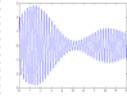


ECE3614
Introduction to
Communications Systems
Fall 2007

Instructor: Dr. R. Michael Buehrer
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

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

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

$$\begin{aligned} s(t) &= \text{Re}\{\tilde{s}(t)e^{j\omega_c t}\} \\ &= \frac{1}{2}\tilde{s}(t)e^{j\omega_c t} + \frac{1}{2}\tilde{s}^*(t)e^{-j\omega_c t} \\ S(f) &= F\left\{\frac{1}{2}\tilde{s}(t)e^{j\omega_c t} + \frac{1}{2}\tilde{s}^*(t)e^{-j\omega_c t}\right\} \\ &= \frac{1}{2}F\{\tilde{s}(t)e^{j\omega_c t}\} + \frac{1}{2}F\{\tilde{s}^*(t)e^{-j\omega_c t}\} \\ &= \frac{1}{2}\tilde{S}(f - f_c) + \frac{1}{2}\tilde{S}^*(-f + f_c) \\ &= \frac{1}{2}\tilde{S}(f - f_c) + \frac{1}{2}\tilde{S}^*(-f - f_c) \end{aligned}$$

Complex Baseband for AM Signals

Type of Modulation	$s_i(t)$	$s_o(t)$	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	$\frac{1}{2} m(t)$	$\frac{1}{2} \hat{m}(t)$	$\hat{m}(t)$ is the Hilbert transform of the message
SSB – Lower sideband tx	$\frac{1}{2} m(t)$	$-\frac{1}{2} \hat{m}(t)$	
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	$\frac{1}{2} m(t)$	$-\frac{1}{2} m'(t)$	

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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

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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

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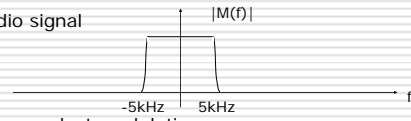
Broadcast AM Radio

- 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.

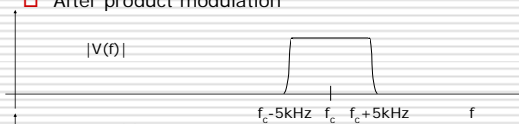
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Broadcast AM Radio – cont.

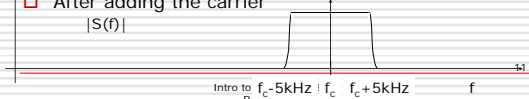
- Audio signal



- After product modulation

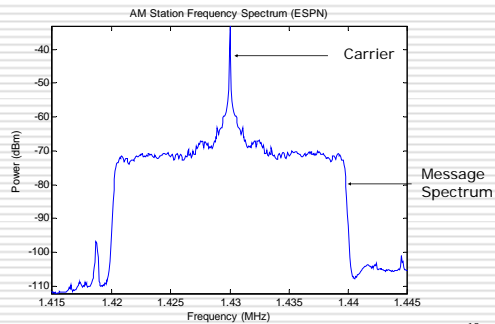


- After adding the carrier



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Example – 1430AM (1430kHz)



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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

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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

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Broadcast Television – cont.

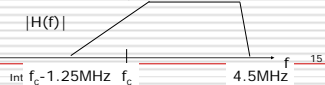
- Video signal



- After product modulation



- VSB Filter

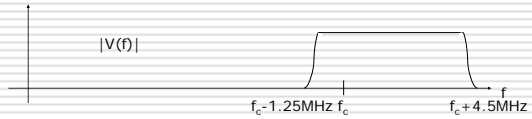


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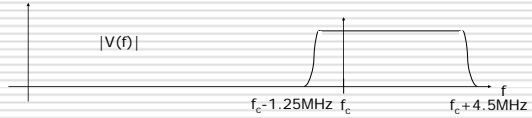
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Broadcast Television – cont.

- VSB signal



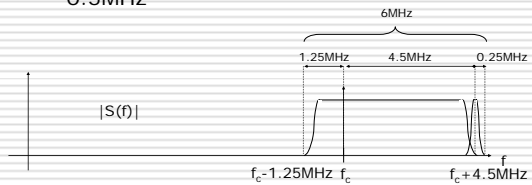
- After adding an unmodulated carrier



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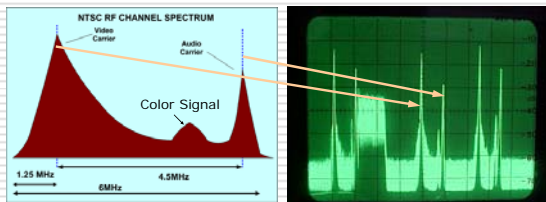
Broadcast Television – cont.

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



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Example Analog TV Spectrum

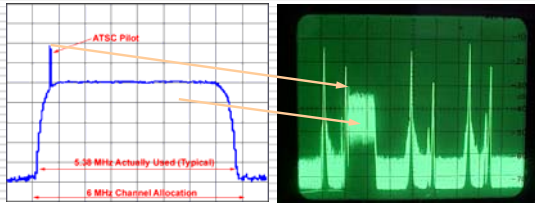


- Power primarily confined to Video and Audio carriers.
- Distinctive double peaked spectrum makes identification by spectrum profiling relatively easy.
- This slide taken from "Exploring the Feasibility and Benefits of Additional Uses of Unused TV Broadcast Spectrum", by Carl R. Stevenson

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Example - Digital TV Spectrum

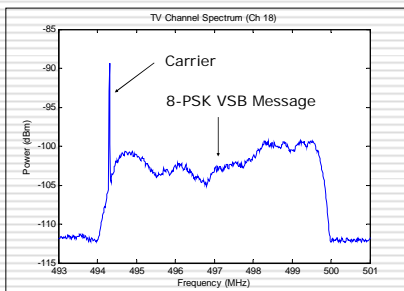
VSB – 8PSK Modulation



- Power spread over center 5.38 MHz within a TV channel.
- 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.

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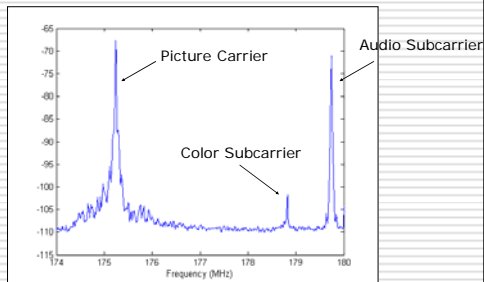
Example – Digital TV (Channel 18)



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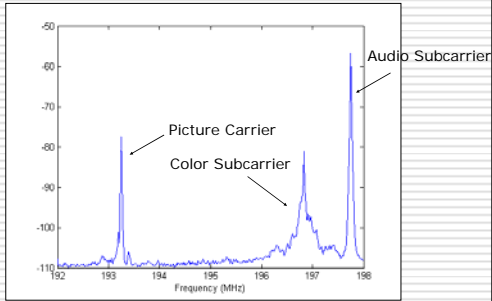
Example – Analog TV (Channel 7)



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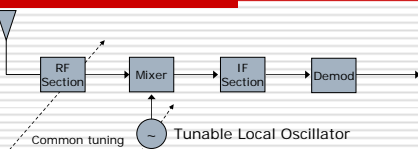
Example – Analog TV (Channel 10)



Superheterodyne Receiver

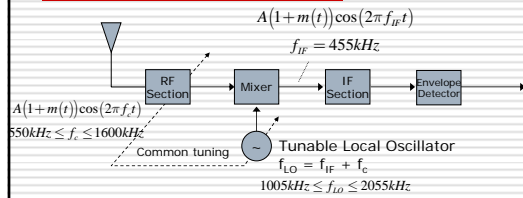
- The receiver for any broadcast system (e.g., AM or FM radio or TV) must
 - tune to the proper carrier frequency (based on the channel desired)
 - filter the desired channel to eliminate other channels
 - amplify the received signal (compensates for the loss in power from the transmitter to the receiver)
- 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

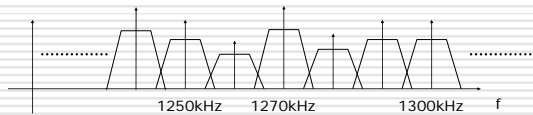
Example AM Radio



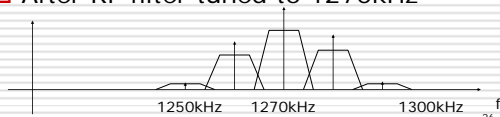
- Tuner changes the LO frequency and the front end filter center frequency at the same time
- IF section has selection filter with bandwidth of 10kHz
- RF has bandwidth much greater than 10kHz

Example – cont.

- Received signal spectrum

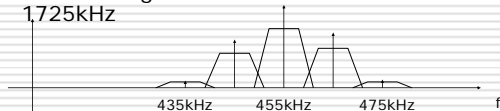


- After RF filter tuned to 1270kHz

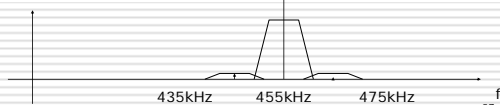


Example – cont.

- 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

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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)

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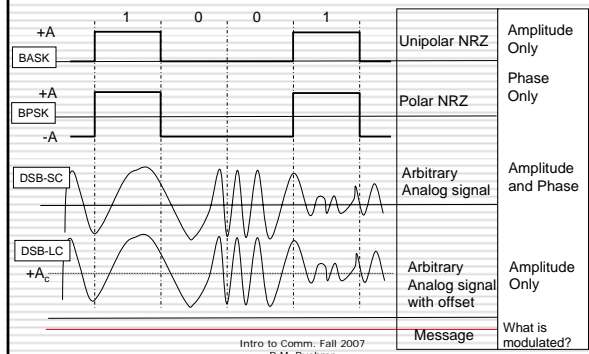
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Relationship between AM and Digital Modulation

- 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

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Relationship Between Analog and Digital Modulation Schemes



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
