From Radio Oceanography Laboratory wiki

Tech: Testing VSWR Pro

Testing the VSWR Protection Board

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Modifications to the VSWR Protection Board

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The VSWR Protection board appears to be functional on all autonomous functions 9/22/2017

It asserts proper control over the TOMCO

We have not tested the basic ARM interactions yet.

In order to properly test the VSWR Protection board, it should first be tested on the bench and trim adjustments set for their nominal levels;
The trimpots should be pre-set to the nominal voltages. This should ensure that the board comes up operational on the first try.
These can most conveniently be set with a signal generator, taking into account the sampling attenuation of the directional coupler and the on-board attenuators.
Actual generator settings will be explained below.

- The RF Input level meter should be set up to trip for drive levels substantially above normal (POT1) "Overdrive".
- The nominal drive for full output is about -10dBm.
- The trigger level for activating the transmitter should be about -28dBm. (18dB below nominal.)
  - That level is high enough to provide reliable triggering over the full range of remote drive powers that might be desirable.
  - This level is not critical, so it simply a FSV to be determined.

- The Forward Power sensor is on J21 "FWD. RF"
- The Reflected Power sensor is on J31 "REFL. RF"
  - Technically, this does not trip on VSWR, but on absolute reflected power.
  - About 13 Watts is a good starting point, which is the equivalent of the rated 3:1 operating VSWR.
  - (At 13 Watts forward power, it can withstand infinite VSWR.)
  - VSWR is not measured, but is a **calculated** parameter.

The RA-50 protection PCB is a stand-alone circuit, independent of any micro-controller.
It essentially duplicates in hardware the functions of the old Rabbit controller.
Protection response is essentially instantaneous, not dependent on the sampling loop in software.
The ARM sampling can probably be slowed to a 1-second logging rate or slower.
The unit is fully protected in the case of a software crash (or debugging).
The ARM computer simply **adds** functionality:

- Monitoring and telemetry of RF Amplifier performance data.
- Programmed override of the hardware responses:
  - To implement recovery strategies.
  - To allow remote intervention.
- The protection should be idiot-proof.
  - Cannot override an actual TOMCO over-temperature alarm.
- AND idiot-computer proof:
  - DIO control port defaults safely to 0000 0000. (INPUT mode, actually)

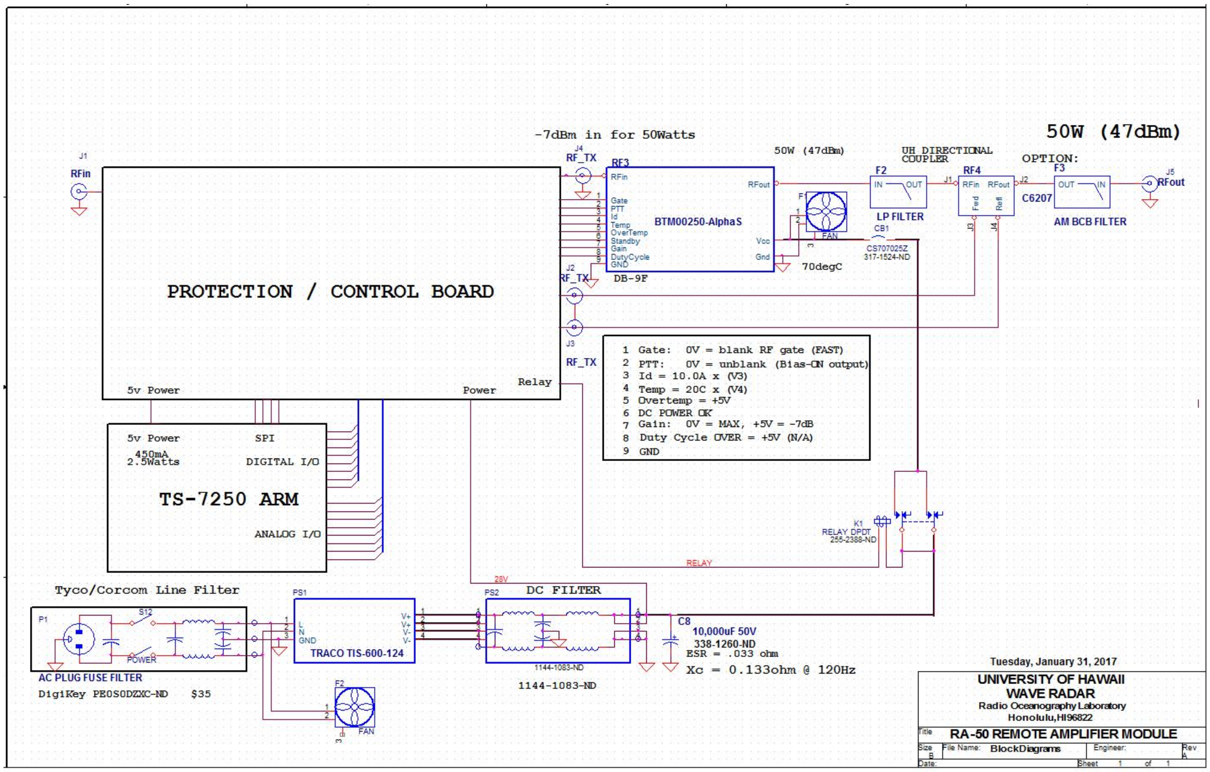

Fig. 1. Block Diagram: two versions, different details.
The details of the protection/control block are outlined below...
We identified some NEMA-rail filter modules..
Still need the power relay and large filter capacitor.
There is an added AC Isolation Transformer.
Sequence of the RF LP Filter and Directional Coupler to be discussed.
'''Not shown here: Fwd, Rev sampling ports -47dB to panel.

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Discussion of Sub-Circuits

Note: in this diagram there is a -7dB attenuator for the TOMCO.
As I recall, the necessary drive level of the new modules is somewhat different from before.
We need to verify this before the boards are assembled. The reference level is 0dBm, so this would be -7dBm drive:

The new LO buffer splitter is putting out +22dBm TX level.

- This would cause a gross OVERDRIVE.
- I have a 20dB attenuator on board.
  - that would require a 2dB external attenuator ** or we could dial in -2dB on the digital attenuator.
  - or we could adjust for a standard +20dBm TX level.
- There is a tiny 32MHz LP filter on input

We actually measured 50 Watts output with only -10dBm input. We will re-adjust the attenuator at the input of the TOMCO. (On 09/12/2017 we added the extra 3dB attenuation at the output of the board to simulate this change.)

- With the nominal +20dBm input, the TOMCO output was a near-perfect +46.8dBm.

NOTE: If the TX is deployed remotely, there will not be 20dBm of drive available. We should probably place a ZEROHM resistor here and use an external attenuator to adjust for line losses. For local mounting, the on-board pad should be OK. The LO Distribution board output should be set for +20dBm output for the cleanest signal.

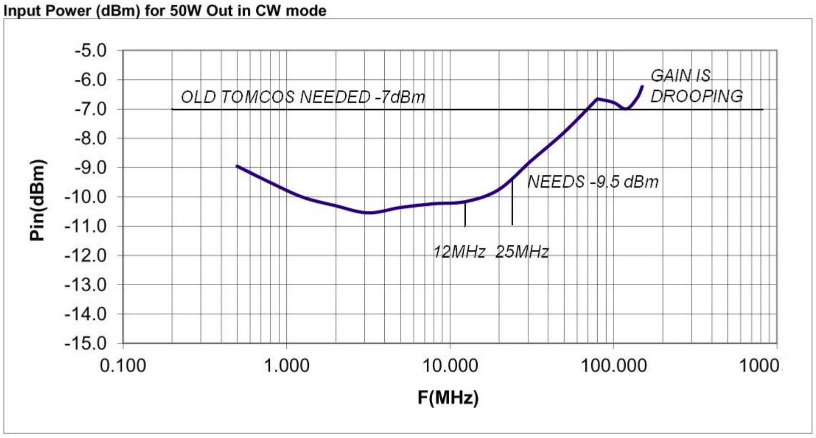

Fig. 2. The input at 10MHz for 47dBm out is -10.2dBm so the gain is 57.2dB for this unit.
At 25MHz it needs -9.5dBm so the gain is 56.5dB. That is only 0.7dB droop.

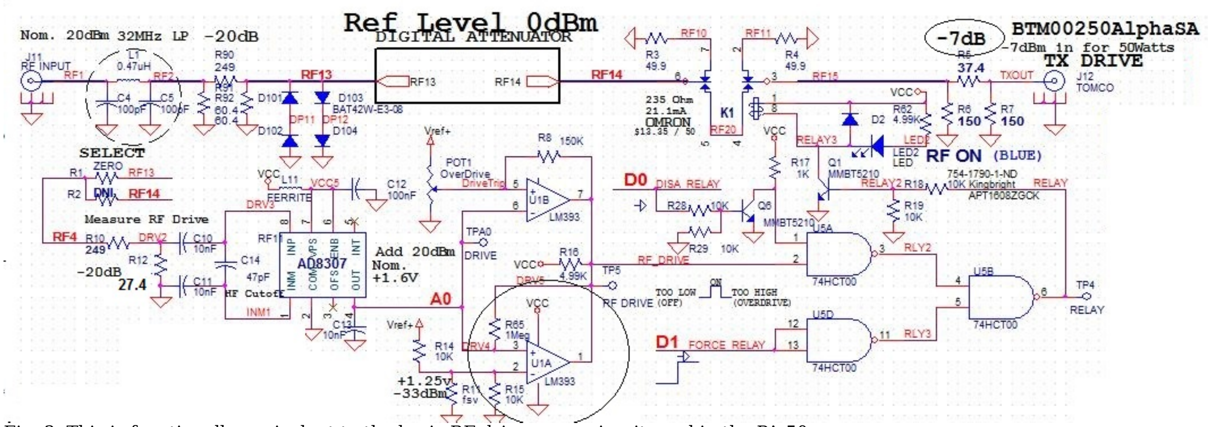

Fig. 3. This is functionally equivalent to the basic RF drive sense circuit used in the PA-50.
The difference is that instead of letting the Rabbit sense the threshold voltages and turn on the transmitter, this is now done directly in hardware.
Function1: "**While** RF drive level is above threshold, enable the relay to drive the TOMCO amplifier."
Function2: "When initiating TX, **RESET the -7dB REDUCED POWER LATCH.**"
Note: This is a "window discriminator". It activates the relay with nominal drive, but **disables** it for excessive drive.
The threshold should be set fairly low to allow operation at reduced levels. 18dBm below full power should be ok.

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This chart calculates the AD8703 DC output for expected RF levels. The measurements were made 09/11/2017:

RF INPUT						BIDIRECTIONAL COUPLER INPUTS					Measured					
						J21										
J11		TEST POINT				J31				TEST POINT						
INPUT	ATTEN	0.026	dcv	Calc		INPUT	ATTEN			0.026	dcv	Calc		dcv	Calc	
	40	2.120	TPA0	dBm	error		10	mW	AC mV	2.120	TPA1	dBm	error	TPA2	dBm	error
20	-20	1.600	1.676	-17.1	2.9	10	0	1.000000	223.607	2.120	2.252	5.1	5.1	2.235	4.4	4.4
18	-22	1.548	1.623	-19.1	2.9	8	-2	0.630957	177.617	2.068	2.197	3.0	5.0	2.186	2.5	4.5
16	-24	1.496	1.573	-21.0	3.0	6	-4	0.398107	141.086	2.016	2.144	0.9	4.9	2.135	0.6	4.6
14	-26	1.444	1.525	-22.9	3.1	4	-6	0.251189	112.069	1.964	2.095	-1.0	5.0	2.085	-1.3	4.7
12	-28	1.392	1.476	-24.8	3.2	2	-8	0.158489	89.019	1.912	2.040	-3.1	4.9	2.031	-3.4	4.6
10	-30	1.340	1.425	-26.7	3.3	0	-10	0.100000	70.711	1.860	1.992	-4.9	5.1	1.981	-5.3	4.7
8	-32	1.288	1.372	-28.8	3.2	-2	-12	0.063096	56.167	1.808	1.943	-6.8	5.2	1.929	-7.3	4.7
6	-34	1.236	1.318	-30.8	3.2	-4	-14	0.039811	44.615	1.756	1.894	-8.7	5.3	1.885	-9.0	5.0
4	-36	1.184	1.266	-32.8	3.2	-6	-16	0.025119	35.439	1.704	1.848	-10.5	5.5	1.837	-10.9	5.1
2	-38	1.132	1.175	-36.3	1.7	-8	-18	0.015849	28.150	1.652	1.798	-12.4	5.6	1.786	-12.8	5.2
0	-40	1.080	1.125	-38.3	1.7	-10	-20	0.010000	22.361	1.600	1.746	-14.4	5.6	1.735	-14.8	5.2
-2	-42	1.028	1.078	-40.1	1.9	-12	-22	0.006310	17.762	1.548	1.692	-16.5	5.5	1.683	-16.8	5.2
-4	-44	0.976	1.027	-42.0	2.0	-14	-24	0.003981	14.109	1.496	1.640	-18.5	5.5	1.631	-18.8	5.2
-6	-46	0.924	0.975	-44.0	2.0	-16	-26	0.002512	11.207	1.444	1.592	-20.3	5.7	1.583	-20.7	5.3
-8	-48	0.872	0.923	-46.0	2.0	-18	-28	0.001585	8.902	1.392	1.544	-22.2	5.8	1.533	-22.6	5.4
-10	-50	0.820	0.871	-48.0	2.0	-20	-30	0.001000	7.071	1.340	1.495	-24.0	6.0	1.486	-24.4	5.6
-12	-52	0.768	0.822	-49.9	2.1	-22	-32	0.000631	5.617	1.288	1.446	-25.9	6.1	1.435	-26.3	5.7
-14	-54	0.716	0.773	-51.8	2.2	-24	-34	0.000398	4.462	1.236	1.393	-28.0	6.0	1.383	-28.3	5.7

Fig. 4. AD8307 RSSI chart
In the schematics below, here is how the RSSI chips and associated circuits operate:
The AD8307 actually produces a current output of 2uA per dB and has a 12.5k internal load. The specifications assume an external load of at least 1 Meg.
The 1 Meg positive feedback resistors (R24, R34) would seem to meet the 1 Meg load specification, but these are active feedbacks. When the output of the comaprator switches (a 5 volt step) that produces a 5 uA step in the current into the node. At 2uA/dB equivalence this provides a 2.5 dB hysteresis. What I had not thought of is that, while that works fine in the autonomous mode, the ARM would see a 2.5dB step in the measured power. I am putting a tiny transistor at the output of the comparator so that I can reverse the connections to the input. The analog node will then be on the high impedance inverting input. For now we can test the functionality, taking into account the hysteresis at the analog node.

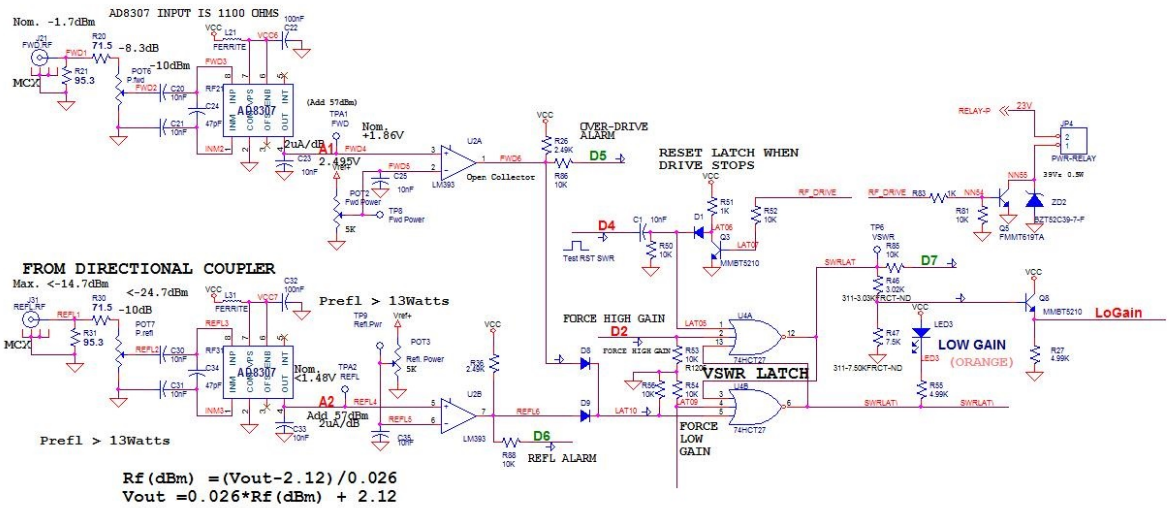

Fig. 5. In the PA-50 we had two MCI Power Sensor modules wired to measure forward and reflected power.
Again, we detect levels and trip the protection directly when there is excessive reflected power.
The TOMCO amplifier is rated to operate with a VSWR of 3.00:1.
This is a reflected power of 13 watts.
The trip point will be set for 13W reflected power
We will trip also on over-drive, if the output power substantially exceeds 50 Watts.

To the Directional Coupler Page.

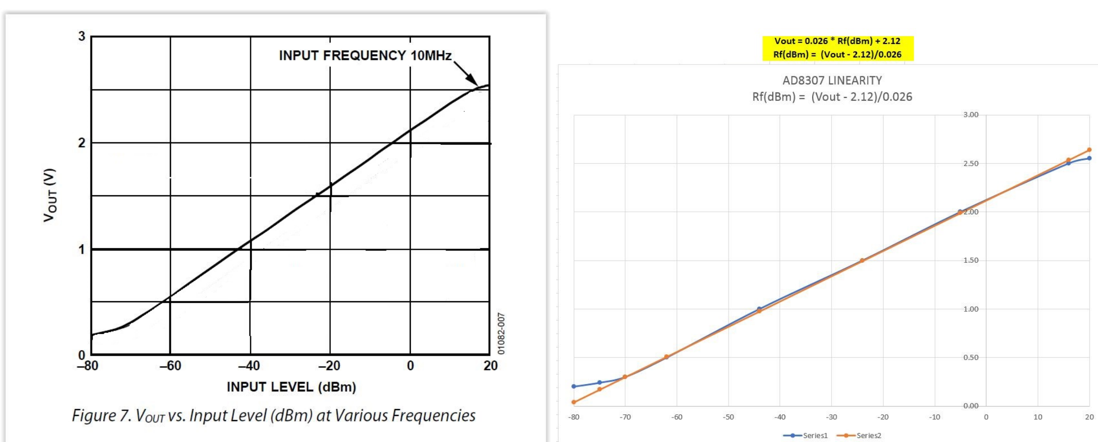

Fig. 6. The MCI Power Sensor modules cost about $85 each. There is the additional cost of SMA cables, power wiring, etc.
The bare chips cost about $12 each. This is their performance spec. We scale our levels to stay in the linear range.
Note that the same chip is used in the $600 calibrated power meter -- with some extra circuitry and a USB interface.
Their "Frequency Calibration" is actually quite simple and linear since the higher frequency curves (removed) are almost perfectly parallel.

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Temperature Sensing

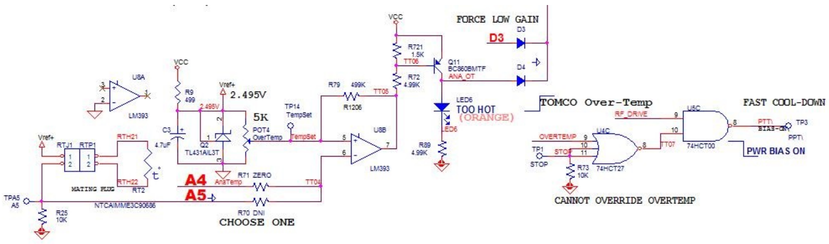

Fig. 7. There are two internal temperature monitors in the TOMCO amplifier.

- There is an analog output. (A4)
- There is a over-temp alarm flag.

You cannot override the alarm flag since this indicates an actual over-temperature condition inside the TOMCO.
The analog output (A4) can be used both as remote telemetry and as a secondary temperature trip (warning level).
A zero ohm jumper can alternately select the external heat sink thermistor (A5) as the temperature warning.
I changed the circuit so that the analog temperature warnings will simply reduce the power by 7dB to allow the amplifier to cool down.
The warning level alarm can be overridden (responsibly) in case the temperature setpoint is perhaps too conservative.

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Raspberry Pi Interface

Note that we have switched from the TS-7250 ARM to a Raspberry Pi Controller:

- **Raspberry Pi Controller**

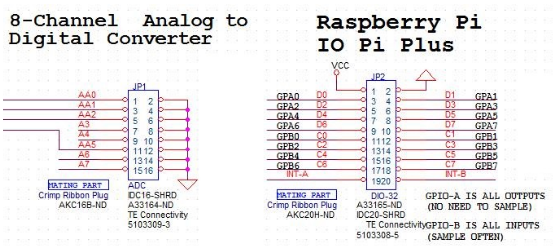

Fig. 8. This is the interface for the Raspberry Pi.
Note that the connector pins match the particular model Digital I/O board.
The serial port controls a MCI digital attenuator, providing up to 15.5dB of attenuation.
It defaults to 0dB (or any preset) at power-on. This allows remote power level setting.

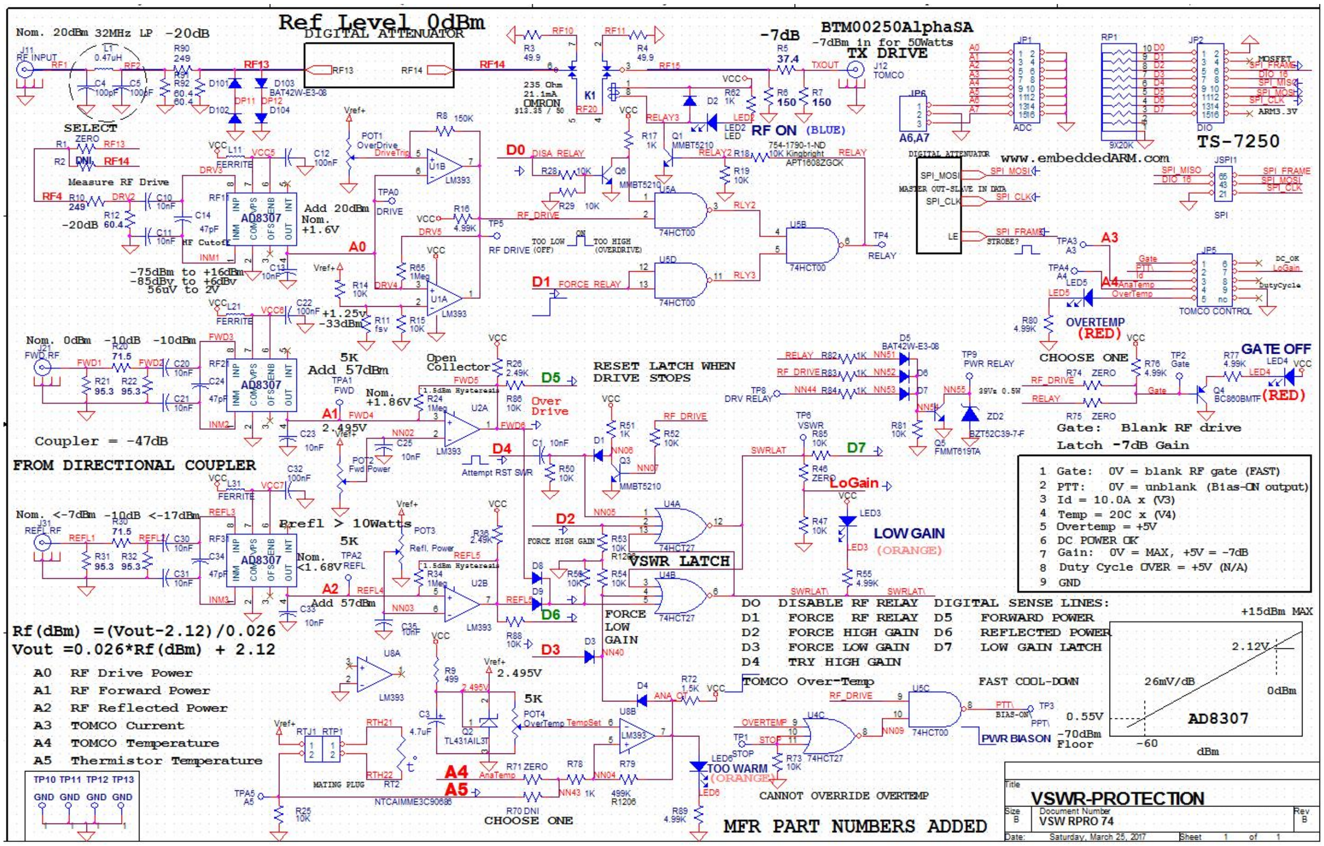

Fig. 9. Complete Prototype schematic.
With the new VSWR protection board, everything should operate independently of the Raspberry Pi.
The only tricky question is whether a computer crash could leave the control lines in an undetermined state.
The circuit board is set up to operate independently with all 00000000 DIO output.
I presume that at boot DIO lines are either programmed as inputs or 00000000.
(Some of those are actually digital input sense lines. These have a series resistance so that they cannot affect operation at boot.)
The 4.99K series resistor also lowers the 5 volt logic down to 3.3 volts.
There are gentle 10K pull-downs on all lines for no computer at all.

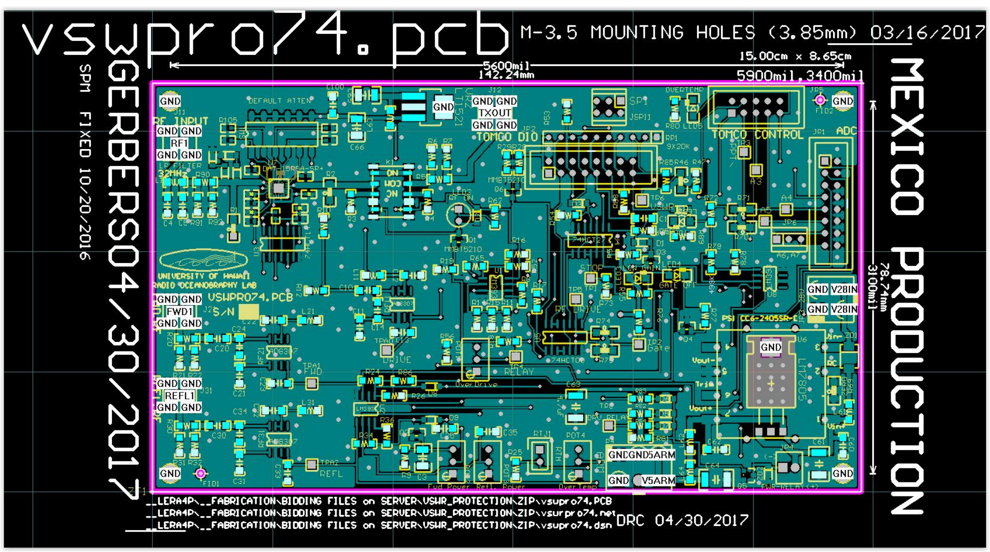

Fig. 10. Prototype Printed Circuit Board

(Old-Style) Rack Mounted Transmitter

This is how the RA-50 configuration would translate to the a standard rack enclosure:

I don't have a picture of the NEMA enclosure, but much the same component substitutions have to take place.

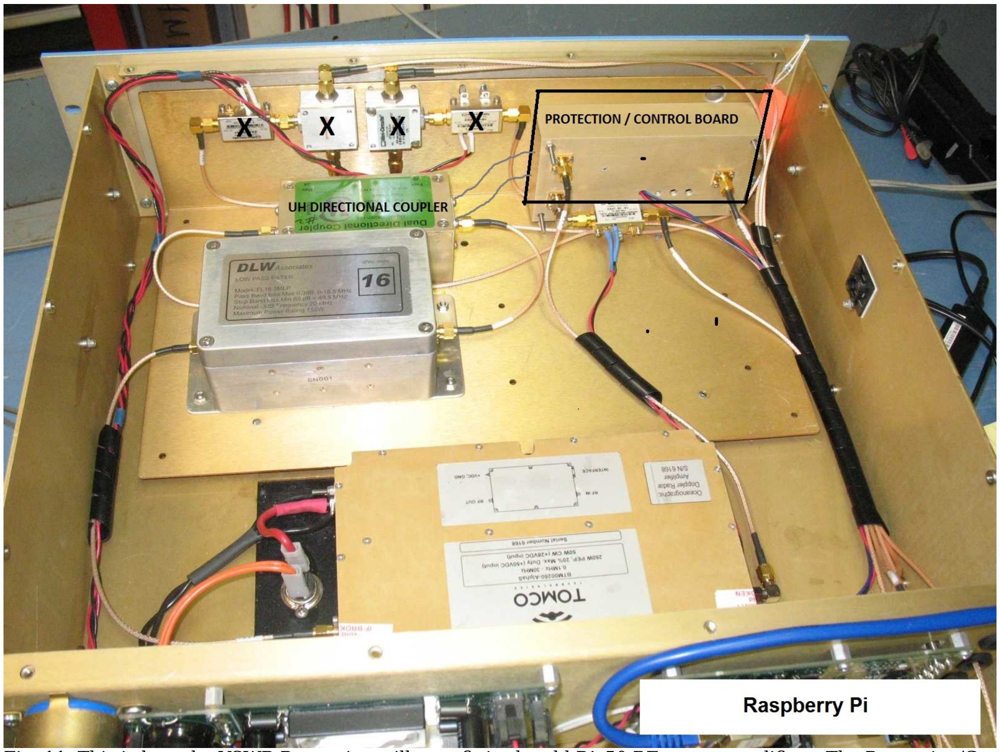

Fig. 11. This is how the VSWR Protection will retrofit in the old PA-50 RF power amplifiers. The Protection/Control board has a power supply for the Raspberry Pi. (5.0V @ 400mA = 2.0 Watts)
(The Rabbit power supply on the left is removed.)

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Directional Coupler

Bi-Directional Coupler Page ==>>

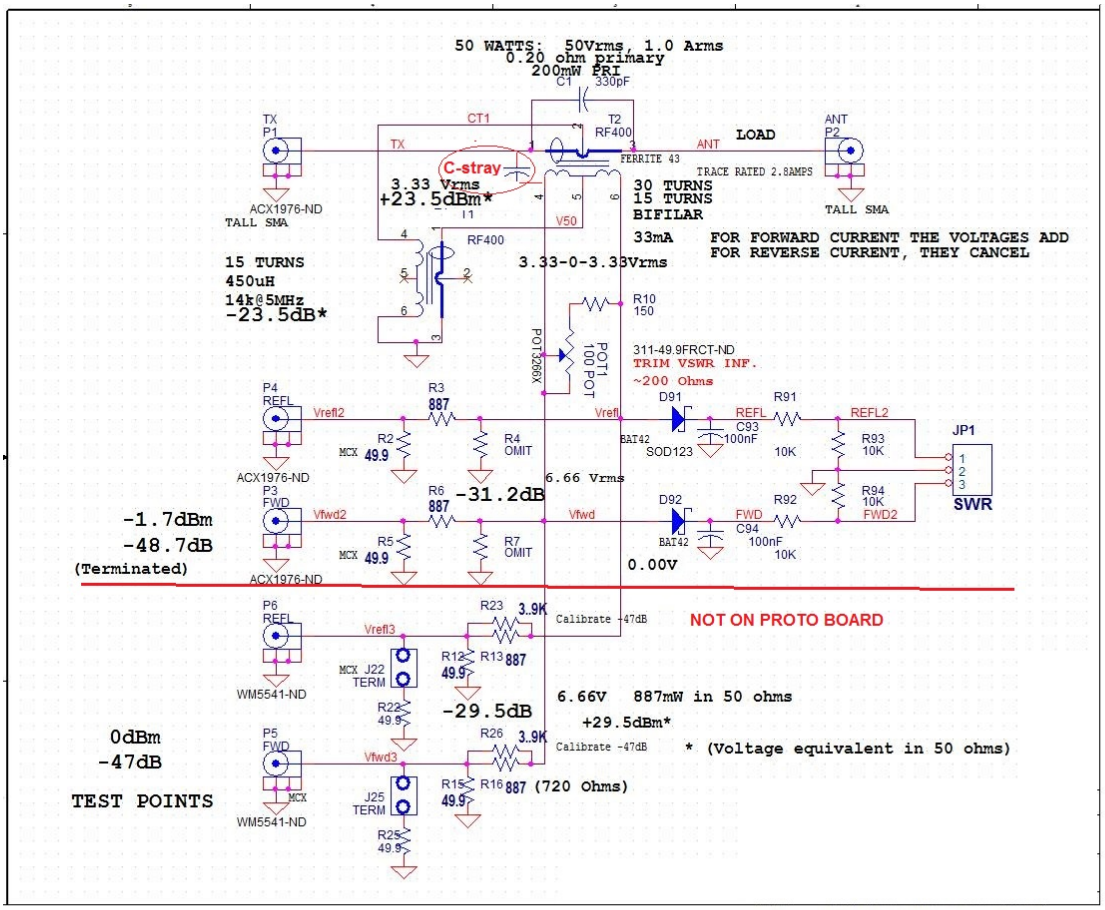

Fig. 12. Full coupler circuit
This model eliminates the minor asymmetry by tapping the voltage sense symmetrically from the center tap.
A "proper" directional coupler turns out to be simple and straight-forward.
It just requires two hand-wound RF transformers (20 turn bifilar, $5 each).
These solder directly to a PCB footprint.
The Forward and Reflected samples on the left go to the RA-50 VSWR Protection Circuit at Ref. Level 0dBm for 50W TX (-47dB).
The two secondary sample ports on the lower left are scaled to -40dB
The optional outputs on the right ore standard "VSWR Meter" DC voltage outputs.

Calibration Procedure:

- Place 50.0 Ohm Dummy Load on Output
- Transmit 50 Watts
- Adjust Pot1 for a NULL on the REFLECTED port.
  - Do not change this NULL setting.
- Measure RF Power on FORWARD port.
  - I will have to adjust the attenuator pad resistors R3, R5, R13, R15 to get the proper 0dBm=50W reference level **(-47dB)**.
  - **NOTE: THIS IS THE SAFE AND LINEAR LEVEL FOR THE SPECTRUM ANALYZER.**
  - The attenuator pad resistors for the ALL ports should be the IDENTICAL.

Theory:

- The sensitivity is governed almost entirely by the **turns-ratios** of the transformers.
- The ultimate coupling ratio will be set by four identical attenuator resistors.
  - (These provide the over-all "calibration constant")
  - The gain calibration is now transferred to the Protection board, so minor differences between couplers are not important.

Fig. 13. Ferrite transformer core (~0.5" x 0.75")
(Center-tapped single-turn primary)

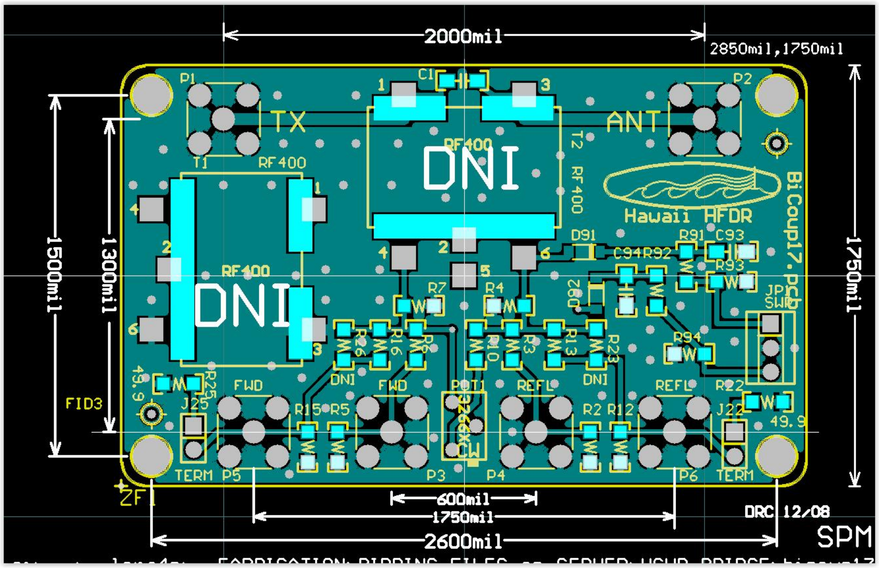

Fig. 14. PCB
There are two "TERM" jumpers which terminate the Aux. Outputs instead of MCX terminators. Remove them when using the ports.
There is also a plug for a portable salvaged MFJ VSWR meter movement to add a visual indicator.

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Functional Review

There are two modes of protection:

- Temporarily latched:
  - For a VSWR fault, the gain is reduced by 7dB.
  - This latch is reset when the cycle is "rebooted" (remove RF drive, initiate a new cycle)
- Not user accessible:
  - A TOMCO over-temperature alarm can NOT be overridden by the user.

Initiating a normal data cycle

- Nominal full drive level is +20dBm input for +47dBm output.

NOTE: For remote location of transmitter, this attenuator should be reduced to 2dB and drive adjusted with an external attenuator.

- The drive input discriminator detects the drive signal.
- The RSSI signal is logged by the ARM
  - The RF drive relay is engaged
  - The power relay turns on the 26.5 volt supply to the TOMCO.
  - Output stage bias is turned on
  - The "Key Down" line enables the TOMCO internal RF gate.

Sensing the performance

The directional coupler now monitors the RF output

- Two RSSI chips monitor the forward and reflected power
  - Those analog voltages go to the ARM computer ADC inputs
- Either excessive output power or excessive reflected power set a latch that reduces the TOMCO output by 7dB.
  - Since the RF output will immediately drop 7dB, the fault would immediately "go away".
  - This would restore full power and generate another fault, in a rapid oscillation.
  - That is why the fault must be latched until reset.

In the case of excessive drive, the 7dB drop MAY be enough to keep the output within bounds.
But in the case of input overdrive, the amplifier might still be overdriven.
The Overdrive sensor on the INPUT RSSI would in that case shut off the RF relay a and power down the TOMCO completely.

Overheating

The TOMCO internal temperature alarm will shut down the output stage bias for a fast cool-down. This is a REAL alarm and the ARM cannot override it.

Speaking of overrides, the ARM can force the RF relay and the TOMCO on, or can inhibit that function, regardless of RF input drive.

SUMMARY

BASIC HARDWARE FUNCTIONS

- Detect RF drive ON
  - Turn on TOMCO power relay

- Turn on TOMCO

- Detect Drive OFF
  - Reset error latches

BASIC HARDWARE PROTECTION

- Detect Excess Reflected Power
  - Set Latch to reduce power -7dB.
  - (This is a generally "safe" mode.)

- Detect hot analog temperature
  - (We can select either TOMCO internal analog temperature or heatsink temperature.)
  - Set Latch to reduce power 7dB for cool-down.

- Detect TOMCO OVERTEMP ALARM
  - Release "Push-to-Talk" (remove bias from output stage for fast cool-down).

Raspberry Pi: SENSE and OVER-RIDES

- Set Input Digital RF Attenuator.
  - (Default = 0dB)
- Monitoring/Telemetry of analog sense voltages and binary flags
- Implement Autonomous Recovery Strategies
- Enable Remote/manual Recovery Strategies

- Can **CAUTIOUSLY** over-ride the -7dB power reduction
  - If error persists, latch will trip again
  - A HARD over-ride will FORCE high gain
  - (Manual incremental attenuation can be implemented)
- CANNOT over-ride TOMCO OVERTEMP ALARM

For testing modes:

- Disable RF Relay
- Force ON RF Relay (even with no RF drive)
- Force High or Low Gain
- Set Input Digital RF Attenuator.

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