The NT7S POTLUCK & QRP-L.ORG GROUP PROJECT RIG
Designed by Jason Milldrum, NT7S

Brief Circuit Analysis and Test Procedures
by Paul Harden, NA5N

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1. INTRODUCTION & RIG DESCRIPTION

INTRODUCTION

Jason Milldrum, NT7S, was the winning entry of the 2007 Potluck design contest. For those expressing interest in building the rig "Manhattan style," Jason developed the circuit further into the "QRP-L.org Group Project."

The protype was sent to Paul Harden NA5N for testing. This document briefly describes the theory of operation and testing procedures for those building the rig. Though an oscilloscope is not necessary to get the rig working, many QRPers now have scopes, for which this document is intended. The waveforms demonstrate how the rig works, and how to use your scope to analyze or troubleshoot radio circuits. For those without a scope, the displays will help you "see" how the circuit works.

RIG DESCRIPTION

The NT7S Potluck/Group Project rig is a direct conversion transceiver for 20M. In spite of the minimal parts count, the direct conversion receiver has good sensitivity and gain; the transmitter provides a solid 5W.

VFO/LO. Jason mixes a 4MHz and an 18MHz oscillator to generate the 14.009-14.087MHz tuning range of the rig. By changing one of the crystal frequencies, it can be easily adapted to other ham bands. RIT is also included.

Good VFO filtering and amplification provides a nice, clean 14MHz LO sinewave to the rig. A power splitter forms the required 50Ω receive (RXLO) and transmit (TXLO) signals, each being about +15dBm, or considerably more LO power than most QRP rigs.

Receiver. The NT7S rig is a direct conversion (DC) receiver. Ample 14MHz band pass filtering attenuates out-of-band signals, a common ill of many DC receivers. A 12dB RF amplifier improves the sensitivity of the receiver.

Product Detector. Jason uses a double balanced mixer, using two trifilar wound toroids and 1N4148 diodes, to achieve a robust mixer. The 14MHz RF and 14MHz LO is mixed - directly forming the audio, and hence the name, "direct conversion."

The audio output of the product detector is well terminated and followed by an active CW filter and several stages of audio amplification.

Audio output amplifier (Q19-Q21) is a totem-pole driver (NPN-PNP pair) for high current drive, suitable for low impedance earphones and not starved for gain.

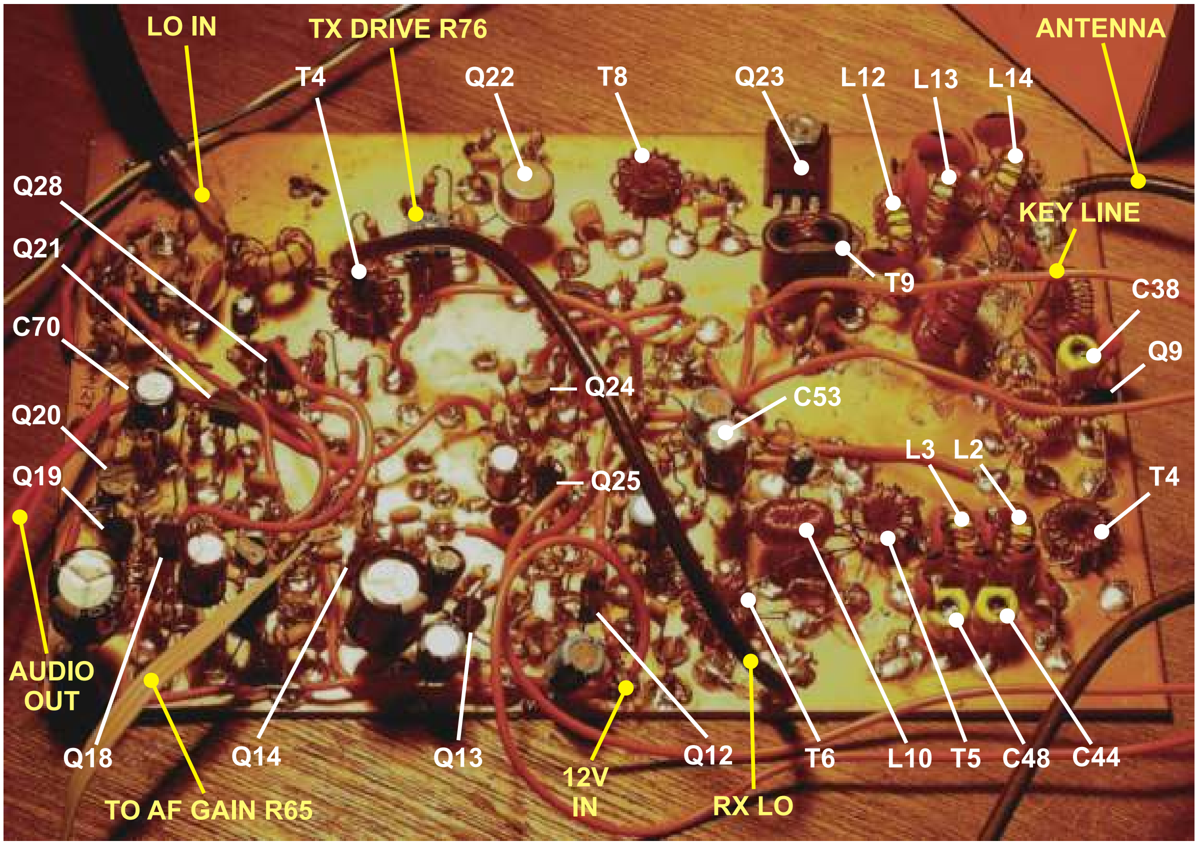
Transmitter. The +15dBm TXLO simplifies the transmitter gain stages. A single TX driver (2N5109 Q22) is all that is needed to drive the PA. The TXLO signal is applied to the TX DRIVE pot, allowing output power to be adjusted over a few hundred mW to a bit more than 5W.

A 2SC5739 (Q23) is used for the PA to easily make the full-gallon 5W output.

The 7-pole low pass filter easily knocks down the 2nd harmonic to 54dB below the carrier, with the 3rd harmonic barely discernable on a spectrum analyzer, greatly exceeding FCC compliance for harmonic rejection.

Major parts locations on the prototype

(Differs slightly from the QRP-L.org group project layout)

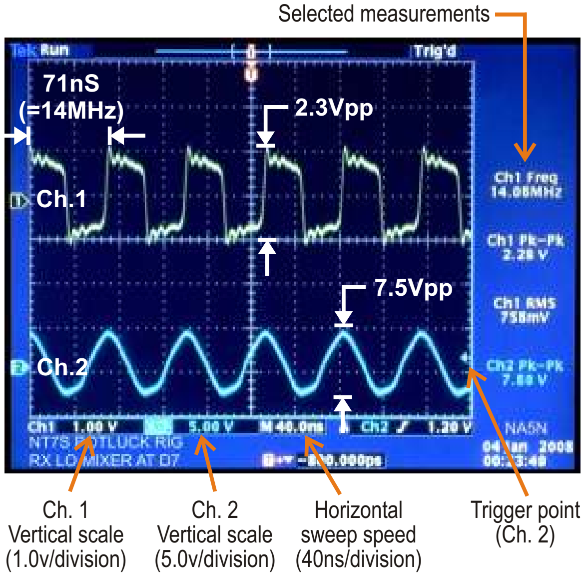


RIG TESTING

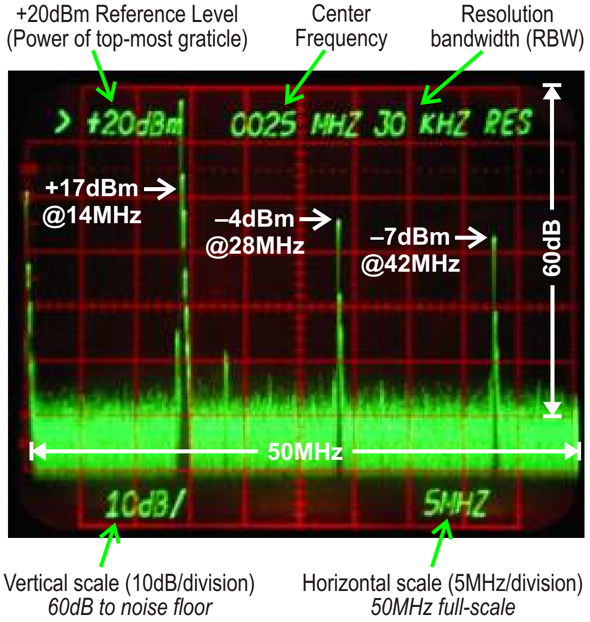
I used my trusty Tektronix 475 scope and 7L13 spectrum analyzer (circa. 1970s) in my home lab. I also used a Tek TDS3032 for the scope photos (better display for photos).

The oscilloscope and spectrum analyzer displays used in this document are described in the photos below for those not familiar with the displays. They are very similar to most any make of these test instruments.

Oscilloscope Display



Spectrum Analyzer Display



2. LOCAL OSCILLATOR

HETRODYNE VFO

Jason chose to generate a tunable 14MHz VFO by mixing an 18MHz crystal oscillator with a 4MHz oscillator using a ceramic resonator. The 4MHz resonator is varicap (MV209) tuned for the tuning range. With this scheme, Jason covers the majority of the 20M CW band, from 14.009 to 14.087 MHz.

The frequency of a ceramic resonator can usually be pulled greater than that of a crystal. The 78 KHz range is .078MHz/4MHz=2%, or greater than the 0.5-1% pulling range of a crystal.

Another MV209 varicap bends the 18MHz crystal for the RIT, yielding a 1700 Hz RIT range, or about ±800Hz. (RIT removed during transmit).

The 14MHz from the 4 and 18MHz mixer is filtered and amplified to about +18dBm by two 50Ω amplifiers, as shown in **Fig 2–1** and **Fig 2–2**. This LO is split and used by both the receiver and transmitter sections (RXLO and TXLO).

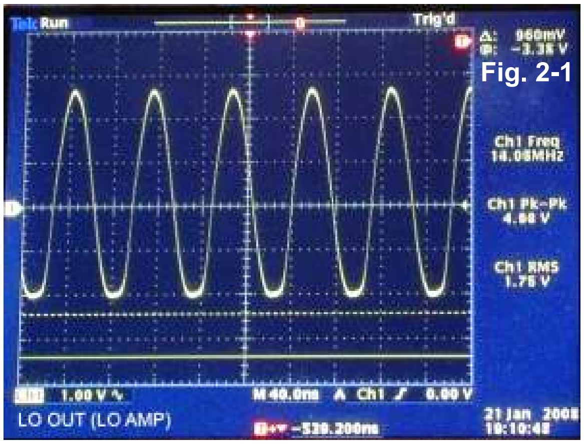


Fig. 2-1

CH.1: 14 MHz LO out at C29 (5Vpp, +18dBm, 50Ω)
CH.2: Not used

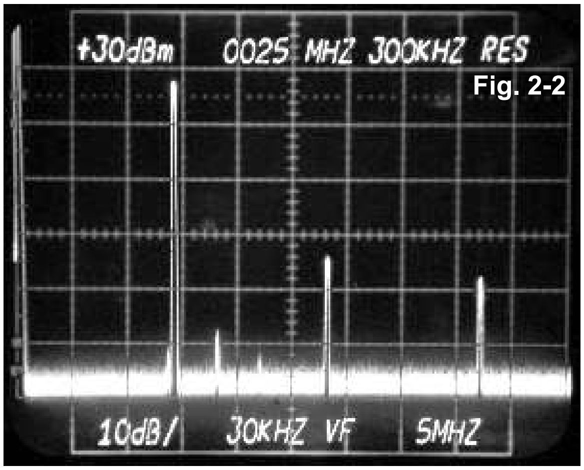


Fig. 2-2

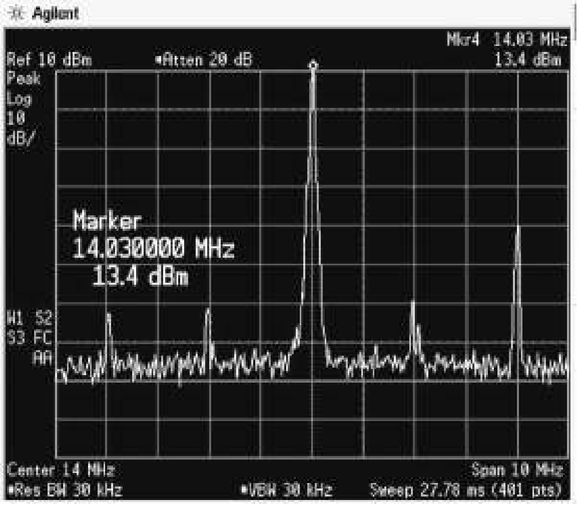
Spectrum display of the 14MHz LO, +18dBm

Below are some displays from an Agilent E4406B spectrum analyzer ($35K+) just to demonstrate the displays of modern instruments. While the basic spectrum display remains unchanged from the older spectrum analyzers, the big difference are the built-in measurement options. In these displays, the harmonics and phase noise of the

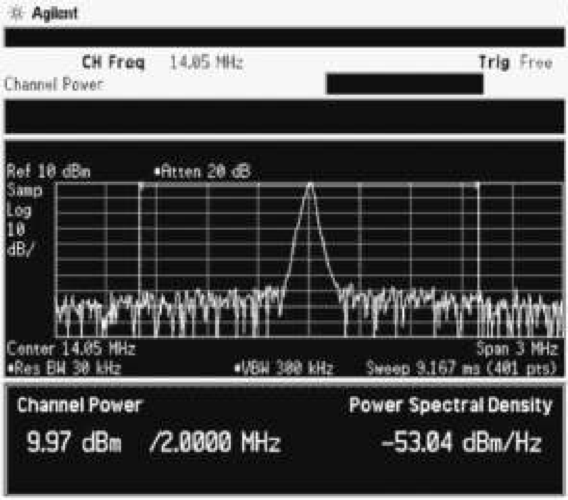
Total Harmonic Distortion
2.48 %
Through Harmonic # 10

	Frequency	Amplitude
1	14.04 MHz	14.05 dBm
2	28.07 MHz	-32.79 dBc
3	42.11 MHz	-40.65 dBc
4	56.15 MHz	-56.08 dBc
5	70.18 MHz	-67.33 dBc
6	84.22 MHz	-79.77 dBc
7	98.25 MHz	-88.03 dBc
8	112.3 MHz	-89.46 dBc

Agilent E4406B listing of harmonic power for the RXLO



Spectrum of the RXLO on Agilent E4406 SA



Channel Power
9.97 dBm /2.0000 MHz
Power Spectral Density
-53.04 dBm/Hz

Agilent E4406B LO phase noise display

3. RECEIVER CIRCUITRY

RECEIVER "FRONT END"

Testing the receiver involves injecting a known signal into the antenna port. I inject -30dBm from a signal generator. This is a strong signal, equating to 20mVpp. This is the minimum sensitivity of most o-scopes and makes a nice level to trace through the receiver without causing gain compression.

(Note: There is a table for converting volts p-p to power in dBm on page 11)

The signal levels of the RF amplifier (RFA) are shown in **Fig 3–1** with 44mVpp input (Q9 source) and 290mVpp output (Q9 drain) for a ***voltage gain*** of:

20log(290/44mVpp) = 20(6.6) = 16dB

Of the 20mVpp signal input, about half is getting to the RFA due to losses through the low pass filter, T-R switch and preselector. The RFA easily makes up for these input circuit losses.

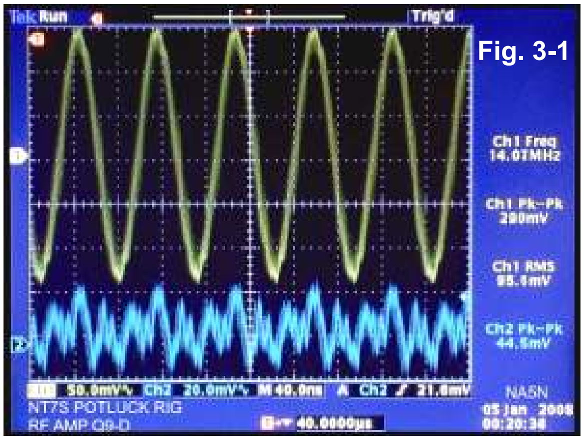
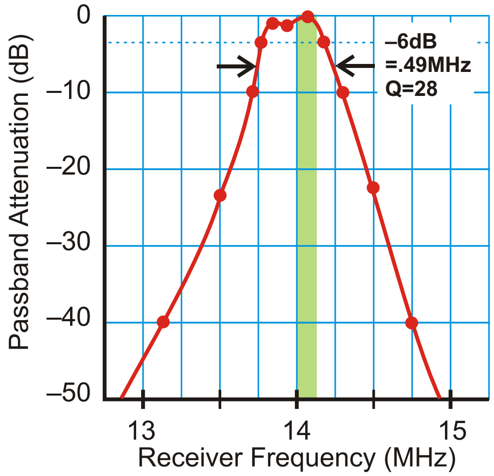


Fig. 3-1

CH.1: RF amplifier output (290mVpp, -7dBm)
CH.2: RFA input (44mVpp, -25dBm)

FIG. 3-2 – Plot of the receiver passband



The spectrum analyzer shows the ***power gain*** of the RFA closer to 13dB with a 50Ω load. By measuring the input and output signals on a scope, you can verify the operation of the RFA (or any amplifier) and calculate the gain in dB.

Following the RFA, the signal is further band-limited by a 2-section 14MHz band-pass filter (BPF) consisting of L8, L9 and associated capacitors. The output of the BPF at C48 is shown in **Fig 3-2**. The plot was made by manually recording the peak-peak voltage on the scope at different frequencies (Vf) compared to the peak voltage (Vp) – occuring at 14.05MHz in this case – then converted to dB by:

dB=20log(Vp/Vf)

The -6dB half-power bandwidth of **Fig 3–2** is about 480 KHz, or Q=14MHz/.48MHz = 28. Since this is measured *in the circuit*, this is the loaded Q of the filtering. You should get similar results.

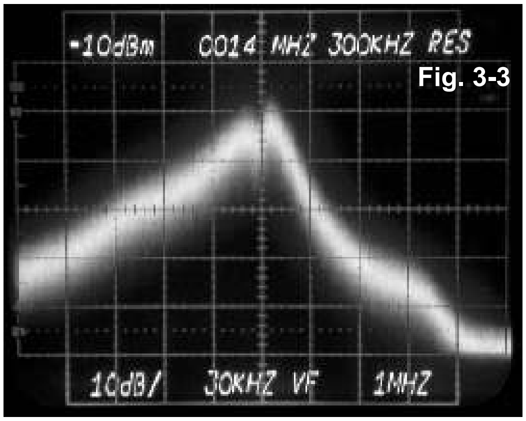


Fig. 3-3

Spectrum display of the RF amplifier Q9 output by injecting a noise source at the antenna jack – before the 14MHz bandpass filter.

Noise Sweep. Another interesting means to plot the response of a circuit, particularly filters, is to inject a noise source and look at the output on a spectrum analyzer. This noise technique sweeps all frequencies instantaneously and will "paint" an exact picture of the response on a spectrum analyzer.

Injecting about -40dBm of noise into the antenna port, the response at the output of RF amp Q9 is shown in **Fig. 3–3**. This shows the combined effects of the receive path through the output low pass filter and the L6-C38 pre-filter. The slight hump at 17MHz is the cutoff of the PA output low pass filter.

Fig. 3-4 shows the noise sweep at the output of the 14MHz bandpass filter, measured at the junction of C48-C49, or the 50Ω RF input to the product detector. The narrower the input response is to the product detector, the better, for rejecting out of band signals. This is especially true for a DC receiver with no IF filters.

Part of mainting the narrow bandwidth, or the high loaded Q of the 14MHz bandwidth filter, is with proper impedance matching throughout. On the input side, the output impedance of RFA T5 is matched to the filter by the split capacitor network C41-C42. The output of the filter is matched to the input of the product detector in an identical manner.

PRODUCT DETECTOR - RF/LO INPUTS

The product detector mixes the 14MHz RF with the 14MHz LO to form the audio. The LO is offset from the RF slightly to form the CW audio tone.

LO Port. The +13dBm LO applied to the product detector at T7 is shown in **Fig 3–5**. The square wave appearance is due to the mixer diodes quickly turning on and off. The high LO drive raises the P1dB (1dB compression point) of the mixer for better strong signal performance.

The measured P1dB is about -14dBm, implying an IP3 around 0dBm. This was measured by plotting the RF input vs. audio power at Q10 and Q14 for the compression point. P1dB could not be measured directly at the product detector due to the presence of the 14MHz LO.

RF Port. RF applied to the product detector is shown in **Fig. 3–6**. The ratty looking signal is caused by the LO, harmonics and other images superimposed on the RF port. If this were not a double balanced mixer (DBM), it would be worse! The LO ripples appear to be about 40mVpp, compared to the 5Vpp (+13dBm) LO is about 42dB isolation between the LO-RF ports. (20log(5V/40mVpp). 30-35dB isolation is considered good for a “roll your own” DBM.

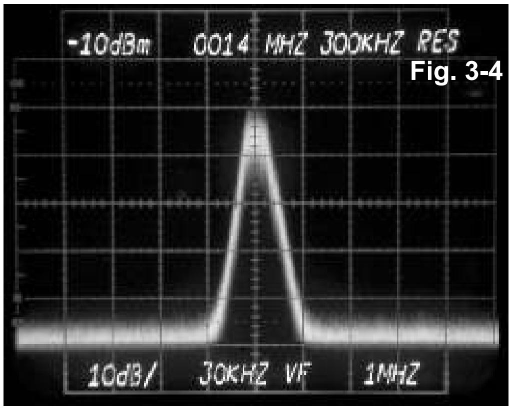


Fig. 3-4

Spectrum display of the receiver passband, similar to Fig. 3-2, by injecting noise into the receiver and measured at the product detector RF input.

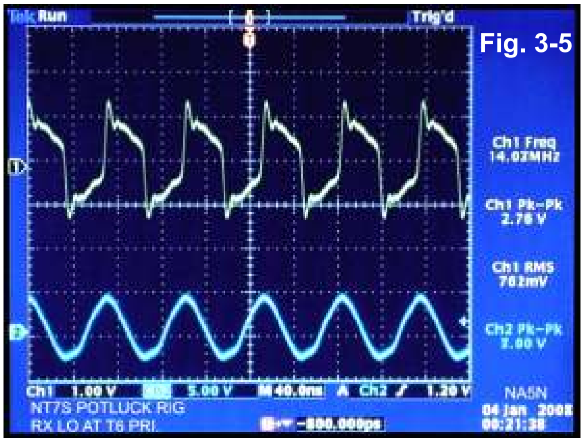


Fig. 3-5

CH.1: RXLO input to mixer (2.8Vpp, +13dBm)
CH.2: LO input from VFO (8Vpp, +21dBm)

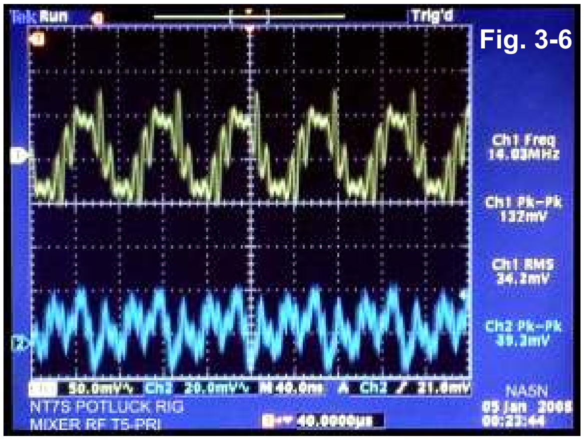


Fig. 3-6

CH.1: RF T5 mixer input (132mVpp, –14dBm)
CH.2: RFA input (39mVpp, -25dBm)

MDS. The minimum discernable signal (MDS) measured was -128dBm. Jason measured -131dBm on his. This is the point where the signal is no longer heard (discernable) and requires a signal generator with very little leakage to measure. In addition to slight differences in layout, I figure the 3-4dB difference in MDS is due to my 50+ year old ears vs. Jason’s much younger ones. Regardless, this rig competes well with most QRP rigs that generally sport around -120dBm, such as an NE602 based transceiver. I was surprised the MDS measured was this good.

Dynamic Range. With -128dBm MDS, and a P1dB of -14dBm, the dynamic range is the difference, or 114dB. This is quite respectable for a DC receiver.

4. AUDIO STAGES

PRODUCT DETECTOR - AUDIO (IF) OUTPUT
In a direct conversion receiver, the audio stages are very important. This is where most of the receiver gain is developed. Jason's design is well thought out for plenty of clean audio.

IF Port. The mixer IF output is 50Ω terminated by the diplexer components to match the product detector impedance. **Fig 4–1** shows the IF output (before the diplexer at C50) consisting of audio, 14MHz LO and LO harmonics. Audio is the desired product.

Port–Port Isolation. LO power is +13dBm; LO on the IF (audio) port is -29dBm, a difference of 42dB, meaning 1/10,000 of the LO signal is leaking through to the IF port. 42dB LO-IF port isolation is very good for a homebrew mixer.

An o-scope will show the relatively weak audio signal at the product detector output when the VFO is tuned to the signal generator (or on-air signal) to produce the desired sidetone, as shown in **Fig 4–2**. The ill defined audio signal at the product detector output (bottom trace) begins to take form after the 12dB gain of common base audio amplifier Q10-Q11 (top trace). An on-air signal will appear much smaller.

The output spectrum of the 1st audio amplifier at Q10 collector is shown in **Fig 4–3**. The unwanted LO signals are knocked down another 10dB, although most of what is measured is the +13dBm LO floating around the circuit.

A spectrum analyzer is not particularly useful at this point in the circuit, except to demonstrate the unwanted frequency components found on the IF output of *any* mixer stage. Also, the audio power level shown (+10dBm) is meaningless over the frequency range (5MHz/div) and bandwidth resolution (300kHz) in use.

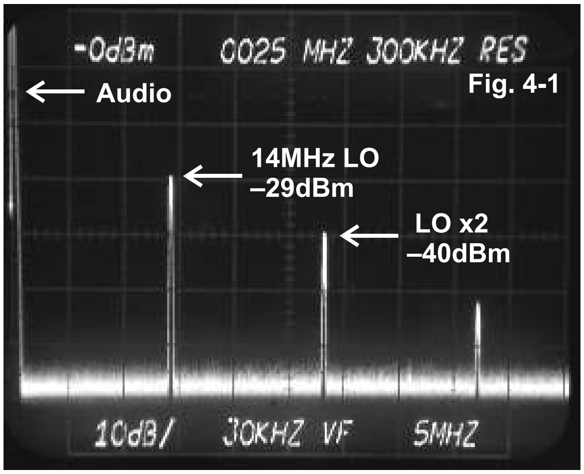


Fig. 4-1

Spectrum of Product detector 50Ω output

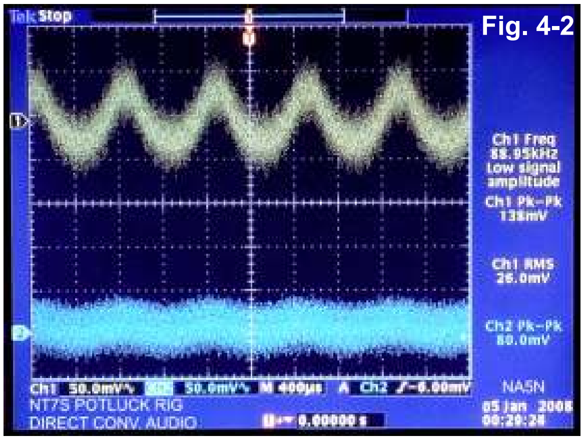


Fig. 4-2

CH.1: Output of 1st Audio Q10 (140mVpp)
CH.2: Prod. Detector output (about 30mVpp)

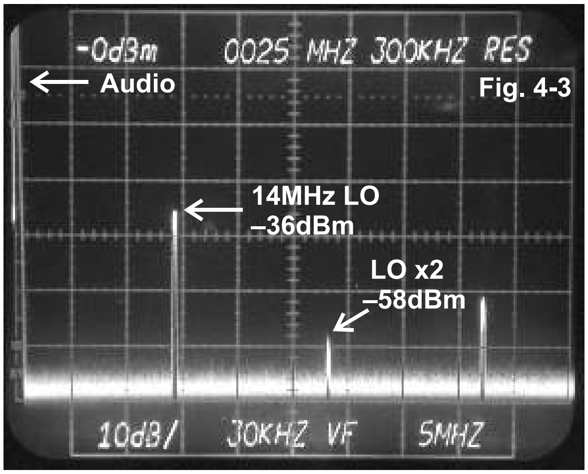


Fig. 4-3

Spectrum of 1st Audio Amplifier Q10 output

CW Filter. Following the 1st audio amplifier, stages Q12 and Q13 form an active audio filter. If you monitor the output of the filter at Q13 (or Q14) at different sidetone frequencies, you will see the level remains relatively flat to about 3KHz, then begins to roll off at higher audio frequencies.

This verifies that the CW filter low-pass action is working properly. Also, since this is a direct conversion receiver, a plot of the frequency response will be identical on both sides of zero beat (LSB and USB sides).

AUDIO OUTPUT

The low-level 40mVpp audio from the CW filter (with -40dBm injected at the antenna) is amplified to 2Vpp by high-gain preamp Q14 for about 33dB gain.

Overload. Audio becomes distorted in any receiver on very strong signals (or poor design), caused by the amplifiers in gain compression. **Fig 4–4** illustrates *gain compression*. With –10dBm input to force an extreme overload condition, the output of Q14 goes from cut-off to saturation, forming a raspy sounding square wave. From –128dBm MDS to –14dBm P1dB, a clean sinewave audio should be seen at Q14 collector.

The following audio waveforms and measurements are based on setting *AUDIO GAIN R63 for 500mVpp on the wiper (700-800Hz tone).* This places 500mVpp on amplifier Q18 base, producing 2.4Vpp collector output for an additional gain of 14dB. This is shown in **Fig. 4–5**.

Output amplifier. The output of amplifier Q18 is direct coupled to Q19, an emitter follower, which drives complimentary output pair Q20 (NPN) and Q21 (PNP).

Crossover Distortion. Diodes D11-D12 offsets the base bias to prevent *crossover distortion*. **Fig 4–6** shows the result by bypassing the diodes (Sorry, Jason). As seen, it is a dramatic effect distorting the output gain. With D11-12 there is no crossover distortion on the audio output.

Output transistors Q20-Q21 can be thought of as NPN-PNP emitter followers. They provide *current gain*, but no voltage gain. The output audio, shown in **Fig 4–7**, is 2.32Vpp, or about the same as the output of *voltage amplifier* Q18.

At this point, it is current that is needed to drive low impedance earphones or a speaker. About 500mVpp into earphones is generally sufficient for comfortable listening, showing Jason's audio chain (2.3V output) has plenty of gain for weak signal work. I had good results with 8Ω, 24Ω, and 32Ω head phones, with the best "sound" (to me) with the 24Ω earphones. Note the clean audio sinewave output in **Fig 4-7** from the rig.

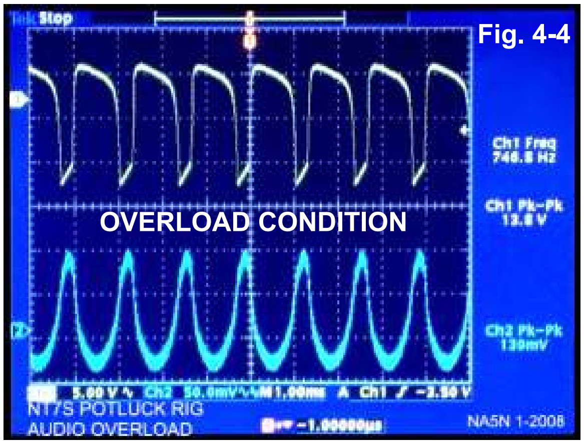


Fig. 4-4

CH.1: Audio Amp Q14 out (13Vpp)
CH.2: CW Filter output (140mVpp)

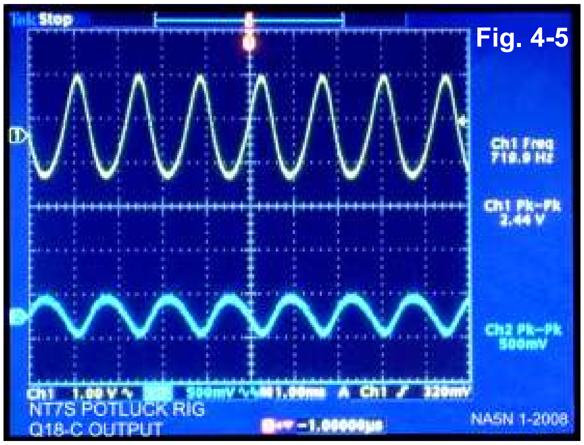


Fig. 4-5

CH.1: Output driver Q18 (2.4Vpp)
CH.2: AUDIO GAIN R65 set to 500mVpp

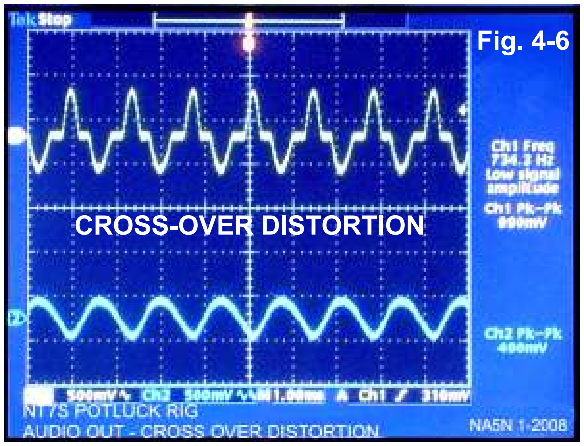


Fig. 4-6

CH.1: Output driver Q18 (2.4Vpp)
CH.2: AUDIO GAIN R65 set to 500mVpp

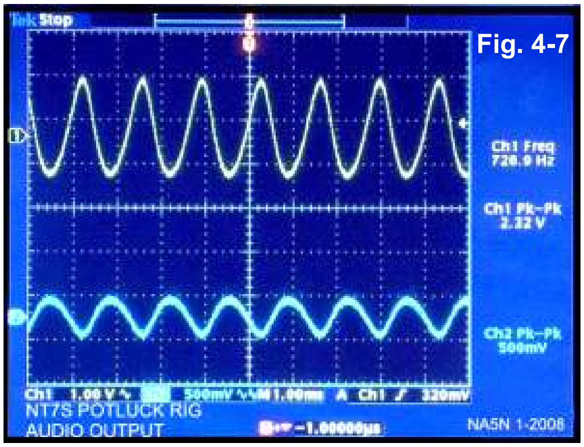


Fig. 4-7

CH.1: Audio Output - phone jack (2.3Vpp)
CH.2: AUDIO GAIN R65 set to 500mVpp

5. TRANSMITTER STAGES

TXLO Input. +18dBm LO from the Hetrodyne VFO is applied to T4 power splitter. T4 divides the +18dBm LO input in two (–3dB), for +15dBm TXLO output (+18dBm–3dB). The TXLO signal is what drives the transmitter. On an o-scope, the TXLO output is about 4.5Vpp (+16dBm) as shown in **Fig. 5–1**. The LO signal is a fairly clean sine wave except for some slight saturation at the negative peaks – typical of most VFO circuits.

TXLO power is a bit higher than the RXLO due to the resistive termination of TX DRIVE R74. +15dBm is a fair amount of LO power compared to most QRP rigs, simplifying the transmitter circuitry.

The TXLO spectrum is shown in **Fig. 5–2**. Note how the +15dBm LO power measured on the spectrum analyzer (50Ω device) is within 1dB of the same power determined from an o-scope (hi–Z device). A 1-2dB difference from your measurements to those shown is acceptable due to variations between circuits – and instruments.

NOTE: *The following tests are based on* ***key–down transmit****. Ensure you have a dummy load connected to the antenna jack before transmitting, and avoid prolonged periods of key–down longer than 30 seconds (though the PA never gets very hot - a sign of good efficiency).*

TXLO is applied to TX DRIVE adjust R74. For my tests, adjusting R74 for 4Vpp at the wiper (base of Q22) produced exactly 5 watts out (assuming your scope has at least a 20MHz bandwidth).

TX Driver Q22. With the TX DRIVE set for 4Vpp drive, this applies about +10dBm to the base of TX Driver Q22 (2N5109). This is shown in **Fig. 5–3** comparing the +18dBm LO input (Ch.2; 7Vpp) to Q22 base (Ch.1; 4Vpp).

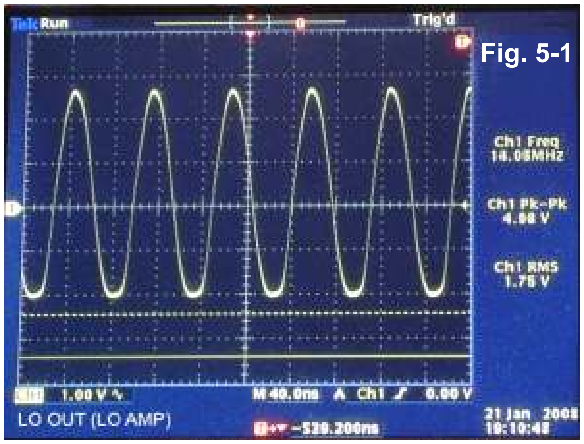


Fig. 5-1

CH.1: LO INPUT AT C29 (4.5Vpp, +16dBm)
CH.2: Not used

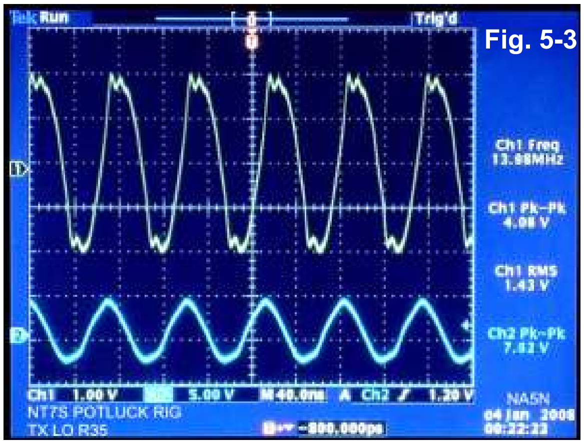


Fig. 5-3

CH.1: INPUT TO DRIVER Q22 (4Vpp, +10dBm)
CH.2: TXLO INPUT (7.5Vpp, +18dBm)

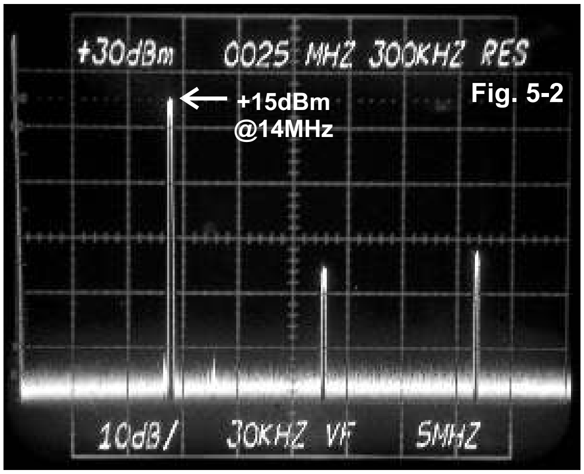


Fig. 5-2

TXLO AT T4 Power Splitter (+15dBm)

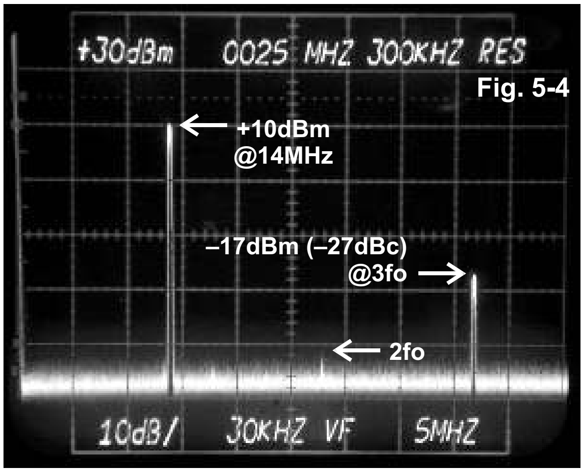


Fig. 5-4

+10dBm Q22 INPUT (TX DRIVE SET TO 4Vpp)

Note how the Q22 drive signal, **Fig. 5–3**, is no longer a perfect sine wave; the ripples at the negative and positive peaks are signs of harmonic energy (mostly 3rd harmonic). This is unavoidable due to TX DRIVE pot R74 and the input impedance to Q22 changing with different power levels. This is normal and easily filtered out later in the output low pass filter.

The spectrum analyzer shows the harmonic energy at Q22 in **Fig. 5–4**. The 3rd harmonic (3fo) is down about -27dBc, 2fo barely discernable.

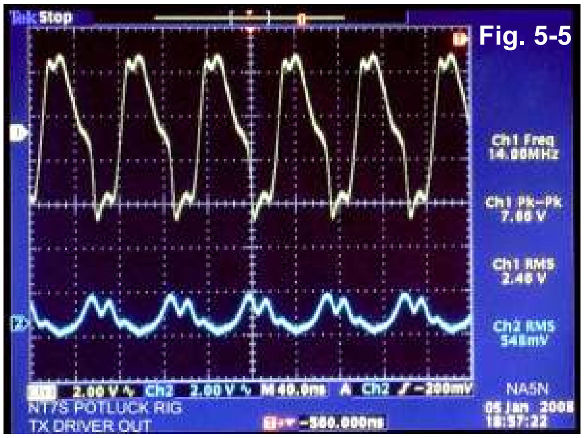
With +10dBm input (4Vpp Q22 base) and +21dBm output (7.6Vpp Q22 collector), TX driver Q22 provides 11dB of power gain. This is more than sufficient to drive the power amplifier (PA). The output of driver Q22 is shown in **Fig. 5–5**.

The +21dBm Q22 driver 50Ω output at T8 passes through T9 to transform the impedance to the PA to about 12Ω. **Fig. 5–6** shows the spectrum at the PA input and the harmonic powers still present.

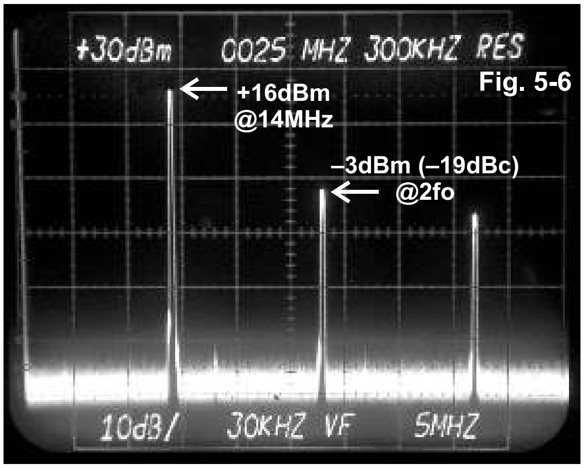
Power Amplifier (PA) Q23. The input to the PA, as seen on an o-scope, is shown in **Fig. 5–7**. Some power is lost through T9, and due to the low impedance input of the PA transistor, such that about 4Vpp (+16dBm) is actually applied.

Fig. 5–8 compares the PA transistor input signal (bottom trace) to the PA output (top trace) at Q23 collector to show the overall gain. The 4Vpp input signal, and the 30Vpp output, clearly shows the 17dB power gain being provided by the PA transistor.

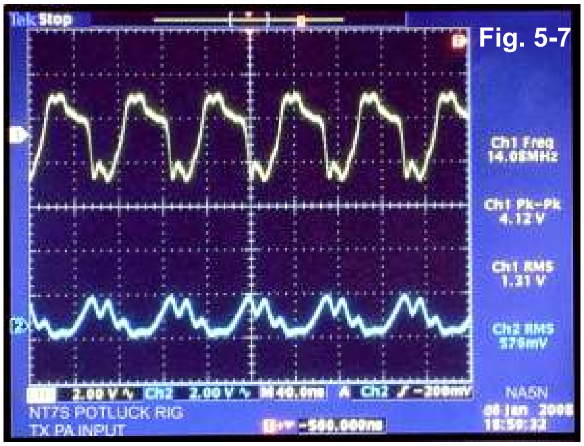
The distorted input signal (Ch. 2) is an artifact of the low impedance drive of the base and the PA input capacitance charging and discharging. The PA collector (Ch.1) shows the amplification of the signal, and how the collector inductance of T9 sustains power to clean up the signal, and elevates the swing from the +12V supply to 30Vpp.



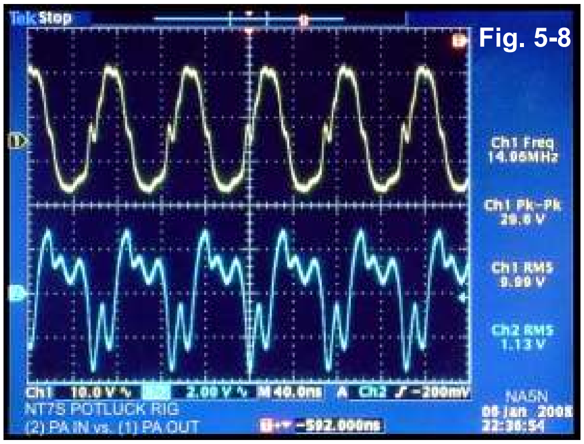
CH.1: Driver Q22 output (7.6Vpp, +21dBm)
CH.2: TXLO input (2Vpp, +10dBm)



Spectrum at Q23 PA base input



CH.1: Q23 PA base drive (4.1Vpp, +16dBm)
CH.2: TXLO input (2Vpp, +10dBm)



CH.1: Q23 PA collector (30Vpp, +33dBm)
CH.2: Q23 PA base drive (4Vpp, +16dBm)

PA Output Impedance. The output impedance of the PA transistor must be transformed to 50Ω to begin the process of matching the transmitter to the antenna. The output impedance of the PA at 5 watts is approximated by the equation:

$$RL = \frac{Vcc^2}{2Po} = \frac{12v^2}{2*5W} = 14\Omega$$

Transformer T9 is a 1:4 transformer; that is, the 14Ω PA output is converted to 56Ω (14Ω x 4), very close to the desired 50Ω. The low pass filter (LPF) network does the rest. Usually this transformer is wound on a T50-43 or similar wideband toroid. Jason uses a binocular core, which yields good efficiency.

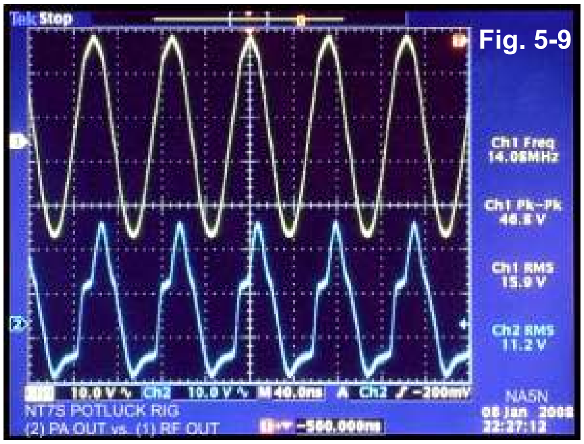


Fig. 5-9

CH.1: Antenna RF out (47Vpp, +37dBm=5W)
CH.2: Q23 PA collector (30Vpp, +33dBm)

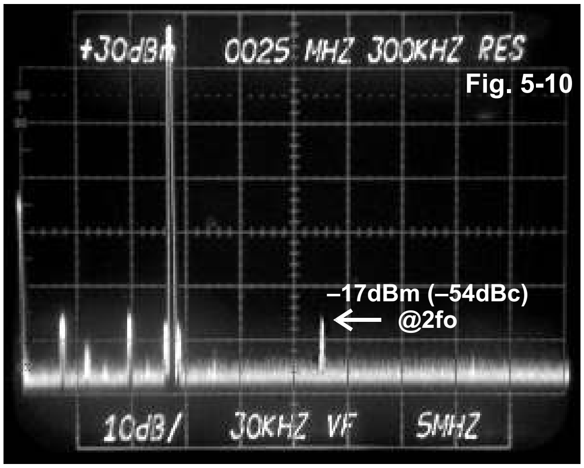


Fig. 5-10

Antenna RF Out spectrum showing +37dBm (5W) 14MHz output and effective attenuation of harmonics. The 2nd harmonic is –17dBm, or 54dB below the carrier (–54dBc). An external 10dB attenuator was used, such that the top +30dBm graticle is actually +40dBm.

Jason uses quite a few bifilar wound transformers to carefully control impedances in both the transmitter and receiver stages.

TX Low Pass Filter (LPF) The main job of the TX low pass filter is to attenuate harmonics and other unwanted power above the desired fundamental. In this case, the fundamental is the 14MHz transmit frequency; the cut-off frequency is set slightly above that – in this case 17MHz. Thus, frequencies above 17MHz are attenuated.

Fig. 5–9 shows the PA output signal (bottom trace) and the signal at the antenna jack (top trace). The antenna output is 46Vpp, or a nice, clean 5W. The nice clean sinewave also indicates there is very little harmonic power, as verified by the output spectrum shown in **Fig. 5–10**. The 2nd harmonic is 54dB below the carrier (-54dBc), far exceeding the -36dBc requirement of the FCC. The 3rd harmonic is barely discernable.

Fig. 5–11 is the noise sweep of the LPF. The peak at 14MHz is due to the 14MHz peaking circuit L11-C77. The Q>2 of the LPF causes the characteristic peak at the cut-off frequency of the filter, 17MHz in this case, followed by the obvious sharp roll-off of the output filter.

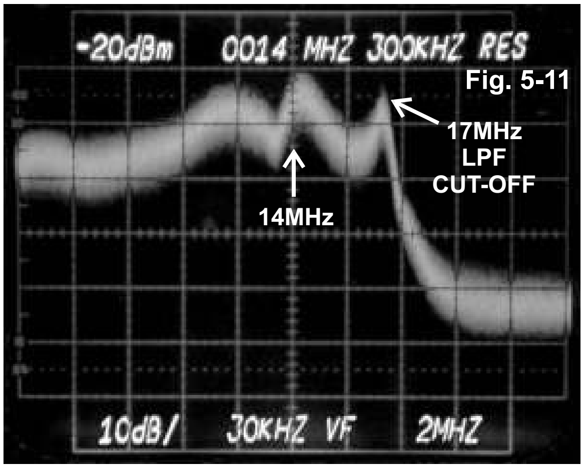


Fig. 5-11

Noise sweep of the output low pass filter

Whether you have an oscilloscope or not, hopefully these waveforms will assist in demonstrating how the circuits in the QRP-L.org Group Project rig works.

Now, disconnect the dummy load and make some contacts :-) GL building and operating yours.

72, Paul NA5N (na5n@zianet.com)

6. APPENDIX

dBm – Volts – Power Conversion Chart

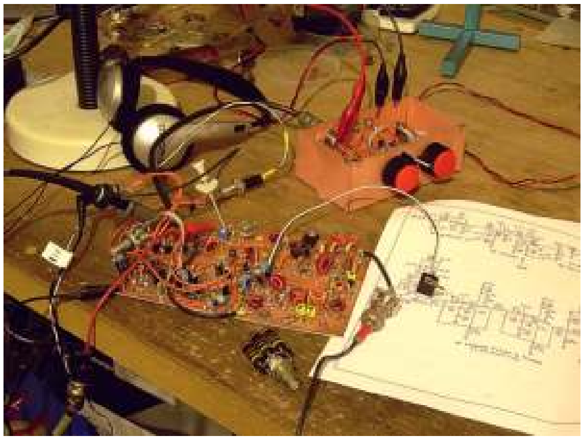
dBm	Volts rms	Volts p-p	Power
+37	16v	45v	5.0W
+35	13v	37v	3.3W
+30	7v	20v	1.0W
+25	4v	11v	320mW
+20	2.3v	6.5v	100mW
+15	1.3v	3.7v	32mW
+10	0.7v	2.0v	10mW
+ 5	0.4v	1.1v	3mW
0dBm	.23v	.65v	1mW
- 5	.13v	.37v	320uW
-10	.07v	.20v	100uW
-15	.04v	.11v	32uW
-20	23mV	65mV	10uW
-25	13mV	37mV	3uW
-30	7mV	20mV	1uW
-35	4mV	11mV	.3uW
-40	2mV	6mV	.1uW

Measure peak-peak voltage on an o-scope
Convert Vp-p to dBm or watts from chart

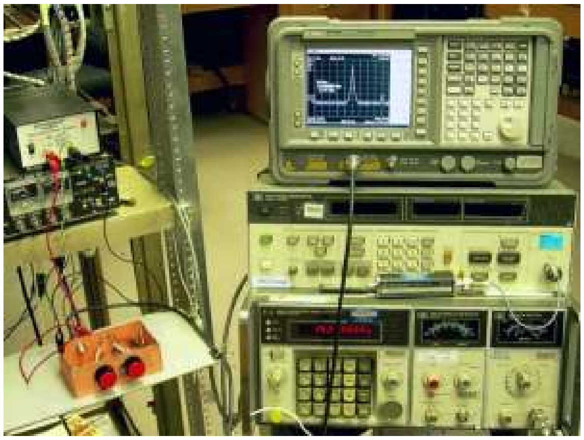
On a calculator:
dBm = 20log(1.59 x Vpp)

Example: *What is 0.5Vpp on a scope in dBm?*
dBm = 20log(1.59 x 0.5Vpp) = –2dBm
What is 1.5Vpp on a scope in dBm?
dBm = 20log(1.59 x 1.5Vpp) = +7.5dBm

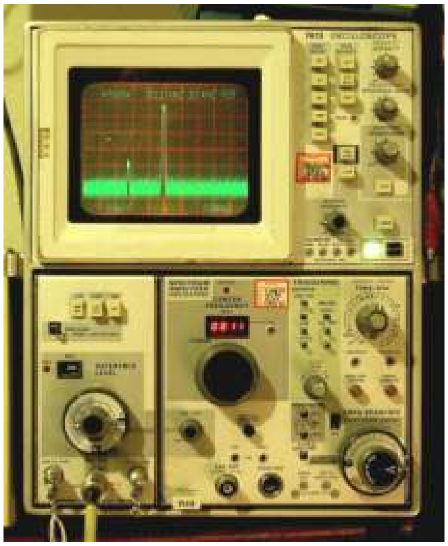
Testing Jason's prototype rig. The new Tek TDS3032 scope was borrowed for the waveform photos. The rest of the junk is is part of the NA5N QRP workbench.



The first prototype of the QRP–L.org group project rig and the hetrodyne VFO. The QRP rig was designed and built by Jason Milldrum, NT7S.



Some of the test equipment at the VLA observatory for testing the low band receiver upconverters (for 74, 196 and 327MHz receivers). The Agilent E4406 spectrum analyzer was used to test the hetrodyne VFO for spectral purity and phase noise.



A closer view of the Tektronix 7L13 spectrum analyzer, circa. 1970-1980s. This is one of the popular spectrum analyzers often found on the used market.