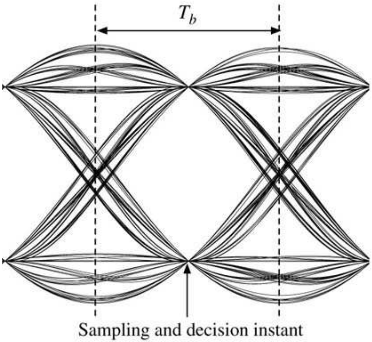
Digital Carrier Modulation

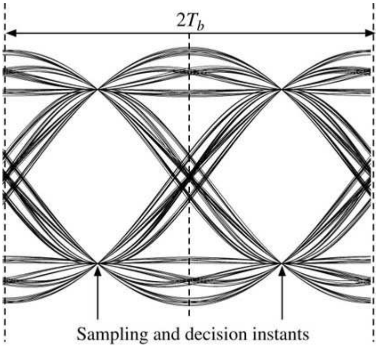
Lecture topics

- Eye diagrams
- Pulse amplitude modulation (PAM)
- Binary digital modulation
  - Amplitude shift keying (ASK)
  - Frequency shift keying (FSK)
  - Phase shift keying (PSK)
- Quadrature PSK and QAM

Based on lecture notes from John Gill

Polar Signaling with Raised Cosine Transform ($r = 0.5$)



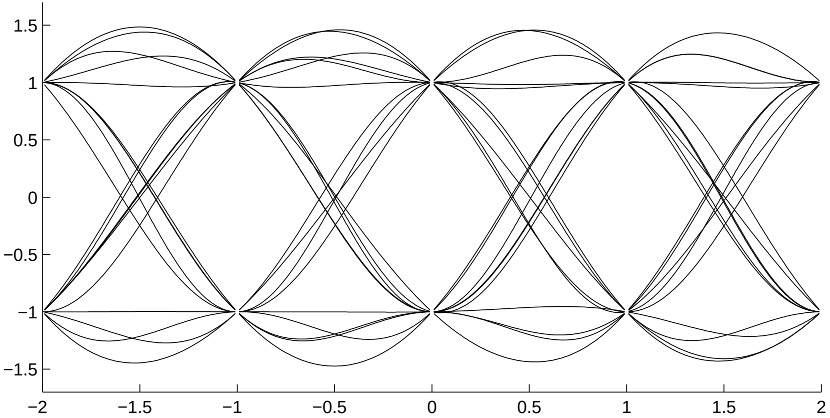


$$P(f) = \begin{cases} 1 & |f| < \frac{1}{4}R_b \\ \frac{1}{2}\left(1 - \sin\pi\left(\frac{f - \frac{1}{2}R_b}{R_b}\right)\right) & \left||f| - \frac{1}{2}R_b\right| < \frac{1}{2}R_b \\ 0 & |f| > \frac{3}{4}R_b \end{cases}$$

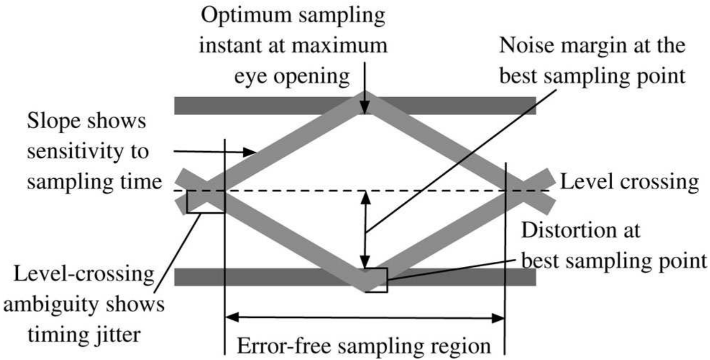
Polar Signaling with Raised Cosine Transform ($r = 0.5$)

The pulse corresponding to $P(f)$ is

$$p(t) = \text{sinc}(\pi R_b t)\,\frac{\cos(\pi r R_b t)}{1 - 4r^2 R_b^2 t^2}$$



Eye Diagram Measurements



- Maximum opening affects noise margin
- Slope of signal determines sensitivity to timing jitter
- Level crossing timing jitter affects clock extraction
- Area of opening is also related to noise margin

PAM: M-ary Baseband Signaling

We can generalize polar signaling to

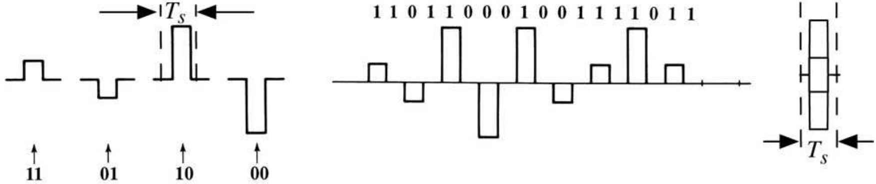
$$y(t) = \sum_k a_k p(t - kT_b)$$

where a_k is chosen from a set of more than two values (i.e., not just ± 1).

Example: one widely used encoding of two bits into four levels is

$$a_k = \begin{cases} -3 & \text{message bits } 00 \\ -1 & \text{message bits } 01 \\ +1 & \text{message bits } 11 \\ +3 & \text{message bits } 10 \end{cases}$$

This is used in ISDN.



PAM: M-ary Baseband Signaling (cont.)

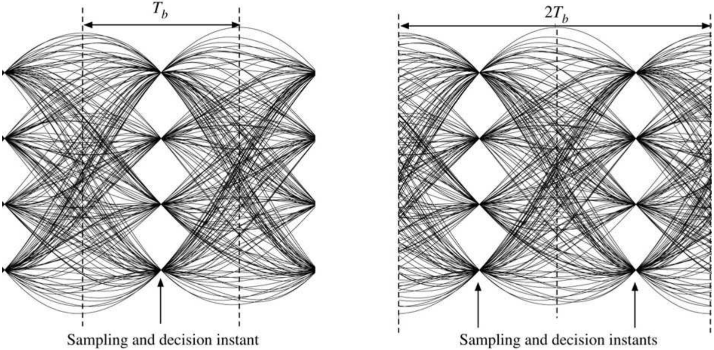
Power of 4-ary signaling:

$$R_0 = \tfrac{1}{4}((-3)^2 + (-1)^2 + 1^2 + 3^2) = \tfrac{1}{4} \cdot 20 = 5\,.$$

If digital values are independent, $R_n = 0$ for $n \neq 0$. Thus PSD is

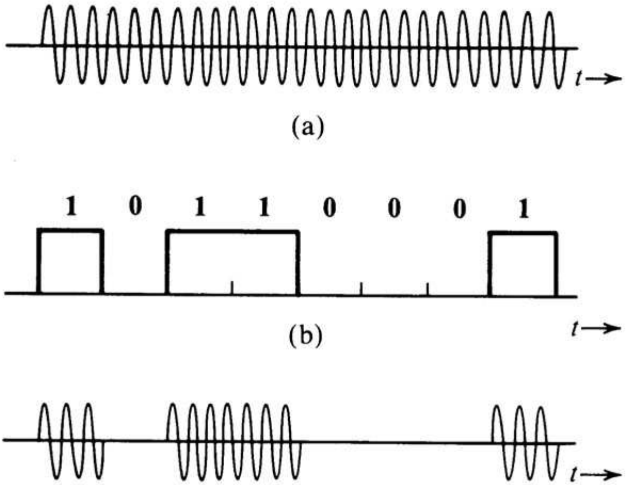
$$S_y(f) = \frac{5}{T_s} |P_x(f)|^2\,,$$

The PSD is the same as binary signaling. More bits use more power.



On-Off Keying (OOK) = Amplitude Shift Keying (ASK)

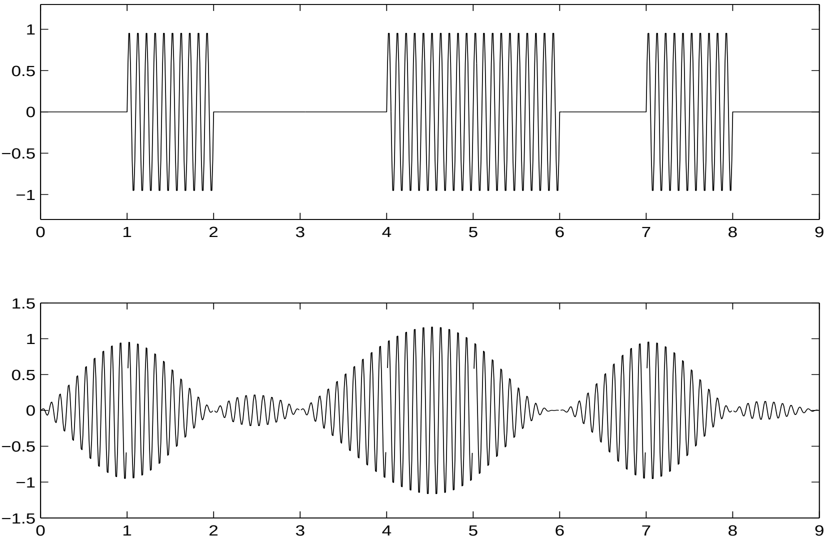
Modulated signal is $m(t)\cos 2\pi f_c t$.



Baseband signal may use shaped pulses, so cosine amplitude varies.

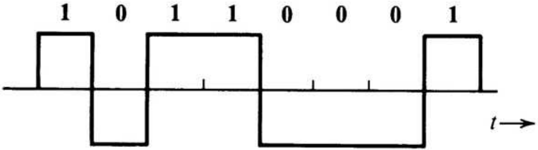
OOK Example

Digital input: $1\ 0\ 0\ 1\ 1\ 0\ 1\ 0\ 0$. Square wave and shaped pulses.

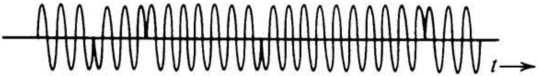


PSK and FSK

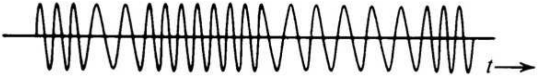
Binary PSK is the same as polar ASK.



(a)



(b)

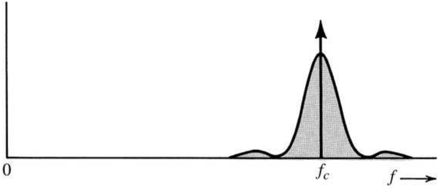


Phase shift keying can use more than two phases (4 and 8 are common).

(FSK often uses only two frequencies, but more are not unusual.)

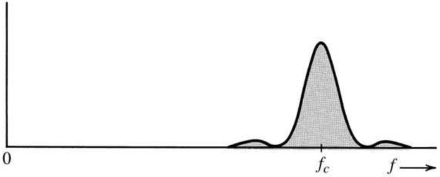
PSD of binary ASK, PSK, FSK

ASK



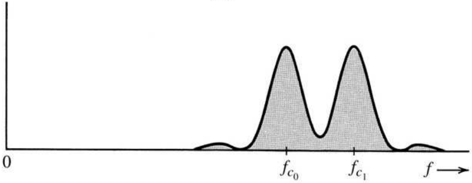
(a)

PSK
(same as ASK)



(b)

FSK



(c)

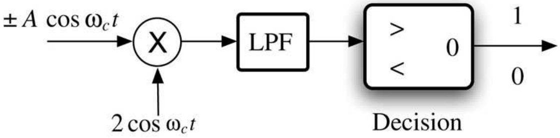
Demodulation of ASK and PSK

- ASK demodulation
  - envelope detector (signal vs. not signal)
  - coherent detector (requires synchronous detection)
- Binary PSK is equivalent to binary PAM with

$$y(t) = \pm A \cos \omega_c t$$

Constant amplitude means envelope detection is not possible.

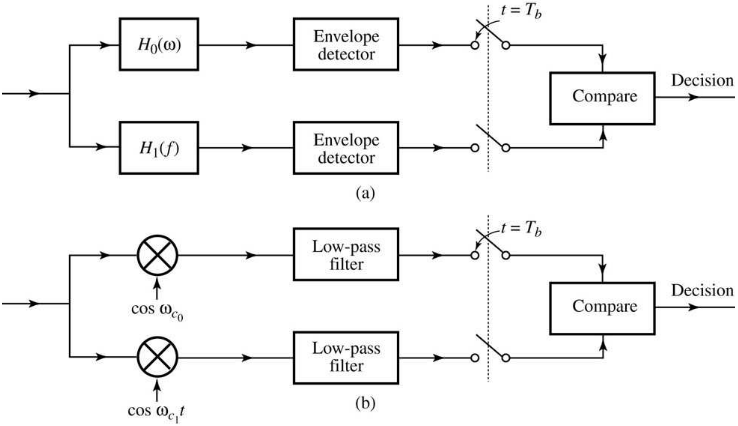
Coherent binary PSK detector is similar to DSB-SC demodulator.



Demodulation of FSK

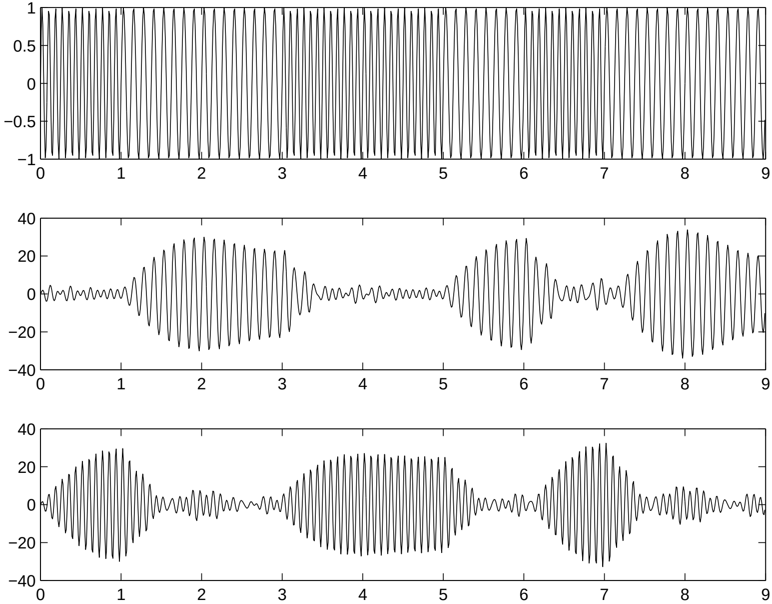
FSK can also use envelope or coherent detector.

In both cases, these are parallel ASK detectors.



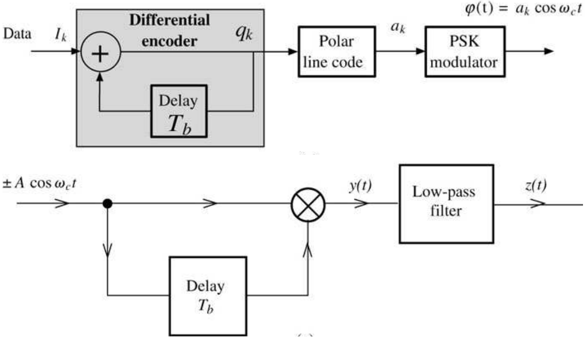
Example: Bell 103 modem (V.21, 300 bps) uses 1270 Hz and 1070 Hz for originating station, only 3 or 4 cycles per bit

FSK Example: $f_0 = 8$, $f_1 = 12$



Differential PSK (DPSK)

Encode 1 by change of phase, $0 \to \pi$ or $\pi \to 0$



- Advantage: local carrier not needed
- Disadvantage: less noise immunity than PSK, more bandwidth, errors occur in pairs
- More than two different phases can be used.

M-ary Digital Carrier Modulation

- M-ary ASK

$$\varphi(t) = 0,\ A\cos\omega_c t,\ 2A\cos\omega_c t,\ \ldots,\ (M-1)A\cos\omega_c t$$

One *symbol* contains $\log_2 M$ bits of information.

Example: $M = 3$, $\log_2 M = 1.584$: 2 trits (ternits) > 3 bits

- M-ary FSK

$$\varphi(t) = A\cos\omega_1 t,\ A\cos\omega_2 t,\ \ldots\ , A\cos\omega_M t$$

Ideally, the possible signals are orthogonal over a bit period. Then

$$\omega_m = \omega_1 + (m-1)\delta f$$

where smallest δf is $1/2T_b$. Bandwidth is (Carson's rule)

$$2(\Delta f + B) = \frac{M+3}{2T_b}$$

Not bandwidth efficient.

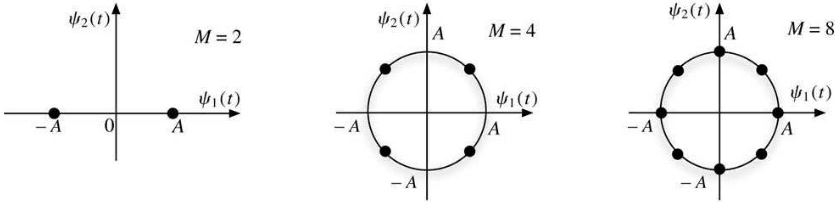
M-ary PSK

- In general,

$$\varphi_{\text{PSK}}(t) = a_m \sqrt{\frac{2}{T_b}} \cos \omega_c t + b_m \sqrt{\frac{2}{T_b}} \sin \omega_c t$$

  Binary PSK: $a_m = A \cos \theta_m,\ b_m = -A \cos \theta_m$. (Ideally, $\theta_m = 0$.)

- In orthogonal signal space, we use more values a_m, b_m where $a^2 + b^2 = A^2$.



- Bell 212A (1200 bps) uses 4-PSK = 4-QAM

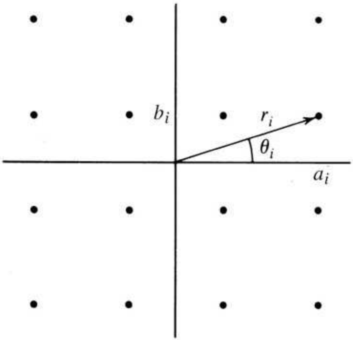
M-ary QAM

QAM, like M-PSK, uses linear combination of orthogonal sinusoids:

$$\varphi_{\text{QAM}}(t) = a_m \sqrt{\frac{2}{T_b}} \cos \omega_c t + b_m \sqrt{\frac{2}{T_b}} \sin \omega_c t$$

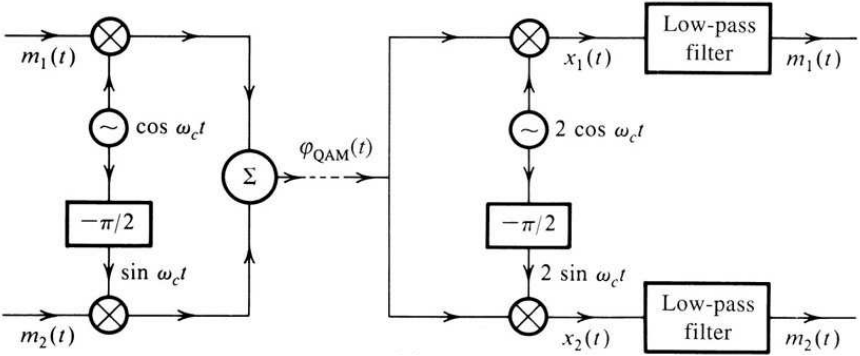
However, amplitude $A = \sqrt{a^2 + b^2}$ can have more than one value.

V.22bis (2400-bps) uses 16-QAM (3 amplitudes, 12 phases)



QAM (cont.)

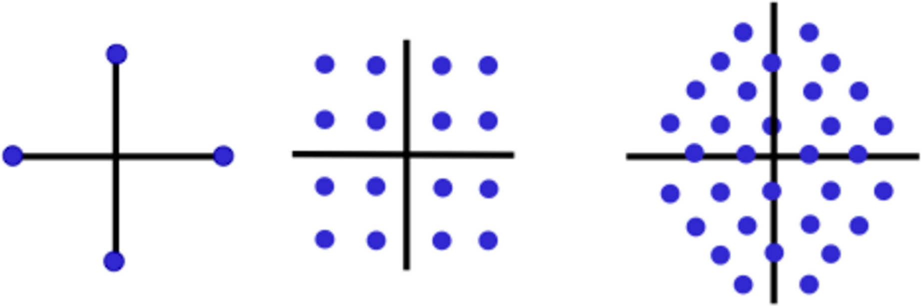
- Modulation and demodulation are combination of PSK and AM.



- V.32 9600 bps uses 32-QAM with trellis coding.

- All modern digital electronic communication uses QAM.

Constellation Examples



V.22
600 baud 1200 bps
PSK

V.22bis
600 baud 2400 bps
QAM

V.32
2400 baud 9600 bps
TCM

- baud = symbol per second
- baud “rate” is proportional to bandwidth