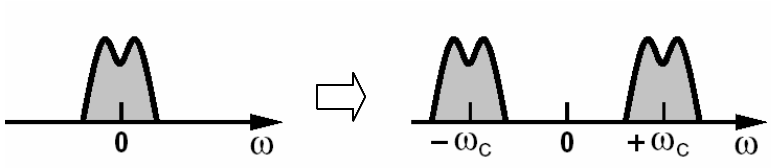
B. Razavi

Introduction to Modulation

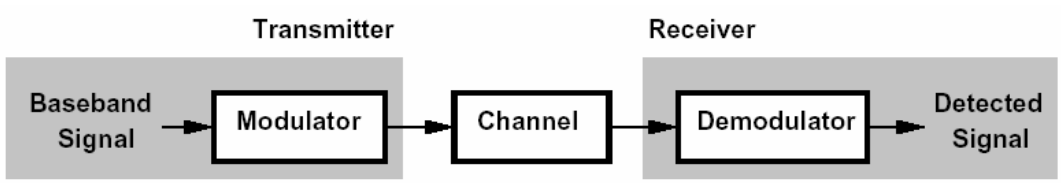
Baseband and Passband Signals



- **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):**

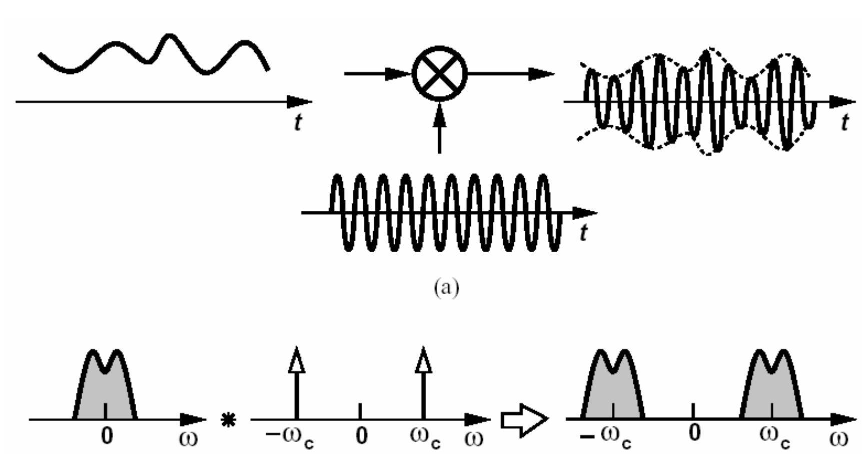


- **Modulation Characteristics:**
  - **Signal quality in the presence of noise**
  - **Bandwidth efficiency**
  - **Power efficiency**

Analog Modulation

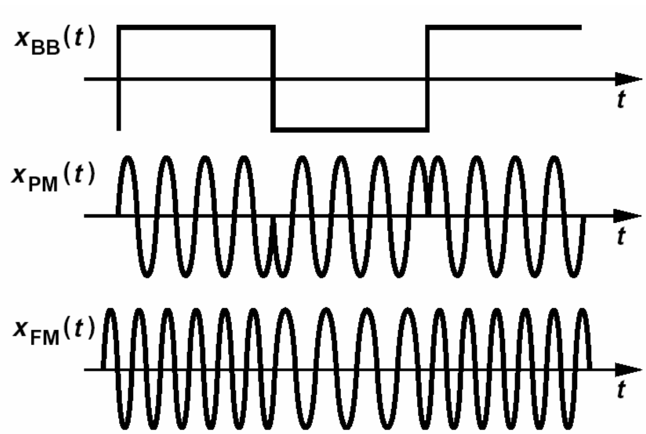
Quality is quantified by SNR.

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



- 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.

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

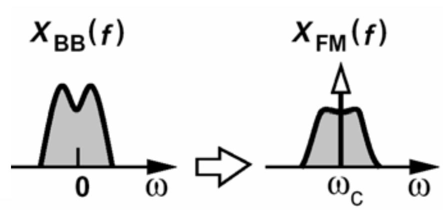
- Insensitive to nonlinearity
- Can operate with nonlinear PA.
- But occupies more BW.

How to build a frequency modulator?

- **Narrowband FM Approximation**

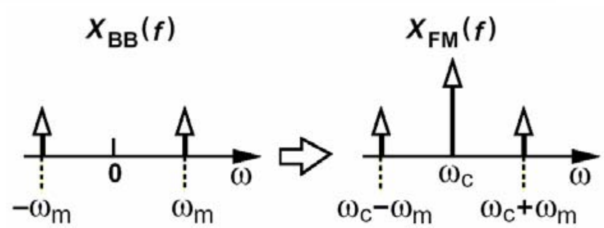
If the phase component is much less than 1 rad, then:

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



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

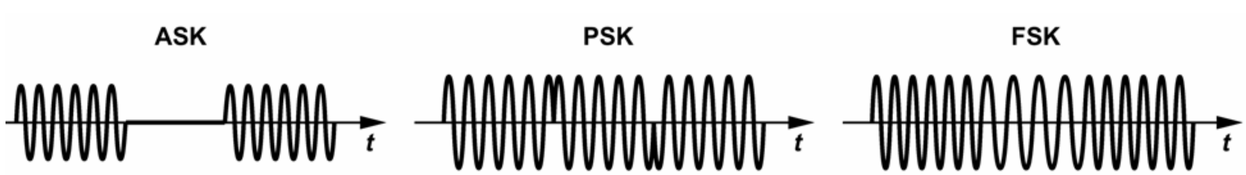
$$\begin{aligned} x_{FM,NB}(t) &\approx A_c \cos\omega_c t - A_m A_c \frac{m}{\omega_m} \sin\omega_c t \sin\omega_m t \\ &= A_c \cos\omega_c t - \frac{A_m A_c m}{2\omega_m} \cos(\omega_c - \omega_m)t + \frac{A_m A_c m}{2\omega_m} \cos(\omega_c + \omega_m)t \end{aligned}$$



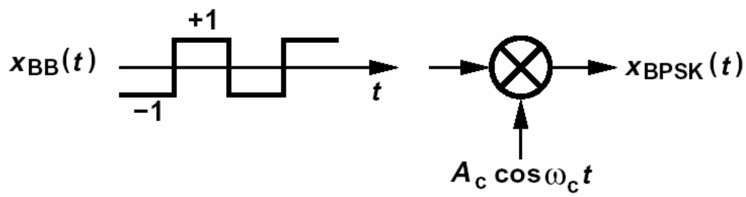
Digital Modulation

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

- **Binary Shift Keying**

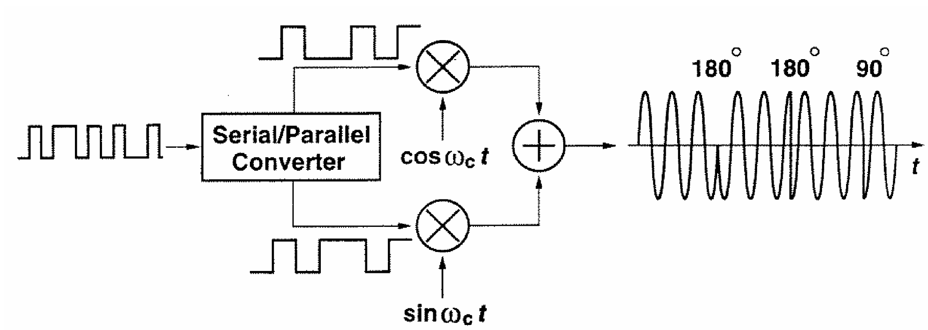


Simple BPSK Modulator:



- **Quadrature Modulation**

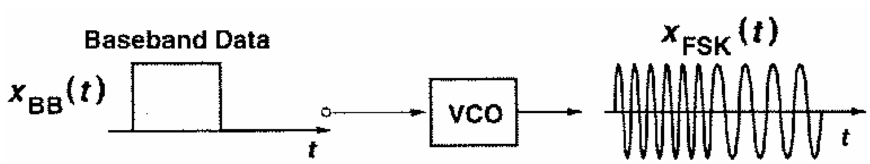
The occupied bandwidth can be reduced by converting the data to two slower streams and impressing each stream on the sine and cosine of carrier. For example, "quadrature phase shift keying" (QPSK) is performed as follows:



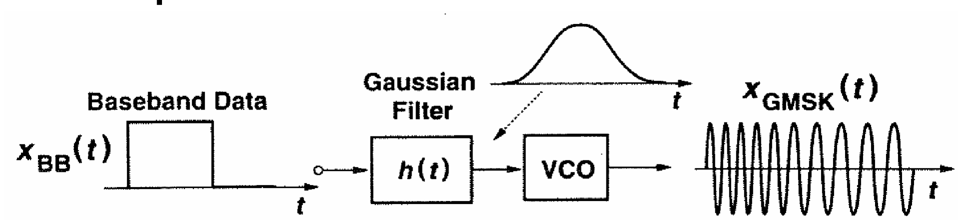
There are other variants of QPSK, e.g., DQPSK, π/4-QPSK, OQPSK.

- **Gaussian Minimum Shift Keying**

FSK occupies too much BW:



Try "shaping" the baseband pulses:



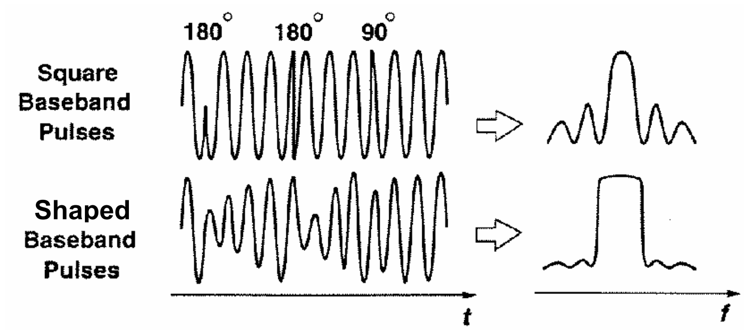
How to build a GMSK modulator?

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

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

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.

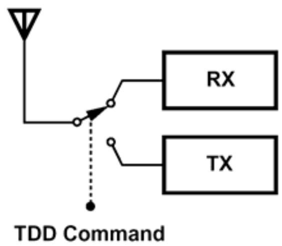
QPSK is used in CDMA cellphones and in 802.11b. GMSK is used in GSM cellphones and in Bluetooth (in which case it is called GFSK).

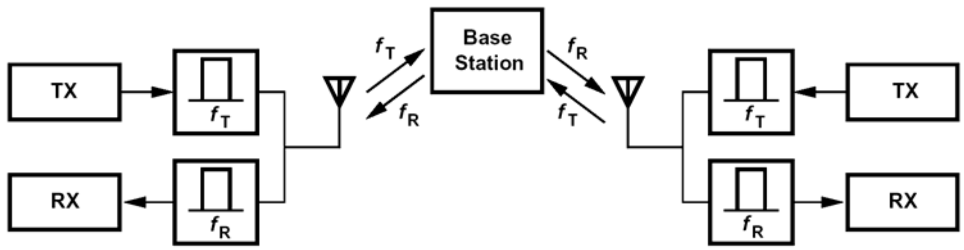
Many other types of modulation are used: QAM, OOK, PAM,

Multiple Access and Wireless Standards

Multiple Access Techniques

- **Time and Frequency Division Duplexing**

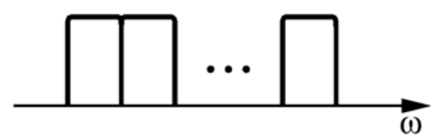




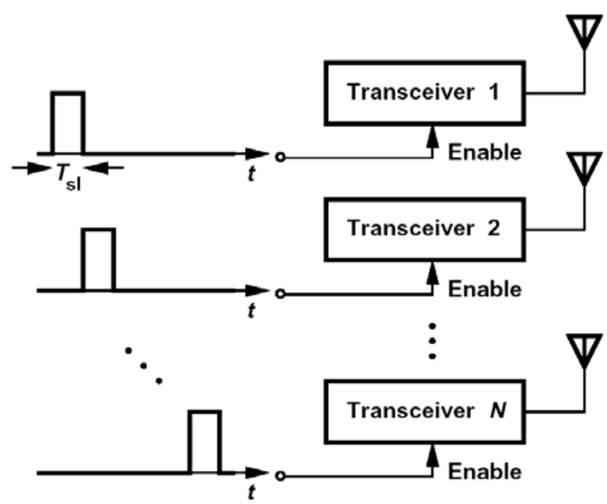
Cellphones use FDD; most other systems use TDD.

- **Multiple Access**

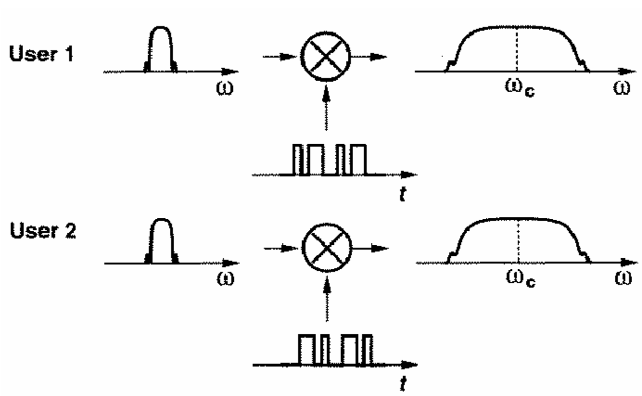
- Frequency Division Multiple Access (FDMA) --- used in cellphones

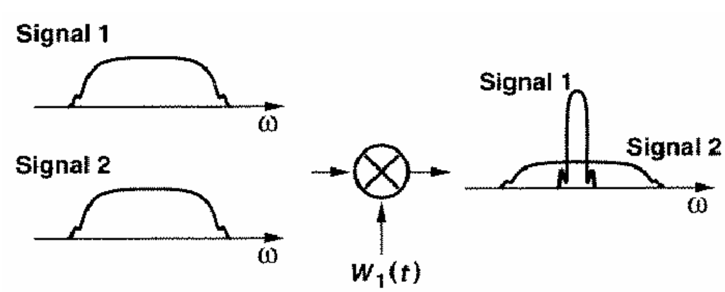


- Time Division Multiple Access (TDMA) --- used in cellphones and most other systems

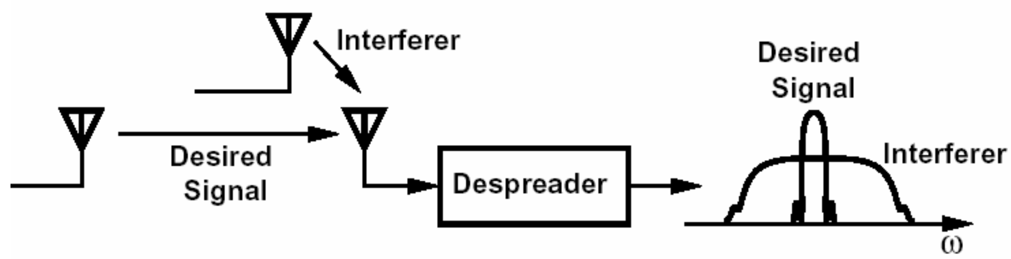


- Code Division Multiple Access (CDMA) --- used in some cellphones





- **Near-Far Problem in CDMA**



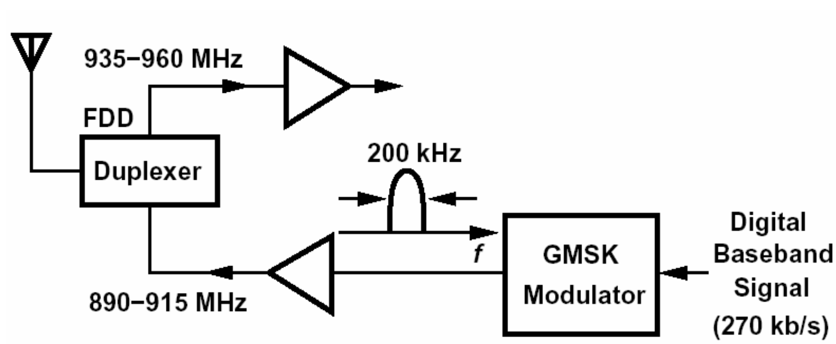
The basestation therefore needs to constantly monitor and control each mobile's output power.

<u>Wireless Standards</u>

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.

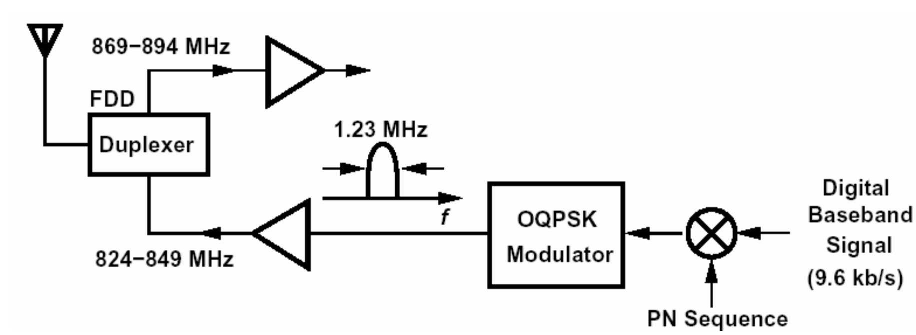
The standard also specifies exact performance tests.

- **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 …

B. Razavi

Transceiver Architectures (I)

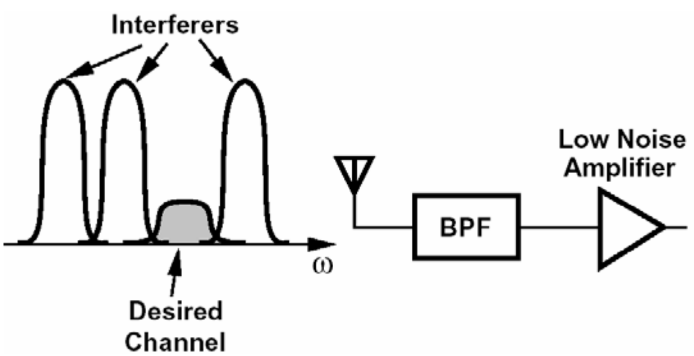
General Considerations

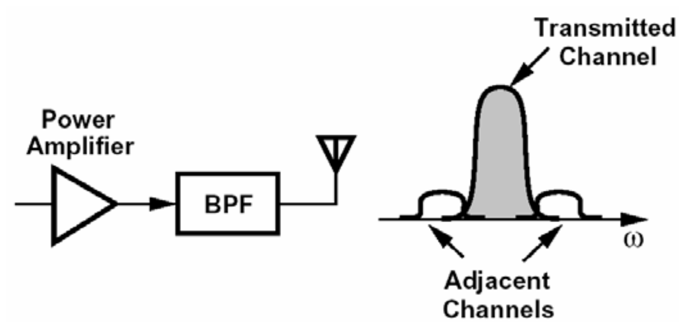
- **RX**

- **Sensitivity**
- **Linearity**
- **Power Dissipation**
- **Dynamic Range**
- **Gain**
- **Complexity**

- **TX**

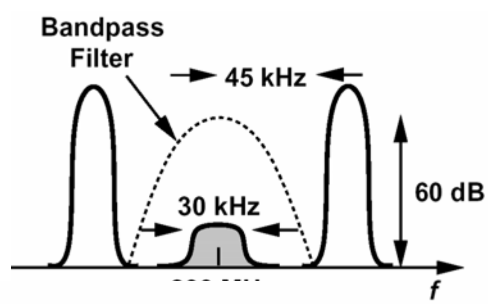
- **Output Power**
- **Spurious Emission**
- **Power Dissipation**
- **Linearity**
- **Efficiency**
- **Complexity**



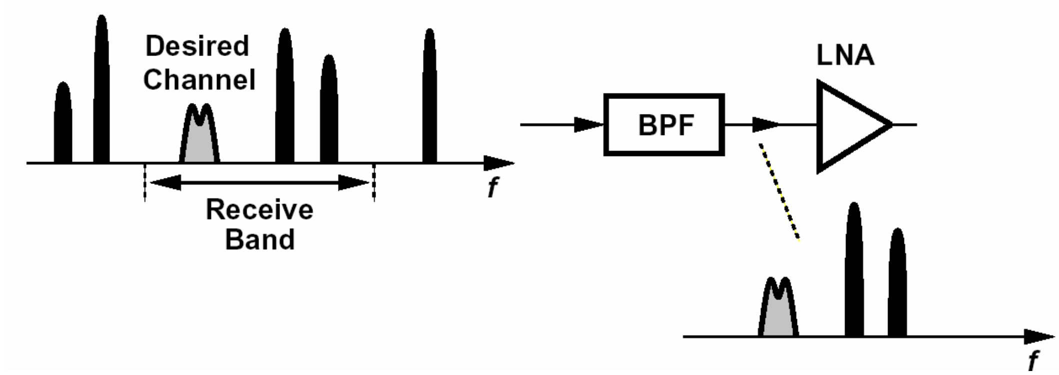


- **Band Selection vs. Channel Selection**

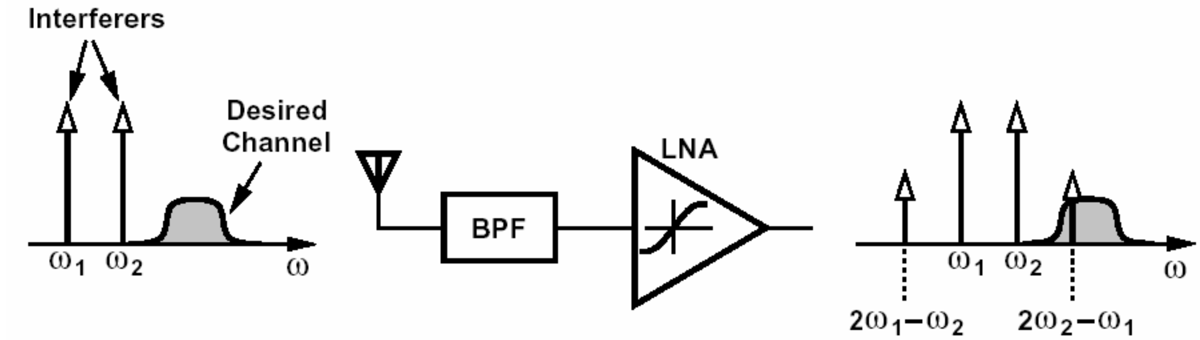
Can we perform "channel selection" at the RX input?



But some "band selection" is possible:

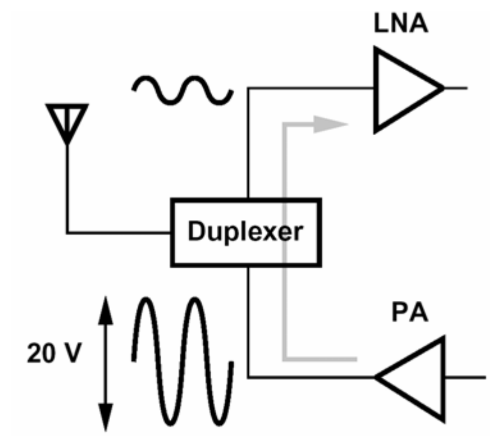


Thus, all stages in the RX chain that precede channel-select filtering must be sufficiently linear:



- **LNA Desensitization by PA**

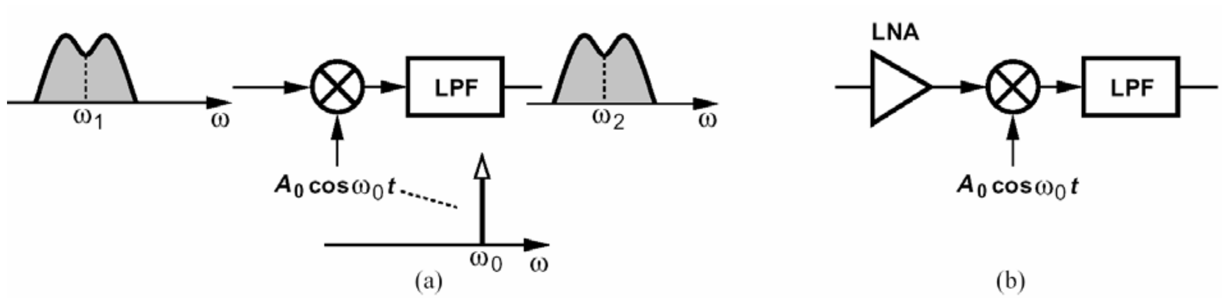
GSM avoids this issue by offsetting The RX and TX time slots.



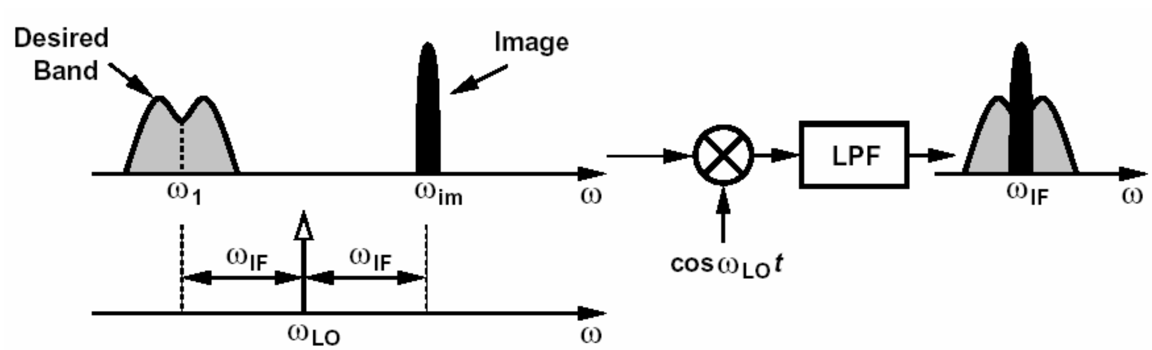
<u>Receiver Architectures</u>

- **Heterodyne Architecture**

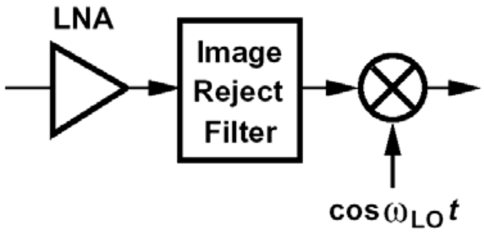
Can't filter interferers at RF → "translate" RF channel to lower frequencies:

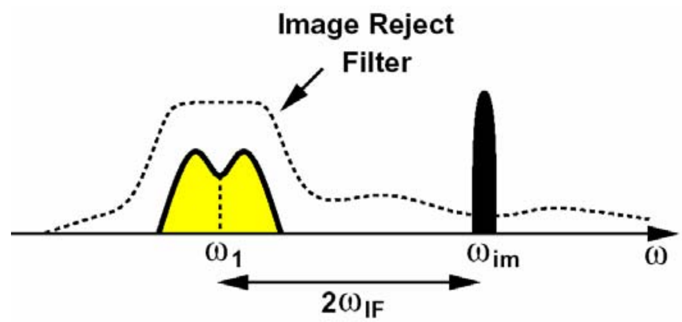


Problem of Image



More Complete Heterodyne RX:





How does a het. RX cover a band of frequencies?

Fixed LO **Fixed IF**

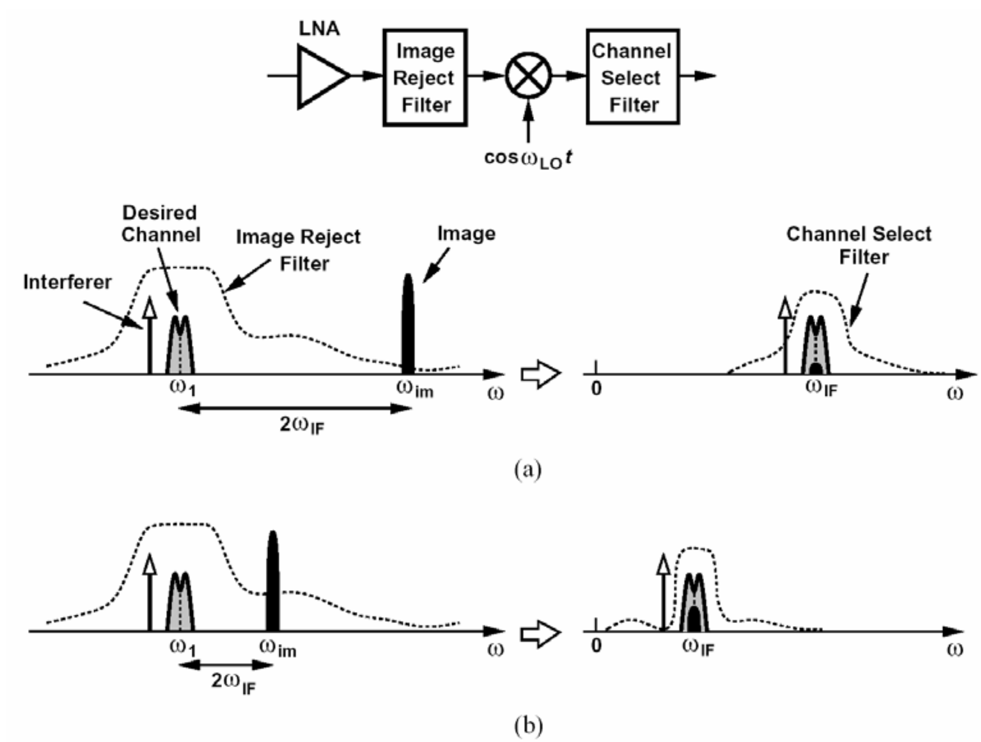
- **Example**

An IEEE802.11g receiver attempts to place the image in the GPS band. Is this possible?

- **Example**

An engineer designing a het. RX for free-space applications reasons that there are no large interferers in space and hence image rejection is unnecessary. Did the engineer take 215C?

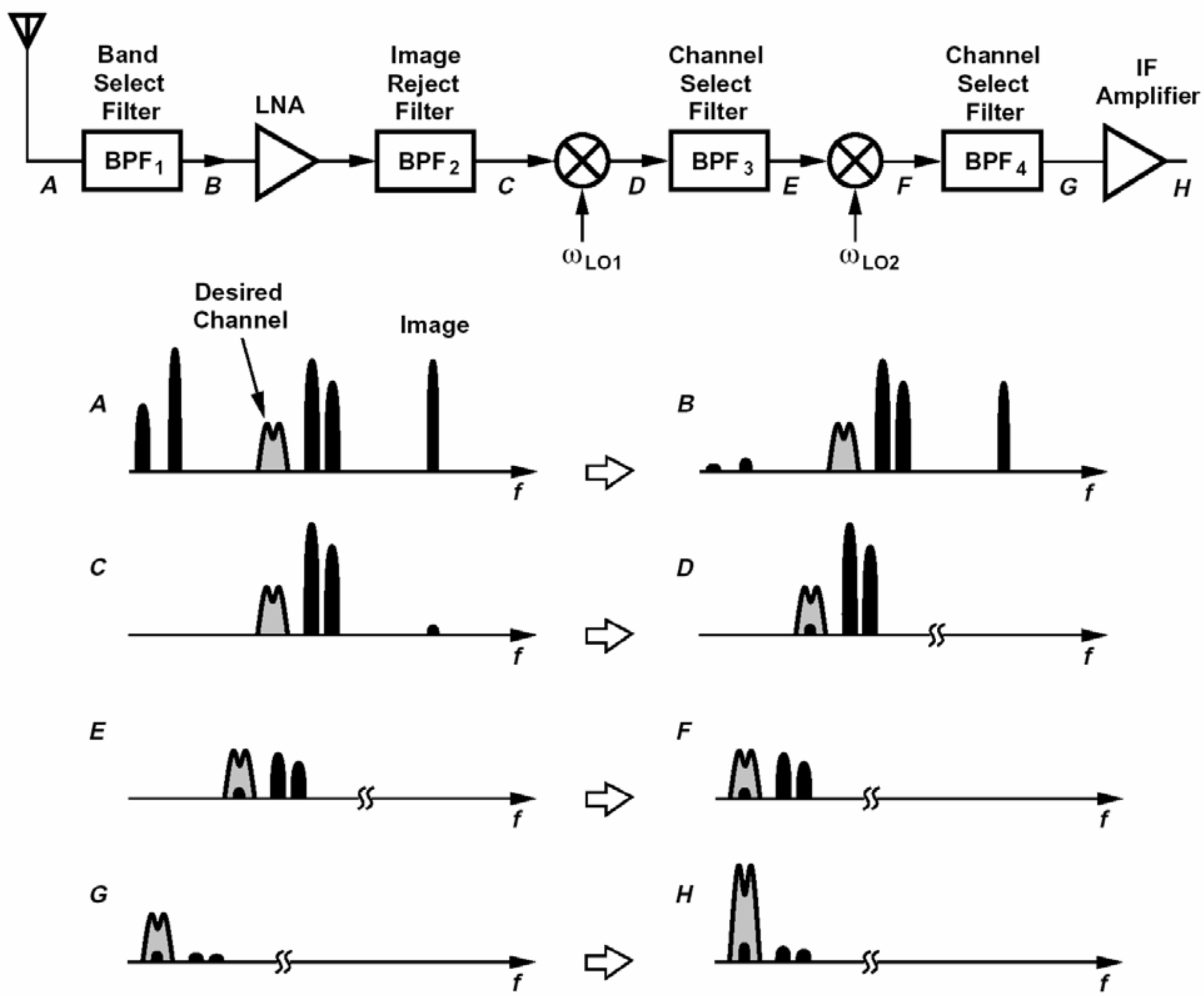
- **Trade-Off Between Image Rejection and Channel Selection**



- **High-Side and Low-Side Injection**

The LO frequency may be chosen higher or lower than the channel of interest:

- **Dual Downconversion**



- How do we choose NF and IP3 of the stages in the chain?

- Every dB of channel-select filtering relaxed the linearity by 1 dB, up to the point where signal compression occurs.

- How about the secondary image?

- **Mixing Spurs**

Each mixing operation convolves the signal and the interferers with many harmonics of the LO:

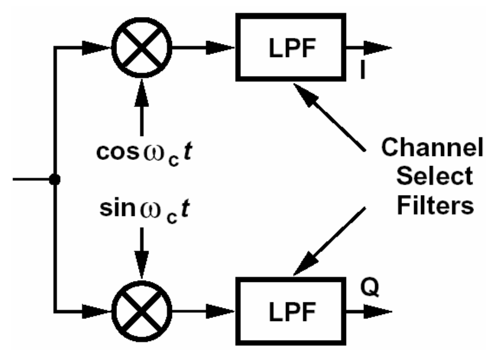
• **Example**
A 2.4-GHz dual downconversion RX employs a first LO at 1.95 GHz and a second at 400 MHz. Determine some of the mixing spurs.

Modern Heterodyne RX Architectures

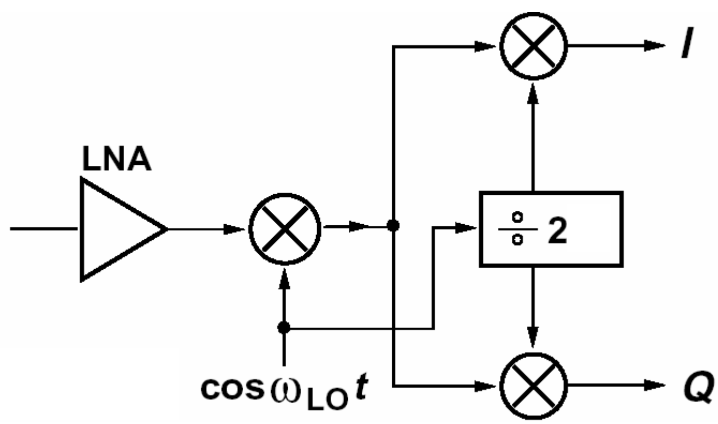
- **Avoid secondary image.**
- **Use a single LO.**
- **Avoid off-chip filters to the extent possible.**
- **Perform detection in digital domain.**

- Downconversion to a Zero IF
Interferers don't fall onto the channel but the channel becomes its own image – an issue if the modulation is "asymmetric."

→ Need to separate the signal to two phases
→ "quadrature downconversion"



- How to reduce the number of LOs to 1?
"Sliding IF RX"



1. What is the LO frequency range?

2. What is the IF range?

3. What is the image frequency range?
4. Repeat the above if the divider divides by 4.