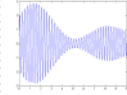


ECE3614
Introduction to
Communications Systems
Fall 2007

Instructor: Dr. R. Michael Buehrer
Lecture #10: DSBSC Amplitude
Modulation



Overview

- We are currently studying analog modulation schemes where an analog message signal modulates a sinusoidal carrier
- Specifically we are studying amplitude modulation schemes
- Previously we examined large carrier AM which is not particularly energy efficient
- Today we will study an AM scheme that uses energy more efficiently by eliminating the unmodulated carrier
- Reading
 - Sections 3.3 – 3.5

Objectives

- The main objectives of this lecture are
 - To demonstrate the power efficiency of Large Carrier AM
 - To motivate and describe Double Sideband Suppressed Carrier (DSB-SC) AM
 - To demonstrate the improved power efficiency (by higher receive complexity) of DSB-SC AM

Power Efficiency of AM

- Recall the transmitted signal for simple Amplitude Modulation

$$s(t) = A_c [1 + k_a m(t)] \cos(2\pi f_c t)$$

- If the message is a sinusoid [$m(t) = \cos(2\pi f_m t)$] the fraction of the total power present in the message is

$$\frac{P_m}{P_{tot}} = \frac{A_c^2 k_a^2 / 4}{A_c^2 / 2 + A_c^2 k_a^2 / 4} = \frac{k_a^2}{2 + k_a^2}$$

- For $k_a = 0.5$, only 1/9 of the total power is devoted to the message.
- For $k_a = 1$ (full modulation), still only 1/3 of the total power is devoted to the message
- This is due to the fact that we waste power in the unmodulated carrier

Improving Power Efficiency of AM

- We can improve the power efficiency of AM by removing the unmodulated carrier altogether
- This is termed Double Sideband Suppressed Carrier (DSB-SC) AM

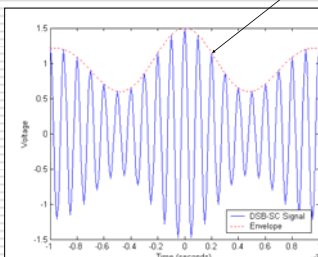
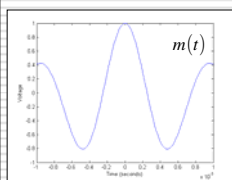
$$s(t) = A_c m(t) \cos(2\pi f_c t)$$

- Now, all of the power is devoted to the message – more power efficient
- However, a simple envelope detector is not possible, as we will see

Example 10.1

- Large Carrier AM ($k_a = 0.5$)

$$s(t) = A_c [1 + k_a m(t)] \cos(2\pi f_c t)$$

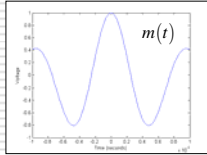


Example 10.1 – cont.

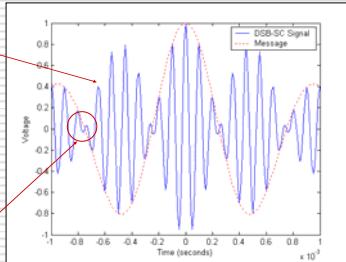
Double Side Band Suppressed Carrier

$$s(t) = A_m(t) \cos(2\pi f_c t)$$

Envelope doesn't follow message



Phase reversals occur whenever message signal is negative



Spectrum of DSBSC

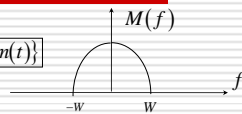
- The spectrum $S(f)$ can be determined from Fourier Theory using the modulation property

$$\begin{aligned} S(f) &= F\{s(t)\} \\ &= F\{A_m(t) \cos(2\pi f_c t)\} \\ &= \frac{A_c}{2} \{M(f - f_c) + M(f + f_c)\} \end{aligned}$$

- Note that the spectrum is similar to Large Carrier AM with the exception that there are no delta functions at \pm carrier frequency

Spectrum of DSB-SC AM

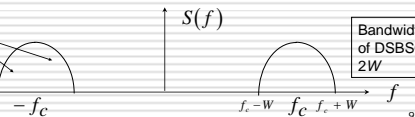
$$M(f) = F\{m(t)\}$$



Bandwidth of message : W
Message

$$S(f) = \frac{A_c}{2} \{M(f - f_c) + M(f + f_c)\}$$

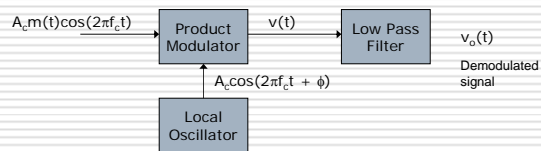
Since both "sidebands" are present we call this *double sideband*



Bandwidth of DSBSC: $2W$

Product Detector

- As we stated previously, we can no longer use a simple envelope detector as a receiver
 - Envelope doesn't follow message signal
- However we can still recover the message through the use of a product detector



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Product Modulator – cont.

- At the output of the product modulator we have
- $$v(t) = A_c m(t) \cos(2\pi f_c t) A_c \cos(2\pi f_c t + \phi)$$
- Let's assume that $\phi = 0$. (We will return to this assumption later.)

$$\begin{aligned} v(t) &= A_c^2 m(t) \cos^2(2\pi f_c t) \\ &= A_c^2 m(t) \frac{1}{2} \{1 + \cos(4\pi f_c t)\} \\ &= \frac{A_c^2}{2} m(t) + \frac{A_c^2}{2} m(t) \cos(4\pi f_c t) \end{aligned}$$

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Product Modulator – cont.

- Now, since the message signal is low pass with bandwidth W , as long as the bandwidth of the LPF is greater than W and less than $2f_c - W$, at the output of the LPF we will get a scaled version of the message signal

$$\begin{aligned} v_o(t) &= LPF \left\{ \frac{A_c^2}{2} m(t) + \frac{A_c^2}{2} m(t) \cos(4\pi f_c t) \right\} \\ &= \frac{A_c^2}{2} m(t) \end{aligned}$$

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Product Detector – Frequency Domain

- At the output of the product demodulator we have

$$V(f) = \frac{A_c}{2} \{M(f-f_c) + M(f+f_c)\} * \frac{A_c}{2} \{\delta(f-f_c) + \delta(f+f_c)\}$$

$$= \frac{A_c^2}{4} \{2M(f) + M(f+2f_c) + M(f-2f_c)\}$$

- If the LPF has a transfer function $H(f)$

$$H(f) = \text{rect}\left(\frac{f}{2B}\right)$$

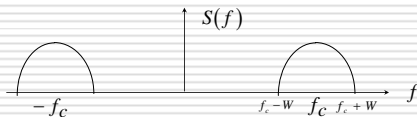
where $2f_c > B > W$, then

$$V_o(f) = \frac{A_c^2}{2} M(f)$$

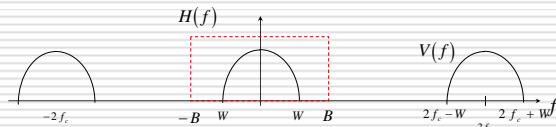
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Frequency Domain – cont.

- The received signal spectrum



- At the output of the product detector:



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Importance of Phase Coherence

- In the previous example, we assumed that the phase of the locally generated carrier was the same as the incoming signal
- What impact does this have?
- At the output of the product detector we have:

$$v(t) = A_c m(t) \cos(2\pi f_c t) A_c \cos(2\pi f_c t + \phi)$$

$$= A_c^2 m(t) \frac{1}{2} \{\cos(\phi) + \cos(4\pi f_c t + \phi)\}$$

$$= \frac{A_c^2}{2} m(t) \cos(\phi) + \frac{A_c^2}{2} m(t) \cos(4\pi f_c t + \phi)$$

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Impact of Phase Coherence – cont.

- At the output of the low pass filter we have

$$v_o(t) = LPF \left\{ \frac{A^2}{2} m(t) \cos(\phi) + \frac{A^2}{2} m(t) \cos(4\pi f_c t + \phi) \right\}$$

$$= \frac{A^2}{2} m(t) \cos(\phi)$$

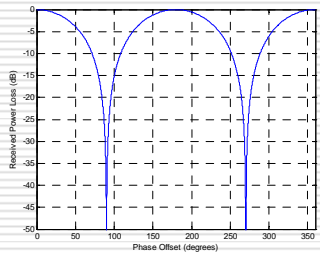
- Now, ϕ is a random value that can take on any value on $[0, 2\pi)$
- If $\phi = 0$, $v_o(t) = \frac{A^2}{2} m(t)$
- However, if $\phi = \pi/2$ $v_o(t) = 0$
- Thus, having phase coherence is absolutely vital
 - i.e., the receiver and incoming signal must be locked in phase synchronization

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Power Loss Due to Phase Offset

- If there is a phase mismatch between the local carrier and the incoming carrier we can see dramatic loss in received power

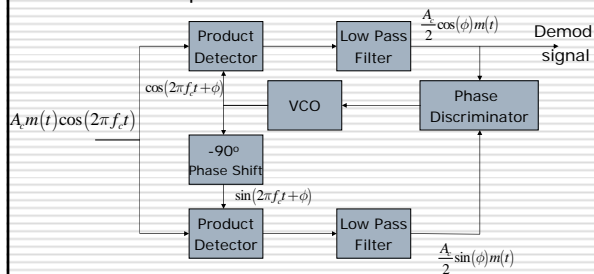


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Costas Receiver

- Receiver that automatically provides coherent phase reference

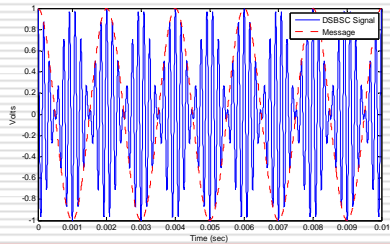


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Example 10.2 – Sinusoidal Message

- Let $m(t) = \cos(2\pi f_m t)$ where $f_m = 500\text{Hz}$.
- Let $f_c = 6\text{kHz}$ (note $f_c \gg f_m$)



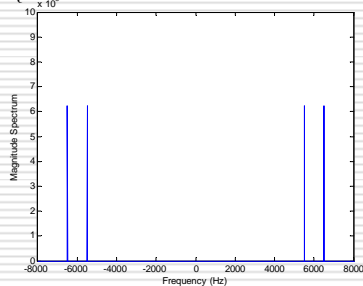
Example 10.2 - Spectrum

- DSBSC Spectrum with Sinusoidal message signal

$$\begin{aligned}
 S(f) &= \frac{A}{2} \{M(f-f_c) + M(f+f_c)\} \\
 &= \frac{A}{2} \left\{ \frac{1}{2} [\delta(f-f_m-f_c) + \delta(f+f_m-f_c)] + \frac{1}{2} [\delta(f-f_m+f_c) + \delta(f+f_m+f_c)] \right\} \\
 &= \frac{A}{2} \left\{ \frac{1}{2} [\delta(f-6500) + \delta(f-5500)] + \frac{1}{2} [\delta(f+5500) + \delta(f+6500)] \right\}
 \end{aligned}$$

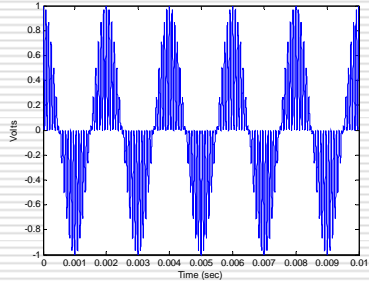
Example 10.2 Spectrum – cont.

$$S(f) = \frac{A}{2} \left\{ \frac{1}{2} [\delta(f-6500) + \delta(f-5500)] + \frac{1}{2} [\delta(f+5500) + \delta(f+6500)] \right\}$$



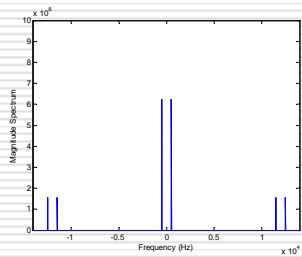
Example 10.2: Product Demodulator

At the output of the product demodulator we obtain



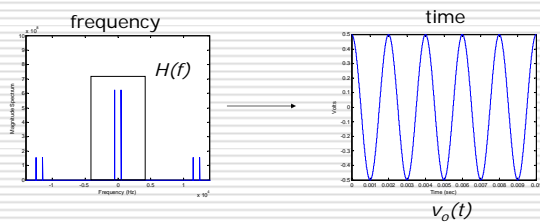
Example 10.2: Prod. Demod. Spectrum

In the frequency domain we have



Example 10.2 – final

After applying a low pass filter, we have



In class drill

- If time

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Summary

- Today we have examined a second form of analog amplitude modulation termed Double Sideband Suppressed Carrier
- DSBSC has better power efficiency than large carrier AM due to the elimination of the unmodulated carrier
- Removing this unmodulated carrier forces us to use a new detector (rather than the simple envelope detector) termed a product detector
 - Requires phase coherence
 - More complex receiver structure

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