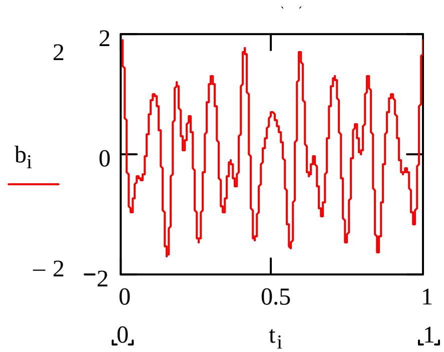
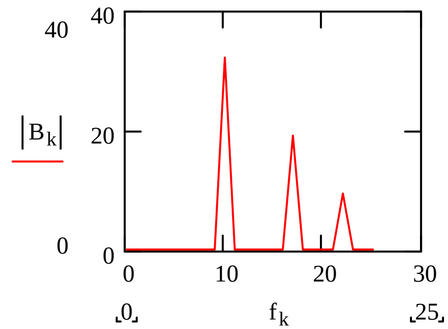
Modulation - baseband signals

- Consider a baseband signal, consisting of a few sinusoids. Examine the signal in the time domain and in the frequency domain:

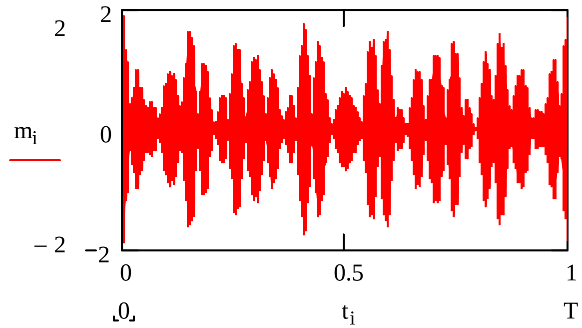


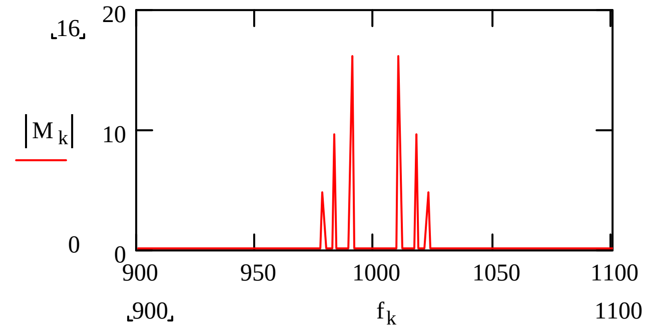


- This signal cannot be transmitted very far in its present format, nor can we allow multiple users to share the same spectrum, so the signal has to be modulated onto a "carrier"

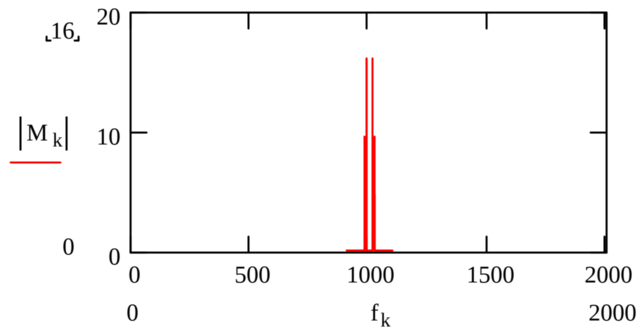
Modulation - passband signals

- By “translating” the previous signal to a “carrier” frequency, we obtain a passband signal:



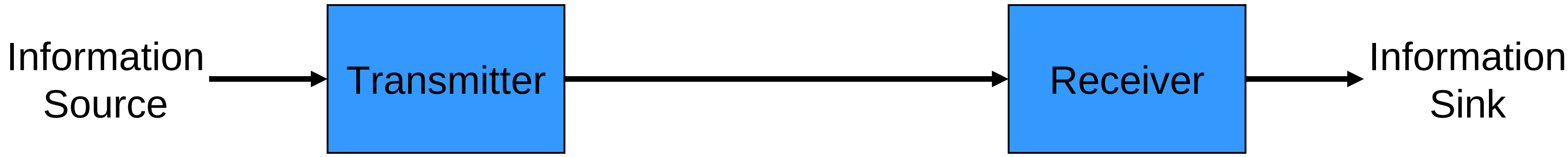


- This signal has all of its energy near the carrier frequency, in this case 1000 Hz



Modulation - a generic communications system

- Consider a simple communications system:



Modulation - a generic communications system

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Modulation - a generic communications system

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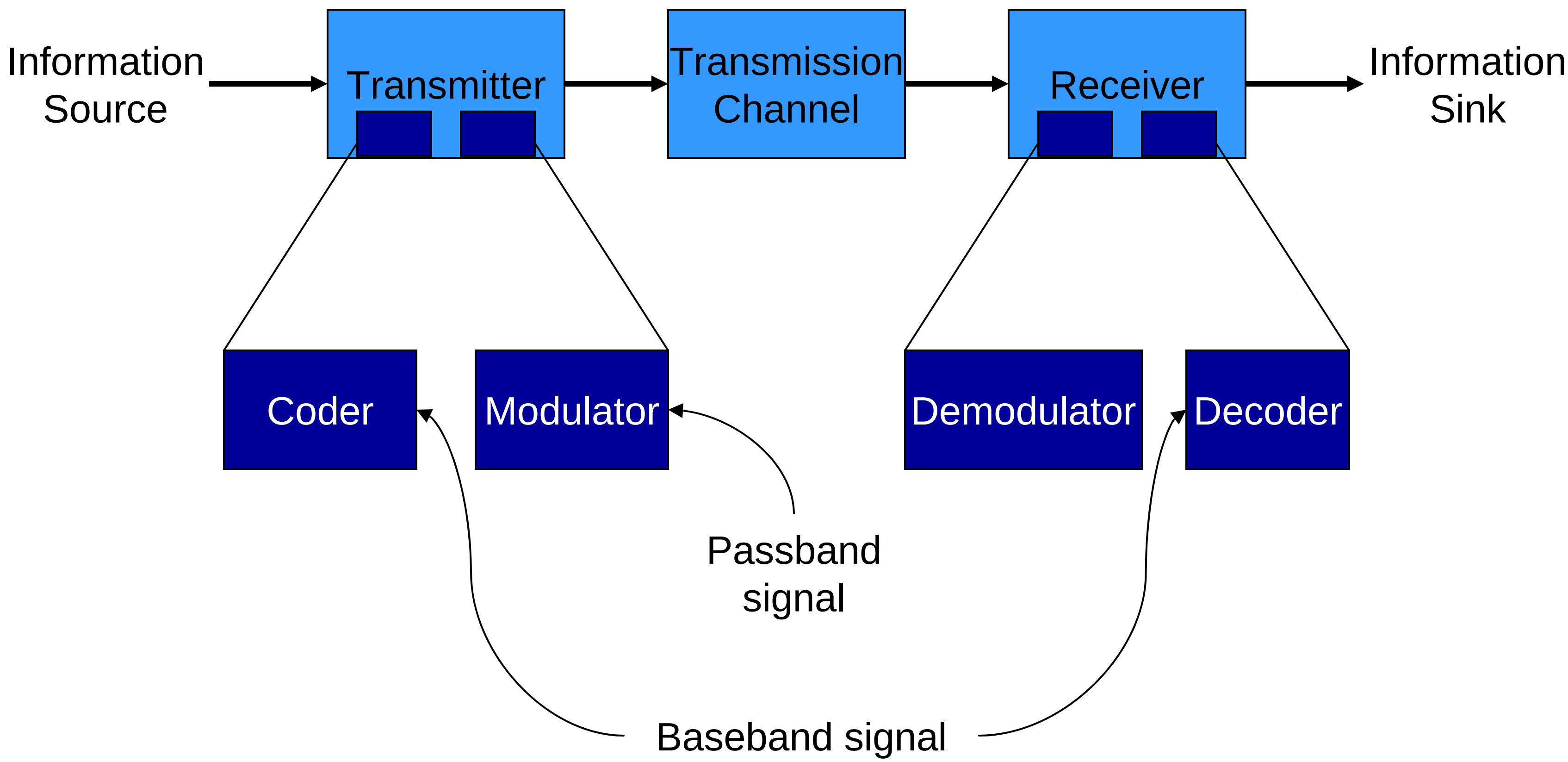


Modulation - modifiable signal parameters

- Consider a generic equation for a modulated signal *m(t)*, generated by a baseband signal *b(t).* Start with an unmodulated carrier signal:

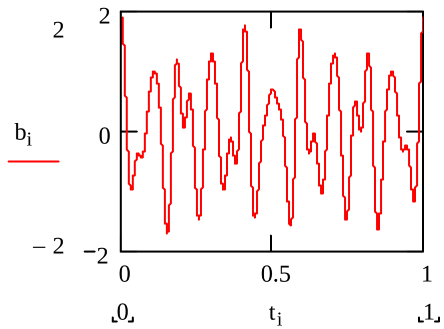
$$m(t) = A_c \cos(w_c t + \phi_c)$$

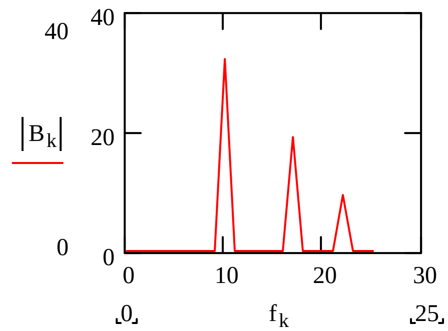
- we can modulate the carrier's
  - amplitude (as set by m_A)
  - frequency (as set by m_f), or
  - phase (as set by m_p)

Or multiple parameters could be modulated simultaneously

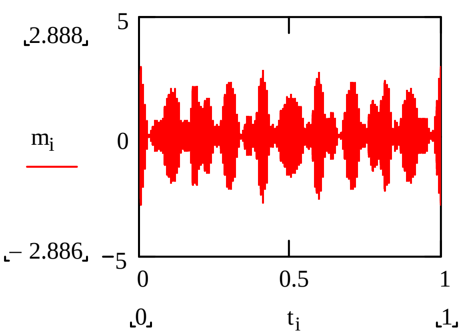
$$m(t) = A_c \left[1 + m_A b(t)\right] \cos((w_c + m_f b(t))t + m_p b(t) + \phi_c)$$

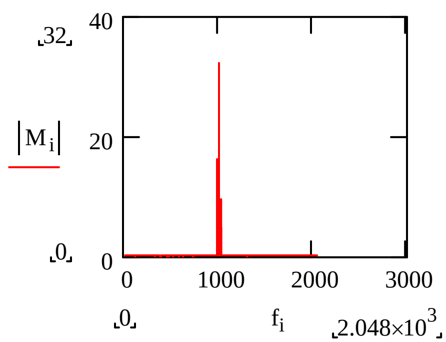
Analog modulation - AM

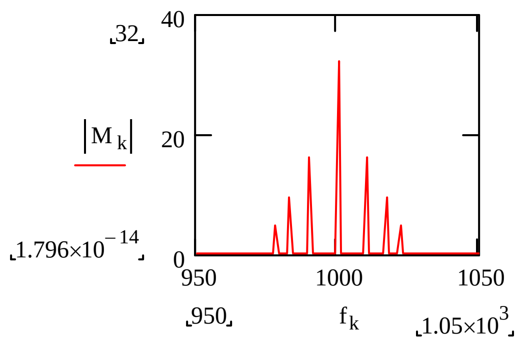




- With the baseband signal as before, set m_A to 1 (100% modulation) and the other modulation parameters to zero to obtain a purely AM signal

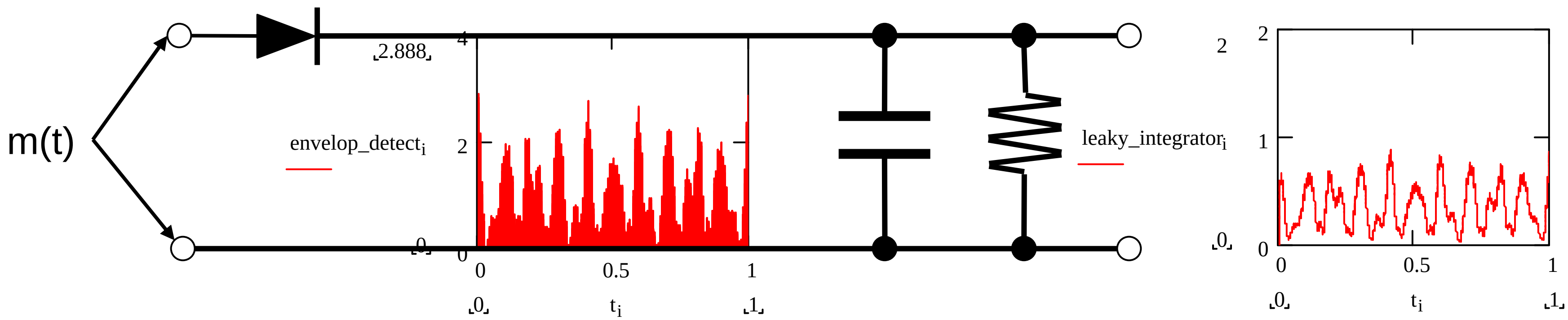




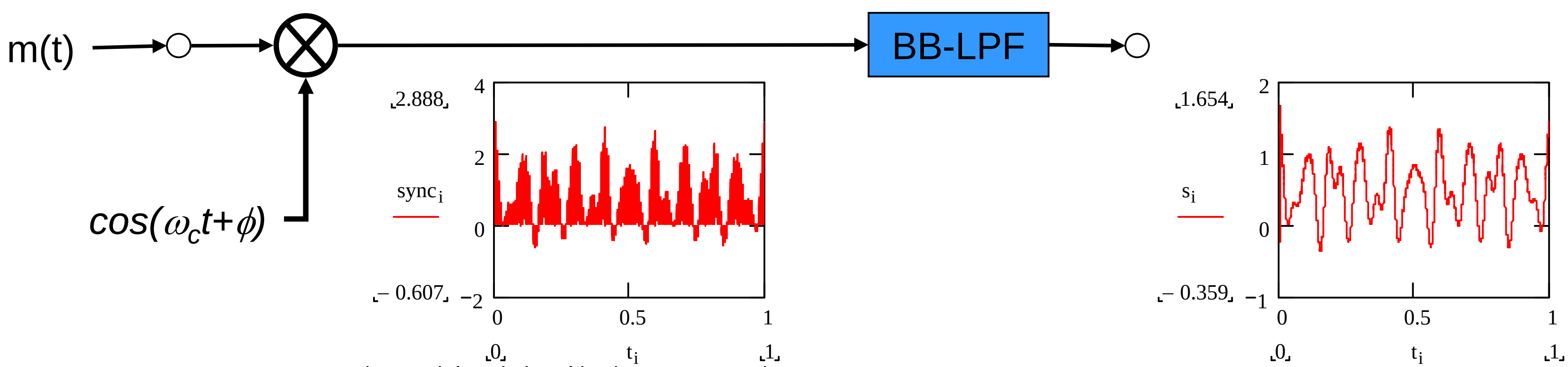


Detecting AM

- There are two types of AM detectors:
  - envelop detectors



  - and synchronous detectors



FM and PM

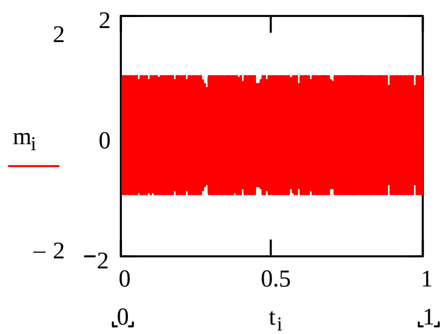
- FM and PM can be thought of as the same modulation technique with proper choice of the input signal:
  - Define the instantaneous phase of a sinusoid:

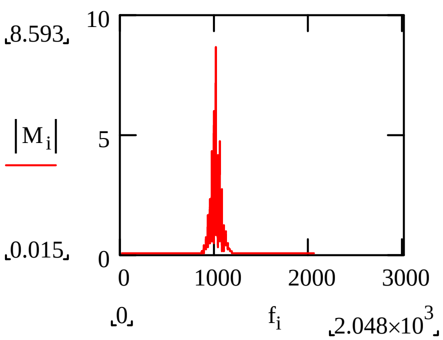
$$\phi(t) = \int_{-\infty}^{t} \omega(x)dx$$

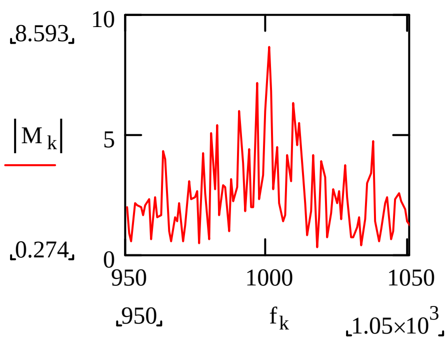
  - so, by integrating the modulating waveform presented to a phase modulation system, we have a frequency modulation system. And conversely, by differentiating the input to a frequency modulated system, we have a phase modulated system.

Bandwidth requirements of FM/PM systems

- Again, consider the earlier baseband modulating signal, this time frequency modulating the carrier.



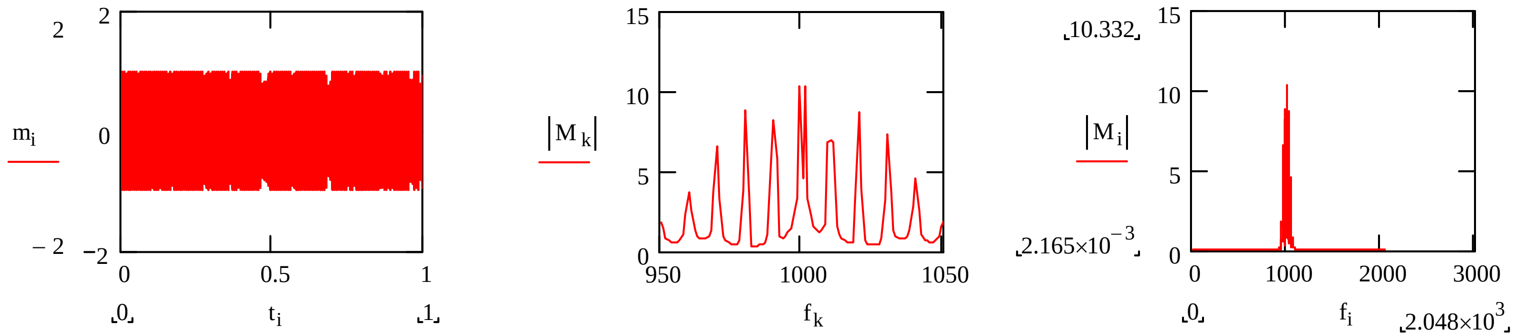




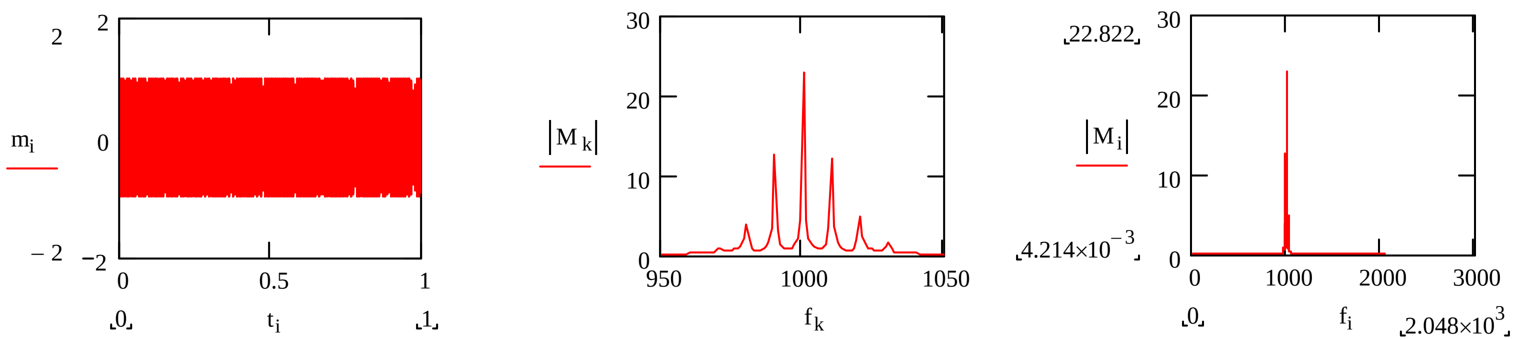
Bandwidth requirements of FM/PM systems

- An FM signal with a simple sinusoidal modulating waveform

$M := \text{fft}(m)$ $\quad m_f = 5\,s^{-1}$

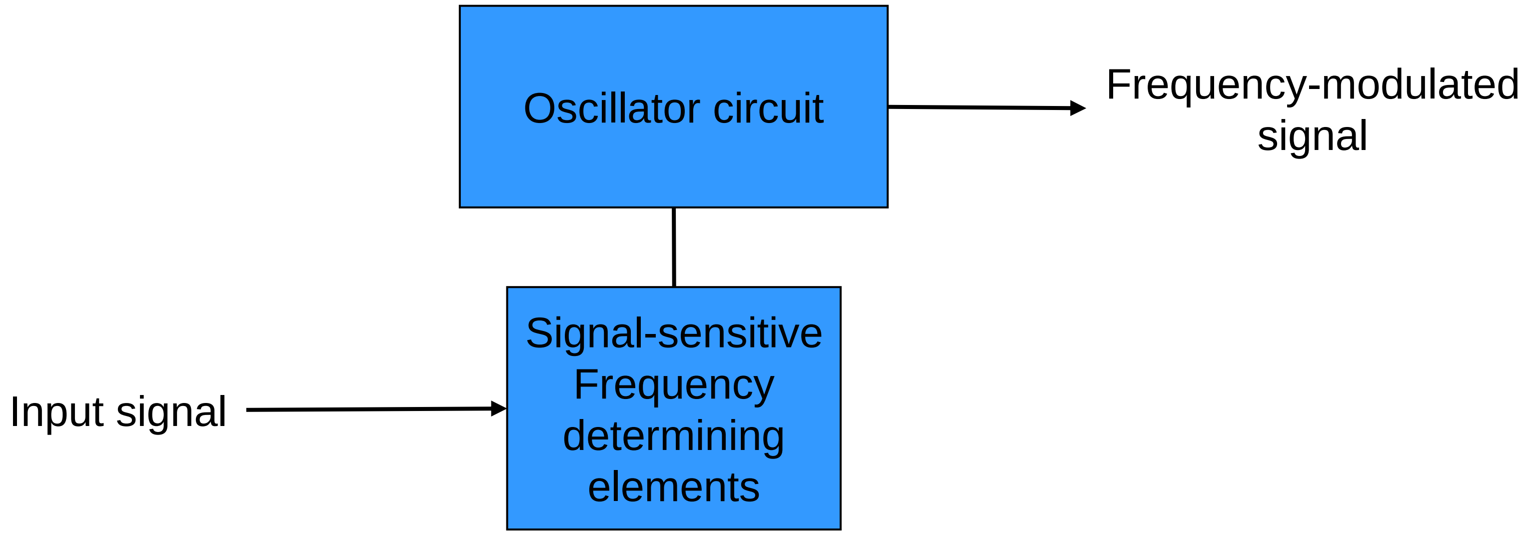


$M := \text{fft}(m)$ $\quad m_f = 2\,s^{-1}$



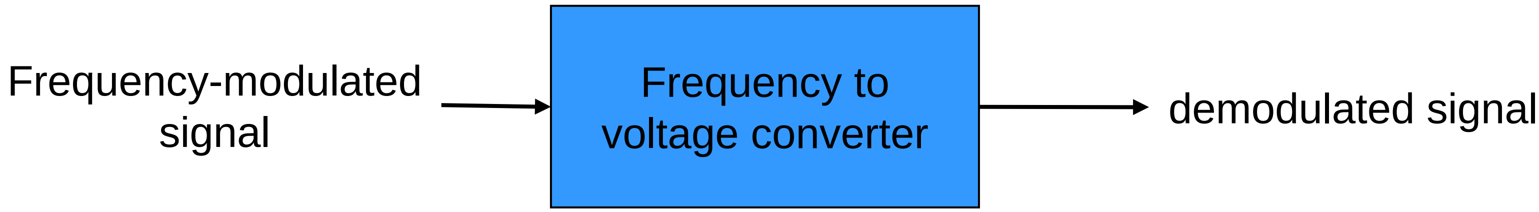
Modulating an FM signal

- Generic FM modulator:



Demodulating FM

- Generic FM demodulator:



Demodulating FM

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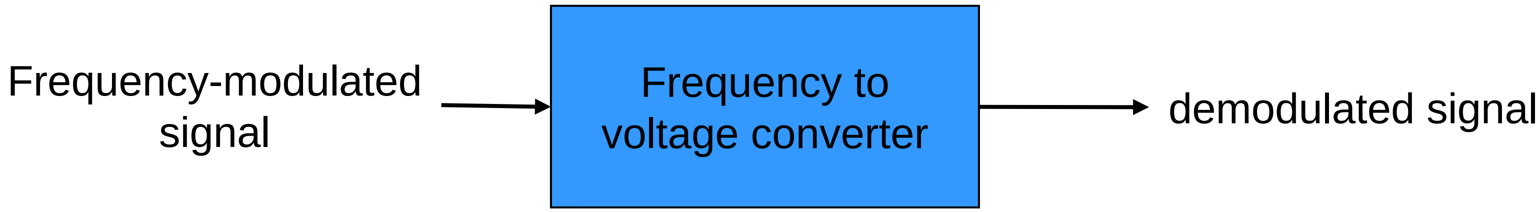
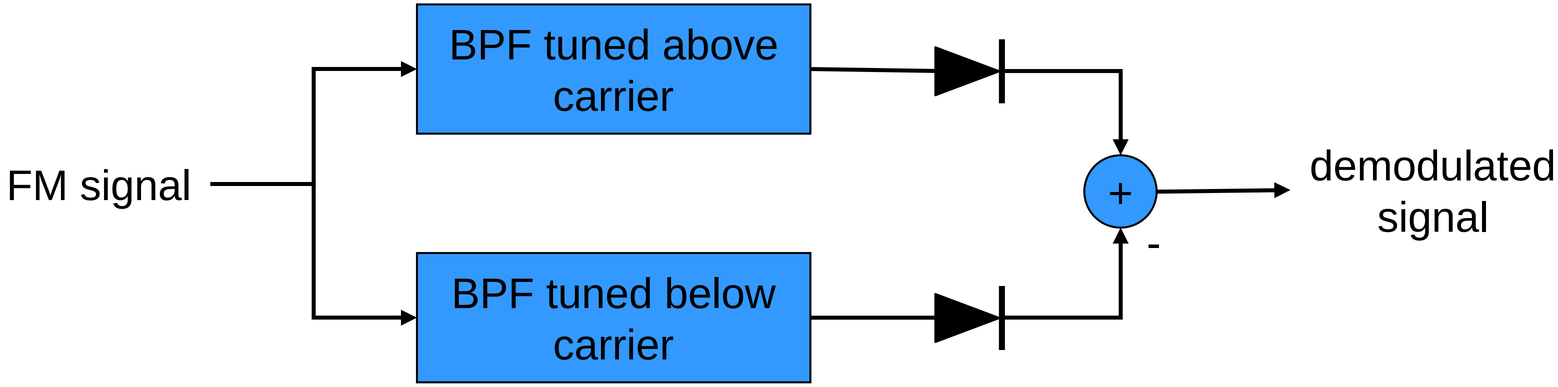


- Frequency Discriminator:



Digital Modulation

- As before, the generic expression for a modulated signal

$$m(t) = A_c\left[1 + m_A b(t)\right]\cos((w_c + m_f b(t))t + m_p b(t) + \phi_c)$$

- For digital modulation, *b(t)* is a digital waveform – discrete in time and level:

$$b(t) = b(nT) \in \{l_1, l_2, ..., l_m\}$$

- The modulated signal "shifts" between discrete states, so digital modulation techniques are referred to differently than analog modulation:

Analog	**Digital**
AM	Amplitude Shift Keying (ASK)
FM	Frequency Shift Keying (FSK)
PM	Phase Shift Keying (PSK)

M-ary signaling

- The size of the baseband signaling set may be binary:

$$b(t) = b(nT) \in \{l_1, l_2\} = \{0,1\}$$

- Or M-ary

$$b(t) = b(nT) \in \{l_1, l_2, ..., l_m\}$$

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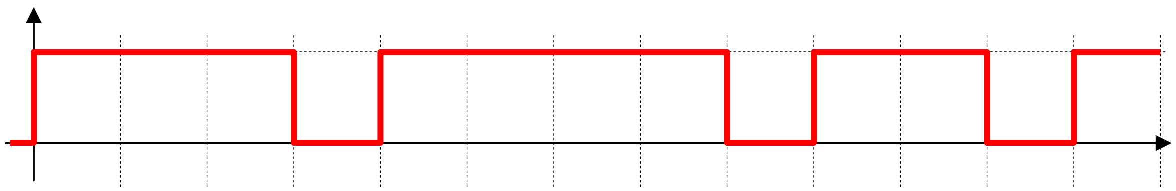
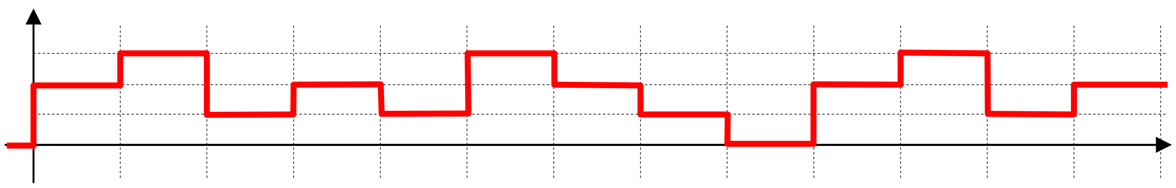
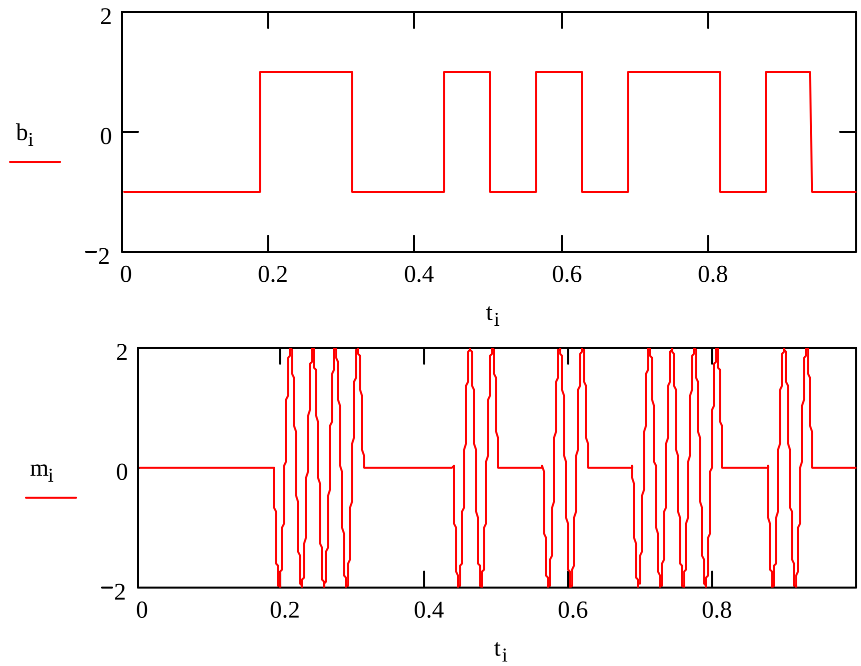




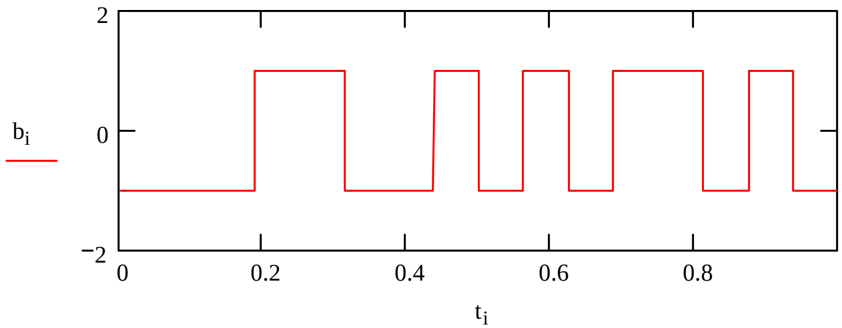
ASK

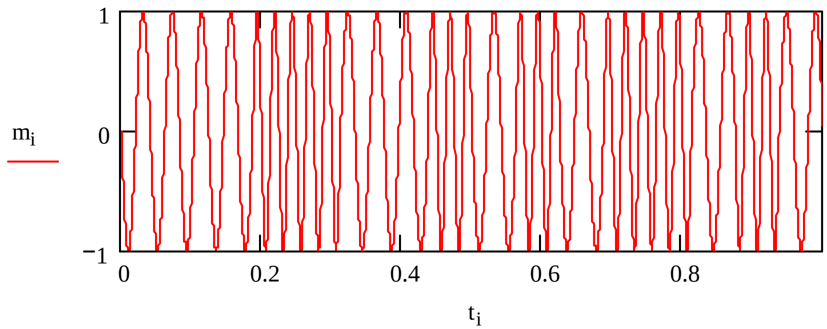
- Amplitude Shift Keying (ASK) = On-Off Keying (OOK) if the modulation is 100%



FSK

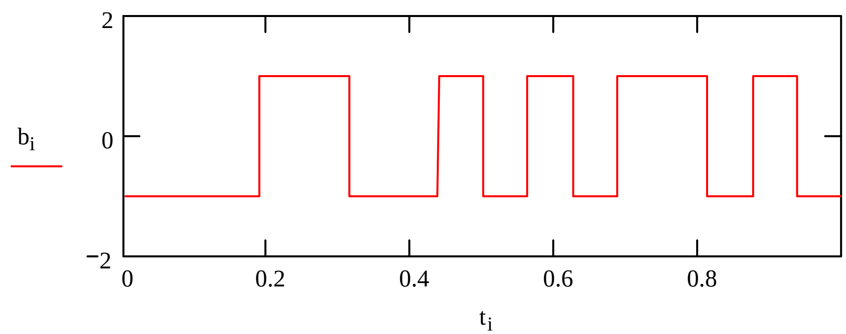
- FSK maintains the carrier magnitude

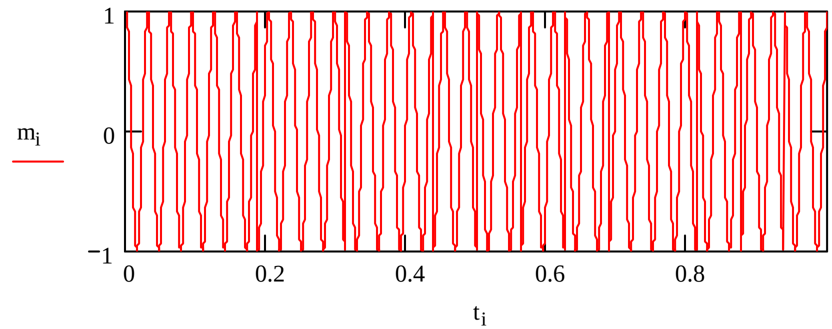




PSK

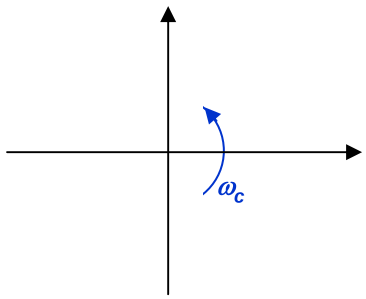
- PSK maintains the carrier amplitude and the ***average*** carrier frequency



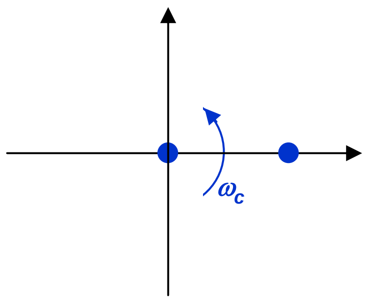


Phasor Representation of Modulated Signals

- Consider a coordinate system, rotating at the carrier frequency:

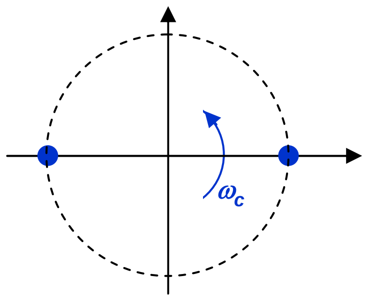


- All signal energy at or nearly related to the carrier frequency will be rotating at approximately the same speed.
  - In particular, consider the “on” and “off” periods of an ASK signal



Phasor Representation of PSK Signals

- First, consider a binary PSK system (BPSK). The two transmit phases are chosen 180 degrees apart.



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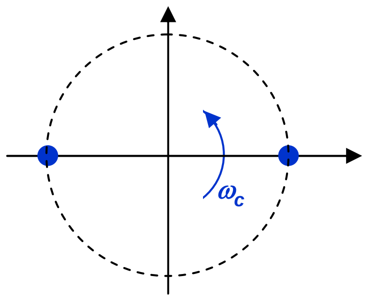
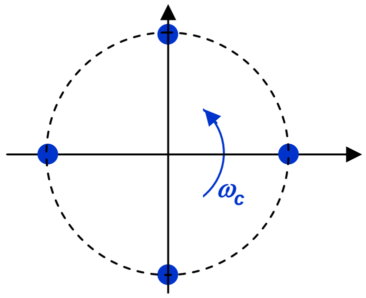
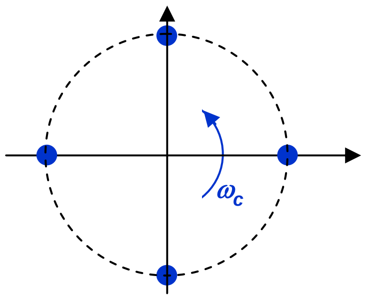


- Next, we can consider an m-ary PSK system, e.g., m=4



PSK and Quadrature Modulation

- Is this signal PSK or ASK?



PSK and Quadrature Modulation

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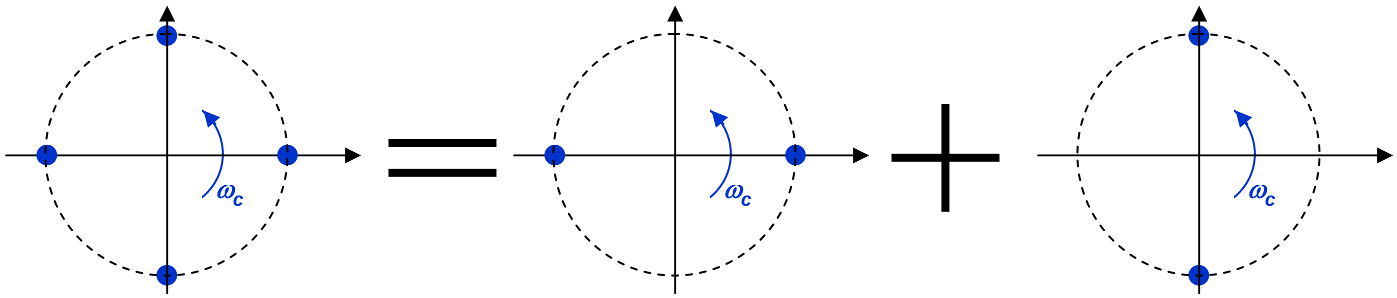

PSK and Quadrature Modulation

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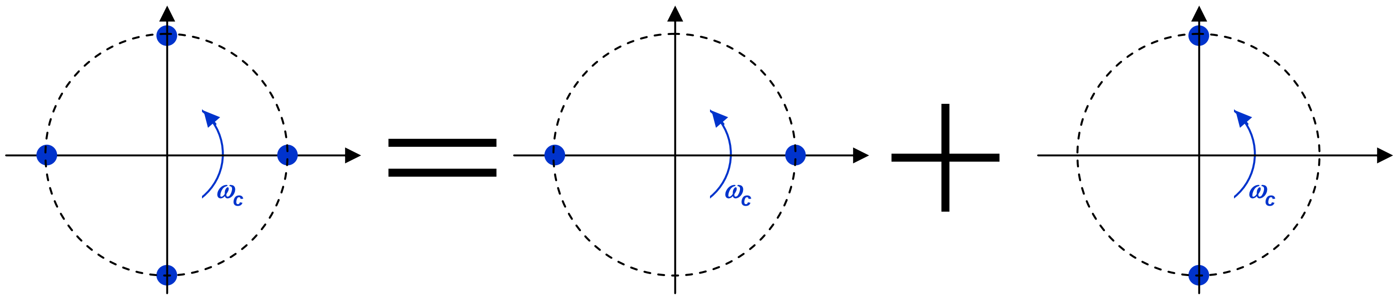
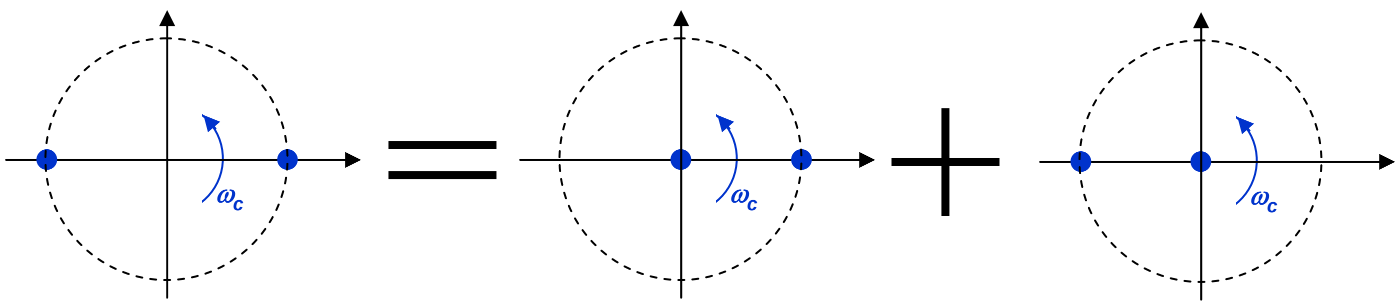
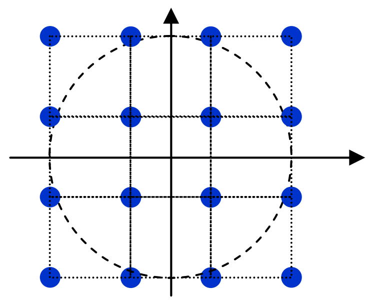




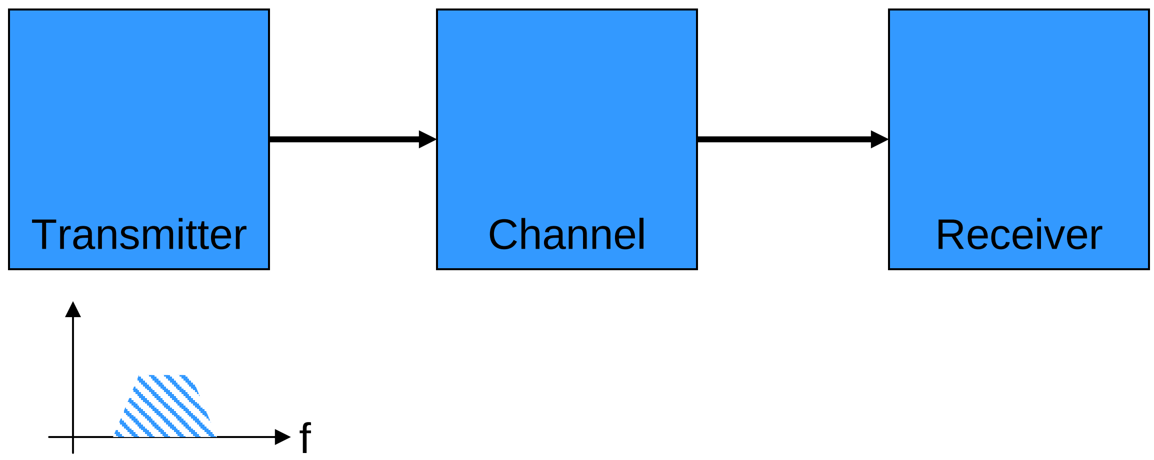
Signal Constellation Design

- A typical 16-QAM constellation:



Filtering Considerations

- Simplest case for a communications system:



Filtering Considerations

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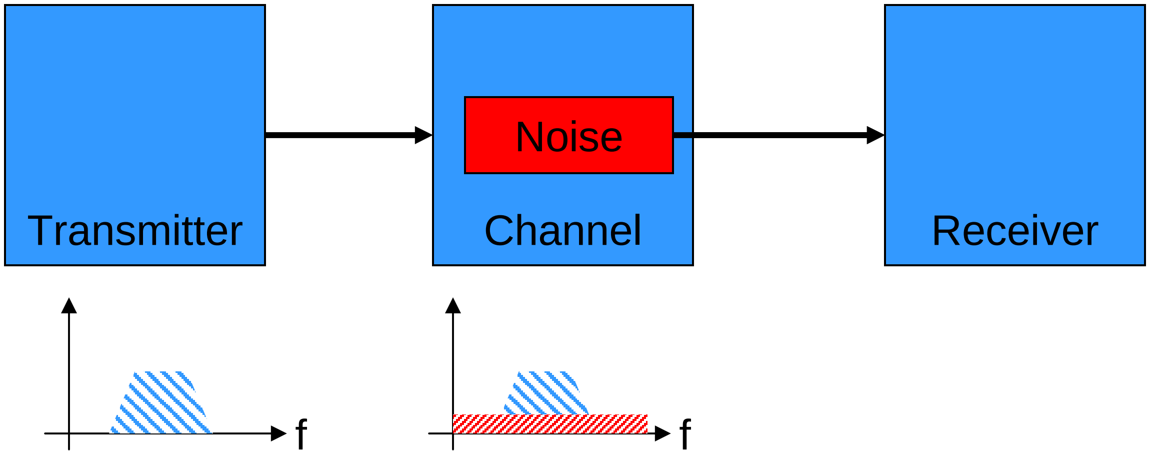

Filtering Considerations

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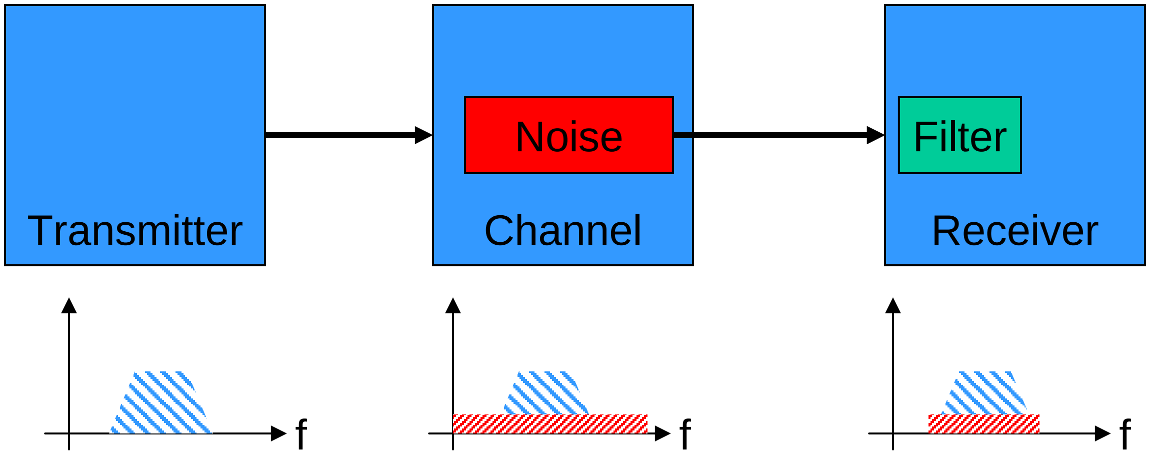

Filtering Considerations

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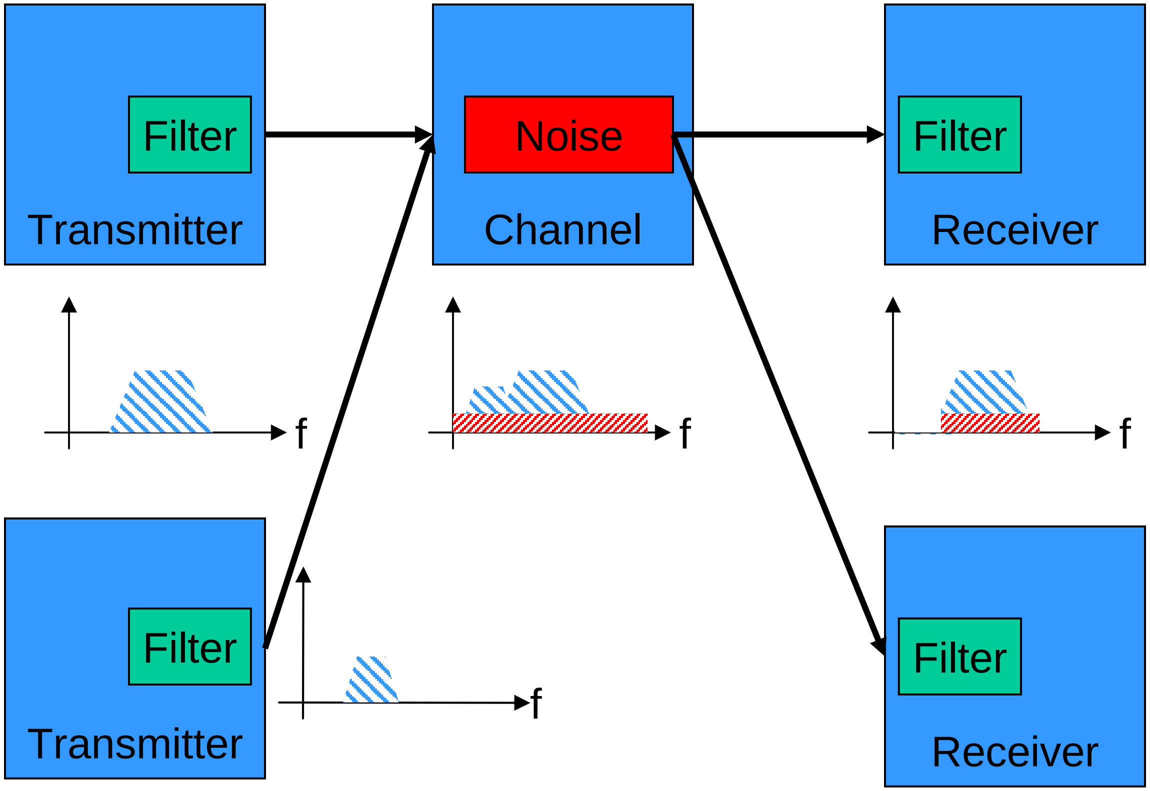
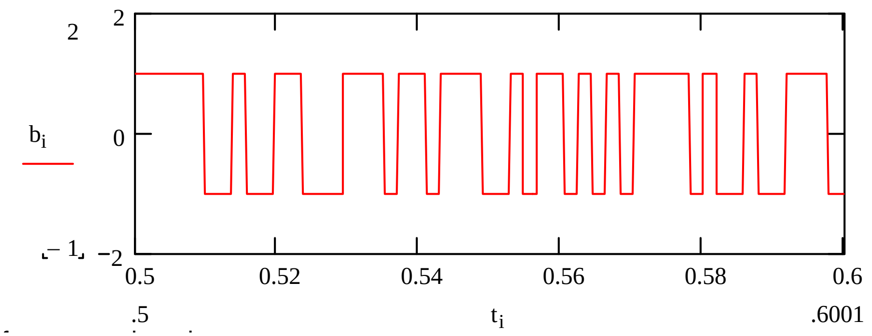


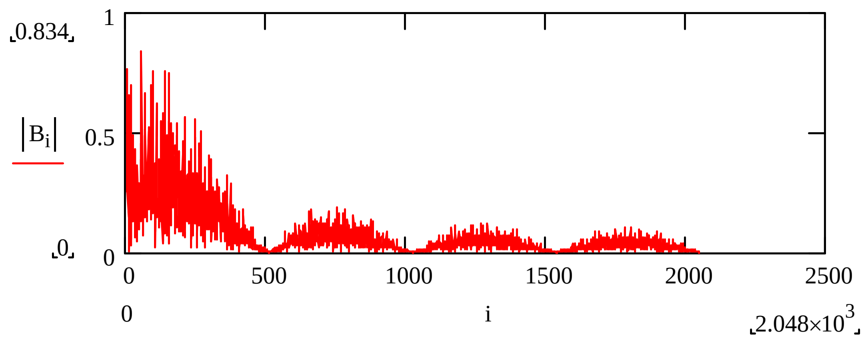
- More realistically, there are other users transmitting and receiving signals

More Filtering Considerations

- For the simplest form of modulation, BPSK, generate a random sequence

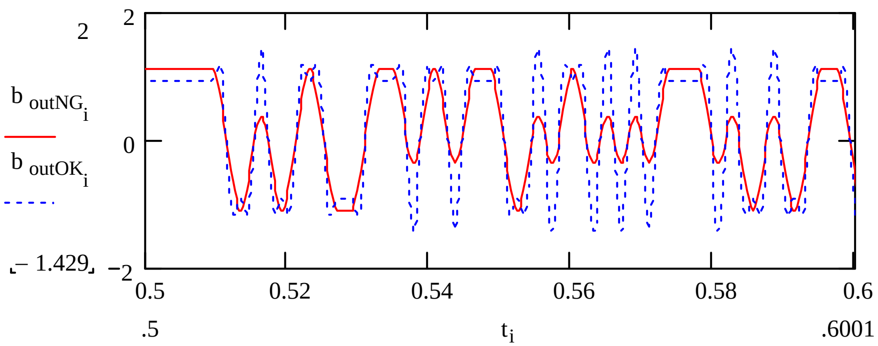


- And look at it in the frequency domain

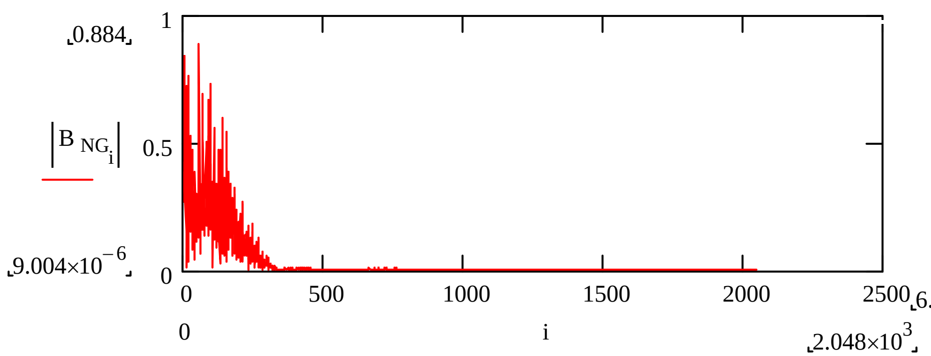


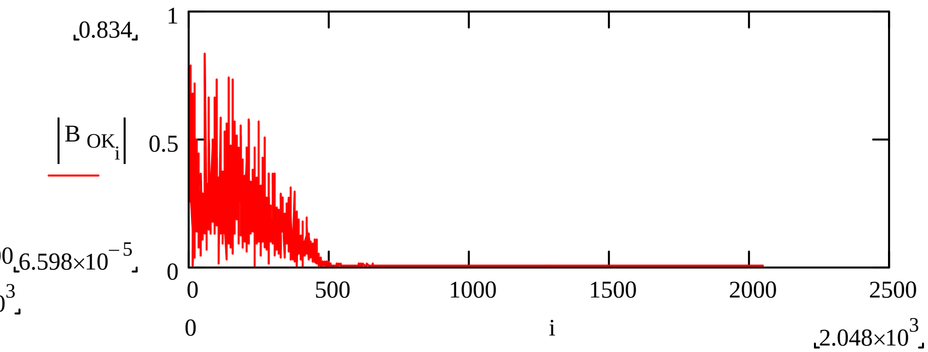
Filtering the Baseband signal

- In the time domain



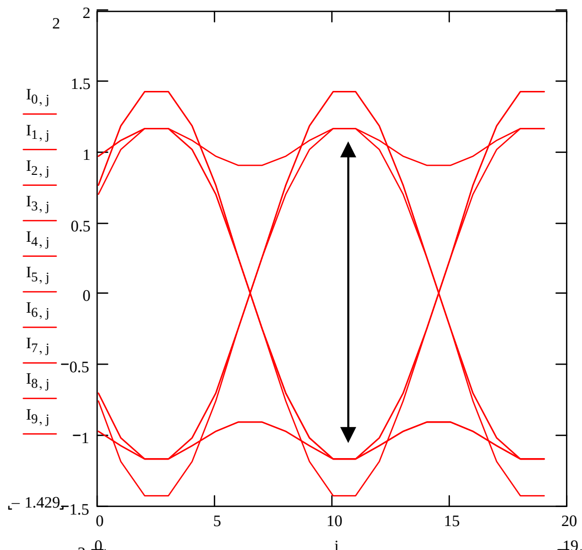
- In the frequency domain



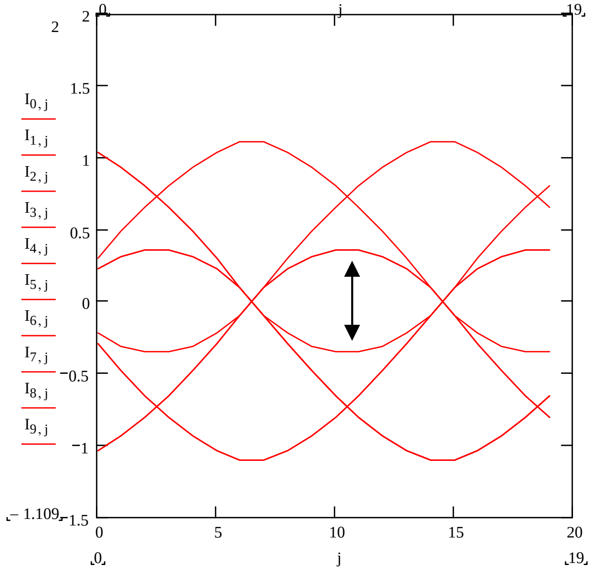


Examining the "Eye Diagram"

- Eye diagram for properly filtered signal

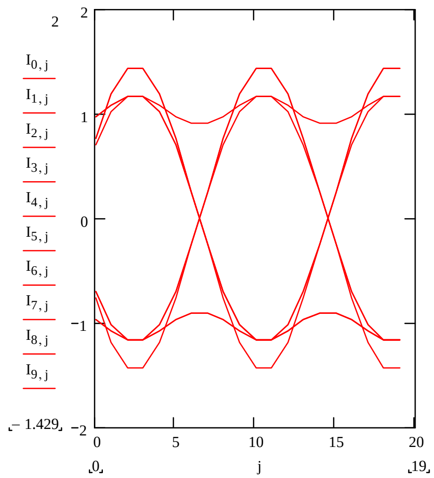


- Eye diagram for over-filtered signal

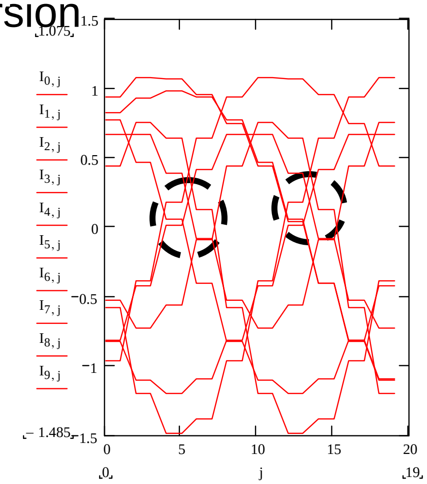


The Effect of ISI on the Eye Diagram

- A filter with no ISI



- ISI due to the filter dispersion



TOPIC 4 – Multiplexing and Coding

4.1 Bandwidth – What is it?

Practical Definition:

- The most valuable resource in telecommunications.
- More detail on the RF Spectrum topic.

▪ Technical Definition:

- The bandwidth (BW) is the difference between the two half-power frequencies of a signal:
- $$BW = \omega_{HI} - \omega_{LO} = \omega_0 / Q$$
- Where Q is the measure of the sensitivity of a circuit.

TOPIC 4 – Multiplexing and Coding

4.1 Bandwidth - Definitions

- Signals are time varying events that can be periodic or nonperiodic.
- A signal can be decomposed into combination of pure tones (sine waves) at different frequencies (Fourier analysis).
- The sine waves that compose a signal can be plotted as a function of frequency to produce the Frequency Spectrum of the signal.
- The range of frequencies occupied by a signal is called the bandwidth of the signal ($BW = \omega_{HI} - \omega_{LO}$).

TOPIC 4 – Multiplexing and Coding

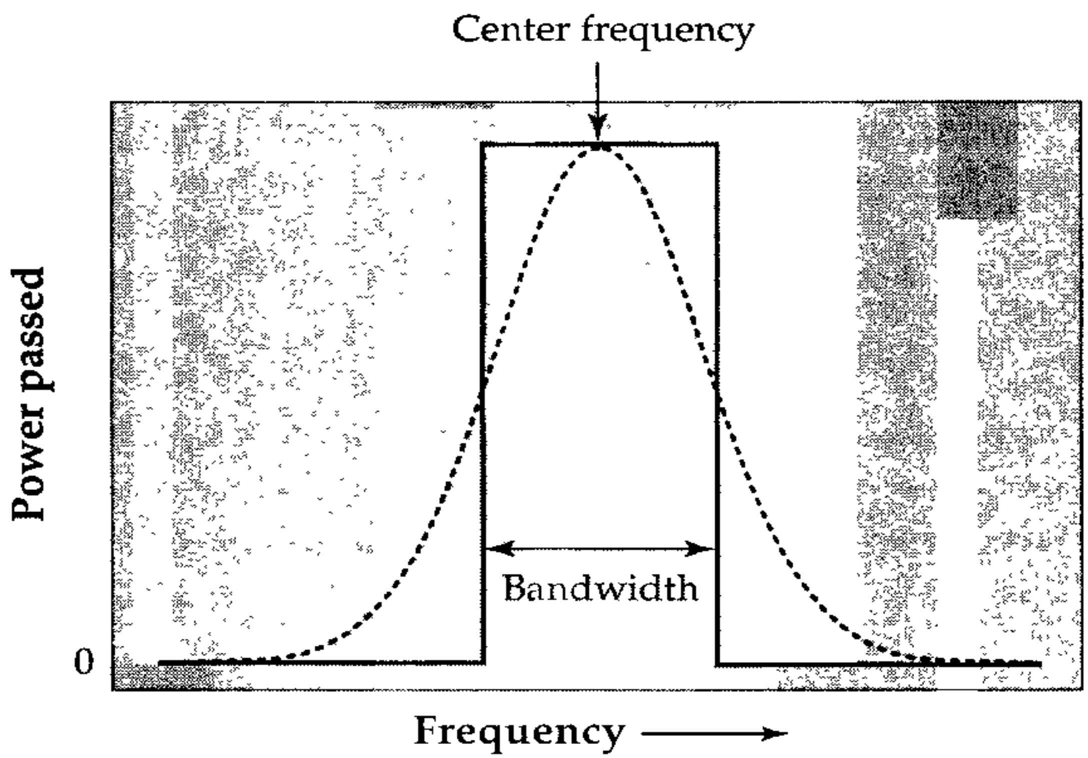
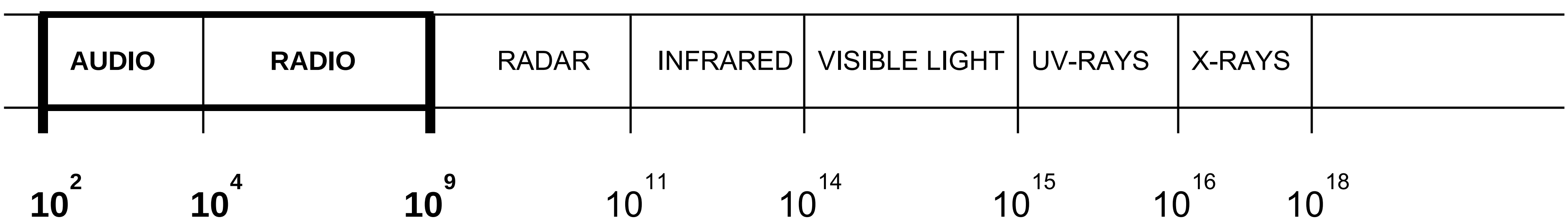


FIGURE 6.10 ▲
Illustration of the concept of bandwidth in electronics.

TOPIC 4 – Multiplexing and Coding

4.1 Bandwidth – EM Spectrum

- **James Clerk Maxwell showed that the electric field due to electron motion is accompanied by a magnetic field.**
- **The combination of these two fields produce an electromagnetic field that travel through space at the speed of light.**
- **Electromagnetic waves can exist from low frequencies to extremely high frequencies.**



Frequency in Hz

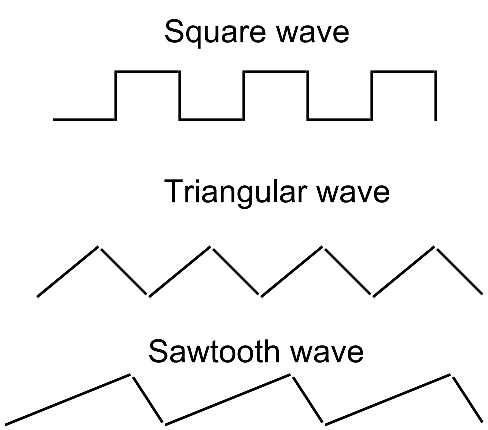
8/17/1996
D.Geneus

TOPIC 4 – Multiplexing and Coding

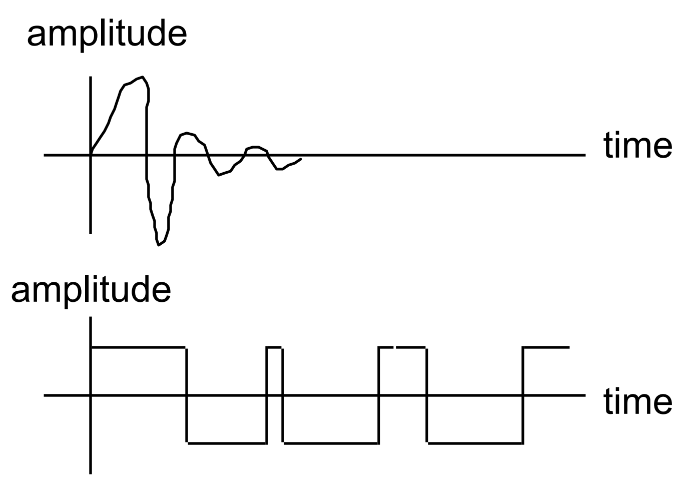
4.1 Bandwidth - Signals

Types of Signals

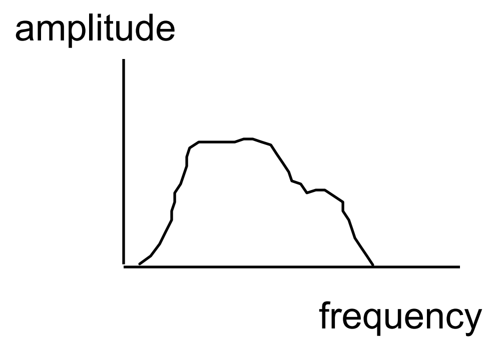
periodic



nonperiodic



continuous spectrum



8/17/1996
D.Geneus

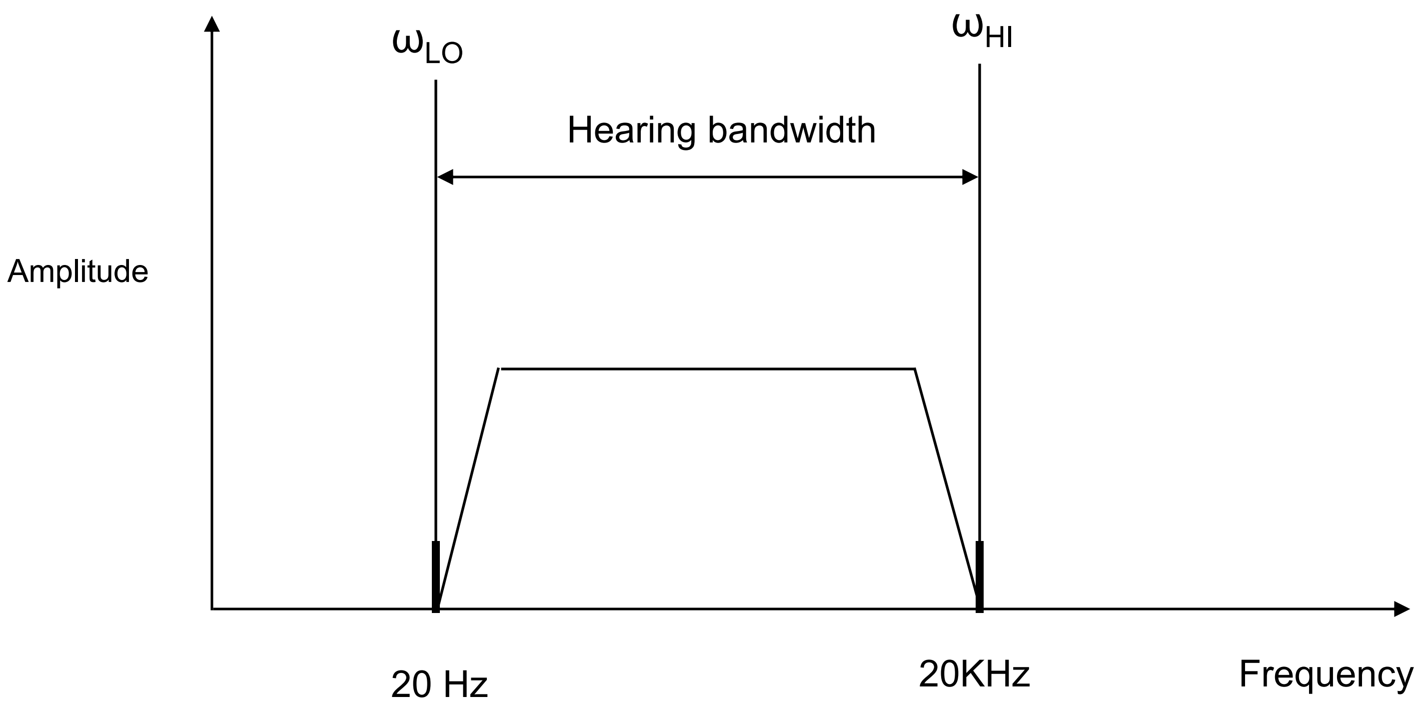
TOPIC 4 – Multiplexing and Coding

4.1 Bandwidth Signal Example - Hearing

- Frequencies in the audio spectrum can be heard by the human ear. The ear “hears” by detecting very small changes in air pressure.
- The frequencies ranging from about 20 Hz to 20,000 Hz are in the audio or sound spectrum. So the bandwith of hearing is about 20KHz.
- Telephone speech cover the frequency range from about 300 Hz to 3000 Hz so the bandwidth of speech is about 3KHz.

TOPIC 4 – Multiplexing and Coding

4.1 Bandwidth Signal Example - Hearing



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TOPIC 4 – Multiplexing and Coding

4.1 Bandwidth Signal Example - Telecom

- All (AM) radio transmissions are within a band of frequencies from 550 KHz to 1,600 KHz.
- Each of the 12 telephone channels on a cable requires about 4KHz of bandwidth. So the band of frequencies for telephone carriers is from 60 to 108 KHz.
- VHF bands (channels 2 to 13) for TV range from 54 MHz to 216 MHz
- UHF bands (channels 14 to 83) for TV range from 470 MHz to 890 MHz.

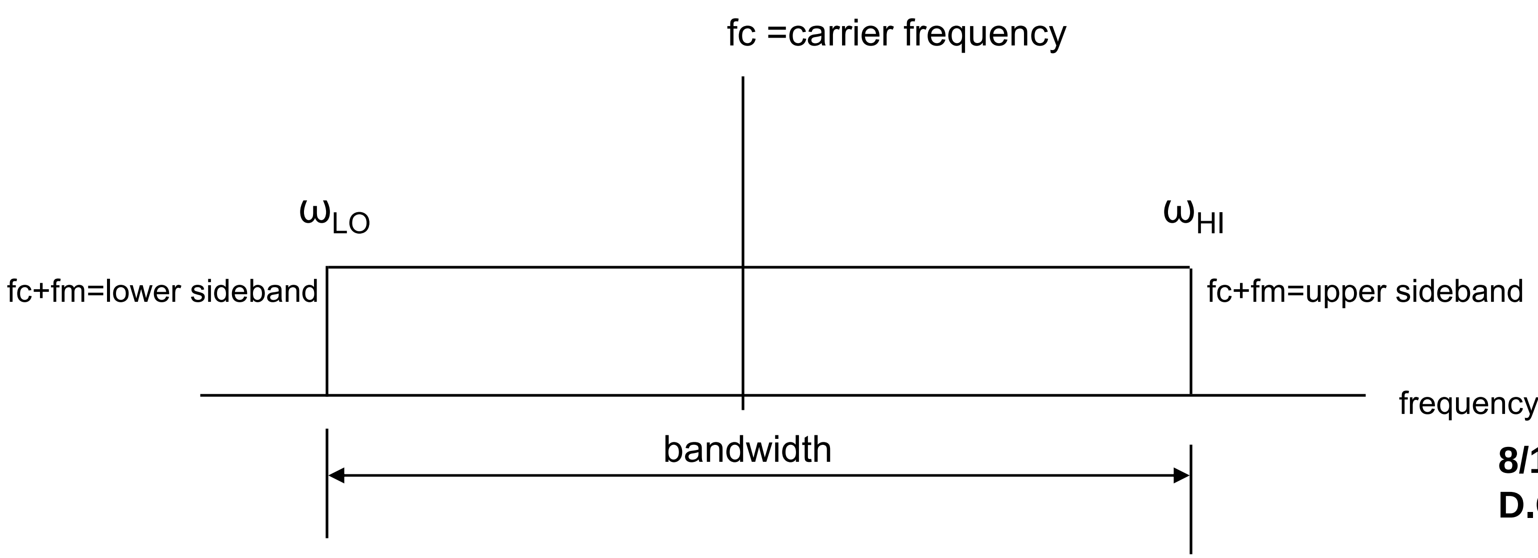
TOPIC 4 – Multiplexing and Coding

4.1 Bandwidth Channel Examples - Telecom

- For a typical AM radio station (1 channel), the bandwidth for is about 10 KHz.
- For a typical FM radio station (1 channel), the bandwidth for is about is about 200 KHz.
- The signal broadcast over the air by a television station (1 channel) has a bandwidth of about 6 MHz.

TOPIC 4 – Multiplexing and Coding

4.1 Bandwidth - Channel Example



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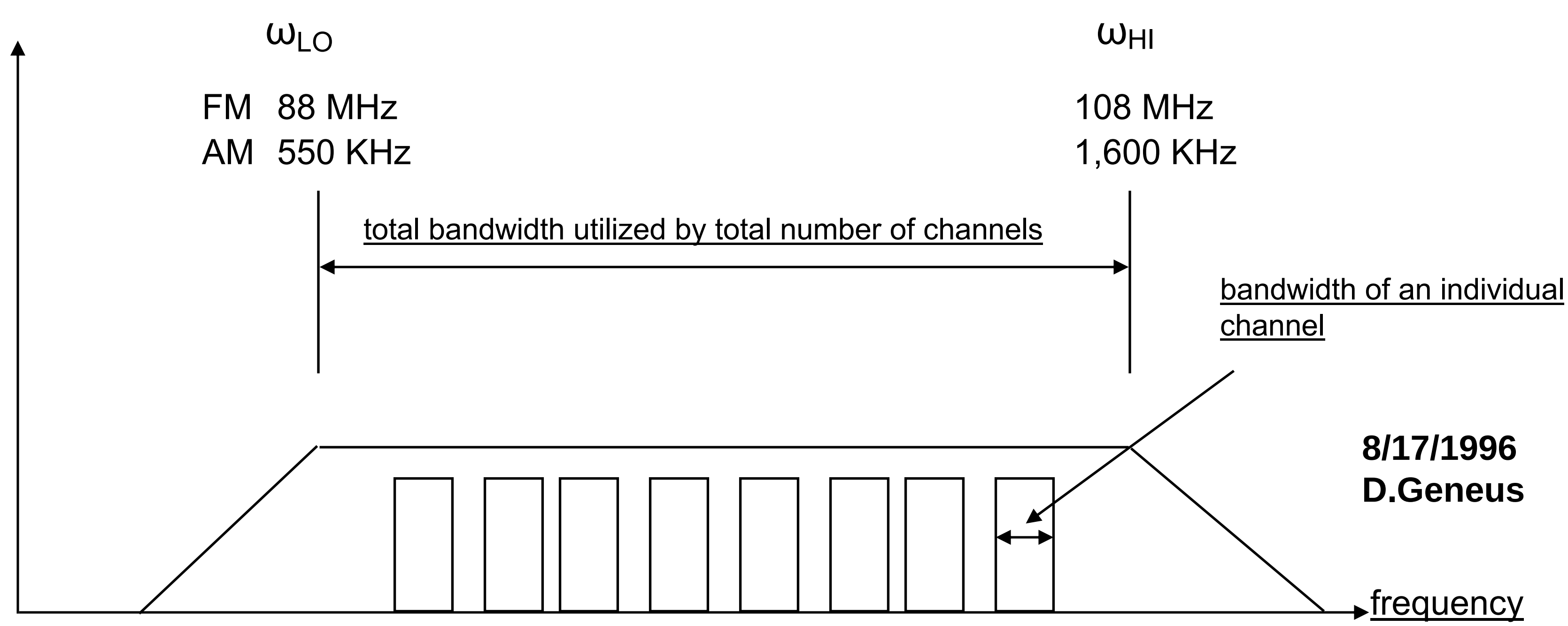
TOPIC 4 – Multiplexing and Coding

4.1 Bandwidth Channel Example - Radio



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TOPIC 4 – Multiplexing and Coding

4.1. Questions

1) How many AM radio channels can fit into the allowed frequency bands allowed by the FCC (Bandwidth = 10KHz)?
2) Same question for FM radio.
3) What frequencies do you think are used by satellite digital radio like XMRadio ?