University of Bahrain
Department of Electrical and Electronics Engineering

EENG370

Communication Systems

Amplitude Modulation (AM)

By Prof. Mohab Mangoud
& Dr. Sana Almansoori

This Topic will cover

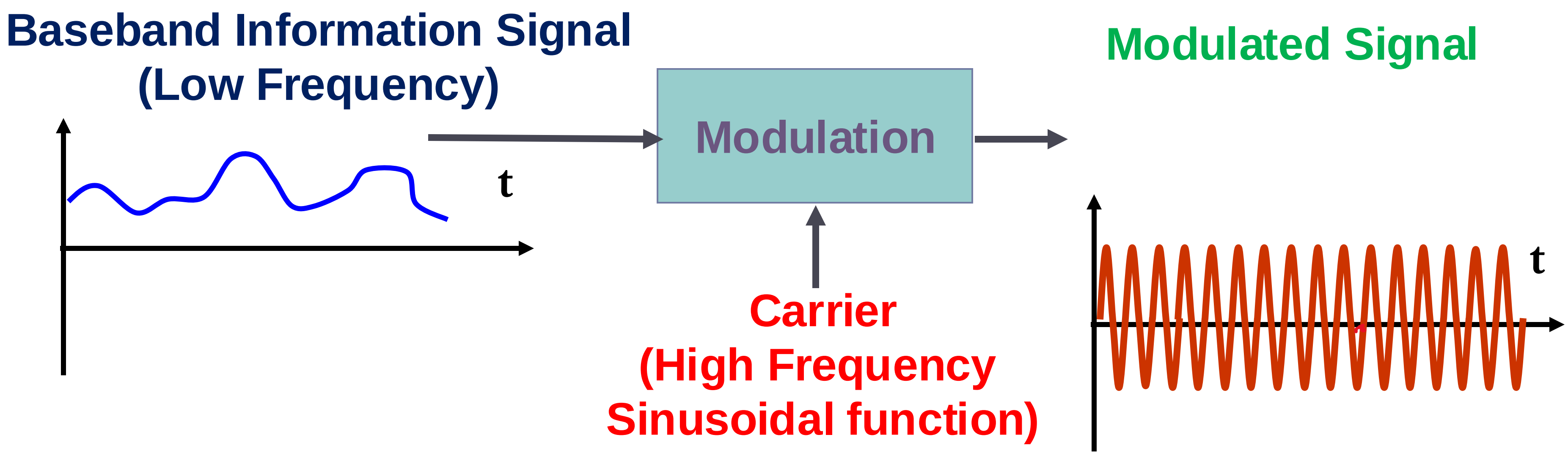
- Why Modulation ?
- Amplitude Modulation (AM)
  - Time Domain
  - Spectrum of AM signals
  - Power in AM signals
- *AM- Suppressed* carrier (SC)
- AM-Single Side Band (SSB)
- AM Demodulation
- AM Receivers

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 **d ≥ λ/10**

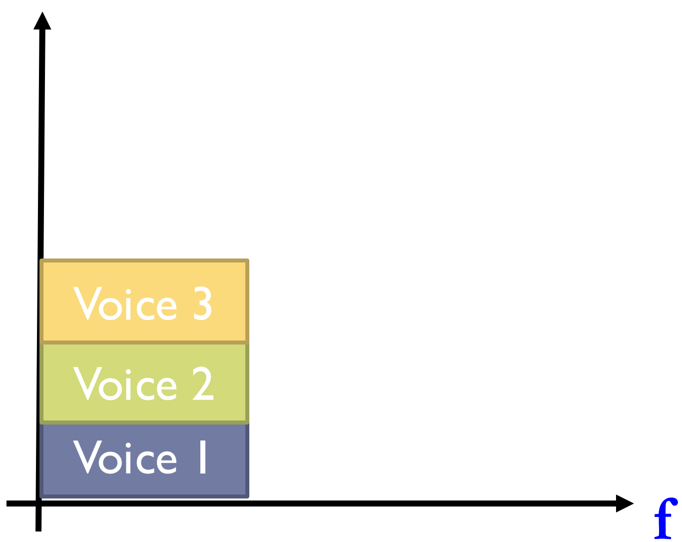
Q: What is the size of the antenna?

Modulation

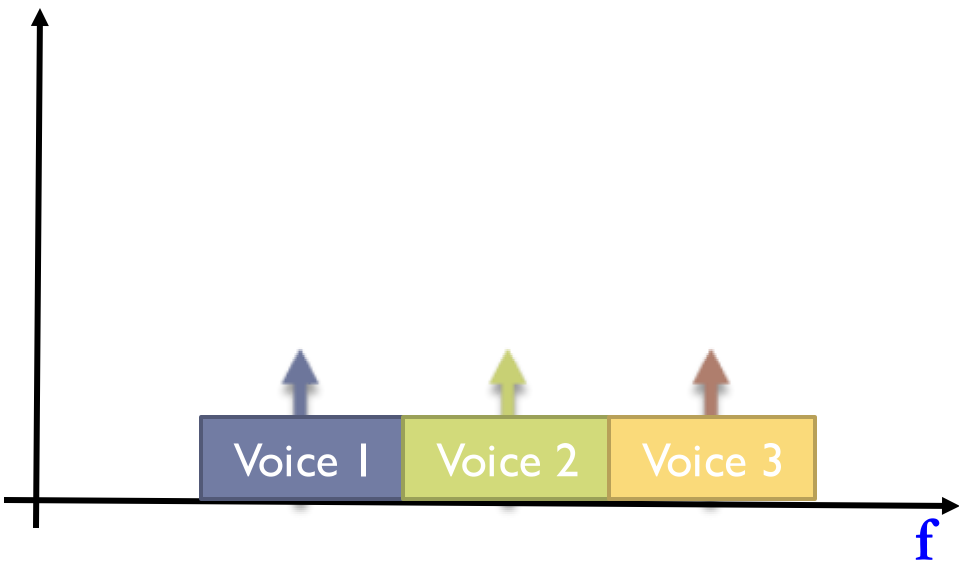
Q: Why is modulation required in communication systems?

2. Simultaneous Transmission of several signals

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



Amplitude Spectrum



Amplitude Spectrum

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

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

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?

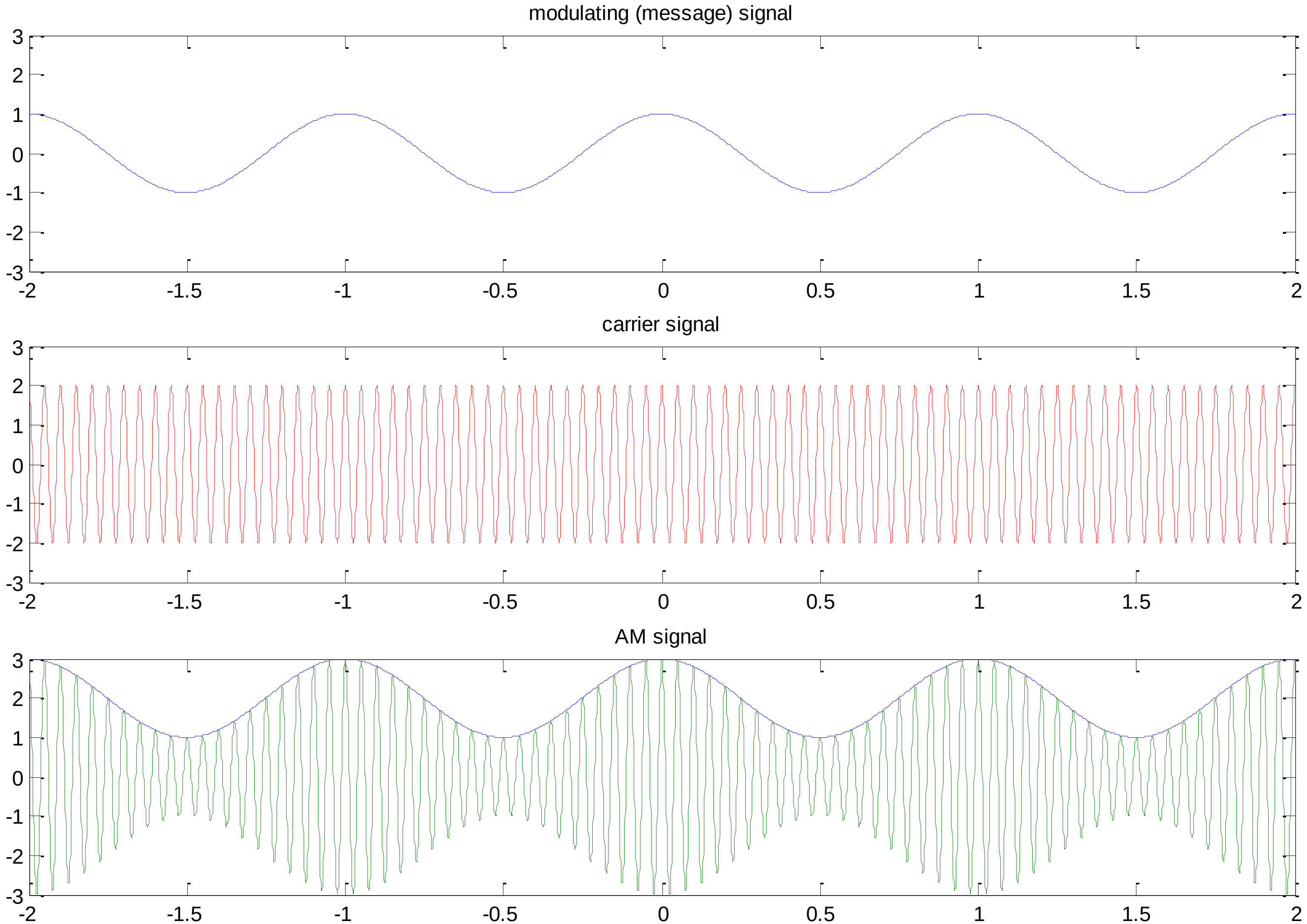
$$v_c(t) = 2\cos(40\pi\, t) \qquad v_m(t) = \cos(2\pi\, t)$$

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

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

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

$$v_{AM}(t) = 2\cos(2\pi\ f_c\ t)\left(1 + \ 0.5\ \cos(2\pi\ f_m\ t)\ \right)$$


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?

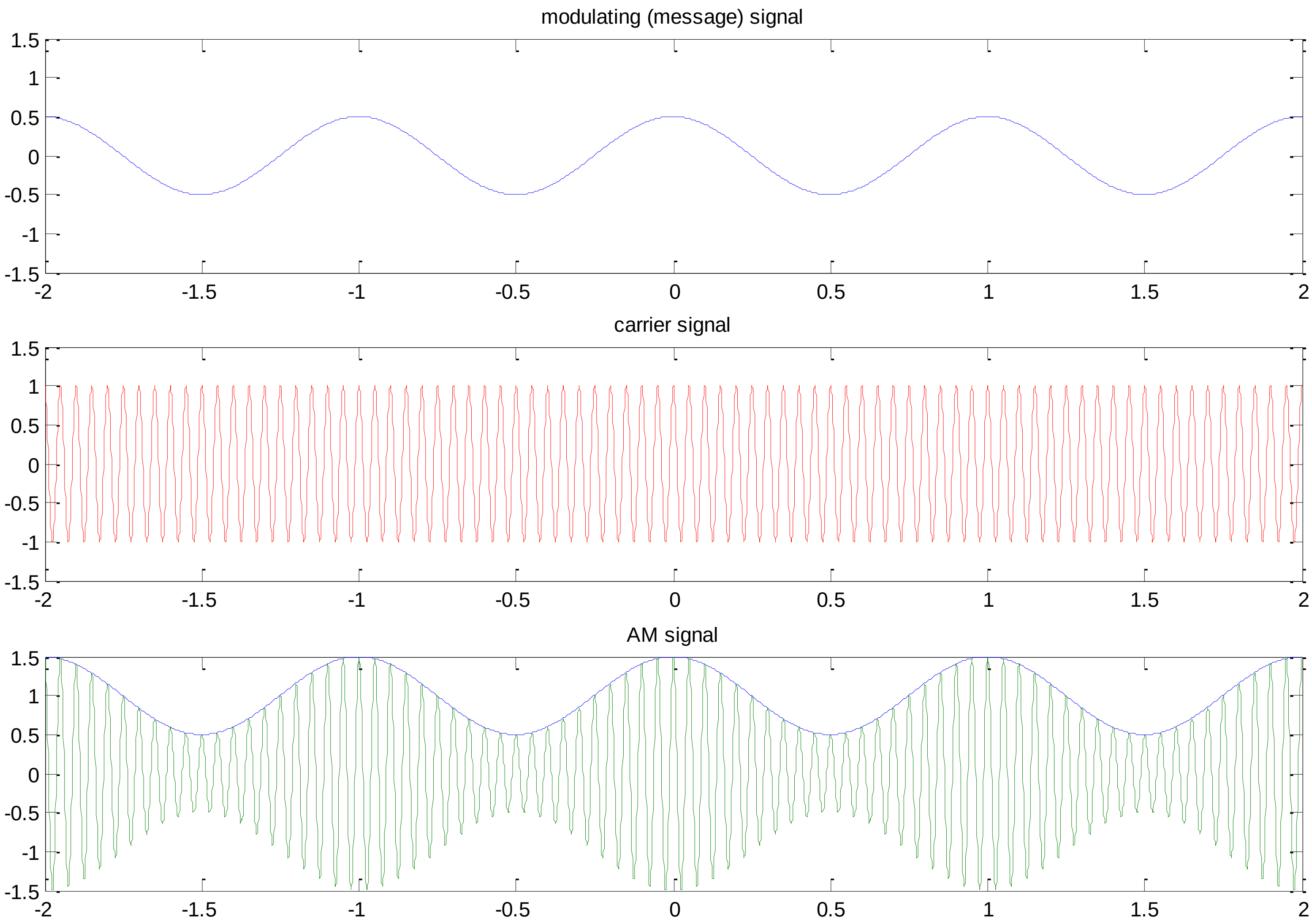
$$v_c(t) = \cos(40\pi\, t) \qquad\qquad v_m(t) = 0.5\cos(2\pi\, t)$$

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

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

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
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?

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

$$f_c = \ldots\ldots$$

$$V_c = \ldots\ldots$$

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

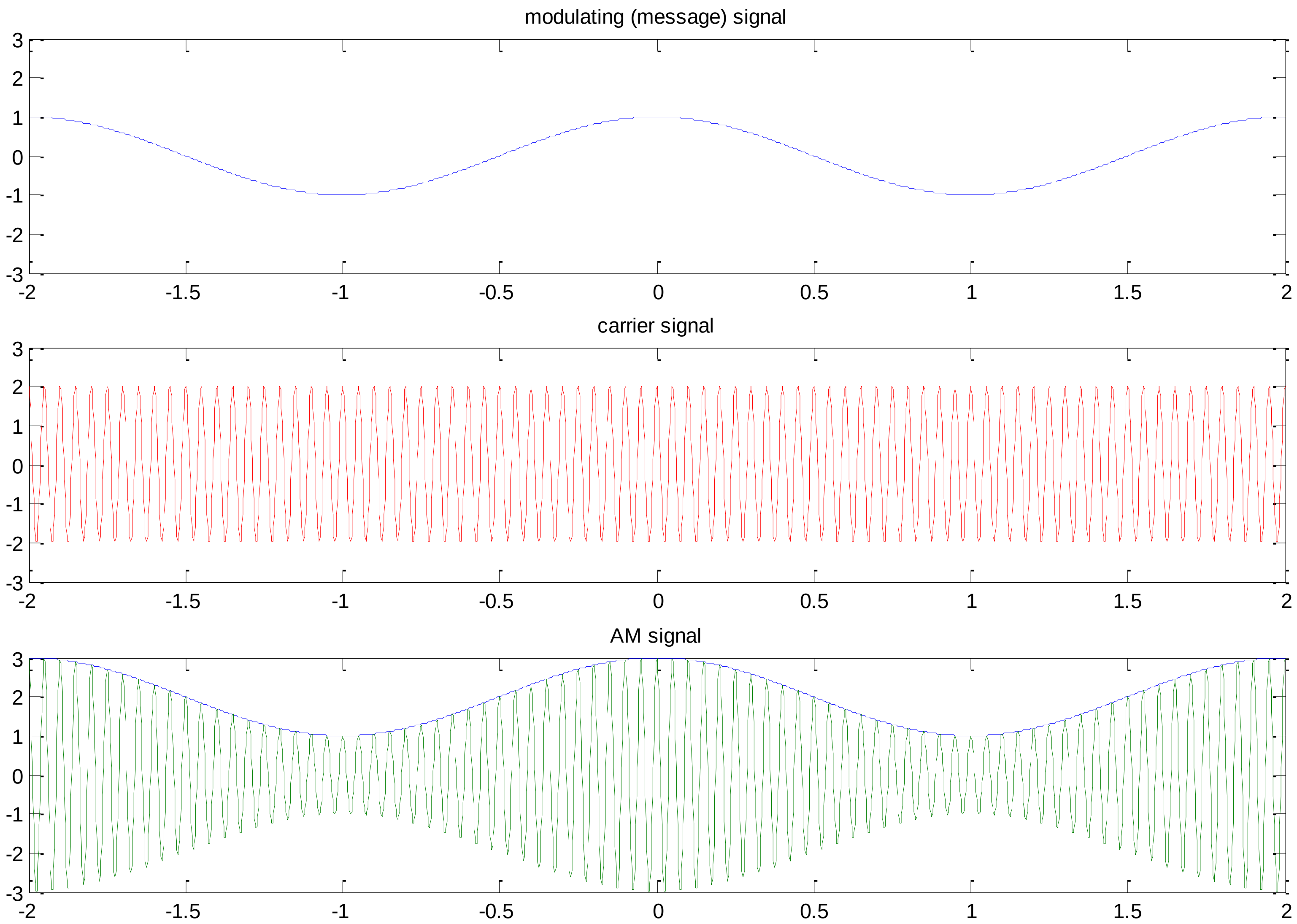
$$f_m = \ldots\ldots$$

$$V_m = \ldots\ldots$$

Modulation index

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

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


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?

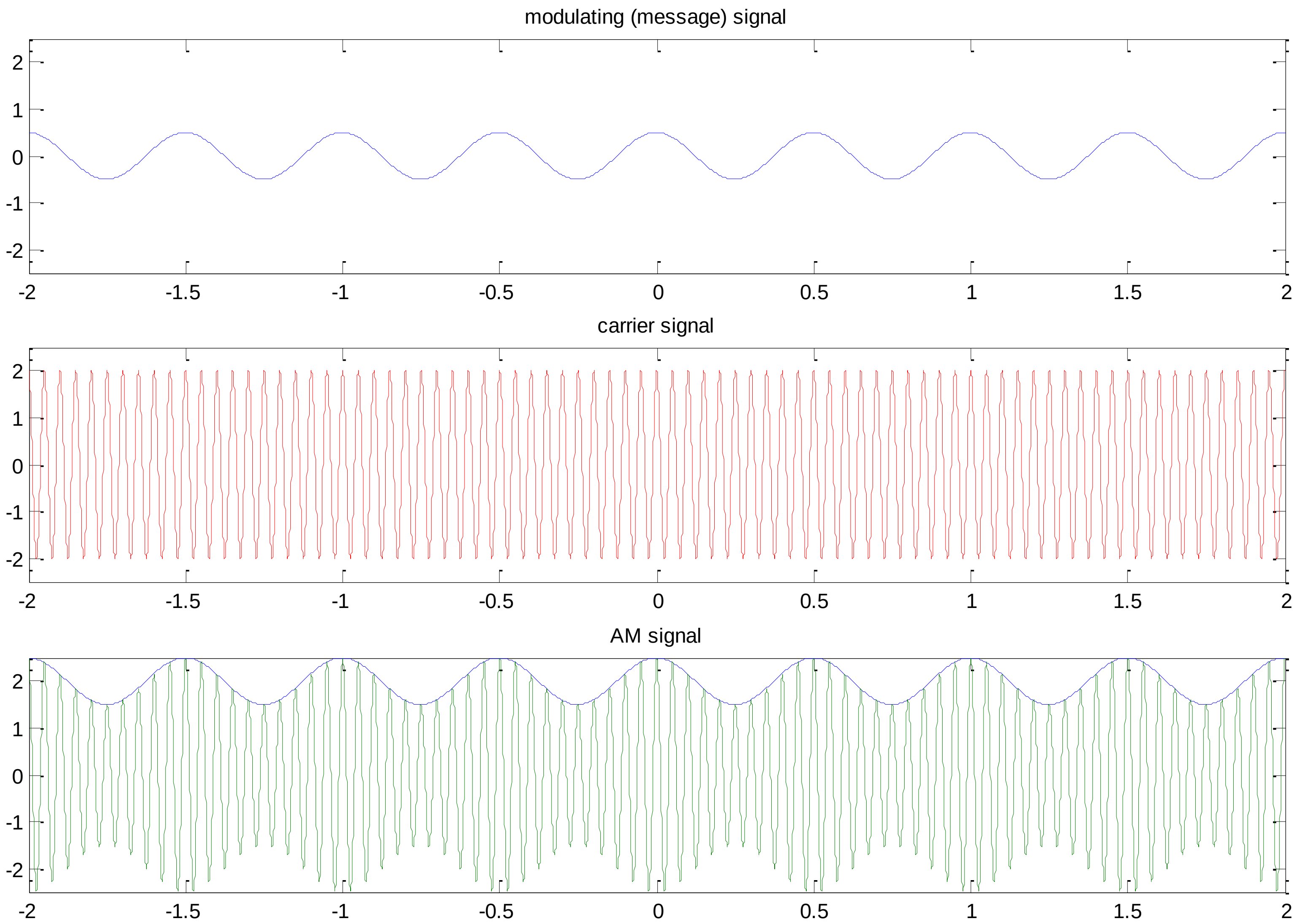
$$v_c(t) = 2\cos(40\pi\, t) \qquad v_m(t) = 0.5\cos(4\pi\, t)$$

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

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

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

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


modulating (message) signal
carrier signal
AM signal
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?

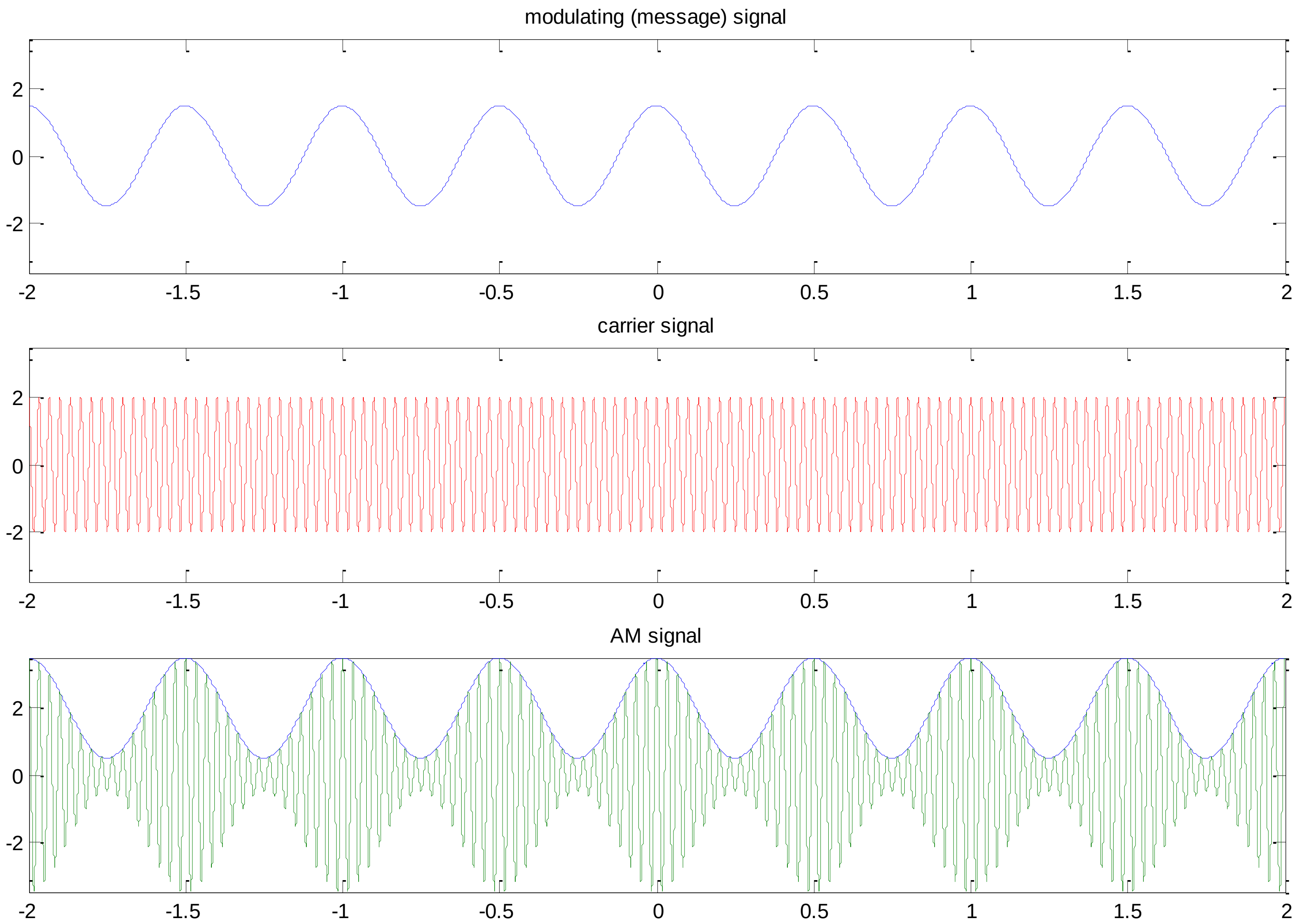
$$v_c(t) = 2\cos(60\pi\, t) \qquad v_m(t) = 1.5\cos(4\pi\, t)$$

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

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

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

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


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

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

$$f_c = \ldots\ldots$$

$$V_c = \ldots\ldots$$

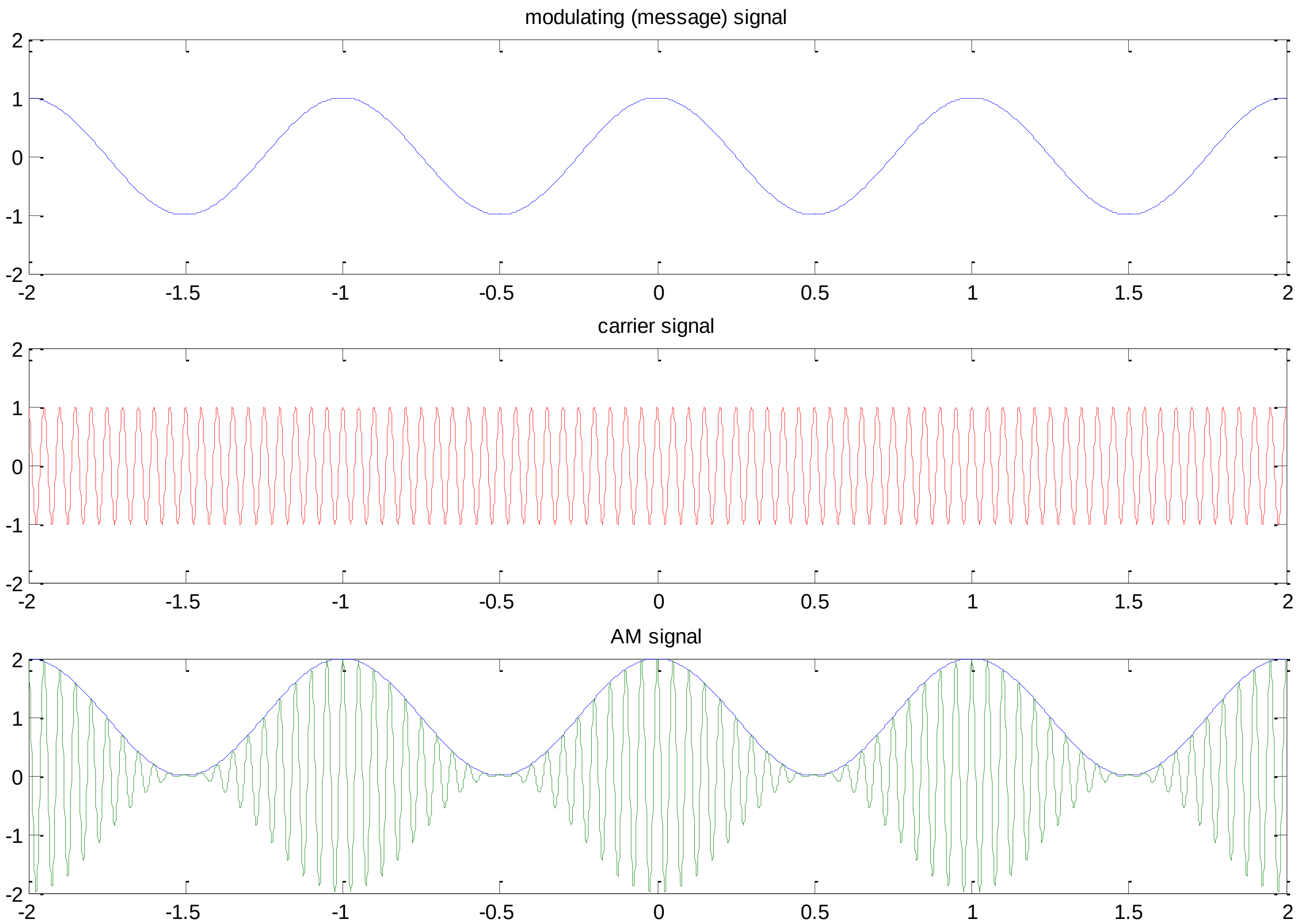
$$v_m(t) = \cos(4\pi\, t)$$

$$f_m = \ldots\ldots$$

$$V_m = \ldots\ldots$$

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
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?

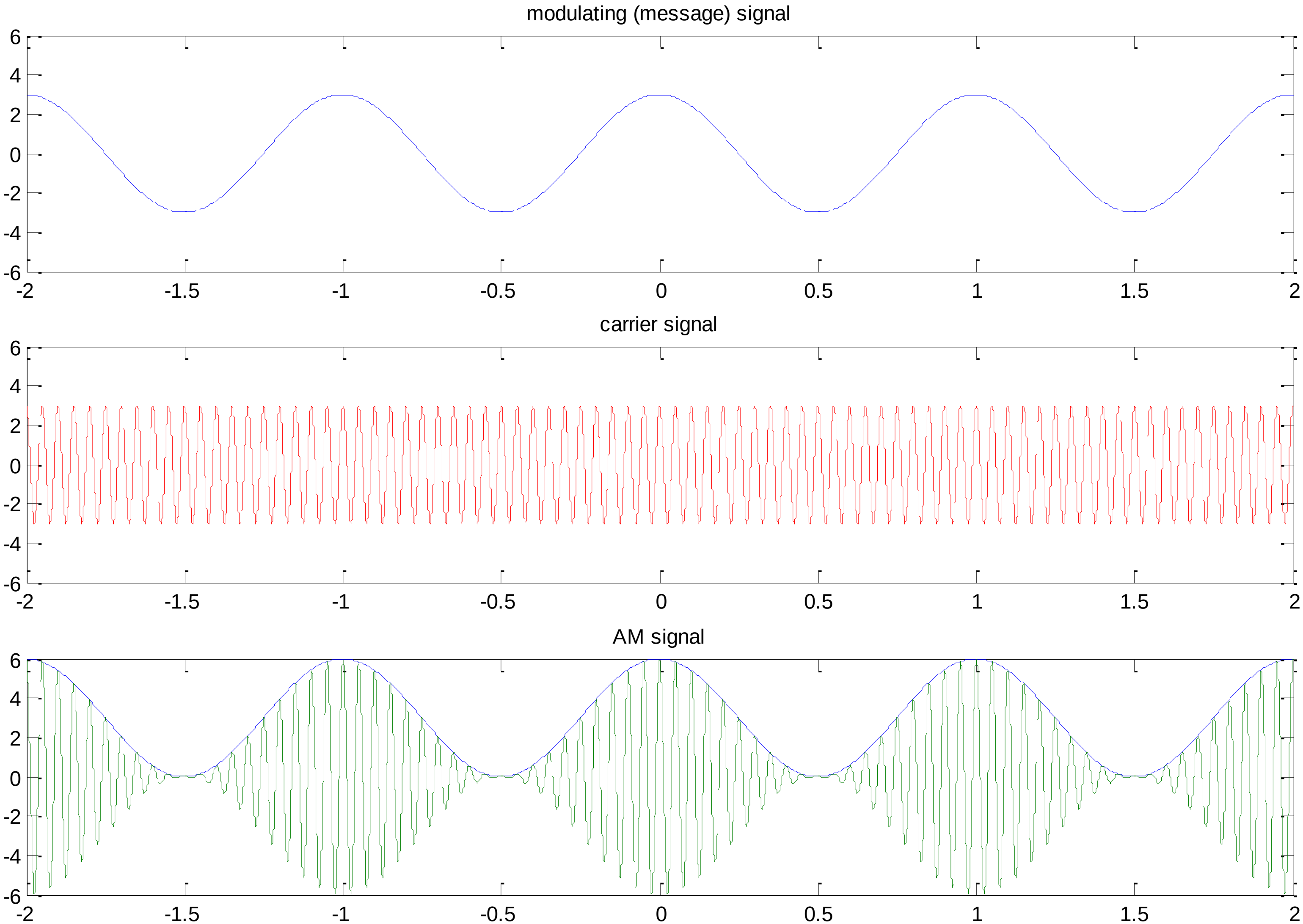
$$v_c(t) = 3\cos(40\pi\, t) \qquad v_m(t) = 3\cos(2\pi\, t)$$

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

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

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

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


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?

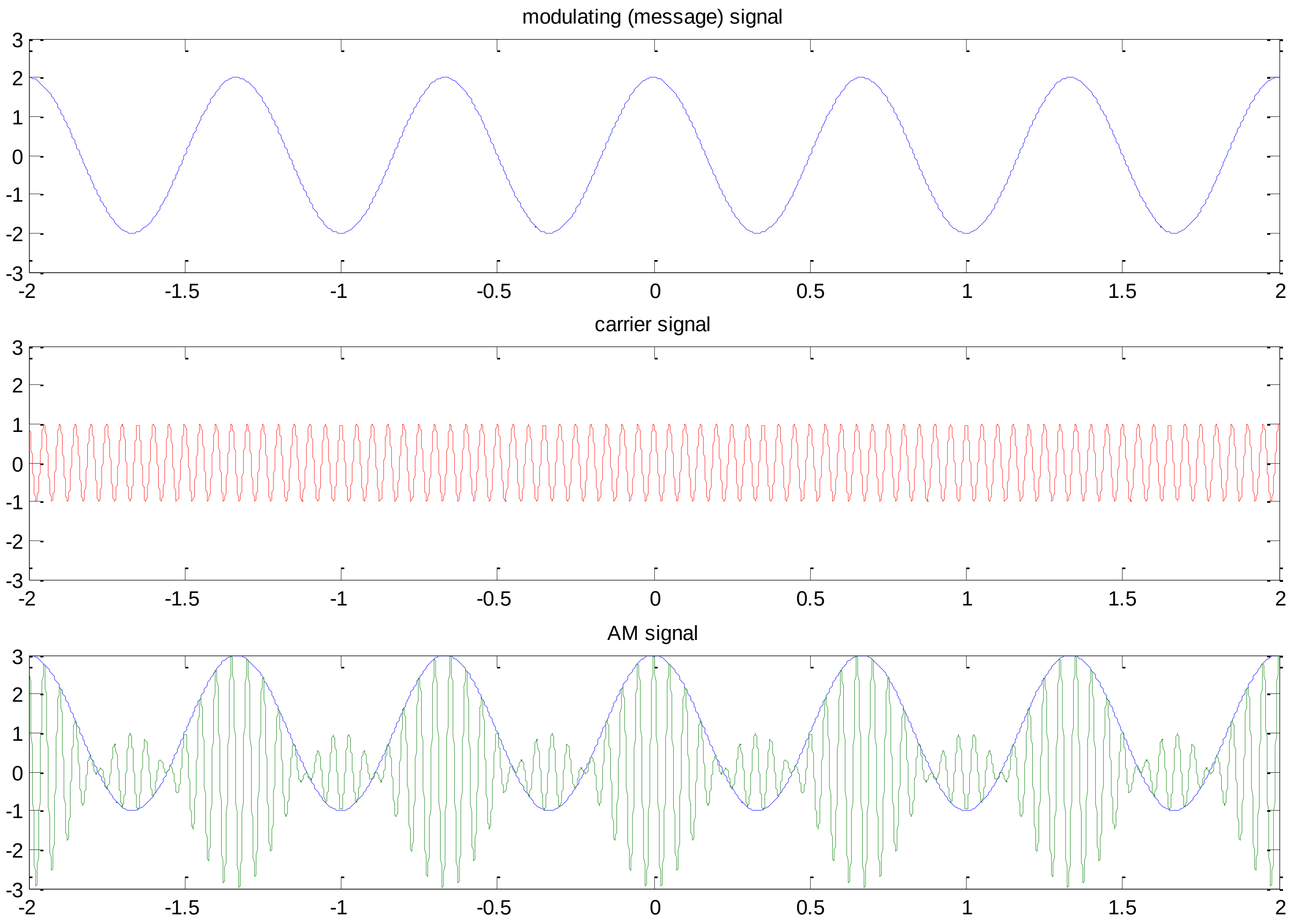
$$v_c(t) = \cos(40\pi\, t) \qquad v_m(t) = 2\cos(3\pi\, t)$$

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

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

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

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


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?

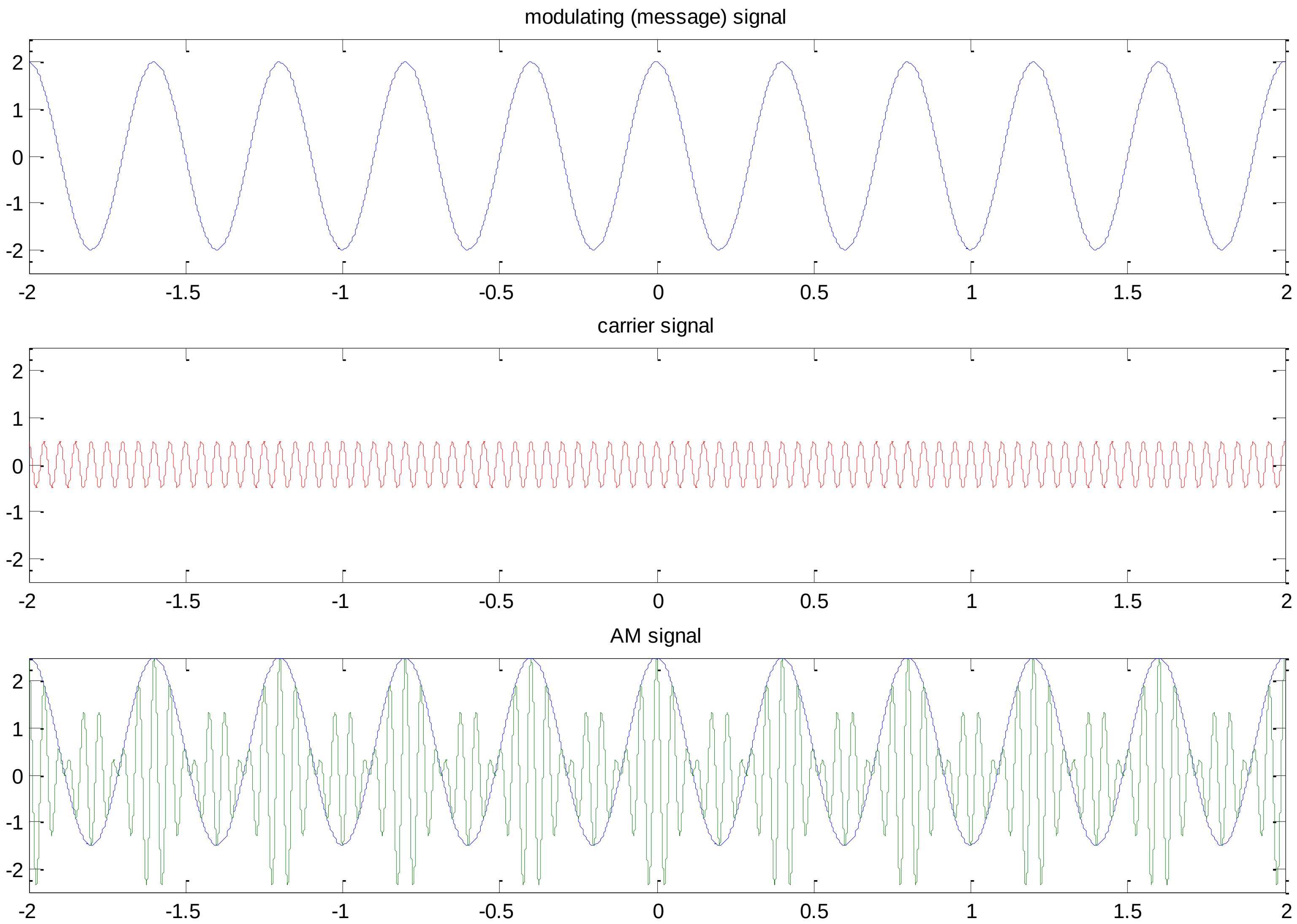
$$v_c(t) = 0.5\cos(40\pi\, t) \qquad v_m(t) = 2\cos(5\pi\, t)$$

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

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

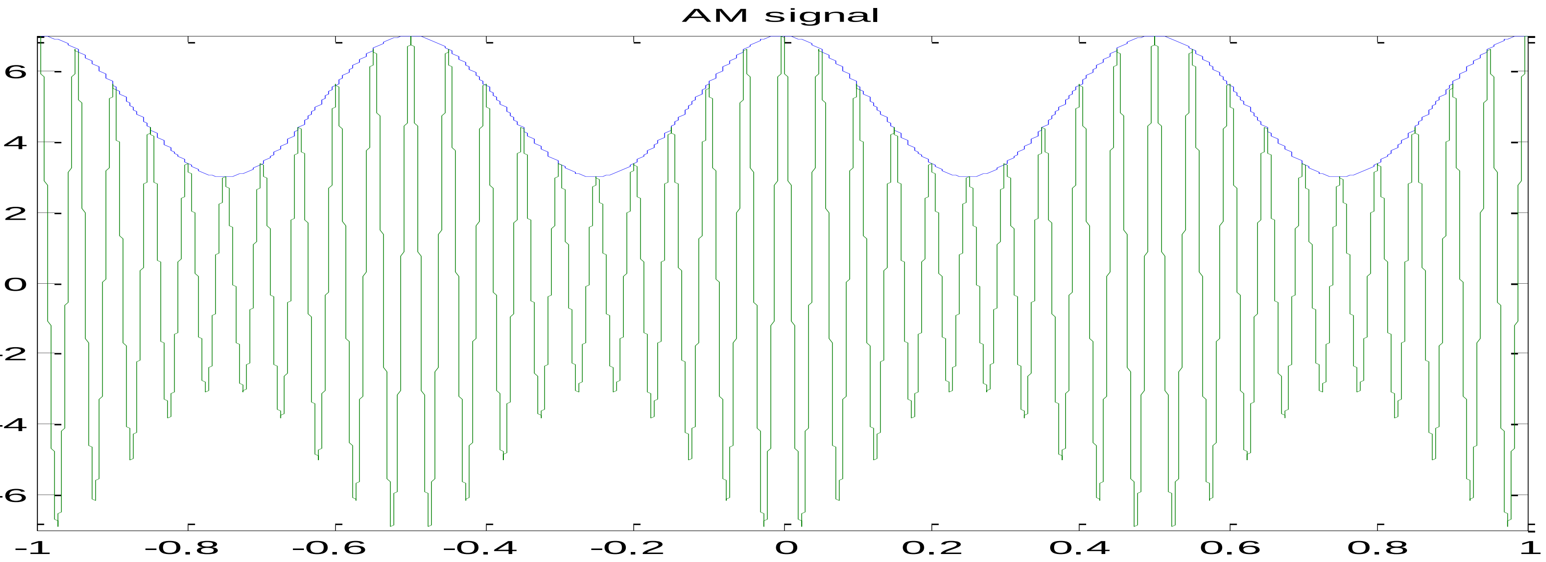
Modulation index $$m = \frac{V_m}{V_c} = \ldots\ldots$$

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


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

Amplitude Modulation

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



Amplitude Modulation

Carrier Signal

$$f_c = \ldots\ldots$$

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

Modulating Signal

$$f_m = \ldots\ldots$$

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

Modulation index

$$m = \ldots\ldots$$

Amplitude Modulation

Carrier Signal

$$f_c = \ldots\ldots$$

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

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

Modulating Signal

$$f_m = \ldots\ldots$$

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

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

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

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

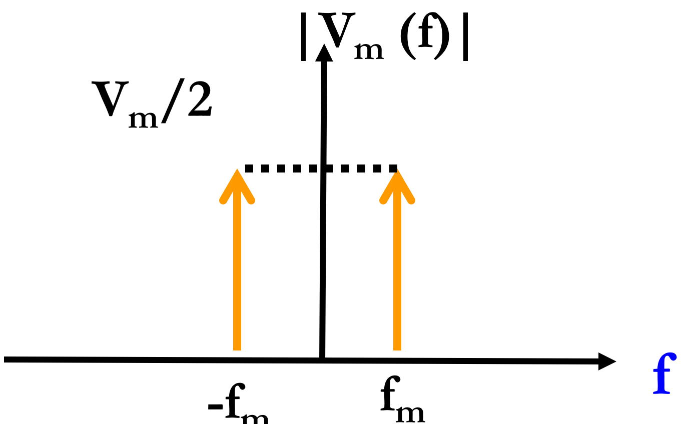
$$V_{AM}(f)$$

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

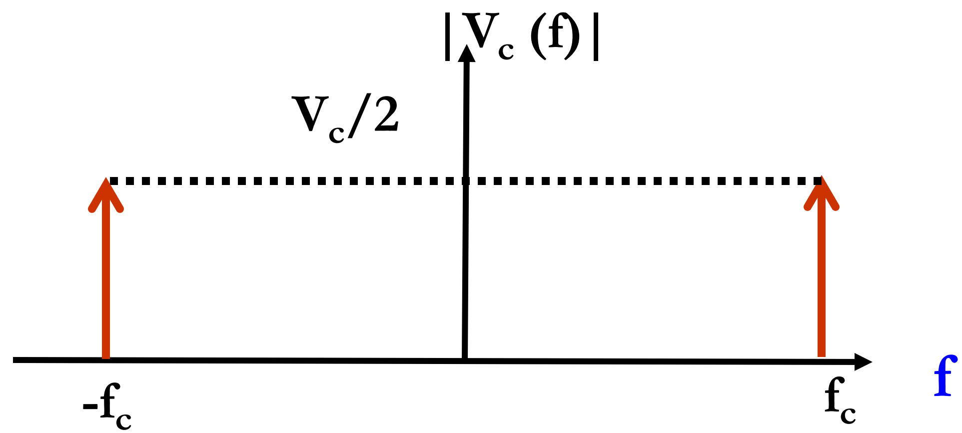
$$+ \frac{V_m}{4}\left[\delta(f - f_{USB}) + \delta(f + f_{USB})\right] \longrightarrow \frac{V_m}{4}\left[\delta(f - (f_c + f_m)) + \delta(f + (f_c + f_m))\right]$$

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

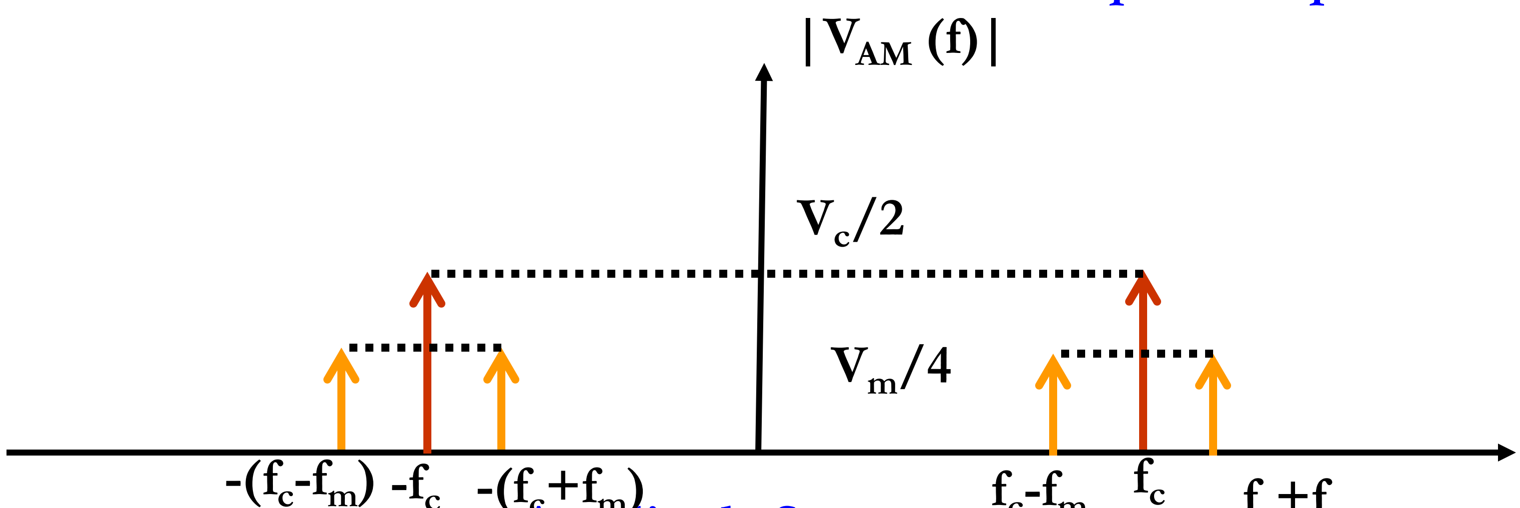
AM Spectrum



Amplitude Spectrum

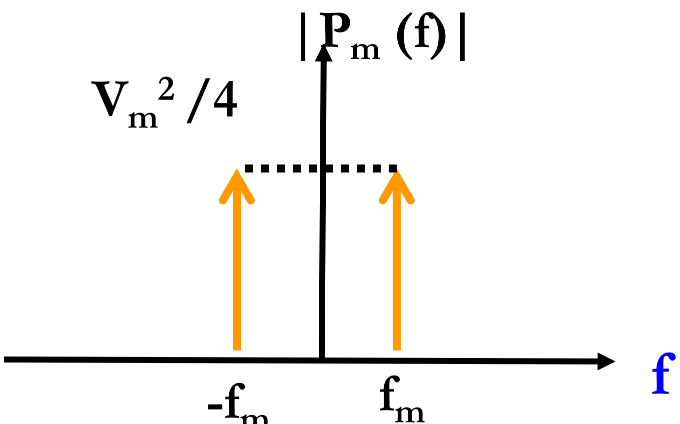


Amplitude Spectrum

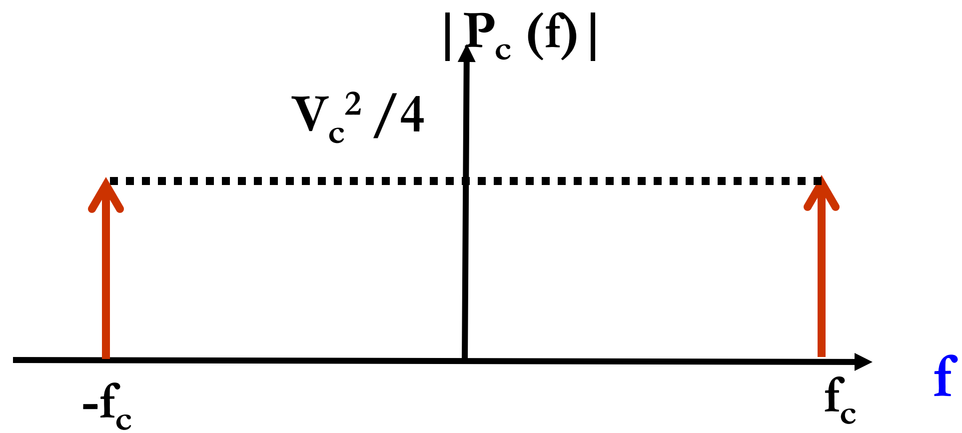


Amplitude Spectrum

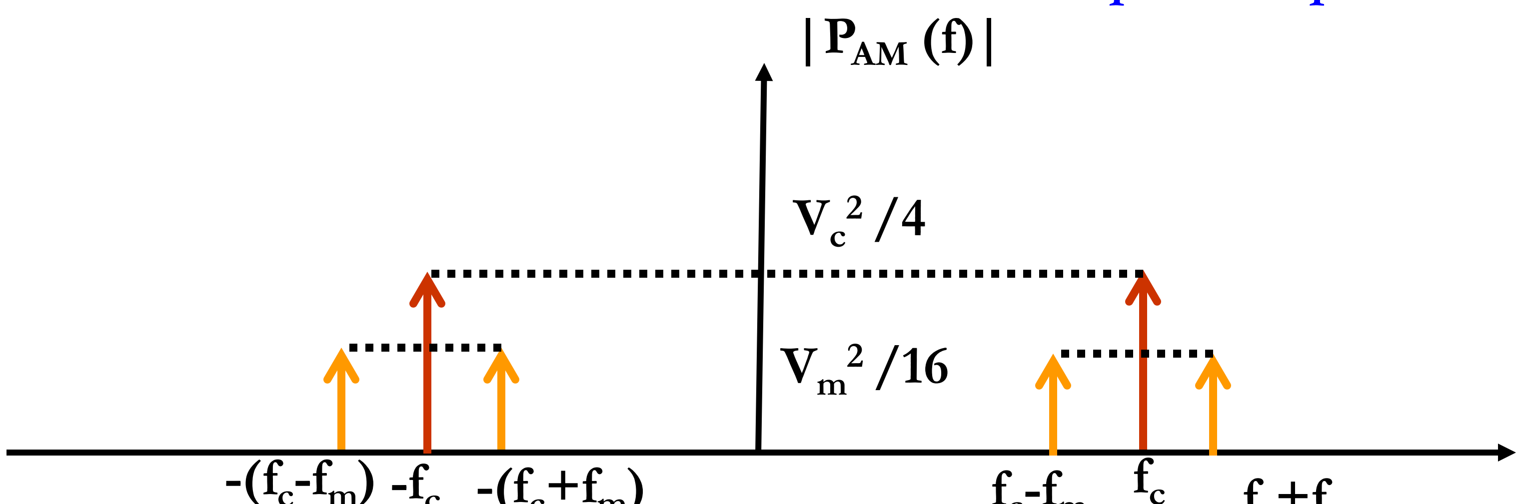
Power spectrum Spectrum



Amplitude Spectrum



Amplitude Spectrum



Amplitude Spectrum

AM Bandwidth

Q: What is the Bandwidth of an AM signal?

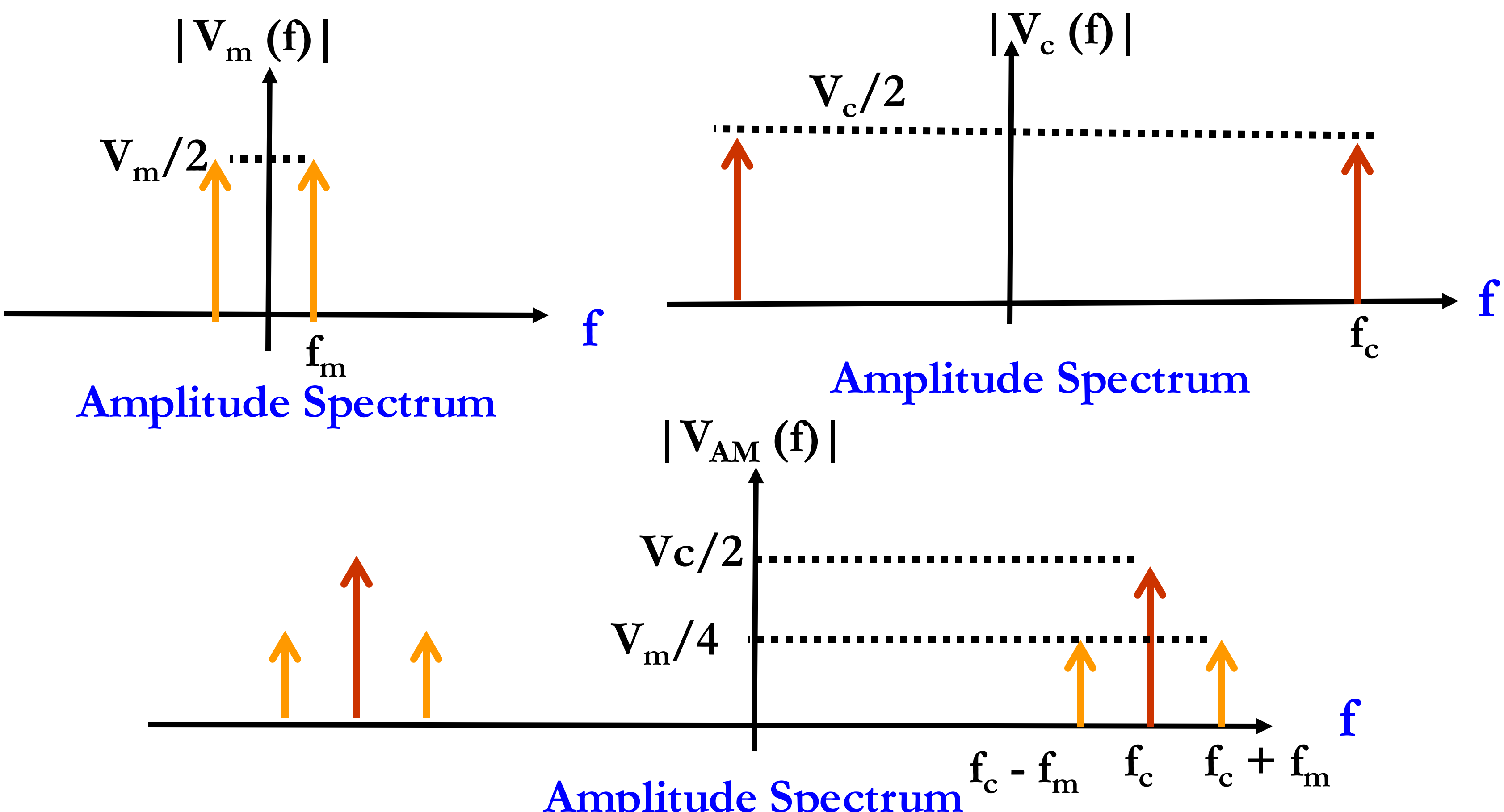
The Bandwidth of the AM signal is defined as:

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

$$BW = 2f_m$$

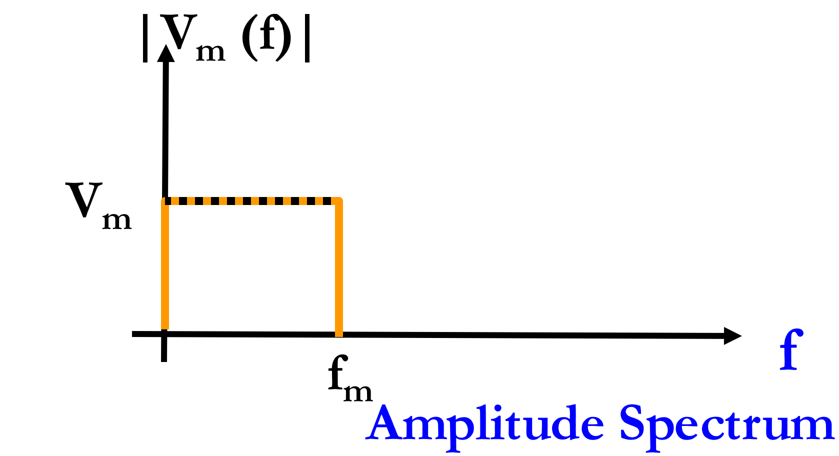
AM Spectrum

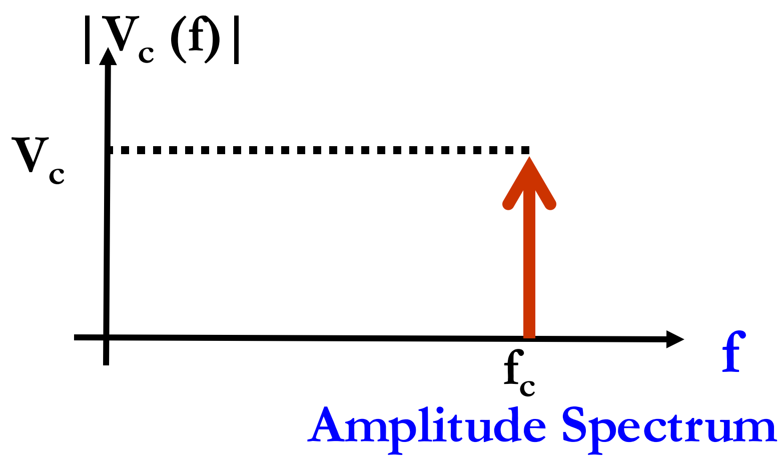
Q: What is the spectrum if the message signal is a sine function ?

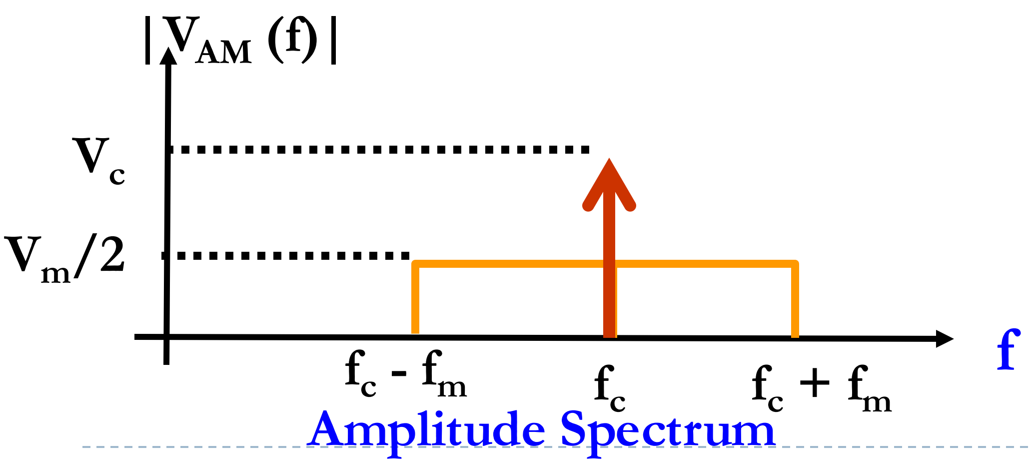


AM Spectrum

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







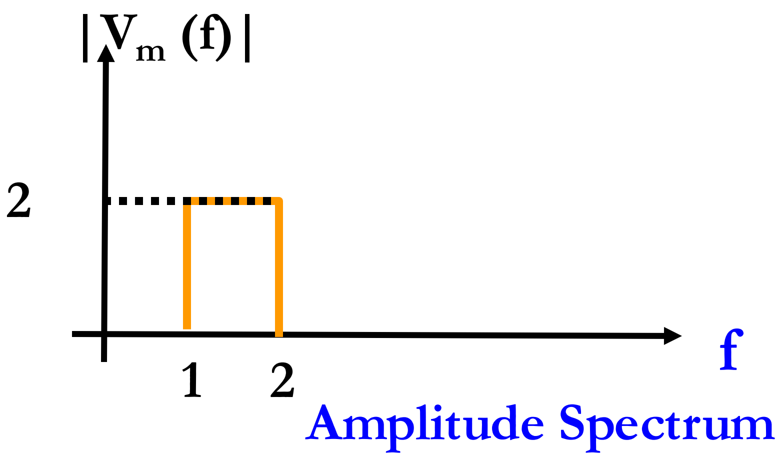
$$f_{USB} = \dots\dots\dots\dots$$

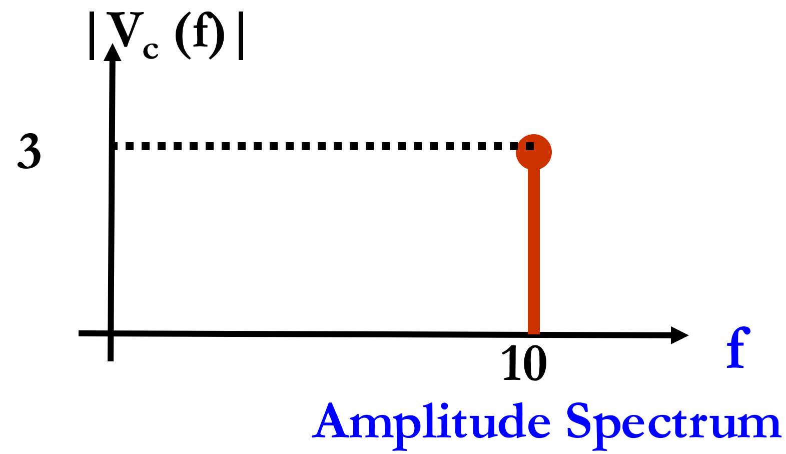
$$f_{LSB} = \dots\dots\dots\dots$$

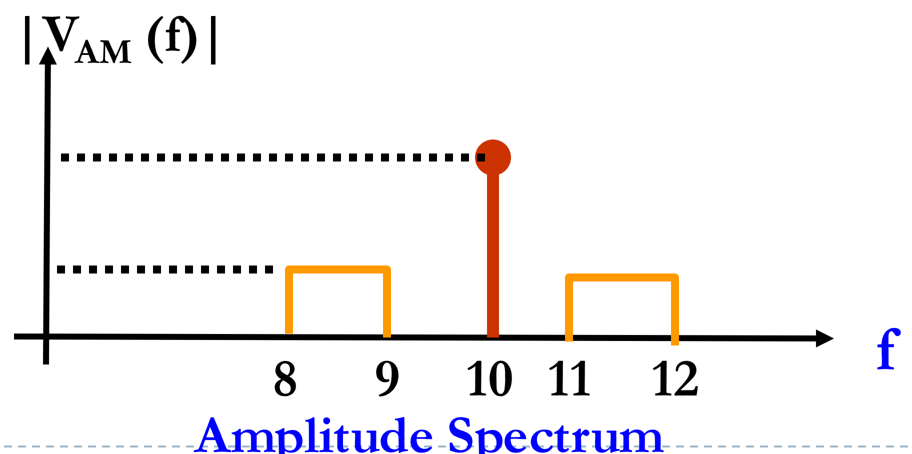
$$BW = f_{USB} - f_{LSB} = 2\, f_{\max}$$

AM Spectrum

Example: Find the spectrum of the following AM signal.







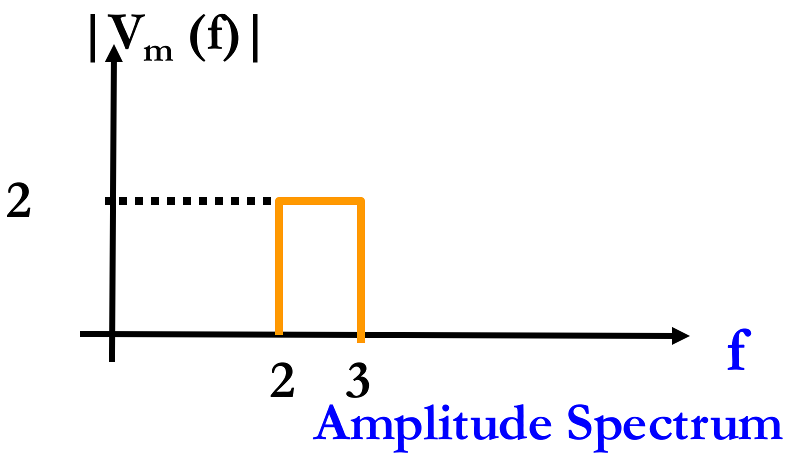
$$f_{USB} = \ldots\ldots\ldots\ldots$$

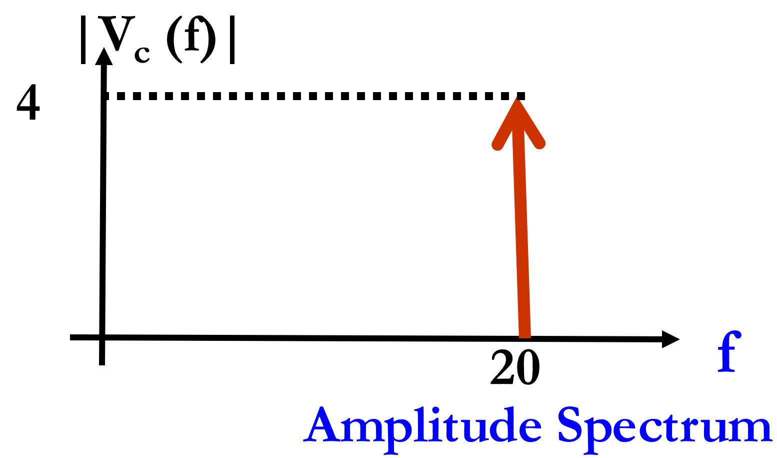
$$f_{LSB} = \ldots\ldots\ldots\ldots$$

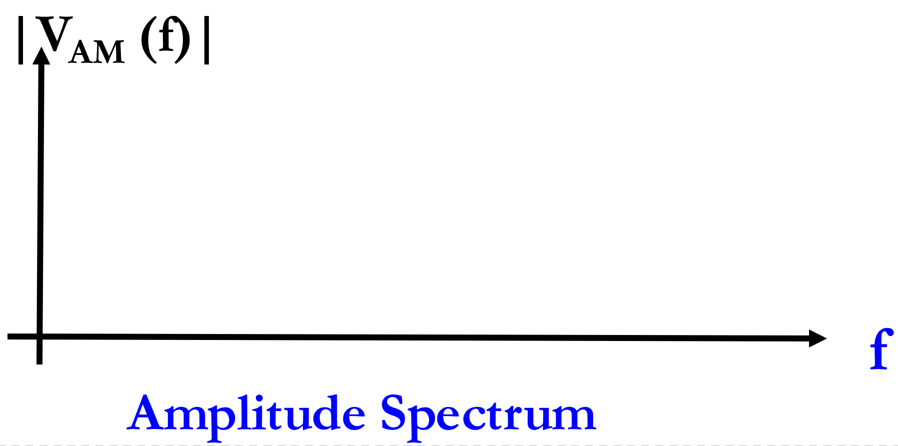
$$BW = f_{USB} - f_{LSB}$$

AM Spectrum

Example: Find the spectrum of the following AM signal.







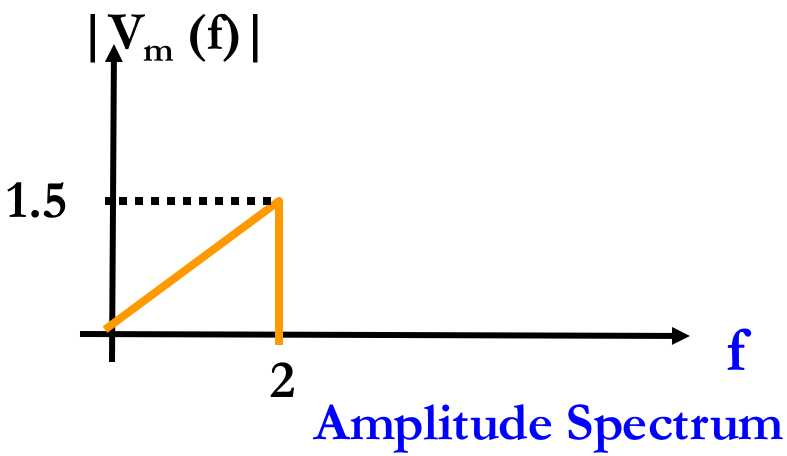
$$f_{USB} = \ldots\ldots\ldots\ldots$$

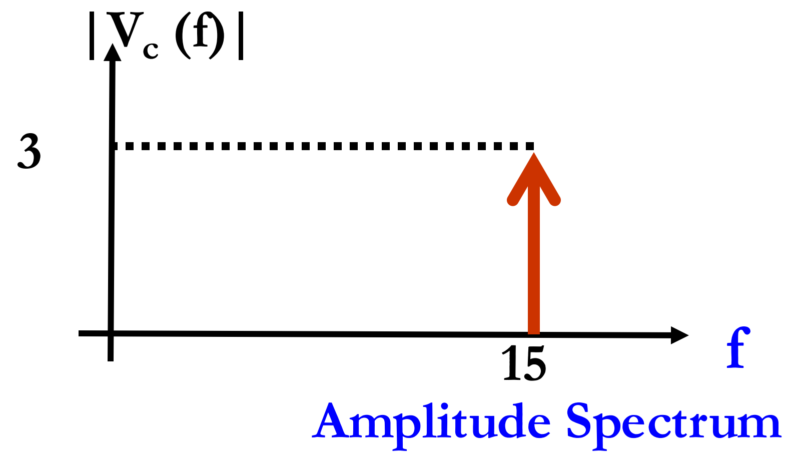
$$f_{LSB} = \ldots\ldots\ldots\ldots$$

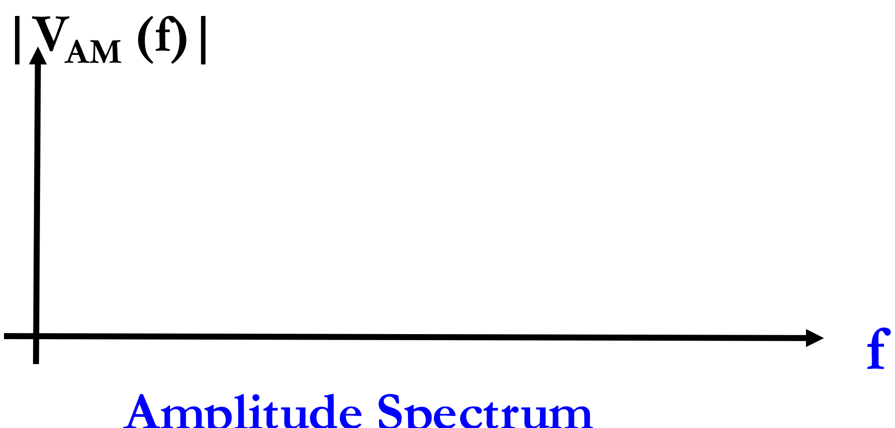
$$BW = f_{USB} - f_{LSB}$$

AM Spectrum

Example: Find the spectrum of the following AM signal.







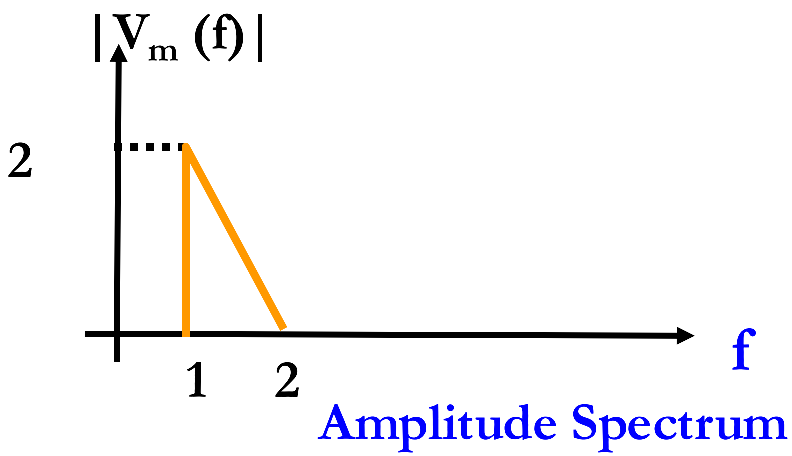
$$f_{USB} = \ldots\ldots\ldots\ldots$$

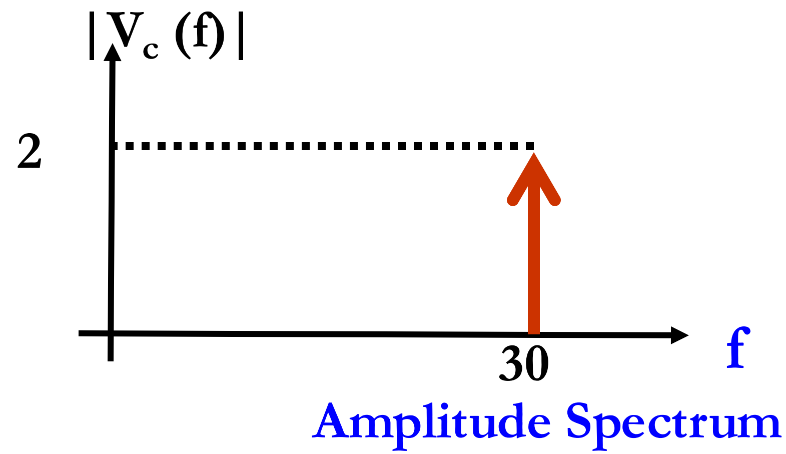
$$f_{LSB} = \ldots\ldots\ldots\ldots$$

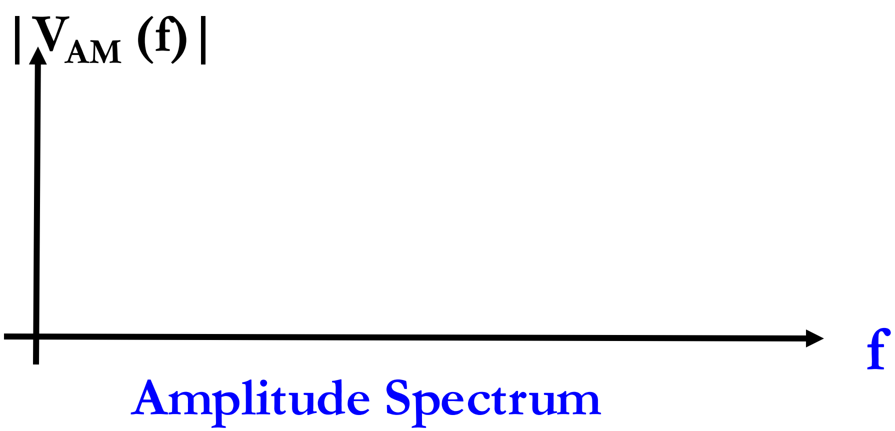
$$BW = f_{USB} - f_{LSB}$$

AM Spectrum

Example: Find the spectrum of the following AM signal.







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

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

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

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:

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

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

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

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

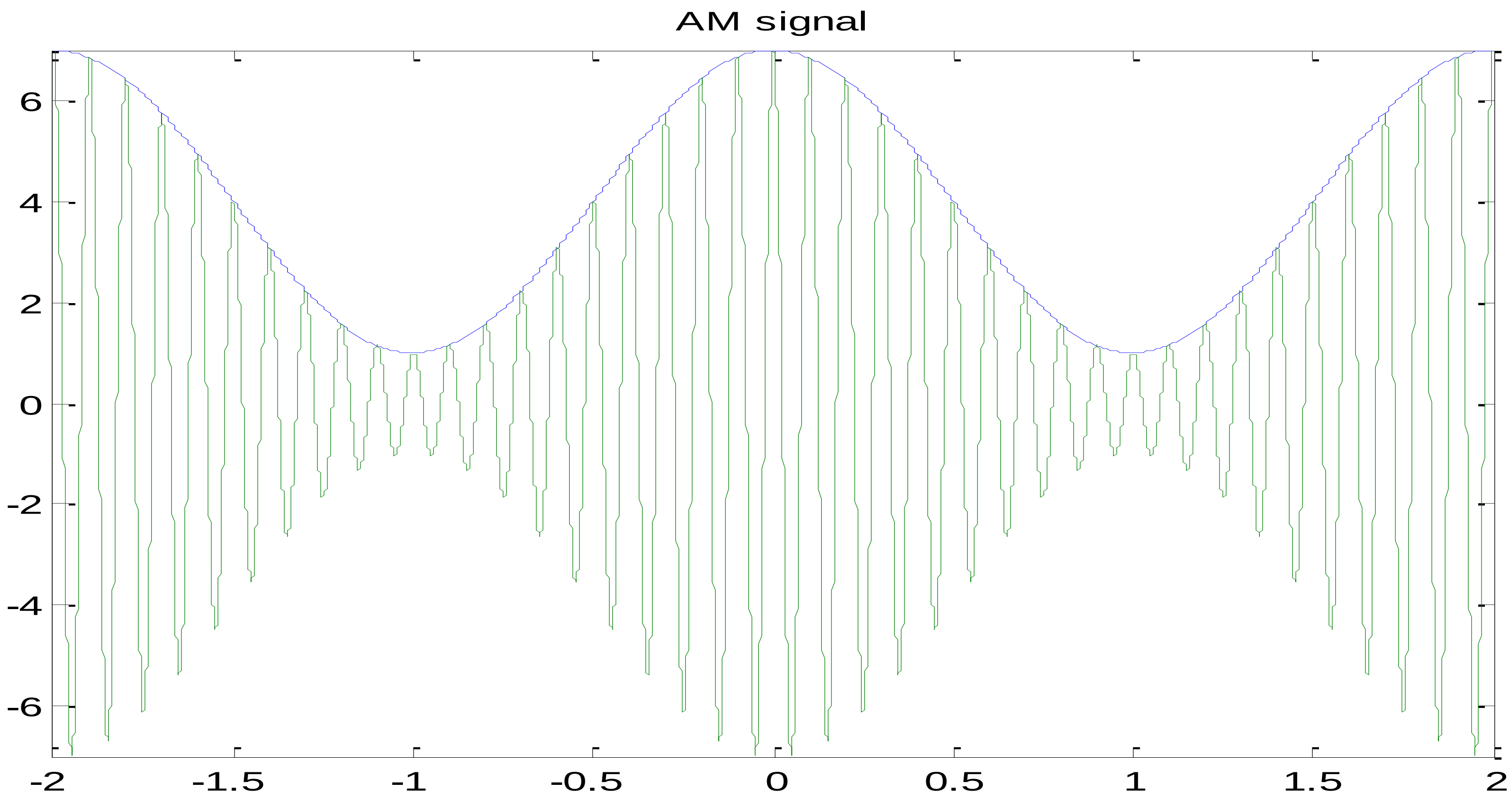
Power in sidebands

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 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)