ECE3614
Introduction to Communications Systems
Fall 2007

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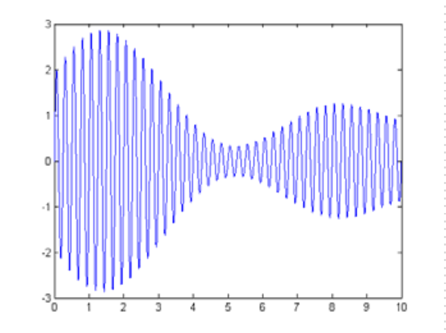
Lecture #10: DSBSC Amplitude Modulation



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

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

- If the message is a sinusoid [$m(t)$ = cos(2πf$_m$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

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

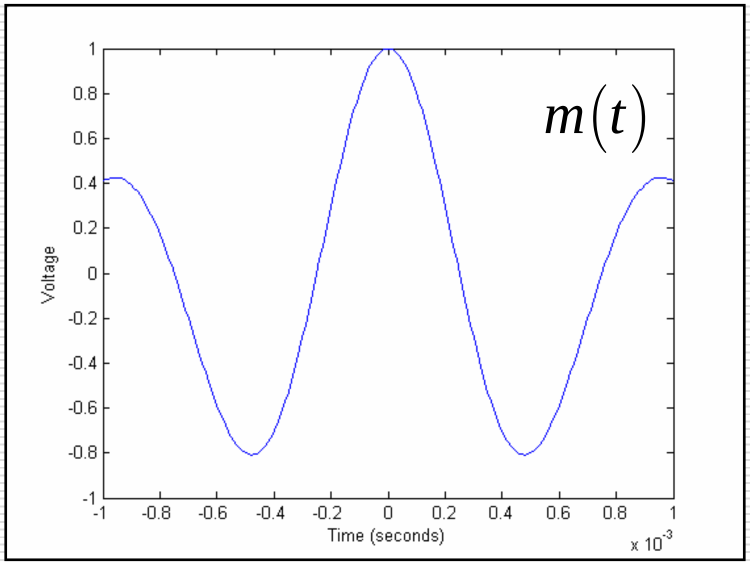
- Now, all of the power is devoted to the message – more power efficient
- However, a simple envelope detector is not possible, as we will see

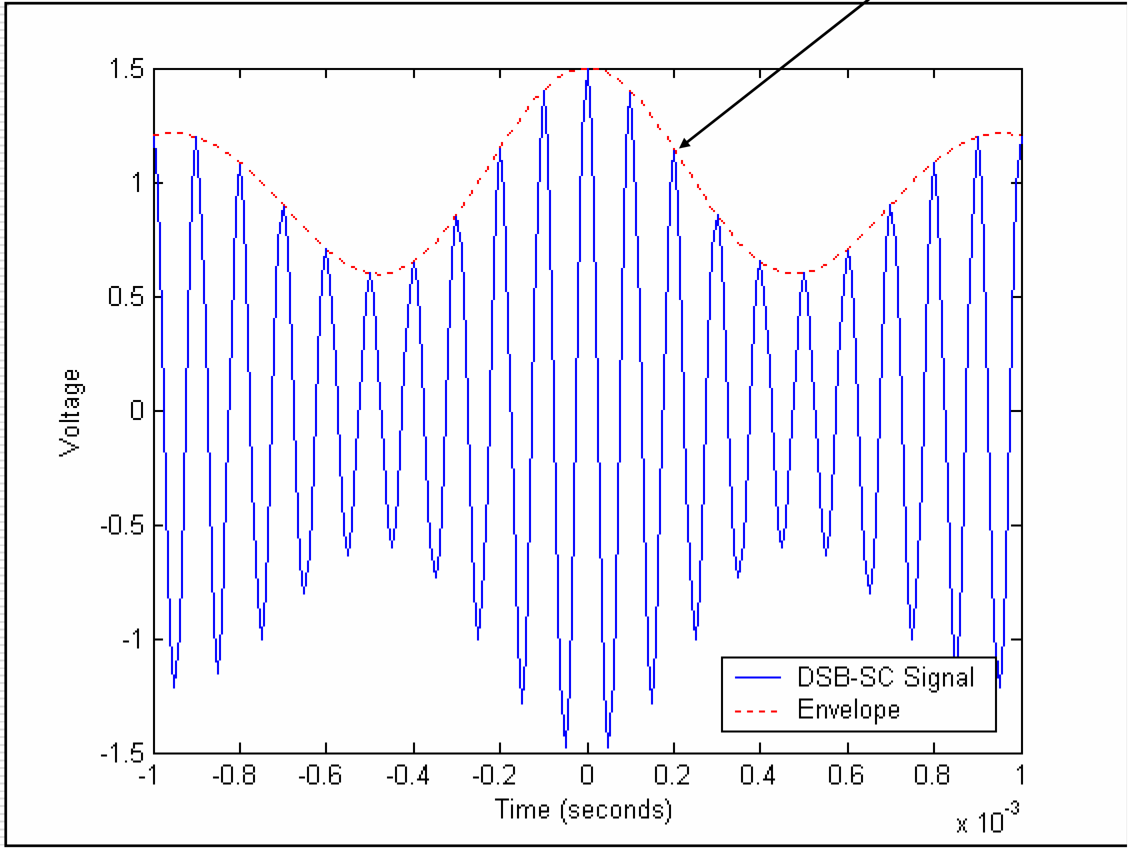
Example 10.1

- Large Carrier AM (k_a = 0.5)

Envelope follows message signal

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



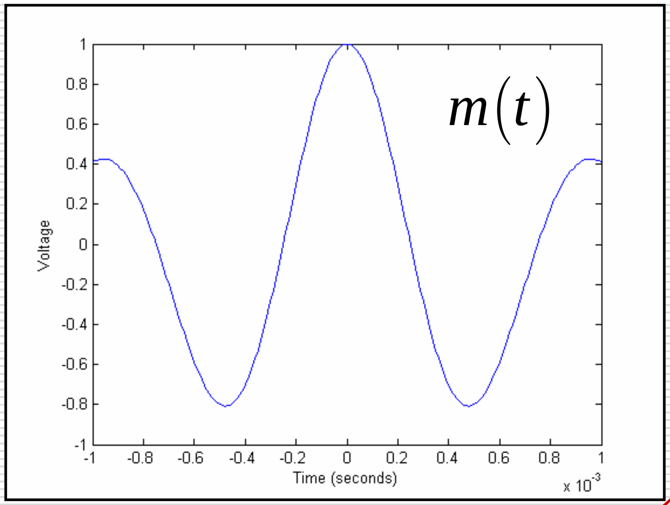


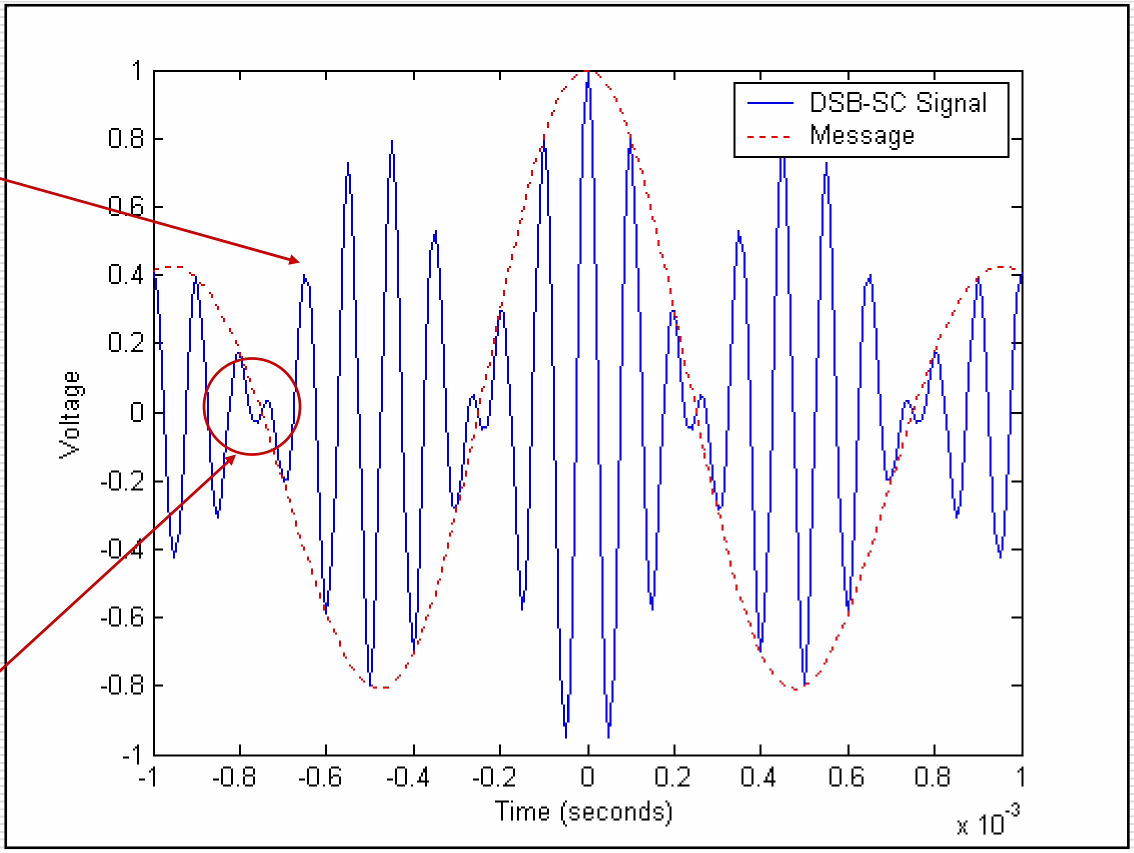
Example 10.1 – cont.

- Double Side Band Suppressed Carrier

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

Envelope doesn't follow message





Phase reversals occur whenever message signal is negative

Spectrum of DSBSC

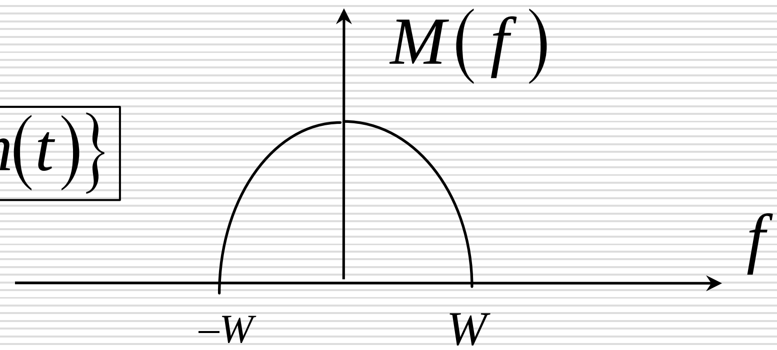
- The spectrum *S(f)* can be determined from Fourier Theory using the modulation property

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

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

Spectrum of DSB-SC AM

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

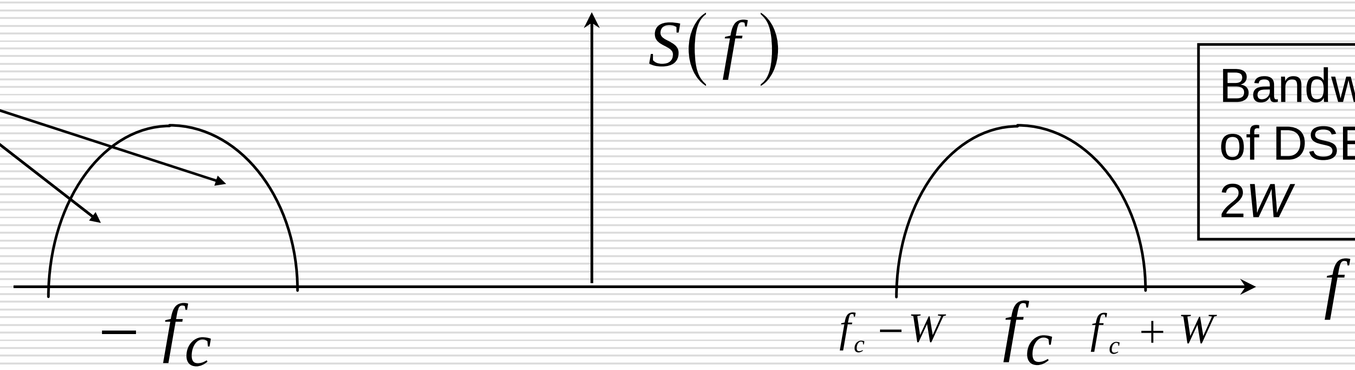


Bandwidth of message : *W*

Message

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

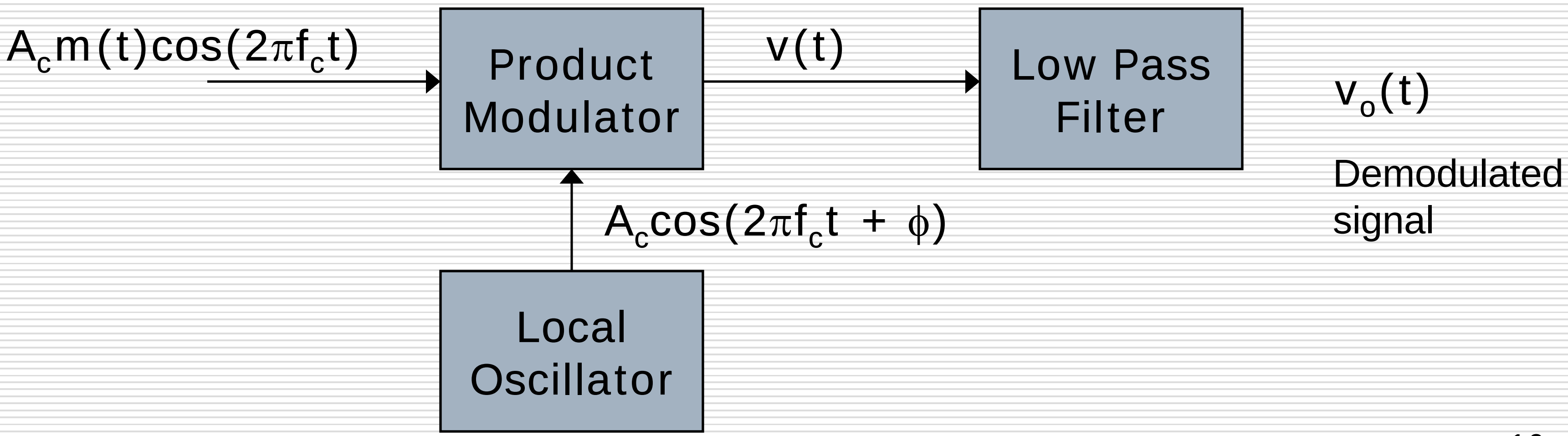
Since both "sidebands" are present we call this *double* sideband



Bandwidth of DSBSC: 2*W*

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



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 ϕ = 0. (We will return to this assumption later.)

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

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

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

$$= \frac{A_c^2}{2}m(t)$$

Product Detector – Frequency Domain

- At the output of the product demodulator we have

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

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

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

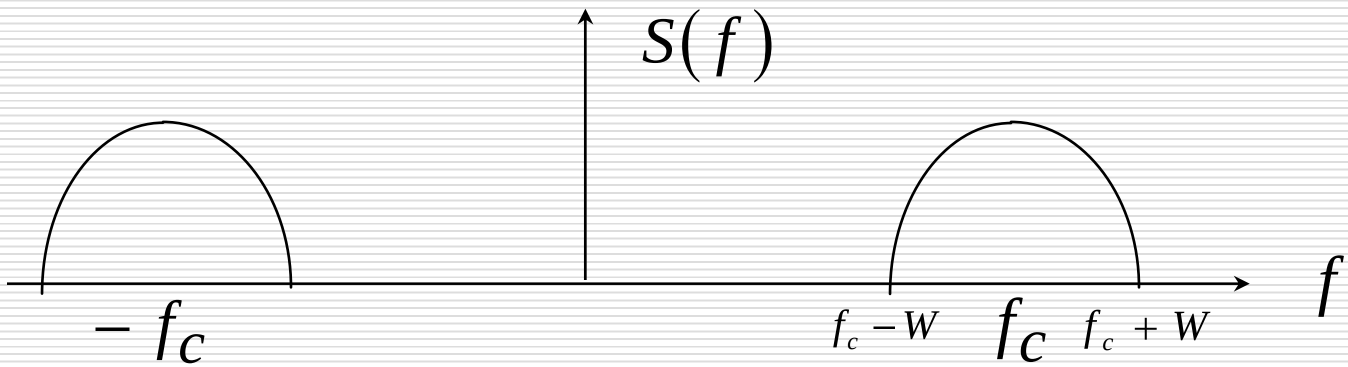
$$H(f) = rect\left(\frac{f}{2B}\right)$$

where $2f_c > B > W$, then

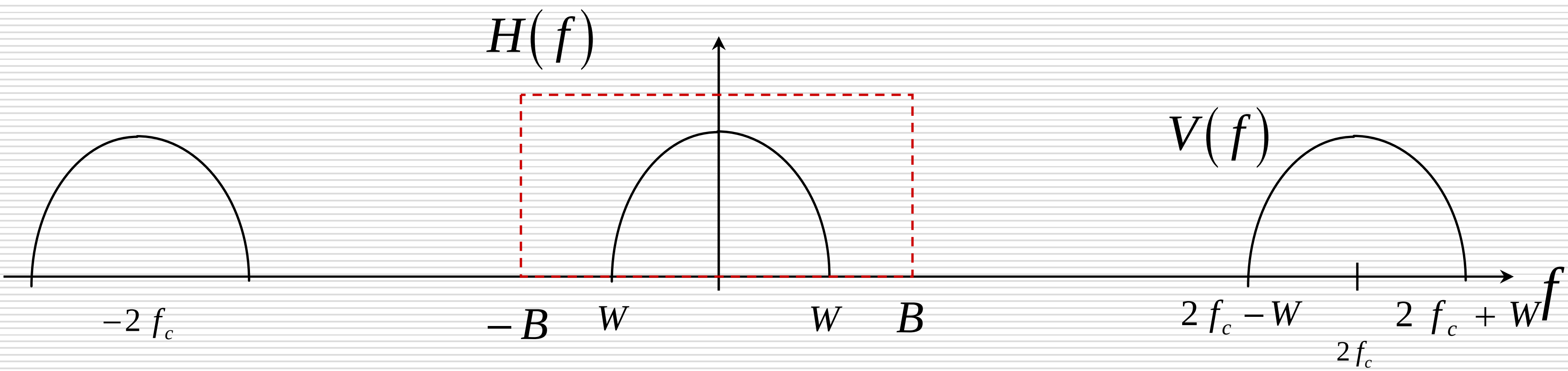
$$V_o(f) = \frac{A_c^2}{2} M(f)$$

Frequency Domain – cont.

- The received signal spectrum



- At the output of the product detector:



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:

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

Impact of Phase Coherence – cont.

- At the output of the low pass filter we have

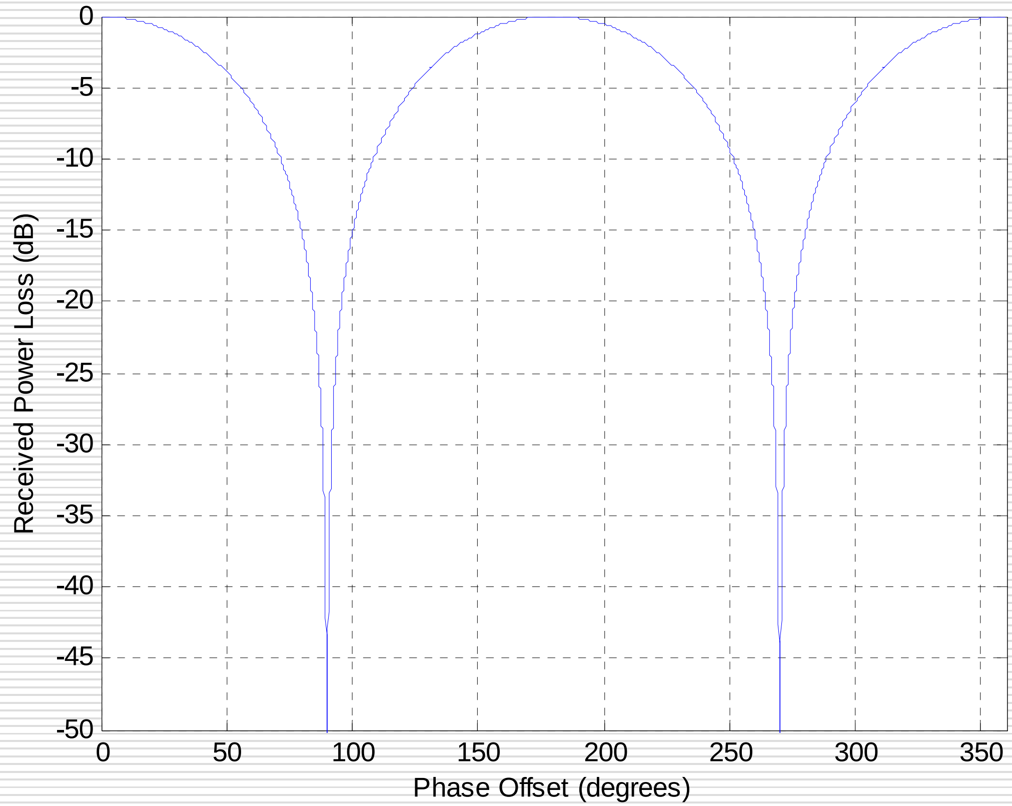
$$v_o(t) = LPF\left\{\frac{A_c^2}{2}m(t)\cos(\phi) + \frac{A_c^2}{2}m(t)\cos(4\pi f_c t + \phi)\right\}$$

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

- Now, ϕ is a random value that can take on any value on $[0,2\pi)$
- If $\phi = 0$, $v_o(t) = \frac{A_c^2}{2}m(t)$
- 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

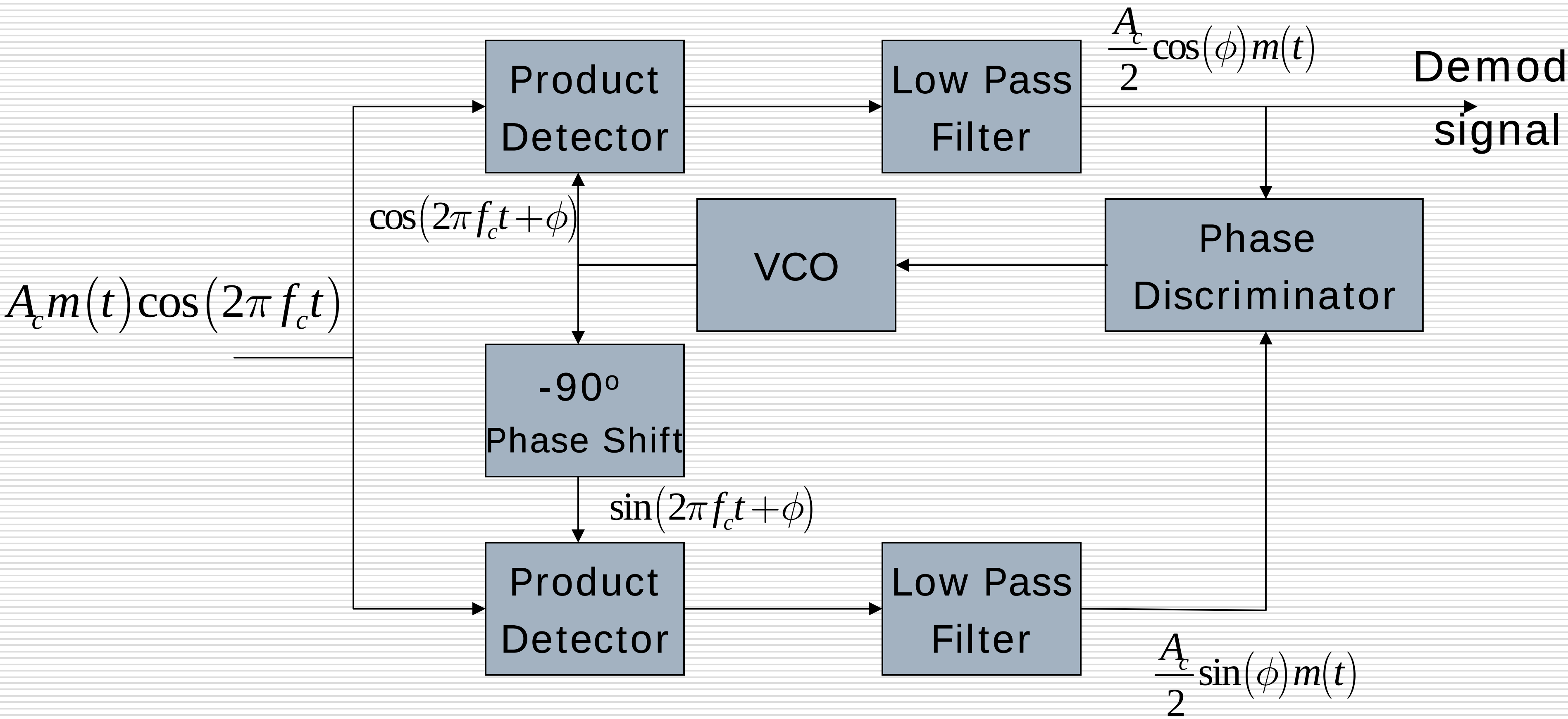
Power Loss Due to Phase Offset

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



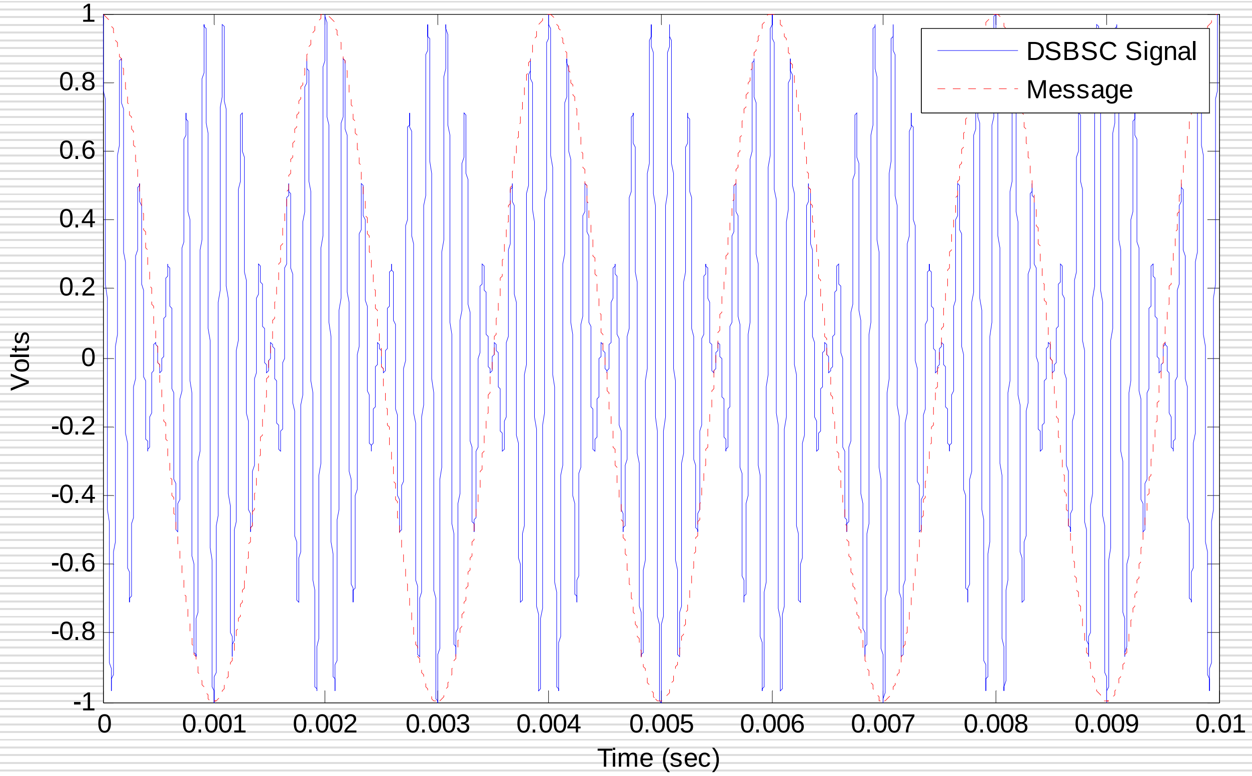
Costas Receiver

- Receiver that automatically provides coherent phase reference



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 $f_c >> f_m$)



Example 10.2 - Spectrum

- DSBSC Spectrum with Sinusoidal message signal

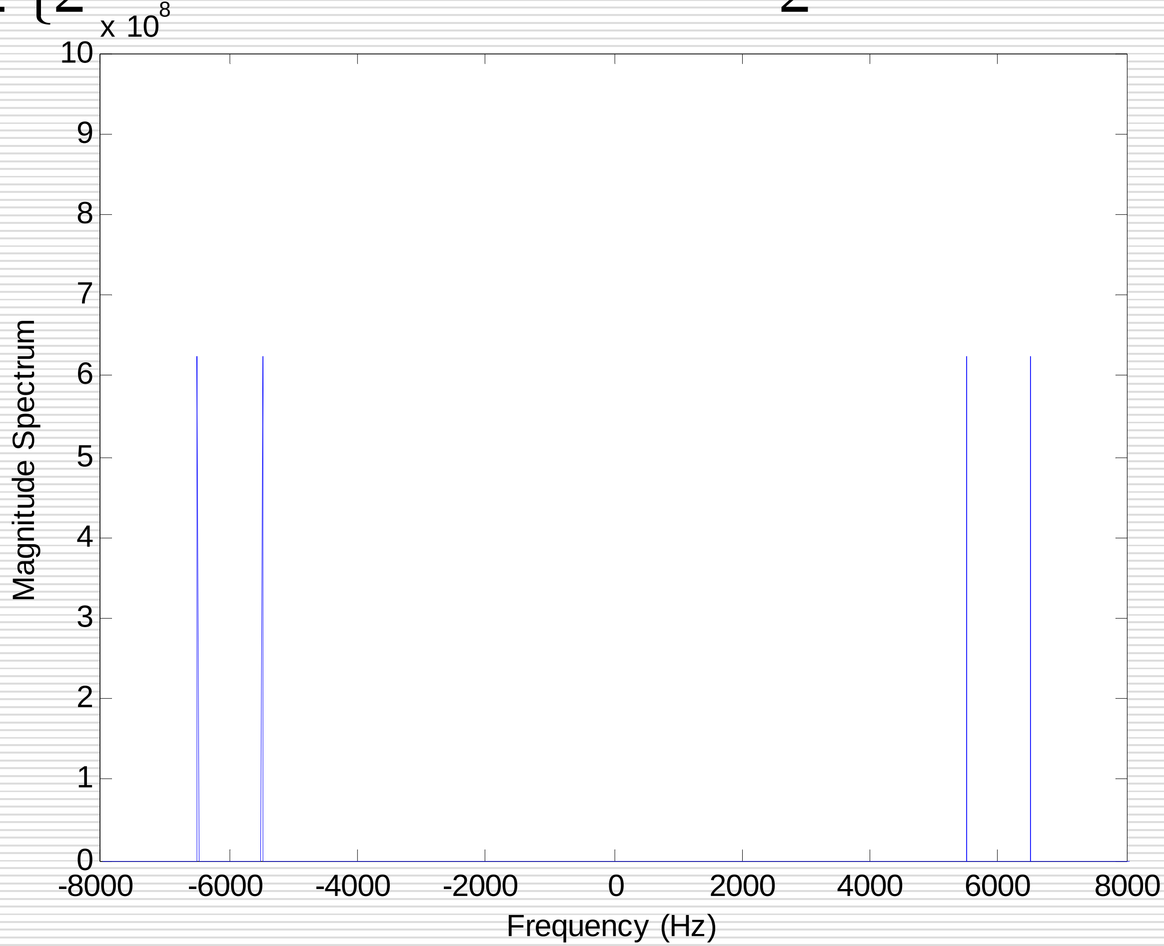
$$S(f) = \frac{A_c}{2}\left\{M(f-f_c)+M(f+f_c)\right\}$$

$$= \frac{A_c}{2}\left\{\frac{1}{2}\left[\delta(f-f_m-f_c)+\delta(f+f_m-f_c)\right]+\frac{1}{2}\left[\delta(f-f_m+f_c)+\delta(f+f_m+f_c)\right]\right\}$$

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

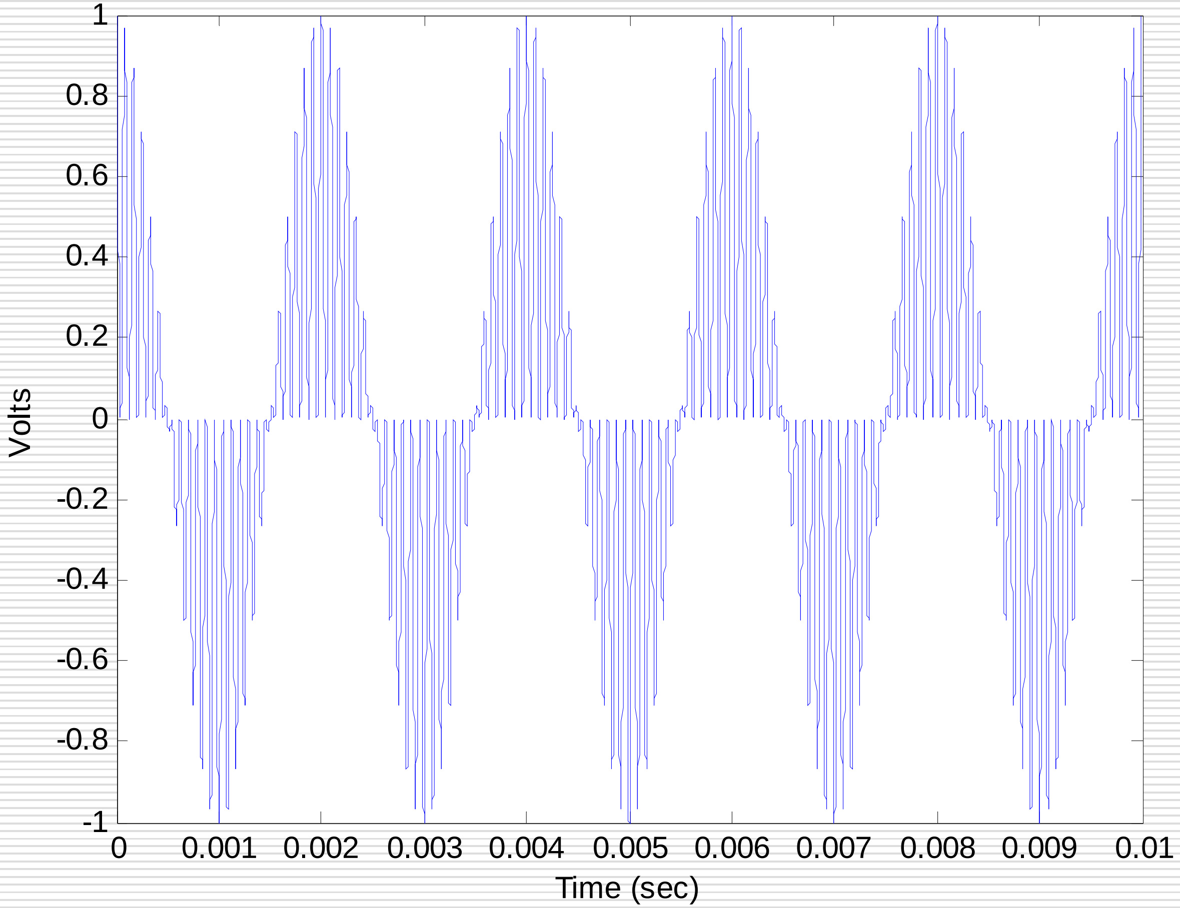
Example 10.2 Spectrum – cont.

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



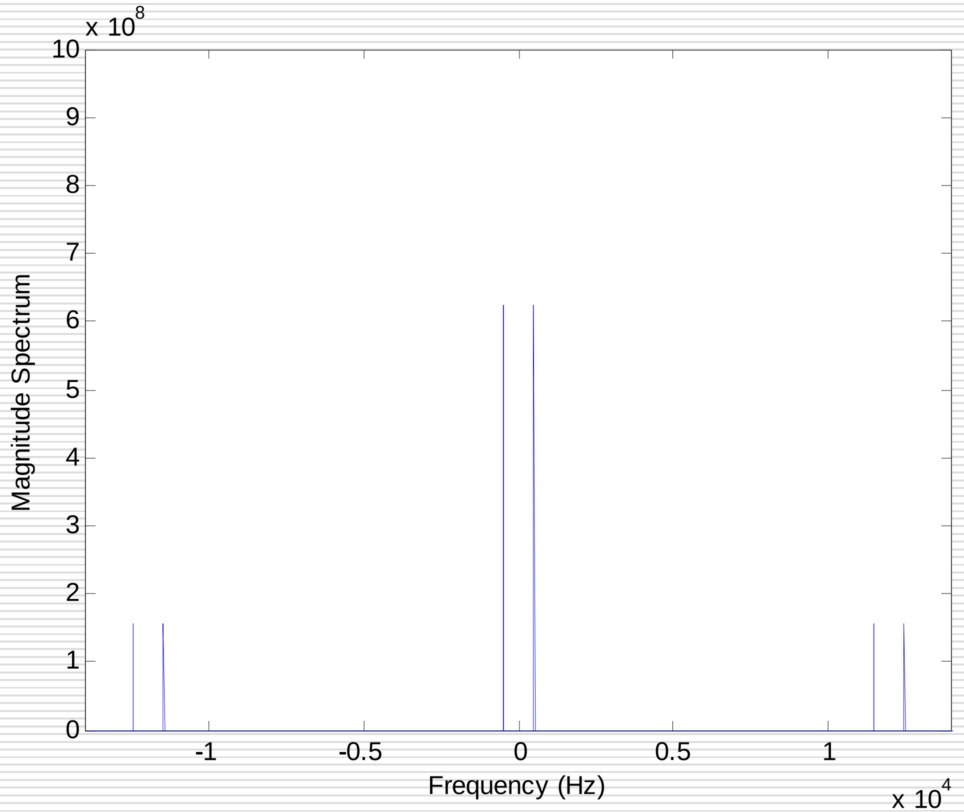
Example 10.2: Product Demodulator

- At the output of the product demodulator we obtain



Example 10.2: Prod. Demod. Spectrum

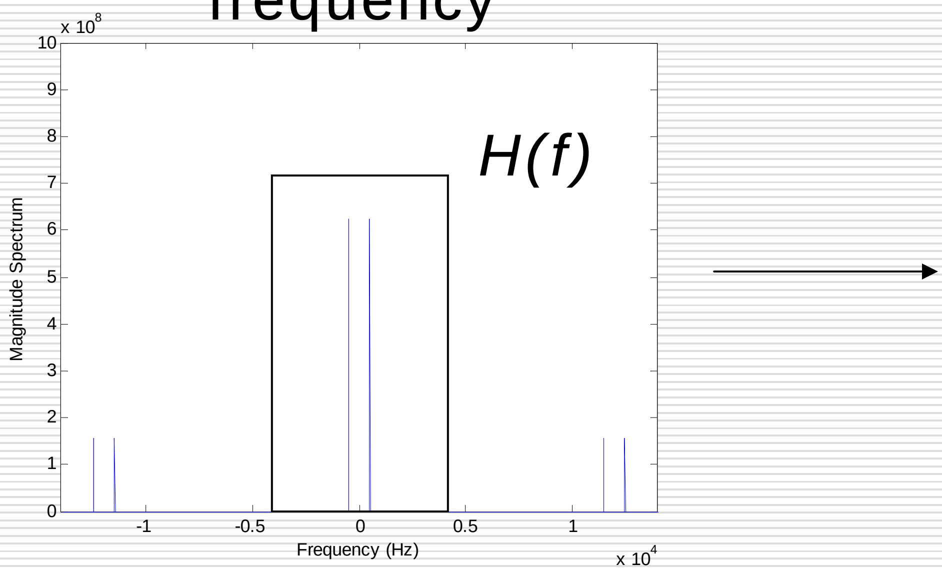
- In the frequency domain we have



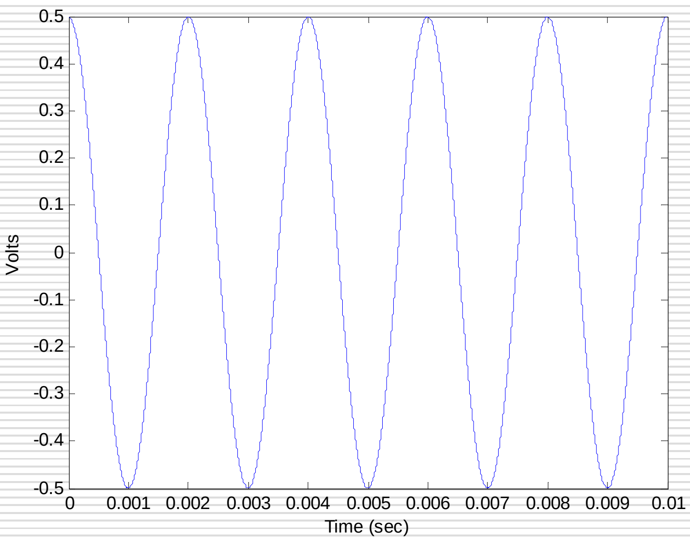
Example 10.2 – final

- After applying a low pass filter, we have

frequency



time



$v_o(t)$

In class drill

- If time

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