Communication concepts

Outline

Modulation

- AM,PM,FM
- Intersymbol Interference
- Signal Constellations
- ASK,PSK,FSK
- QPSK,GMSK,QAM
- OFDM
- Spectral Regrowth

Mobile Systems

- Cellular System
- Handoff
- Multipath Fading
- Diversity

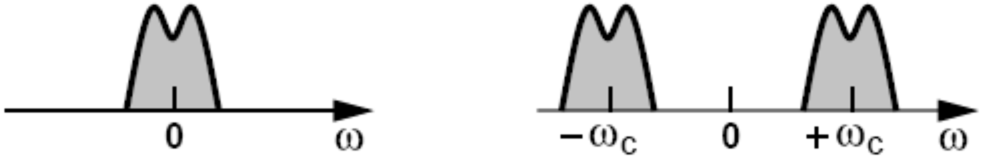
Multiple Access Techniques

- Duplexing
- FDMA
- TDMA
- CDMA

Wireless Standards

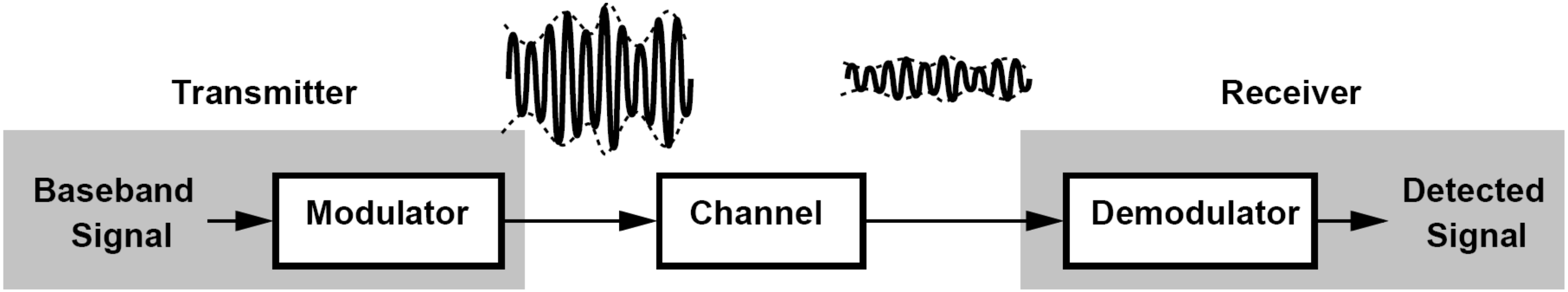
- GSM
- IS-95 CDMA
- Wideband CDMA
- Bluetooth
- IEEE802.11 a/b/g

Journey of the Signal



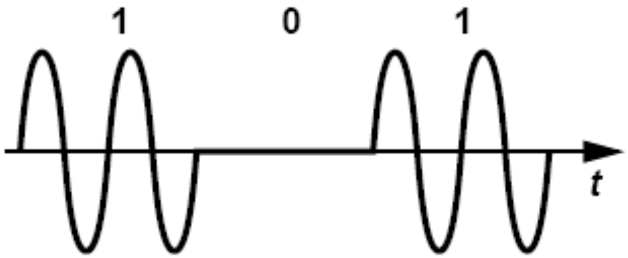
$$x(t) = a(t)\cos[\omega_c t + \theta(t)]$$

- Modulation varies certain parameters of a sinusoidal carrier according to the baseband signal.

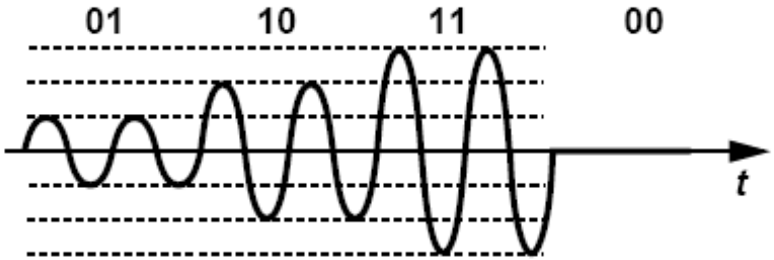


- A simple communication system consists of a modulator/transmitter, a channel, and a receiver/demodulator

Important Aspects of Modulation



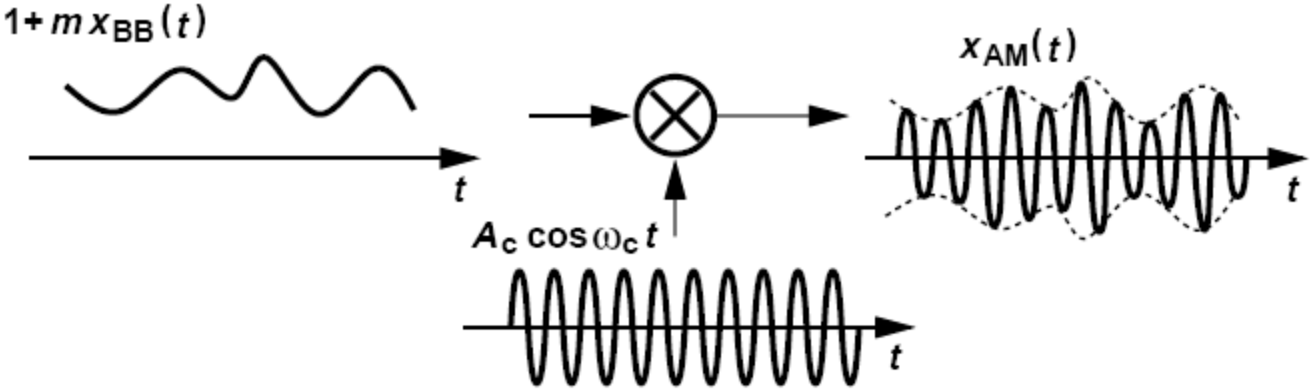
2-level



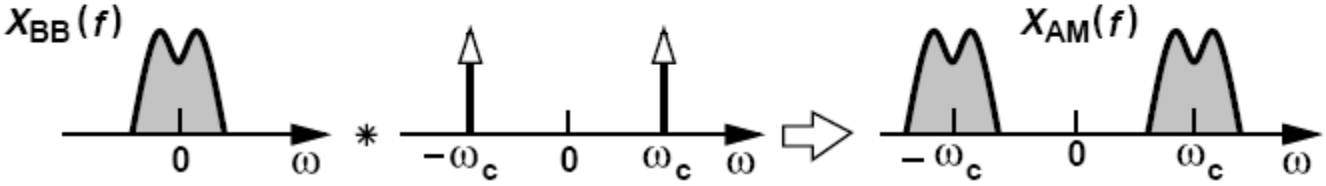
4-level

- ***Detectability*: the quality of the demodulated signal for a given amount of channel attenuation and receiver noise**
- ***Bandwidth Efficiency*: the bandwidth occupied by the modulated carrier for a given information rate in the baseband signal**
- ***Power Efficiency*: the type of power amplifier (PA) that can be used in the transmitter**

Analog Modulation: Amplitude Modulation



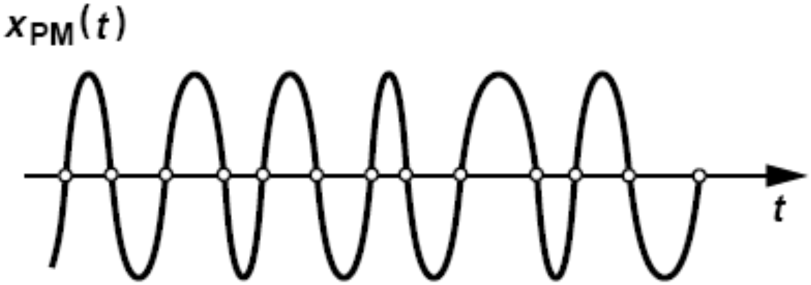
(a)



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

- ***m*** **is called the "*modulation index*"**

Analog Modulation: Phase & Frequency Modulation



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

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

- **Phase Modulation: Amplitude is constant and the excess phase is linearly proportional to the baseband signal**

- **Frequency Modulation: the excess frequency is linearly proportional to the baseband signal**

Example of Phase & Frequency Modulation

Determine the PM and FM signals in response to (a) $x_{BB}(t) = A_0$, (b) $x_{BB}(t) = \alpha t$.

Solution:

(a) For a constant baseband signal

$$x_{PM}(t) = A_c \cos(\omega_c t + mA_0)$$

PM output simply contains a constant phase shift

$$\begin{aligned} x_{FM}(t) &= A_c \cos(\omega_c t + mA_0 t) \\ &= A_c \cos[(\omega_c + mA_0)t] \end{aligned}$$

FM output exhibits a constant frequency shift equal to mA_0

(b) If $x_{BB}(t) = \alpha t$

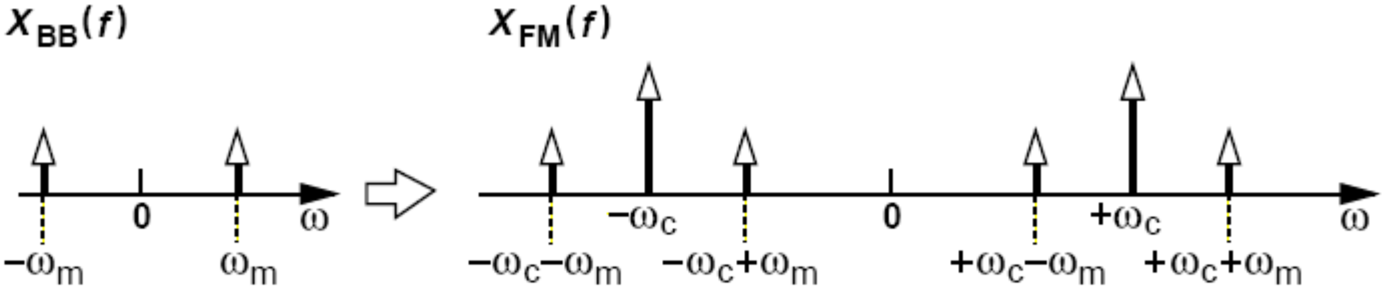
$$\begin{aligned} x_{PM}(t) &= A_c \cos(\omega_c t + m\alpha t) \\ &= A_c \cos[(\omega_c + m\alpha)t] \end{aligned}$$

PM output experiences a constant frequency shift

$$x_{FM}(t) = A_c \cos\left(\omega_c t + \frac{m\alpha}{2} t^2\right)$$

This signal can be viewed as a waveform whose phase grows quadratically with time

Narrowband FM Approximation



If mA_m/ω_m << 1rad

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

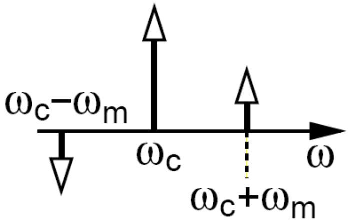
Example of AM, PM and FM Modulation(Ⅰ)

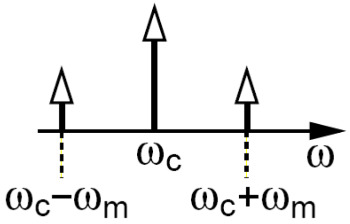
It is sometimes said that the FM(or PM) sidebands have opposite signs whereas AM sidebands have identical signs. Is this generally true?

Solution:

Equation above indeed suggests that cos($\omega_c - \omega_m$)t and cos($\omega_c + \omega_m$)t have opposite signs. Figure below (left) illustrates this case by allowing signs in the magnitude plot. For a carrier whose amplitude is modulated by a sinusoid, we have

$$
\begin{aligned}
x_{AM}(t) &= A_c(1 + m\cos\omega_m t)\cos\omega_c t \\
&= A_c\cos\omega_c t + \frac{mA_c}{2}\cos(\omega_c + \omega_m)t + \frac{mA_c}{2}\cos(\omega_c - \omega_m)t.
\end{aligned}
$$

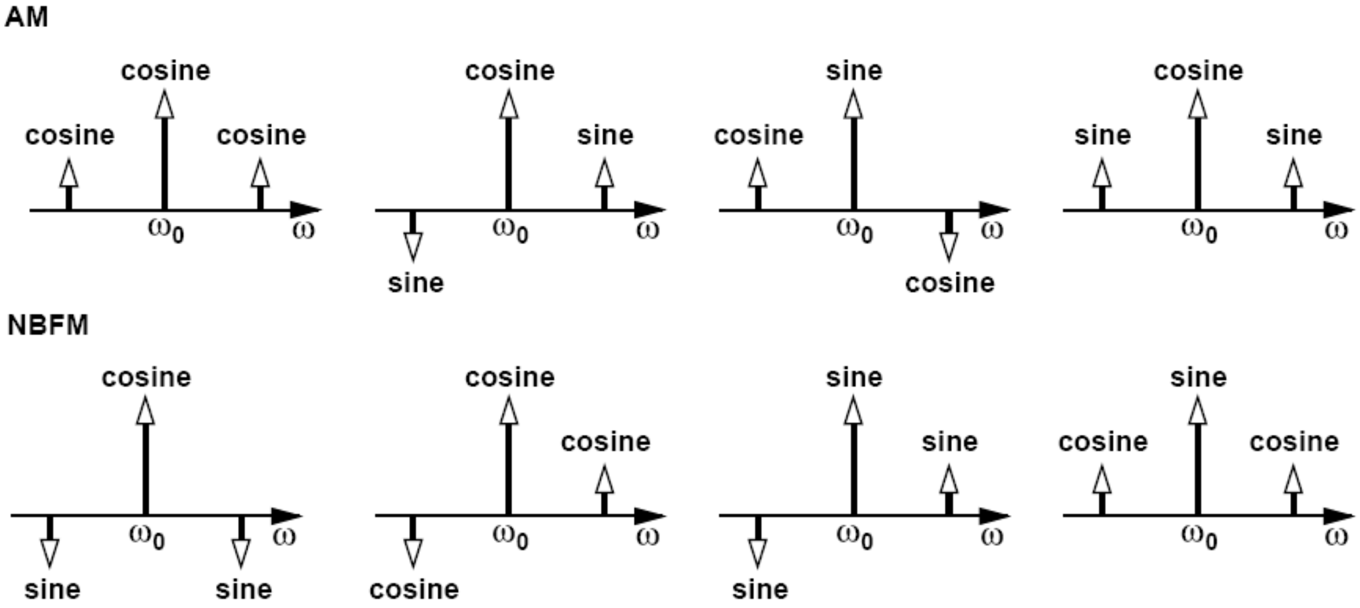


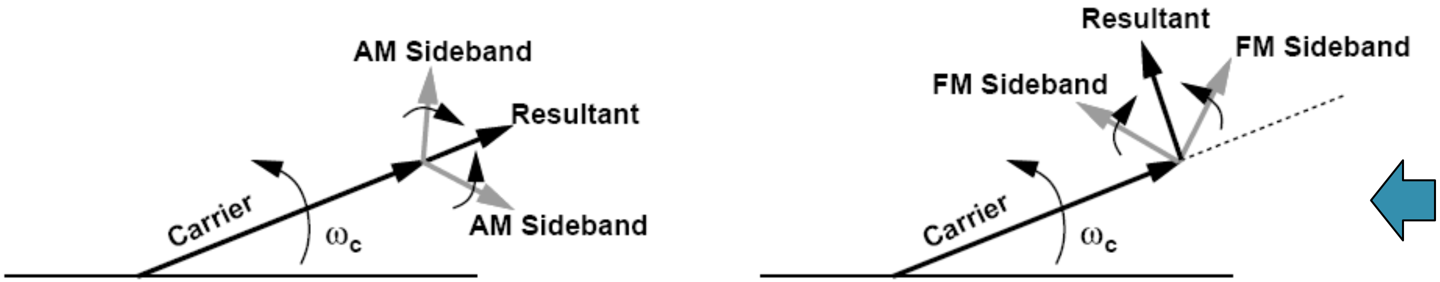


Thus, it appears that the sidebands have identical signs. However, in general, the polarity of the sidebands per se does not distinguish AM from FM. Writing the four possible combinations of sine and cosine, the reader can arrive at the spectra shown below. Given the exact waveforms for the carrier and the sidebands, one can decide from these spectra whether the modulation is AM or narrowband FM.

Example of AM, PM and FM Modulation(Ⅱ)

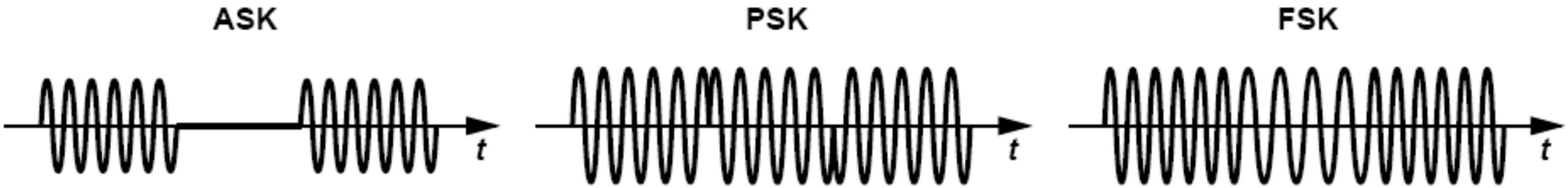
It is sometimes said that the FM(or PM) sidebands have opposite signs whereas AM sidebands have identical signs. Is this generally true?



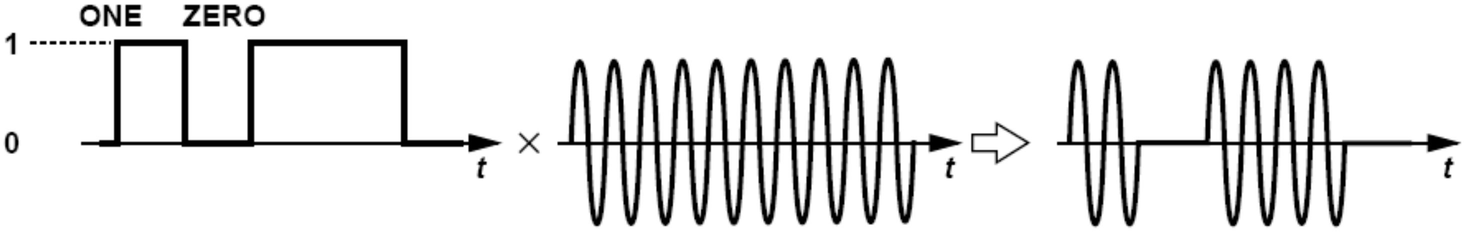


Phasor Interpretation Of AM & FM

Digital Modulation: ASK.PSK.FSK

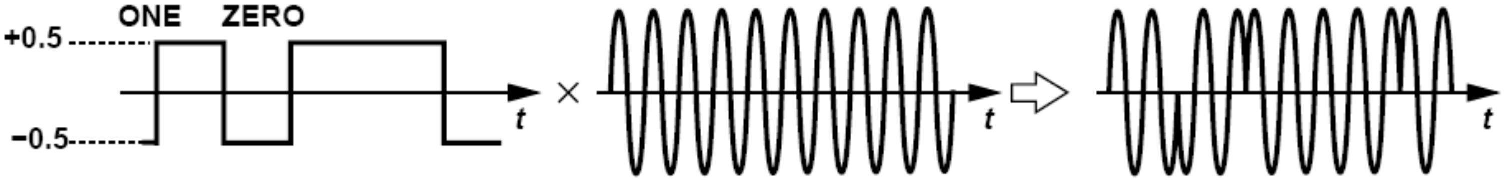


$$\begin{aligned} x_{PSK}(t) &= A_c \cos \omega_c t && \textbf{If data = ZERO} \\ &= A_c \cos(\omega_c t + 180^\circ) && \textbf{If data = ONE} \end{aligned}$$



(a)

ASK

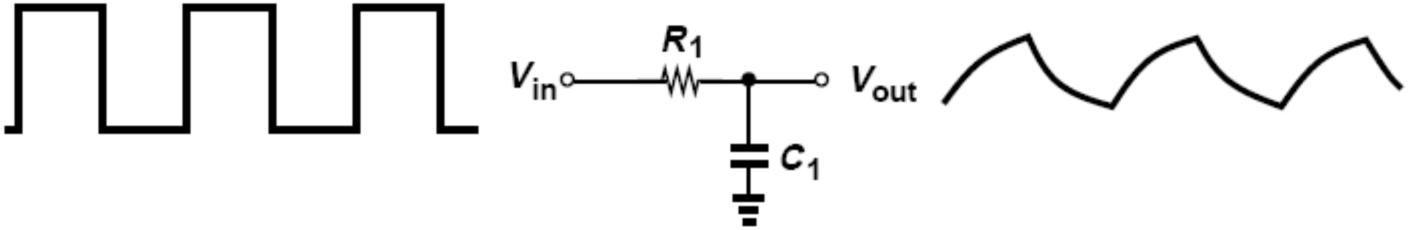


(b)

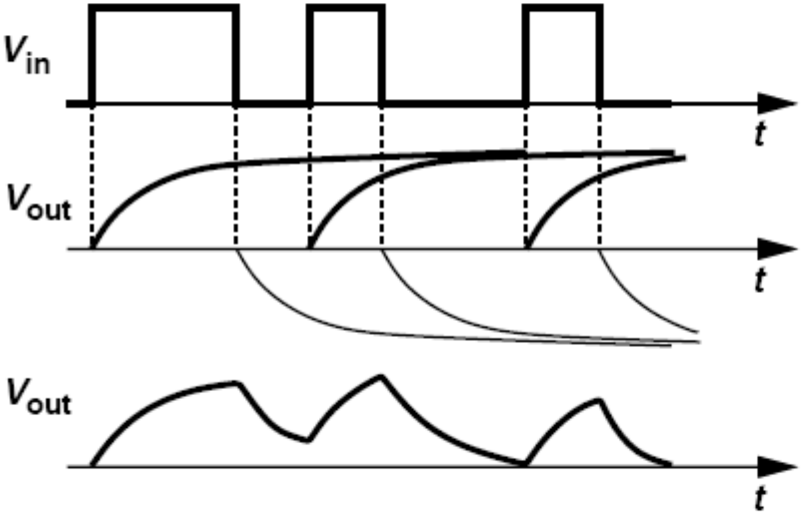
PSK

- Called “*Amplitude Shift Keying*”, “*Phase Shift Keying*”, and “*Frequency Shift Keying*”

Digital Modulation: Intersymbol Interference (ISI)



(a)



- **A signal cannot be both time-limited and bandwidth-limited.**
- **Each bit level is corrupted by decaying tails created by previous bits.**

Example of Intersymbol Interference

Determine the spectrum of the random binary sequence, $x_{BB}(t)$, in figure below and explain, in the frequency domain, the effect of low-pass filtering it.

Solution:

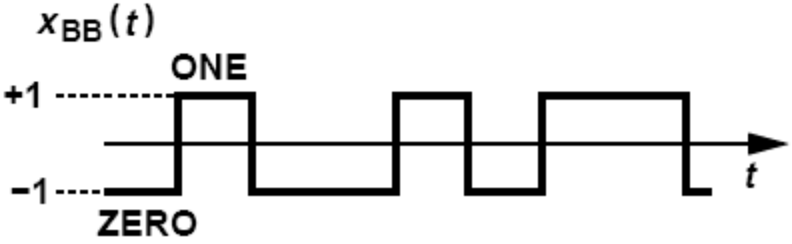
We can express the sequence as

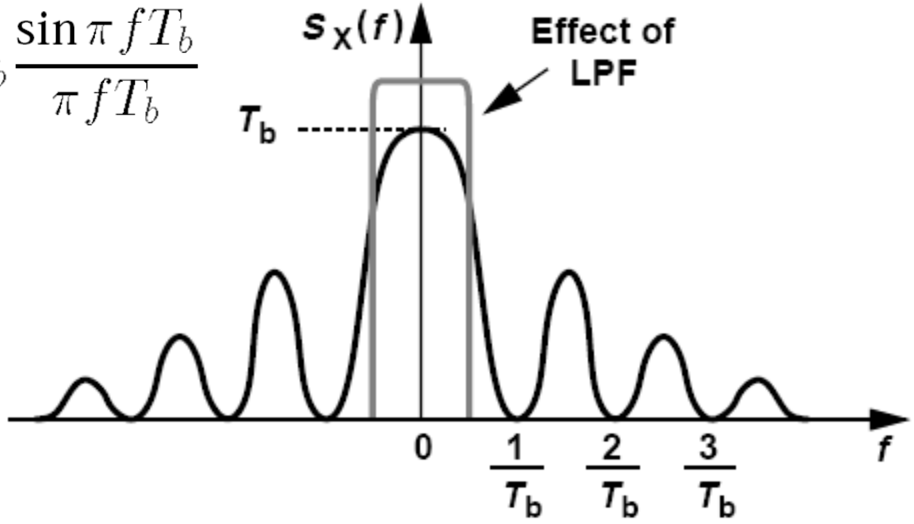
$$x_{BB}(t) = \sum_{n=0}^{\infty} a_n p(t - nT_b)$$

The spectrum is given by: $S_x(f) = \frac{1}{T_b}|P(f)|^2$

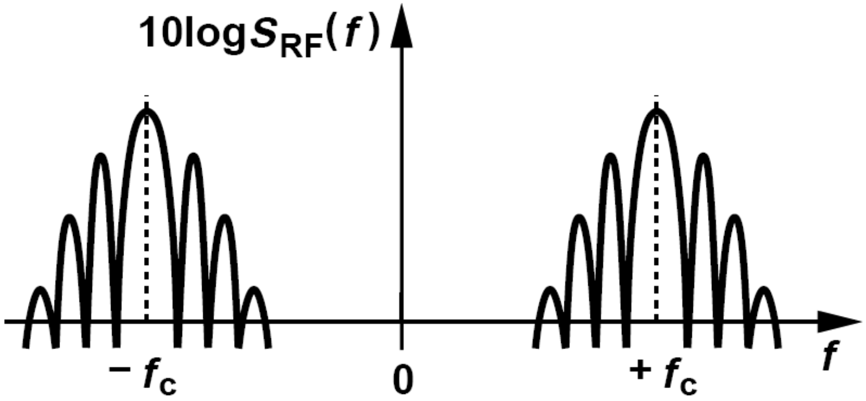
For a rectangular pulse of width *T*$_b$ $P(f) = T_b \frac{\sin \pi f T_b}{\pi f T_b}$

$$S_x(f) = T_b \left(\frac{\sin \pi f T_b}{\pi f T_b} \right)^2$$





The Spectrum of PSK and ASK Signal

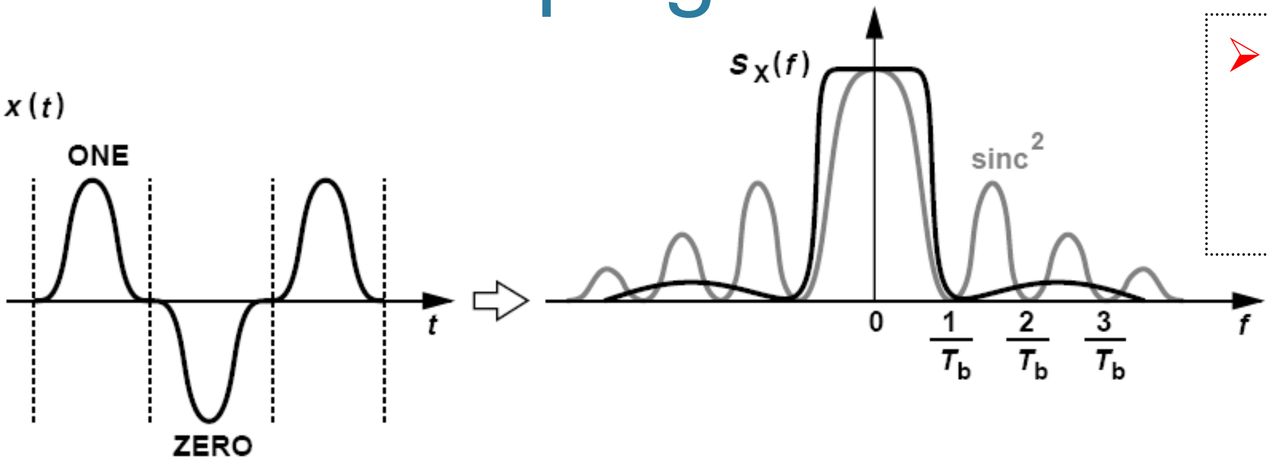


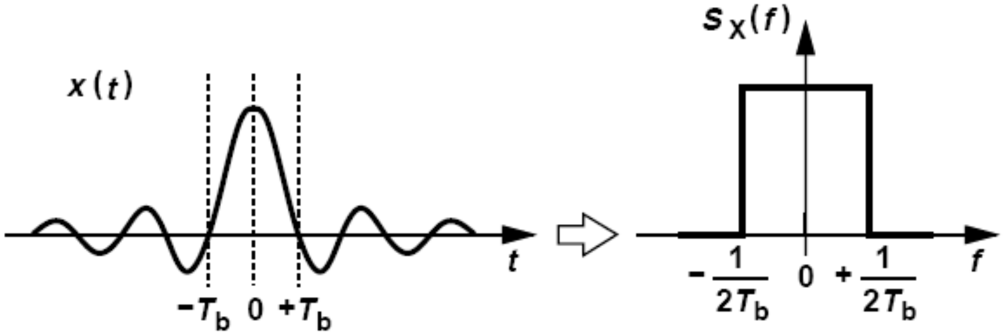
$$x_{PSK}(t) = x_{BB}(t)\cos\omega_c t$$

- **The upconversion operation shifts the spectrum to ±f_c**
- **Spectrum of ASK is similar but with impulses at ±f_c**

Pulse Shaping

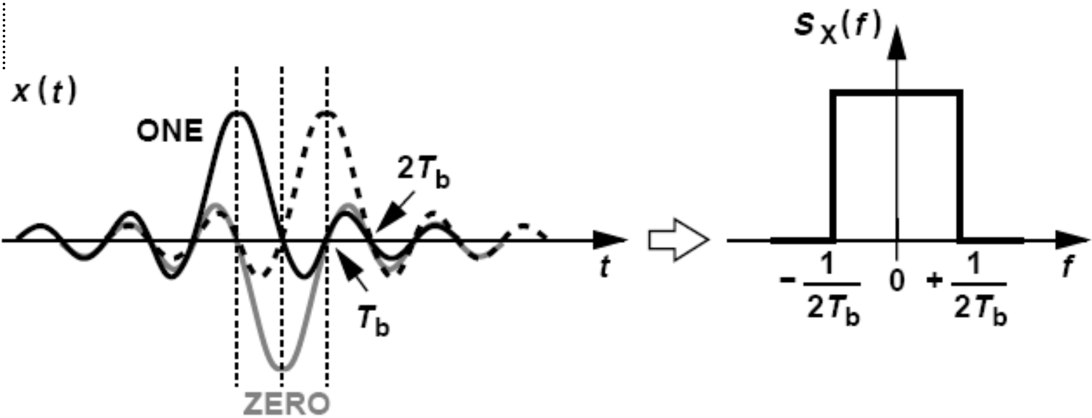
- **Baseband pulse is designed to occupy a small bandwidth.**



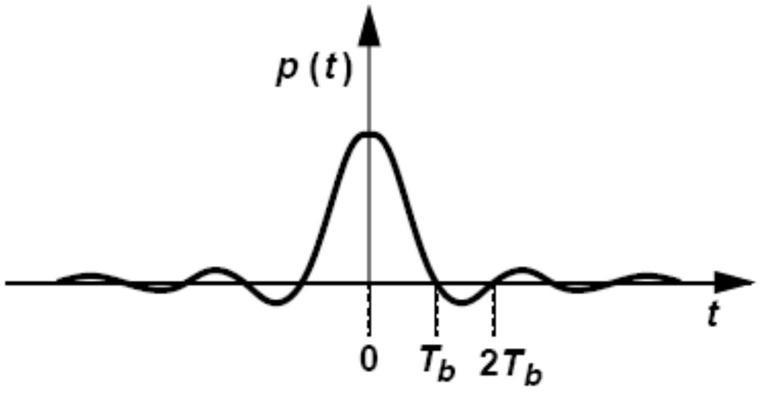


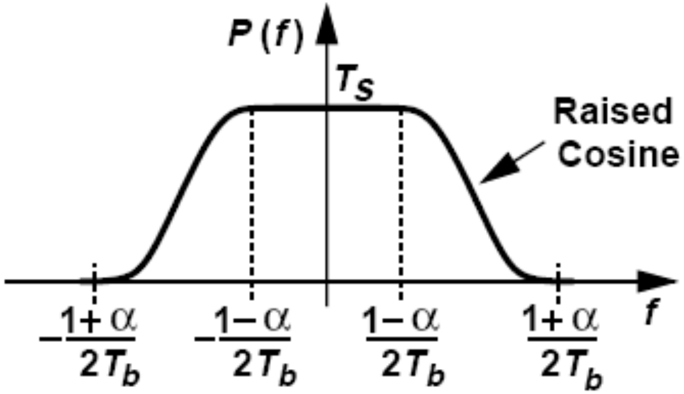
(a)

- **Random binary sequence spectrum still remains a rectangle.**



Raised-cosine Pulse Shaping



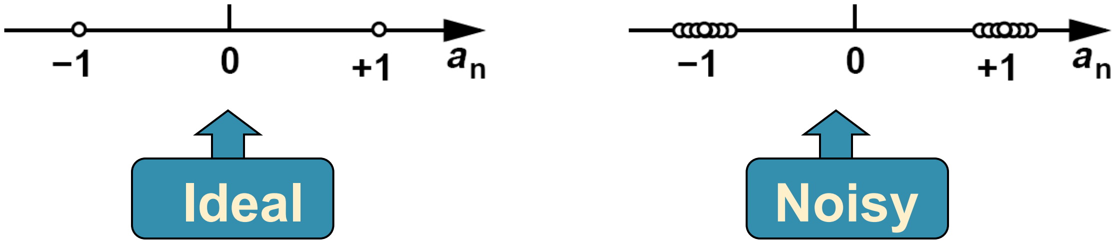


$$p(t) = \frac{\sin(\pi t/T_S)}{\pi t/T_S}\,\frac{\cos(\pi\alpha t/T_S)}{1-4\alpha^2t^2/T_S^2}$$

- **α: roll-off factor, typical values are in the range of 0.3~0.5**

Signal Constellation: Binary PSK and ASK

$$x_{PSK}(t) = a_n \cos \omega_c t \qquad a_n = \pm 1$$

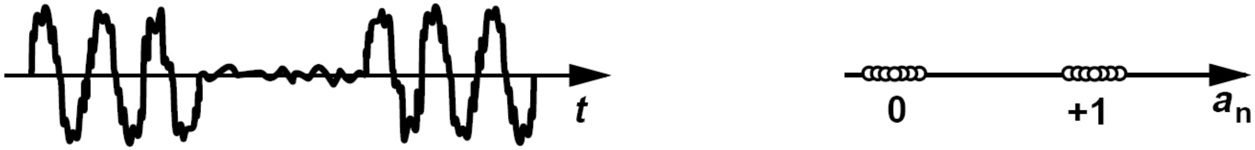


Plot the constellation of an ASK signal in the presence of amplitude noise.

Solution:

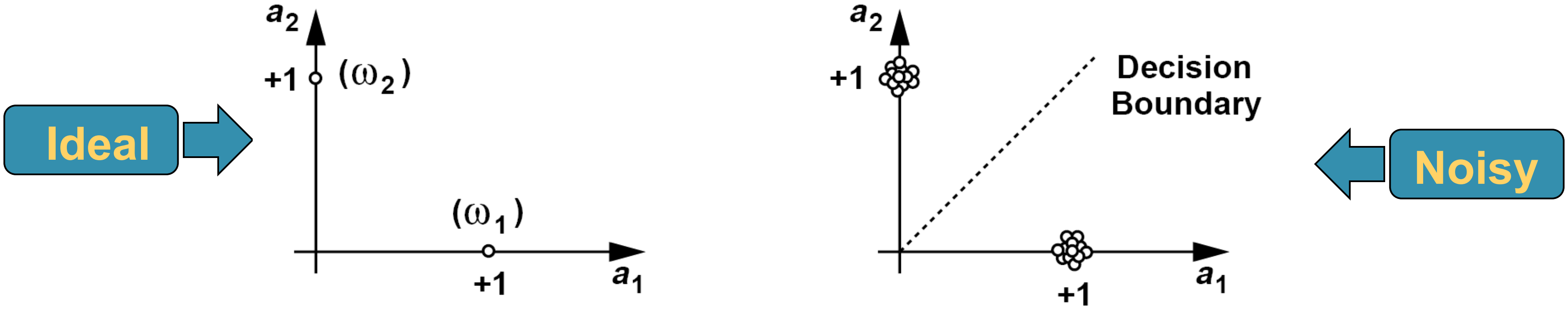
$$x_{ASK}(t) = a_n \cos \omega_c t \qquad a_n = 0,\ 1$$

Noise corrupts the amplitude for both ZEROs and ONEs.

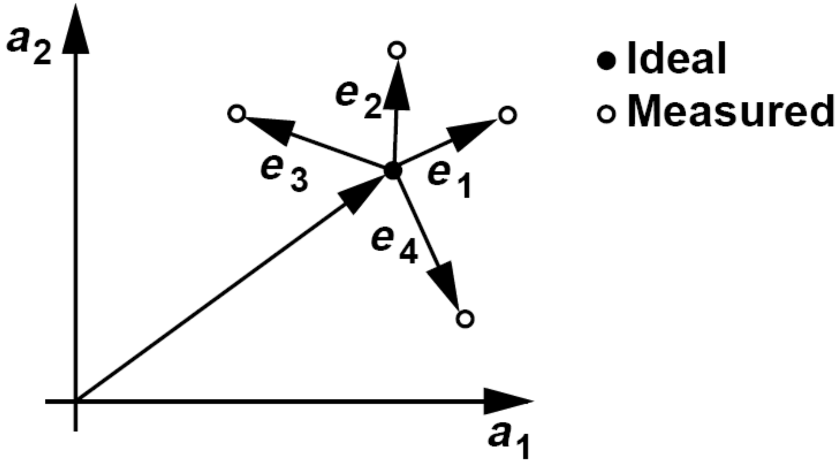


Signal Constellation: FSK and EVM

For FSK: $x_{FSK}(t) = a_1 \cos \omega_1 t + a_2 \cos \omega_2 t \qquad a_1 a_2 = 10 \text{ or } 01.$



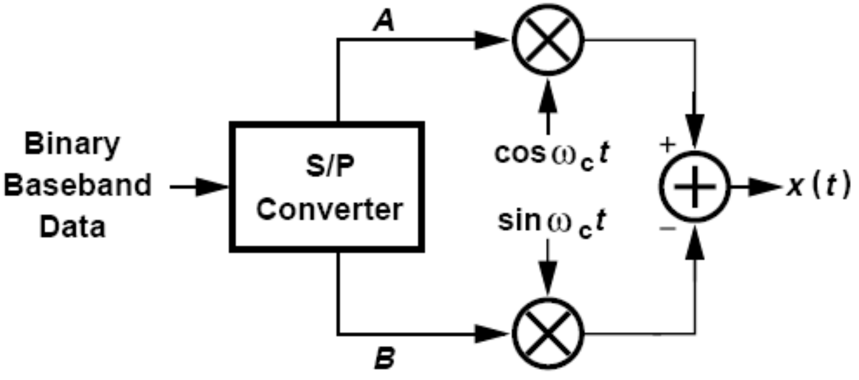
The constellation can also provide a quantitative measure of the impairments that corrupt the signal. Representing the deviation of the constellation points from their ideal positions, the "error vector magnitude" (EVM) is such a measure.

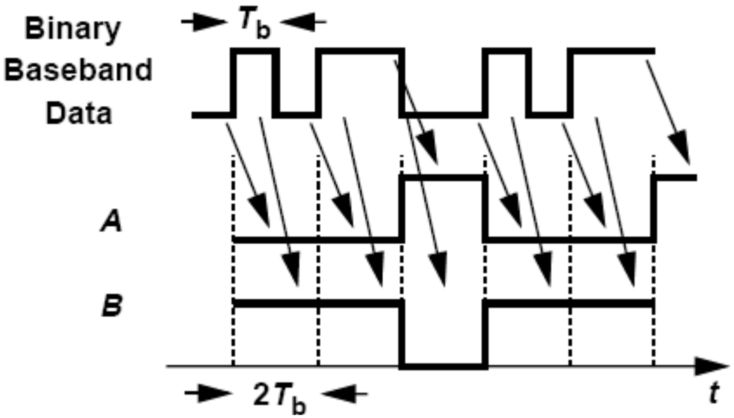


$$\mathrm{EVM}_1 = \frac{1}{V_{rms}} \sqrt{\frac{1}{N} \sum_{j=1}^{N} e_j^2},$$

$$\mathrm{EVM}_2 = \frac{1}{P_{avg}} \cdot \frac{1}{N} \sum_{j=1}^{N} e_j^2,$$

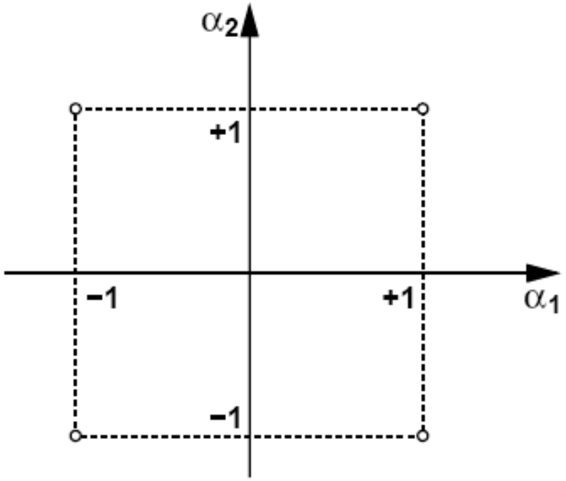
Quadrature Modulation

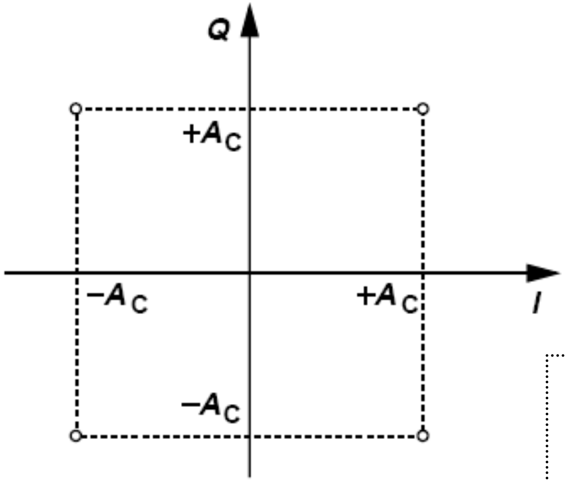




$$x(t) = b_{2m} A_c \cos\omega_c t - b_{2m+1} A_c \sin\omega_c t$$

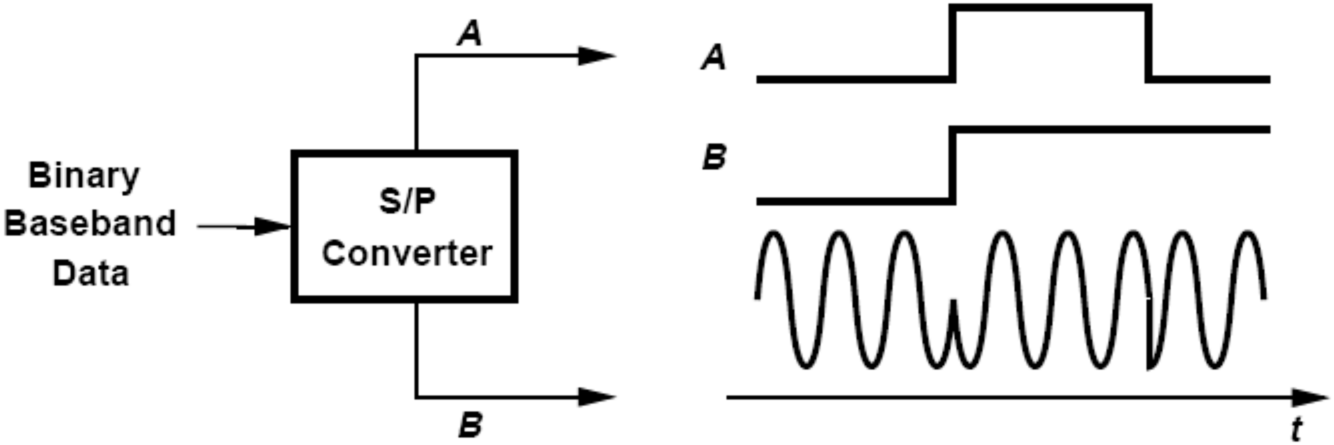
- **QPSK halves the occupied bandwidth**
- **Pulses appear at *A* and *B* are called *symbols* rather than *bits***

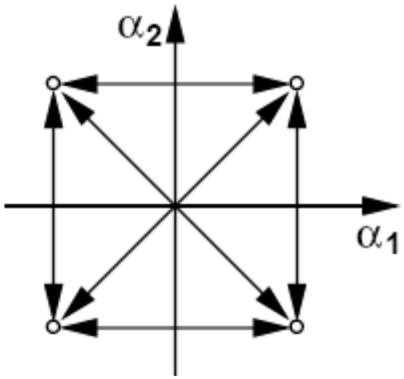




- ***I* for in-phase and *Q* for Quadrature**

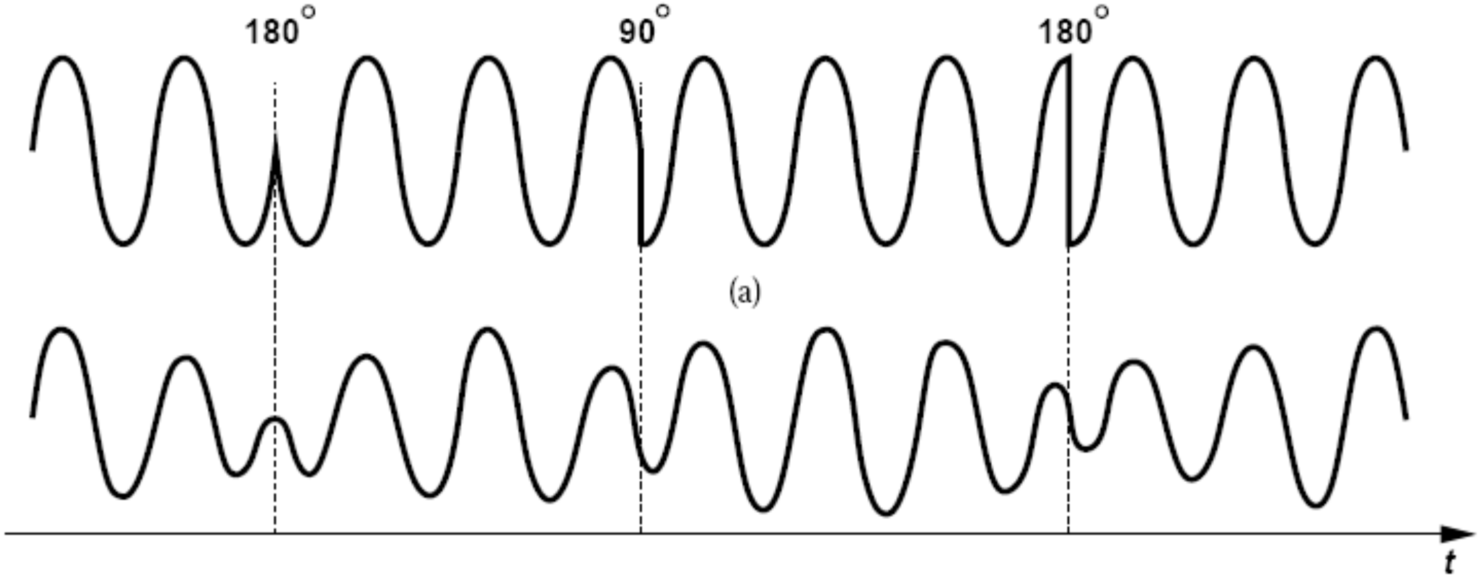
Important Drawback of QPSK (Ⅰ)





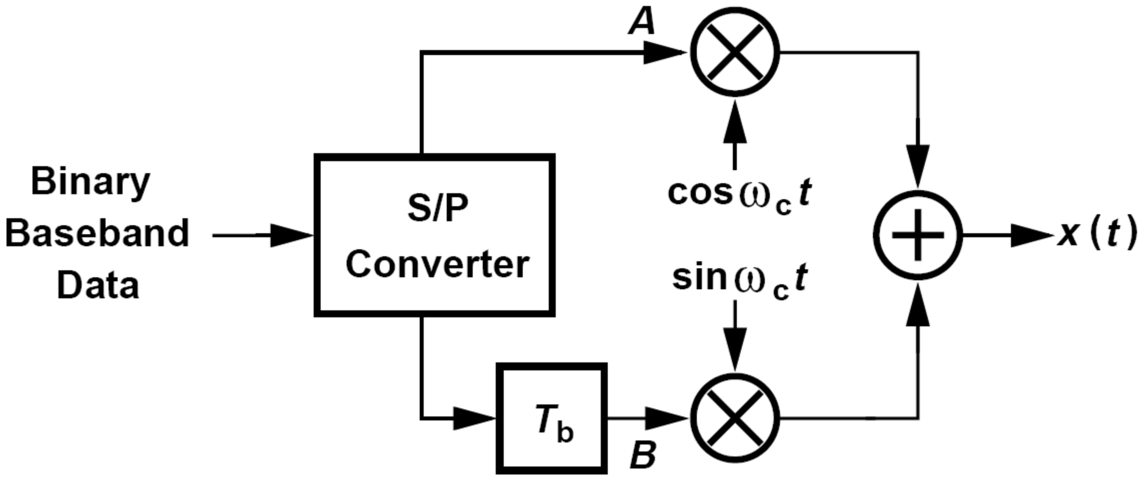
- ➢ **Important drawback of QPSK stems from the large phase changes at the end of each symbol.**

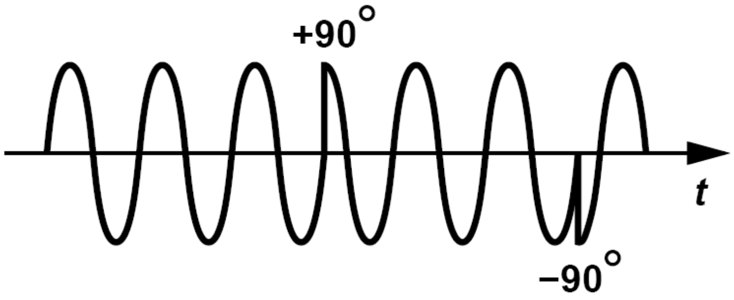
Important Drawback of QPSK (Ⅱ)

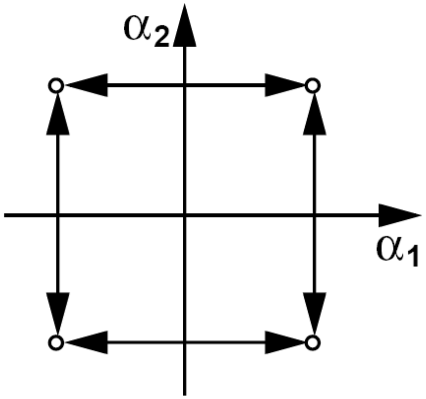


- With pulse shaping, the output signal amplitude (“envelope”) experiences large changes each time the phase makes a 90 or 180 degree transition.
- Resulting waveform is called a “variable-envelope signal”. Need linear PA

OQPSK

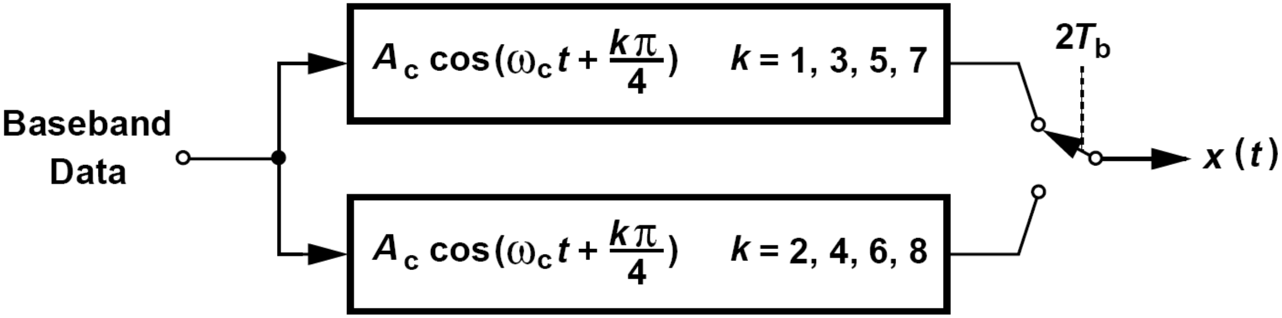




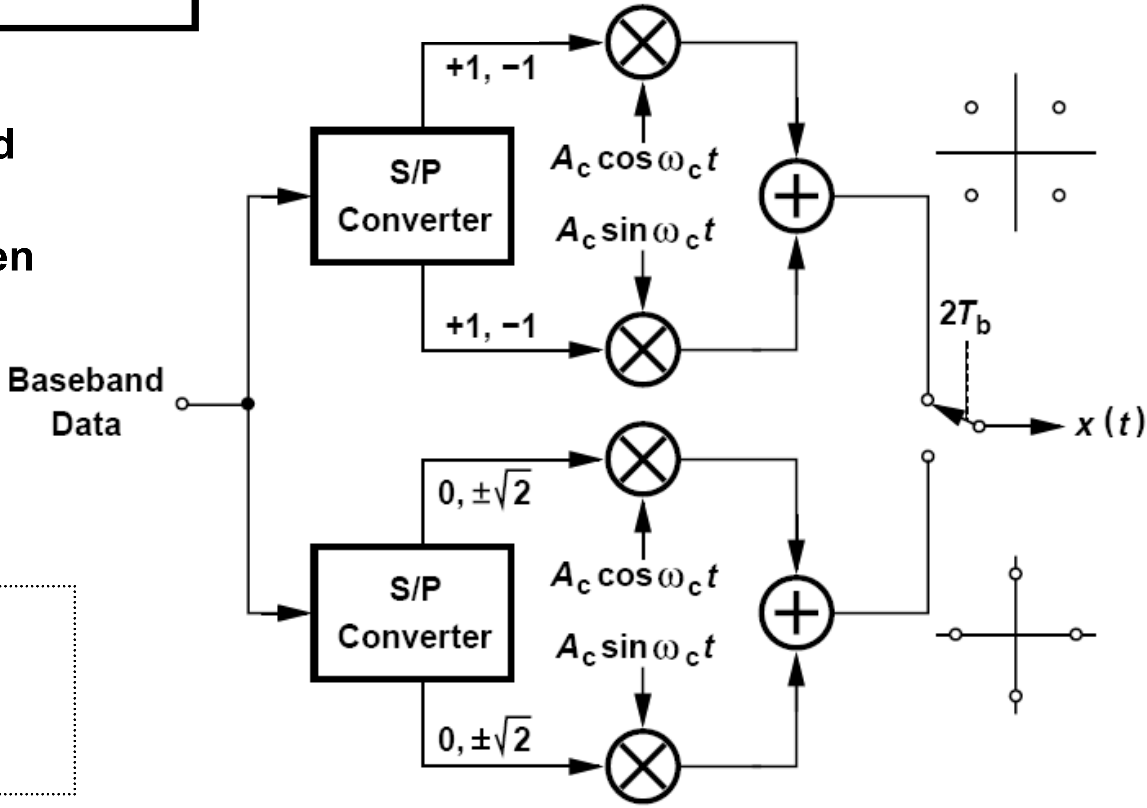


- **OQPSK does not lend itself to differential encoding**

π/4 QPSK

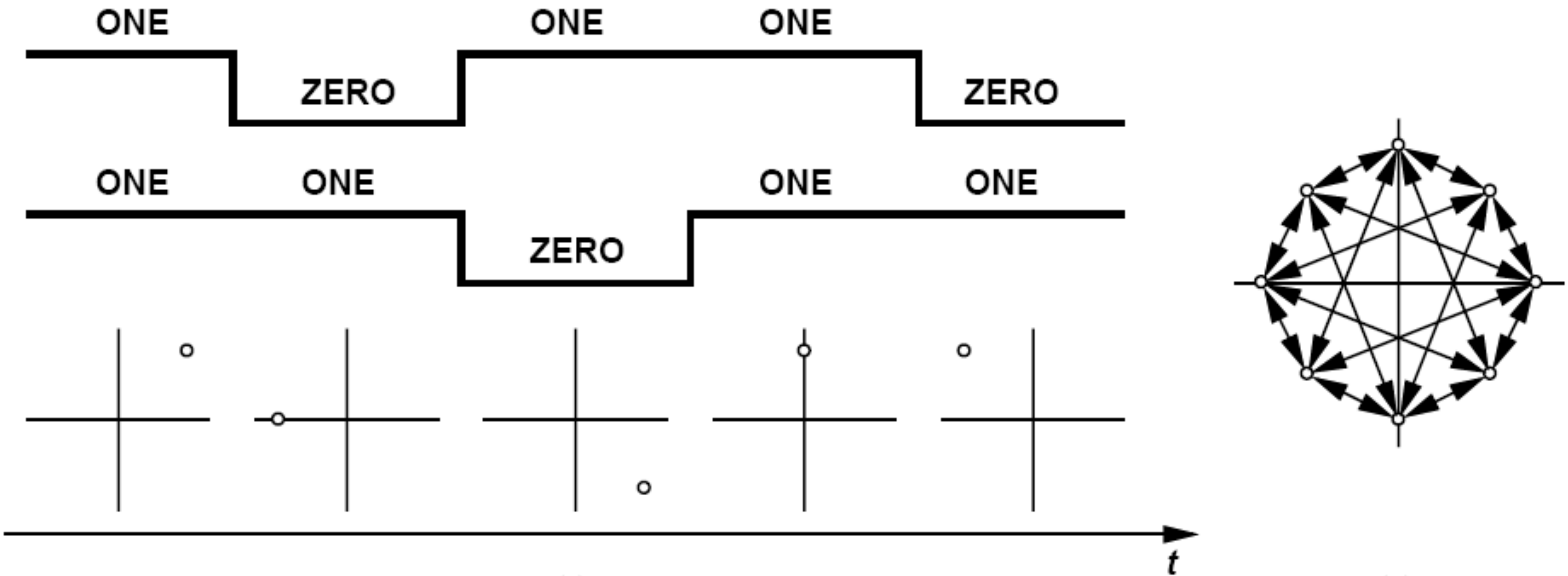


$$
\begin{aligned}
x_1(t) &= A_c \cos\left(\omega_c t + k\frac{\pi}{4}\right) \quad \textbf{\textit{k} odd} \\
x_2(t) &= A_c \cos\left(\omega_c t + k\frac{\pi}{4}\right) \quad \textbf{\textit{k} even}
\end{aligned}
$$



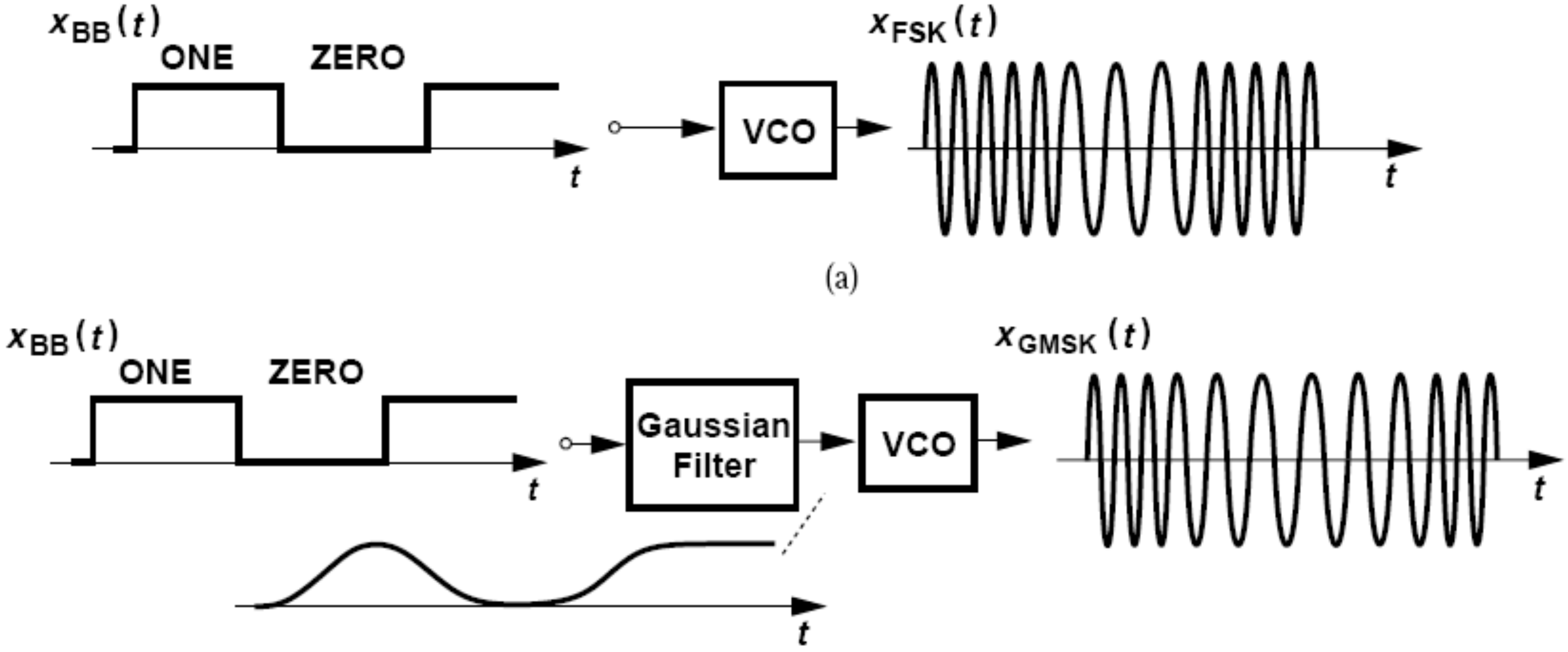
- **Modulation is performed by alternately taking the output from each QPSK generator**

π/4 QPSK: Spectral and Power Efficiency



- Maximum phase step is 135 degree compared with 180 degree in QPSK
- QPSK and its variants provide high spectral efficiency but need linear PA

GMSK and GFSK Modulation



(a)

(b)

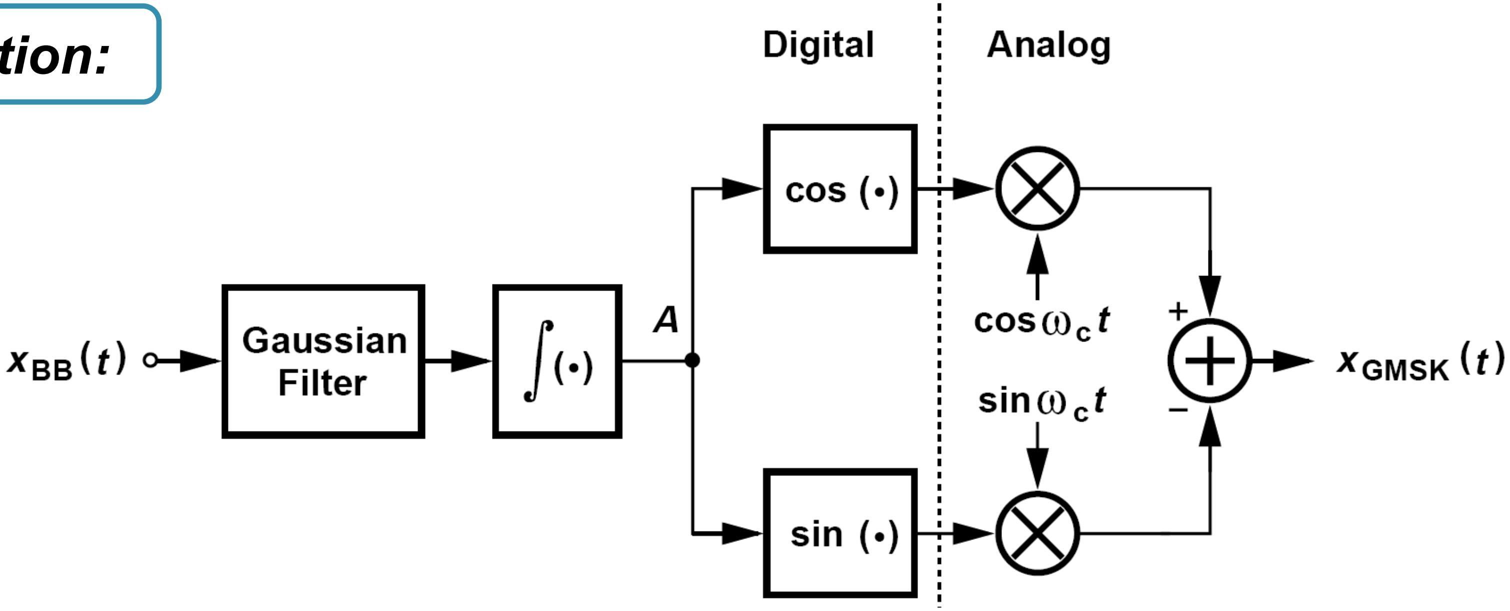
$$x_{GMSK}(t) = A_c \cos[\omega_c t + m \int x_{BB}(t) * h(t) dt]$$

- **Gaussian minimum shift keying (GMSK), modulation index *m* = 0.5**
- **Gaussian frequency shift keying (GFSK), modulation index *m* = 0.3**

Example of GMSK Modulator Construction

Construct a GMSK modulator using a quadrature upconverter.

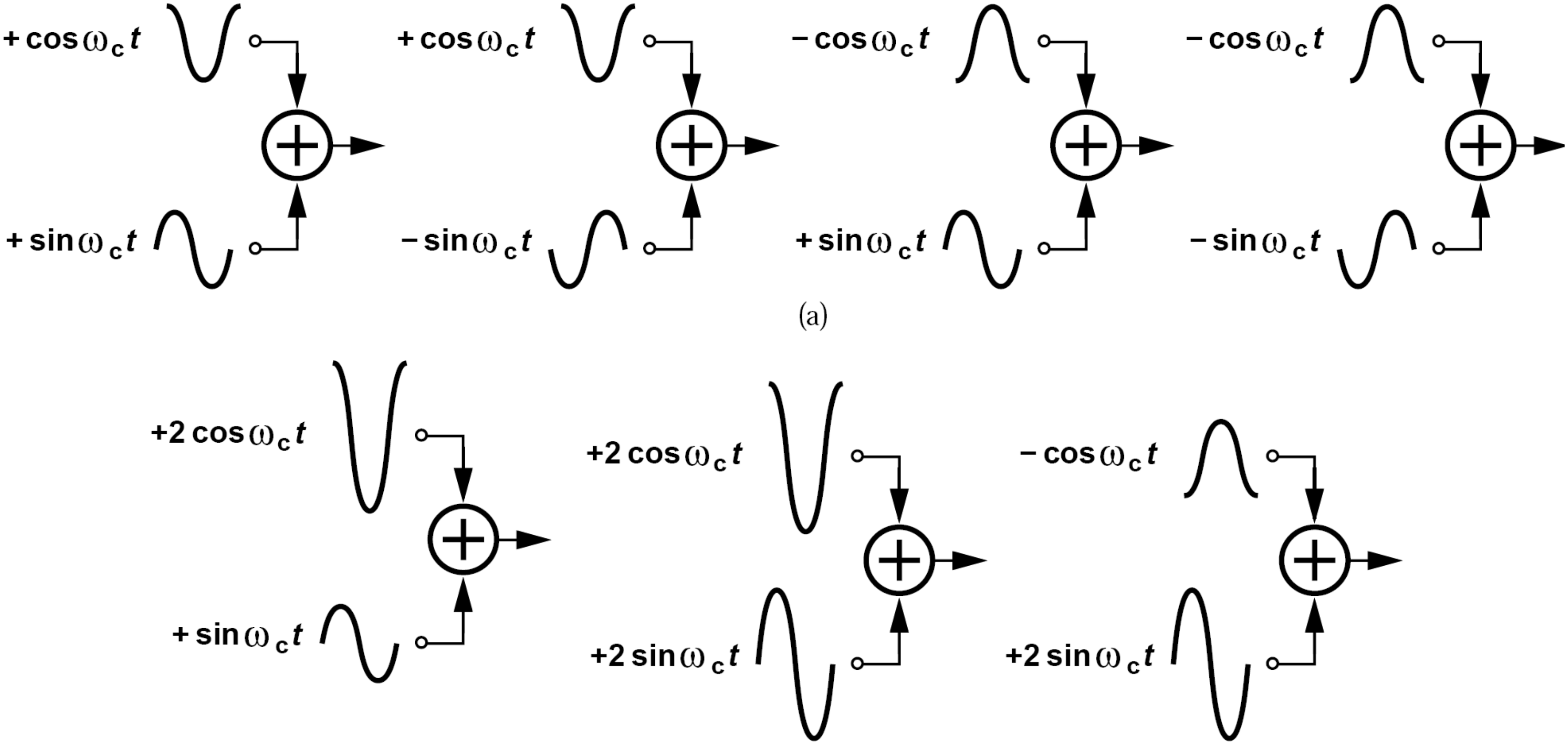
Solution:



$$x_{GMSK}(t) = A_c \cos[m\int x_{BB}(t) * h(t)dt]\cos\omega_c t - A_c \sin[m\int x_{BB}(t) * h(t)dt]\sin\omega_c t.$$

We can therefore construct the modulator as shown above, where a Gaussian filter is followed by an integrator and two arms that compute the sine and cosine of the signal at node A. The complexity of these operations is much more easily afforded in the digital domain than in the analog domain (Chapter 4).

Quadrature Amplitude Modulation

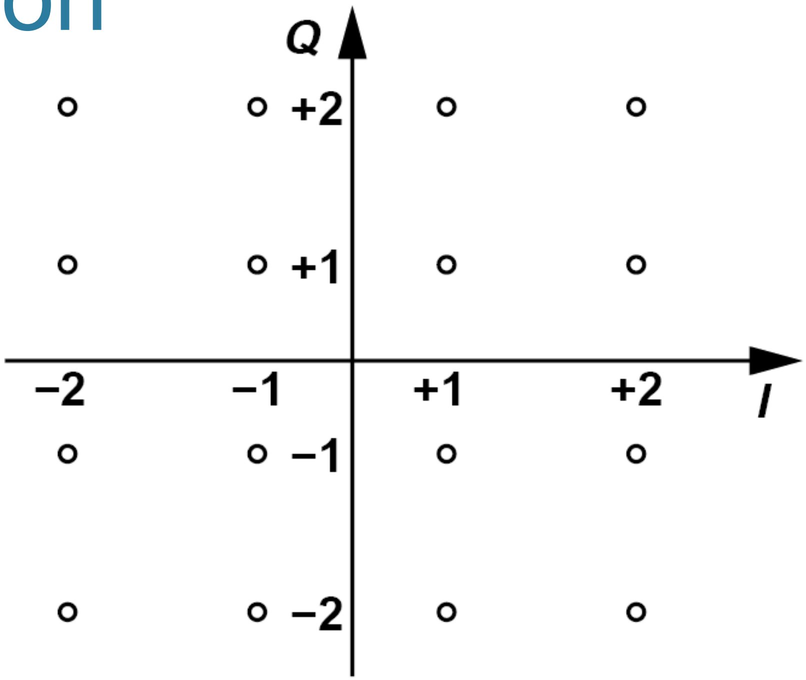


(a)

(b)

- **QAM allows four possible amplitudes for sine and cosine, ±1, ±2**

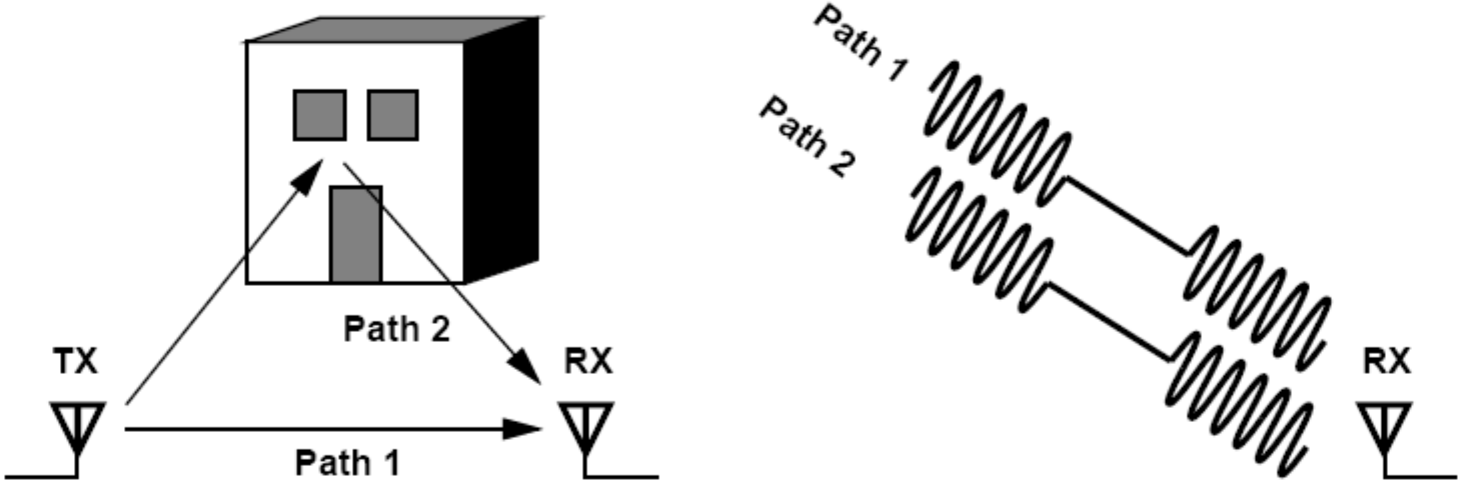
Quadrature Amplitude Modulation: Constellation



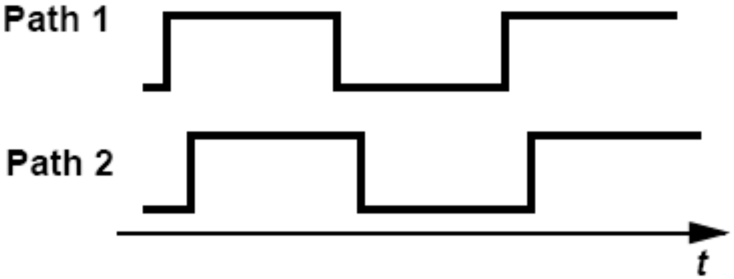
$$x_{16QAM}(t) = \alpha_1 A_c \cos \omega_c t - \alpha_2 A_c \sin \omega_c t \quad \alpha_1 = \pm 1, \pm 2, \ \alpha_2 = \pm 1, \pm 2.$$

- **Saves bandwidth**
- **Denser constellation: making detection more sensitive to noise**
- **Large envelope variation: need highly linear PA**

OFDM: Multipath Propagation

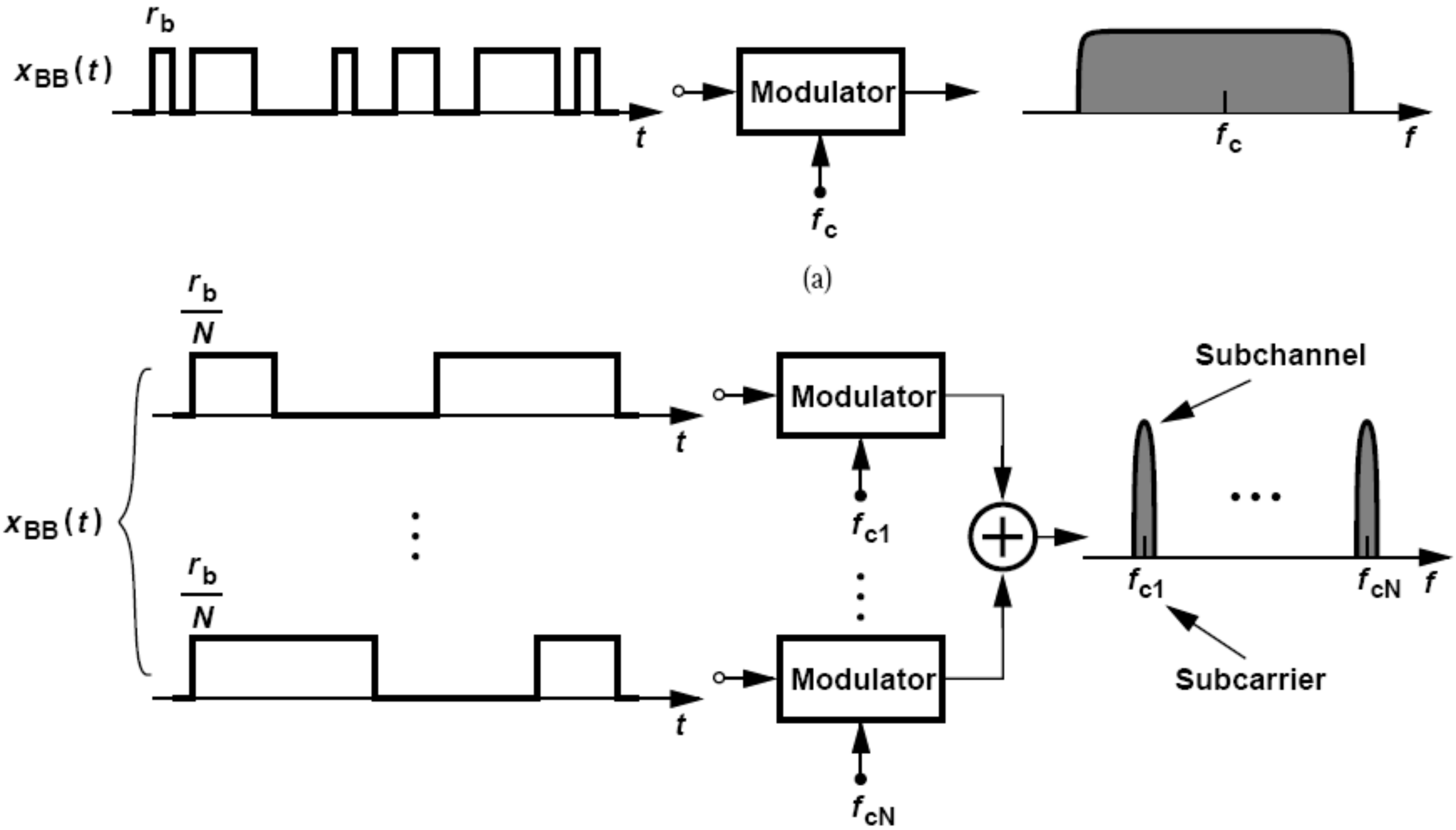


(a) (b)



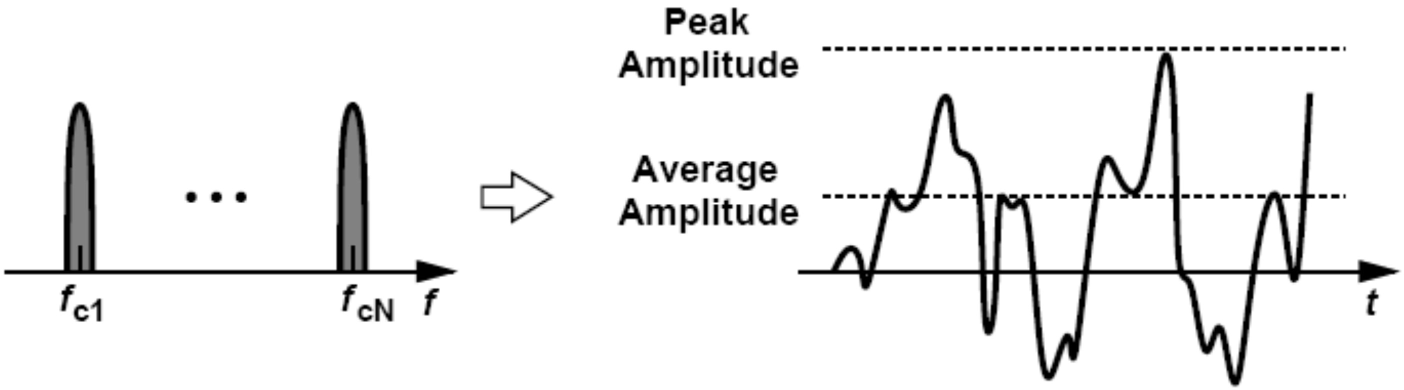
- **OFDM: Orthogonal Frequency Division Multiplexing**
- **Multipath Propagation may lead to considerable *intersymbol interference***

How OFDM Works



In OFDM, the baseband data is first demultiplexed by a factor of *N* The *N* streams are then impressed on *N* different carrier frequencies.

Peak-to-Average Ratio



$$\text{PAR} = \frac{\text{Max}[x^2(t)]}{\overline{x^2(t)}}$$

- **Large PAR: pulse shaping in the baseband, amplitude modulation schemes such as QAM, orthogonal frequency division multiplexing**

Spectral Regrowth: Constant vs. Variable Envelope

Constant Envelope

$$x(t) = A(t)\cos[\omega_c t + \phi(t)]$$

Suppose *A(t)* = A_c

$$\begin{aligned} y(t) &= \alpha_3 x^3(t) + \cdots \\ &= \alpha_3 A_c^3 \cos^3[\omega_c t + \phi(t)] + \cdots \\ &= \frac{\alpha_3 A_c^3}{4}\cos[3\omega_c t + 3\phi(t)] + \frac{3\alpha_3 A_c^3}{4}\cos[\omega_c t + \phi(t)] \end{aligned}$$

- **Shape of the spectrum in the vicinity of ω_c remains unchanged**

Variable Envelope

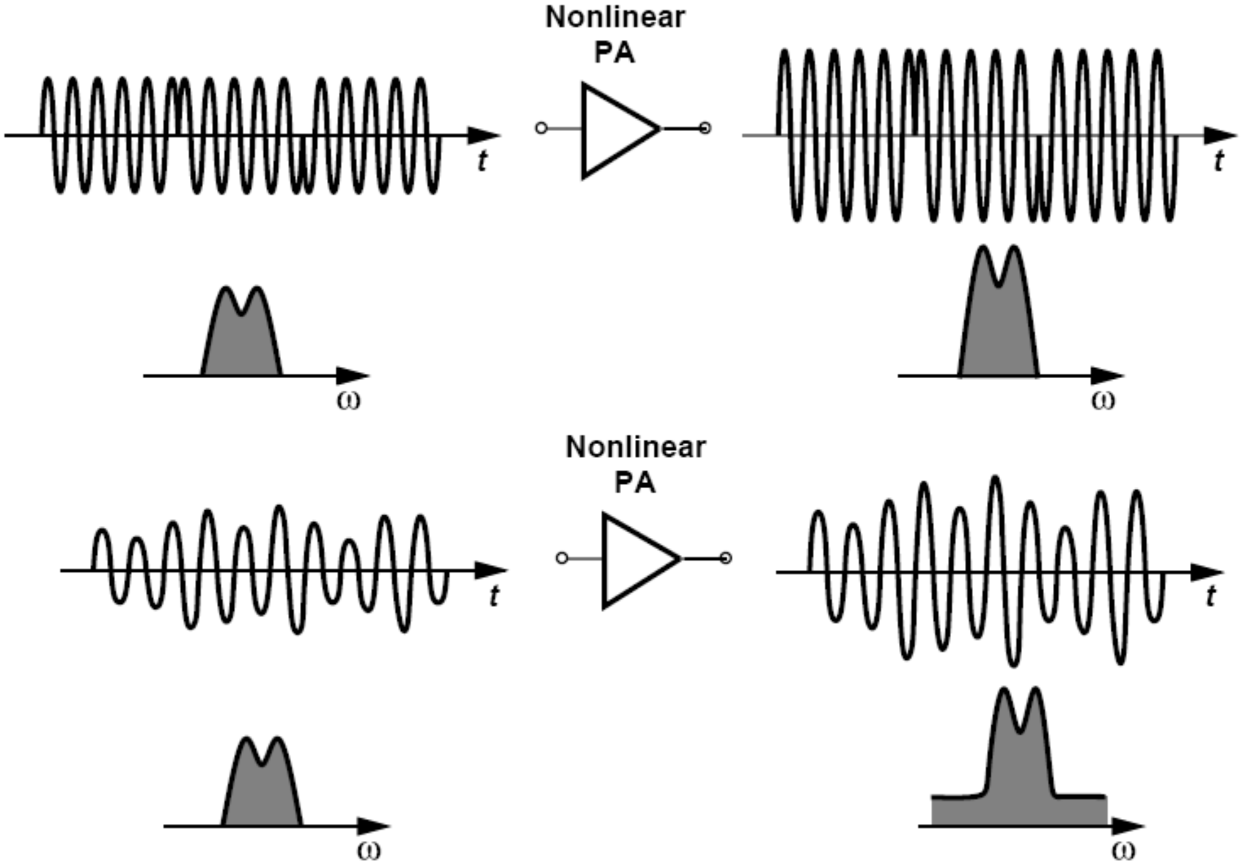
$$x(t) = x_I(t)\cos\omega_c t - x_Q(t)\sin\omega_c t$$

Where x_I and $x_Q(t)$ are the baseband *I* and *Q* components

$$\begin{aligned} y(t) &= \alpha_3[x_I(t)\cos\omega_c t - x_Q(t)\sin\omega_c t]^3 + \cdots \\ &= \alpha_3 x_I^3(t)\frac{\cos 3\omega_c t + 3\cos\omega_c t}{4} - \alpha_3 x_Q^3(t)\frac{-\cos 3\omega_c t + 3\sin\omega_c t}{4} \end{aligned}$$

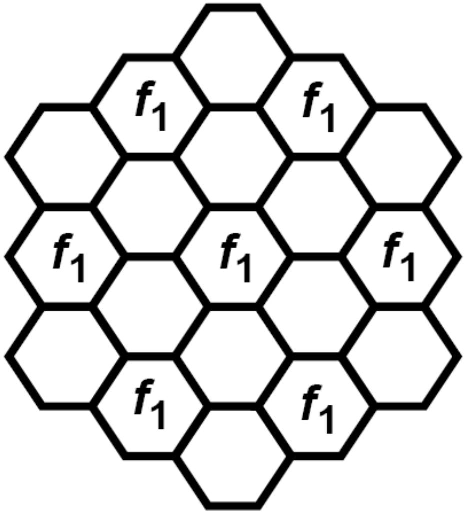
- **Spectrum "grows" when a variable-envelope signal passes through a nonlinear system.**

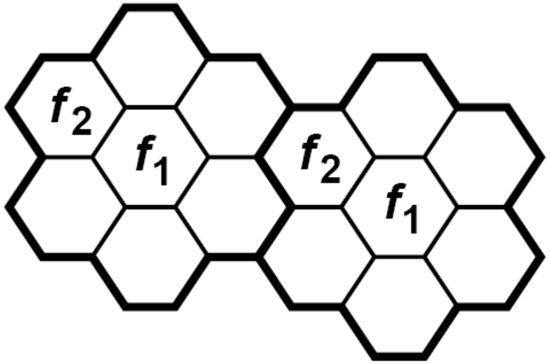
Spectral Regrowth: An Illustration



- **Constant Envelope: Shape of Spectrum unchanged**
- **Variable Envelope: Spectrum grows**

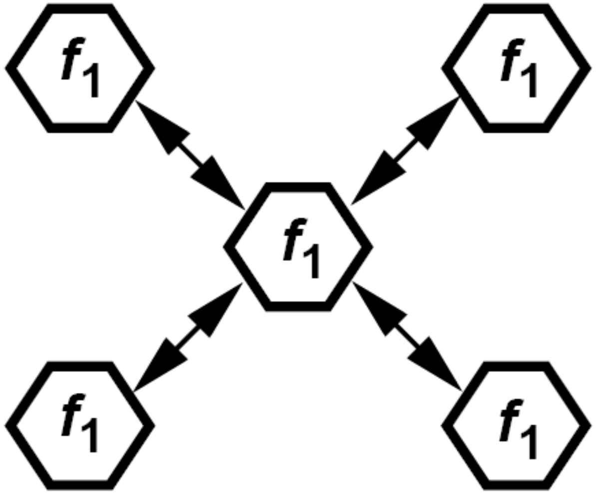
Mobile RF Communications: Cellular System





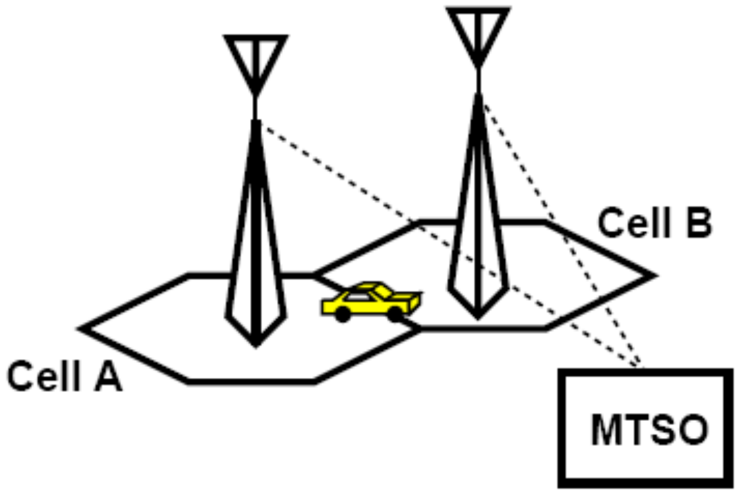
- **Immediate neighbors cannot utilize same frequency**
- **The mobile units in each cell are served by a base station, and all of the base stations are controlled by a “mobile telephone switching office” (MTSO)**

Co-Channel Interference



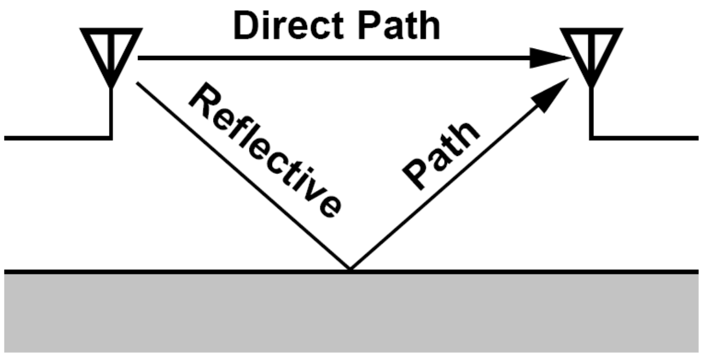
- **CCI: depends on the ratio of the distance between two co-channel cells to the cell radius, independent of the transmitted power**
- **Given by the frequency reuse plan, this ratio is approximately equal to 4.6 for the 7-cell pattern.**

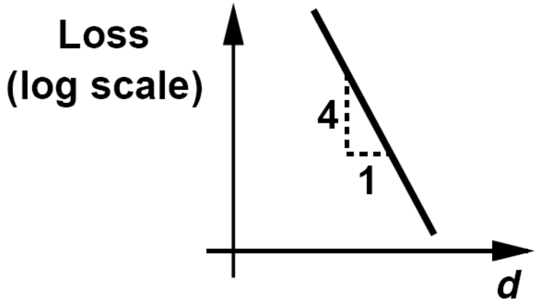
Hand-off



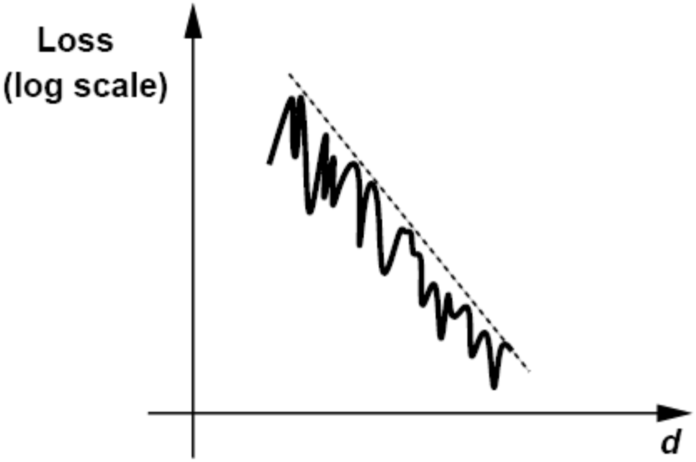
- **When a mobile unit roams from cell A to cell B, since adjacent cells do not use the same group of frequencies, the channel must also change.**
- **Second-generation cellular systems allow the mobile unit to measure the received signal level from different base stations, thus performing hand-off when the path to the second base station has sufficiently low loss**

Path Loss and Multi-Path Fading (Ⅰ)





- Direct path: signals experience a power loss proportional to the square of the distance
- Reflective path: loss increases with the fourth power of the distance



- Multi-path fading: two signals possibly arriving at the receiver with opposite phases and roughly equal amplitudes, the net received signal may be very small

Diversity & Interleaving

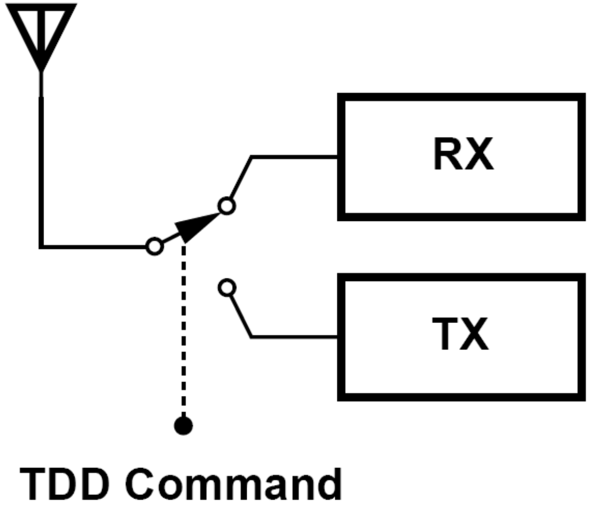
Diversity

- *Space Diversity* or *Antenna Diversity* employs two or more antennas spaced apart by a significant fraction of the wavelength so as to achieve a higher probability of receiving a nonfaded signal
- *Frequency Diversity* refers to the case where multiple carrier frequencies are used
- *Time Diversity*: the data is transmitted or received more than once to overcome short-term fading

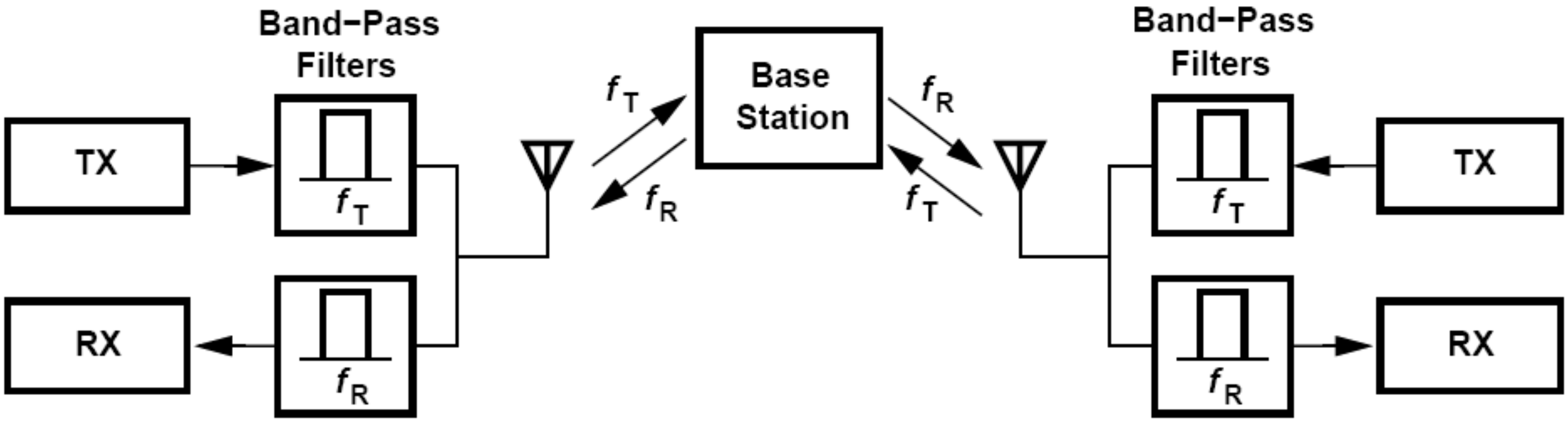
Interleaving

- Errors occur in clusters of bits
- To lower the effect of these errors, the baseband bit stream in the transmitter undergoes “interleaving” before modulation

Time and Frequency Division Duplexing



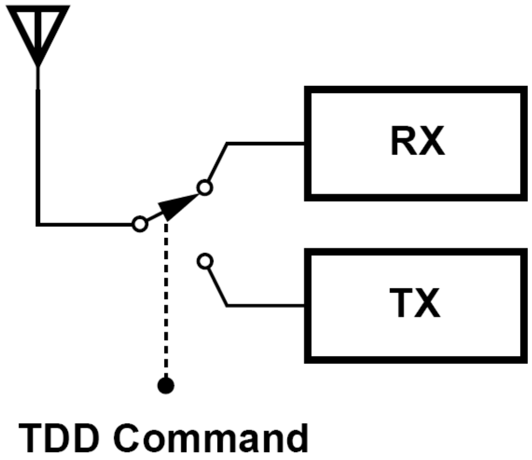
- **TDD: same frequency band is utilized for both transmit and receive paths but the system transmits for half of the time and receives for the other half.**



- **FDD: employ two different frequency bands for the transmit and receive paths.**

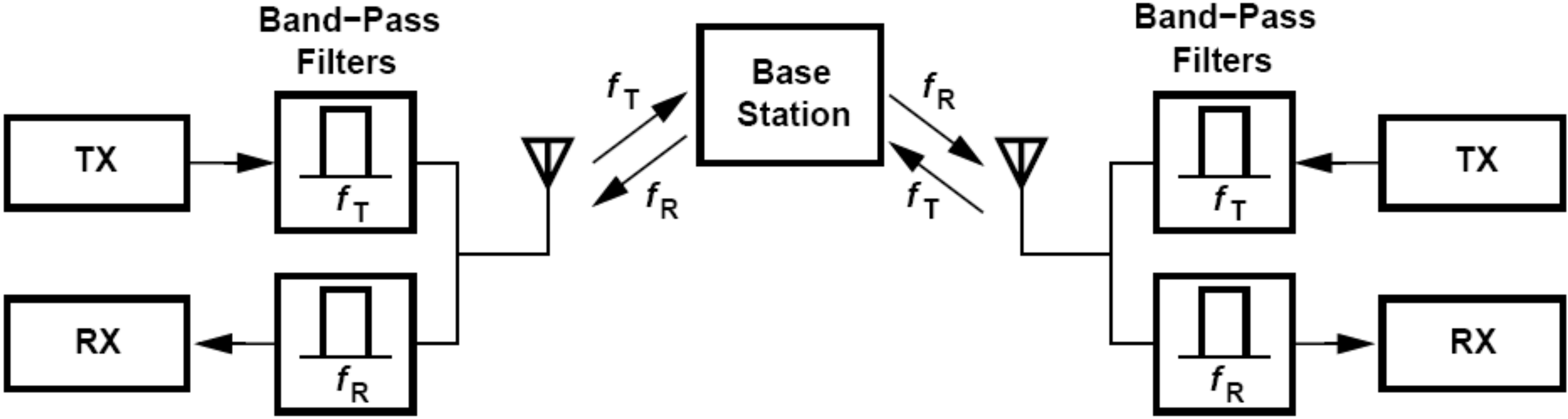
TDD vs. FDD: Features of TDD

- **TDD: two paths (RX,TX) do not interfere because the transmitter is turned off during reception**
- **TDD: allows direct (peer-to-peer) communication between two transceivers**
- **TDD: strong signals generated by all of the nearby mobile transmitters fall in the receive band, thus desensitizing the receiver.**

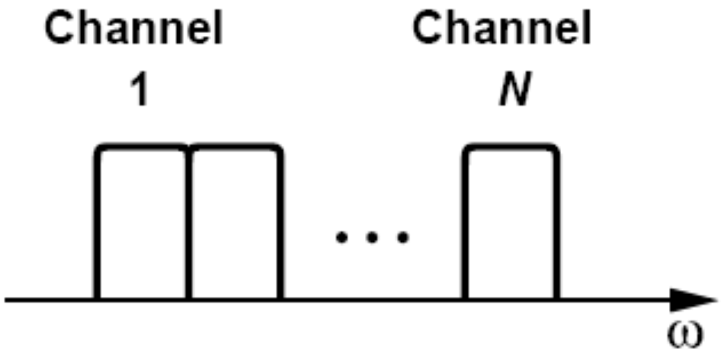


TDD vs. FDD: Features of FDD

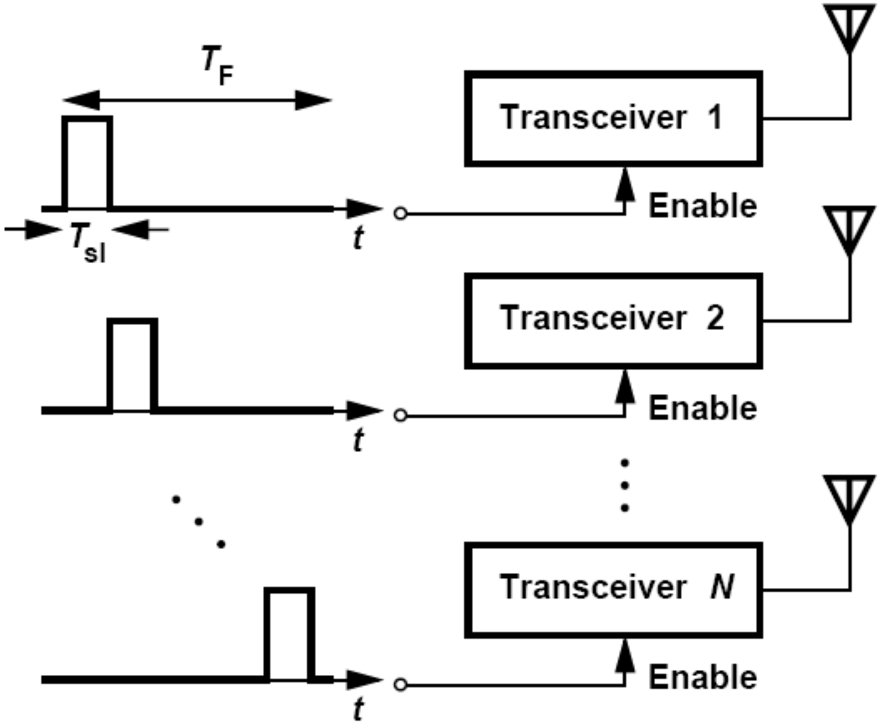
- FDD: components of the transmitted signal that leak into the receive band are attenuated by typically only about 50 dB.
- FDD: owing to the trade-off between the loss and the quality factor of filters, the loss of the duplexer is typically quite higher than that of a TDD switch.
- FDD: spectral leakage to adjacent channels in the transmitter output



Frequency-Division / Time-Division Multiple Access



- **FDMA: available frequency band can be partitioned into many channels, each of which is assigned to one user.**

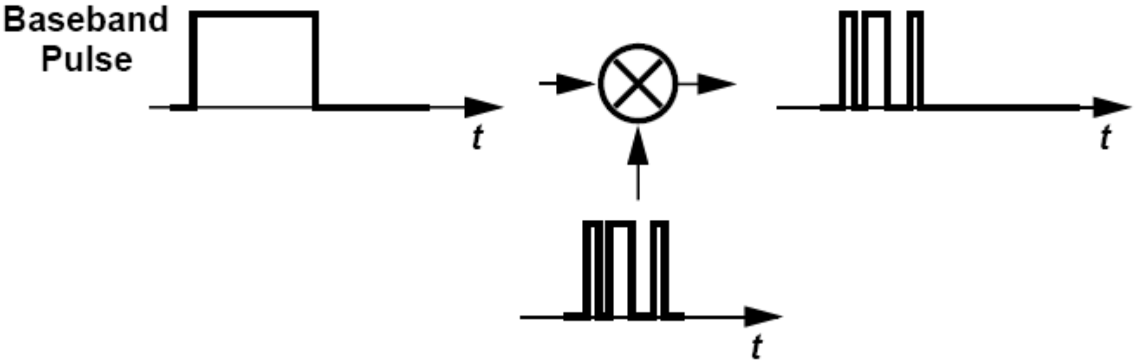


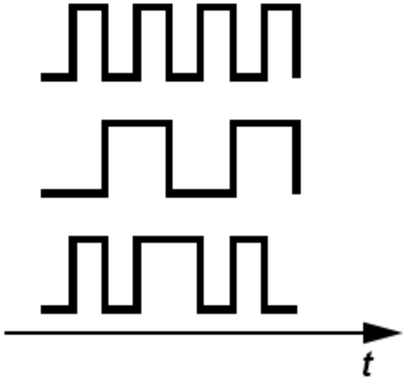
- **TDMA: same band is available to each user but at different times**

TDMA Features: Compared with FDMA

- **TDMA: power amplifier can be turned off during the time of the frame out of assigned time slot**
- **TDMA: digitized speech can be compressed in time by a large factor, smaller required bandwidth.**
- **TDMA: even with FDD, TDMA bursts can e timed so the receive and transmit paths are never enabled simultaneously**
- **TDMA: more complex due to A/D conversion, digital modulation, time slot and frame synchronization, etc.**

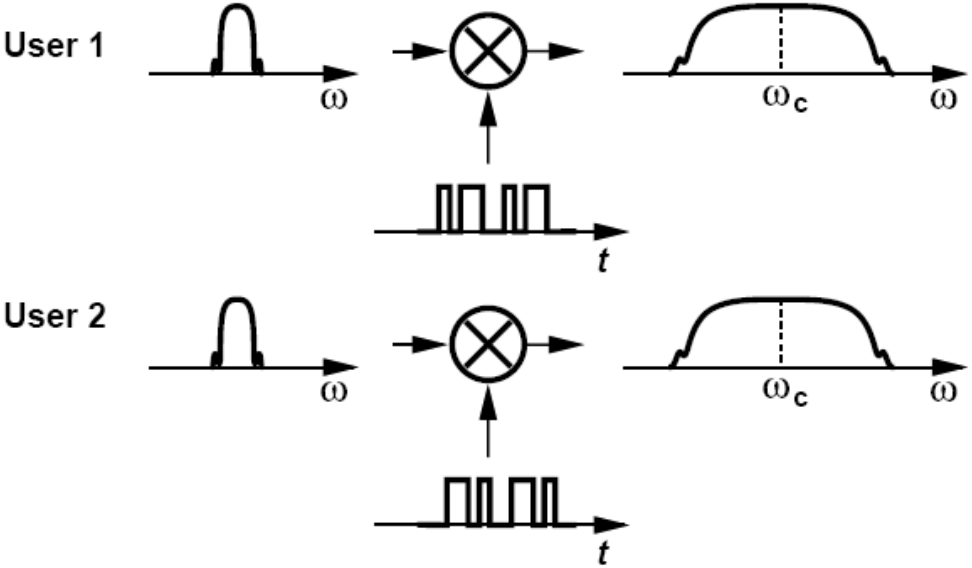
Code-Division Multiple Access: Direct-Sequence CDMA





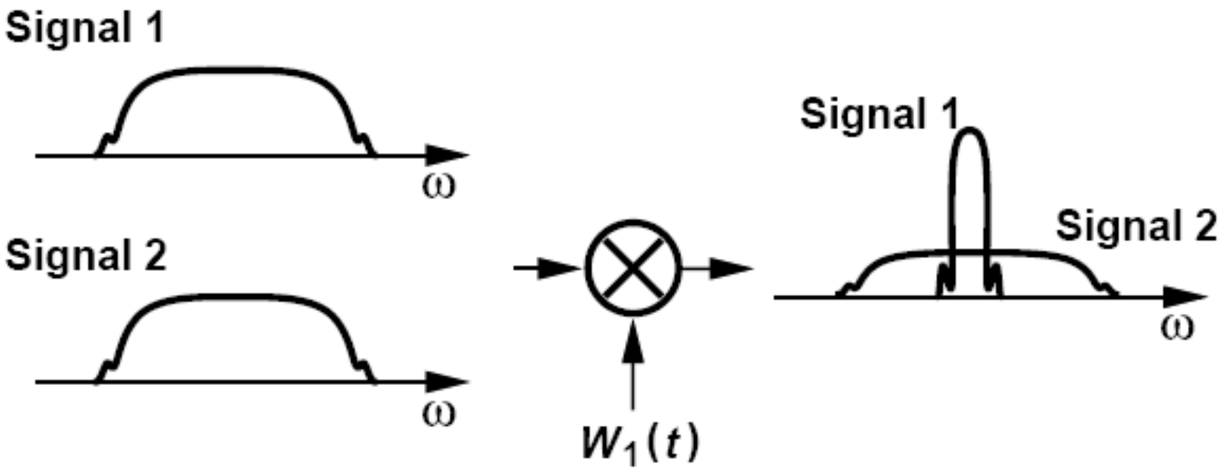
Walsh's recursive equation

$$W_{2n} = \begin{bmatrix} W_n & W_n \\ W_n & \overline{W_n} \end{bmatrix}$$

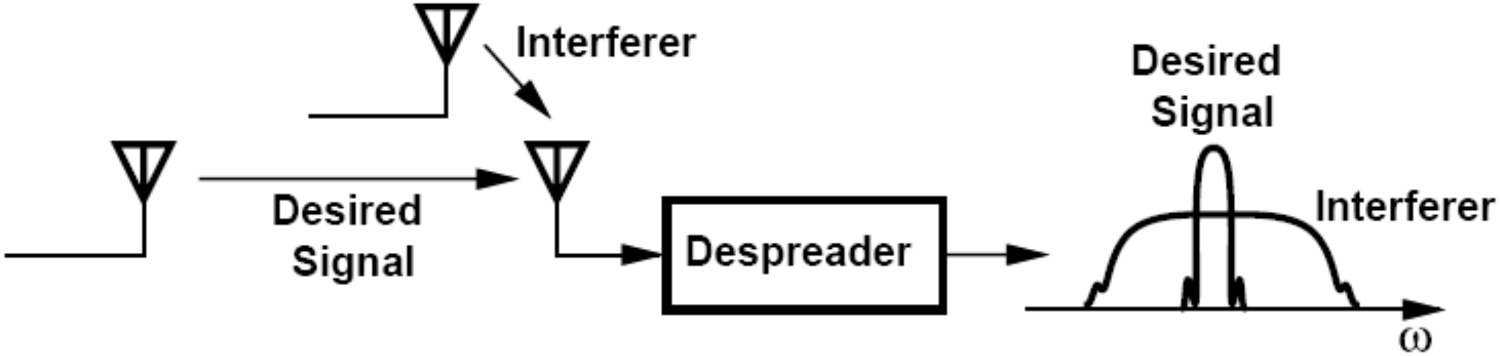


- **CDMA allows the widened spectra of many users to fall in the same frequency band**

Direct-Sequence CDMA: Spectrum and Power

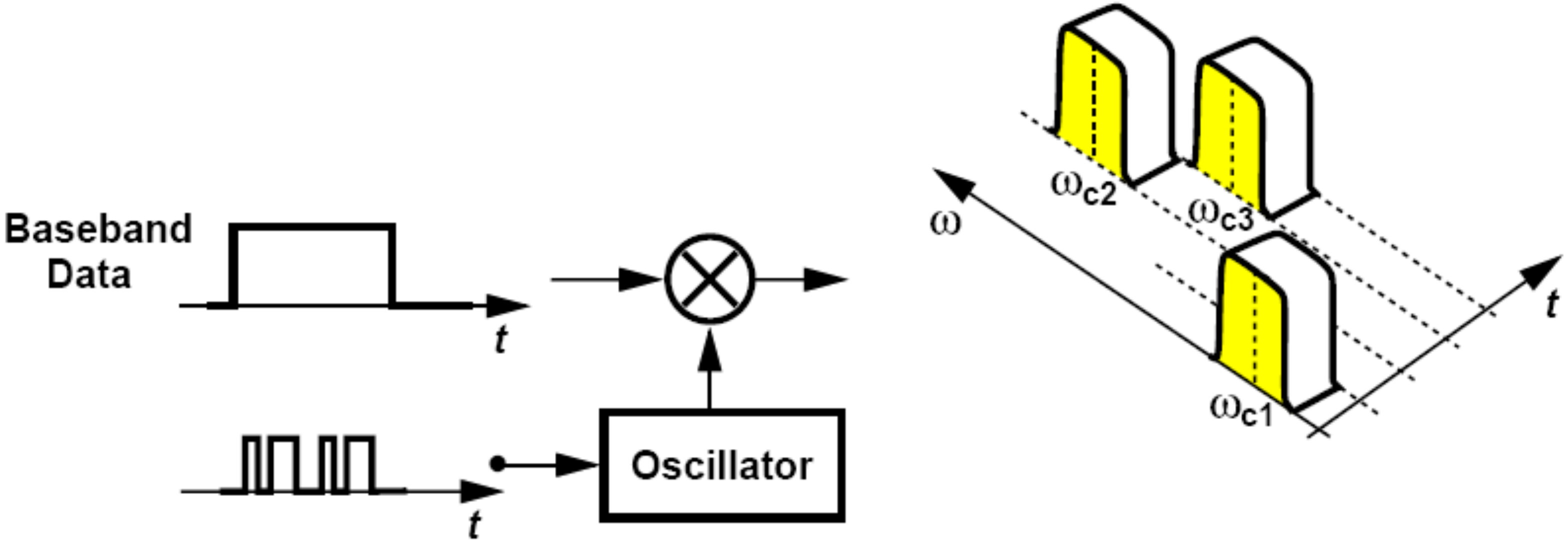


- **Desired signal is "despread"; Unwanted signal remains spread**



- **Near/Far Effect: one high-power transmitter can virtually halt communications among others: Requires Power Control**

Frequency-Hopping CDMA



- **Can be viewed as FDMA with pseudo-random channel allocation.**
- **Occasional overlap of the spectra raises the probability of error**

Wireless Standards: Common Specifications (I)

- **1. *Frequency Bands and Channelization:***

  Each standard performs communication in an allocated frequency band

- **2. *Data Rates:***

  The standard specifies the data rates that must be supported

- **3. *Antenna Duplexing Method:***

  Most cellular phone systems incorporate FDD and other standards employ TDD

- **4. *Type of Modulation:***

  Each standard specifies the modulation scheme.

Wireless Standards: Common Specifications (Ⅱ)

- **5. *TX output power:***

  The standard specifies the power levels that the TX must produce

- **6. *TX EVM and Spectral Mask:***

  The signal transmitted by the TX must satisfy several requirements like EVM and spectral mask

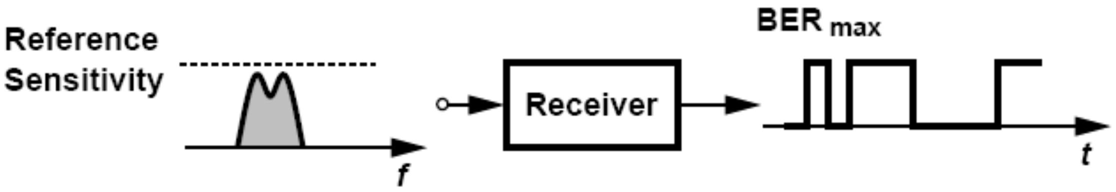
- **7. *RX Sensitivity:***

  The standard specifies the acceptable receiver sensitivity, usually in terms of maximum BER

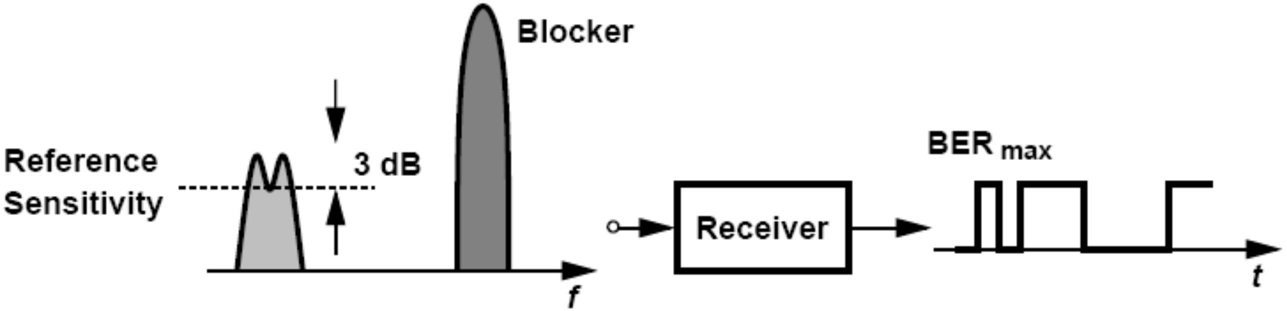
- **8. *RX Input Level Range:***

  The standard specifies the desired signal range that the receiver must handle with acceptable noise or distortion

Wireless Standards: Common Specifications (Ⅲ)



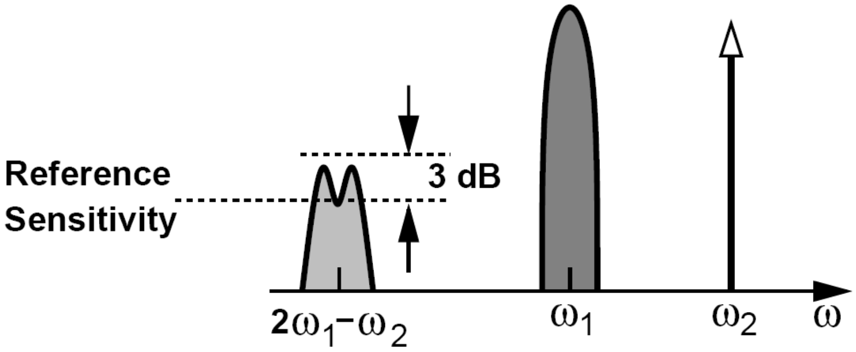
(a)



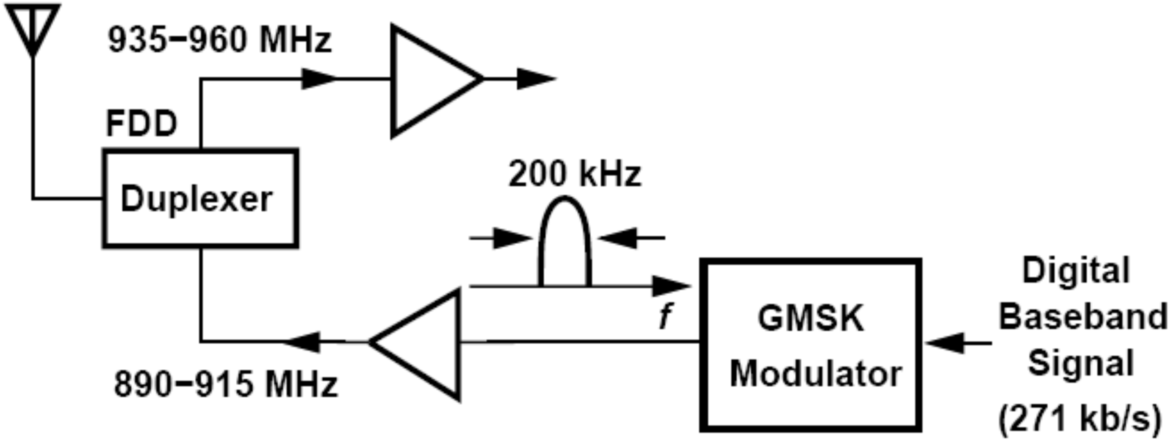
- **9. *RX Tolerance to Blocks:***

  The standard specifies the largest interferer that the RX must tolerate while receiving a small desired signal.

- **Many standards also stipulate an intermodulation test**



GSM: Air Interface and an Example



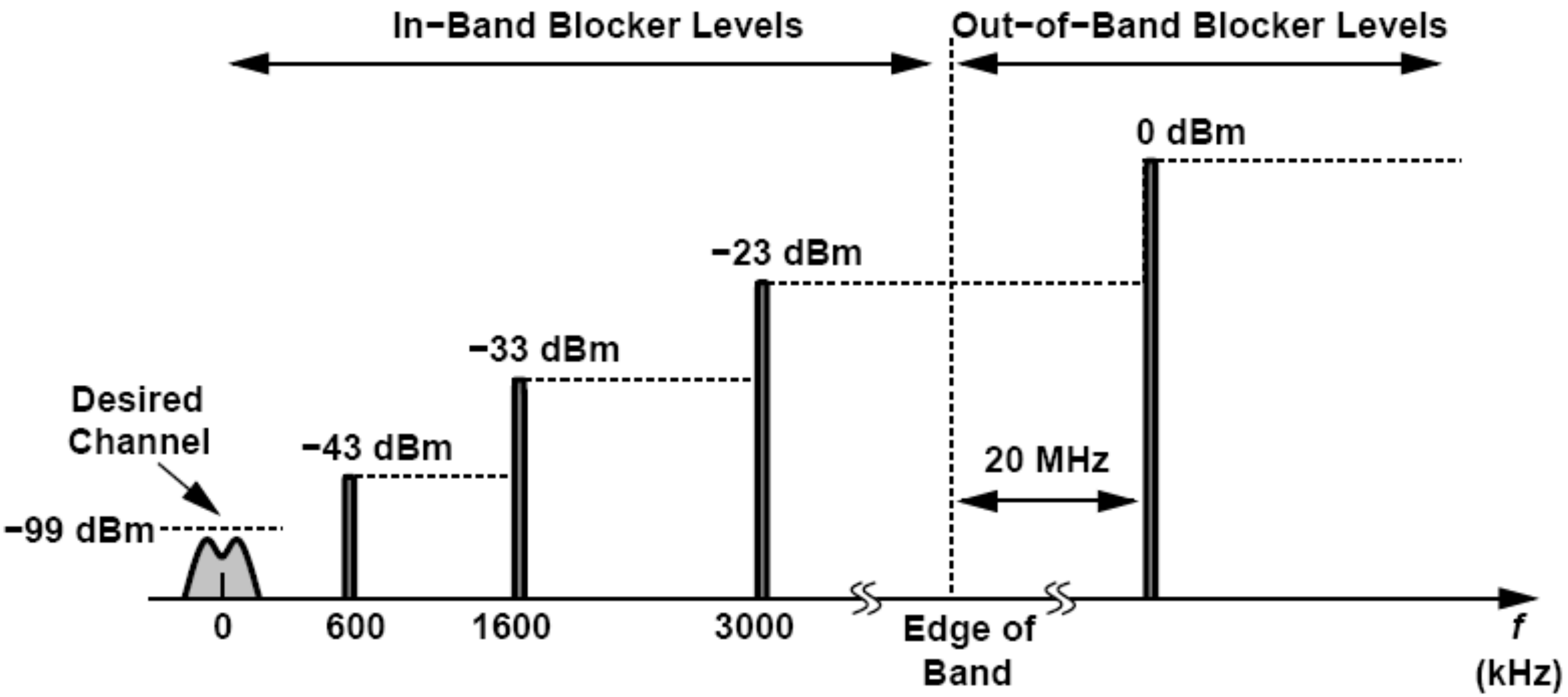
- **GSM standard is a TDMA/FDD system with GMSK modulation, operating in different bands and accordingly called GSM900, GSM1800, and GSM 1900**

GSM specifies a receiver sensitivity of -102 dBm. The detection of GMSK with acceptable bit error rate (10^{-3}) requires an SNR of about 9 dB. What is the maximum allowable RX noise figure?

Solution:

$$\begin{aligned} \mathrm{NF} &= 174\ \mathrm{dBm/Hz} - 102\ \mathrm{dBm} - 10\log(200\ \mathrm{kHz}) - 9\ \mathrm{dB} \\ &\approx 10\ \mathrm{dB}. \end{aligned}$$

GSM: Blocking Requirements



- **With the blocker levels shown in above figure, the receiver must still provide the necessary BER**

Example of GSM Blocking Tests

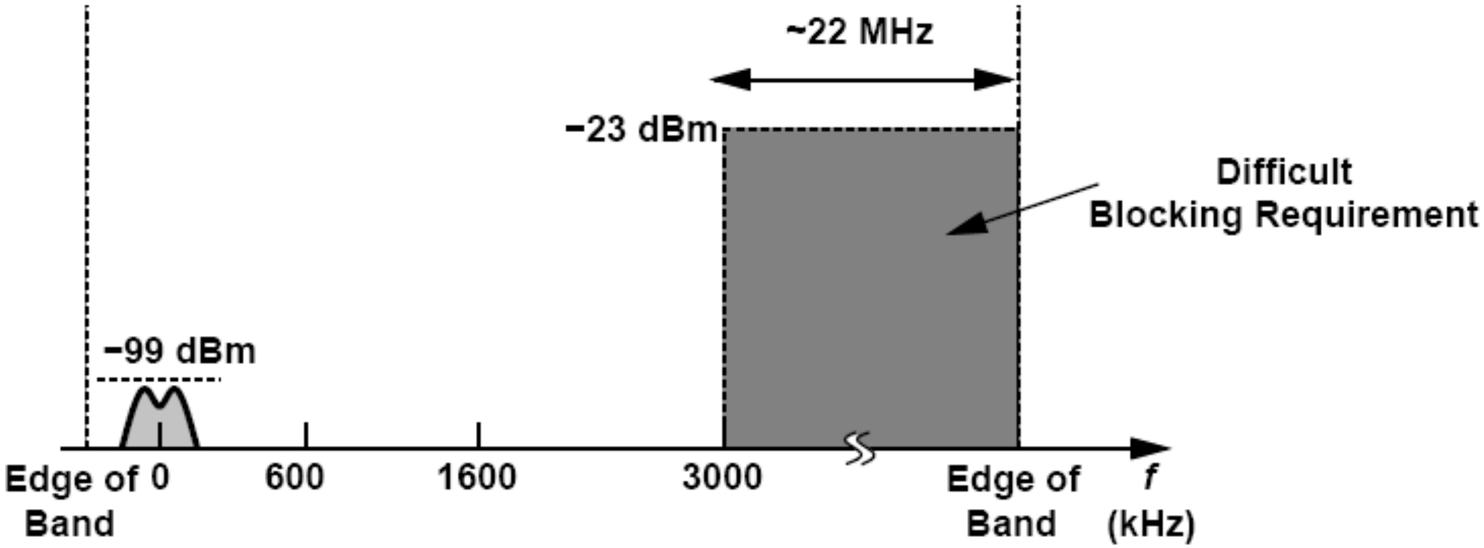
How must the receiver P_{1dB} be chosen to satisfy the above blocking tests?

Solution:

Suppose the receiver incorporates a front-end filter and hence provides sufficient attenuation if the blocker is applied outside the GSM band. Thus, the largest blocker level is equal to -23 dBm (at or beyond 3-MHz offset), demanding a P_{1dB} of roughly -15 dBm to avoid compression. If the front-end filter does not attenuate the out-of-band blocker adequately, then a higher P_{1dB} is necessary.

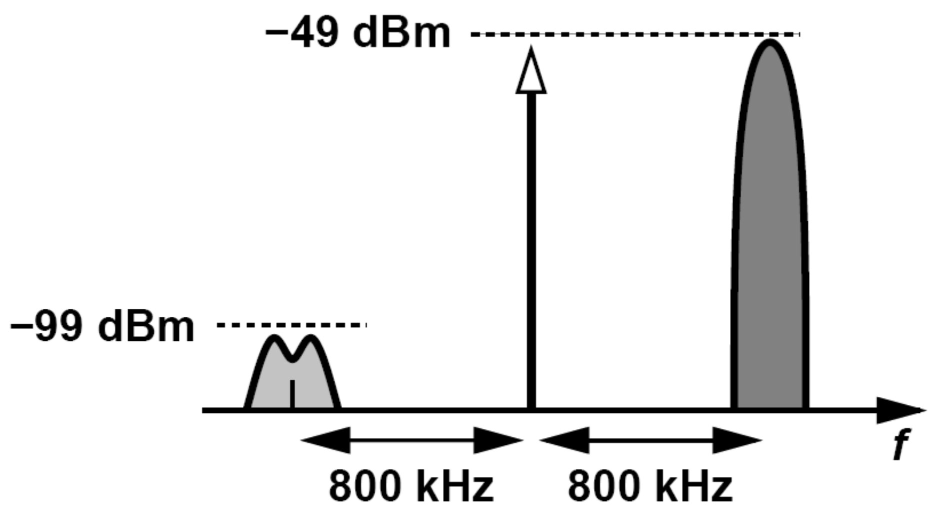
GSM Blocking Requirements: Spurious Response Exceptions

Worst-case channel for GSM blocking test:



- **GSM stipulates a set of *spurious response exceptions*, 6 in band, 24 out of band**
- **Do not ease the compression and phase noise requirements.**

GSM: Intermodulation Requirements



- Desired channel 3 dB above the reference sensitivity level
- A tone and a modulated signal applied at 800-kHz and 1.6-MHz offset at -49 dBm and BER requirement must be satisfied

Example of GSM Intermodulation Tests

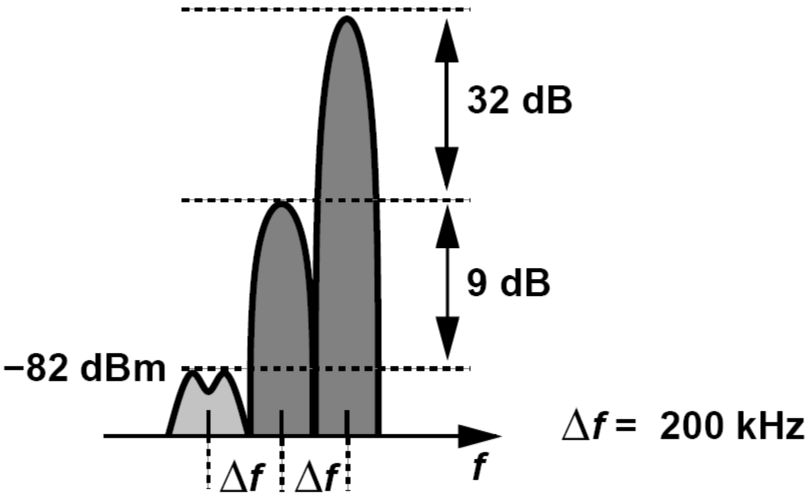
Estimate the receiver IP$_3$ necessary for the above test.

Solution:

For an acceptable BER, an SNR of 9 dB is required, i.e., the total noise in the desired channel must remain below -108 dBm. In this test, the signal is corrupted by both the receiver noise and the intermodulation. If, from previous example, we assume NF = 10 dB, then the total RX noise in 200 kHz amounts to -111 dBm. Since the maximum tolerable noise is -108 dBm, the intermodulation can contribute at most 3 dB of corruption. In other words, the IM product of the two interferers must have a level of -111 dBm so that, along with an RX noise of -111 dBm, it yields a total corruption of -108 dBm. It follows from Chapter 2 that

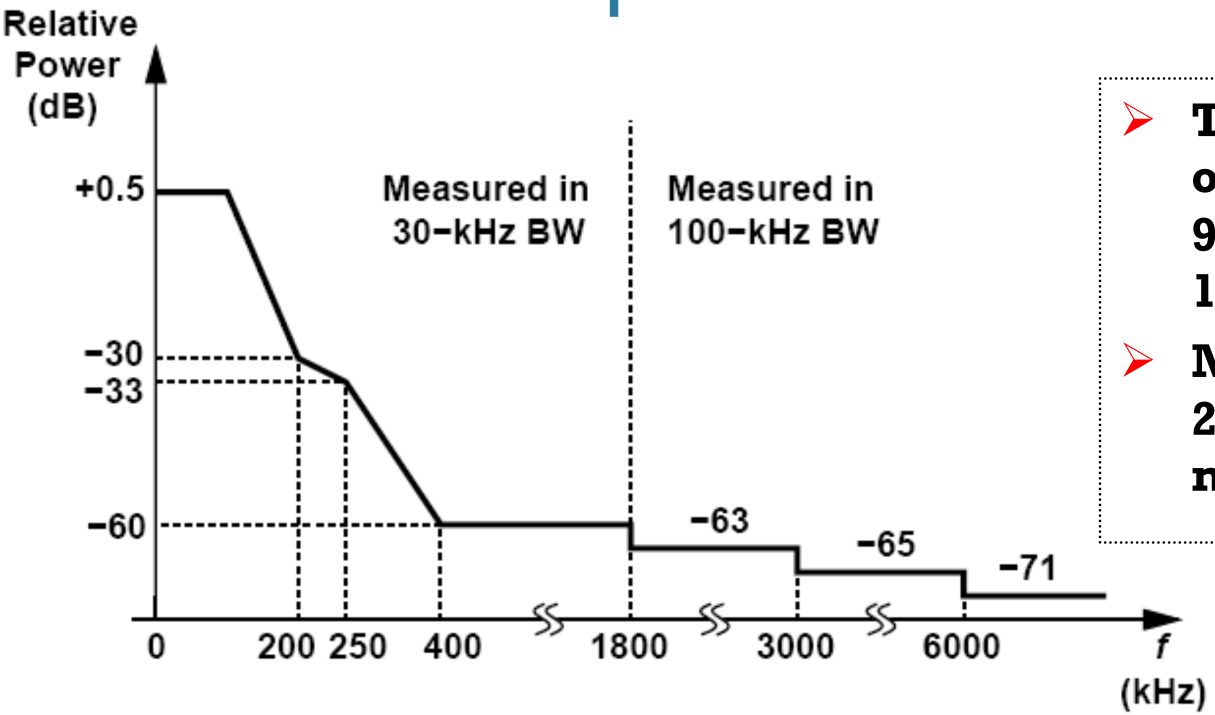
$$\begin{aligned}\mathrm{IIP}_3 &= \frac{-49\ \mathrm{dBm} - (-111\ \mathrm{dBm})}{2} + (-49\ \mathrm{dBm}) \\ &= -18\ \mathrm{dBm}.\end{aligned}$$

GSM: Adjacent-Channel Interference

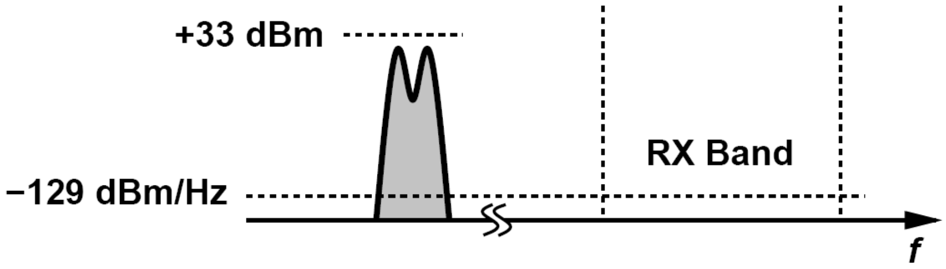


- **Desired channel 20 dB above the reference sensitivity level**
- **Must withstand an adjacent-channel interferer 9 dB above desired signal or and alternate-adjacent channel interferer 41 dB above signal**

GSM: TX Specifications

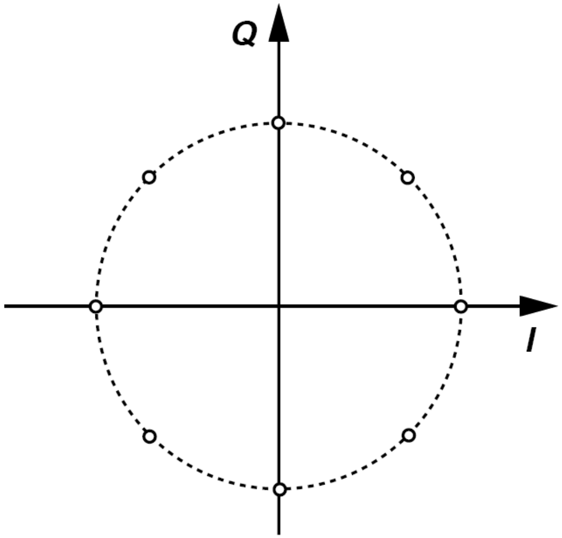


- Transmitter must deliver an output of at least 2 W in the 900-MHz band or 1 W in the 1.8-GHz band
- Must be adjustable in steps of 2 dB from +5 dBm to the maximum level



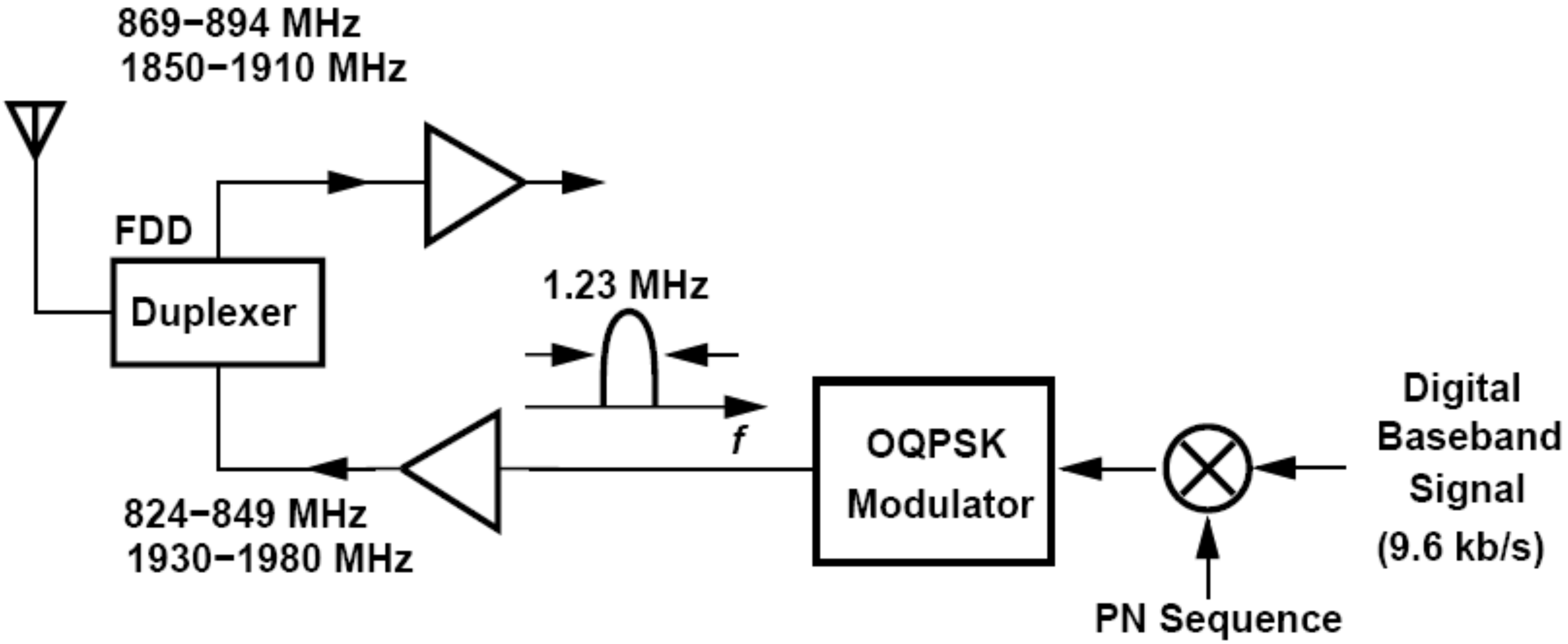
- The maximum noise that the TX can emit in the receive band must be les than -129 dBm/Hz.

GSM: EDGE



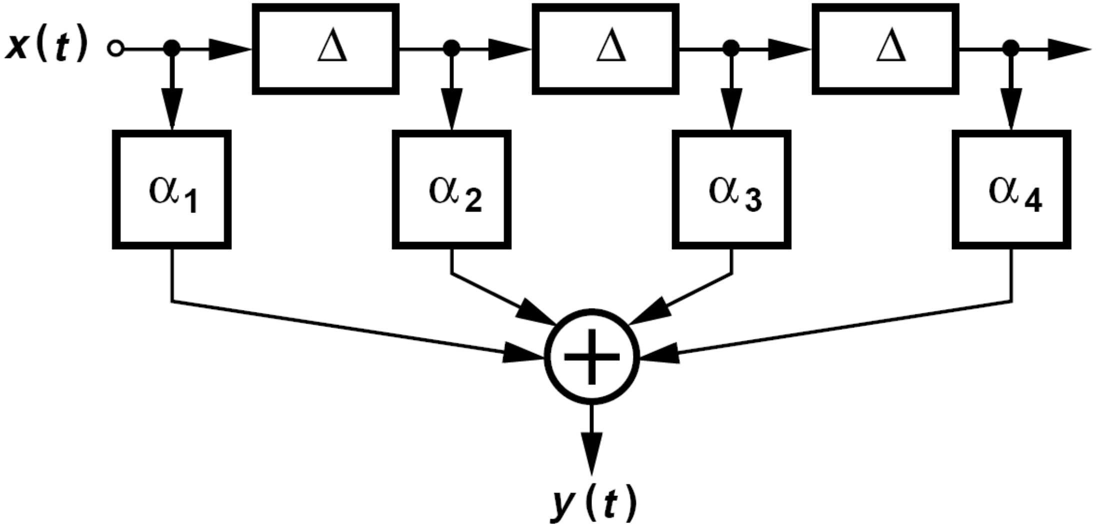
- Enhanced Data Rates fro GSM Evolution: 384kb/s, 8-PSK modulation
- Need pulse shaping, linear PA; requires a higher SNR

IS-95 CDMA: Air Interface



- **9.6 kb/s spread to 1.23 MHz and modulated using OQPSK.**
- **Coherent detection and pilot tone used**

IS-95 CDMA: Frequency and Time Diversity



- **IS-95 spread spectrum to 1.23 MHz, provides frequency diversity**
- **Rake receiver to provides time diversity**

IS-95 CDMA: Power, Rate, Hand-off

Power Control

- Output power controlled by an open-loop procedure at the beginning of communication to perform a rough, but fast adjustment.

$$P_{bs} - k + P_m = -73\ \mathrm{dBm}.$$

$$P_m - k = -73\ \mathrm{dBm} - P_{bs}$$

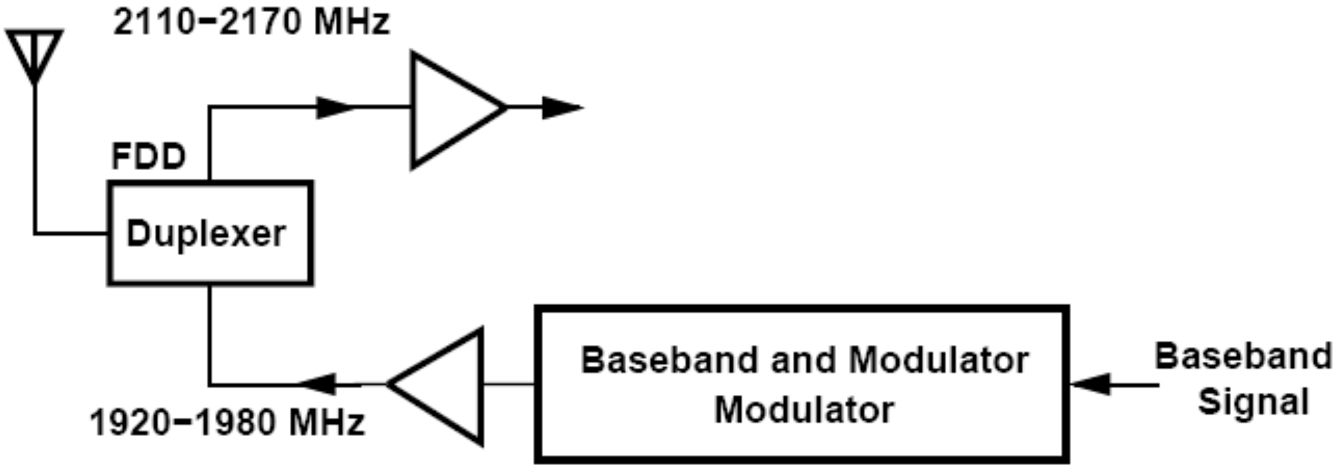
Variable Coding Rate

- Data rate can vary in four discrete steps: 9600, 4800, 2400, and 1200b/s

Soft Hand-off

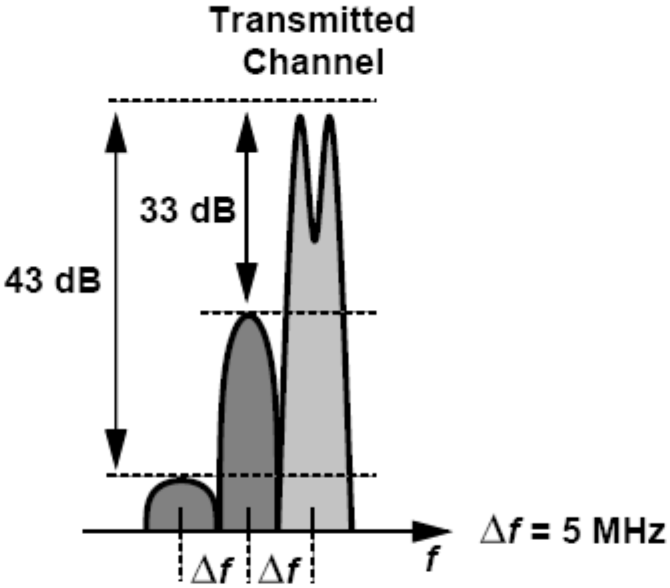
- Signal strength corresponding to both stations can be monitored by means of a rake receiver. Hand-off performed when nearer base station has a strong signal.

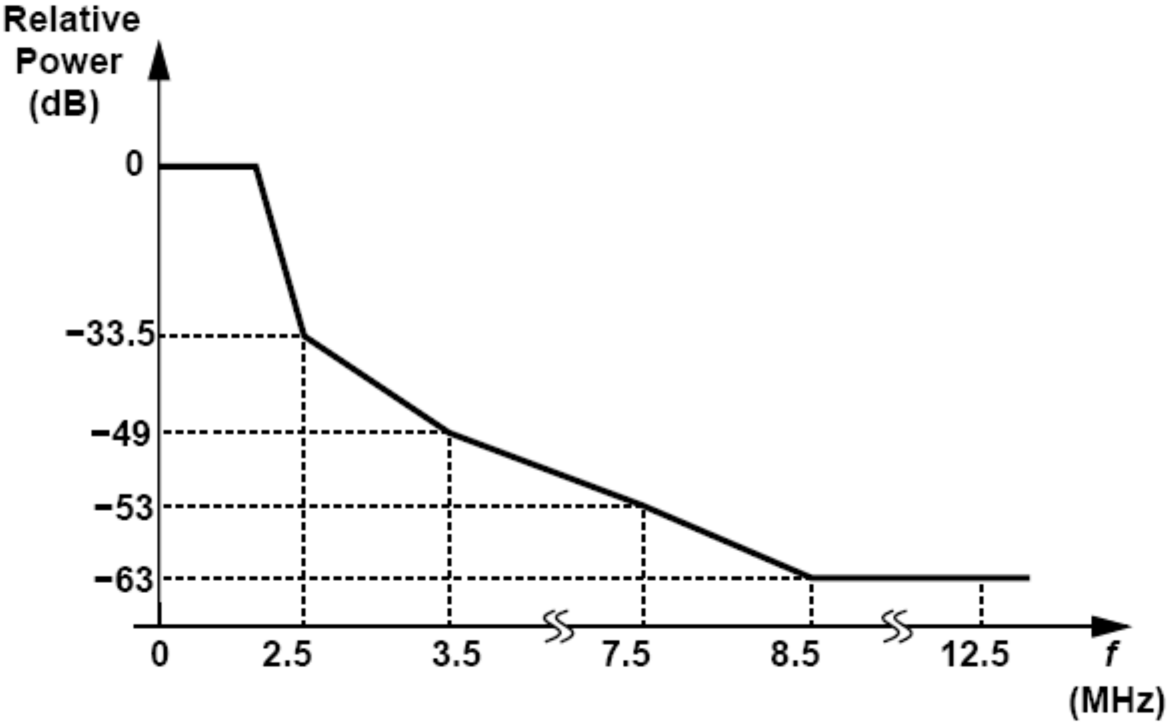
Wideband CDMA: Air Interface



- **BPSK for uplink, QPSK for downlink, nominal channel bandwidth 5MHz, rate 384 kb/s**
- **IMT-2000: total bandwidth 60 MHz, data rate 384 kb/s in a spread bandwidth of 3.84 MHz, channel spacing 5 MHz**

Wideband CDMA: Transmitter Requirements

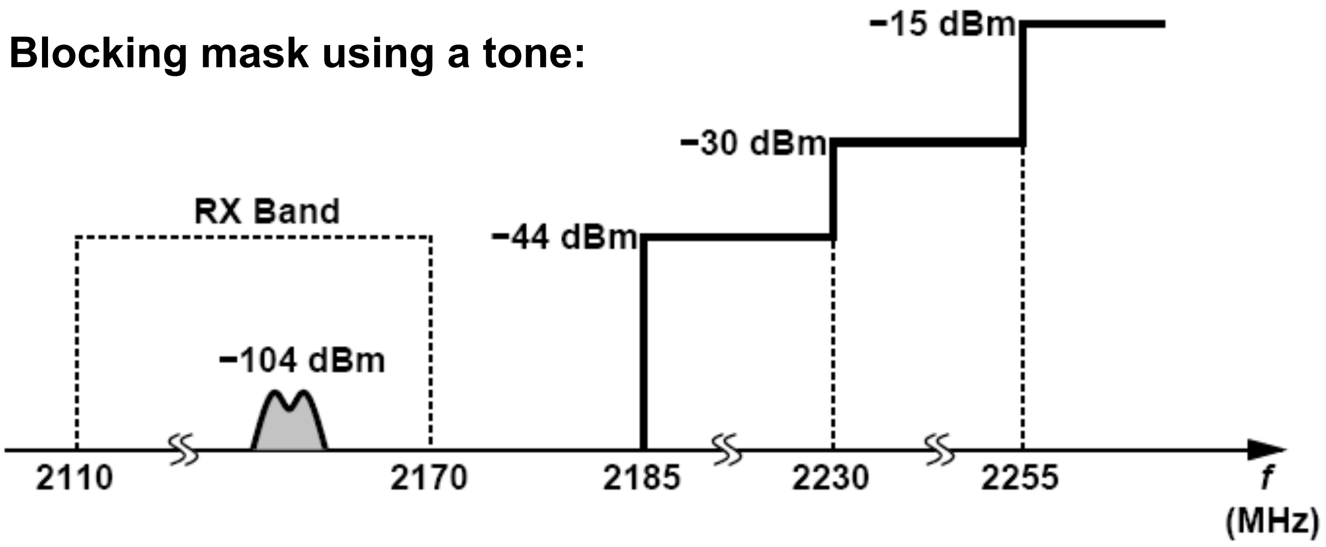




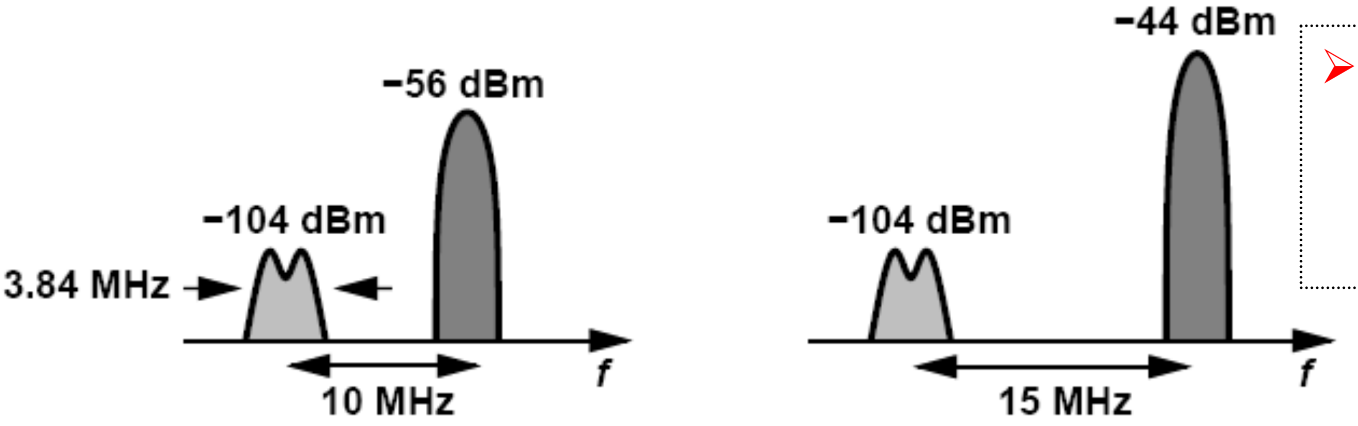
- **Output power: -49 dBm to +24 dBm. Adjacent and alternate adjacent channel power 33 dB and 43 dB below main channel.**

Wideband CDMA: Receiver

Blocking mask using a tone:



Blocking test using a modulated interferer:

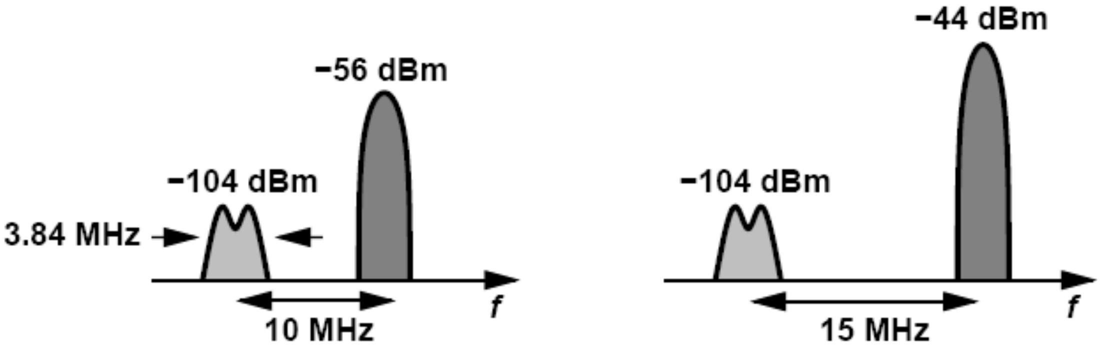


- **Reference sensitivity: -107 dBm. Sinusoidal test for only out-of-band blocking**

Example of Wideband CDMA Receiver Requirements (I)

Estimate the required P_{1dB} of a WCDMA receiver satisfying the in-band test of figure above.

Solution:



To avoid compression, P_{1dB} must be 4 to 5 dB higher than the blocker level, i.e., P1dB ≈ -40 dBm. To quantify the corruption due to cross modulation, we return to our derivation in Chapter 2. For a sinusoid $A_1 \cos \omega_1 t$ and an amplitude-modulated blocker $A_2(1 + m\cos \omega_m t)\cos \omega_2 t$, cross modulation appears as

$$y(t) = \left[\alpha_1 A_1 + \frac{3}{2}\alpha_3 A_1 A_2^2 \left(1 + \frac{m^2}{2} + \frac{m^2}{2}\cos 2\omega_m t + 2m\cos\omega_m t\right)\right]\cos\omega_1 t + \cdots$$

Example of Wideband CDMA Receiver Requirements (Ⅱ)

Estimate the required *P*$_{1dB}$ of a WCDMA receiver satisfying the in-band test of figure above.

Solution:

$A_1(1+m\cos\omega_{m1}t)\cos\omega_1 t$ and $A_2(1+m\cos\omega_{m2}t)\cos\omega_2 t$

$m^2/2 \ll 2m$

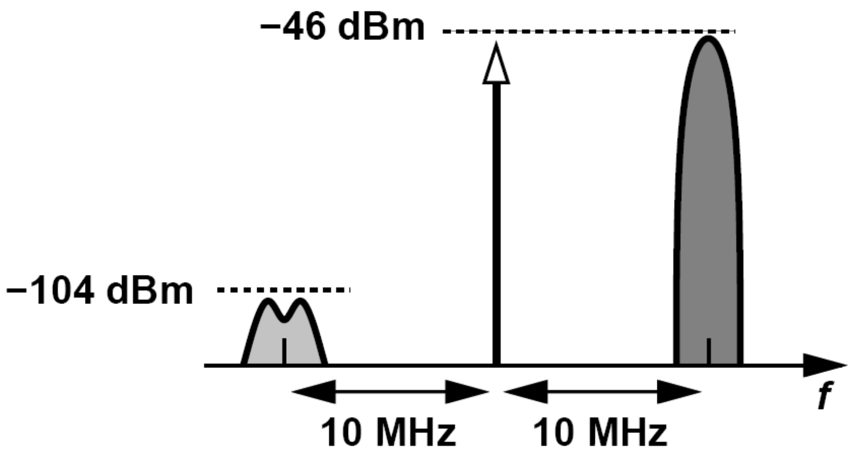
$\Downarrow$

$$\begin{aligned} y(t) &= [\alpha_1 A_1(1+m\cos\omega_{m1}t) \\ &+ \frac{3}{2}\alpha_3 A_1(1+m\cos\omega_{m1}t)A_2^2 \times (1+2m\cos\omega_{m2}t)]\cos\omega_1 t + \cdots \\ &= [\alpha_1 A_1(1+m\cos\omega_{m1}t) \\ &+ \frac{3}{2}\alpha_3 A_1 A_2^2(1+m\cos\omega_{m1}t+2m\cos\omega_{m2}t+2m^2\cos\omega_{m1}t\cos\omega_{m2}t)]\cos\omega_1 t + \cdots \end{aligned}$$

$$\frac{\left(\frac{3}{2}\alpha_3 A_1 A_2^2\right)^2(1+m^2+4m^2+4m^4)}{(\alpha_1 A_1)^2(1+m^2)} \ll 1 \quad \Rightarrow \quad \frac{\frac{3}{2}|\alpha_3|A_2^2}{|\alpha_1|} = 0.178 \quad \Rightarrow \quad A_{1dB} = 1.1A_2$$

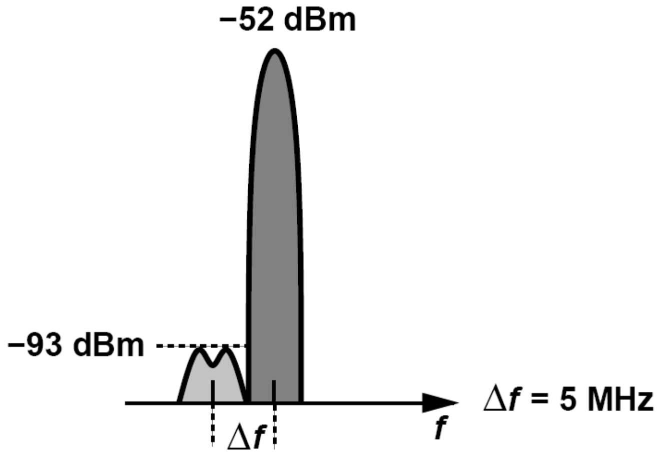
Wideband CDMA Receiver Requirements: Intermodulation Test & Adjacent Channel Test

IMT-2000 intermodulation test:



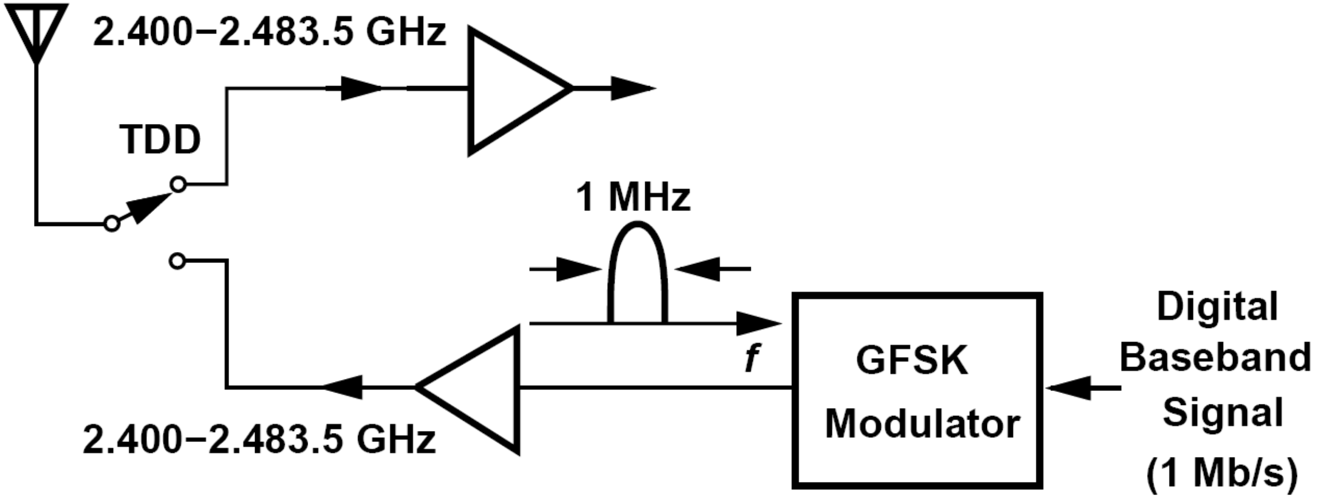
- A tone and a modulated signal each at -46 dBm applied in the adjacent and alternate adjacent channels, desired signal at -104 dBm

IMT-2000 receiver adjacent-channel test:



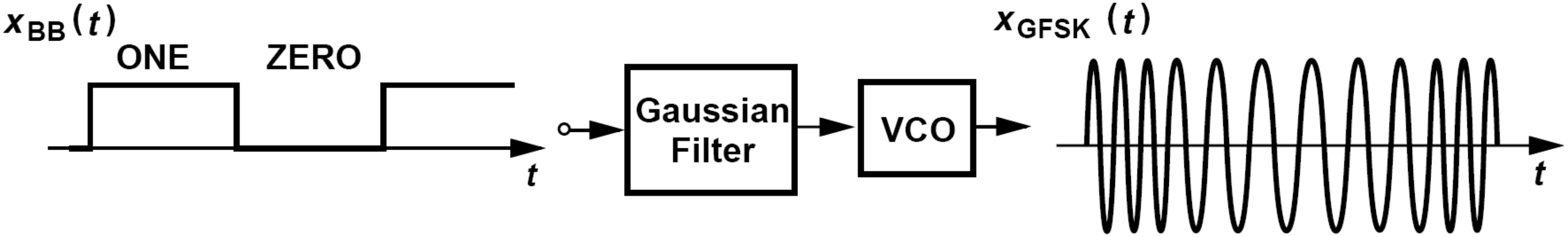
- Desired signal -93 dBm, adjacent channel -52 dBm

Bluetooth: Air Interface



- **2.4-GHz ISM band. Each channel carries 1 Mb/s, occupies 1 MHz**

Bluetooth Transmitter Characteristics: Modulation

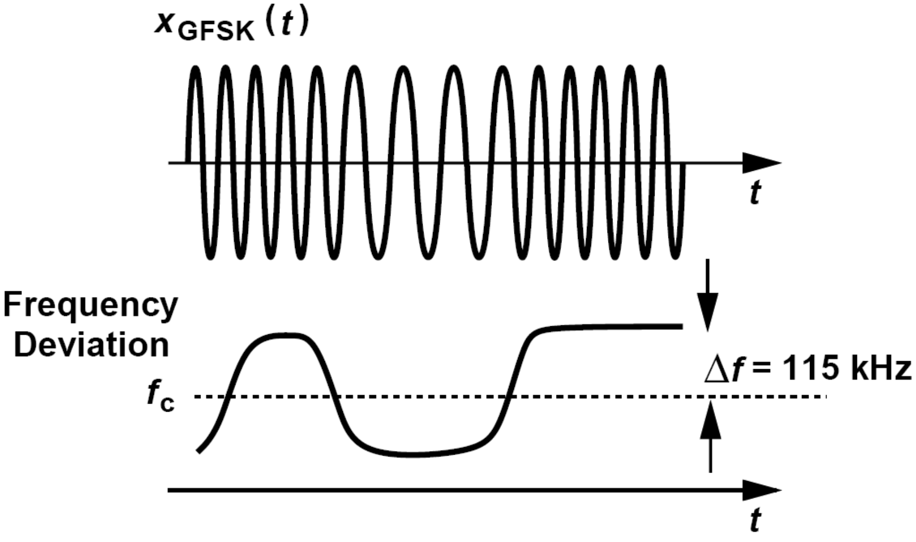


$$x_{TX}(t) = A\cos[\omega_c t + m\int x_{BB}(t) * h(t)dt],$$

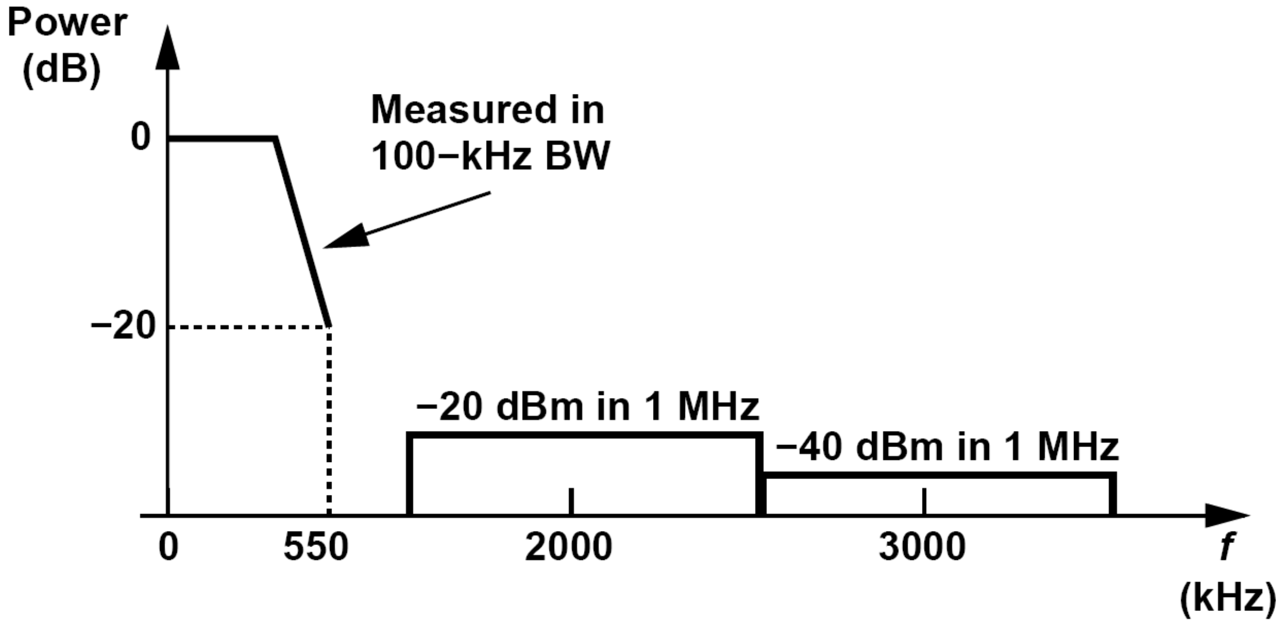
$$f_{inst} = \frac{1}{2\pi}[\omega_c + m x_{BB}(t) * h(t)]$$

$$\Delta f = \frac{1}{2\pi} m[x_{BB}(t) * h(t)]_{max}$$

$$\frac{m}{2\pi} x_{BB,max} = 115 \text{ kHz}$$

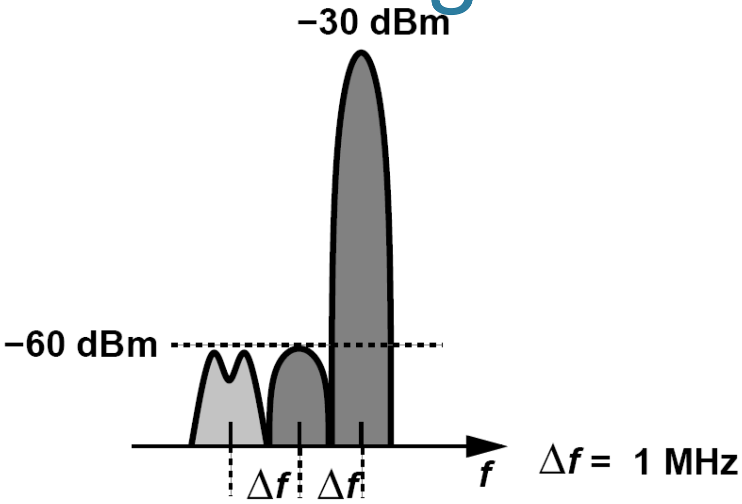


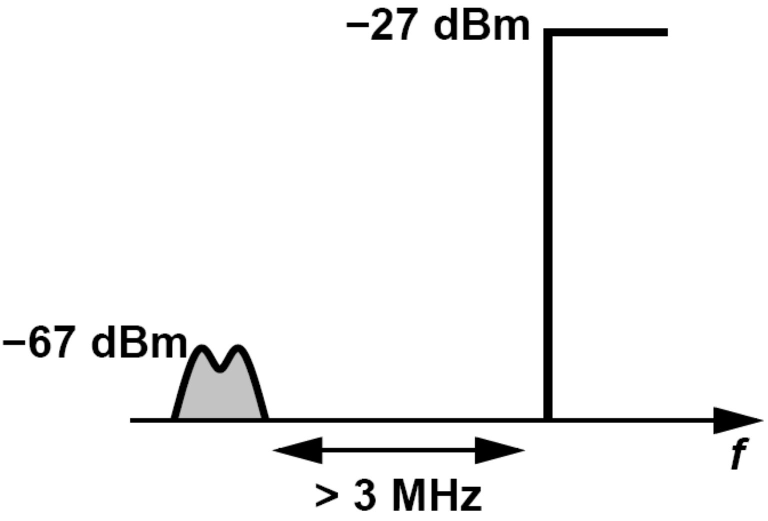
Bluetooth Transmitter Characteristics: Spectrum Mask



- Bluetooth specifies an output level of 0 dBm.
- Bluetooth TX must minimally interfere with cellular and WLAN systems
- Carrier frequency of each Bluetooth carrier has a tolerance of ±75 kHz

Bluetooth Receiver Characteristics: Blocking Test



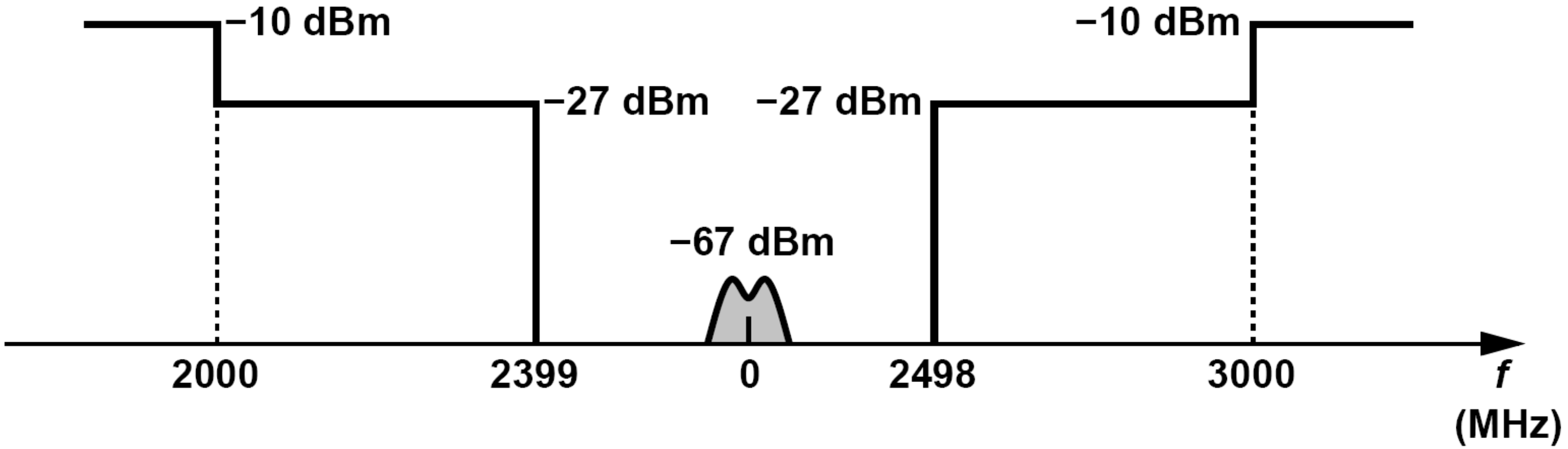


- **Reference sensitivity of -70 dBm.**
- ***Blocking test for adjacent and alternate channels:***

  desired signal 10dB higher than reference sensitivity. Adjacent channel with equal power, modulated. Alternate adjacent channel with -30 dBm, modulated.
- ***Blocking test for third or higher adjacent channel:***

  Desired signal 3 dB above sensitivity, modulated blocker in third or higher adjacent channel with power -27 dBm.

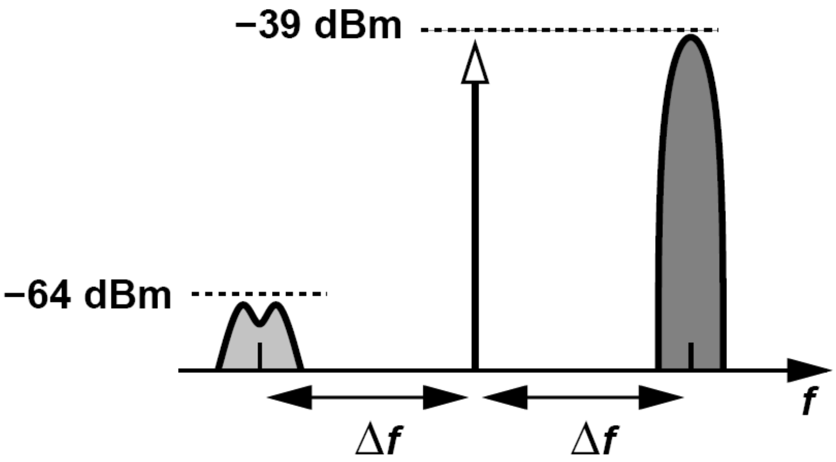
Bluetooth Receiver Characteristics: Out-of-band Blocking Test



- **Reference sensitivity of -70 dBm.**
- ***Out of band Blocking Test:***

Desired signal -67 dBm, tone level of -27 dBm or -10 dBm must be tolerated according to the tone frequency range.

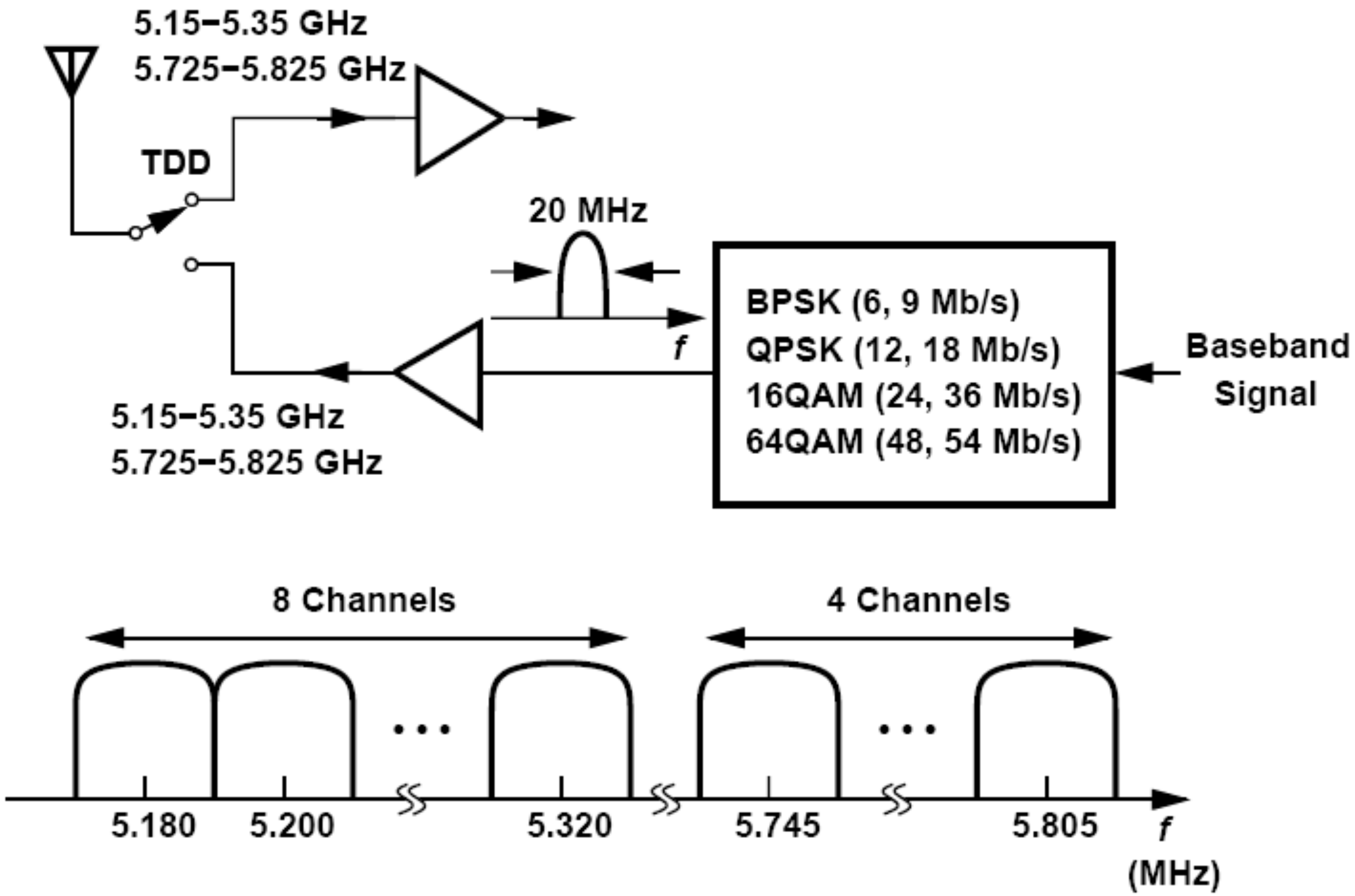
Bluetooth Receiver Characteristics: Intermodulation Test



- Reference sensitivity of -70 dBm.
- *Intermodulation Test:*

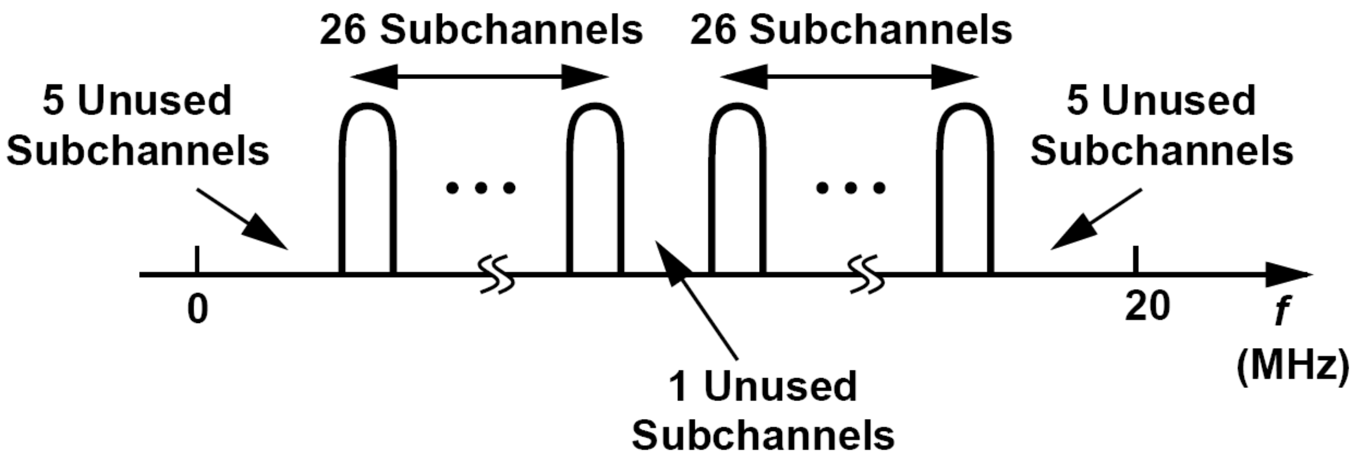
  Desired signal 6 dB higher than reference sensitivity, blockers applied at -39 dBm with *Δf* = 3, 4, or 5 MHz
- Maximum usable input level -20 dBm

IEEE 802.11 a/b/g: Air Interface



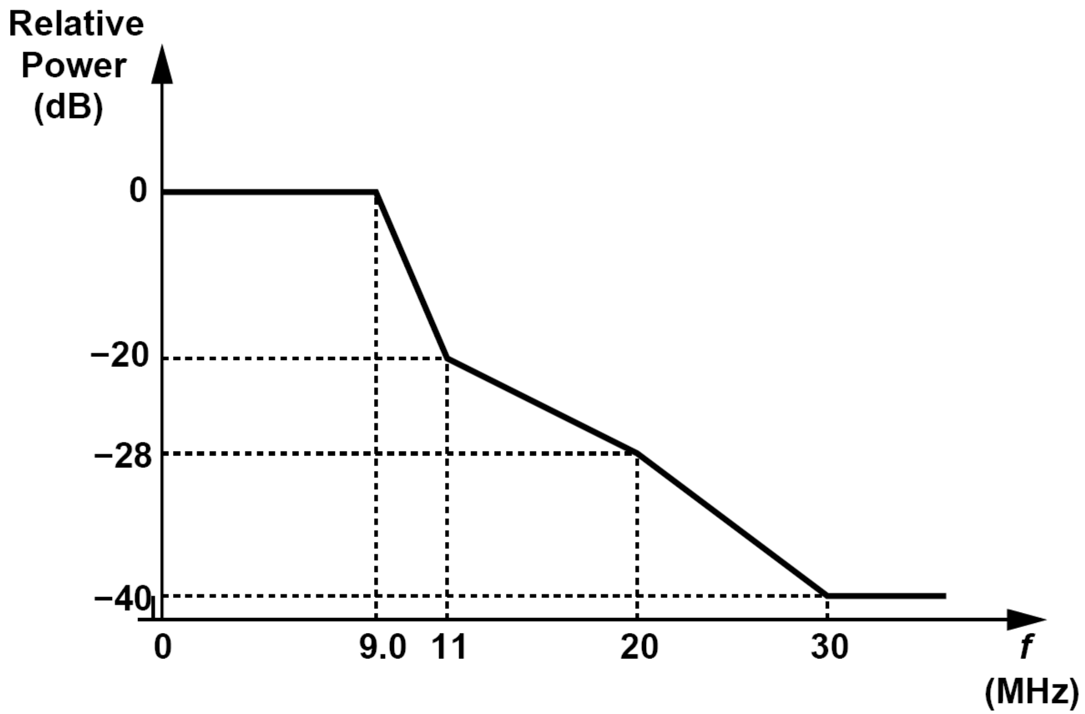
- **Channel spacing 20 MHz**

IEEE 802.11 a/b/g: OFDM Channelization



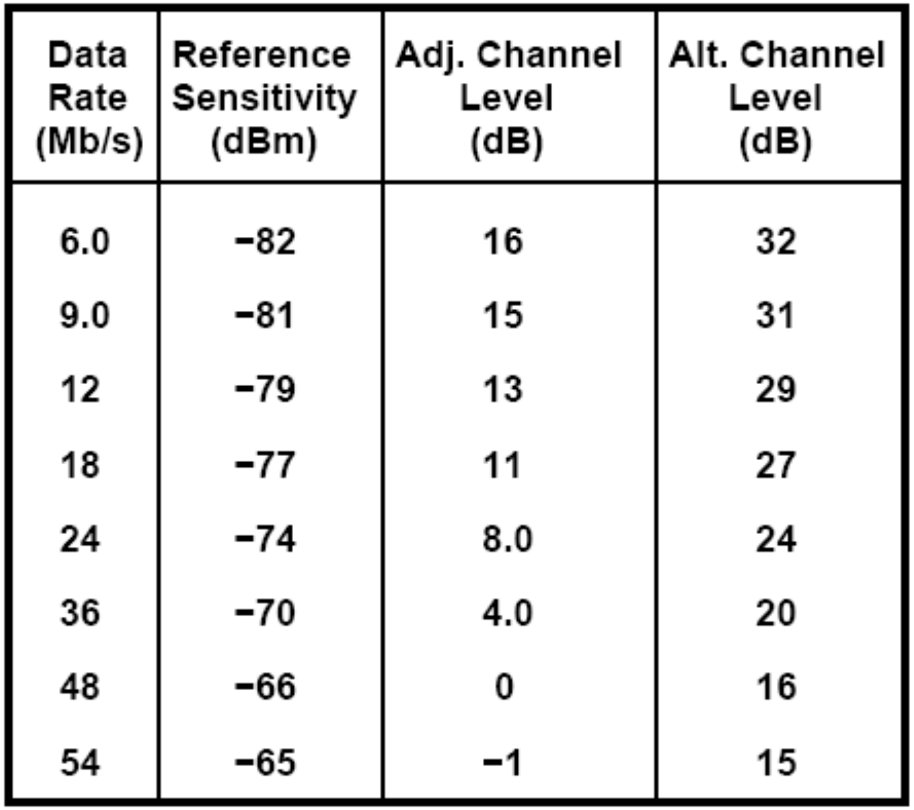
- **OFDM: 52 subcarriers with spacing of 0.3125 MHz, middle sub-channel and first and last 5 sub-channels are unused. 4 subcarriers are occupied by BPSK-modulated “pilots”.**

IEEE 802.11 a: Transmission Mask



- **TX must deliver a power of at least 40 mW.**
- **Pulse shaping: 16.6 MHz**
- **Carrier leakage: 15 dB below the overall output power.**

IEEE 802.11 a: Data Rates, Sensitivities, Adjacent Channel Levels



Data Rate (Mb/s)	Reference Sensitivity (dBm)	Adj. Channel Level (dB)	Alt. Channel Level (dB)
6.0	−82	16	32
9.0	−81	15	31
12	−79	13	29
18	−77	11	27
24	−74	8.0	24
36	−70	4.0	20
48	−66	0	16
54	−65	−1	15

- **11a/g receiver must operate properly with a maximum input -30 dBm**

Example of Noise Figure and 1-dB Compression Point Calculation in 802.11a/g

Estimate the noise figure necessary for 6-Mb/s and 54-Mb/s reception in 11a/g.

Solution:

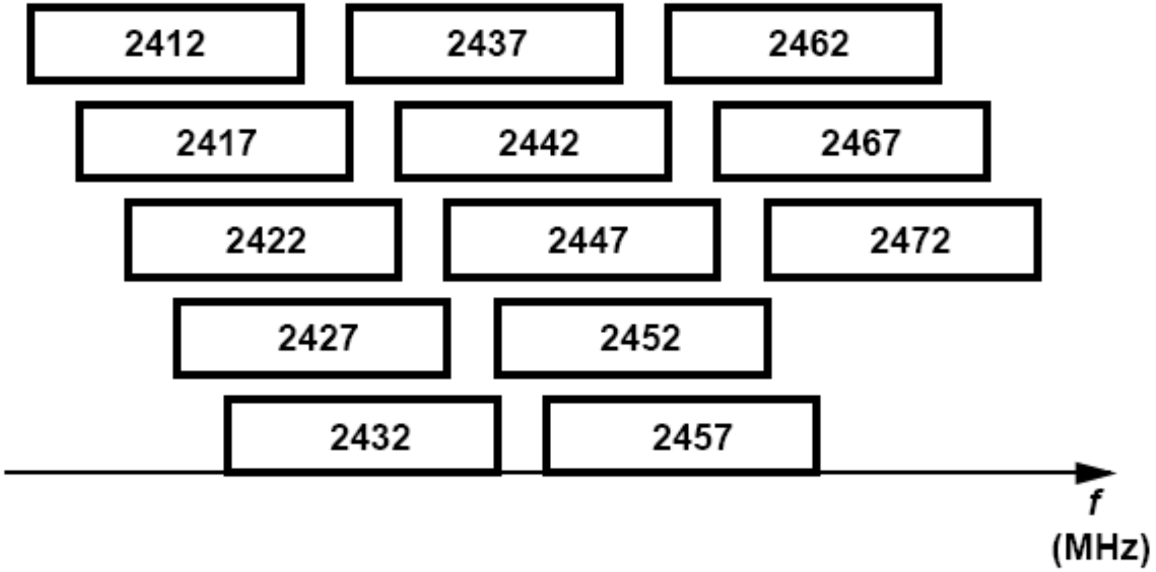
First, consider the rate of 6 Mb/s. Assuming a noise bandwidth of 20 MHz, we obtain 19 dB for the sum of the NF and the required SNR. Similarly, for the rate of 54 Mb/s, this sum reaches 36 dB. An NF of 10 dB leaves an SNR of 9 dB for BPSK and 26 dB for 64QAM, both sufficient for the required error rate. In fact, most commercial products target an NF of about 6 dB so as to achieve a sensitivity of about -70 dBm at the highest date rate.

Estimate the 1-dB compression point necessary for 11a/g receivers.

Solution:

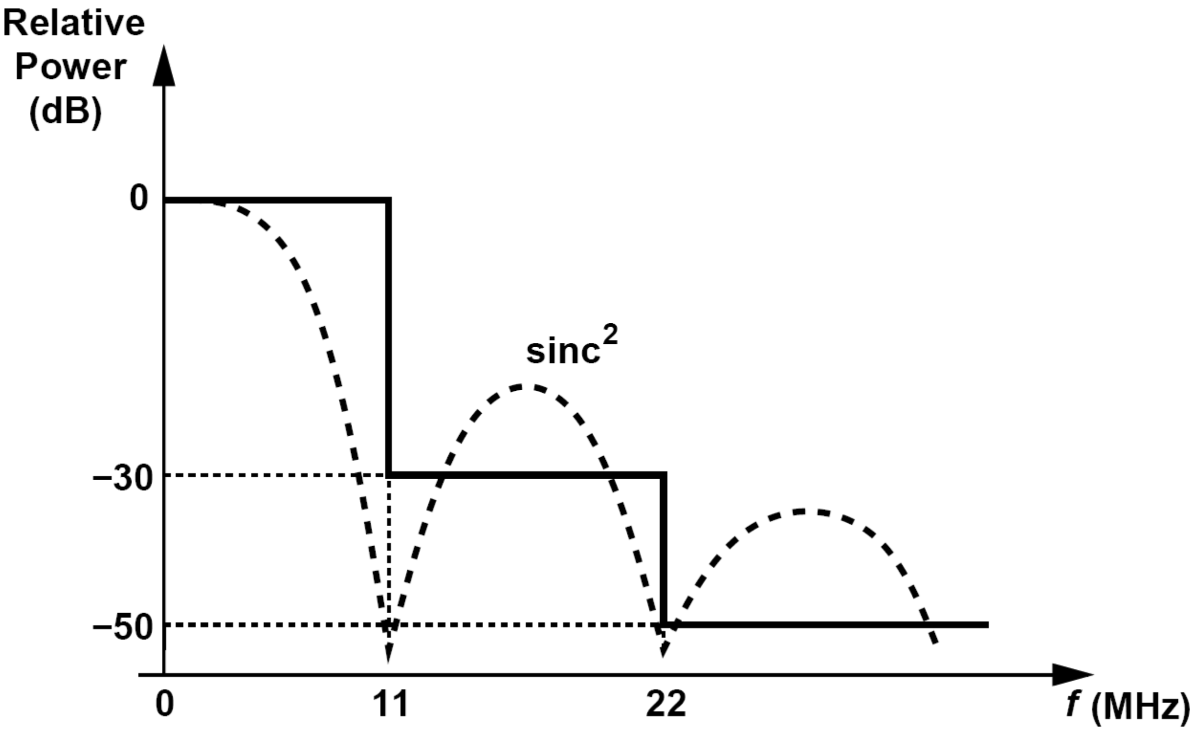
With an input of -30 dBm, the receiver must not compress. Furthermore, recall from previous section that an OFDM signal having *N* subchannels exhibits a peak-to-average ratio of about 2 ln*N*. For *N* = 52, we have PAR = 7.9. Thus, the receiver must not compress even for an input level reaching -30 dBm + 7.9 dB = -22.1 dBm. The envelope variation due to baseband pulse shaping may require an even higher P_{1dB}.

IEEE 802.11 b Overlapping Channel Frequencies



- 11b specifies overlapping channel frequencies to offer greater flexibility. Users operating in close proximity of one another avoid overlapping channels
- The carrier frequency tolerance is ±25 ppm

IEEE 802.11 b Transmission Mask



- **11b standard stipulates a TX output power of 100 mW (+20 dB) with the spectrum mask.**