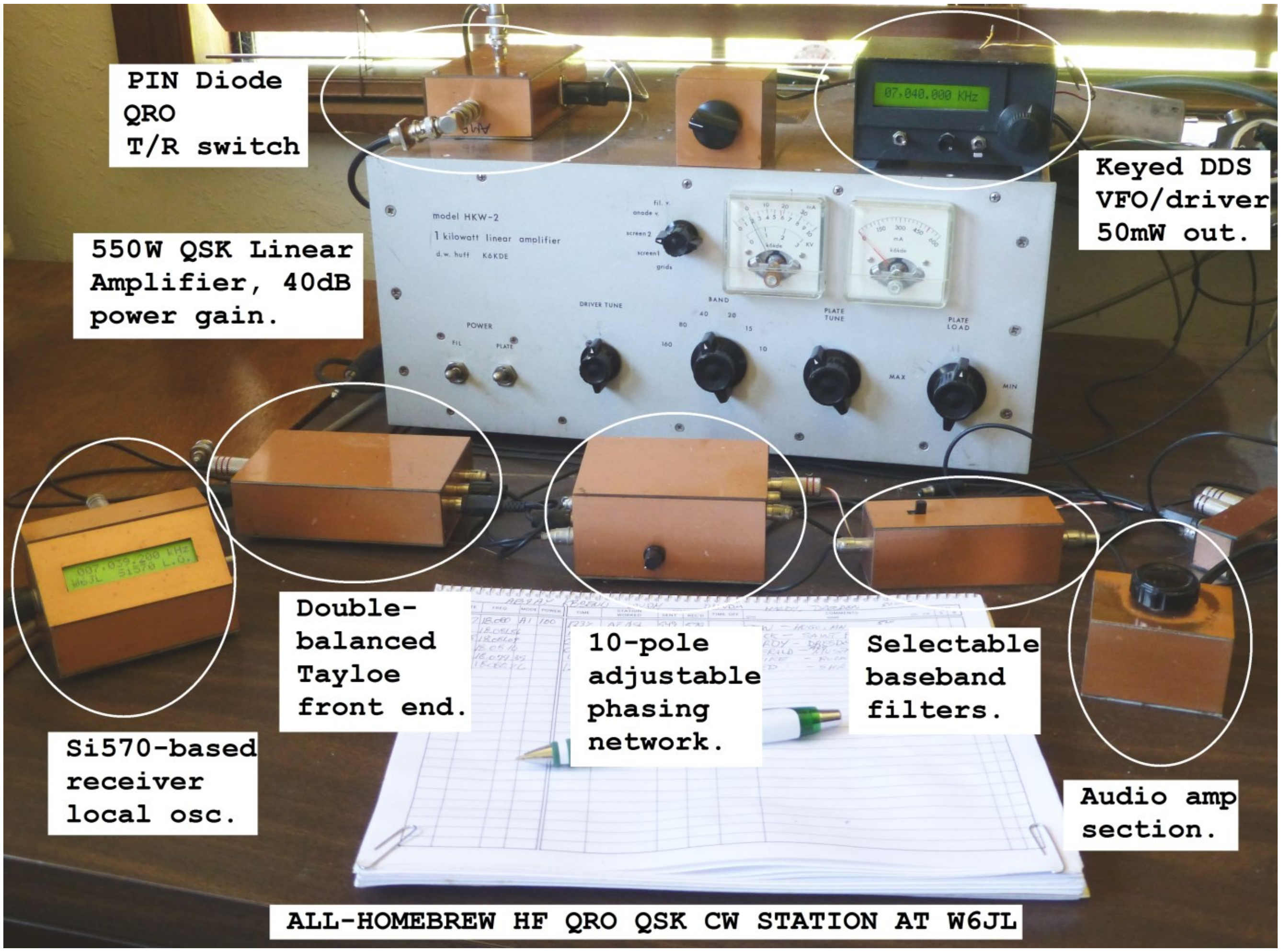
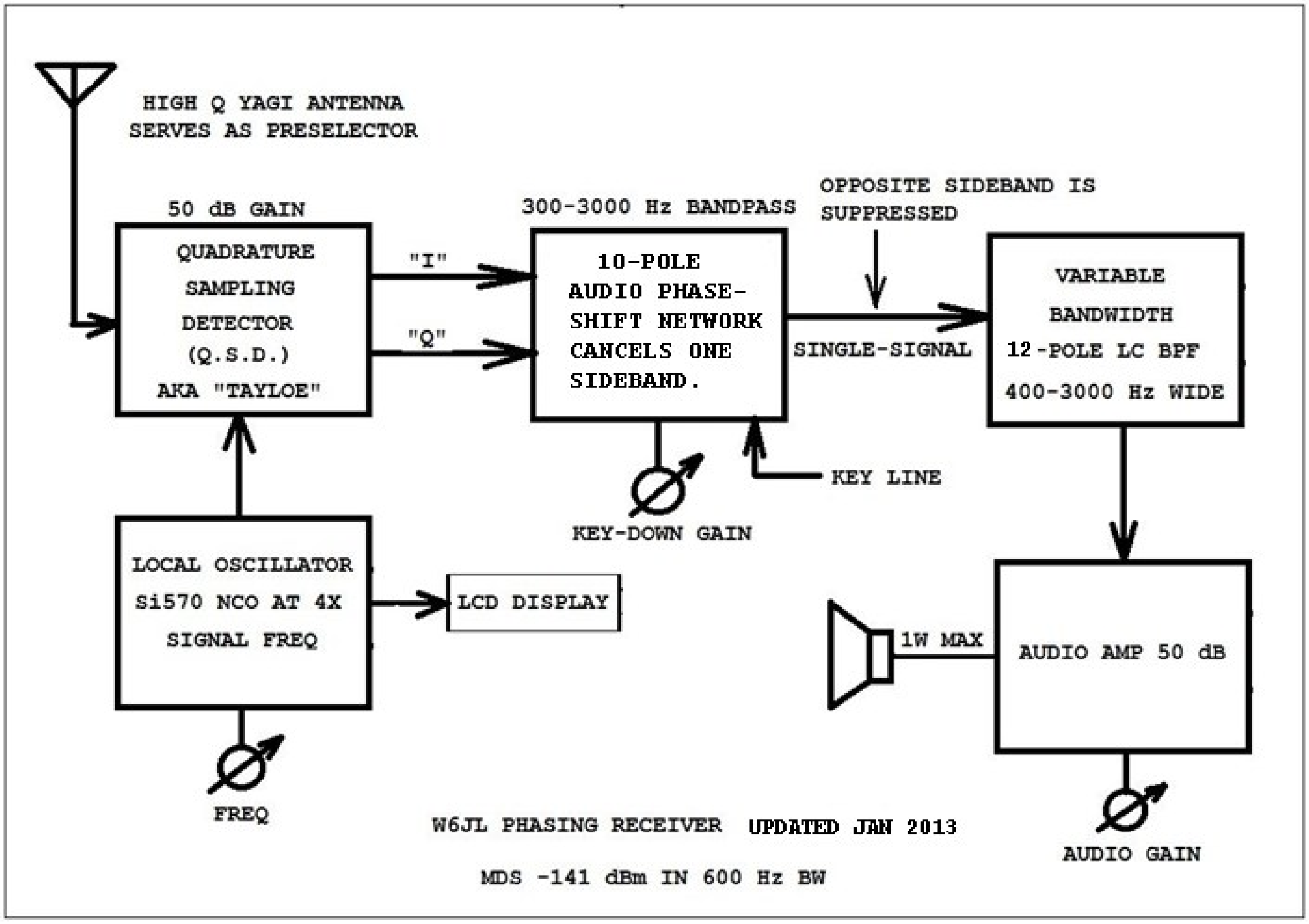
HOMEBREW QSK QRO CW STATION AT W6JL
USING A PHASING RECEIVER WITH "TAYLOE" FRONT END
and Si570 VFO AS LOCAL OSCILLATOR.
1 September 2015 update



Homebrew station at W6JL. 550W output, using a keyed AD9850 DDS VFO. HB amplifier is one I built in 1972 and has 40 dB of power gain (10,000). (Homebrew rigs last forever :o)). The all band phasing receiver uses a double-balanced version of the Tayloe (also known as a Quadrature Sampling Detector, Q.S.D.) front end. The receiver is contained in the boxes shown. The Tayloe replaces the lossy dual ring balanced mixers, quadrature high level L.O's; power splitter, LC diplexers, and post mixer attenuators used in previous phasing receiver designs. This receiver's MDS is less than -142dBm, using no RF gain whatsoever. This is an equivalent noise figure of under 7 dB. Like most phasing receivers, it has beautiful audio. The receiver has 4 controls, all falling where my hands naturally lie on the operating desk. This is why the receiver is spread out. I don't care for tiny (especially vertical) front knobs and buttons; I find them uncomfortable to use. As usual, if you want things *your* way, you build it! The receiver has plug-in phase shift networks to enable experimenting with different types of phasing networks. PC boards are homebrew single-side etched with copper ground plane back side, with etched side tin-plated.

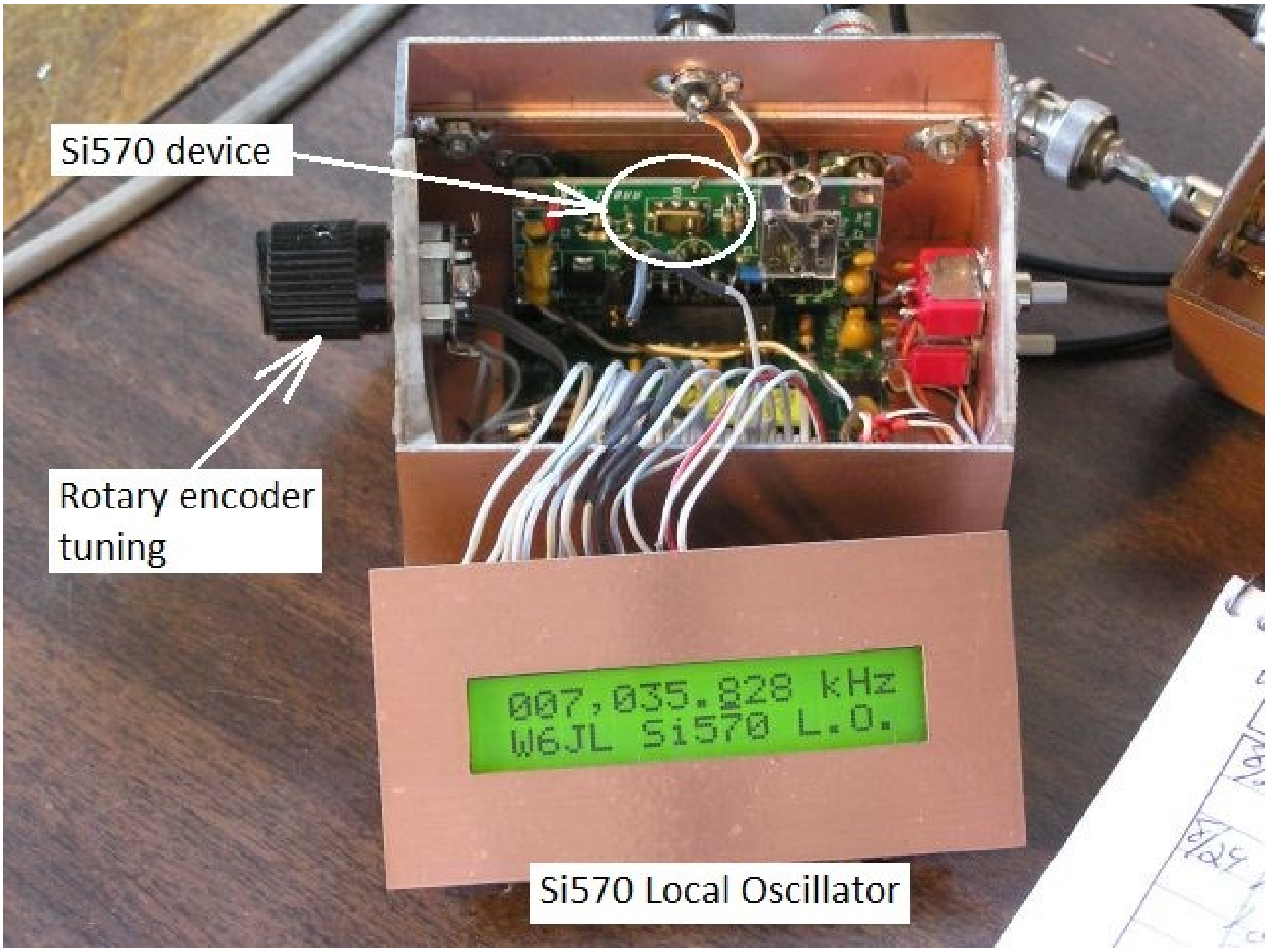
W6JL PHASING RECEIVER

(Shown with 10-pole all-pass phase shift network)

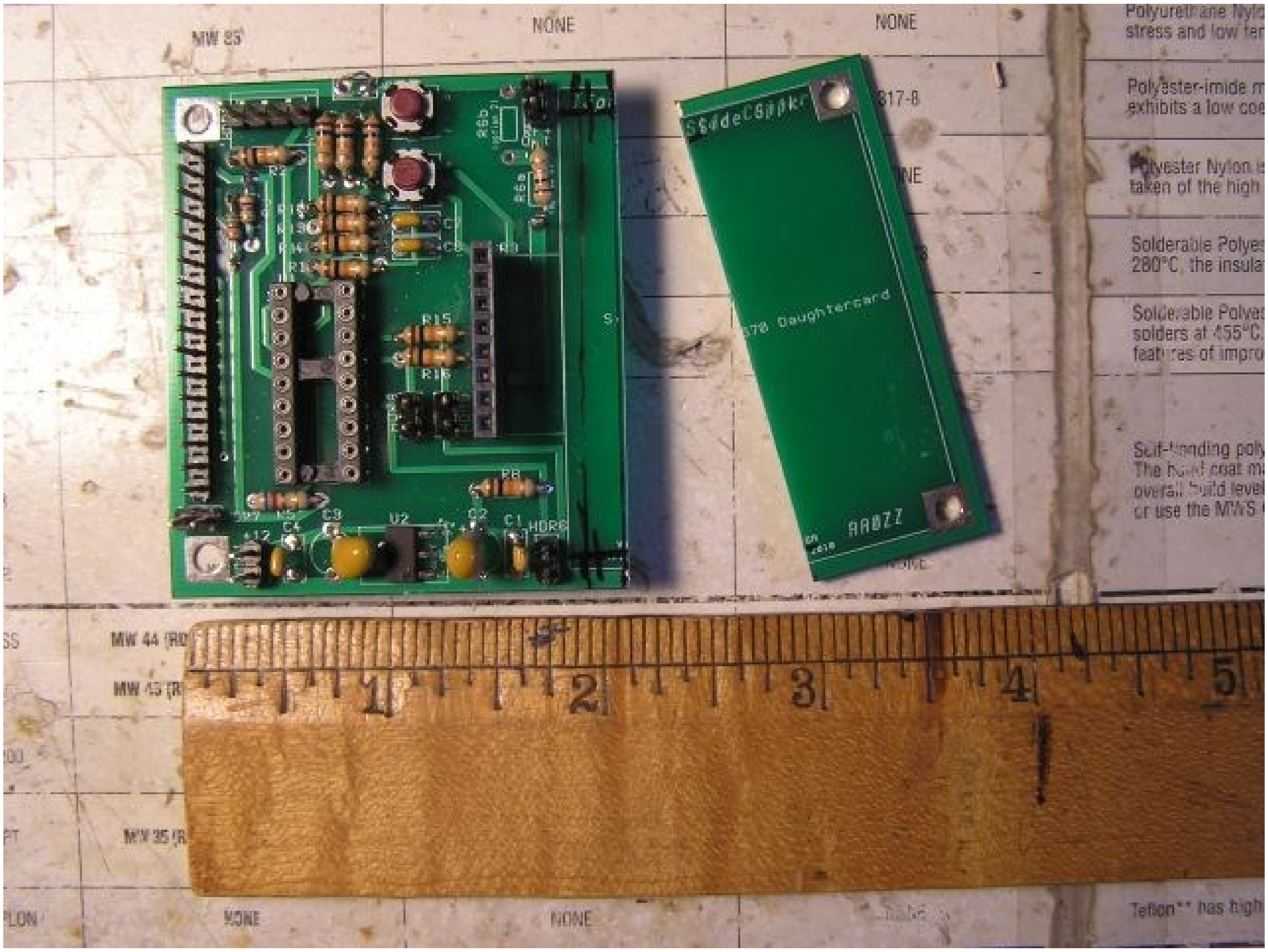


W6JL Phasing Receiver simplified block diagram.

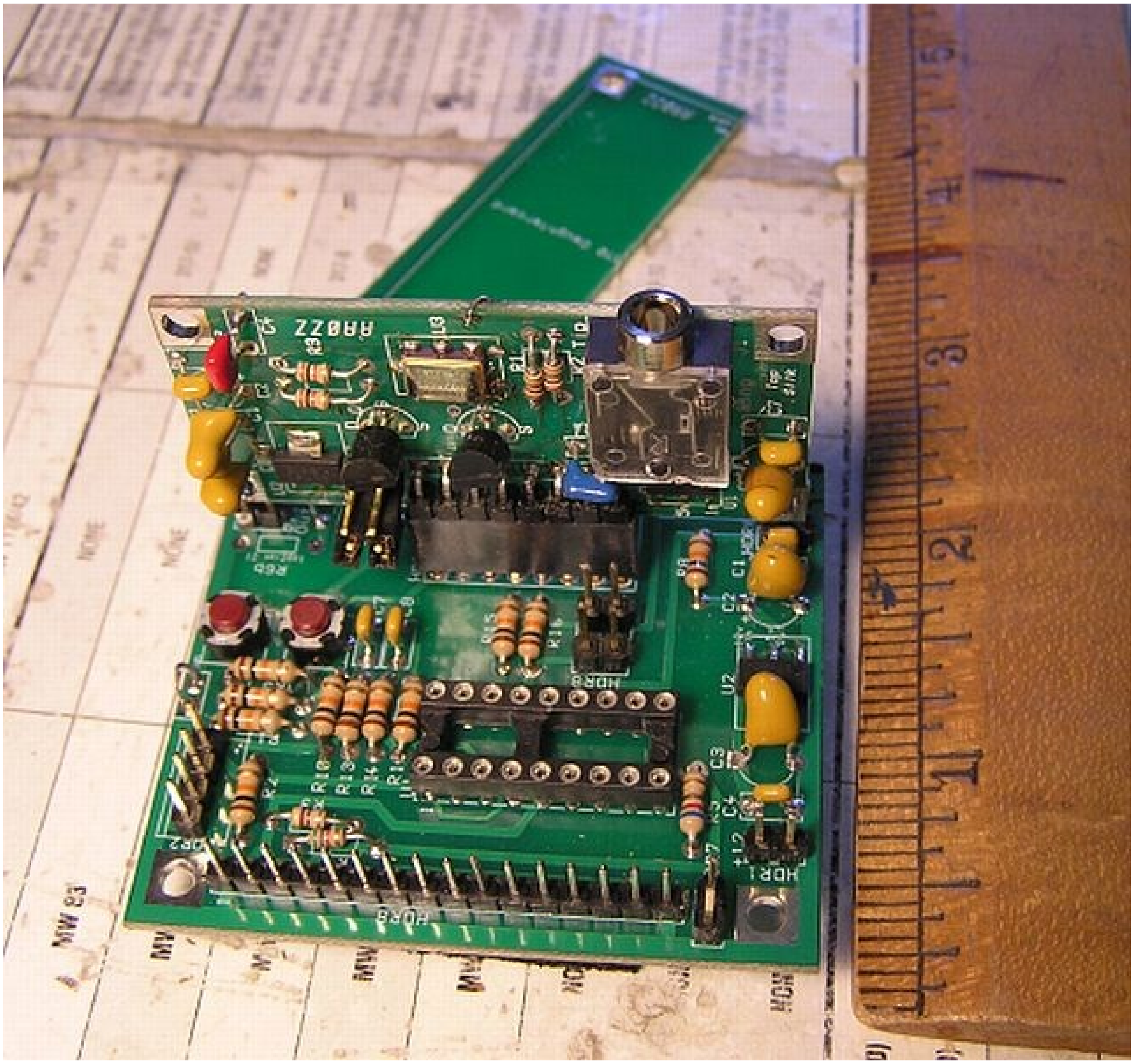
Local Oscillator:



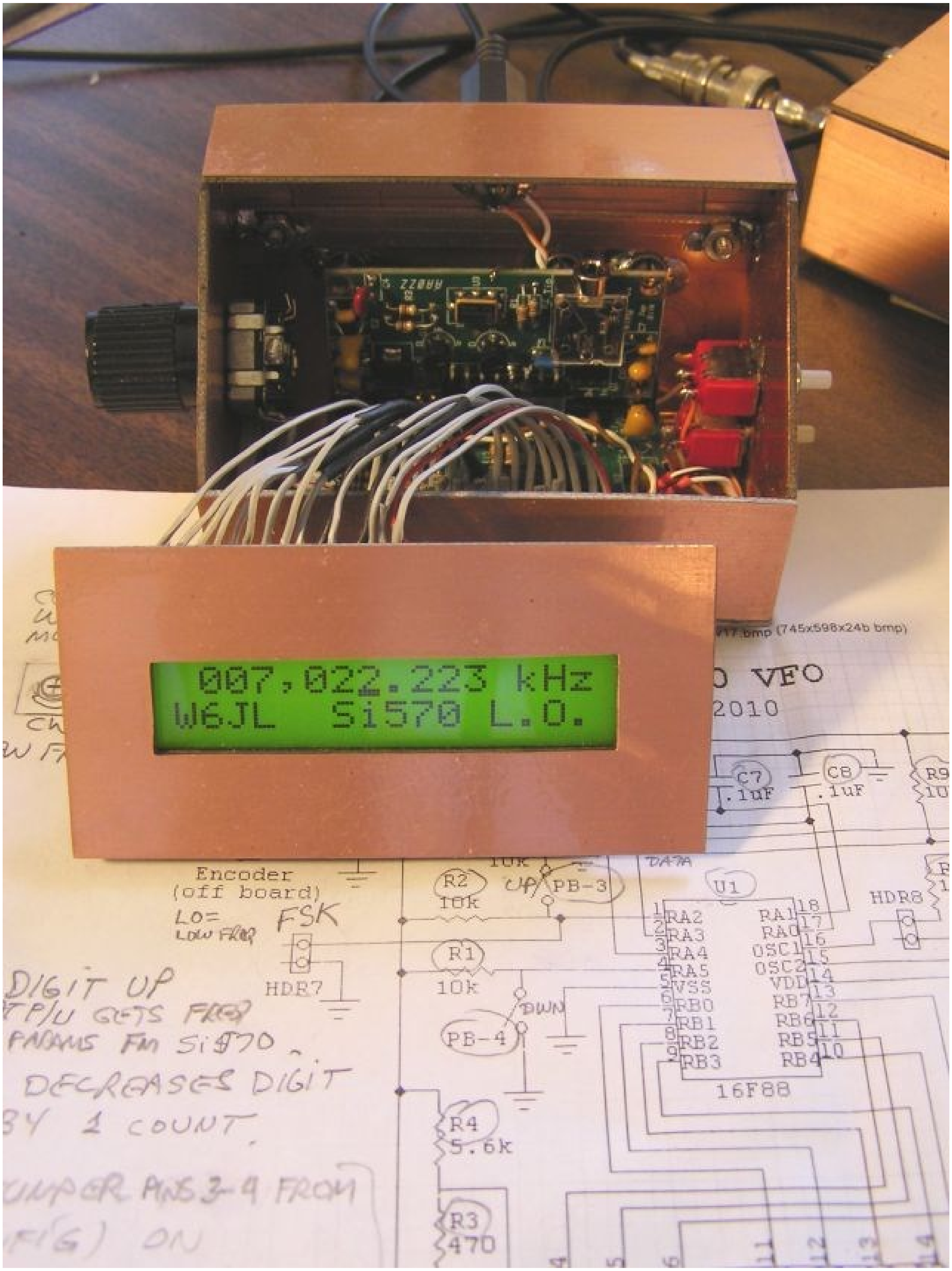
Si570 L.O. interior. This is built from Craig, AA0ZZ's Si570 VFO board, see http://cbjohn.com/aa0zz/index.html and http://www.kangaus.com/si570_project.htm. I cut off the back end of Craig's board, making it a two-piece board, so as to enable fitting in this homebrew enclosure. I also modified Craig's PIC16F88 source code slightly, to put my callsign on the LCD and format the frequency readout to my liking. The Si570 has much lower spurs and phase noise than a DDS, and a much higher maximum frequency, making it ideal for a double-balanced Tayloe receiver using an L.O. Running at 4X the signal frequency. Copper-clad boxes are easy and inexpensive to build of most any size and shape, and make excellent RF shielded enclosures. Placing the rotary encoder tuning on the left side makes it easier to tune in actual use, than being on the front panel. When you homebrew, you have complete control over the electronic features and physical arrangement of your rig. You do not have to settle for what some other designer thought was best for you, in *your* rig.



I cut off the top of the AA0ZZ Si570 control board so as to mount the Si570 daughter-card vertical instead of horizontal, to save space.

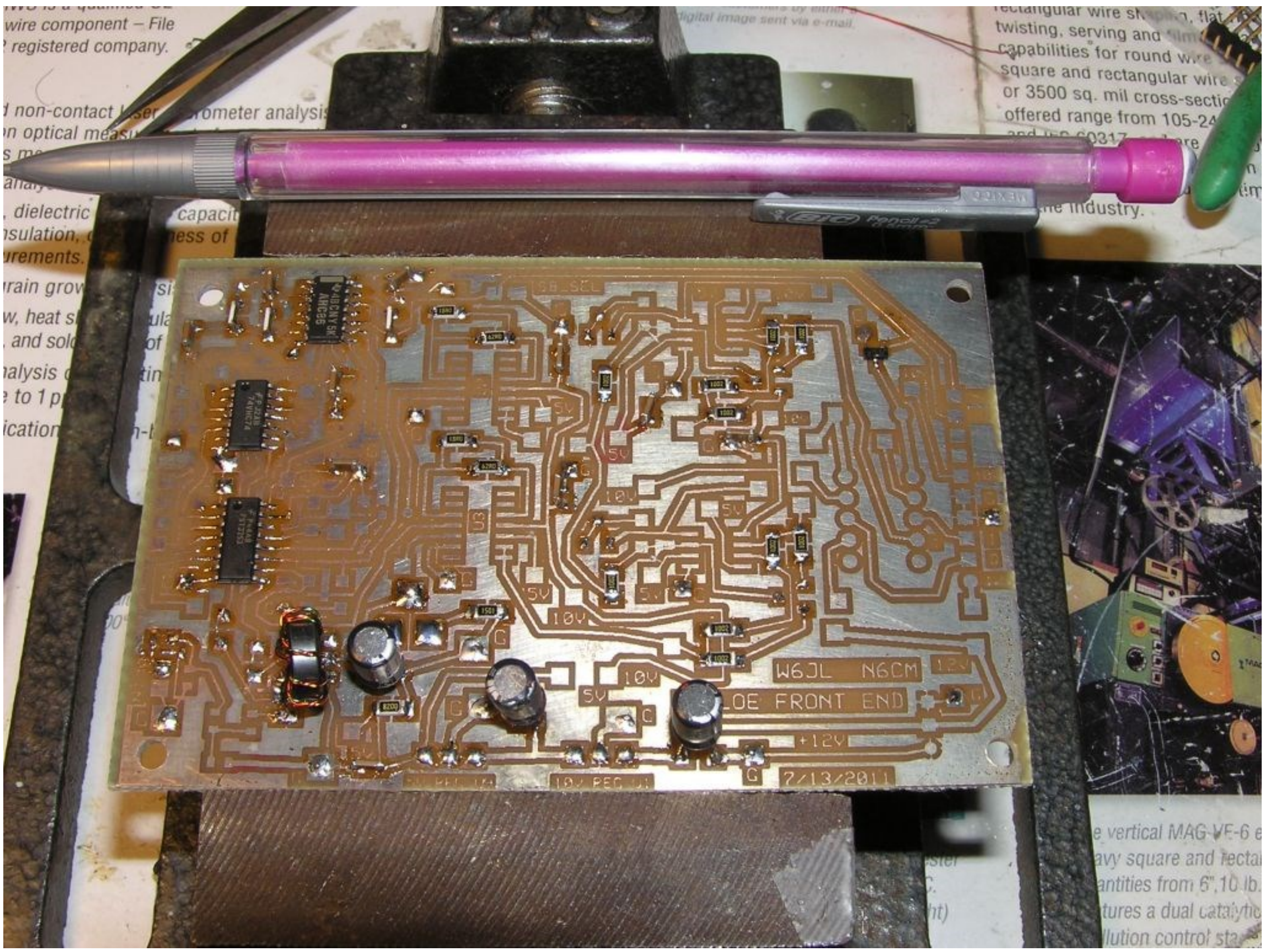


Modified AA0ZZ Si570 board, with daughtercard now vertically plugged In.

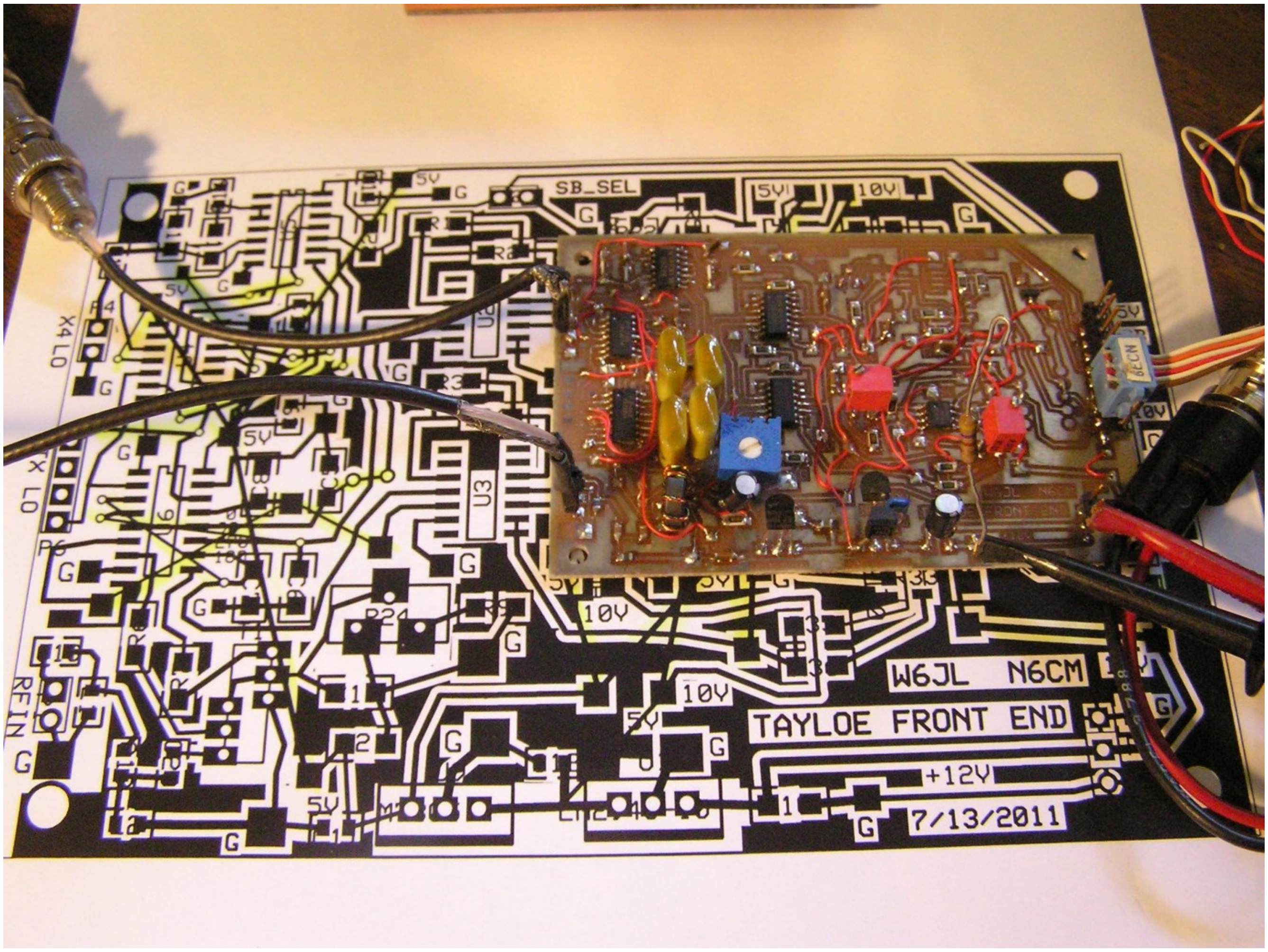


Modified AA0ZZ Si570 board mounted in HB enclosure.

TAYLOE (Q.S.D.) FRONT END:

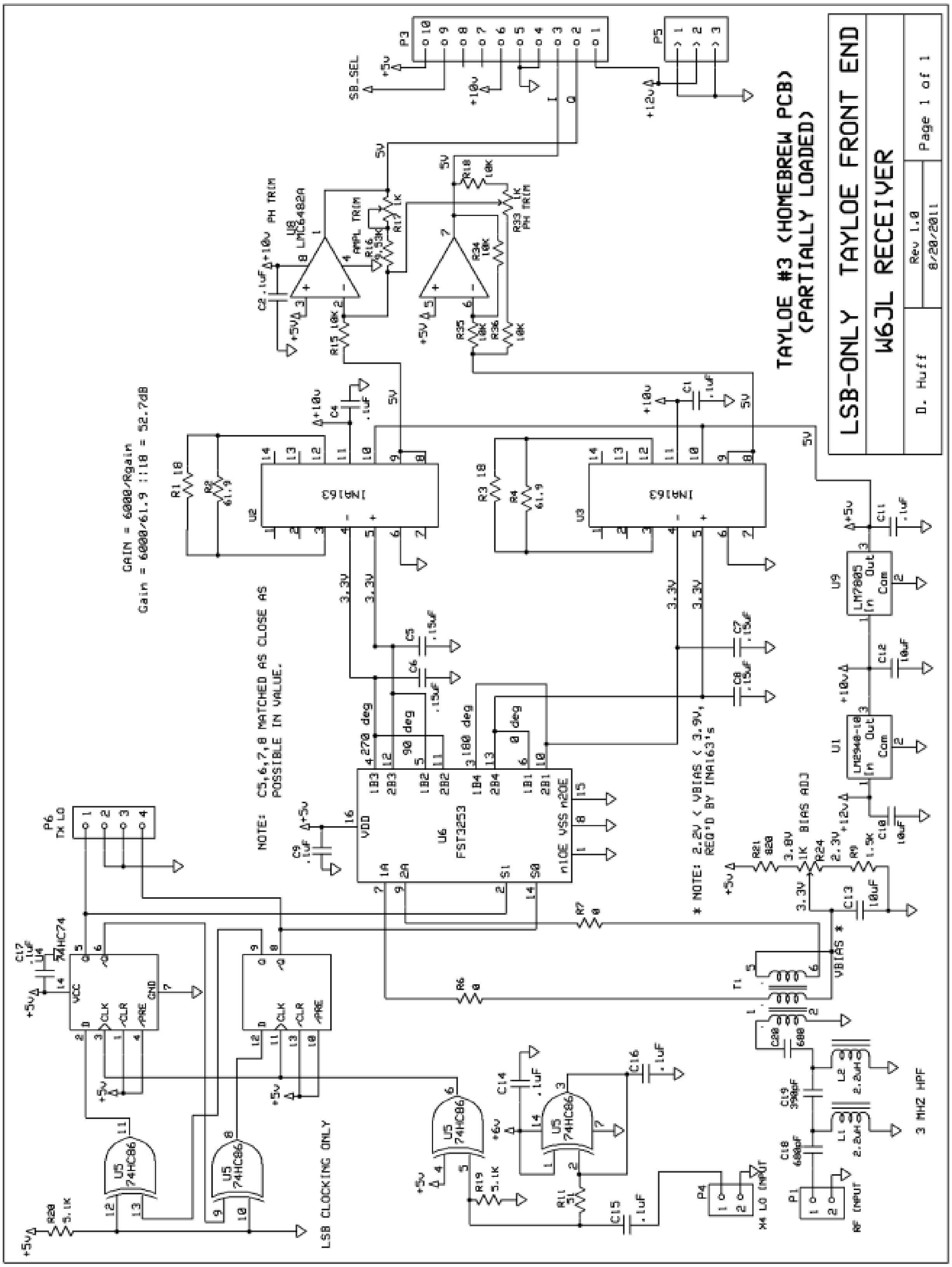


HB Tayloe front end board being loaded.



Working board, on copy of its PC mask.

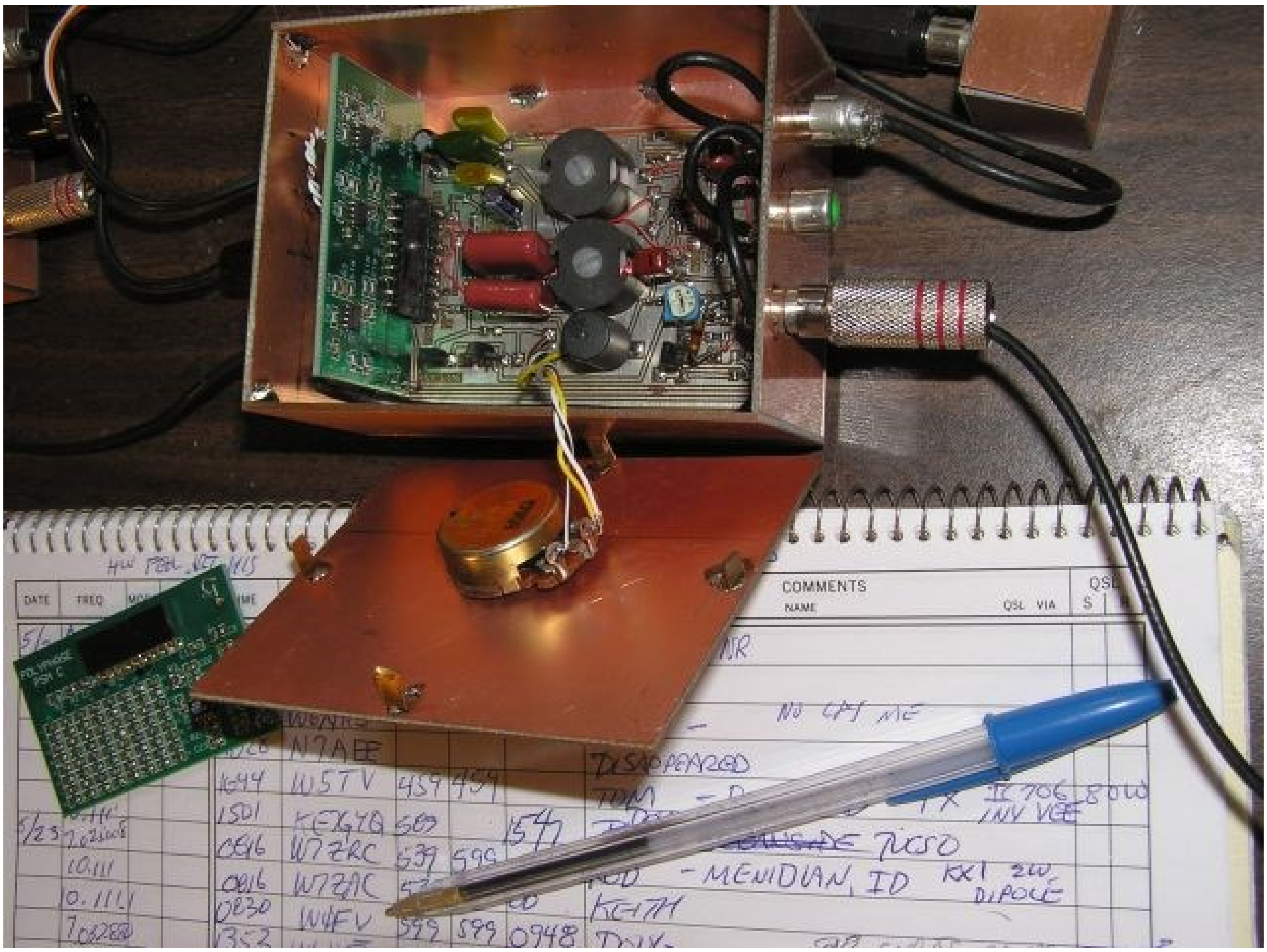
Tayloe front end, mounted in shield box. Partially loaded for LSB only.



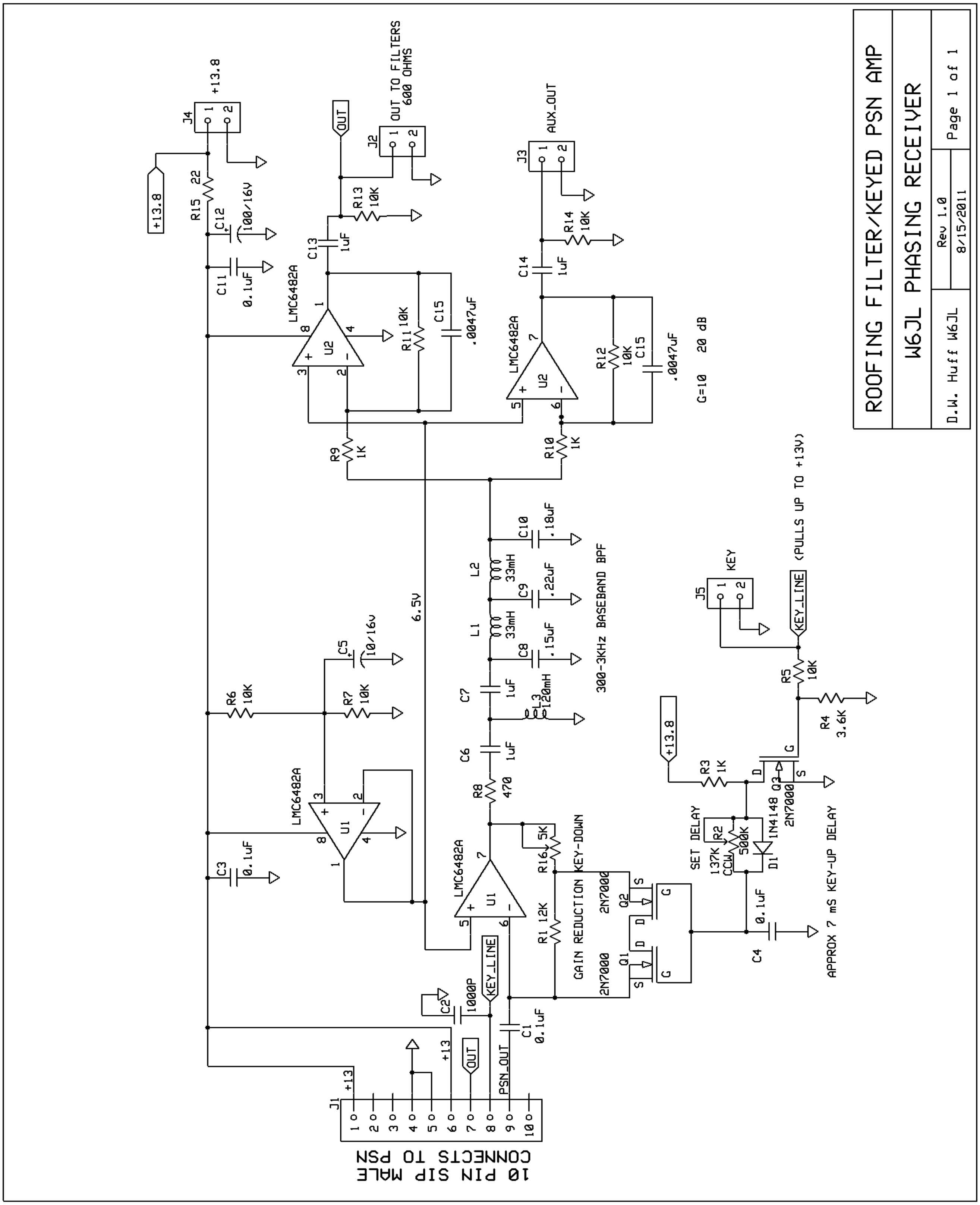
Schematic of double-balanced Tayloe (aka Q.S.D.) front end, configured for LSB-only operation on CW, HF bands.

The Tayloe, or Quadrature Sampling Detector (Q.S.D.), is a simple but elegant (I would even say amazing) circuit popularized in recent years by Dan Tayloe, N7VE. It has revolutionized (at least for me) the building of homebrew phasing receivers for both hardware defined (HDR, like this one), and software defined (SDR) architectures. For a descriptive paper by Dan Tayloe on how this circuit works, see: http://www.norcalqrp.org/files/Tayloe_mixer_x3a.pdf

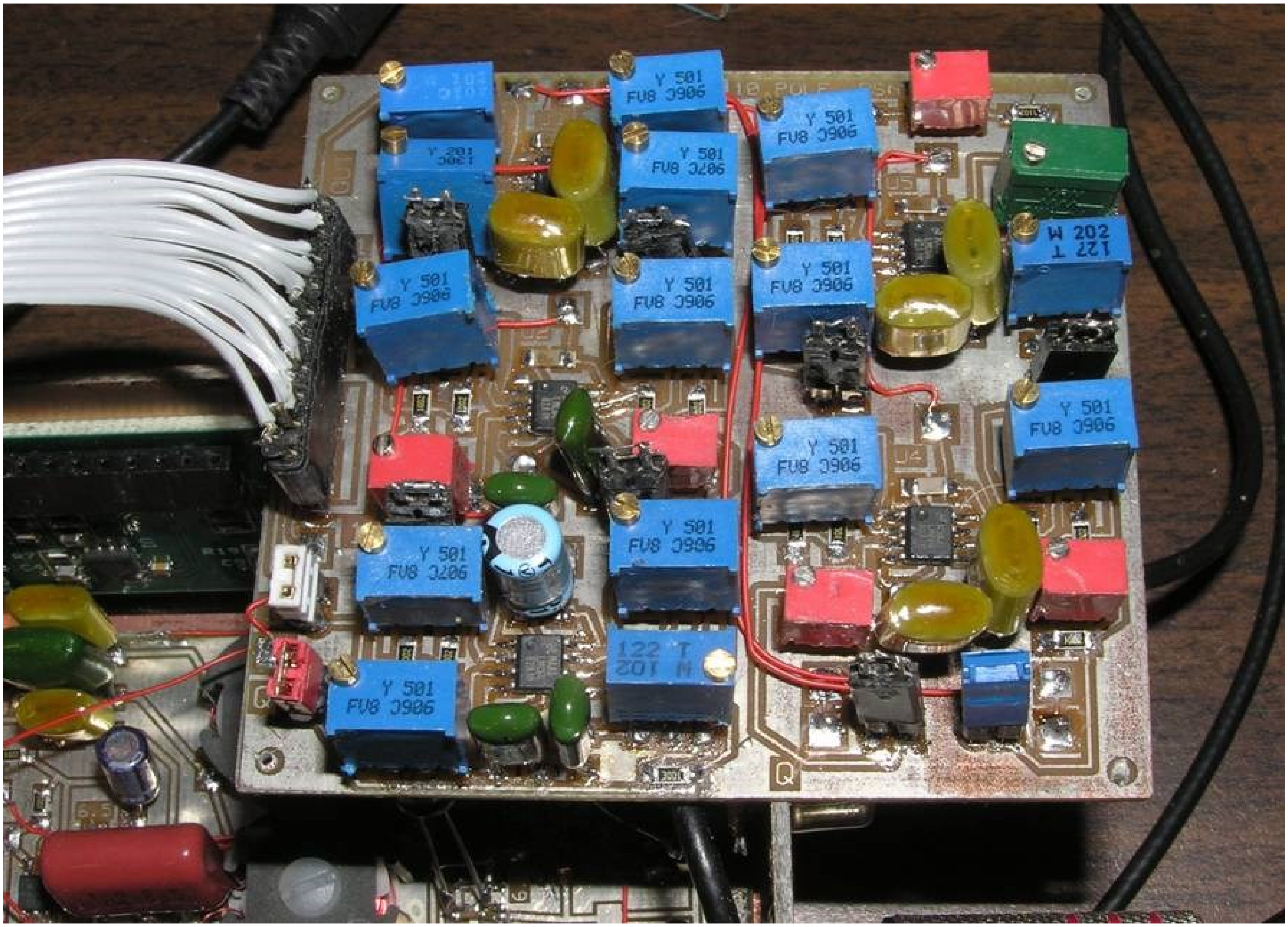
PHASING SECTION WITH PLUG-IN PHASE SHIFT NETWORKS:



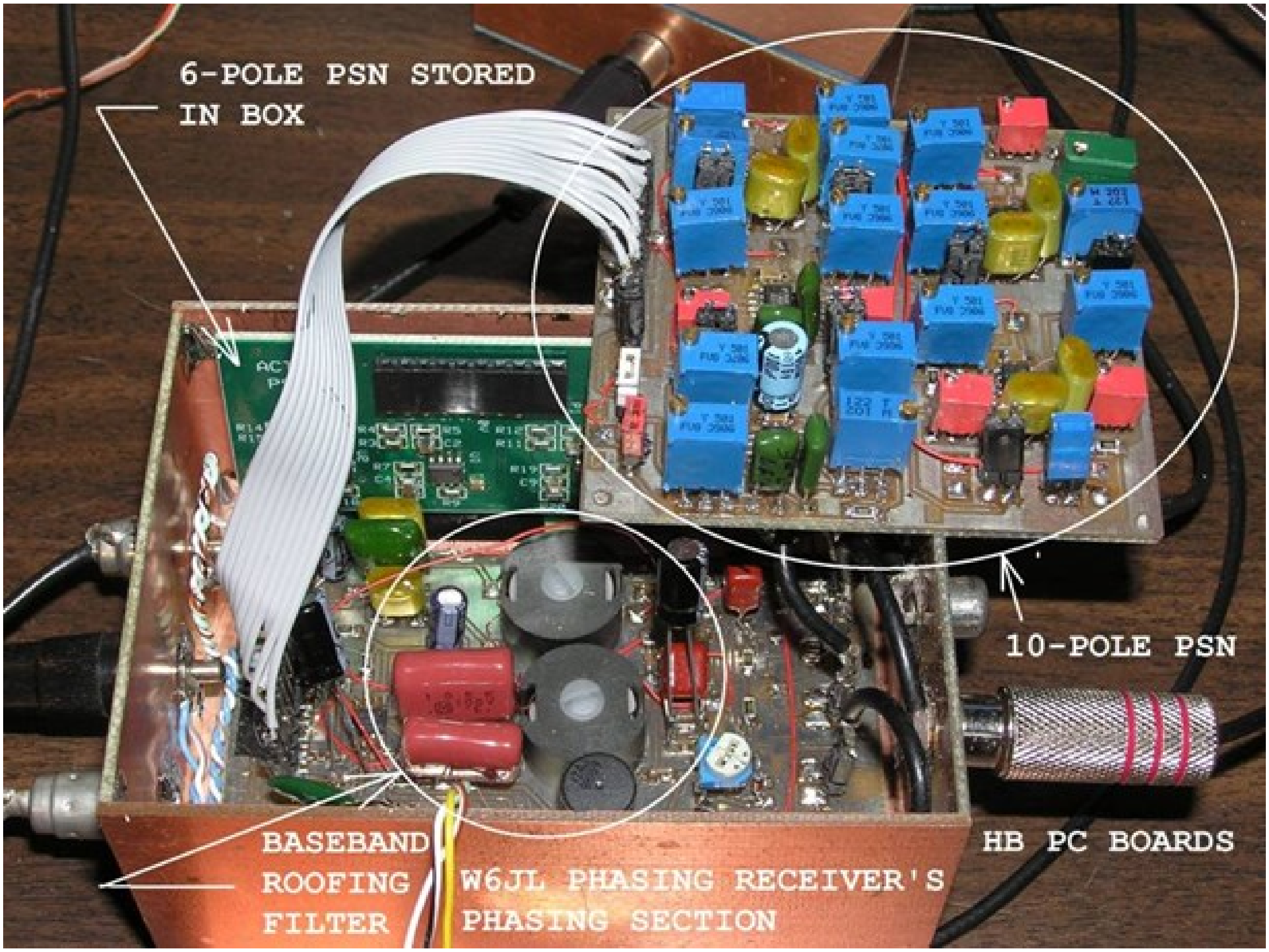
Receiver phasing and amplifier section. Uses plug-in phasing networks to facilitate experimenting with various phase shift networks. A 6-pole all-pass and a 8-pole polyphase network as well as a 10-pole all-pass network have been built, the first two using 0.1% tolerance hand-matched components. The main board is homebrewed and tin-plated. The pot sets the level of the key-down signal as heard in the receiver, using the PIN diode QSK system.



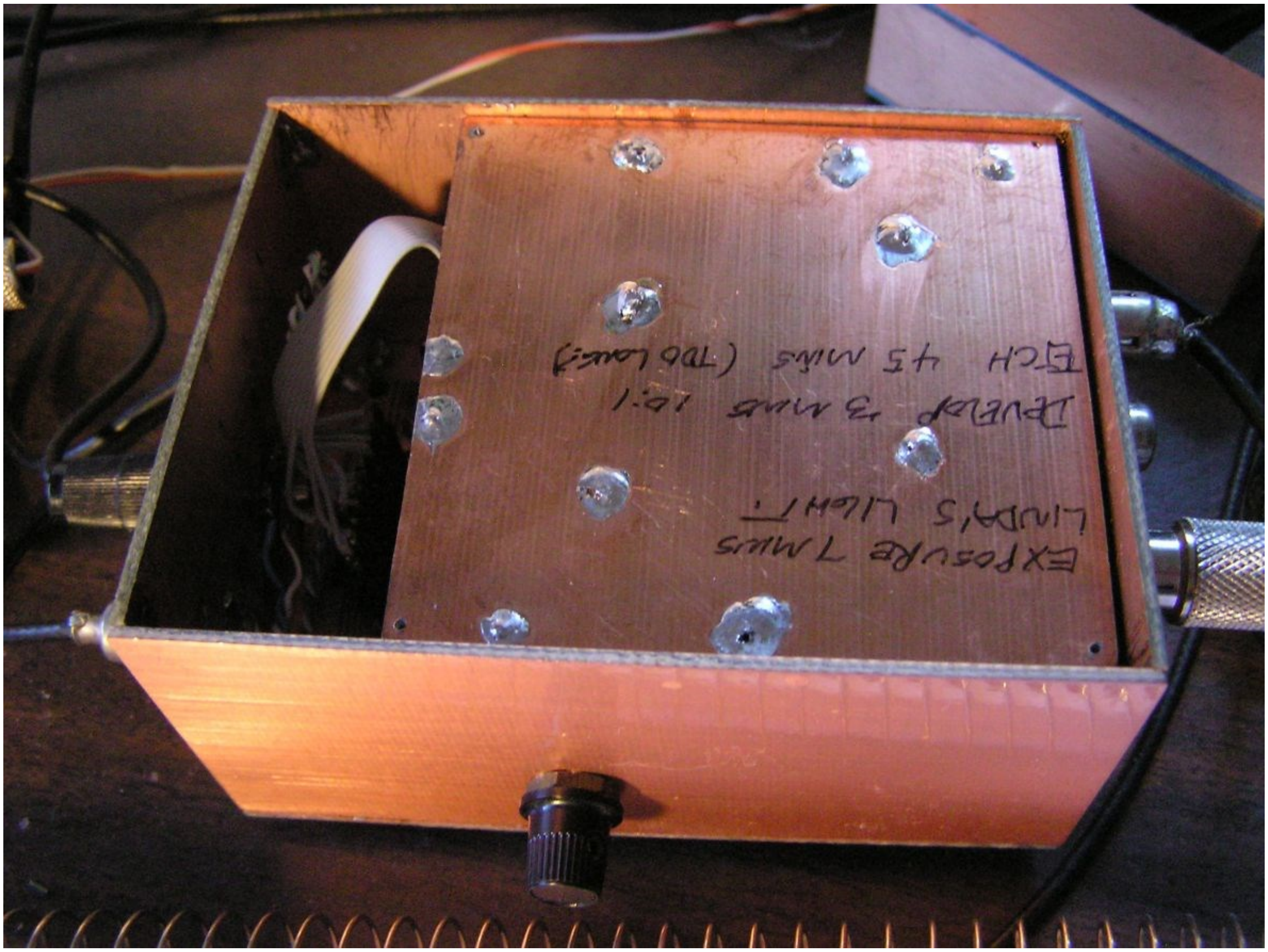
W6JL Receiver phasing section schematic, with baseband roofing filter and QSK gain reduction.



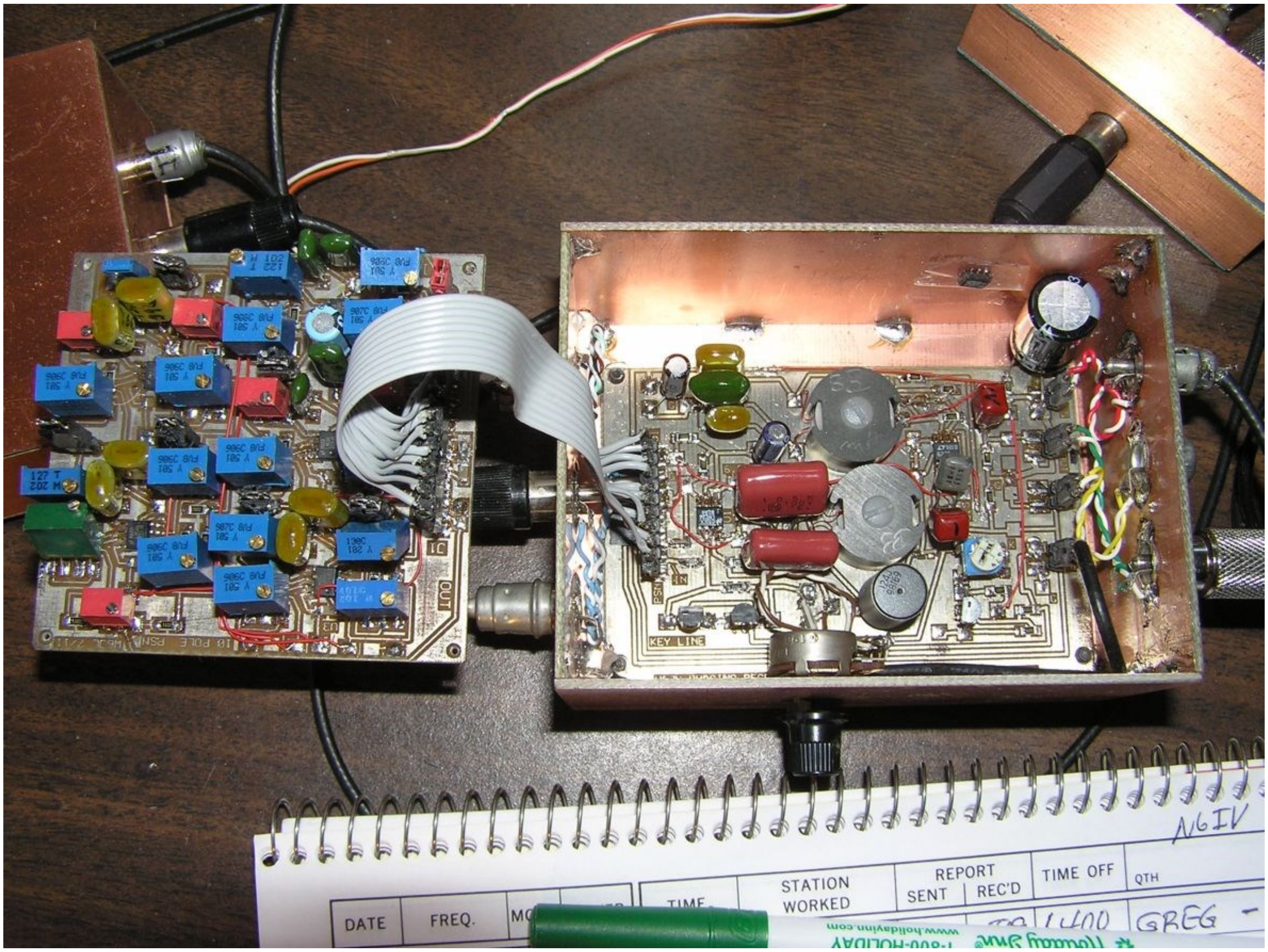
10-pole adjustable all-pass phasing network on HB PC board.



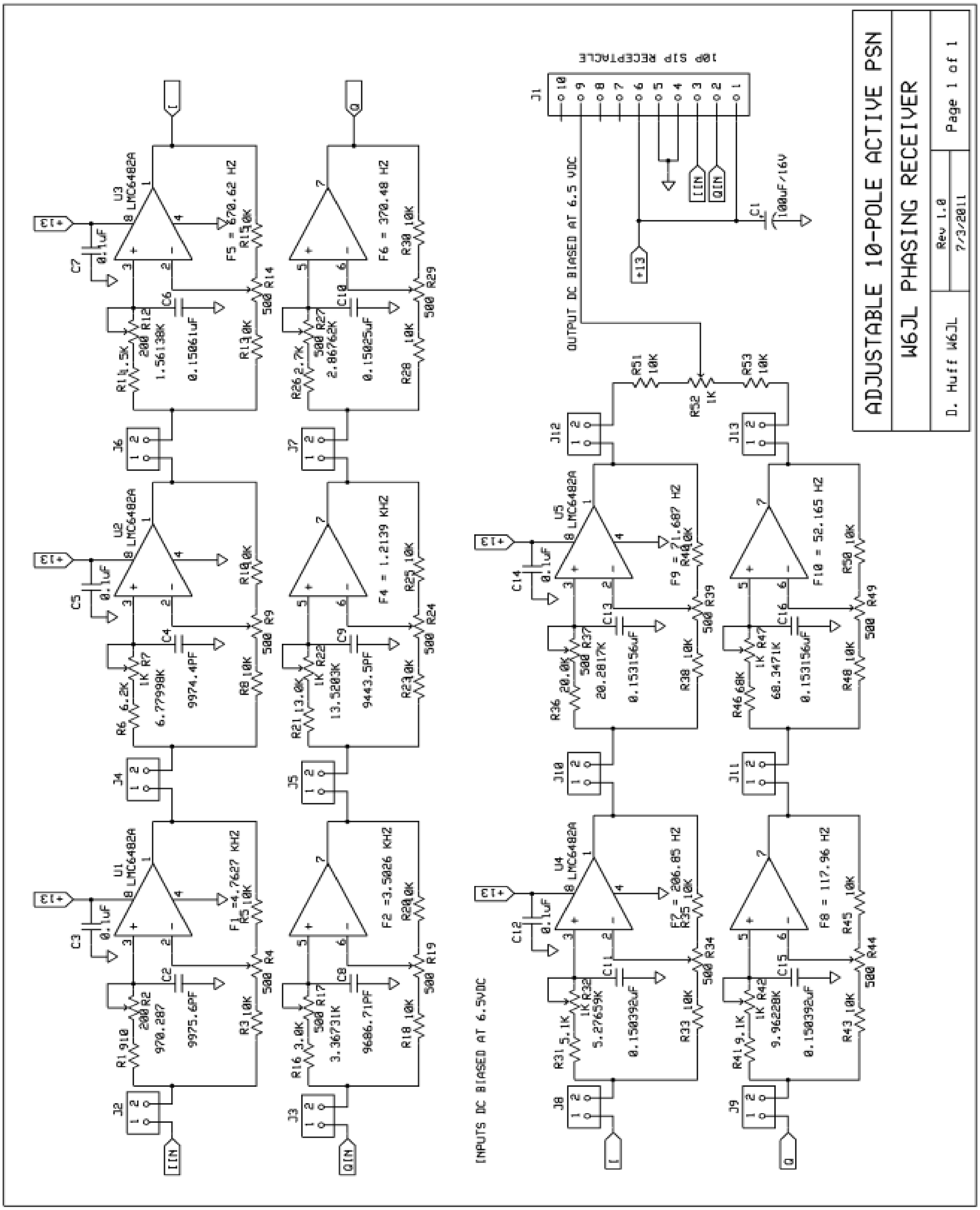
W6JL receiver with phasing section module and 10-pole adjustable all-pass PSN attached, both on HB PC boards.



Phasing section with 10P PSN installed inverted.

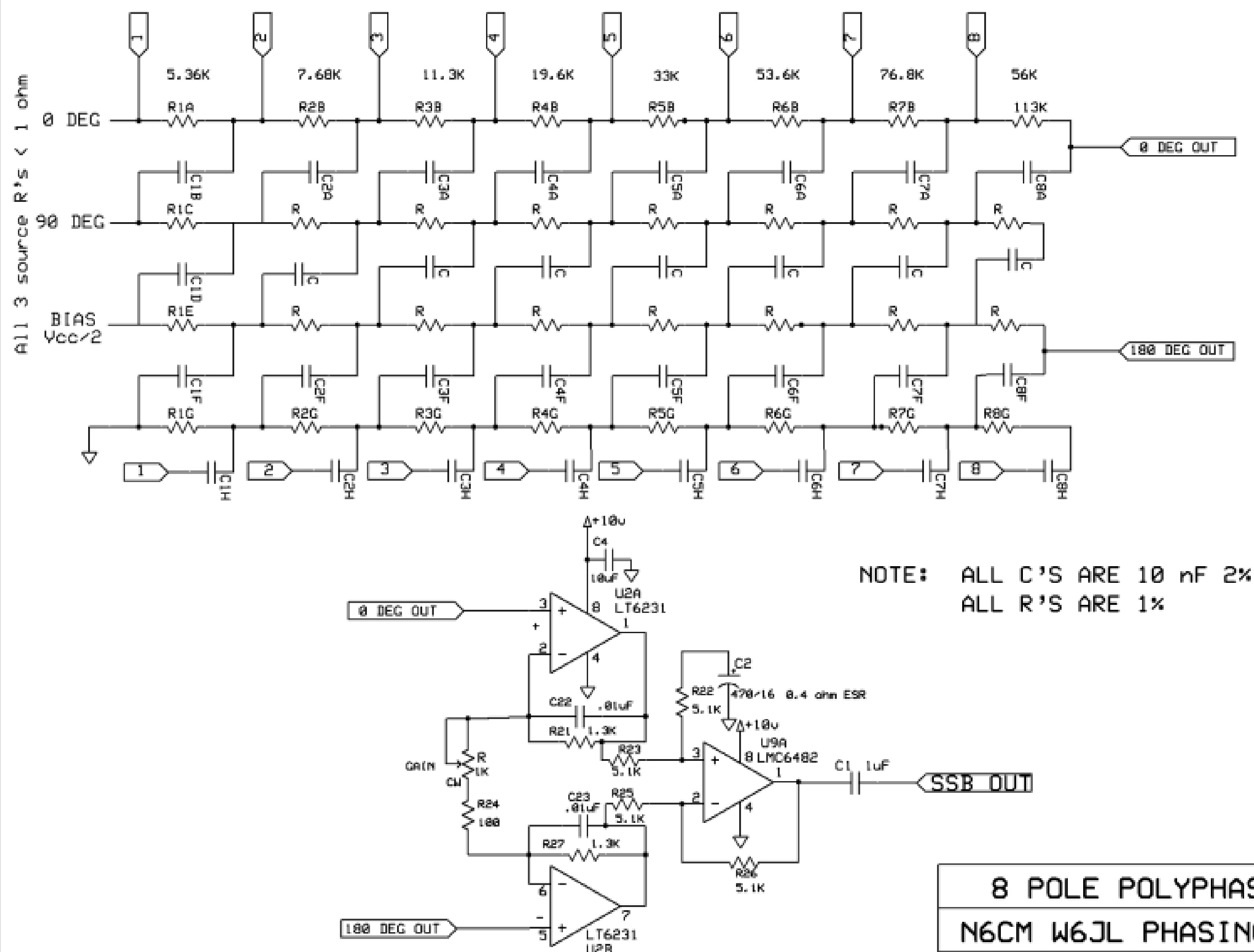


Phasing section with 10 pole PSN opened outward.



10-Pole all-pass adjustable phase shift network schematic.

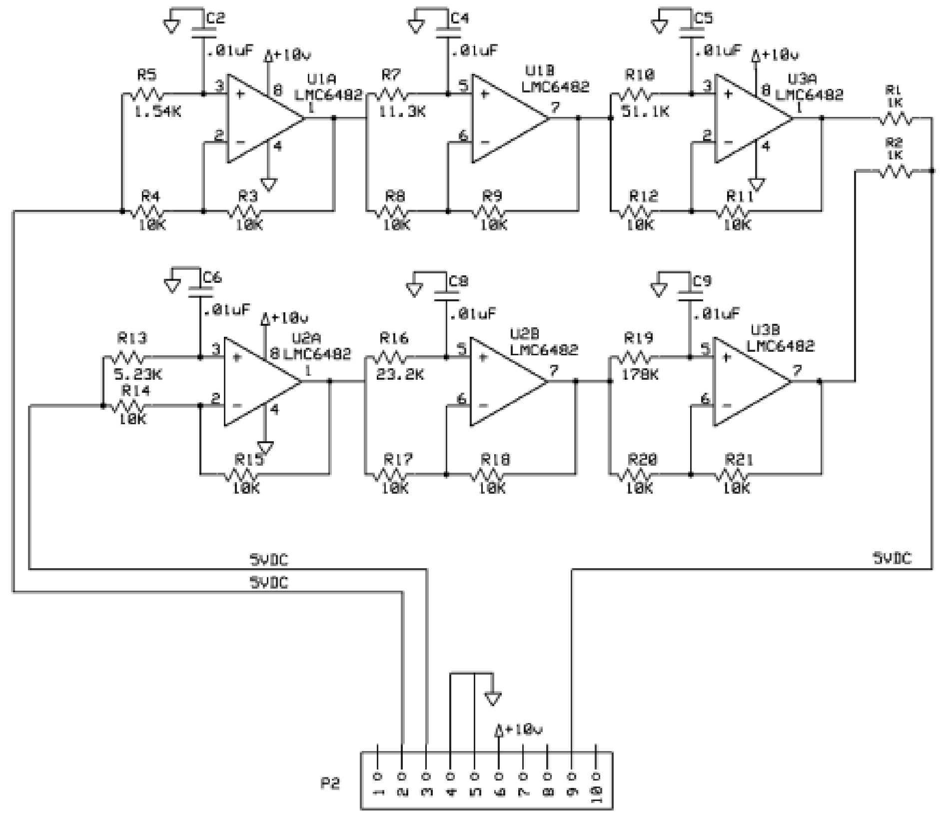
W6JL Receiver's Phasing Section, with three alternate plug-in phasing boards. The 10-pole all-pass is on a homebrew board, and uses twenty 10-turn pots to set ten gains and ten null frequencies.



NOTE: ALL C'S ARE 10 nF 2%
ALL R'S ARE 1%

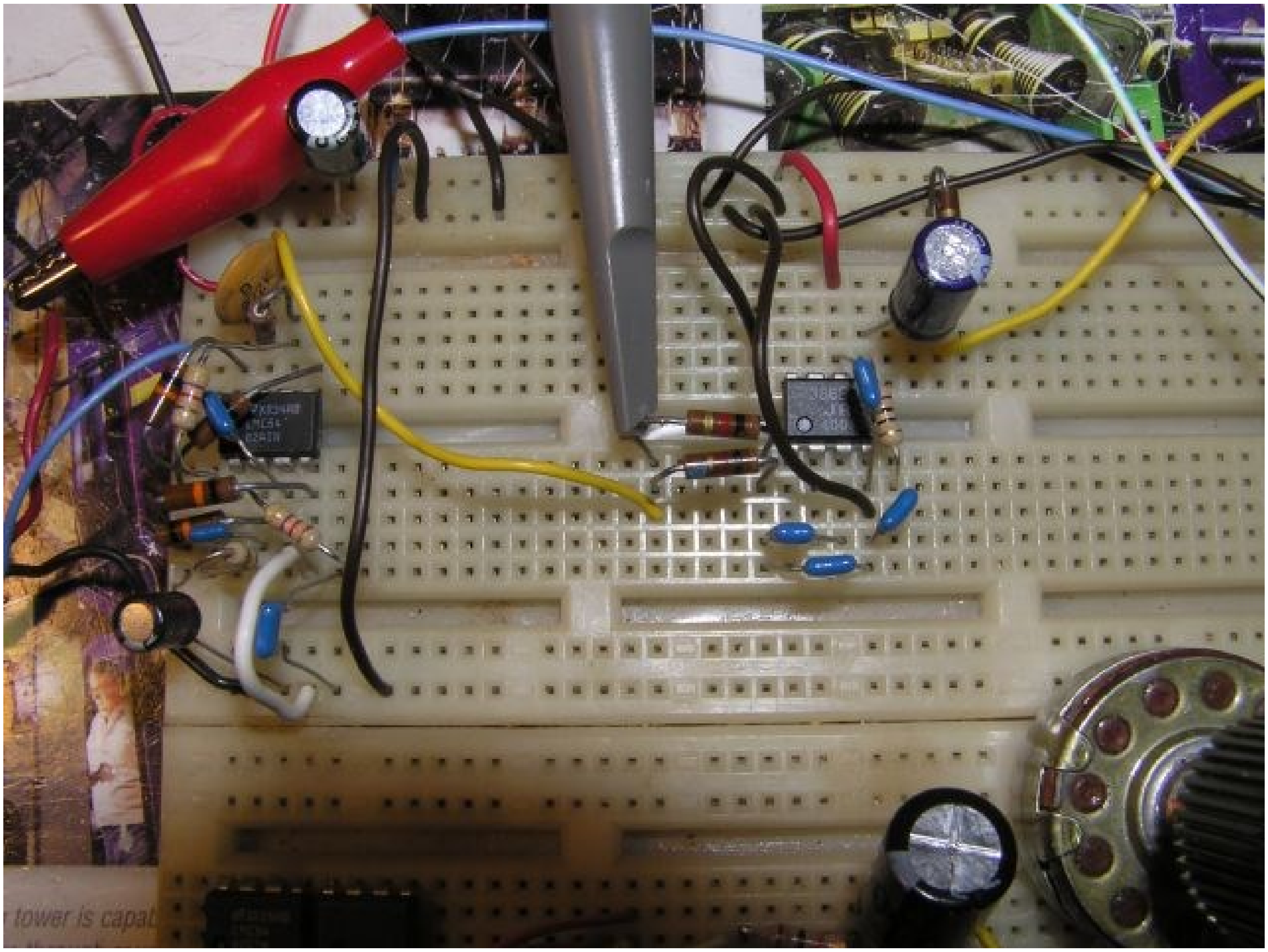
ALL CAPS ARE 10.0nF +/-1%

8 POLE POLYPHASE BOARD		
N6CM W6JL PHASING RECEIVER		
Don Huff	Rev 1.0 8/18/2009	Page 1 of 1

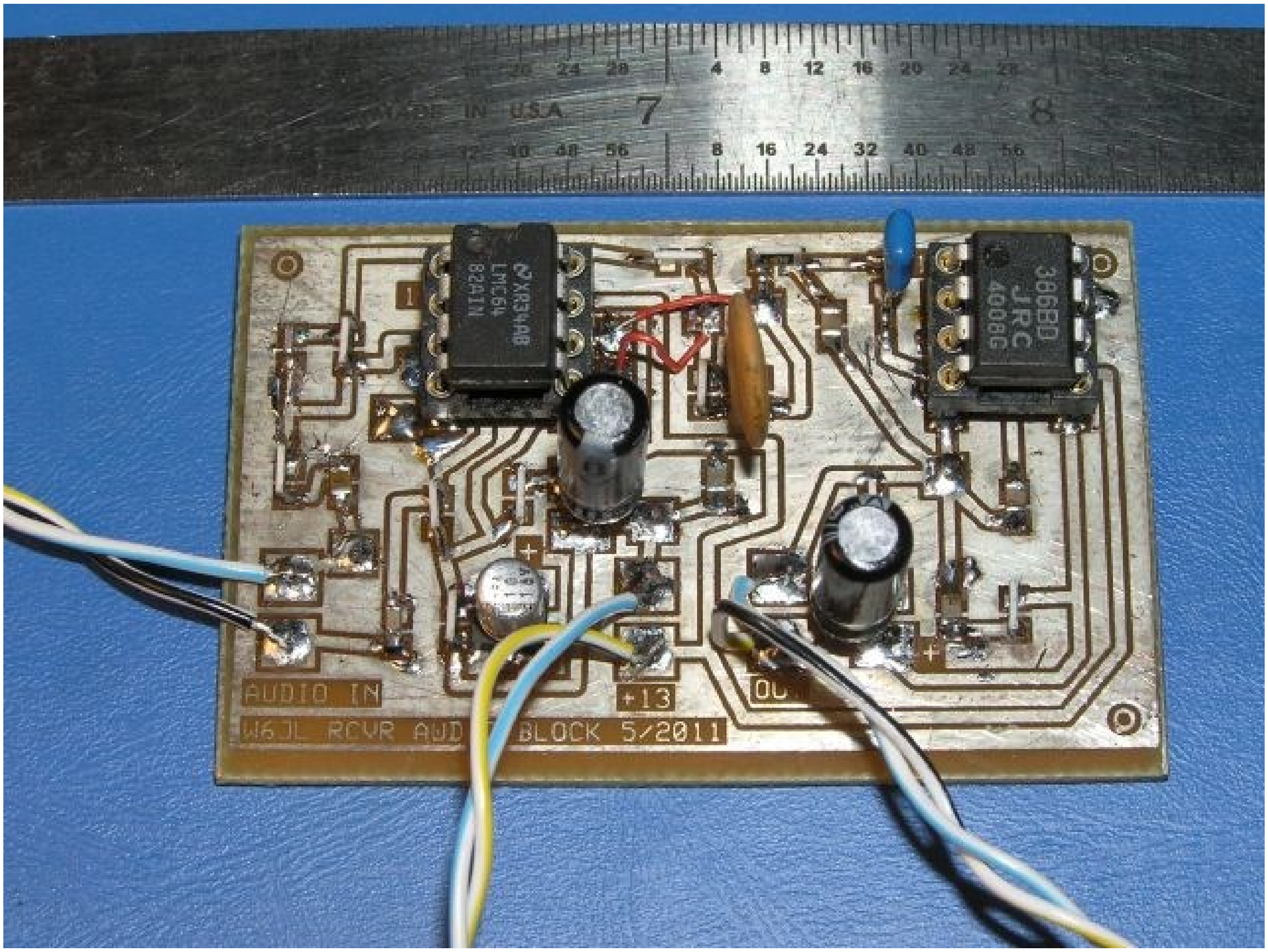


6-POLE PHASE SHIFT NETWORK		
W6JL PHASING RECEIVER		
N6CM W6JL	Rev 1.0 11/09/2009	Page 1 of 1

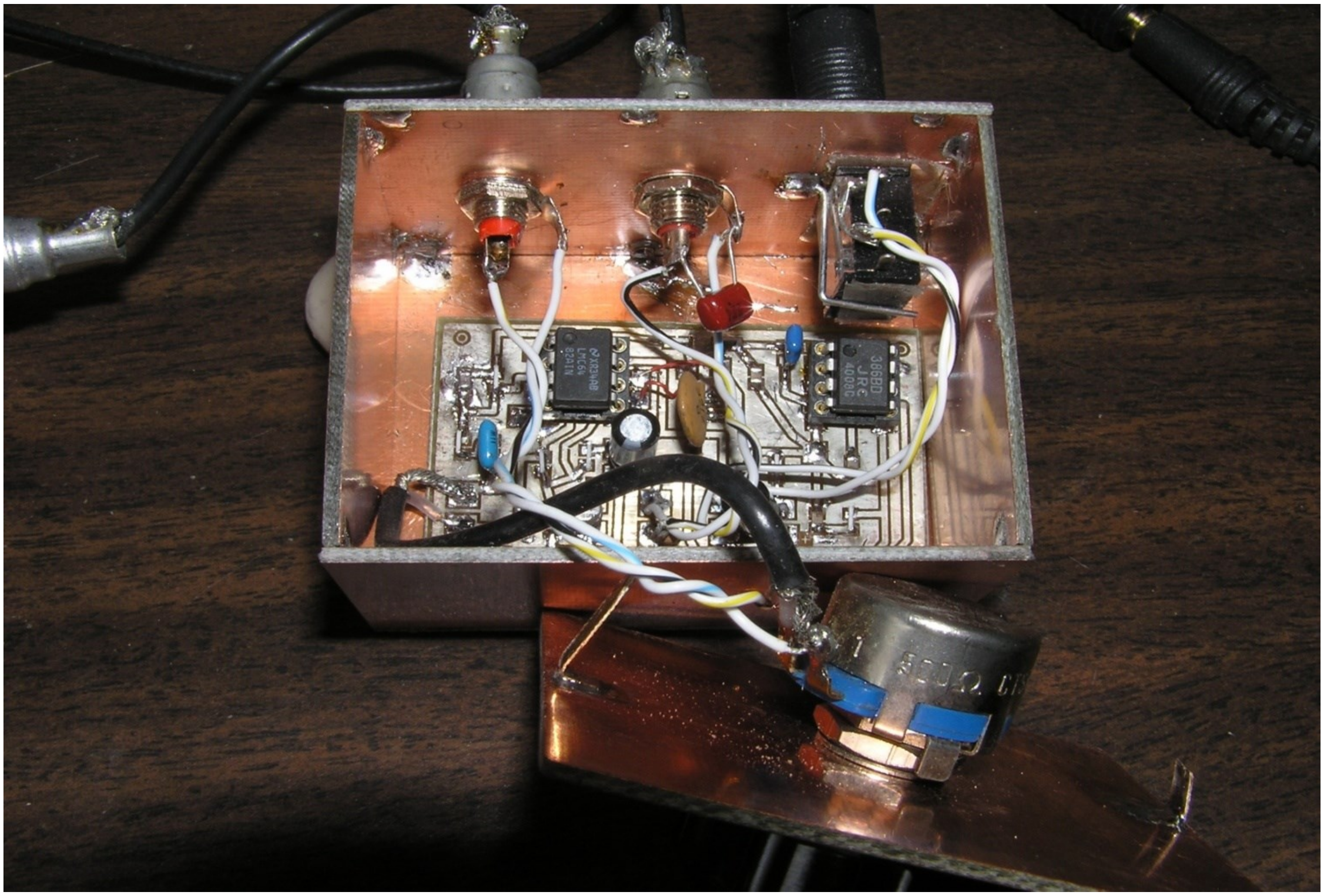
AUDIO OUTPUT SECTION OF RECEIVER:



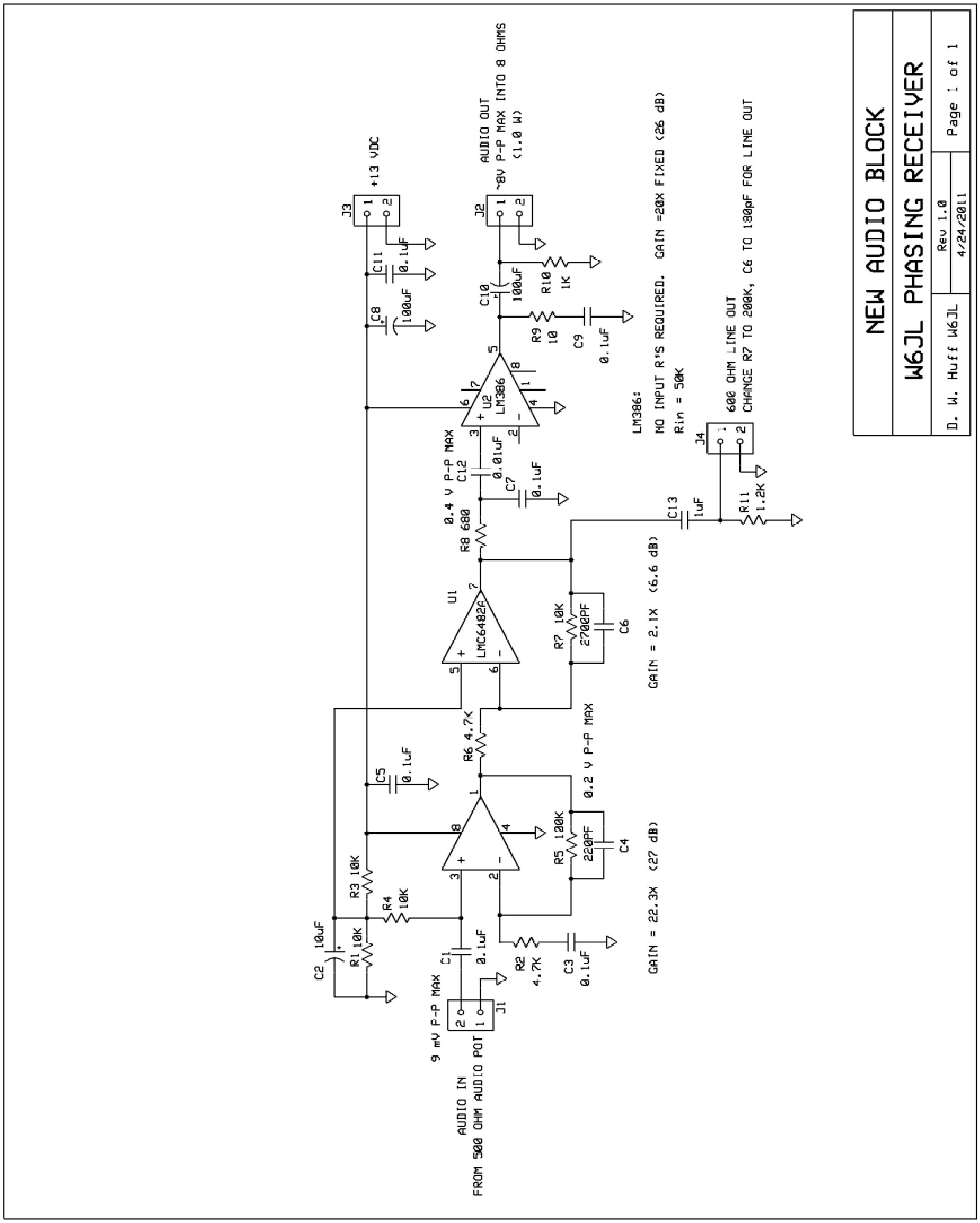
Receiver's output audio section, during testing in a solderless breadboard. This is an easy way to verify circuit performance on low-frequency circuits before laying out a PC board.



Audio output section, on homebrewed tin-plated PC board. All components are surface-mounted onto top-surface pads, even the through-hole ones, such as the 8P DIP sockets and electrolytic capacitors and interconnect wires. This minimizes the need for drilling holes in the board. I am surprised more homebrewers do not adopt simplification techniques such as this. After you, YOU are building it, so you have complete control over how it is made. This is not the case with kits and factory-built gear.



Audio output board installed in box.



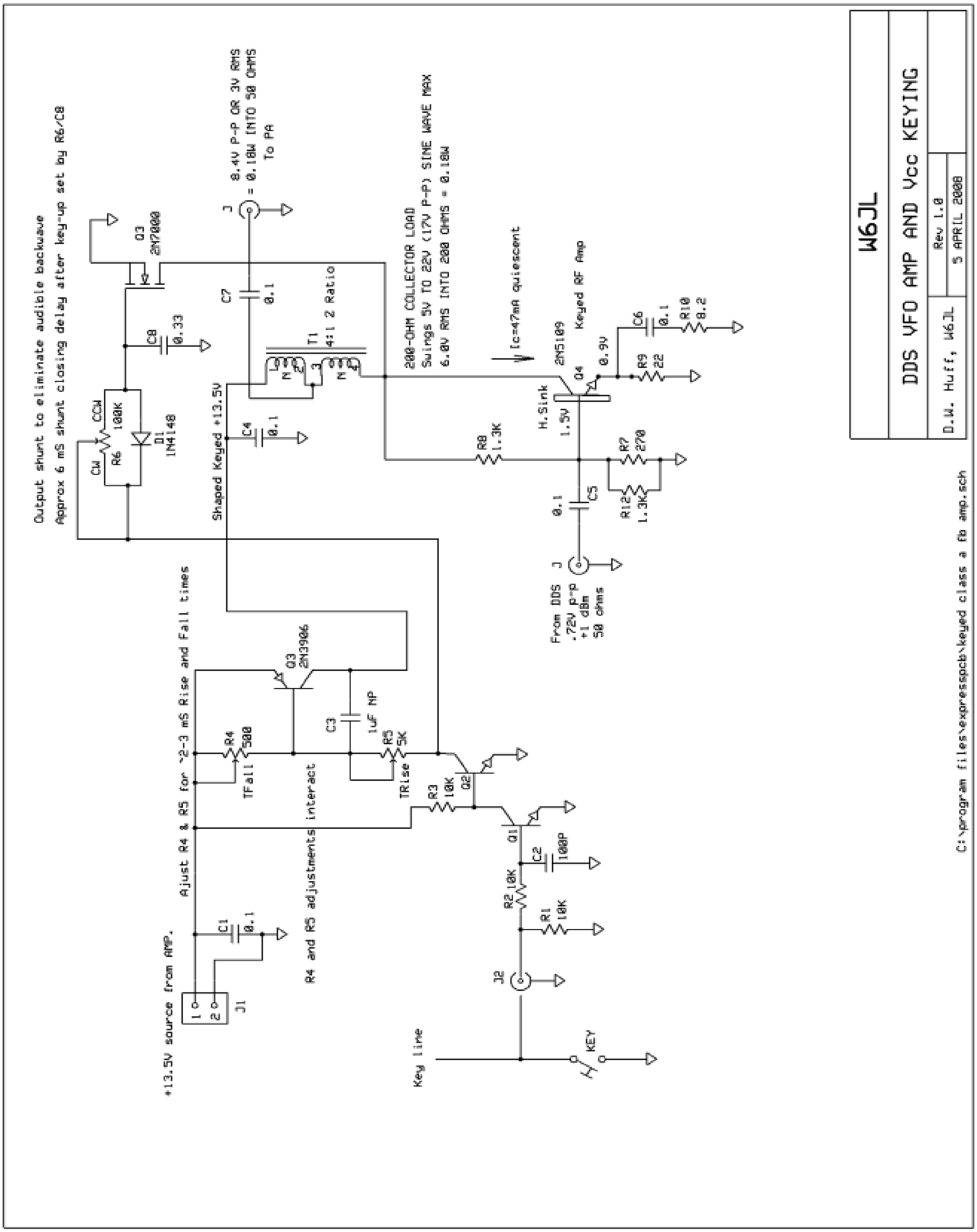
Audio output section schematic.

TRANSMITTER:

KEYED DDS VFO/EXCITER:

AD9850 DDS VFO/exciter for XMTR. The VFO output is keyed and shaped and drives the 40 dB gain HB amp. Just 50mW of drive from the DDS VFO gives 550W out on the HF bands. I built this VFO many years ago from an article by Curtis, WB2V, in July 1997 QEX. The bare board and programmed PIC 16F84 microcontroller are available from FAR CIRCUITS. For several years, Analog Devices provided free samples of DDS devices to any homebrewer who requested them online. This resulted in many getting their feet wet with DDS (including me) which makes it so easy now to build a VFO. DDS eliminates dial drives, variable capacitors, inductors, band calibrations, and bandswitching. Plus, it has DC to 30 MHz coverage, (useful even as a clean sine wave audio source), and no drift. Homebrew has never been easier (or cheaper!) than it is today. The AD9850 DDS output is amplified by a 2N5109 class A keyed amplifier to +17 dBm (50mW), which drives a homebrew high gain QRO amplifier which has 40 dB of gain, yielding

550W output on most HF bands.



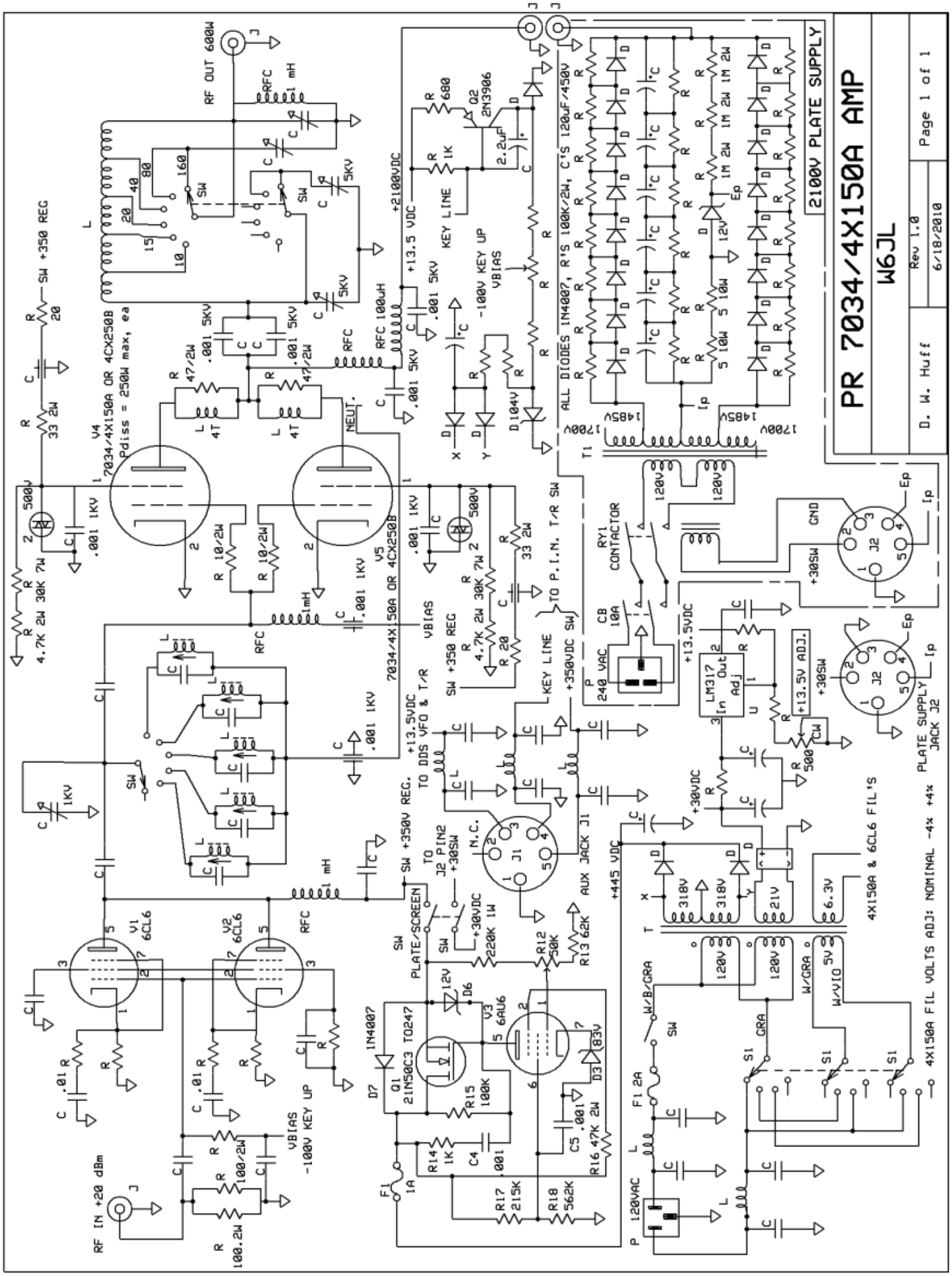
Schematic of DDS VFO output’s keyed class A broadband amplifier. Keying and shaping is done with a simple one-transistor integrator, Keying the 12 Vcc line to the class A 2N5109 feedback amplifier stage. This keying/shaping circuit is not new; it has been used in many published HB transmitter designs over the past 30+ years.

AMPLIFIER:

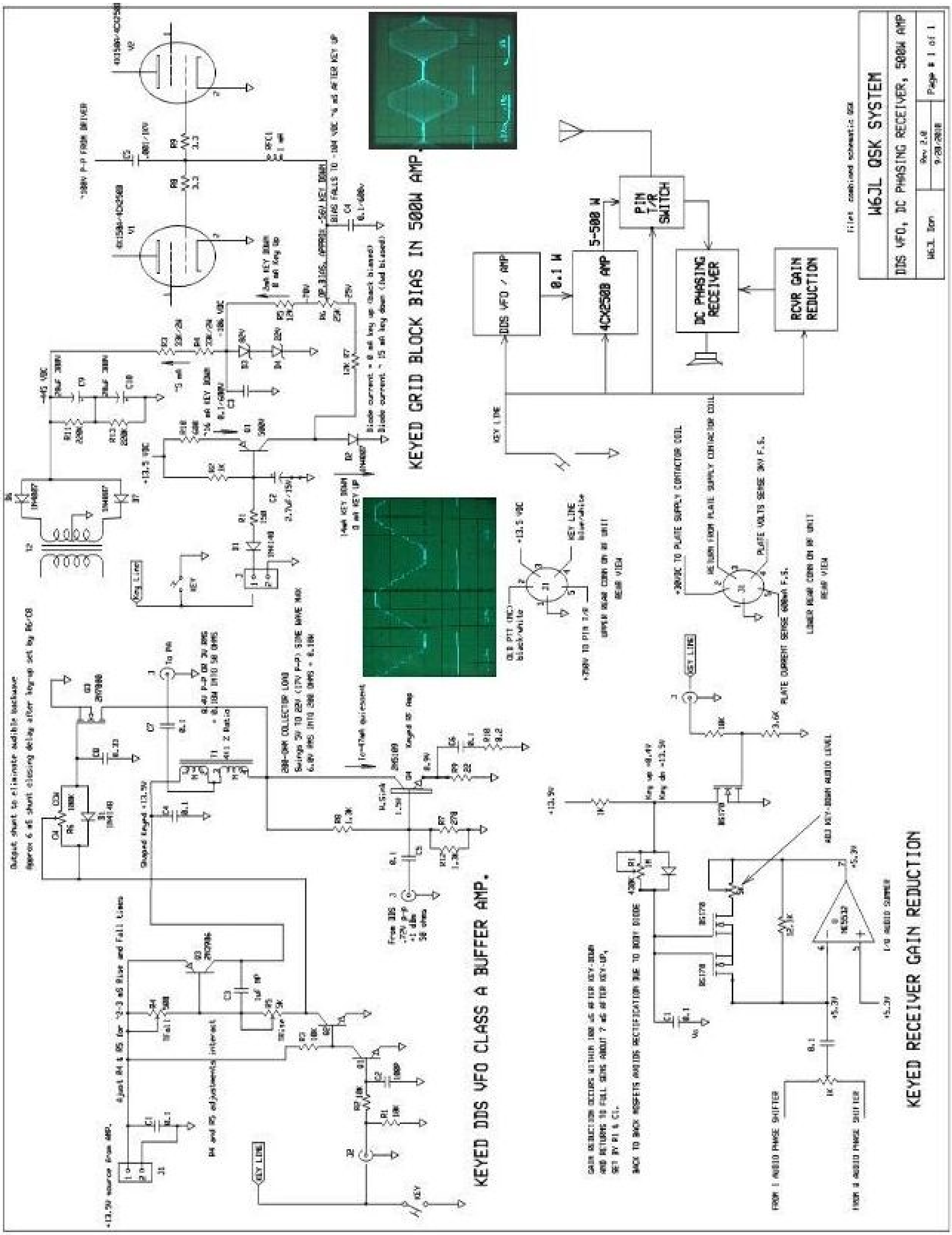
I built the homebrew amplifier in 1972. It was originally designed to be driven by transistor VFO's. It is two stages, the first being a pair of 6CL6 pentodes in class A with 200 ohm passive grids, driving a pair of 7034/4X150A tetrodes in AB1. These tubes have the same plate dissipation rating, 250W, as the more expensive 4CX250B, a fact which many hams seem to not be aware of. NOS 7034's have been seen recently on EBay for less than $50 each. I never dreamed that one day this amplifier would be driven by a tiny DDS VFO/amp. The amplifier has been in continuous use for the past 43 years. Homebrew rigs last forever :o).

HB 550W amplifier, which dwarfs the HB DDS VFO/exciter on top at right. I built this amplifier in 1972. A cracked-glass meter reads SWR of 30M full wave loop antenna. Its 100uA meter movement survived an inadvertent free-fall plunge from a 40 ft tower years ago. It still works nicely, albeit with a multi-faceted glass :o).

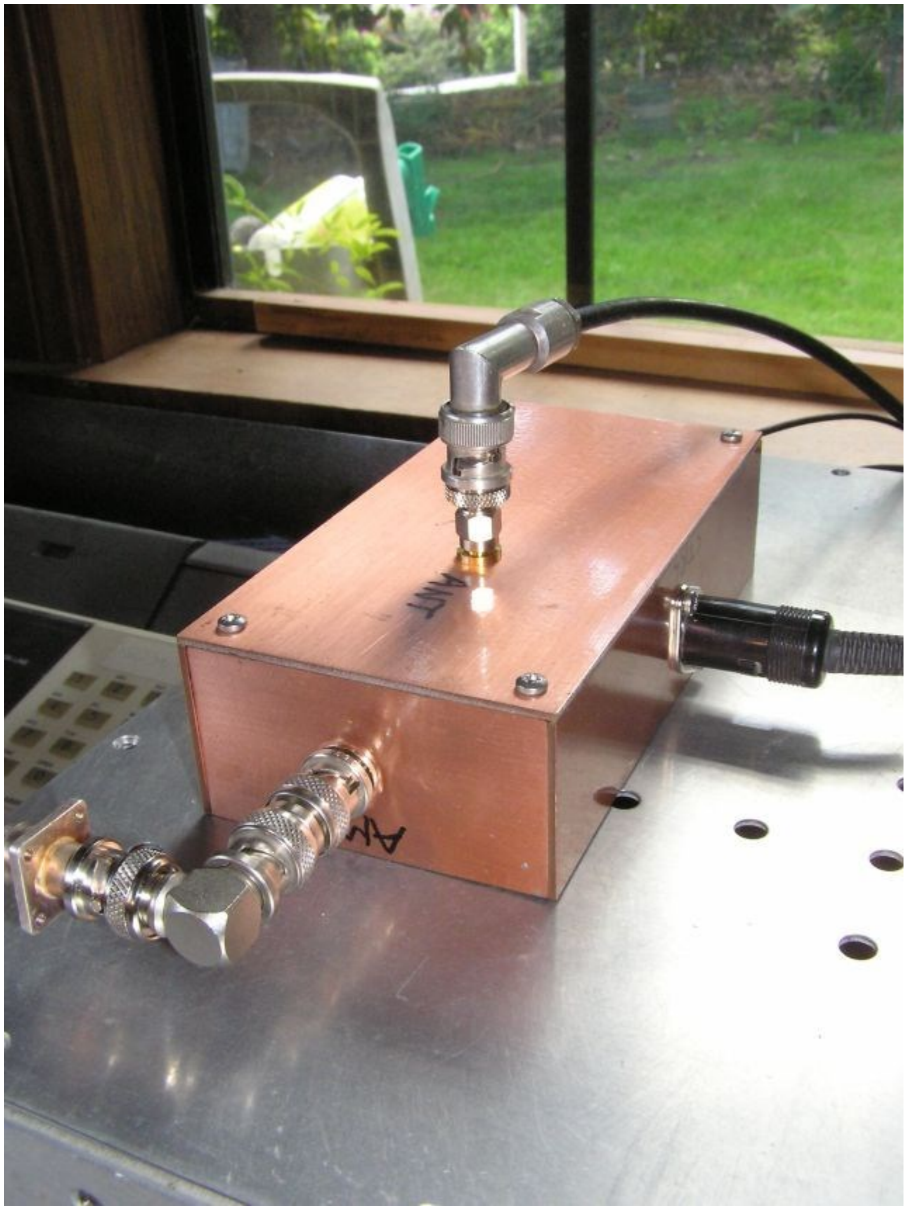
Top three-quarter view of amplifier. It was built from 100% junk-box parts and some scrap aluminum, so represents nearly zero out-of-pocket cost.



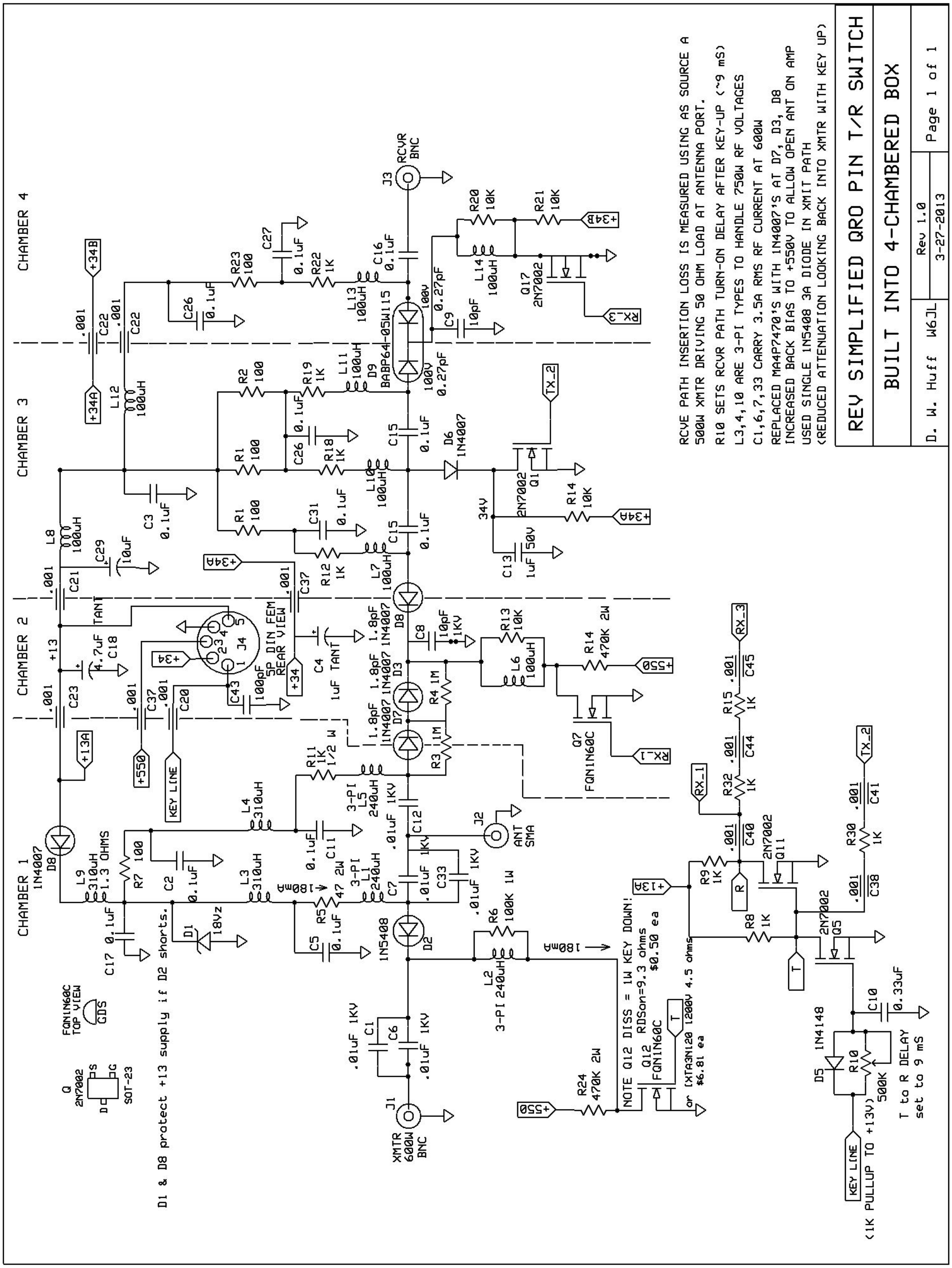
Complete amplifier schematic.



Combined schematic of QSK keying of amplifier and DDS exciter.



PIN diode QSK antenna T/R switch. Cost to build: nearly $0 out of pocket; the best kind of project :o). This switch easily handles 600W and has been in daily use for several years, with thousands of accumulated hours. Oh, and brand new 1N4007 and 1N5408 rectifier diodes are 10 cents each. Homebrew can be *very* cost-effective.



PIN T/R switch schematic. The inspiration for using high voltage rectifiers as RF PIN diodes came from a 1995 Wes Hayward (W7ZOI) QEX article. Thanks, Wes.

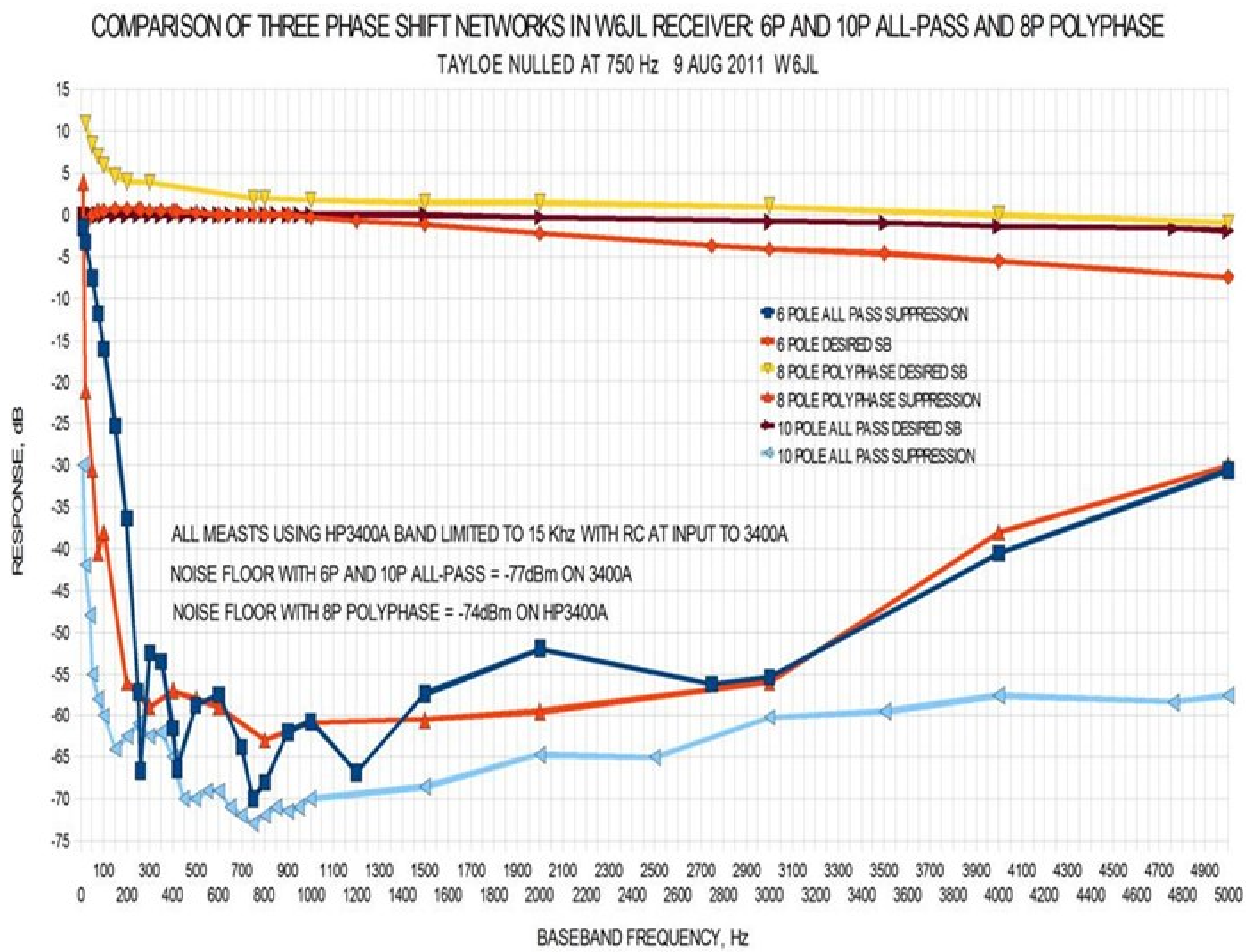
To say that I enjoy using this sweet transmitter and receiver on the air every day is an understatement. Fun stuff!

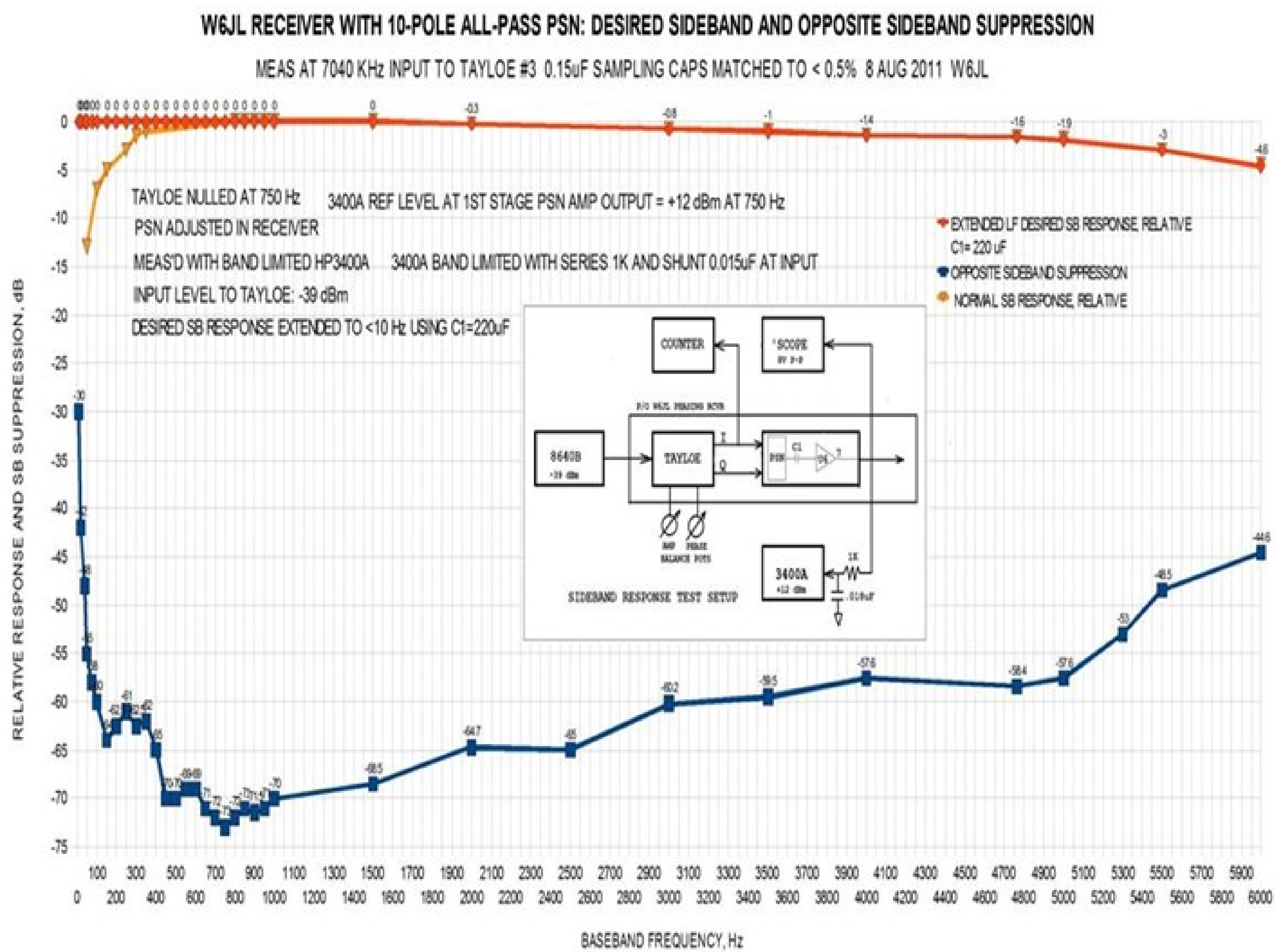
73, Don, W6JL

Below, a series of receiver response tests were conducted, with various Tayloe sampling capacitor sizes and using three different audio phase shift networks, in the W6JL receiver.

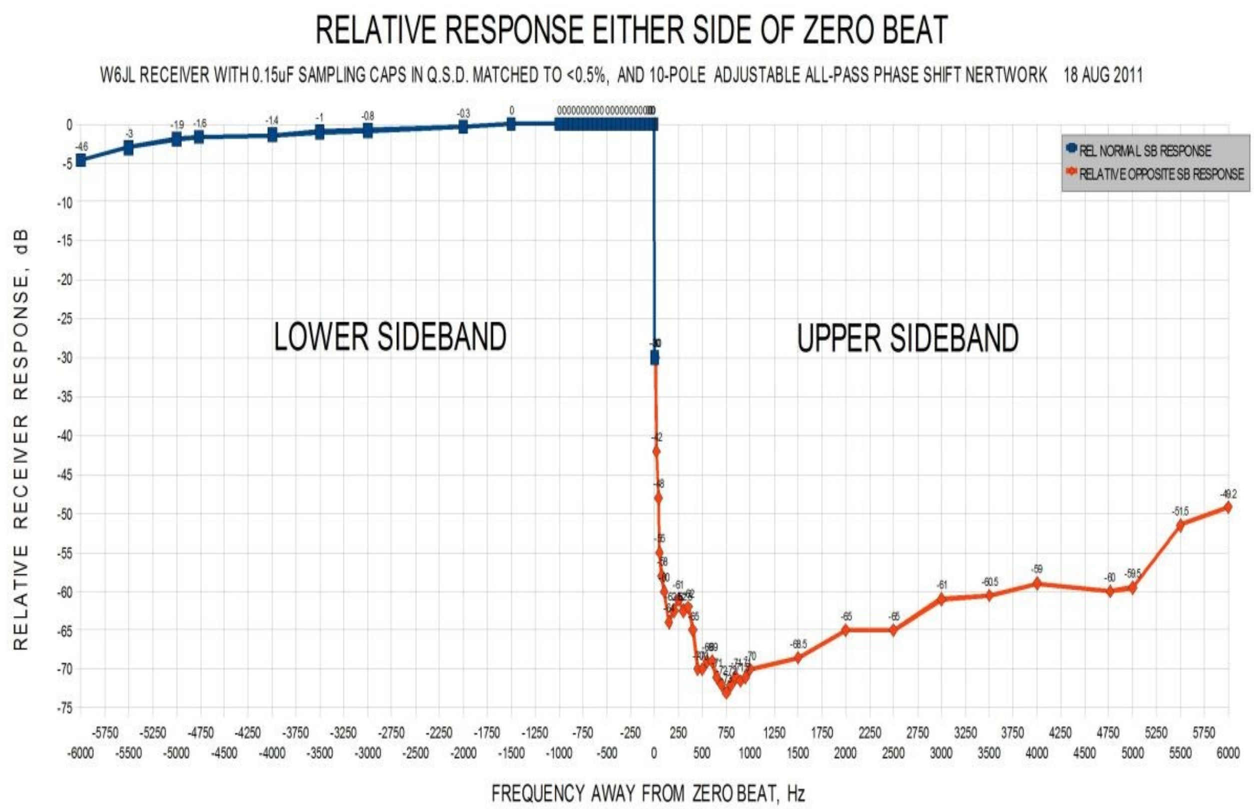
TEST DATA

Phasing receiver response measurements:


COMPARISON OF THREE PHASE SHIFT NETWORKS IN W6JL RECEIVER: 6P AND 10P ALL-PASS AND 8P POLYPHASE
TAYLOE NULLED AT 750 Hz 9 AUG 2011 W6JL
6 POLE ALL PASS SUPPRESSION
6 POLE DESIRED SB
8 POLE POLYPHASE DESIRED SB
8 POLE POLYPHASE SUPPRESSION
10 POLE ALL PASS DESIRED SB
10 POLE ALL PASS SUPPRESSION
ALL MEASTS USING HP3400A BAND LIMITED TO 15 Khz WITH RC AT INPUT TO 3400A
NOISE FLOOR WITH 6P AND 10P ALL-PASS = -77dBm ON 3400A
NOISE FLOOR WITH 8P POLYPHASE = -74dBm ON HP3400A
RESPONSE, dB
BASEBAND FREQUENCY, Hz


W6JL RECEIVER WITH 10-POLE ALL-PASS PSN: DESIRED SIDEBAND AND OPPOSITE SIDEBAND SUPPRESSION
MEAS AT 7040 KHz INPUT TO TAYLOE #3 0.15uF SAMPLING CAPS MATCHED TO < 0.5% 8 AUG 2011 W6JL
TAYLOE NULLED AT 750 Hz
3400A REF LEVEL AT 1ST STAGE PSN AMP OUTPUT = +12 dBm AT 750 Hz
PSN ADJUSTED IN RECEIVER
MEAS'D WITH BAND LIMITED HP3400A
3400A BAND LIMITED WITH SERIES 1K AND SHUNT 0.015uF AT INPUT
INPUT LEVEL TO TAYLOE: -39 dBm
DESIRED SB RESPONSE EXTENDED TO <10 Hz USING C1=220uF
EXTENDED LF DESIRED SB RESPONSE, RELATIVE C1= 220 uF
OPPOSITE SIDEBAND SUPPRESSION
NORMAL SB RESPONSE, RELATIVE
COUNTER
SCOPE
8640B
TAYLOE
I
Q
PSN
C1
3400A
+12 dBm
1K
AMP PHASE BALANCE POTS
SIDEBAND RESPONSE TEST SETUP
RELATIVE RESPONSE AND SB SUPPRESSION, dB
BASEBAND FREQUENCY, Hz

Above: Opposite and desired sideband response plots of phasing networks tested in the W6JL Receiver. These are busy graphs, and warrant careful study. Second graph is the current receiver, using matched 0.15uF sampling capacitors in the Tayloe front end. The adjustable 10-pole all-pass network has excellent performance, especially over the CW passband of the receiver where it has roughly 70 dB of opposite sideband suppression. This is excellent performance for such a simple receiver architecture.



Same data shown previously, using the 10-pole adjustable PSN, plotted in a different way, to illustrate the remarkable ability of a phasing receiver to abruptly change response, as you pass through zero beat to the opposite sideband. Within a few Hz of zero beat there is a tremendous change in response, not easily achievable by using a superhet architecture and crystal filters.

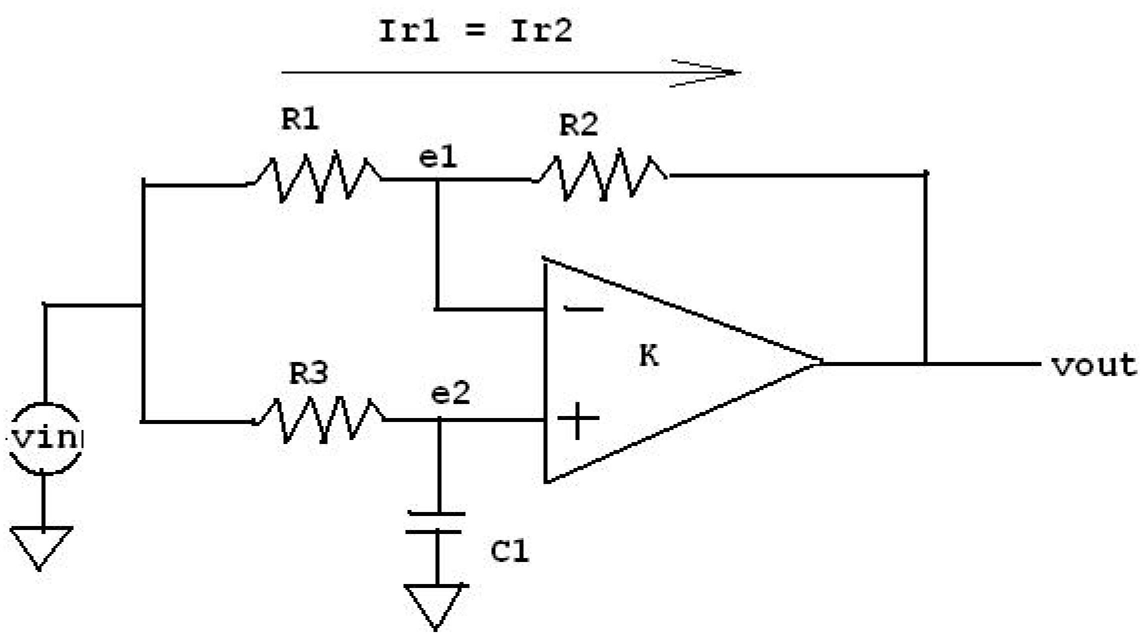
The desired sideband response (on the low side of zero beat) extends basically to near DC, with the opposite sideband response down over 60 dB less than 200 Hz away. 60 dB is one part in 1000, remember. And this is done with no frequency selective filters whatsoever. This enables me to have very good low-frequency response in the receiver, which I prefer, and together with the beautiful sounding audio of a phasing receiver, enhances the enjoyment of listening to it. Most factory gear greatly suppresses the audio below 300 Hz. With a phasing receiver, you can have audio response to 50 Hz or less, if you desire. Again, more choices are available with homebrew vs factory-built rigs.

It is always best to understand how any circuit you are using actually works, rather than relying on published "formulas", whose assumptions you do not know (and whose printed accuracy may not be good). This is where mathematical circuit analysis becomes indispensable, even in this age of computer simulation. How does an all-pass network *actually work*? Let's find out ourselves:

APPENDIX

ALL-PASS PHASE SHIFT NETWORK SINGLE STAGE ANALYSIS

W6JL 23 Aug 2011



If amplifier's Rin = large, and K (open-loop gain of the op amp) is large, and if the amplifier input signal currents are insignificant (high input impedance), then

$$(\mathrm{e2} - \mathrm{e1}) = 0, \qquad so\ \ e2 = e1\ \ and\ \ Ir1 = Ir2$$

$$e2 = \frac{Vin\left(\frac{1}{C1S}\right)}{R3 + \frac{1}{C1S}}Vin \quad and\ \ IR1 = IR2 = \frac{(Vin - e1)}{R1} = \frac{(e1 - Vout)}{R1}$$

If $R1 = R2$, then:

$$(\boldsymbol{vin} - \boldsymbol{e1}) = (\boldsymbol{e1} - \boldsymbol{vout}),\ \ \boldsymbol{2e1} = (\boldsymbol{vin} + \boldsymbol{vout}),\quad \boldsymbol{e1} = \frac{\boldsymbol{vin} + \boldsymbol{vout}}{\boldsymbol{2}}$$

$$vout = K(e2 - e1) = \ K\left[\left(\frac{vin\left(\frac{1}{C1S}\right)}{R3+\frac{1}{C1S}}\right) - \left(\frac{vin+vout}{2}\right)\right], and$$

$$\frac{vout}{K} = \frac{\frac{vin}{C1S}}{R3 + \frac{1}{C1S}} - \frac{(vin + vout)}{2}$$

$since\ \ K\ is\ numerically\ \gg vout,\ \ then\ \frac{vout}{K} = 0,\ \ leaving$

$$\frac{\frac{vin}{C1S}}{\left(R3 + \frac{1}{C1S}\right)} - \frac{vin + vout}{2} = 0$$

Cross multiplying and solving for Vout/Vin,

$2vin = R3vinC1S + vin + R3voutC1S + vout,\quad 2 = R3C1S + 1 + R3\left(\frac{Vout}{Vin}\right)C1S + \frac{Vout}{Vin}$

$\frac{Vout}{Vin} = (2 - R3C1S + 1))/(R3C1S + 1)$

$\frac{Vout}{Vin} = (1 - R3C1S)/(1 + R3C1S)$

Let S=jω for steady-state solution:

$\frac{\mathrm{Vout}}{\mathrm{Vin}} = \frac{1-\mathrm{j\omega rR3C1}}{1+\mathrm{j\omega R3C1}}\quad and\ if\ \omega 0 = \frac{1}{R3C1},\ \ then$

$$\frac{\boldsymbol{Vout}}{\boldsymbol{Vin}} = \frac{\left[\boldsymbol{1} - \boldsymbol{j}\left(\frac{\boldsymbol{\omega}}{\boldsymbol{\omega 0}}\right)\right]}{\left[\boldsymbol{1} + \boldsymbol{j}\left(\frac{\boldsymbol{\omega}}{\boldsymbol{\omega 0}}\right)\right]}$$

This is the desired result. Let’s examine this equation:

If ω << ω0, then Vout/Vin = 1/1 = **1 at 0 degrees or 1**

(Ie, unity gain and no phase shift, at very low frequencies).

If ω >> ω0, then Vout/Vin = (1 at -90 degrees)/(1 at +90 degrees) = **1 at -180 degrees, or -1**

(unity gain at high frequencies, with a phase lag of 180 degrees).

If ω = ω0, then Vout/Vin = (1-j1)/(1+j1) = (1.4 at -45 degrees)/(1.4 at +45 degrees) = **1 at -90 degrees**

(at the pole frequency, gain is unity and phase lag is 45 degrees**).**

Thus, gain is constant at 1.0 and phase shifts from 0 degrees at low frequencies, to -180 degrees at high frequencies. Just what we want for an audio phase shifter. The phase vs frequency slope is negative

By a similar analysis, it can be shown that, for a high-pass RC configuration (reverse the positions of R3 & C1),

$$\frac{\boldsymbol{Vout}}{\boldsymbol{Vin}} = \frac{[-\mathbf{1} - \boldsymbol{j}\left(\frac{\boldsymbol{\omega}}{\boldsymbol{\omega}\mathbf{0}}\right)]}{[\mathbf{1} + \boldsymbol{j}\left(\frac{\boldsymbol{\omega}}{\boldsymbol{\omega}\mathbf{0}}\right)]}$$

If ω << ω0, then Vout/Vin = -1/1 = **1 at -180 degrees, or -1**

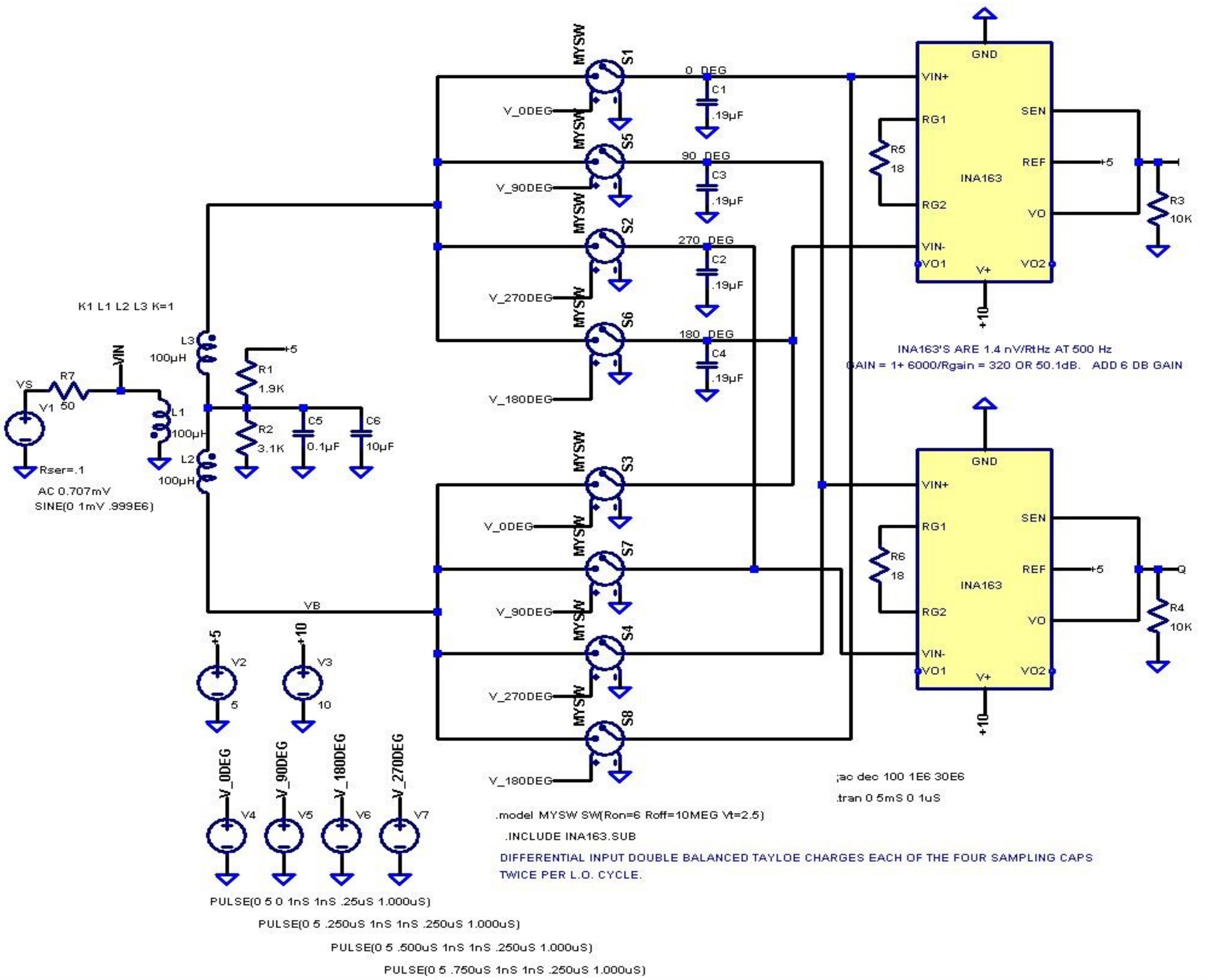
If ω >> ω0, then Vout/Vin = (-1 at -90 degrees)/(1 at +90 degrees) = -**1 at -180 degrees, or 1**

If ω = ω0, then Vout/Vin = (-1-j1)/(1+j1) = (-1.4 at -45 degrees)/(1.4 at +45 degrees) = -**1 at -90 degrees , or 1 at -90 degrees**

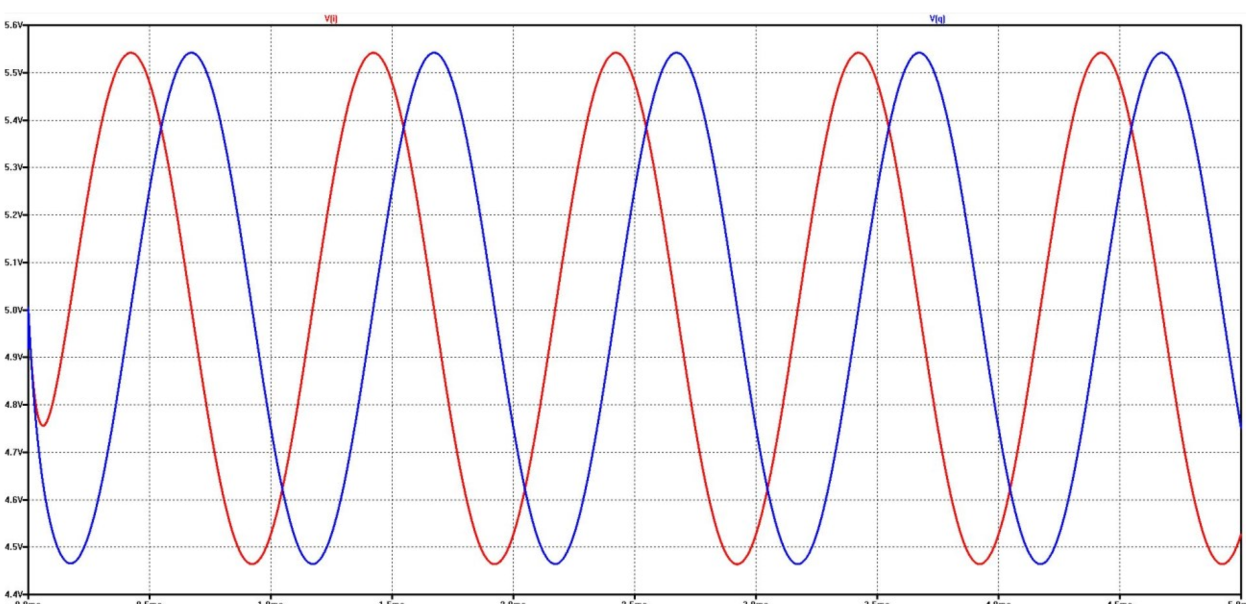
Thus, gain is constant at 1.0 and phase shifts from -180 degrees at low frequencies, to 0 degrees at high frequencies. Phase slope is positive.

As used in an I & Q phase shift network, the operation of either form of the network is the same. In fact, low-pass and high-pass configurations could be mixed in a multiple stage phase shifter if desired. One advantage of the low-pass configuration is that multiple stages are direct-coupled on the RC side, and only a single supply is needed, since the DC level can be ½ the supply using the low-pass configuration. In addition, one side of the capacitors can be grounded. By using two parallel channels of multiple series-connected networks, a nearly constant *phase difference* of 90 degrees can be obtained, over a limited frequency range. If the two channels are simply summed together at the output, the result is that one sideband is enhanced by a factor of 2 (6dB) in amplitude, while the other sideband is cancelled in the output. This is just what is needed for our single-signal phasing receiver.

LTSPICE TRANSIENT SIMULATION OF TAYLOE FRONT END:



LTSpice simulation schematic.



Development of I and Q baseband outputs with 1KHz offset.