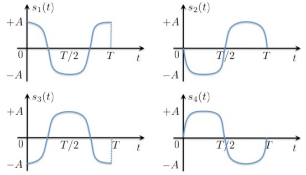


e.g. $\mathcal{U} = \{a_2, a_3, a_3, a_1, a_4, a_2, a_4\}$



QPSK

- $M = 4$ quaternary modulation
- $\mathcal{A} = \{a_1, a_2, a_3, a_4\} = \{00, 01, 10, 11\}$
- $s_1(t) = A\cos(2\pi f_0 t)\text{rect}\left(\frac{t-T/2}{T}\right)$
  $s_2(t) = A\cos(2\pi f_0 t + \frac{\pi}{2})\text{rect}\left(\frac{t-T/2}{T}\right)$
  $s_3(t) = A\cos(2\pi f_0 t + \pi)\text{rect}\left(\frac{t-T/2}{T}\right)$
  $s_4(t) = A\cos(2\pi f_0 t + \frac{3\pi}{2})\text{rect}\left(\frac{t-T/2}{T}\right)$



e.g. $\mathcal{U} = \{a_2, a_3, a_3, a_1, a_4, a_2, a_4\}$