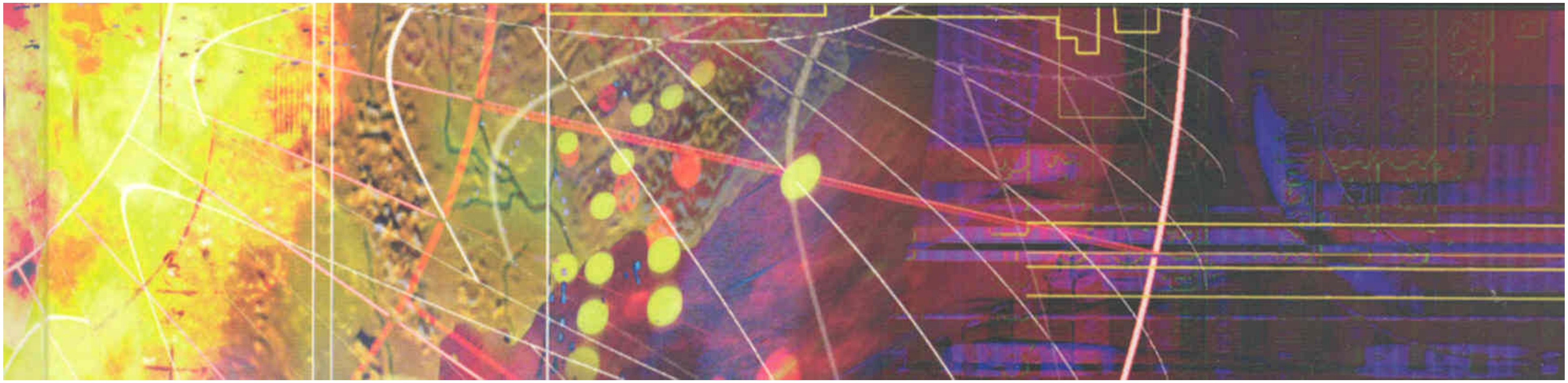
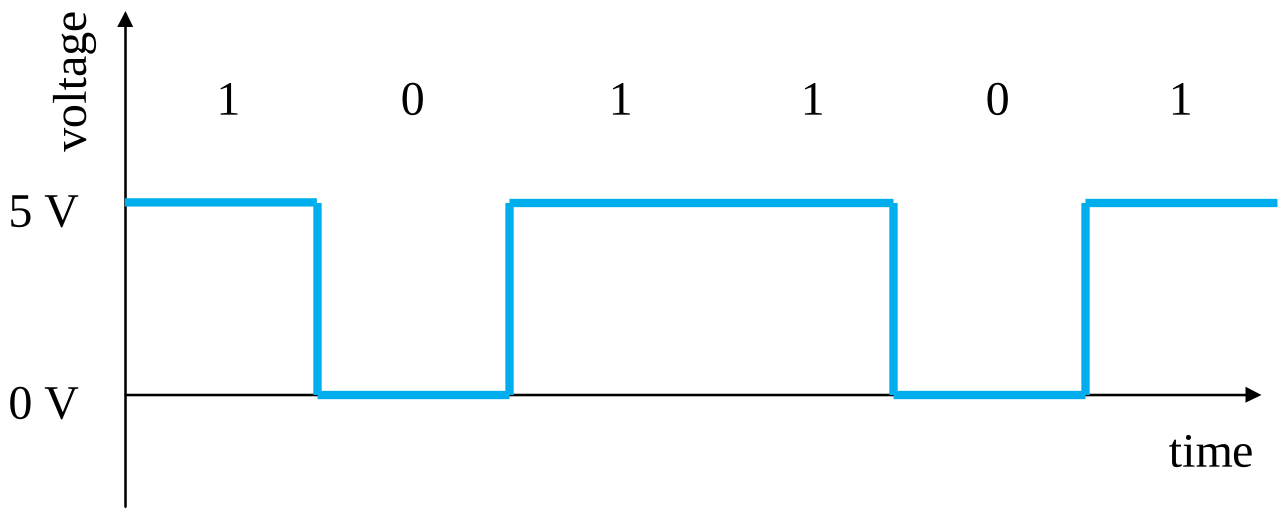


EE303 Lesson 19: Digital Modulation 1

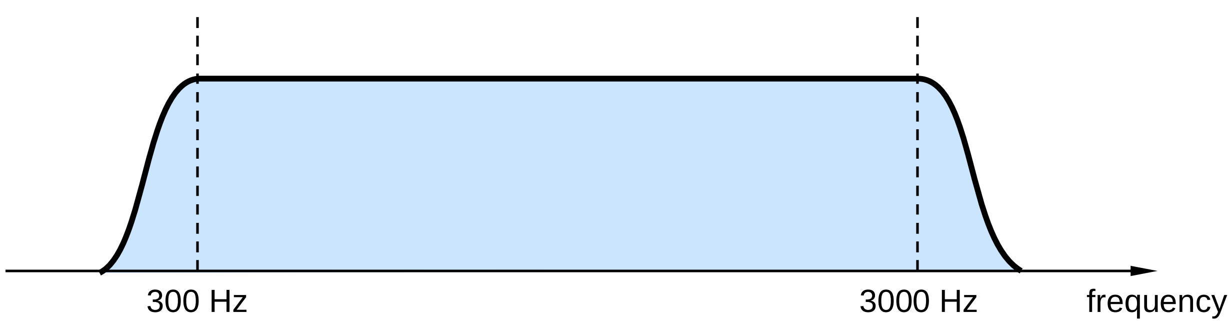
Digital signals

- Binary digital signal below represents 1 or 0 using switched dc pulses.
- However, dc signals are not compatible with communication networks (cable TV and telephone) which carry only ac signals.



Modulation

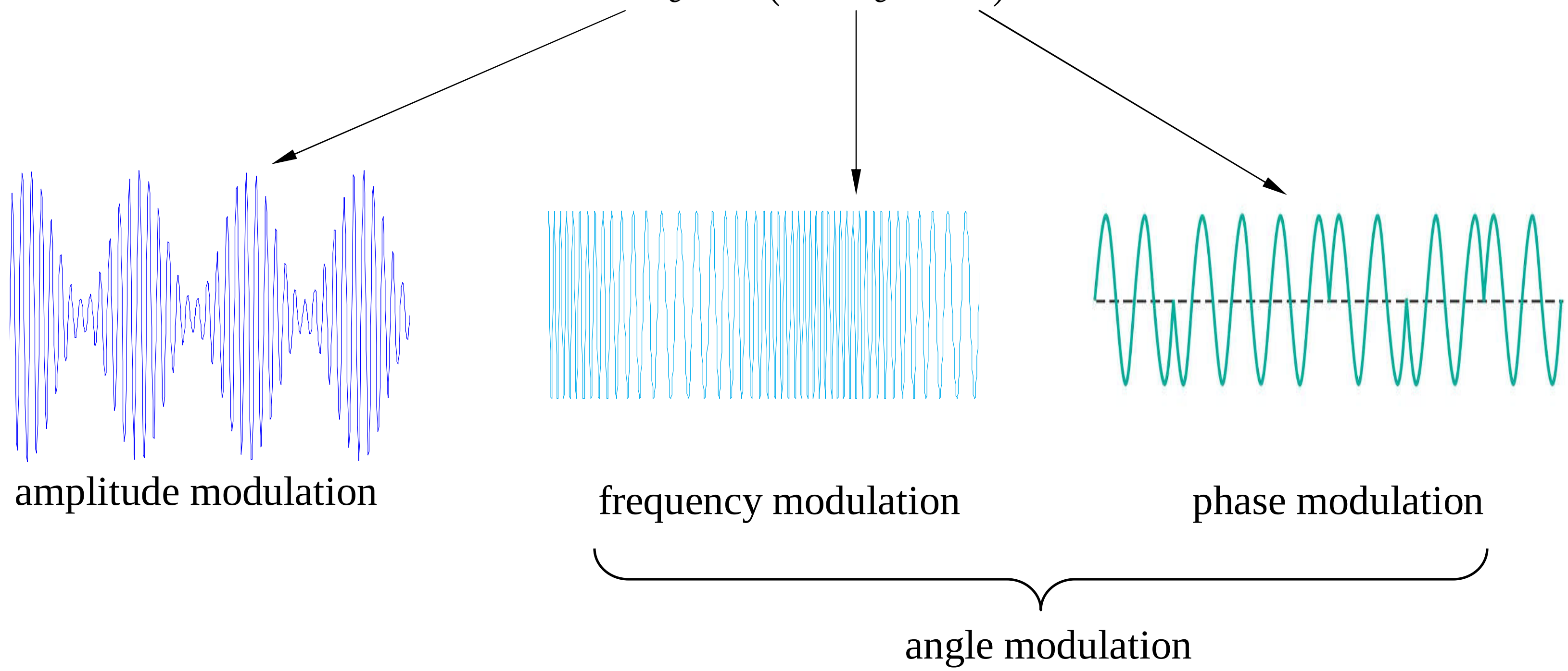
- Just as with baseband analog signals, modulation is required to translate these digital signals to a frequencies appropriate for the transmission media.
- Consider the telephone channel below.



Modulation

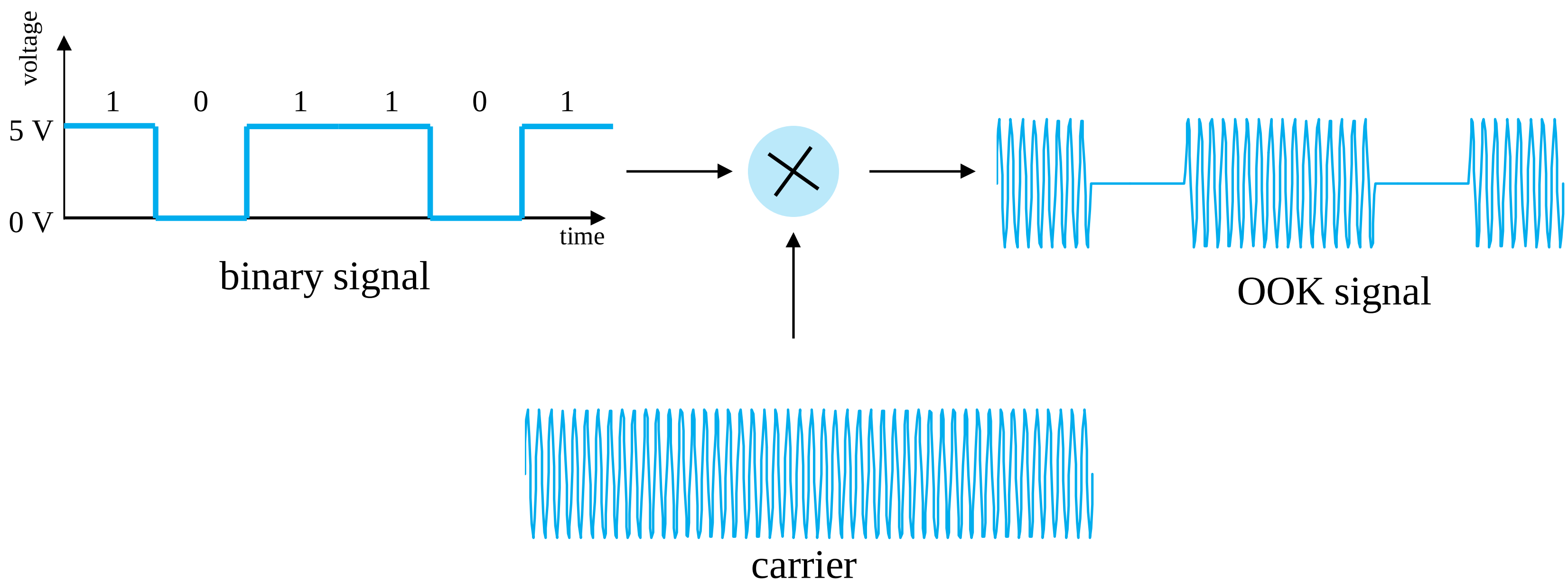
- A sinusoidal carrier can be modulated by varying its amplitude, frequency, or phase.

$$v = V_c \sin\left(2\pi f_c t + \theta\right)$$



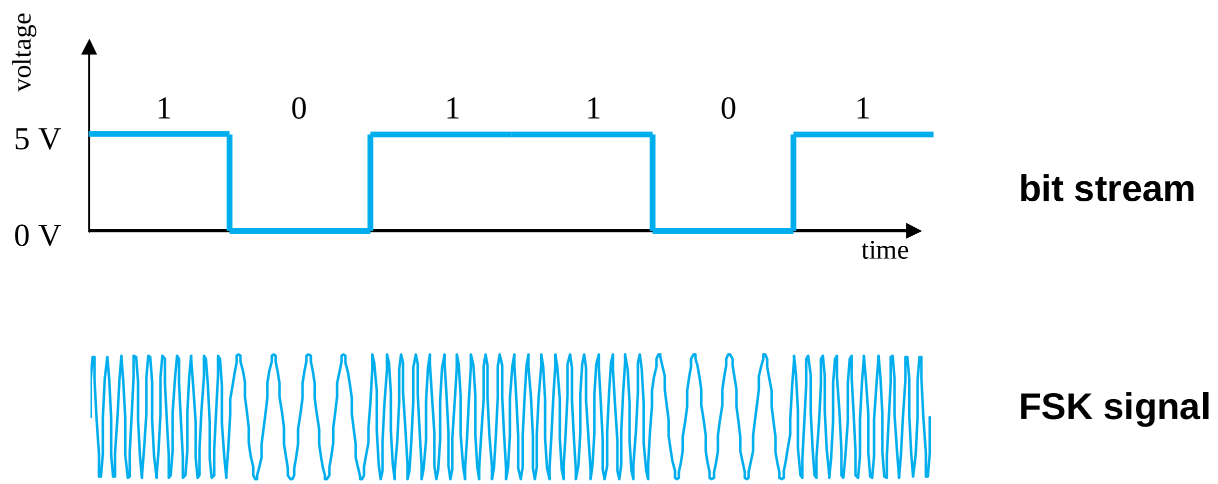
On-off keying

- The simplest digital modulation scheme is a form of AM called on-off keying (OOK) or amplitude-shift keying (ASK).
- This is analogous to Morse code.



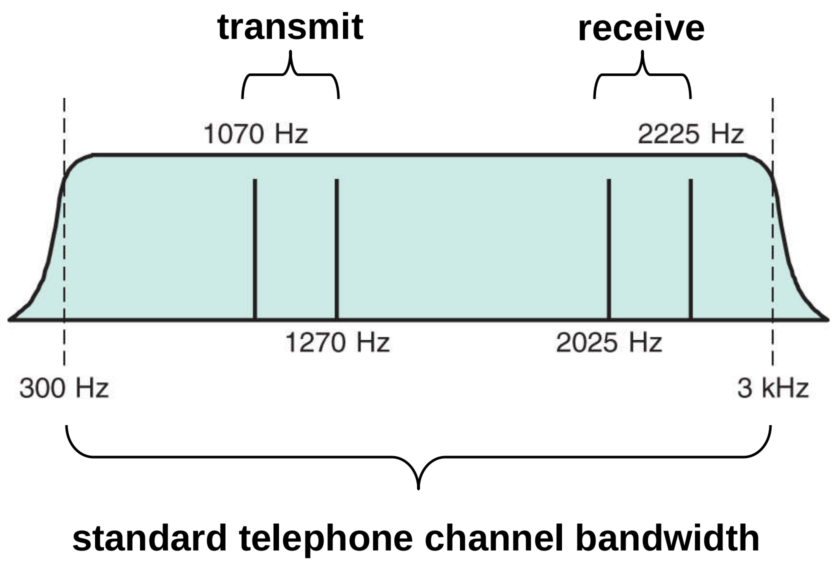
Frequency-shift keying

- The oldest form of modulation used in modems frequency-shift keying (FSK).
- Bits are represented by two frequencies.
  - Binary 0 (space) has a frequency of 1070 Hz.
  - Binary 1 (mark) has a frequency of 1270 Hz.



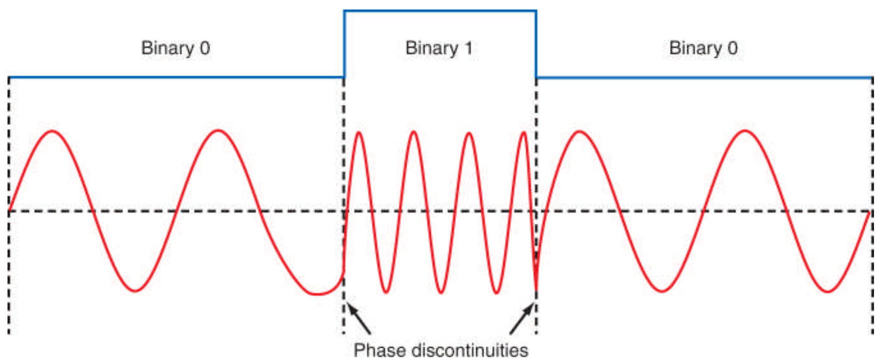
Frequency-shift keying

- Full duplex (simultaneous transmission and reception) operation requires a second set of frequencies.
  - For reception, binary 0 and 1 are represented by 2025 and 2225 Hz.



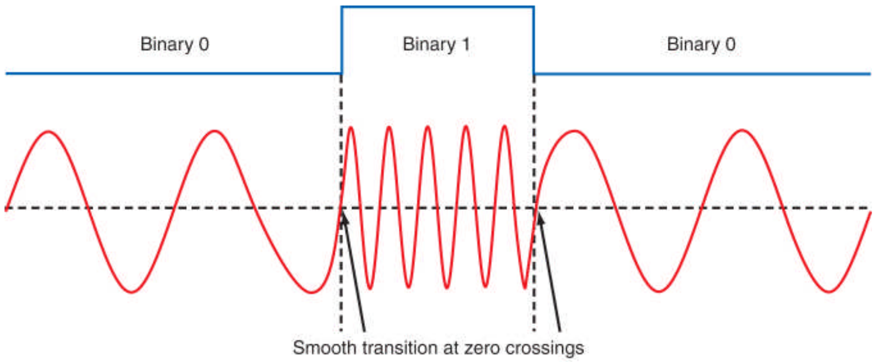
Phase discontinuities

- FSK signals occupy a wide bandwidth because of sidebands produced by the FM process.
  - Higher bit rates generate larger sidebands.
- Abrupt signal changes caused by phase discontinuities further aggravate the problem.



Continuous phase

- Space and mark frequencies can be chosen so that the periods both cross zero.
  - Smooth transitions result in less bandwidth.
  - This type of modulation is called continuous-phase frequency-shift keying (CPFSK).
- This is improved in minimum shift keying (MSK) in which mark and space frequencies are integer multiples of the bit clock frequency,



FSK bandwidth

- Recall that with analog FM, the number of side-bands is proportional to the modulation index.
- For FSK, the modulation index is

$$m = \Delta f\,(T)$$

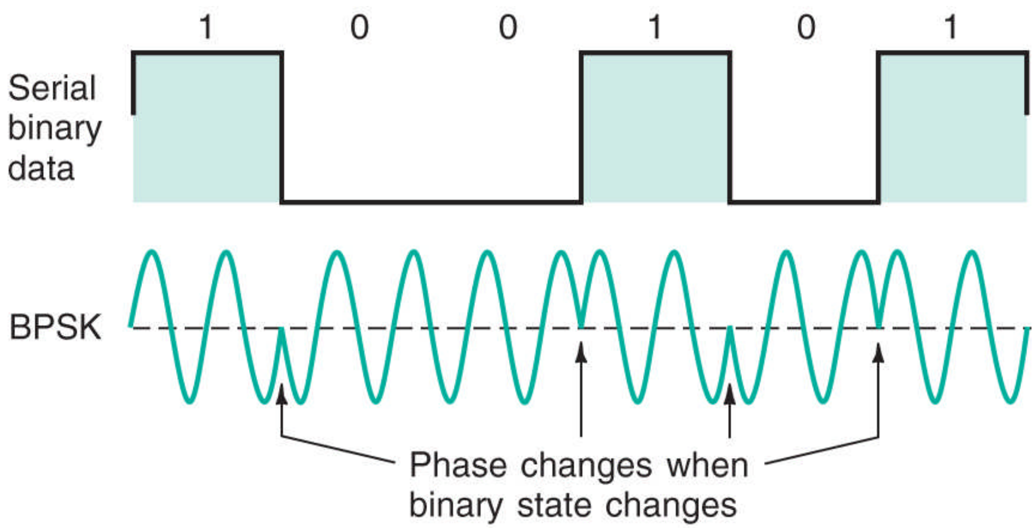
  - T is bit time, the reciprocal of the data rate
  - $\Delta f = f_{\mathrm{mark}} - f_{\mathrm{space}}$ is the frequency shift between mark and space.
- Bandwidth can be obtained as in before in FM.

$$B = 2\,f_m N$$

  - N = number significant sidebands, $f_m = 1/2T$

Phase-shift keying

- Another modulating option is phase modulation know as phase-shift keying (PSK)
- For binary phase shift keying (BPSK), the carrier phase is shifted by 0° or 180°.
  - “1” the carrier phase is unchanged.
  - “0” the carrier phase is shifted by 180°.

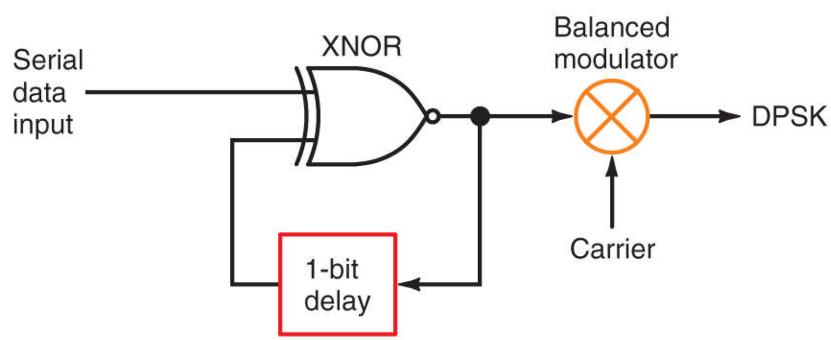


Differential phase-shift keying

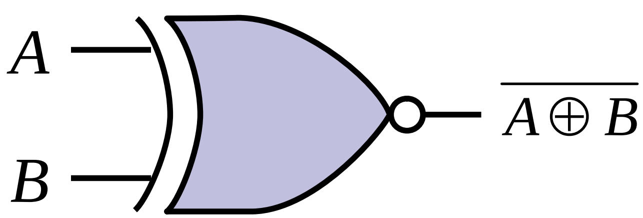
- One difficulty in demodulating a BPSK signal is that the carrier must be recovered to determine the correct phase relationship.
- To simplify demodulation, a version of BPSK known as differential phase-shift keying (DPSK) can be used.
- For DPSK the bit stream undergoes a process called differential phase coding.

Differential phase-shift keying

- Passing the bit stream through an XNOR gate with the previous output.



- Recall the truth table for XNOR

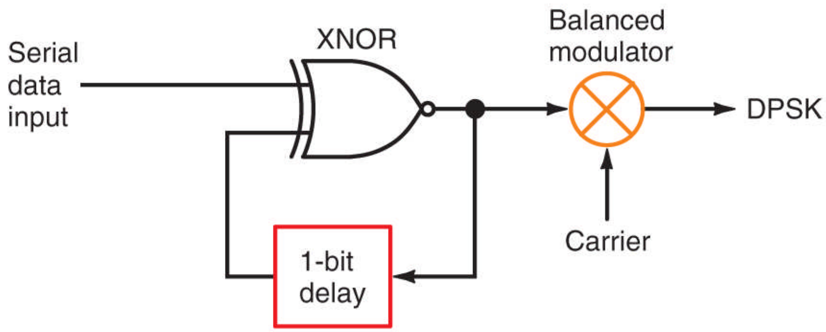


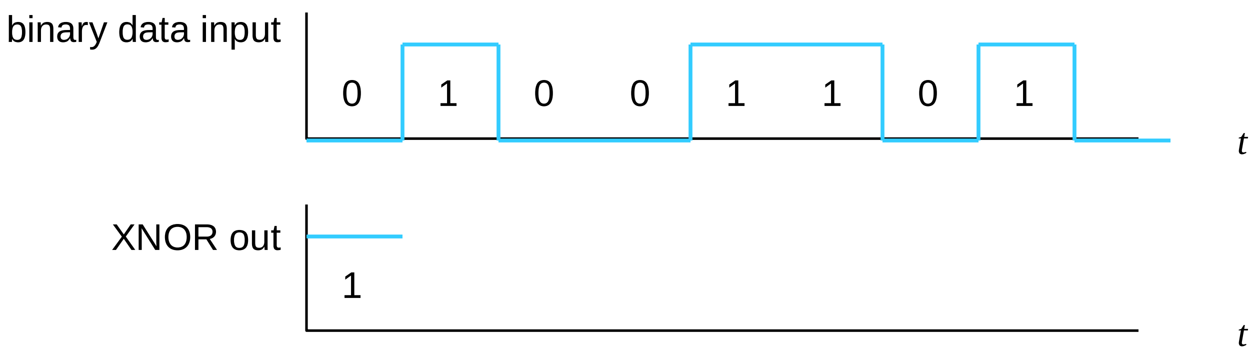
Symbol for an XNOR gate

A	B	$\overline{A \oplus B}$
0	0	1
0	1	0
1	0	0
1	1	1

Example Problem 1

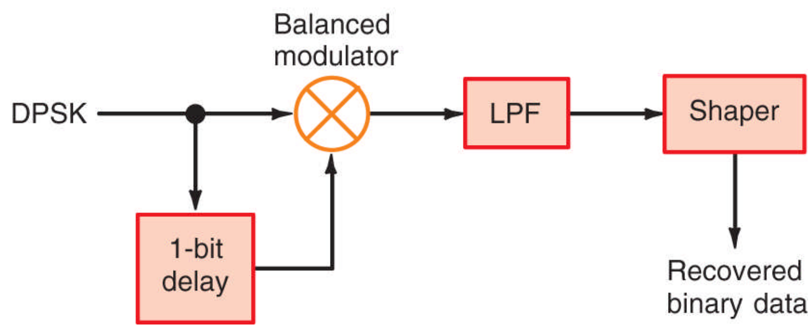
Consider the binary data input below. Calculate the resulting output of the XNOR gate.

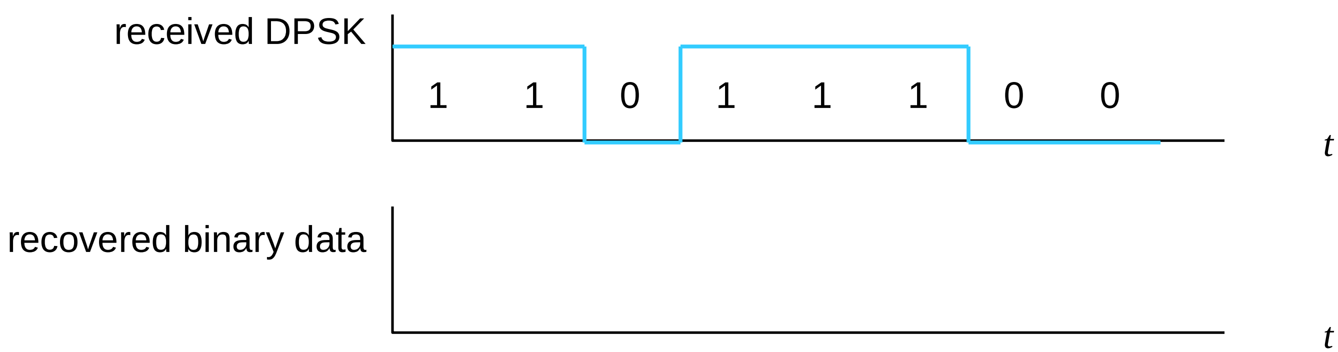




Example Problem 2

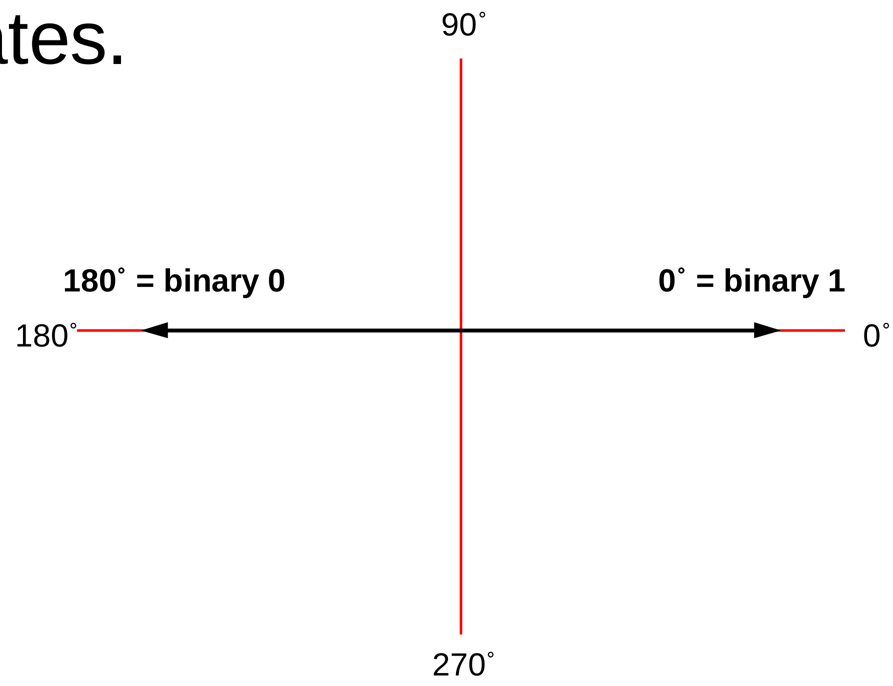
Recovery of the original bit stream is performed in the receiver as depicted below. Consider the balanced modulator as performing the logical XNOR operation to recover the original bit stream.





Phasor diagram

- We can represent the BPSK signal using a phasor diagram which shows the two possible BPSK states.



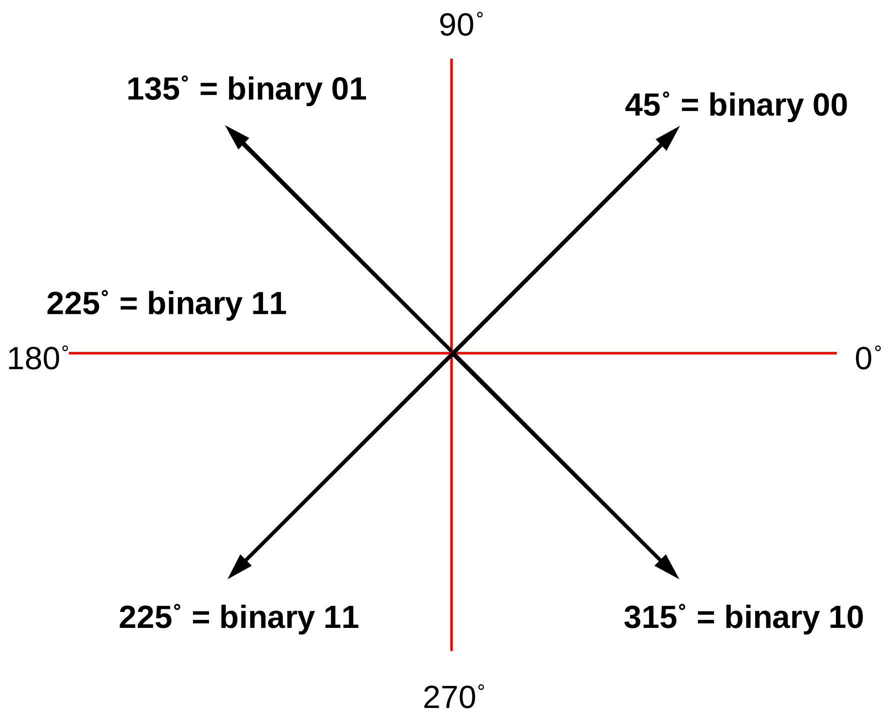
- This is referred to as a signal constellation.

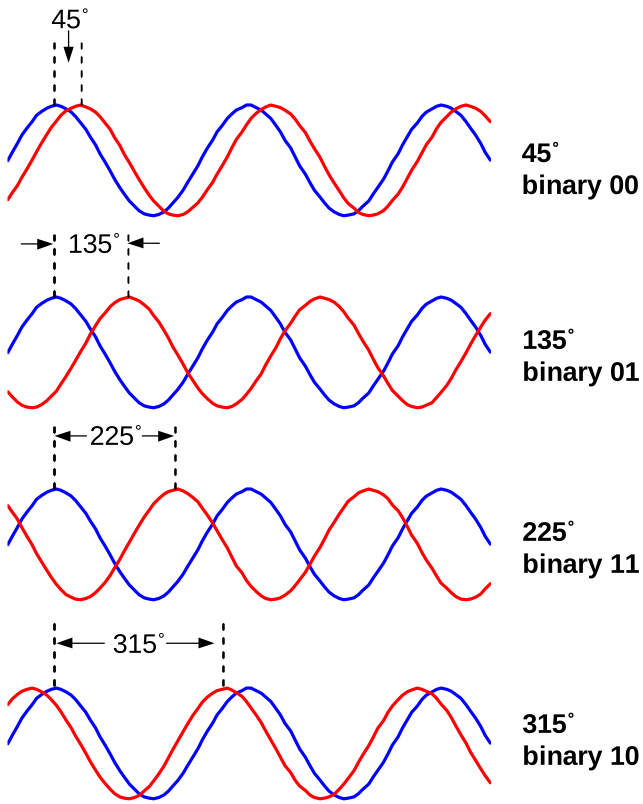
Phasor diagram

- BPSK and DPSK are limited to transmitting just one bit per symbol.
  - Simply increasing the number of bits per second would result in an increase in the signal's bandwidth.
- However, we can preserved bandwidth if we keep the symbol rate the same and increase the number of bits per symbol.
  - Instead of transmitting just 2 possible phase shifts (0˚and 180˚), we could transmit 4 possible phase shifts per symbol (45˚, 135˚, 225˚, and 315˚).
  - This is called quadrature or quaternary PSK (4-PSK or QPSK).

QPSK

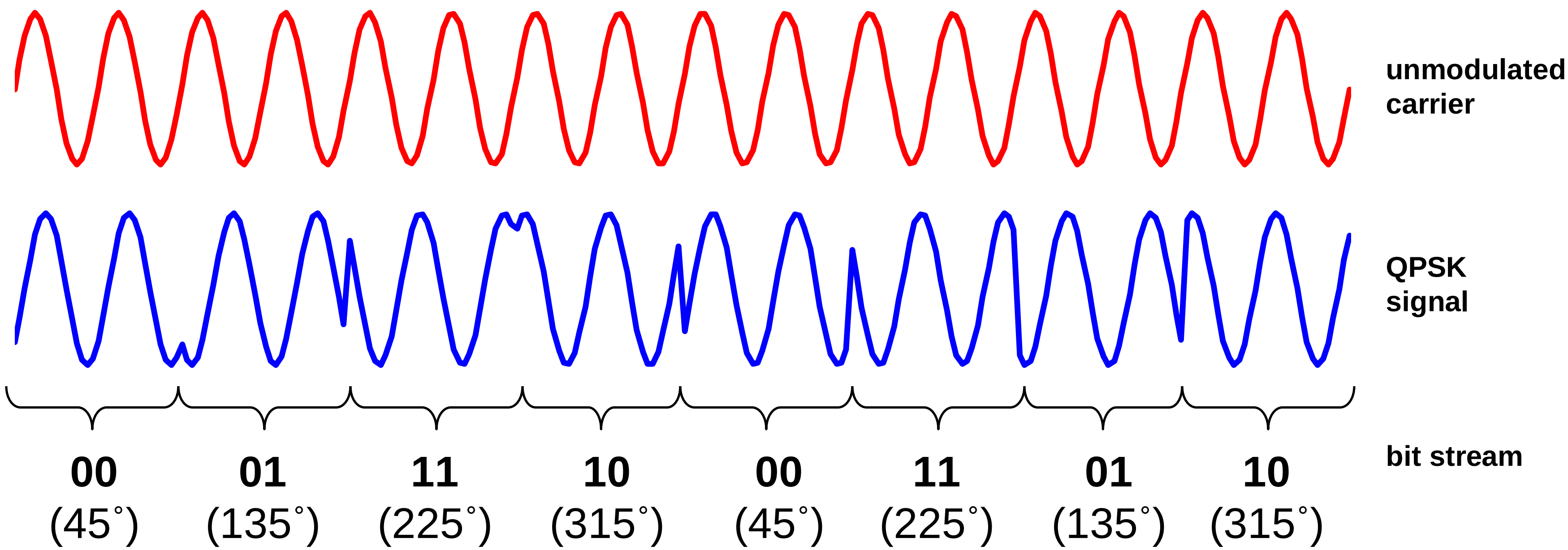
- In QSPK, because there are 4 possible states per symbol, we are transmitting 2 bits per symbol.





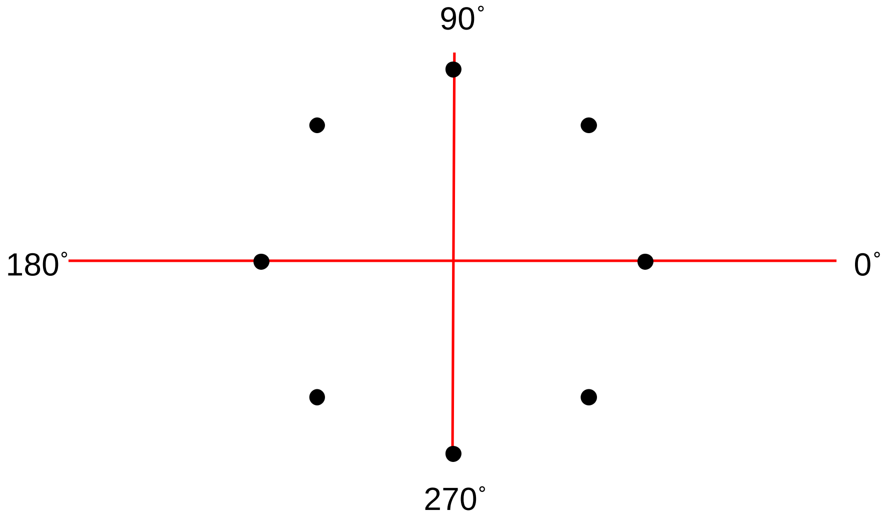
QPSK

- Consider the bit stream below and the resulting QPSK signal.



M-ary PSK

- We can further increase the number of bits per symbol by increase the number of possible phase shifts.
- Consider the 8-PSK constellation below.



0˚ = binary 000

45˚ = binary 001

90˚ = binary 011

135˚ = binary 010

180˚ = binary 110

225˚ = binary 111

270˚ = binary 101

315˚ = binary 100

- How many bits per symbol are transmitted?