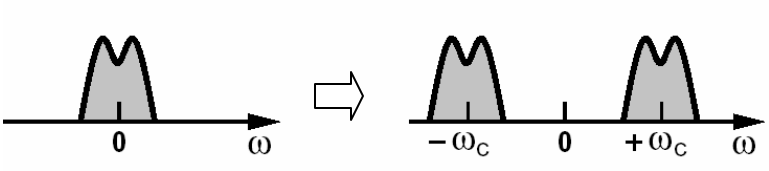
Introduction to Modulation

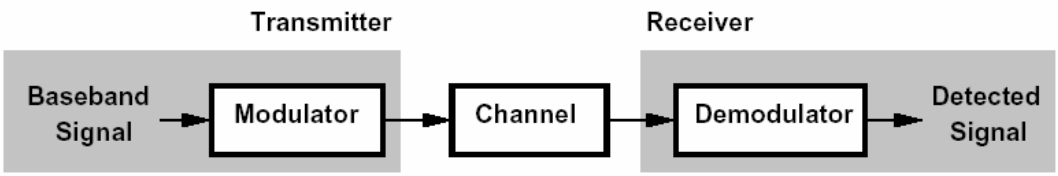
Baseband and Passband Signals



- **A passband signal can be expressed as:**

$$x(t) = a(t)\cos[\omega_c t + \theta(t)]$$

- **Modulation converts a baseband signal to a passband signal (in most cases):**



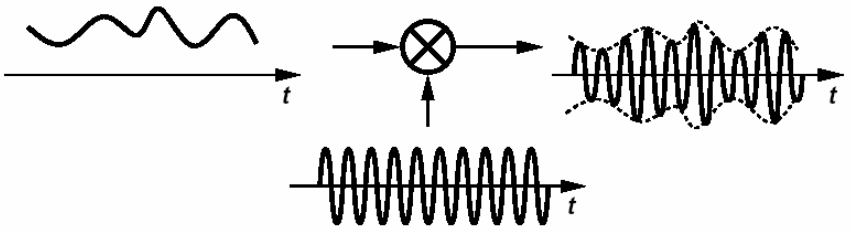
- **Modulation Characteristics:**
  - **Signal quality in the presence of noise**
  - **Bandwidth efficiency**
  - **Power efficiency**

Analog Modulation

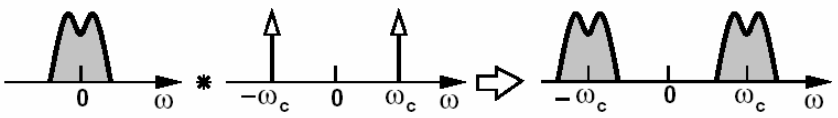
Quality is quantified by SNR.

- **AM**

$$x_{AM}(t) = A_c[1 + mx_{BB}(t)]\cos\omega_c t$$

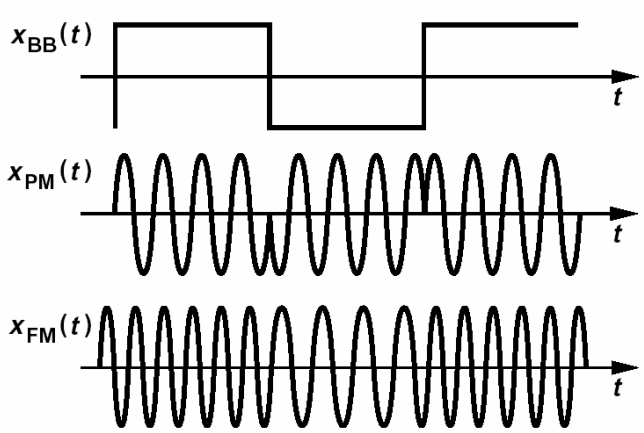


(a)



- **Sensitive to noise and nonlinearity**
- **Requires linear PA.**

- **PM and FM**



$$x_{PM}(t) = A_c \cos[\omega_c t + m x_{BB}(t)]$$

- Insensitive to nonlinearity
- Can operate with nonlinear PA.
- But occupies more BW.

$$x_{FM}(t) = A_c \cos[\omega_c t + m \int_{-\infty}^{t} x_{BB}(t)dt]$$

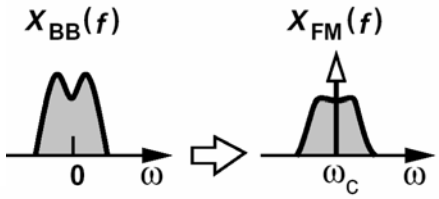
- Insensitive to nonlinearity
- Can operate with nonlinear PA.
- But occupies more BW.

How to build a frequency modulator?

- **Narrowband FM Approximation**

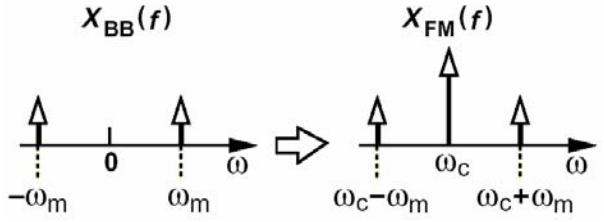
If the phase component is much less than 1 rad, then:

$$x_{FM,NB}(t) \approx A_c \cos\omega_c t - A_c m (\sin\omega_c t) \int x_{BB}(t)dt$$



For example, if $x_{BB}(t) = A_m \cos\omega_m t$

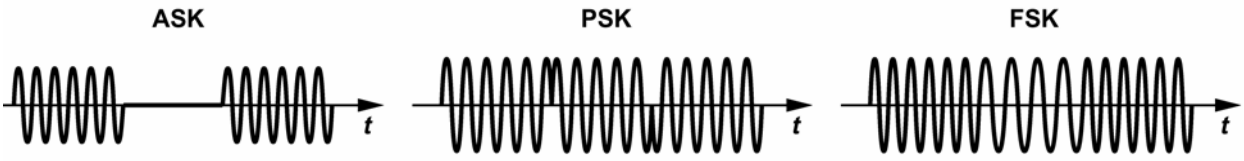
$$\begin{aligned} x_{FM,NB}(t) &\approx A_c \cos\omega_c t - A_m A_c \frac{m}{\omega_m} \sin\omega_c t \sin\omega_m t \\ &= A_c \cos\omega_c t - \frac{A_m A_c m}{2\omega_m} \cos(\omega_c - \omega_m)t + \frac{A_m A_c m}{2\omega_m} \cos(\omega_c + \omega_m)t \end{aligned}$$



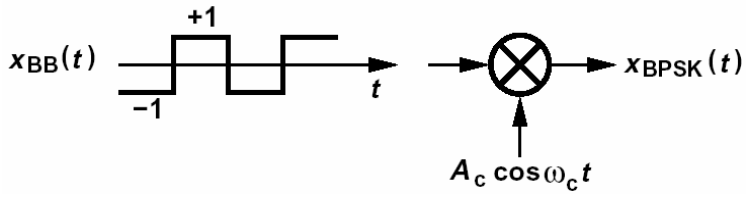
<u>Digital Modulation</u>

Quality is quantified by bit error rate (BER). For voice, BER = 10^{-3}.

- **Binary Shift Keying**

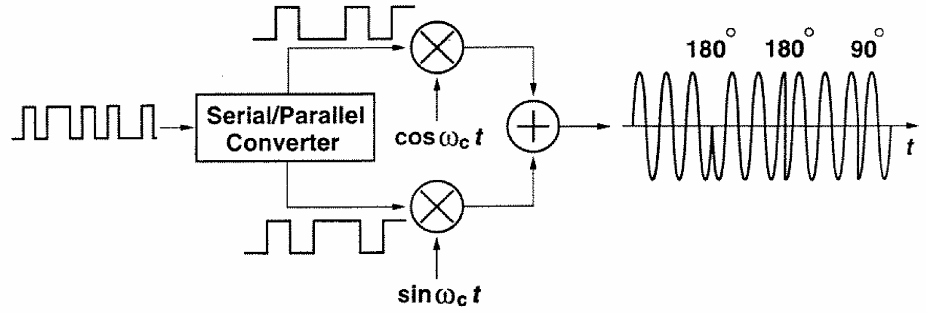


Simple BPSK Modulator:



- **Quadrature Modulation**

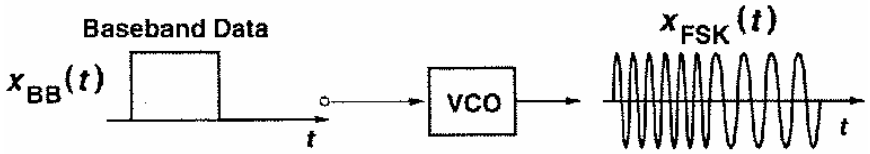
The occupied bandwidth can be reduced by converting the data to two slower streams and impressing each stream on the sine and cosine of carrier. For example, "quadrature phase shift keying" (QPSK) is performed as follows:



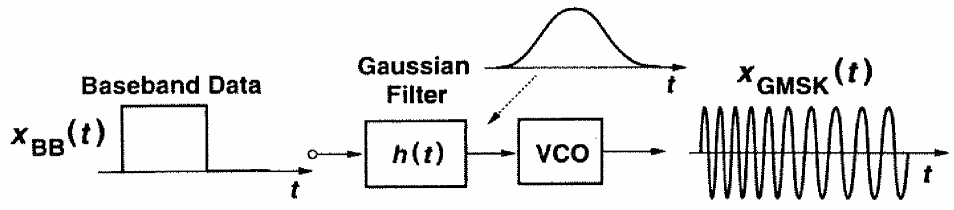
There are other variants of QPSK, e.g., DQPSK, π/4-QPSK, OQPSK.

- **Gaussian Minimum Shift Keying**

FSK occupies too much BW:



Try "shaping" the baseband pulses:



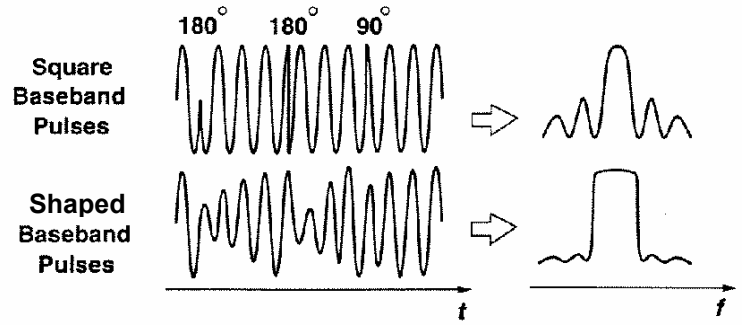
How to build a GMSK modulator?

$$x_{GMSK}(t) = A\cos[\omega_c t + K_0 \int x_{BB}(t) * h(t)dt]$$

$$= A\cos\omega_c t\cos\theta - A\sin\omega_c t\sin\theta$$

Important Difference Between QPSK and GMSK

QPSK also usually incorporates baseband pulse shaping:



Thus, shaped QPSK has a variable amplitude (envelope) and hence requires a linear PA. GSMK, on the other hand, has a constant envelope and can operate with nonlinear PAs.

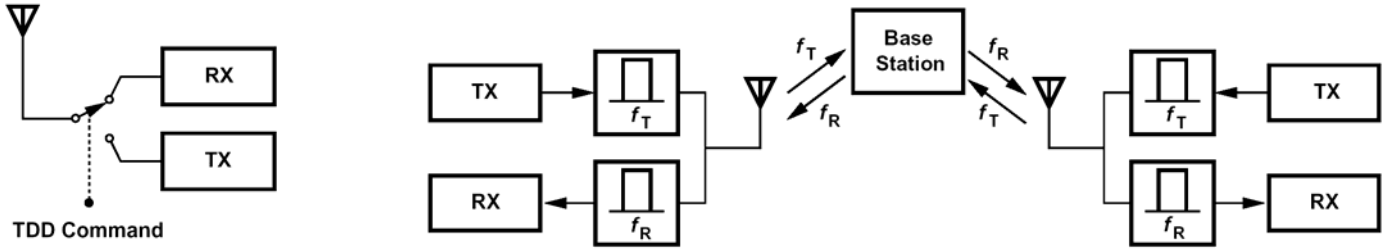
QPSK is used in CDMA cellphones and in 802.11b. GMSK is used in GSM cellphones and in Bluetooth (in which case it is called GFSK).

Many other types of modulation are used: QAM, OOK, PAM,

Multiple Access and Wireless Standards

Multiple Access Techniques

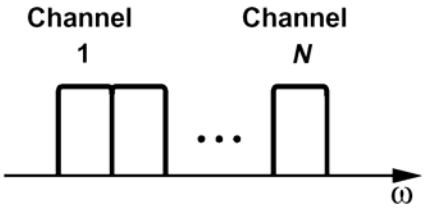
- **Time and Frequency Division Duplexing**



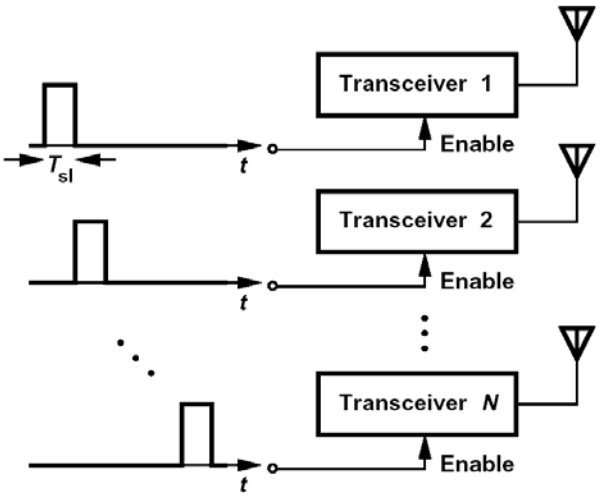
Cellphones use FDD; most other systems use TDD.

- **Multiple Access**

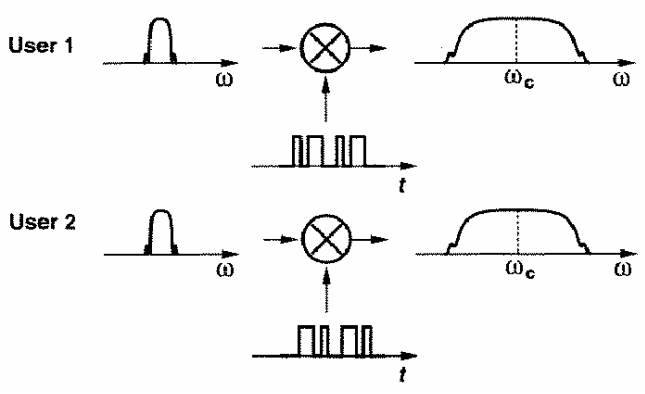
- Frequency Division Multiple Access (FDMA) --- used in cellphones

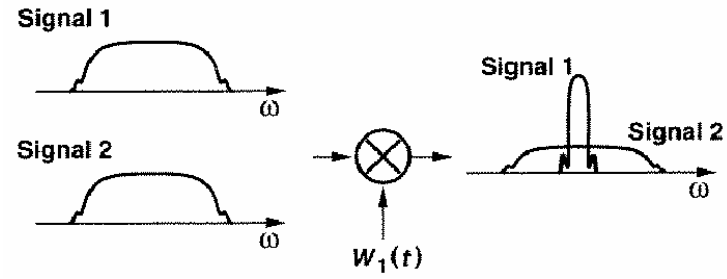


- Time Division Multiple Access (TDMA) --- used in cellphones and most other systems

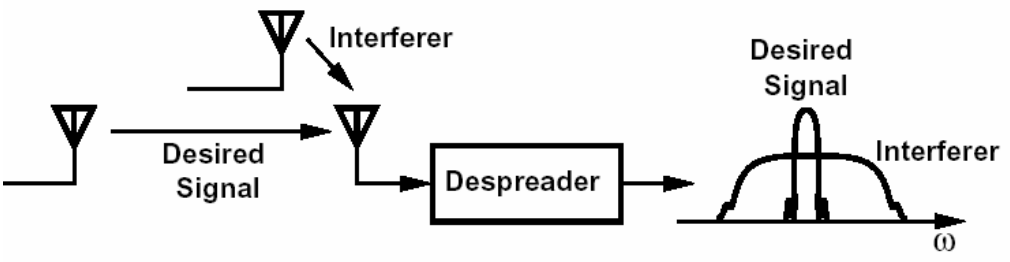


- Code Division Multiple Access (CDMA) --- used in some cellphones





- **Near-Far Problem in CDMA**



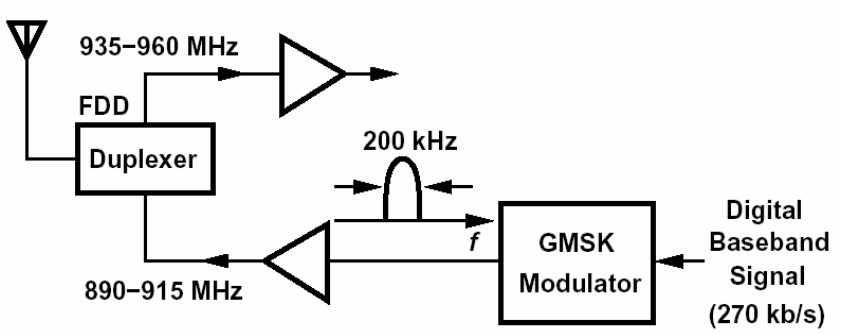
The basestation therefore needs to constantly monitor and control each mobile's output power.

Wireless Standards

A "standard" specifies all of the details of how a communication system must operate, e.g., modulation, bit rate, duplexing, multiple access, frequency band, channel bandwidth.

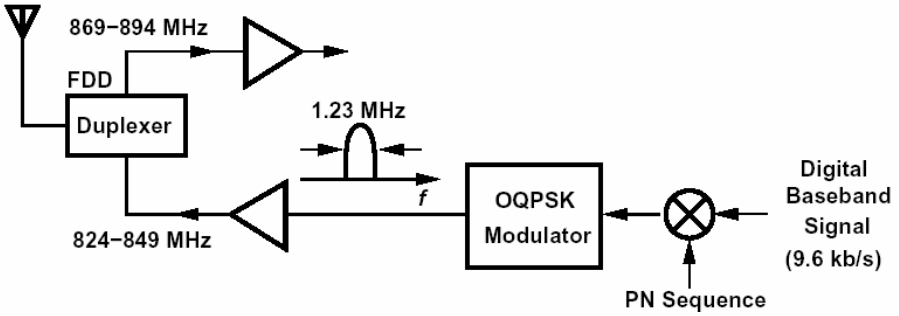
The standard also specifies exact performance tests.

- **GSM**



Now we have GPRS and EDGE. EDGE uses variable-envelope modulation and requires a linear PA.

- **CDMA**



- **Bluetooth**

  - **Frequency band = 2.400-2.480 GHz**
  - **Channel BW = 1 MHz**
  - **Bit rate = 1 Mb/s**
  - **TDD**

- **802.11a**

- Frequency band = 5.18-5.24 GHz, 5.26-5.32 GHz, 5.745-5.805 GHz
- Channel BW = 20 MHz
- Bit rate = 54 Mb/s
- TDD

And there are others …