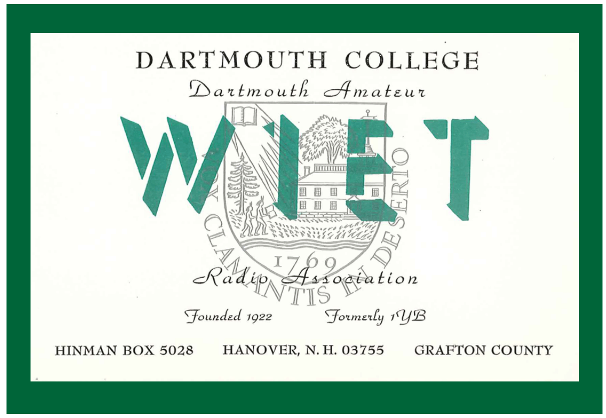

Radio 101

Eric Hansen, KB1VUN

How does radio work?

- Transmitter: Convert message to radio frequency (RF) voltage
- Antenna: Convert RF to propagating electromagnetic (EM) wave
- Propagation path
- Antenna: Convert EM wave to RF voltage
- Receiver: Extract message from RF

- **This session: communication modes, transmitters and receivers**

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Modulation

- **Baseband** signal = message you want to send (voice or data)
- **Carrier** signal = radio frequency sine wave
- **Modulation** impresses the message on the carrier by modifying the carrier wave's properties
  - **Amplitude** modulation (AM)
  - **Frequency** modulation (FM)
  - **Phase** modulation (PM)
  - FM and PM are sometimes lumped together and called **angle** modulation.

Figure from ARRL Handbook, 2009 Edition

Amplitude modulation

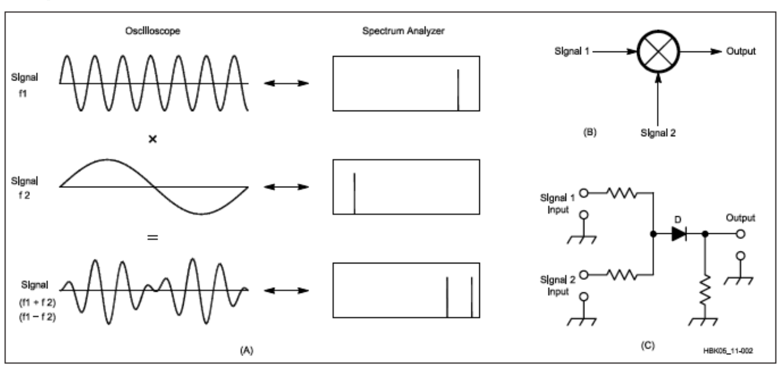


Fig 11.2 — *Multiplying* two sine waves of different frequencies produces a new output spectrum. Viewed with an oscilloscope, the result of multiplying two signals is a composite wave that seems to have little in common with its components. A spectrum-analyzer view of the same wave reveals why: The original signals disappear entirely and are replaced by two new signals — at the *sum* and *difference* of the original signals' frequencies. Drawing B diagrams a multiplier, known in radio work as a mixer. The *X* emphasizes the stage's mathematical operation. (The circled *X* is only one of several symbols you may see used to represent mixers in block diagrams, as Fig 11.3 explains.) Drawing C shows a very simple multiplier circuit. The diode, D, does the mixing. Because this circuit does other mathematical functions and adds them to the sum and difference products, its output is more complex than f1 + f2 and f1 − f2, but these can be extracted from the output by filtering.

Figure from ARRL Handbook, 2009 Edition

AM radio

- True AM is $(1 + m\,x(t)) \cos 2\pi f_c t$ — large pure carrier component
- *Advantage:* easy to generate and demodulate
- *Disadvantage:* wasteful of power (no information in the carrier)

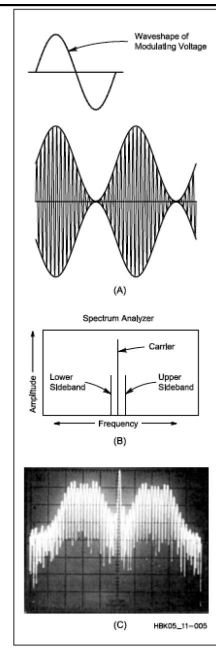
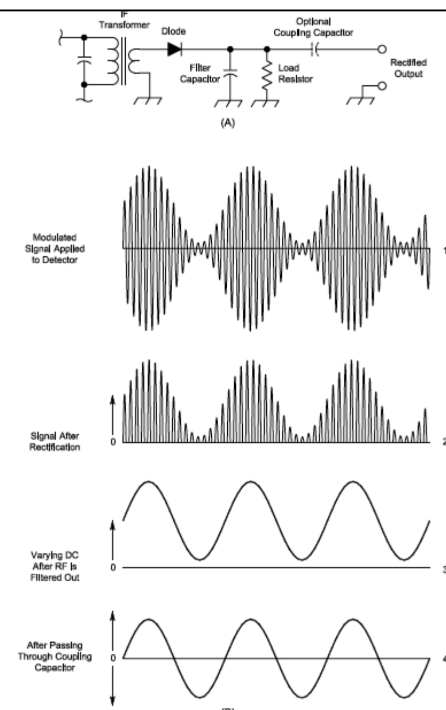


Fig 11.5 — Graphed in terms of amplitude versus time (A), the *envelope* of a properly modulated AM signal exactly mirrors the shape of its modulating waveform, which is a sine wave in this example. This AM signal is

Figure from ARRL Handbook, 2009 Edition, p. 11.8

AM demodulation

- An AM signal can be demodulated with a **half-wave rectifier** circuit (**envelope detector**, "crystal set").



Suppressed carrier

- Double sideband, suppressed carrier (DSB)

$$x(t) \cos 2\pi f_c t$$

Gets rid of the wasted carrier power, but more complex to demodulate (simple rectifier doesn't work anymore)

- Basic *de*modulator is another mixer (also called a **product detector**). Local (receiver) oscillator matches the carrier frequency (and, ideally, phase):

$$[x(t) \cos 2\pi f_c t\ ] \cos 2\pi f_c t = ½\, x(t)\ [1 + \cos 4\pi f_c t\ ]$$

- Remove second harmonic term with a lowpass filter, message remains

Figures from ARRL Handbook, 2009 Edition

Morse telegraphy (CW)

- The keying circuit merely interrupts the carrier (amplitude-shift keying, ASK)

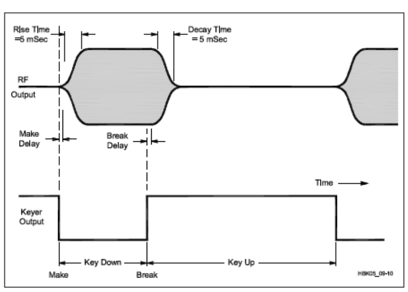


Fig 9.8—Optimum CW keying waveforms. The on-off transitions of the RF envelope should be smooth, ideally following a sine-wave curve. See text.

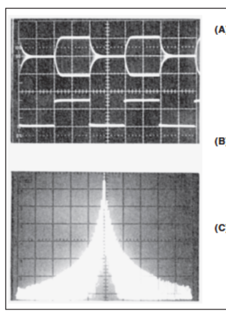


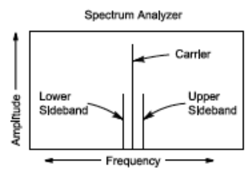
Fig 11.8 — Telegraphy by on-off-keying a carrier is also a form of AM, called *CW* (short for *continuous wave*) for reasons of tradition. *Waveshaping* in a CW transmitter often causes a CW signal's RF envelope (the amplitude-versus-time display at A) to contain less harmonic energy than the faster transitions of its keying waveform (B) suggest should be the case. C, an amplitude-versus-frequency display, shows that even a properly shaped CW signal has many sideband components.

- Demodulate with a local oscillator frequency offset from carrier to produce an audible tone (**beat frequency**).

Figure from ARRL Handbook, 2009 Edition, Fig. 11.5

Single sideband

- There is redundant information in a DSB signal: upper and lower sidebands have identical content.



- Single sideband (SSB) removes upper or lower sideband (as well as the carrier). Reduces power, bandwidth.

Single sideband generation: filter method

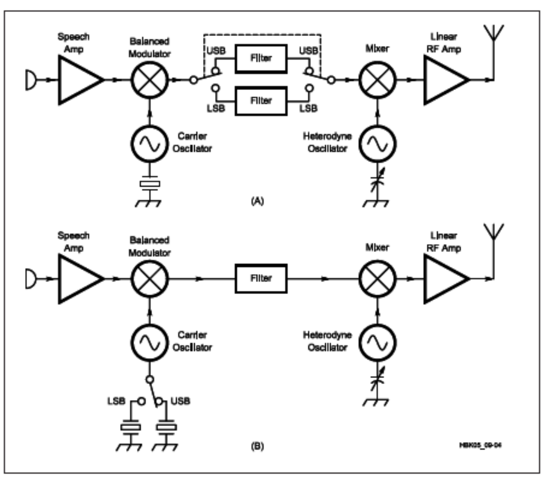


Fig 9.34—Block diagrams of filter-method SSB generators. They differ in the manner that the upper and lower sideband are selected.

Figure from ARRL Handbook, 2009 Edition

Single sideband generation: phase shift method

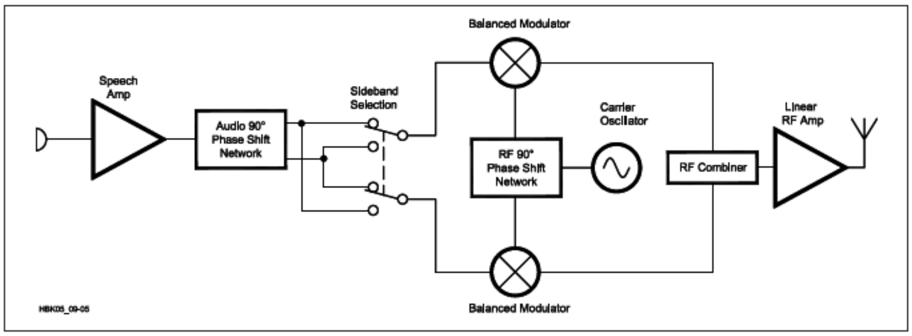


Fig 9.35—Block diagram of a phasing SSB generator.

Figure from ARRL Handbook, 2009 Edition

Single sideband

- SSB is the dominant mode for voice communication on HF bands and for DX on VHF bands.
- Sideband conventions:
  - 160 meters, 80 meters, 40 meters: LSB
  - 30 meters and above: USB
  - 60 meters (many special rules): USB
- Typical SSB bandwidth is 2.4 kHz. Be careful not to overdrive the transmitter, which generates spurious harmonics (**flat-topping**, **splatter**).
  - Use speech processors with discretion
  - Watch transmitter's "automatic level control" (ALC)

Figure from ARRL Handbook, 2009 Edition

Receiver block diagram

- "Superheterodyne" design downconverts the signal in stages, for better selectivity.

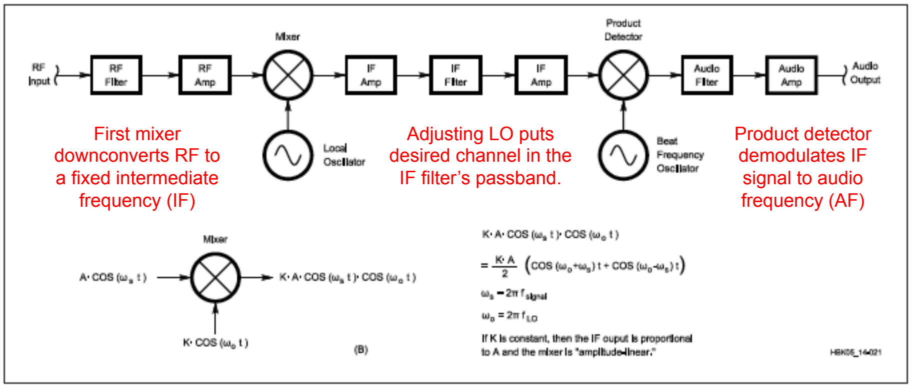


Fig 14.21—(A) Basic block diagram of a superhet receiver. (B) Showing how the input signal and a constant LO input produce a linear mixing action.

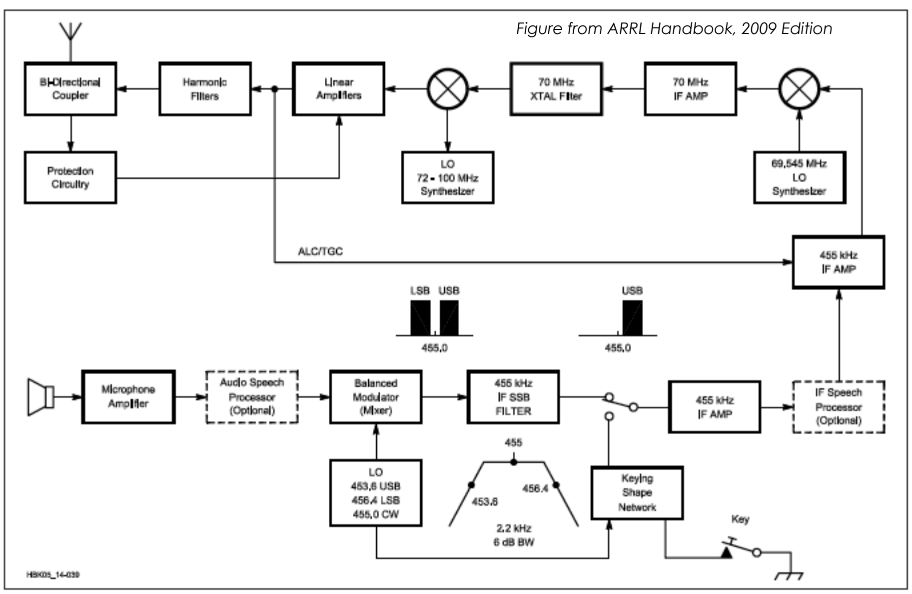


Fig 14.39—Block diagram of an up conversion SSB/CW transmitter. The various functions are discussed in the text.

Transmitter block diagram

Frequency modulation (FM)

- Angle modulation: $\cos\theta(t) = \cos(2\pi f_c t + \varphi(t))$
- $d\theta/dt = 2\pi f_c + d\varphi/dt$ is the **instantaneous frequency**, $d\varphi/dt$ is the **deviation**
- PM: $\varphi(t) = m\,x(t)$
- FM: $d\varphi/dt = m\,x(t)$
- FM has better noise immunity than AM as long as signal is sufficiently strong (threshold effect).

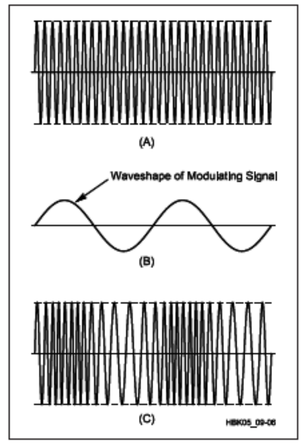


Fig 9.6—Graphical representation of frequency modulation. In the unmodulated carrier (A) each RF cycle occupies the same amount of time. When the modulating signal (B) is applied, the radio frequency is increased and decreased according to the amplitude and polarity of the modulating signal (C).

Figure from ARRL Handbook, 2009 Edition

FM generation

- Oscillator = amplifier with positive feedback through a tuned (resonant LC) circuit.
- **Reactance modulator:** baseband signal changes the capacitance (varactor diode) in the tuned circuit = voltage-controlled oscillator
- Other methods (phase-locked loop, PLL)
- Generate FM at a low carrier frequency, then up convert to the final carrier frequency (**frequency multiplier**).

Figure from ARRL Handbook, 2009 Edition

FM bandwidth

- FM is highly nonlinear, generates a lot of harmonics, wider bandwidth
- "Narrow band FM" is just carrier + 2 sidebands (looks like AM, but not the same)
- Rule of thumb for NBFM: $\mathrm{BW} = 2 \times (D+M)$, where D = frequency deviation, M = maximum modulating audio frequency.
- A frequency multiplier increases both the carrier and the deviation by the same factor.

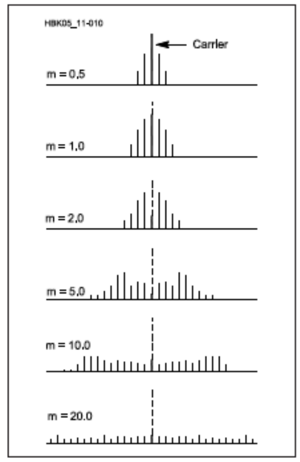


Fig 11.10 — Angle-modulation produces a carrier and an infinite number of upper and lower sidebands spaced from the average ("resting," unmodulated) carrier frequency by integer multiples of the modulating frequency. (This drawing is a simplification because it only shows relatively strong, close-in sideband pairs; space constraints prevent us from extending it to infinity.) The relative amplitudes of the sideband pairs and carrier vary with modulation index, *m*.

FM demodulation

- **Limiter**: Restores constant amplitude of the received FM signal.
- **Discriminator**: Convert frequency to amplitude (a special kind of highpass filter).

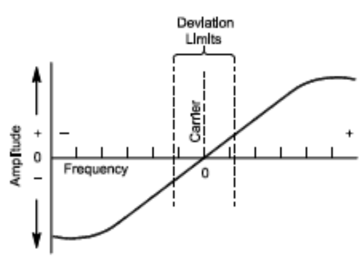


Figure from ARRL Handbook, 2009 Edition, Fig. 11.15

Bandwidth comparisons

- CW: 100-300 Hz (150 Hz typical) — narrowest, best performance in crowded, weak signal conditions.
- SSB voice: 2-3 kHz (2.4 kHz typical) — compare with amateur AM (6 kHz) and broadcast AM (10 kHz)
- FM voice: 5-15 kHz — compare with broadcast FM (150 kHz)

- Because of sidebands, your operating frequency is not the "dial frequency" of your radio. Be careful near band edges, and don't overdrive your transmitter! Your entire transmitted signal must stay within the allowed band.