SCARS

Technician / General

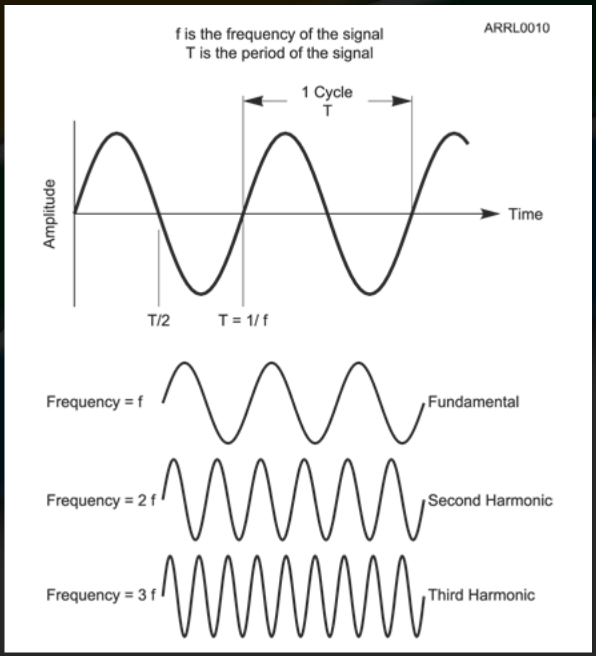
License Course

Week 2

Wave Vocabulary

Before we study radio, we need to learn some wave vocabulary.

- Amplitude
- Frequency (hertz, Hz)
- Period (seconds, s)
- Fundamental
- Harmonics



Electromagnetic Waves

- Electromagnetic waves are made up of electric and magnetic energy. (fields)
- The electric and magnetic fields vary in the pattern of a sine wave.
- Electromagnetic waves travel at the speed of light.

Electromagnetic Waves

- Moving electrons in an antenna take the place of the moving magnet.

- A signal from a transmitter can make the electrons in an antenna move, transferring energy from the signal to electromagnetic waves.

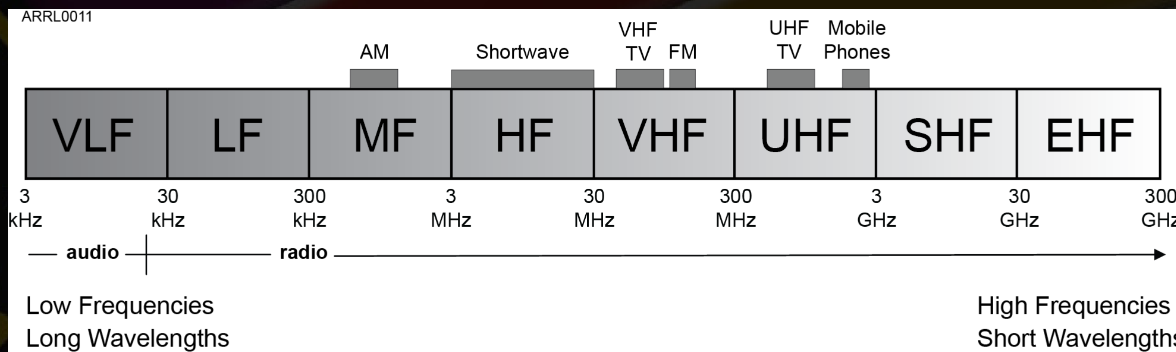
Electromagnetic Waves

- The same process works "backwards" too.
- Electromagnetic waves encountering an antenna make its electrons move in sync with the wave.
- Electromagnetic energy is transferred from the wave to the electrons.
- The moving electrons create a signal that can be detected by a receiver.

Electromagnetic Spectrum

- The electromagnetic spectrum is divided into ranges of frequencies in which electromagnetic waves behave similarly.
- Each range or segment has a different name.
- Waves with a certain range of frequencies which can be used for communication are called radio waves.

Radio Spectrum



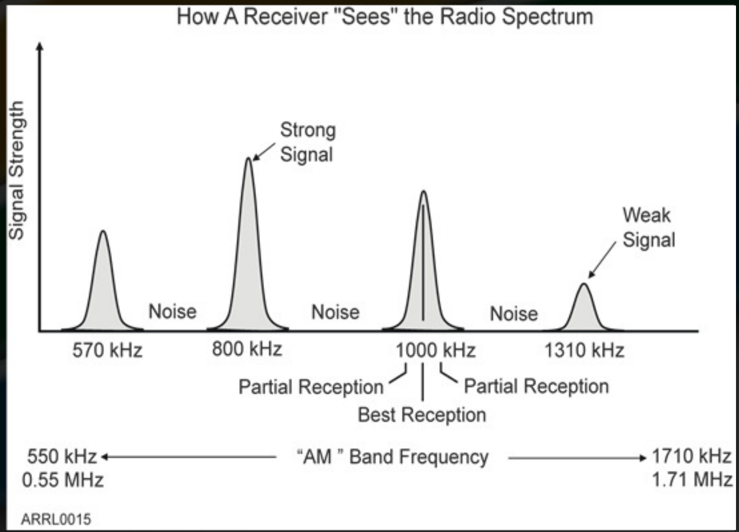
- The part of the electromagnetic spectrum Composed of radio waves is called the *Radio Frequency* or *RF* spectrum

Radio Spectrum

- Parts of the spectrum allocated for a common purpose are called a *band,* such as the “AM Band” or “CB Band”.
  - Signals in these bands are usually of the same for commercial purposes.
- Hams share the band across many signals of different types.

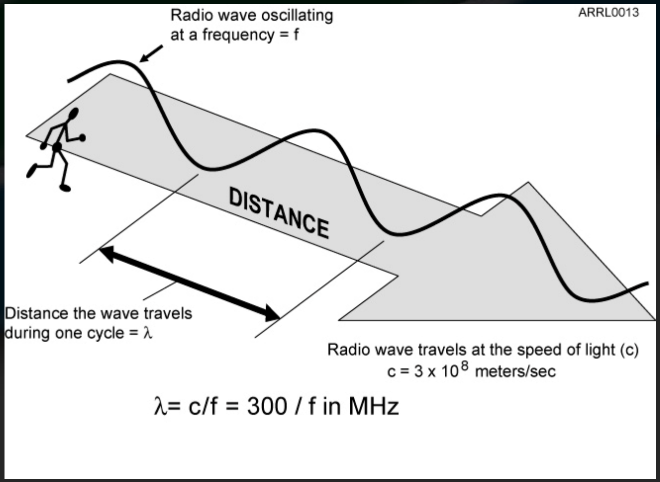
Radio Signals

- A radio wave carrying information is a *radio signal*.
- Each signal occupies a range of frequencies.
- Receivers "tune in" a signal by listening at the signals frequency.



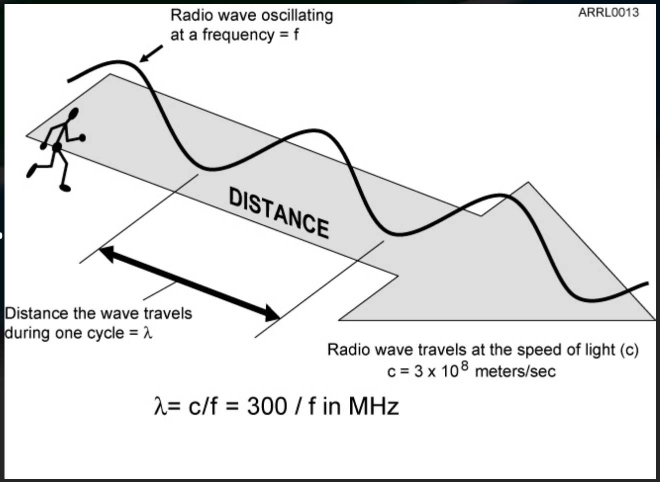
Wavelength

- *Wavelength* is the distance a radio wave travels during one cycle of the wave's electric and magnetic fields.
- λ (lambda) is the symbol for wavelength.

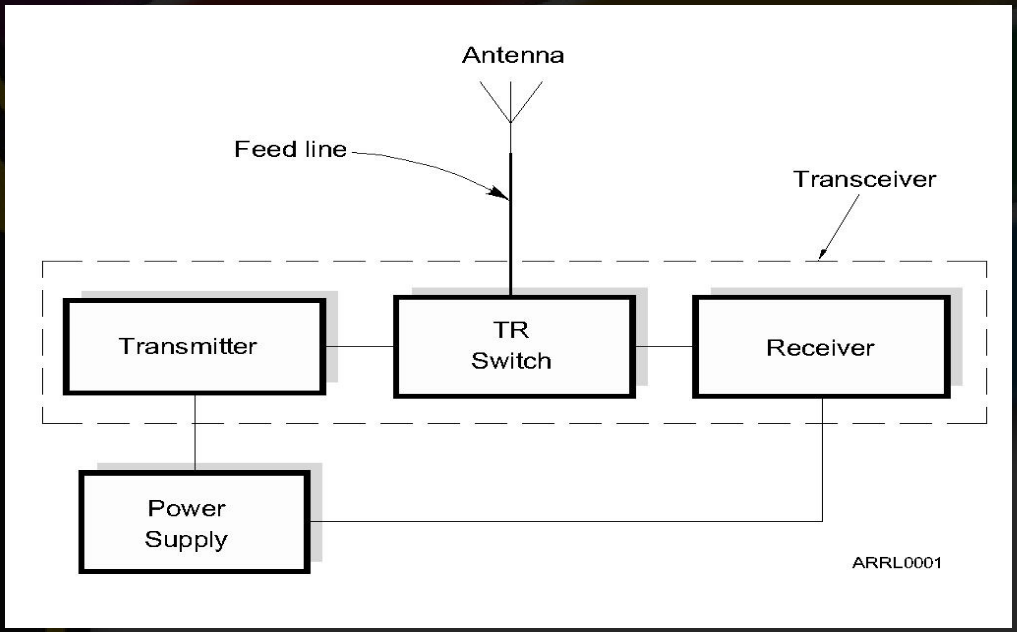


Wavelength

- *Wavelength* is the distance a radio wave travels during one cycle of the wave's electric and magnetic fields.
- λ (lambda) is the symbol for wavelength.
- Waves travel at the speed of light, *c*.
- Hams can refer to bands by frequency (50MHz) or wavelength (6 meters).



The Basic Radio Station



What Happens During Radio Communication?

- Transmitting (sending a signal):
  - –Information (voice, data, video, commands, etc.) is converted to electronic form.
  - –The information in electronic form is added to a radio wave.
  - –The radio wave carrying the information is sent from the station antenna into space.

What Happens During Radio Communication?

- Receiving:
  - The radio wave carrying the information is intercepted by the receiving station's antenna.
  - The receiver extracts the information from the received wave.
  - The information is then presented to the user in a format that can be understood (sound, picture, words on a computer screen, response to a command, etc.).

What Happens During Radio Communication?

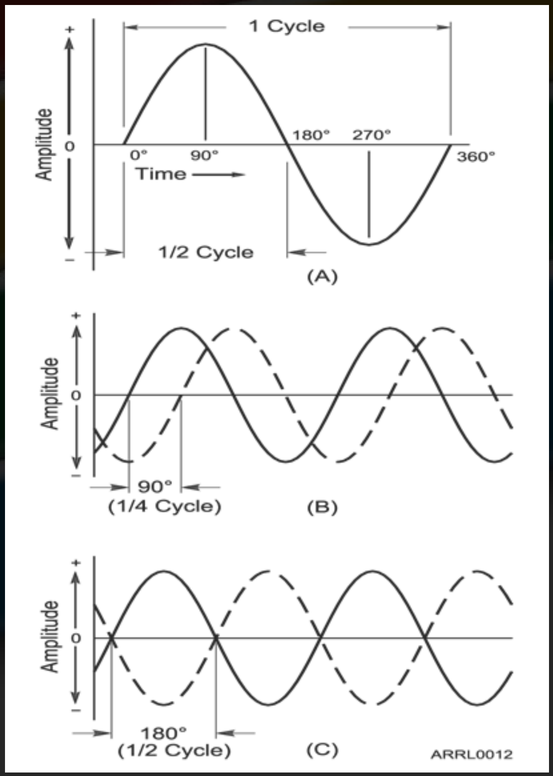
- Adding and extracting the information can be simple or complex.
- This makes ham radio fun…learning all about how radios work.
- Don’t be intimidated. You will be required to only know the basics, but you can learn as much about the “art and science” of radio as you want.

Adding Information – Modulation

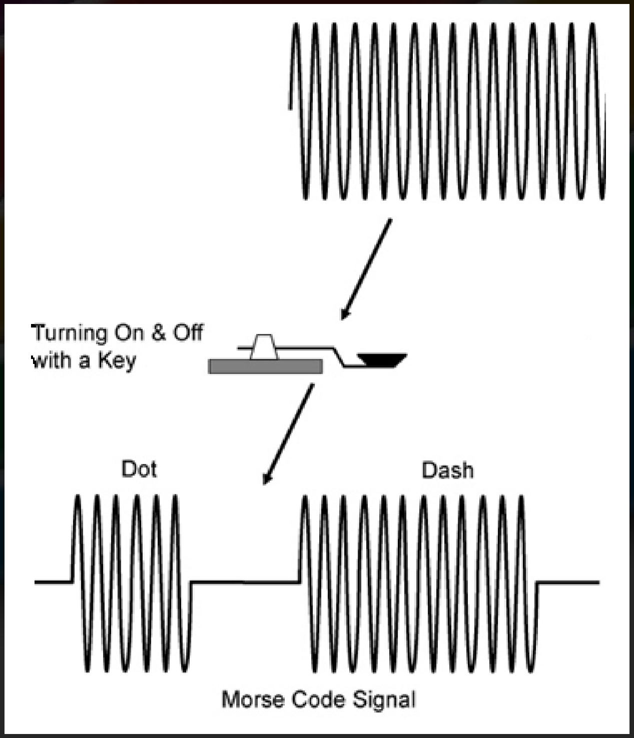
- When we add some information to the radio wave, (the *carrier*) we *modulate* the wave.
  - Turn the wave on and off (Morse code)
  - Speech or music
  - Data
- Different modulation techniques vary different properties of the wave to add the information:
  - Amplitude, frequency, or phase

Phase

- Along with frequency and period, another important property of waves is *phase*.
- Phase is a position within a cycle.
- Phase is also a relative position between two waves.

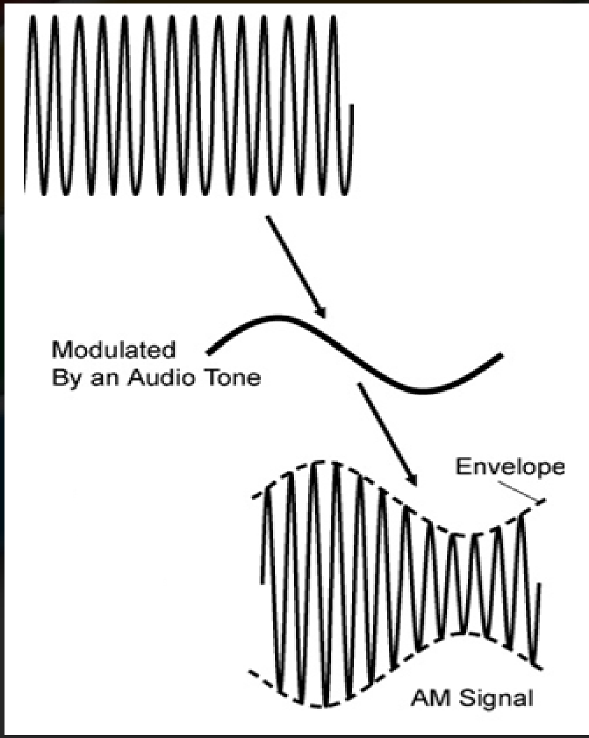


CW - Morse Code – On and Off



Amplitude Modulation (AM)

- In AM, the amplitude of the carrier wave is modified in step with the waveform of the information (the tone shown here).



Composite Signals

- The process of adding information to an unmodulated radio wave creates additional signals called *sidebands*.
- The sidebands and carrier work together to carry the information.
- The combination of carrier and sidebands creates a *composite signal*.

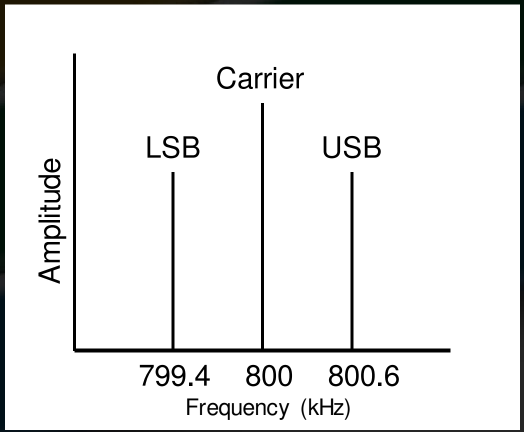
Bandwidth

- The carrier and sidebands have different frequencies, occupying a range of spectrum space.
- The occupied range is the composite signal's *bandwidth.*
- Different types of modulation and information result in different signal bandwidths.

Characteristics of Voice AM

AM signals consist of three components:
- –Carrier
- –Lower sideband (LSB)
- –Upper sideband (USB)

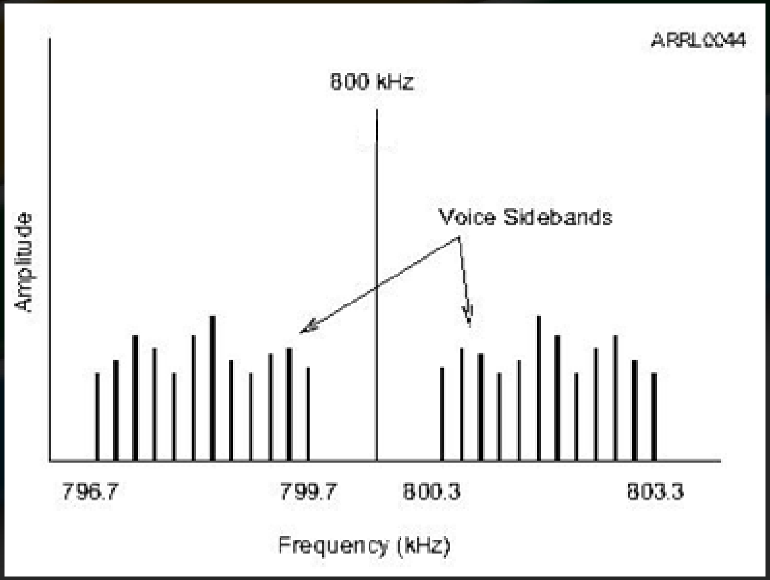
- AM bandwidth is twice the information bandwidth.



AM signal being modulated by a 600 Hz tone

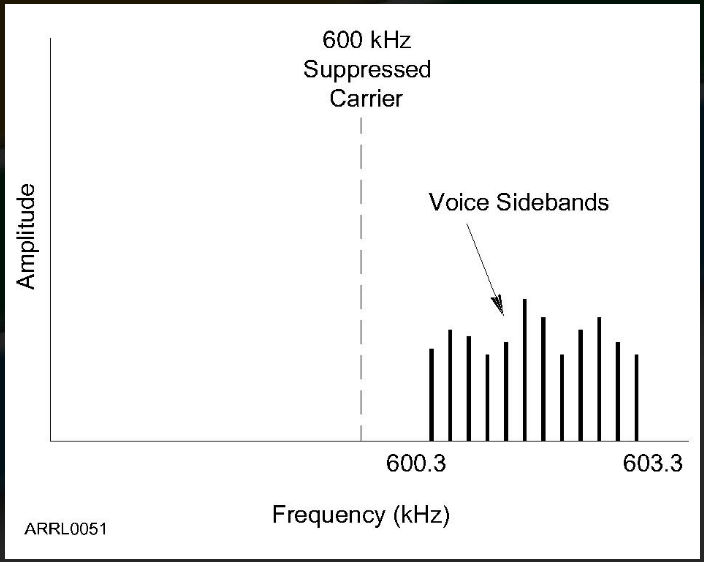
Characteristics of Voice Information

- Sounds that make up voice are a complex mixture of multiple frequencies from 300–3000 Hz
- Two mirror-image sets of sidebands are created, each up to 3000 Hz wide.
- AM voice signal bandwidth 2 x 3000 Hz = 6000 Hz



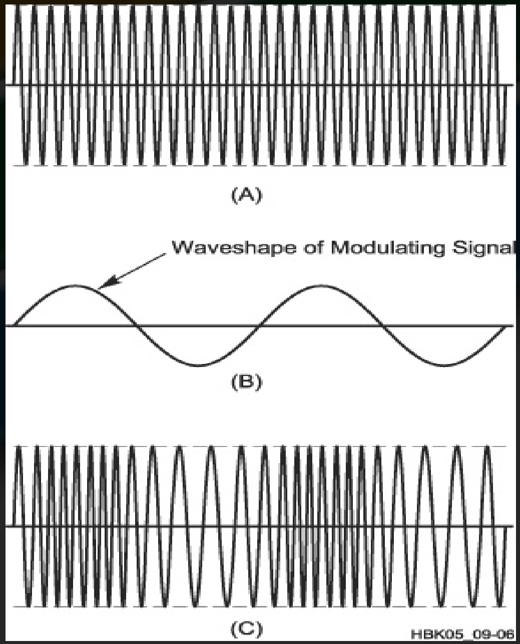
Single Sideband Modulation (SSB)

- The two sets of voice sidebands carry duplicate information.
- We can improve efficiency by transmitting only one sideband and reconstructing the missing carrier in the receiver.
- SSB bandwidth is only 3000 Hz for voice signals.



Frequency and Phase Modulation (FM and PM)

- Instead of varying amplitude, if we use the information to vary the carrier's frequency, *frequency modulation (FM)* is produced.
- FM bandwidth (for voice) is between 5 and 15 kHz.
- We can also shift the signal's phase back and forth, creating *phase modulation (PM)* that is very similar to FM.



Typical Signal Bandwidths

Signal Bandwidths

Type of Signal	*Typical Bandwidth*
AM voice	6 kHz
AM broadcast	10 kHz
Commercial video broadcast	6 MHz
SSB voice	2 to 3 kHz
SSB digital	500 to 3000 Hz (0.5 to 3 kHz)
CW	150 Hz (0.15 kHz)
FM voice	10 to 15 kHz
FM broadcast	150 kHz

Signal Review

- *Continuous wave* (CW) – A radio signal at one frequency whose strength never changes
- *Modulation* – adding information to a signal by changing its frequency, phase angle, or amplitude
- *Demodulation* – recovering the information from a modulated signal

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Signal Review

- If speech is the information used to modulate a signal, the result is a *voice mode* or *phone* (short for *radiotelephone*) signal
- If data is the information used to modulate a signal, the result is a *data mode* or *digital mode* signal

Signal Review

- Analog modes carry information, such as speech, that can be understood directly by a human
- Digital or data modes carry information as data characters between two computers

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Amplitude Modulated Modes

- *Amplitude modulation* (AM) is the instantaneous varying of the power or amplitude of a signal by adding speech or data information
  - The AM signal's *carrier* is a continuous wave whose amplitude does not change and contains no information
  - The AM signal's *envelope* follows the modulating signal. The modulating information can be recovered from the envelope by *detection*

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Amplitude Modulated Modes

- An AM signal is composed of a *carrier* and two *sidebands* – one higher than the carrier frequency (upper sideband – USB) and one lower (lower sideband – LSB).
- Each sideband contains a copy of the modulating information.
- A s*ingle sideband* (SSB) signal is an AM signal with the carrier and one sideband removed.

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Angle Modulated Modes

- *Frequency modulation* (FM) is a mode that varies the frequency of a signal to add speech or data information
- *Deviation* is the amount that an FM signal's frequency varies when modulated
- *Phase modulation* (PM) is created by varying a signal's *phase angle*
- FM and PM have many sidebands but the signals have a constant power

Bandwidth Definition

- *Bandwidth*:
  - The FCC limits signal bandwidth so that many stations and types of signals can share the limited amount of spectrum
  - Single sideband is the phone emission which uses the narrowest bandwidth
  - Defined as the range within which the signal is no more than 26 dB (1/400th) below the average signal power.

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Oscillators

- An oscillator consists of an amplifier that increases signal amplitude (*gain*) and a *feedback* circuit to route some of the amplifier's output signal back to its input
- Oscillator circuits must include a filter so that feedback is present at only the intended frequency
- The oscillator output frequency can be fixed or variable

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Oscillators

- The filter of an LC oscillator is a resonant circuit made from inductors and capacitors. It sets the oscillator's frequency
  - Resonant LC circuits are sometimes called *tank circuits* because they store energy
- The output frequency of a *variable-frequency oscillator* (VFO) can be adjusted by changing the L or C. VFOs are used to tune a radio to different frequencies

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Oscillator

- Two other widely used VFO circuits:
  - *Phase-locked loop* (PLL)
  - *Direct digital synthesizer* (DDS)
    - The DDS has the advantage of being controllable by software and having stability comparable to a crystal oscillator

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Mixers

- A mixer circuit combines signals with two frequencies, f_1 and f_2, and produces signals with the sum and difference frequencies at its output (*heterodyning)*
  - Example: If f_1 = 14.050 MHz and f_2 = 3.35 MHz, the output of the mixer will contain signals at both 10.7 MHz ($f_1 - f_2$) and at 17.4 MHz ($f_1 + f_2$).
  - A mixer can change a signal to any other frequency
  - The input signals are called the RF and LO (Local Oscillator) and the outputs are mixing products

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Multipliers

- *Multipliers* – create harmonics of an input signal
- Multipliers are often used when a stable VHF or UHF signal is required that cannot be generated directly at VHF/UHF
- A low-frequency oscillator supplies the multiplier input, and the output is tuned to the desired harmonic of the input signal

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Modulators

- Modulator circuits add information to a carrier signal by varying its amplitude, frequency, or phase
- The modulating information can be speech, data, or images

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Amplitude Modulators

- AM and double-sideband (DSB) can be generated by a *balanced modulator*
- SSB is generated by removing the unwanted sideband and carrier with a filter (filter method) or by combining signals with certain phase relationships (phasing method)
- Using only one sideband uses transmitted output power more effectively

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Frequency & Phase Modulation

- Frequency modulation (FM) – the signal frequency varies (deviates) in proportion to the modulating signal’s amplitude
- Phase modulation (PM) – deviation varies with both amplitude and frequency of the modulating signal
  - PM is produced by a *reactance modulator* connected to a tuned RF amplifier following the oscillator

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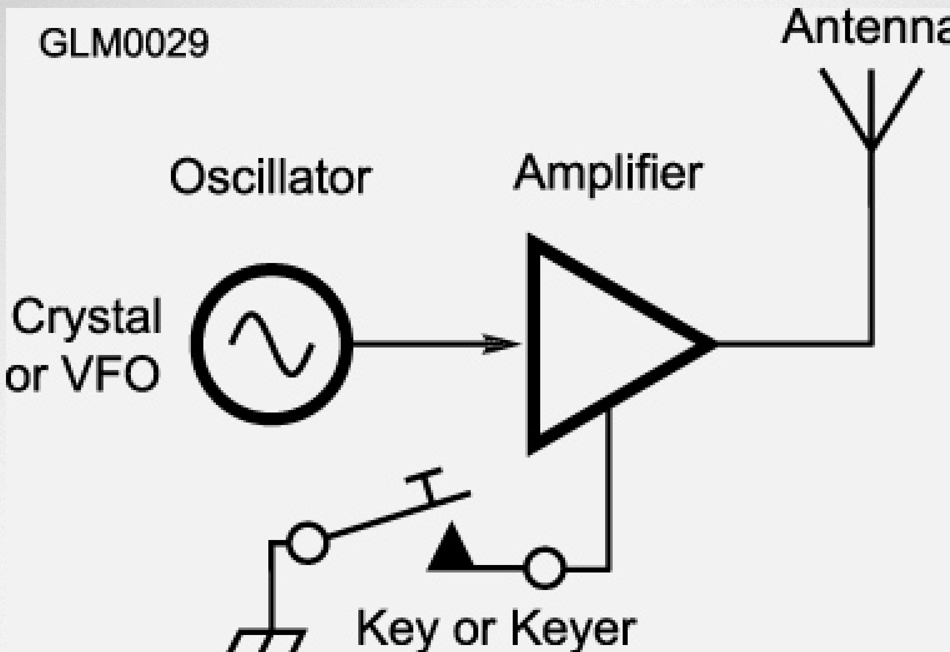
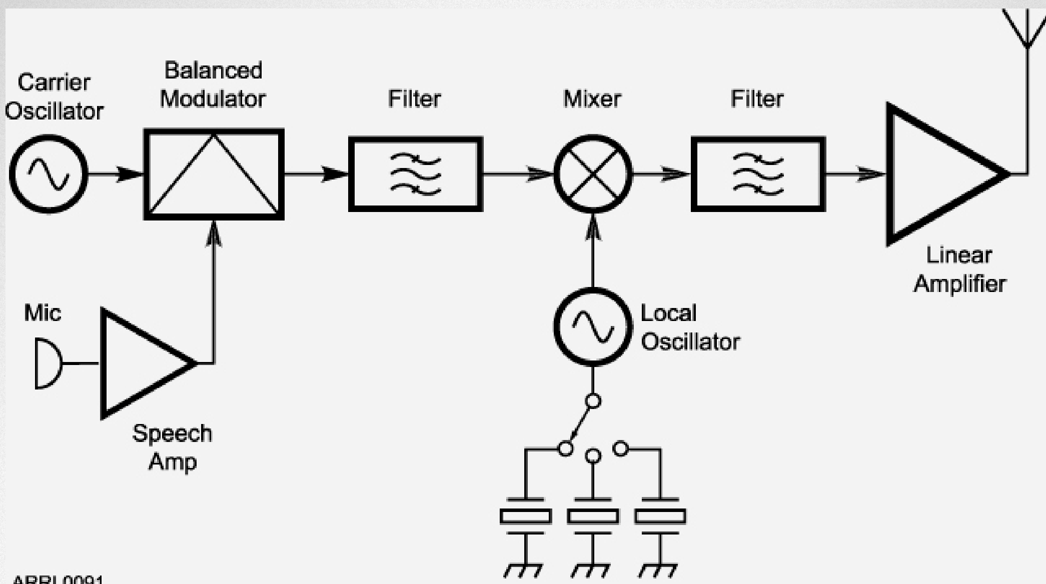
CW Transmitters

- Simplest transmitter is a two-stage CW transmitter
- It consists of an oscillator and an amplifier, with the amplifier turned on and off by a key or keyer



SSB Phone Transmitters

- A *balanced modulator* stage combines signals from the carrier oscillator and speech amplifier to produce DSB
- The first filter removes the unwanted sideband, producing SSB.



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FM Transmitters

- In a 2 meter FM transmitter, the modulated oscillator frequency is approximately 12 MHz
- Multipliers then select the 12th harmonic for transmission (12 x 12 = 144)
- For example, for an output on 146.52 MHz, the oscillator must produce a 146.52 ÷ 12 = 12.21 MHz signal

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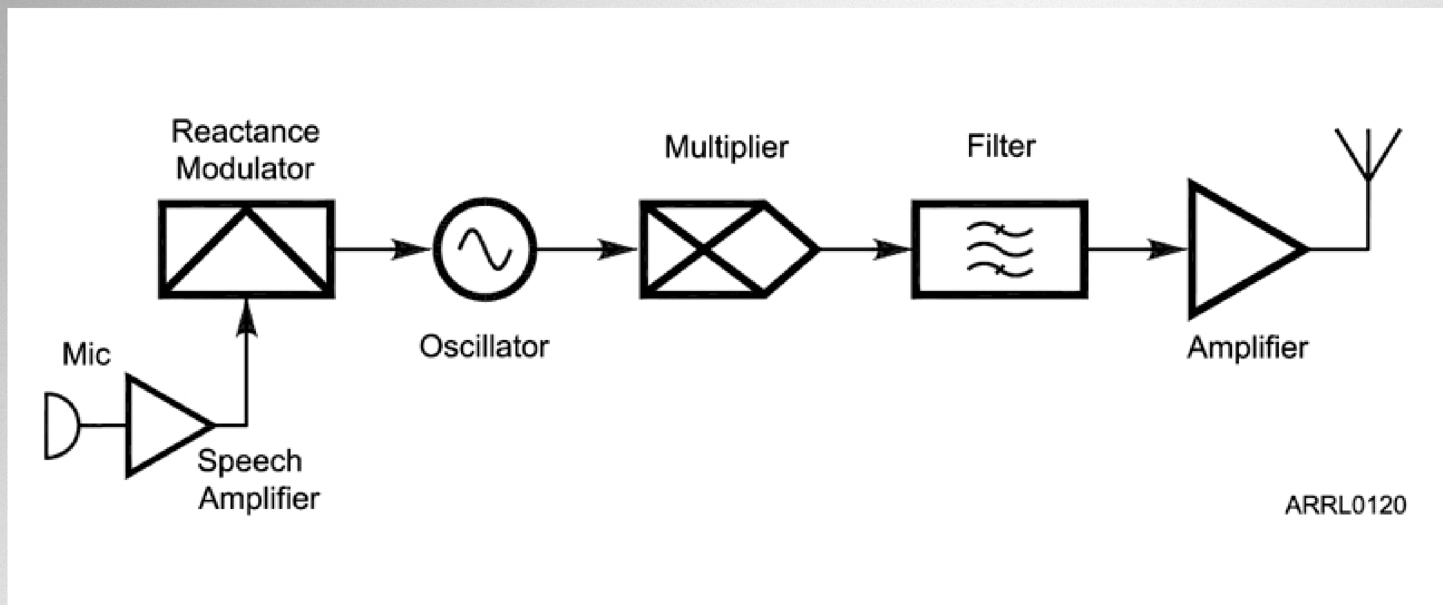
FM Transmitters



FM Transmitters

- Deviation of the modulated oscillator output is also multiplied, increasing with each harmonic
- Example: If the 146.52 FM signal produced from the 12 MHz oscillator is to have the standard deviation of 5 kHz, the maximum deviation of the oscillator is:

$$5 \text{ kHz} \div 12 = 416.7 \text{ Hz}$$

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FM Transmitters

- *Carson's Rule* is a formula that gives an approximation of an FM signal's bandwidth:

BW = 2 × (peak deviation + highest modulating frequency)

- Example: If an FM phone signal's peak deviation is limited to 5 kHz and the highest modulating frequency is 3 kHz, then:

BW = 2 × (5 + 3) = 16 kHz

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Signal Quality

- Overmodulation – AM Modes:
  - Distorts the transmitted audio
  - Increases the signal's bandwidth by creating unwanted spurious signals called splatter or buckshot
  - Often caused by mis-adjustment
    - Mic gain set too high (reduce microphone gain or speak more quietly)
    - Speech processor set too high (turn it down or off

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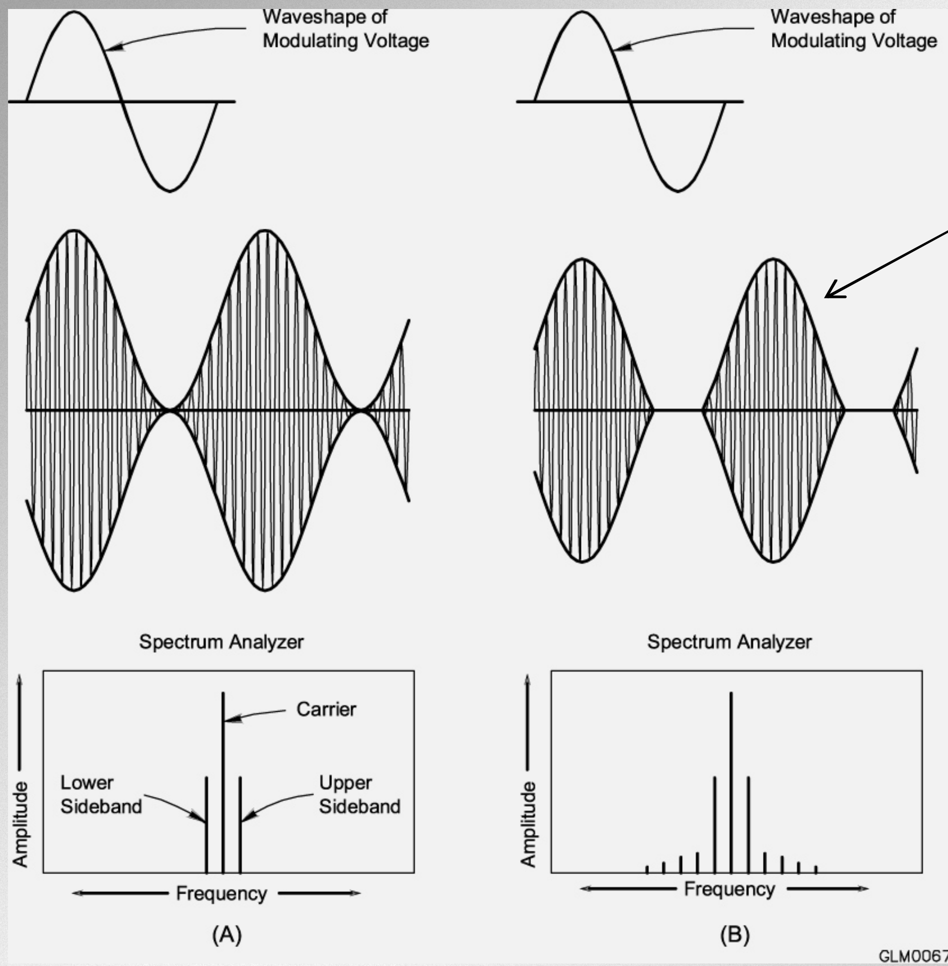
Overmodulation



Modulation Envelope

Overmodulation

- If the drive level to transmitter output stages or external amplifiers is increased beyond the point of maximum output power level, the result is *flat-topping* or *clipping*
  - Use normal speech or audio levels during both testing and on-the-air contacts
  - Under difficult conditions it's natural to raise your voice (only reduces intelligibility)

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Overmodulation

- Automatic level control (ALC) system helps prevent overmodulation and excessive drive
  - ALC reduces output power on voice peaks
  - Mic gain should be adjusted to cause the ALC to activate only on voice peaks
  - *Two-tone test* for transmitter linearity is very helpful in keeping your signal clean
    - Test consists of modulating your transmitter with a pair of audio tones that are not harmonically related (700 and 1900 Hz)

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Speech Processing

- *Speech processing* increases the average power of the speech signal without excessively distorting the signal
- The result is improved intelligibility of the received signal in poor conditions
- Speech processors can also amplify low-level background noise, reducing intelligibility (balance power increase against reduction in intelligibility)

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Overmodulation

- Overmodulated FM signals:
  - *Overdeviation* is caused by speaking too loudsly or mic gain too high
  - The received signal is distorted
  - Creates interference to adjacent channels

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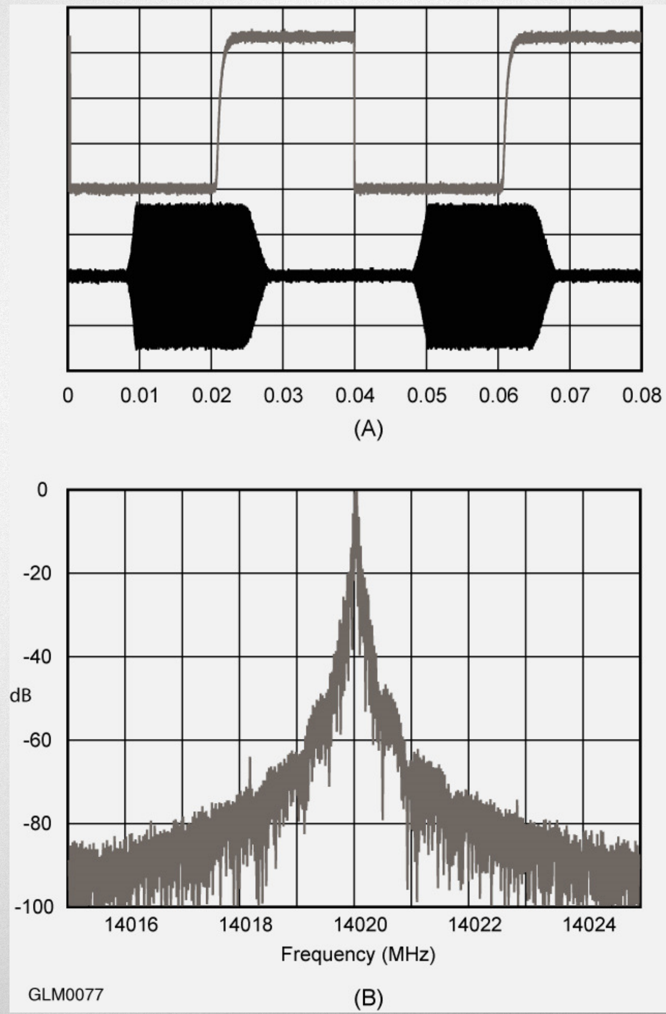
Key Clicks

- Key clicks are sharp transient clicking sounds heard on adjacent frequencies as a transmitter turns on and off too rapidly during CW transmissions



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Amplifiers

- High-power HF amplifiers usually use vacuum tube circuits that require operator adjustment
  - Solid-state becoming more common
- AM modes such as SSB require linear amplifiers that accurately reproduce the input signal waveform

Amplifier Classes

- *Class A* – The most linear
  - Lowest signal distortion
  - Least efficient
- *Class B* – (*push-pull)* a pair of amplifying devices each active during complementary halves of the signal's cycle
  - Good efficiency
  - Linearity can be good

Amplifier Classes

- *Class AB* – the amplifying device is active for more than one-half but less than an entire signal cycle
  - Linearity is not as good as Class A, but efficiency is improved
- *Class C* – amplifying devices are active for less than one-half of the signal's cycle
  - The highest efficiency but poor linearity
  - Only suitable for CW and FM because they have very poor linearity

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Amateur Amplifiers

- Most linear amplifiers can be operated in either Class AB for SSB operation or in Class C for CW
- The efficiency of an amplifier is defined as the RF output power divided by the dc input power

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Amplifiers

- Transceivers often include a delay in the keying circuit
  - T/R relay is completely switched before the transceiver is allowed to supply any RF output
  - Delay prevents *hot-switching*
  - *Hot-switching* can destroy the relay or other external devices

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Amplifier Tuning

- Set the band switch to proper frequency
- Apply a small amount of drive power while adjusting the TUNE control for a minimum setting ("*dip*") plate current
- Adjust the LOAD control to maximize (or "peak") output power

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Amplifier Tuning

- Continue to adjust drive, tune, load for desired output power
- Watch meters to prevent exceeding the maximum grid and plate current
- Input power may also be adjusted during the process
- Continue adjustments until desired output power is reached

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Neutralization

- HF amplifiers are capable of becoming an oscillator (called *self-oscillation*)
- Self-oscillation creates spurious output signals and may damage the tube or amplifier components
- The technique of preventing self-oscillation is called *neutralization*

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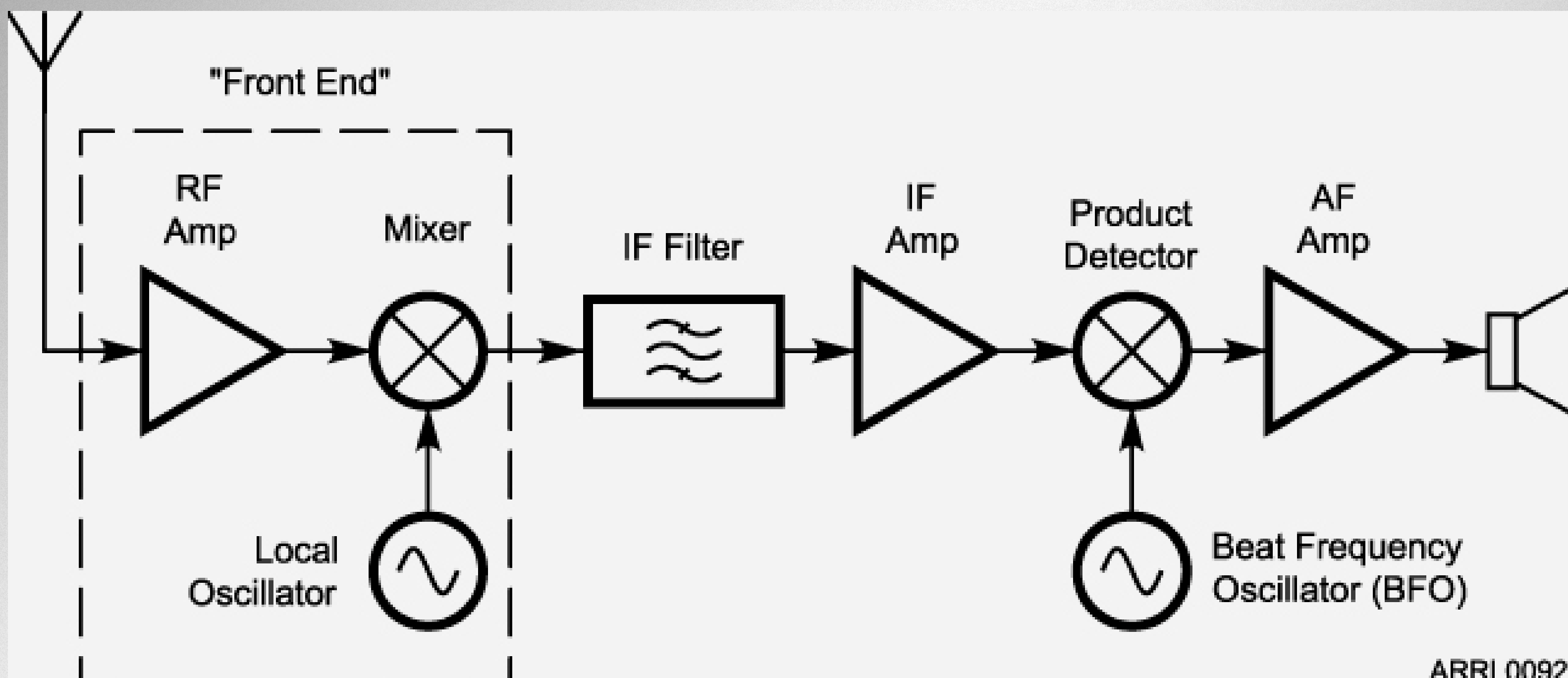
Superheterodyne Receivers

- Received signals are incredibly weak – on the order of nano or picowatts



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Superhet Receiver

- Received signals are first boosted by the RF amplifier, then applied to the RF input of a mixer
- The local oscillator (LO) is adjusted so that the desired signal creates a mixing product at the *intermediate frequency* (IF)
- A detector or demodulator stage follows the IF to recover the modulating information

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Simplest Superhet

- The simplest possible superhet consists of a mixer connected to the antenna, an HF oscillator to act as an LO, and a detector that operates directly on the resulting IF signal
- Once amplified to a more usable level, SSB and CW signals are demodulated by a *product detector*
    - A type of mixer that combines the IF signal with the output of a *beat frequency oscillator* (BFO) to produce an audio frequency mixing product

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Superhet Receiver

- The receiver's *front end* is made up of the RF amplifier (if any) and the first mixer
  - A preamplifier is used for weak signals
  - A preselector is an RF filter to remove strong *out of band* signals
- In an FM receiver the linear IF amplifier is replaced by a *limiter*.
- A *discriminator* or a *quadrature detector* replaces the product detector

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Doing the Math

- Example: If the IF is 455 kHz and the LO frequency is 13.800 MHz, signals at both 14.255 and 13.345 MHz will create a mixing product at 455 kHz
- Assuming the receiver is supposed to receive the 14.255 MHz signal, the undesired signal at 13.345 MHz is called an *image*
- Filters in the RF Front End remove signals at image frequencies to eliminate this source of interfering signals.

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Superhet Receiver

- Superhet receivers may have one, two, or three IF stages, resulting in a single-, double-, or triple-conversion receiver
- Filters are applied at each IF to remove unwanted signals and noise
- Filters improve signal quality with the lowest unwanted noise and interference, maximizing the *signal-to-noise ratio* (*SNR*)

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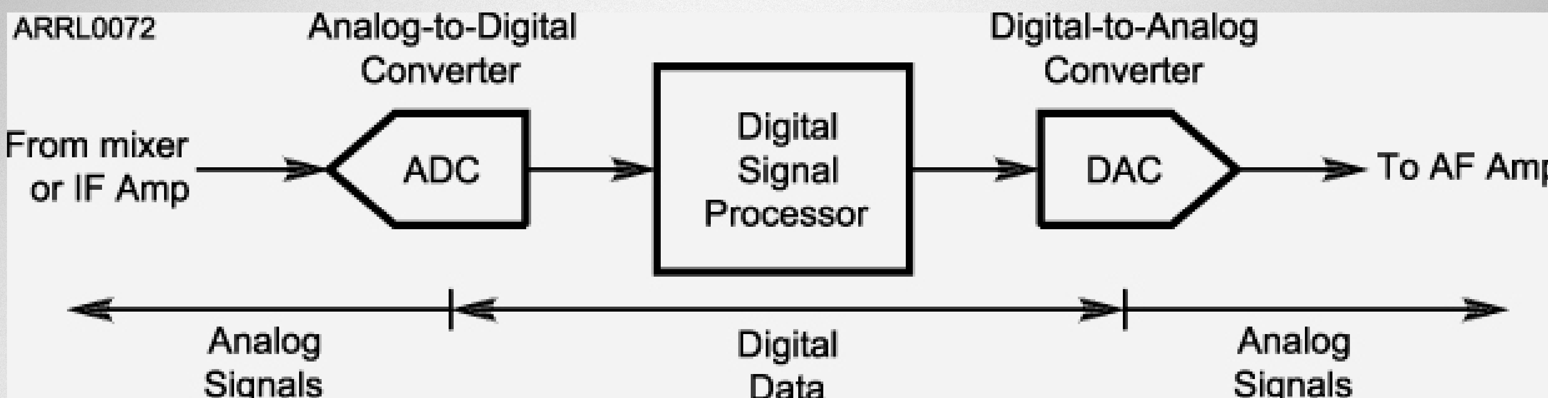
Digital Signal Processing

- The general term for converting signals from analog to digital form, operating on them with a microprocessor, and converting them back to analog is digital signal processing (DSP)



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SDR

- Some transceivers have so much of their functions implemented by DSP that the entire structure can be changed by running different software
  - These radios are referred to as SDR, for software-defined radios
  - SDR is rapidly becoming the dominant technology in high-performance transceivers

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Common DSP Functions

- *Signal filtering* – offers selectable preprogrammed filters and adjustable filter bandwidth and shape, such as *notch* filters
- *Noise reduction* – DSP can distinguish and remove some kinds of noise, leaving only the desired speech or CW for the operator to copy
- *Audio frequency equalization* – Adjustable receive or transmit audio frequency response to suit preferences

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Common DSP Functions

- *Notch filtering* – Interfering signals in the receiver's passband, particularly carriers from broadcast stations, can be sensed and removed by DSP
- An *automatic notch filter* can track interfering signals as they change frequency and eliminate more than one at a time

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RF Gain Control

- Set the RF gain control to maximum for the highest receiver sensitivity
  - Lower values of RF gain reduces background noise and helps prevent receiver overload
  - Maximum sensitivity may not be the best
- The *automatic gain control* (AGC) circuits vary the gain of the RF and IF amplifiers so that the output volume of a signal stays relatively constant for both weak and strong signals

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S Meter

- The AGC circuit adjusts receiver gain by changing a voltage that controls the RF and IF amplifier gain
  - The voltage is read by the *S meter* of the receiver, which is used to measure received signal strength
  - “S” stands for “signal”

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S Meter

- S meters are calibrated in *S units*, equal to 6 dB change per S unit
- S9 is at the midpoint of the S meter display – good signal
- Additional markings 20, 40, and 60 correspond to *dB above S9*
- A reading of S9 + 20 dB, therefore corresponds to a signal 20 dB (100 times) stronger than an S9 signal

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Receiver Linearity

- If the received signal is distorted, spurious signals will appear just as if a transmitting station were emitting them
- The most common form of receiver nonlinearity is caused by *front-end overload*
- The *attenuator* and RF gain controls can reduce received noise and distortion caused by strong signals

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Mobile Installations

- Mobile 100 W HF rigs require 20 A or more current at 11.5 or 12 V minimum
- Power connection is direct to the battery using heavy gauge wire with a fuse in both the positive and negative leads
- Do not use a cigarette lighter socket
  - Wiring not rated for 20 A
  - Socket may be damaged

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Mobile Installations

- Do not assume that the vehicle's metal chassis is a suitable dc ground connection
  - Vehicles made from separate subsections insulated by paint or plastic
  - Body parts may be plastic
- Connect the radio power ground either directly to the battery or to the battery ground strap where it attaches to the engine block or vehicle chassis

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Antenna Connections

- The most significant limitation of mobile HF operating is the antenna system
  - Usually smaller in terms of a wavelength than for a home station
  - Can be full-size on 10 and 12 meters
  - 40, 60, 80/75, 160 meters are particularly challenging because of electrically short antennas

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Mobile HF Antennas

- The entire vehicle is part of the antenna system
- Use the most efficient antenna you can
- Make sure RF ground connections to the vehicle are solid
- Mount the antenna where it is as clear as possible of metal surfaces

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Mobile Interference

- Ignition noise from arcs in the spark plugs
- Vehicle's onboard control computers
- Electric fuel pumps and windows
- Battery charging systems
- Manufacturer service bulletins can help deal with interference and noise problems

Grounding & Bonding

- AC safety ground wiring can act more like an antenna than a ground
- RF bonding is to keep all equipment at the same RF voltage
  - Minimizes “hot spots” (high RF voltage)
  - Reduces RF current flowing between pieces of equipment which can cause audio distortion or improper operation

Grounding & Bonding

- During digital operation:
  - Unwanted RF currents can cause audio distortion or erratic operation of computer interfaces
  - Activate the transmitter improperly (such as when using VOX)
  - Garble digital protocols causing data or connections to be lost

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Grounding & Bonding

- External ground or earth connections – make the connection as short as possible with heavy wire or strap
  - As ground connection length approaches an odd number of ¼-wavelengths:
    - Presents a high impedance
    - Allows RF voltages on equipment enclosures and connecting cables

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Ground & Bonding

- Ground loops are created when a continuous current path exists through enclosures and cables. Loops are nearly impossible to avoid.
- The loops act as single-turn inductors picking up voltages from magnetic fields. The result can be a “hum” or “buzz” in audio signals or an ac signal that interferes with control or data signals
- Minimize the effect of loops by minimizing loop area and bonding equipment together.

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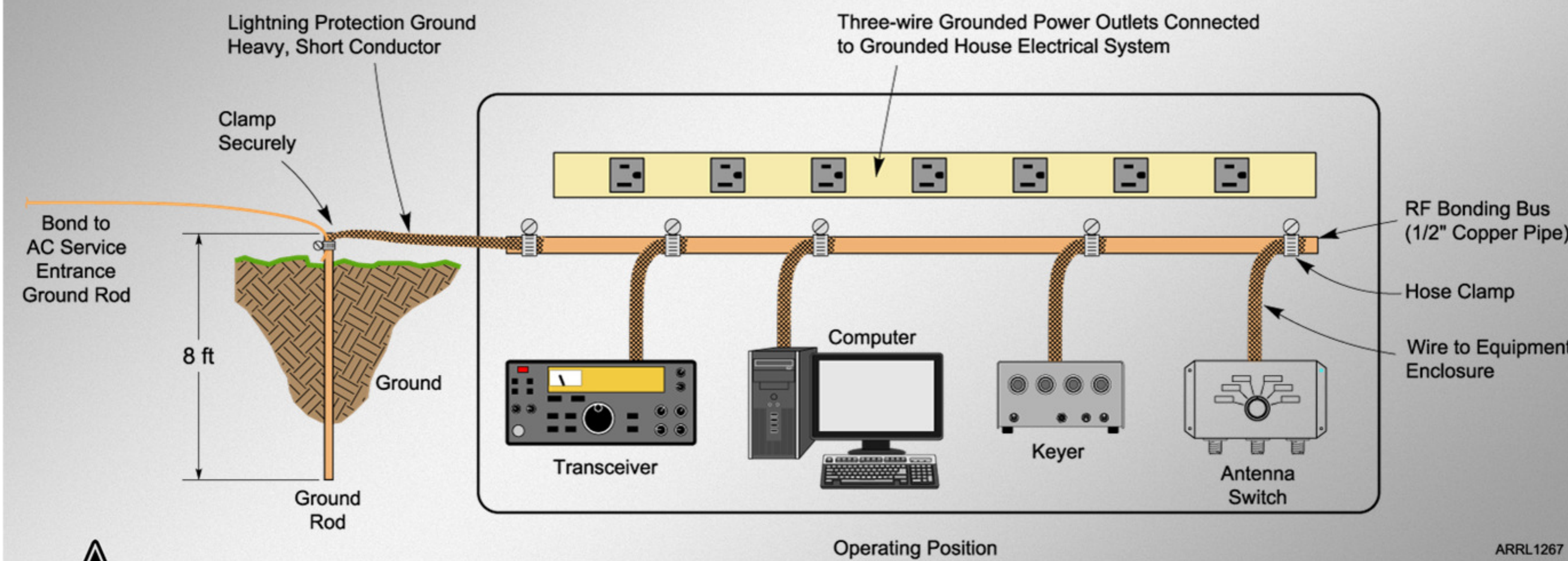
Ground & Bonding

- Good practice is to provide good bonding and make earth connections short
- All earth connections must be bonded per code



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RF Interference

- *Fundamental overload* – radio or TV receivers unable to reject a strong signal. This causes distortion or inability to receive the desired signal.
- Cure – prevent the offending signal from entering the equipment by using filters in the path of the signal.

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RF Interference

- *Common-mode and direct pickup* (or *direct detection)* – The signal is picked up as *common-mode current* on the outside of cable shields or on all conductors of an unshielded connection
  - Power cords, speaker leads, telephone cable
  - Conducted into the equipment where it causes erratic operation or audio noise
  - Cure – block current with RF chokes

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RF Interference

- *Harmonics* – spurious emissions from an amateur station may be received by radio or TV equipment
- Cure – use a low-pass filter at the transmitter to remove the spurious emissions
  - The filter's impedance must match the characteristic impedance of the feed line
  - RFI to cable TV may be due to bad connectors allowing external signals to get in (or out – also known as *cable leakage*)

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RF Interference

- *Rectification* – Poor contacts between conductors picking up RF signals can create a mixer and mixing products from the signals
  - Cure - repair the contact or connection
- *Arcing* – A spark or sustained arc creates radio crackling or buzz over a wide frequency range, typically from power-line hardware
  - May require the power company to make the necessary repairs

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RF Interference Suppression

- Filters remove strong signals from antenna feed lines
- RF chokes made from ferrite cores and beads block common-mode RF current
- AC line filters may help block RF on the hot or neutral connections for ac power.
  - Combine line filter and RF choke to block RF on all three ac conductors.

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RF Interference Suppression

- Bypass capacitors may be recommended in older texts. This is not recommended for modern, solid-state audio amplifier outputs – it may cause them to become unstable and damage the amplifier.
  - Use RF chokes first
  - Twisted-pair speaker cable also helps.
  - Only try bypass capacitor as a last resort on power and non-audio signal connections

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