Filters to Separate Same Band Signals at 1 KW

Operating multiple radios with high power 1 kW linear amplifiers on the same HF band that are also located at the same site presents significant problems with interference. This may be an issue for Field Day (although Field Day operations are now limited to 100 Watts) or it may be an issue for QSO parties where club stations may operate CW and phone on the same band with high power linear amplifiers. A separate paper provided details on the construction of large aluminum boxes measuring almost a foot per side and the construction of 6.5 inches diameter coils using ¼" and 3/8" copper tubing to form very high Q HF helical resonators capable of handling 1 kW power levels. An article in the November 2021 NCJ described filters capable of same-band signal separation for TX power levels up to 100 Watts. Even for 100 watts operations however, the filters detailed in this paper can provide higher performance than filters designed for 100 watts maximum operations.

In this paper, construction details, tuning and performance results are presented to build 3 resonator/chamber Ultra-Sharp Low-Loss (USLL) filters capable of same band separation of signals on 40 and 20 meters at 1 kW power levels. Four filter designs are presented in detail for CW and phone filters for 40 and 20 meters, and experimental results are included. These USLL filters provide 20 to 40 dB of isolation between the CW and phone segments of those bands with only about 0.5 dB of loss in the desired band segment. A key benefit of these filters is the suppression of TX and linear amplifier noise from a high power CW transmitter that is generated in the nearby phone band and vice versa, and they also protect the RX from strong nearby signals. These filters should be combined with conventional techniques for isolation between radios operating on the same band including cross-polarized or end-to-end antenna arrangements, high performance radios and power supply isolation. This work can be extended to 160, 80, 15 and 10 meters.

Discussion

USLL filters previously constructed for 100 W operations used 6" on a side aluminum chambers and 3 to 3.5 inch coils to make 2 helical resonator filters for 20 and 15 meters and 3 resonator filters for 80 and 40 meters. To achieve higher performance on 20 meters, significantly lower loss and higher Q are needed combined with increasing the number of resonators from 2 to at least 3. This can increase the sharpness of the transition band from the pass-band to the stop-band as well as reduce the losses in the pass-band which is more critical for high power operations. Work on helical resonators with chambers almost 1 foot on a side constructed of aluminum sheet metal using coils made of copper refrigeration tubing formed at 6.5 inches diameter suggested that this was feasible. The larger chambers and coils with volumes almost 8 times higher than the smaller 6 inch per side chambers appeared consistent with handling power levels 10 times higher or 1 kW compared to 100 W.

Since aluminum chambers that are about 1 foot in all 3 dimensions are not readily available, they were homebuilt as were the large coils made of 3/8" and ¼" diameter copper tubing with diameters of 6.5". But also HV RF capacitors (15 to 20 kV at several Amps of RF current and at 15 pF and 30 pF) were needed to loosely couple to the coils at a mid point. RF capacitors were obtained from UR4LL of 15 PF rated at 15 kV and 35 kVar. One capacitor was used for coupling on 20 meters to each coil and two capacitors were used in parallel on 40 meters to achieve 30 pF to couple to each coil. Coupling inductors between filter stages/chambers needed for the CW filters were homemade using T200-6 toroid cores. Coupling RF capacitors between filter stages/chambers used 150pF and 300 pF TX RF doorknob capacitors with 2 placed in parallel to provide 300 pF for 20 meters and 600 pF for 40 meters. The inductors were homemade, the chambers were homemade, and the RF capacitors were high

Voltage/current RF doorknob capacitors. This was partly due to availability of appropriate components, but also was necessary to achieve the required performance at reasonable cost.

The use of helical resonators that are almost 1 foot on a side presents some issues. Their size does mean that space needed in the radio shack is an issue. Because of the usage of aluminum for the chamber, and thin wall copper tubing (as opposed to solid copper wire) for the coils, the overall weight of 3 resonators is not very high and is only about 15 pounds. The tuning of the filters is very critical, requiring accuracy of about +- 5 KHz at 14 MHz, and because of the large coils and chambers, the filters are fairly sensitive and a bit fragile, so care must be taken in moving the filters, not disturbing the positioning of the coils, and in assuring that their tuning is correct for operations.

The large size of the filters also means that the ground paths between the 3 resonators used to form a filter become significant. As discussed later, a compact arrangement of the 3 resonators/chambers in the shape of an L with the SO-239 input/output connectors and all ground connections concentrated in a central area of the chamber group is important to achieve good results. Without such an arrangement, the inductances of the ground paths in the filter significantly degrade the results, especially for the high performance results targeted for these filters. Making the resonator chambers smaller to reduce the ground path inductance is not possible since that is driven by the need for very high Q and high power capability which requires large chamber size. Alternative arrangements are possible where ground path inductance effects are mitigated by actually making the ground connections resonant with series capacitance, but that requires isolating the chambers electrically except for low-impedance resonant grounds and signal coupling paths (such an arrangement can be sensitive to external ground paths). Instead a compact arrangement allowing all ground paths to be reduced to a few inches was used providing good performance and robustness to external components.

Overall, isolations of 80 to 90 dB may be needed for same band HF operations such as simultaneous phone and CW operations when operating at 1 kW (or 1.5 kW legal limit) power levels to avoid TX noise impairing RX performance. RF leakage between amplifiers and radios to achieve that level of isolation must be rigorously minimized. Without discussing details, the grounding system, power supply isolation, coaxial radiation and other issues must be considered. Actually measuring the isolations with dummy loads used in place of the antennas allows investigating and correcting RF leakage paths where coupling over the dominant antenna to antenna path is removed from the system.

Performance

Figures 1 to 4 show the measured frequency response for phone/CW filters for 20 meters and phone/CW filters for 40 meters. The extremely sharp nulls are less than 10 KHz wide for the 20 meter filters at the 3 dB point which is most visible in Figure 2 for the CW filter where the nulls are more widely spaced than for the phone filter. This is consistent with Q's of 1500 to 2000.

The 20 meters phone filter shows a loss of only 0.36 dB at 14.250 MHz in the middle of the phone band. The loss increases to 0.575 dB at 14.200 MHz, then 0.80 dB at 14.175 MHz, and 1.19 dB at 14.150 MHz. Over the bottom 60 KHz of the CW band, the loss is greater than 30 dB with loss of over 40 dB around 14.025 MHz, and in the region of digital transmissions around 14.080 MHz, the loss in about 20 dB. Operating below 14.200 MHz should be avoided or the TX power should probably be reduced.

The 20 meters CW filter showed a loss of about 0.45 dB at 14.00 MHz; 0.49 dB at 14.050 MHz; 0.54 dB at 14.075 MHz; and 0.64 dB at 14.100 MHz. From 14.200 MHz to 14.3500 MHz, the loss is generally between 25 dB and 30 dB with a sharp transition around 14.200 MHz and loss at 14.200 MHz of about

12 dB. The loss in the phone band will provide significant suppression of TX and high power amplifier noise in the phone band from a CW transmitter. The loss in the CW band of about 0.5 dB is slightly higher than the loss for the 20 meters phone filter in the phone band of about 0.36 dB. This may be due to the coupling inductors using toroids for the CW filters versus coupling capacitors for the phone filters. The toroid inductors may have Q's of only 300 to 400 while the coupling capacitors probably have Q's of at least several thousand. Perhaps the slightly higher loss of the CW filters could be improved by using air inductors, but care would be needed to minimize mutual inductance between the coupling coil/inductor and the large helical coil.

The 40 meters phone filter shows a loss of only 0.34 dB at 7.250 MHz in the middle of the phone band. The loss increases to 0.46 dB at 7.200 MHz, then 0.60 dB at 7.175 MHz, and 0.87 dB at 7.150 MHz. Over the bottom 60 KHz of the CW band, the loss is between 25 dB and 40 dB, and in the region of digital transmissions around 7.080 MHz, the loss in about 20 dB. Operating below 7.175 MHz should be avoided or the TX power should probably be reduced.

The 40 meters CW filters shows a loss of 0.49 dB at 7.050 MHz in the middle of the CW band (again the CW filter shows slightly higher pass-band loss than the phone filter for 40 meters as was the case for 20 meters). The loss is -0.49 dB at 7.075 MHz and increases to 0.54 dB at 7.025 MHz and 0.61 dB at 7.000 MHz. The loss is 0.68 dB at 7.1 MHz.

Stress tests were run on the 20 meters phone filter using a Heathkit SB220 amplifier operating in CW mode with an output of 800 Watts and transmitting at 14.250 MHz. A continuous string of dots was sent for about 5 minutes for one period with the frequency response measured before and after the test, and then a second string of dots was sent after a gap of 2 to 3 minutes for another 5 minutes continuously. Again, the frequency response was measured before and after the test. Movement in the frequency response was barely perceptible, but the resonant frequencies of the filter appeared to shift downwards 2 to 3 KHz total over the 2 test periods. The fans which have ratings of about 20 CFM with a separate fan for each chamber ran during these tests to minimize temperature change. It may be possible to slightly bias the tuning of the filters under room/cold conditions to minimize the drift with frequency due to some heating with heavy usage. Due to the extreme sharpness of these filters and operating at high power, this issue should be monitored although the design is robust for high power operation.

A similar test was performed on the 20 meters CW filter which uses toroid inductors with T200-6 cores. After the completion of two 5 minute tests of continuous dots, the cover of the one end chambers was removed and each element was touched to attempt to detect any heating. The toroid core as well as the loose coupling cap and helical coil were all cold to the touch. Also the frequencies of the filter moved 2 or 3 KHz over the test and after cooling for 10 to 15 minutes returned to about the starting frequencies.

The 40 meter phone and CW filters were also tested at 800 W TX CW power levels.

Filter Design and Construction

A schematic for the 20 meters phone filter is shown in Figure 5. It is similar to filters detailed in the November 2021 NCJ article. All of the filters detailed in this paper use 3 stages of helical notch resonators with band-pass bump coupling. Capacitive coupling is used between stages for phone filters to place the band-pass bump above the helical resonator notch frequencies, and inductive coupling is used between stages for CW filters to place the band-pass bump below the helical resonator notch frequencies. Small value capacitors tap the coils near a mid-point for loose coupling of each helical notch resonator to the circuit. A fan was mounted on the top plate of each chamber to pull air through each chamber for cooling, and the top plate and bottom plate were each drilled with a pattern of large holes near the middle of the plates to allow air flow. The 3-chamber filter assembly is mounted on 4 large rubber feet with about 1 inch height to provide good airflow into the chambers.

For the 20 meter filters, the coils are about 8.5 turns of 3/8 inch copper tubing formed on a 6 inch diameter PVC pipe (but removed from the PVC pipe for usage in the chambers) resulting in a coil diameter of about 6.5 inches with a coil length of about 7 inches. Two ½" diameter rexolite rods cut to 8 to 9 inches in length are then tie wrapped to opposite sides of the coils to support the coils vertically in the chambers. Each coil could be wound from a single supply of 15 to 20 feet or 3 coils could be wound from a single 50 feet supply. The cold end of the coil is attached to the chamber wall by flattening about 2 inches of the tubing, pulling the cold end away from the coil several inches to meet the chamber wall, and using two ½" #4-40 machine bolts about 1 inch part. A thin sheet of stainless steel measuring ¾" by 2 " is placed between the copper tubing and the aluminum chamber to isolate those metals. The loose coupling capacitors are 15 pF rated at 15 kV and 35 kVar and they tap each coil at 5 turns from the bottom or cold end of the coil. The coupling capacitors between stages for the phone filter are 300 pf using two 150 pF capacitors in parallel to increase RF current capacity, and the inductors between stages for the CW filter are about 0.5 uH total using #12 enameled wire with 4.5 turns on T200-6 cores plus the parasitic inductances of the connecting wires and tubes.

For the 40 meter filters, the coils are about 15 to 16 turns for the phone filter and 14 to 15 turns for the CW filter of 1/4 inch copper tubing formed on a 6 inch diameter PVC pipe (but removed from the PVC pipe for usage in the chambers) resulting in a coil diameter of about 6.5 inches with a coil length of about 8 inches. The coils require about 24 to 26 feet each of copper tubing. Three 40 meter coils can be conveniently wound from a 100 feet supply, but it is possible to splice copper tubing for good RF performance by splitting 1 to 2 inches of tubing on one piece of tubing, overlapping a second piece by about 1 inch, clamping the split tubing to the other piece, and then soldering the pieces together with a heavy 100 W soldering iron. The loose coupling capacitors are 2x 15 pF in parallel (total of 30 pF) rated at 15 kV and 35 kVar each and they tap each coil at 9 turns from the bottom or cold end of the coil. The coupling capacitors between stages for the phone filter are 660 pf using two 330 pF capacitors in parallel to increase RF current capacity, and the inductors between stages for the CW filter is about 1 uH total using #12 enameled wire with 9 turns on T200-6 cores plus the parasitic inductances of the connecting wires and tubes.

If the pass-band bump loss is higher than expected (0.35 to 0.5 dB at pass-band center), it may be due to the coupling inductance or capacitance being too high/low. Another possibility is that the helical notch resonator tuned closest to the transition band is not the center chamber. Other possibilities include some degradation of resonator Q due to any material in the chamber with high dissipation factors or other factors that might degrade Q.

The construction of the large aluminum chambers and copper pipe coils is detailed in a separate paper. Measurements and simulations showed that placing the grounds in a straight line with 3 chambers in a line where the spacing would be about 2 feet between the 2 outer chamber ground regions would seriously impair performance due to the significant inductance between the ground regions of the chambers (although the entire chamber is "grounded", "ground region" is used to refer to the area near the ground connection points of each chamber). The solution to that problem was to place the 3 chambers in the shape of an "L" and design the placement of all ground regions to be closely clustered in the center of the "L". Figure 6 is a picture of the 20 meters phone filter showing the "L" shape layout of the 3 chambers with all grounds closely clustered in the center. The coils inside the chambers are connected to the chamber walls about 3 inches from the center of the “L” in each case and about 2 inches from the bottom plate. The input/output SO-239 connectors are also about 3 inches from the center of the “L” and about 1 inch from the bottom plate in the first and last stage/chamber.

Figure 7 shows a diagram of large aluminum ground straps which create short and very low inductance ground paths between the ground regions of the three chambers. Three straps of about 0.020 inch thick aluminum sheeting that are 4 inches wide and 10 inches long were used. Two are bent 90 degrees in the middle and one is used straight. These heavy ground straps are placed directly above the SO-239 connectors and the screws connecting the coils to the chamber wall on the inside go directly through the chamber walls and then through the large ground straps. The ground straps are pressed between 2 of the chambers for the ground region of the center chamber. Sheet metal screws connect the ground straps to the chambers and between the chambers for the center chamber. A related issue is that the seams for each chamber is placed opposite the center of the “L” where the grounds are clustered, so that small RF currents flow across the seams which will have poorer characteristics than a solid corner formed by bending the aluminum. This is because the RF current on the chamber walls are maximum near the ground regions.

Figure 8 shows a close-up of the center chamber’s loose coupling capacitor and connections for the 20 meters phone filter. It connects to the coil at 5 turns from the bottom/cold end of the coil with a short piece of #12 copper wire and a small stainless steel clamp. The other side of the loose coupling capacitor connects to a short piece of ¼” copper tubing that connects the signal between the 3 chambers through ½” holes in the aluminum chambers in the center region of the “L” shaped filter. The ¼” copper tubing is insulated with 3 layers of shrink tubing where it passes through the sides of the aluminum chambers. For the 40 meter filters using ¼” copper tubing, the taps on the coils for the loose coupling capacitor used soldered connections.

Figure 9 shows a close-up of one of the end chamber’s loose coupling capacitor, coupling capacitors between stages and the SO-239 connection. Below the large 15 pF loose coupling capacitor to the coil are two 150 pF capacitors in parallel to couple the end chamber to the center chamber. Also, the SO-239 connector is seen below the large 15 pF capacitor. A #12 wire connects from the SO-239 center conductor to one side of the two 150 pF capacitors, and the other side of the two 150 pF capacitors connect to the piece of ¼” copper tubing that connects the signal between the 3 chambers. The use of the “L” layout for the filter significantly reduces ground inductance, but it also significantly reduces the distance and inductance on the signal path between chambers.

To extend the design of these filters to 15 meters, the 20 meters coils of about 8 turns would need to be reduced to 5 to 6 turns and the spacing between turns should be increased to make the coil length 6 to 7 inches. Also the loose coupling capacitors would need to be reduced to about 10 pF for phone filters and the coupling capacitors between filter stages for phone filters would need to be reduced to about 200 pF total and the coupling inductors for CW filters would need to be reduced to about ½ the size used for the 20 meter filters considering parasitic inductance.

To modify the 40 meter filters for 80 meters, the 40 meter coils could be reused and shortened by a few turns and capacitors of about 100 pF added mounted and connected to the chamber wall ground and connecting on the other side to the top or hot end of the coil. This arrangement broadens the width of each notch resonator null as a percentage of operating frequency which is appropriate for 80 meters. Such resonating capacitors may need to be rated at 15 kV or higher and 20 kVAR or higher. Simulations with QUCS or other modeling tools are recommended both for frequency response analysis and for induced voltages analysis. The loose coupling caps could either be increased to 60 to 75 pF or eliminated with direct coupling to the cold end of the coil to the circuit (and removal of the ground connection of the coil – see reference [2]). Doubling of the coupling capacitor and coupling inductor values used for 40 meters would be needed for 80 meters. The chambers could be used for kW USLL filters for 160 meters, but more extensive changes would be needed for the coils and coupling capacitors and inductors.

Filter Tuning

The center chamber/resonator was tuned to the notch frequency which was closest in frequency to the transition band, and the end chambers were tuned to the other notch frequencies. A NanoVNA with a PC was used to measure the filter response during tuning. The top plate placed ON/OFF the chamber typically moved the resonator frequency by a few hundred KHz for the 20 meters filter, so it needed to be in place for tuning, but connecting the top plate with sheet metal screws to the chamber usually only moved the frequency a few KHz, so tuning can be done very close to a final frequency by keeping the top plates loose and simply placing them on top of each chamber to measure the filters frequency response as the coil is trimmed and the fine tuning piece adjusted. During tuning, the supporting ½" rexolite rods for the coil was not attached to the chamber but simply rested on the bottom plate, but once tuning was complete, the rods were secured to the bottom plate with a small amount of high temperature epoxy (the epoxy is easily broken).

The center chamber frequency was tuned first. In a first step, 2 to 4 inches of coil was removed at a time to increase the frequency of the coil to slightly above the final desired frequency (with the top plate laid over the chamber for frequency measurements). A small hacksaw can be used to trim the coil. In a second step, a 4 inch piece of copper tubing that had been split open down the tube was clamped to the end of the coil with some overlap with a small stainless steel clamp for the 20 meter filters. By increasing/decreasing the overlap of the 4 inch piece of copper tubing with the coil end, the frequency was fine tuned to within a few KHz. For the 40 meter filters, the final turn of the coil can be easily moved slightly up/down to fine tune the resonator frequency (measured with the top plate in place) and no overlapping piece of copper tubing was used. Once the center chamber was within a few KHz, then the end chambers were each tuned in a similar fashion.   One trick to clearly show the frequency of a single resonator during tuning is to detune the other chambers by temporarily attaching clip leads to the ends of each of the other coils to lower their frequency significantly.

The resonators need to maintain their frequency within a few KHz during operations. It is advisable to measure and adjust the tuning of one of these filters each time it is moved, and to monitor performance during operations with power and SWR meters. Stress testing after construction is also advisable.

Conclusions

Same-band separation of signals on 20 and 40 meters (and other HF bands) is very feasible at 1 kW power levels using USLL filters based on large chamber helical notch resonators. A key benefit of these filters is the suppression of TX and linear amplifier noise from a high power CW transmitter in nearby phone band segments by 20 to 40 dB and vice versa. The large chambers and coils are low cost constructed of aluminum sheet metal and refrigeration copper tubing. However, commercially available high Voltage and current RF capacitors are needed. These filters can significantly reduce same-band interference on 20 and 40 meters for QSO parties and Field Day when using 1 kW TX power levels or lower TX power levels.

Filters to Separate Same Band Signals at 1 KW

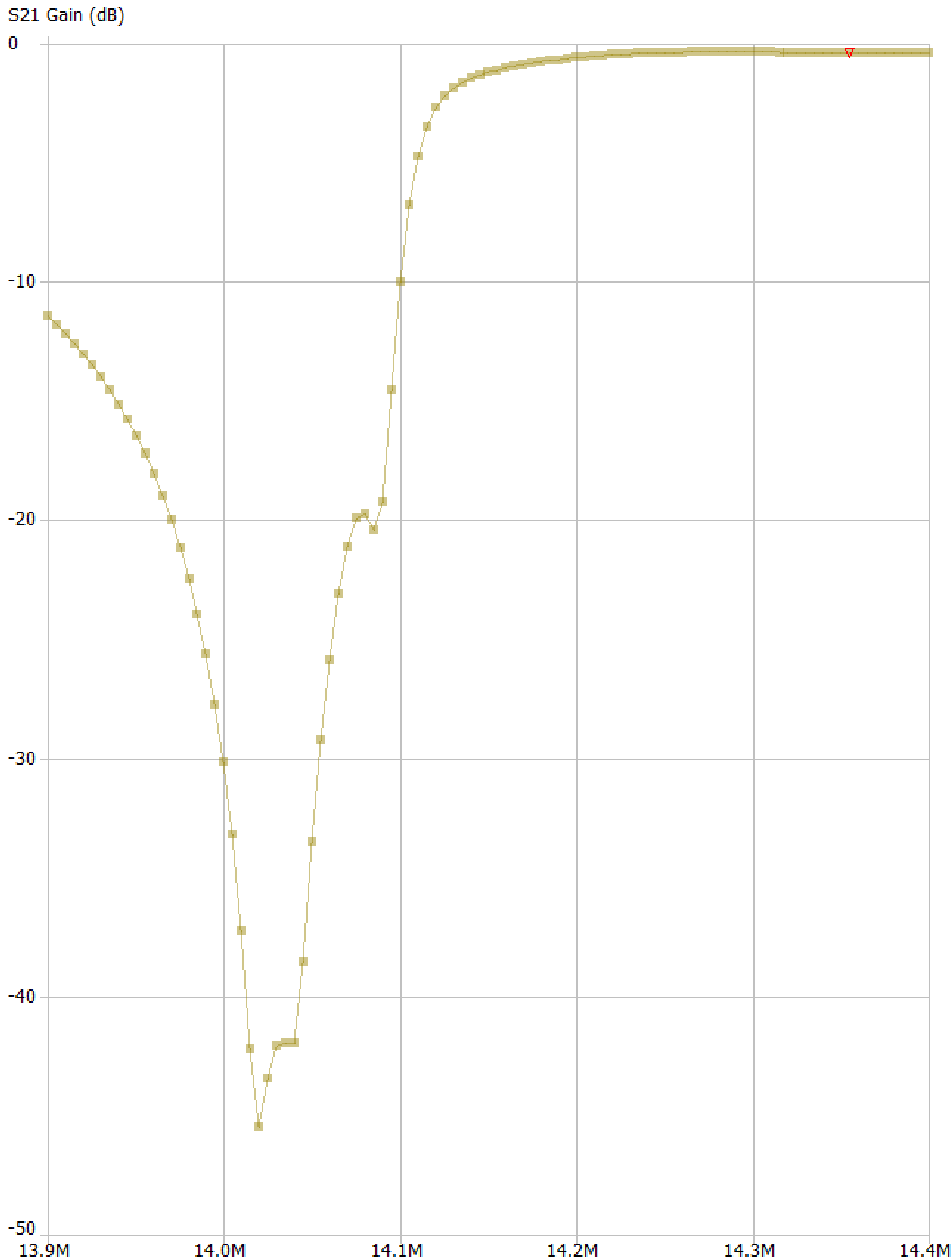

Figure 1 – 20 Meters Phone Filter Measured Response

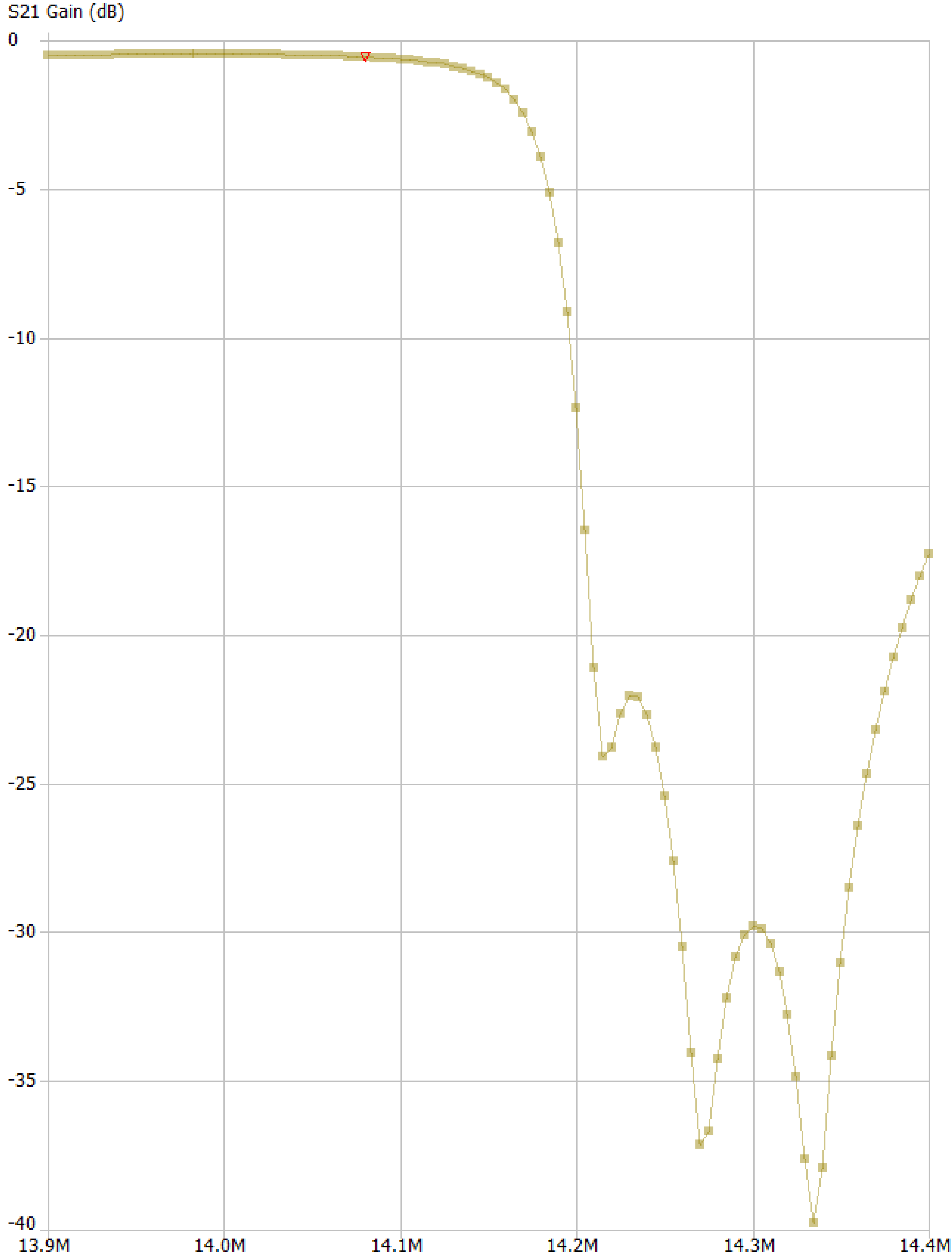

Figure 2 – 20 Meters CW Filter Measured Response

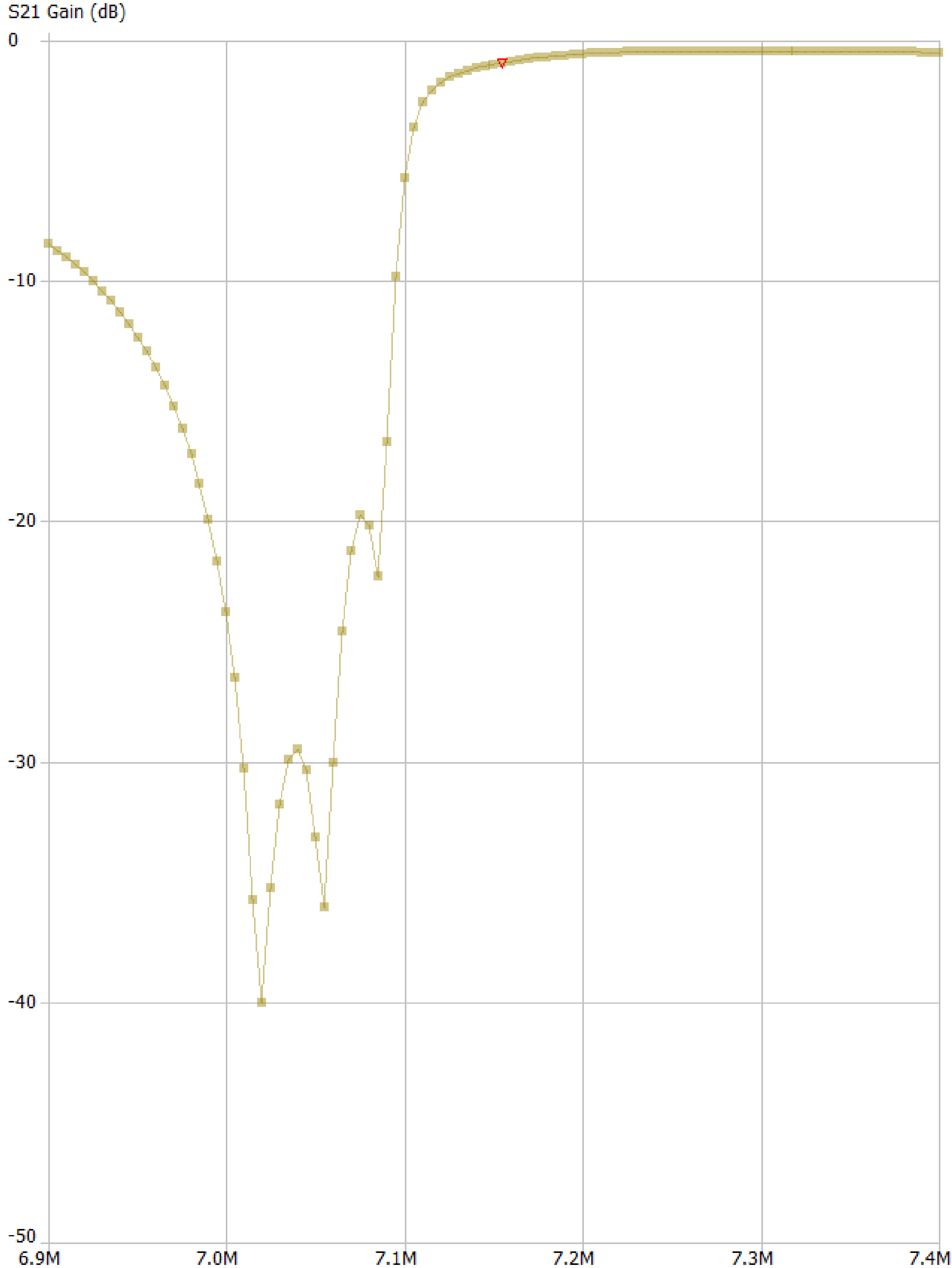

Figure 3 – 40 Meters Phone Filter Measured Response

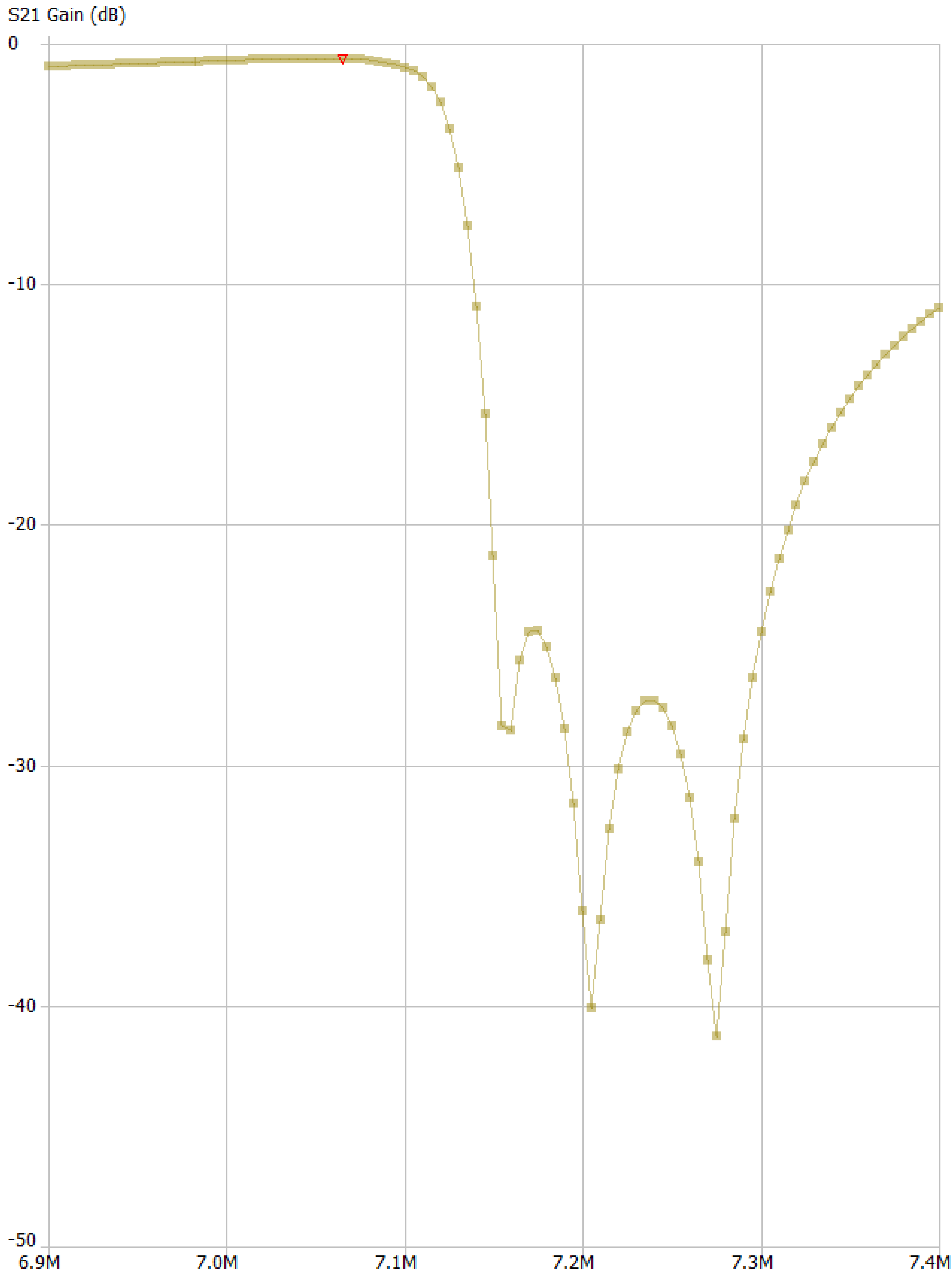

Figure 4 – 40 Meters Phone Filter Measured Response

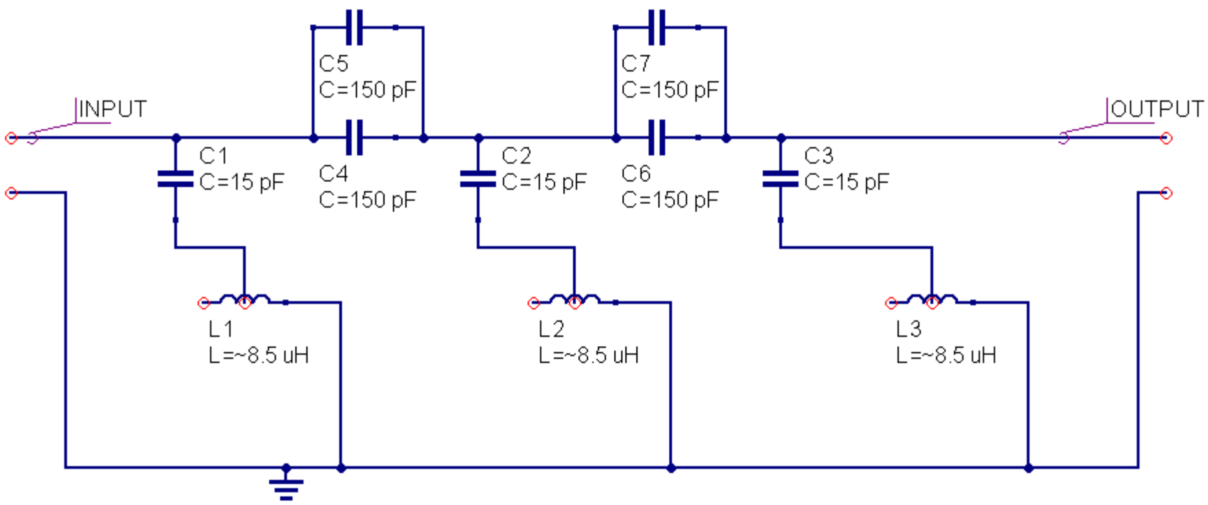

Figure 5 – 20 Meters Phone Filter Schematic

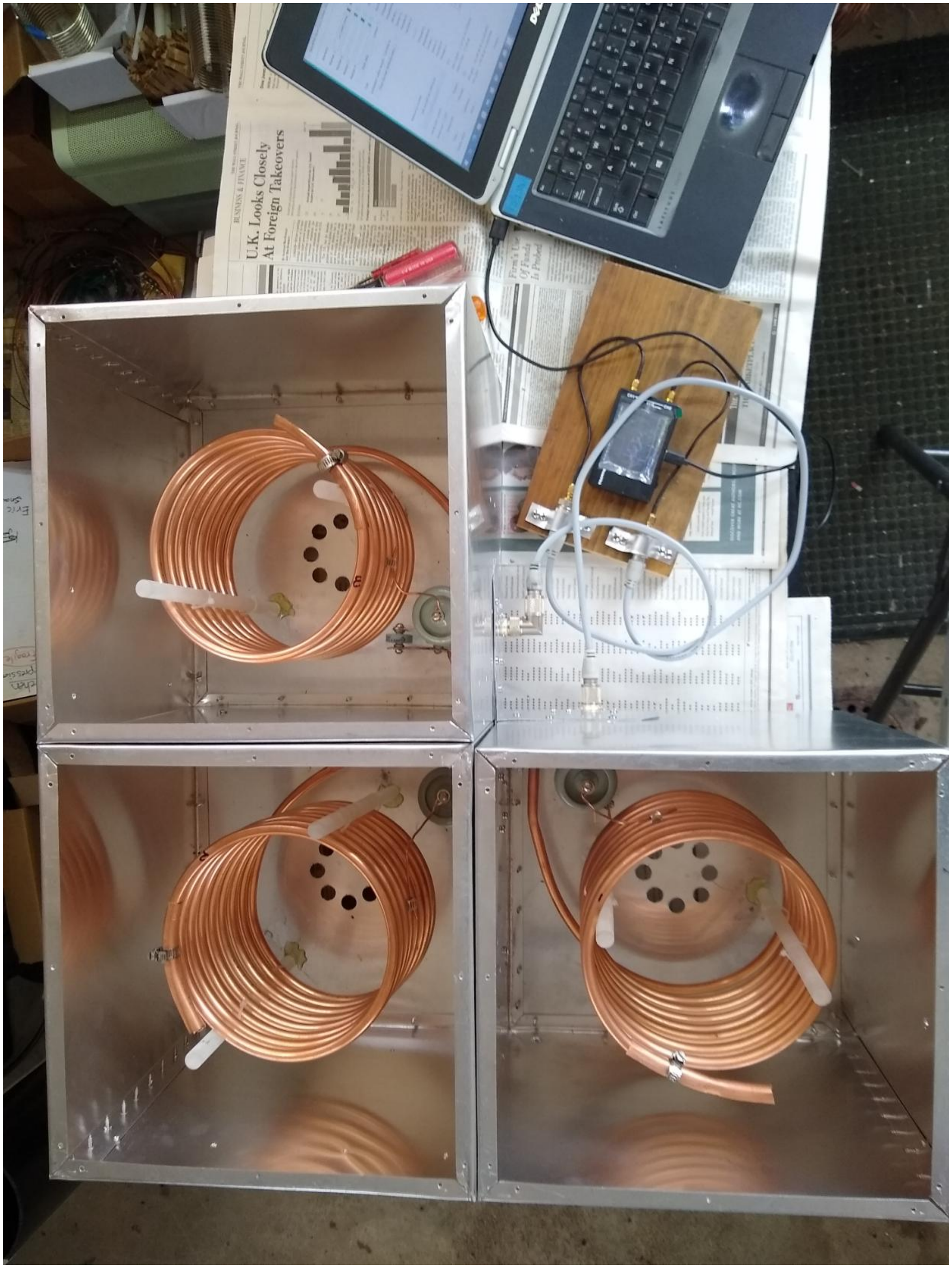

Figure 6 – 20 Meters Phone Filter with 3 Large Chambers

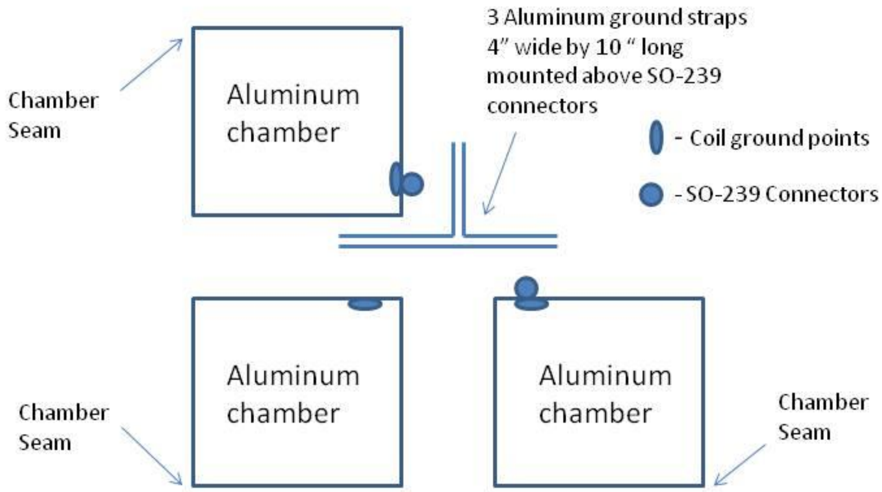

Figure 7 – Ground Straps Between Chambers

Figure 8 – Center Chamber Coupling and Ground

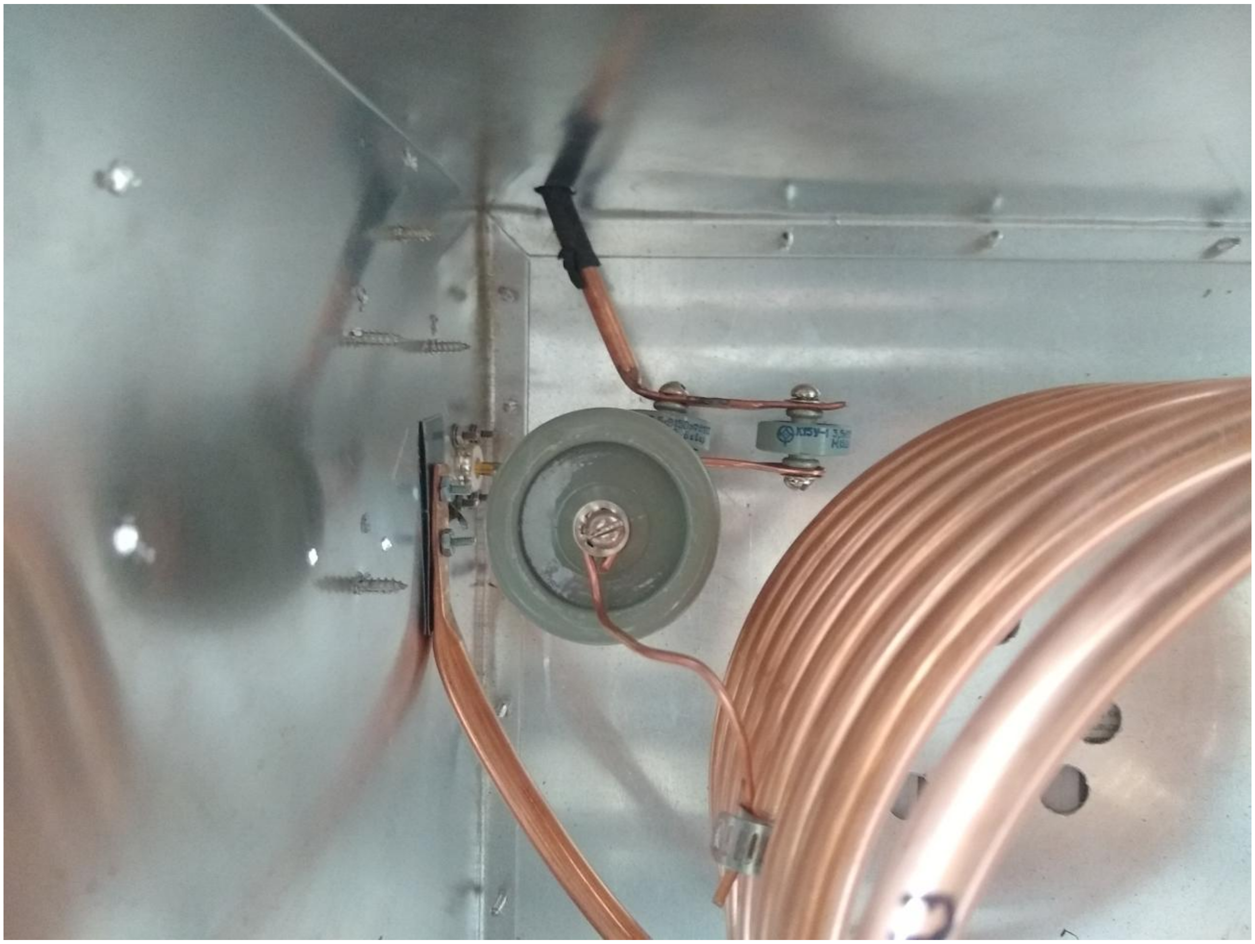

Figure 9 – End Chamber Coupling and Ground