ECE 447 Fall 2025

Lesson 27

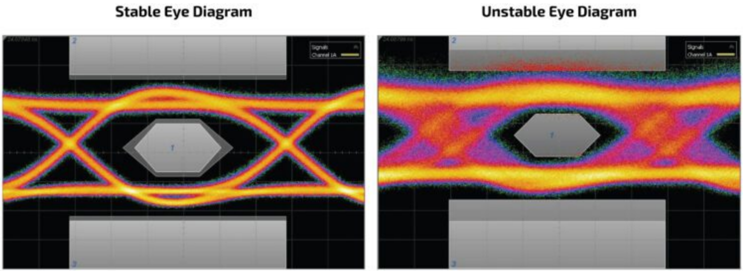
M-ary Baseband Signaling

UNITED STATES AIR FORCE ACADEMY

Schedule and Admin

- Schedule updated.
- Admin
  - **HW4**. Graded. Submit any regrade requests via Gradescope.
  - **Lab 4**. Need to grade.
  - **HW5**. Posted on website. Due TONIGHT.
  - **Lab 5**. PDF due 6 Nov to Gradescope.

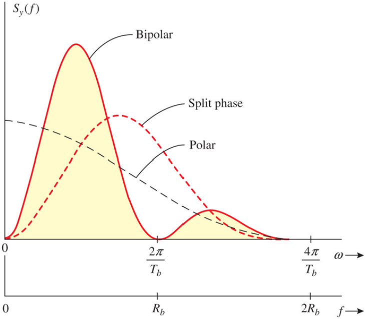
Review



- Where are the optimum sampling points in the figures?
- Where are the error free sampling regions for both?
- Where do you look to see how much timing jitter there is? What about distortion at the sampling point?

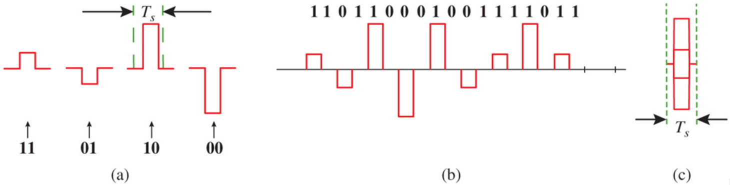
The Quest for Higher Data Rates

- Covered pulses & line codes using *binary baseband* modulations
- All transmit 1 bit at $R_b = 1/T_b$ bits per second
- The bandwidth required is proportional to R_b (see figure below)
- How can we increase our data rate?



M-ary Baseband Signaling

- Assign multiple bits to each pulse - to transmit n bits per pulse, you need $M = 2^n$ pulses (which is where the M in M-ary comes from)
- M-ary PAM: amplitudes define the pulses (other types of M-ary)
- Not a free lunch! See Example 6.6 in textbook - 4-ary PAM results in the same bandwidth as binary, but requires **5x** the original signal power
- New term! **Baud rate**: pulse or symbol rate. Ex: if using 16-ary PAM at a baud rate of 250 MBd (mega baud), the bit rate is 1 Gbps
- Baud rate focuses on physical transmission speed and should be used with Nyquist's theorem (2 bps/Hz → 2 baud/s/Hz)



Example: Graphing *M*-ary Baseband Signals

10. M-ary PAM is a well-known baseband modulation method in which one of M allowable amplitude levels is assigned to each of the M vector symbols of the signal constellation. A standard 4-PAM signal constellation consists of four real numbers located symmetrically around the origin, that is,

$$\mathcal{C}_{\text{4-PAM}} = \left\{-\frac{3}{2}, -\frac{1}{2}, \frac{1}{2}, \frac{3}{2}\right\}. \tag{2.41}$$

Since there are four possible levels, one symbol corresponds to 2 bits of information. Let $i[n]$ denote the sequence of input bits, $s[n]$ a sequence of symbols, and $x(t)$ the continuous-time modulated signal.

(a) Suppose we want to map the information bits to constellation symbols by their corresponding numeric ordering. For example, among the four possible binary sequences of length 2, 00 is the smallest, and among the constellation symbols, $-\frac{3}{2}$ is the smallest, so we map 00 to $-\frac{3}{2}$. Following this pattern, complete the mapping table below:

$i[n]$	$s[n]$
00	$-\frac{3}{2}$

(b) Let $g(t)$ denote the pulse shape and let

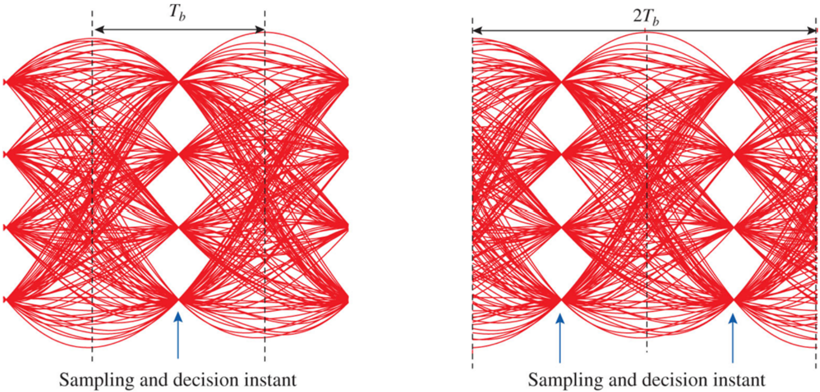
$$x(t) = \sum_n s[n]g(t - nT) \tag{2.42}$$

denote the modulated baseband signal. Let $g(t)$ be a triangular pulse shape function defined as

$$g(t) = \begin{cases} 1 - 2\frac{|t-\frac{T}{2}|}{T}, & \text{if } t \in [0, T], \\ 0, & \text{otherwise.} \end{cases} \tag{2.43}$$

By hand, draw a graph of $x(t)$ for the input bit sequence 11 10 00 01 11 01, with $T = 2$. You can illustrate for $t \in [0, 12]$.

Eye Diagrams with M-ary Signals



(a) (b)