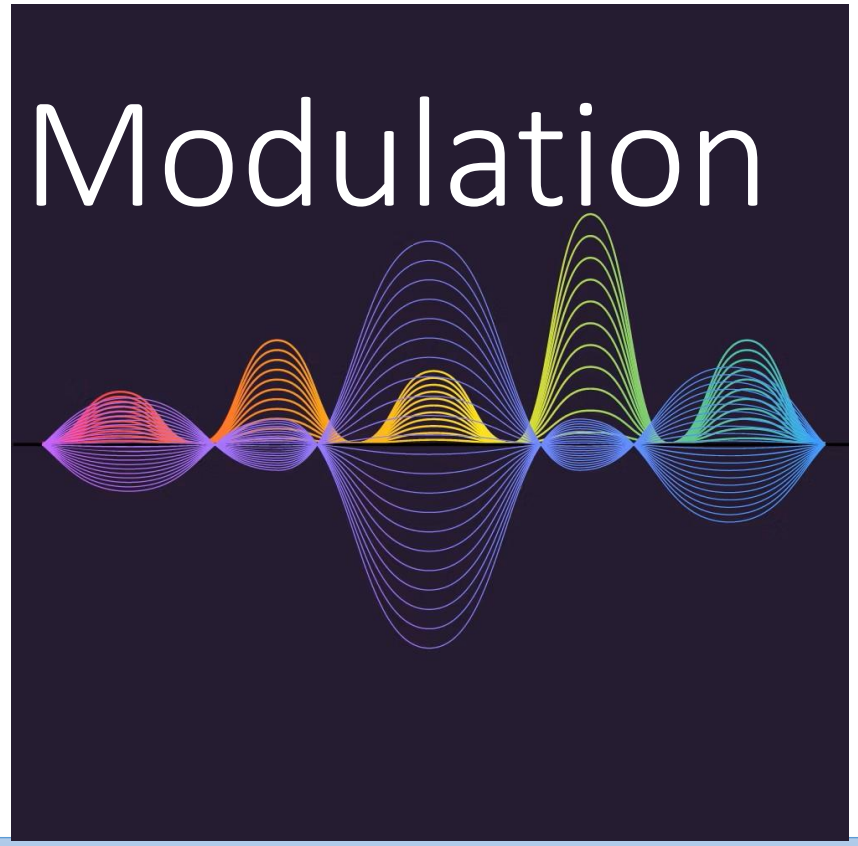
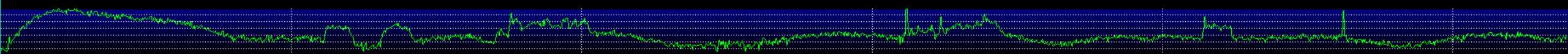
Understanding Modulation

Martin Buehring – KB4MG



CHEROKEE AMATEUR RADIO SOCIETY

WX4CAR



Why study modulation?

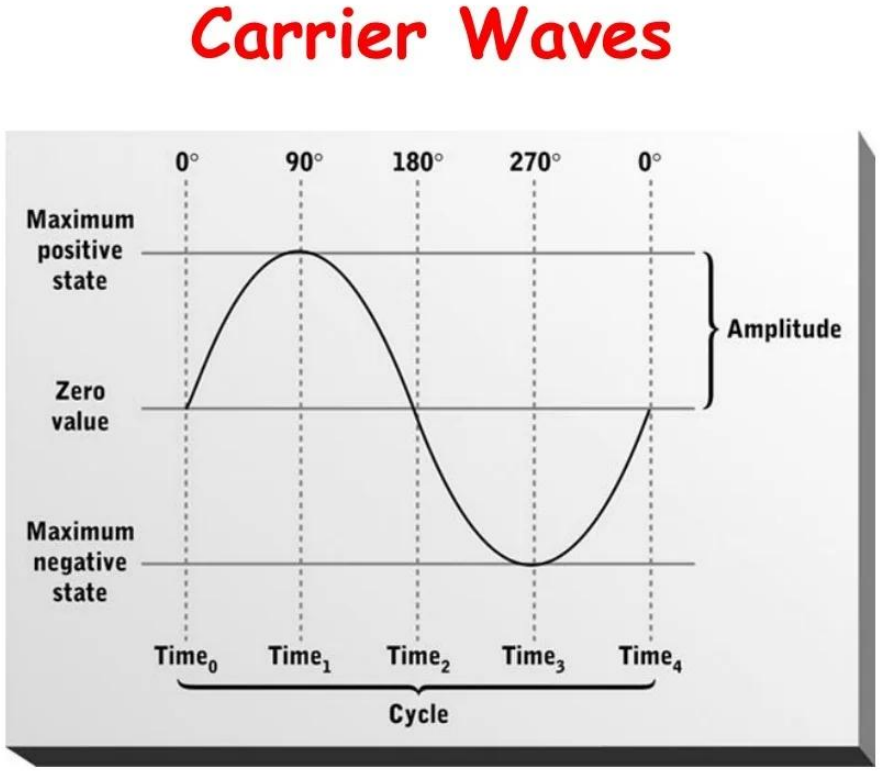
Concept that governs our communications methods

The FCC deems understanding of it to obtain an amateur radio license

Understanding modulation helps you troubleshoot issues at your station

What is Modulation?

- What is Modulation?
- Must begin with fundamentals
  - What is a carrier wave?
  - What does it mean to modulate a carrier wave?
- Carrier Waves
  - Have frequency and amplitude
- Modulation
  - Any alteration of a carrier wave, intentional or not, can be called **Modulation**



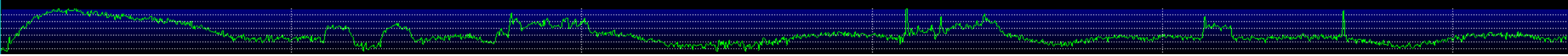
Ham Test Questions about modulation

T8A01
Which of the following is a form of amplitude modulation?
A. Spread-spectrum
B. Packet radio
C. Single sideband
D. Phase shift keying

T8A04
Which type of modulation is most commonly used for VHF and UHF voice repeaters?
A. AM
B. SSB
C. PSK
D. FM

T8A05
Which of the following types of emission has the narrowest bandwidth?
A. FM voice
B. SSB voice
C. CW
D. Slow-scan TV

T8A07
What is the primary advantage of single sideband over FM for voice transmissions?
A. SSB signals are easier to tune
B. SSB signals are less susceptible to interference
C. SSB signals have narrower bandwidth
D. All of these choices are correct



By our definition,
is CW (Morse code)
a form of Modulation?

Yes! Since it alters the carrier
using on/off keying
to convey information

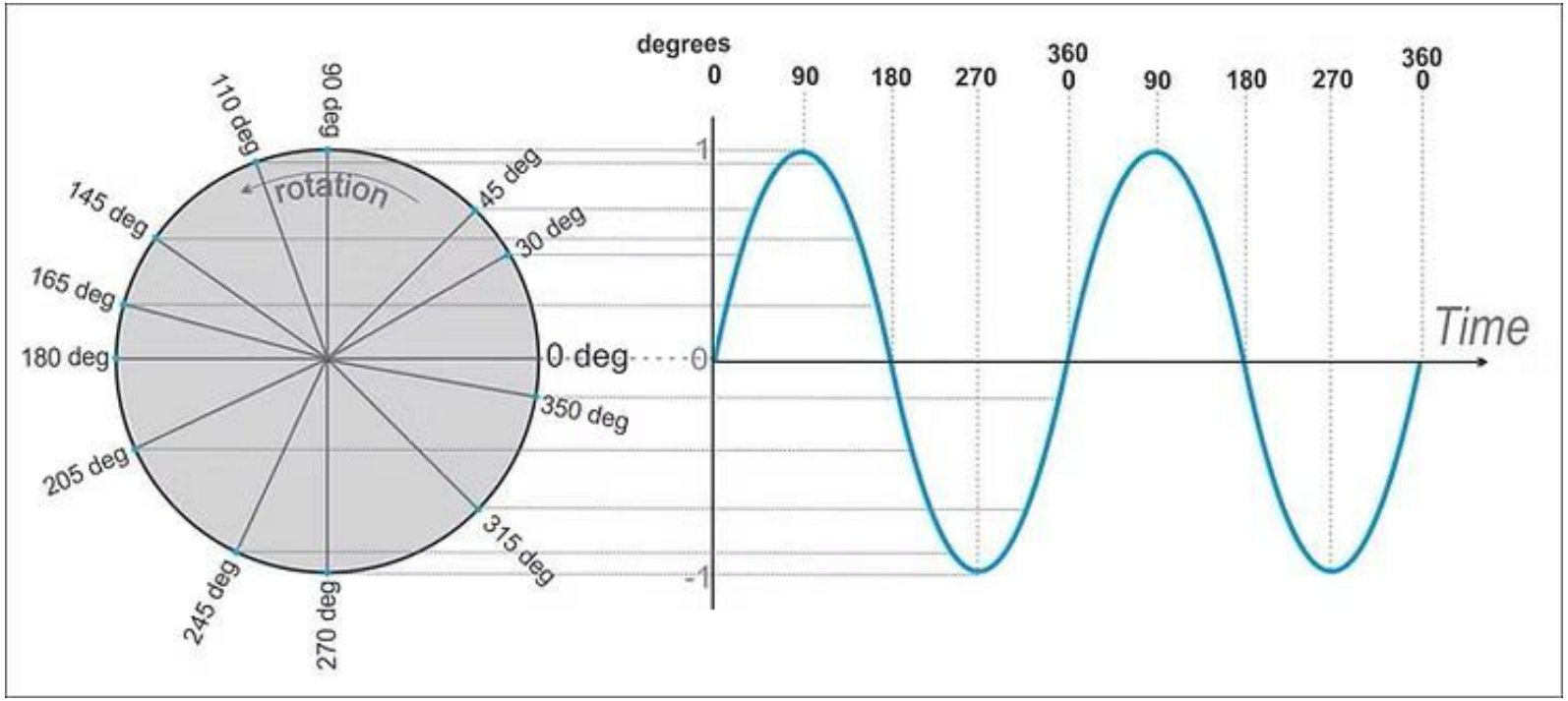
Definitions and Background

- We will talk about signals both in Time Domain and Frequency Domain
- What does that mean?

$$\omega = 2\pi f$$

ω *is called the angular frequency*

Y- axis is Amplitude

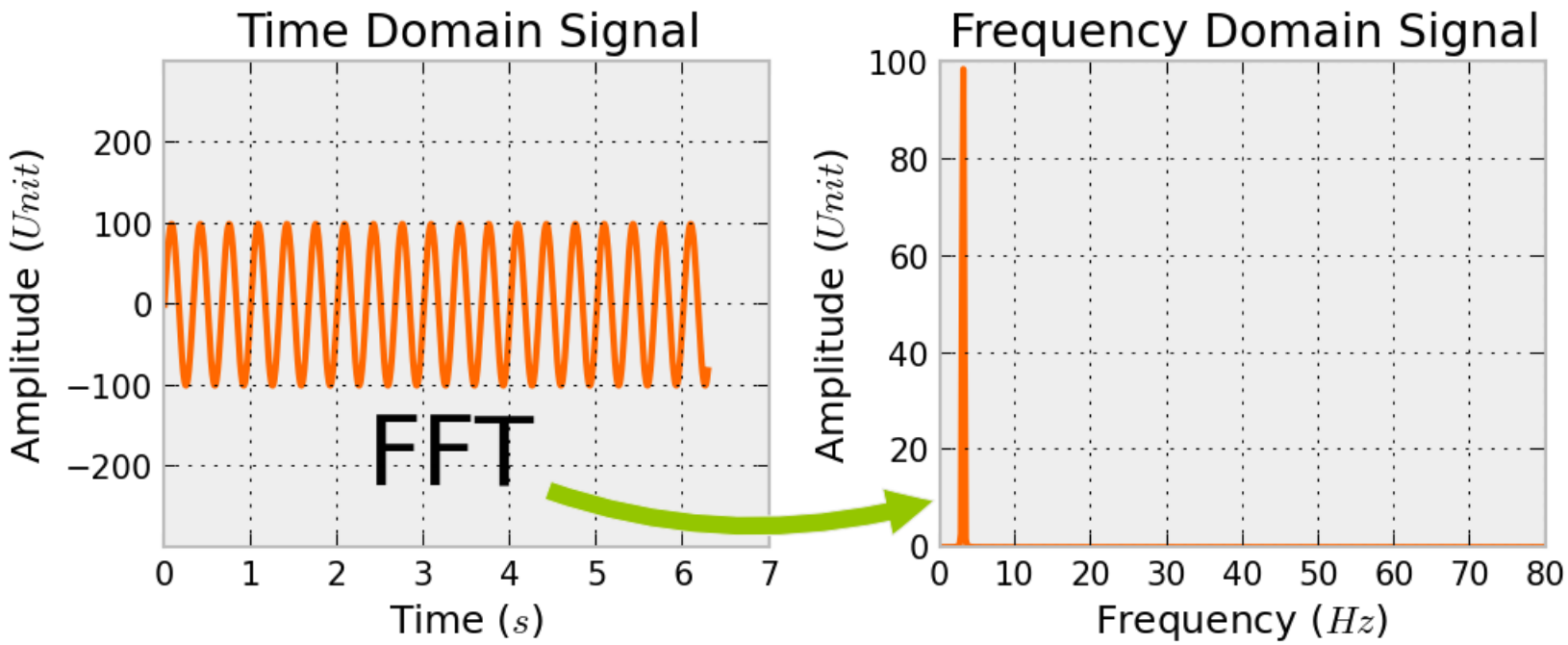


X- axis is Time

Time vs Frequency Domain

- Frequency domain shows us the “spectrum” that the signal uses.
- For a pure sine wave it would be a vertical line at the frequency of the signal with its amplitude.

Y- axis is Amplitude



X- axis is Frequency

Modulation is Altering the Carrier

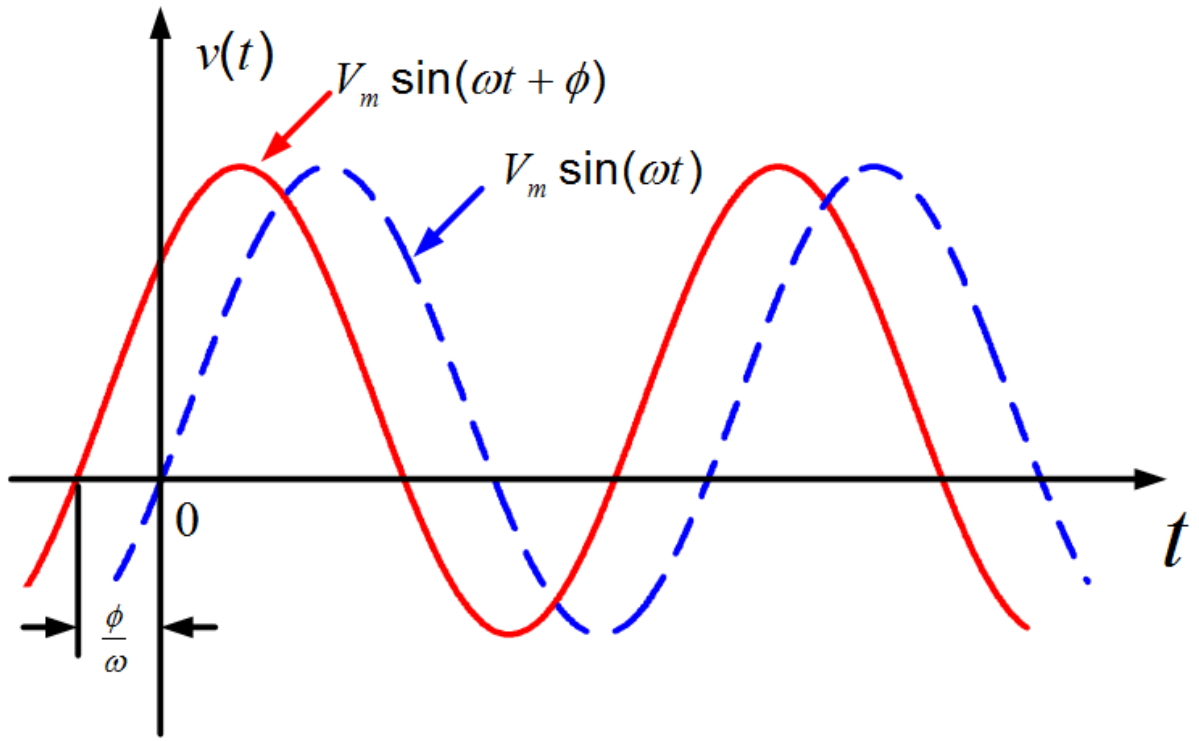
We can only change 3 things about a sine wave:

Amplitude (A)

Frequency (f)

Phase (φ)

$\omega = 2\pi f$



$$v(t) = A(t) * \underbrace{\sin(2\pi f(t) + \varphi(t))}_{\text{Carrier}}$$

Modulation types	AM	FM	PM

Please Excuse the Math

Amplitude Modulation is the multiplication of two sine (or cosine) waves

One is called the CARRIER and is higher in frequency. f_c

The "MODULATING" wave is lower in frequency (usually just audio range) f_m

$$v(t) = A(t) * \sin\left(2\pi f(t) + \varphi(t)\right)$$

$$V(t) = \sin(2\pi f_m(t)) * \sin(2\pi f_c(t))$$

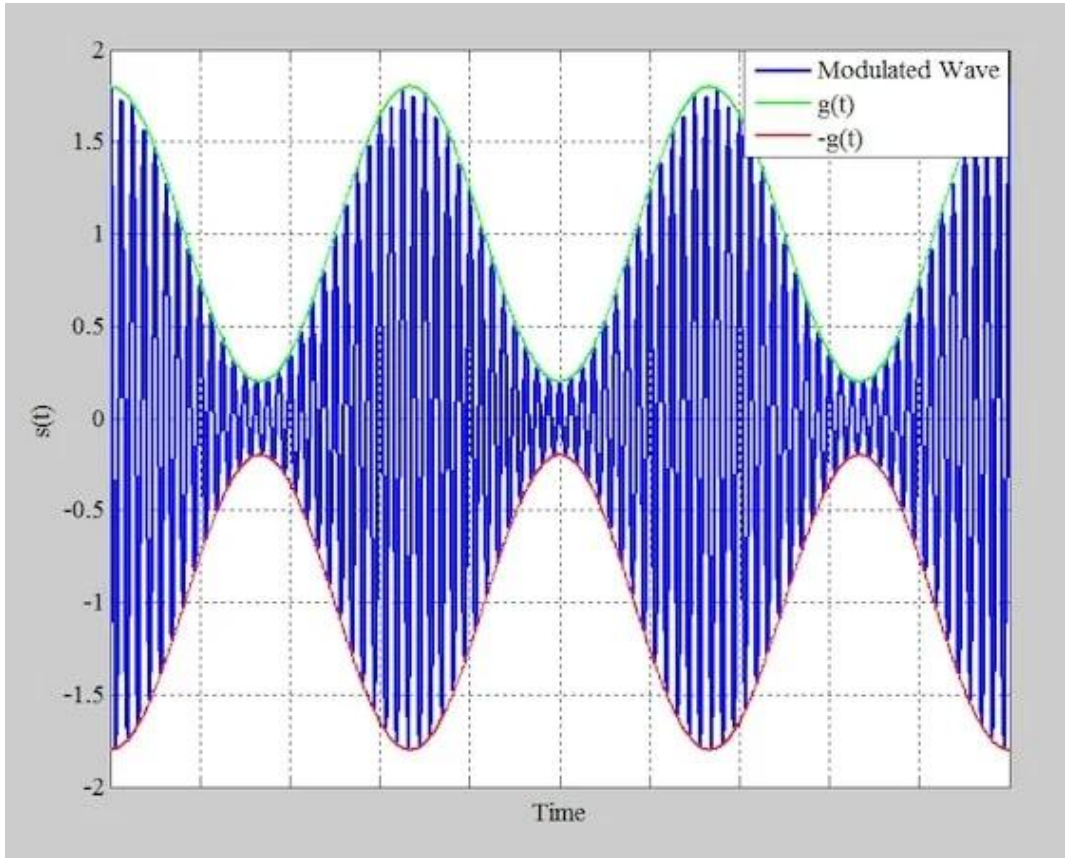
$$\sin(A)*\sin(B) = \tfrac{1}{2}\sin(A-B) + \tfrac{1}{2}\sin(A+B)$$ *this is a trig identity*

$$V(t) = \underbrace{\tfrac{1}{4}\sin[2\pi f_m(t) - 2\pi f_c(t)]}_{\text{LOWER SIDEBAND}} + \underbrace{\tfrac{1}{4}\sin[2\pi f_m(t) - 2\pi f_c(t)]}_{\text{UPPER SIDEBAND}} + \underbrace{\tfrac{1}{2}\sin(2\pi f_c(t))}_{\text{CARRIER}}$$

AM Modulated Signal

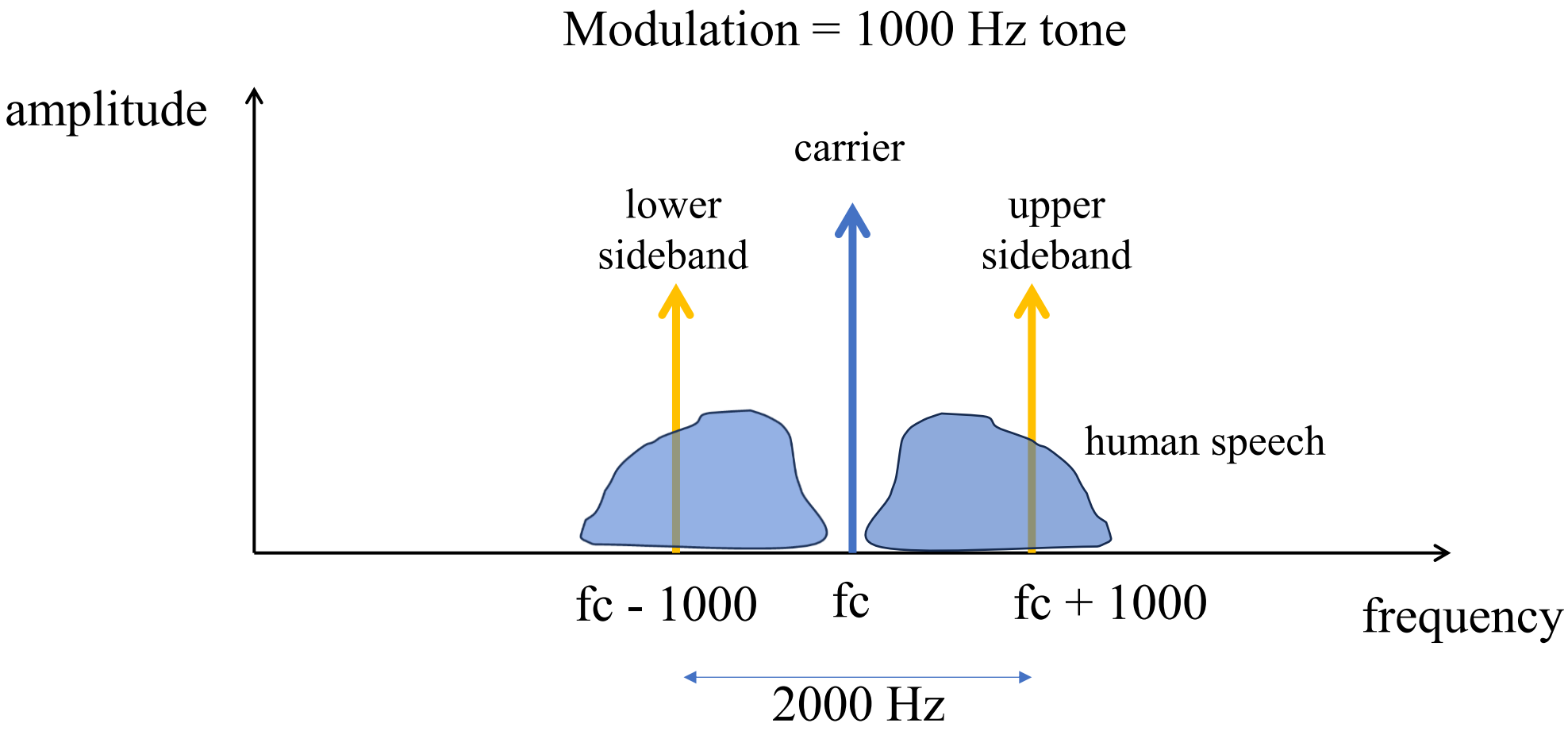
- Carrier Wave (blue) f
- Two components
  - g(t) [green] and –g(t) [red]
- The result is multiplication of the carrier and modulation
  - FFT shows both g(t) and –g(t)
- The spectrum is centered about the carrier frequency

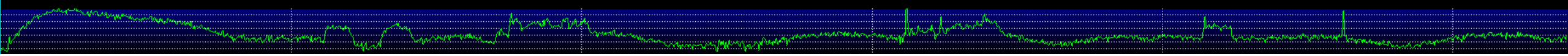
UPPER SIDEBAND



LOWER SIDEBAND

AM Modulation – **Frequency Domain**



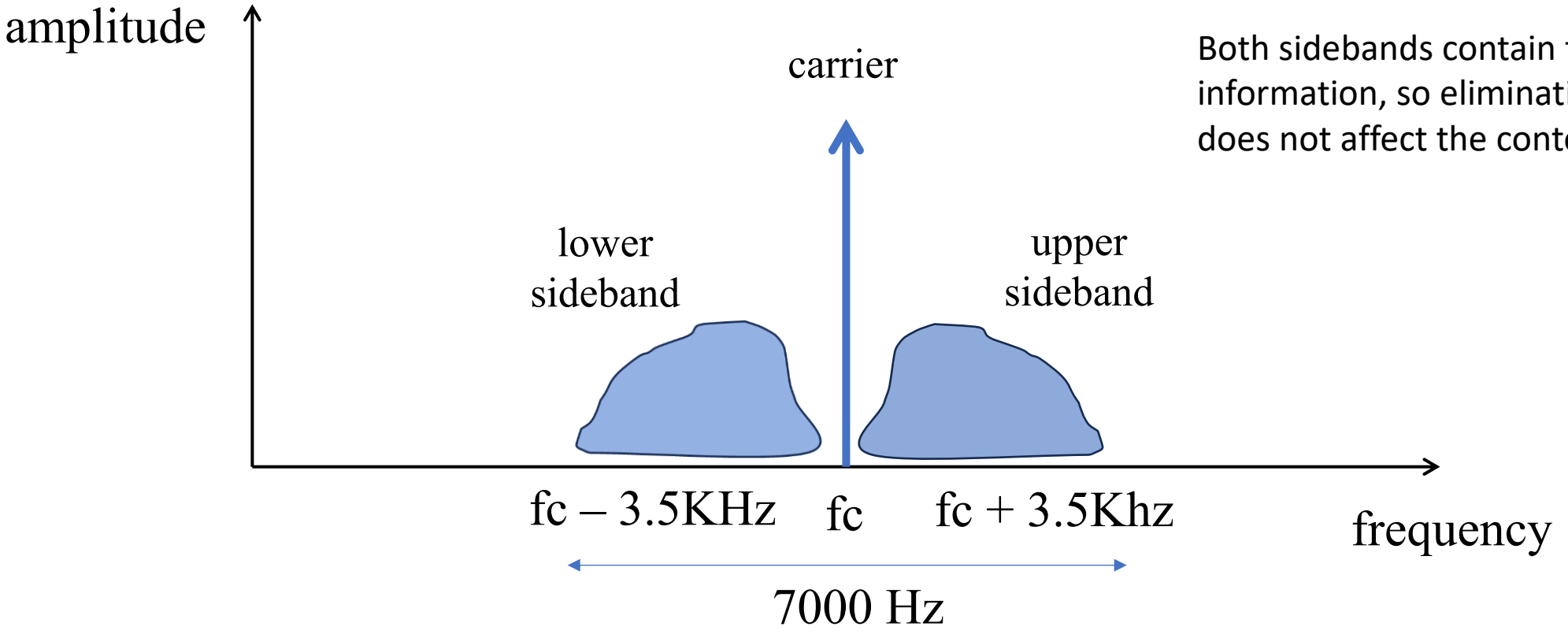


Types of Amplitude Modulation (AM)

- Double Sideband Full Carrier (DSBFC)
  - Type used for AM broadcast stations
  - Not power efficient but made receivers easier(cheaper) to build
- Double Sideband Suppressed Carrier (DSBSC)
  - Carrier is removed and sidebands carry all the information
  - Analog TV used this method
- Single Sideband Suppressed Carrier (SSB) –> **think ham radio**
  - Power and bandwidth efficient. Good for long distance communications
- Vestigial Sideband (VSB)
  - Uses one sideband and a portion of the other (the vestige).
  - Commercial analog TV broadcasting uses this method

SSB Modulation – Frequency Domain

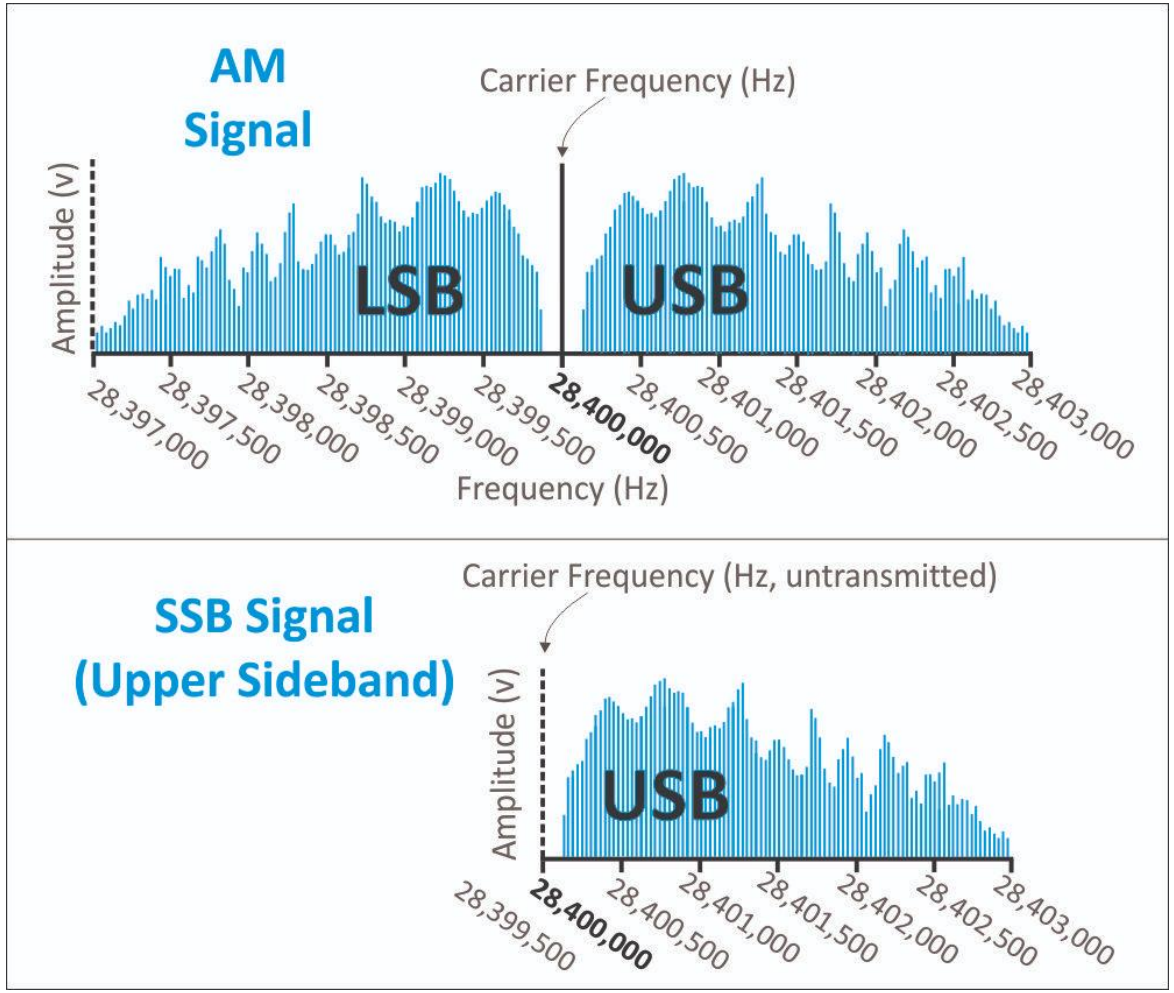
Modulation = human speech at 3.5KHz bandwidth

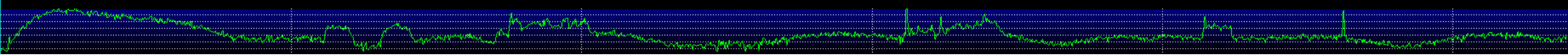


Both sidebands contain the same information, so eliminating one does not affect the content

Single Sideband – Suppressed Carrier

- Ham radio SSB uses both filtering and phasing to remove the unwanted sideband as well as the CARRIER.
- One-half the bandwidth of AM
- More power focused on a narrower bandwidth
- Requires the CARRIER to be **re-injected** by the receiver.





Advantages and Disadvantages of AM & SSB

Advantages

- Simplicity
- Cost effective receivers
- Simple demodulation

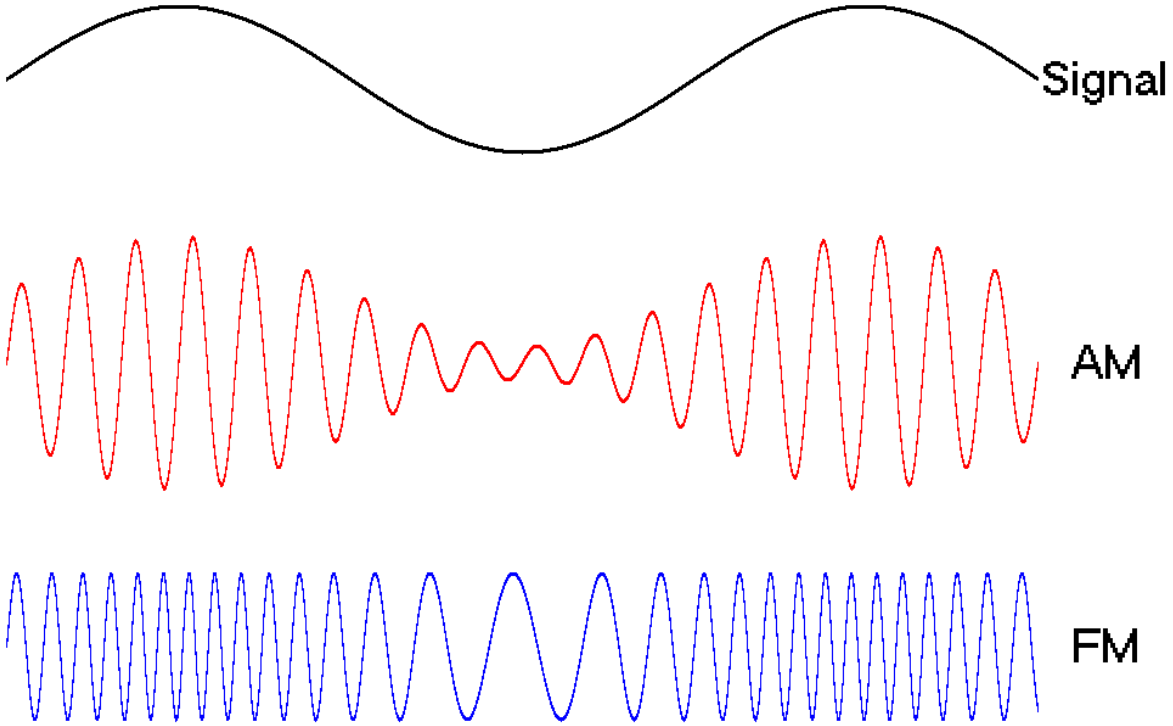
Disadvantages

- High susceptibility to noise
  - Electrical noise is AM
- Susceptible to electromagnetic disturbances
- Inefficient use of bandwidth
  - As compared to other modulation methods

Interesting Fact: our aviation industry still uses AM radios for voice communications

FM – Frequency Modulation

- Constant carrier mode
- Our modulation changes the frequency of the carrier, but not the amplitude.
- Much more robust in presence of noise.
- Max Bandwidth is determined by Carson's Rule (not Johnny)



Carson’s Rule

Carson's rule for FM bandwidth states that the bandwidth required for a frequency-modulated signal can be approximated using the formula:

$FM_{bw}=2(\Delta f+fm)$

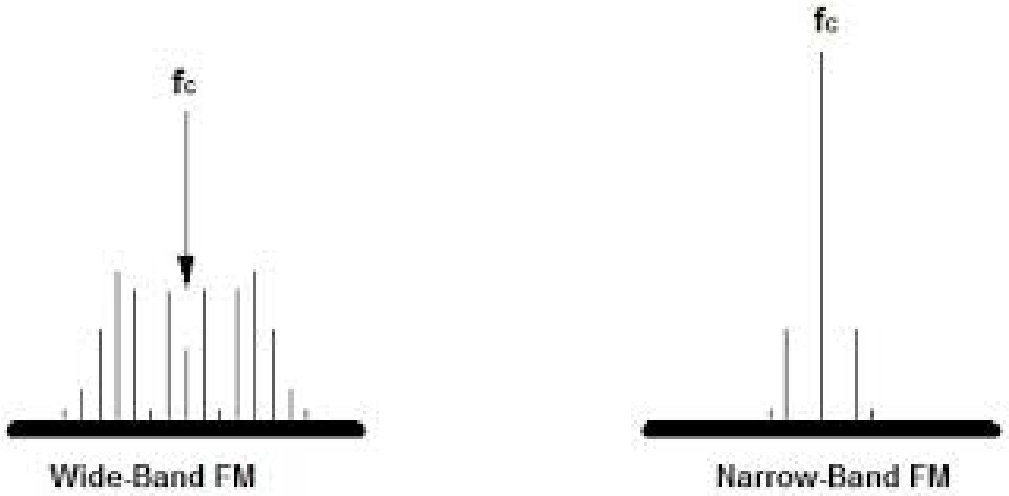
Example from General Ham Exam , question G8B06
For a typical FM signal, if the peak deviation (Δf) is 5 kHz and the highest modulating frequency (fm) is 3 kHz, what is the bandwidth?
Using the formula given:

$FM_{bw}=2(5\ kHz+3\ kHz)=16\ kHz$

This means the FM signal would require approximately 16 kHz of bandwidth.
Note: the 5KHz BW is considered “standard” for amateur radio FM

WBFM versus NBFM

- Spectral efficiency



Wideband FM is for broadcast and has bandwidth to support stereo audio to 15KHz.

Narrowband FM is used for communications systems and limits the audio bandwidth to 3KHz.

FSK is a form of FM as it also shifts the carrier frequency in a pattern that encodes 1’s and 0’s

Advantages and Disadvantages to FM

Advantages

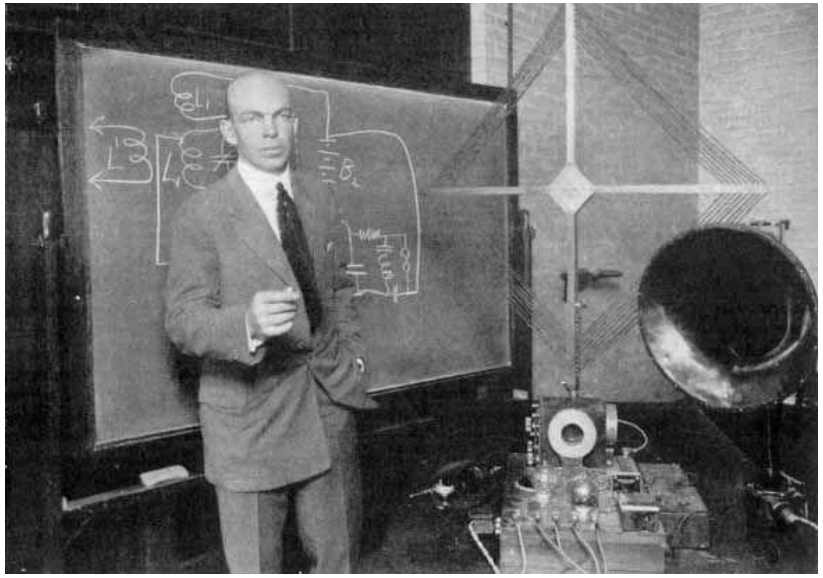
- Noise immunity superior when compared to AM
- Offers better fidelity than AM
  - Dynamic range
- Works in places where signal strength is varying

Disadvantages

- Larger bandwidth than AM
- More complex demodulation
  - Adds to cost
- Subject phase noise

Tragic Story of FM

- Invented by Edwin Armstrong in 1933 and received a US Patent
- FCC awarded the 42 to 50 MHz spectrum for FM radio broadcast
- Stations and equipment were made for this band as well as receivers
- David Sarnoff (RCA) and NBC saw the threat to AM radio and lobbied the FCC to move the spectrum to 88-108MHZ
- Entangled Amstrong in a patent battle
- Wife left him. Legal problems mounted

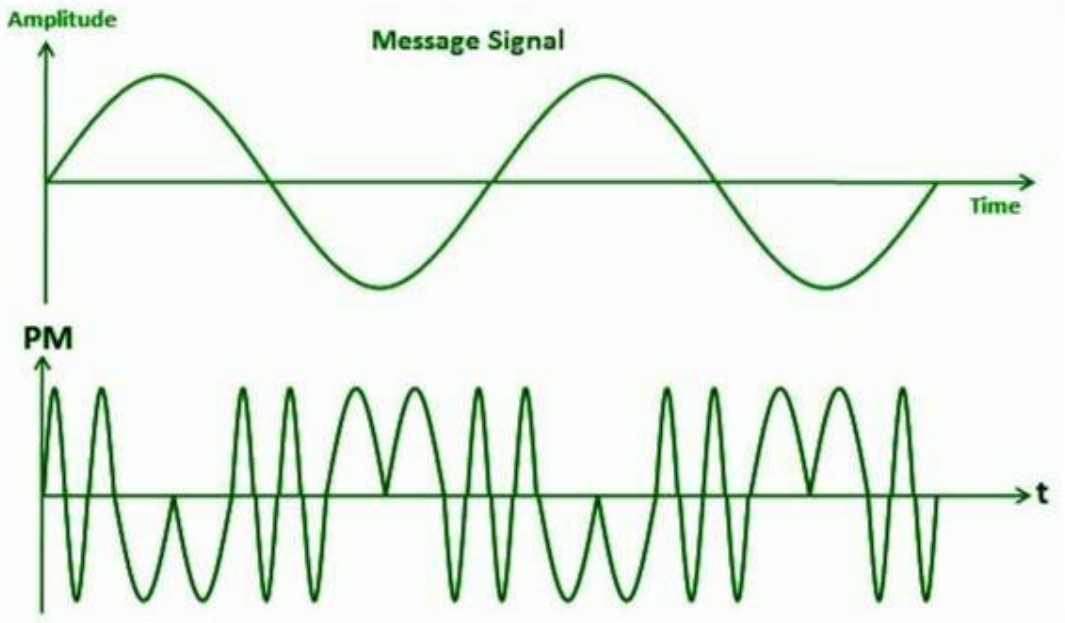


Armstrong committed suicide on Feb 1, 1954.
His widow eventually got $10M in damages, but FM commercial radio took decades to reach its potential.

https://www.damninteresting.com/the-tragic-birth-of-fm-radio

Phase Modulation

- Closely related to FM
- Phase angle of the carrier is altered by the modulating signal.
- Commonly used in analog TV, digital TV, and digital modems



The equation of a PM signal is represented by

$$V(t) = A\cos[\omega_c t + \Phi(t)]$$

Where,

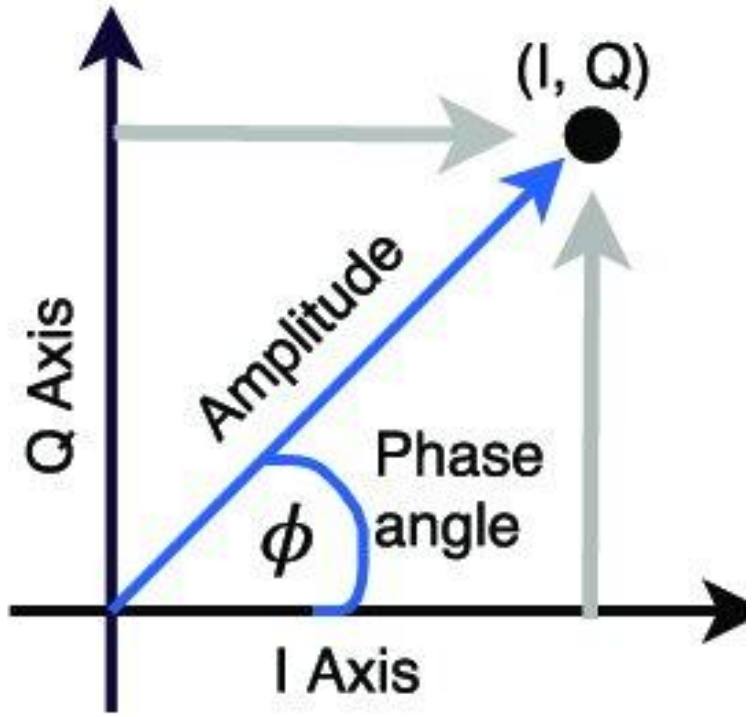
ω_c is the carrier frequency constant

A is the amplitude constant

ϕ (t) is the phase angle, which is not constant. It is a function of the baseband signal.

Polar Modulation

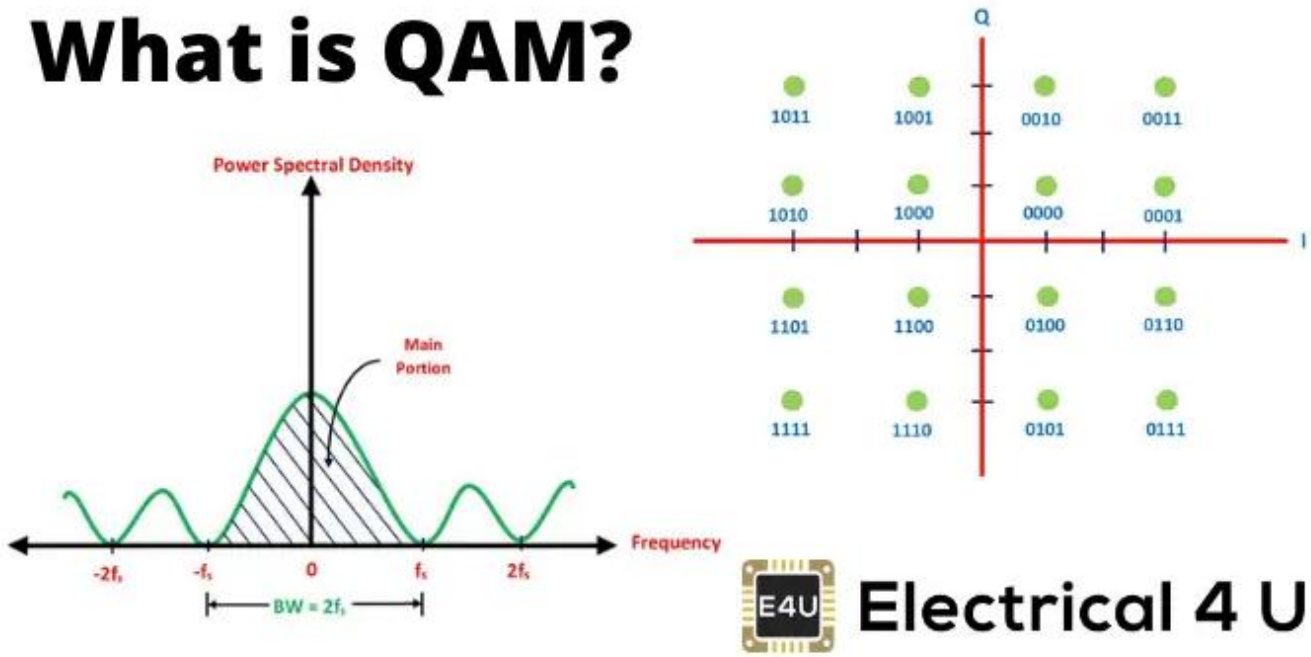
- What is Polar Modulation?
  - Uses Phase an Amplitude as the components.
  - It is a time varying Phasor
  - Goal is to increase the efficiency of the amplification stage
  - Drives non-linear amplifiers properly
- New **Flex Radio Aurora** Transceiver uses this technology to get **80%** efficiency and cleaner signal. They use a Class D Power Amplifier.



https://hackaday.com/tag/polar-modulation/

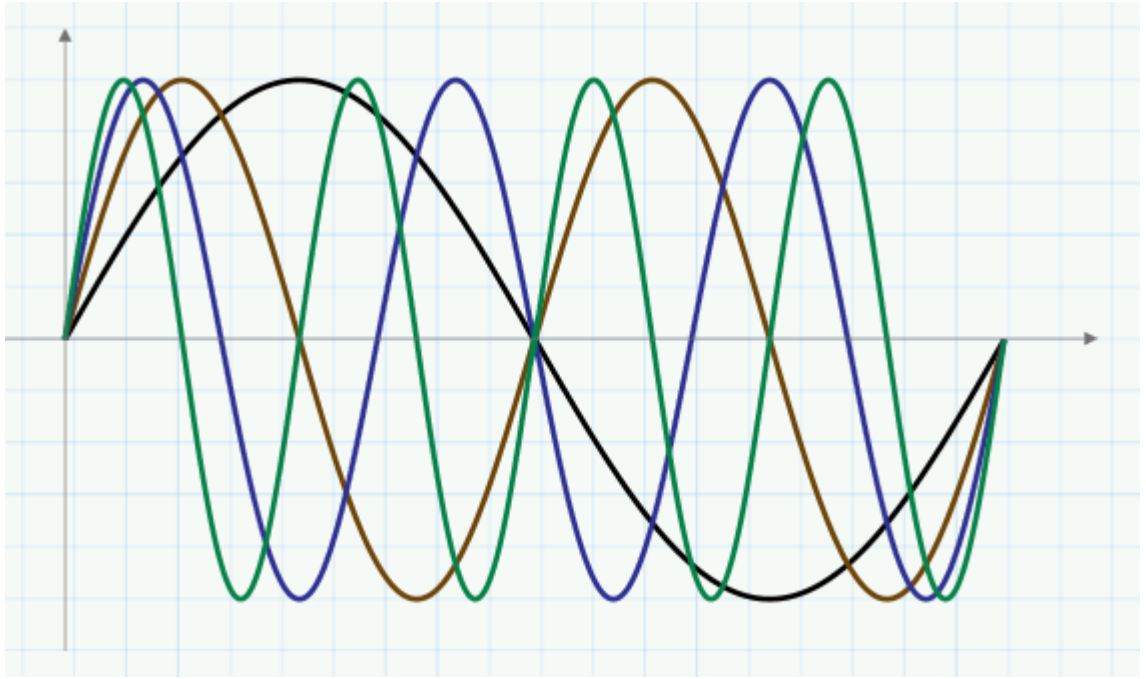
QAM (Quadrature Amplitude Modulation)

- Uses both amplitude and phase to modulate the carrier.
- Used in WiFi, cable modems, and high-speed data applications

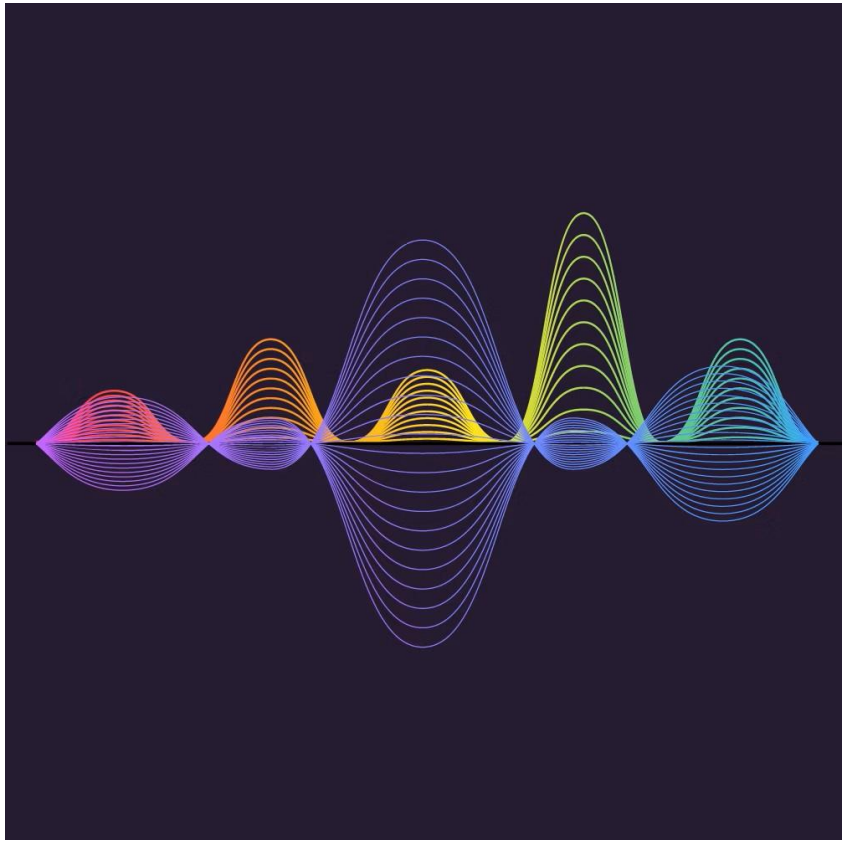


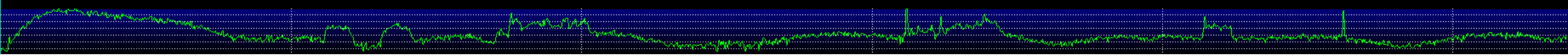
What about cellular phones?

- Cell Phone technology uses a technique call OFDM
  - Orthogonal Frequency Division Multiplexing, which combines QAM and Frequency Division Multiplexing to increase capacity
- Use 4 carriers spaced Δf apart.
- Both amplitude & phase can encode 64 bits of data.



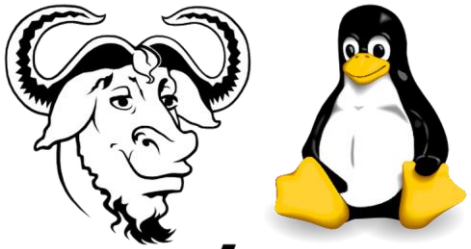
Demonstrations





GNU Radio
THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM

- GNU is the mascot for open software, funded by the Free Software Foundation.
- Originally referred to the OS and eventually LINUX – which in NOT UNIX.
- Many tools followed like compilers, editors, many free tools for programming
- GNURadio – free software toolkit for experimenting with software defined radios (SDR's)
- Building blocks are in C++ wrapped in Python



GNU/Linux

Gnu is an African Wildebeest

GNURadio Setup

antenna

RF Front-end
& VCO

USB

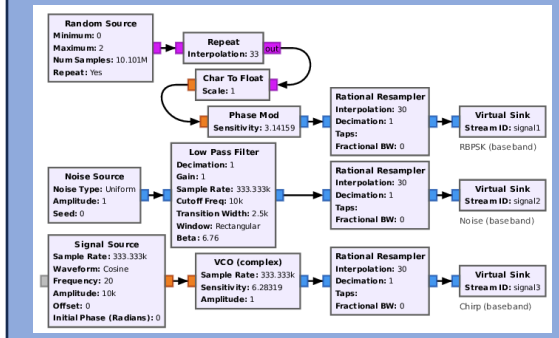
LINUX Computer
MINT-OS

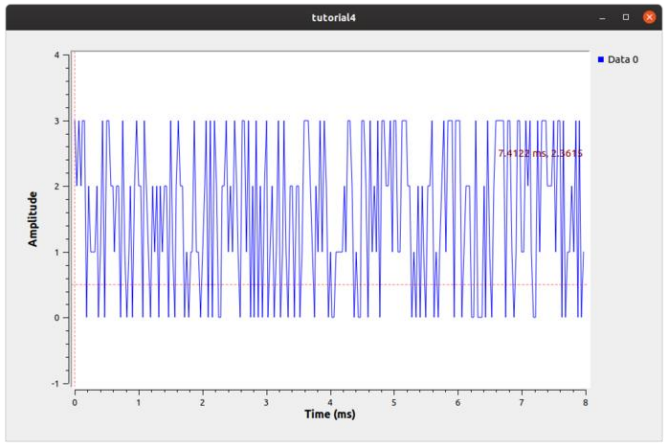
PC speaker

SDR Dongle

Digital Sampled Signal
8 bits ADC

GNURadio app

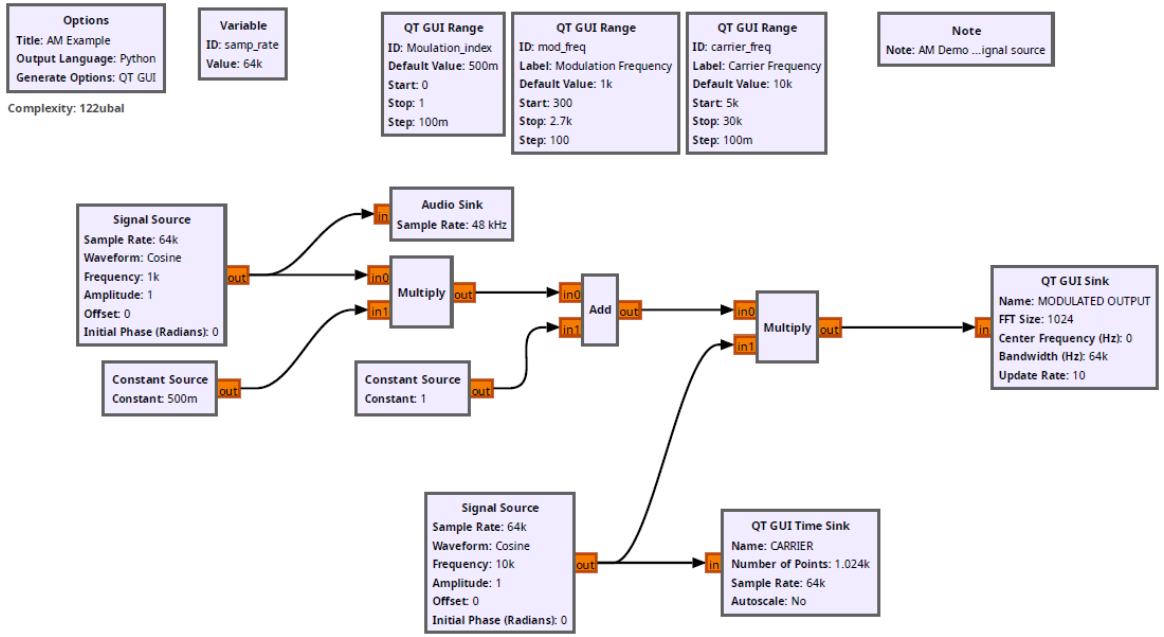


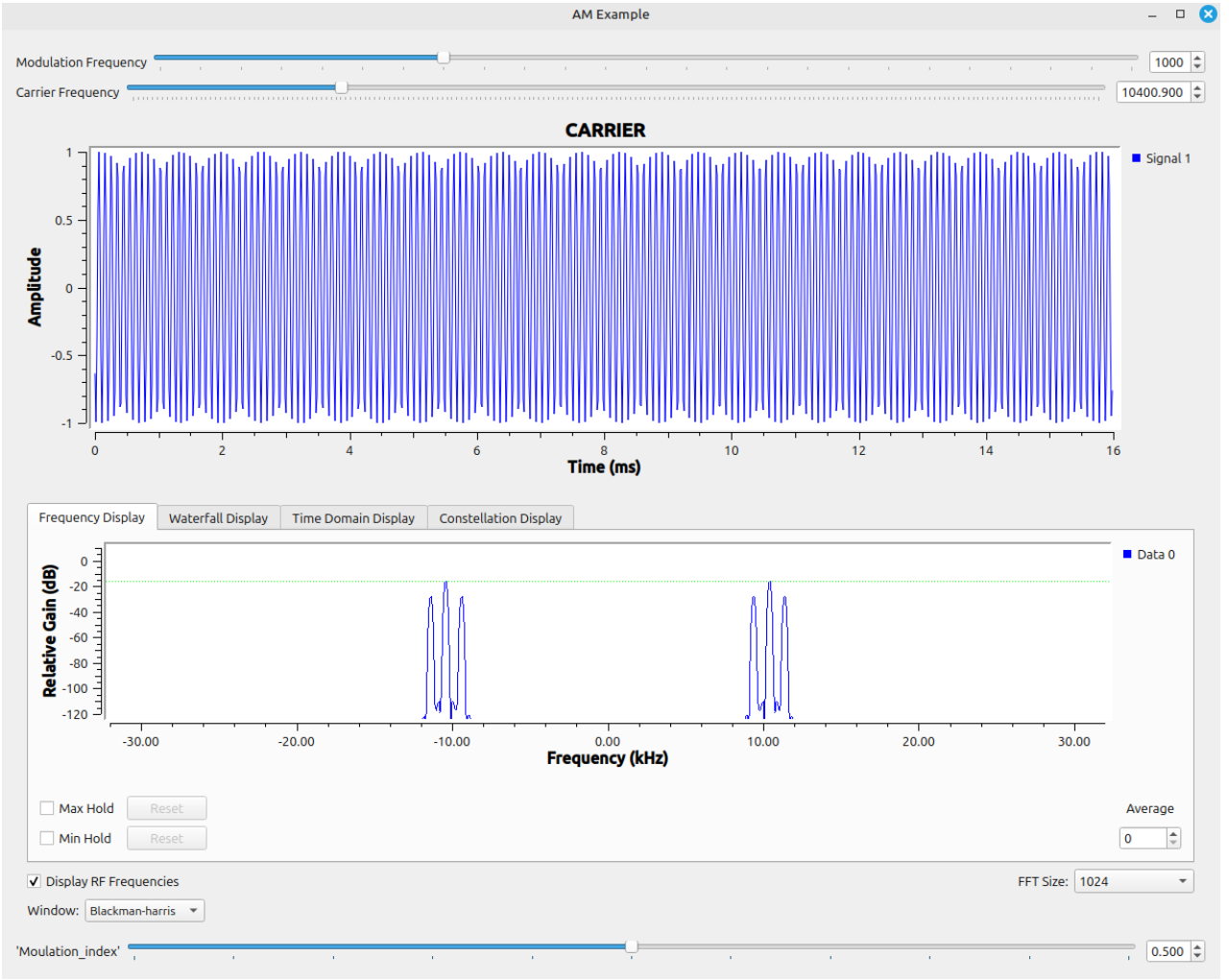


Graphical Display

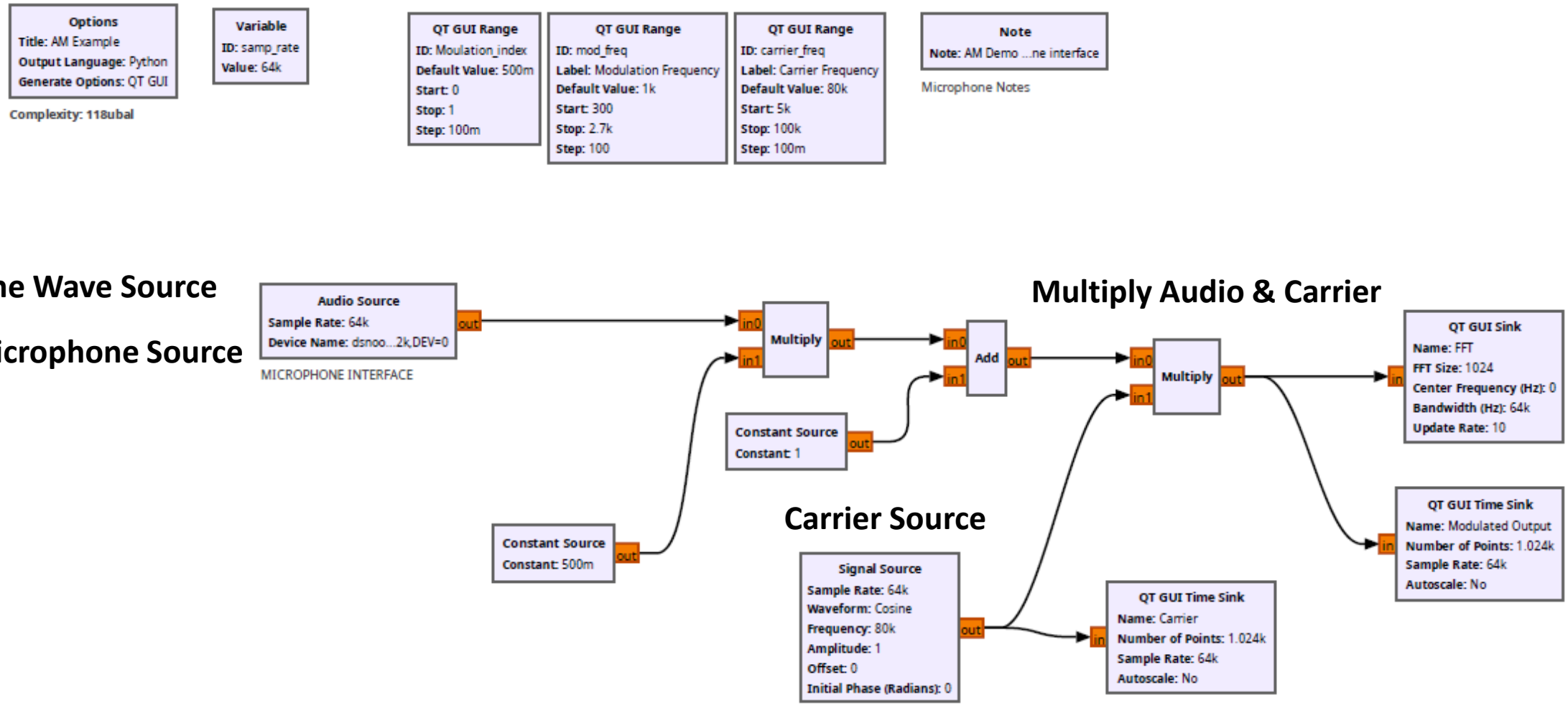
AM Modulation – Constant Source

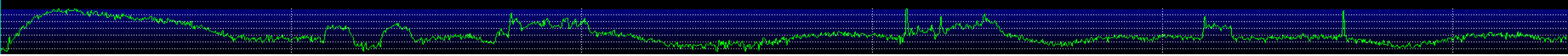
Sliders to control:
Mod Frequency
Carrier Frequency
Mod Index





AM Modulation Flow Chart





GNURadio

THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM

Demo’s on LINUX MINT-OS with GNURadio

Thank you! Questions?