Observing Transceiver Signal Paths Using Tiny-SA Spectrum Analyzer

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Abstract: Recent advances in low cost RF integrated circuits and Microcontrollers makes sophisticated test equipment available at modest prices. This makes it practical for the average amateurs to explore and evaluate the signal chain in simpler, older transceivers. One can readily gain hands-on lab experience with what previously was just “book knowledge”

Goals Of This Talk

- Encourage others to gain hands-on knowledge of HF transceiver circuitry
- Learn about medium/low cost test equipment
  - Mostly Tiny-SA Spectrum Analyzer
- Share some photos of key parts of signal chains
- Give away fabulous prizes for questions and staying engaged (even in difficult parts)

My History

- Novice License at age16 in 1964
- Ham interest helped direct my career
  - BSEE 1970
  - MSE 1973
  - Worked in Computer industry rather than RF
- Became pretty fair “appliance operator”
- Amateur Extra in 2017
- Always regretted “books only” knowledge of radio design.

Changes enabling beyond “books only” knowledge

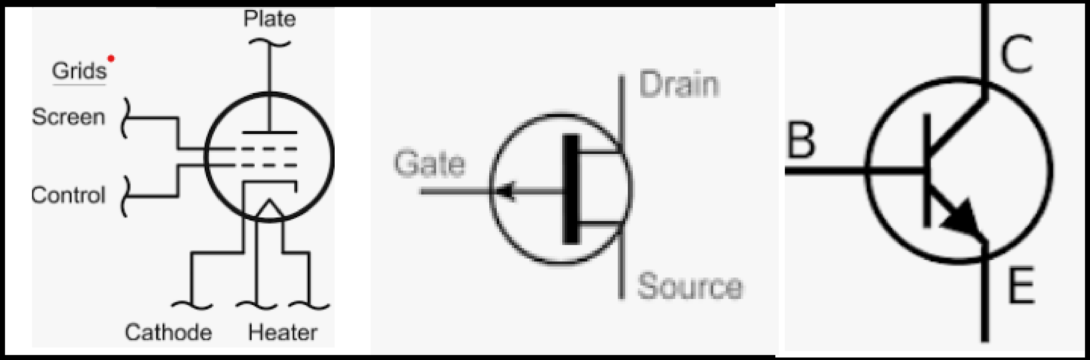
- Retired – I had plenty of time
- Kids moved out – I had plenty of space
- Bottom of Solar Cycle – little DX to be had
- Test equipment got cheap
  - Microcontrollers driving sophisticated rf chips
  - Used Oscilloscope for $150
  - Digital Multimeter for $35
  - Signal Generator ~$50
  - NanoVNA (Vector Network Analyzer) <$100
  - TinySA (Spectrum Analyzer) <$100

Final Push to Go Beyond “book knowledge”

- Was given a Heathkit HW16 station
  - a 1965 era vacuum tube novice rig
- Why use HW16 to study radio?
  - Cheap
  - Would not risk disassembling my modern transciever
  - Heath Is famous for detailed manuals
  - Huge team of experts on https://groups.io/g/heathkit
  - Everything is visible & touchable
  - Don’t have major functions buried inside large microchips
  - One big flat circuit board, filled with axial components
  - Big signals – high voltage & current, not millivolts and microamps

Yeah, but what about the Antique Vacuum Tubes?

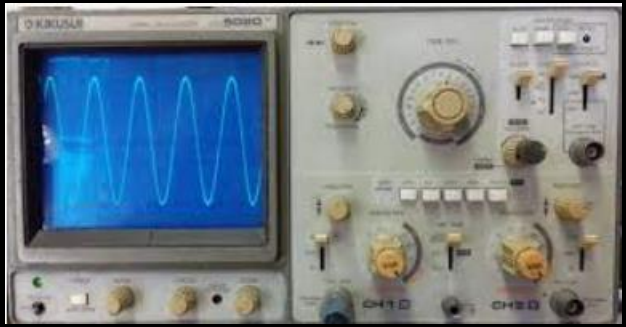
- Principals are the same Tubes, Transistors, FETs
- A small input signal controls a larger output signal
  - Tube - Plate, Grid, Cathode
  - FET – Drain, Gate, Source
  - Bipolar Transistor – Collector, Base, Emitter



- Tube and FET are most alike (voltage driven)
- Bipolar transistor is current driven
- Small detail – voltage on plate of final tube can kill you

OK – Deep dive Technical Slides #1

- An Oscilloscope displays in the "*Time Domain*"
  - X axis is time (increasing left to right) as set by "time base selector
  - Y axis is voltage – as set by "volts/div selector
  - Has circuitry to "trigger" on a repeating waveform so you see a stationary display
  - Usually has 2 or more channels – can see relationship between 2 points in a circuit
- A Spectrum Analyzer displays in the "Frequency Domain"
  - X axis is frequency
  - Y axis is signal strength (usually in DBm)



OK – Deep dive Technical Slides #2

- Some transceiver signals (like local oscillators) are simple pure sine waves
- Many signals (like mixer outputs) are a combination of several frequencies
- A “fuzzy” O’Scope display may be fuzzy because the signal contains multiple frequencies
- It is very instructive to look at those signals with a Spectrum Analyzer

Deep dive Technical Slides #3

- Fourier Transforms is the field of mathematics that allows you to move between Time and Frequency Domain
- A square wave of frequency “X” in the time domain translates into a series of sine wave of the odd harmonics of frequency “X”
- Similar solutions for triangle wave
- Similar solutions for a low frequency audio wave imposed on top of a high frequency radio wave

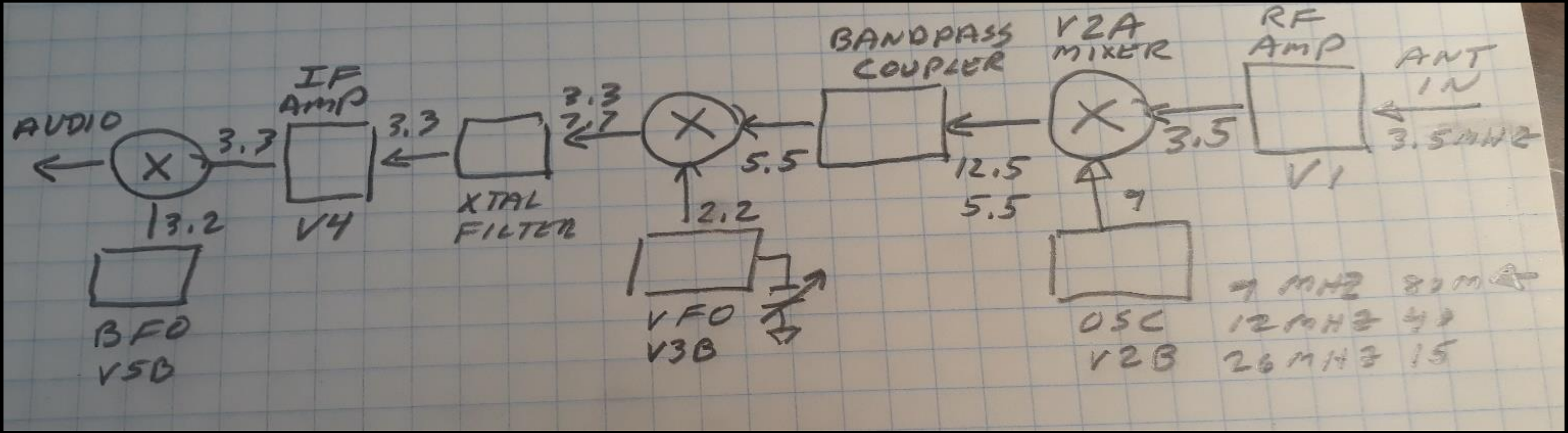
Deep dive Technical Slides #4

- *Superhetrodyne* Radio designed by EH Armstrong in 1919
  - Existed in almost all radios (until SDR era)
- Principal is you shift the signal up to or down from RF frequency using *Mixers*
- If multiband radio, do all the “heavy lifting” at a common *Intermediate Frequency* and then mix with different local oscillators to get to final frequency
- Superhet design is based on Analytic Geometry
  - Multiply 2 sine waves together and you get 1 frequency that is the sum and another that is the difference

The Receive Chain in the HW16

- *The Superhet receiver down-converts the RF signal to one of more IF frequencies.*
- *The mixers mix the signal with a local oscillator resulting in sum and difference signals*
- *The difference is usually the keeper. The sum is eliminated with a filter on the output*
- *The HW16 mixes 3 times to finally get to audio*

The Receive Chain in the HW16

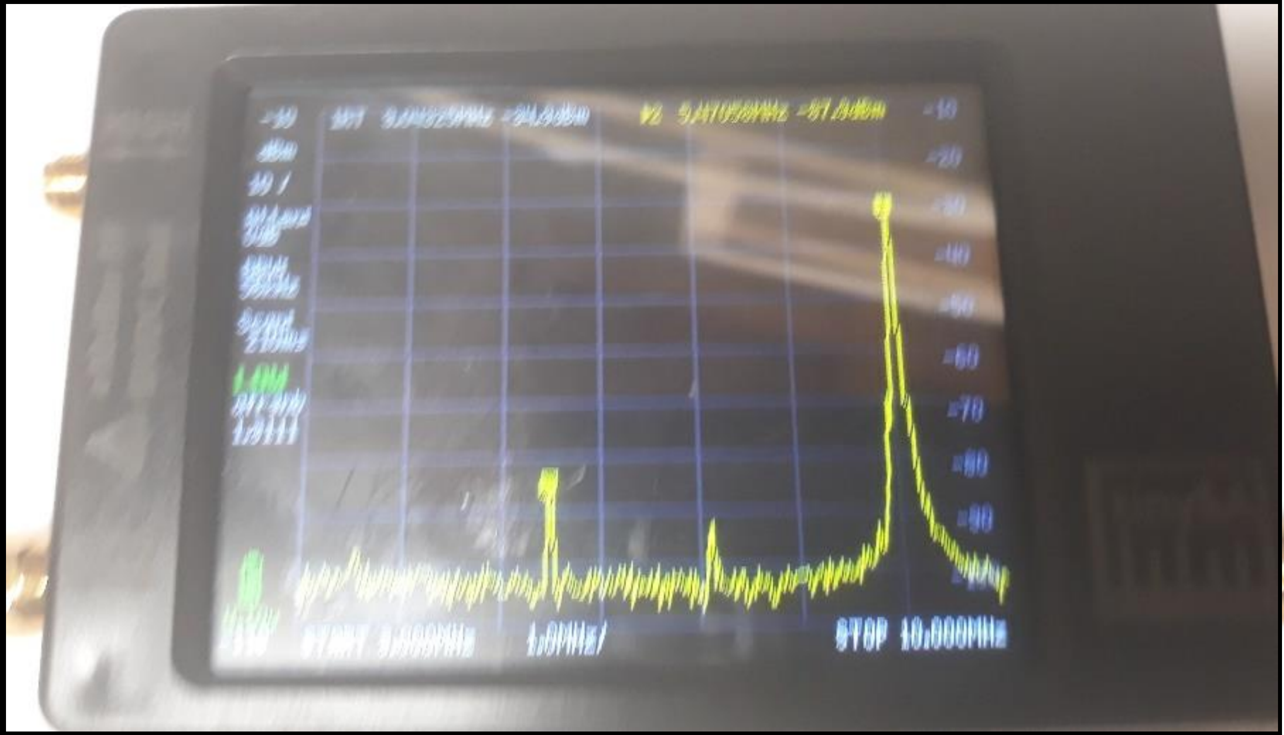


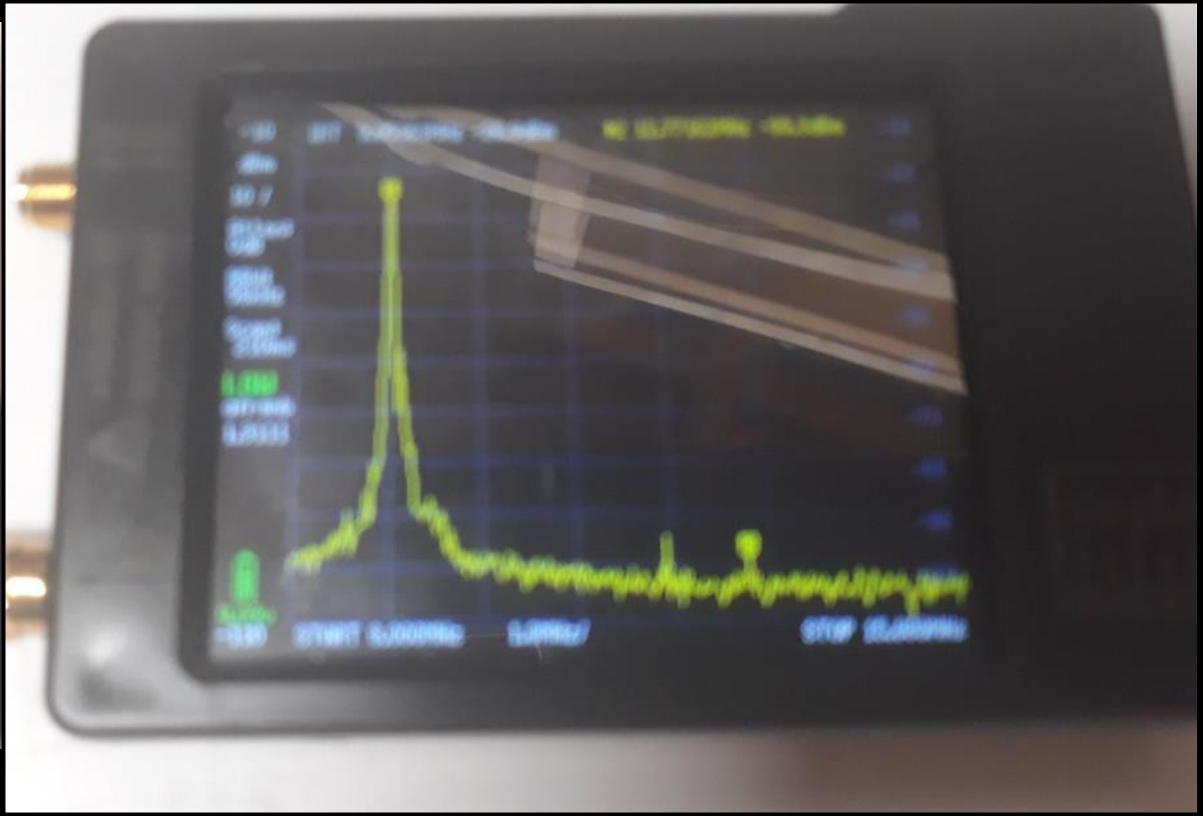
Finally – Some Lab Work

- Tiny SA doesn't actually have to connect to a signal (at least on tube rigs). It simply has to have its probe near the signal. Each tube (or transistor) is actually a tiny transmitter

Finally – Some Lab Work

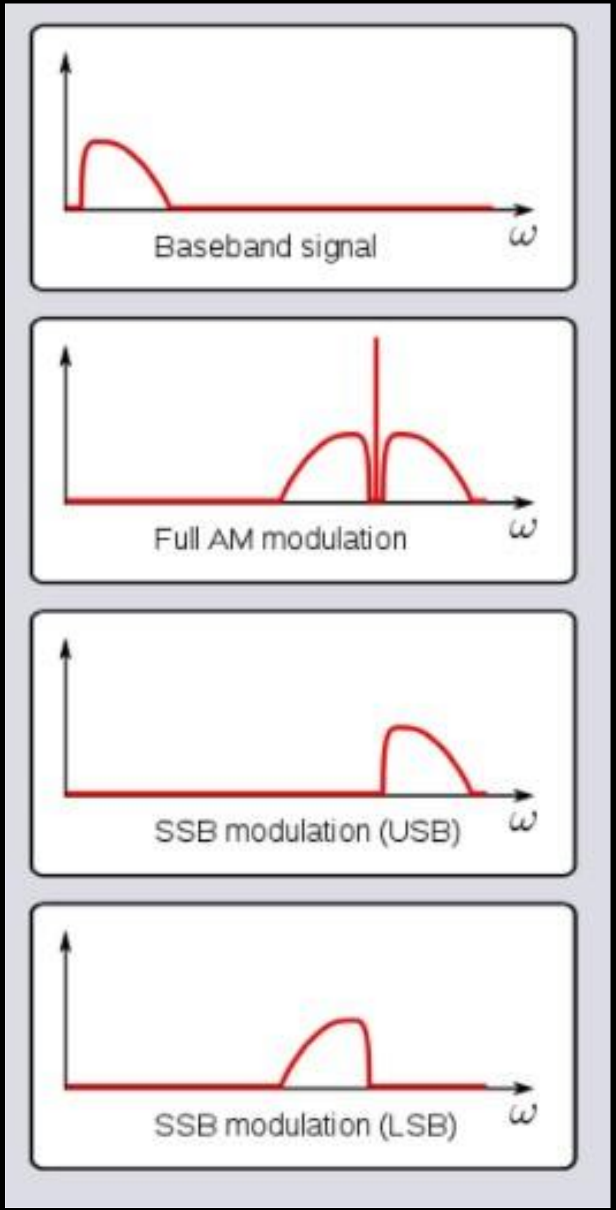
Below are 2 photos of the 9Mhz Oscillator mixed with the 3.5 Mhz input signal from the rf amplifier. They show the 5.2Mhz and 12.2 Mhz sum and difference. Two pictures because the NanoSA cant sweep that full range and show everything in one setting





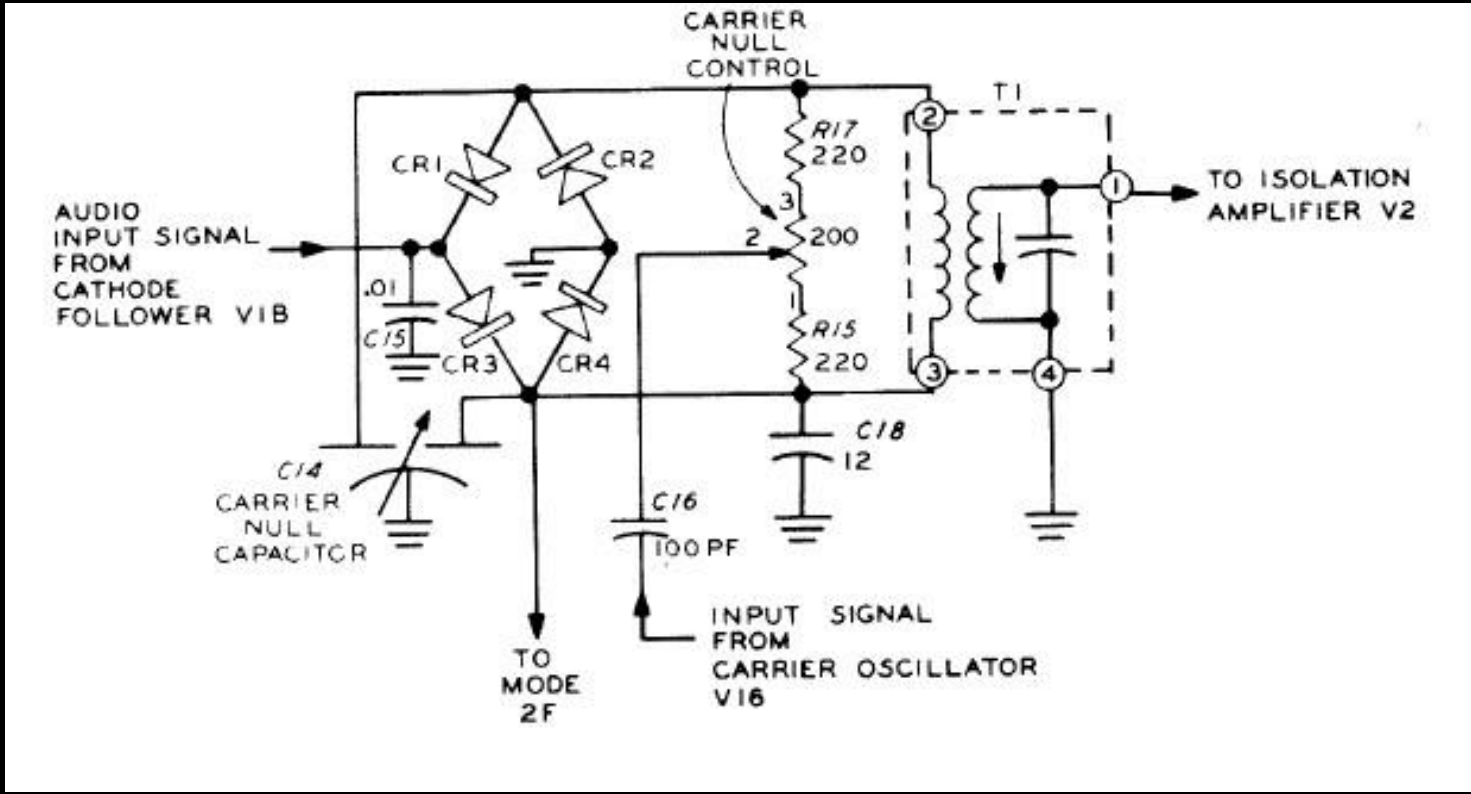
Couldn’t Stop with HW16, Bought HW100

- HW100 is a 1965 era tube 5 band SSB transceiver
- Having it allowed me to study SSB signal generation
- The Fourier Transform of an audio signal imposed on a RF carrier is the carrier plus 2 “*sidebands*”
  - Upper and Lower Sidebands extend out as wide as the audio signal



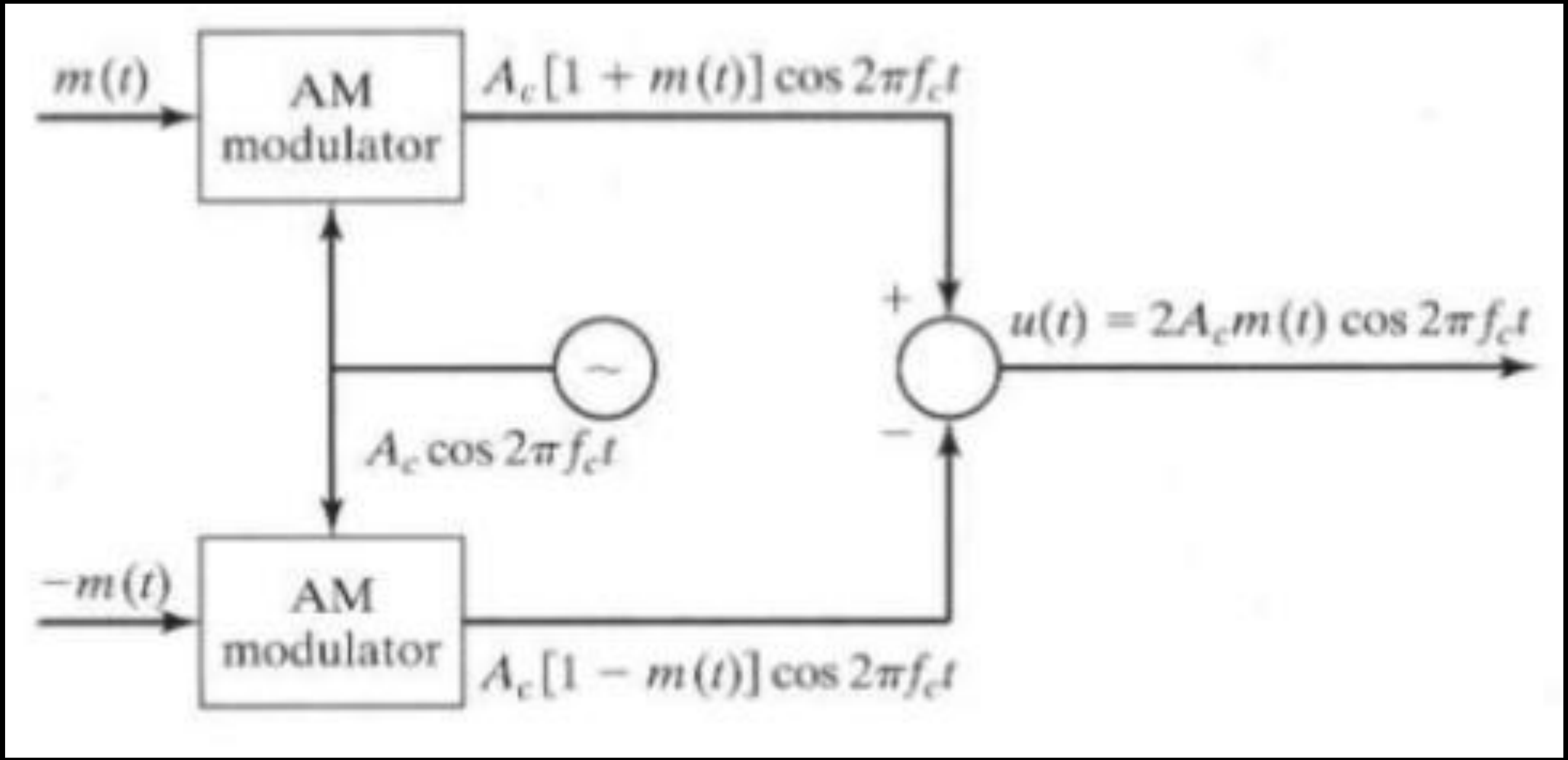
Filter Signal Down to Single Sideband

- Single Sideband contains all the information. Carrier and other sideband is simply a waste of energy.
- Many ways to reduce signal to SSB
- HW100’s diode bridge balanced modulator produces DSB, suppressed carrier
- Crystal Filter after modulator suppresses unwanted sideband


CARRIER
NULL
CONTROL
T1
CR1
CR2
R17
220
3
2
200
1
R15
220
TO ISOLATION
AMPLIFIER V2
AUDIO
INPUT SIGNAL
FROM
CATHODE
FOLLOWER V1B
.01
C15
CR3
CR4
C18
12
C14
CARRIER
NULL
CAPACITOR
C16
100 PF
INPUT SIGNAL
FROM
CARRIER OSCILLATOR
V16
TO
MODE
2F

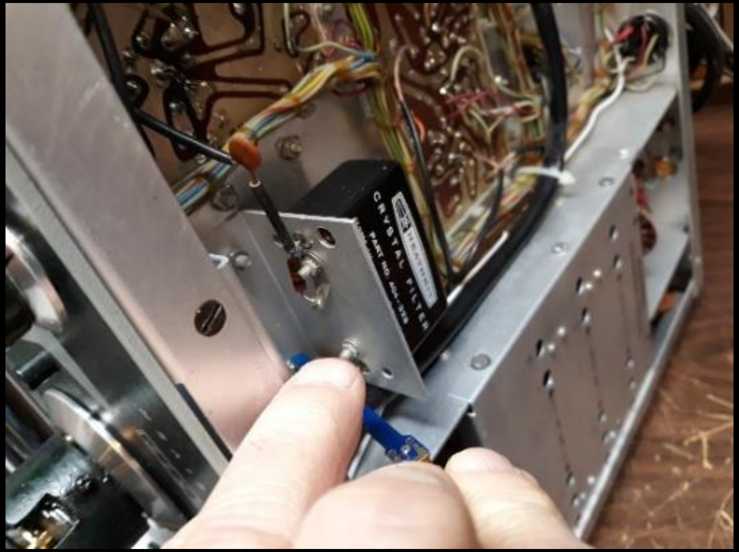
Other Ways to Do it

- SDRs use a math model run in a computer instead of circuitry



Lab Work Around SSB Modulator

- Before and After the Crystal Filter DSBSC Becomes SSB



Summary

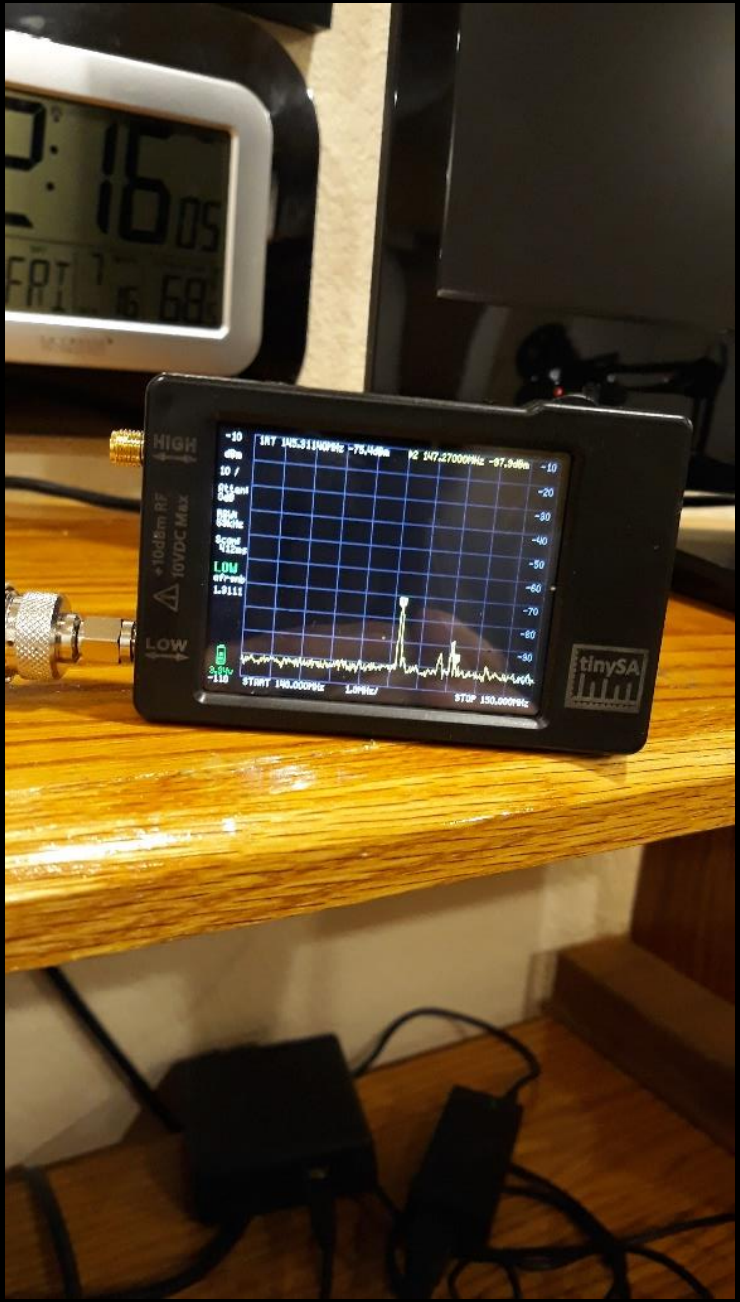
- Time and Frequency Domain – ‘Scope and SA
- Laplace Transform analysis to move between time and freq
- Superhet uses trig rule F1 * F2 = (F1+F2) + (F1-F2)
- Superhet up and down converts using mixers and filters
- AM signal is carrier + 2 sidebands. SSB modulator suppresses carrier and unwanted sideband
- Lab equipment won’t break the bank – buy some!
- Lab work is fun! Make you an “informed appliance operator”
- If you stay alert, you get “Fabulous Prizes”

Extra Credit – Identify Intermod with Tiny-SA

- I like to check in to weekly LARC 2M 8PM Thur Net
- I live in Erie – about equidistant Longmont and Boulder
- LARC repeater would sound fine almost all the time
- Sometimes, LARC sounded garbled
- That sometimes frequently included Thur 8PM net time
- It was a mystery for about 2 years
- Then I bought a Tiny-SA
- I sniffed all around my house and yard. Found nothing

Extra Credit – Resolve Intermod with Tiny-SA

- Connected Tiny-SA to one ant & rig to another
- Observed when LARC repeater was garbled, Boulder was transmitting.
- Turns out, there are nets on Boulder repeaters on Thur
- I knew of intermod before but never clearly experienced it
- Shouldn’t a modern radio be immune to adjacent signals?
  - Hams love their 144/440 rigs that can also receive aircraft, FM broadcast, etc. Filters are broad.
- Solution – use beam pointed at Longmont and broadside to Boulder. Knock down strong Boulder signal



http://www.arrl.org/files/file/Technology/Intermod/Intermod_Urban_Problem.pdf