NOTES ON WHITE BOX 10 GHz TRANSVERTER CONVERSION

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Introduction

The purpose of this document is to share the methods, observations, and conclusions drawn from a conversion of a M/A-COM "White Box" transverter to amateur 10 GHz service, carried out by Steve Kavanagh, VE3SMA, for Murray Hill, VE3NPB.

This document contains notes, calculations, schematics, and tuning methods derived from the conversion process. The approach used in the conversion was to keep the modifications to the original hardware to a minimum and the additional circuitry as simple as possible, while ensuring a design that would be reasonably foolproof in operation and not likely to be "blown up" in case of operator error. This differs a little from the approach used by some others in that the primary goal was to actually get the conversion finished and get it on the air, rather than to aim for the best performance, lowest size and weight or lowest current drain from the batteries. The conversion process was completed without requiring any specialized tools or microwave test equipment of more than the most rudimentary kind. At the time of writing a few items still need to be attended to (packaging, a proper antenna, minimizing LO crystal oscillator frequency shift between transmit and receive). We hope that any significant information found during these steps will be incorporated in an update of this document.

This is not intended as a stand-alone "how to" document; you should read this document after you have familiarized yourself with the material contained in the White Box conversion articles listed in the references section.

Mechanical

Component modules in the M/A-COM White Box are mounted on an aluminum tray in the bottom of the box; the dimensions of the tray are approximately 13 ¾ inches by 11 ¾ inches. While many construction configurations are possible, the author found it convenient to use this tray as the "chassis" on which to assemble the 10GHz transverter.

Figure 1: The White Box original configuration

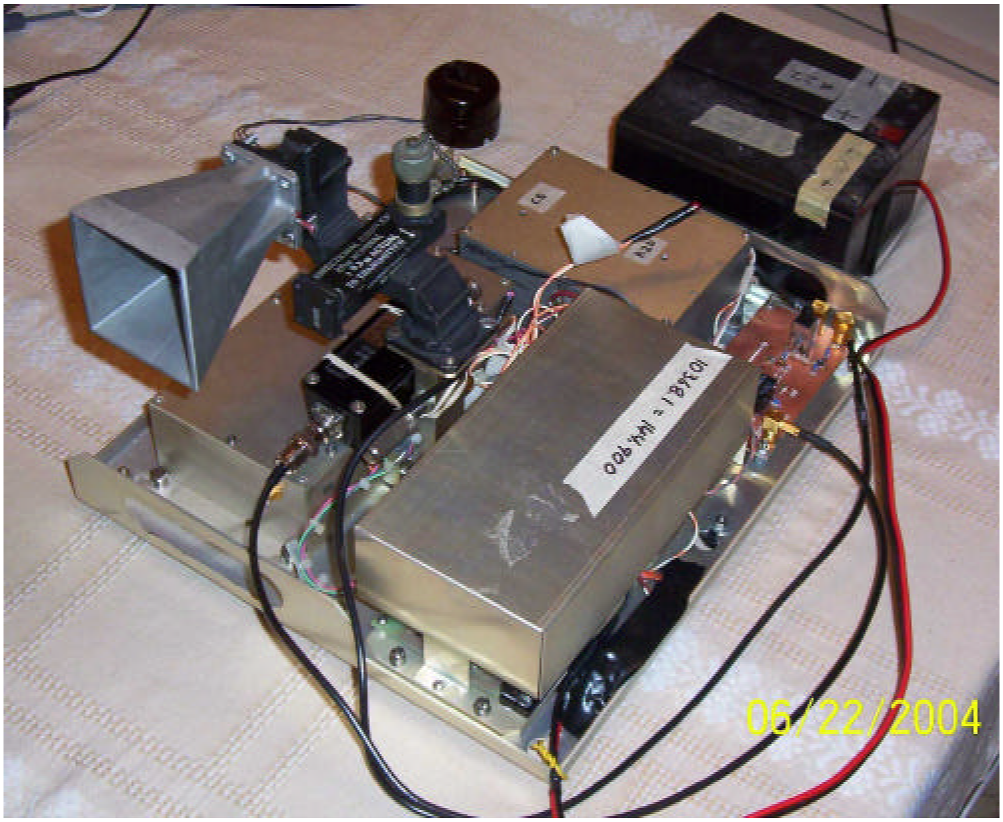


Figure 2: The modified transverter in the configuration used for its first QSO

Cables

The White Box employs an unusual type of push-on coaxial connector throughout; one of the connecting cables has this push-on connector on one end and an N-connector on the other. Beware! The male N-connector is a 75-ohm type which will not normally make contact with a standard 50 ohm female N-connector, due to having a smaller diameter pin.

Kenwood TR-751A IF Radio

This conversion was undertaken for use with a Kenwood TR-751A 144 MHz multimode transceiver as the I.F. rig. The following observations apply to the TR-751A that was used:

1. The TR-751A has a socket on the rear panel which provides a normally open pair of relay contacts which close with the PTT. These may be used to control the transverter. The socket is VERY non-standard, but a matching plug was obtained from East Coast Parts in the US. Note that there were two different sockets used at different points of the TR-751A production run and they only stock one of the matching plugs.
2. The power output in the low power position is adjustable with an internal potentiometer.
3. The power output was measured using an MFJ-810 SWR/Power Meter as 5.3 W (pretty much as specified) in the low power position and 20 W (specified at 30 W) in the high power position. This measurement was performed at supply voltages of 11.9 V and 13.8 V with identical results.
4. The TR-751A is specified to have better than 0.13uV sensitivity for 10 dB (S+N)/N (in SSB mode). Using ohm's law we find that 0.13uV across 50 ohms corresponds to $3.38\text{x}10^{-16}$ watts (or

-124.7 dBm). At 10 dB (S+N)/N the sum of signal plus noise powers at the input to the receiver is ten times the noise power alone. In other words the signal power is nine times the noise power. Therefore, the noise power in this case is $3.38\text{x}10^{-16}/9 = 3.76\text{x}10^{-17}$ watts (or -134.3 dBm). Noise power at the receiver input is given by the formula N = kTBF, where $k = 1.38\text{x}10^{-23}$ (Boltzmann's Constant), T = 290 Kelvin (standard temperature), B = 2200 Hz (approximate receiver bandwidth) and F is the receiver noise factor.

Based on the above, the TR-751A receiver noise figure (NF) can be calculated to be 6.3 dB (maximum), as shown by the following equation:

$$\begin{aligned} NF &= 10\log_{10}(F) = 10\log_{10}(N/kTB) = 10\log_{10}[3.76\text{x}10^{-17}/(1.38\text{x}10^{-23}\text{ x }290\text{ x }2200)] \\ &= 6.3\text{ dB (maximum)}. \end{aligned}$$

Receive Noise Figure Analysis

Because we wanted not to modify the TR-751A 2M rig, the decision was made to include an attenuator in line with its antenna socket at all times, to prevent damage to the low power transverter interface circuits. It was necessary therefore, to add a receive preamp between the microwave mixer and this attenuator, to compensate for the effect of this attenuator loss on the IF noise. The following analysis was carried out to determine the appropriate IF preamp specifications, given the attenuator losses and the receiver noise figure determined above. The initial analysis was carried out assuming that this attenuator will have a loss of 21 dB.

The White Box transverter module already contains a two-stage amplifier which, according to WA6CGR (Fig. 42a) has about 30 dB gain. But is this enough, or is more gain needed?

The estimated conversion gain budget for the existing White Box transverter module is as follows:

Component	**Gain (dB)**	**Source of Estimate**
Circulator	-0.5	VE3SMA guess
Filter	-4.0	WA6CGR (G3PHO says 6 dB)
Isolator	-0.5	VE3SMA guess
Mixer	-7.0	VE3SMA guess
Existing IF Preamp	+30.0	WA6CGR
TOTAL	+18.0 (power gain $G_x = 63.1$)	

Note that the 12 dB loss before the existing IF preamp added to the 2 dB preamp noise figure quoted by WA6CGR, makes for a 14 dB noise figure for the transverter module (noise factor $F_x = 25.1$), which is within the range quoted by WA6CGR.

The noise figure of the TR-751A (6.3 dB) plus the loss in the attenuator (21 dB), gives a total of 27.3 dB (noise factor $F_1 = 537$). Without an additional preamp, the overall noise figure is given by the following equation:

$$NF_{TOTAL} = 10\log_{10}[F_x + (F_1 - 1)/G_x] = 10\log_{10}[25.1 + (537-1)/63.1] = 15.3\text{ dB}.$$

Therefore the effect of the noise figure of the TR-751A plus attenuator has been to increase the overall noise figure by 1.3 dB over what would be achievable with a noiseless IF receiver.

Now, if a MSA-1105 preamp is added between the transverter module and the attenuator, with approximately 3 dB noise figure (noise factor $F_p = 2$) and 12 dB gain (power gain $G_p = 15.8$), the noise factor for the combination of this amplifier, the attenuator and the TR-751A becomes:

$$F_2 = F_p + (F_1 - 1)/G_p = 2 + (537\text{-}1)/15.8 = 25.9$$

F_2 is equivalent to a noise figure of 15.6 dB, a significant improvement over the 27.3 dB value without the additional amplifier. Now the total noise figure is 14.1 dB, as calculated below:

$$NF_{TOTAL} = 10\log_{10}[F_x + (F_2 - 1)/G_x] = 10\log_{10}[25.1 + (25.9\text{-}1)/63.1] = 14.1 \text{ dB} .$$

Thus the addition of an MSA-1105 preamp reduces the degradation of noise figure by the IF components to 0.1 dB. This is a barely worthwhile improvement from a noise figure point of view alone, but the amplifier also provides some additional protection to the transverter module from damage from IF transmitter power, and the reduced noise figure will reduce the gain needed from any eventual 10 GHz preamp in order to get state-of-the art overall noise figure.

It is tempting to see if more attenuation can be accommodated to reduce the chances of blowing up the additional preamp if the TR-751A were accidentally left in the high power position. The following table summarizes the noise figure calculated with the additional MSA-1105 preamp in place and with various attenuation values. It shows that a few dB more attenuation will have only a small impact on noise figure, but as the additional attenuation nears the gain of the MSA-1105, the performance degrades towards what is achieved without the MSA-1105 amplifier:

Attenuation (dB)	**Overall Noise Figure (dB)**
21	14.1
24	14.2
27	14.4
30	14.7

Another consideration is the noise figure of the additional amplifier. If the noise figure of this stage is allowed to be 6 dB rather than the 3 dB assumed above, the overall noise figure (with 21 dB attenuation) remains at 14.1 dB. With 24 dB attenuation it remains at 14.2 dB. So the noise figure of this stage is not very critical.

An overall attenuation of 23 dB was selected, 15 dB in the form of a Microwave Modules attenuator inserted in line with the TR-751A's antenna socket and 8 dB on the Control Board (R2, R3, R4). An IF amplifier using an MSA-1105 was included as well, on the Control Board. The noise figure (in theory) should therefore be about 14.2 dB.

Transmit Power Levels and Attenuator Survival

Four attenuators are used in this conversion in order to set signal levels and provide protection for the M/A-COM transverter module from being damaged by the RF output power of the 2m IF rig. They are:

Atten. 1: Connected between IF rig and Control Board. Microwave Modules, 15 dB, high power. This was available but does not provide enough attenuation for protection of the circuitry from high power RF damage. The additional attenuation needed is provided by Attenuator 2.

Atten. 2: On Control board in common path. 8.0 dB nominal attenuation, VSWR (IF rig side) = 1.07 at 50 ohms. Consists of pi network with 130 ohms 1W, 56 ohms ½ W, 120 ohms ¼ W (R2, R3, R4).

Atten. 3: On Control Board in transmit path between relay and Atten. 4. 31 dB attenuation. Consists of pi network with 56 ohms, 1100 ohms, 82 ohms (R6, R7, R8, R9). Provides most of the additional attenuation needed to reduce the transmit IF level to that needed by the White Box transverter module (beyond that provided by Attenuators 1 and 2).

Atten. 4: On Control Board between Atten. 3 and Transverter module. 75 ohm 20 dB variable. Provides the rest of the attenuation needed (and a degree of adjustability) to set the transmit IF level for the White Box transverter module. Reference designation is A1 on Control Board schematic.

See the Top Level Wiring diagram for the location of Attenuator 1 in the circuit, and the Control Board schematic for Attenuators 2-4. These diagrams are in the Schematics section of this document.

The following analysis provides checks of the power handling capability of each of these attenuators with respect to the IF power from the TR-751A.

The following table summarizes the design power levels at various points in the chain, relative to the attenuators listed above. The nominal target power after Atten. 4 is -20 dBm (-12 dBm max.) according to WA6CGR:

Location	Power with 5W from TR-751A	Power with 30W from TR-751A
After Atten. 1	158 mW (+22 dBm)	949 mW (+30 dBm)
After Atten. 2 (applied to RX path limiter)	25 mW (+14 dBm)	152 mW (+22 dBm)
After Atten. 3	20 µW (-17 dBm)	120 µW (-9 dBm)
After Atten. 4 (min. atten. setting)	20 µW (-17 dBm)	120 µW (-9 dBm)
After Atten. 4 (nominal setting)	10 µW (-20 dBm)	60 µW (-12 dBm)
After Atten. 4 (max. atten. setting)	200 nW (-37 dBm)	1.2 µW (-29 dBm)

Note that, if Atten.4 is set to minimum attenuation (fully clockwise) it is possible to feed more power to the transverter unit than is recommended by WA6CGR if the TR-751A is set to high power.

Next, consider the survival scenario for attenuators 1 and 2 at 30 W from the TR-751A, assuming 50% duty cycle (typical of CW, SSB should give a lower duty cycle). Attenuator 1 consists of a pi network with 68 ohm 10 watt (based on size and comparison with catalogues) resistors at each end and a series resistance consisting of 150 ohms (5 watts) in parallel with 390 ohms (2 watts). Attenuator 1 sees an average input power of 15 W. Simulation of this circuit using SIMetrix Spice indicates that the power dissipations for this input power are as shown in the following table:

Resistor	Average Power (W)	Power Rating (W)
68 Ω (TX side)	5	10
150 Ω	1.4	5
390 Ω	0.5	2
68 Ω (load side)	0.2	10

(Note that the actual RF resistance values at 145 MHz must be slightly different, since the measured attenuation is indeed 15 dB rather than the 17 dB predicted by the simulation.)

Attenuator 1 will not overheat as all resistor dissipations are well within the ratings. But there is enough heat dissipated for it to get quite hot.

Attenuator 2 sees an average input power of 949 mW/2 = 425 mW. Simulation of this circuit using SIMetrix Spice indicates that the power dissipations for this input power are as shown below.

Resistor	Average Power (mW)	Power Rating (mW)
130 Ω	174	1000
56 Ω	153	500
120 Ω	28	250

Attenuator 2 will not overheat as all resistor dissipations are well within the ratings. The power levels at attenuators 3 and 4 are too low to be of any concern with respect to heating.

Schematic for Internal TX IF Amplifier

The following schematic was traced from the PC board on the top side of the existing transverter module (at the upper right of the following photo).

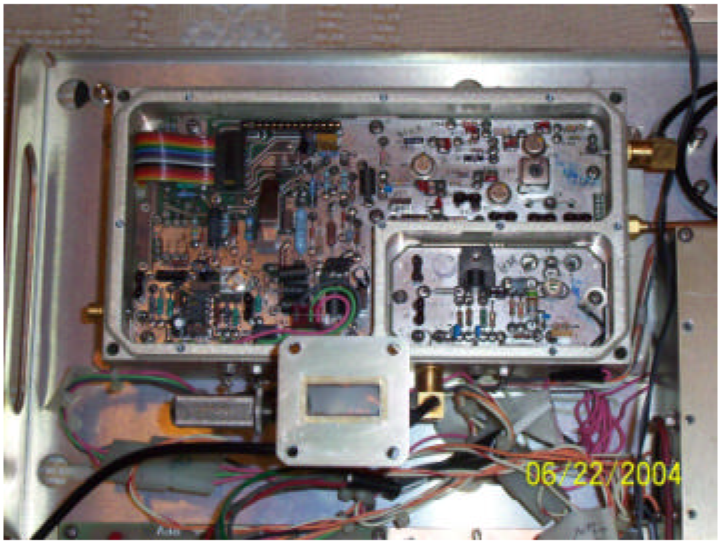
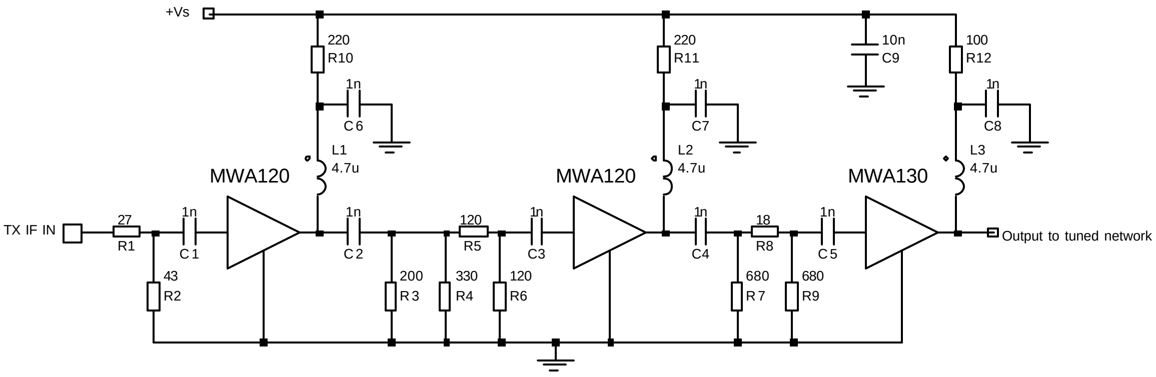


Figure 3: The top side of the transverter module

It is not really critical that you need to know this circuit but the author wanted to understand any potential limits on TX IF input power that might exist in this circuit. From comparison of the MWA series amplifiers with data sheets it appears that damage could possibly occur at the microwave mixer diodes at a lower input level than in any part of this TX IF amplifier.



The values of the following parts are somewhat uncertain:

C7, C9, R3, R5

VE3SMA

Title: Internal Transmit IF Amplifier,
M/ACOM "White Box" Transverter

Version: 1

Date: March 10, 2004

Drawn By: Steve Kavanagh

Figure 4: Transverter Module internal TX IF amplifier schematic

The MWA amplifiers are all rated at 14 dB nominal gain. The approximate calculated attenuations of the resistive networks are 6 dB for the input network (R1,R2), 10 dB for the first interstage network (R3-R6, with values as shown in the schematic) and 2 dB for the second interstage network (R7-R9). The total gain is therefore about 24 dB.

In deriving this schematic the board was not removed from the box, so the traces could not be followed directly. There is, therefore, a small chance that the schematic may not be correct.

Power Supply

The White Box requires +20 V for the local oscillator module and +12 V and -5 V for the transverter module. The simplest approach (if perhaps not the most operationally convenient) to providing these in the field was to run the unit from a +24 V supply (two +12 V batteries in series). The following notes describe how this was achieved.

1. I decided to reuse as much of the existing Power Supply Board functionality as possible. All the existing regulators are used, with the +12 V and +20 V regulators fed from a +24V battery supply and the -5 V regulator fed from the same battery through an added inverter circuit. The transformer was removed and the inverter installed in its place on the power supply base plate. The inputs to the existing Power Supply Board were made through the wires that formerly went to the transformer. The schematic and wire colour code for the existing power supply are given in G3PHO's on-line article.

2. The Inverter Board schematic is provided in the Schematics section of this document. The output is approximately -20V (varies with load), which is then regulated down to -5V using the regulator on the original Power Supply Board. This circuit is very inefficient but it does not require any parts which are challenging to procure and I have had good luck with it in other projects.

3. Reverse polarity protection diode CR4 (originally used as a rectifier) for the +20V supply was replaced with a Schottky type (1N5819) to reduce the voltage drop and thus extend the lower end of the useful battery voltage range. The measured diode voltage drop improved from 0.78 V to 0.32 V(when the oven is warmed up).

4. The connections to J1 on the Power Supply Board are as follows (refer to Power Supply Board schematic in G3PHO article):

Pin No.	Function	Connects to
1	(none)	Wire not connected at other end
2	(none)	No wire attached to this pin
3	(none)	Wire not connected at other end
4	Ground	Connectors for Transverter and LO Modules
5	+12 V (from U2)	Connector for Transverter Module (then goes to Control Board +12V pin)
6	+12 V (from U3)	Connector for Transverter Module (then goes to Transverter Module +12V RX pin)
7	+12 V (from U3)	Wire not connected at other end
8	-5 V	Connector for Transverter Module (then goes to Transverter Module -5Vpin)
9	+20 V	Connector for LO Module (then goes to LO Module +20V pin)
10	+20 V	PLL Unlocked indicator circuit

5. I decided to replace the three large electrolytic filter capacitors on the existing power supply board with ones of lower capacitance. This reduces the inrush current at turn-on, reducing the stress on

the fuse, on/off switch and reverse-polarity-protection diodes. The filtering formerly provided by these capacitors is no longer required with DC inputs to this board. As well, the components in the inverter for the -5V supply have reduced turn-on stress with a smaller capacitance across the load. The replacements I used are as follows:

4700uF (+12 V supply) changed to 47 uF
1000uF (-5 V supply) changed to 10 uF (minimum permissible for 7905 regulator)
680uF (+20 V supply) changed to 47 uF.

The following photo shows the power supply circuitry (with the cover removed). The fuse arrangement is temporary until the final packaging is worked out.

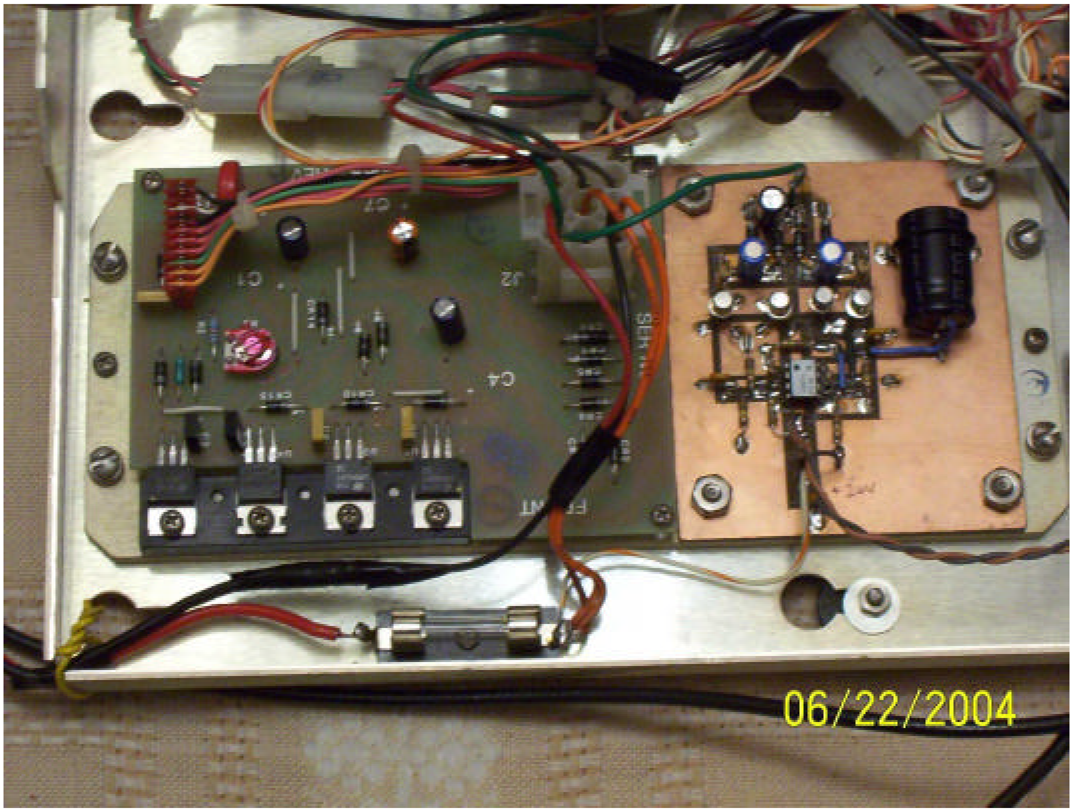


Figure 5: Power supply circuitry (original board on the left and new inverter board on the right)

Local Oscillator

The following points summarize the author's modifications and observations pertaining to the Local Oscillator module in the White Box. Part reference designations are those used on the PC board and shown in the diagrams in the articles by G3PHO and WA6CGR. The top board in the LO module is shown in the following photo. The microwave portions of the circuit are on the bottom side of the module.

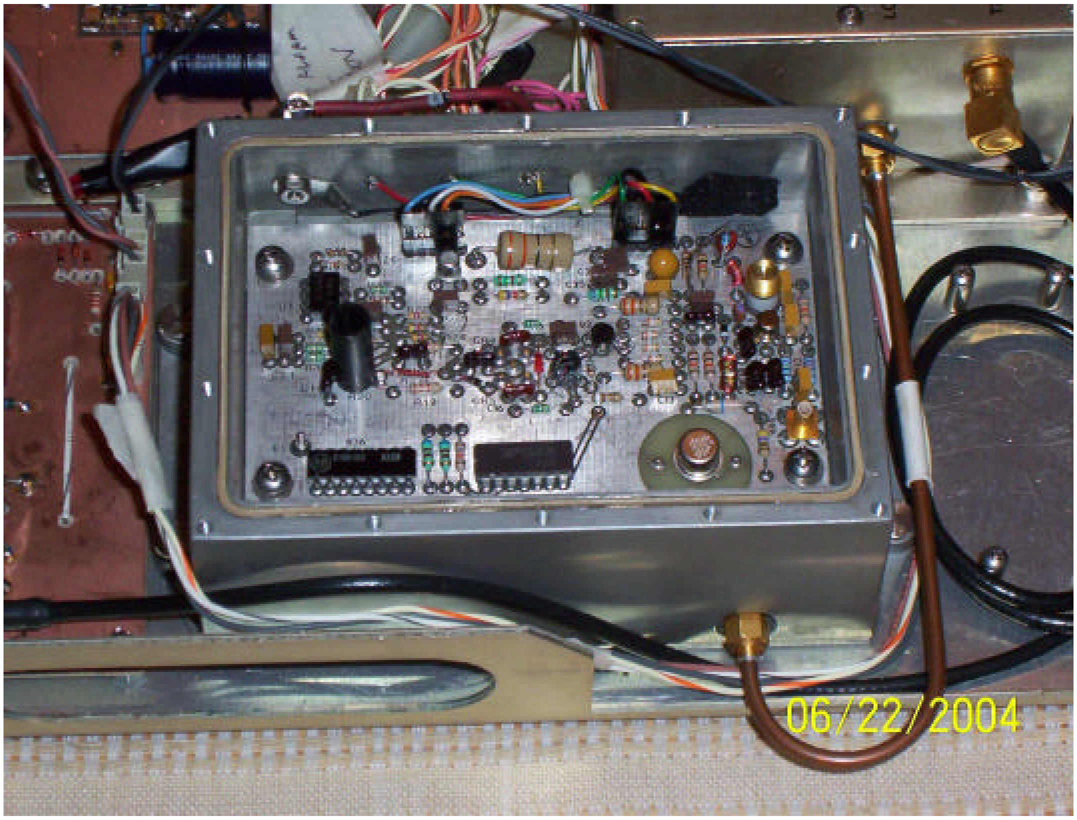

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Figure 6: Top side of LO module with cover and crystal oven removed

1. Be sure that the crystal leads are cut off sufficiently short so that they do not short out against the case below the board.
2. I used the WA6CGR LED lock alarm circuit. It works fine.
3. I initially used a pair of resistors in a voltage divider configuration to provide the AFC voltage. Approximately 1 kHz offset between transmit and receive frequencies was noted in the first QSO in this configuration, which may be partly attributed to the AFC voltage changing as a result of imperfect +20 V regulation and a change in battery voltage as a result of the additional current drawn in transmit mode as compared to receive. Later this was changed to a zener bias scheme which improved the transmit/receive offset slightly. Yet to be tried is to add an additional regulator for the oscillator transistor.
4. The crystal (from the OVHFA common buy) is intended to provide a local oscillator output at 10513.2 MHz (crystal frequency of 103.07058 MHz). I found that, with an AFC voltage of 7 V (as specified to be nominal on the White Box test data sheet) the LO frequency was at least a couple of hundred kHz low (at 10 GHz). This is not particularly a problem. However it may turn out to be more convenient to use a slightly different IF calibration than was originally intended (the original plan was to have 10368.1 MHz to correspond to 145.1 MHz on the IF rig). A rough calibration of LO frequency versus AFC voltage was carried out using a frequency counter

plugged into the crystal oscillator test port J4 on the LO low frequency board, with the measured crystal oscillator frequency then multiplied by 102 to give the corresponding output frequency. For this test the crystal oscillator trimmer capacitor C5 was set approximately for maximum output amplitude at the test port. Neither the crystal oscillator nor the counter were fully warmed up, nor was any error due to counter reference frequency offset accounted for, since the main purpose was to find the tuning sensitivity. The results are shown in the following graph. It appears the originally intended calibration can be obtained at an AFC voltage of around 12 V. This calibration will change with changes in the setting of the crystal trimmer capacitor C5 so should be considered as a relative curve for determining AFC sensitivity and not as an absolute frequency calibration chart.

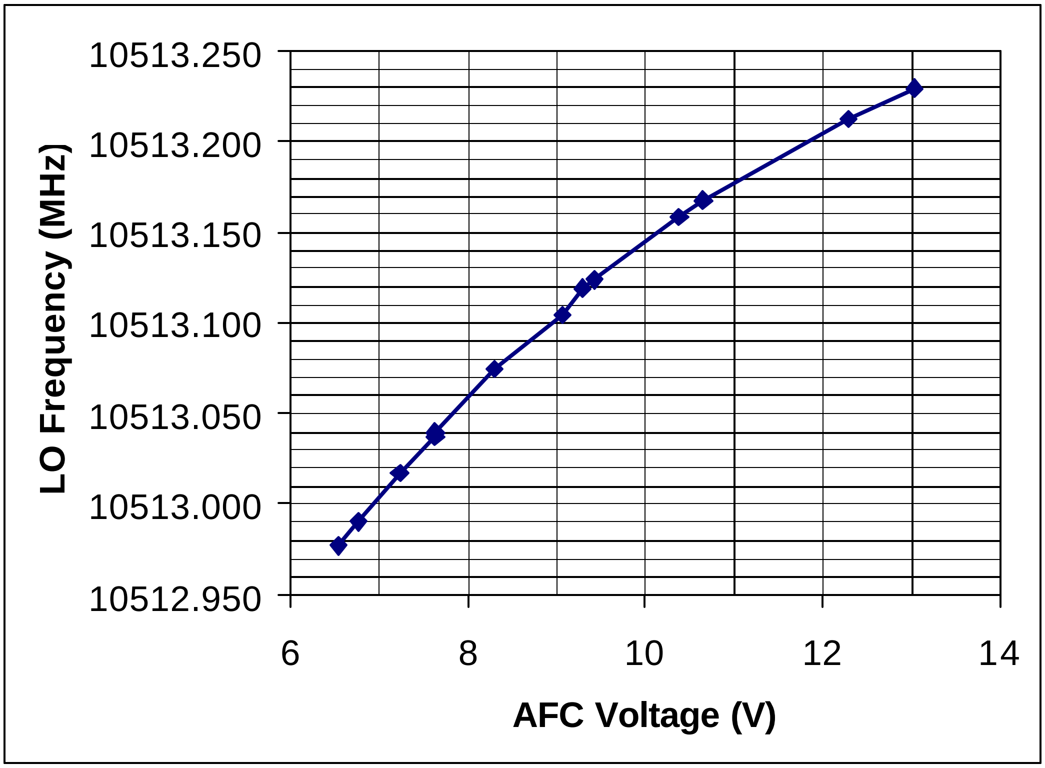


Figure 7: Typical dependence of LO frequency on AFC voltage

5. Note that at around 7 V AFC voltage the tuning sensitivity is 60 kHz/V. About a 1 kHz shift was noticed between transmit and receive (at an AFC voltage of 7.6 V), with the original resistors-only AFC biasing scheme. If this was due to a change in AFC voltage (because of a change in the 20 V line) the AFC voltage would have to change by 17 mV(and therefore the 20V line would have to change by about 45 mV) to have this effect. This is certainly a possible cause of at least part of the shift as I was able to detect about a 6-7 mV change on the AFC line between transmit and receive.
6. The phase-locked loop remains locked over a bit more than one turn of the crystal oscillator trimmer capacitor. However, this trimmer is part of a parallel tuned circuit across the output of the crystal oscillator and so has a strong impact on the output level. For maximum output and best PLL locking behaviour it seems that it should be tuned to give the maximum RF output at the SMB test jack and should not be operated close to the edges of the locking range.
7. I did not need to tune the microwave portion of the local oscillator module, originally intended for an LO near 10539 MHz.

8. The current drain from the +20V supply is about 250 mA when the crystal oven is warmed up (and about 400 mA when first starting from the cold state), both at room temperature.
9. Notes on the LO schematics in the G3PHO article (with reference to his figure numbers):

   Figure 4:
   - The schematic for the crystal oscillator stage is not quite the same as the schematic given in Fig.4 of WA6CGR's article. I don't know which is correct.
   - R18 & R19 are 2.2 kΩ (not quite legible in article)
   - The 910 Ω bias resistor for Q2 appears to connect to the collector of Q2 rather than to the +20 V supply.
   - R21 is in fact a microwave choke (but is still marked R21 on the board).

   Figure 5:
   - The resistor between U1 output and C26 appears to be R41 and is not 1kΩ – it looks like 680 Ω.
   - The pins of U2 are mis-numbered. U2A has inputs at pins 12(+) and 13(-) and output at pin 14. U2B is shown correctly. The resistive voltage divider at the inputs to U2A & B appears to use two 6.2 kΩ resistors with an 18 kΩ resistor in the middle. U2D has inputs at pins 10(+, reference voltage) and 9(-, from U2A & B) and output at pin 8.

   Figure 12:
   - The voltage on the white wire was measured at 6.2 V, not 0.86 V. Later measurements gave in the vicinity of 5 V so it is somewhat variable. The chip resistor connected to the white wire is 1kΩ. The measured voltage at the junction of this resistor and the 220 Ω resistor is 0.39 V.
   - The measured voltage at the ground end of the choke connected to the oscillator transistor collector (as shown in the figure) is 0.33V, implying about 1.6 ohms to ground – this seems surprisingly high.
   - The chip resistor connected to the blue wire is 270 Ω. The junction between this resistor and the choke is bypassed by a chip capacitor not shown in the figure.
   - Given the measured voltages the oscillator transistor is probably an NPN transistor operating in class C, not PNP as shown in the figure. The collector is connected (through the hi-Z line) to the orange wire and the emitter (through the choke) to the black wire. The base is connected as shown in the figure.
10. There is slightly more hiss from the IF receiver when the LO is locked than when it is unlocked, but probably not enough difference to be used as a useful diagnostic tool.
11. Phase locking is extremely sensitive to the setting of the phase detector balance potentiometer, R20. Rotation of this potentiometer by just a few degrees makes a significant difference.
12. Holes were drilled in the cover of the LO module to provide access to both the crystal oscillator trimmer capacitor C5 and the phase detector balance pot R20 so that the cover would not have to be removed to make adjustments. A small piece of plastic tubing was slipped over R20 to prevent the screwdriver from going astray and shorting out parts of the circuitry.
13. The phase locking of the LO module was found to be rather flaky and unreliable. One step that helped a bit with this was to wedge a piece of microwave foam-type absorber (surplus, of unknown type) in the access hole between the top and bottom compartments of the module to reduce the 1.7 GHz energy leaking through this hole from the high power VCO in the bottom compartment. It can be seen as the black object at the upper right of the board in the photo. This reduced the dependence of the phase locking on the movement of hands, screwdrivers, etc. near the upper board. Careful adjustment of R20 also helped.

Control Board

The Control Board added to the White Box combines the functions of transmit/receive switching, attenuation of the transmit IF signal and both amplification and attenuation of the receive IF signal. It also provides an interlock that prevents the +12 V being applied to the transmit portion of the transverter module if the -5 V is not present.

Turning the variable attenuator clockwise increases the transmit IF power reaching the transverter module.

The schematic is provided in the Schematics section of this document. A simplified top view of the board layout is shown below.

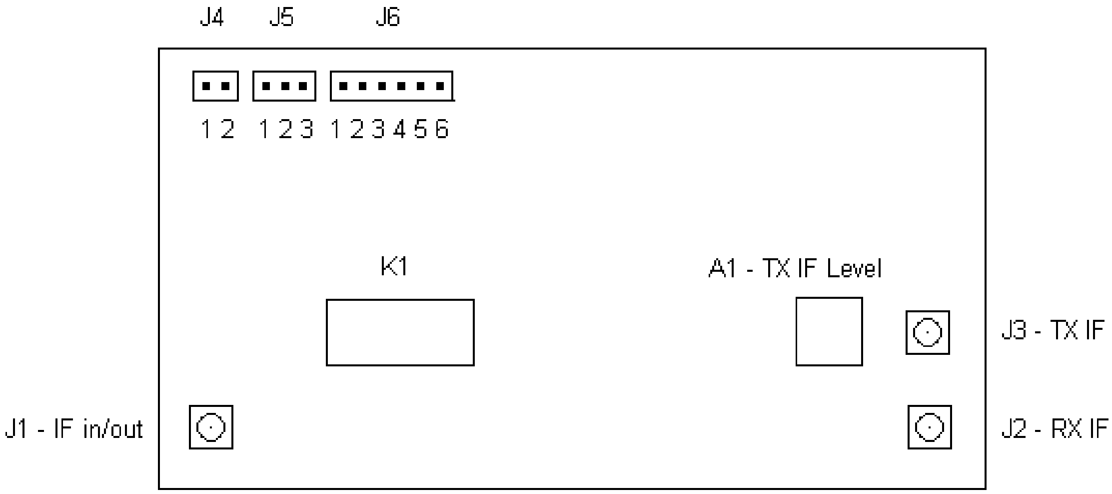


Figure 8: Control Board layout

The pinouts for J4, J5 and J6 are as follows. Pins are numbered from left to right when viewed as in the above diagram.

Connector	Pin No.	Function	Connects to
J4	1	Ground to transmit	IF rig T/R output or manual T/R switch
	2	Ground	IF rig T/R output or manual T/R switch
J5	1	No connection	(not used)
	2	+24 V input	Power Supply Board input (on circuit side of reverse polarity protection diode)
	3	Ground	Power Supply Board ground
J6	1	-5 V input	Transverter Module -5 V feedthrough
	2	+12 V input	Transverter Module power supply plug (transmit +12 V pin)
	3	Ground	Transverter Module ground pin
	4	+12 V output (RX)	(not currently used)
	5	+12 V output (TX)	Transverter Module +12 V transmit feedthrough
	6	Ground	(not currently used)

The following photos show the top and bottom (just to show that fancy construction is unnecessary !) of the Control Board.

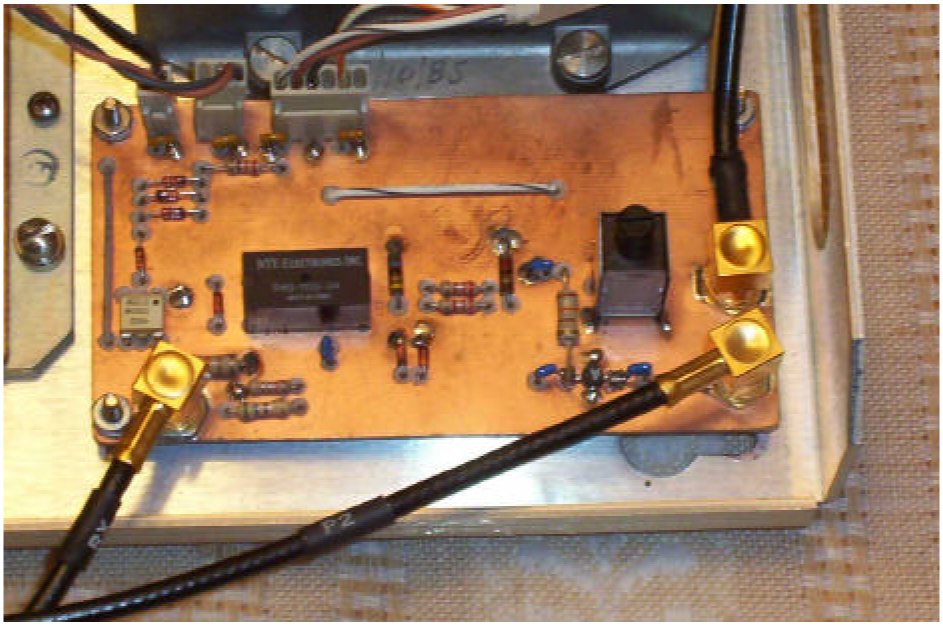


Figure 9: Control Board – top view

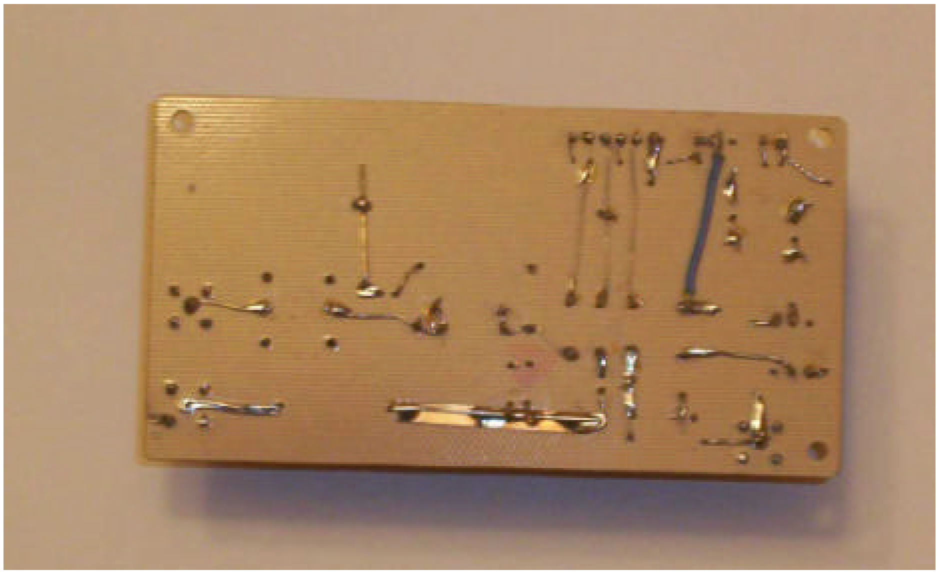


Figure 10: Control Board – bottom view

Receive Filter Tuning Method

I found it was possible to achieve acceptably accurate tuning of the receive filters without requiring more than very rudimentary test equipment. The following paragraphs describe the process I followed for doing this.

I used a Gunn oscillator (part of an old 10 GHz wideband FM rig) as a signal source to enable tuning of the receive filter. I began by tuning the Gunn for the nominal receive frequency as shown on the test data sheet that came with the White Box. I then used the setup shown in the following figure for tuning the receive filter. The Gunn/attenuator/wavemeter assembly is all WR-90 waveguide, as is the input to the White Box transverter assembly, but a short piece of coax was needed to be able to arrange things conveniently on the bench.

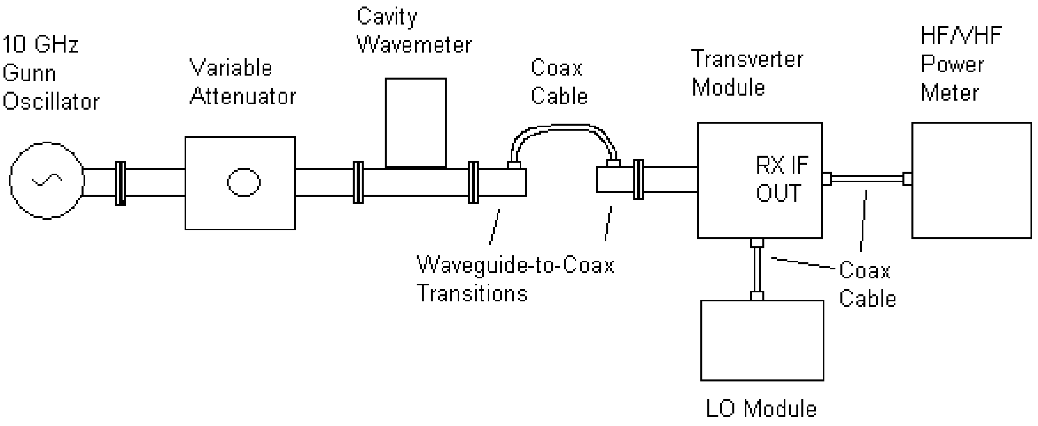


Figure 11: Receive filter tuning setup

I used a 3/16” nut driver from a socket set to loosen the nuts on the resonator screws (see WA6CGR article). Then I removed the driver handle and just used the 3/16” socket itself between my fingers to keep the nut moderately tight while tuning using an Allen Key (0.050”) passing through the middle of the 3/16” socket.

I set the attenuator so the power level from the Gunn (about 10 mW) was attenuated to about 100 microwatts so as not to destroy the mixer in the transverter module. The attenuator also stops the Gunn oscillator frequency from locking onto the resonance of the cavity wavemeter! I applied +20 V to the LO and +12 V to only the RX side of the transverter module. At this point I was able to observe the IF output power on the power meter, and I could check the Gunn frequency by looking for a dip in the power meter reading when I tuned the wavemeter through the Gunn frequency. I readjusted the Gunn for a slightly lower frequency where the IF output power was starting to drop off – i.e. the frequency was on the low edge of the filter passband. I then peaked all the resonator screws in the filter to maximize the power meter reading. I repeated this process of reducing the Gunn frequency a few MHz and repeaking the resonator screws over and over again until I got the Gunn to just a few MHz above the LO frequency. Then I reset it about the same amount below the LO frequency and repeaked the screws. This was a bit more of a jump than previously and required a bit of guesswork as to where the screws should be set, but it wasn’t particularly difficult. I was then able to carry on with the same iterative procedure until I got the filter roughly peaked at 10.368 GHz. Only at this point did I need to bother with the coupling (or “aperture”) screws. A few cycles around all the screws got the measured conversion gain to about the level calculated in the previous section (measured by comparing the IF output power to the Gunn oscillator power measured with a diode detector calibrated at 10 GHz against someone else’s expensive test gear). Then the handle from the socket set was replaced and the nuts tightened.

For this process, no spectrum analyzer or microwave sweep generator was required! The power meter used was a homebrew one and only has to work from about 5 MHz to 145 MHz, so it is not very exotic. It is basically as described on page 147 of *Solid State Design for the Radio Amateur* with a surplus step attenuator in front of it. A diode detector, possibly with a simple MMIC broadband amplifier in front of it, would probably work fine as a substitute for the power meter.

Transmit Filter Tuning Method

I used the setup shown in the following figure for tuning the transmit filters. Again, no specialized test equipment was required to achieve satisfactory results.

The wavemeter/attenuator/detector assembly is all WR-90 waveguide, as is the output from the White Box transverter assembly, but a short piece of coax was needed to be able to arrange things conveniently on the bench. The variable attenuator was needed to protect the detector from the full power of the White Box transverter which would probably be enough to burn out the detector diode. However, the attenuator built in to the waveguide section of the White Box transverter module could be used instead.

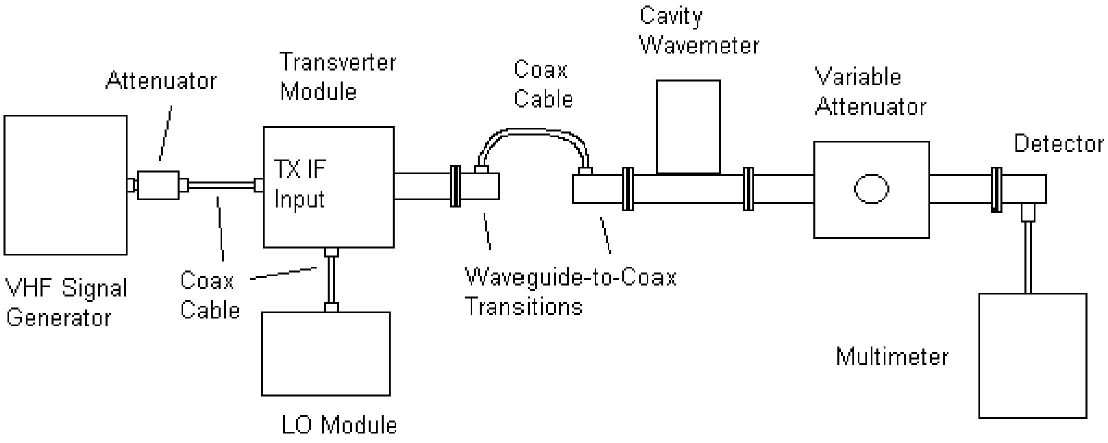


Figure 12: Transmit filter tuning setup

I set the signal generator (using the homebrew VHF power meter) so the power level after the 10 dB attenuator (used to ensure a good match) was about 5 microwatts (-23 dBm). I applied +20 V to the LO and -5V and +12 V to the TX side of the transverter module.

With the signal generator set to about 130 MHz I was able to detect output power at 10 GHz on the multimeter and confirm by dipping the wavemeter that it was at about 10.64 GHz. The TX filters in the transverter module were then peaked up to produce maximum output (resonator screws only). Next the signal generator was set to a slightly lower frequency and the filters re-peaked. This continued until the signal generator reached about 80 MHz. At this point the output available was quite low (I think due to the tuned circuit at the output of the internal IF amplifier). The final filter tuning at this point was such that the output was beginning to drop (in other words the filters were tuned with the upper edge of the pass band just below the mixer output frequency of about 10.580 GHz. At this stage it was possible to switch off the signal generator and still get a little output, due to LO leakage through the mixer. The filters were then peaked up on this signal and then tuned a bit further so the output began to drop. At this point the upper edge of the filter passband was just below the 10.513 GHz LO frequency. Now, switching the signal generator back on, some additional output could be detected, now on the low side of the LO. The filters were then walked down to the desired frequency in the same manner as at the start (but now increasing the

VHF signal frequency at each step). The final filter tuning was done with the TX IF input provided from a 2m rig, through an attenuator and the Control Board.

Again no expensive test equipment was needed. The signal generator was an old and very cheap one made by StarKit. Heathkit and Eico made similar models.

I found that at times there was RF power coming out the TX IF input jack on the transverter module, indicating a spurious oscillation. I also found that at times there was 10 GHz output with no TX IF input, further confirming the spurious oscillation. This resulted in a randomly varying output power when the TX IF input was present. This would usually go away after a minute or two in transmit mode.

When I opened the top panel I found that prodding on various parts of the TX IF amplifier made the spurious output go away. Tightening the nearest board mounting screw did the trick in a (hopefully) more permanent fashion. I guess the board warming up (when switched to TX) warped it enough to make contact. None of the screws holding this board in were found to be fully tight.

I peaked the inductor at the output of the transmit IF amplifier in the Transverter Module (upper right of Figure 6) to the degree possible at 145 MHz. Maximum output was obtained with the slug fully out.

Performance Measurements

Measured TX IF Power

The following graph shows the measured TX IF level at the output of the control board, for a variety of attenuator settings, with the TR-751A at both low and high power settings.

A 4 foot length of RG-58A/U, with negligible loss, was used between the TR-751A and the input 15 dB attenuator. The TX IF power was measured with a homebrew power meter with characteristic impedance of 50 ohms, while the output impedance of the control board is 75 ohms. The error resulting from the impedance mismatch is negligible compared to the power meter accuracy. The turns count for attenuator A1 (on the Control Board) is such that integral numbers of quarter turns correspond to the settings where the screwdriver slot is parallel to the edges of the Control Board (i.e. the fully counterclockwise position is not quite zero turns, while the fully clockwise position is not quite 3 turns).

Note that the average difference between the two curves is 6.9 dB, somewhat more than the 5.8 dB measured on the TR-751A output directly (20 W compared to 5.3 W), indicating a small discrepancy in one or the other of the measurements, or a dependency on slightly different load impedances in the two cases.

The maximum output is -17 dBm (as in the above theoretical analysis) in low power and -10.7 dBm in high power, slightly lower than predicted due to the TR-751A having less than specified output power in high power mode.

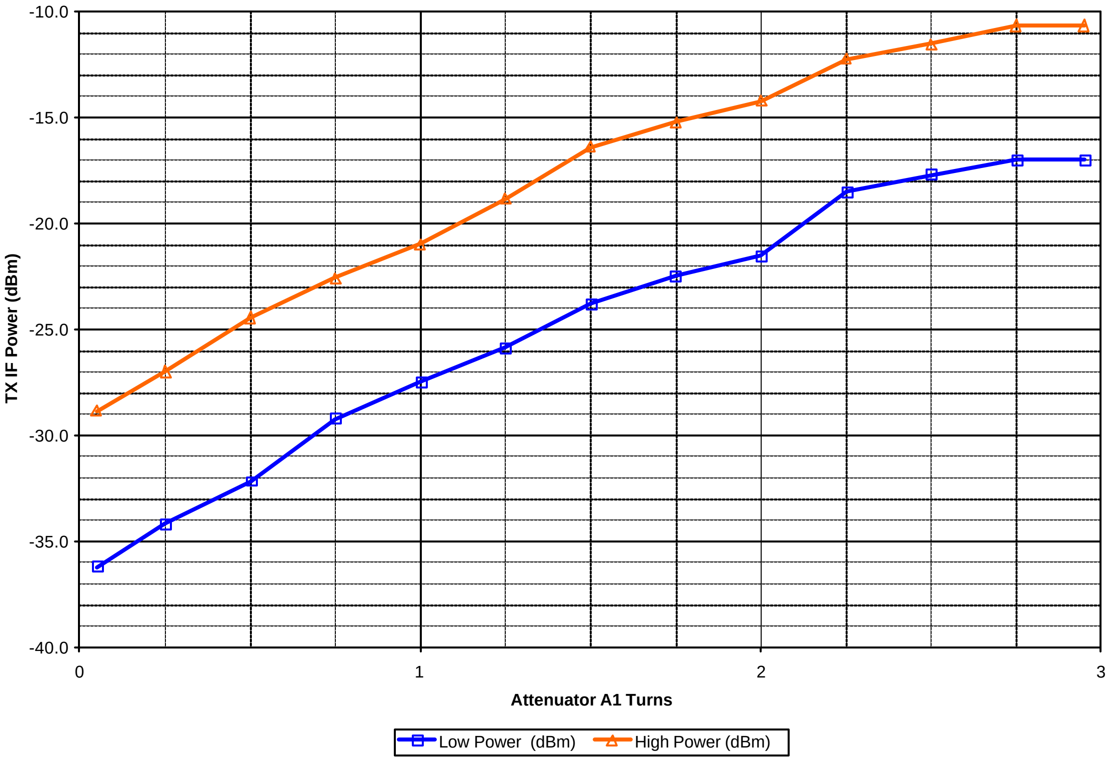


Figure 13: Variation of TX IF power at Control Board output with setting of A1

Measured Compression

The 10 GHz output power was measured in a relative fashion while the attenuator A1 on the Control Board was varied as in the previous section (with the TR-751A in low power mode on CW at 145.000 MHz). This was done by setting a waveguide attenuator to give the same reading on a detector for each setting of attenuator A1. The relative output power at 10 GHz is then proportional to the setting of the waveguide attenuator. The results are shown in the following graph. The 1 dB compression point (suitable setting for SSB peak power) appears to be at about -23 or -24 dBm TX IF power. This corresponds to an attenuator A1 setting of about 1½ turns (i.e. the midpoint of its travel) when using the TR-751A on low power. At this setting the TX IF power when the TR-751A is set to high power is just -16 dBm, low compared to WA6CGR's suggested limit of -12 dBm.

For maximum power output on CW or FM (about 1.5 dB more than at the 1 dB compression point) there is no point in going above about -21 dBm TX IF power, corresponding to about 2 turns on attenuator A1, for low power on the TR-751A. This seems a little more sensitive than some amateurs have suggested, perhaps because the inductor at the output of the Transverter Module TX IF amplifier was adjusted for maximum output.

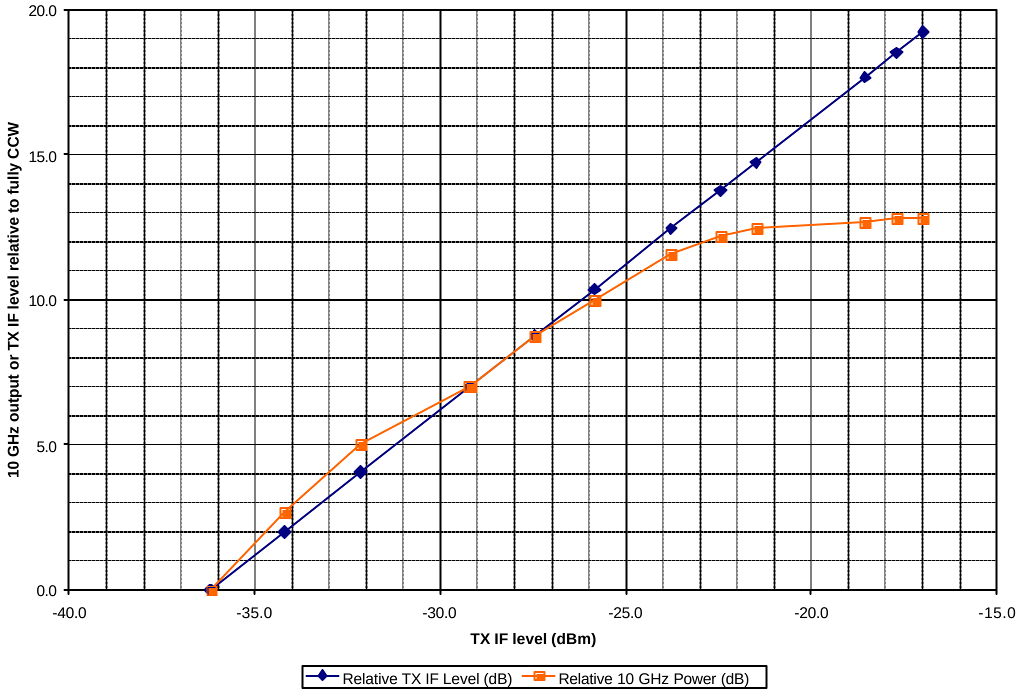


Figure 14: Transmit compression

Measured Output Power

Measurements of output power at 10 GHz were made with two different detectors and with several different calibrations for the detectors and the waveguide attenuator between the transverter output and the detector. They vary over about a 3:1 range for any given TX IF drive level. However, my best estimates are that the output is about 170 mW at the 1 dB compression point (TR-751A on low power, CW, 145.000 MHz, A1 at 1½ turns) and about 240 mW when saturated.

With an HP 430C Power Meter and HP 477B Power Meter Head the saturated power was measured at 160 mW and 110 mW at a reasonable setting of the TX IF attenuator for linearity. It is likely, but not certain, that this is a more accurate measurement.

Measured TX MON Output

The White Box provides a TX MON (transmit monitor) output voltage which can be used to drive a meter for use as a relative indicator of 10GHz transmitted power.

The TX MON output was measured at 3.0 V with the TR-751A on low power CW at 145.000 MHz and attenuator A1 on the Control Board set to 1½ turns (approximately at the 1 dB compression point). This was with very high (megohms) load resistance. With 3.3kΩ load resistance the voltage dropped to 2.9V. The load current in this case is 2.9v/3.3kΩ = 0.88 mA.

This would suggest that a 1 mA full-scale meter could be used as a relative power monitor, perhaps with a series resistor of about 4.7kΩ so that the normal power would put the needle at about 60 percent of full scale.

Measured Current Drain

The measured total current drains from the +24 V supply are as follows. All measurements were made at room temperature, about 23°C:

Condition	**Total Current from 24V Supply (mA)**
When first switched on, in receive mode	590
After 1 minute warm up, in receive mode	450
After 2 minutes warm up, in receive mode	440
After 2 minutes warm up, in transmit mode	1030

Possible Future Changes

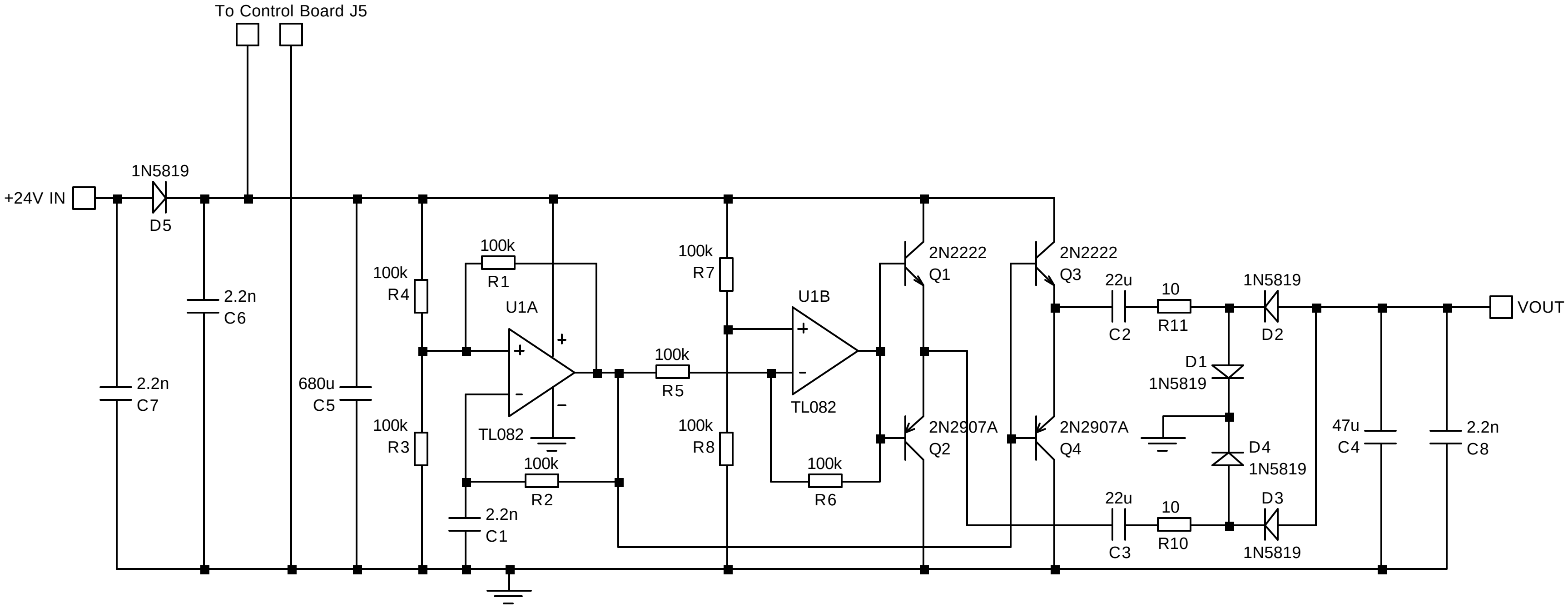
1. To reduce current drain the crystal oscillator could be operated without the oven. Just unplug the oven from the board in the top compartment of the LO Module. The stability characteristics without the oven, and the change in LO frequency from the oven-on condition have not been tested.
2. To reduce current drain (by about 100 mA) in transmit mode the IF preamplifier inside the Transverter Module could be powered from the +12 V output (RX) pin on J6 of the control board. It is currently wired directly to the +12 V pin on the power supply connector and is on all the time.
3. The modifications describe retain the original circulator to connect the transmit and receive sides of the transverter to the antenna, using the original microstrip-to-waveguide transition (with the built-in variable attenuator set to minimum attenuation !). For better performance a 10 GHz receive preamplifier and transmit power amplifier could be added using an arrangement like that shown in WA6CGR's article. A sequencer should be used for protection of the microwave circuitry, but is not needed to protect the transverter from excessive 2m IF power as the attenuator arrangement described here already accomplishes that.

References

1. Dave Glawson, WA6CGR, "A Complete X-Band SSB Portable Communicatins System", Microwave Update 1991, ARRL, Newington CT (also available from www.febo.com).
2. Peter Day, G3PHO, "Modifying the Microwave Associates "White Box" for 10 GHz", http://www.qsl.net/g3pho/whitebox.htm.
3. Wes Hayward, W7ZOI, and Doug DeMaw, W1FB, Solid State Design for the Radio Amateur, ARRL, Newington CT, 1977.

Schematics for New and Modified Circuits

(a) Inverter Board (new board)
(b) Control Board (new board)
(c) Top Level Wiring (incorporating some original, some modified and some new circuitry)



Notes:

1. Reference designation R9 is not used.

Figure 15: Inverter Board Schematic

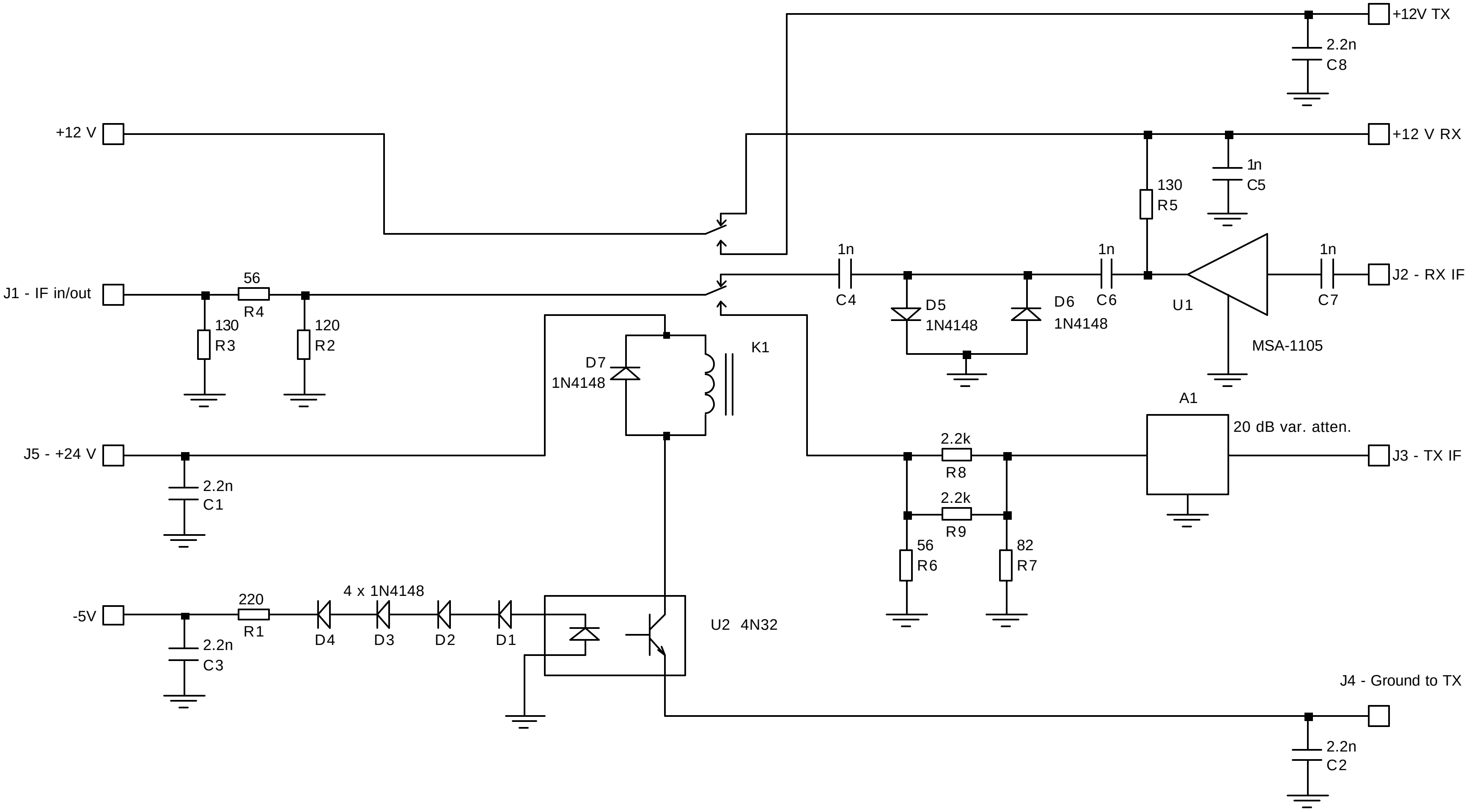
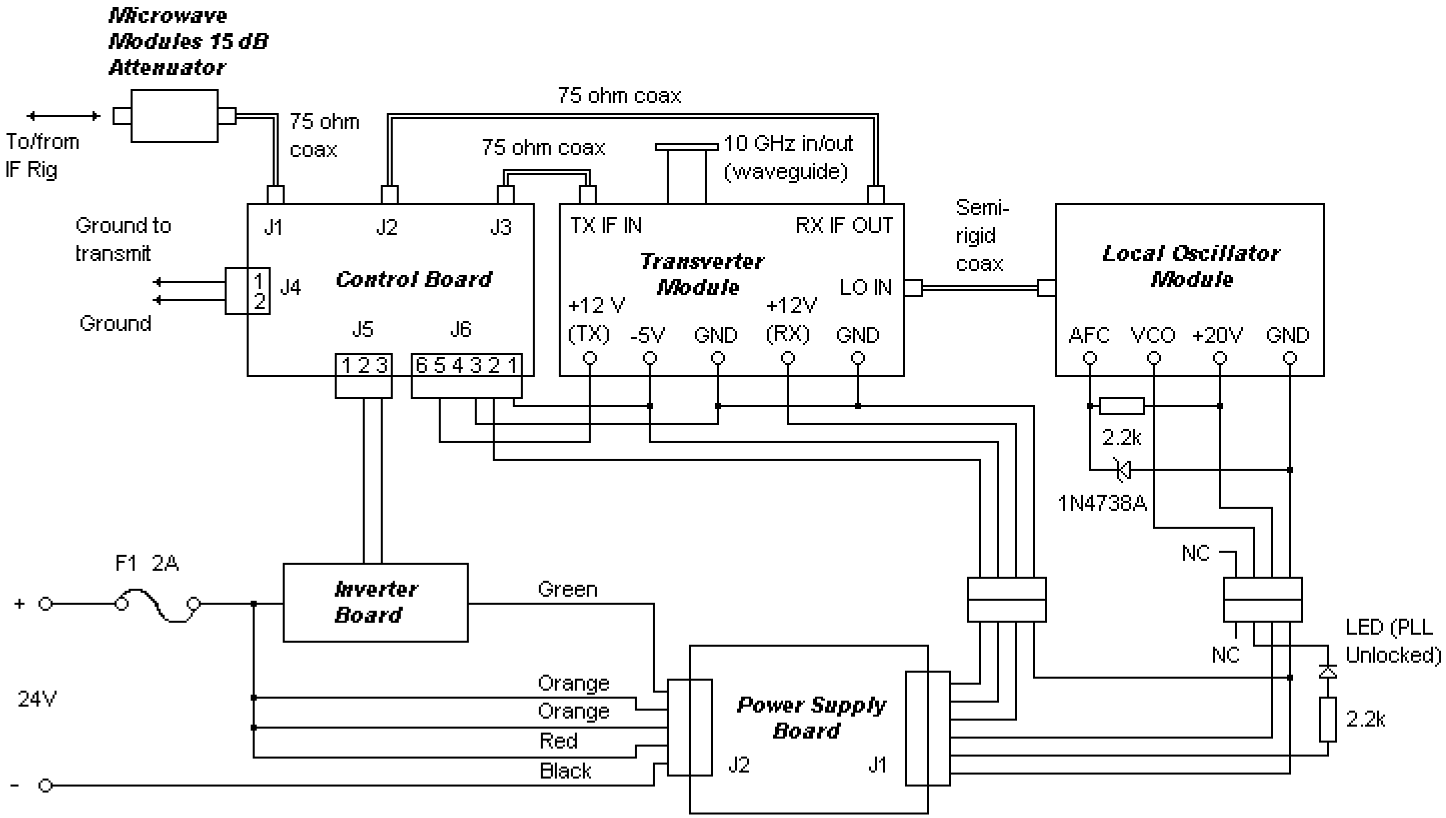


Figure 16: Control Board Schematic



Notes:
1. There are additional unused wires at the power supply input and output connectors.
2. NC means no connection to this wire.
3. The 24 V negative input is not connected to ground at the power supply, only through the various modules powered from it.

Figure 17: Top Level Wiring Diagram

PARTS LIST FOR VE3NPB "WHITE BOX" TRANSVERTER MODIFICATION

Item No.	Description	Used In	Ref.	Qty.	Source	Price for N	N	Cost	Units (if any)
1	Cap., Electrolytic, 47uF 50V	Existing PS Board	C1	1	Sayal	$1.10	5	$0.22	
2	Cap., Electrolytic, 47uF 50V	Existing PS Board	C4	1	Sayal	$1.10	5	$0.22	
3	Cap., Electrolytic, 10uF 100V	Existing PS Board	C7	1	Sayal	$1.10	5	$0.22	
4	Diode, Schottky Rectifier, 1N5819	Existing PS Board	CR4	1	Sayal	$1.00	4	$0.25	
5	Cap., Ceramic, 2.2 nF 50V	Inverter	C1	1	Sayal	$1.00	4	$0.25	
6	Cap., Electrolytic, 22uF 50V	Inverter	C2	1	Sayal	$1.00	5	$0.20	
7	Cap., Electrolytic, 22uF 50V	Inverter	C3	1	Sayal	$1.00	5	$0.20	
8	Cap., Electrolytic, 47uF 50V	Inverter	C4	1	Sayal	$1.10	5	$0.22	
9	Cap., Electrolytic, 680uF 50V	Inverter	C5	1	Orig.PS	-	-	$0.00	
10	Cap., Ceramic, 2.2 nF 50V	Inverter	C6	1	Sayal	$1.00	4	$0.25	
11	Cap., Ceramic, 2.2 nF 50V	Inverter	C7	1	Sayal	$1.00	4	$0.25	
12	Cap., Ceramic, 2.2 nF 50V	Inverter	C8	1	Sayal	$1.00	4	$0.25	
13	IC, Op-Amp, TL082CP	Inverter	U1	1	Sayal	$1.00	1	$1.00	
14	Transistor, NPN, 2N2222A	Inverter	Q1	1	Sayal	$1.30	2	$0.65	
15	Transistor, NPN, 2N2222A	Inverter	Q3	1	Sayal	$1.30	2	$0.65	
16	Transistor, PNP, 2N2907A	Inverter	Q2	1	Sayal	$1.25	2	$0.63	
17	Transistor, PNP, 2N2907A	Inverter	Q4	1	Sayal	$1.25	2	$0.63	
18	Diode, Schottky Rectifier, 1N5819	Inverter	D1	1	Sayal	$1.00	4	$0.25	
19	Diode, Schottky Rectifier, 1N5819	Inverter	D2	1	Sayal	$1.00	4	$0.25	
20	Diode, Schottky Rectifier, 1N5819	Inverter	D3	1	Sayal	$1.00	4	$0.25	
21	Diode, Schottky Rectifier, 1N5819	Inverter	D4	1	Sayal	$1.00	4	$0.25	
22	Diode, Schottky Rectifier, 1N5819	Inverter	D5	1	Sayal	$1.00	4	$0.25	
23	PC Board, .062" double sided, 3 x 3.5"	Inverter		10.5	Orion	$1.49	27	$0.58	sq.in.
24	Resistor, 100 kohms, 0.25 W	Inverter	R1	1	Sayal	$1.00	10	$0.10	
25	Resistor, 100 kohms, 0.25 W	Inverter	R2	1	Sayal	$1.00	10	$0.10	
26	Resistor, 100 kohms, 0.25 W	Inverter	R3	1	Sayal	$1.00	10	$0.10	
27	Resistor, 100 kohms, 0.25 W	Inverter	R4	1	Sayal	$1.00	10	$0.10	

28	Resistor, 100 kohms, 0.25 W	Inverter	R5	1	Sayal	$1.00	10	$0.10	
29	Resistor, 100 kohms, 0.25 W	Inverter	R6	1	Sayal	$1.00	10	$0.10	
30	Resistor, 100 kohms, 0.25 W	Inverter	R7	1	Sayal	$1.00	10	$0.10	
31	Resistor, 100 kohms, 0.25 W	Inverter	R8	1	Sayal	$1.00	10	$0.10	
32	Resistor, 10 ohms, 0.5 W	Inverter	R10	1	Sayal	$1.00	6	$0.17	
33	Resistor, 10 ohms, 0.5 W	Inverter	R11	1	Sayal	$1.00	6	$0.17	
34	Attenuator, Variable, 20 dB	Control Board	A1	1	Orig.IF	$0.00	1	$0.00	
35	Capacitor, Ceramic, 2.2nF 50V	Control Board	C1	1	Sayal	$1.00	4	$0.25	
36	Capacitor, Ceramic, 2.2nF 50V	Control Board	C2	1	Sayal	$1.00	4	$0.25	
37	Capacitor, Ceramic, 2.2nF 50V	Control Board	C3	1	Sayal	$1.00	4	$0.25	
38	Capacitor, Ceramic, 1nF 50V	Control Board	C4	1	Sayal	$1.00	5	$0.20	
39	Capacitor, Ceramic, 1nF 50V	Control Board	C5	1	Sayal	$1.00	5	$0.20	
40	Capacitor, Ceramic, 1nF 50V	Control Board	C6	1	Sayal	$1.00	5	$0.20	
41	Capacitor, Ceramic, 1nF 50V	Control Board	C7	1	Sayal	$1.00	5	$0.20	
42	Capacitor, Ceramic, 2.2nF 50V	Control Board	C8	1	Sayal	$1.00	4	$0.25	
43	Connector, Coaxial	Control Board	J1	1	Orig.IF	$0.00	1	$0.00	
44	Connector, Coaxial	Control Board	J2	1	Orig.IF	$0.00	1	$0.00	
45	Connector, Coaxial	Control Board	J3	1	Orig.IF	$0.00	1	$0.00	
46	Diode, Signal, 1N4148	Control Board	D1	1	Sayal	$1.00	6	$0.17	
47	Diode, Signal, 1N4148	Control Board	D2	1	Sayal	$1.00	6	$0.17	
48	Diode, Signal, 1N4148	Control Board	D3	1	Sayal	$1.00	6	$0.17	
49	Diode, Signal, 1N4148	Control Board	D4	1	Sayal	$1.00	6	$0.17	
50	Diode, Signal, 1N4148	Control Board	D5	1	Sayal	$1.00	6	$0.17	
51	Diode, Signal, 1N4148	Control Board	D6	1	Sayal	$1.00	6	$0.17	
52	Diode, Signal, 1N4148	Control Board	D7	1	Sayal	$1.00	6	$0.17	
53	Header, polarized, 2 pin	Control Board	J4	1	Supreme.	$0.10	1	$0.10	
54	Header, polarized, 3 pin	Control Board	J5	1	Supreme.	$0.10	1	$0.10	
55	Header, polarized, 6 pin	Control Board	J6	1	Supreme.	$0.10	1	$0.10	
56	MMIC Amplifier, Agilent MSA-1105	Control Board	U1	1	AA1IP	$2.00	1	$2.00	
57	Optoisolator, 4N32	Control Board	U2	1	Sayal	$1.30	2	$0.65	
58	PC Board, .062" single sided, 2.3"x4.3"	Control Board		9.9	Supreme.	$1.15	62	$0.19	sq.in.
59	Relay, DPDT, 24V 2880 ohm coil, 1A	Control Board	K1	1	Orion	$8.95	1	$8.95	

60	Resistor, 220 ohms	Control Board	R1	1	Junkbox	$0.00	1	$0.00	
61	Resistor, 120 ohms	Control Board	R2	1	Junkbox	$0.00	1	$0.00	
62	Resistor, 130 ohms, 1 watt	Control Board	R3	1	Sayal	$1.00	6	$0.17	
63	Resistor, 56 ohms, 1/2 watt	Control Board	R4	1	Sayal	$1.00	6	$0.17	
64	Resistor, 130 ohms, 1 watt	Control Board	R5	1	Sayal	$1.00	6	$0.17	
65	Resistor, 56 ohms	Control Board	R6	1	Junkbox	$0.00	1	$0.00	
66	Resistor, 82 ohms	Control Board	R7	1	Junkbox	$0.00	1	$0.00	
67	Resistor, 2.2 kohms	Control Board	R8	1	Junkbox	$0.00	1	$0.00	
68	Resistor, 2.2 kohms	Control Board	R9	1	Junkbox	$0.00	1	$0.00	
69	LED, Red, unknown type	Local Osc. (Alarm)		1	Junkbox	$0.00	1	$0.00	
70	Resistor, 2.2 kohms	Local Osc. (Alarm)		1	Junkbox	$0.00	1	$0.00	
71	Resistor, 2.2 kohms	Local Osc. (AFC)		1	Junkbox	$0.00	1	$0.00	
72	Zener diode, 8.2 V, 1N4738A	Local Osc. (AFC)		1	Sayal	$1.00	6	$0.17	
73	Fuse, 2A Fast Blow	Top Assembly	F1	1	Radio Sh.	$2.99	3	$1.00	
74	Plug, BNC	Common IF Cable		1	Sayal	$2.09	1	$2.09	
75	Attenuator, 15 dB, 10 W (Micro.Modules)	Top Assembly		1	Murray	$0.00	1	$0.00	

Subtotal	$27.85
GST	$1.95
PST	$2.23
Total Cost	$32.03

1. Sayal Electronics (several branches in southern Ontario – what is in stock is always changing)
2. Orion Electronics (40 Lancaster St. W., Kitchener, ON)
3. Supremetronic Inc. (333 Queen Street West, Toronto, ON)
4. Brad Thompson, AA1IP (P.O. Box 307, 202 Whitaker Rd. Meriden. NH 03770-0307)
5. Radio Shack (everywhere)