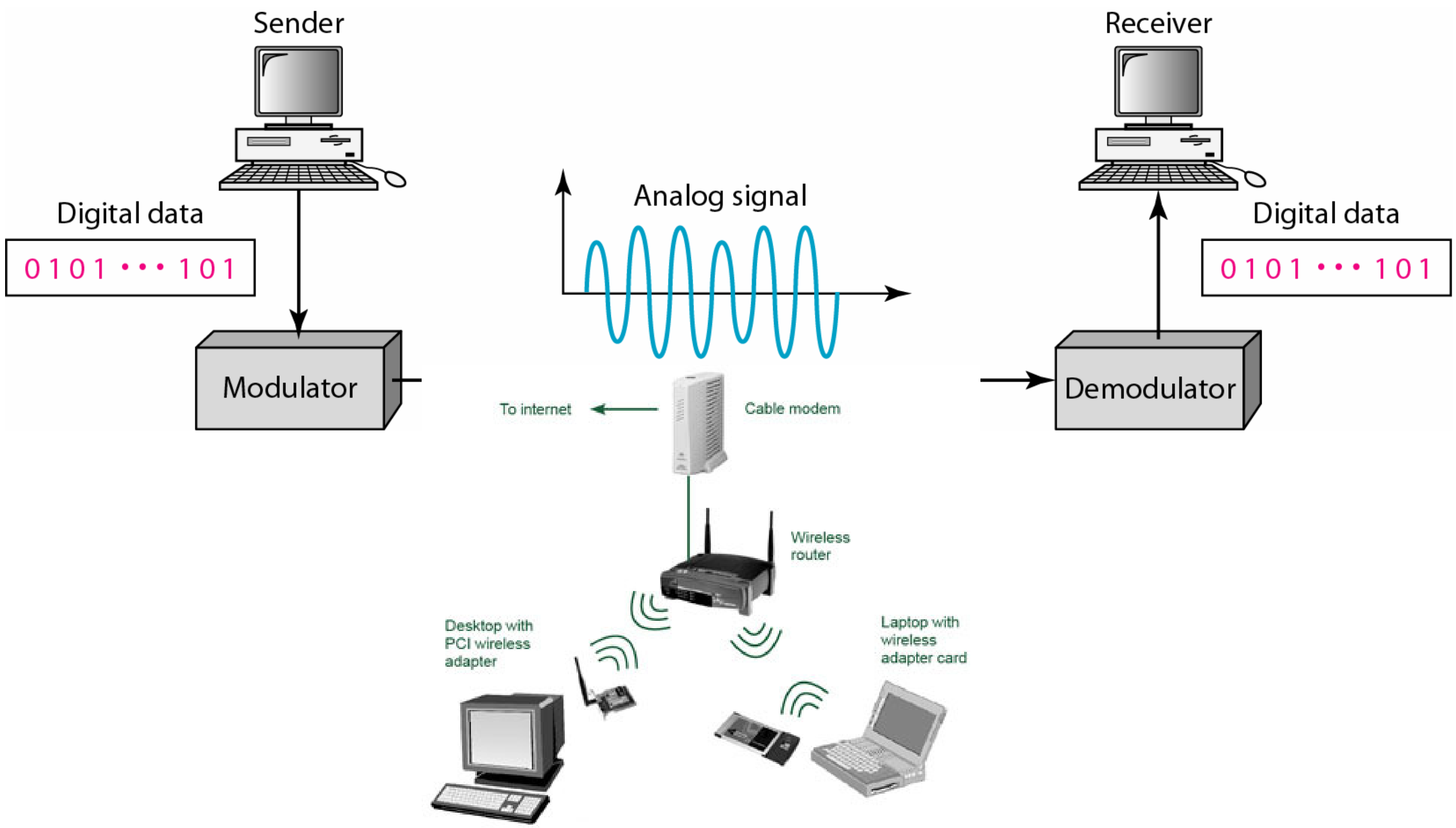
Analog Transmission of Digital Data:

ASK, FSK, PSK

Required reading:
Garcia 3.7

CSE 3213, Fall 2010
Instructor: N. Vlajic

Why Do We Need Digital-to-Analog Conversion?!

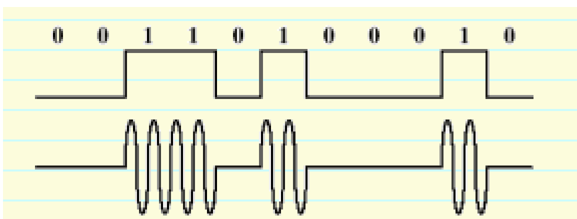


1) The medium/channel is band pass, and/or

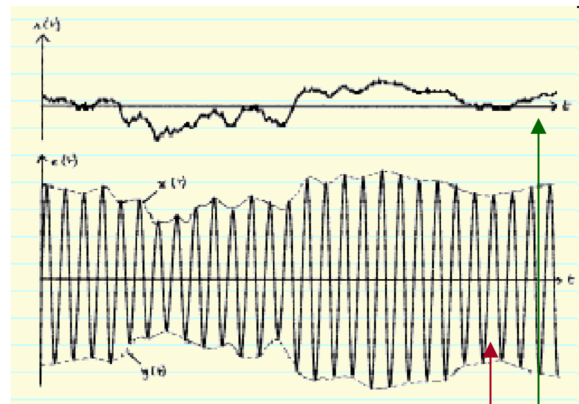
2) Multiple users need to share the medium.

Modulation of Digital Data

Modulation – process of converting digital data or a low-pass analog to band-pass (higher-frequency) analog signal



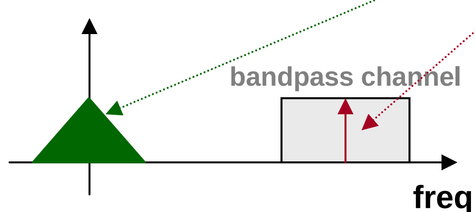
Digital-to-analog modulation.



Analog-to-analog modulation.

Carrier Signal – aka carrier freq. or modulated signal - high freq. signal that acts as a basis for the information signal

- information signal is called modulating signal

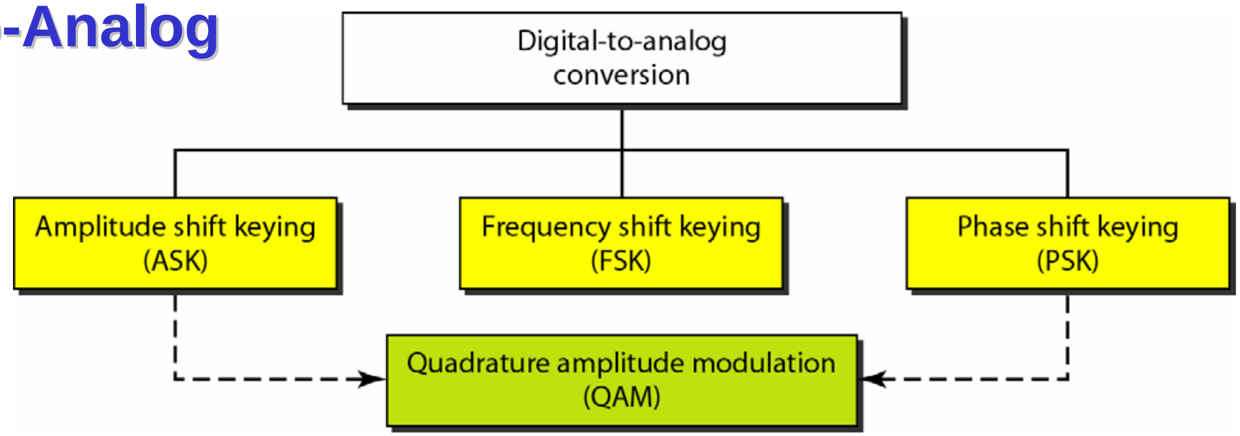


Modulation of Digital Data (cont.)

Digital-to-Analog Modulation – **process of changing one of the characteristic of an analog signal (typically a sinewave) based on the information in a digital signal**

- **sinewave is defined by 3 characteristics (amplitude, frequency, and phase) ⇒ digital data (binary 0 & 1) can be represented by varying any of the three**
- **application: transmission of digital data over telephone wire (modem)**

Types of Digital-to-Analog Modulation



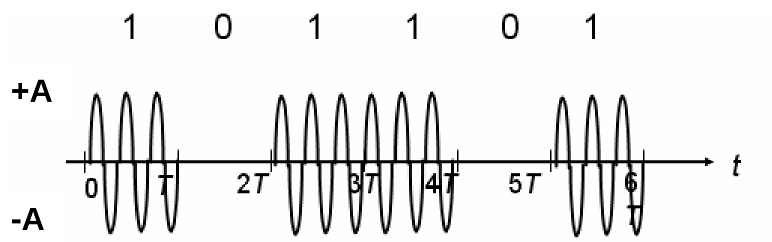
Modulation of Digital Data: ASK

ASK – strength of carrier signal is varied to represent binary 1 or 0

- **both frequency & phase remain constant while amplitude changes**
- **commonly, one of the amplitudes is zero**

$$s(t) = \begin{cases} A_0 \cos(2\pi f_c t), & \text{binary } 0 \\ A_1 \cos(2\pi f_c t), & \text{binary } 1 \end{cases}$$

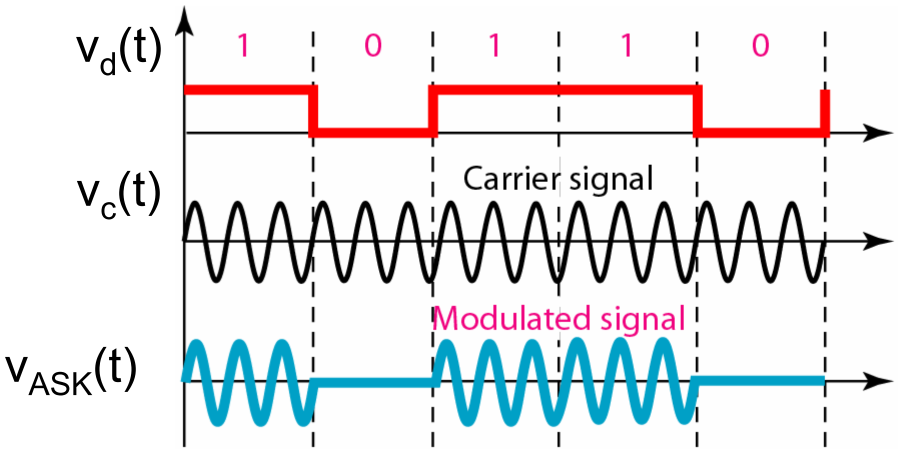
Is this picture, from the textbook, entirely correct?!

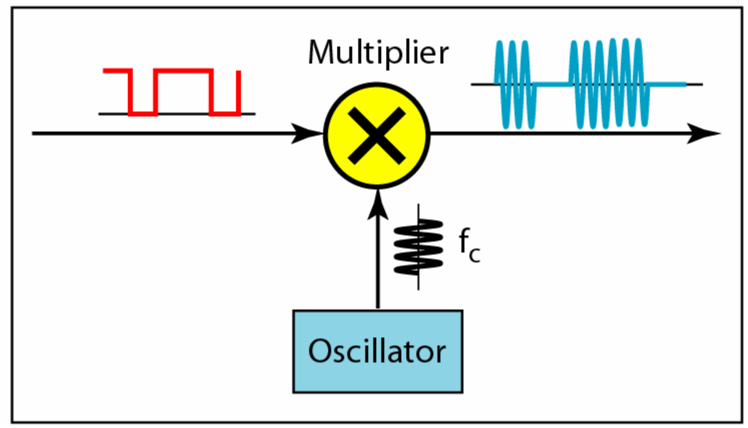


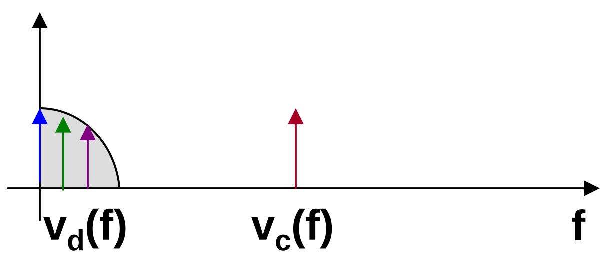
- **demodulation: only the presence or absence of a sinusoid in a given time interval needs to be determined**
- **advantage: simplicity**
- **disadvantage: ASK is very susceptible to noise interference – <u>noise usually (only) affects the amplitude</u>, therefore ASK is the modulation technique most affected by noise**
- **application: ASK is used to transmit digital data over optical fiber**

Modulation of Digital Data: ASK (cont.)

Example [ASK]







How does the frequency spectrum of $v_{ASK}(t)$ look like!?

Modulation of Digital Data: ASK (cont.)

ASK-Modulated Signal: Frequency Spectrum

$$\cos A \cdot \cos B = \frac{1}{2}\left(\cos(A-B) + \cos(A+B)\right)$$

Carrier signal: $v_c(t) = \cos(2\pi f_c t) = \cos(\omega_c t)$ **, where $2\pi f_c = \omega_c$**

Digital signal:
(unipolar!!!)

$$v_d(t) = A \cdot \left[\frac{1}{2} + \frac{2}{\pi}\cos\omega_0 t - \frac{2}{3\pi}\cos 3\omega_0 t + \frac{2}{5\pi}\cos 5\omega_0 t - \ldots\right]$$

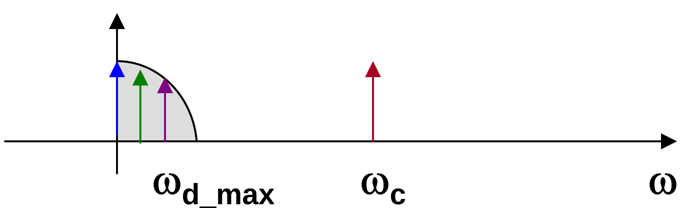
Modulated signal: $v_{ASK}(t) = v_c(t) \cdot v_d(t) =$

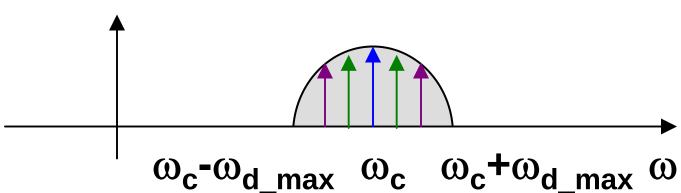
$$= \cos\omega_c t \cdot \left[\frac{1}{2} + \frac{2}{\pi}\cos\omega_0 t - \frac{2}{3\pi}\cos 3\omega_0 t + \frac{2}{5\pi}\cos 5\omega_0 t - \ldots\right] =$$

$$= \frac{1}{2}\cos\omega_c t + \frac{2}{\pi}\cos\omega_c t \cdot \cos\omega_0 t - \frac{2}{3\pi}\cos\omega_c t \cdot \cos 3\omega_0 t + \ldots =$$

$$= \frac{1}{2}\cos\omega_c t + \frac{1}{\pi}\left[\cos(\omega_c - \omega_0)t + \cos(\omega_c + \omega_0)t\right] -$$

$$- \frac{1}{3\pi}\left[\cos(\omega_c - 3\omega_0)t + \cos(\omega_c + 3\omega_0)t\right] + \ldots$$



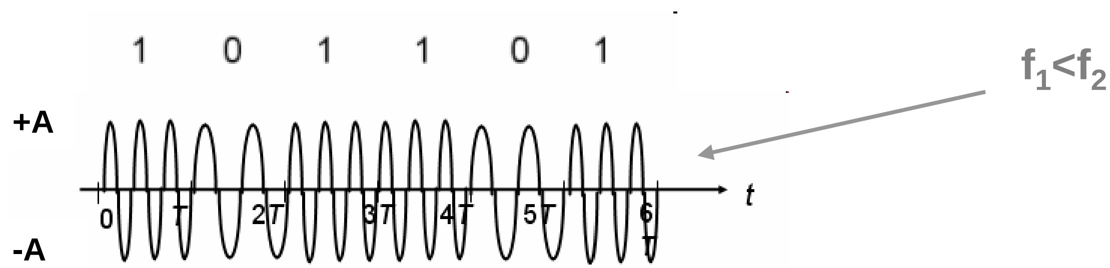


Modulation of Digital Data: FSK

FSK – frequency of carrier signal is varied to represent binary 1 or 0

- **peak amplitude & phase remain constant during each bit interval**

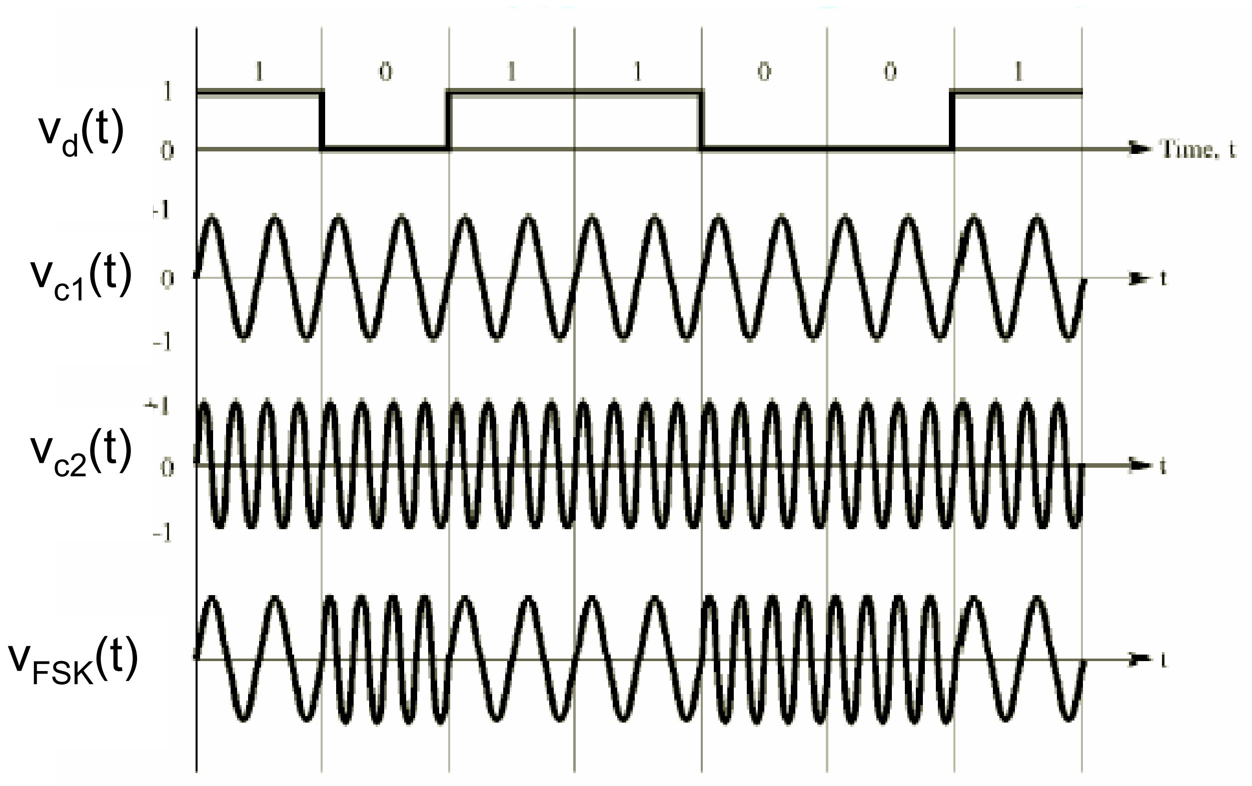
$$s(t) = \begin{cases} A\cos(2\pi f_1 t), & \text{binary } 0 \\ A\cos(2\pi f_2 t), & \text{binary } 1 \end{cases}$$

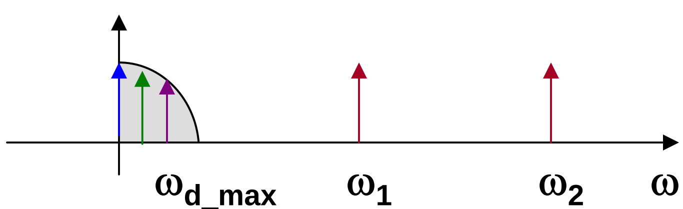


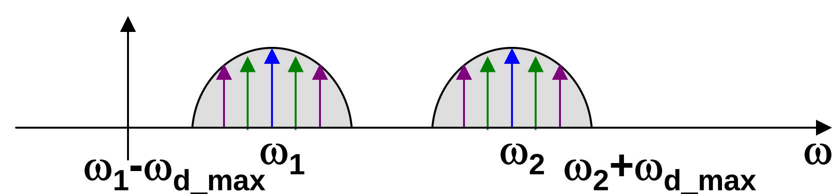
- **demodulation: demodulator must be able to determine which of two possible frequencies is present at a given time**
- **advantage: FSK is less susceptible to errors than ASK – receiver looks for specific frequency changes over a number of intervals, so voltage (noise) spikes can be ignored**
- **disadvantage: <u>FSK spectrum is 2 x ASK spectrum</u>**
- **application: over voice lines, in high-freq. radio transmission, etc.**

Modulation of Digital Data: FSK (cont.)

Example **[FSK]**







Modulation of Digital Data: FSK (cont.)

FSK-Modulated Signal: Frequency Spectrum

Digital signal: $v_d(t)$ **- modulated with ω_1, and**

$v_d'(t) = 1 - v_d(t)$ **- modulated with ω_2**

Modulated signal:

$$v_{FSK}(t) = \cos\omega_1 t \cdot v_d(t) + \cos\omega_2 t \cdot (1 - v_d(t)) =$$

$$= \cos\omega_1 t \cdot \left[\frac{1}{2} + \frac{2}{\pi}\cos\omega_0 t - \frac{2}{3\pi}\cos 3\omega_0 t + \frac{2}{5\pi}\cos 5\omega_0 t - \ldots\right] +$$

$$+ \cos\omega_2 t \cdot \left[\frac{1}{2} - \frac{2}{\pi}\cos\omega_0 t + \frac{2}{3\pi}\cos 3\omega_0 t - \frac{2}{5\pi}\cos 5\omega_0 t - \ldots\right] =$$

$$= \ldots$$

$$= \frac{1}{2}\cos\omega_1 t + \frac{1}{\pi}\left[\cos(\omega_1 - \omega_0)t + \cos(\omega_1 + \omega_0)t\right] -$$

$$- \frac{1}{3\pi}\left[\cos(\omega_1 - 3\omega_0)t + \cos(\omega_1 + 3\omega_0)t\right] + \ldots +$$

$$\frac{1}{2}\cos\omega_2 t - \frac{1}{\pi}\left[\cos(\omega_2 - \omega_0)t + \cos(\omega_2 + \omega_0)t\right] -$$

$$+ \frac{1}{3\pi}\left[\cos(\omega_2 - 3\omega_0)t + \cos(\omega_2 + 3\omega_0)t\right] + \ldots +$$

Modulation of Digital Data: PSK

PSK – phase of carrier signal is varied to represent binary 1 or 0

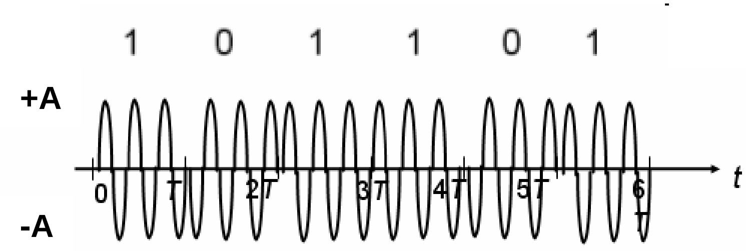
- **peak amplitude & freq. remain constant during each bit interval**
- **example: binary 1 = 0º phase, binary 0 = 180º (πrad) phase**

  ⇒ PSK is equivalent to multiplying carrier signal by +1 when the information is 1, and by -1 when the information is 0

2-PSK, or Binary PSK, since only 2 different phases are used.

$$s(t) = \begin{cases} A\cos(2\pi f_c t), & \text{binary } 1 \\ A\cos(2\pi f_c t + \pi), & \text{binary } 0 \end{cases}$$

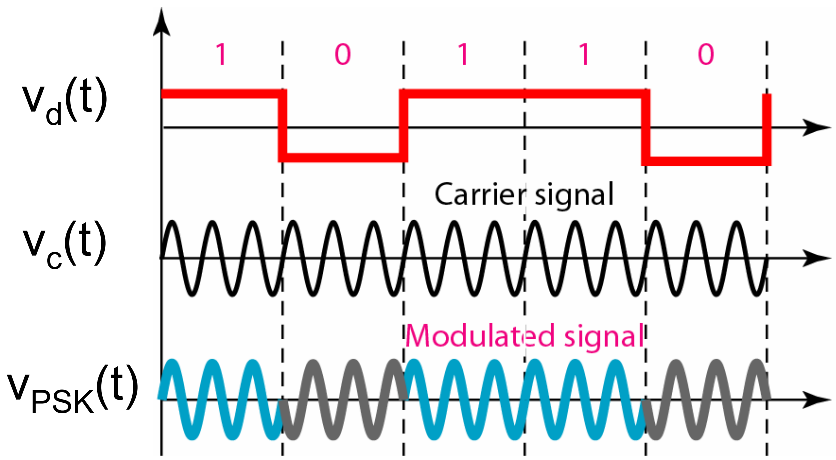
$$s(t) = \begin{cases} A\cos(2\pi f_c t), & \text{binary } 1 \\ -A\cos(2\pi f_c t), & \text{binary } 0 \end{cases}$$

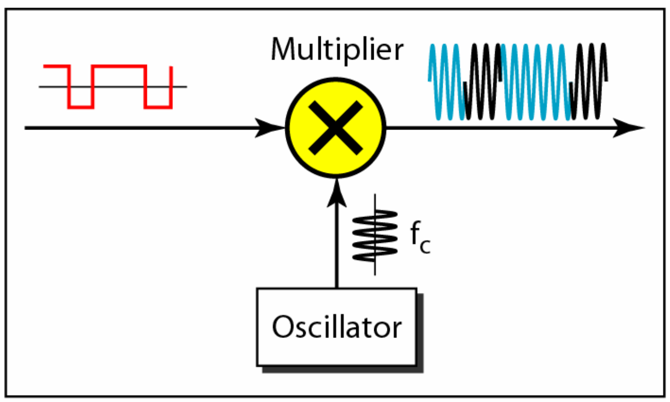


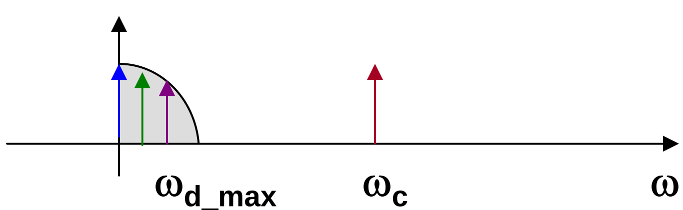
- **demodulation: demodulator must determine the phase of received sinusoid with respect to some reference phase**
- **advantage:**
  - **PSK is less susceptible to errors than ASK, while it requires/occupies the same bandwidth as ASK**
  - **more efficient use of bandwidth (higher data-rate) are possible, compared to FSK !!!**
- **disadvantage: more complex signal detection / recovery process, than in ASK and FSK**

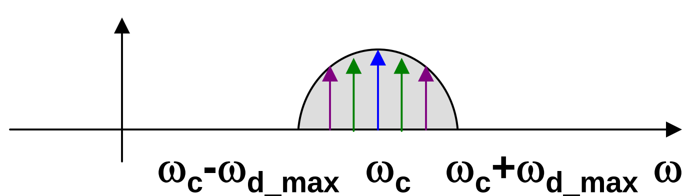
Modulation of Digital Data: PSK (cont.)

Example [PSK]









Modulation of Digital Data: PSK (cont.)

PSK Detection

$$\cos^2 A = \frac{1}{2}(1+\cos 2A)$$

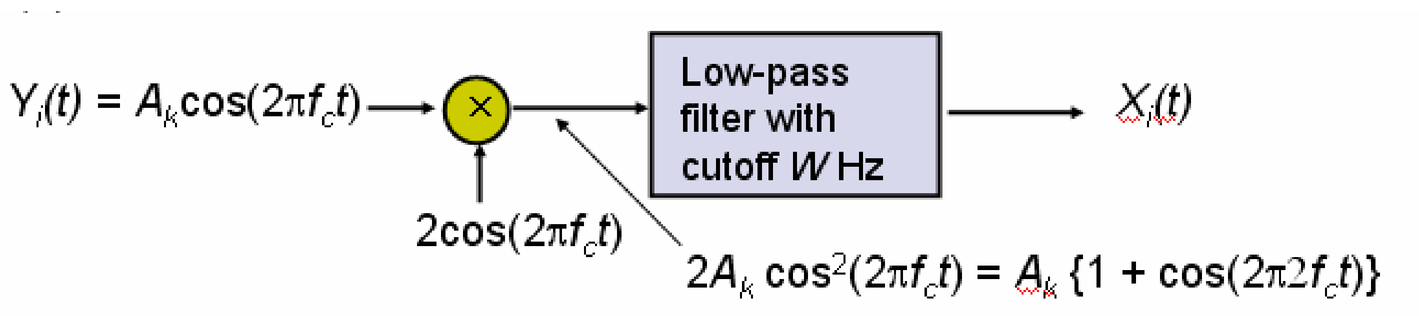
– **multiply the received / modulated signal $\pm A\cos(2\pi f_c t)$ by 2*cos(2πf_c t)**

- **resulting signal**

$$2A\cos^2(2\pi f_c t) = A[1+\cos(4\pi f_c t)], \quad \text{binary } 1$$

$$-2A\cos^2(2\pi f_c t) = -A[1+\cos(4\pi f_c t)], \quad \text{binary } 0$$

- **by removing the oscillatory part with a low-pass filter, the original baseband signal (i.e. the original binary sequence) can be easily determined**



Modulation of Digital Data: PSK (cont.)