- • - • - - • - - •• • • • • - • - - • • • - • • • • • - •

HF Receivers, Part 2

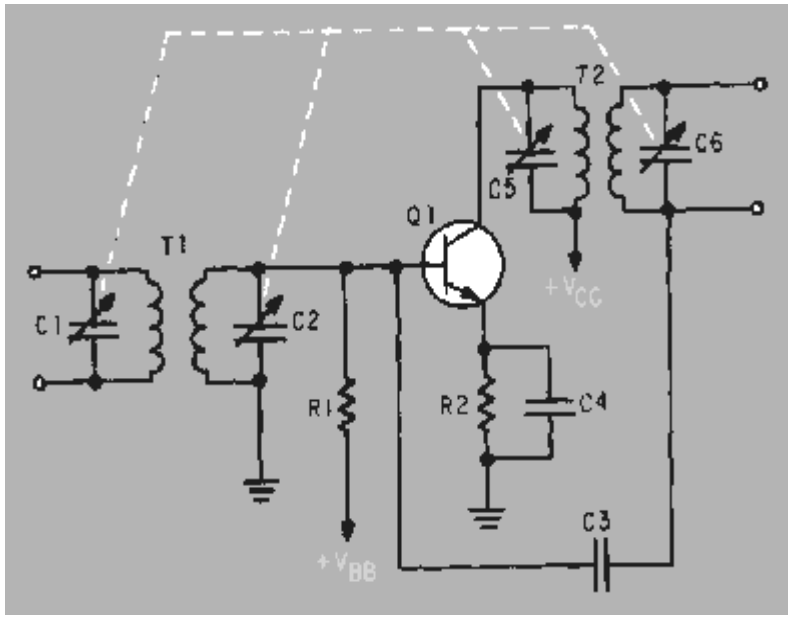
Superhet building blocks: AM, SSB/CW, FM receivers

Adam Farson
VA7OJ

View an excellent tutorial on receivers

The RF Amplifier
(Preamp)

- - - • - - - • - - • • • • - • - - - • • - - • • • • - •



- Typical RF amplifier has double-tuned RF circuits T1, T2 for image rejection and protection from overload by strong out-of-band signals.
- RF amplifier transistor Q1 has low noise figure & high gain for good sensitivity.
- Tuning capacitors C1, C2, C5, C6 ganged to local oscillator.

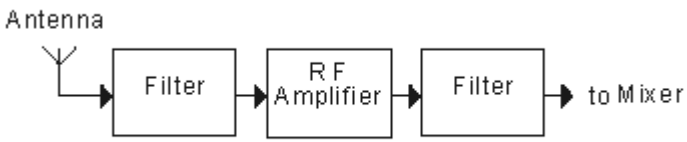
RF Amplifier Criteria

-•-• -•-• -•• • •••- • -••-•• -• ••• •-•

- **Trade-off:** Weak-signal vs. strong-signal performance.
- HF band noise usually 10 ~ 12 dB above receiver noise floor. Thus, narrower input filter with higher insertion loss will not degrade usable sensitivity.
- RF amplifier gain > 10 dB to overcome mixer noise figure and insertion loss of interstage circuits. Gain usually < 16 dB.
- **More trade-offs:** 1. Gain vs. linearity: excessive gain can degrade linearity, causing:
  - **intermodulation** (in-band products from strong out-of-band signals),
  - **cross-modulation** (modulation of desired by undesired signal)
- 2. Gain vs. stability: excessive gain can lead to self-oscillation.
- **Dynamic range:** RF amplifier should be designed for highest practical 1 dB compression point. AGC can be applied to RF amplifier.

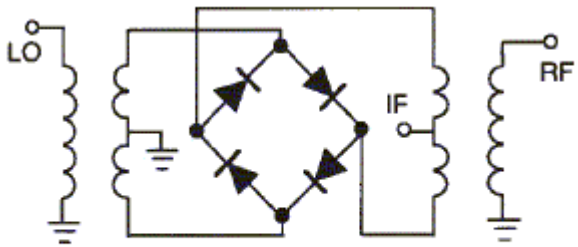
Bandpass RF Amplifier

- • - • - - • - - - • • • - • - - • • • - - • • • • - •



- **Modern multi-band HF receiver** has RF amplifier with switched, fixed-tuned bandpass filters (BPF) at input, instead of ganged tuned circuits.
- Output LPF (low-pass filter) cuts off at highest receive frequency.
- Filters switched by mechanical switch, relays or diodes.
- Switching diodes can generate noise and intermodulation at high input levels; special large-signal diodes required.
- High-grade receivers use relay switching to select BPFs.
- For strong-signal reception, RF amplifier can be bypassed by a relay.

Mixer Criteria: a simple mixer



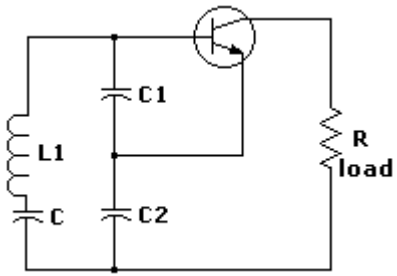
Generic diode DBM.

•Diodes are nonlinear devices

- **Diode doubly-balanced mixer (DBM)**
  - Maximum IF rejection at RF input port.
  - Maximum isolation between LO and RF ports (reduces “birdies”, spurious responses due to LO products in RF freq. range).
  - Low noise figure yields good sensitivity, even without RF amplifier.
  - Requires fairly high LO drive; increased risk of LO spurious (“spurs”).
  - Conversion loss; active devices (e.g. FET’s) instead of diodes yield conversion gain.

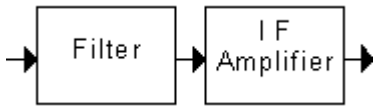
The Local Oscillator

- • - • - - • - - • • • • - • - - • • • - • • • - • - •



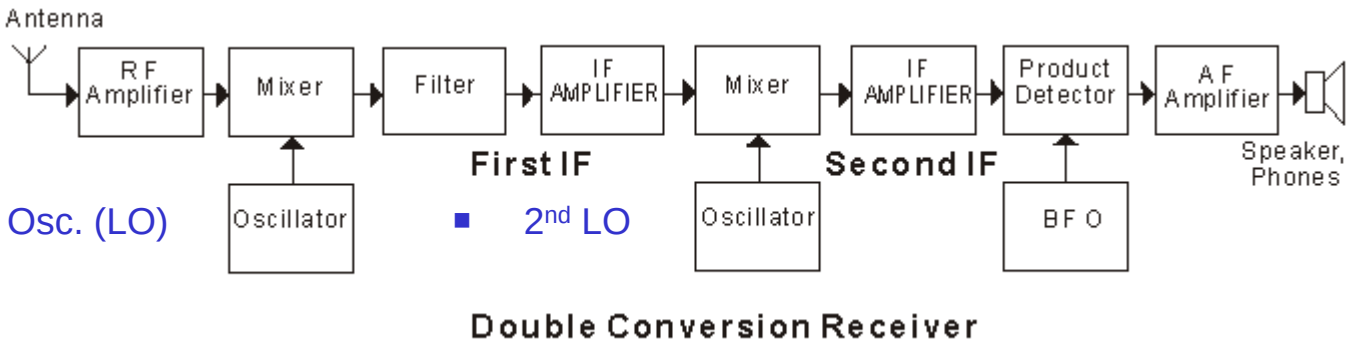
- **Local oscillator** can be free-running or crystal-controlled. (Example above is Clapp oscillator).
- Tuning capacitor **C** is **ganged** *(mechanically coupled)* to RF-stage tuning capacitors. Calibrated tuning dial is on common shaft.
- **Local-oscillator criteria:**
  - **Frequency stability** (to minimize drift of received signal). A buffer stage is often placed between oscillator and mixer to prevent “pulling”.
  - **Spectral purity**, to minimize spurious responses (“birdies”) and sensitivity degradation caused by oscillator harmonics and noise sidebands, respectively.
  - **Adequate output** for optimum mixer performance.

IF Amplifier & Filters



- **Simple IF amplifier** in broadcast receiver has 2 stages with double-tuned input, interstage & output IF transformers. Typical BW = 6 kHz at -6 dB (OK for AM broadcast signals). Early tube-type superhet had 1-stage IF amplifier with input and output transformers.
- Classical **tuned** IF amplifiers are too broad to reject adjacent-channel interference in SSB reception. An **IF filter** is now placed between the mixer IF output and the IF-amplifier input.
- IF filter is a **passive network** utilizing crystals (or mechanical resonators & transducers). The principal **filter properties** are:
  - **Bandwidth** (specified at the -6dB and -60dB points on the response curve).
  - **Shape factor** (-60dB BW/-6dB BW). Better filter has lower shape factor, yielding better adjacent-channel rejection.
  - **Insertion loss** (signal loss across filter). The IF amplifier must make up this loss.

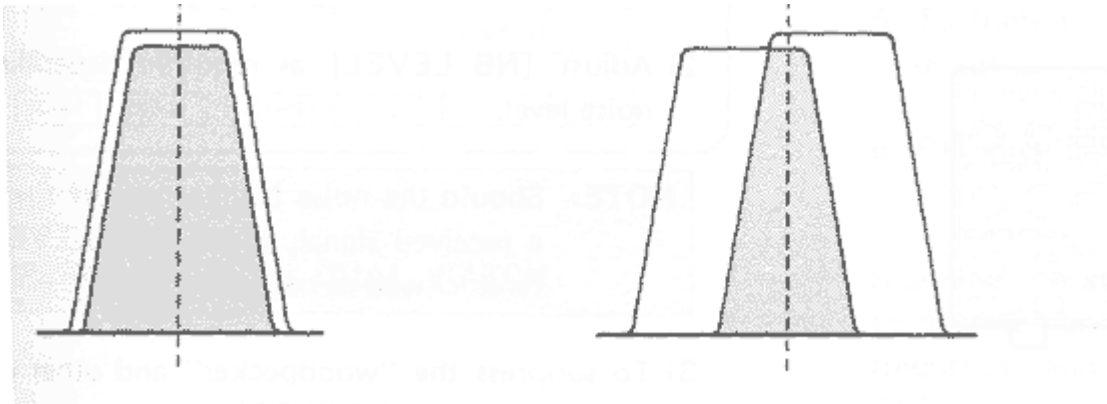
Dual-Conversion Superhet Receiver



- 1st Local Osc. (LO)
- 2nd LO

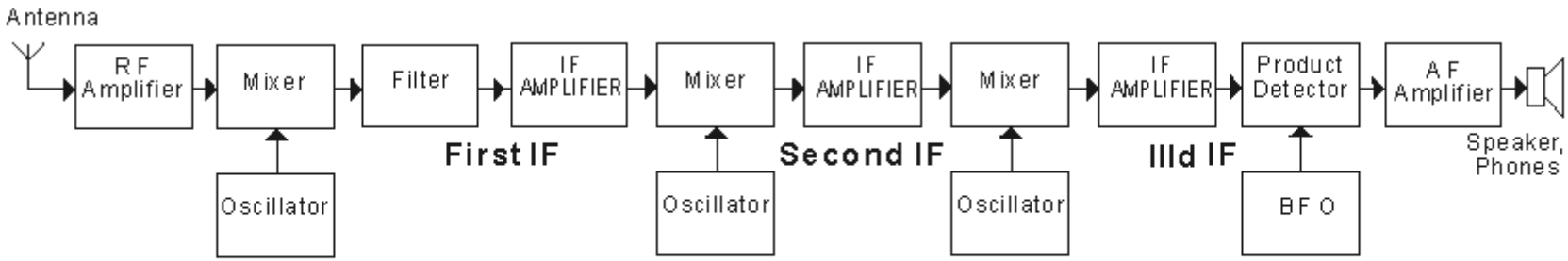
- **Dual-conversion superhet receiver** yields good points from both IF choices. A high frequency IF is selected for good image rejection, followed by a low-frequency IF for high selectivity and gain.
- Examples: 9 MHz 1st IF, 455 kHz 2nd IF.
- Another approach: Crystal-controlled 1st LO, 5 ~ 5.5 MHz bandpass 1st IF, 455 kHz 2nd IF. 2nd LO covers 5.455 ~ 5.955 MHz (Collins design).
- Dual-conversion more complex than single-conversion. LO frequencies chosen carefully to minimize spurious signals ("birdies").
- 1st & 2nd IF filters effectively cascaded for better selectivity.

Passband Tuning



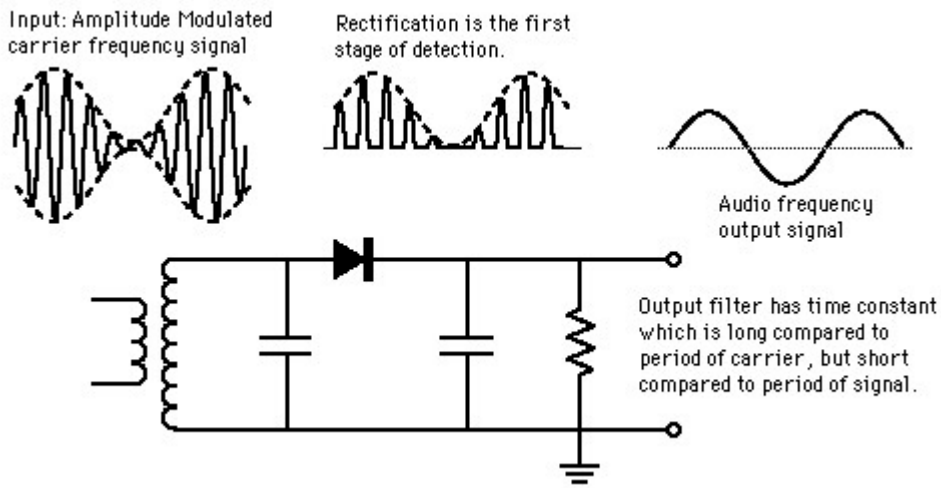
- **Passband Tuning** allows operator to adjust IF BW.
- **Neutral** (left): In previous slide, 1st LO, 2nd LO and BFO frequencies are set to overlap 1st & 2nd IF filter passbands, and place carrier 20 dB down filter flank.
- **Offset** (right): 2nd LO is offset to shift 2nd IF passband relative to 1st IF. BFO is offset by same amount in opposite direction. This narrows effective BW (shaded area), whilst maintaining carrier set point and receive freq. calibration.
- **Example:** Shifting 2nd LO -2 kHz & BFO +2 kHz reduces IF BW from 3 to 1kHz.
- Offsetting PBT degrades shape factor (-60/-6dB BW ratio) slightly.

Triple-Conversion General-Coverage Superhet Receiver



- **Typical frequency coverage:** 0.5 ~ 30 MHz. 1st IF > 30 MHz (typ. 45~ 70 MHz).
- Each RF amplifier BPF covers ½ octave, e.g. 6 ~ 9, 9 ~ 13.5 MHz. Approx. 12 BPFs required for complete range.
- **1st LO in VHF range.** For 70 MHz 1st IF, 1st LO covers 70.5 ~ 100.5 MHz.
- 1st IF filter is **roofing filter:** BW sufficient to pass widest mode (15 kHz for FM).
- Roofing filter protects IF chain against strong out-of-band signals.
- **Typically:** 2nd IF is 9 MHz, 3rd IF is 455 kHz.

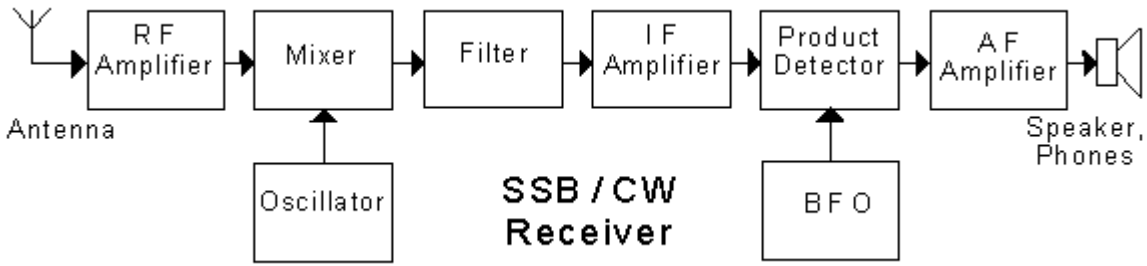
AM Demodulation



- **Envelope Detector:** the simplest AM demodulator.
- Can be considered as a **rectifier** with an output low-pass filter whose cutoff frequency is just above the highest modulating frequency.
- By averaging the rectified envelope with a long time constant, it is possible to derive **AGC** voltage from the envelope detector.

CW & SSB Demodulation

- - - . - - - . - - . . . . - . - - - . . - . . . . . - .

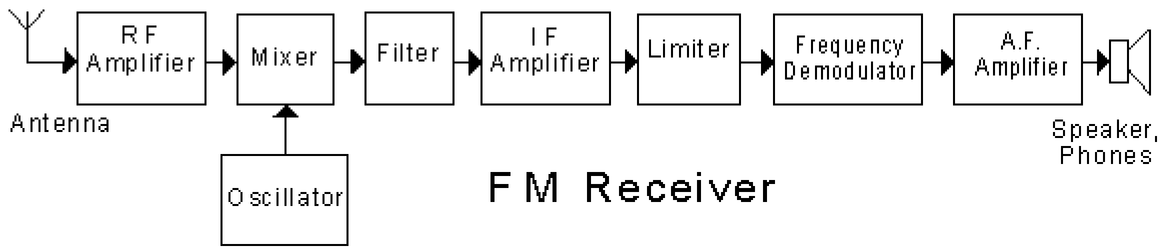


- **Product Detector: M**ixer which mixes IF with locally-generated carrier. Difference frequency (IF – carrier) is audio frequency. Suitable for SSB and CW reception.
- **Example:** 455 kHz IF. USB signal with suppressed *(virtual)* carrier at 455.000 kHz. Lowest and highest baseband frequencies are 455.300 and 458.000 kHz resp. Local carrier is 455.000 kHz. Recovered audio is 300 Hz ~ 3 kHz.
- **BFO** (Beat Frequency Oscillator, also termed Carrier Insertion Oscillator) is set to a frequency corresponding to -20dB point on filter skirt. This aids suppression of carrier and unwanted (opposite) sideband.
- To **switch** from USB to LSB, shift BFO by +3 kHz and local oscillator by -3 kHz to maintain tuning-dial accuracy.

IF Shift

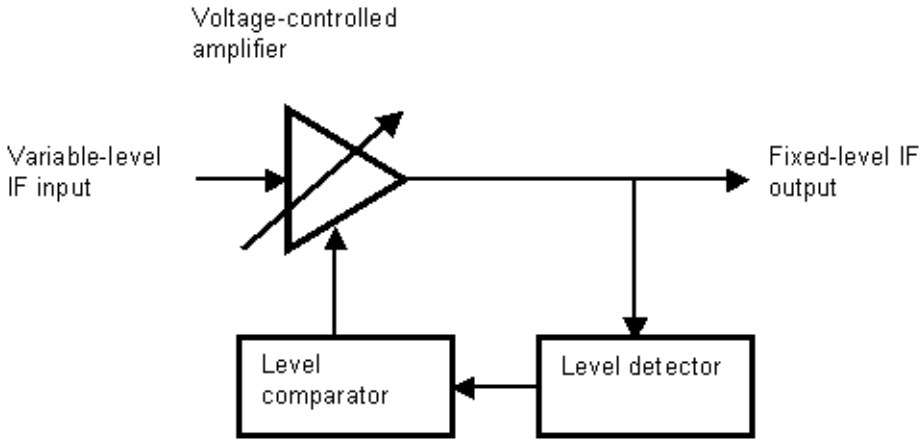
- **IF Shift** allows operator to shift IF passband, to eliminate QRM.
- **Neutral** (left): In previous slide, BFO freq. is set to place carrier 20 dB down filter flank. LO is set so that displayed freq. = virtual carrier freq.
- **Offset** (right): LO is offset to shift centre freq. relative to IF passband. BFO is offset by same amount in opposite direction. This shifts IF passband up, eliminating QRM below centre freq., whilst maintaining carrier set point and receive freq. calibration.

FM Demodulation



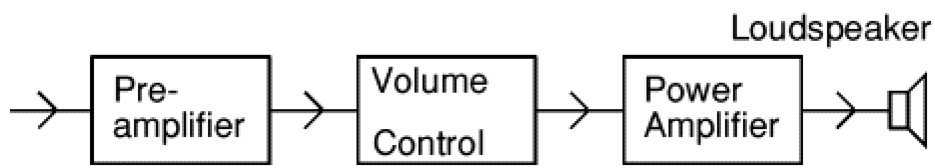
- **Frequency demodulator:** converts instantaneous frequency deviation of carrier into audio.
- Recovered audio voltage is proportional to deviation **(Df).**
- IF amplifier **(limiter)** preceding demodulator limits IF amplitude to suppress AM response. When input signal is sufficiently strong to saturate limiter, FM receiver rejects AM signals, static, noise etc. ***(full quieting)***
- FM receivers do not generally require AGC.

Automatic Gain Control (AGC) & S-meter



- Level detector may be part of demodulator, or separate circuit at IF output. Develops DC voltage proportional to average IF voltage.
- AGC voltage is fed back to voltage-controlled IF and/or RF amplifiers to adjust their gain. Higher AGC voltage = less gain.
- AGC subsystem is a **feedback** (servo) loop.
- AGC holds audio output level constant over wide range of RF signal strengths. This extends receiver ***dynamic range***, and ensures comfortable listening in the presence of fading.
- AGC circuit also drives S-meter (signal-strength meter).

Audio Amplification



- Demodulator output drives preamplifier.
- Preamplifier may incorporate adjustable audio filter.
- Power amplifier typically delivers 2 ~ 5W at 10% THD (total harmonic distortion).
- Power amplifier drives internal speaker, external speaker or headset.
- Internal speaker muted when external speaker or headset is plugged in.