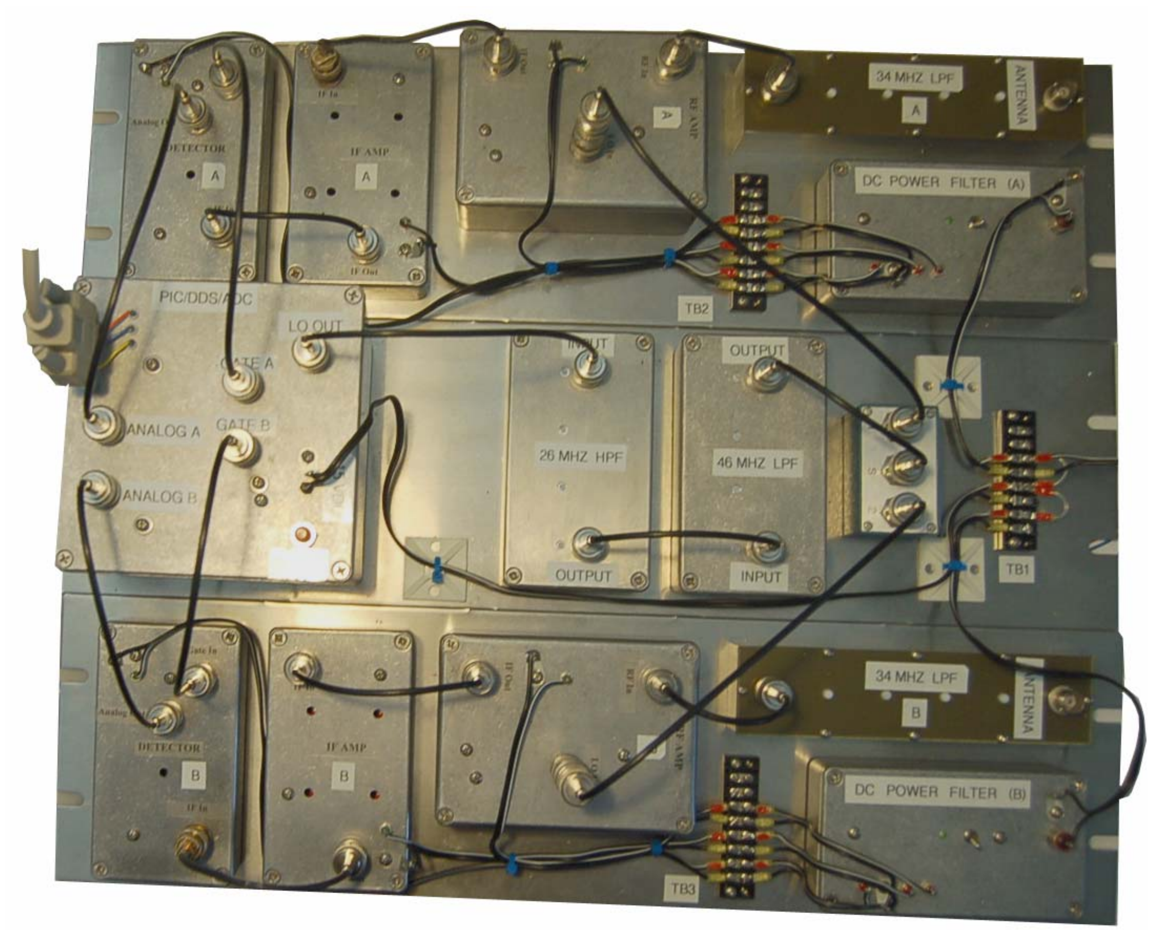
DUAL POLARIZATION SPECTROGRAPH



Hardware Manual

RF Associates LLC
February 2013

The Dual Polarization Spectrograph (DPS) is designed to operate between 17 and 34 MHz. The instrument comprises two identical receivers sharing a common computer controlled, step frequency, local oscillator. The local oscillator operates in the range of 27.7 to 44.7 MHz. The image frequency range is from 38.4 to 55.4 MHz.

Each receiver employs a 10.7 MHz center frequency, 30 kHz wide IF amplifier providing approximately 49 dB of gain.

Following each IF strip is a sensitive, wide dynamic range log-detector that develops an output voltage proportional to the log of the input power. The detector develops a DC output voltage that changes by 25 millivolts for each 1dB change of input power. A low pass filter and adjustable gain DC amplifier follow the detector. The resulting signal from each receiver detector feeds a separate 12-bit analog to digital converters (ADC).

The ADCs are read synchronously by a PIC that also generates commands for the direct digital synthesis (DDS) local oscillator, and pulses for the blanking gate circuits which inhibit signals to the ADCs during the time when the DDS is changing frequency.

The dual spectrograph could be fed with RCP and LCP antennas or it could be fed with orthogonal linear antennas. In the later case a polarization hybrid operating at 10.7 MHz could be inserted between the IF strips and the detectors. Either configuration could produce RCP and LCP signals at the detector inputs.

Documentation will simply label the two LO sharing receivers as (A) and (B). Each receiver uses identical modules (M1 - M4) as seen in Figure 1. The local oscillator signal generated in M5 is routed thru filters and a power splitter (M6 - M8). The module interconnect diagram is seen in Figure 2.

The DPS requires a 15 volt DC power supply (15-18vdc) at 500 ma.

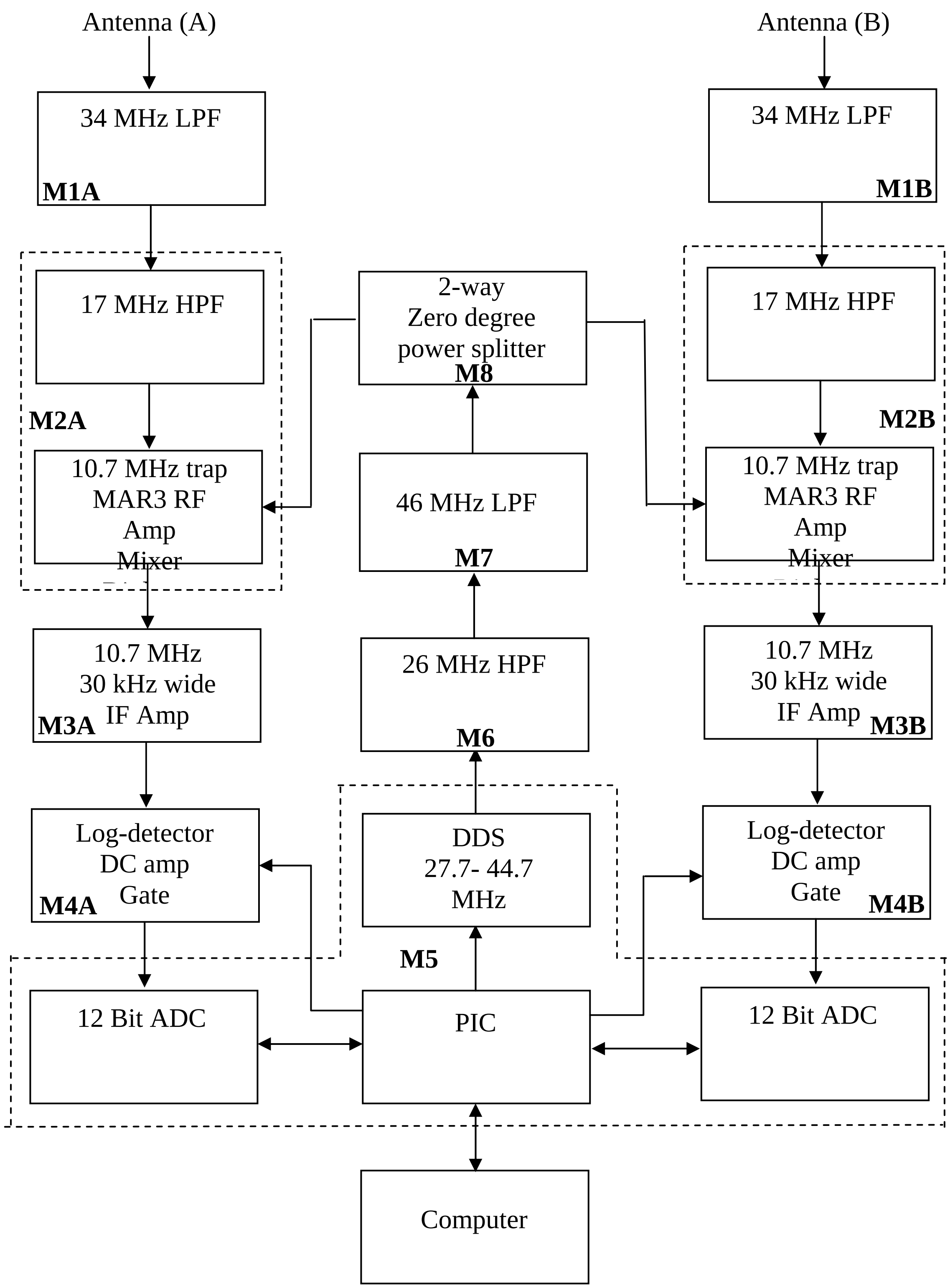


Figure 1. DPS block diagram

M1 34 MHz Low Pass Filter
This 9th order 34 MHz low-pass filter is designed to minimize the effect of image response signals in the 38.4 to 55.4 MHz frequency range.

M2 RF Front End – HPF, RF Amp, Mixer and Diplexer
The front-end module contains a 17 MHz high pass filter, a 10.7 MHz notch filter, an MAR-3 RF amplifier, a mixer, and a diplexer to provide a broadband impedance match to the mixer output.

M3 10.7 MHz IF Strip
The single conversion spectrograph receiver uses a 10.7 MHz intermediate frequency (IF) amplifier. The IF amp uses 8 poles of monolithic crystal filtering to shape the 30 kHz wide response. Gain is approximately 49 dB.

M4 Log Detector and Blanking Gate
The detector uses an Analog Devices AD8307 Log Detector followed by a low-pass filter and an adjustable gain DC amplifier. A 2N7000 MosFet blanking gate inhibits signals from reaching the ADC during the interval when the DDS is changing frequency. The blanking gate is controlled by a pulse train from the PIC microcontroller.

M5 PIC/DDS/ADCs
This module contains a16F873 microcontroller that communicates with the main control computer via an RS232 link. [*Note – do not use a 16F873A in place of the 16F873 as the 16F873 code and the Microchip PICkit3 programmer will not work correctly.*] The PIC generates commands to set the frequency of the DDS-60 DDS oscillator, generates gate pulses, and synchronously samples a pair of MAX 187, 12-bit ADCs. The ADCs digitize the analog signal outputs of the A and B receiver detectors. The DDS signal is routed thru low pass and high pass filters before being power split to feed the two receiver mixers.

M6 26 MHz HPF
The 26 MHz HPF is used to minimize signals below 26 MHz generated spuriously in the DDS oscillator.

M7 46 MHz LPF
The 46 MHz LPF is used to minimize signals above 46 MHz generated spuriously in the DDS oscillator.

M8 Power Splitter
The Mini Circuits 2-way zero degree power splitter is used to route the local oscillator signal to the receiver mixers (in M2A and M2B).

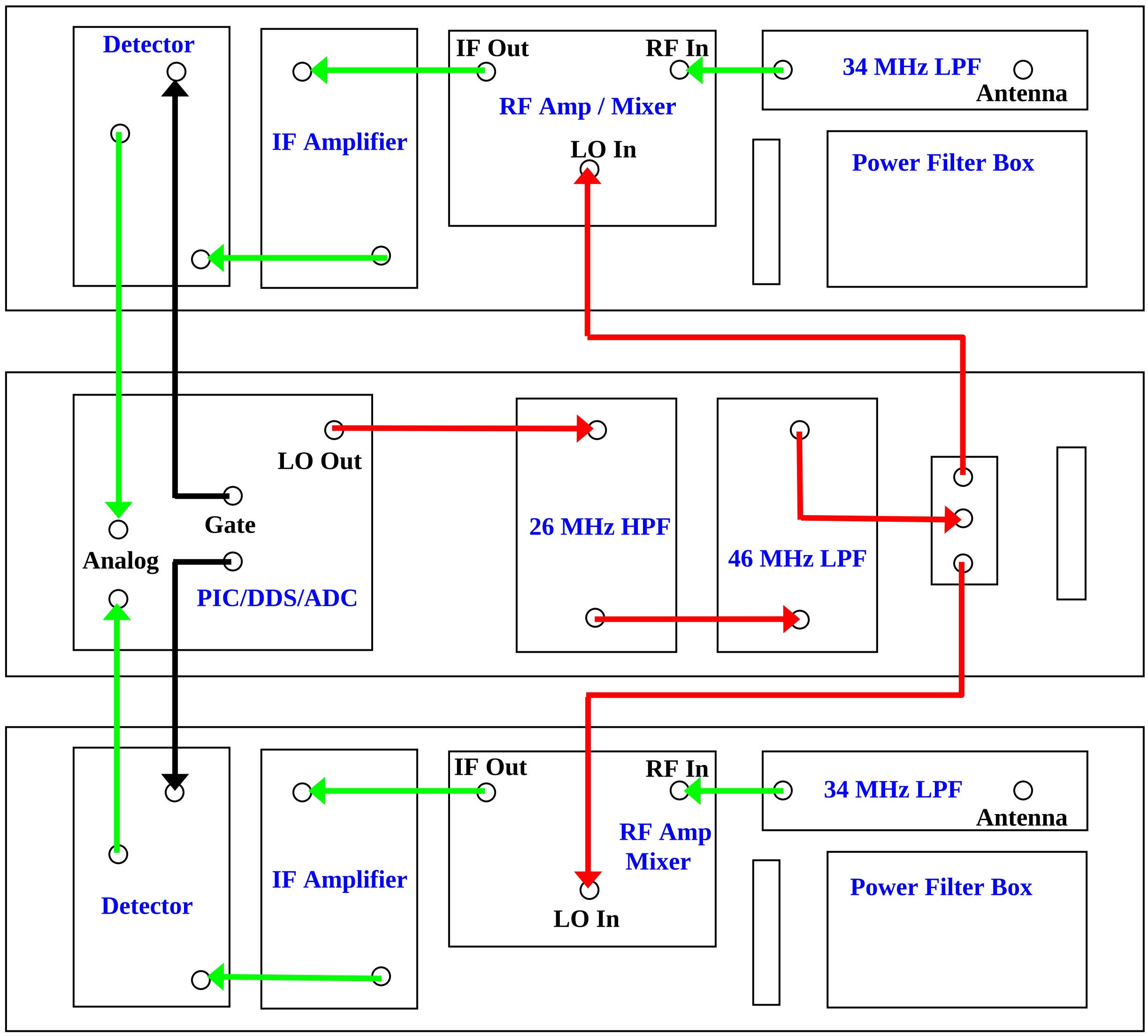
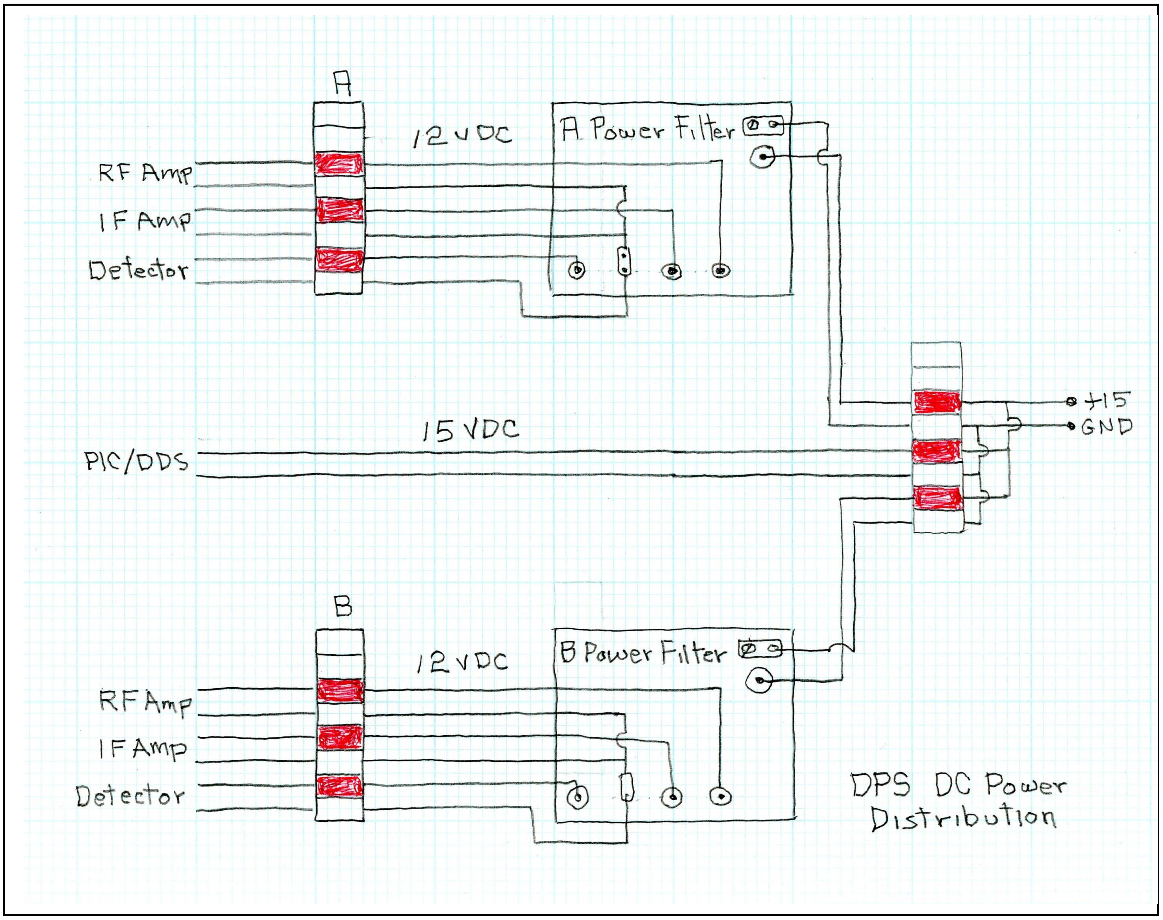
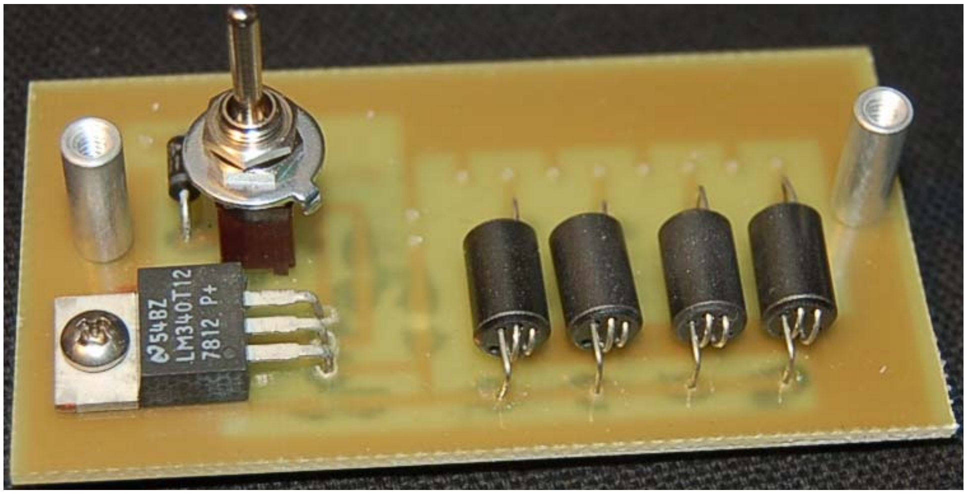


Figure 2. RF and Control Interconnect diagram (green = signal, red=local oscillator, black = gate pulses) Not shown are 3dB pads located at the LO input ports of the A and B channel RF Amp/Mixers.

Power Distribution

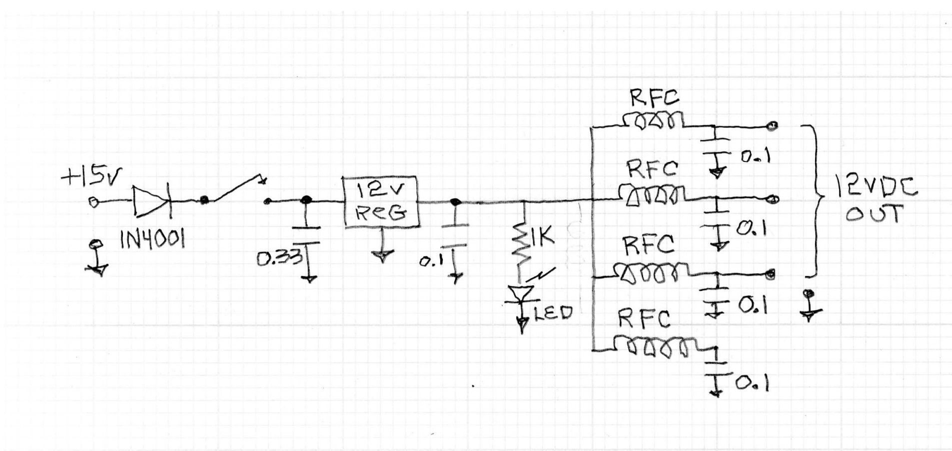


The DPS nominal input voltage is 15 vdc (connected to TB1 – right center of drawing). The allowable range of input voltages is 14.5 to 18 vdc. At 15 volts the DPS draws approximately 500 ma. TheDPS is not fused, however steering diodes in the power filter boxes and M5 provide polarity protection. The DPS comprises three 19" rack panels. The top panel is the "A channel" receiver, the middle panel contains the PIC / DDS/ ADC module and the local oscillator chain filters. The bottom panel is the "B channel" receiver. The A and B receivers each have a power filter box which includes a 12 volt three-terminal regulator providing 12 volts to the M2, M3, and M4 modules. Input power is attached to a barrier strip on the middle panel. Power is then distributed to the A and B power filter boxes and the PIC/DDS/ADC module (M5). Module M5 also includes an internal 12 volt three-terminal regulator. Twelve volt lines from each power filter box are attached to barrier strips for distribution (TB2 for the A receiver and TB3 for B). When 15 volts is applied to the input barrier strip the local oscillator receives power. Normal current to M5 is 140 ma. Each power filter box has a toggle switch to control power to its receiver. The ability to turn each receiver on and off may be useful for testing purposes.

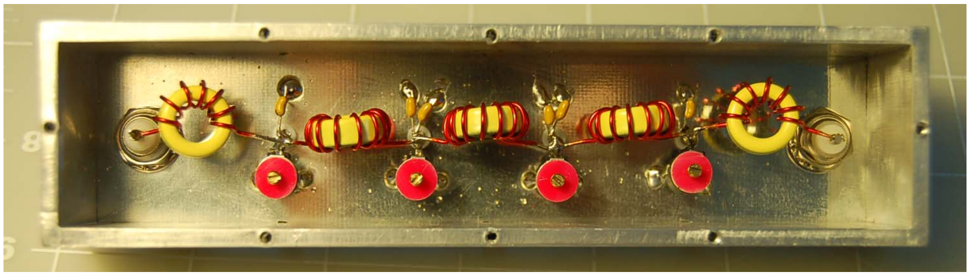


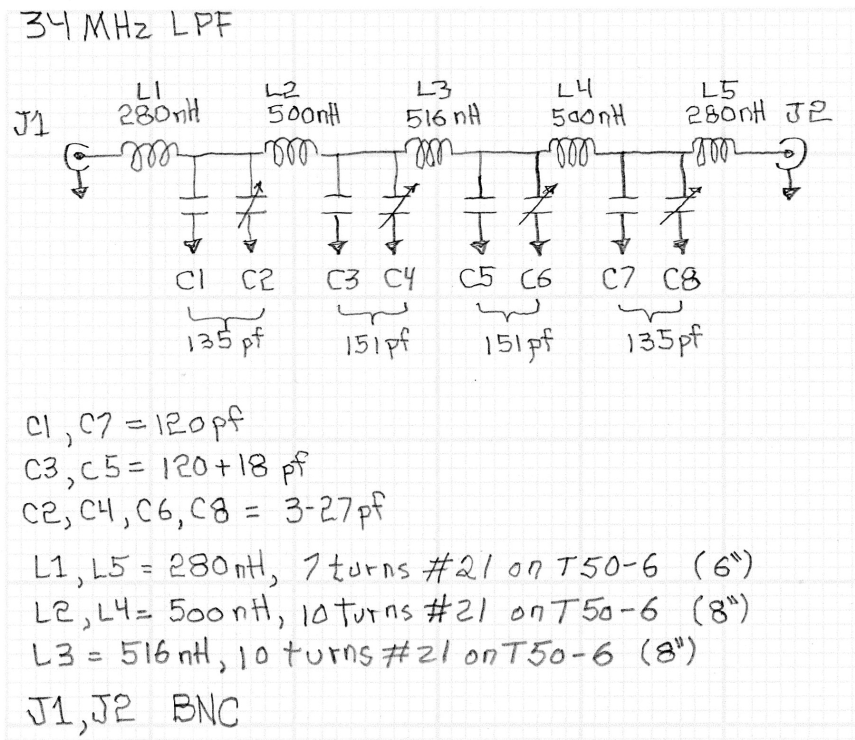
DC Power filter board – 12 volt regulator, steering diode, and RF chokes

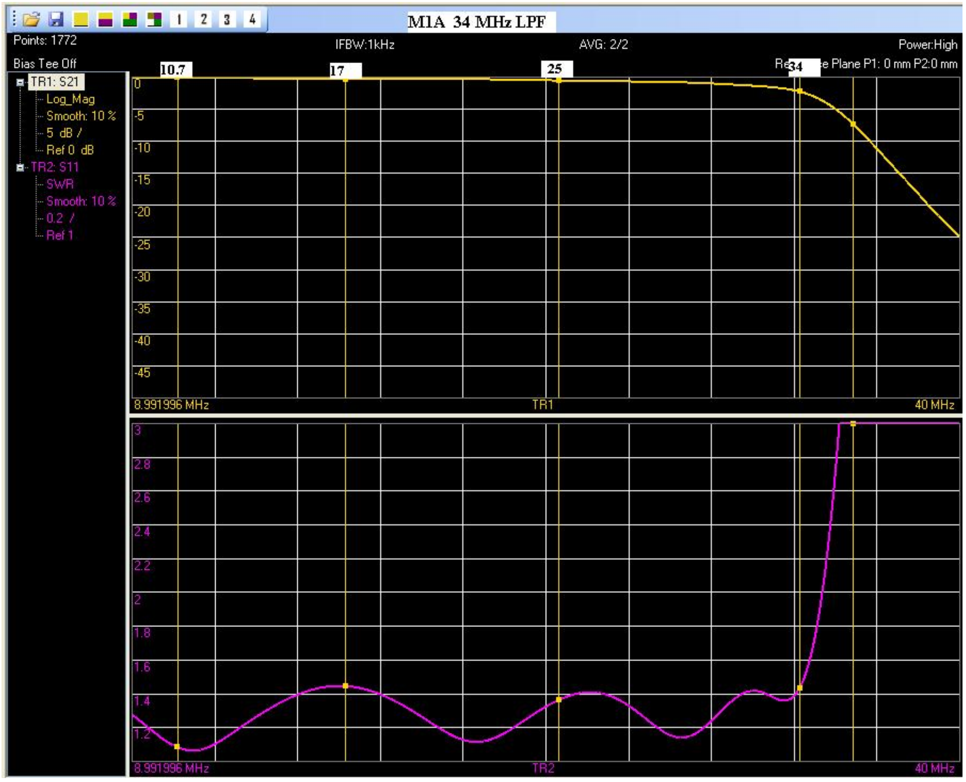
DC Power filter board – trace side



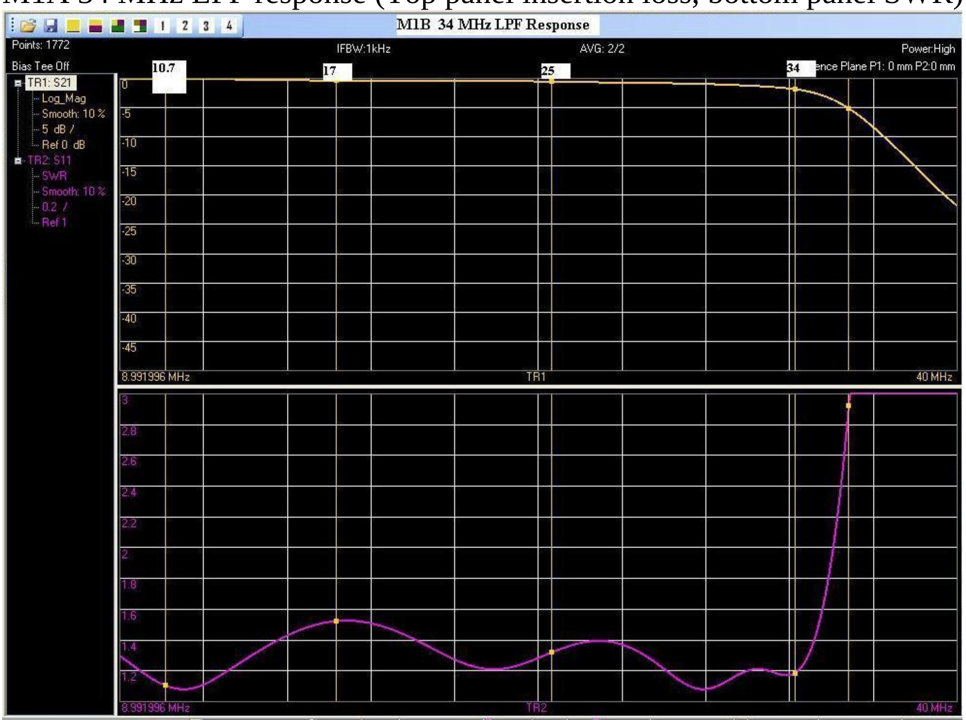
M1A, M1B 34 MHz LPF





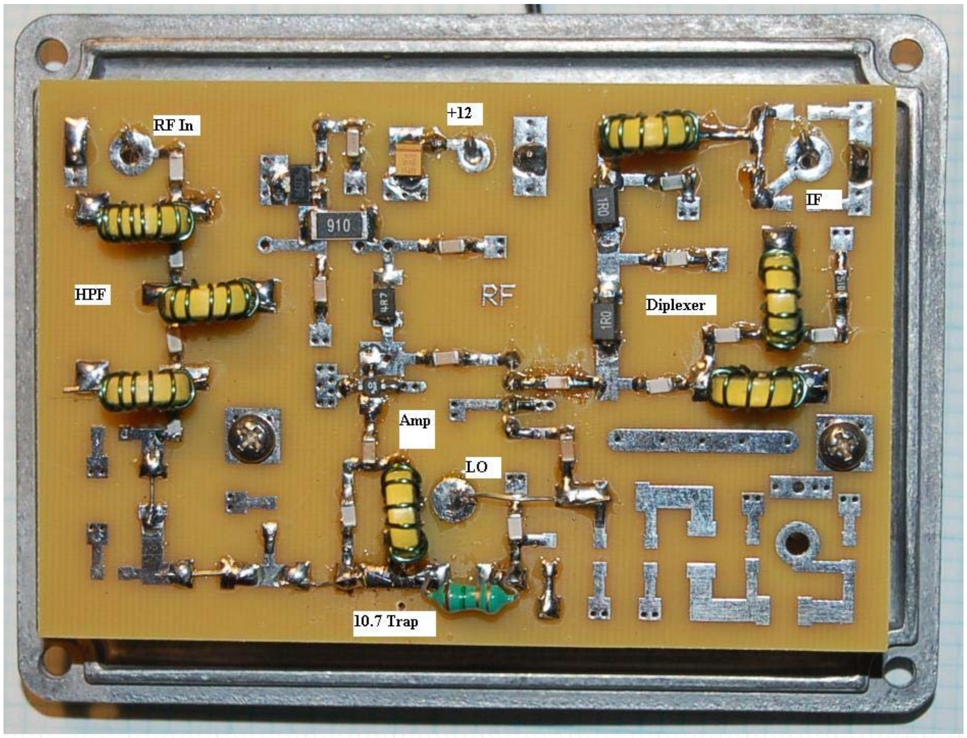


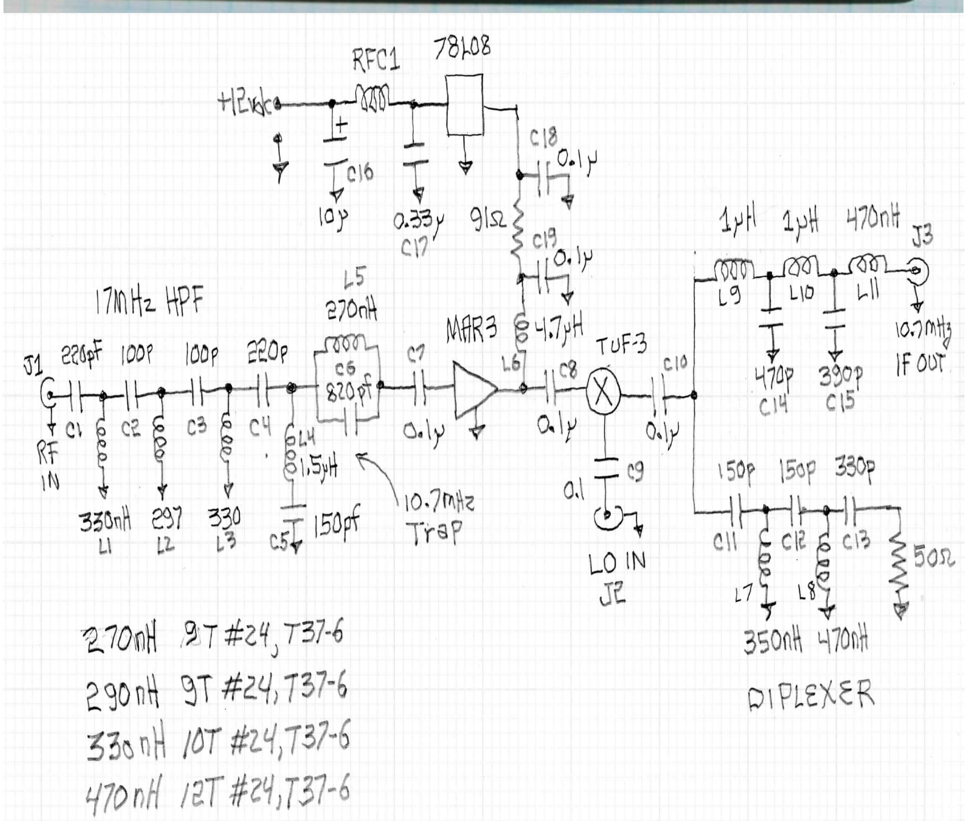
M1A 34 MHz LPF response (Top panel insertion loss, bottom panel SWR)

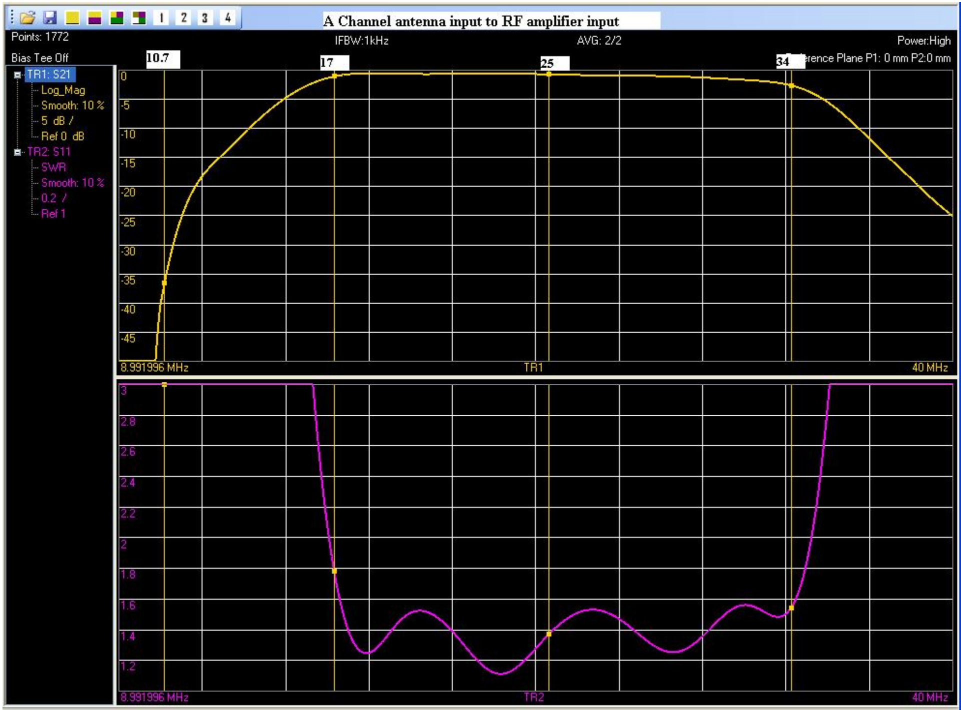


M1B 34 MHz LPF response (Marker frequencies are shown in boxes just above the vertical marker lines.)

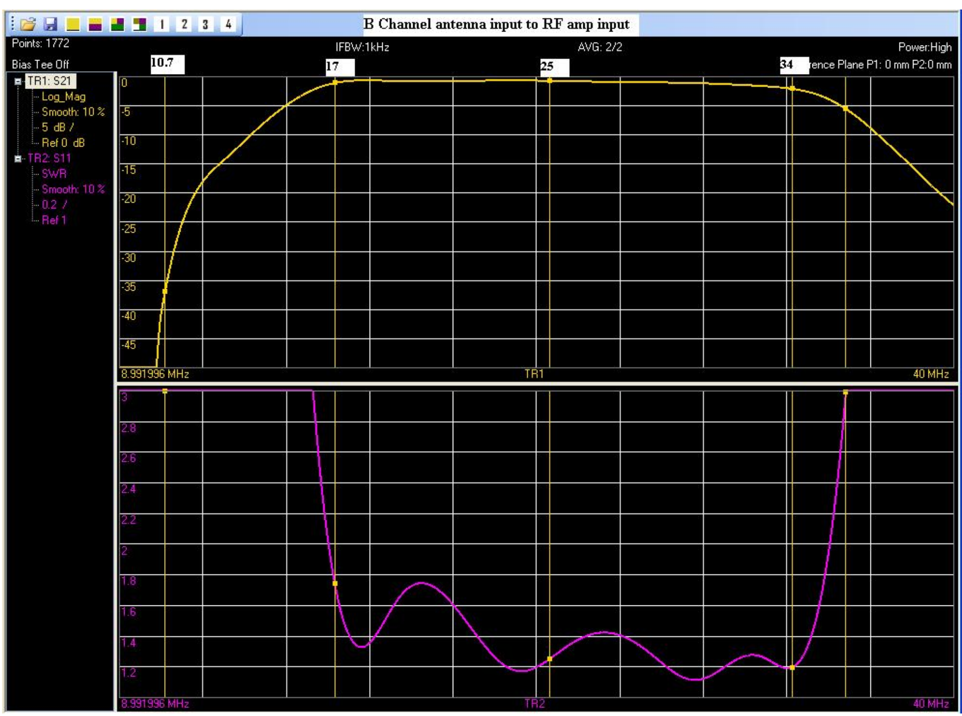
M2A, M2B 17 MHz HPF, 10.7 MHz Notch, RF Amplifier, Mixer, Diplexer



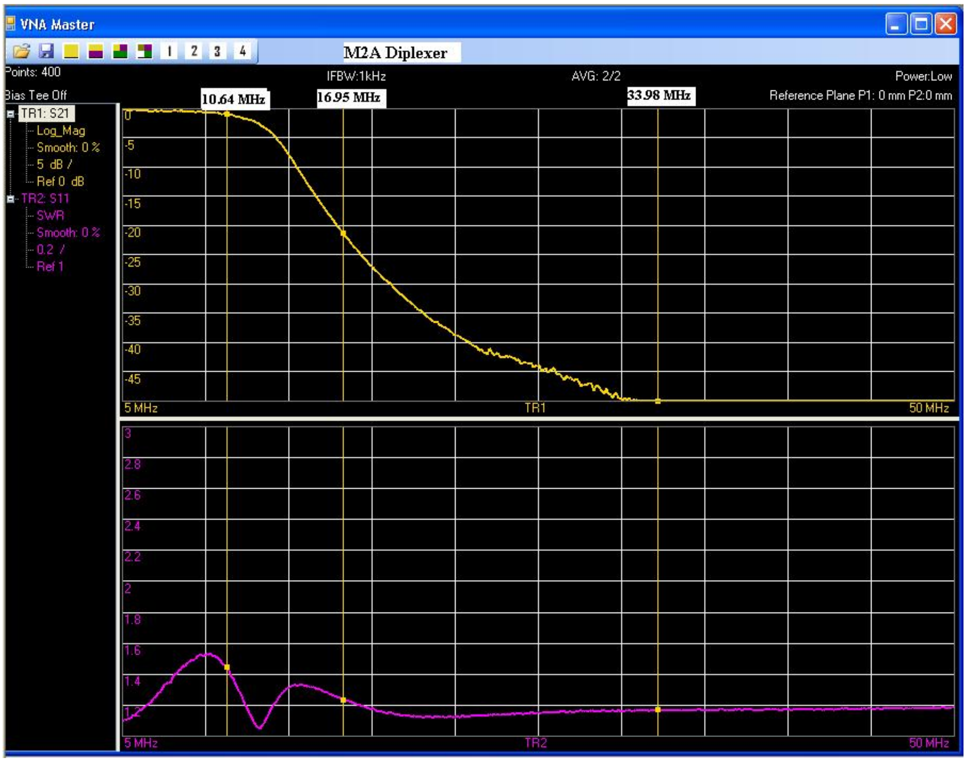




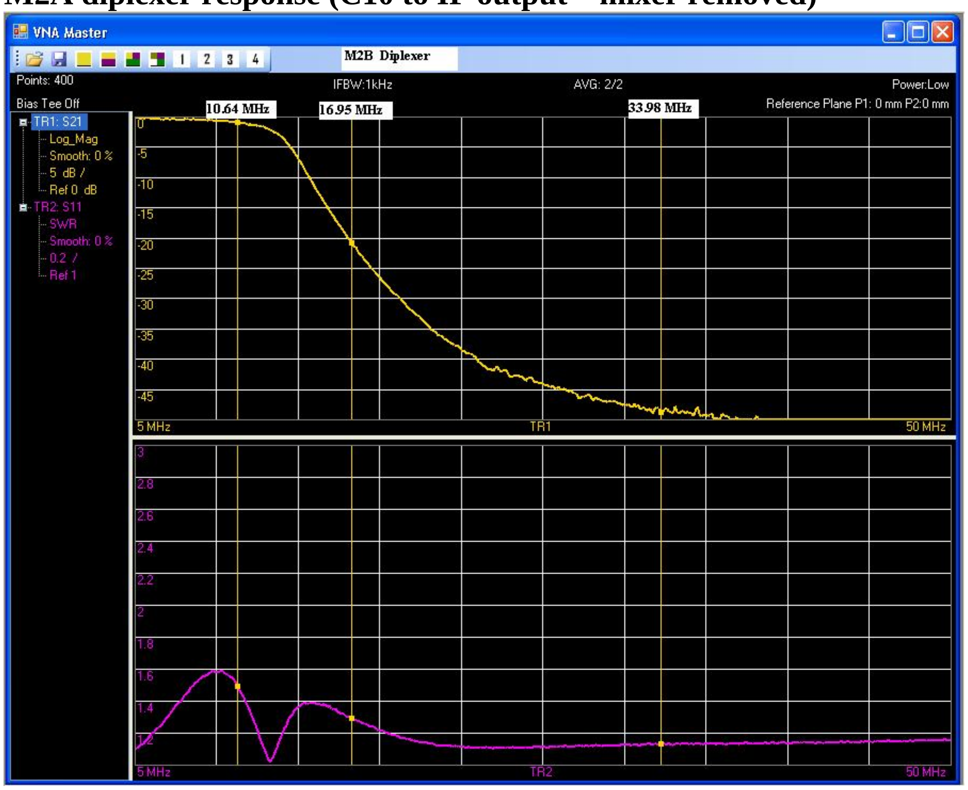
(A) channel antenna input (M1) to MAR-3 RF amplifier input – C7, with MAR3 removed.



(B) channel antenna input (M1) to MAR-3 RF amplifier input – C7, with MAR3 removed.

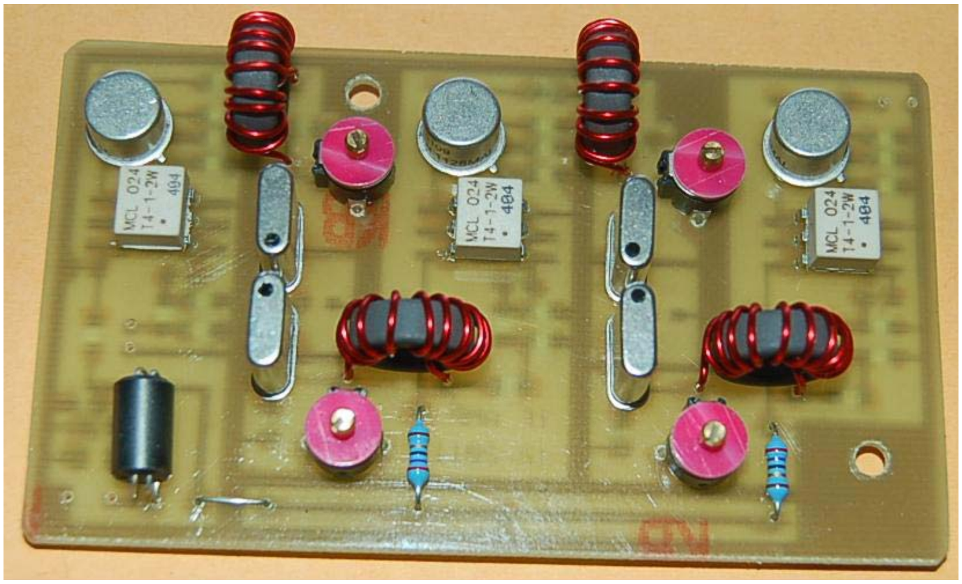


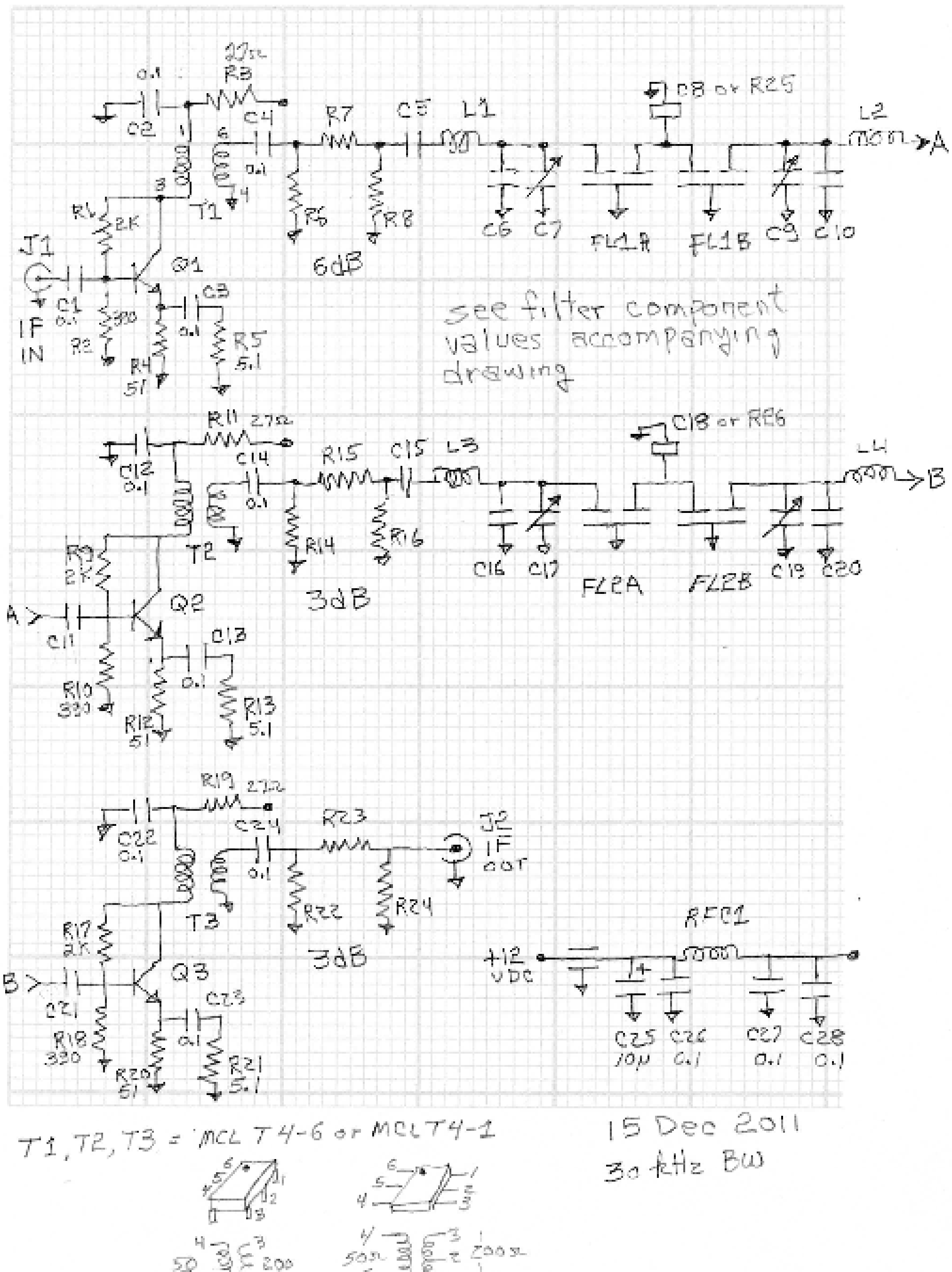
M2A diplexer response (C10 to IF output – mixer removed)



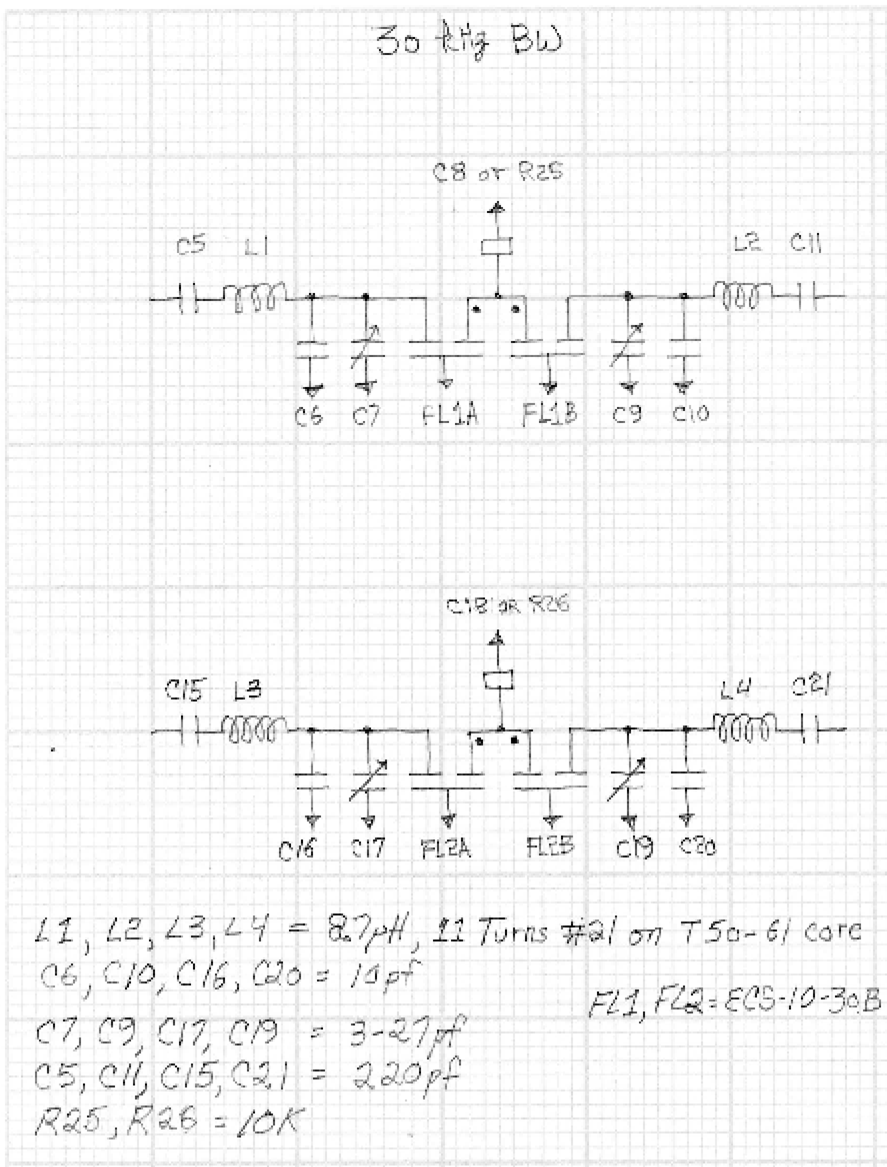
M2B diplexer response (C10 to IF output – mixer removed)

M3A, M3B 10.7 MHz IF Amplifier (30 kHz BW)

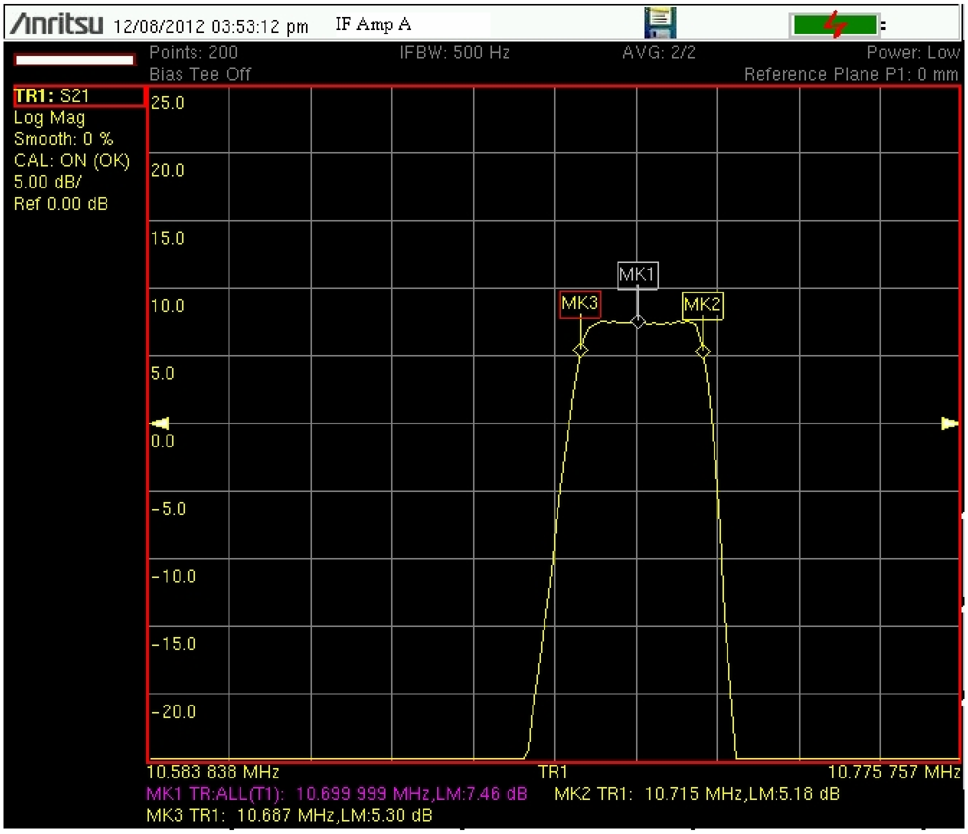


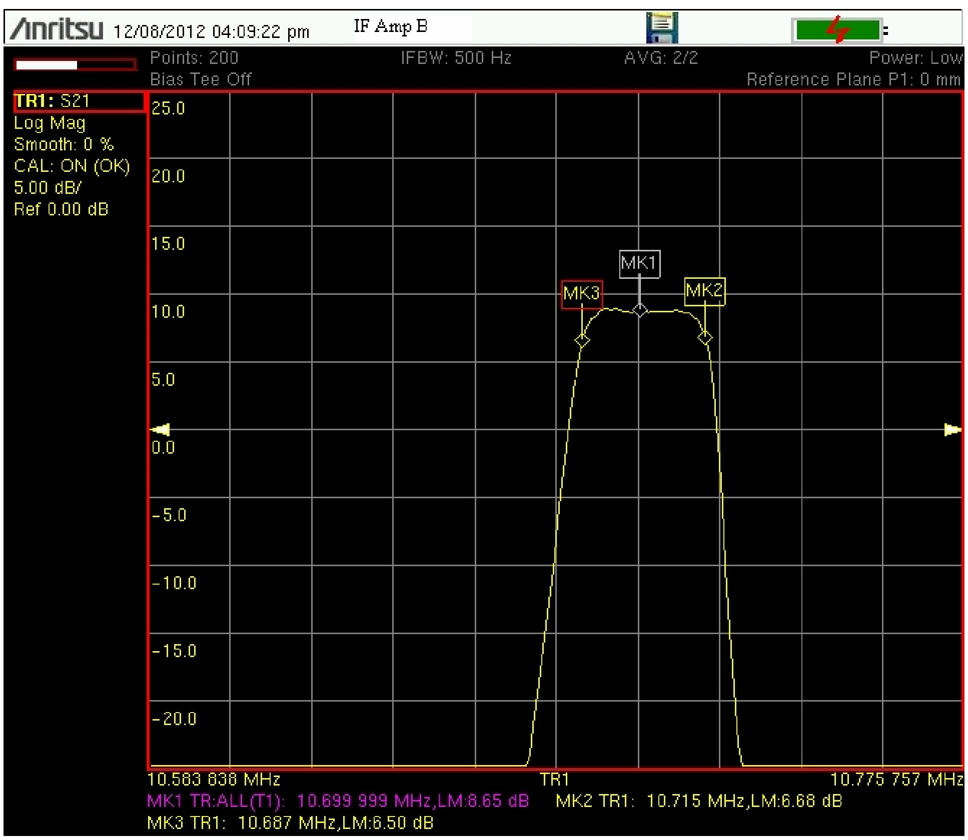


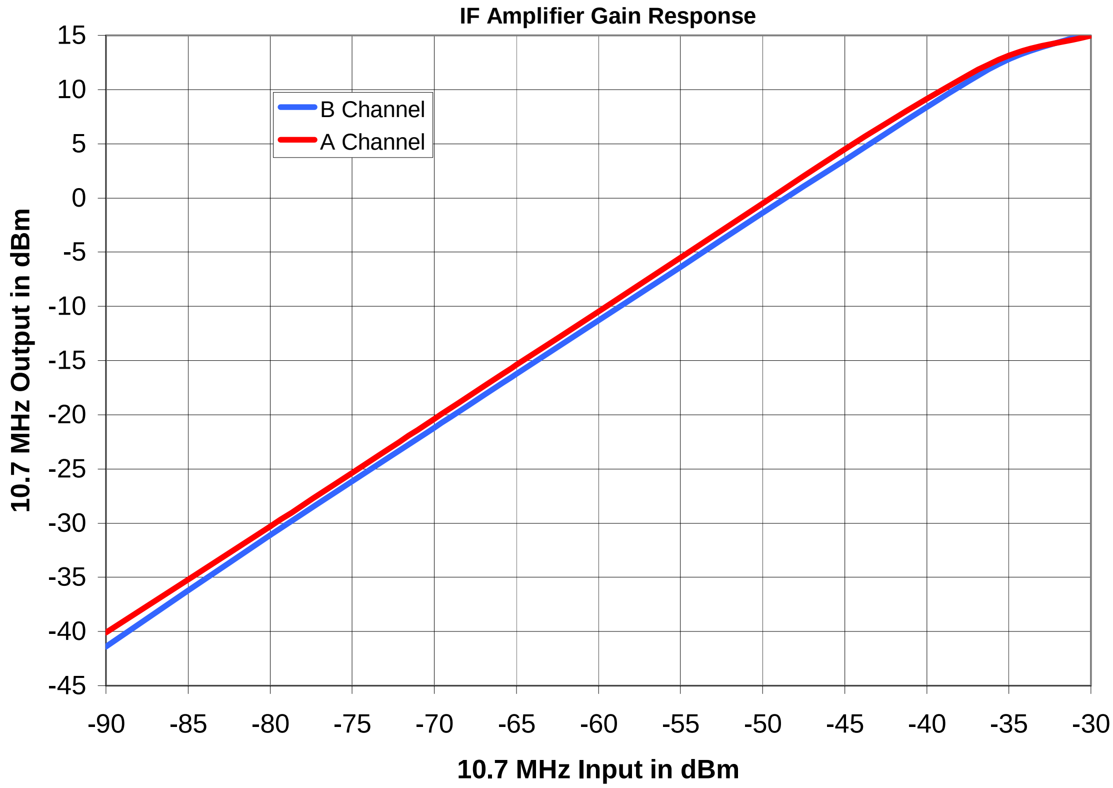
10.7 MHz, 30 kHz bandwidth IF amplifier (Gain = 50 dB nominal)



Crystal filter impedance matching network

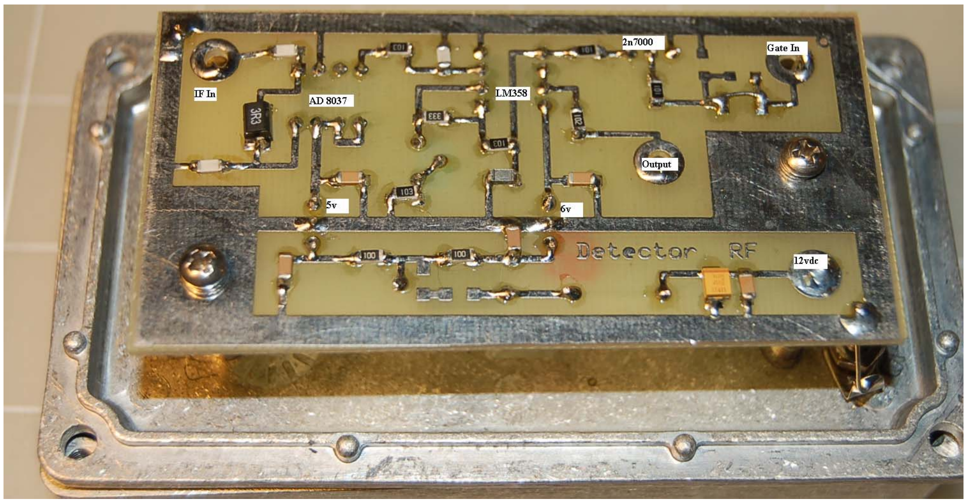

12/08/2012 03:53:12 pm
IF Amp A
Points: 200
IFBW: 500 Hz
AVG: 2/2
Power: Low
Bias Tee Off
Reference Plane P1: 0 mm
TR1: S21
Log Mag
Smooth: 0 %
CAL: ON (OK)
5.00 dB/
Ref 0.00 dB
10.583 838 MHz
TR1
10.775 757 MHz
MK1 TR:ALL(T1): 10.699 999 MHz,LM:7.46 dB
MK2 TR1: 10.715 MHz,LM:5.18 dB
MK3 TR1: 10.687 MHz,LM:5.30 dB

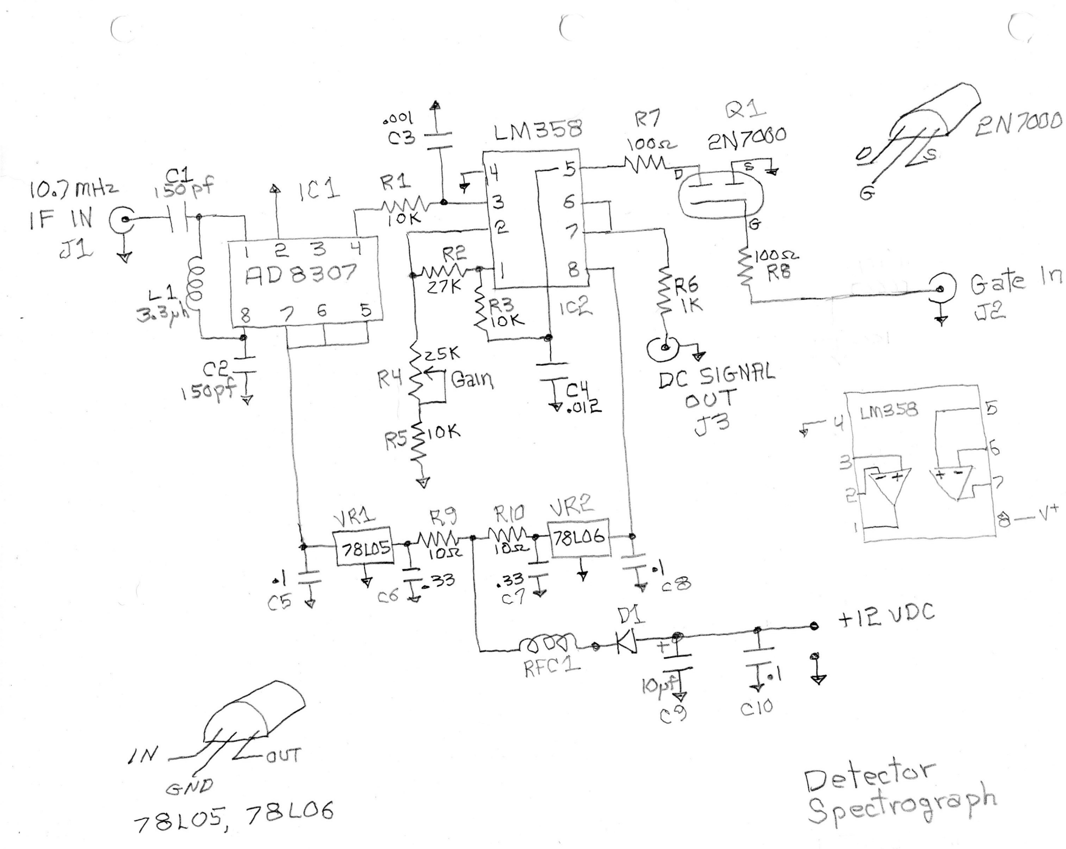

12/08/2012 04:09:22 pm
IF Amp B
Points: 200
IFBW: 500 Hz
AVG: 2/2
Power: Low
Bias Tee Off
Reference Plane P1: 0 mm
TR1: S21
Log Mag
Smooth: 0 %
CAL: ON (OK)
5.00 dB/
Ref 0.00 dB
10.583 838 MHz
TR1
10.775 757 MHz
MK1 TR:ALL(T1): 10.699 999 MHz,LM:8.65 dB
MK2 TR1: 10.715 MHz,LM:6.68 dB
MK3 TR1: 10.687 MHz,LM:6.50 dB



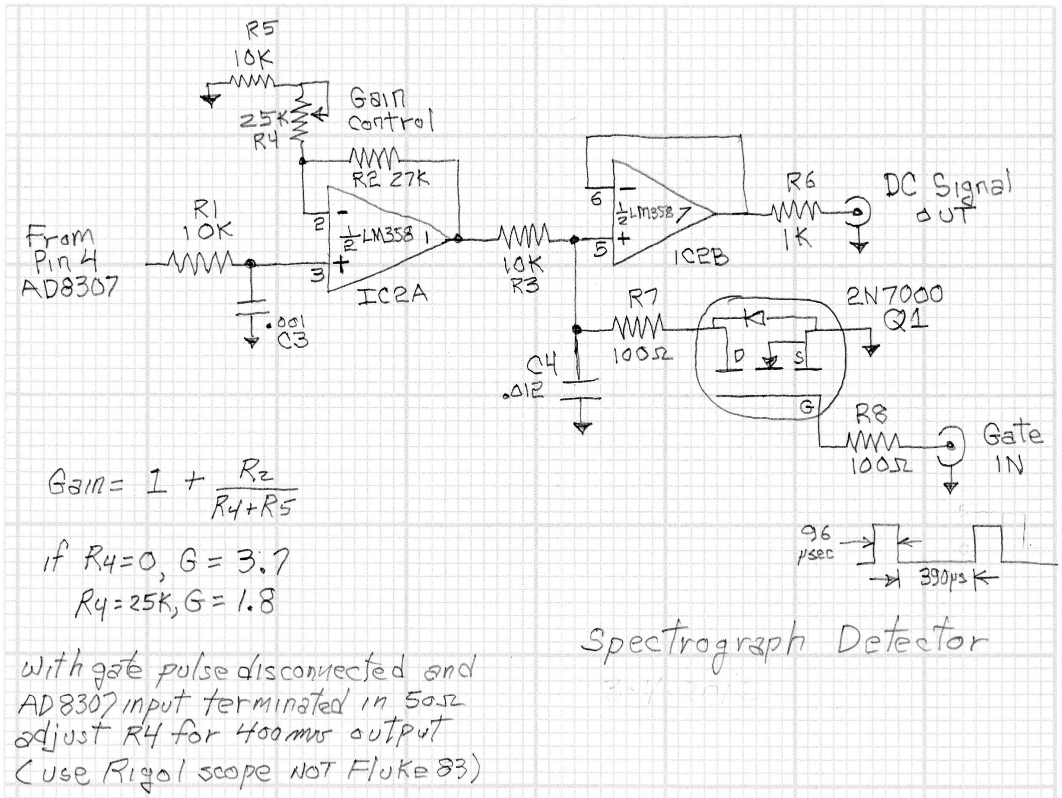
Amplifier (A) gain =49.5 dB, Amplifier (B) gain = 48.7dB. Compression begins at about -40 dBm input.

M4A, M4B Log-Detector, DC Amplifier, Gate



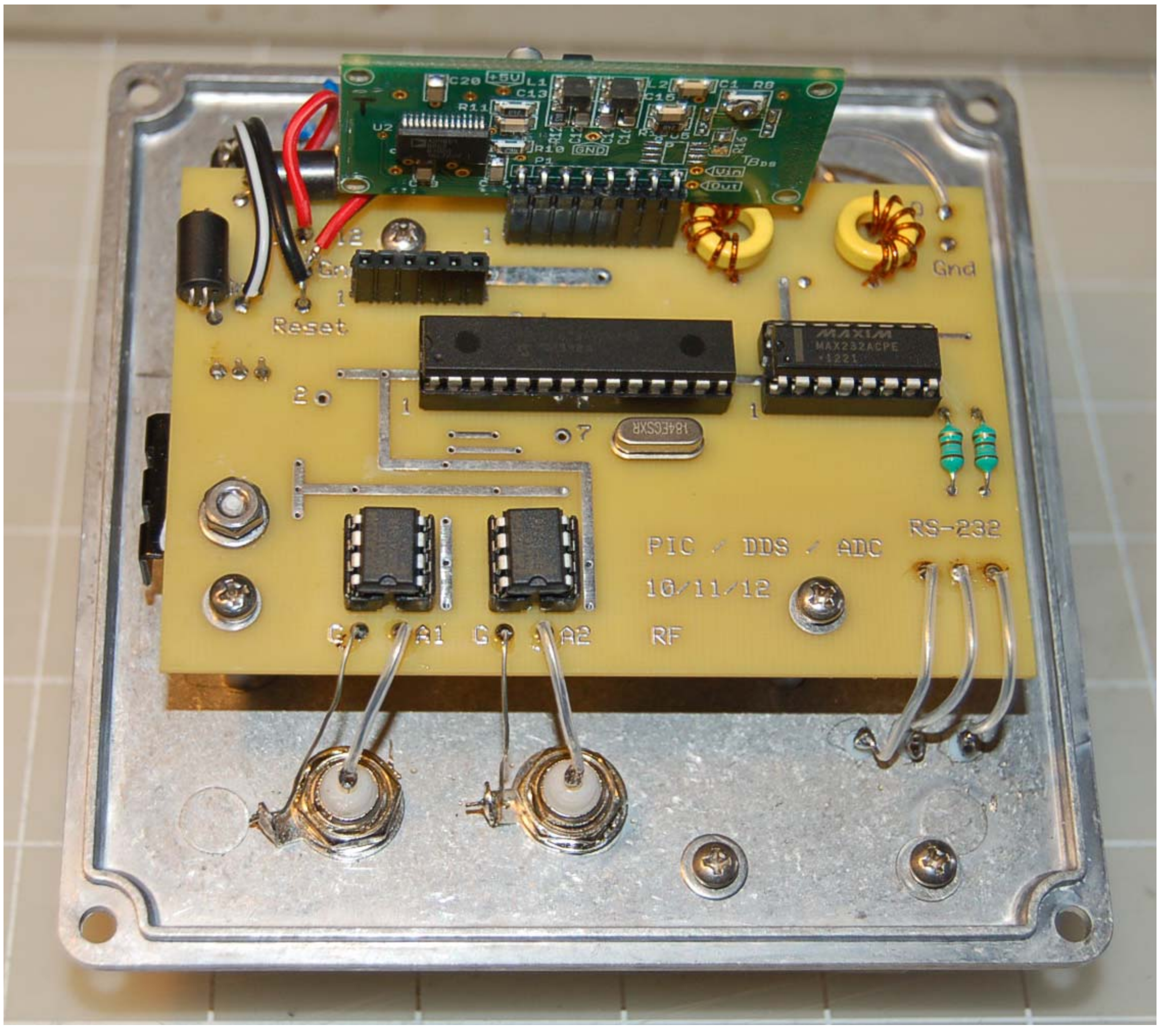


Overall detector schematic

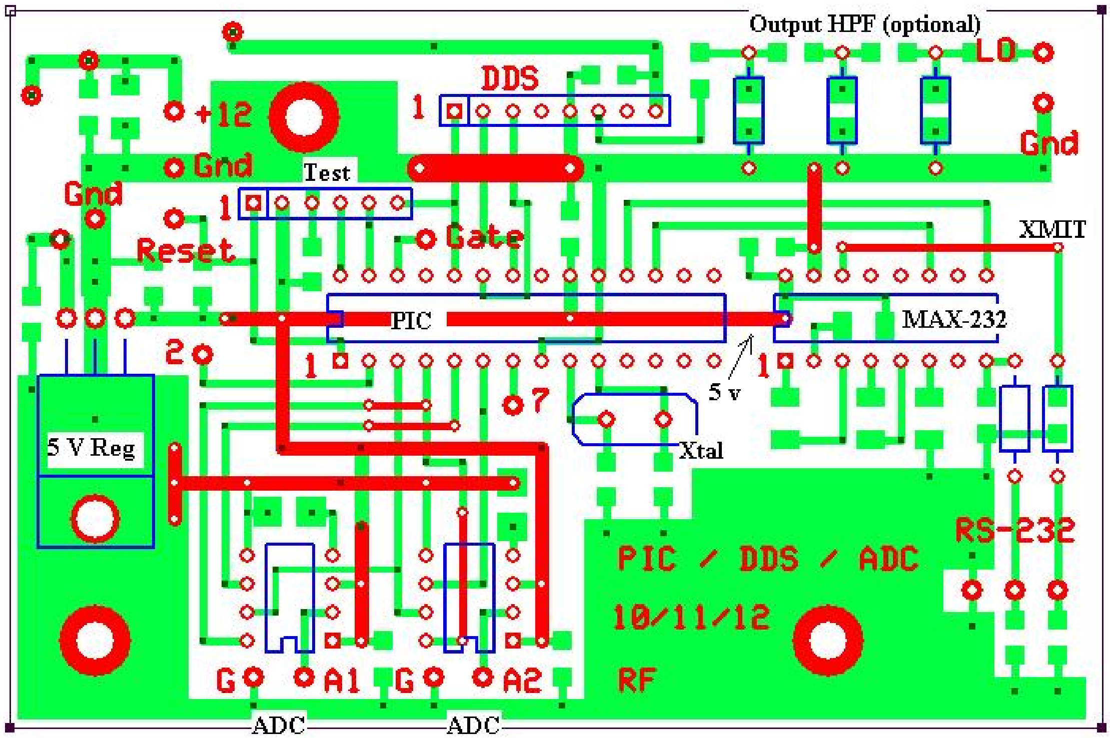


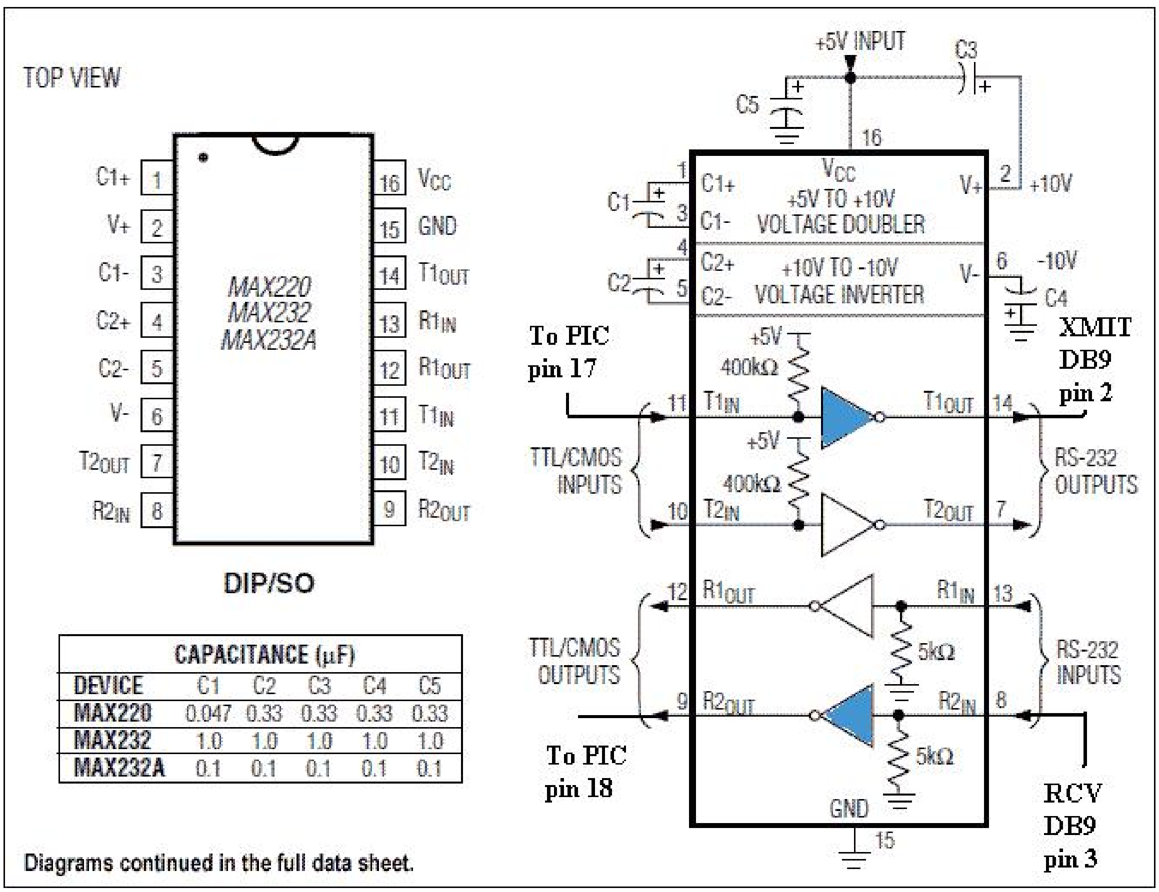
Detail of LM358 Op amp and gate circuit

M5 PIC / DDS / Dual ADC



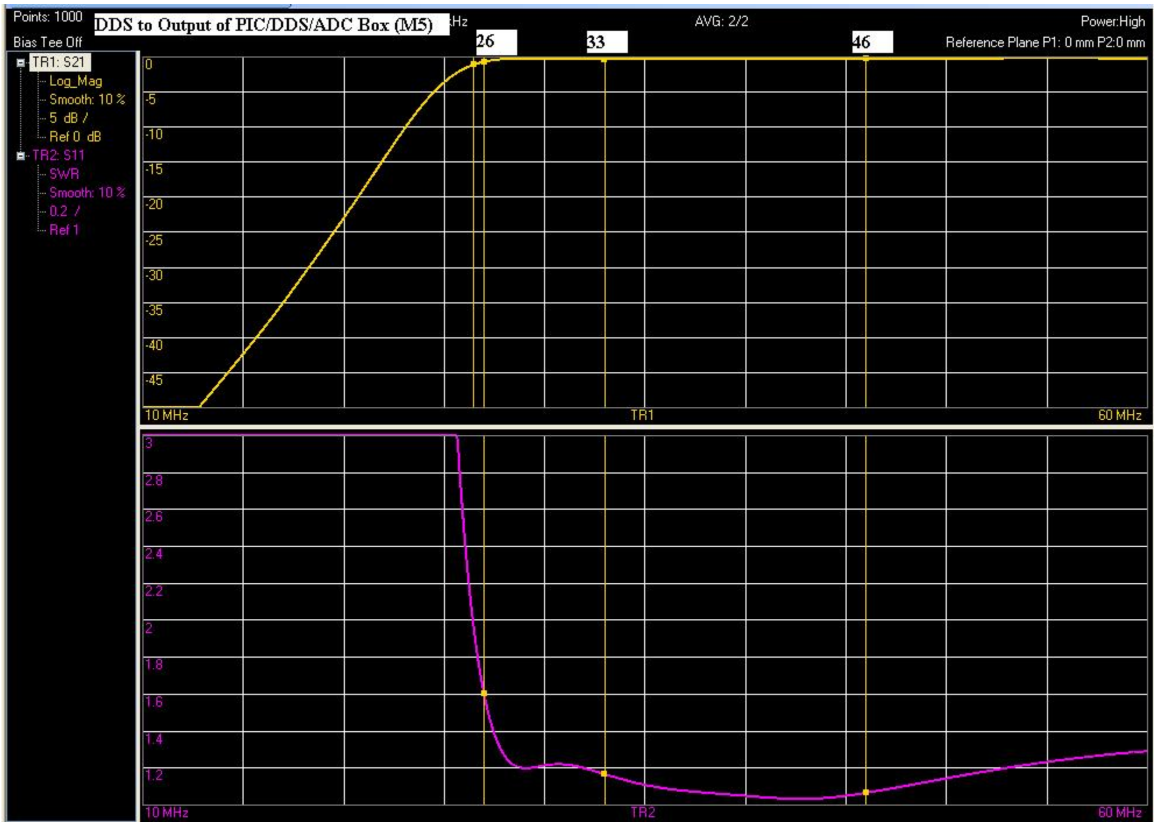
M5 PIC / DDS / Dual ADC





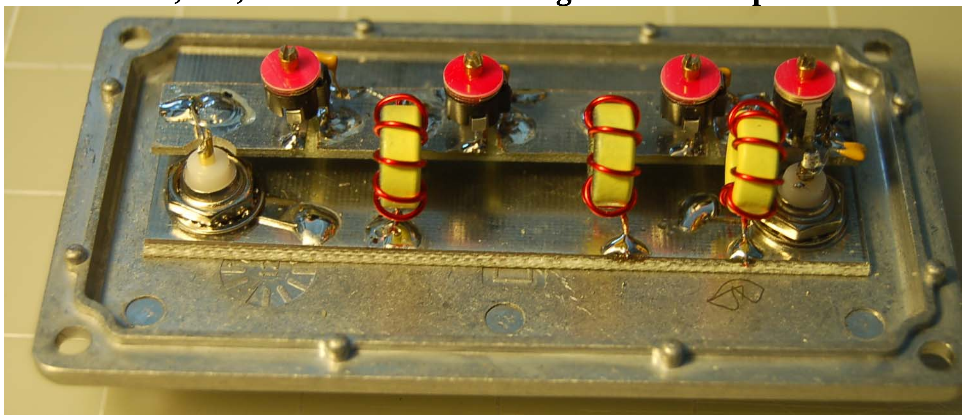
CAPACITANCE (μF)					
DEVICE	C1	C2	C3	C4	C5
MAX220	0.047	0.33	0.33	0.33	0.33
MAX232	1.0	1.0	1.0	1.0	1.0
MAX232A	0.1	0.1	0.1	0.1	0.1

Diagrams continued in the full data sheet.

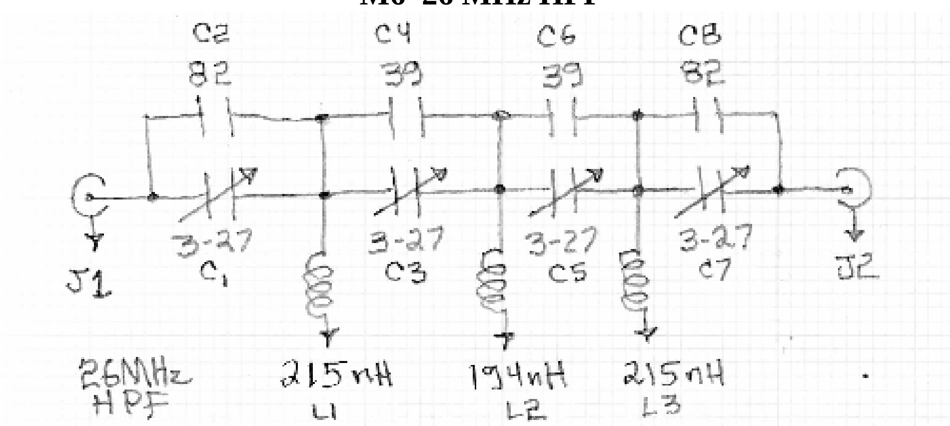


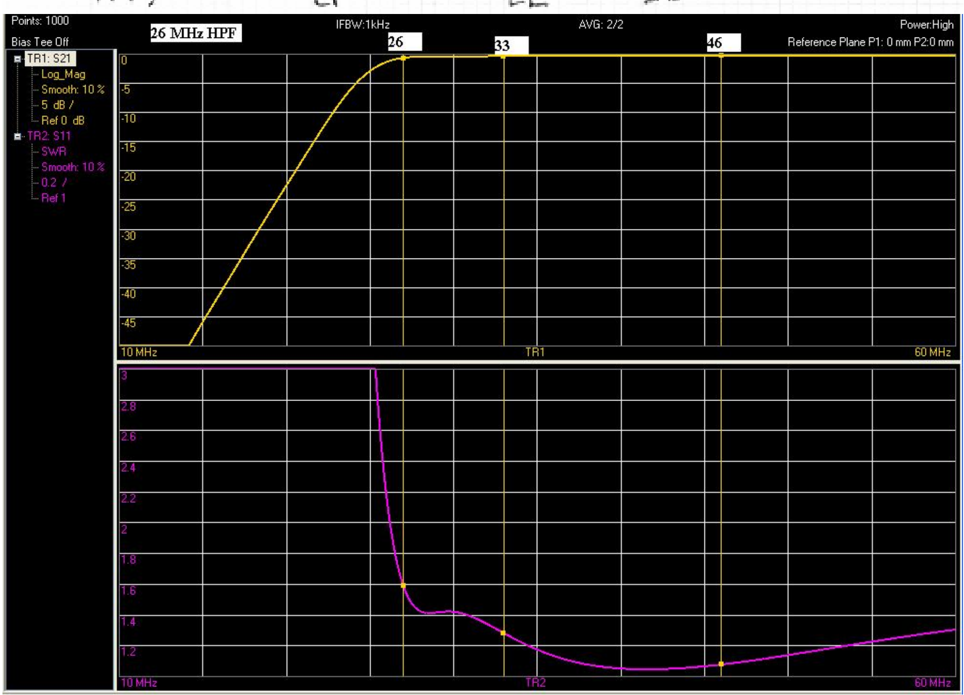
26 MHz HPF Response – this is the HPF in M5 at the output of the DDS.

M6, M7, M8 LO Chain Filtering and Power Splitter

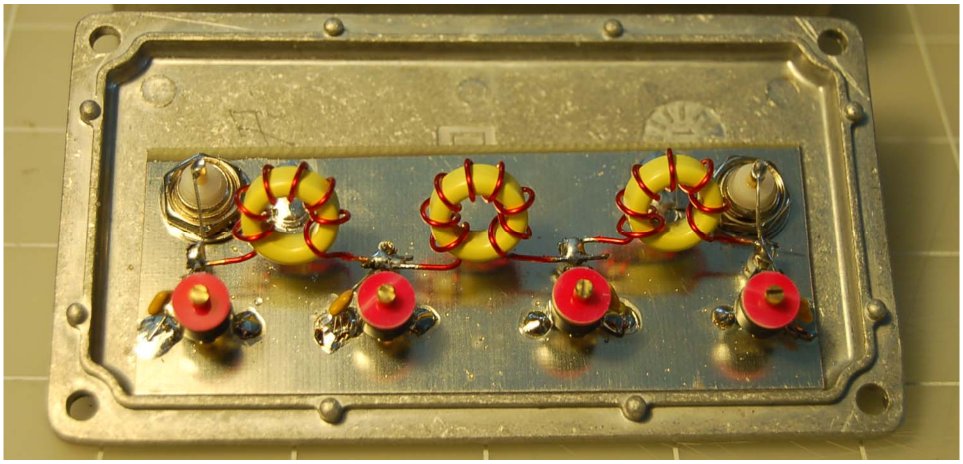


M6 26 MHz HPF

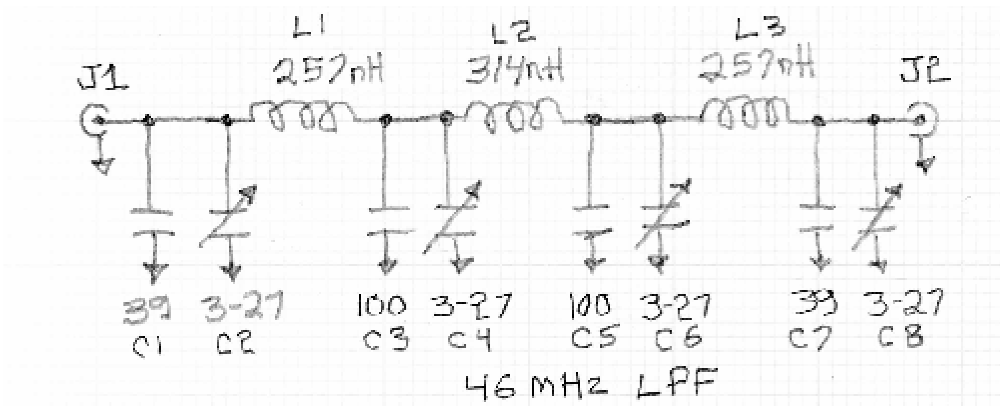


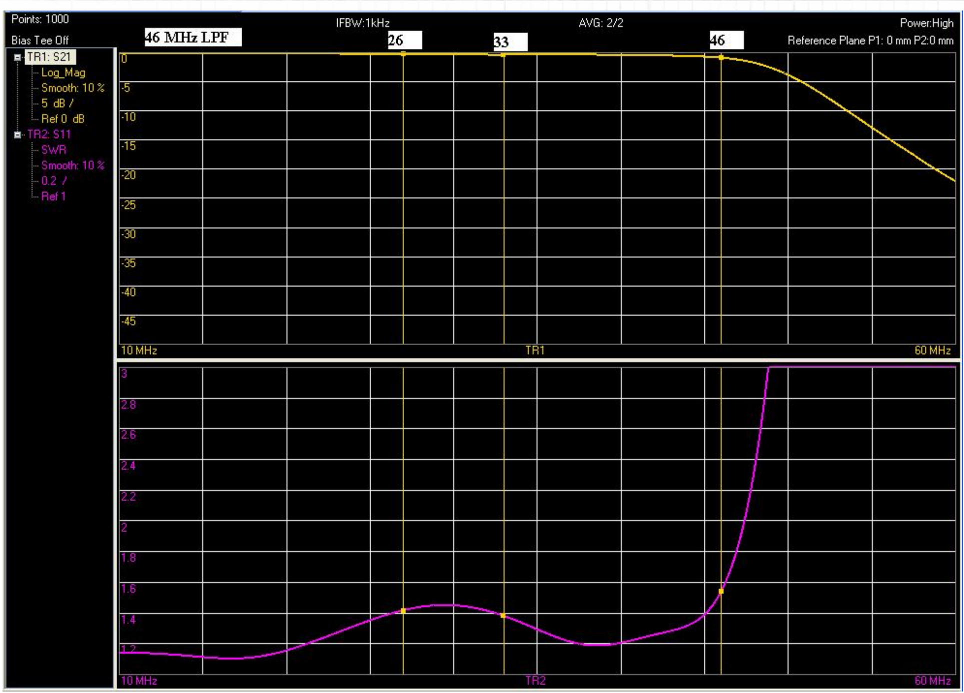


26 MHz HPF Response

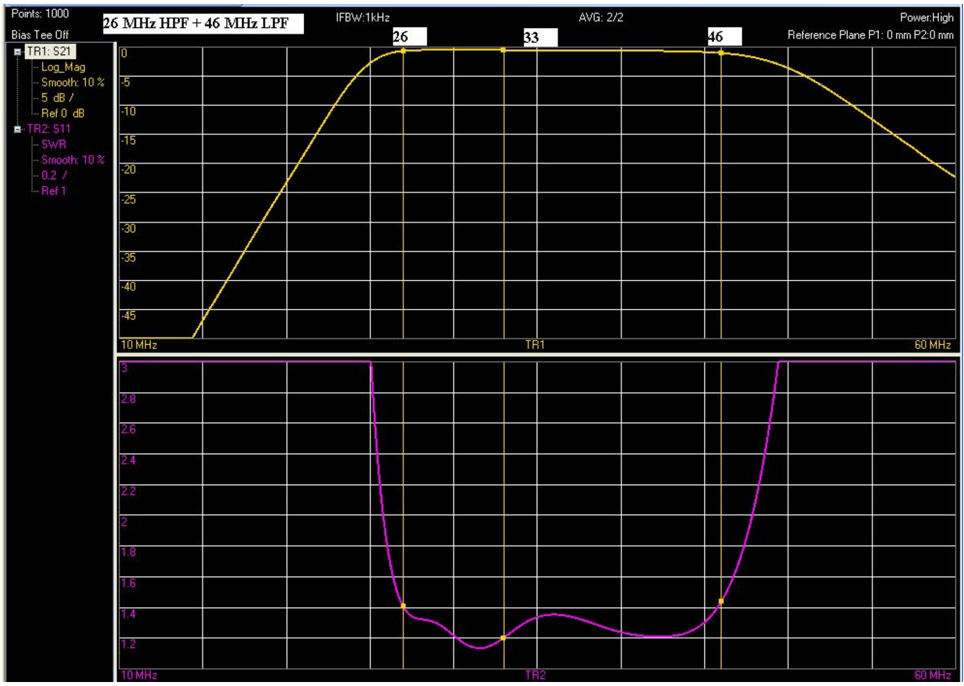


M7 46 MHz LPF

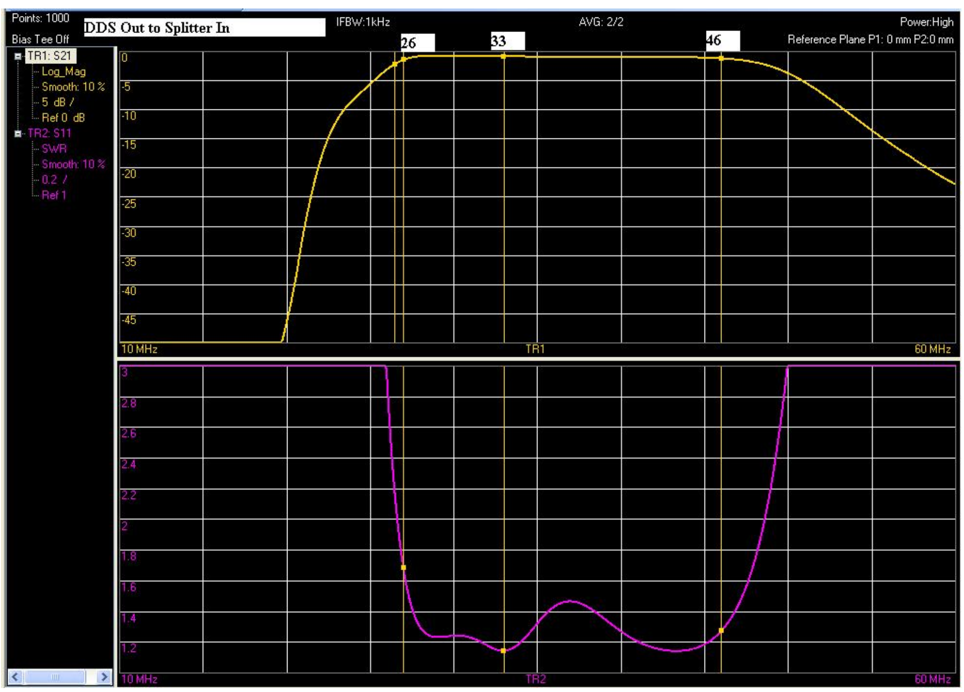




46 MHz LPF response



Response of 26 MHz HPF and 46 MHz LPF combined



Response from output of DDS to input of power splitter – this includes the 26 MHz HPF on the PIC/DDS/ADC board and the external 26 MHz HPF and 46 MHz LPF.

Overall Performance Measurements and Parameters

RF stage (M2) Gain = 7 dB from RF in to IF out. This is consistent with the gain of the MAR-3 amplifier specd at 13.5 dB (at 50 MHz), and the TUF-3 mixer with a loss of 5 dB. MAR-3 noise figure spec is 3.7 dB (at 50 MHz).

IF Amplifier (M3) Gain = 49 dB. NF of 2N5109 transistor =3dB. NF of IF approximately 4 dB.

Spectrogaph NF theoretical is 5 dB (temp = 625 kelvin)

With a galactic background temperature of 25kK at the input of M1 the signal level in a 30 kHz BW is -110 dBm. At the 10.7 Mhz IF output of M2 this level is 130 kK (-103 dBm). The IF (M3) begins to go into saturation at an input level of -40 dBm which is 63dB above the background noise level at the input of M3.

The galactic background level present at the input of the detector is approximately minus 54 dBm, equivalent to 1E10 kelvin.

With the RF module (M2) IF port terminated in 50 ohms and a 33 MHz LO signal at +7 dBm applied to the mixer, the LO signal level at the RF input port of M2 is -44 dBm. When the LO is sweeping in the range 27 to 34 MHz this signal level will be present at the antenna terminals of the spectrograph. The 34 MHz LPF (M1) will attenuate leakage of LO signals above 34 MHz.

DPS Performance Summary

Detector Sensitivity Setting

An HP8640 signal generator (10.700 MHz) followed by a Kay step attenuator was fed into each detector input and the detector gains were adjusted to yield the same DC output voltage to the ADCs. The generator output level was fixed at -40 dBm and the Kay attenuator set to -20 dB yielding an input signal to the detectors of -60 dBm. Gains were adjusted to yield 1763.8 mv out to each ADC. No splitter was used – the detector inputs were fed directly from the Kay attenuator. RG58 cables running from the generator to the Kay attenuator and from the attenuator to the detector each had clamp on ferrite chokes. Next the 10.7 MHz signal level was varied in 5 dB steps as seen in the following table. The A channel detector sensitivity averages **50.65 mv/dB** while the B channel detector sensitivity averages **48.32** mv/dB. (Table 1)

-70	1251.5	1276.9				
-65	1502.4	1517.2	50.18	48.06	2.12	
-60	1763.8	1763.8	52.28	49.32	2.96	
-55	2015.2	2002.9	50.28	47.82	2.46	
-50	2263	2241.7	49.56	47.76	1.8	
-45	2523.5	2489.8	52.1	49.62	2.48	
-40	2770.9	2726.6	49.48	47.36	2.12	
			50.65	**48.32**	**2.32**	Averages
10.7 MHz dbm in	A volt	B volt	A chan mv/dB	B chan mv/dB	A-B mv/dB	

Table 1 Detector sensitivity measuremets

After setting the detector sensitivities to match as close as possible, and in particular to yield the same output voltage at a level expected from the galactic background, the following measurements were obtained.

Channel A and B, ADC Input Voltage vs Antenna Terminal Temperature

The antenna input of each channel of the spectrograph was connected to the 72 M Kelvin HP461 noise source in series with a Kay step attenuator. No power splitter was used – direct connection to the Kay attenuator.

The voltmeter option in the DPS software was used to obtain the input voltage to the ADCs as a function of input temperature to each receiver. This measurement was made at 24.490 MHz. (the frequency read by the voltmeters). The sweep range of the spectrograph for this measurement was 18-30 MHz.

The attenuator was varied from 40 to 0 dB in 5 dB steps. At each setting three readings of voltage were obtained and the three numbers averaged to yield a single value for each temperature setting. Figure 2 shows the close tracking of the two channels as a function of signal input temperature over a 40 dB range. Channel (A) levels are slightly higher above 30 kK, diverging more from the (B) channel at higher signal amplitudes.

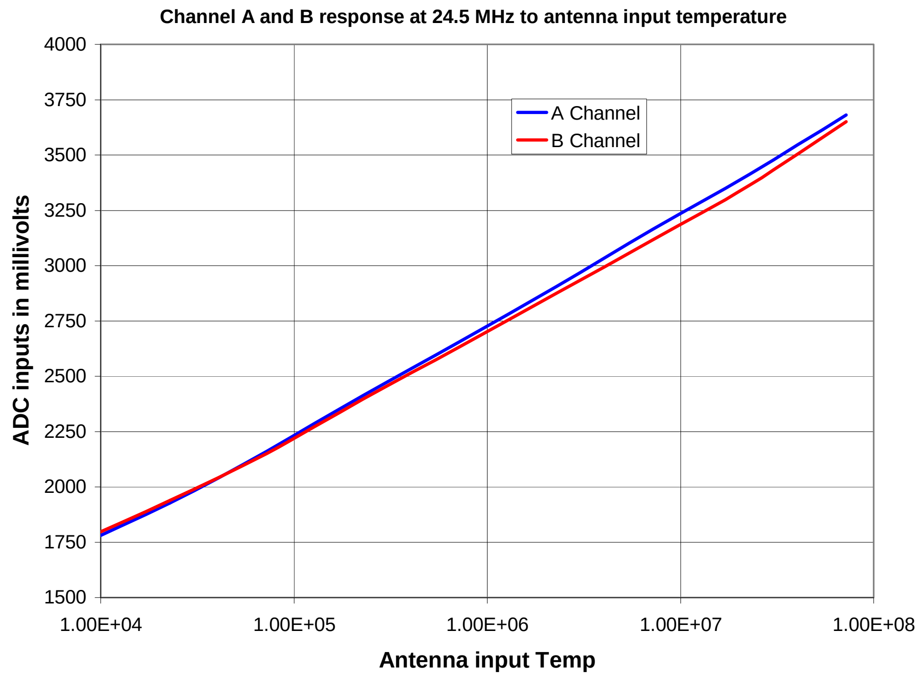


Figure 1. ADC input voltage in millivolts vs antenna input temperature in Kelvin.

In order to get a more detailed view of the divergence between the two channels the difference (expressed in dB) was calculated assuming an average detector sensitivity of 49 mv/dB. (Figure 2).

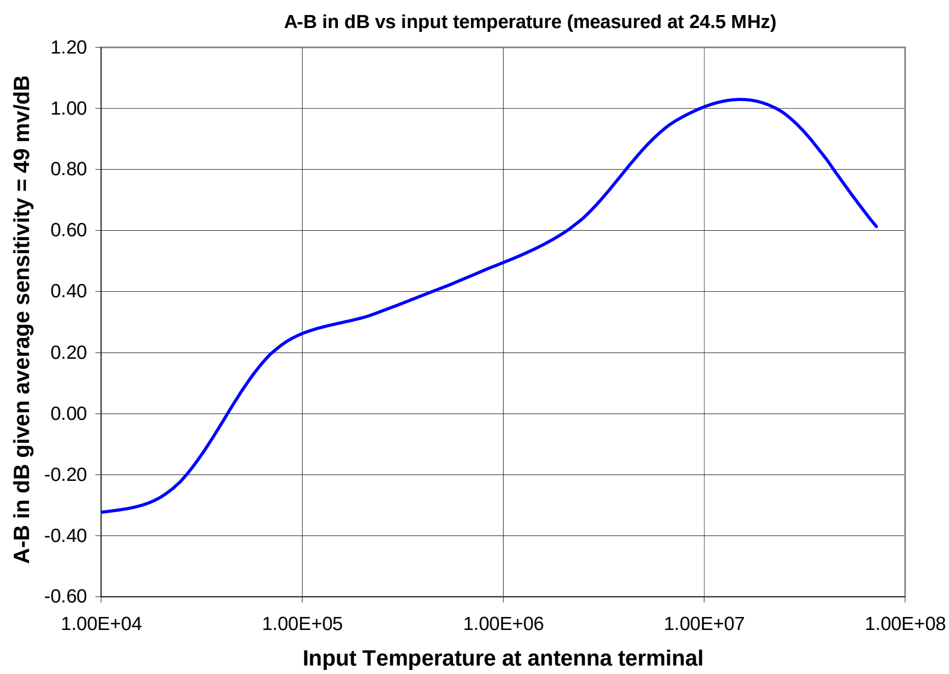


Figure 2. A-B difference in dB vs antenna terminal temperature. The difference is close to zero at the expected level of the galactic background and reaches a maximum of 1 dB near 10 M Kelvin.

ADC Input Voltage vs Frequency for a constant antenna terminal temperature.
A measurement was made of ADC input voltage vs frequency using a constant input temperature of 228kK. The voltmeter frequency was varied in 1 MHz steps from 19 to 33 dB while the sweep range of the spectrograph was set at 18-34 MHz. The result is seen in Figure 3
Figure 3 ADC reading for both Channels A and B as a function of frequency.

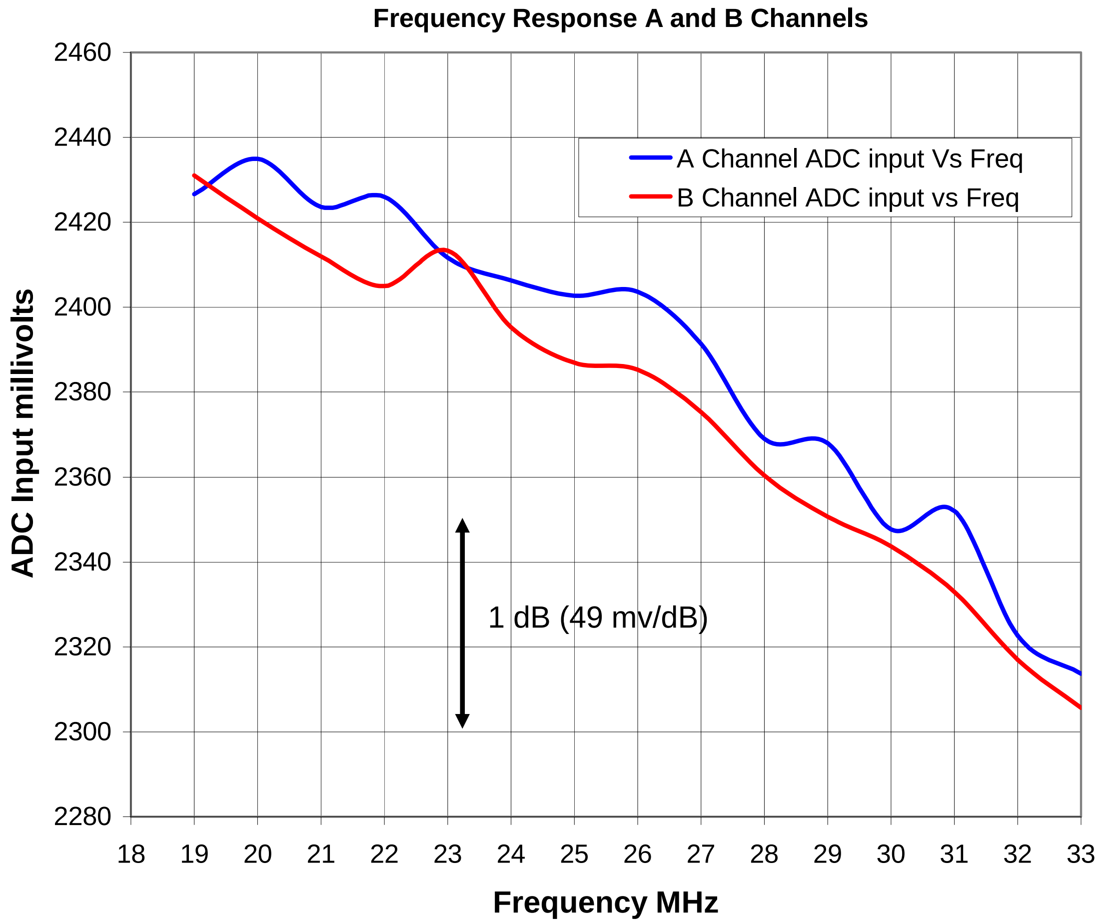
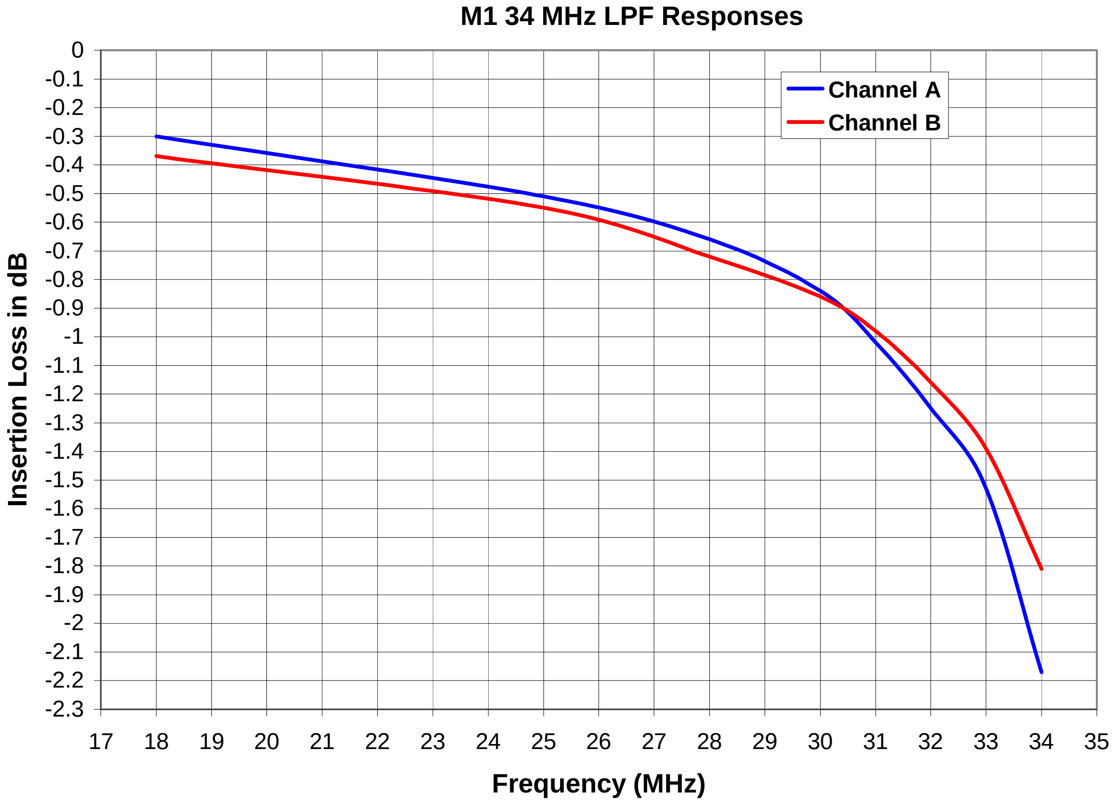


Figure 3. ADC reading for both Channels A and B as a function of frequency.

Ideally this response should be flat – it isn't. There is a gradual drop off in response amounting to about 2.5 dB over the 19 to 33 MHz range. Both channels do track quite closely – within about a quarter dB. The hardware reason for this droop is likely a combination of the RF front end gain (including the 34 MHz LPF response) and the LO power which decreases slightly with frequency.

The effect of this frequency response droop is that the higher frequencies of the spectrograms will be visibly different in color, even if the instrument is driven with a constant temperature, frequency independent, noise source.

A detailed view of the M1 34 MHz LPF responses for both the A and B channels (Figure 4) shows that approximately 1.75 dB of this droop can be explained by the 34 MHz LPF response.



Recall that this filter was required to minimize image response problems when the spectrograph is tuned to low frequencies. So the droop in response was necessitated by the desire to cover both low frequencies – down to 17 MHz and perhaps lower, while also covering high frequencies.

Solution

The solution to the droop is likely a simple table of frequency dependent correction coefficients which are applied to the ADC data before the offset and gain controls. Since both channels track each other quite well, a single correction table applied to both channels should be sufficient.

rf 11 Feb 2013

Circuitry details are provided to Dave Typinsky for use in operation and maintenance of the DPS. This information should not be distributed to others without the express permission of RF Associates LLC.