ARX Rev. I Filter Selection & Evaluation

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1. Description:

This document describes the filter designs for the Rev. I ARX including methods, synthesis, simulation, and prototype construction and measurements. An appendix describes the filters used in the earlier ARX Rev. G and H.

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2. ARX Rev. I block diagram:

Refer to the master system block diagram in the Reports folder.

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3. Design methods:

Software:

The AADE Filter Design software synthesis and simulation tool was used to synthesize all filters according to the requirements described herein. The synthesis of each filter produced exact component values. The exact values were then replaced with the nearest catalog values, and AADE was used to simulate the filter characteristics and produce the plots shown in this document. Multiple prototypes of every filter were built.

Filter designs:

1) The Rev. I filters were simulated using Butterworth, Chebyshev and Elliptic types but only Butterworth and Elliptic were used in the initial and final designs;
2) Both Pi- and T-configurations were investigated for the highpass filters;
3) The tolerance for all inductor and capacitor values is ±2% and the inductor Q tolerance is ±20%;
4) The desirable self-resonant frequency (SRF) of the inductors is at least 10X the highest operating frequency (≥ 1 GHz SRF). However, this was not achievable in the high-value inductors required in the 3 MHz highpass filter, so inductors with SRF = 90 MHz (the highest available) were used in this filter. An alternative investigated during the prototype stage was to use smaller value, higher SRF inductors connected in series; however, the added SMD pad capacitance tended to reduce the filter return loss at the higher frequencies, so this idea was abandoned;
5) Coilcraft inductors in 0805 size were used in the designs where possible. Some 1008 size inductors were necessary to obtain the needed SRF or inductance value;
6) MLCC C0G (NP0) capacitors in size 0805 were used in all designs. C0G capacitors are relatively immune to capacitance variations due to voltage and temperature effects on the dielectric;
7) All filters are isolated from dc, which provides relief from capacitance changes caused by bias voltage on the dielectric. Similarly, inductance changes due to direct current are avoided;
8) Parallel capacitors and series inductors were not used in the initial designs to fine-tune the filter component values but were used in later designs for the prototypes; see also 4) above. Some final designs used parallel capacitors to obtain the needed capacitance;

9) The filter simulations addressed only insertion loss and return loss; phase and group delays were not analyzed;
10) Monte Carlo statistical analyses, in which component values are randomly varied within predetermined tolerances, are for most filters. The following tolerances are used with the Monte Carol method:
    - ✓ Input and output resistances: 10% (always real, never imaginary)
    - ✓ Inductors, Inductor Qs, and capacitors as noted is 3) above
11) The existing 83.7 MHz lowpass filter from the Rev. H ARX was retained for the Rev. I without any changes. All other filters were designed to meet the desired characteristics.

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4. Lowpass Filters:

The Rev. I ARX uses two lowpass filters with nominal cutoff frequencies of 73.5 and 83.7 MHz. The 73.5 MHz filter primarily is used to reject the FM broadcast band (88 to 108 MHz) whereas the 83.7 MHz filter provides a higher cutoff frequency at the expense of lower FM band rejection. The 73.5 MHz LPF may be referred to as a 70 MHz filter in the following discussions.

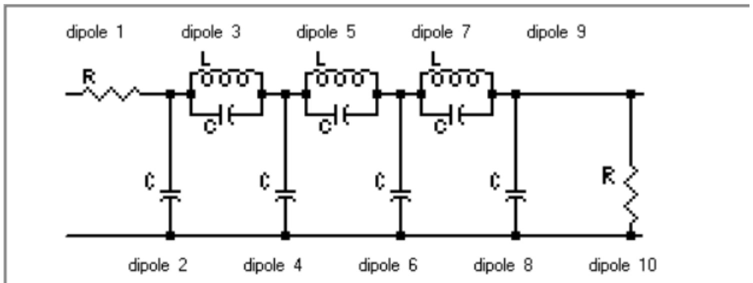
Several versions of the 73.5 MHz LPF were investigated including 5th order and 7th order Elliptic filters with frequencies between about 70 and 74 MHz. It was difficult finding a suitable combination of cutoff and stopband frequencies and passband return loss and stopband insertion loss that resulted in readily available inductor catalog values. The final design uses a 7th order Elliptic with a cutoff frequency of 73.5 MHz.

Although both lowpass filter designs use the Elliptic filter type, other filter types were evaluated including the Butterworth and Chebyshev; however, these generally did not provide the necessary roll off without using excessively high order. The Elliptic filter trades off ripple in both the passband and stopband for a steeper roll off in the stopband. The designed passband ripple was 0.1 dB for both lowpass filters. The lowpass Elliptic filter theoretically rolls off at approximately 10db/octave/order.

<u>73.5 MHz lowpass filter</u>:
The 73.5 MHz lowpass filter design criteria are:
Fc = 73.5 MHz with ≤ 0.1 dB ripple in the passband and at the cutoff frequency Fc
Fs = 91.5 MHz for design
Fs = 88 MHz achieved with ≥ 40 dB rejection

The 73.5 MHz lowpass filter is shown below with the nearest catalog component values.

Characteristics of the 73.5 MHz LPF from the simulation:
- ✓ Type: Elliptic
- ✓ Order: 7
- ✓ Attenuation at 70 MHz: 1.3 dB
- ✓ Attenuation at 88 MHz: 40.9 dB
- ✓ Attenuation at 108 MHz: > 40.9 dB
- ✓ Minimum return loss in passband: 16.6 dB at 52.2 MHz
- ✓ Return loss at 70 MHz: 18.3 dB



DIPOLE 1
R 1=50.

DIPOLE 2
C 2=47.pF

DIPOLE 3
C 3=6.pF
L 3=.14uHy
Qu~50.
F(L3C3)=
173.652279MHz

DIPOLE 4
C 4=68.pF

DIPOLE 5
C 5=30.pF
L 5=.1uHy
Qu~50.
F(L5C5)=
91.888149MHz

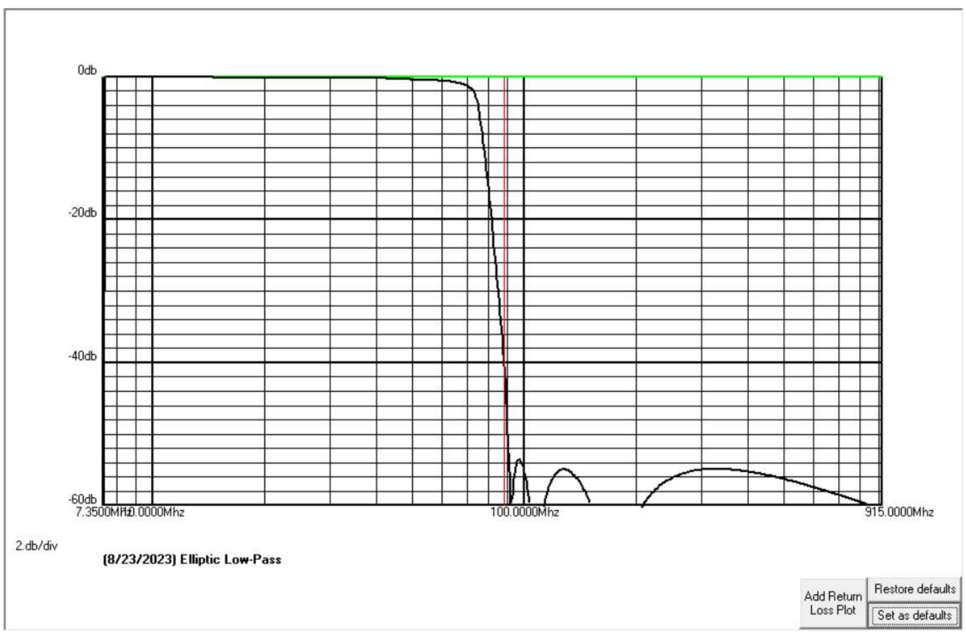
DIPOLE 6
C 6=58.pF

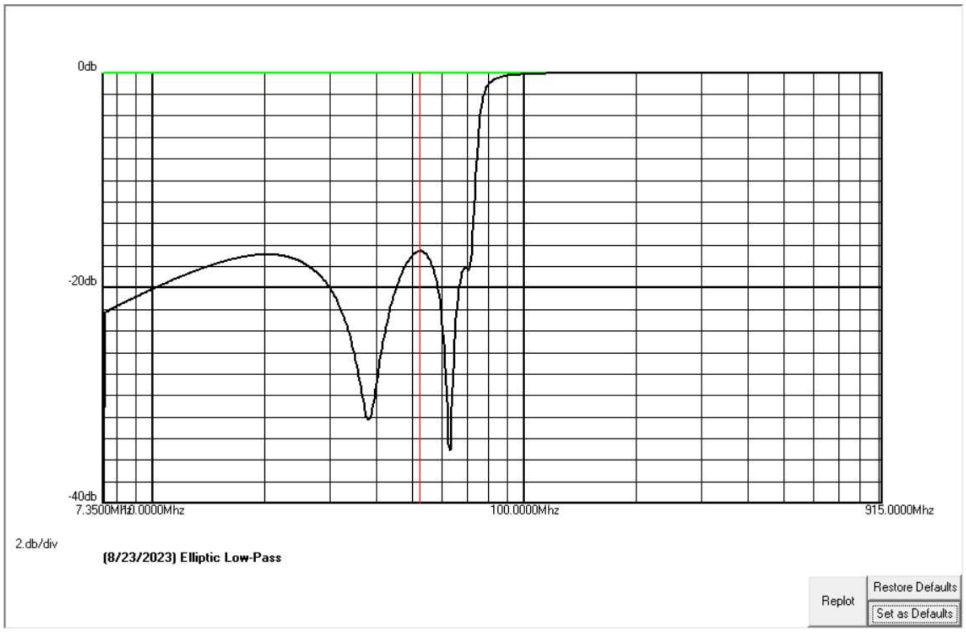
DIPOLE 7
C 7=22.pF
L 7=.1uHy
Qu~50.
F(L7C7)=
107.302241MHz

DIPOLE 8
C 8=33.pF

DIPOLE 10
R 10=50.

7.th order (8/23/2023) Elliptic Low-Pass
Cutoff = 100.m db @ 73.5Mhz
Stopband = 55.002 db minimum @ 91.5Mhz
Design Impedance=50. ohms
Input Impedance = 50. ohms
Output Impedance = 50. ohms
Capacitance Spread = C 4 : C 3 = 11.333
Inductance Spread = L 3 : L 5 = 1.4





<u>83.7 MHz lowpass filter</u>:

The 83.7 MHz lowpass filter design is a replication of the Rev. H 83.7 MHz lowpass filter:

Fc = 83.7 MHz with ≤ 0.1 dB ripple in the passband and at the cutoff frequency Fc (according to schematic)

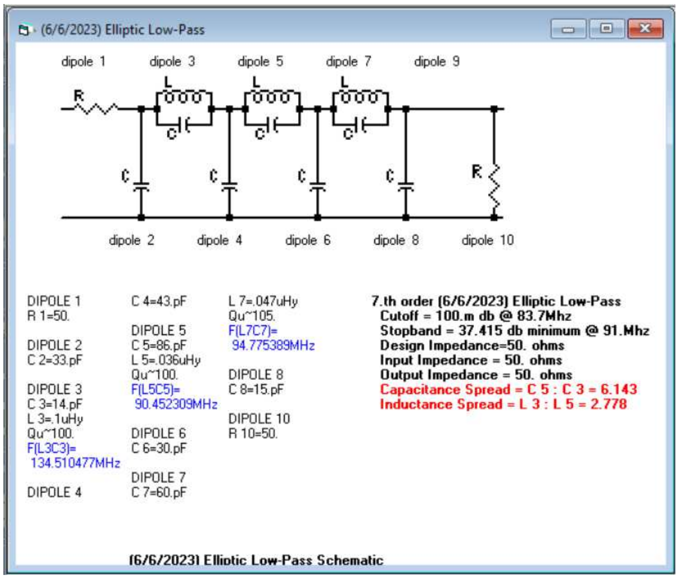
Fs =The stopband frequency Fs used in the original design is unknown

The filter is shown below with the component values from the original Rev. H schematics.

Characteristics of the final 83.7 MHz LPF from the simulations:

- ✓ Type: Elliptic
- ✓ Order: 7
- ✓ Attenuation at 88 MHz: 17.5 dB
- ✓ Attenuation at 108 MHz: 30.5 dB
- ✓ Minimum attenuation between 88 and 108 MHz: 17.5 dB at 88 MHz
- ✓ Minimum return loss in passband: 8.4 dB at 82.8 MHz
- ✓ Return loss at 88 MHz: 2.7 dB

Rev. H 83.7 MHz LPF Schematic:



Rev. H 83.7 MHz LPF Insertion Loss and Return Loss:

5. Highpass Filters:

Four highpass filters with nominal cutoff frequencies of 3, 10, 20 and 30 MHz are used. The 3 and 10 MHz highpass filters generally are used for ionospheric research; one or the other is selected based on ionospheric conditions and observation requirements. The 3 MHz highpass filter provides moderate rejection of the medium frequency (MF) AM broadcast band. The 20 and 30 MHz filters allow celestial observations and are designed to reduce interference from HF radio traffic. The 20 MHz filter is a compromise that allows celestial observations when ionospheric conditions are relatively quiet, whereas the 30 MHz filter is specifically designed to reduce terrestrial interference from the Citizen Band Radio Service (CBRS) regulated under FCC Part 95. The CBRS frequency range is 26.96 to 27.41 MHz (including sidebands).

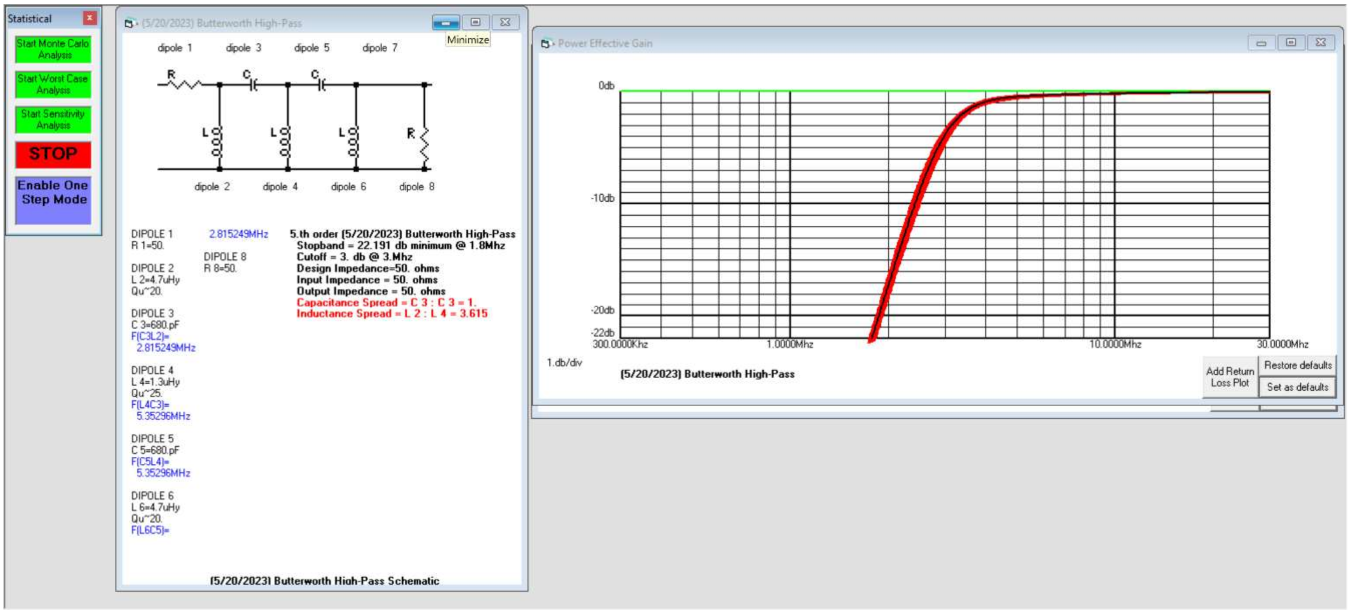
The proposed highpass filter designs are based on the Butterworth type for the 3, 10 and 20 MHz filters and Elliptic type for the 30 MHz highpass filter. The Butterworth filters exhibit a flat response in the passband and roll off at 6db/octave/order. The Elliptic filter trades off ripple in both the passband and stopband for a steeper roll off in the stopband, a characteristic necessary for rejecting the CBRS interference while still providing useful observation bandwidth. As with the lowpass Elliptic filters described previously, the highpass Elliptic filter theoretically rolls off at approximately 10db/octave/order.

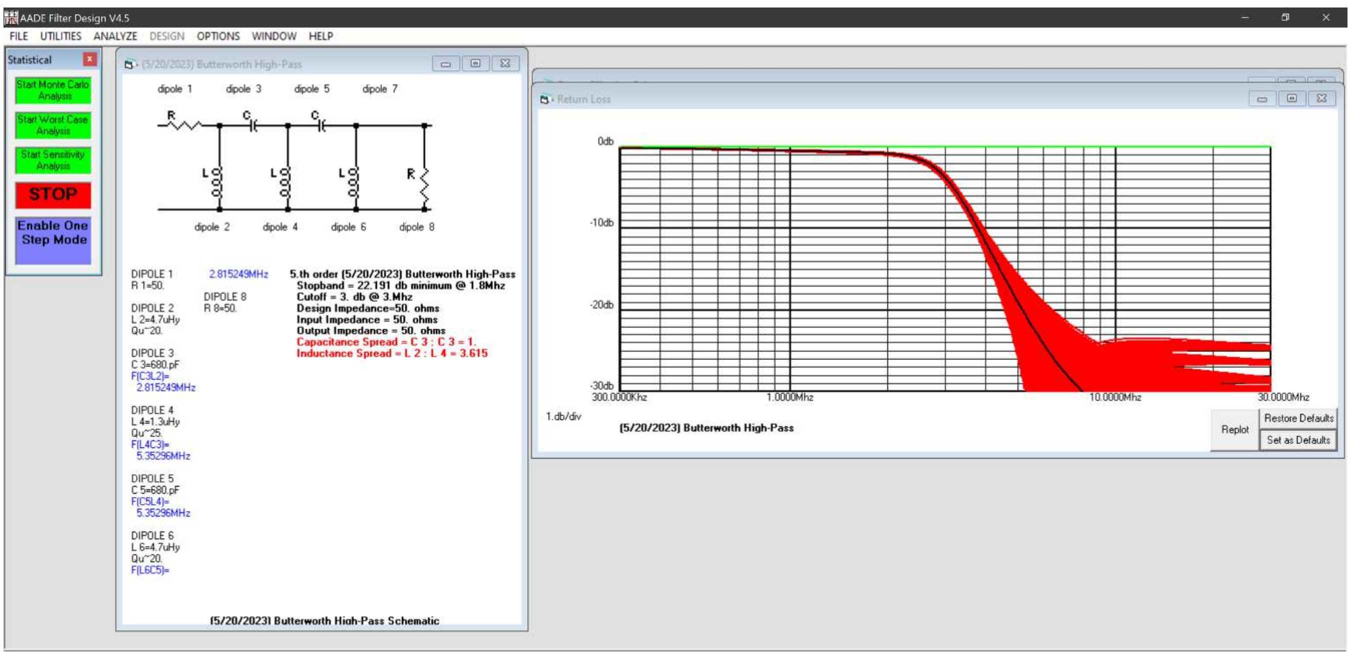
<u>3 MHz highpass filter</u>:
The 3 MHz highpass filter design criteria are:
Fc = 3 MHz with ≤ 3.0 dB attenuation at the cutoff frequency Fc
Fs = 1.8 MHz with ≥ 20 dB rejection in the stopband and at the stopband frequency Fs

The proposed 3 MHz filter is shown below with catalog component values. Also shown are the filter attenuation and return loss after Monte Carol statistical analysis.

Characteristics of the final 3 MHz HPF from the simulation with single catalog component values:

- ✓ Type: Butterworth
- ✓ Order: 5
- ✓ Attenuation at 3 MHz: 3.8 dB
- ✓ Attenuation at 1.8 MHz: 21.5 dB
- ✓ Return loss at 3 MHz: 3.8 dB
- ✓ Return loss at 4.5 MHz: 15.5 dB





<u>10 MHz highpass filter</u>:

The 10 MHz highpass filter design criteria are:

Fc = 10 MHz with ≤ 3.0 dB attenuation at the cutoff frequency Fc

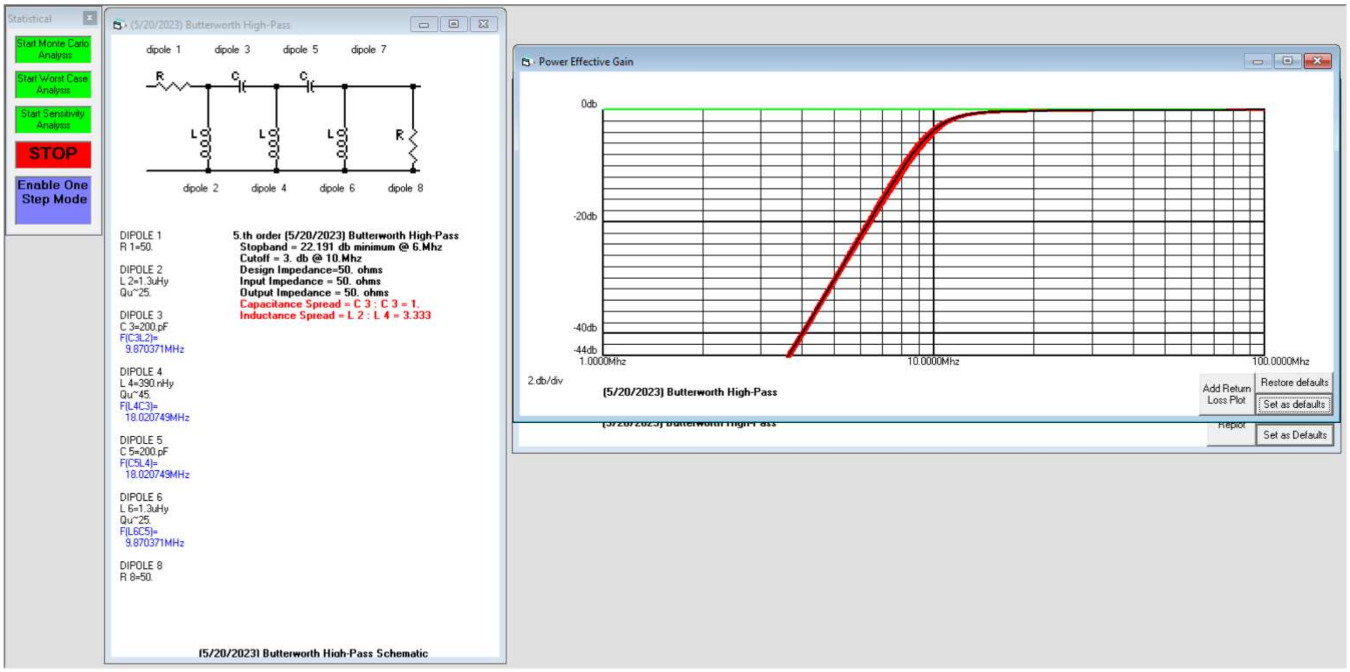
Fs = 6 MHz with ≥ 20 dB rejection in the stopband and at the stopband frequency Fs

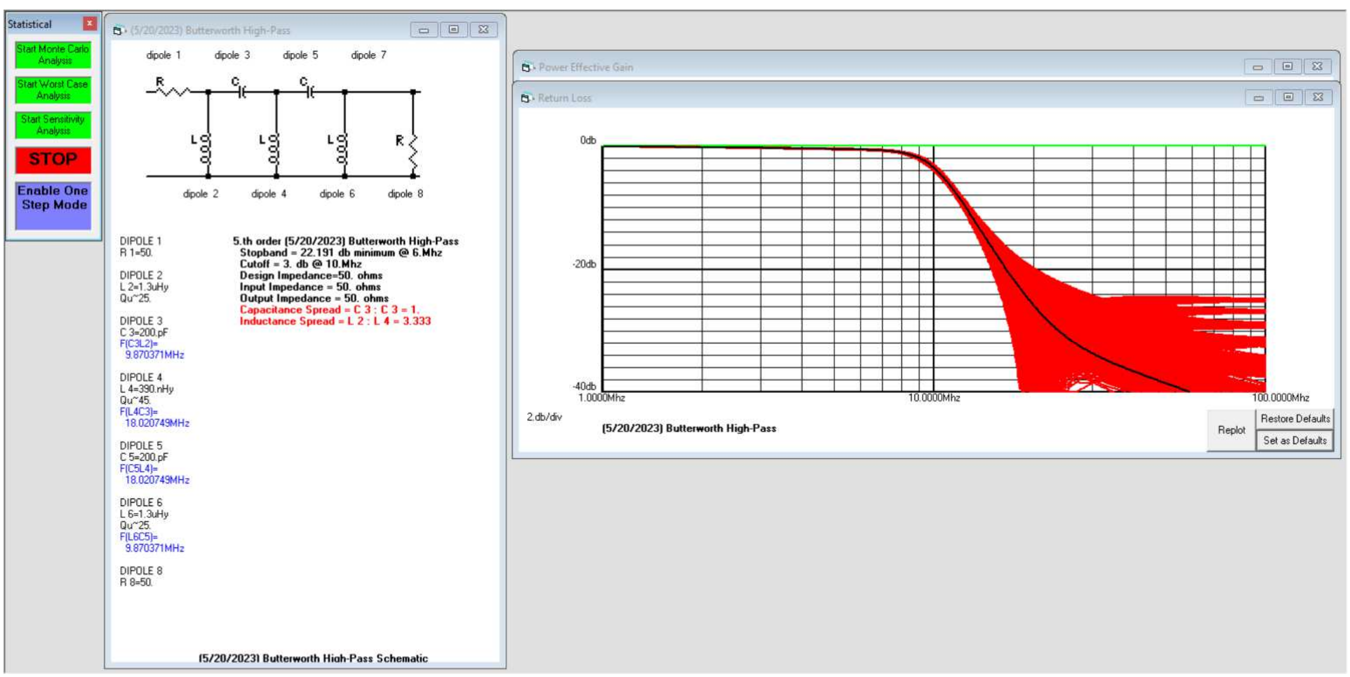
The proposed 10 MHz filter is shown below with catalog component values. Also shown are the filter attenuation and return loss after Monte Carol statistical analysis.

Characteristics of the final 10 MHz HPF from the simulation with single catalog component values:

- ✓ Type: Butterworth
- ✓ Order: 5

- ✓ Attenuation at 10 MHz: 3.6 dB
- ✓ Attenuation at 6 MHz: 22.5 dB
- ✓ Return loss at 10 MHz: 3.5 dB
- ✓ Return loss at 15 MHz: 16.6 dB





<u>20 MHz highpass filter</u>:

The 20 MHz highpass filter design criteria are:

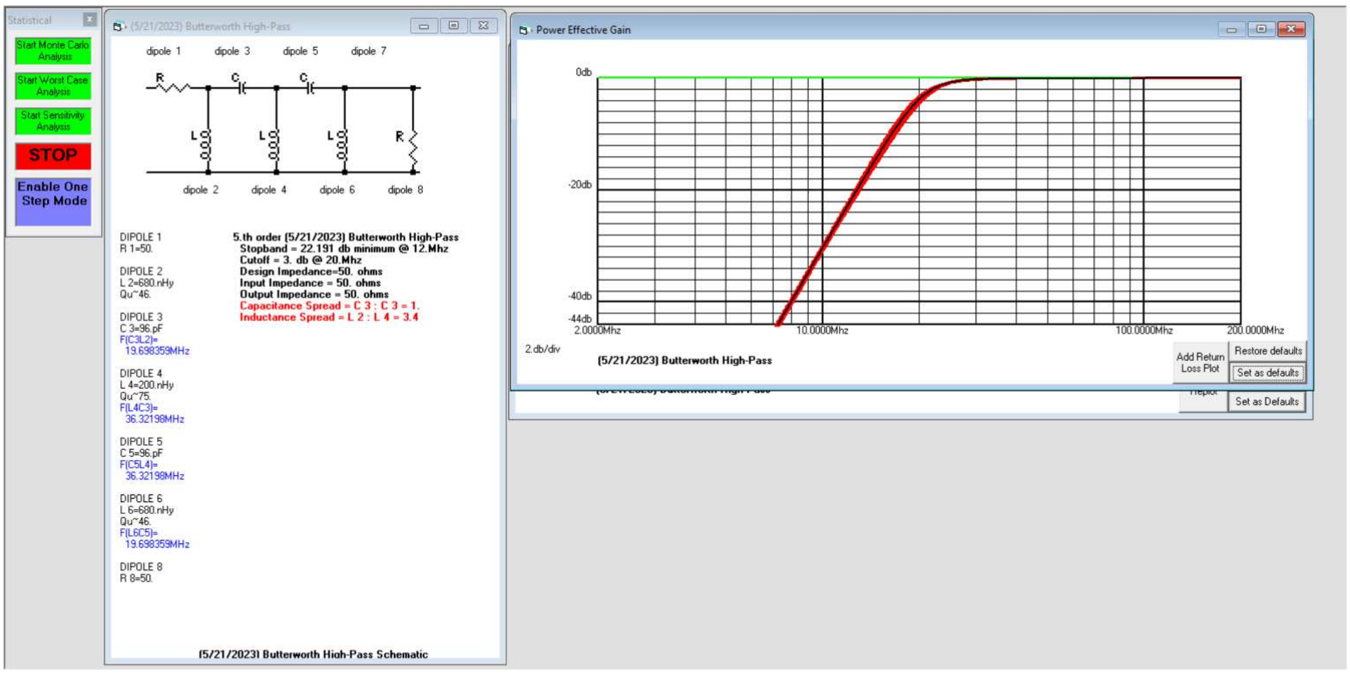
Fc = 20 MHz with ≤ 3.0 dB attenuation at the cutoff frequency Fc

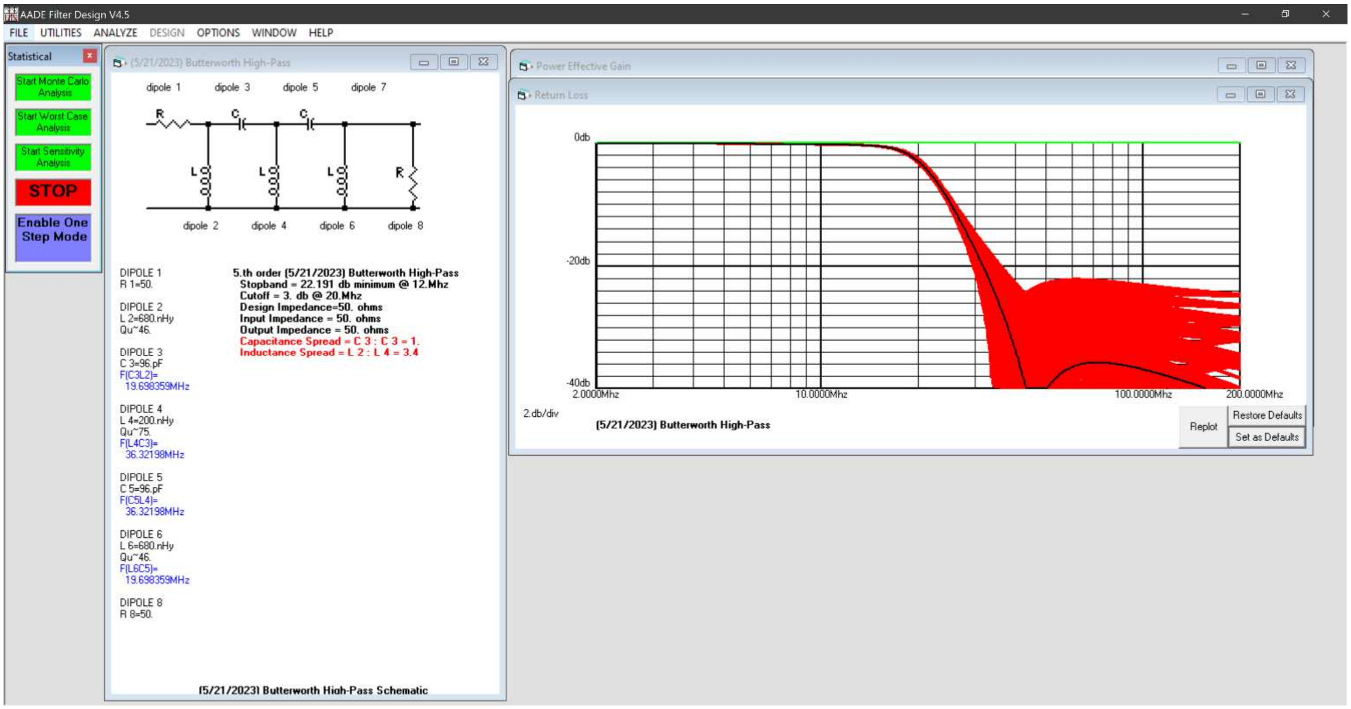
Fs = 12 MHz with ≥ 20 dB rejection in the stopband and at the stopband frequency Fs

The proposed 20 MHz filter is shown below with catalog component values. Also shown are the filter attenuation and return loss after Monte Carol statistical analysis.

Characteristics of the final 20 MHz HPF from the simulation with single catalog component values:

- ✓ Type: Butterworth
- ✓ Order: 5
- ✓ Attenuation at 20 MHz: 3.8 dB
- ✓ Attenuation at 12 MHz: 22.6 dB
- ✓ Return loss at 20 MHz: 2.9 dB
- ✓ Return loss at 30 MHz: 17.3 dB





<u>30 MHz highpass filter</u>:

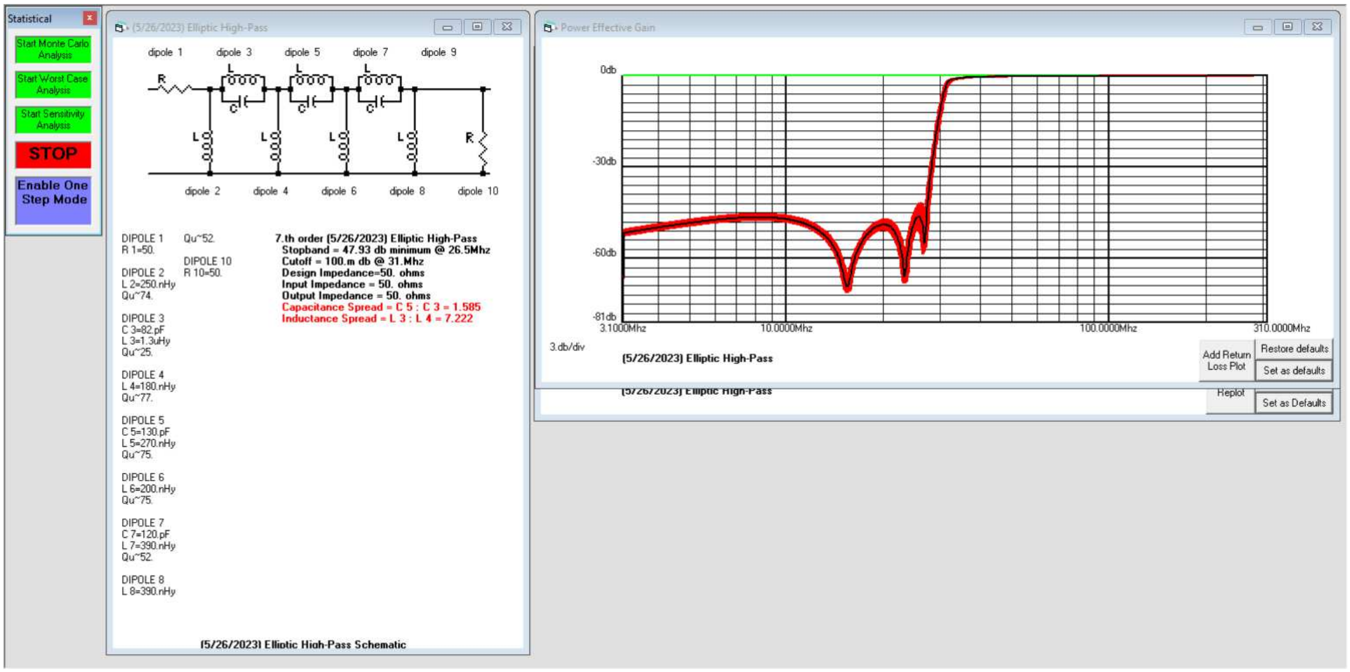
It is desirable to have 40 dB attenuation at the Citizen Band upper band edge of 27.410 MHz without too much loss above 30 MHz. These requirements indicate a relatively high order Chebyshev or Elliptic type. Of these, the Elliptic provides the best overall performance.

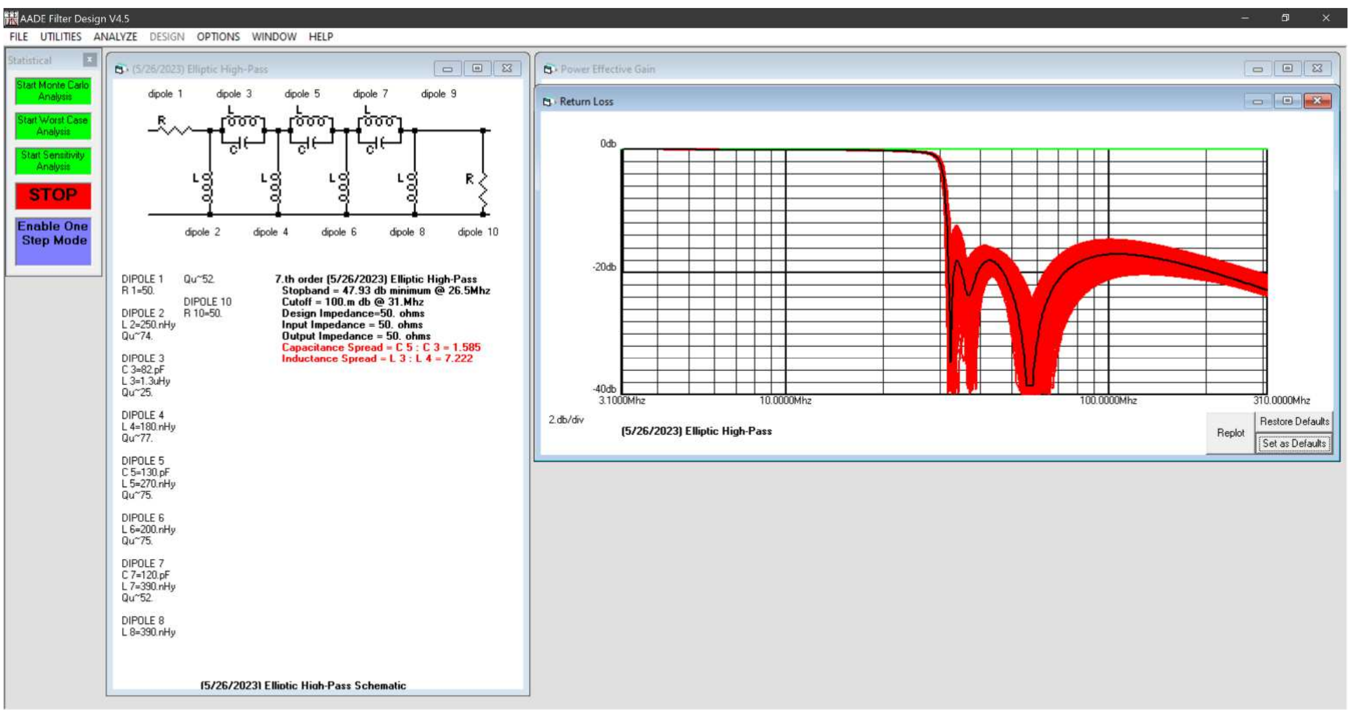
The 30 MHz highpass filter design criteria are:
Fc = 31 MHz with ≤ 0.1 dB ripple in the passband and at the cutoff frequency Fc
Fs = 26.5 MHz with ≥ 40 dB rejection in the stopband and at the stopband frequency Fs

The proposed 30 MHz filter is shown below with catalog component values. Also shown are the filter attenuation and return loss after Monte Carol statistical analysis.

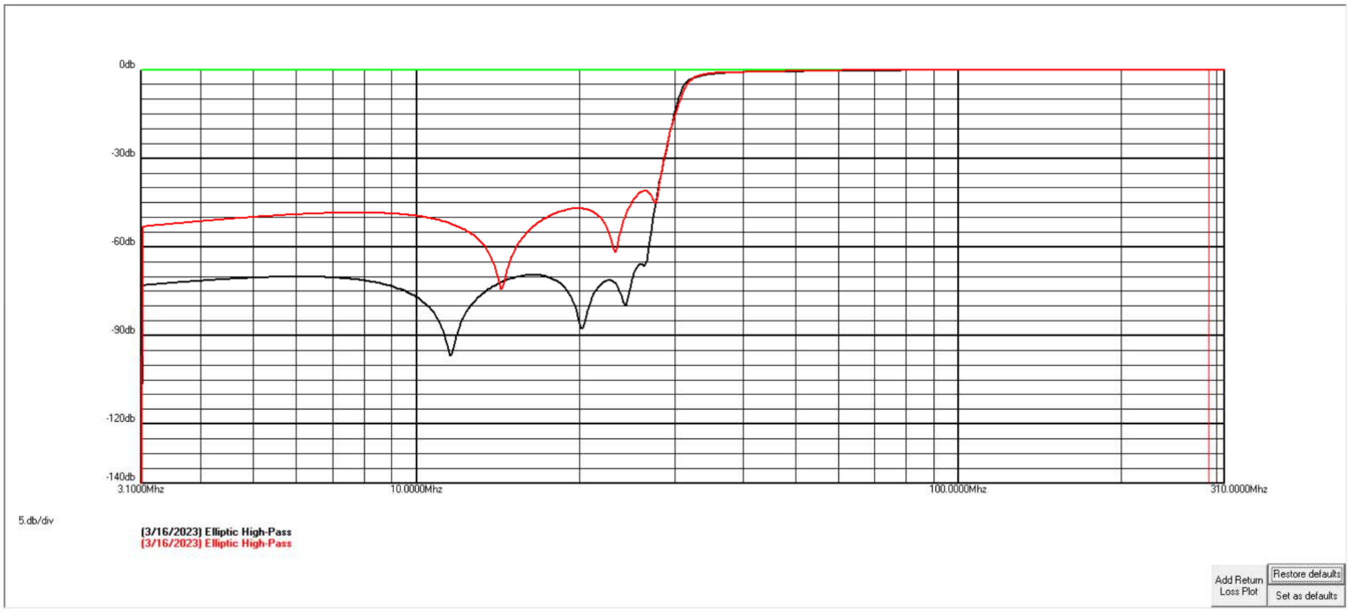
Characteristics of the final 30 MHz HPF from the simulation with single catalog component values:

- ✓ Type: Elliptic
- ✓ Order: 7
- ✓ Attenuation at 27.410 MHz: 41.5 dB
- ✓ Attenuation at 30.0 MHz: 11.5 dB
- ✓ Attenuation at 31.3 MHz: 3.0 dB
- ✓ Return loss at 31.0 MHz: 6.3 dB
- ✓ Minimum return loss above 31 MHz: 17.1 dB





Comparison of 30 MHz HPF 7th (red) and 9th (black) order Elliptic HPF for CBRS rejection:



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6. ARX Rev. I Filters

The following sections describe the construction and measurements of prototype lowpass and highpass filters to be used in the Rev. I ARX. The filters are: 3 MHz HPF, 10 MHz HPF, 20 MHz HPF, 30 MHz HPF, 73.5 MHz LPF and 83.7 MHz LPF. All filters except the 83.7 MHz lowpass filter were synthesized and simulated with the AADE Filter Design tool as described in section 3. The 83.7 MHz filter is copied from the 83.7 MHz filter used in the Rev. H ARX. Several versions of the filters were designed and constructed. The filter simulations were compared to measurements with a Vector Network Analyzer.

All filter PCBs were designed as 4-layer boards with FR4 laminate. The Signal path traces are on the Top layer and the associated Return path traces are on the Inner Layer-1 (IN1). Vias interconnect the SMD ground pads on the Top Layer to IN1 and the Bottom Layer. The Inner Layer-2 (IN2) is not connected to the vias or anything else in the prototype filter PCBs. Stitching vias also connect the Top Layer to IN1 and the Bottom Layer. This stackup emulates the planned stackup for the final ARX PCBs in which IN2 will be used but not for the RF signal or return paths.

PCBs were procured from Galaxy and JLCPCB. The specified stackup was identical except for the materials used in the inner layers. The Galaxy order was supplied with 0.21 mm (8 mil) FR4 outer core layers and 1.02 mm (40 mil) inner core layer whereas JLCPCB was supplied with 0.21 mm (8 mil) prepreg inner layers and 1.07 mm FR4 inner core. In both cases, the copper was 1 oz on the outer layers and 0.5 oz on the inner layers.

Galaxy stackup total thickness 1.63 mm (64 mils) (upper) and JLCPCB stackup total thickness 1.59 mm (62.4 mils) (lower):

2) JLC04161H-7628 Stackup

Layer	Material Type	Thickness	
Layer	Copper	0.035mm	
Prepreg	7628*1	0.2104mm	
inner Layer	Copper	0.0152mm	1.1mm (with copper core)
Core>	Core	1.065mm	
inner Layer	Copper	0.0152mm	
Prepreg	7628*1	0.2104mm	
Layer	Copper	0.035mm	

For reference, the stackup used with the Rev. G ARX PCBs is shown below.

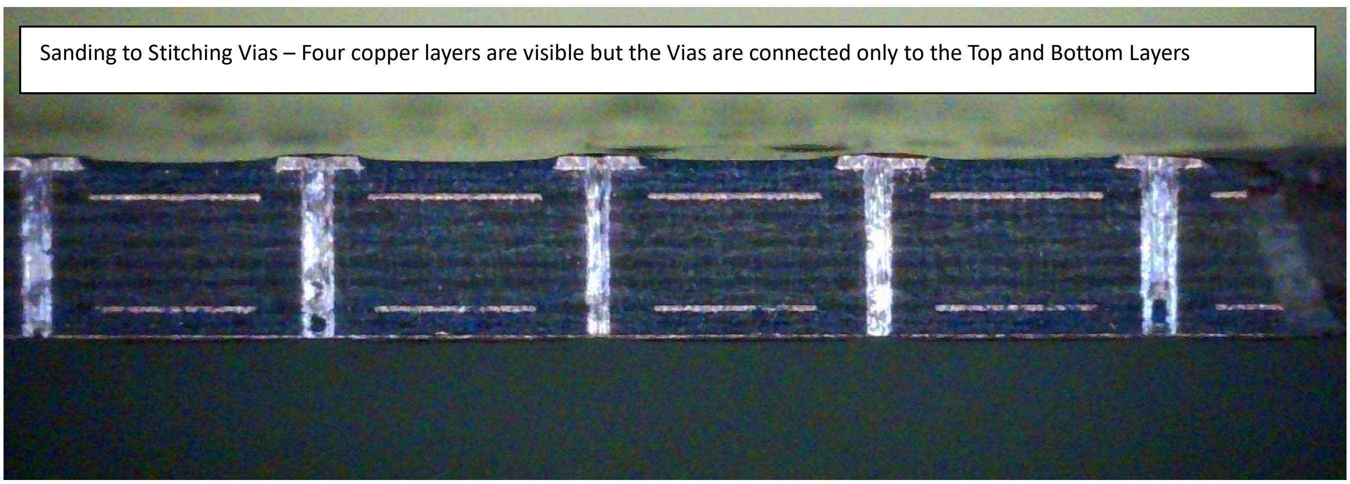
Layer Name	Type	Material	Thickness (mil)	Dielectric Material	Dielectric Constant	Pullback (mil)	Orientation	Coverlay Expansion
Top Overlay	Overlay							
Top Solder	Solder Mask/...	Surface Mat...	0.4	Solder Resist	3.5			0
Top Layer	Signal	Copper	1.4				Top	
Dielectric1	Dielectric	None	12.6	FR-4	4.8			
Mid-Layer 1	Signal	Copper	1.4				Not Allowed	
Dielectric2	Dielectric	None	12.6	FR-4	4.8			
Mid-Layer 2	Signal	Copper	1.4				Not Allowed	
Dielectric3	Dielectric	None	12.6	FR-4	4.8			
Bottom Layer	Signal	Copper	1.4				Bottom	
Bottom Solder	Solder Mask/...	Surface Mat...	0.4	Solder Resist	3.5			0
Bottom Over...	Overlay							

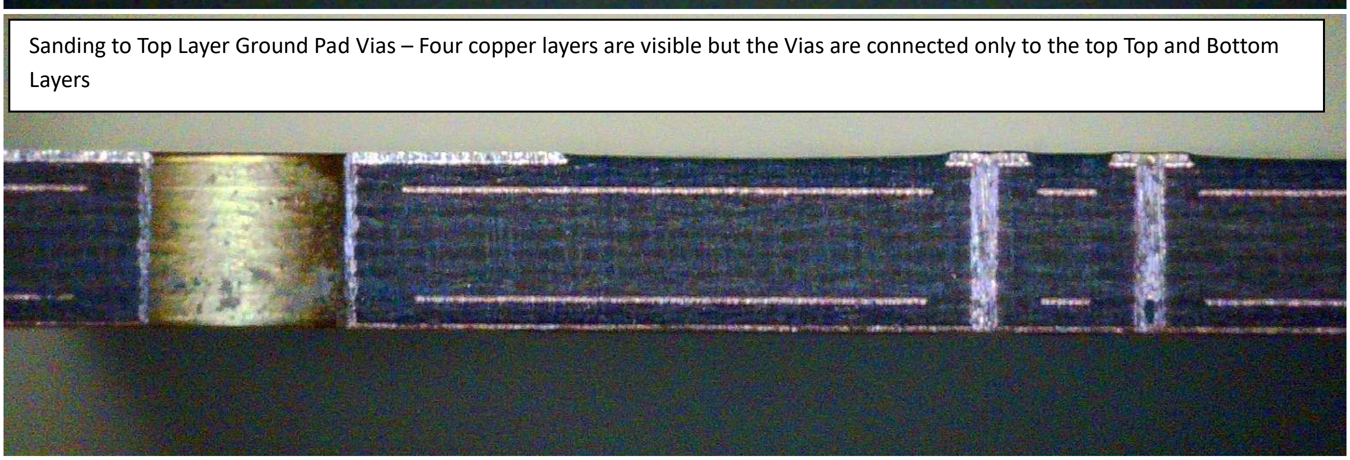
7. Comparison of *Universal Filter* PCB cross-sections used in the first phase of the evaluation:

We attempted to design a *universal* printed circuit board that would allow construction of all types of relevant filter types including Butterworth, Chebyshev, Elliptic and others of order up to 7th while allowing capacitors to be connected in parallel and inductors to be connected in series to enable fine tuning. This section describes that effort.

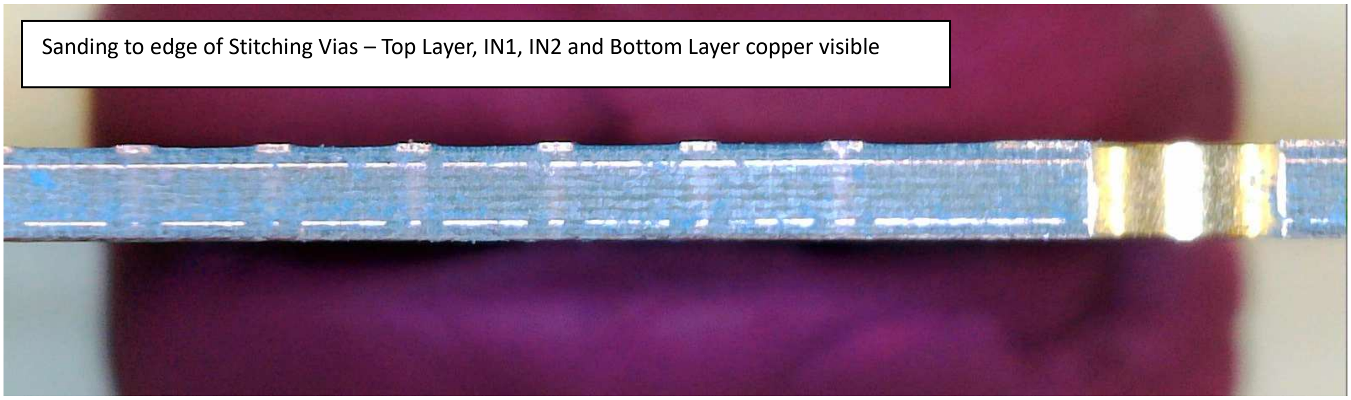
The first batch of the Universal Filter PCBs produced by Galaxy had the vias incorrectly connected from the Top Layer only to the Bottom Layer and not IN1. This was corrected in the second batch of PCBs produced by Galaxy. PCBs also were procured from JLCPCB and were correctly made. The PCB cross-sections were examined by sanding down one long edge until the Stitching vias and then the Grounding vias were exposed as shown below.

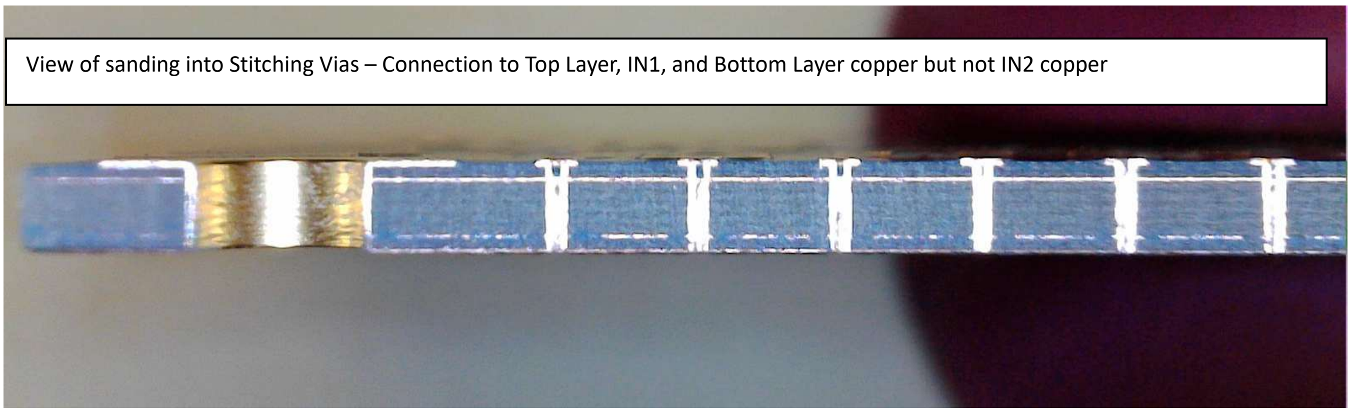
<u>Galaxy Original Filter PCBs: Top of PCB is up</u>

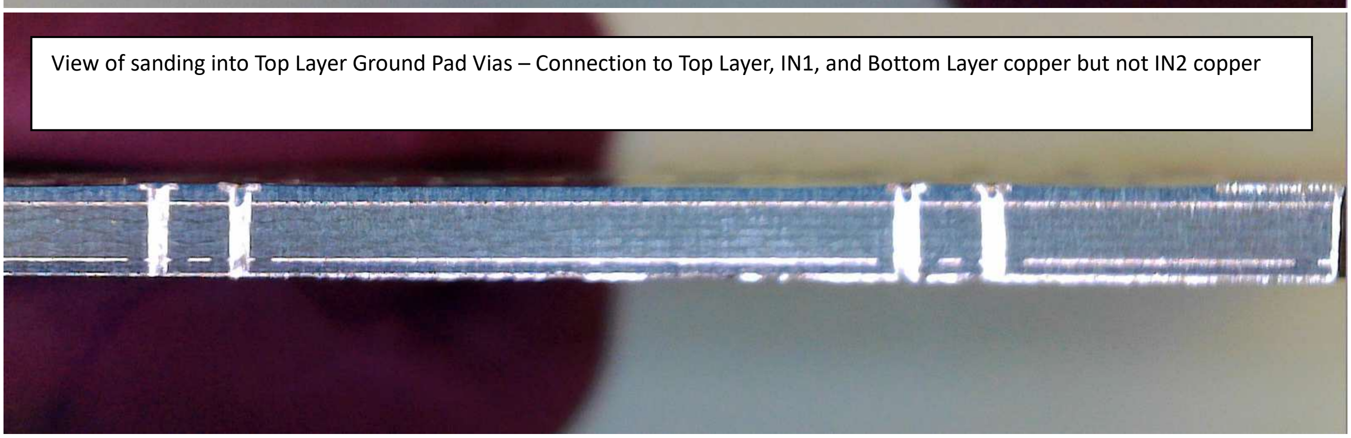


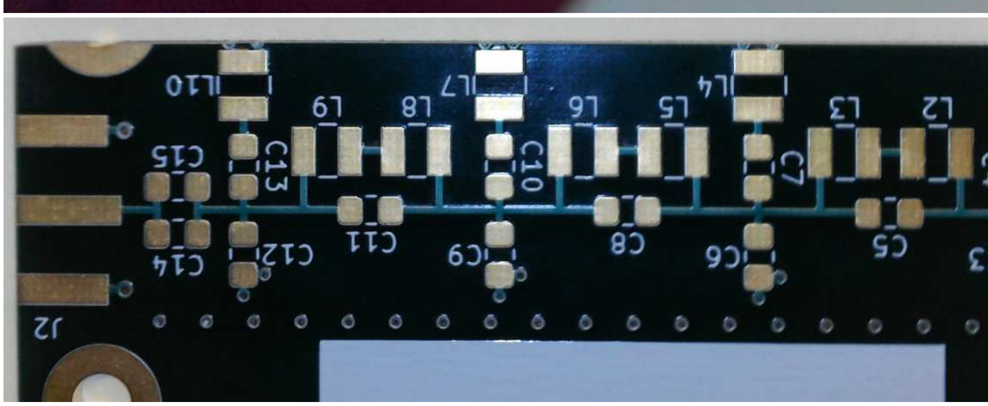


Galaxy Replacement Filter PCBs: Top of PCB is up


Sanding to edge of Stitching Vias – Top Layer, IN1, IN2 and Bottom Layer copper visible

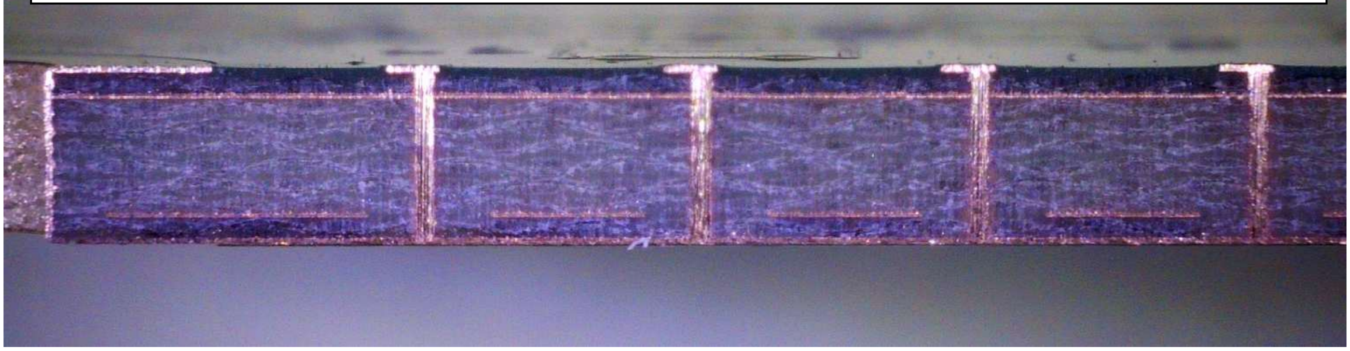

View of sanding into Stitching Vias – Connection to Top Layer, IN1, and Bottom Layer copper but not IN2 copper


View of sanding into Top Layer Ground Pad Vias – Connection to Top Layer, IN1, and Bottom Layer copper but not IN2 copper

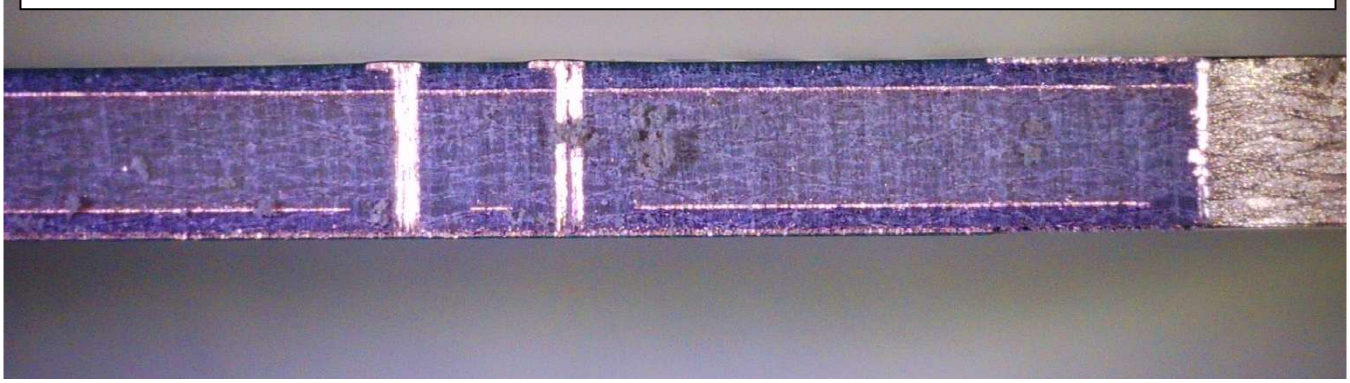


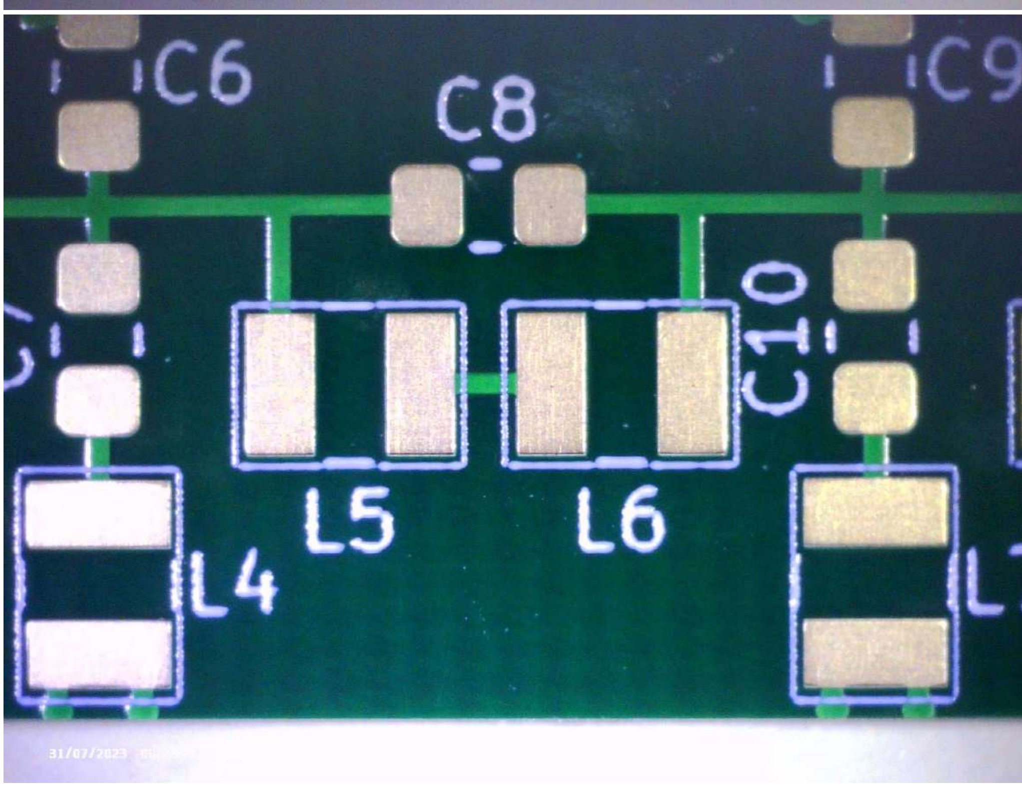
JLCPCB No. 1 Filter PCBs: Top of PCB is up

Sanding to Stitching Vias – Four copper layers are visible and the Vias are connected to the Top, IN1 and Bottom Layers



Sanding to Top Layer Ground Pad Vias – Four copper layers are visible and the Vias are connected to the top Top, IN1 and Bottom Layers





8. Filter Measurements & Simulation:

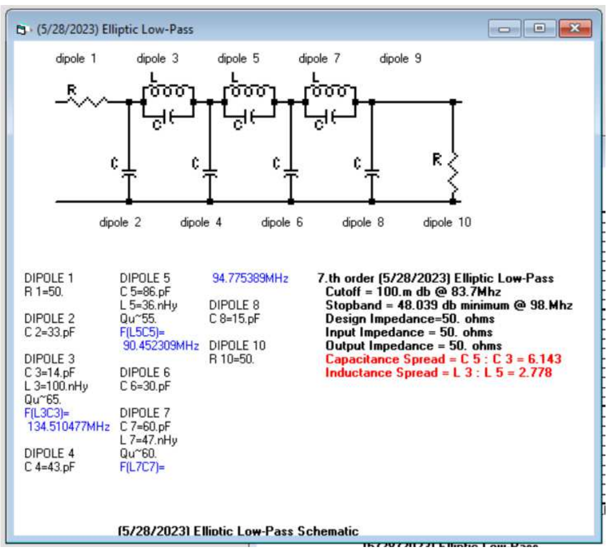
The filters on the Universal PCB did not perform as expected in the VHF range as shown by the representative measurements below. The measured insertion loss of the VHF lowpass filters far exceeded the simulated loss at the cutoff frequency and return losses at VHF were lower than expected.

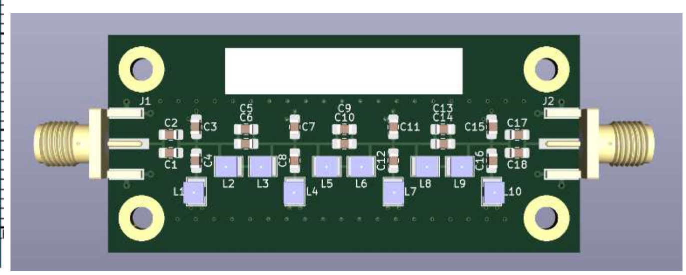
VHF-HI (83.7 MHz cutoff frequency):

Note: (LPF No1 is original Galaxy PCB and LPF No4 is replacement Galaxy PCB)

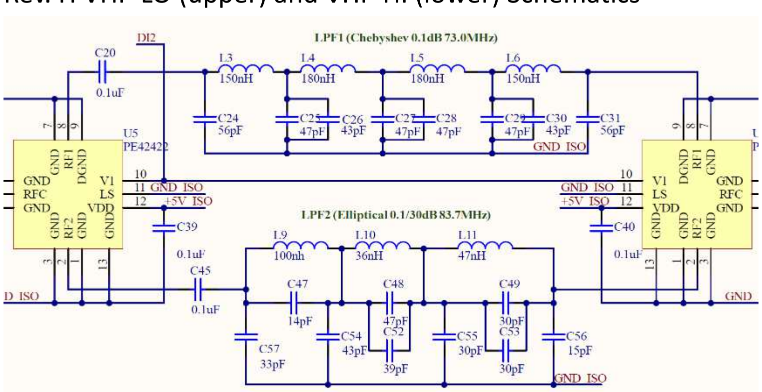
Freq (MHz)	LPF No1 – As Built Insertion Loss	LPF No4 – As Built Insertion Loss	LPF Simulation Insertion Loss	Remarks
MHz	dB	dB	dB	
3	0.11	0.11	0.01	
10	0.17	0.18	0.05	
30	0.42	0.44	0.19	
82.2	14.7	16.3	2.2	
83.7	23.8	26.1	2.8	
88.0	31.1	34.4	17.2	
198.6	29.8	31.4	29.8	
3 dB freq	77.4 MHz	77.0 MHz	84.1 MHz	

LPF Simulation Schematic of the VHF-HI (83.7 MHz) LPF alongside a Gerber Viewer image of the Universal PCB



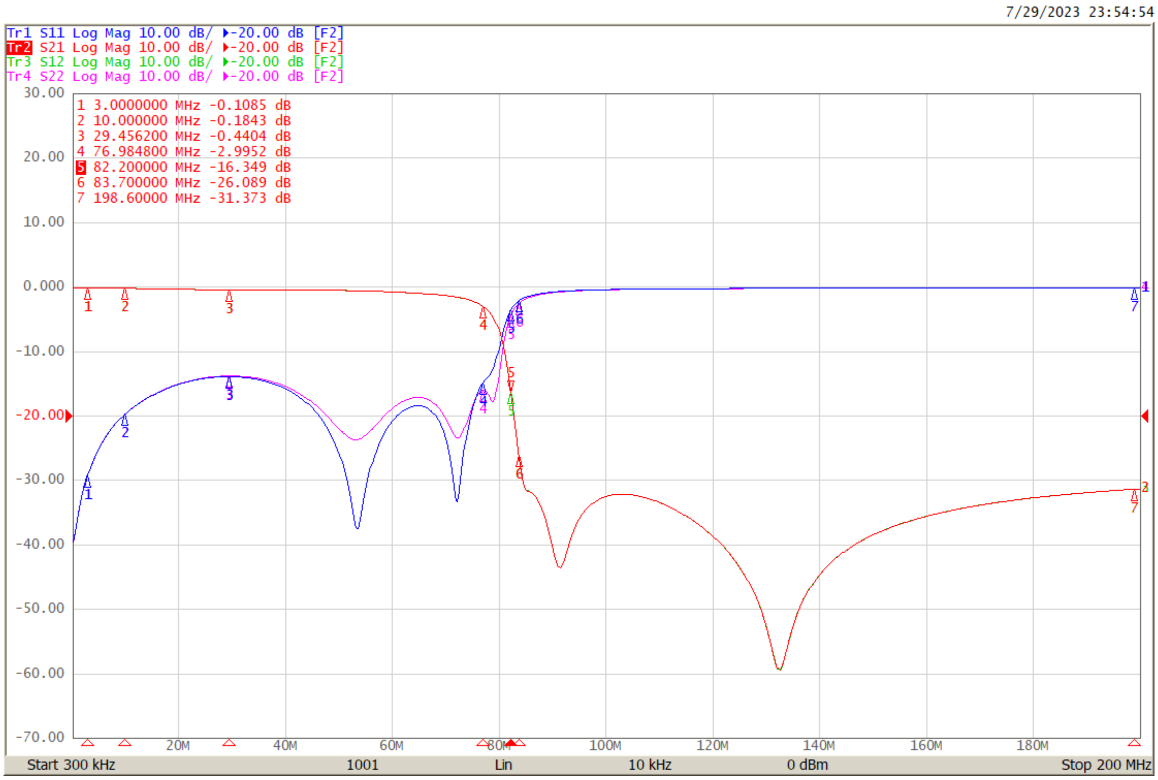


Rev. H VHF-LO (upper) and VHF-HI (lower) Schematics



VHF-HI No1 VNA Plot (Original Galaxy PCB):

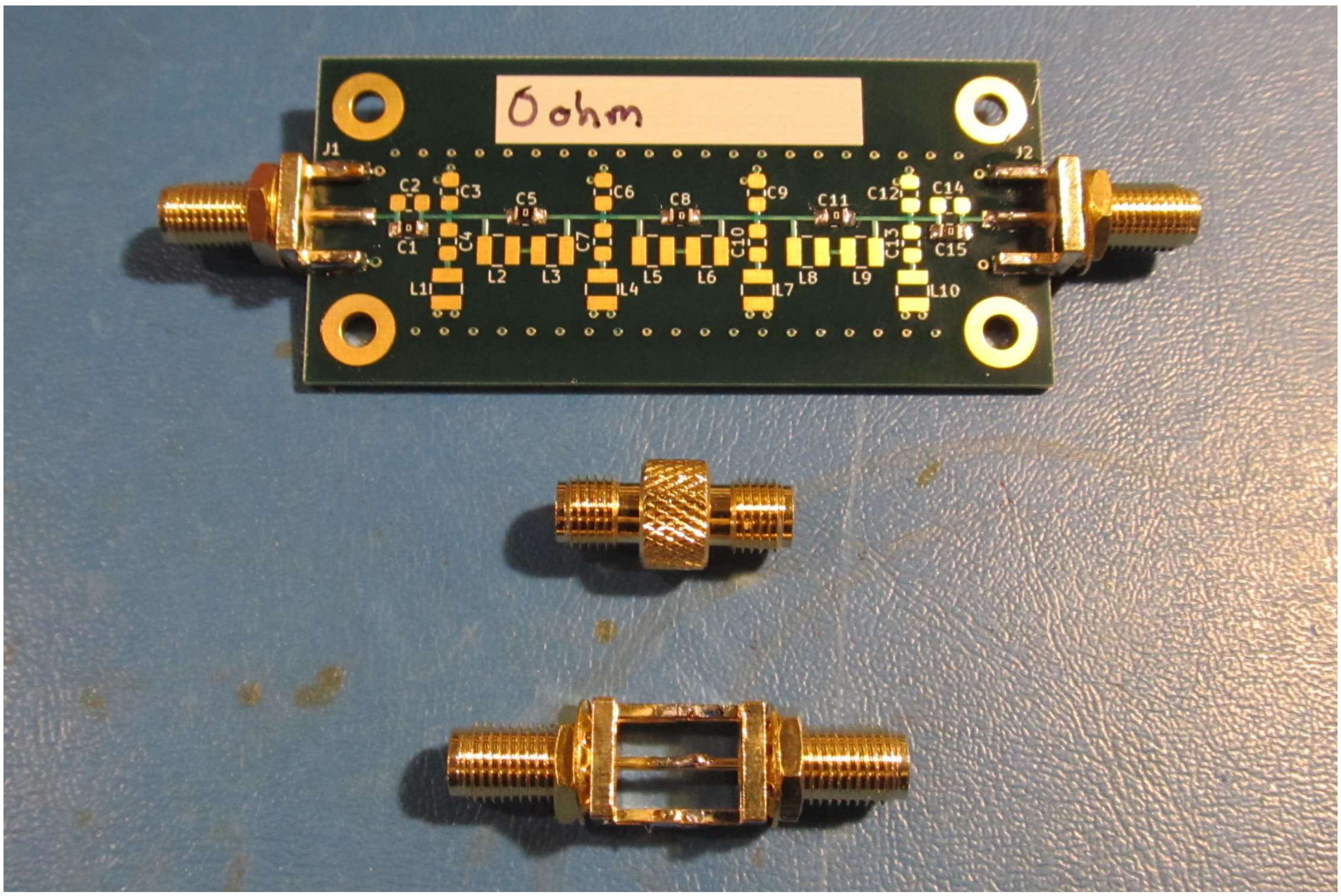
VHF-HI No4 VNA Plot (Replacement Galaxy PCB):



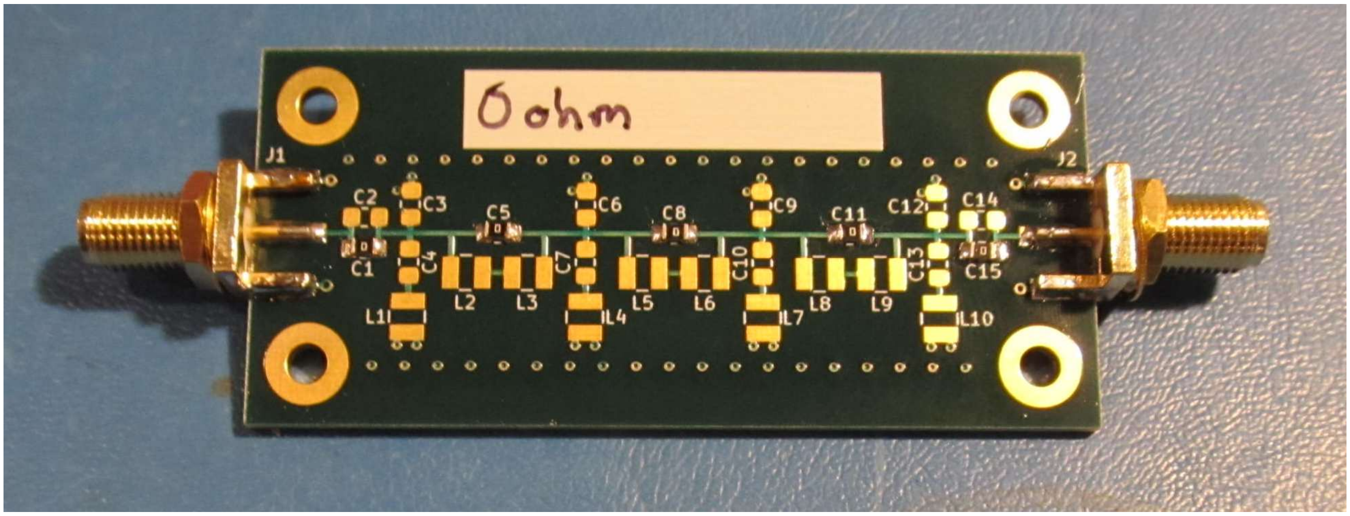
To troubleshoot the measured response problems, the Universal Filter PCBs were equipped only with 0 ohm resistors in the RF path; no reactive components were installed. The transmission and reflection coefficients were then measured with a VNA and compared to the same measurements for a coaxial coupler and back-to-back edge connectors as shown below.

- ☐ Galaxy Replacement PCB with 0 Ohm Resistors in C1, C5, C8, C11 and C15
- ☐ SMA-F : SMA-F Coupler (inexpensive type bought through Aliexpress)
- ☐ Back-to-Back SMA-F PCB Edge Connectors (inexpensive types bought through Aliexpress)

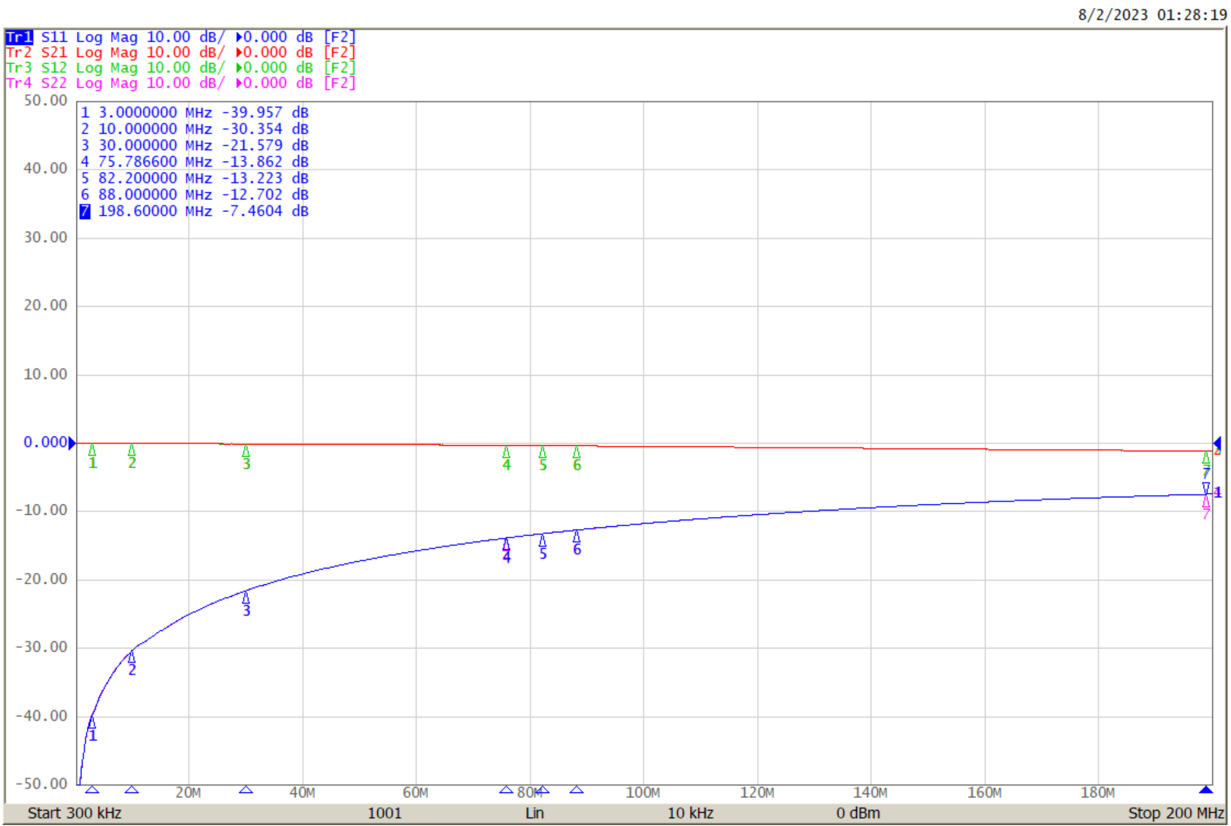
Image of devices used in the following measurements:



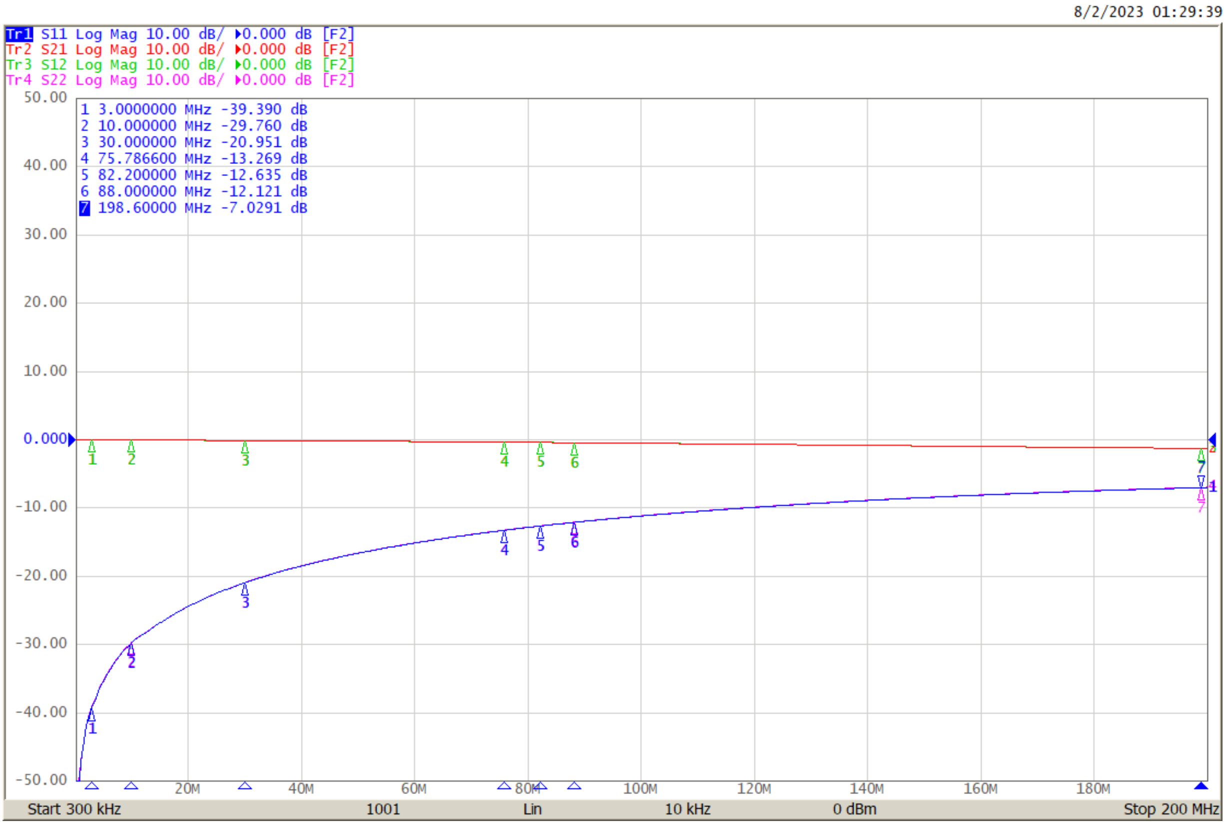
Typical PCB with 0 Ohm Resistors in C1, C5, C8, C11 and C15:



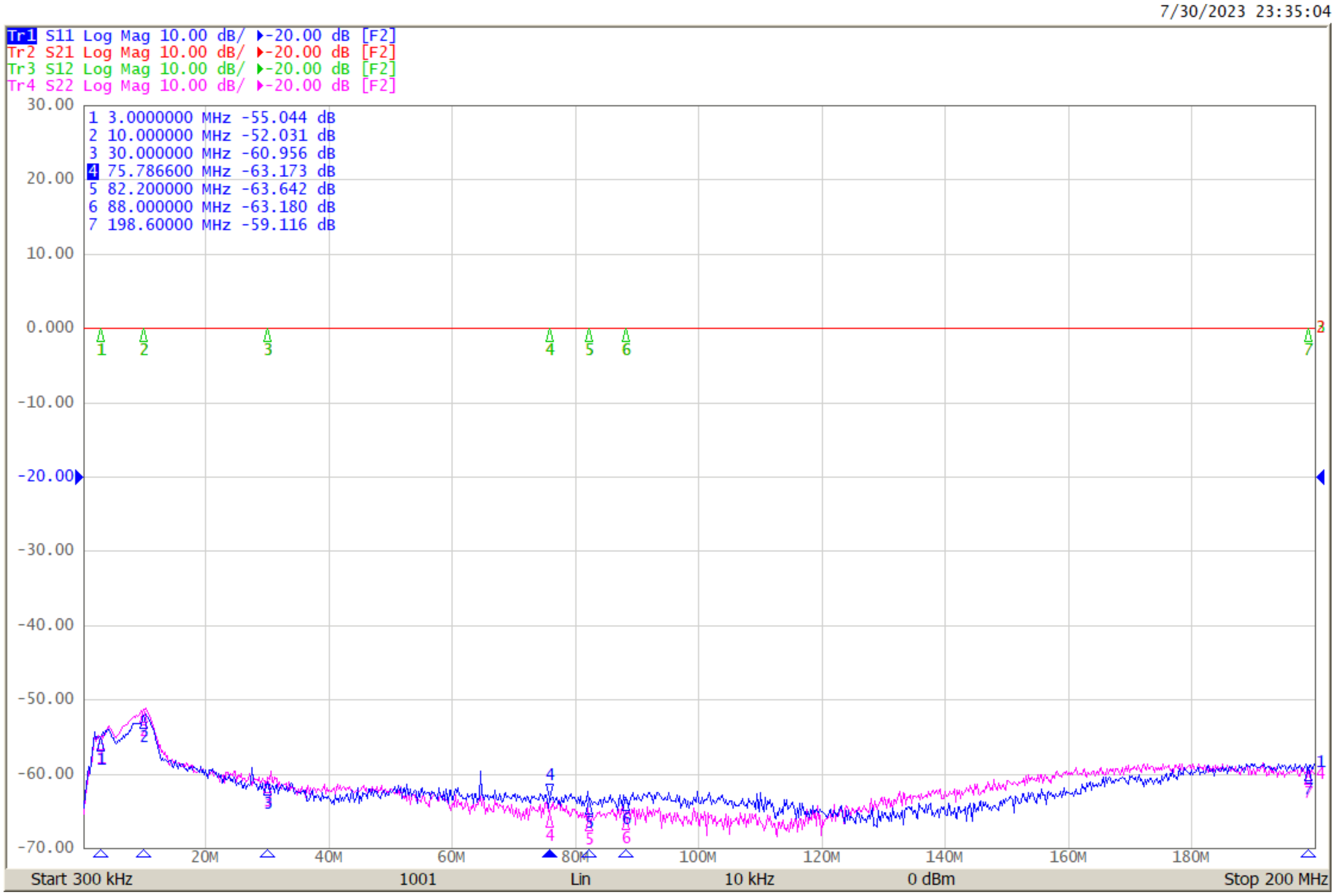
Galaxy Replacement PCB with 0 Ohm Resistors in C1, C5, C8, C11 and C15. Note poor return loss at 100 MHz:



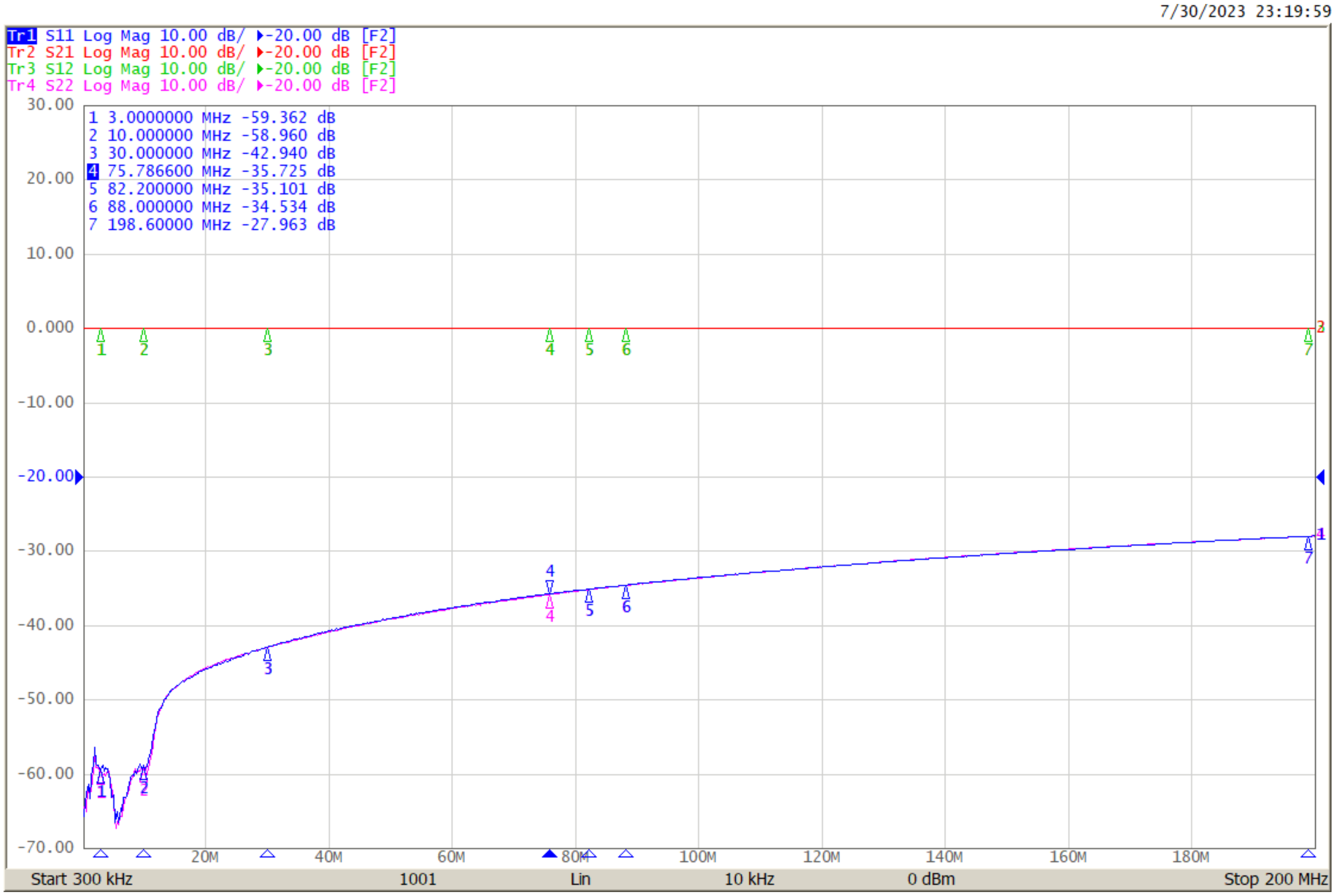
JLCPCB No. 1 PCB with 0 Ohm Resistors in C1, C5, C8, C11 and C15. Note poor return loss at 100 MHz:



SMA-F : SMA-F Coupler:



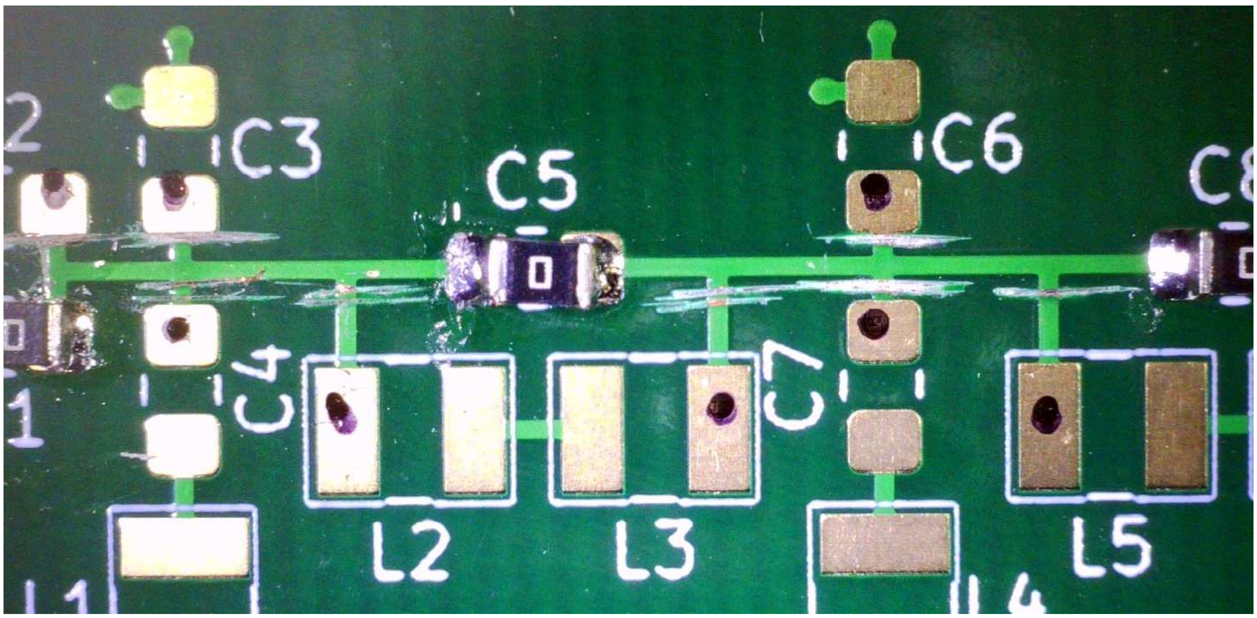
Back-to-Back SMA-F PCB Edge Connectors:



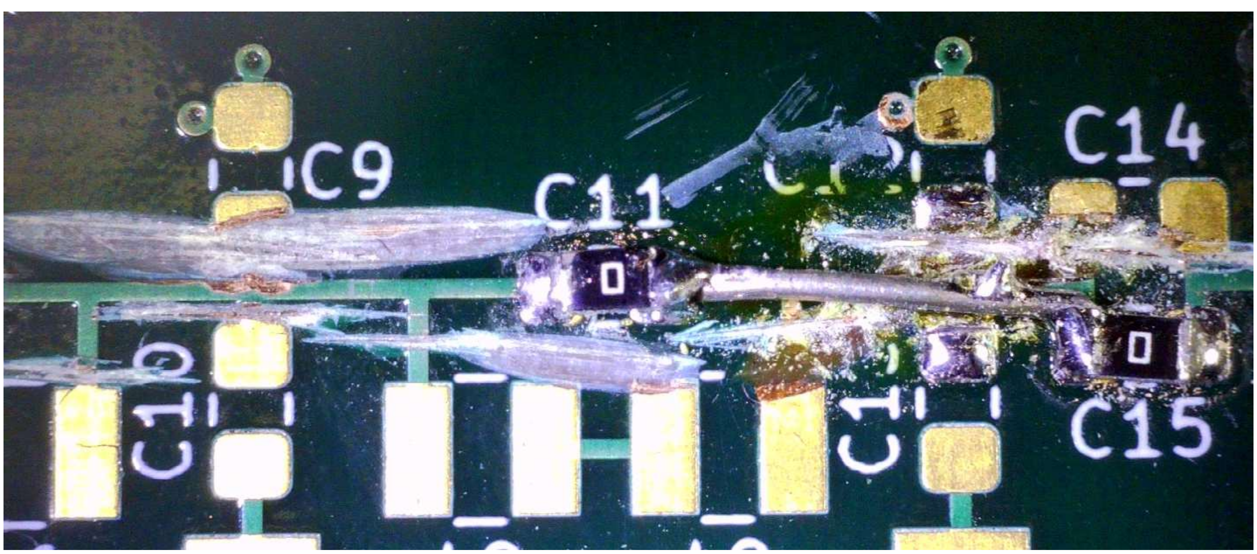
9. Comparison of PCBs with all unused pads cut out:

The above measurements revealed that the PCBs likely caused the incorrect responses. Based on a paper by Ed Troy of Aerospace Consulting LLC [https://rfandmicrowavedesign.com/assets/debug-lc-filter.pdf] that describes calculations of SMD pad capacitances and their effects on filter response characteristics, the traces to all unused pads on the Universal Filter PCB were cut and the boards with 0 ohm resistors were remeasured. Cutting out the unused pads improved the return loss by almost 10 dB at 100 MHz, indicating that our attempt to produce a universal prototype PCB would not support filters covering the VHF range.

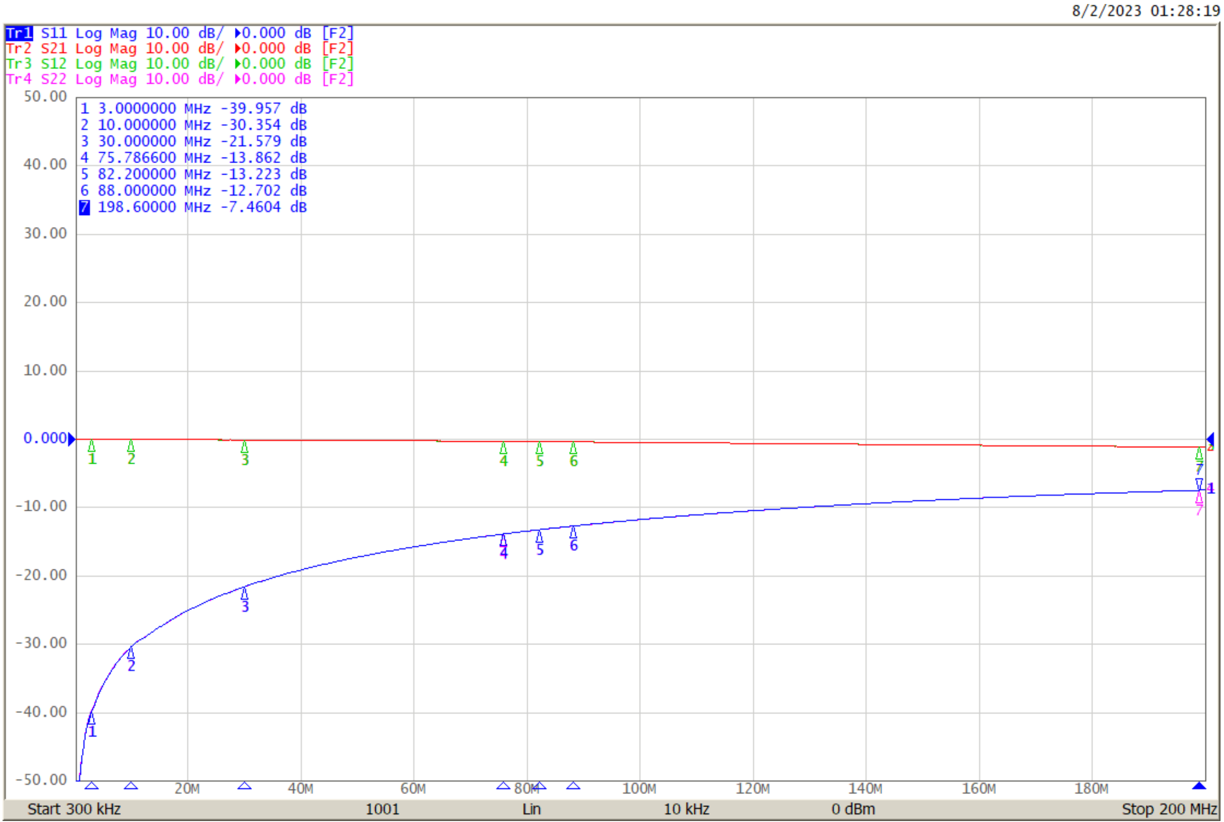
Exacto hobby knife: The black dots on the pads indicate that an ohmmeter was used to verify the open circuit from the pad to the center RF path trace. Note that a 0 ohm resistor can be seen in place of capacitor C5.



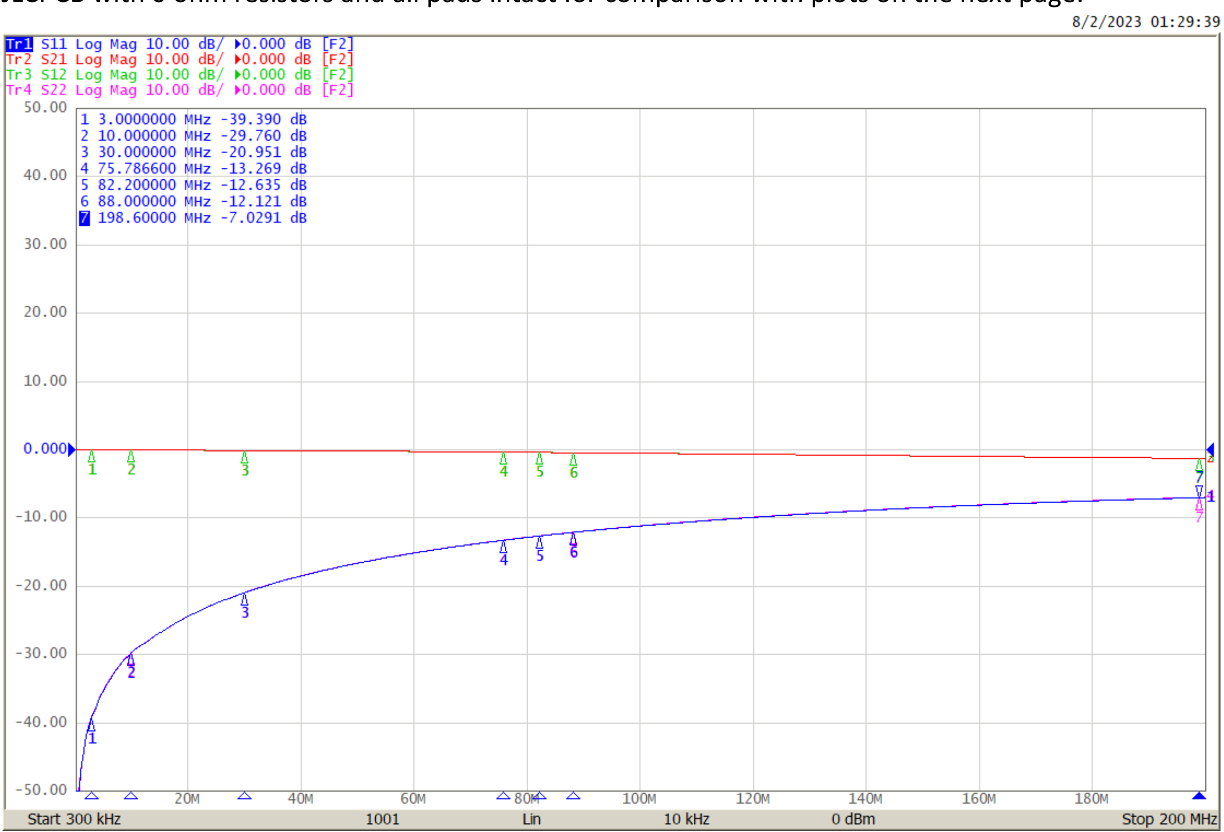
Dremel cutter: Too hard to control and did not work as expected.



Galaxy PCB with 0 ohm resistors and all pads intact for comparison with the plots on the next page:

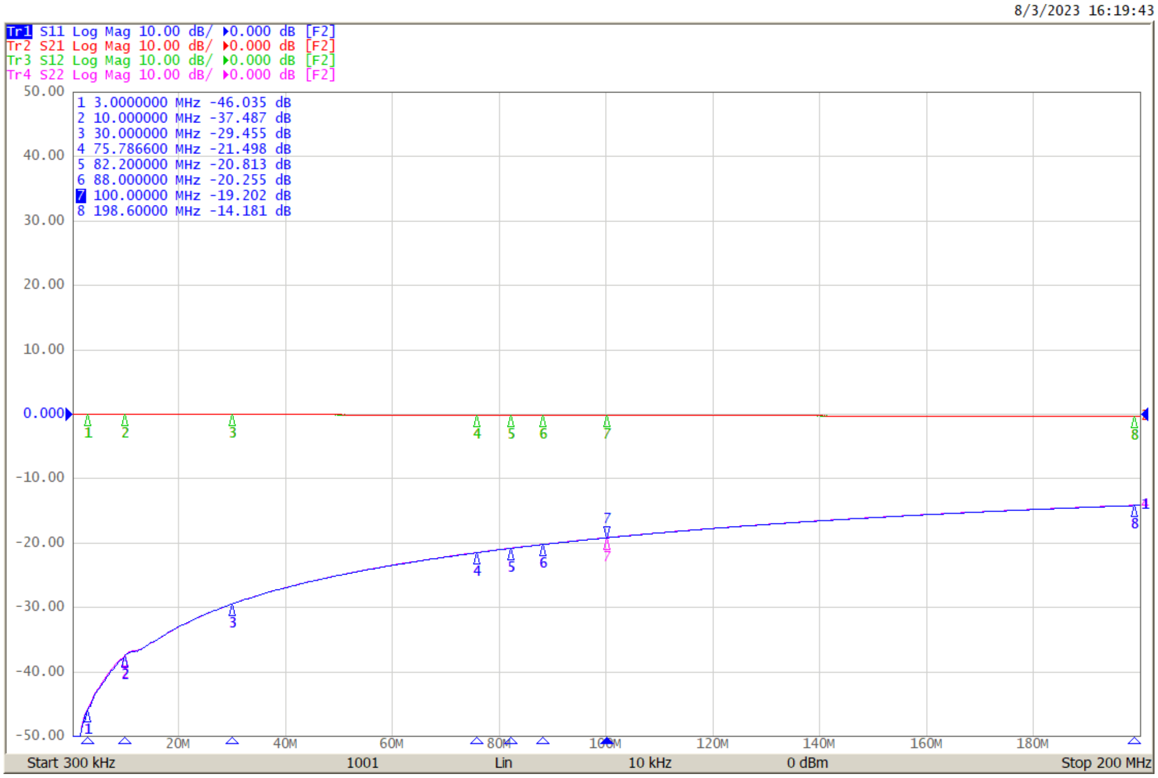


JLCPCB with 0 ohm resistors and all pads intact for comparison with plots on the next page:

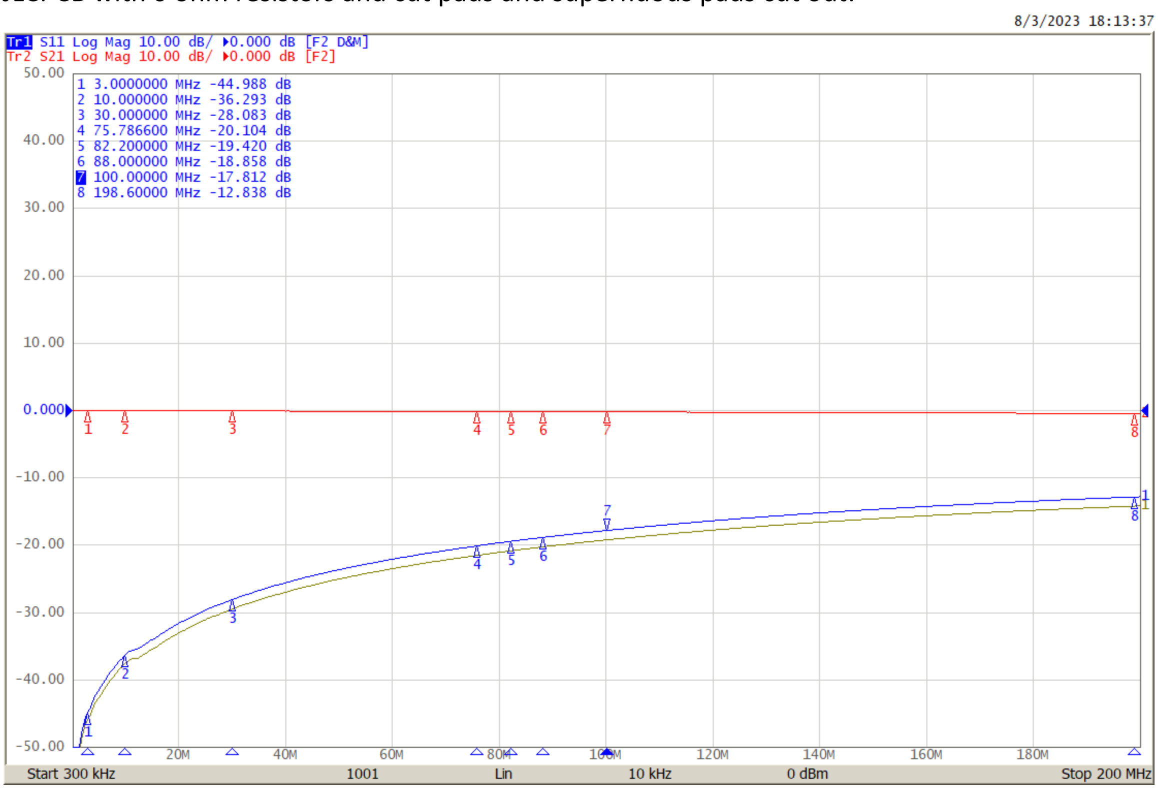


Galaxy PCB with 0 ohm resistors and superfluous pads cut out:

Note improvement in return loss at 100 MHz compared to the intact boards on the previous page



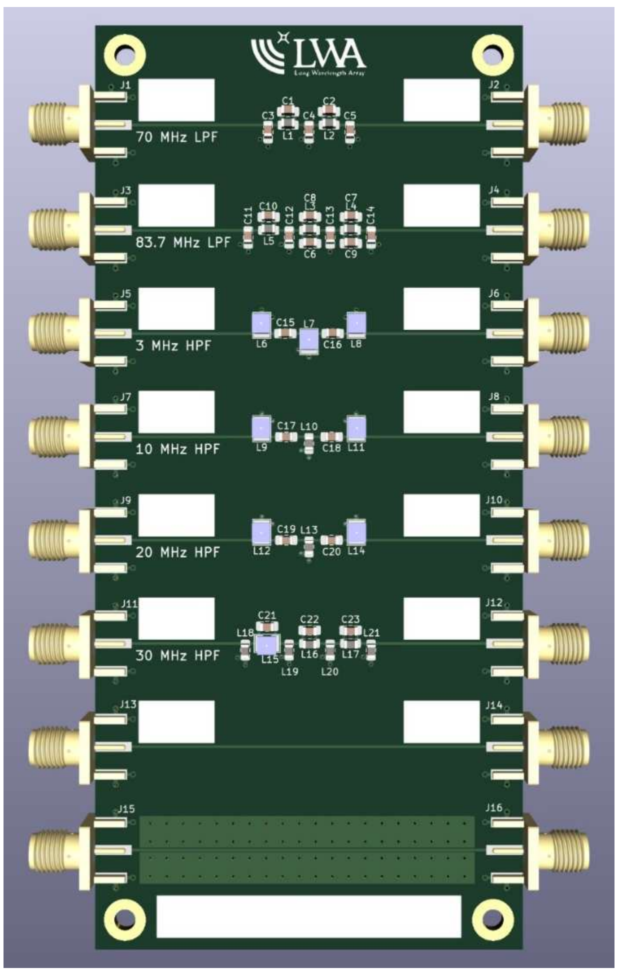
JLCPCB with 0 ohm resistors and cut pads and superfluous pads cut out:

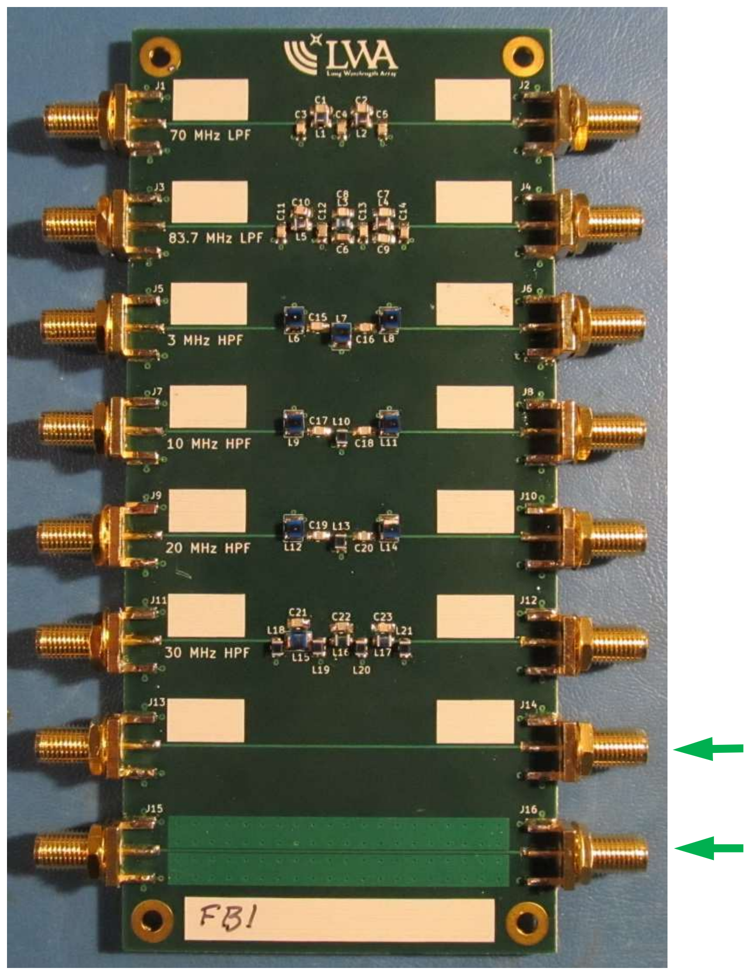


10. All-In-One Filter PCB:

Because of its poor performance, the Universal Filter PCB concept described above was abandoned, and the prototype filter PCBs were then redesigned. The layouts of the six filters were based on the specific components used in each filter and no unnecessary pads or traces were placed. Also, the component spacings were tightened up to reduce trace inductance. All six filters were placed on one PCB, referred to herein as the *All-In-One Filter* PCB, along with Microstrip and Coplanar Waveguide traces for comparison with previous measurements. The PCB stackup and via connections between the layers of the All-In-One Filter PCB are identical to the Universal Filter PCB.

Gerber Viewer image (left) and actual filter PCB (right) of the All-In-One Filter PCB with Microstrip (upper arrow at lower right) and Coplanar Waveguide Traces (lower arrow) for investigation of PCB transmission properties and comparison:



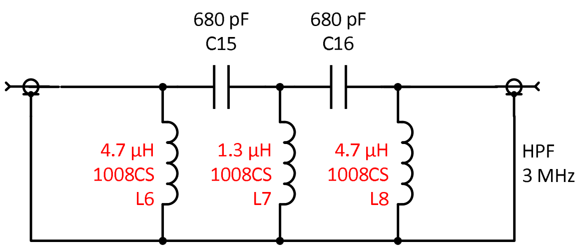


The original 5th order Elliptic 70 MHz LPF was later deemed inadequate in terms of insertion loss at 88 MHz and minimum return loss in the passband, so it was redesigned as a 7th order Elliptic 73.5 MHz LPF. Rather than produce another run of PCBs, the new filter was built on the existing All-In-One PCBs in the position for the 7th order 83.7 MHz filter (2nd filter from the top). The measurements below are for the new filter.

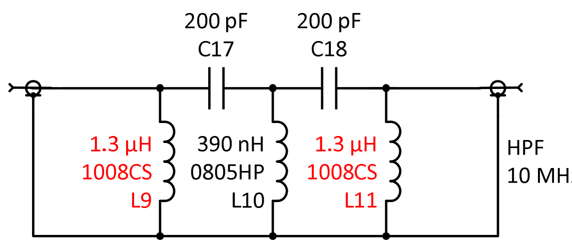
11. Filter Schematics:

The schematics below are of the filters to be used in the Rev. I ARX and show the actual component catalog values and the Coilcraft inductor series used in the designs and constructions of the prototype filters. All capacitors and inductors have ±2% tolerance. Capacitors are from various name brand manufacturers (Vishay, Kemet, Kyocera, Yageo, and Walsin) in size 0805 and C0G (NP0) dielectric. All inductors are ceramic core chip inductors from Coilcraft.

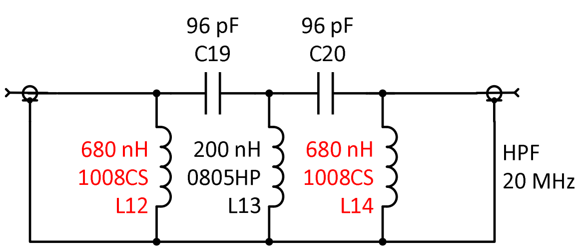
3 MHz Highpass Filter



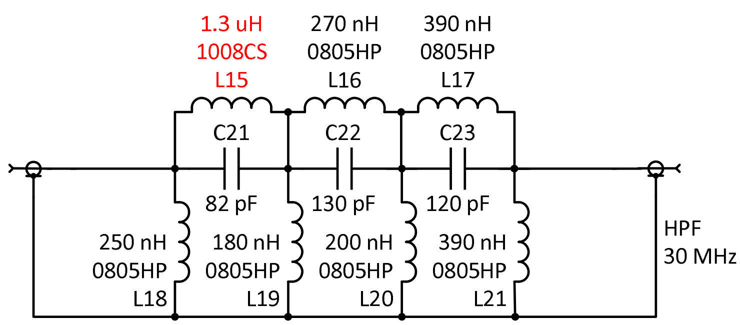
10 MHz Highpass Filter



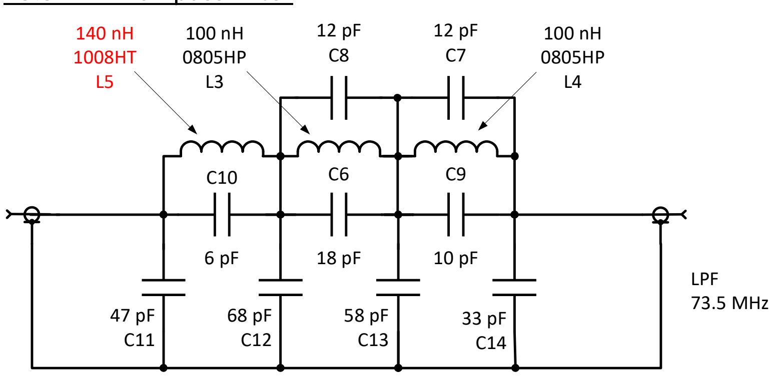
20 MHz Highpass Filter



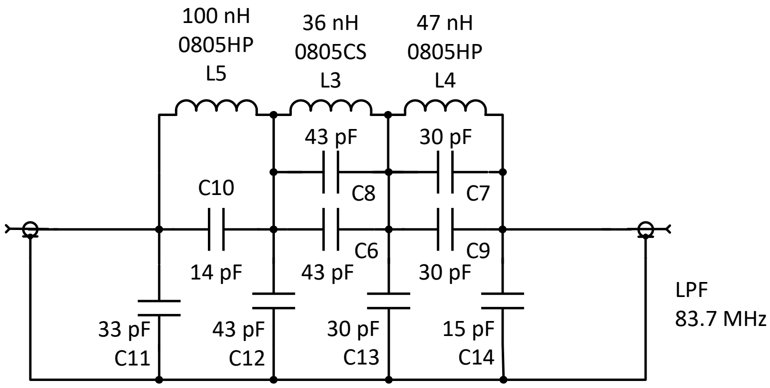
30 MHz Highpass Filter



73.5 MHz Lowpass Filter



83.7 MHz Lowpass Filter



12. Prototype Filter Measurements:

Summary of prototype filter characteristics and measurements:

3 MHz highpass filter Butterworth, 5th order Simulation: Fc = 3.0 MHz, Simulated = 3.8 dB; Measured = 4.5 dB Fs = 1.8 MHz, Simulated = 21.5 dB; Measured = 27.7 dB	10 MHz highpass filter Butterworth, 5th order Simulation: Fc = 10.0 MHz, Simulated = 3.6 dB, Measured = 3.8 dB Fs = 6.0 MHz, Simulated = 22.5 dB, Measured = 22.8 dB
20 MHz highpass filter Butterworth, 5th order Fc = 20 MHz, Simulated = 3.8 dB; Measured = 3.8 dB Fs = 12 MHz, Simulated = 22.6 dB; Measured = 23.0 dB	30 MHz highpass filter (design Fc = 26.5 MHz) Elliptic, 7th order Fc = 31.0 MHz, Simulated = 4.2 dB; Measured = 6.6 dB Fs = 27.41 MHz, Simulated = 41.5 dB; Measured = 43.1 dB
73.5 MHz lowpass filter Elliptic, 7th order Fc = 70 MHz, Simulated = 1.0 dB; Measured = 1.8 dB Fs = 88 MHz, Simulated = 40.0 dB; Measured = 39.1 Simulated minimum attenuation 88 to 108 MHz = 29.8 dB Measured minimum attenuation 88 to 108 MHz = 41.0 dB	83.7 MHz lowpass filter Elliptic, 7th order Fc = 82.2 MHz, Simulated = 2.1 dB; Measured = 3.4 dB Fs = 88 MHz, Simulated = 17.5 dB; Measured = 24.5 dB Simulated minimum attenuation 88 to 108 MHz = 15.2 dB Measured minimum attenuation 88 to 108 MHz = 24.5 dB

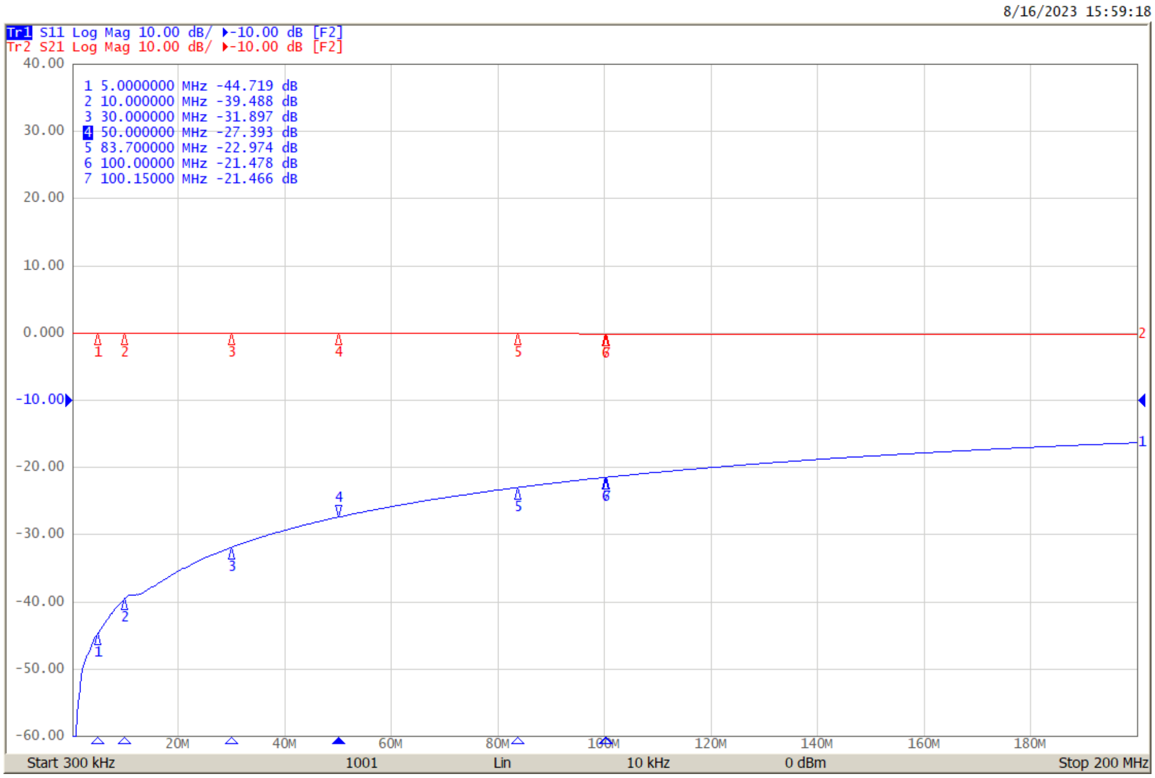
In addition to the filters, the Microstrip and Coplanar Waveguide transmission lines were measured and plotted as shown on the next page for reference. Note that the Microstrip is roughly equivalent to the previous measurements of the Universal Filter PCB with 0 ohm RF path resistors and the unused traces and SMD pads cutout.

The filter plots follow the Microstrip and Coplanar Waveguide plots. The individual filter S2P measurements and plots were made with a Copper Mountain Technologies M5045 Vector Network Analyzer; the M5045 plot for only one filter of each type is shown in this document. Also included are combined plots for three filters of each type. For the combination plots, the S2P data for the three filters from the M5045 measurements were imported into the DG8SAQ Vector Network Analyzer Software for plotting.

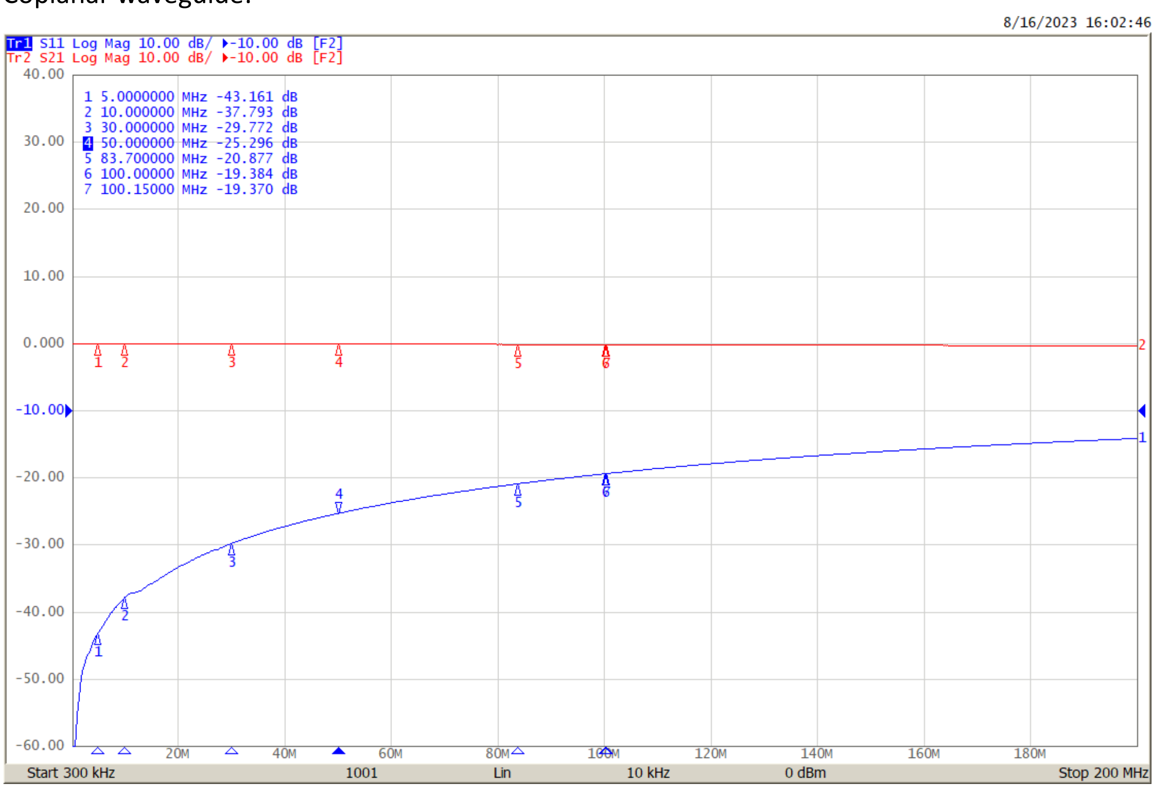
The combined plots are annotated to indicate the filter frequency and Filter Board Numbers used in the measurements. The combined plots share a common scale (10 dB/div) and 0 dB reference (2nd division from top). The traces and marker table along the bottom of each plot are color coded as follows:

- ✓ Plot1 (blue trace): S21 measured on Filter Board 1 (Filter Board 5 for 73.5 MHz LPF)
- ✓ Plot2 (red trace): S11 measured on Filter Board 1 (Filter Board 5 for 73.5 MHz LPF)
- ✓ Plot3 (green trace): S21 measured on Filter Board 2 (Filter Board 6 for 73.5 MHz LPF)
- ✓ Plot4 (magenta trace): S11 measured on Filter Board 2 (Filter Board 6 for 73.5 MHz LPF)
- ✓ Plot5 (black trace): S21 measured on Filter Board 3 (Filter Board 7 for 73.5 MHz LPF)
- ✓ Plot6 (purple trace): S11 measured on Filter Board 3 (Filter Board 7 for 73.5 MHz LPF)

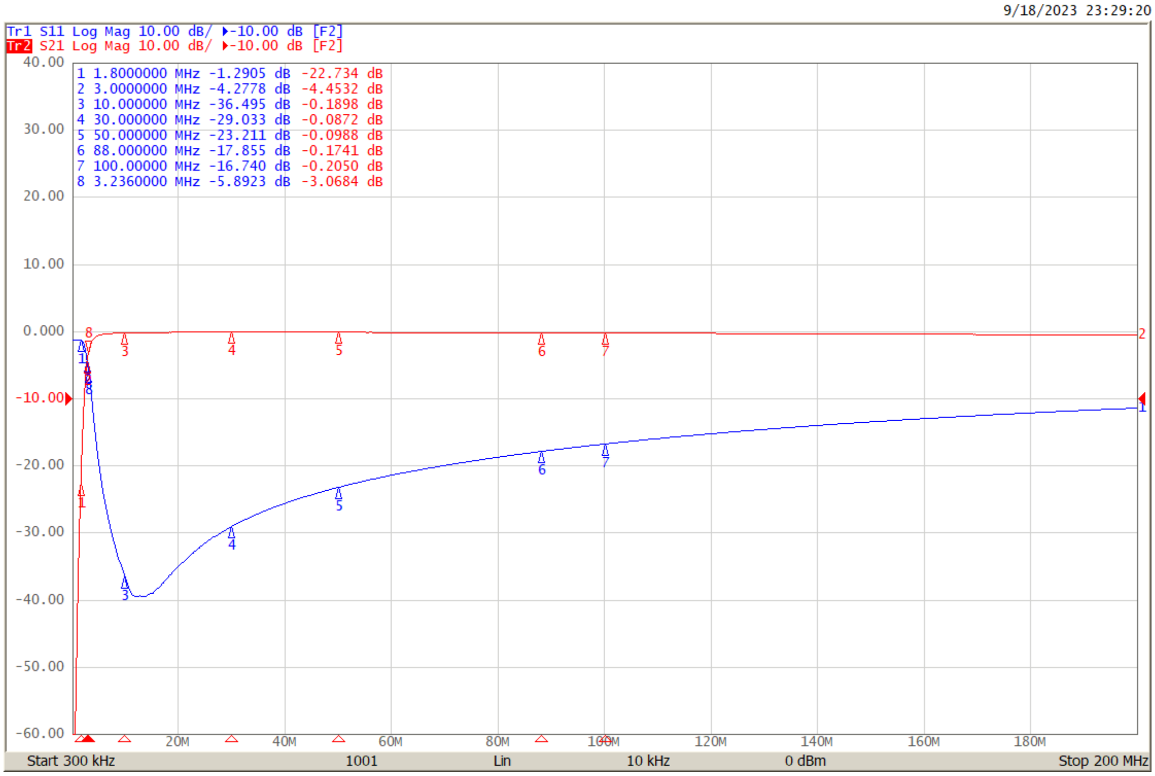
Microstrip:



Coplanar waveguide:

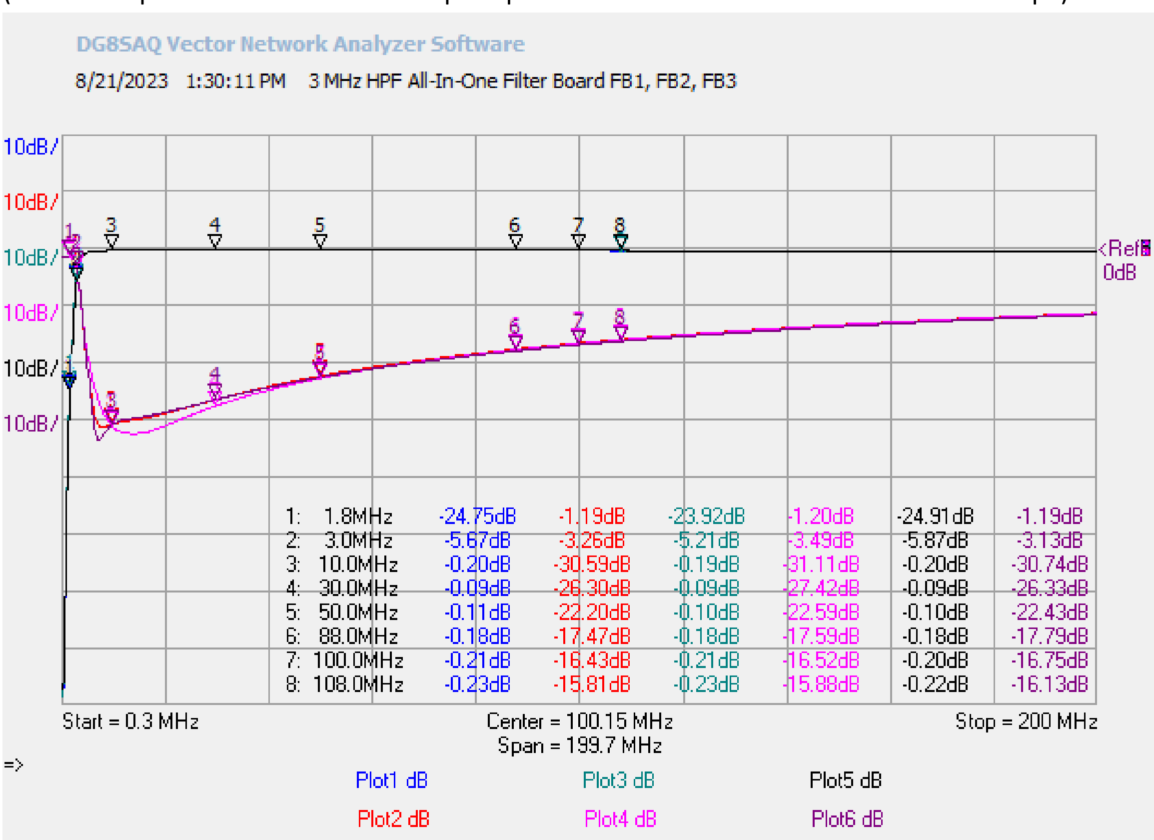


3 MHz Highpass Filter: (Note: this plot is for a filter with 680 pF capacitors, the value used in the final filter)

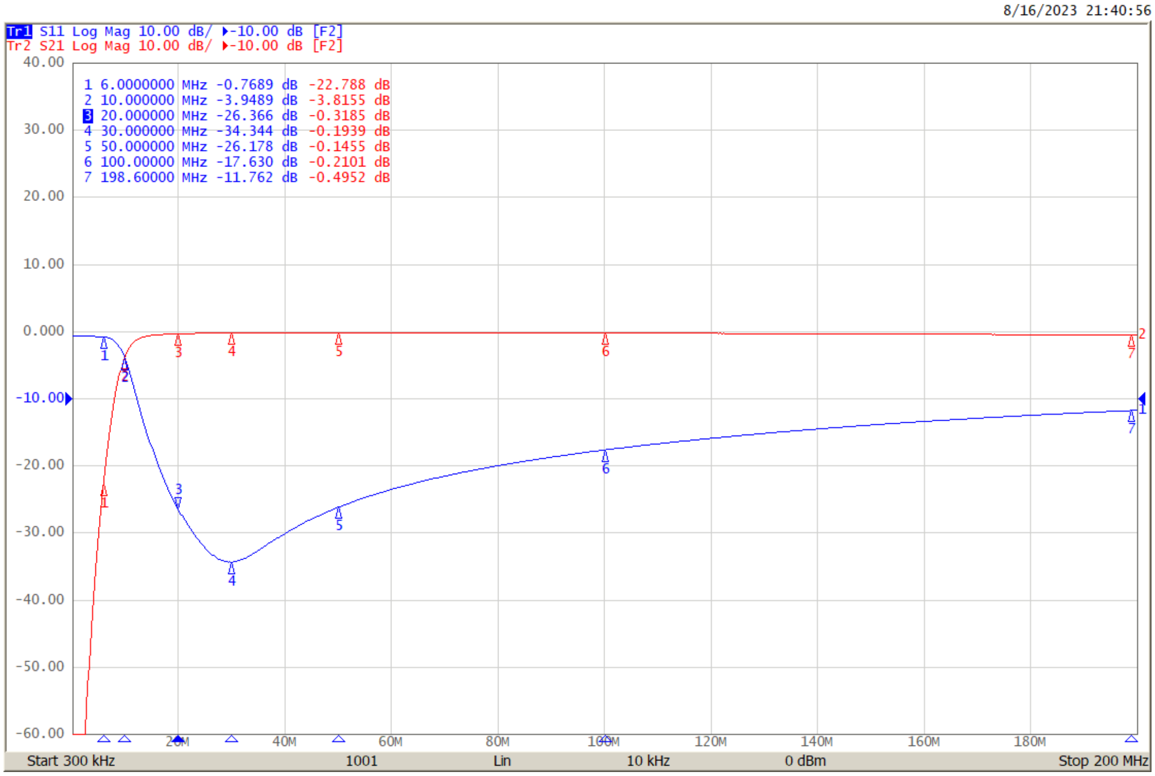


3 MHz Highpass Filter, Combination of three filters:

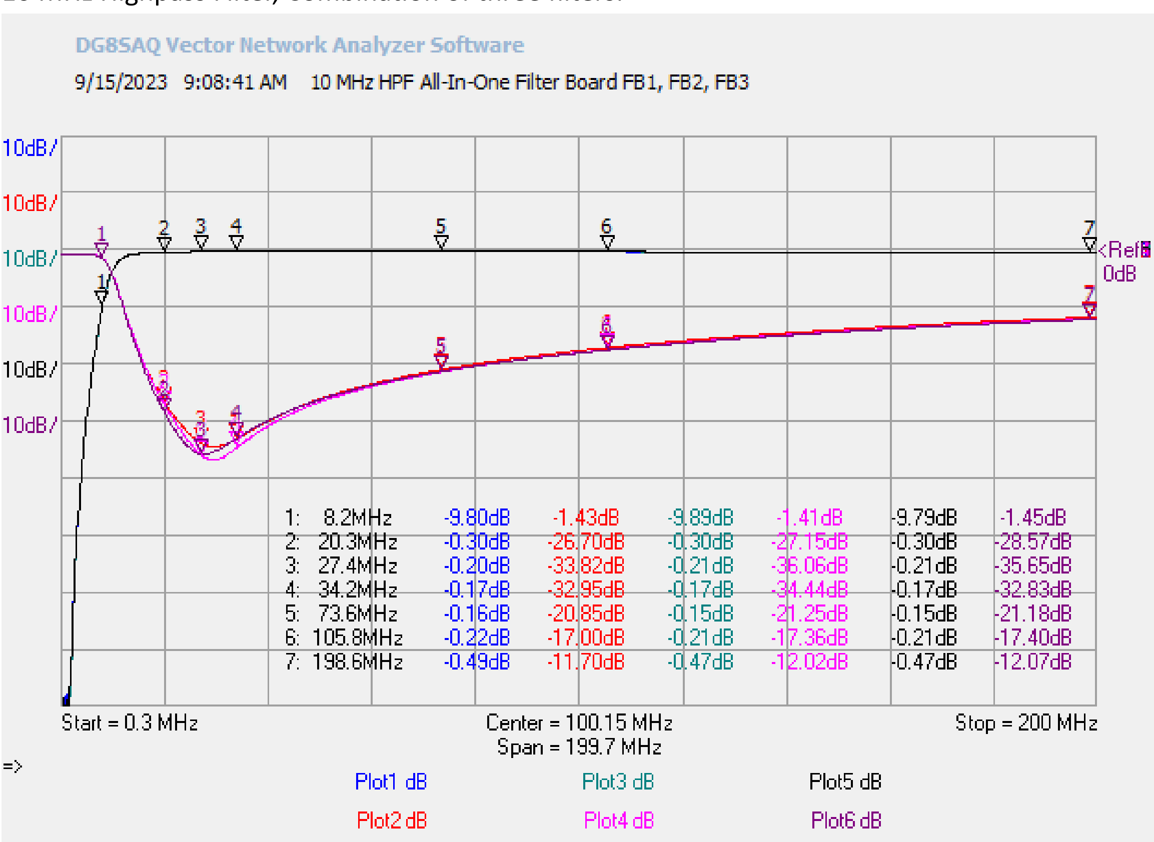
(Note: This plot is for filters with 620 pF capacitors whereas the Rev. I ARX will use 680 pF)



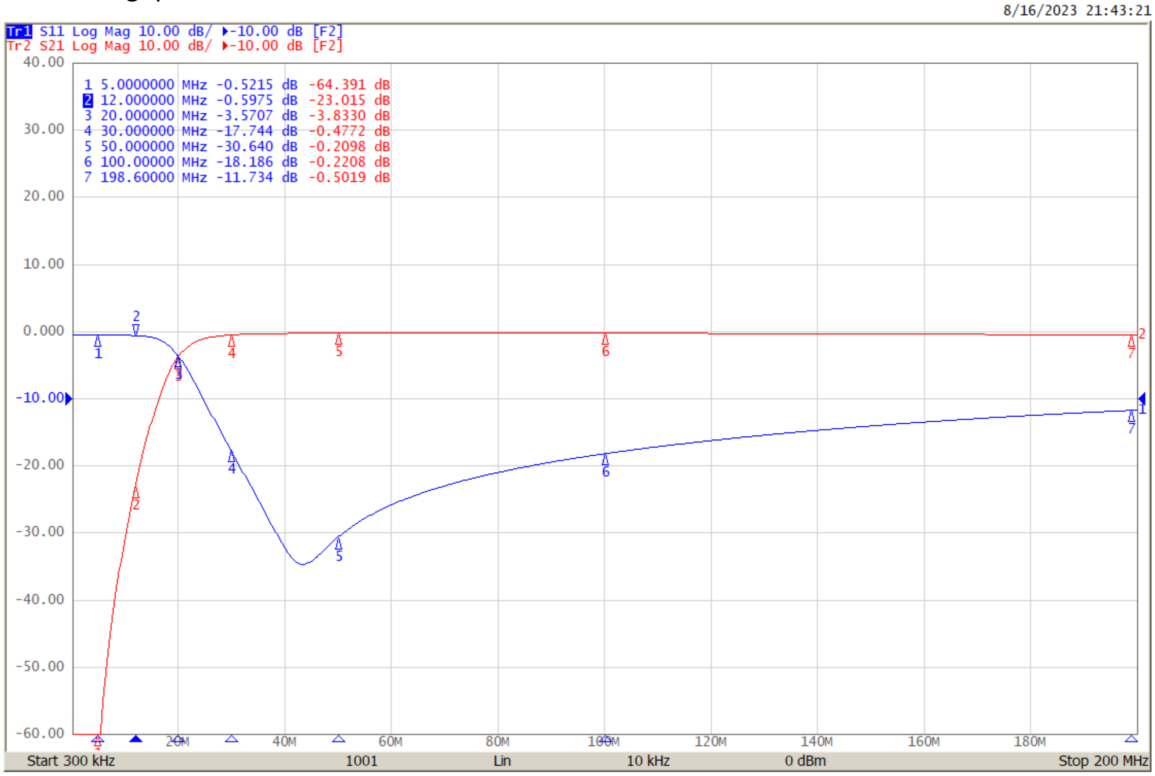
10 MHz Highpass Filter:



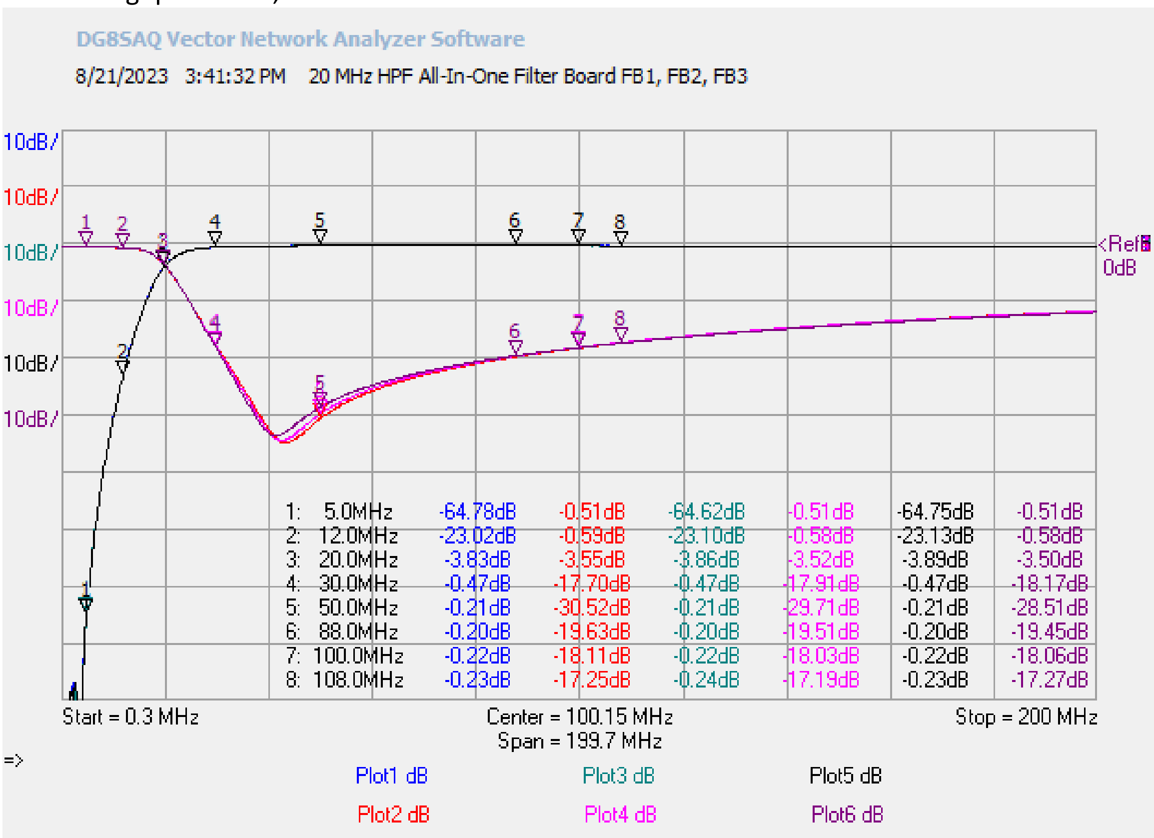
10 MHz Highpass Filter, Combination of three filters:



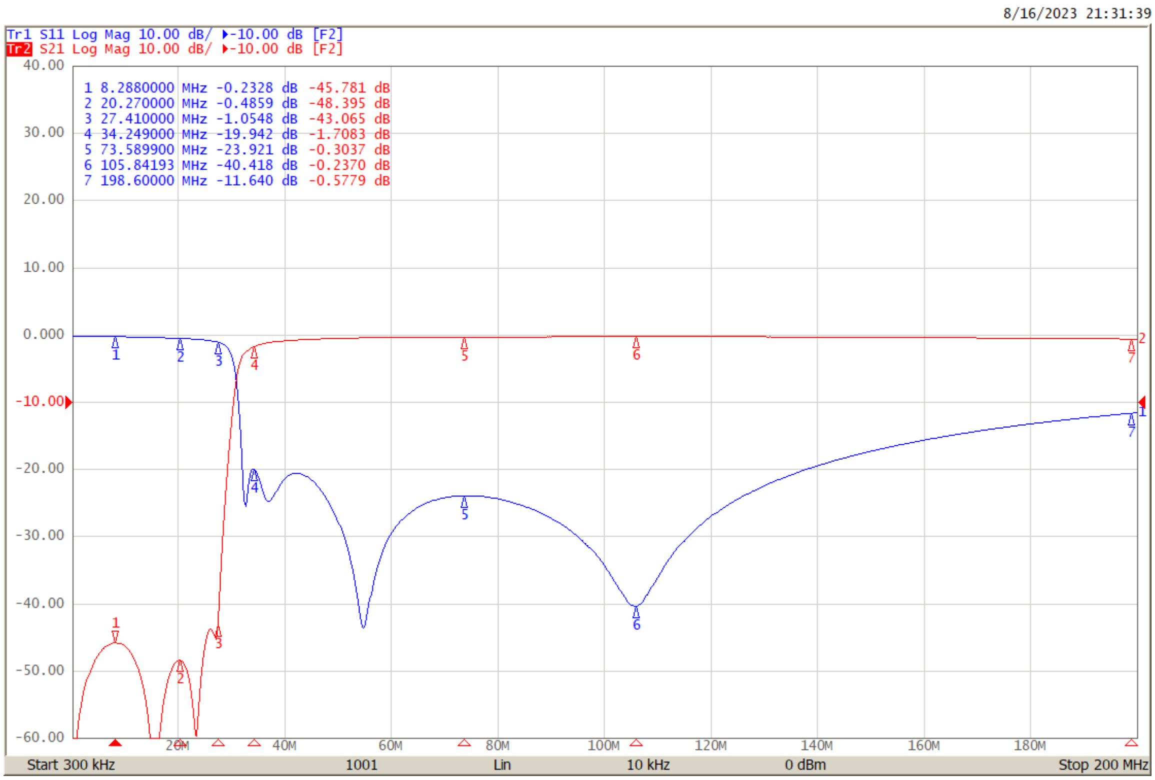
20 MHz Highpass Filter:



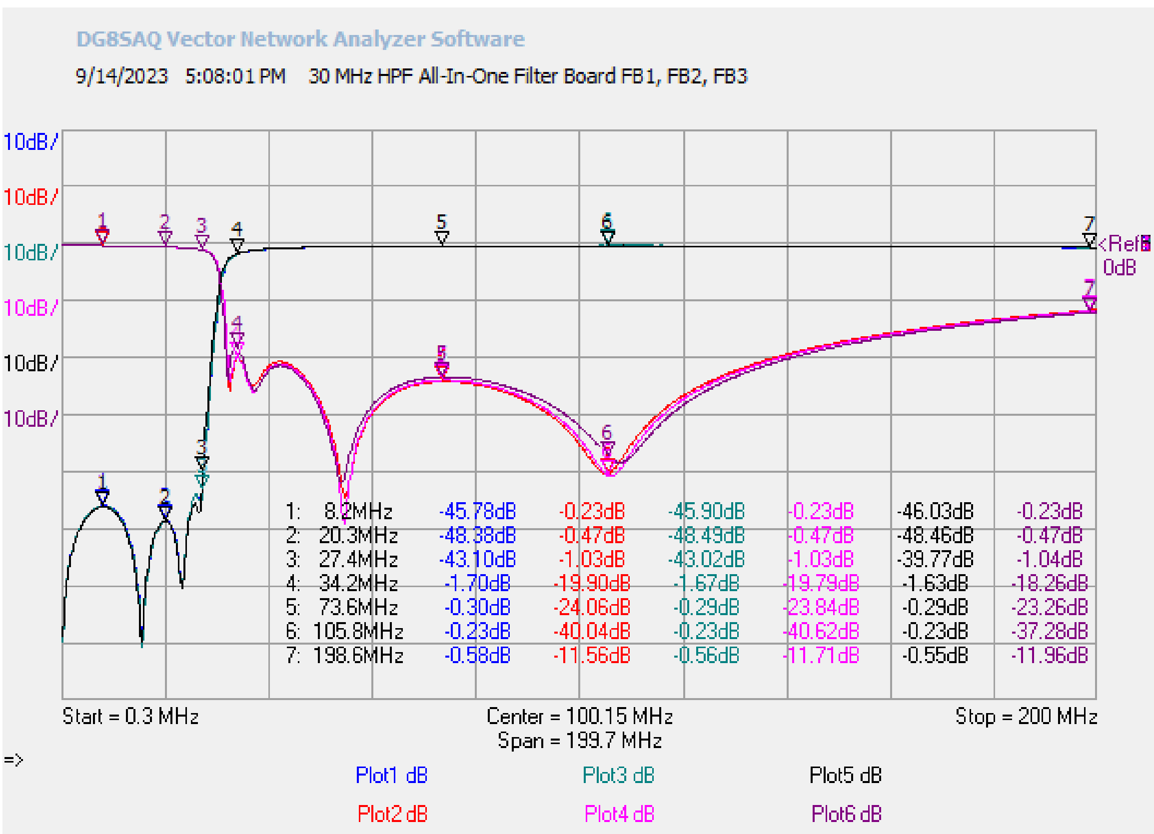
20 MHz Highpass Filter, Combination of three filters:



30 MHz Highpass Filter:

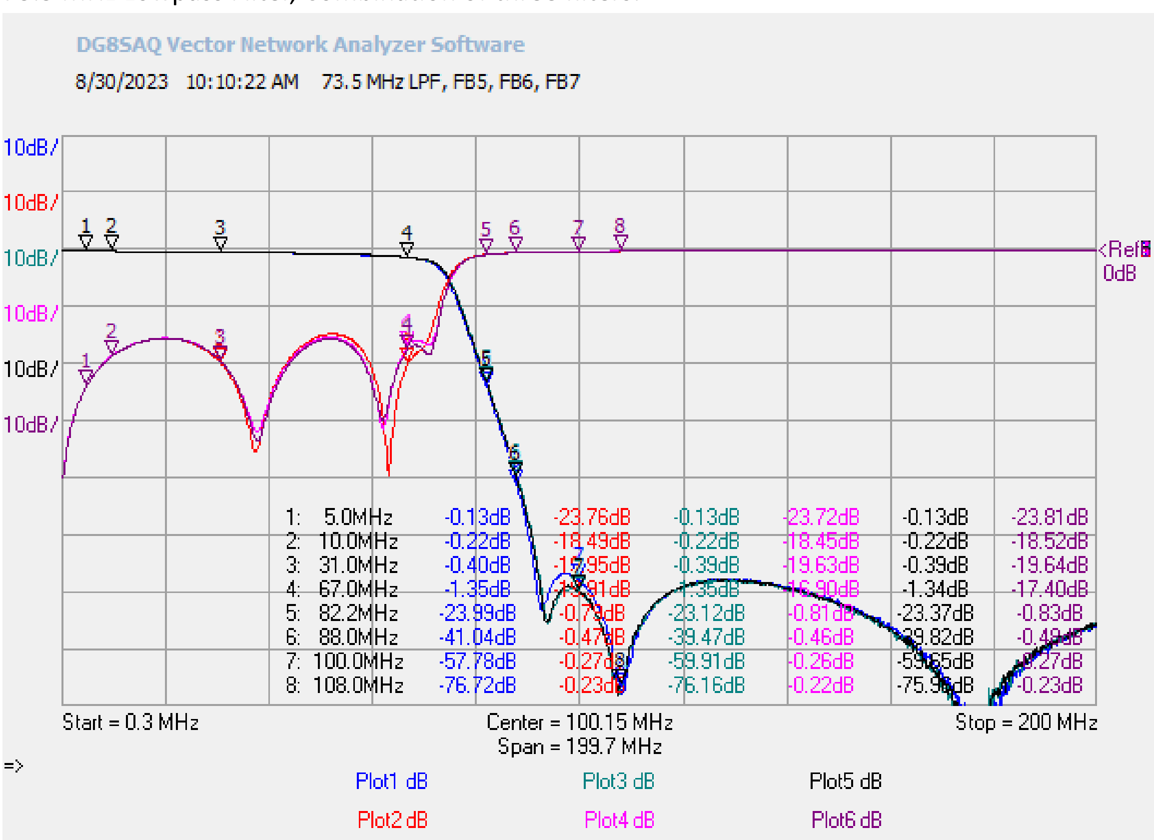


30 MHz Highpass Filter, Combination of three filters:

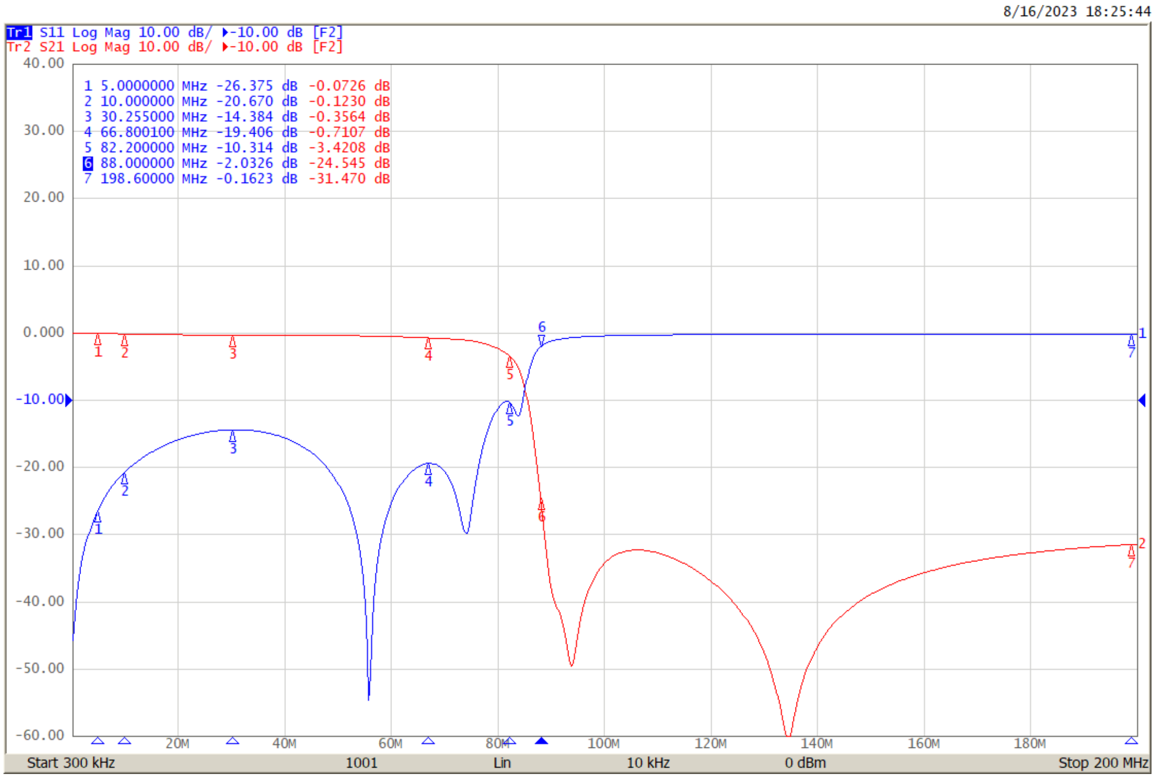


73.5 MHz Lowpass Filter:

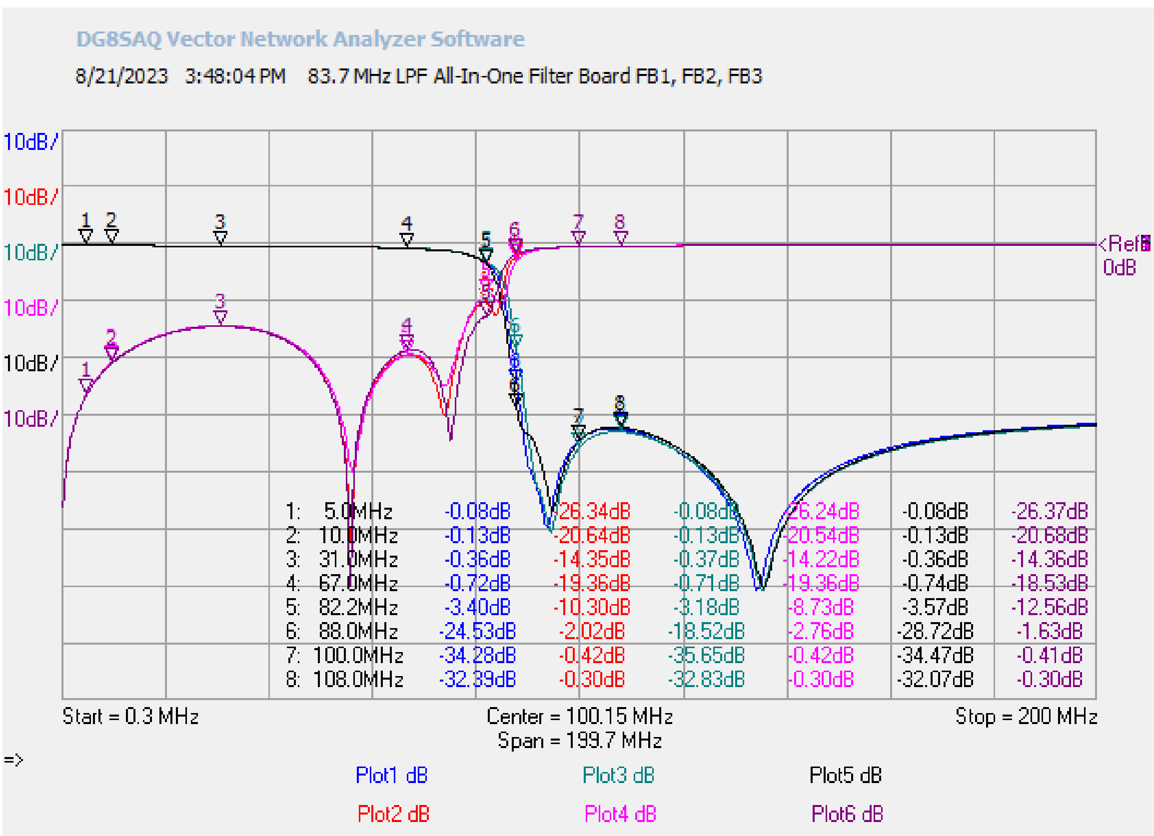
73.5 MHz Lowpass Filter, Combination of three filters:

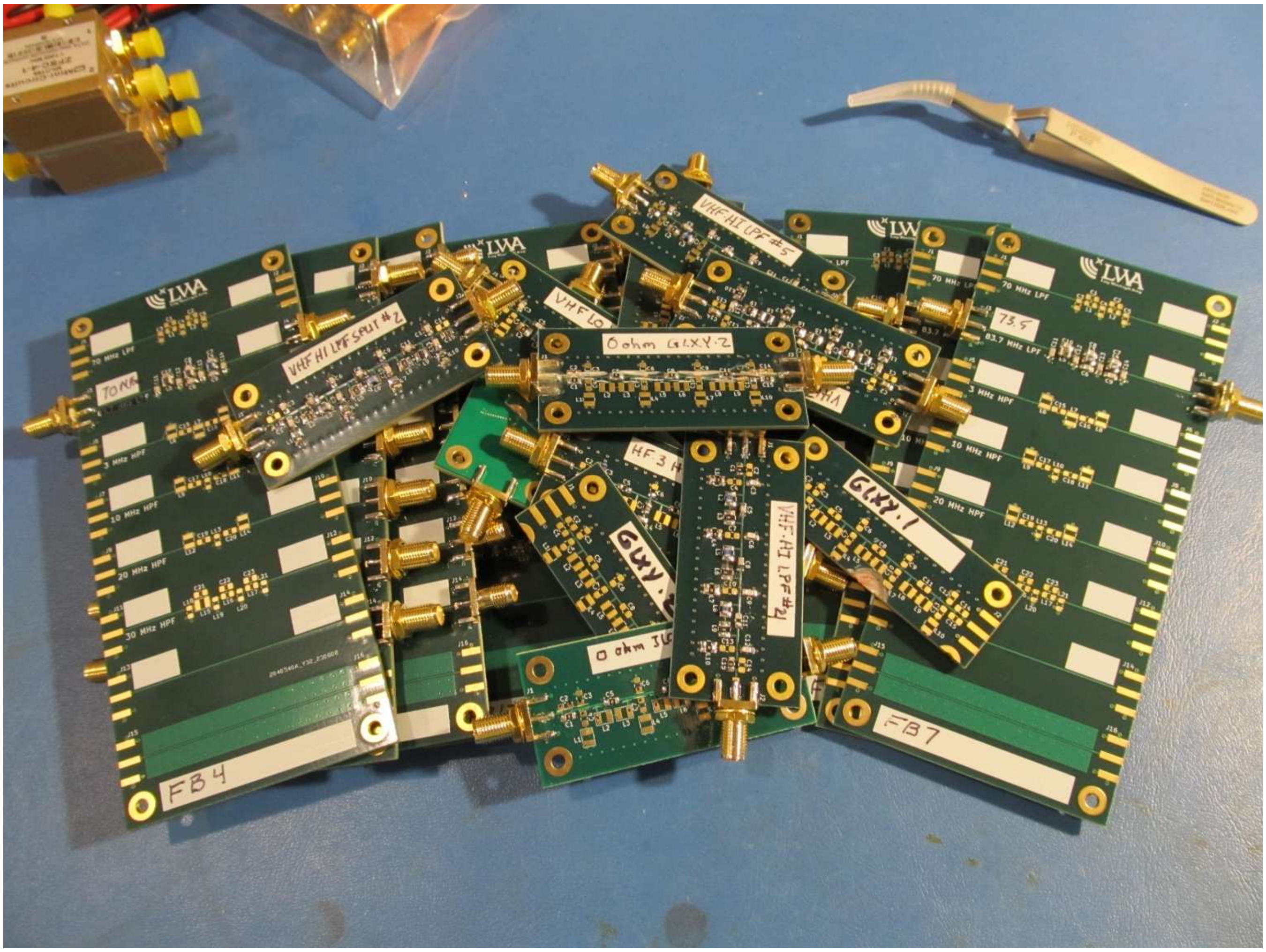


83.7 MHz Lowpass Filter:



83.7 MHz Lowpass Filter, Combination of three filters:



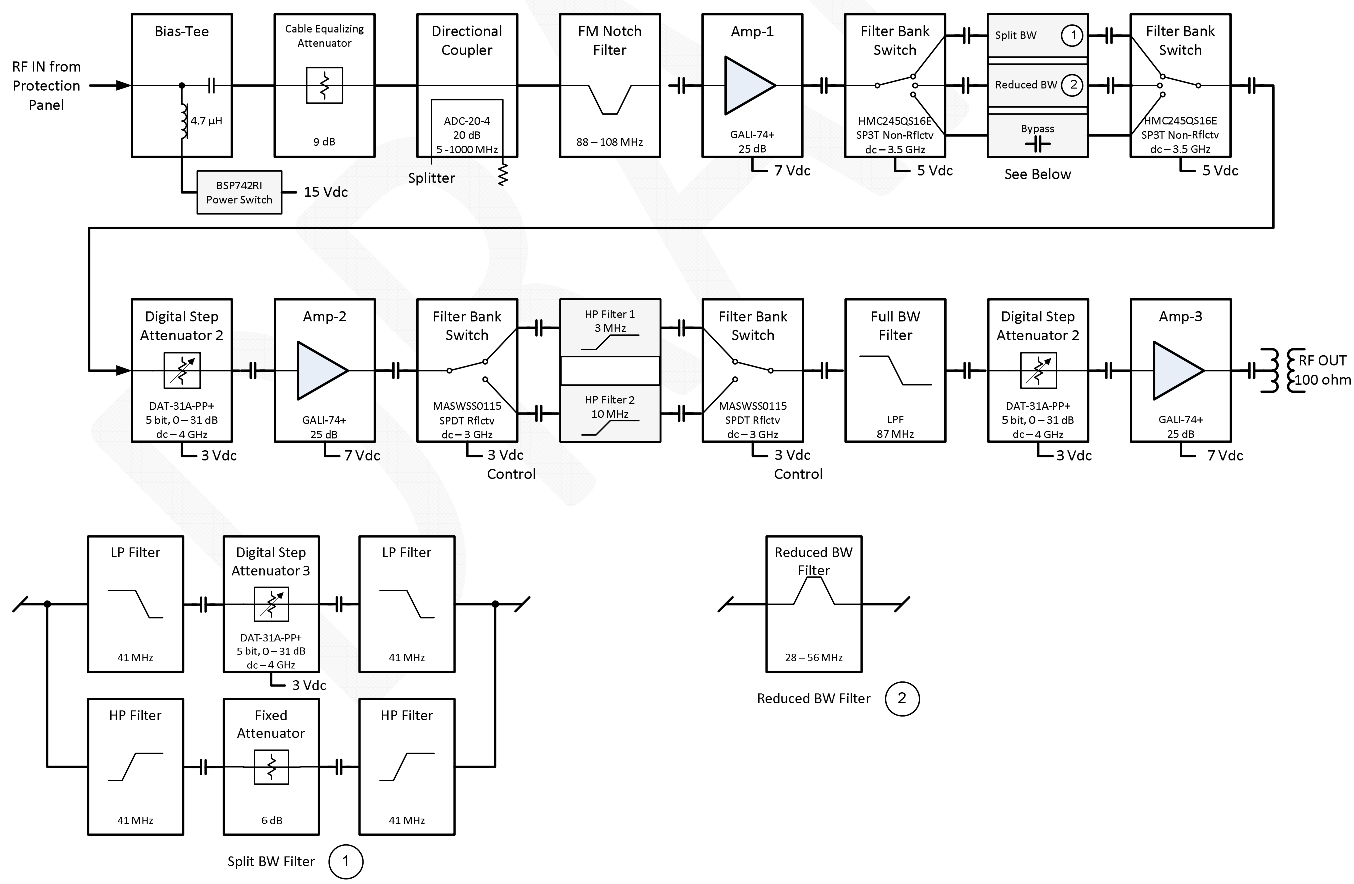

LWA
70 MHz LPF
3 MHz HPF
10 MHz HPF
20 MHz HPF
30 MHz HPF
FB4
VHF HI LPF SPLIT #2
VHF HI LPF #5
0 ohm GLXY.2
73.5
83.7 MHz LPF
GLXY.1
VHF HI LPF #2
FB7

Appendix ~ ARX Rev. G and H Filters

Rev. G ARX filters:

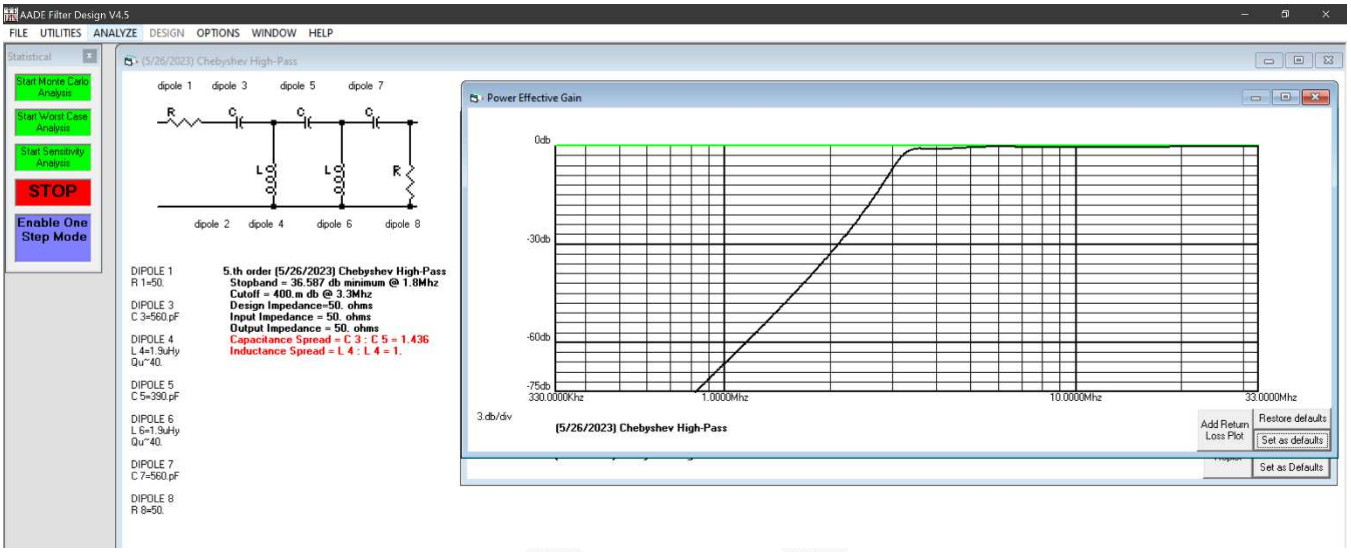
The Rev. G ARX filters and their relationship to the gain and other major blocks in the receiver are shown below. An FM Notch filter is placed immediately before the first gain stage for protection from the FM broadcast band (88 to 108 MHz). This filter was found to introduce ripples in the passband below the notch frequency range. These ripples were then reduced by the 9 dB Cable Equalizing Attenuator in front of the notch filter. Additional details are shown for the two filters in the first filter bank annotated ① and ②. The Split Bandwidth filter in ② is a diplexer that allows varying selection of the attenuation and frequency ranges above and below approximately 41 MHz.

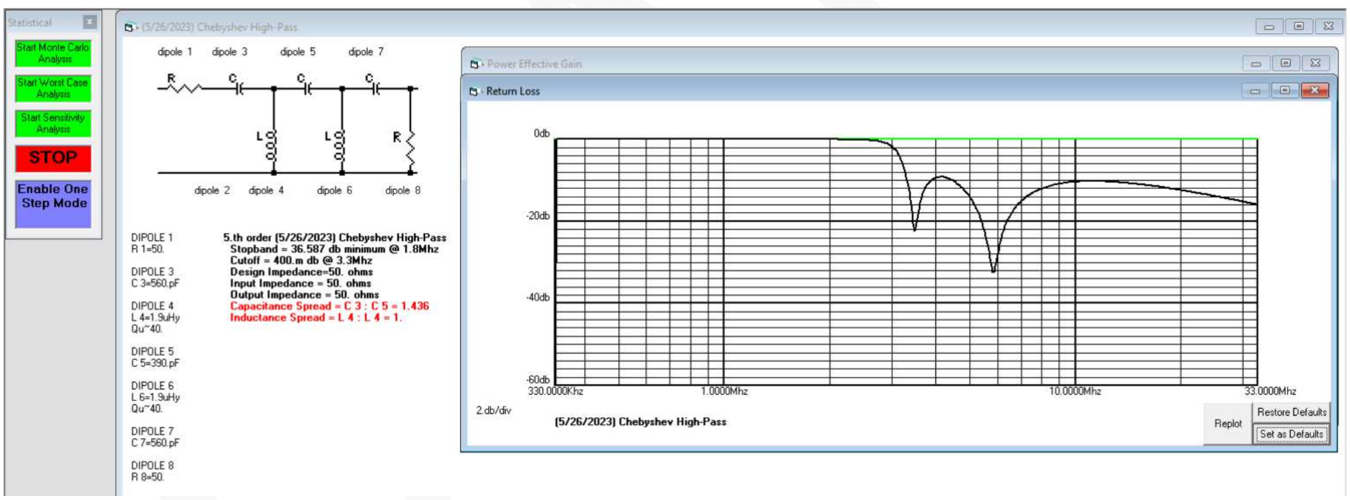
The filter bank immediately following the second gain stage consists of nominal 3 and 10 MHz highpass filters. Simulation shows these have 3 dB cutoff frequencies of 3.2 and 10.5 MHz. The 3 MHz HPF appears to be a Chebyshev type. The 10 MHz HPF is a Butterworth type that uses a T-configuration and has identical response to the proposed Rev. I Butterworth type that uses a Pi configuration. A Full Bandwidth filter is used in front of the last gain stage. This is a lowpass filter with response from dc to just under 88 MHz. Its calculated attenuation at 88 MHz is 3.8 dB.



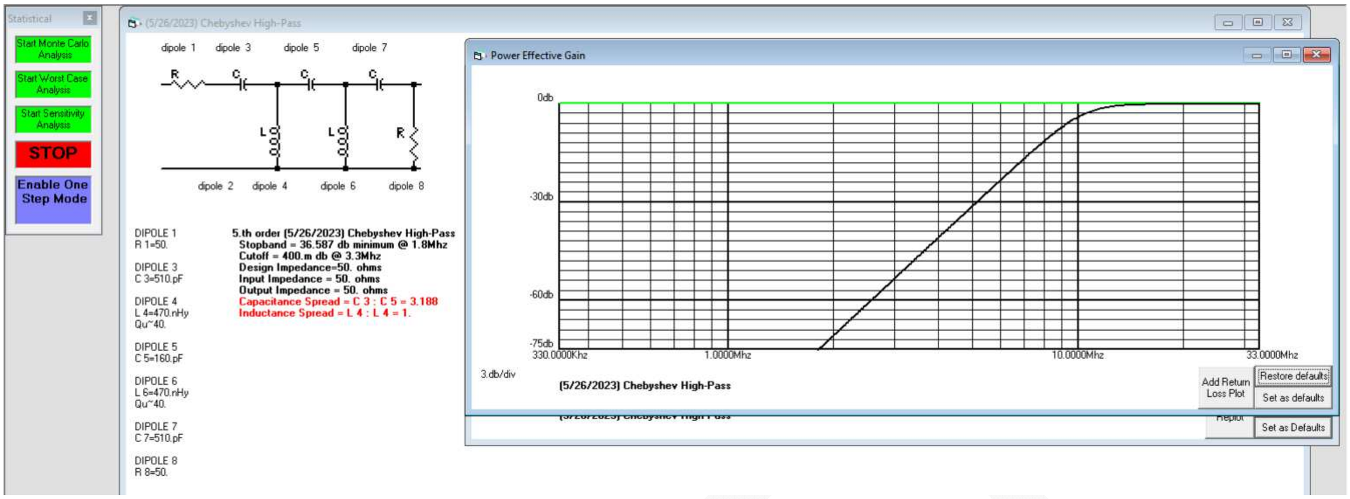
The Rev. G filter schematics are shown below along with plots of the insertion loss and return loss from simulatons. Component values for all filters were taken from the original schematics.

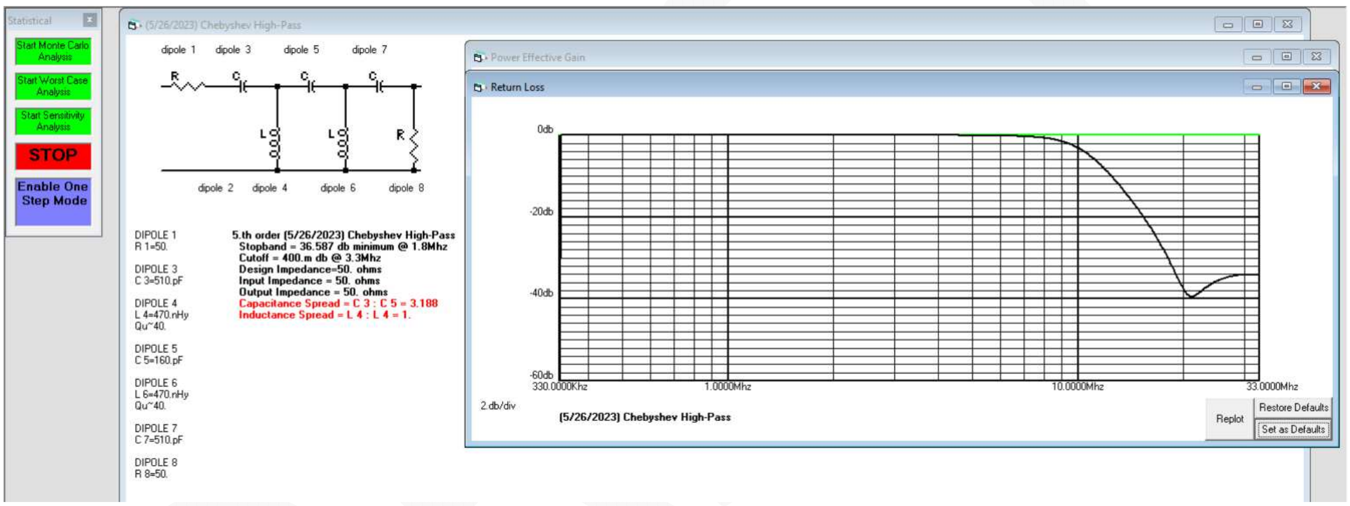
Rev. G 3 MHz Lowpass Filter Insertion Loss and Return Loss:



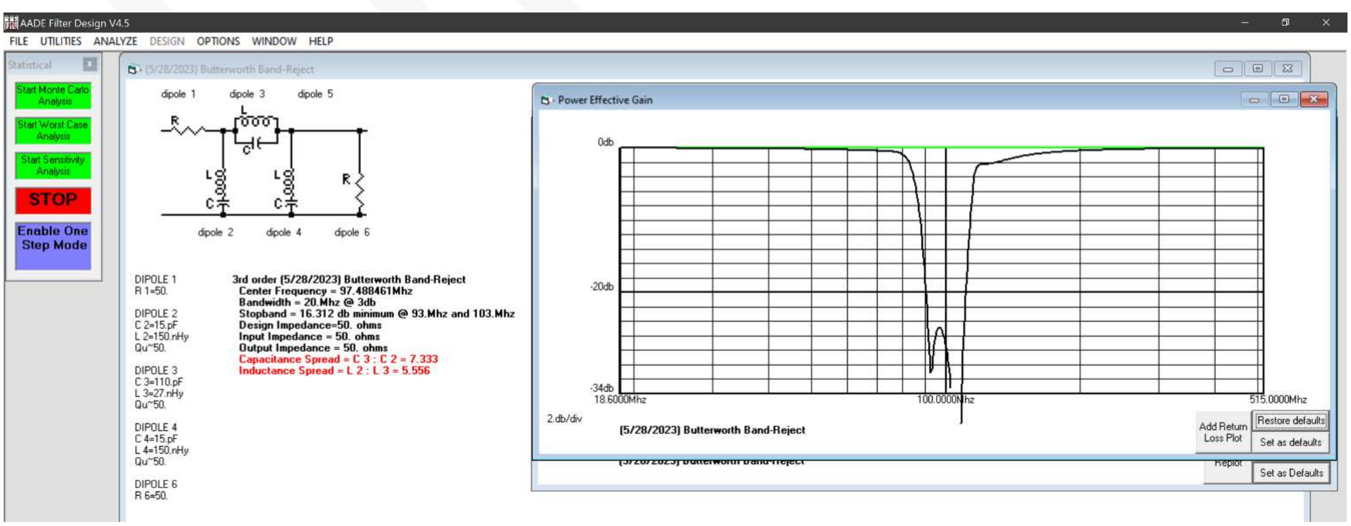


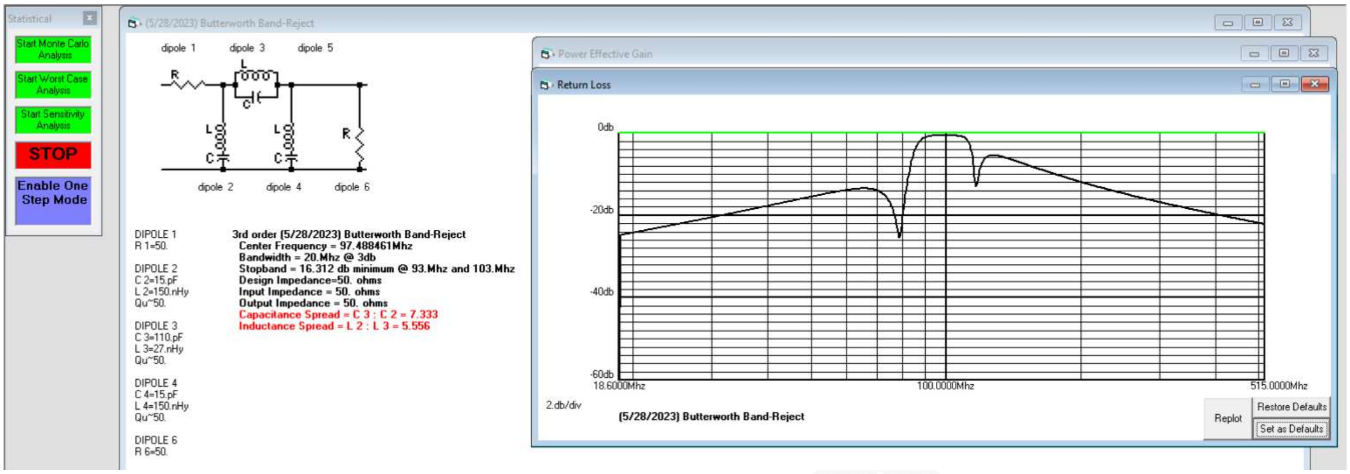
Rev. G 10 MHz Highpass Filter Insertion Loss and Return Loss:





Rev. G FM Broadcast Band Notch filter:

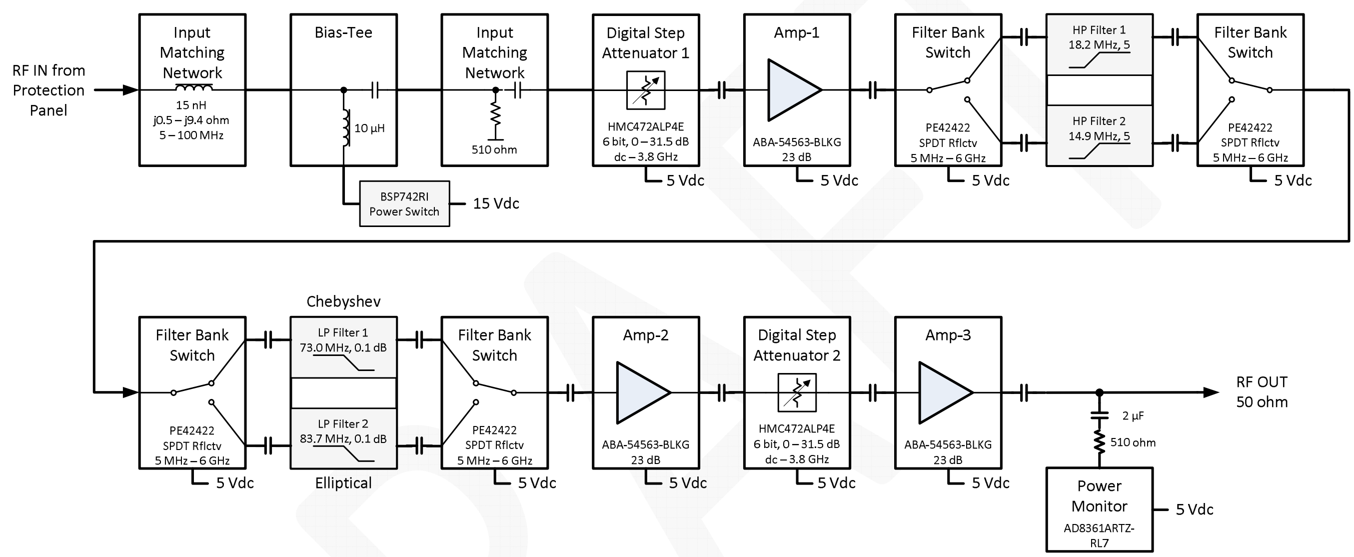



Statistical
Start Monte Carlo Analysis
Start Worst Case Analysis
Start Sensitivity Analysis
STOP
Enable One Step Mode
(5/28/2023) Butterworth Band-Reject
dipole 1
dipole 3
dipole 5
dipole 2
dipole 4
dipole 6
DIPOLE 1
R 1=50.
DIPOLE 2
C 2=15.pF
L 2=150.nHy
Qu~50.
DIPOLE 3
C 3=110.pF
L 3=27.nHy
Qu~50.
DIPOLE 4
C 4=15.pF
L 4=150.nHy
Qu~50.
DIPOLE 6
R 6=50.
3rd order (5/28/2023) Butterworth Band-Reject
Center Frequency = 97.488461Mhz
Bandwidth = 20.Mhz @ 3db
Stopband = 16.312 db minimum @ 93.Mhz and 103.Mhz
Design Impedance=50. ohms
Input Impedance = 50. ohms
Output Impedance = 50. ohms
Capacitance Spread = C 3 : C 2 = 7.333
Inductance Spread = L 2 : L 3 = 5.556
Power Effective Gain
Return Loss
0db
-20db
-40db
-60db
18.6000Mhz
100.0000Mhz
515.0000Mhz
2.db/div
(5/28/2023) Butterworth Band-Reject
Replot
Restore Defaults
Set as Defaults

Rev. H ARX filters:

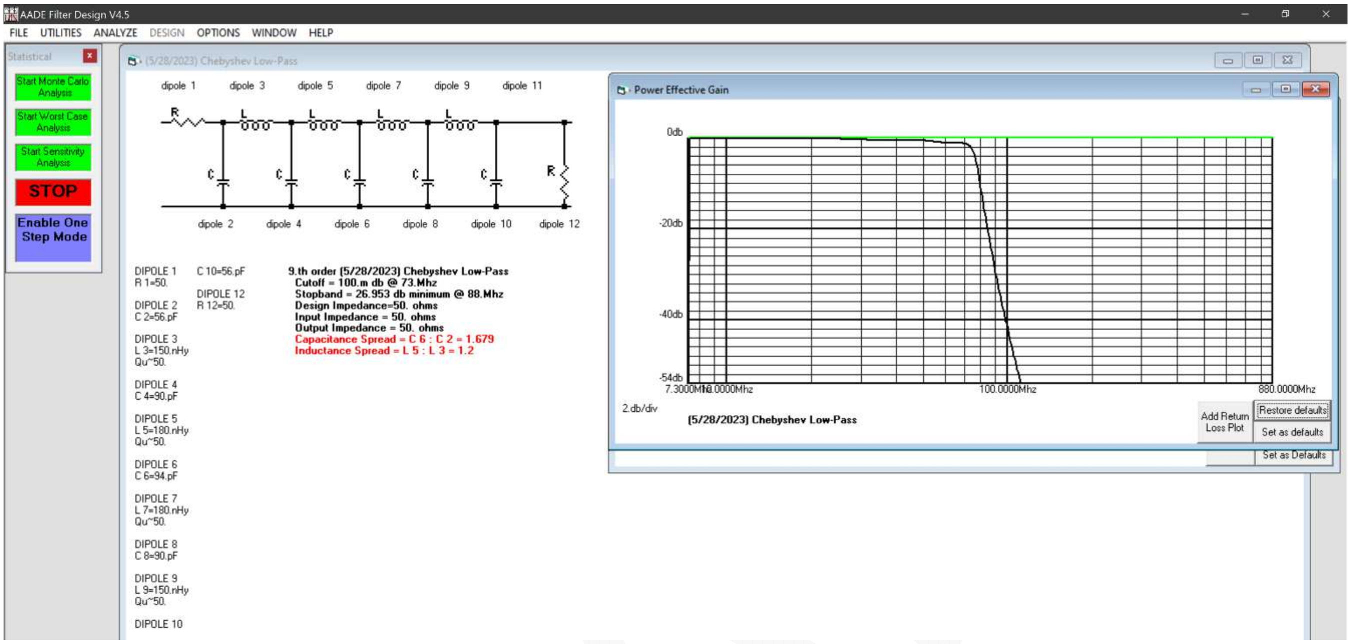
The Rev. H ARX filters and their relationship to the gain and other major blocks in the receiver are shown below. The overall filter scheme in the Rev. H ARX is less complex than the Rev. G ARX. The two highpass filters that follow the first gain stage are 5th order Butterworth designs with design cutoff frequencies of 14.9 and 18.2 MHz.

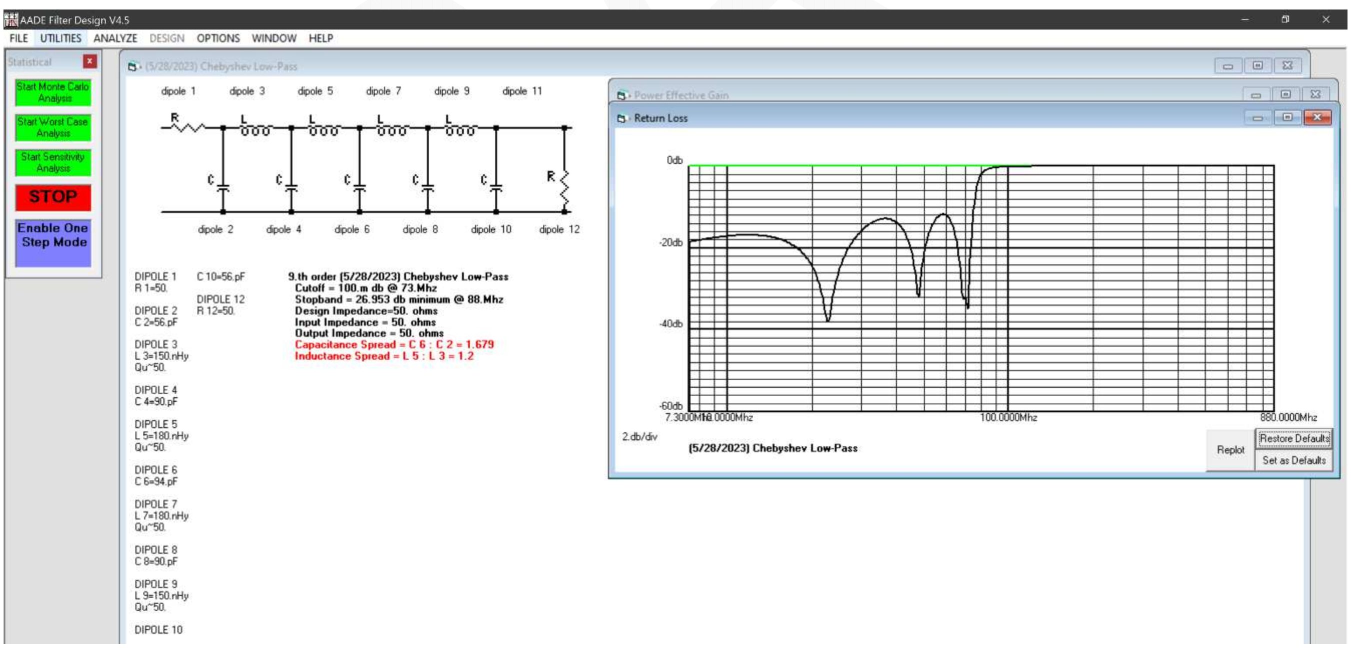
The second filter bank consists of two lowpass filters, a 9th order Chebyshev design with a cutoff frequency of 73.0 MHz and a 7th order Elliptic design with a cutoff frequency of 83.7 MHz. Both filters are designed for 0.1 dB ripple and loss at the cutoff frequency and both are designed to reduce FM broadcast band interference. The 73.0 MHz filter provides 25.7 dB attenuation at 88 MHz, and the 83.7 MHz filter provides 17.5 dB attenuation at 88 MHz.



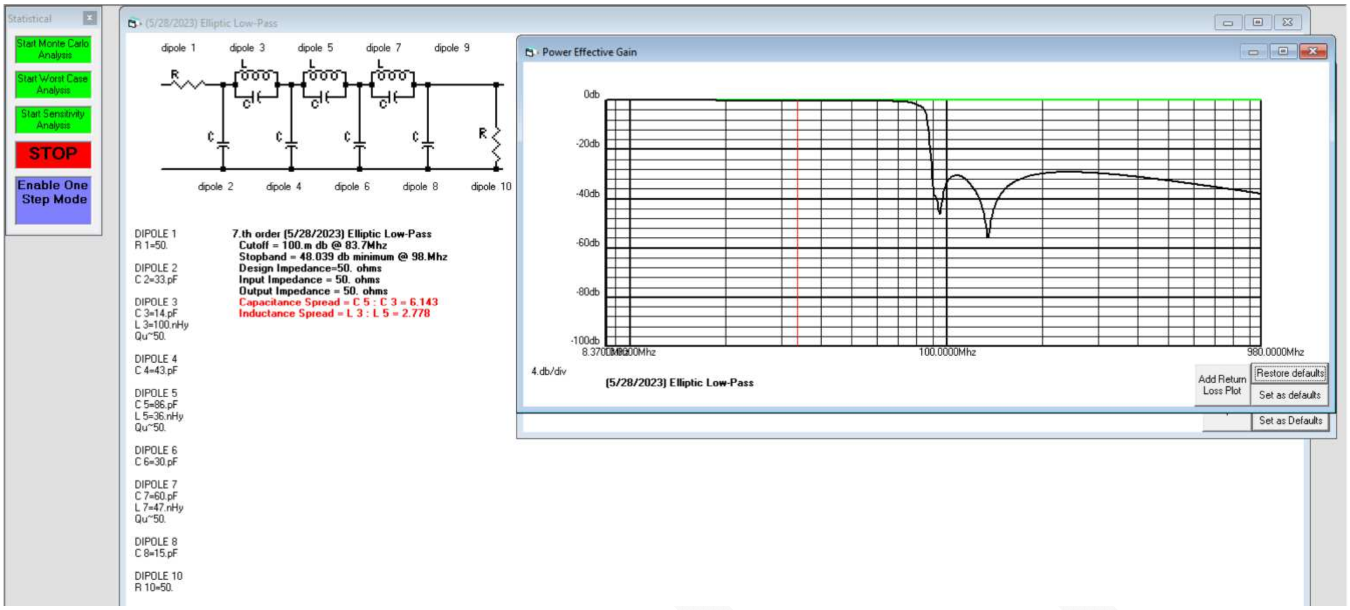
The Rev. H filter schematics are shown below along with plots of the insertion loss and return loss from simulations. Component values for both filters were taken from the original schematics.

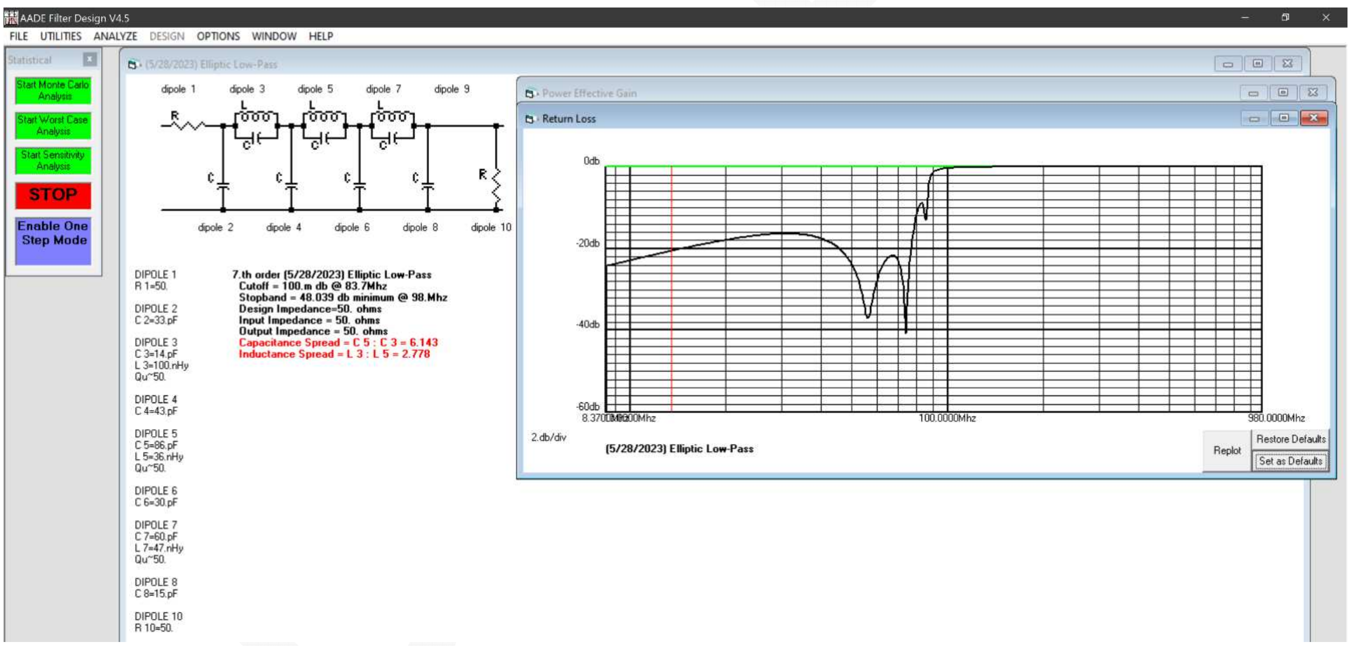
Rev. H 73.0 MHz LPF Insertion Loss and Return Loss:





Rev. H 83.7 MHz LPF Insertion Loss and Return Loss:





Document Information

Author: Whitham D. Reeve

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0.1 (Edits, 23 May 2023)

0.2 (Transferred Rev. G and H info to his document, 24 May 2023)

0.3 (Added Rev. G and H filter plots, 28 May 2023)

0.4 (Updated 30 MHz HPF, 06 Jun 2023)

0.5 (Revised text and added revised generic filter schematic, 13 Jun 2023)

0.6 (Added Monte Carlo analysis for 83.7 MHz LPF, deleted measurements section, 17 Aug 2023)

0.7 (Added filter PCB design details and filter measurements, 14 Sep 2023)

0.8 (Distribution of draft, 15 Sep 2023)

0.9 (Updated 3 MHz HPF to show 680 pF capacitors, 18 Sep 2023)

1.0 (Removed DRAFT watermark for distribution of final, 20 Sep 2023)

1.1 (Removed system block diagram, 29 Sep 2023)

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