ECE 215 Spring 2025

Objective 3.1: Amplitude Modulation

UNITED STATES
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ACADEMY

Objective 3.1

I can determine the modulation index, output signal, and output signal bandwidth of an Amplitude Modulation (AM) system and assess whether the system is under-modulated, over-modulated, or fully modulated.

What is Modulation?

- Modulation is the variation or modification of one or more properties of a signal
- Pick our transmission frequency
- Communication over long distances
- Transmission of multiple channels over one frequency band
- Smaller antenna size
- Message signal: contains data for transmission, can be any format
- Carrier signal: "carries" the message data
  - Much higher frequency than message signal
  - Always a sinusoidal signal
- What properties of a signal can we modify?

$$\text{V}_{\text{carrier}} = A_c * \cos\left(2\pi f_c t + \phi_c\right)$$

Types of Modulation - AM, FM, PM

Amplitude Modulation

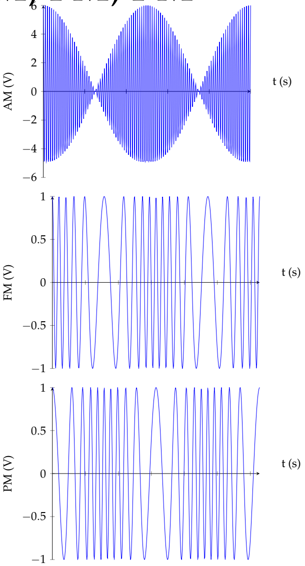
- Cheap, readily available technology
- Long distance transmission
- Uses less bandwidth

Frequency Modulation

- Noise Resistant
- Higer quality

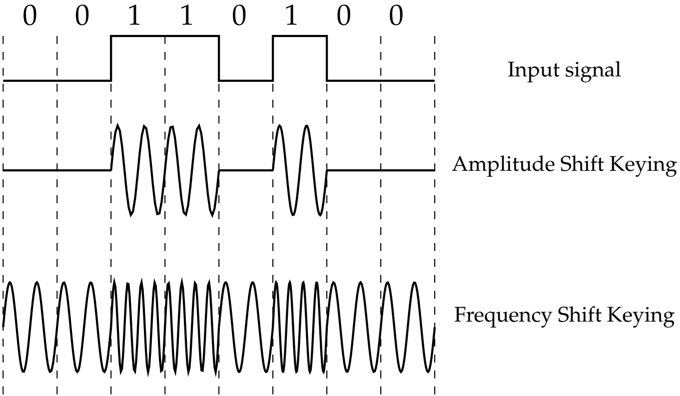
Phase Modulation

- Noise Resistant
- Higer quality
- Used in cell phones



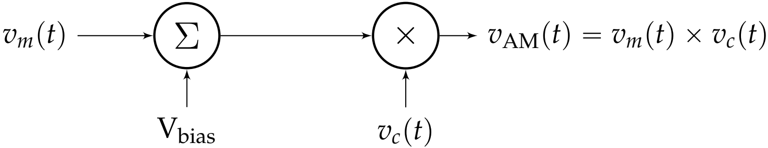
Types of Modulation - Analog vs. Digital

- Input changes but same approach!
- A carrier can be modulated by <u>**ANY**</u> data (analog or digital)



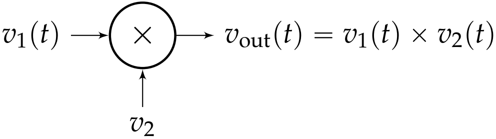
AMPLITUDE MODULATION

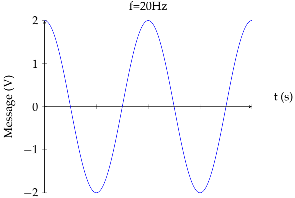
- Function multiplier "multiplies" input signals
  - Message signal: modulat**ing** the carrier - single tone sinusoid, for now
  - Carrier signal: being modulat**ed**
- Output (**modulated**) signal
  - Exists at the same frequency as the carrier signal
  - Amplitude changes according to the message signal

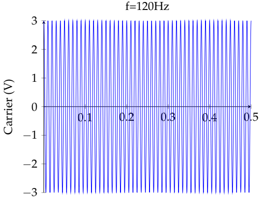


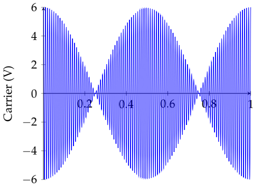
$$\boxed{\begin{aligned} v_{\mathrm{AM}}(t) = {} & \frac{A_{\mathrm{c}}A_{\mathrm{m}}}{2}\cos\left[2\pi(f_{\mathrm{c}}+f_{\mathrm{m}})\right] + \frac{A_{\mathrm{c}}A_{\mathrm{m}}}{2}\cos\left[2\pi(f_{\mathrm{c}}-f_{\mathrm{m}})\right] \\ & + A_{\mathrm{c}} * B\cos\left(2\pi f_{\mathrm{c}}t\right) \end{aligned}}$$

Function Multiplier









$$v_m(t) \quad \times \quad v_c(t) \quad = \quad v_{out}$$

$\boxed{\text{Note: } v_{out} \text{ is in Volts, } \underline{\textbf{not}} \text{ V}^2!}$

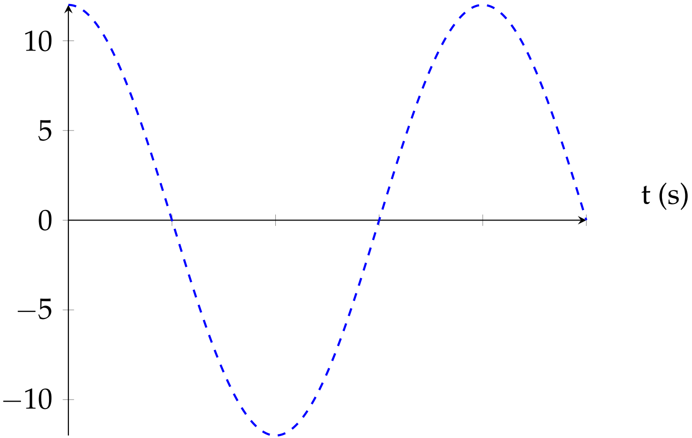
Amplitude Modulation Example

- Determine and plot v_{out} for $v_{\text{m}} = 3\cos(2\pi * 5 * t)$ and $v_{\text{c}} = 4\cos(2\pi * 120 * t)$
- Recall:

$$\boxed{v_{\text{out}} = \frac{A_c A_m}{2}\cos[2\pi * (f_c + f_m)] + \frac{A_c A_m}{2}\cos[2\pi * (f_c - f_m)]}$$

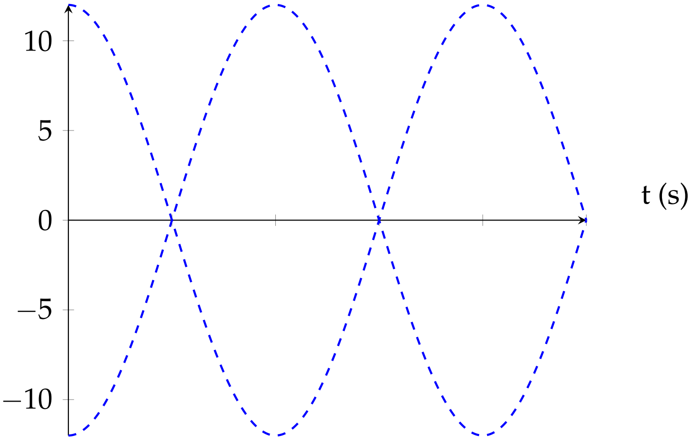
Drawing AM Graphs

DRAW the message signal



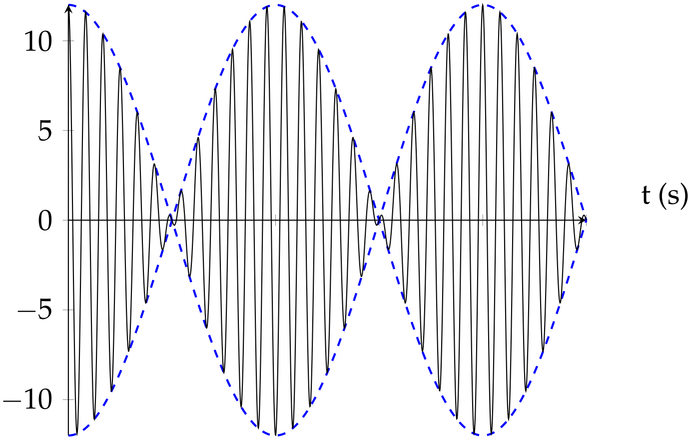
Drawing AM Graphs

REFLECT the message signal

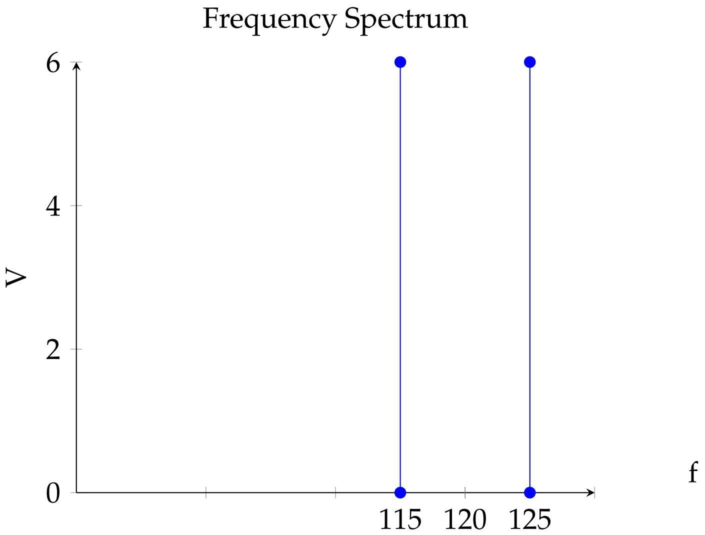


Drawing AM Graphs

Carrier signal "colors in"

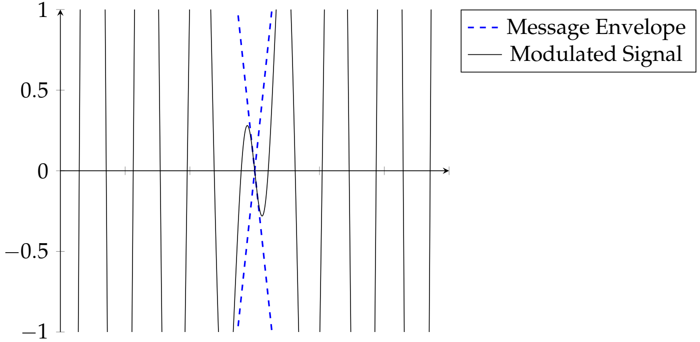


Drawing AM Graphs



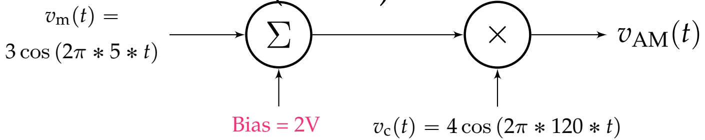
Crossover Point

Zooming in on where the sign of the message signal changes...



Is there a way to make the modulated signal better behaved at these inflection points?

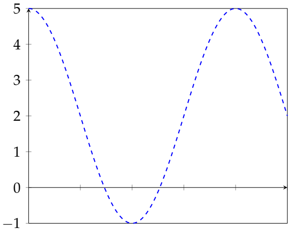
Overmodulation ($\alpha > 1$)



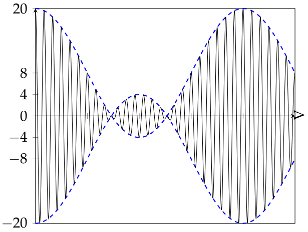
Modulation index

$$\alpha = \frac{\mathrm{A_m}}{\mathrm{B}} = \frac{3\mathrm{V}}{2\mathrm{V}} = 1.5$$

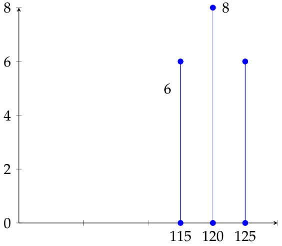
Message Signal



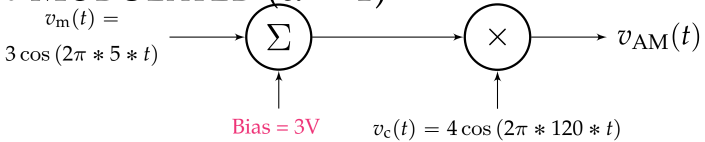
Modulated Signal



Frequency Spectrum

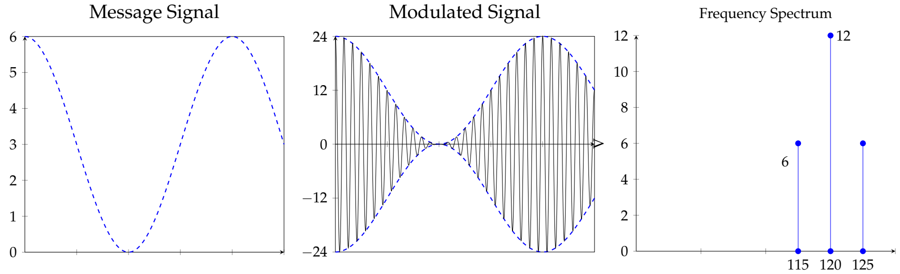


100% Modulated ($\alpha = 1$)

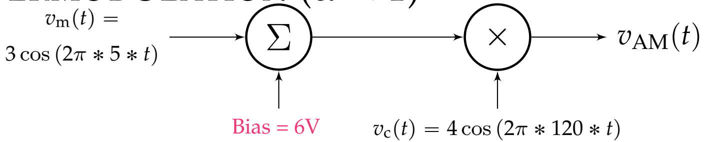


Modulation index

$$\alpha = \frac{A_m}{B} = \frac{3\text{V}}{3\text{V}} = 1$$



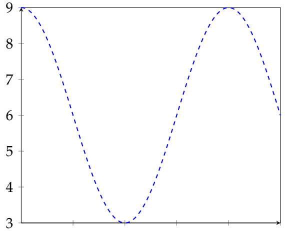
UNDERMODULATION ($\alpha < 1$)



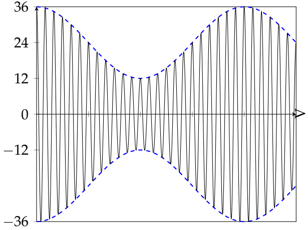
Modulation index

$$\alpha = \frac{A_m}{B} = \frac{3V}{6V} = 0.5$$

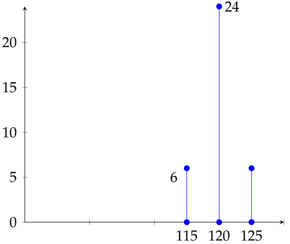
Message Signal



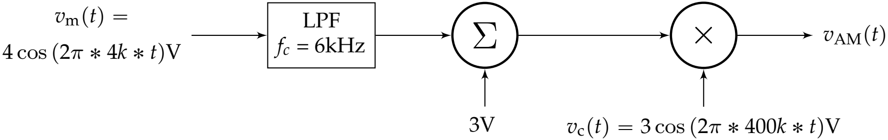
Modulated Signal



Frequency Spectrum

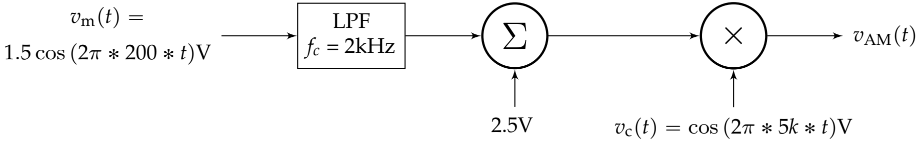


AM EXAMPLE 1



- What is the modulation index (α)?
- Will the signal be under-, over-, or fully modulated?
- What is the equation for the output signal?
- What do the time and frequency domain graphs look like?
- What would happen if the bias changed to 6V ?

AM EXAMPLE 2 - HANDS ON!

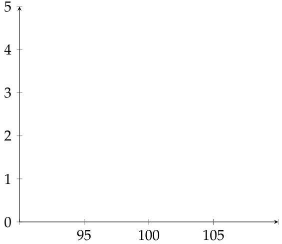


- What is the modulation index?
- Turn on function generator (FG) and oscilloscope (OS). Connect the red mini-grabber from FG to Channel 1 probe of OS.
- FG: Turn on Chan 1 & set Output Load to High Z.
- FG: Waveforms → Sine.
- FG: Parameters → Freq → 5kHz; → Amp → 5Vpp; → Offset/Phase → 0.
- FG: Modulate → Modulate → On; → Type → AM; → AM Depth → 60%; → Shape → Sine; → More → AM Freq → 200Hz.
- OS: Delete all measurements and math windows
- OS: Set Horizontal scale to 2-4ms/div; set Vertical scale to 1V/div. (*Note: the AM signal will be a little jumpy*)
- OS: To show the frequency domain, push the Math button (right side near channel buttons); in the Math Type box, select FFT. (*Touch outside the MATH 1 box anywhere to close it*)
- OS: Touch the magnifying glass in the top right corner of the Math 1 - FFT window; slide AB box to far left; zoom in using touch screen (pinch, drag) until centered on 5kHz with 2-3kHz on either side.
- FG: adjust AM Freq (message frequency), AM Depth (mod index), and Shape to see what happens in the time and frequency domains.

Multiple message frequencies

- Distributive property applies
- Carrier frequency modulates each message signal separately
- Plot frequency spectrum of:

$$
\begin{aligned}
v_{\mathrm{m}}(t) &= 5\cos(2\pi * 5k * t) + 2\cos(2\pi * 6k * t) + 4\cos(2\pi * 7k * t) \\
v_{\mathrm{c}}(t) &= 2\cos(2\pi * 100k * t) \\
v_{\mathrm{out}}(t) &= 5\cos(2\pi * 95k * t) + 5\cos(2\pi * 105k * t) + 2\cos(2\pi * 94k * t) \\
&\quad + 2\cos(2\pi * 106k * t) + 4\cos(2\pi * 93k * t) + 4\cos(2\pi * 107k * t)
\end{aligned}
$$



Bandwidth =

Bandwidth

Bandwidth

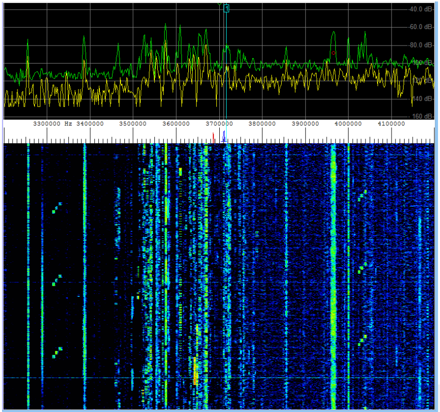
$$\text{Bandwidth} = f_{\text{high}} - f_{\text{low}}$$

What is the message bandwidth (BW_m) compared to the output AM signal (BW_{AM})?

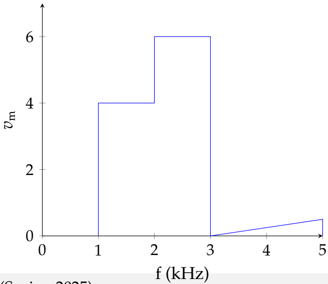
Non-sinusoidal Messages

Waterfall plot:

- Power is the color, frequency the horizontal axis, and time the vertical axis
- Useful for displaying random signals (e.g., talking or music over the radio)
- Aka, a *spectrograph*

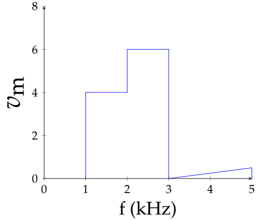


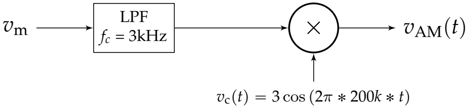
- Most messages are not purely sinusoidal tones (but decompose into a sum of sinusoids)
- In this class, shapes in the frequency domain represent either:
  - Random signals with an *voltage spectral density* in units of $V/\sqrt{\text{Hz}}$
  - A single signal sample composed of many sinusoids

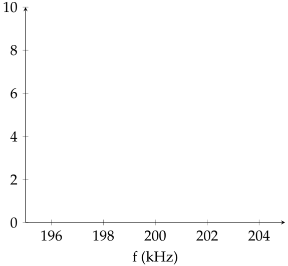


Non-sinusoidal Message Example

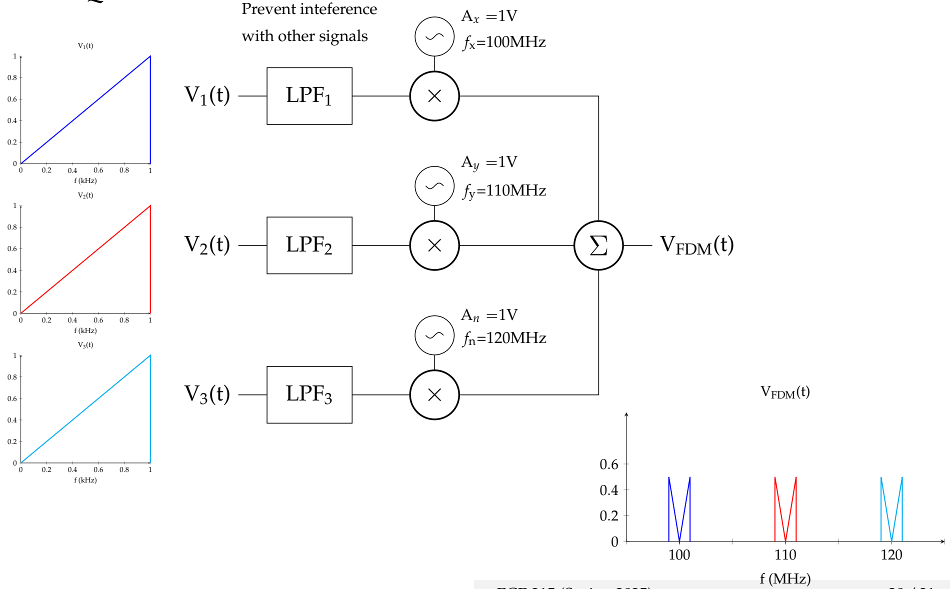
What is the output of the following system? What is the bandwidth?



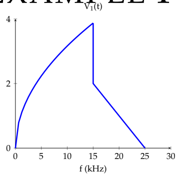


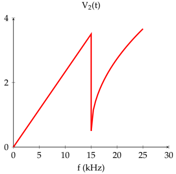


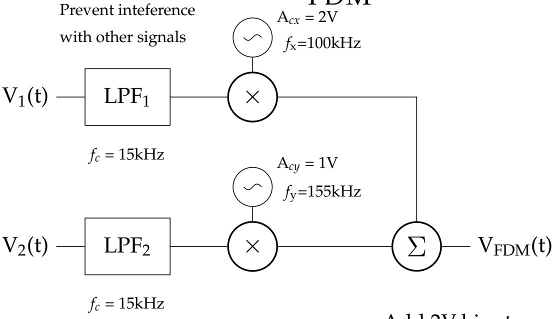
FREQUENCY DIVISION MULTIPLEXING



Example Problem 1 - Plot V_{FDM}







Add 2V bias to each signal?