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HF Transceiver 101

- what's inside my radio?

Adam Farson VA7OJ

What is a transceiver?

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- **A transceiver is a transmitter-receiver combination in which the transmit and receive functions share one or more common elements.**
- **One or more system components (subsystems) are used both for transmitting and for receiving.**
- **With careful design, this is achievable without compromising transmitter or receiver performance.**
- **Modern transceivers are based on superheterodyne *(superhet)* architecture.**

A brief history

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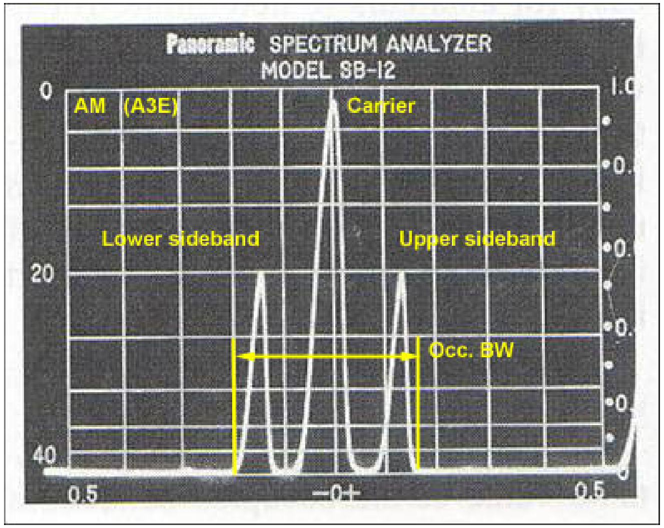
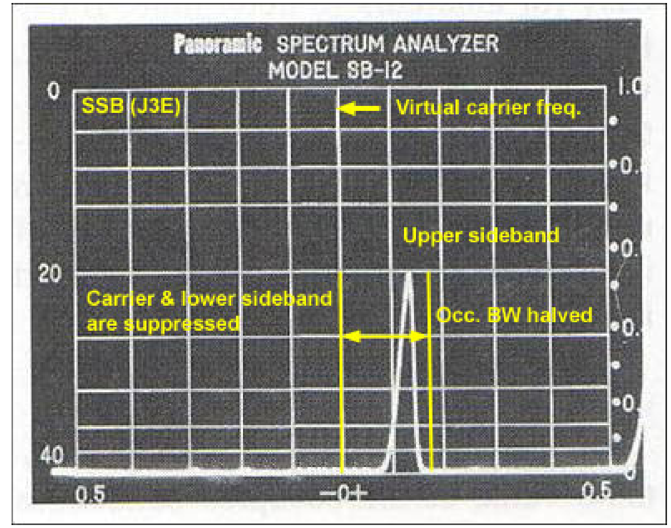
- **Prior to the advent of SSB in the mid-1950's, an amateur HF station generally used "separates":**
  - **A superhet receiver, usually single-conversion with 455 kHz IF.**
  - **An AM/CW transmitter consisting of a crystal oscillator or VFO, buffer/multipliers, driver, PA and modulator.**
- **The receiver and transmitter had no common subsystems other than the transmit/receive (T/R) relay and possibly an antenna tuner.**
- **Acceptance of the heterodyne SSB exciter with crystal or mechanical filters (a superhet in reverse) drove research into sharing RX and TX subsystems.**
- **Hence, the SSB transceiver was born (1957)**
  - **First commercial transceivers: Hallicrafters FPM-200, Collins KWM-1.**

AM vs. SSB:
"Kilowatts from Heaven"





100W (PEP) AM signal:

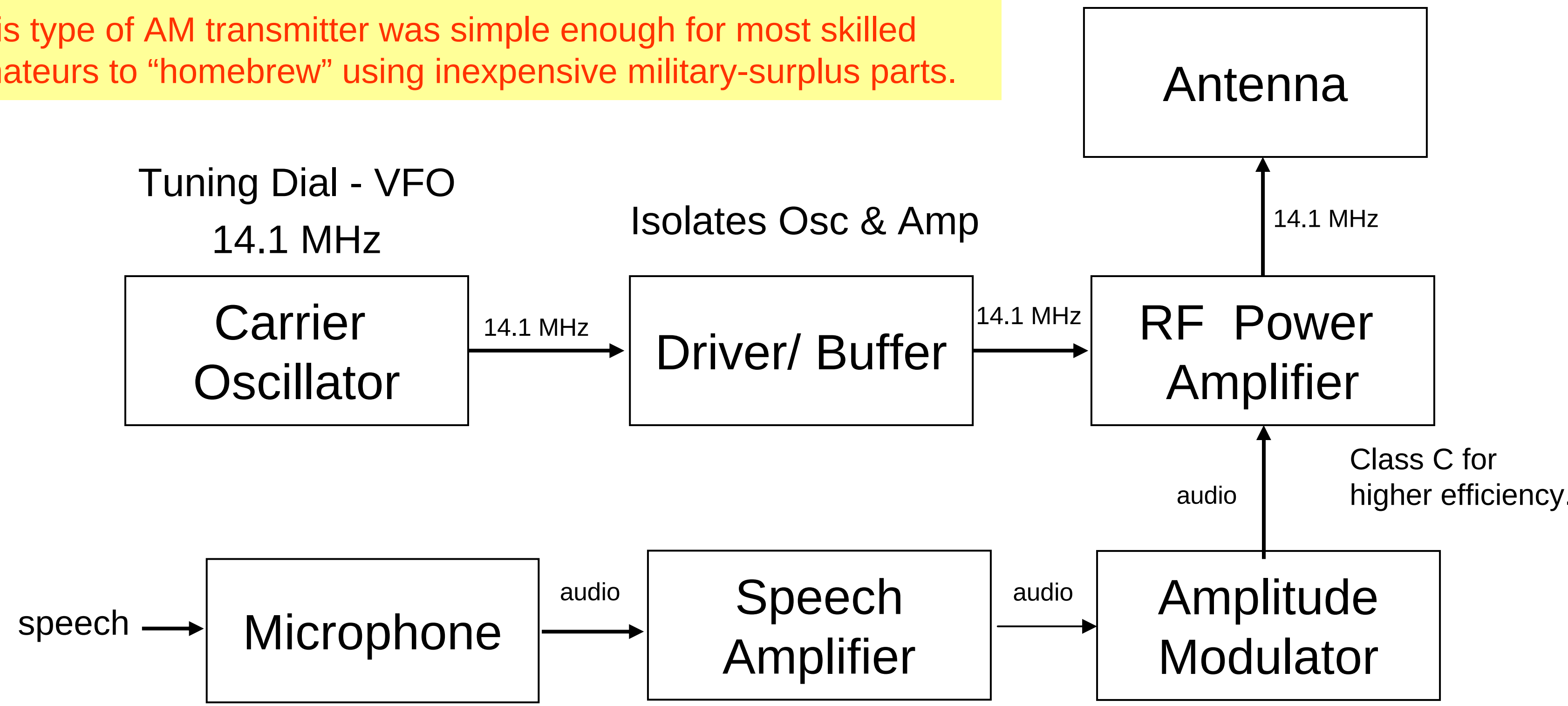
- 50W in carrier
- 25W in upper sideband
- 25W in lower sideband
- 6 kHz occupied bandwidth (typical)
- 25% of transmitter power carries unique intelligence

100W (PEP) SSB signal (USB):

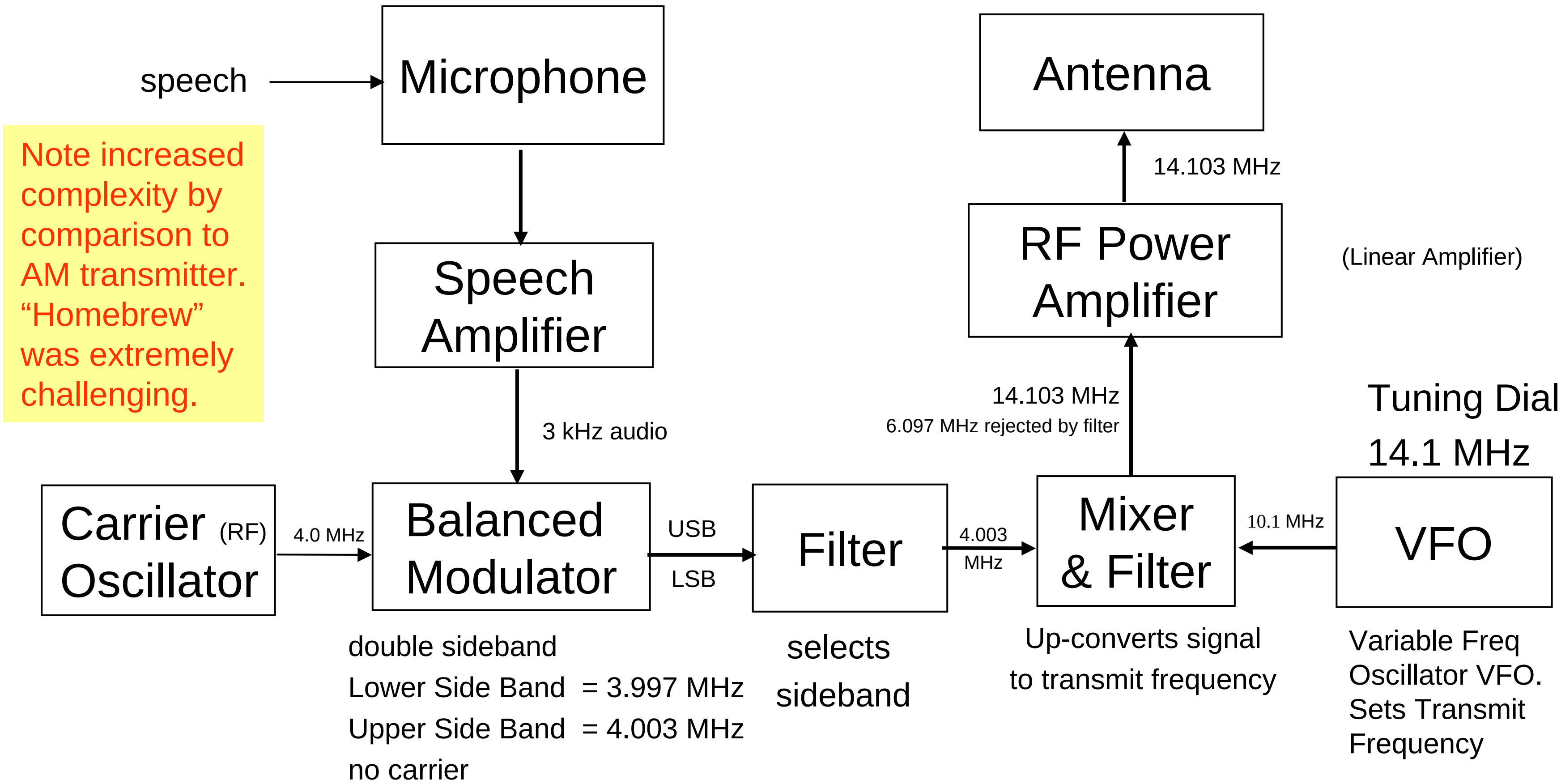
- **100W in upper sideband**
- Carrier & lower sideband suppressed
- 3 kHz occupied bandwidth (typical)
- 100% of transmitter output carries unique intelligence
- S/N improvement: 6 dB for 4X increase in sideband power + 3 dB for 50% less BW **= 9 dB total**

AM Transmitter
simplified block diagram

This type of AM transmitter was simple enough for most skilled amateurs to “homebrew” using inexpensive military-surplus parts.



SSB Transmitter
simplified block diagram



1960's "Separates"

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Hallicrafters SX-115 Receiver 1961 - 64

Hallicrafters HT-37 Transmitter 1960 – 64
Courtesy Rigpix

- **Early amateur SSB stations featured separate receivers and transmitters.**
- **The transmitter's antenna relay switched the antenna between RX and TX, and muted the receiver on transmit.**
- **Many transmitter-receiver pairs allowed one-knob "transceive" operation by tuning both the receiver and transmitter with the RX or TX VFO.**

The Collins KWM-1 (1957)

nsarc NORTH SHORE AMATEUR RADIO CLUB

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- **The Collins KWM-1 was one of the first true SSB/CW transceivers.**
- **It was introduced in 1957, and cost USD 820 at the time.**
- **The Collins PTO (permeability-tuned oscillator), developed during WW2, assured good frequency stability for SSB and CW.**
- **The KWM-1 covered the 20, 15 and 10m bands. It employed 22 tubes (2 x 6146 in PA). Its RF power output was approx. 90W.**

Simple Superhet Receiver: *frequency relationships*

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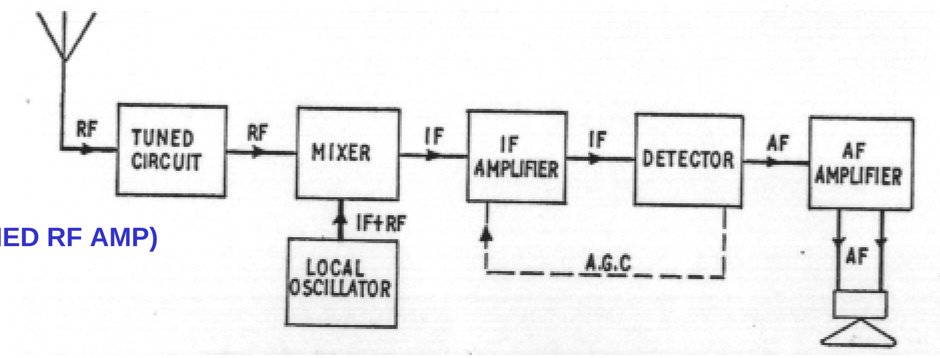

•(OR TUNED RF AMP)

- **Example:** RF = 1800 ~ 2000 kHz (tunable); IF = 455 kHz.
- Tracking (ganged) RF and LO tuning.
- Alternative: RF bandpass filter (BW = tuning range for specific band).
- Local Oscillator (LO) = RF + IF = 2255 ~ 2455 kHz. (high-side injection).
- Alternative: RF – IF = 1345 ~ 1545 kHz (low-side injection).
- Bandpass IF amplifier has sufficient BW for mode in use (e.g. AM: 6 kHz).
- AGC (automatic gain control) holds output constant over wide range of RF signal strengths.

The Superhet Receiver:
the problem of images

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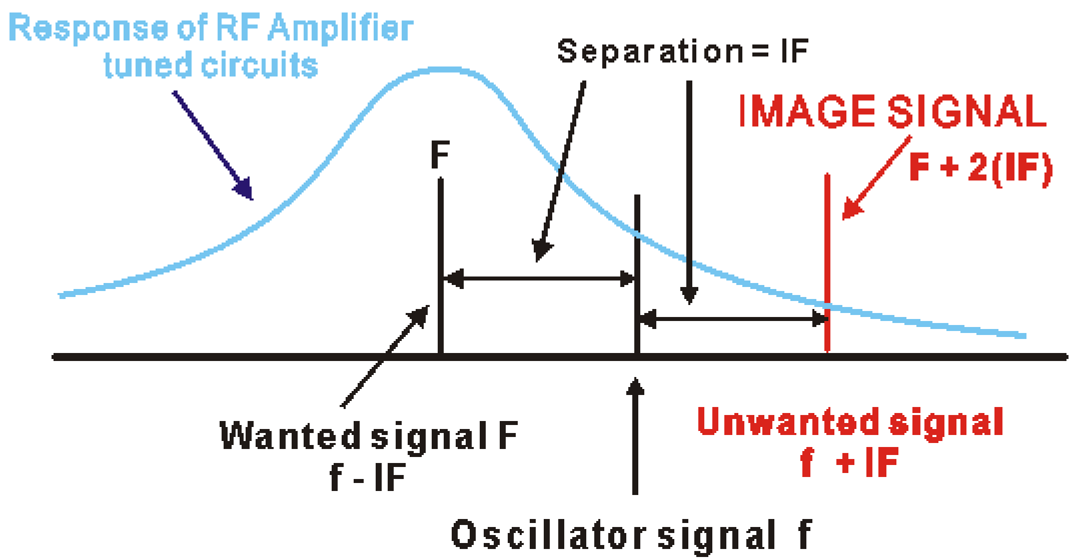
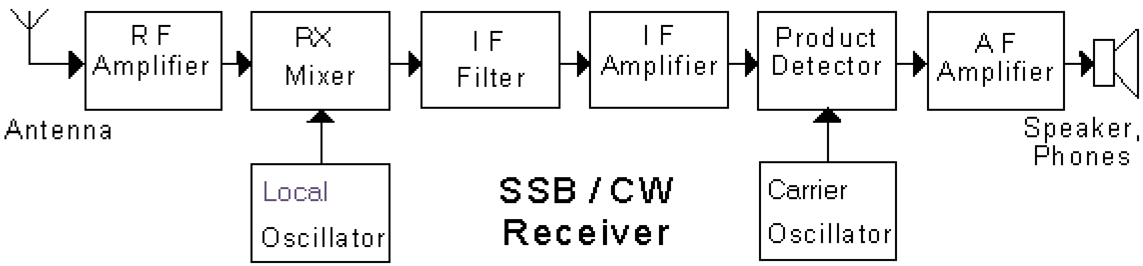
- Per Slide 9, f_1 = 2255 kHz (LO), f_2 = 1800 kHz (RF); (f_1 - f_2) = 455 kHz (IF).
- If f_1 = 2255 kHz (LO), f_2 = 2710 kHz (RF), ($f_2 – f_1$) = 455 kHz. Thus, 2710 kHz signal will pass through the IF amplifier and be demodulated. This undesired response is termed the **image,** and is offset from the desired response by ***twice the IF.***
- BW of RF amplifier with single-tuned input & output circuits is narrow enough to provide adequate image rejection at frequencies below 10 MHz. (Typical BW = 300 kHz at -3 dB).
- Above 10 MHz, cascaded RF amplifiers with 3 or more tuned circuits are required for acceptable image rejection. Higher IF also improves image rejection, but narrow IF BW is more difficult to obtain at higher freq.
- RF tuned circuits with narrower BW have higher **insertion loss.** This degrades sensitivity. Cascaded RF amplifiers offset this loss, but are more prone to **overload**.

The Superhet Receiver:

the problem of images

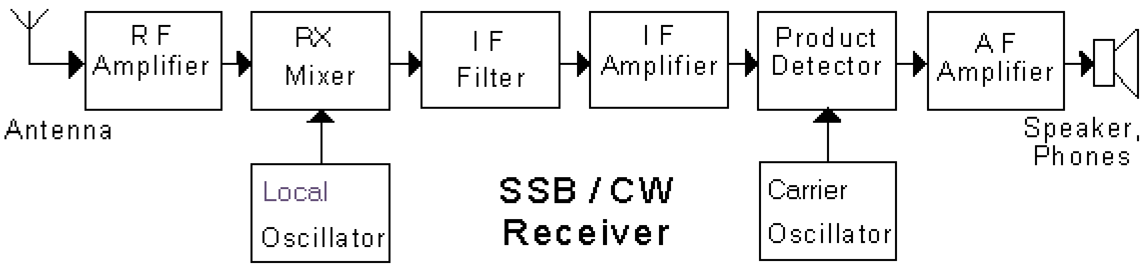


Basic SSB/CW Superhet Receiver (20m USB)



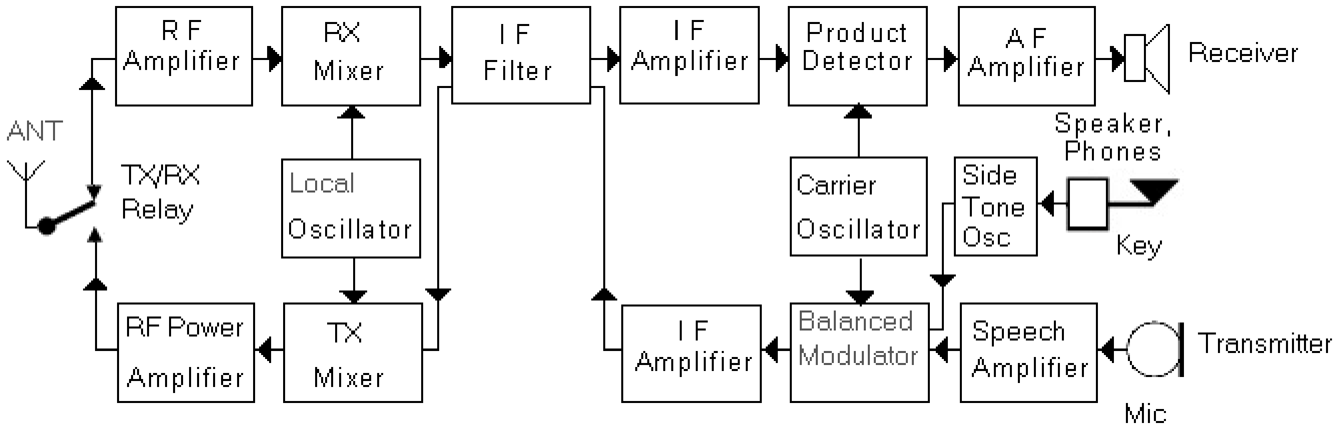
- Example 1: RF signal is 14100 kHz USB (suppressed carrier frequency).
- Actual USB signal typically occupies 14000.3 ~ 14002.4 kHz.
- IF = 9000 kHz. IF filter BW = 2.4 kHz. IF signal is 9000.3 ~ 9002.4 kHz.
- Local oscillator (LO) tuned to (14100 – 9000) = 5100 kHz.
- LO tunes 5000 – 5350 kHz to cover entire 20m band (14000 ~ 14350 kHz).
- Carrier oscillator set at 9000 kHz (at -20 dB point on filter skirt, for best suppression of opposite sideband and carrier).
- Product detector mixes 9000.3 ~ 9002.4 kHz IF with 9000 kHz carrier oscillator output to yield audio output, 300 Hz ~ 2.4 kHz.
- Image frequency is (9000 – 5100) = 3900 kHz. 20m bandpass filter at RF amplifier input suppresses image response.

Basic SSB/CW Superhet Receiver (80m LSB)



- **Example 2: RF signal is 3600 kHz LSB (suppressed carrier frequency).**
- **Actual LSB signal typically occupies 3597.6 ~ 3599.7 kHz.**
- **IF = 9000 kHz. IF filter BW = 2.4 kHz. IF signal is 8997.6 ~ 8999.7 kHz.**
- **Local oscillator (LO) tuned to (9000 ~ 3600) = 5400 kHz.**
- **LO tunes 5500 – 5000 kHz to cover entire 80m band (3500 ~ 4000 kHz).**
- **80m and 20m bands use same LO tuning range.**
- **Carrier oscillator set at 9000 kHz (at -20 dB point on filter skirt, for best suppression of opposite sideband and carrier).**
- **Product detector mixes 8997.6 ~ 8999.7 kHz IF with 9000 kHz carrier oscillator output to yield audio output, 300 Hz ~ 2.4 kHz.**

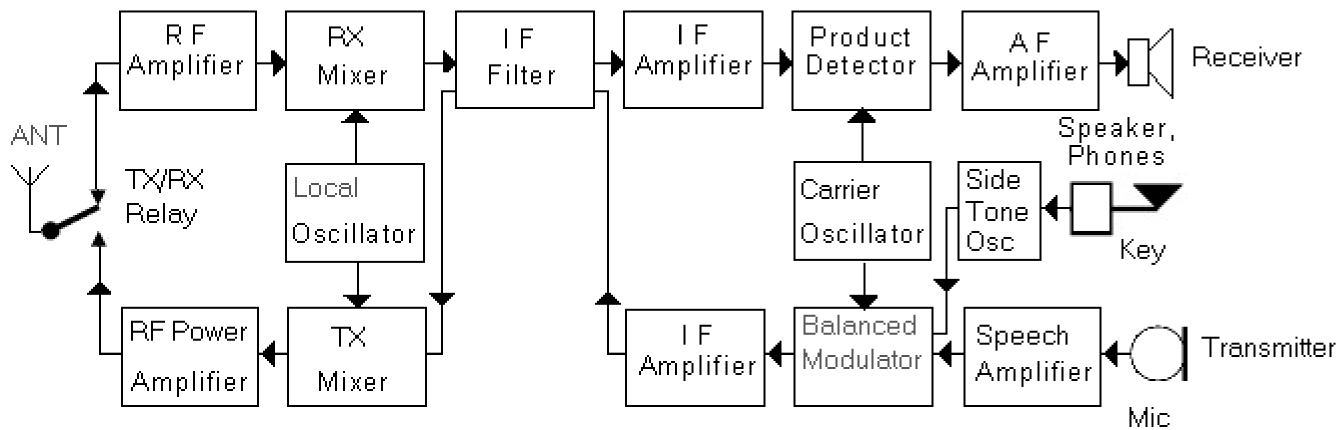
Now let's add the transmitter section!



SSB-CW Transceiver

- Carrier oscillator, IF filter and local oscillator are shared between receiver and transmitter.
- Carrier oscillator feeds 9000 kHz carrier to Balanced Modulator.
- Mic audio is amplified and mixed with carrier to yield USB 9000.3 ~ 9002.4 kHz and LSB (8997.6 ~ 8999.7 kHz). IF Filter passes USB and suppresses LSB.
- Local oscillator tuned to (14100 – 9000) = 5100 kHz.
- TX mixer mixes IF with local oscillator output to yield USB TX signal (14000.3 – 14002.4 kHz).
- RF power amplifier raises TX signal power to 100W (typical).
- TX/RX relay routes antenna to RX input or TX output as required.

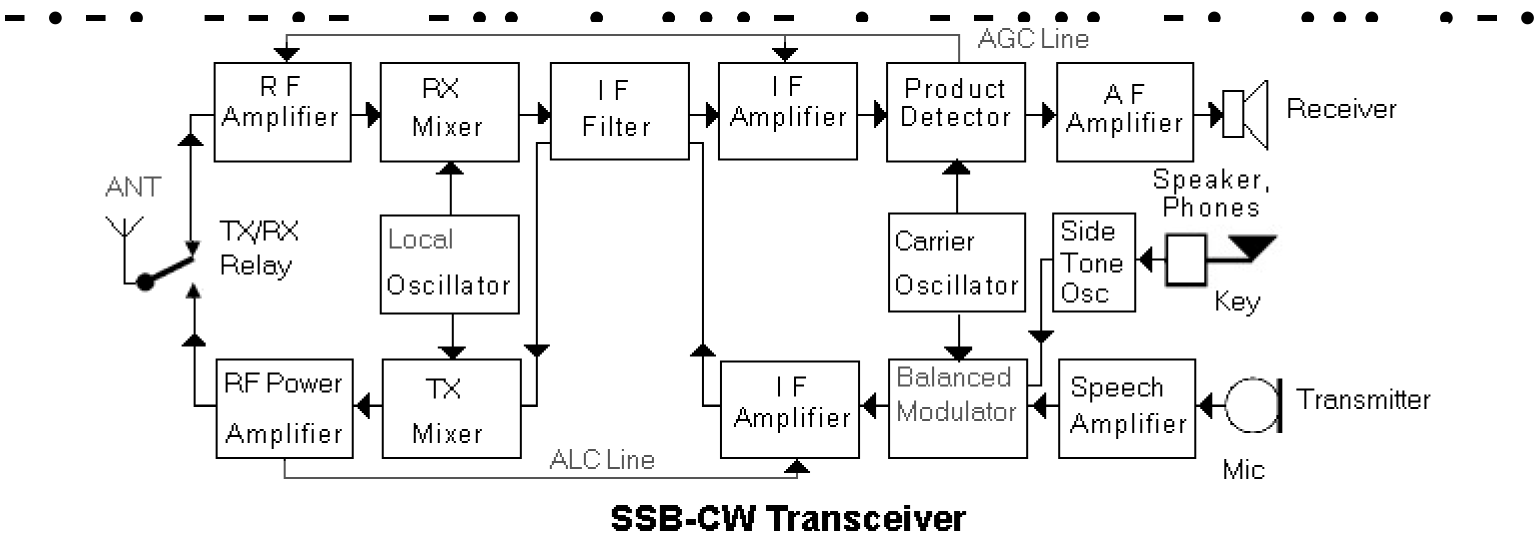
CW Operation



SSB-CW Transceiver

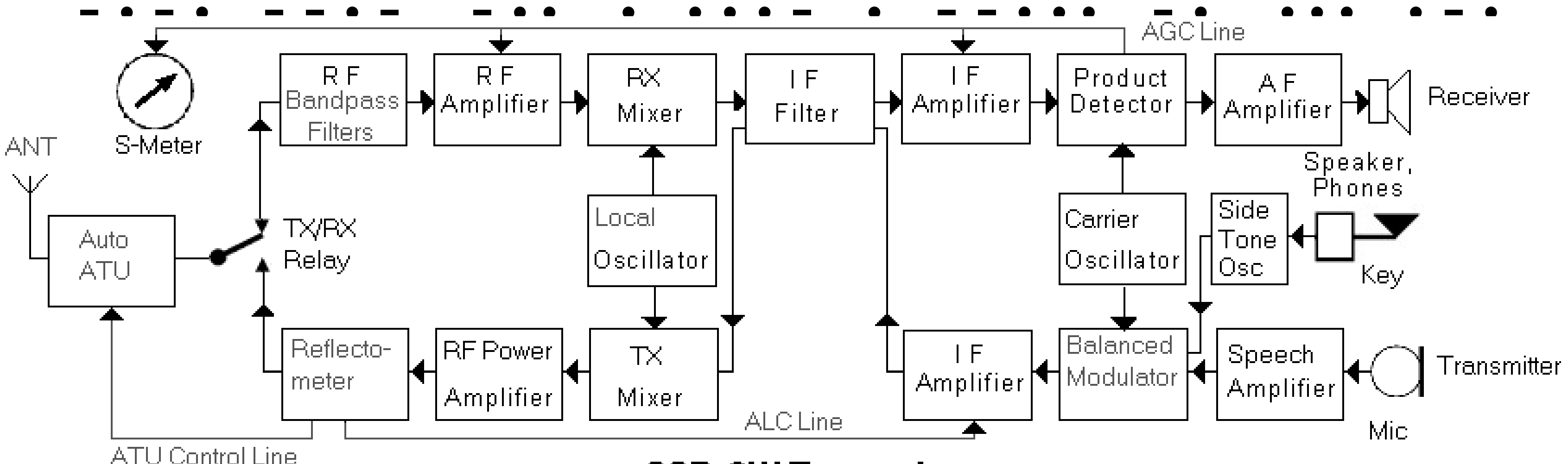
- CW IF filter is narrower than for SSB (usually 500 or 250 Hz). Centre frequency is 9000 kHz.
- Example: 500 Hz IF filter. Signal is at 14010 kHz. Local oscillator at 5009.650 kHz yields IF at 9000.350 kHz (-20 dB point on upper filter skirt).
- Carrier oscillator at 8999.650 kHz yields 700 Hz CW pitch at audio output.
- When transmitting, sidetone oscillator is keyed and feeds 700 Hz tone to balanced modulator. This is mixed with 8999.650 Hz carrier to produce 9000.350 kHz IF.
- Transmit mixer mixes this IF with 5009.650 kHz local oscillator output to yield 14010 kHz RF signal which is amplified to 100W and transmitted as for SSB.

AGC and ALC



- **Receiver AGC (automatic gain control): An AGC detector samples the average audio or IF output signal level, and feeds it back to the RF and/or IF stages to hold the gain constant over a range of input signal levels. The AGC line also drives the S-meter.**
- **Transmitter ALC (automatic level control): A reflectometer samples the forward and reflected power at the output of the RF power amplifier , and feeds it back to the transmit IF amplifier to level the transmitter output at a preset value and protect the transmitter against damage due to load mismatch.**

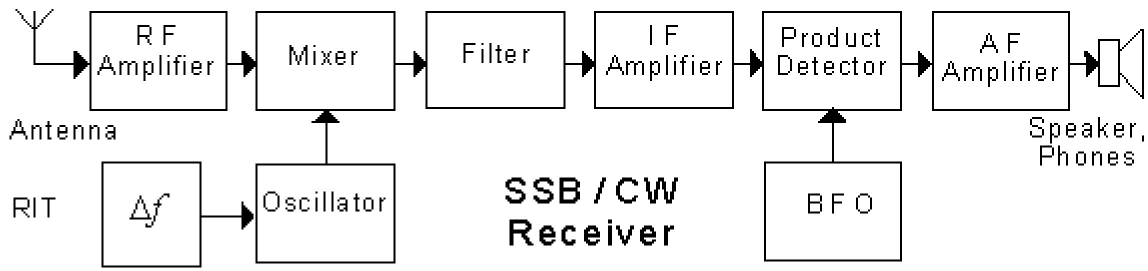
Auto Antenna Tuner
and RF Bandpass Filters



SSB-CW Transceiver

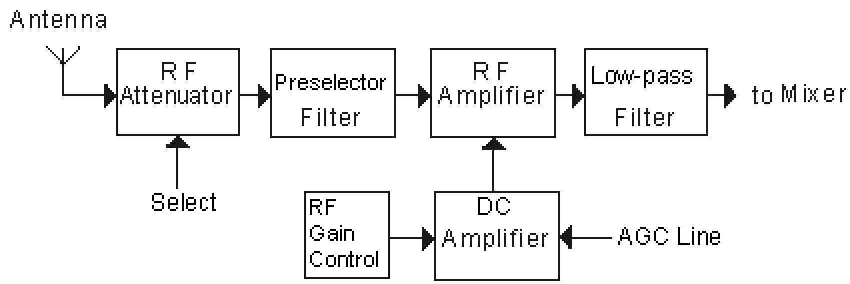
- **Automatic Antenna Tuner (Auto ATU): A T-network (series C – shunt L – series C) located between the antenna socket and the TX/RX relay. It can be switched out of signal path if desired.**
- **Auto ATU matches complex antenna impedance to the 50Ω load required by the transmitter. It will also provide near optimum noise matching for the receiver.**
- **Auto ATU is controlled by reflected-power signal from reflectometer in transmitter.**
- **RF Bandpass Filters *(preselector filters)* suppress image response, and protect receiver RF amplifier (preamp) against overload by strong out-of-band signals.**

RIT & XIT Tuning



- **RIT** (Receiver Incremental Tuning) applies a small offset Δf (± 10 kHz or less) to the local oscillator on receive.
- Allows operator to tune in SSB, CW and RTTY signals accurately.
- RIT is also termed ***Clarifier***.
- Modern transceivers also have **XIT** (Transmitter Incremental Tuning) – similar function for transmitter.
- RIT and XIT Δf displayed separately from main freq. display.
- Pushbuttons allow addition of RIT/XIT offset to operating freq.

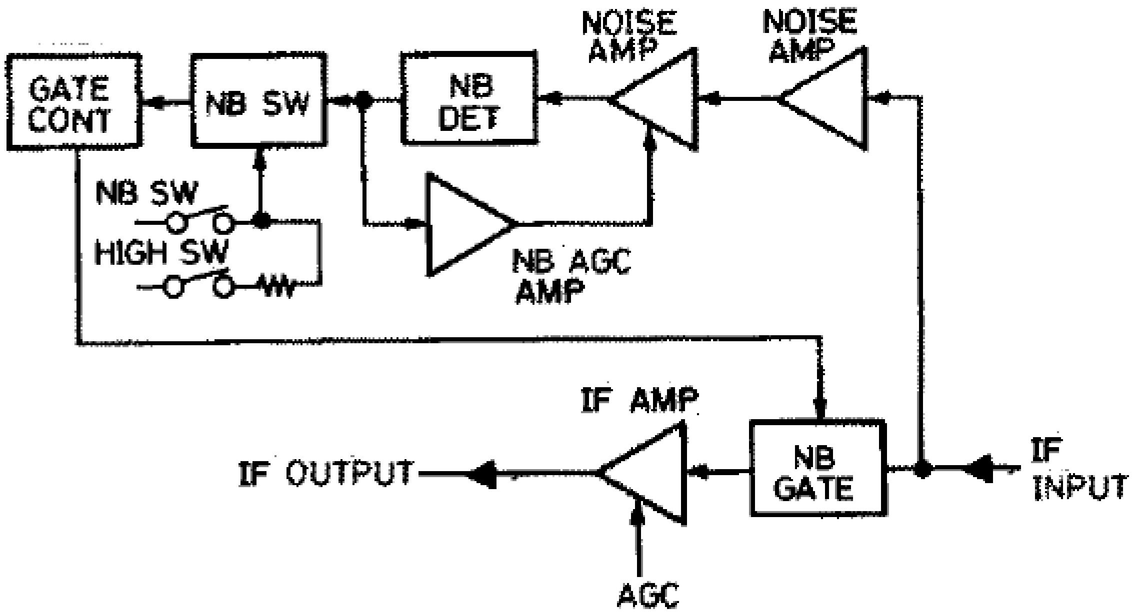
RF Gain & Attenuator



Gain-Controlled RF Amplifier with Front-End RF Attenuator

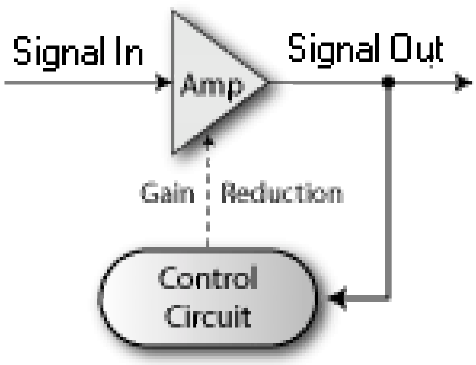
- **RF front-end attenuator** located between antenna input and preselector filter.
- 6, 12 or 18 dB attenuation (typ.) selected by front-panel control.
- **RF Gain control** increases AGC bias on gain-controlled RF amplifier (and/or 1st IF amplifier in some designs); raises AGC threshold.
- Receiver dynamic range increases by amount of attenuation inserted.
- Usually, band noise is 10 to 12 dB above Rx noise floor; attenuation does not significantly degrade noise figure. Attenuator & RF Gain can be used together.

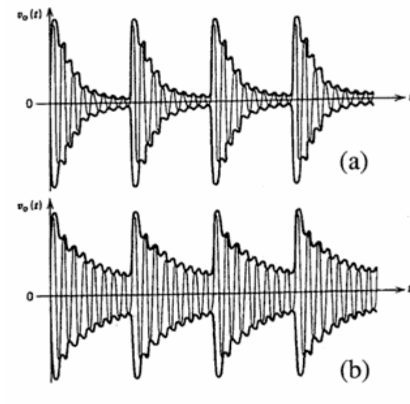
Noise Blanker *(pulse-gate type)*



- A portion of IF signal is amplified by **NOISE AMP**, detected by **NB DET** and applied to **NB SW. HIGH SW** switch increases **NB SW** threshold.
- When detected noise voltage exceeds **NB SW** threshold, **NB SW** sends transition to **GATE CONT** to close **NB GATE** & break IF signal path for duration of noise pulse.
- **NB AGC** loop time constant holds average signal level at **NB DET** constant, but is too long to respond to impulse noise.

Compressor
(transmit speech processor)

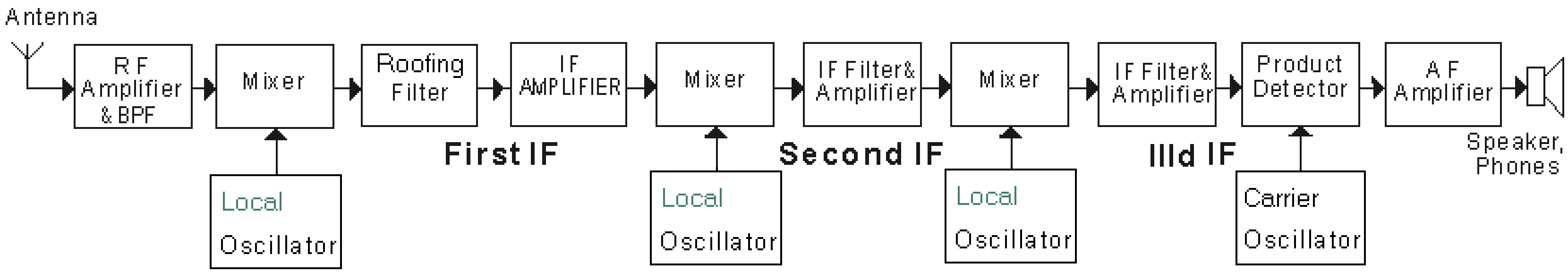




SSB waveforms: (a) unprocessed speech (the repeated word "three") with 16dB peak-to-average ratio; (b) the same word with 6dB of compression

- **Compressor is a gain-controlled amplifier driving an envelope detector with an integrator. The detector output controls the amplifier gain and holds output level constant over a wide input level range. Typically, the compressor is in the TX IF signal path and acts on the TX IF amplifier.**
- **Compressor decreases peak/average ratio of SSB signal, increasing average power output ("talk power").**

Triple-Conversion General-Coverage Transceiver RX Section (up-converting)



- **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. Image rejection is high, as image freq. >> 30 MHz.
- **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.
- **Transmit signal flow:** audio ➔ 455 kHz ➔ 9 MHz ➔ 70 MHz ➔ RF
- Almost all modern HF transceivers employ up-converting architecture.
- Many current transceivers have DSP (digital signal processing) at the final IF.

Links for further study

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- **NSARC Series on HF Receivers**
  - **Part 1**
  - **Part 2**
  - **Part 3**
- **DSP in HF Radios**
  - **Presentation**