University of Bahrain

Department of Electrical and Electronics Engineering

EENG372

Communication Systems I

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Topic 1:

Amplitude Modulation (AM)

This Topic will cover

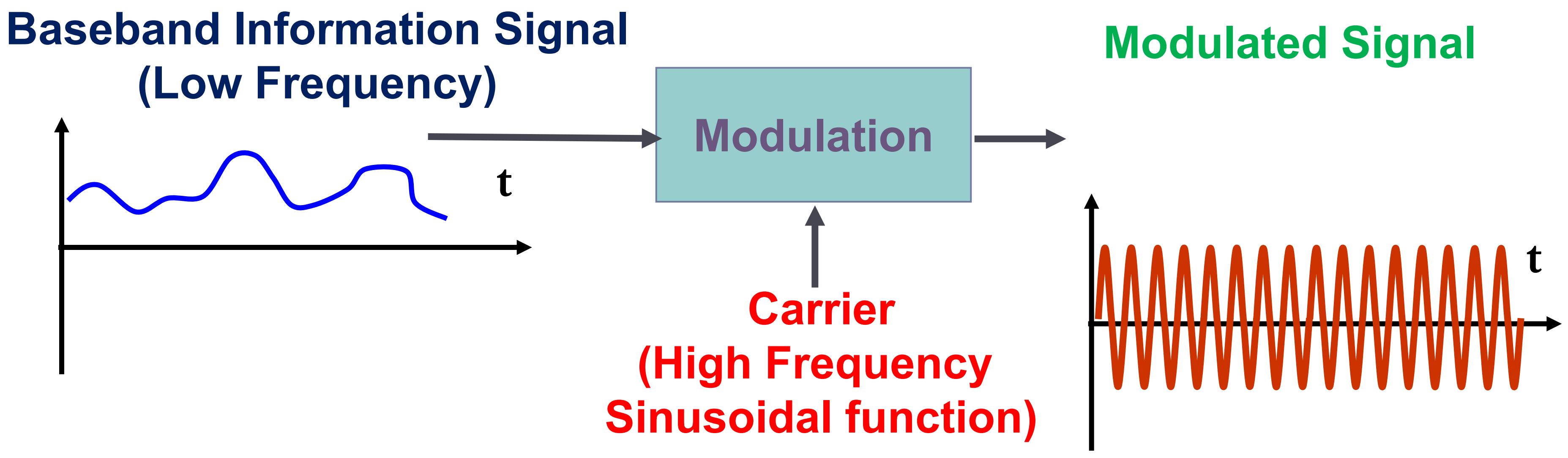
- Modulation
- Amplitude Modulation (AM)
  - Time Domain
  - Percentage Modulation
  - Spectrum of AM signals
  - Power in AM signals
- *AM- Supressed* carrier (SC)
- AM-Single Side Band (SSB)
- AM Demodulation
- AM Receivers

Modulation

Q: What is modulation?

Modulation is having the message signal alter a carrier signal for transmission.

The process of impressing a low frequency baseband signal information signal) onto a high frequency carrier signal



Modulation

Q: Why is modulation required in communication systems?

1. Ease of radiation of higher frequencies.

   Antenna size for baseband will be very large

For voice signal (100Hz to 3KHz): Length of Antenna $\mathbf{d} \geq \lambda/\mathbf{10}$

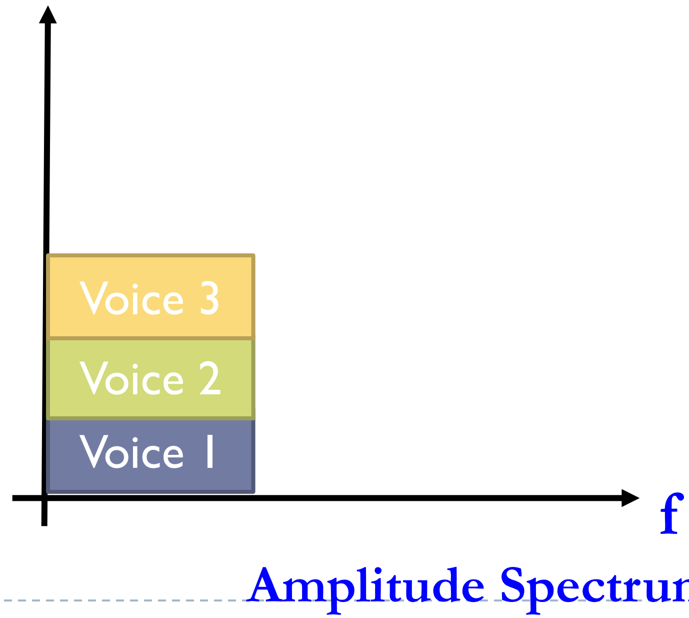
Q: What is the size of the antenna?

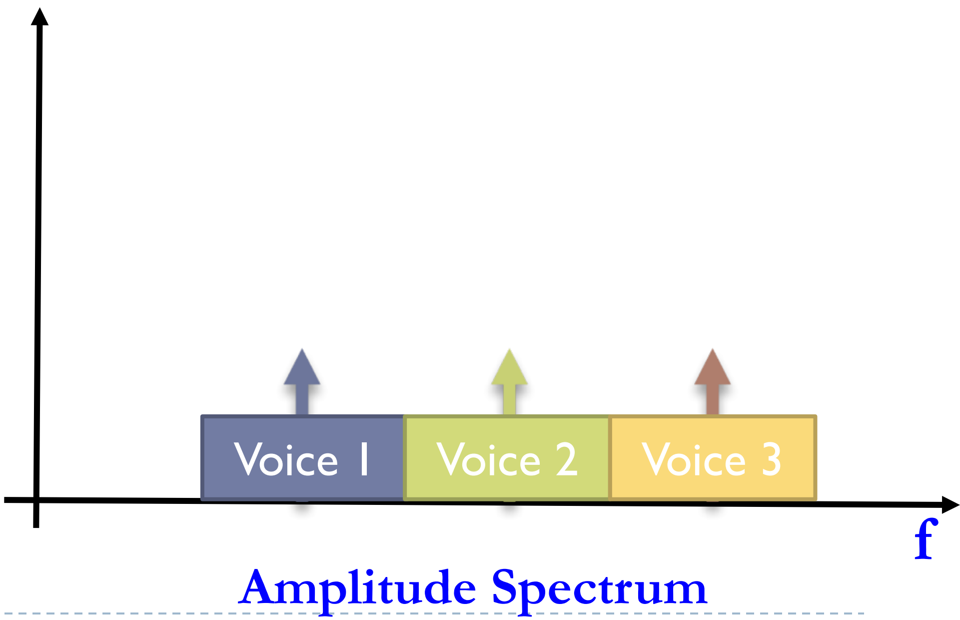
Modulation

Q: Why is modulation required in communication systems?

2. Simultaneous Transmission of several signals

More than one baseband signal can be transmitted on the same channel





Modulation

Q: What are the different types of Modulation?

The carrier is usually a sinusoidal signal:

$$v_c(t) = V_c \cos(2\pi f_c t + \phi)$$

Three things can be changed by the information signal:

1. Amplitude
2. Angle
   i. Frequency
   ii. Phase

Amplitude Modulation: Time Domain

Amplitude Modulation

Q: What is Amplitude Modulation ?

Amplitude Modulation is having the message signal alter the amplitude of a carrier signal for transmission.

$$v_c(t) = V_c \cos(2\pi f_c t + \phi)$$

Amplitude Modulation

Q: How is AM done?

Assume our carrier signal is:

$$v_c(t) = V_c \cos(2\pi f_c t)$$

And our message (modulating) signal is:

$$v_m(t) = V_m \cos(2\pi f_m t)$$

where

$$f_c >> f_m \qquad f_c > 10 f_m$$

Amplitude Modulation

Q: What do we get?

The carrier amplitude is changing with the modulating signal:

$$v_{AM}(t) = \left(V_c + V_m \cos(2\pi f_m t)\right) \cos(2\pi f_c t)$$

$$v_{AM}(t) = V_c \cos(2\pi f_c t) + V_m \cos(2\pi f_m t) \cos(2\pi f_c t)$$

$$v_{AM}(t) = V_c \cos(2\pi f_c t)\left(1 + \frac{V_m}{V_c} \cos(2\pi f_m t)\right)$$

$$v_{AM}(t) = V_c \cos(2\pi f_c t)\left(1 + m \cos(2\pi f_m t)\right)$$

Modulation index

AM Time Domain

Q: What does an AM signal look like it the time domain?

Amplitude Modulation

Example: Draw the following AM signal?

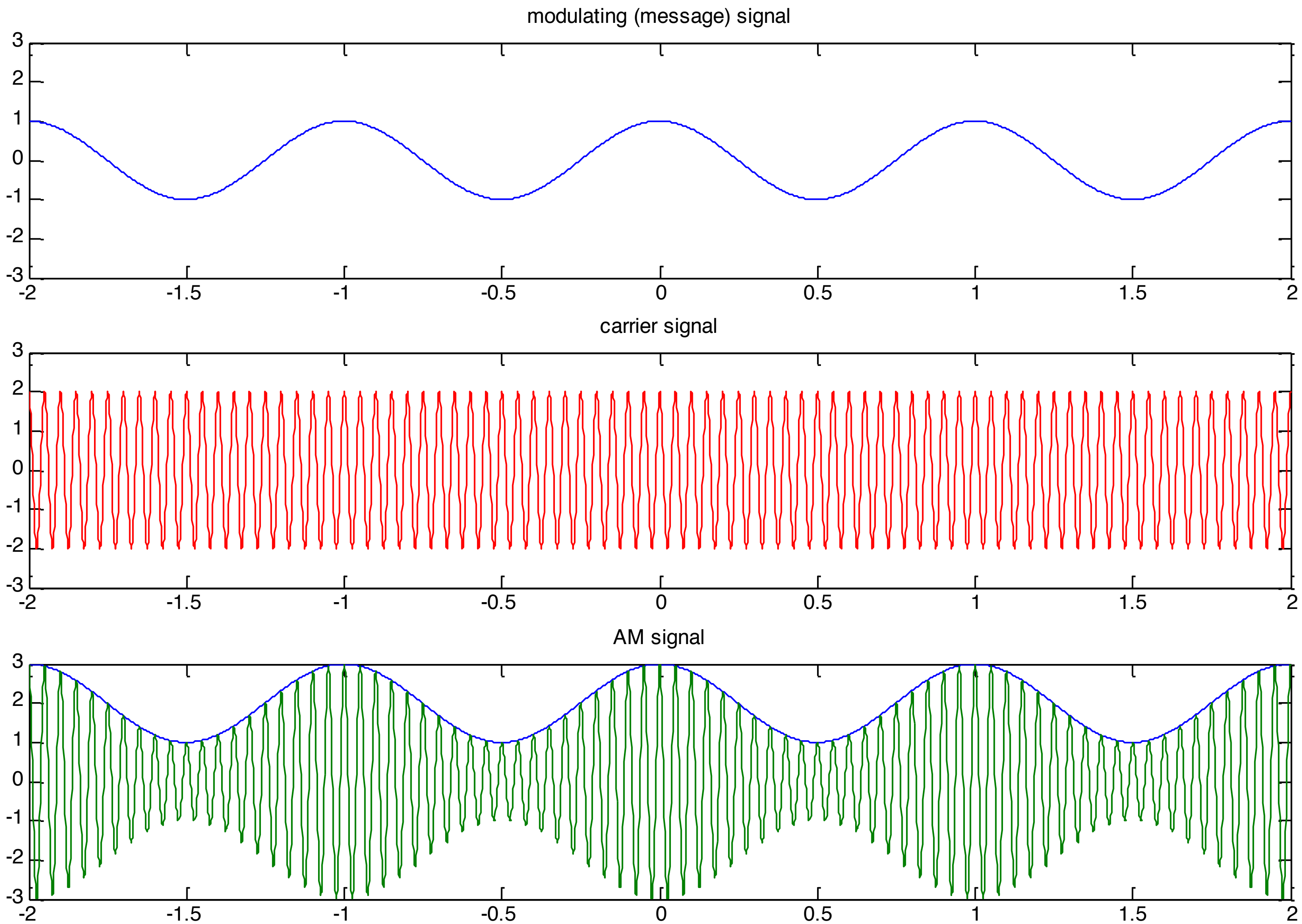
$$v_c(t) = 2\cos(40\pi\, t) \qquad v_m(t) = \cos(2\pi\, t)$$

$$f_c = \ldots\ldots \qquad f_m = \ldots\ldots$$

$$V_c = \ldots\ldots \qquad V_m = \ldots\ldots$$

Modulation index $m = \dfrac{V_m}{V_c} = \ldots\ldots$

$$v_{AM}(t) = 2\cos(2\pi\, f_c\, t)\big(1 + \; 0.5 \;\cos(2\pi\, f_m\, t)\;\big)$$


modulating (message) signal
carrier signal
AM signal
3
2
1
0
-1
-2
-3
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Amplitude Modulation

Example: Draw the following AM signal?

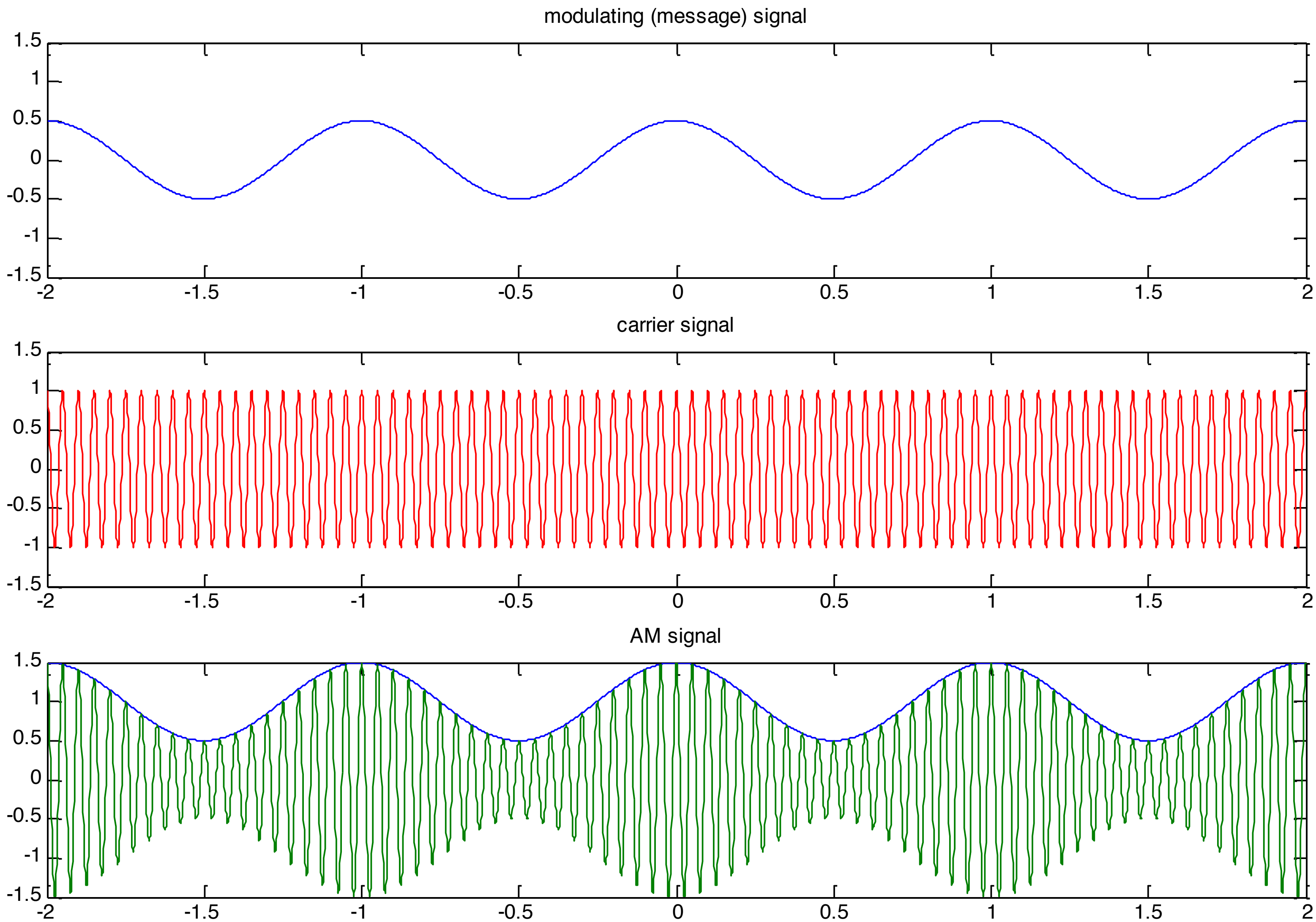
$$v_c(t) = \cos(40\pi\, t) \qquad v_m(t) = 0.5\cos(2\pi\, t)$$

$$f_c = \ldots\ldots\ldots \qquad f_m = \ldots\ldots\ldots$$

$$V_c = \ldots\ldots\ldots \qquad V_m = \ldots\ldots\ldots$$

Modulation index $m = \dfrac{V_m}{V_c} = \ldots\ldots\ldots$

$$v_{AM}(t) = \ldots..\cos(2\pi\ f_c\ t)\left(1 + \ \ldots\ldots\ \cos(2\pi\ f_m\ t)\ \right)$$


modulating (message) signal
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
carrier signal
AM signal

Amplitude Modulation

Example: Draw the following AM signal?

$$v_c(t) = 2\cos(40\pi\, t)$$

$$f_c = \ldots\ldots.$$

$$V_c = \ldots\ldots.$$

$$v_m(t) = \cos(\pi\, t)$$

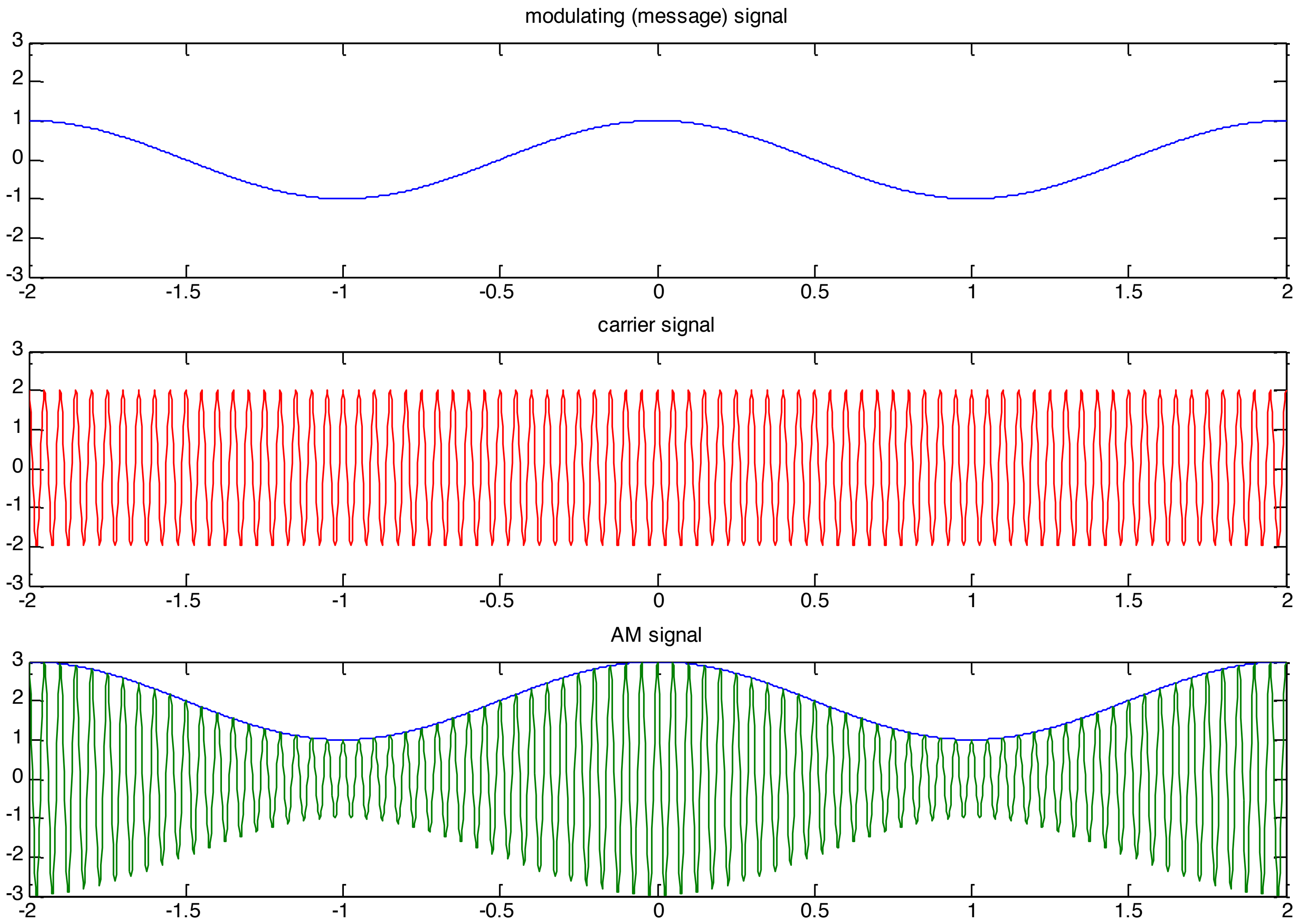
$$f_m = \ldots\ldots.$$

$$V_m = \ldots\ldots.$$

Modulation index

$$m = \frac{V_m}{V_c} = \ldots\ldots.$$

$$v_{AM}(t) = \ldots..\cos(2\pi\, f_c\, t)\left(1 + \;\ldots\ldots\; \cos(2\pi\, f_m\, t)\,\right)$$


modulating (message) signal
carrier signal
AM signal
3
2
1
0
-1
-2
-3
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Amplitude Modulation

Example: Draw the following AM signal?

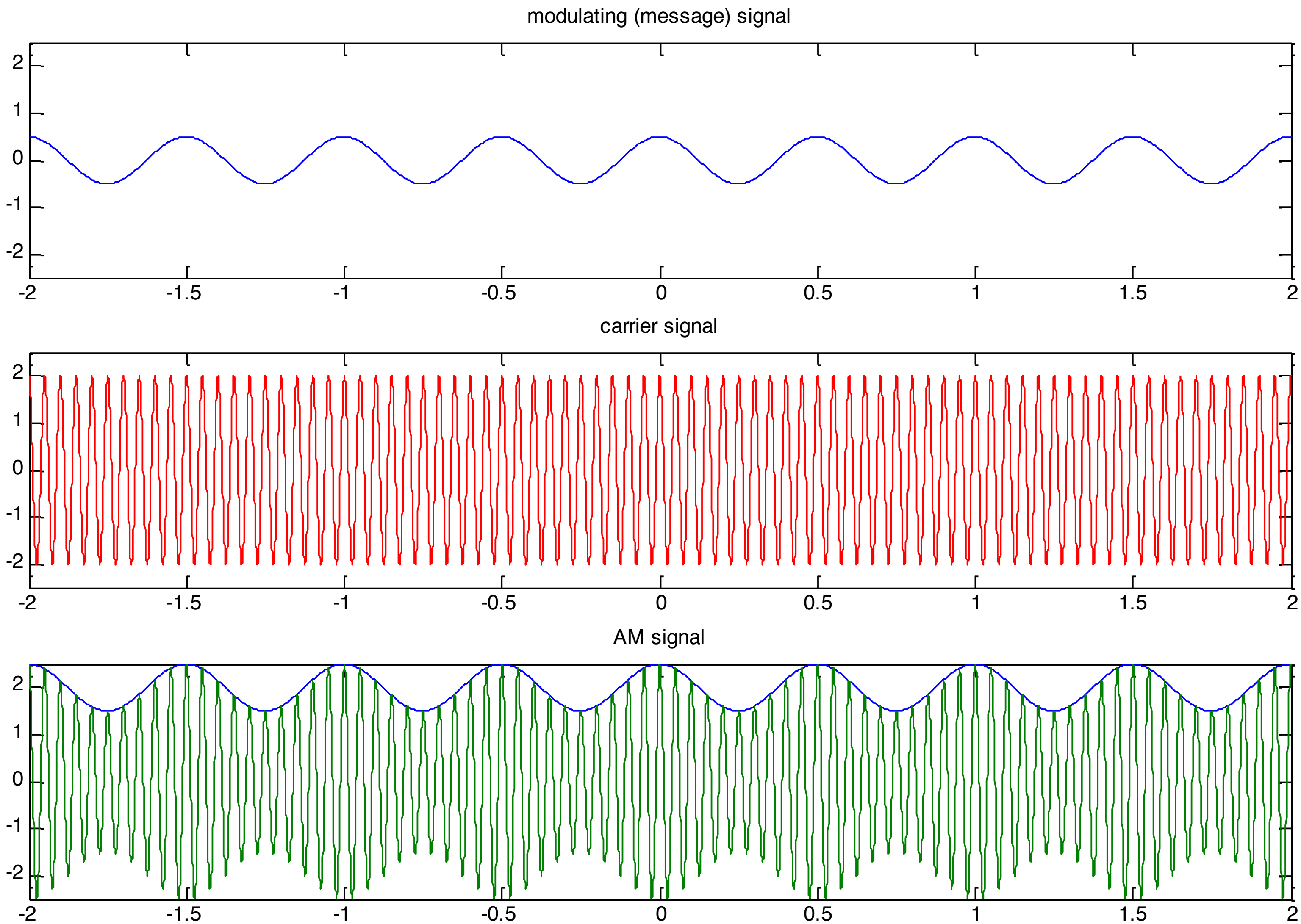
$$v_c(t) = 2\cos(40\pi\, t) \qquad v_m(t) = 0.5\cos(4\pi\, t)$$

$$f_c = \ldots\ldots\ldots \qquad f_m = \ldots\ldots\ldots$$

$$V_c = \ldots\ldots\ldots \qquad V_m = \ldots\ldots\ldots$$

Modulation index $m = \dfrac{V_m}{V_c} = \ldots\ldots\ldots$

$$v_{AM}(t) = \ldots\ldots\cos(2\pi\, f_c\, t)\big(1 + \ \ldots\ldots\ \cos(2\pi\, f_m\, t)\ \big)$$


modulating (message) signal
carrier signal
AM signal
2
1
0
-1
-2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Amplitude Modulation

Example: Draw the following AM signal?

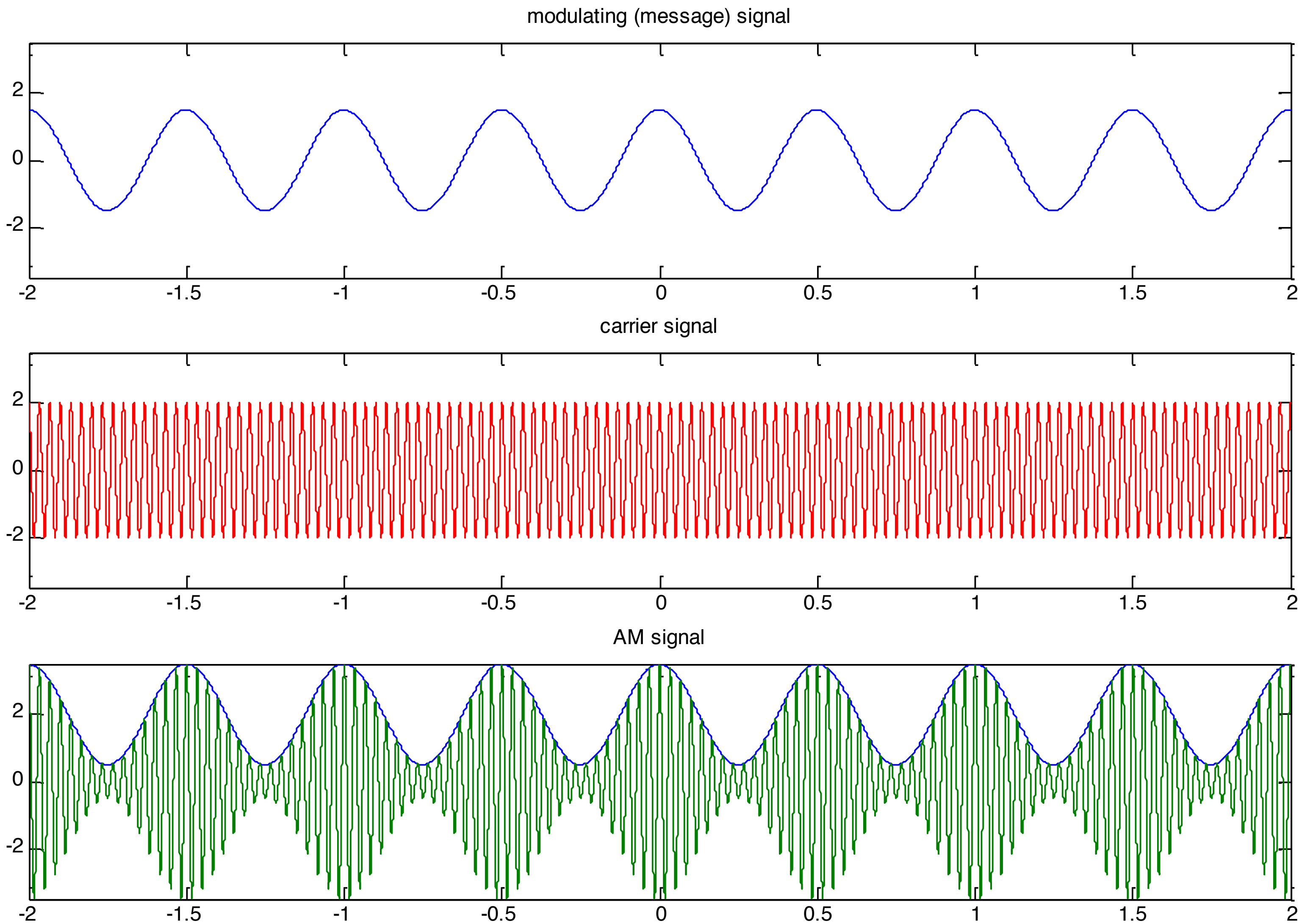
$$v_c(t) = 2\cos(60\pi\, t) \qquad v_m(t) = 1.5\cos(4\pi\, t)$$

$$f_c = \ldots\ldots \qquad f_m = \ldots\ldots$$

$$V_c = \ldots\ldots \qquad V_m = \ldots\ldots$$

Modulation index $m = \frac{V_m}{V_c} = \ldots\ldots$

$$v_{AM}(t) = \ldots\ldots\cos(2\pi\, f_c\, t)\left(1 + \ \ldots\ldots\ \cos(2\pi\, f_m\, t)\ \right)$$


modulating (message) signal
carrier signal
AM signal
2
0
-2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Amplitude Modulation

Example: Draw the following AM signal?

$$v_c(t) = \cos(40\pi\, t)$$

$$f_c = \ldots\ldots$$

$$V_c = \ldots\ldots$$

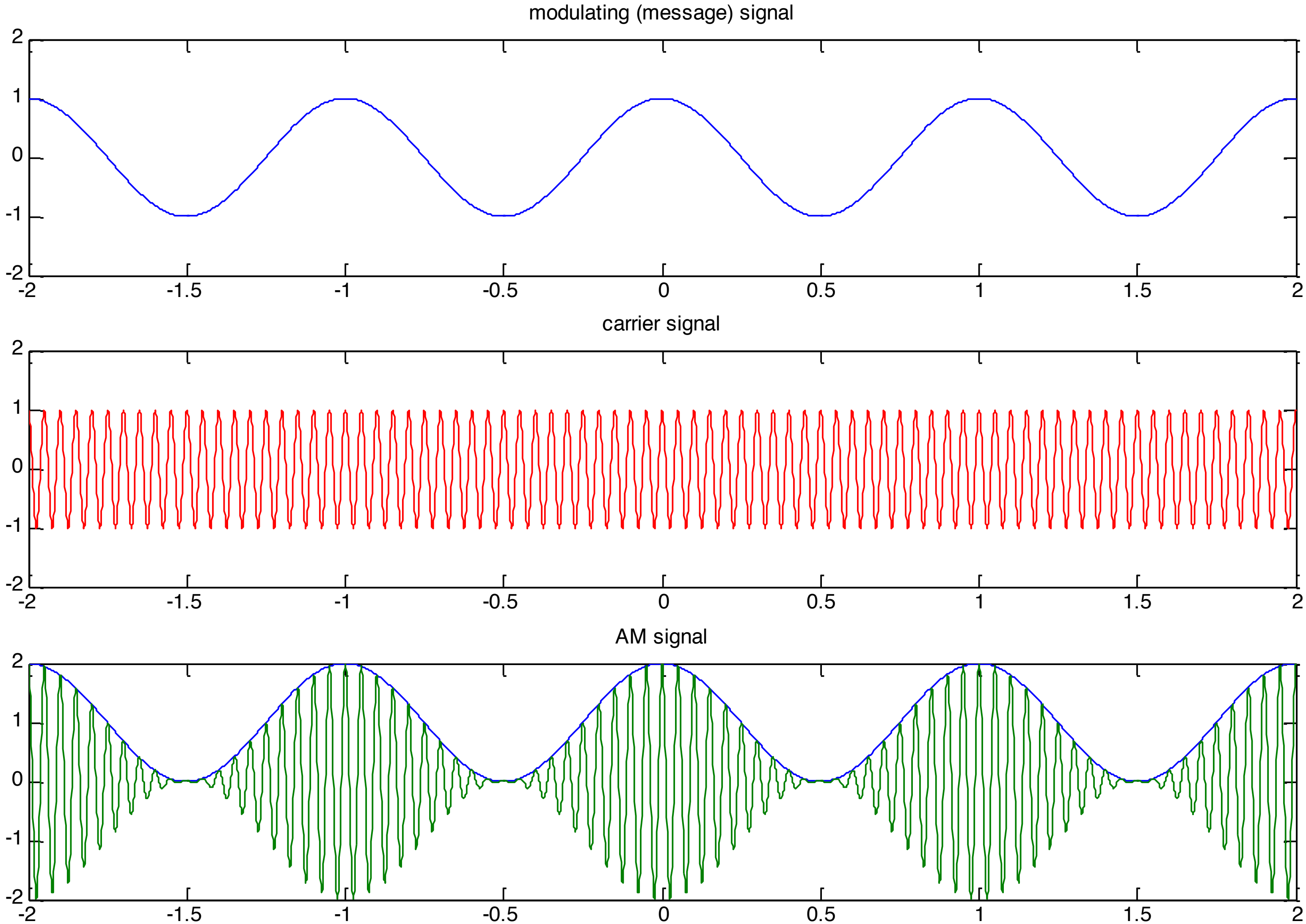
$$v_m(t) = \cos(4\pi\, t)$$

$$f_m = \ldots\ldots$$

$$V_m = \ldots\ldots$$

Modulation index $m = \dfrac{V_m}{V_c} = \ldots\ldots$

$$v_{AM}(t) = \ldots\ldots\cos(2\pi\, f_c\, t)\left(1 + \;\ldots\ldots\; \cos(2\pi\, f_m\, t)\,\right)$$


modulating (message) signal
2
1
0
-1
-2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
carrier signal
AM signal

Amplitude Modulation

Example: Draw the following AM signal?

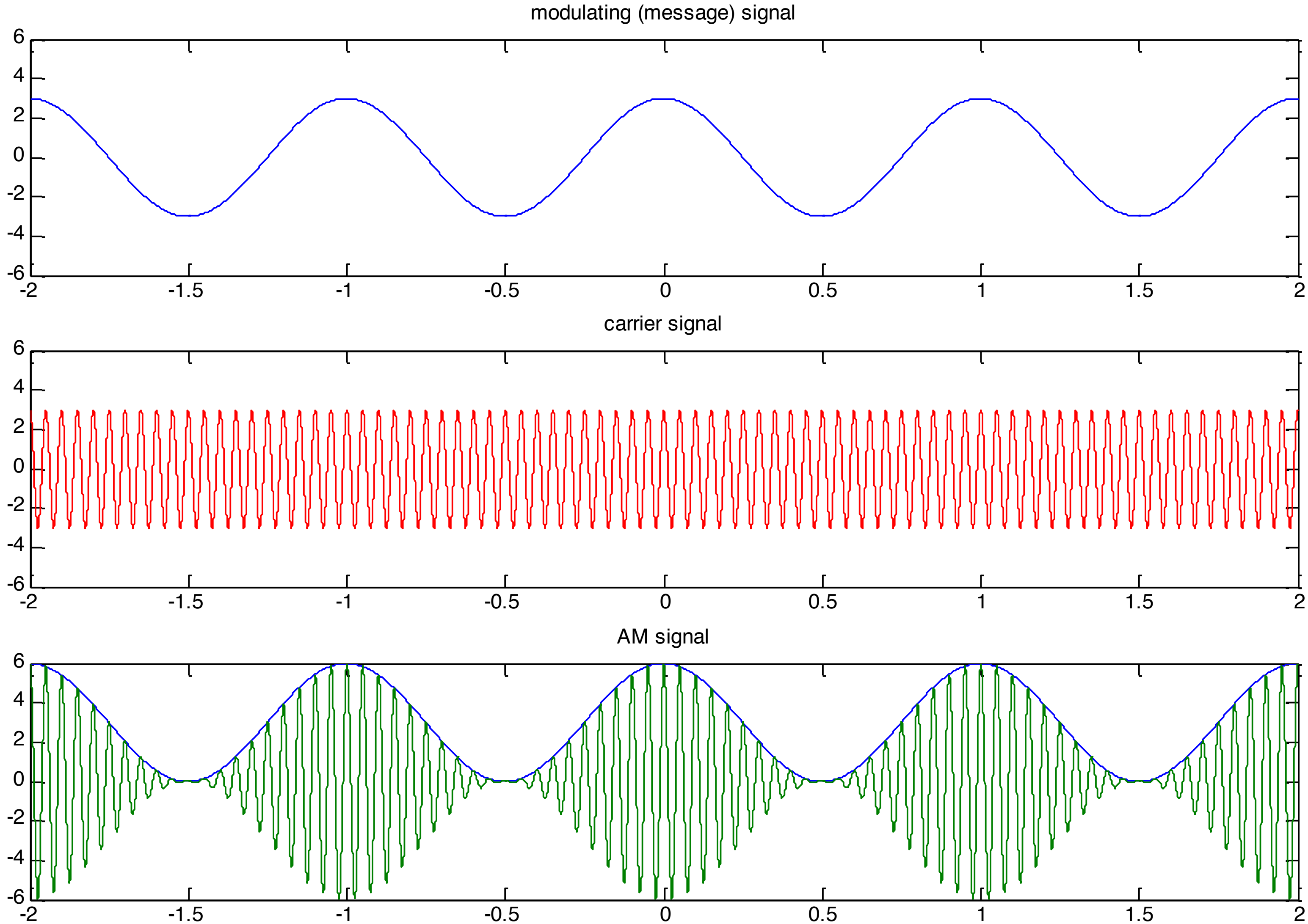
$$v_c(t) = 3\cos(40\pi\, t) \qquad v_m(t) = 3\cos(2\pi\, t)$$

$$f_c = \ldots\ldots \qquad f_m = \ldots\ldots$$

$$V_c = \ldots\ldots \qquad V_m = \ldots\ldots$$

Modulation index $m = \dfrac{V_m}{V_c} = \ldots\ldots$

$$v_{AM}(t) = \ldots\ldots\cos(2\pi\, f_c\, t)\big(1 + \ \ldots\ldots\ \cos(2\pi\, f_m\, t)\ \big)$$


modulating (message) signal
carrier signal
AM signal
6
4
2
0
-2
-4
-6
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Amplitude Modulation

Example: Draw the following AM signal?

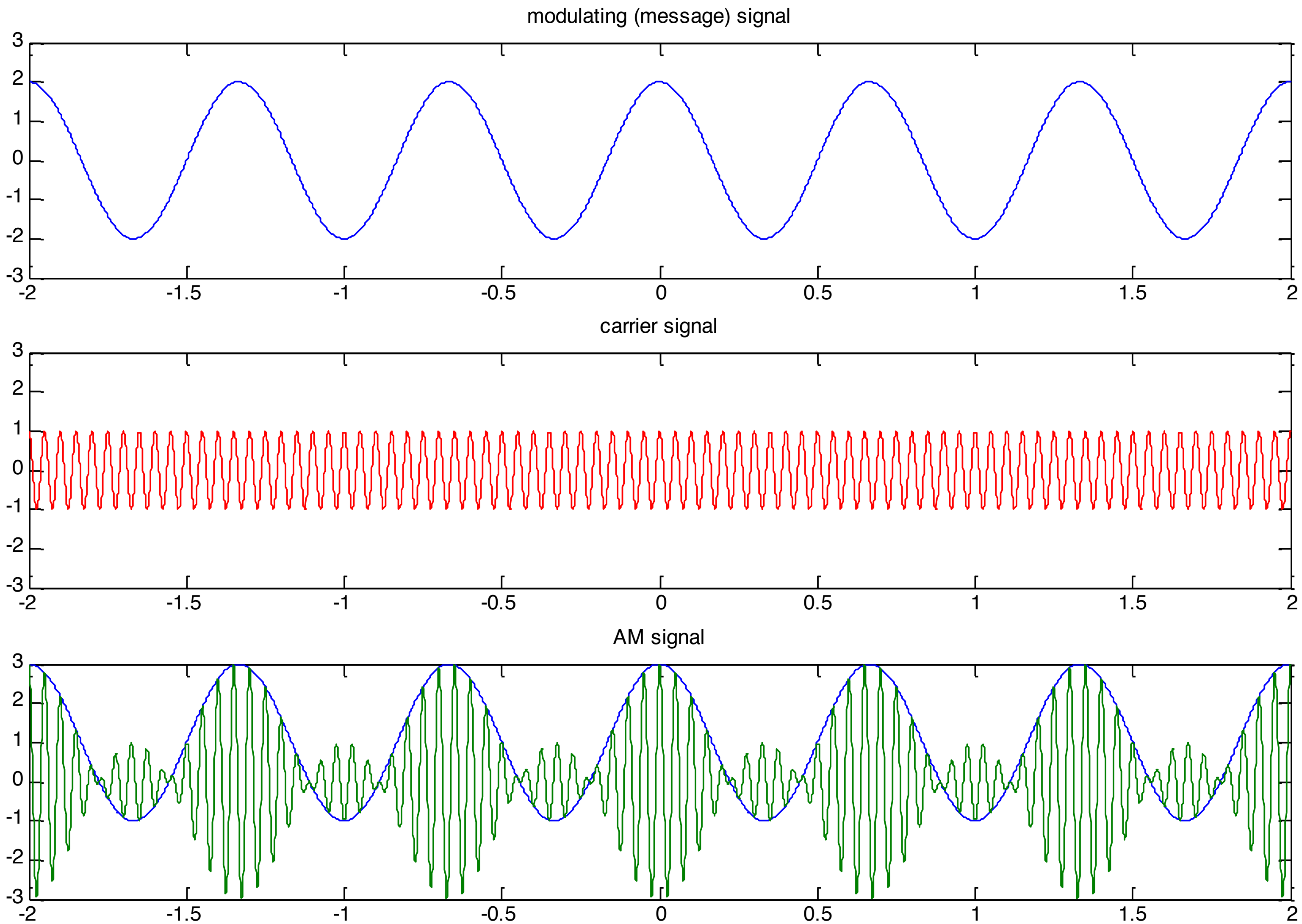
$$v_c(t) = \cos(40\pi\, t) \qquad v_m(t) = 2\cos(3\pi\, t)$$

$$f_c = \ldots\ldots\ldots \qquad f_m = \ldots\ldots\ldots$$

$$V_c = \ldots\ldots\ldots \qquad V_m = \ldots\ldots\ldots$$

Modulation index $m = \dfrac{V_m}{V_c} = \ldots\ldots\ldots$

$$v_{AM}(t) = \ldots\ldots\cos(2\pi\, f_c\, t)\left(1 + \ \ldots\ldots\ \cos(2\pi\, f_m\, t)\right)$$


modulating (message) signal
carrier signal
AM signal
3
2
1
0
-1
-2
-3
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Amplitude Modulation

Example: Draw the following AM signal?

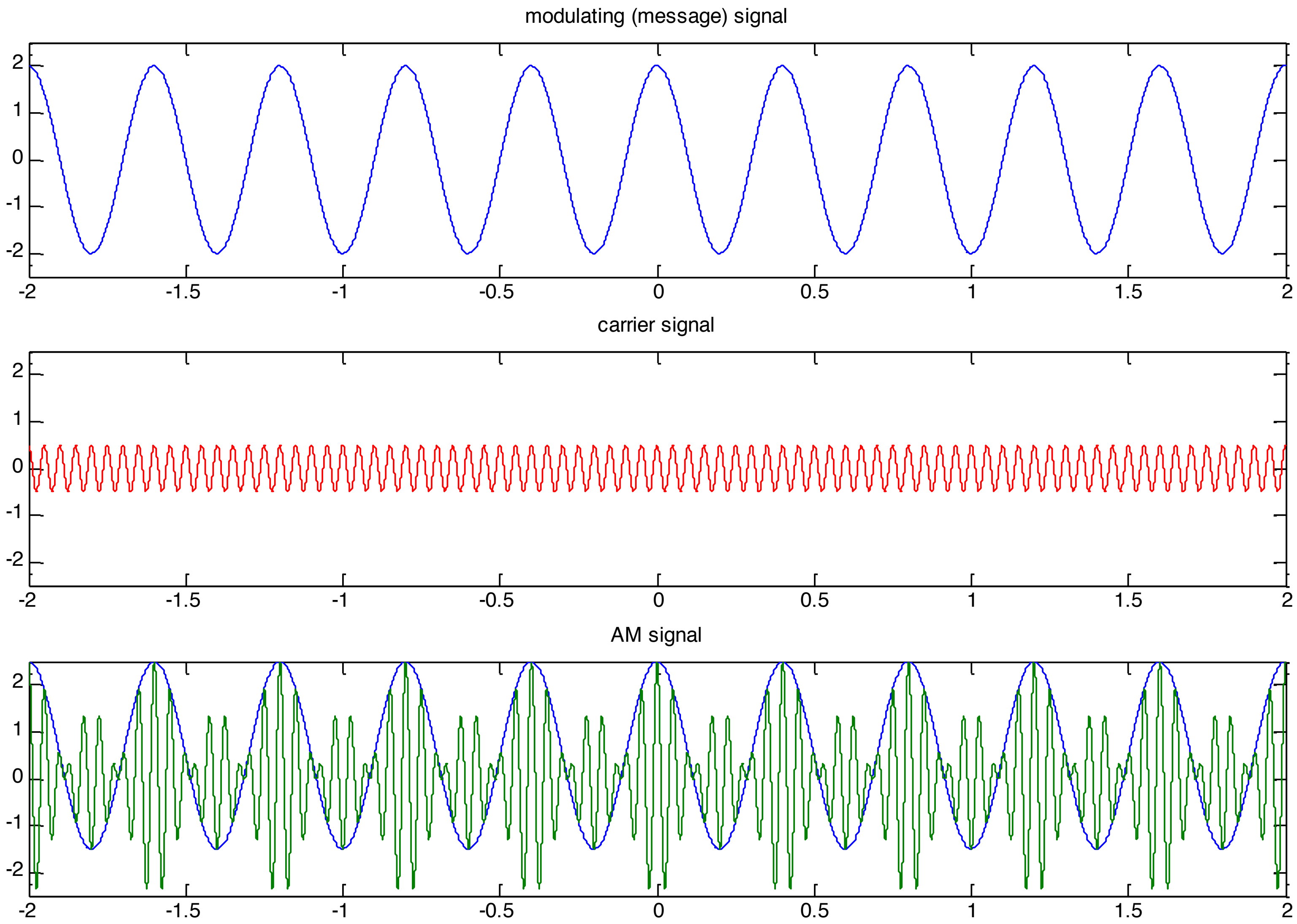
$$v_c(t) = 0.5\cos(40\pi\, t) \qquad v_m(t) = 2\cos(5\pi\, t)$$

$$f_c = \ldots\ldots \qquad f_m = \ldots\ldots$$

$$V_c = \ldots\ldots \qquad V_m = \ldots\ldots$$

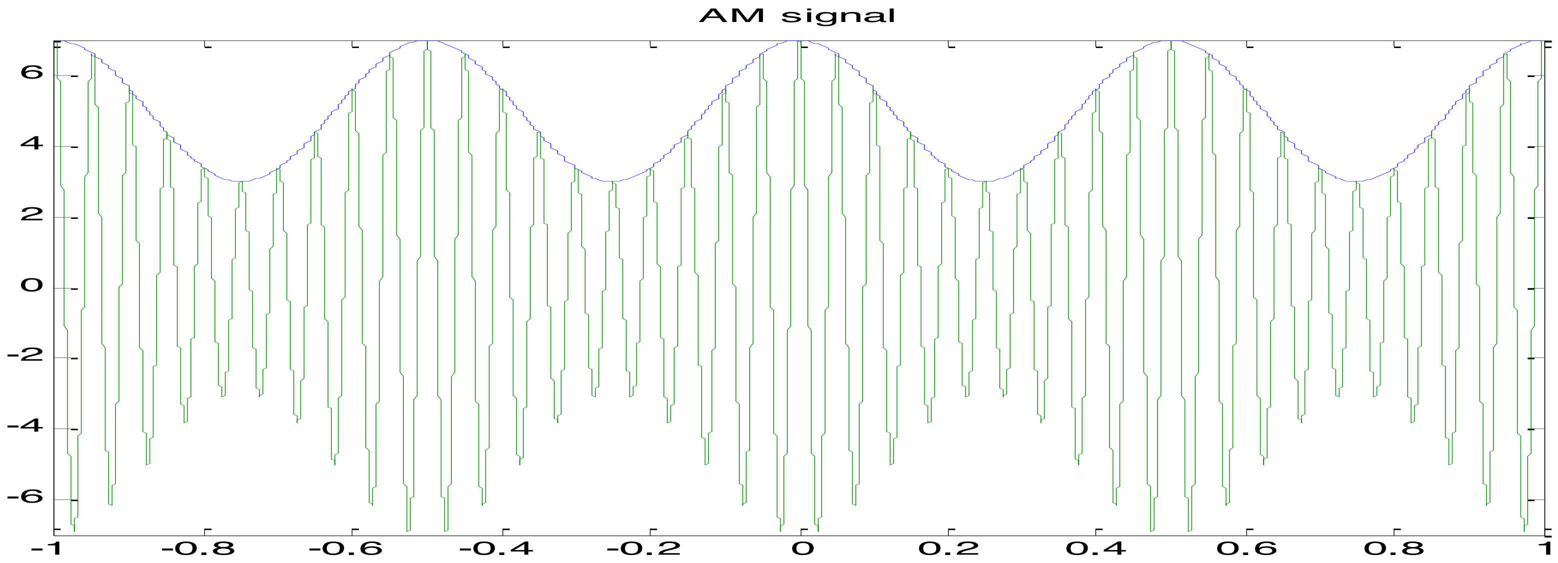
Modulation index $m = \dfrac{V_m}{V_c} = \ldots\ldots$

$$v_{AM}(t) = \ldots\ldots\cos(2\pi\, f_c\, t)\left(1 + \ \ldots\ldots\ \cos(2\pi\, f_m\, t)\ \right)$$


modulating (message) signal
carrier signal
AM signal

Amplitude Modulation

Example: Find the carrier signal, modulating single and modulation index?



Amplitude Modulation

Carrier Signal

$$f_c = \dots\dots$$

$$V_c = \dots..$$

$$v_c(t) = \dots\dots\cos(2\pi\dots\dots t)$$

Modulating Signal

$$f_m = \dots\dots$$

$$V_m = \dots..$$

$$v_m(t) = \dots\dots\cos(2\pi\dots\dots t)$$

Modulation index

$$m = \dots\dots$$

Amplitude Modulation

Carrier Signal

$$f_c = \ldots\ldots$$

$$V_c = \frac{V_{\max} + V_{\min}}{2} = \ldots\ldots$$

$$v_c(t) = \ldots\ldots\cos(2\pi\ldots\ldots t)$$

Modulating Signal

$$f_m = \ldots\ldots$$

$$V_m = \frac{V_{\max} - V_{\min}}{2} = \ldots\ldots$$

$$v_m(t) = \ldots\ldots\cos(2\pi\ldots\ldots t)$$

Modulation index

$$m = \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}} = \ldots\ldots$$

Amplitude Modulation: Frequency Domain

AM Spectrum

Q: How does the spectrum of an AM signal look?

Going back to the defining equation:

$$v_{AM}(t) = V_c \cos(2\pi\ f_c\ t) + V_m \cos(2\pi\ f_m\ t)\cos(2\pi\ f_c\ t)$$

$$v_{AM}(t) = V_c \cos(2\pi\ f_c\ t) + \frac{V_m}{2}\left(\cos(2\pi\left(f_c + f_m\right)t) + \cos(2\pi\left(f_c - f_m\right)t)\right)$$

$$v_{AM}(t) = V_c \cos(2\pi\ f_c\ t) + \frac{V_m}{2}\left(\cos(2\pi\ f_{USB}\ t) + \cos(2\pi\ f_{LSB}\ t)\right)$$

It consists of the: carrier, upper side band (USB) and the lower side band (LSB)

AM Spectrum

Q: How does the spectrum of an AM signal look?

Covert to the frequency domain

$$v_{AM}(t) = V_c \cos(2\pi f_c t) + \frac{V_m}{2}\cos(2\pi f_{USB} t) + \frac{V_m}{2}\cos(2\pi f_{LSB} t)$$

$$V_{AM}(f)$$

$$= \frac{V_c}{2}\delta(f - f_c) + \delta(f + f_c)$$

$$+ \frac{V_m}{4}\left[\delta(f - f_{USB}) + \delta(f + f_{USB})\right]$$

$$+ \frac{V_m}{4}\left[\delta(f - f_{LSB}) + \delta(f + f_{LSB})\right]$$

AM Spectrum

Q: How does the spectrum of an AM signal look?

Covert to the frequency domain

$$v_{AM}(t) = V_c \cos(2\pi\ f_c\ t) + \frac{V_m}{2}\left(\cos(2\pi\ f_{USB}\ t) + \cos(2\pi\ f_{LSB}\ t)\right)$$

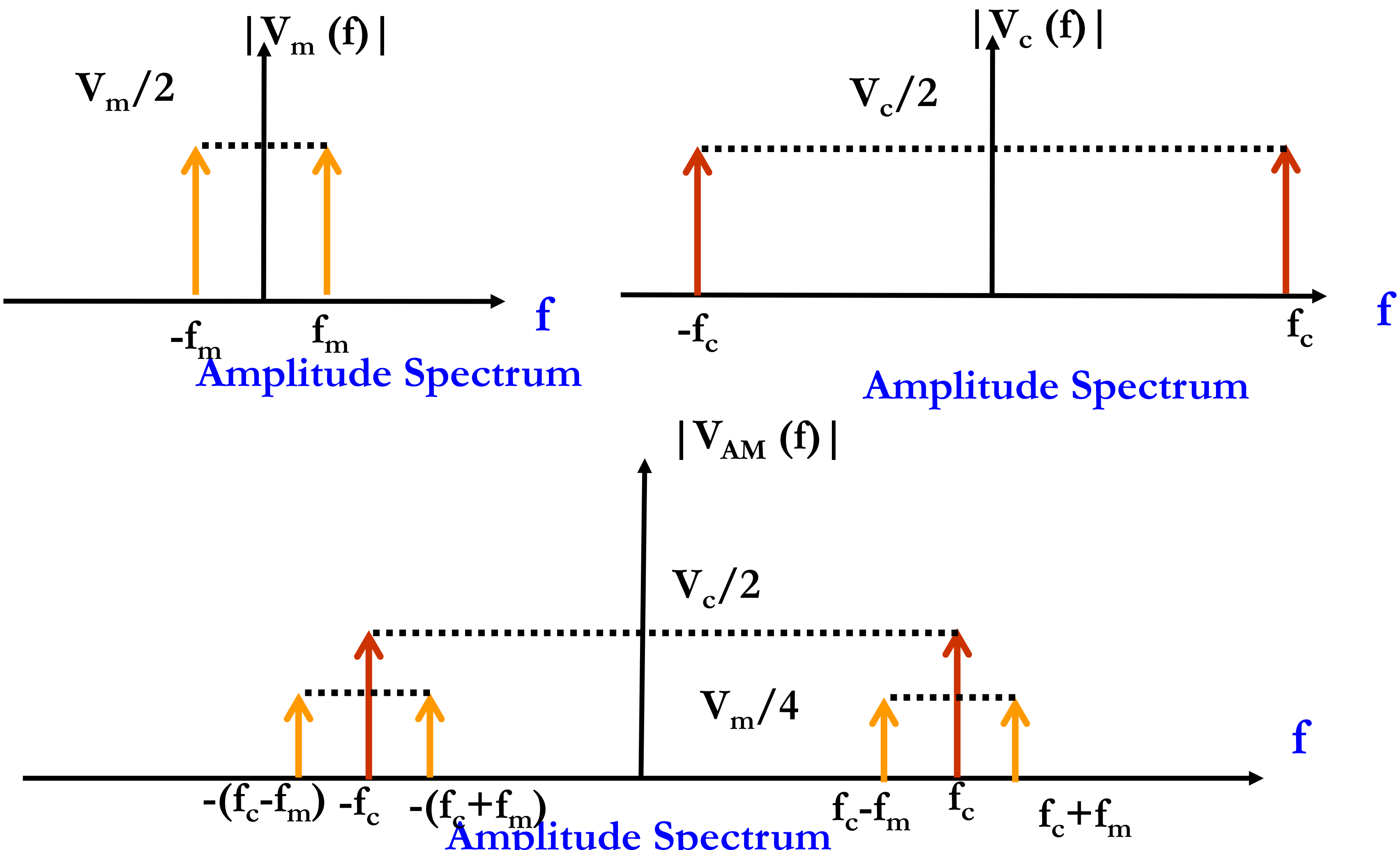
$$V_{AM}(f)$$

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

$$+ \frac{V_m}{4}\left[\delta(f - f_{USB}) + \delta(f + f_{USB})\right] \rightarrow \frac{V_m}{4}\left[\delta(f - (f_c + f_m)) + \delta(f + (f_c + f_m))\right]$$

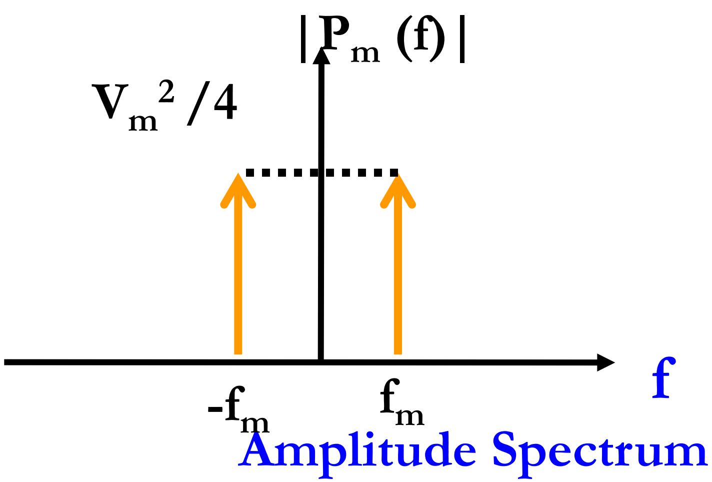
$$+ \frac{V_m}{4}\left[\delta(f - f_{LSB}) + \delta(f + f_{LSB})\right] \rightarrow \frac{V_m}{4}\left[\delta(f - (f_c - f_m)) + \delta(f + (f_c - f_m))\right]$$

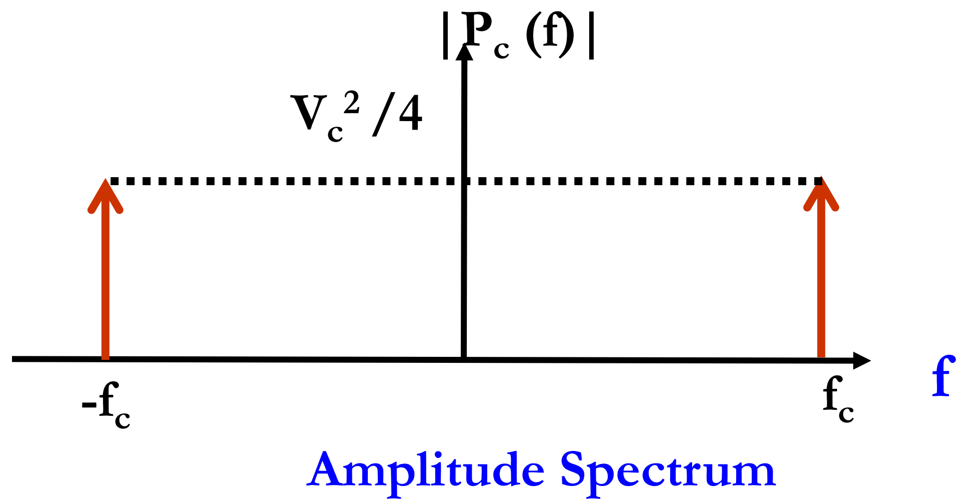
AM Spectrum

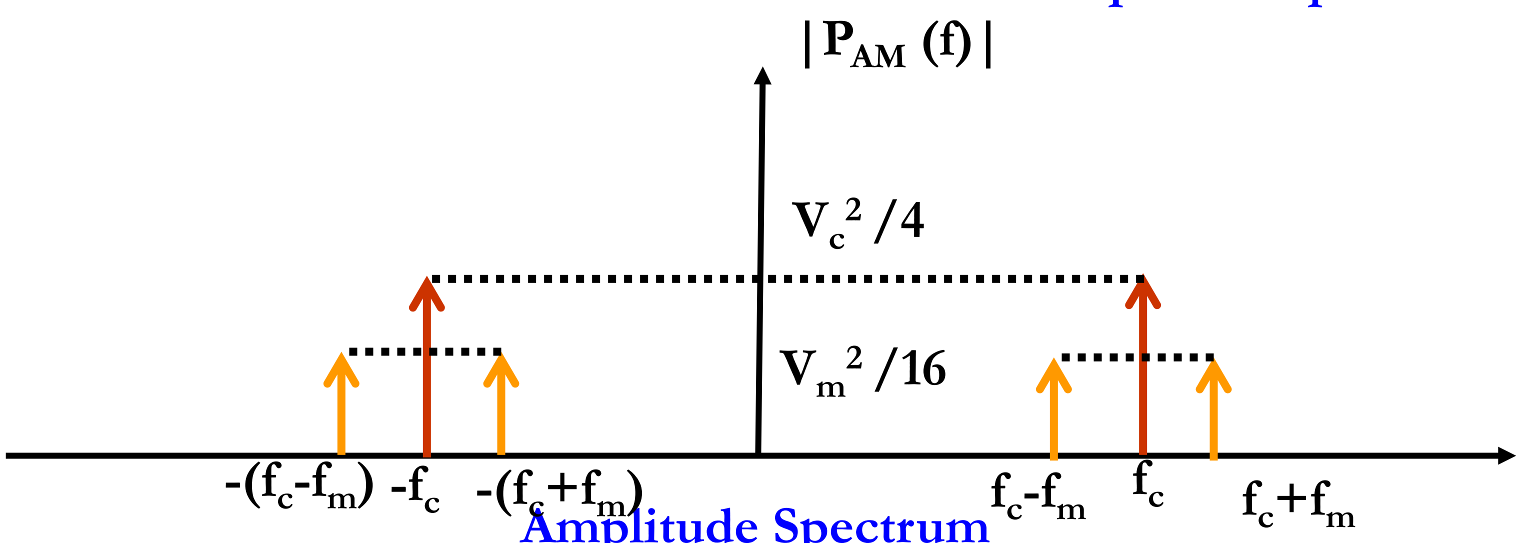


|Vm (f)|
Vm/2
-fm
fm
f
Amplitude Spectrum
|Vc (f)|
Vc/2
-fc
fc
f
Amplitude Spectrum
|VAM (f)|
Vc/2
Vm/4
f
-(fc-fm)
-fc
-(fc+fm)
fc-fm
fc
fc+fm
Amplitude Spectrum

Power spectrum Spectrum







AM Bandwidth

Q: What is the Bandwidth of an AM signal?

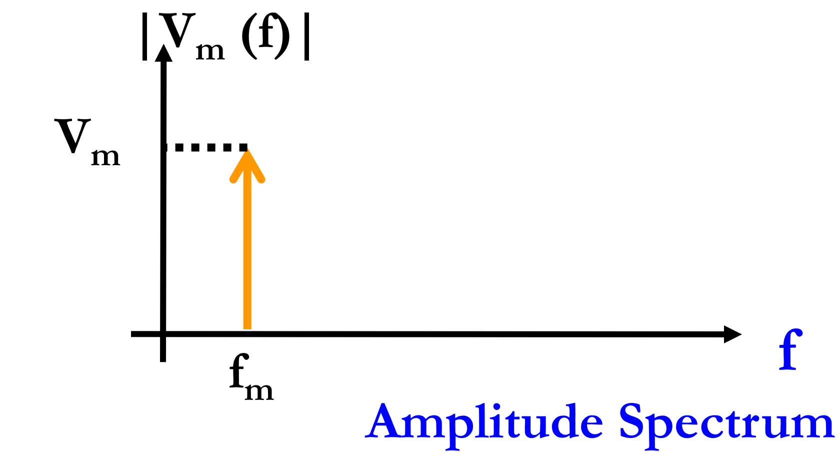
The Bandwidth of the AM signal is defined as:

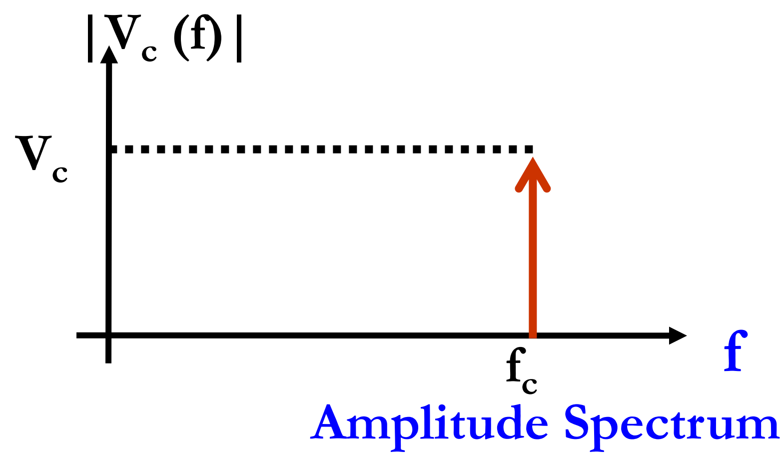
$$BW = f_{USB} - f_{LSB}$$

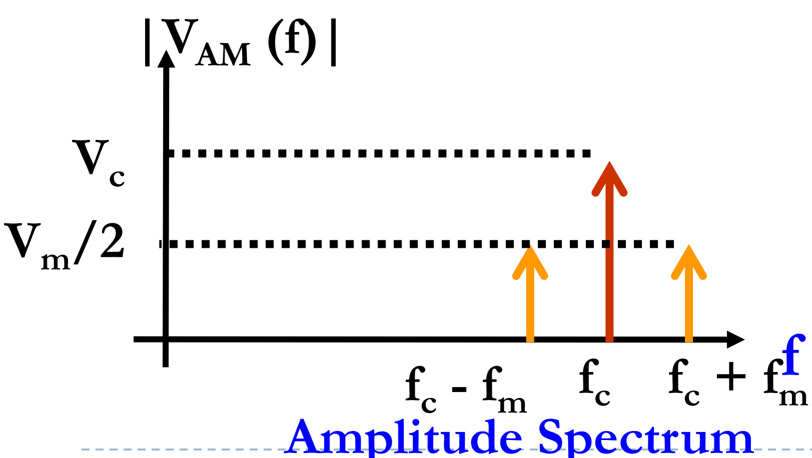
$$BW = 2 f_m$$

AM Spectrum

Q: What is the spectrum if the message signal is a sine function ?







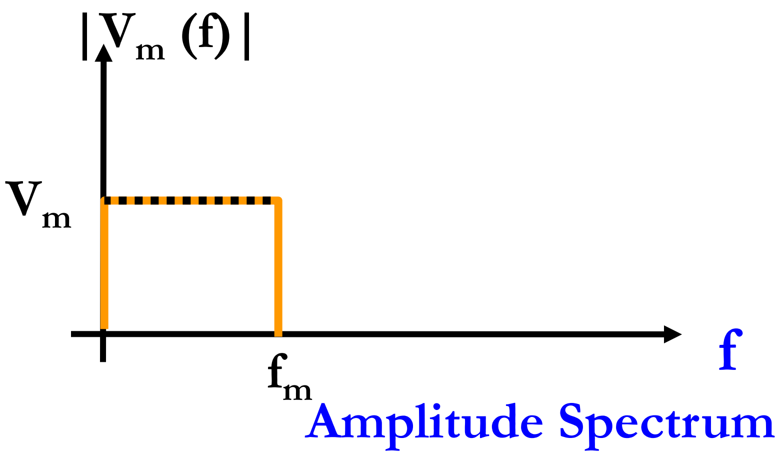
$$f_{USB} = \dots\dots\dots$$

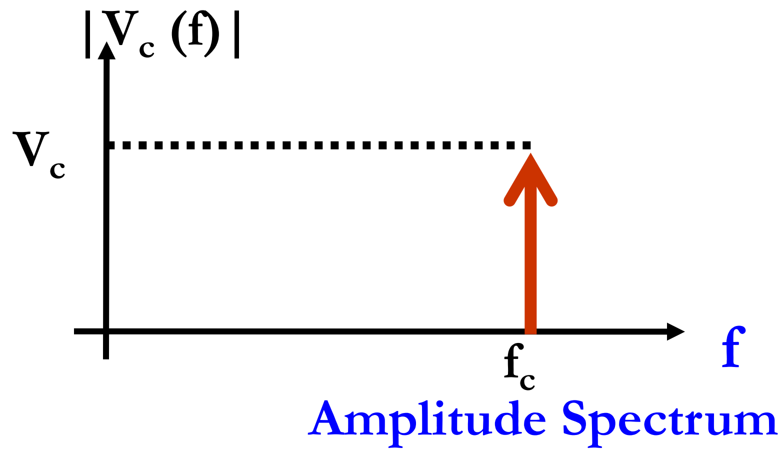
$$f_{LSB} = \dots\dots\dots$$

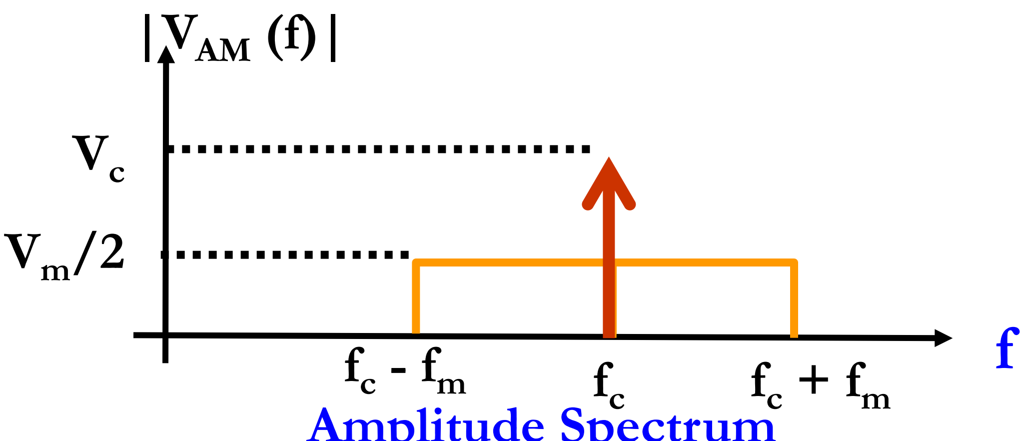
$$BW = f_{USB} - f_{LSB}$$

AM Spectrum

Q: What if the modulating signal is not a sine?







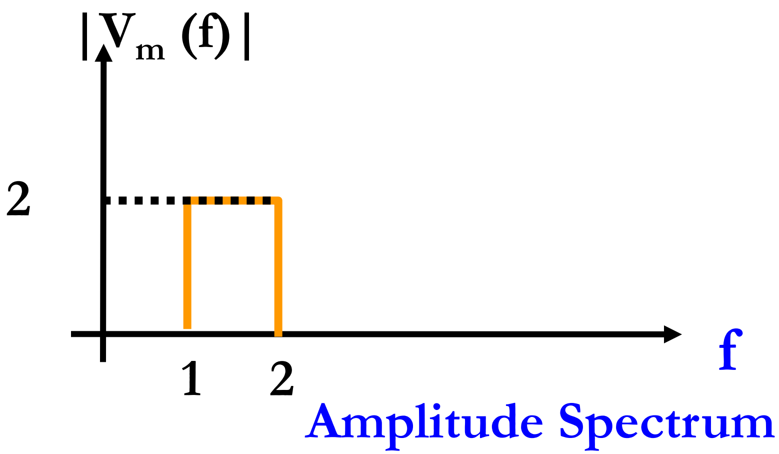
$$f_{USB} = \dots\dots\dots$$

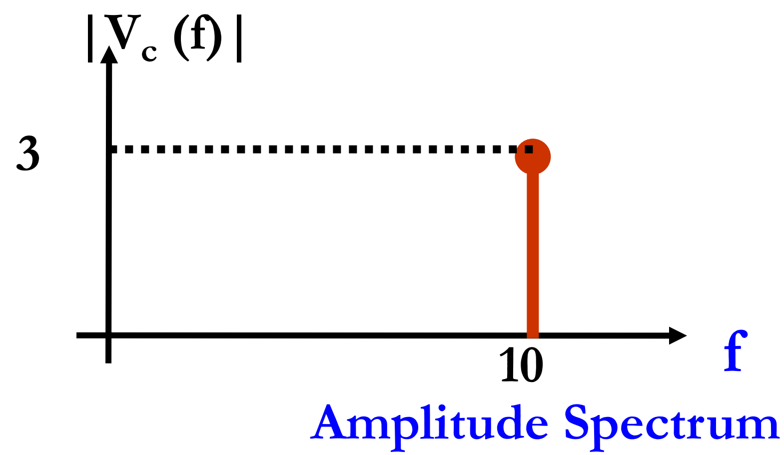
$$f_{LSB} = \dots\dots\dots$$

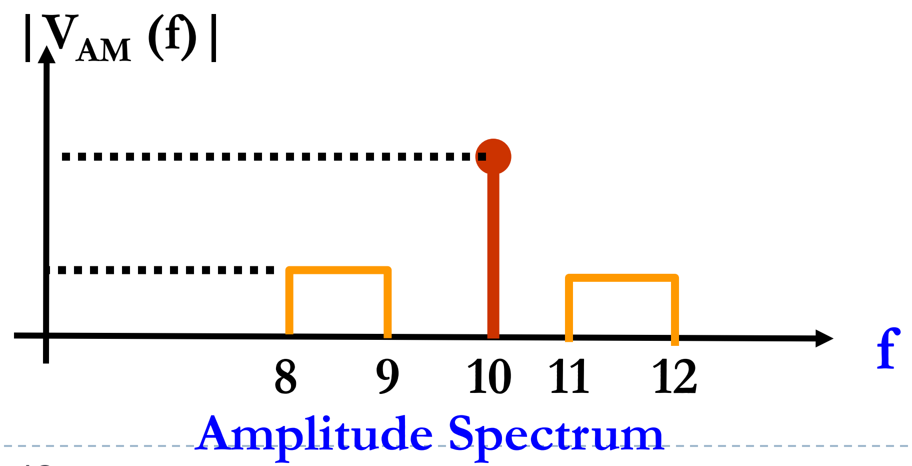
$$BW = f_{USB} - f_{LSB} = 2 f_{\max}$$

AM Spectrum

Example: Find the spectrum of the following AM signal.







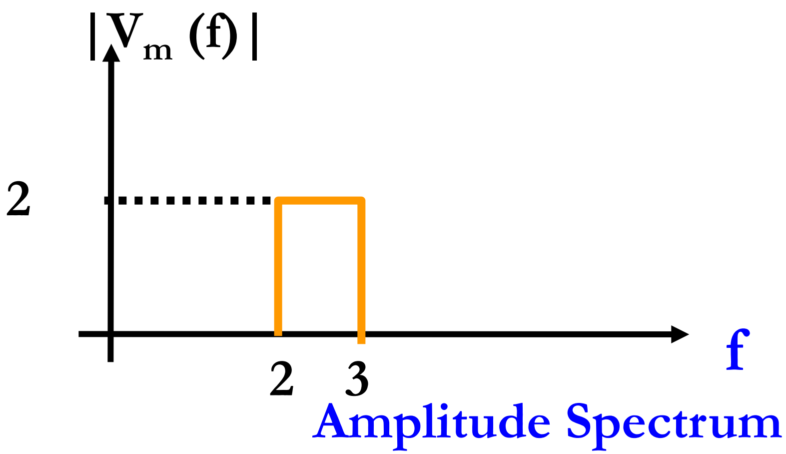
$$f_{USB} = \ldots\ldots\ldots$$

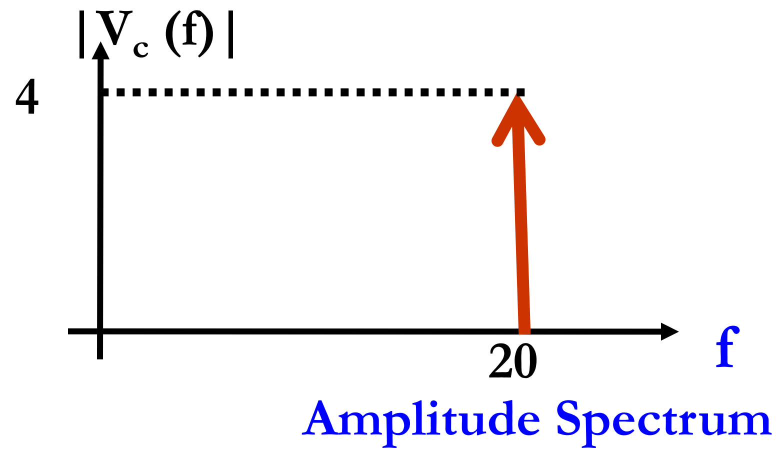
$$f_{LSB} = \ldots\ldots\ldots$$

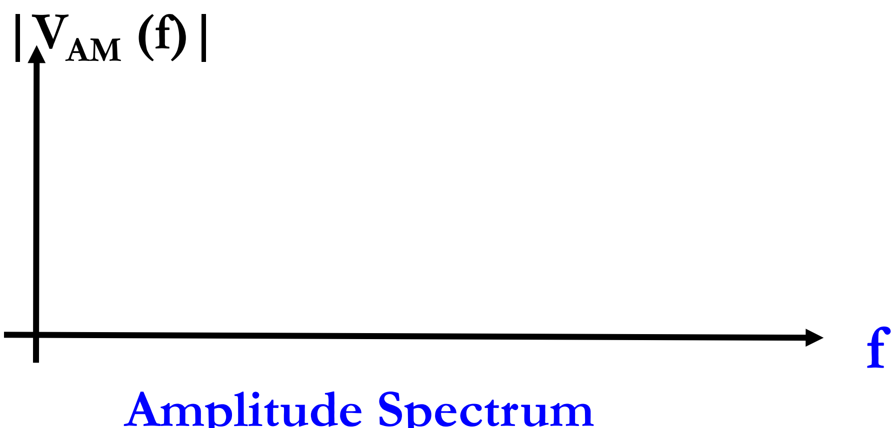
$$BW = f_{USB} - f_{LSB}$$

AM Spectrum

Example: Find the spectrum of the following AM signal.







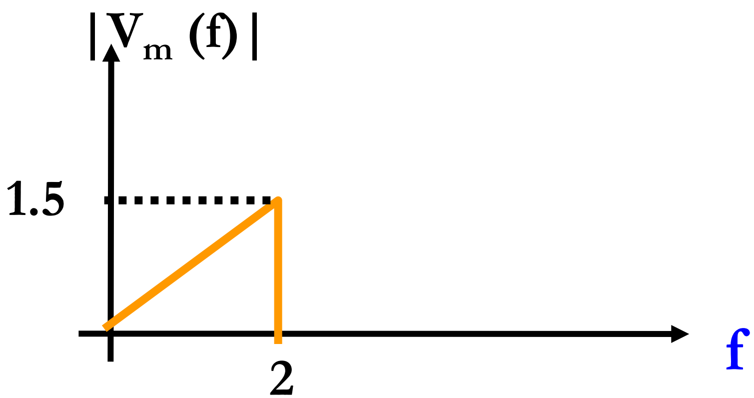
$$f_{USB} = \ldots\ldots\ldots$$

$$f_{LSB} = \ldots\ldots\ldots$$

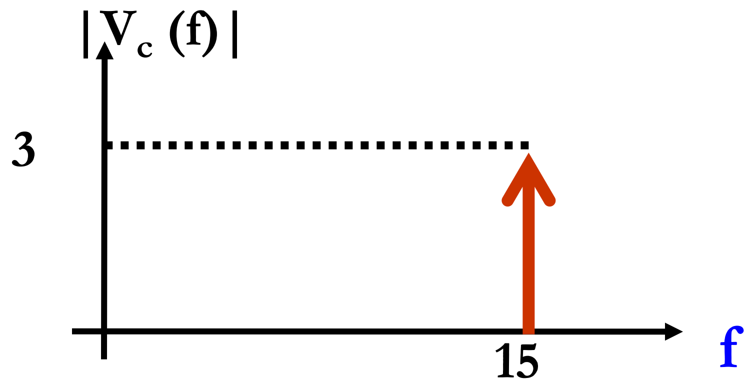
$$BW = f_{USB} - f_{LSB}$$

AM Spectrum

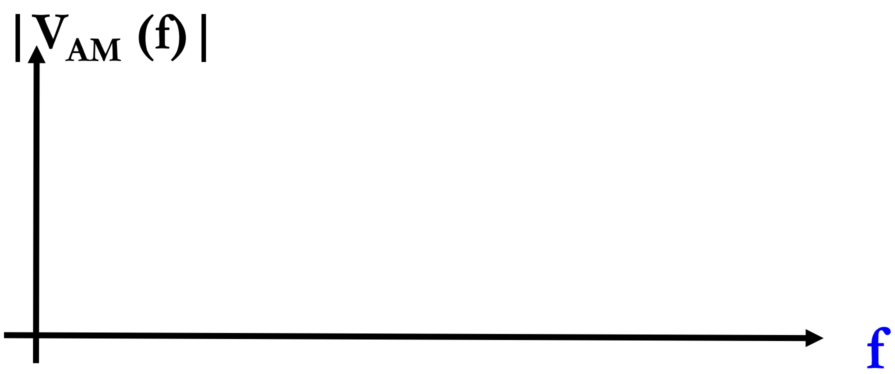
Example: Find the spectrum of the following AM signal.



Amplitude Spectrum



Amplitude Spectrum



Amplitude Spectrum

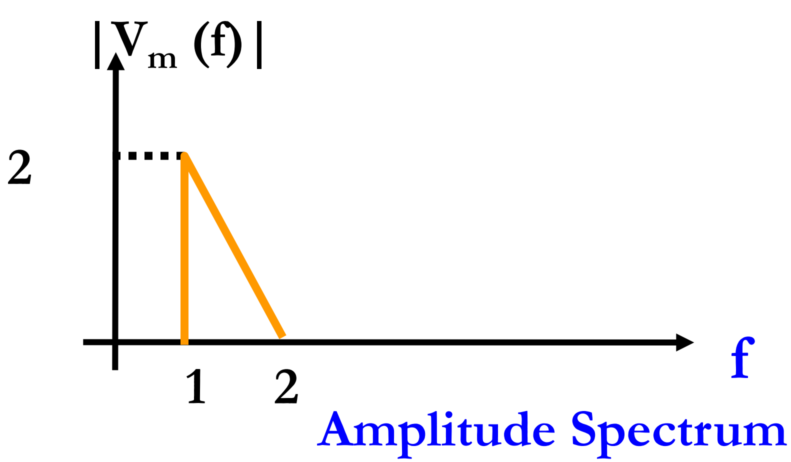
$$f_{USB} = \ldots\ldots\ldots$$

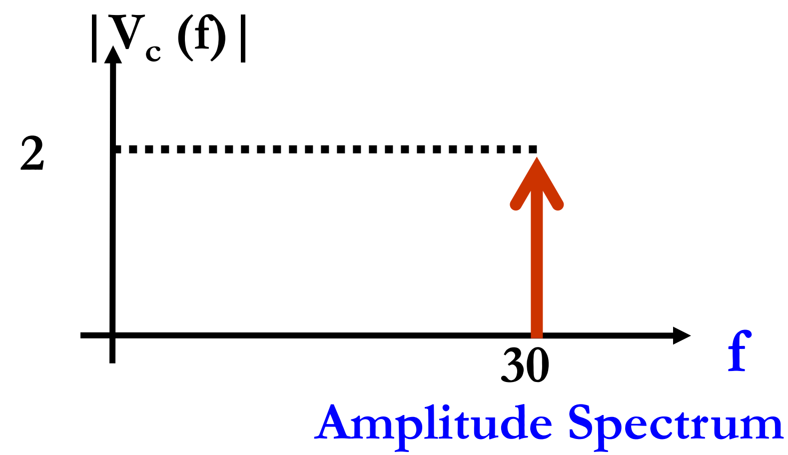
$$f_{LSB} = \ldots\ldots\ldots$$

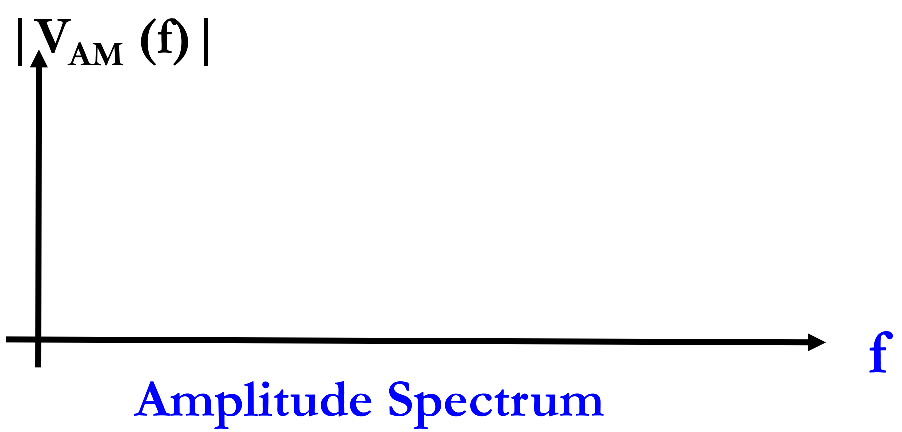
$$BW = f_{USB} - f_{LSB}$$

AM Spectrum

Example: Find the spectrum of the following AM signal.







$$f_{USB} = \dots\dots\dots\dots$$

$$f_{LSB} = \dots\dots\dots\dots$$

$$BW = f_{USB} - f_{LSB}$$

Amplitude Modulation: Power

AM Total transmitted Power

Q: What is the total power in an AM signal?

The total power in the AM signal is equal to:

$$P_T = P_C + P_{USB} + P_{LSB} \quad = P_C + P_{SB} \quad = P_C(1 + \frac{m^2}{2})$$

$$P_C = \frac{V_C^2}{2}$$

$$P_{USB} = P_{LSB} \quad = \frac{\left(V_m/2\right)^2}{2} = \frac{(V_m)^2}{8} = \frac{(mV_C)^2}{8} = \frac{m^2}{4}\frac{V_C^2}{2} = \frac{m^2}{4}P_C$$

$$P_T = P_C + \frac{m^2}{4}P_C + \frac{m^2}{4}P_C = P_C + \frac{m^2}{2}P_C = P_C(1 + \frac{m^2}{2})$$

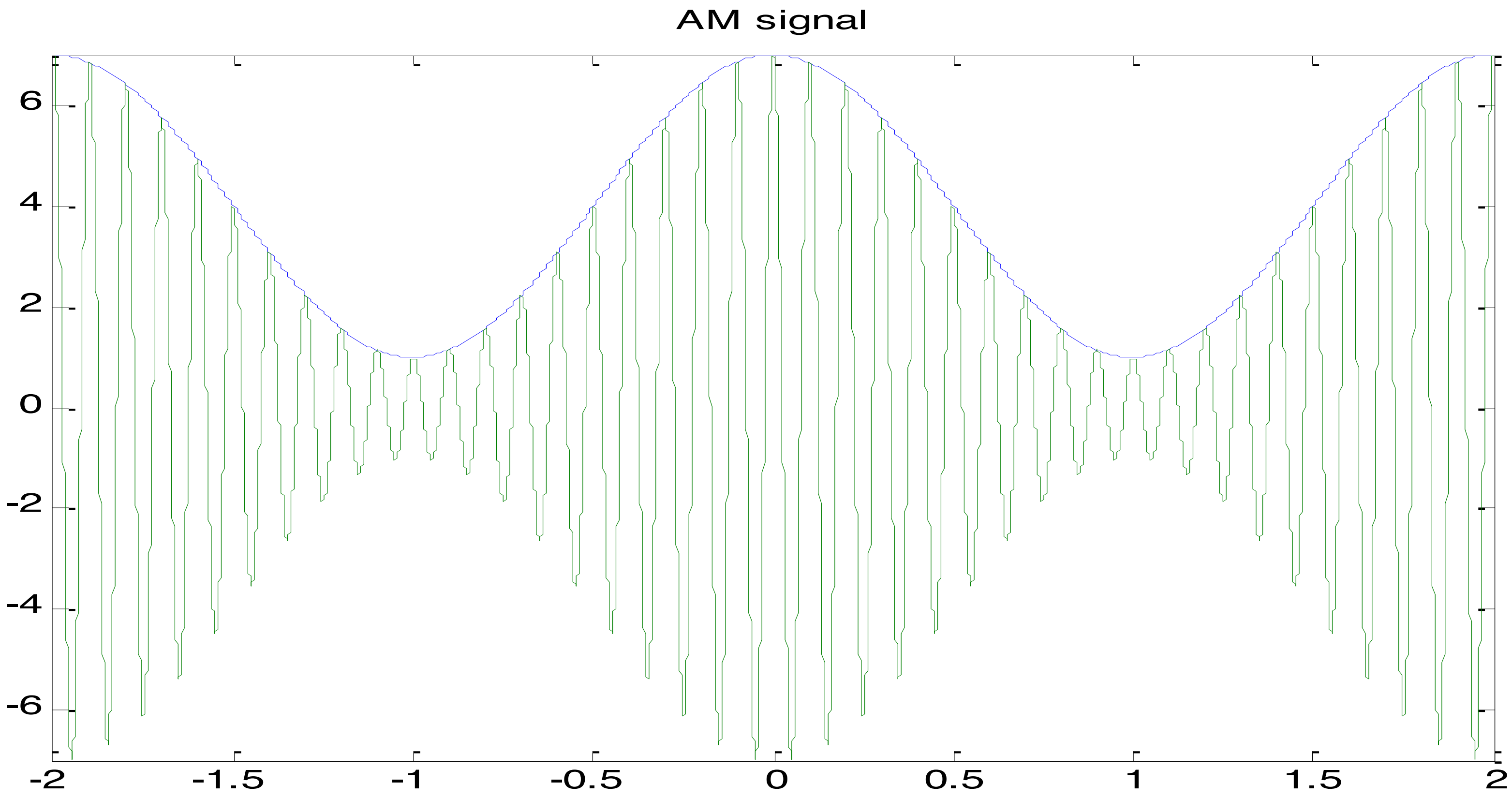
Power in sidebands

Q: What is the total power in the side bands?

$$P_{SB} = P_{USB} + P_{LSB} = \frac{V_m^2}{8} + \frac{V_m^2}{8} = \frac{V_m^2}{4} = \frac{(mV_C)^2}{4} = \frac{m^2}{2}\frac{V_C^2}{2} = \frac{m^2}{2}P_C$$

$$P_{SB} = \frac{V_m^2}{4} = \frac{V_m^2/2}{2} = \frac{P_m}{2}$$

Note that the total power in the sidebands is half the power of the message signal


AM signal
6
4
2
0
-2
-4
-6
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

AM

Example: For the AM signals on the previous slide, find:

1. The spectrum
2. The power spectrum
3. The power spectrum in dB
4. The bandwidth
5. The Total transmitted power

Percentage Modulation Index

Q: What is the percentage modulation index?

The modulation index is defined as:

$$m = \frac{V_m}{V_c}$$

The percentage modulation index is defined as:

$$percentage \quad m = \frac{V_m}{V_c} \times 100\%$$

Percentage transmitted Power

Q: What is the percentage power in the Side bands?

Fraction of power in the side bands μ:

$$\mu = \frac{P_{SB}}{P_T} = \frac{\frac{m^2}{2} P_C}{P_T} = \frac{\frac{m^2}{2}}{1+\frac{m^2}{2}} = \frac{m^2}{2+m^2}$$

Percentage of power in the side bands %μ:

$$\%\mu = \frac{P_{SB}}{P_T} \times 100\% = \frac{m^2}{2+m^2} \times 100\%$$

Percentage transmitted Power

Q: What is the percentage power in the carrier?

Fraction of power in the carrier
(1-μ):

$$\frac{P_C}{P_T} = 1 - \mu \quad = \frac{1}{1 + \frac{m^2}{2}} = \frac{2}{2 + m^2}$$

Percentage of power in the carrier %(1-μ):

$$\%(1 - \mu) = \frac{P_C}{P_T} \times 100\% = \frac{2}{2 + m^2} \times 100\%$$

AM Percentage Power

Example: Determine the percentage of the total power carried in the sidebands of an AM signal for tone modulation when

a. The modulation index is 0.5
b. The modulation index in 0.3

AM Percentage Power

Example: For the previous examples

1. the percentage power in the side bands
2. the percentage power in the carrier in this case

AM Percentage Power

Example: A given AM broad cast station transmits an average carrier power output of 40kW and uses modulation index of 0.707 for sinewave modulation. Calculate,

1. The total average power output
2. The transmission efficiency

AM Percentage Power

Example: The amplitude of the modulating signal in the previous example is reduced until the total transmitted power is 40kW. Assuming that the carrier power remained constant, compute the new modulation index and transmission power.

AM Percentage Power

Example:

What is the **maximum** percentage power in the side bands?

What is the **maximum** percentage power in the carrier in this case?

$$\%\mu = \frac{m^2}{2+m^2} \times 100\% = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

AM efficiency

Q: What do you conclude from the previous example?

From the example we notice that the maximum percentage power in the side bands = 33%

The remaining 66% of transmitted power is in the carrier, which does not contain any information

i.e: 66% of the transmitted AM power is wasted

Therefore,

AM is an inefficient method of communication

Advantages and Disadvantages of AM

Advantages:

+ Simple idea
+ Ease of generation and detection
+ AM communication system cheap to build

Disadvantages:

- Wasteful in power
- Wasteful in Bandwidth
- Susceptible to Noise.

AM Efficiency

Q: Can AM be more efficient?

To obtain a more efficient method of transmitting information using AM two techniques are used:

1. AM Suppressed carrier (DSB-SC)
2. AM Single Side Band (SSB)

Note that the AM we have been talking about so far is called:

Double Side Band – Large carrier (DSB-LC)

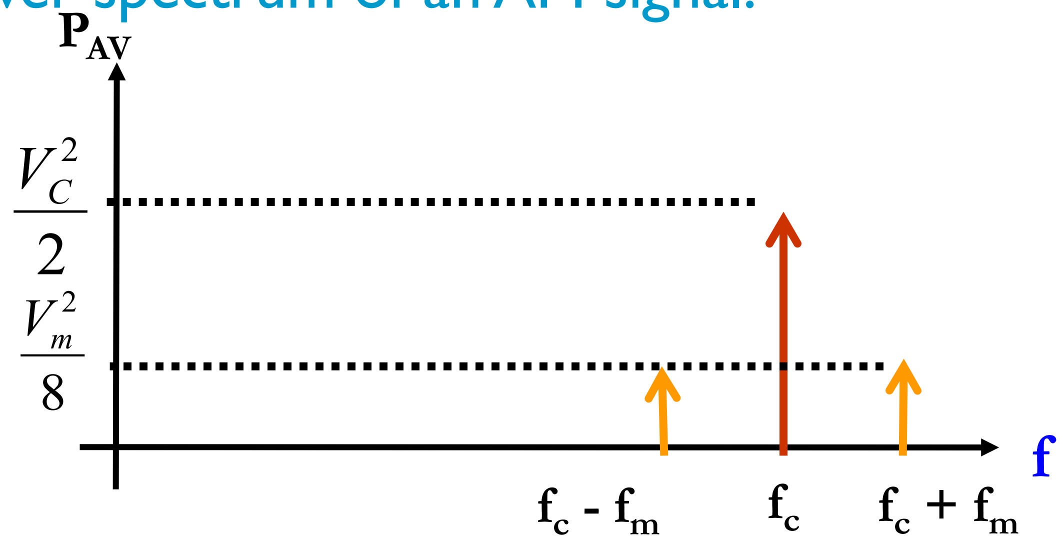
Double Side Band – Transmit Carrier (DSB-TC)

Amplitude Modulation:
Double Sideband Suppressed carrier

DSB Suppressed carrier

Q: What is DSB Suppressed Carrier (SC)?

This is the power spectrum of an AM signal:



Power Spectrum

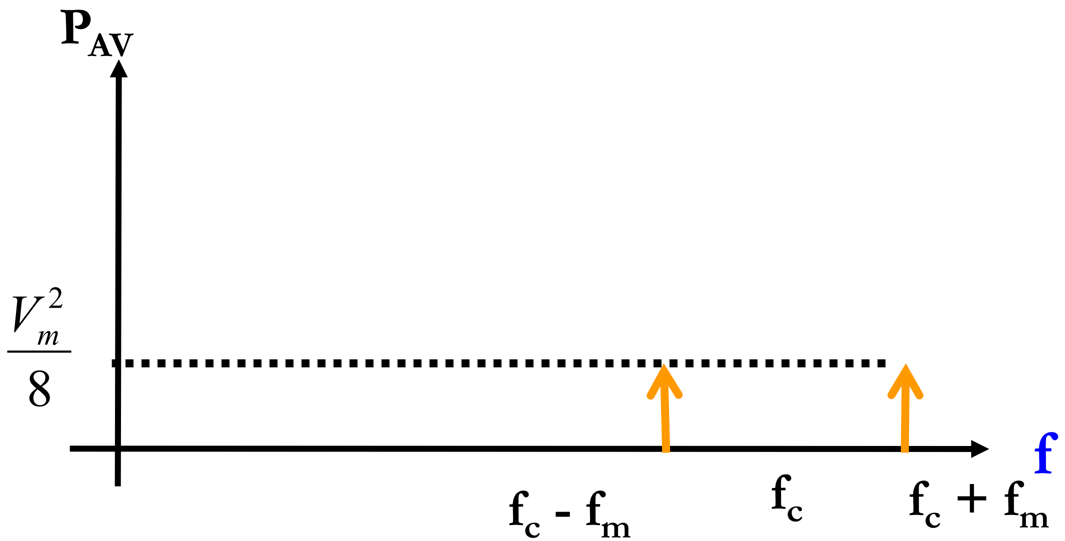
For m=1:

$$\mu = \frac{P_{SB}}{P_T} = \ldots\ldots\ldots\ldots$$

DSB Suppressed carrier

Q: What is DSB Suppressed Carrier?

This is the power spectrum of an AM SC signal:



Power Spectrum

$$\mu = \frac{P_{SB}}{P_T} = 1$$

DSB Suppressed carrier

Q: What is DSB Suppressed Carrier in the Time Domain?

In the Frequency Domain:

$$V_{AM}(f)=\frac{V_c}{2}[\delta(f-f_c)+\delta(f+f_c)]$$

$$+\frac{V_m}{4}[\delta(f-f_{USB})+\delta(f+f_{USB})]+\frac{V_m}{4}[\delta(f-f_{LSB})+\delta(f+f_{LSB})]$$

$$V_{DSB-SC}(f)=\frac{V_m}{4}[\delta(f-f_{USB})+\delta(f+f_{USB})]+\frac{V_m}{4}[\delta(f-f_{LSB})+\delta(f+f_{LSB})]$$

In the time domain:

$$v_{DSB-SC}(t)=\frac{V_m}{2}\cos(2\pi\ f_{USB}\ t)+\frac{V_m}{2}\cos(2\pi\ f_{LSB}\ t)$$

DSB - Suppressed carrier

Q: What is AM Suppressed Carrier in the Time Domain?

In the time domain:

$$v_{DSB-SC}(t) = \frac{V_m}{2}\cos(2\pi\ f_{USB}\ t) + \frac{V_m}{2}\cos(2\pi\ f_{LSB}\ t)$$

$$v_{DSB-SC}(t) = \frac{V_m}{2}\cos(2\pi\ (f_c + f_m)\ t) + \frac{V_m}{2}\cos(2\pi\ (f_c - f_m)\ t)$$

$$v_{DSB-SC}(t) = V_m \cos(2\pi\ f_m t) \bullet \cos(2\pi\ f_c\ t)$$

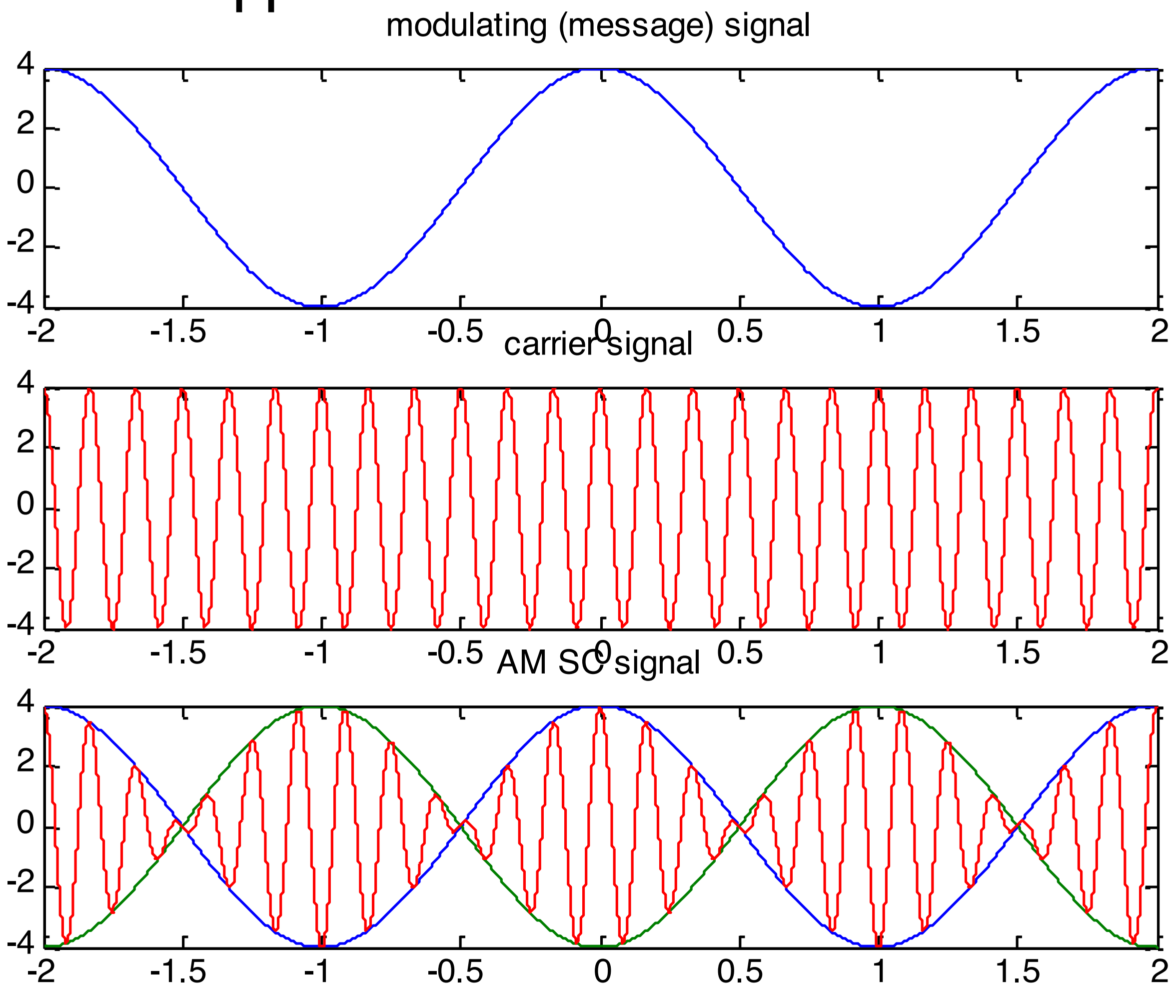
Compare to:

$$v_{DSB-TC}(t) = \left(V_c + V_m \cos(2\pi\ f_m\ t)\right)\ \cos(2\pi\ f_c\ t)$$

$$v_{DSB-TC}(t) = V_c \cos(2\pi\ f_c\ t) + V_m \cos(2\pi\ f_m\ t)\cos(2\pi\ f_c\ t)$$

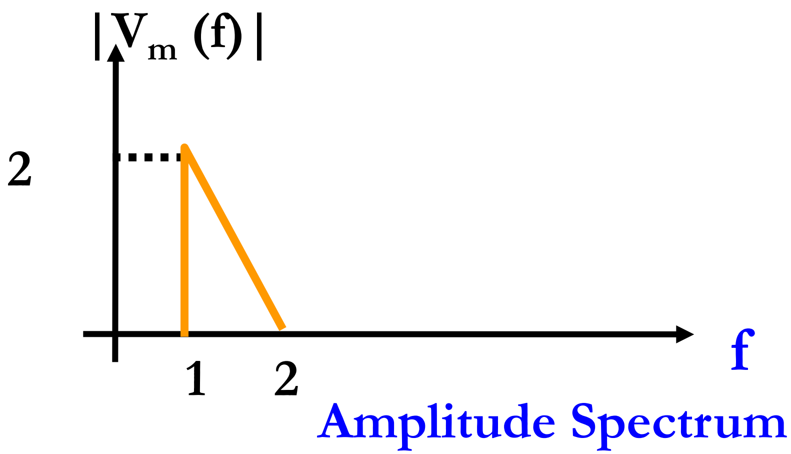
DSB Suppressed carrier

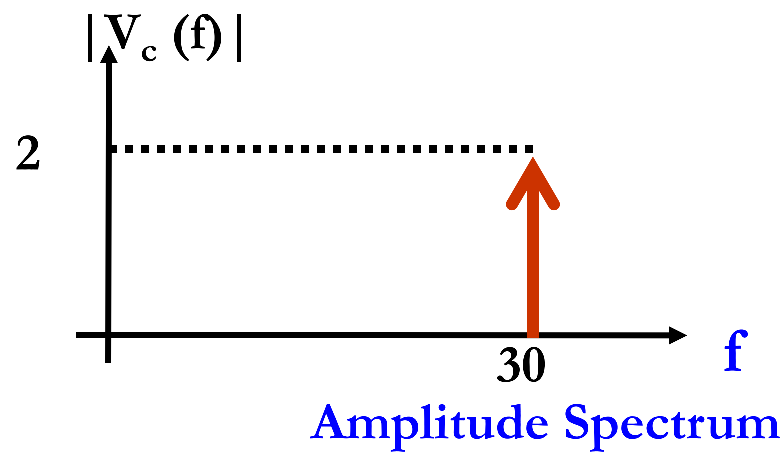
Q: What is AM Suppressed Carrier in the Time Domain?

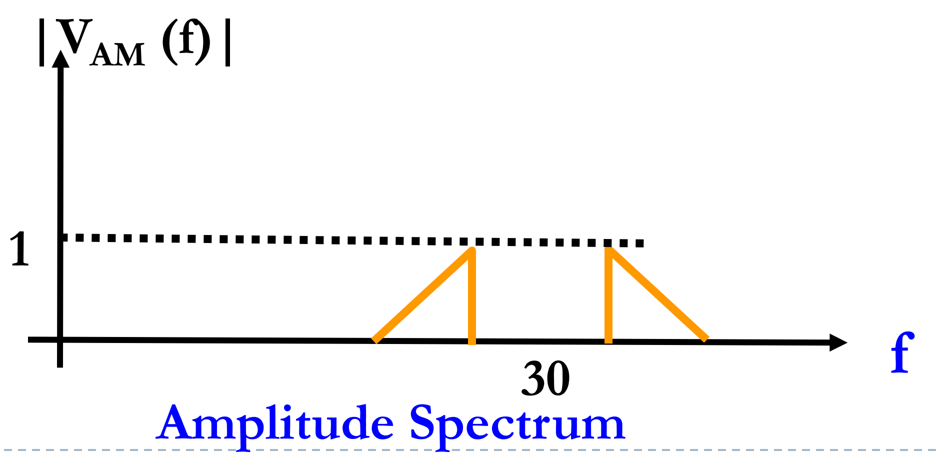


DSB-SC spectrum

Example: Find the spectrum of the following DSB-SC signal.







$$BW = f_{USB} - f_{LSB} = 2f_{\max}$$

DSB still requires twice the information BW