ECE3614
Introduction to Communications Systems
Fall 2007

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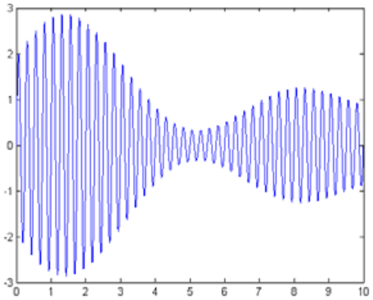
Lecture #12: Amplitude Modulation – Baseband representation, the Superhet Receiver and AM System Examples



Overview

- In today's lecture we wrap up our discussion of Amplitude Modulation (AM) by
  - discussing complex baseband representation and
  - the superheterodyne receiver and
  - going through a couple of common AM examples
    - Broadcast radio
    - Broadcast television
- We will discuss Signal-to-Noise performance of AM later in the class.
- Reading
  - Sections 3.8-3.9

Baseband Representation

- In bandpass modulation schemes, the information is entirely in the original baseband modulating signal
- As a result, we can represent the bandpass signal in a baseband form termed the *complex baseband*
- This format allows for
  - more convenient analysis in many cases
  - computer simulation with reasonable computational complexity

Complex Baseband

- Any bandpass signal (particularly linearly modulated signals) can be represented in a format termed *Inphase and Quadrature (I&Q)* form

$$s(t)=s_I(t)\cos(2\pi f_c t)-s_Q(t)\sin(2\pi f_c t)$$

where $s_I(t)$ is termed the *inphase* channel and $s_Q(t)$ is termed the *quadrature* channel

- Note that the inphase and quadrature carriers $\cos(2\pi f_c t)$ and $\sin(2\pi f_c t)$ are orthogonal to each other
- Note further that in complex numbers the real and imaginary parts are also orthogonal.
- This leads us to define a complex baseband signal as

$$\tilde{s}(t)=s_I(t)+js_Q(t)$$

Complex baseband – cont.

- We may thus write

$$s(t) = \mathrm{Re}\left\{\tilde{s}(t)e^{j2\pi f_c t}\right\}$$

where $\tilde{s}(t)$ is the complex baseband and $e^{j2\pi f_c t}$ is the complex carrier

- Note that the complex baseband is useful because
  - we can determine the spectrum of the bandpass signal from the complex baseband
  - we can analyze the performance by examining the complex baseband
  - we can simulate the bandpass signal using the complex baseband since the highest frequency of the complex baseband is significantly less than the bandpass signal
- Note also that the complex baseband is a fictitious signal

Spectrum of Bandpass Signals

$$s(t) = \mathrm{Re}\left\{\tilde{s}(t)e^{j\omega_c t}\right\}$$

$$= \frac{1}{2}\tilde{s}(t)e^{j\omega_c t} + \frac{1}{2}\tilde{s}^*(t)e^{-j\omega_c t}$$

$$S(f) = F\left\{\frac{1}{2}\tilde{s}(t)e^{j\omega_c t} + \frac{1}{2}\tilde{s}^*(t)e^{-j\omega_c t}\right\}$$

$$= \frac{1}{2}F\left\{\tilde{s}(t)e^{j\omega_c t}\right\} + \frac{1}{2}F\left\{\tilde{s}^*(t)e^{-j\omega_c t}\right\}$$

$$= \frac{1}{2}\tilde{S}(f - f_c) + \frac{1}{2}\tilde{S}^*(-(f + f_c))$$

$$= \frac{1}{2}\tilde{S}(f - f_c) + \frac{1}{2}\tilde{S}^*(-f - f_c)$$

Complex Baseband for AM Signals

Type of Modulation	$s_I(t)$	$s_Q(t)$	Comments
AM	$1+k_a m(t)$	0	k_a = sensitivity constant $m(t)$ is message signal
DSB-SC	$m(t)$	0	
SSB – Upper sideband tx	$\frac{1}{2} m(t)$	$\frac{1}{2}\widehat{m}(t)$	$\widehat{m}(t)$ is the Hilbert transform of the message
SSB – Lower sideband tx	$\frac{1}{2} m(t)$	$-\frac{1}{2}\widehat{m}(t)$	
VSB – Lower sideband tx	$\frac{1}{2} m(t)$	$\frac{1}{2} m'(t)$	$m'(t)$ is the quadrature portion of the VSB filter response
VSB – Upper sideband tx	$\frac{1}{2} m(t)$	$-\frac{1}{2} m'(t)$	

Comparison of AM schemes

Type of Modulation	*Bandwidth for message bandwidth of W*	*Power Efficiency*	Comments
AM	$2W$	Least efficient	*Least complex*
DSB-SC	$2W$	More efficient than AM	Requires coherent demodulator
Single Sideband	W	Same efficiency as DSB-SC	Requires coherent demodulator; Requires complex transmitter
Vestigial Sideband	$W(1+\Delta)$ $(0<\Delta<1)$	Same efficiency as DSB-SC	Requires coherent demodulator; tx less complex than SSB

Commercial Examples of AM

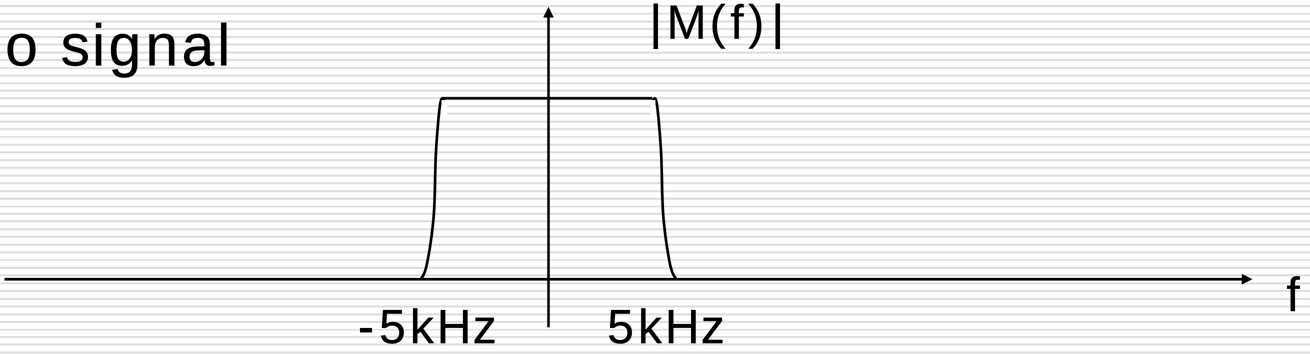
- AM is used in broadcast services due to
  - extremely cheap receivers – important for mass market
  - decent bandwidth efficiency (as compared to FM)
- Most common examples
  - Broadcast radio – Large Carrier AM
  - Broadcast Television – Video portion transmitted using VSB

Broadcast AM Radio

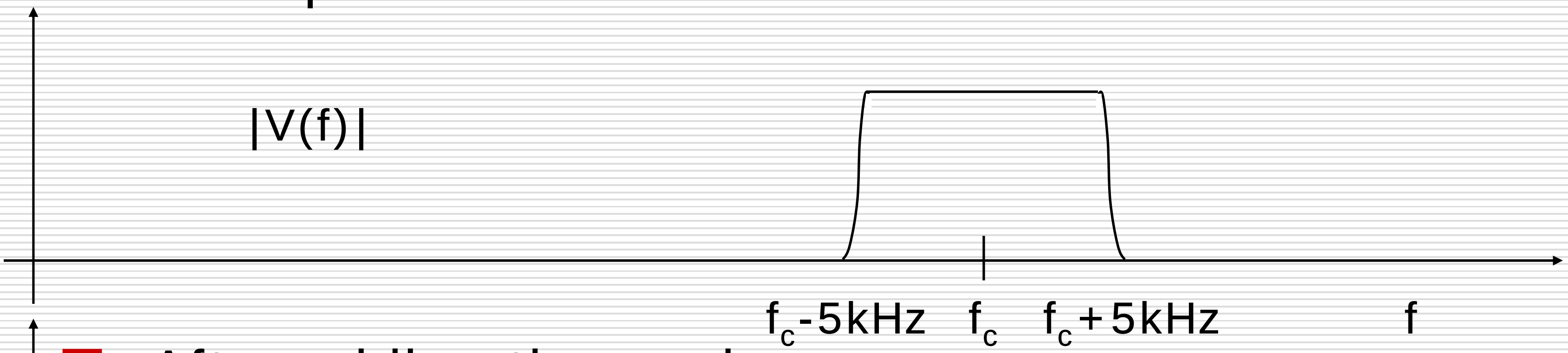
- Uses Large Carrier AM modulation
- Frequency spectrum from 540 kHz to 1700 kHz
- 10 kHz channel spacing
  - Allows for 5kHz baseband message
  - Sufficient for voice and low frequency music
  - NOTE: The FCC allows some stations to broadcast a 10kHz message signal which spills into neighboring channels
- Transmitted power:
  - up to 50 kW, depending on license
- Radios for AM are very cheap to build, but have very low gain antennas
  - good propagation conditions and high transmit power allow reception of AM signals.

Broadcast AM Radio – cont.

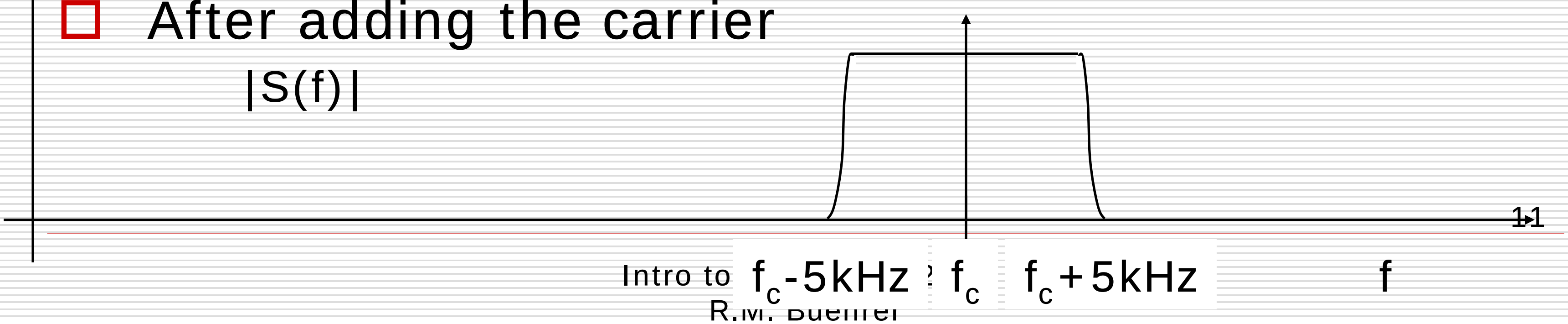
- Audio signal



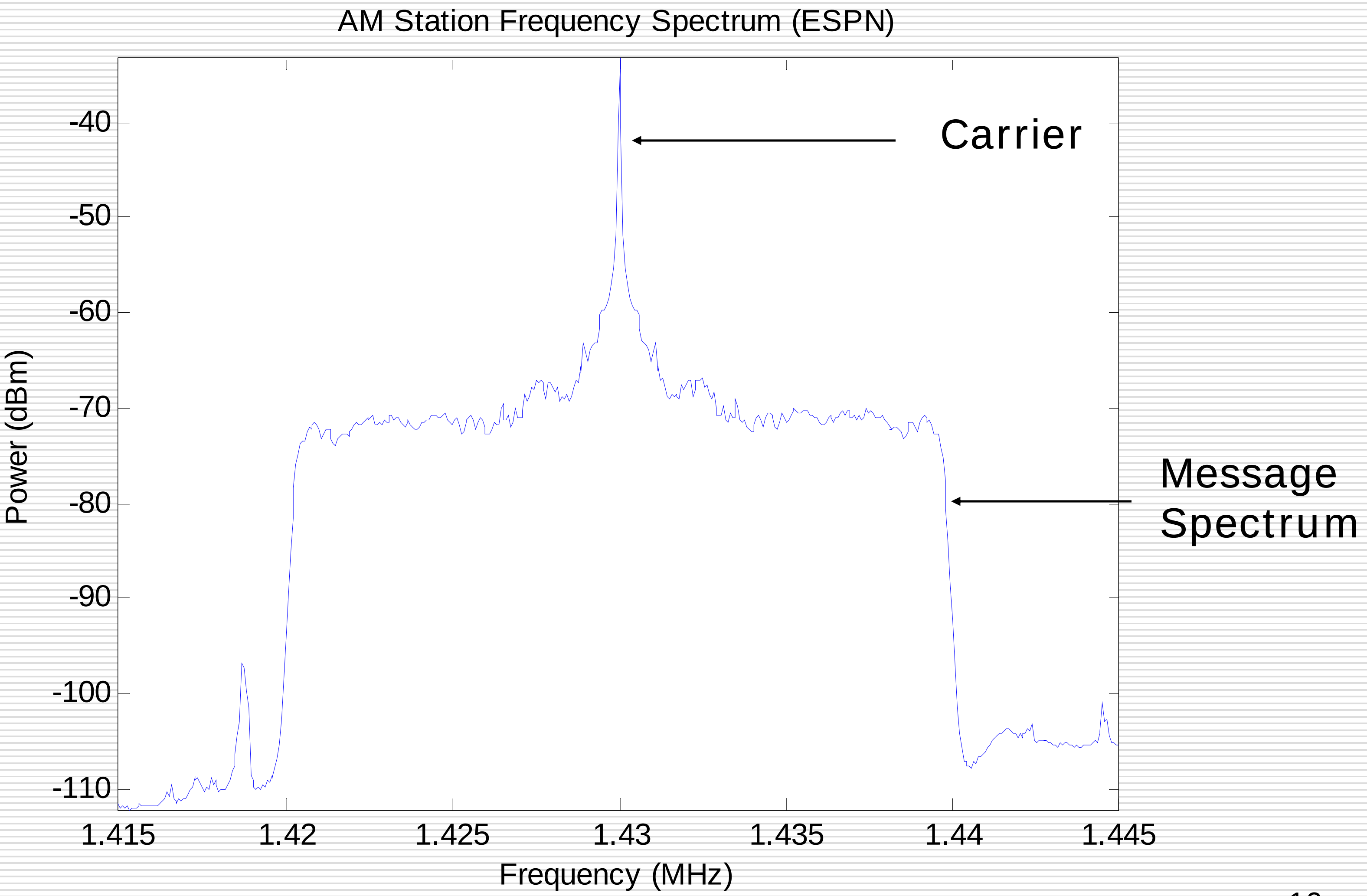
- After product modulation



- After adding the carrier



Example – 1430AM (1430kHz)



Broadcast Television

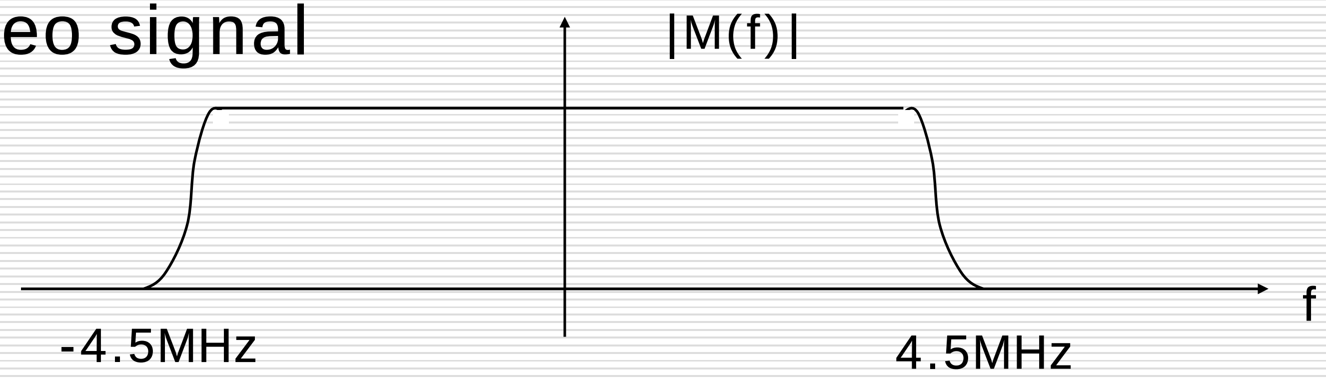
- Video signals have extremely large bandwidth (esp. compared to voice or music)
  - Voice signals ~ 3.4kHz
  - Music ~ 16kHz
  - Video ~ 4.5 MHz
- We still require a cheap receiver
- The first point above leads to Vestigial Sideband modulation
- The second point above leads to the addition of a carrier to allow envelope detection

Analog Broadcast Television

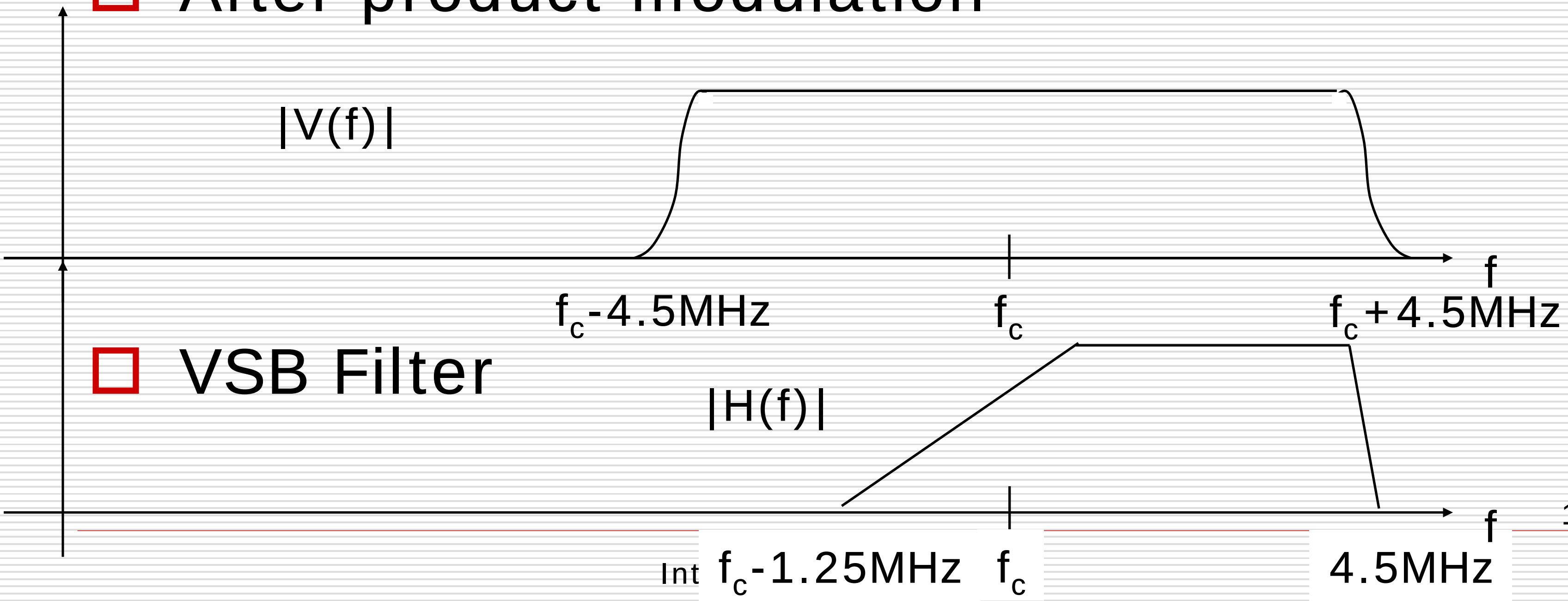
- Channel Bandwidth: 6 MHz
- Modulation type: Vestigial Sideband AM
  - Carrier frequency is located 1.25 MHz from lowest frequency in channel
  - Luminance VSB-AM modulates picture carrier
  - Chrominance VSB-QAM modulates color subcarrier
    - Color subcarrier is located 3.58 MHz from bottom of the channel
- Audio Modulation
  - FM with bandwidth of 50kHz
  - Audio subcarrier is located 4.5 MHz from bottom of channel

Broadcast Television – cont.

- ☐ Video signal

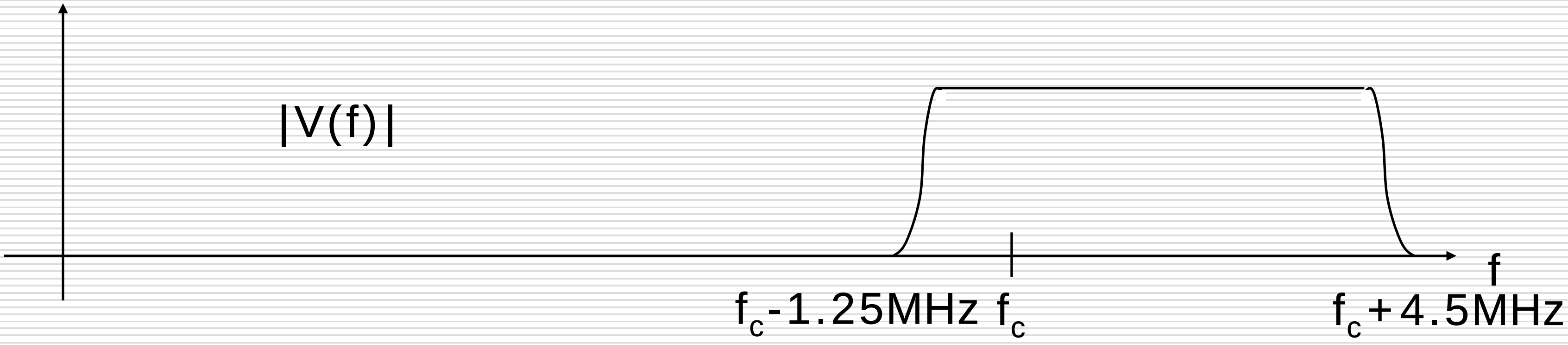


- ☐ After product modulation
- ☐ VSB Filter

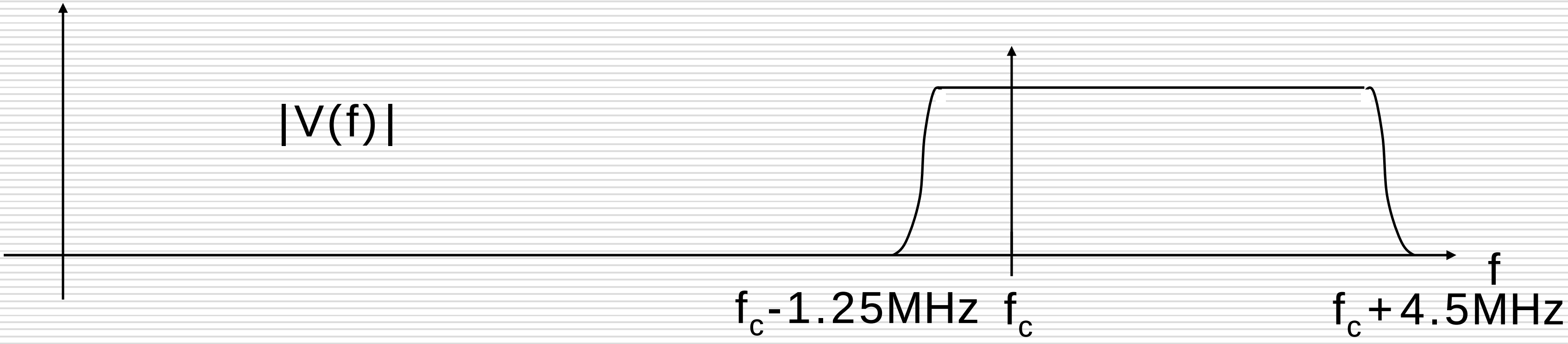


Broadcast Television – cont.

- VSB signal

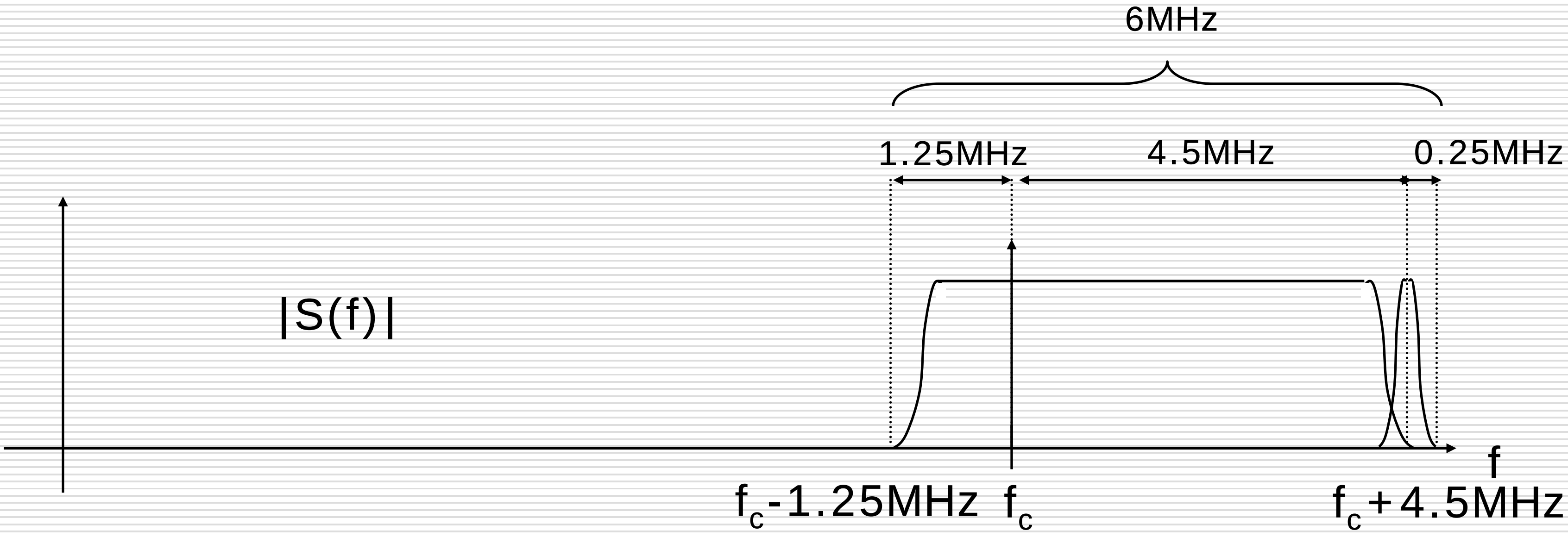


- After adding an unmodulated carrier

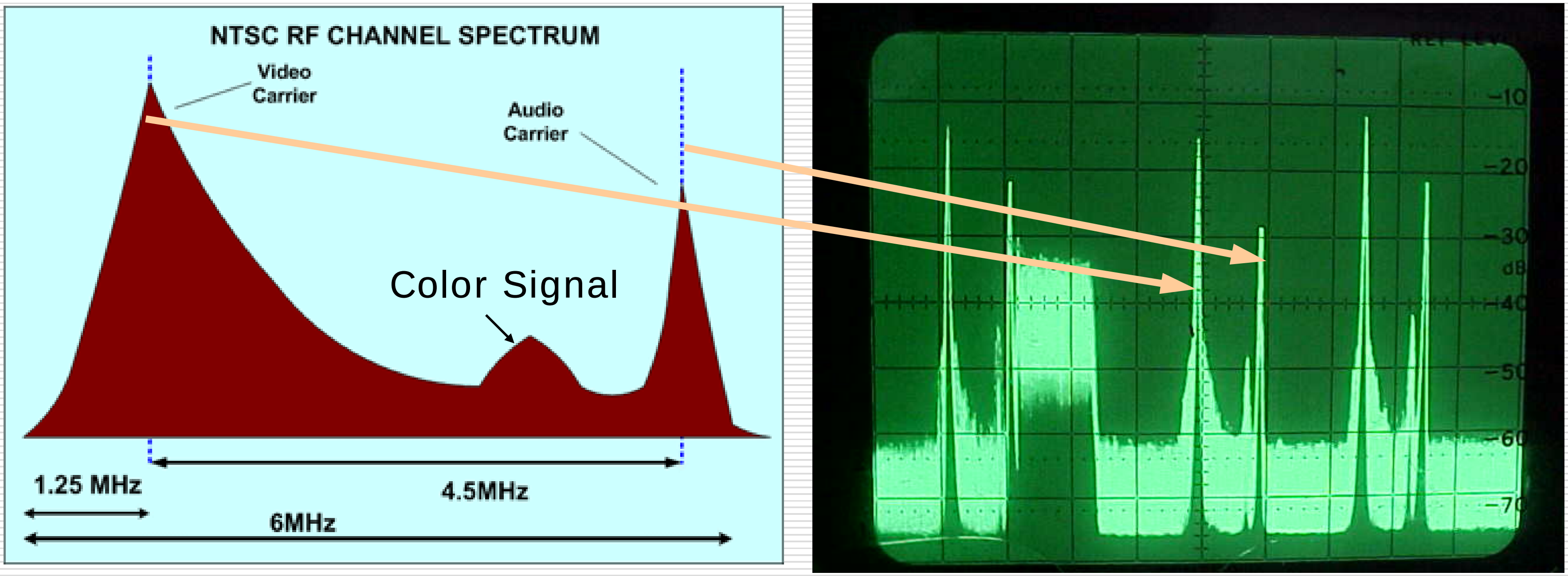


Broadcast Television – cont.

- Finally the audio signal is added at 4.5MHz above the picture carrier
- This signal is an FM signal with BW of 0.5MHz



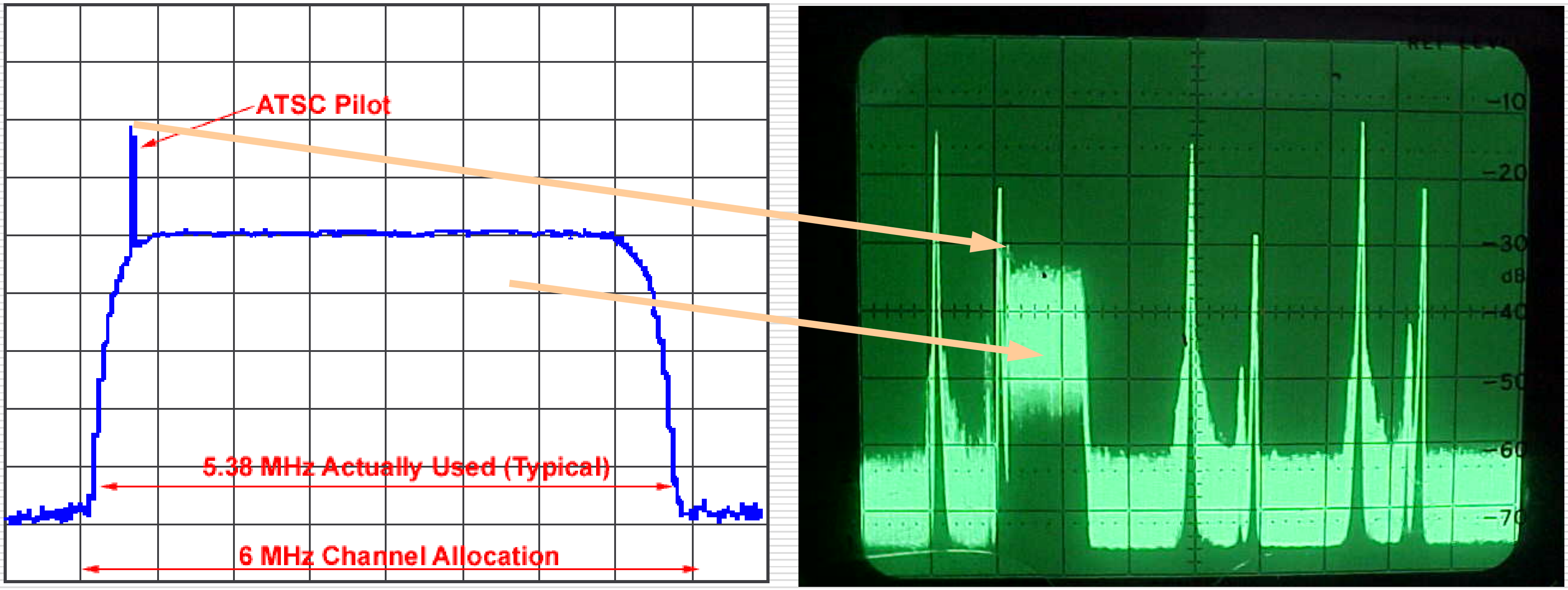
Example Analog TV Spectrum



- Power primarily confined to Video and Audio carriers.
- Distinctive double peaked spectrum makes identification by spectrum profiling relatively easy.
- *This slide taken from "Exploring the Feasibility and Benefits of Additional Uses of Unused TV Broadcast Spectrum", by Carl R. Stevenson*

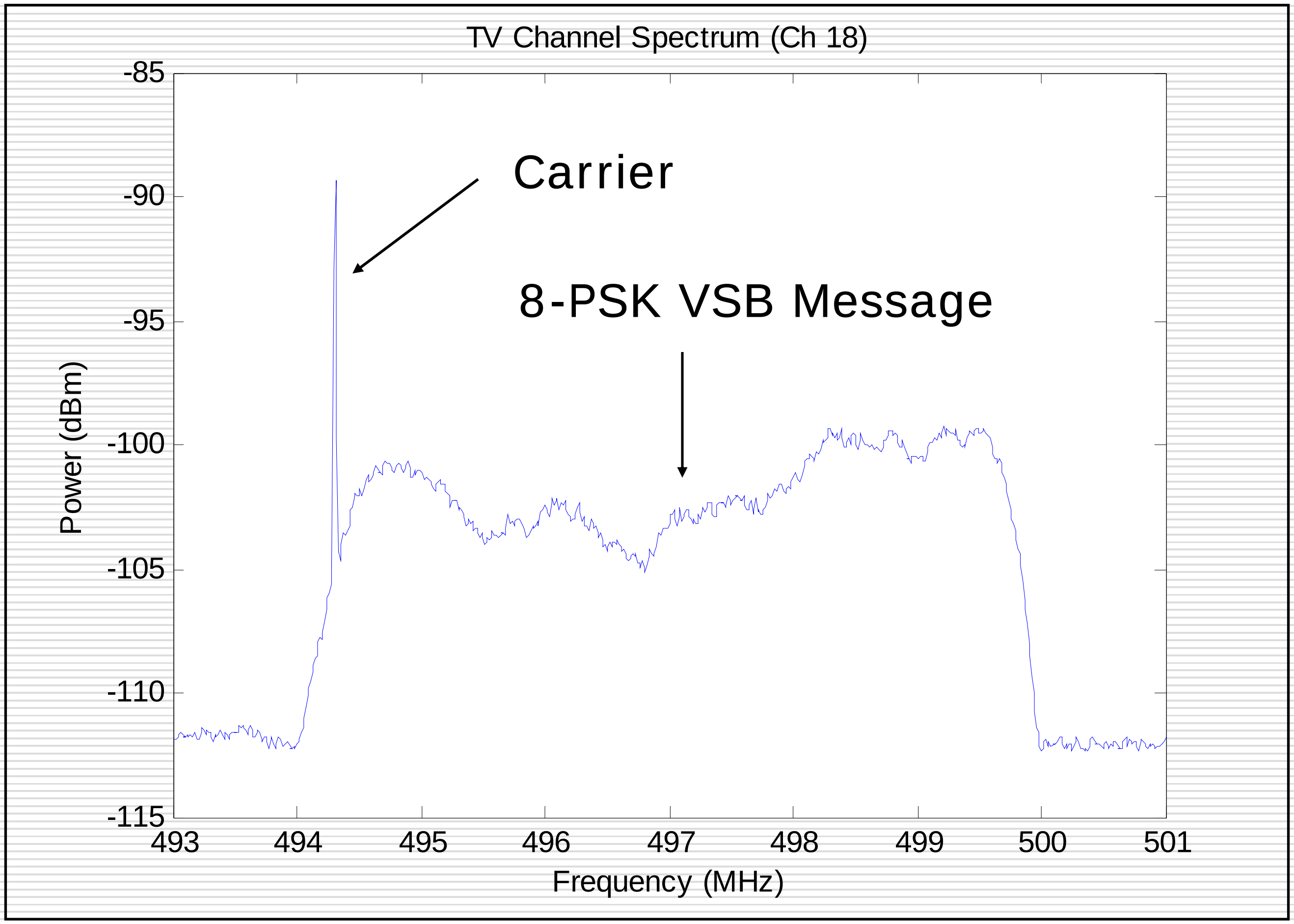
Example - Digital TV Spectrum

VSB – 8PSK Modulation

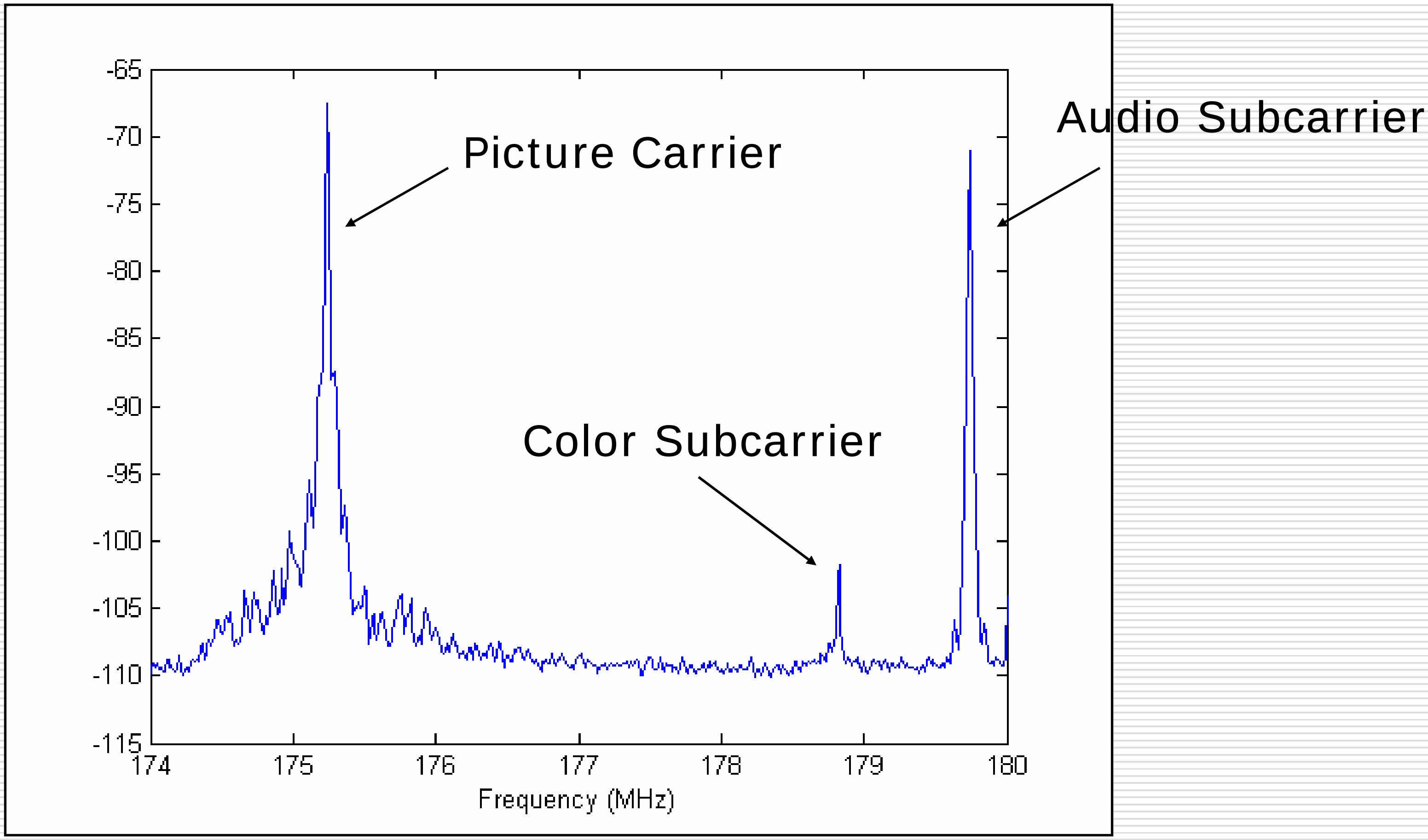


- Power spread over center 5.38 MHz within a TV channnel.
- Pilot tone is a distinct and is 11.3 dB below average power measured in a 6 MHz bandwidth
- *This slide taken from "Exploring the Feasibility and Benefits of Additional Uses of Unused TV Broadcast Spectrum", by Carl R. Stevenson*.

Example – Digital TV (Channel 18)



Example – Analog TV (Channel 7)

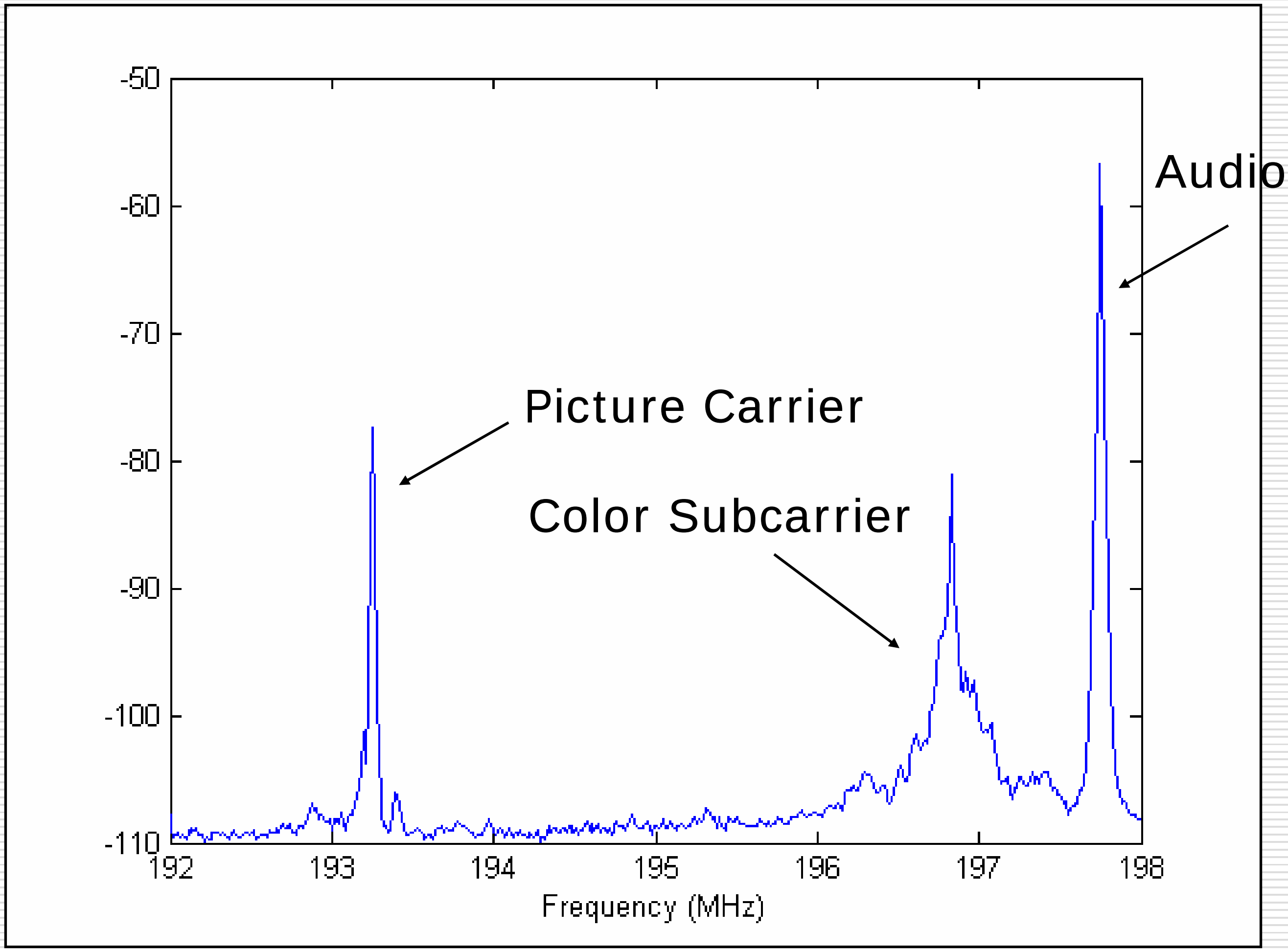


Picture Carrier

Audio Subcarrier

Color Subcarrier

Example – Analog TV (Channel 10)



Audio Subcarrier

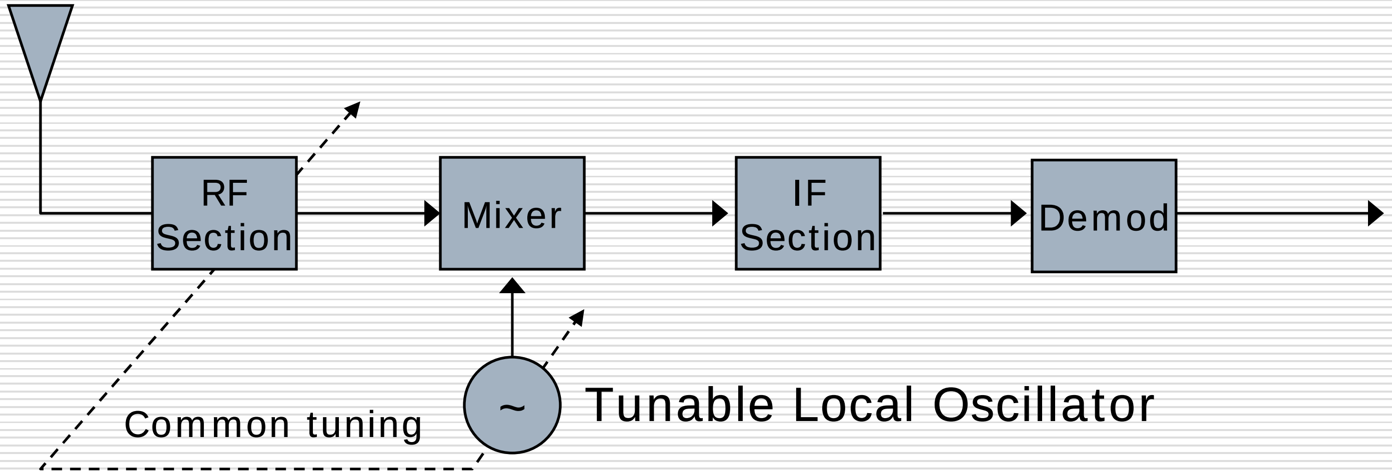
Picture Carrier

Color Subcarrier

Superheterodyne Receiver

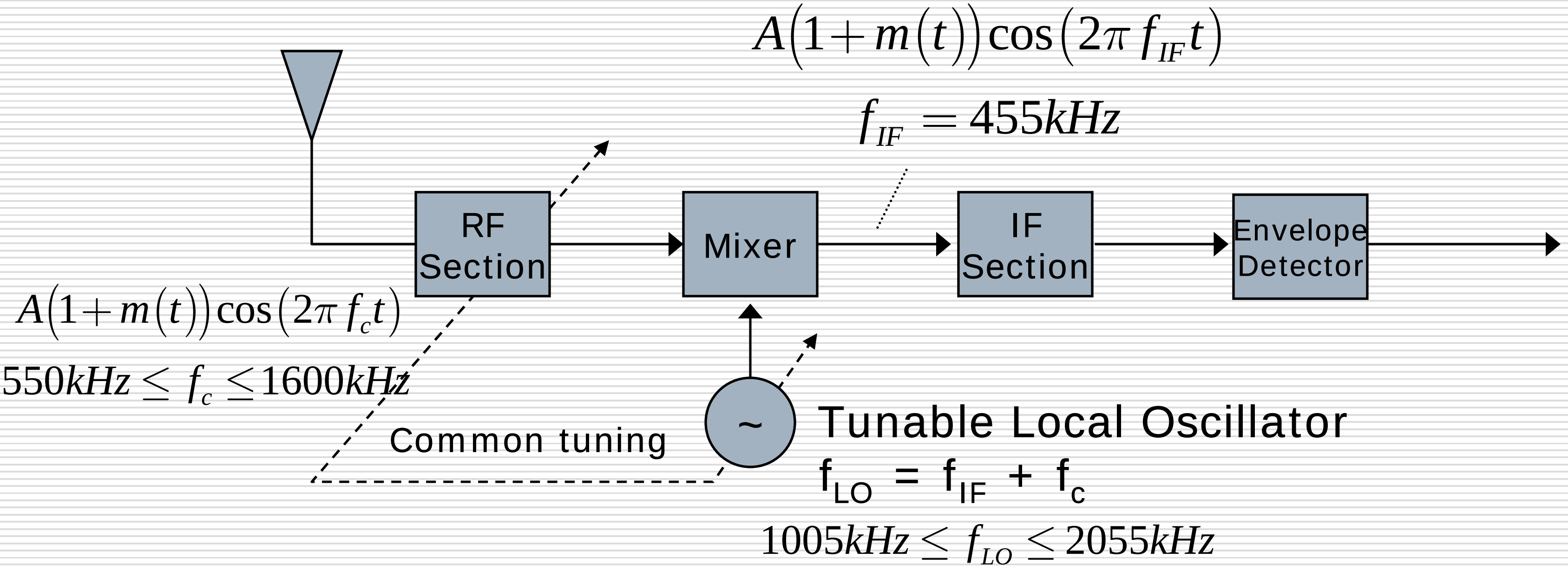
- The receiver for any broadcast system (e.g., AM or FM radio or TV) must
  - tune to the proper carrier frequency (based on the channel desired)
  - filter the desired channel to eliminate other channels
  - amplify the received signal (compensates for the loss in power from the transmitter to the receiver)
- One of the most common receiver structures for such systems
- Overcomes the difficulty of building a highly selective (i.e., narrow filters) receiver at very high frequencies
- Receiver sections
  - A radio frequency (RF) section
  - A mixer/local oscillator section
  - An intermediate frequency (IF) section
  - Final demodulator/detector (determines the message)

Superhet Receiver – cont.



- RF section has tunable filter with bandwidth much larger than the desired signal bandwidth (makes it easier to build) and low-noise amplifier
- Mixer multiplies the signal by local oscillator and filters image to translate the signal down to fixed intermediate frequency (same no matter what channel is being received)
- IF section has filter with fixed bandwidth and fixed center frequency
- Demodulator converts the IF carrier wave back to the original message signal

Example AM Radio



$A\left(1+m(t)\right)\cos\left(2\pi f_{IF}t\right)$

$f_{IF} = 455kHz$

$A\left(1+m(t)\right)\cos\left(2\pi f_c t\right)$

$550kHz \le f_c \le 1600kHz$

Tunable Local Oscillator

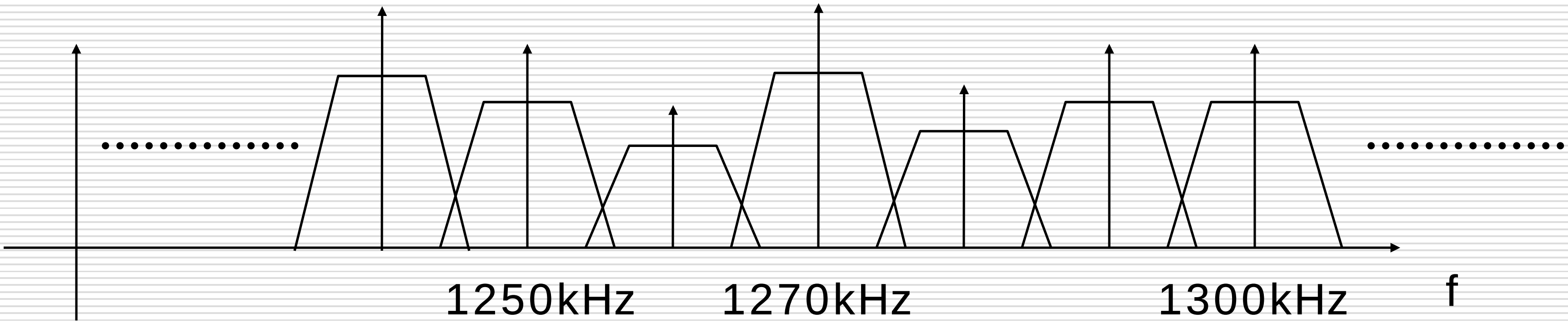
$f_{LO} = f_{IF} + f_c$

$1005kHz \le f_{LO} \le 2055kHz$

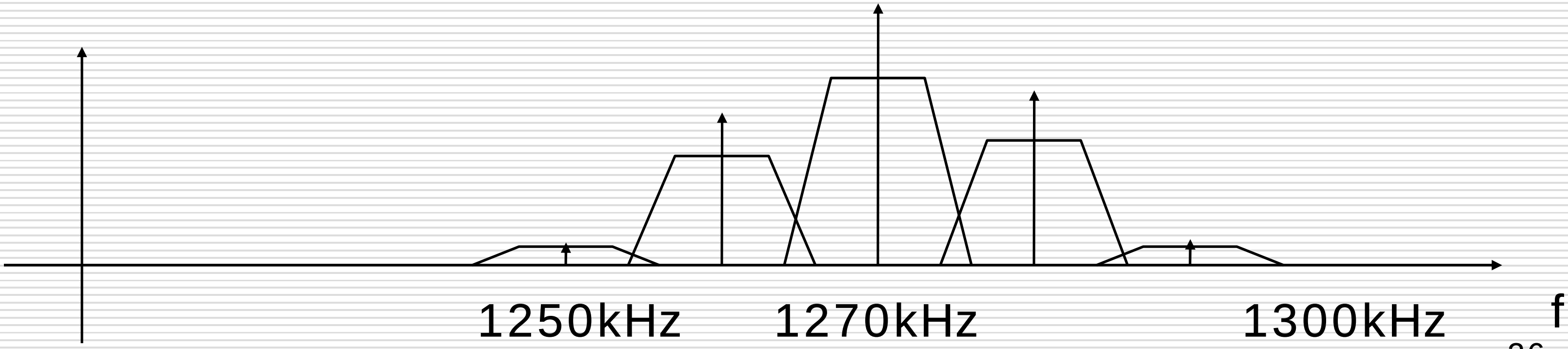
- Tuner changes the LO frequency and the front end filter center frequency at the same time
- IF section has selection filter with bandwidth of 10kHz
- RF has bandwidth much greater than 10kHz

Example – cont.

- ☐ Received signal spectrum

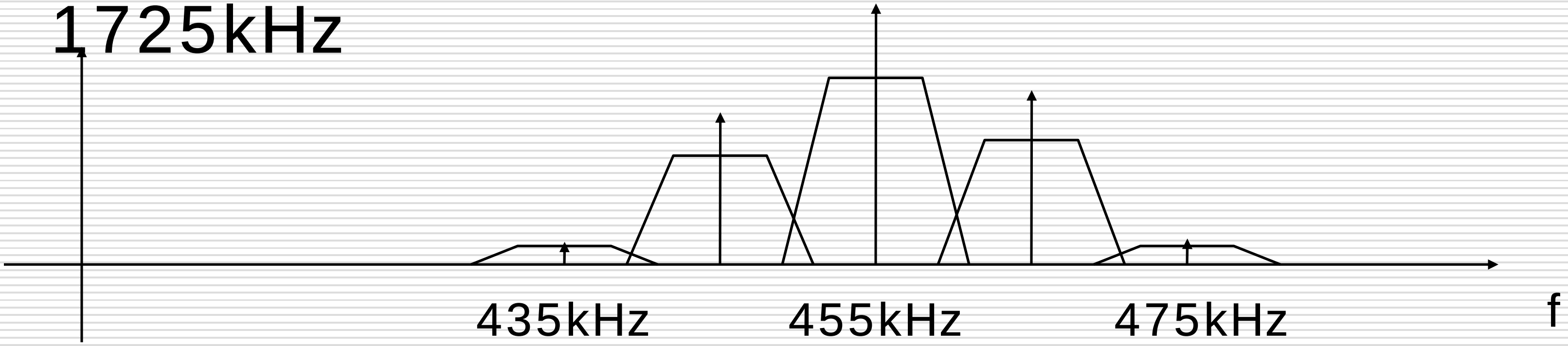


- ☐ After RF filter tuned to 1270kHz

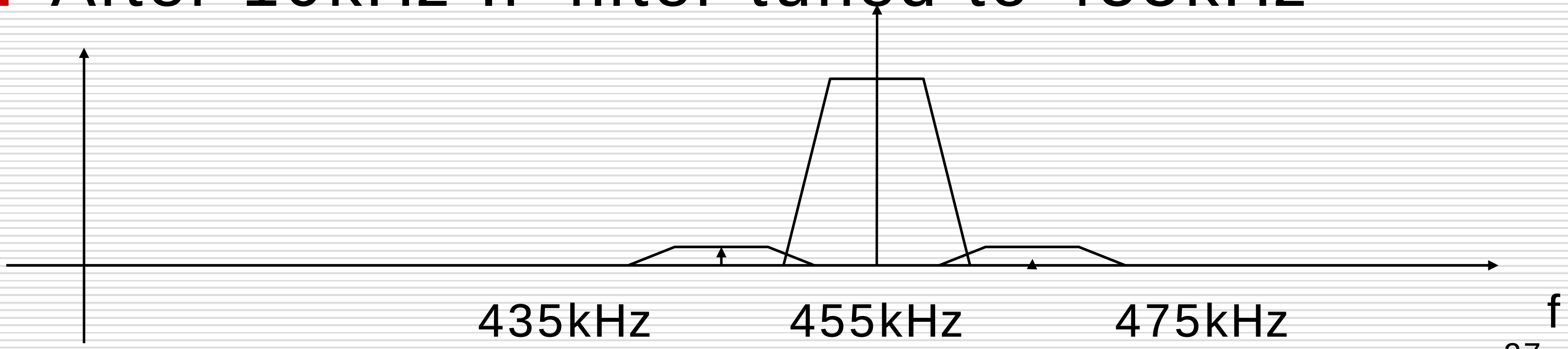


Example – cont.

- After mixing with oscillator tuned to 1725kHz



- Note: Image at 1995kHz is eliminated by filters in the mixer
- After 10kHz IF filter tuned to 455kHz



Superhet Parameter Examples

	AM Radio	FM Radio
RF Carrier Range	0.535-1.605 MHz	88-108MHz
IF Frequency	0.455 MHz	10.7 MHz
IF Bandwidth	10kHz	200kHz

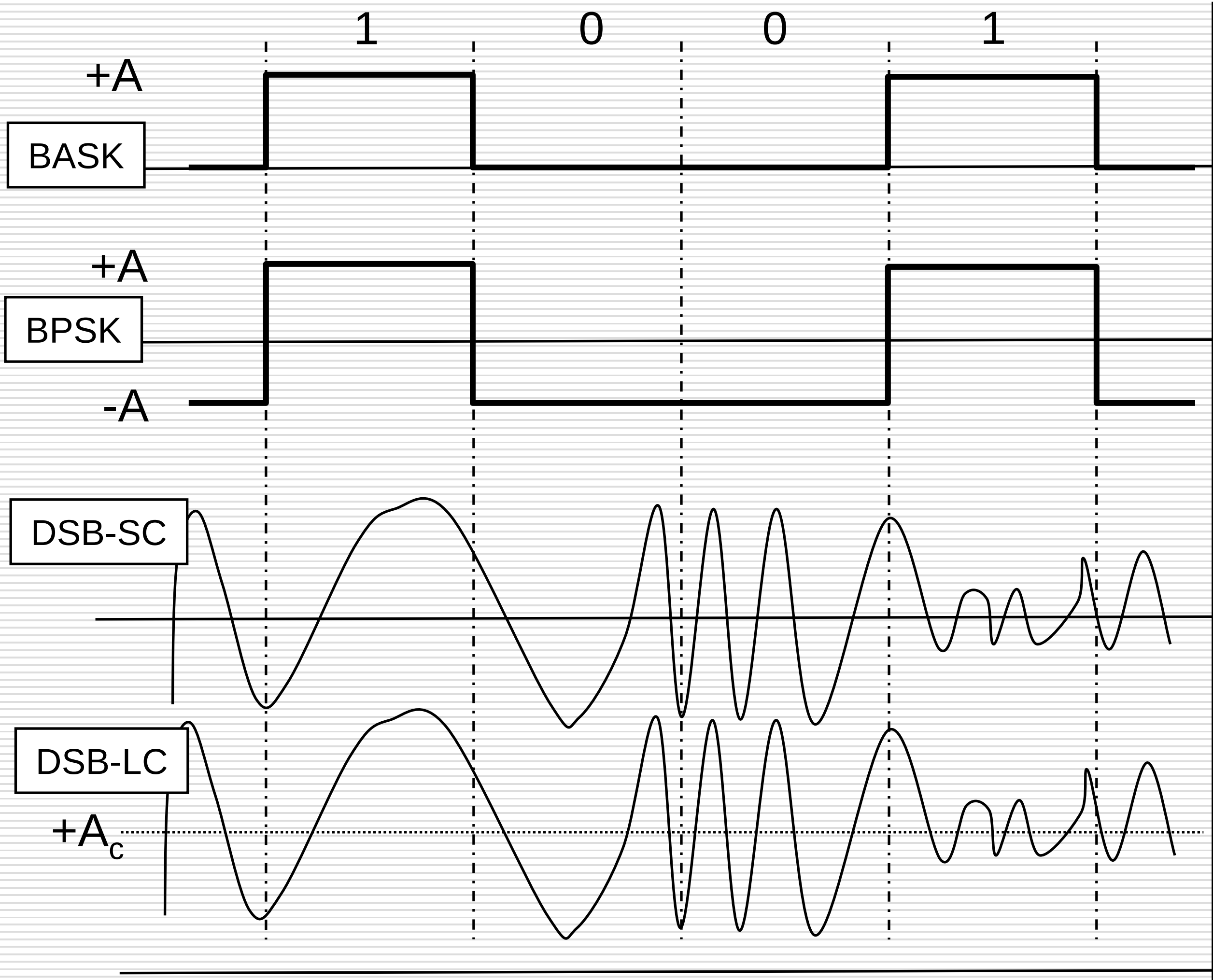
Up converting vs. Down converting

- When mixing the incoming signal to an IF range, we can use either up conversion or down conversion
- Ex: Typical AM radio RF value is 1410 kHz while IF is 455kHz
  - LO frequency could be 955 kHz
    - produces signals at 455 kHz and 2365 kHz
  - LO frequency could also be 1865 kHz
    - produces signals at 455 kHz and 3275 kHz
  - The first approach would require LO frequencies between 95 kHz and 1145 kHz (12:1 ratio)
  - The second approach would require frequencies between 1005 kHz and 2055 kHz (2:1 ratio)

Relationship between AM and Digital Modulation

- DSB-LC AM → BASK
  - Message is entirely in the amplitude
- DSB-SC AM → BPSK, BASK
  - Message is in the phase and amplitude
  - In BPSK, amplitude is always 1 since the message is square wave.
  - In BASK the message signal doesn't go negative so there are no phase changes.
- SSB AM → QPSK
  - Since message is all real, we can eliminate ½ of spectrum
  - QPSK is based on fact that since a real message only needs ½ of the spectrum, 2 messages can be sent in quadrature in original BW

Relationship Between Analog and Digital Modulation Schemes



Unipolar NRZ	Amplitude Only
Polar NRZ	Phase Only
Arbitrary Analog signal	Amplitude and Phase
Arbitrary Analog signal with offset	Amplitude Only
Message	What is modulated?

Summary

- Today's lecture finalizes our discussion of AM analog modulation
  - We will discuss noise performance later in the course
- We examined two common examples of AM
  - Broadcast radio
  - Broadcast TV
- We also examined a common receiver architecture for broadcast systems – the superheterodyne receiver
- We will examine FM next