Improvements for Transverters with Pipe-Cap Filters
And Multiplier PC Boards As Well

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Recently, while developing the QBeacon boards for Q65 beacons[1], Tom, WA1MBA found some nice pins from Mouser that are perfect input and output probes for the ½ inch pipe-cap filters[2] at 8 to 12 GHz, also used in the Simple and Cheap 10 GHz Transverter[3]. The Mill-Max pins, Mill-Max 5068-0-00-15-00-00-03-0 (Mouser #575-5068000150000000, Digikey 54-5068-0-00-15-00-00-03-0-ND), have a nail head so the head sits flat on the board for perfect alignment – with a small amount of solder, capillary action pulls the nail head flat so the pin stands up straight. The diameter slips nicely into the plated-thru hole in the board. They are gold plated for easy soldering and the flat head also eliminates a solder bump over the probe that adds a bit of loss.

Tom also found some longer Mill-Max pins that work well at lower frequencies with the larger pipe caps used in the 2.3, 3.4, and 5.76 GHz transverters, and in the multiplier PC boards.

½ inch Pipe-cap Filters

The new Qbeacon PC boards have a bit longer transmission lines in a couple of places, so I was able to chop one up with enough line to fit SMA connectors next to the pipe caps and make some filter bandwidth measurements. Figure 1 shows the bandwidth at 10 GHz for a range of probe lengths including the Mill-Max 0.172” pins that make a 0.135” probe..

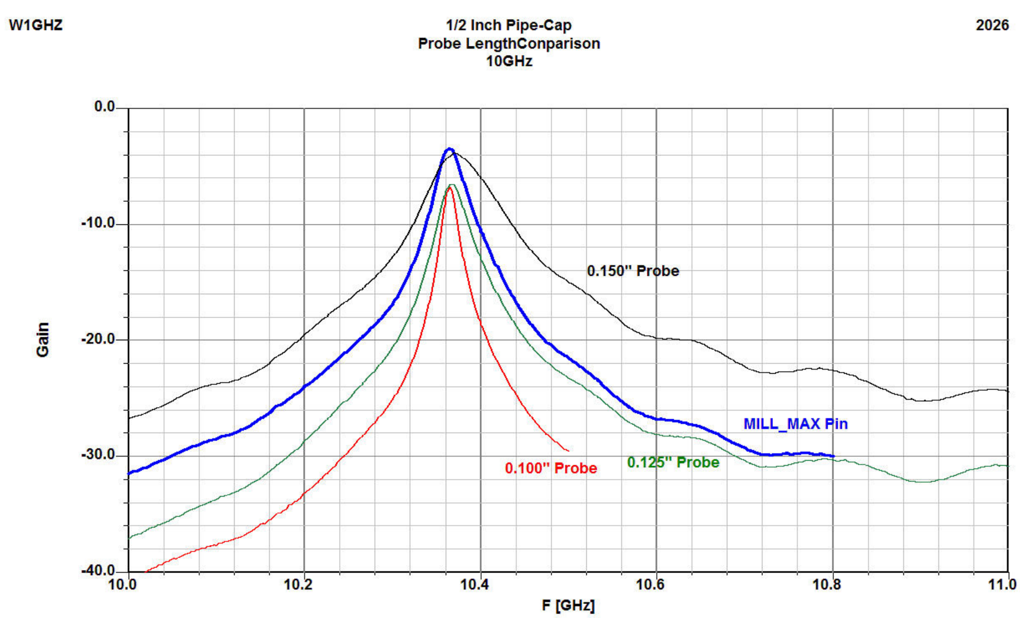

Figure 1 – ½ inch pipe-cap filter response with varying probe length at 10 GHz

The losses are probably a bit high since I was using cheap SMA connectors, but that shouldn't affect the bandwidth. Another factor is that the pipe-cap is only clamped to the scrap of PC board, with a chunk of foam on the circuit side for support. This arrangement allows for multiple pipe-caps tuned to different frequencies and for easy changes of probe length by starting long and trimming – data was not taken in the order shown. Probe length was controlled by taking a small pad of Post-It notes, removing pages until the pad was the desired thickness, then using the pad next to the pin as a spacer for flush-cutting wirecutters – see Figure 9. All ½ inch pipe-caps are tuned with 4-40 brass screws.

With the Mill-Max pins, the 3 dB bandwidth is roughly 35 MHzat 10 GHz, and the LO rejection 144 MHz away is about 20 dB. Two pipe-caps surrounded by amplifier stages form a synchronous filter with twice as much rejection; 40 dB should be adequate for a transverter. The Qbeacon board has three pipe-caps surrounded by four amplifier stages for even more LO and image rejection.

While I was testing, I tried even shorter probes, shown in Figure 2. The filter gets even sharper, but loss goes up considerably. The Mill-Max pins seem to be near the sweet spot. Even longer pins, not shown, provide wider bandwidth and very little LO rejection.

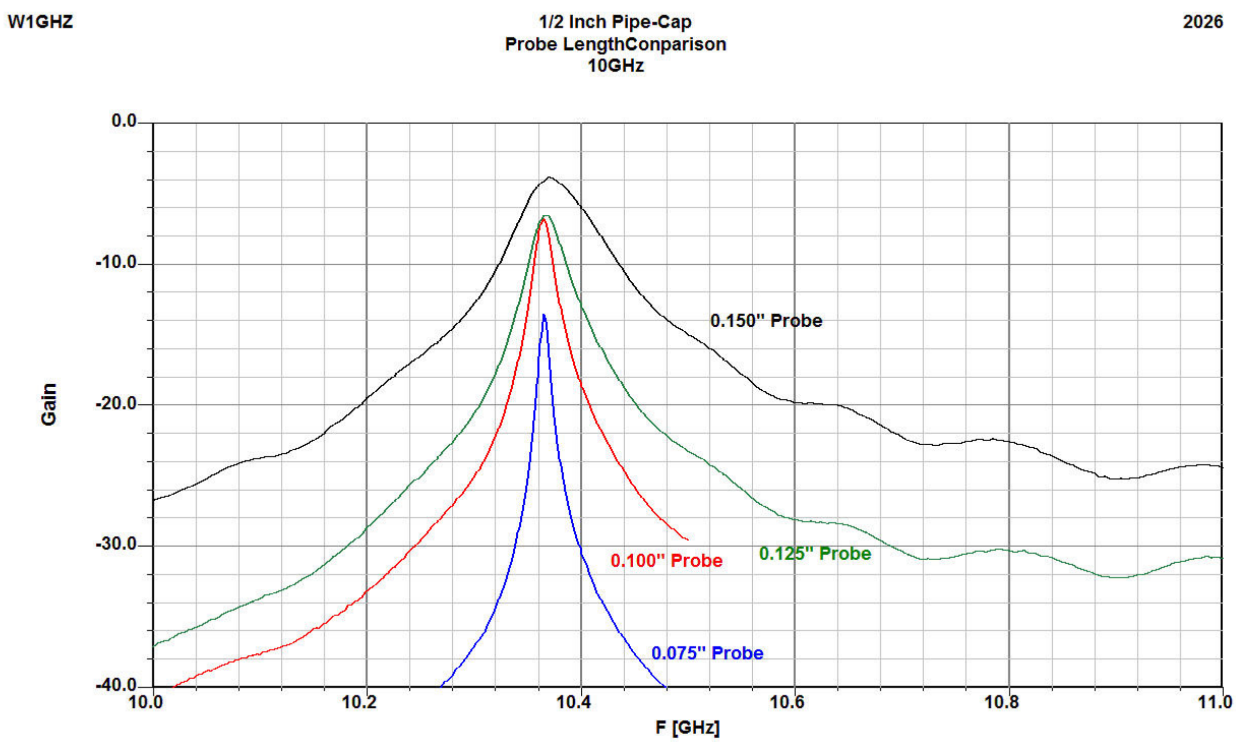

Figure 2 – ½ inch pipe-cap filter response with short probe lengths at 10 GHz

12 GHz

The Qbeacon board is intended for 24 and 47 GHz beacons as well, multiplying up from near 12 GHz, so the pipe-caps were retuned for 12 GHz and measured. Results in Figure 3 show the Mill-Max pins work well, with about 3 dB bandwidth of about 100 MHz. LO rejection is not good enough for a 2-meter IF, but fine for 432 MHz IF, which was Tom's goal.

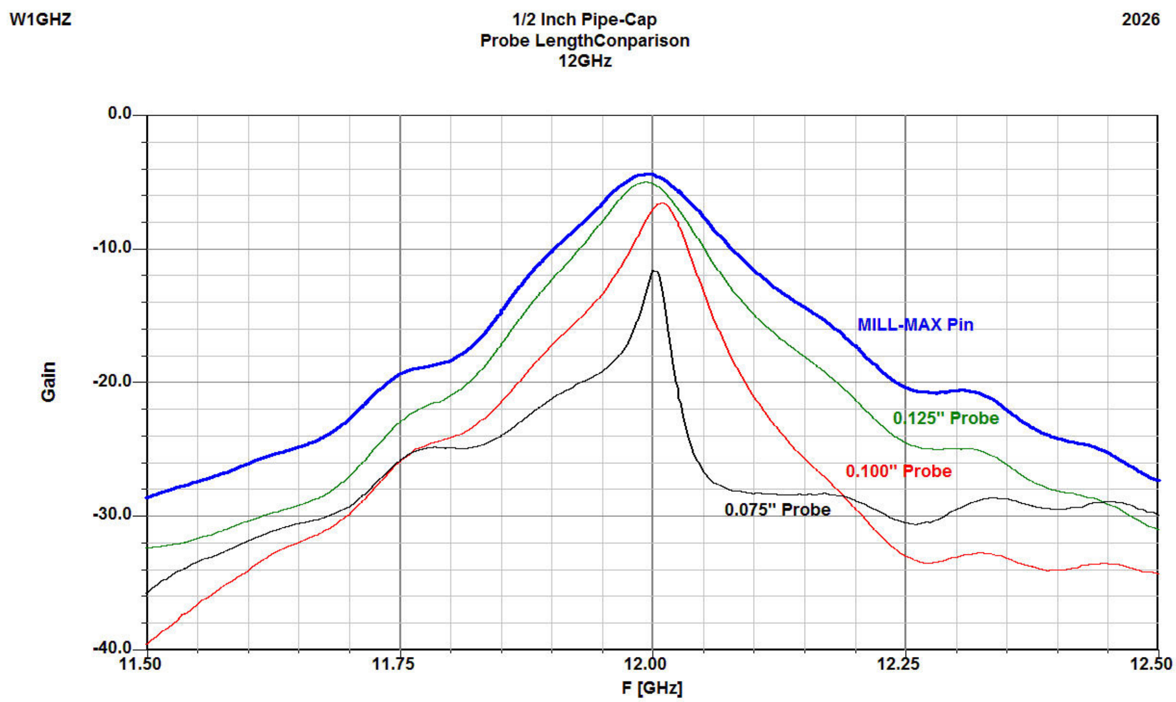

Figure 3 – ½ inch pipe-cap filter response with varying probe length at 12 GHz

5760 MHz

One of my 10 GHz transverter boards was retuned to use at 5760 MHz by Don, W1FKF, so I knew they could be tuned that low. I ran the screws way in one of the pipe caps and took data at 5760 with the longer probes – I started with long probes and trimmed them rather than changing them. Figure 4 shows the plots. The Mill-Max 0.172" pins (0.135" probe) might do a good job of LO and image rejection for a 144 MHz IF, but turned out to be too sharp to tune up three stages in the Qbeacon board. Using a longer pin, 0.175 long, worked much better, with easier tuning and excellent LO and Image rejection, both moer than 50 db down. . At this frequency, cheaper MMICs that are readily available have good gain – *Gain is Cheap*.

The next longer MILL-MAX pins, 7113-0-00-15-00-00-03-0, are 0.211" long, for a 0.180" probe on the 0.031" thick PC board. This is very close to the 0.175" probe length and provides a slightly narrow response curve in Figure 4, probably because the diameter is slightly smaller than the capacitor lead used for the pin – this is capacitive coupling.

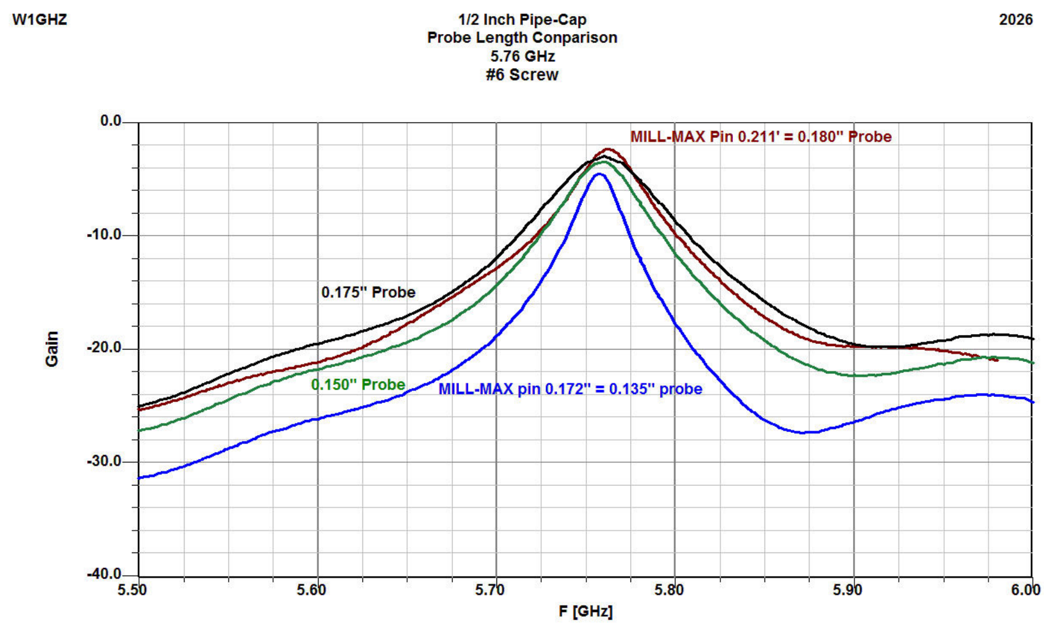

Figure 4 – ½ inch pipe-cap filter response with varying probe length at 5760 MHz

8.2 GHz

While tuning down to 5760, it occurred to me that the 10 GHz transverter can be used as a receive-only converter for 8.2 GHz space communications. Freddy, ON6UG, has received the NASA MARS orbiter on a 1-meter dish. So pipe-cap data at 8.2 GHz in Figure 5 might be useful:

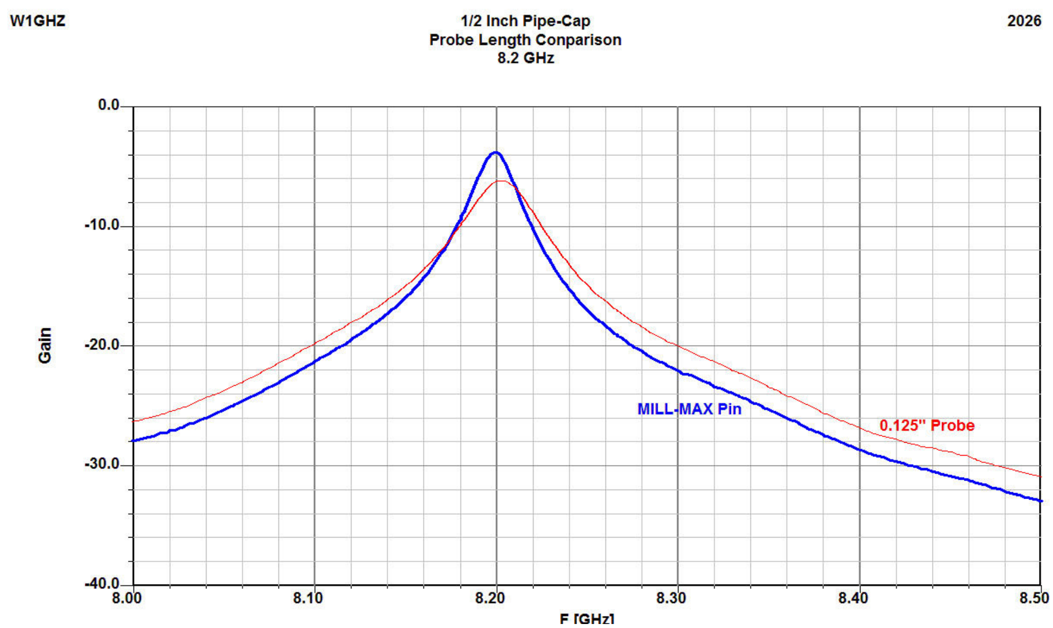

Figure 5 – ½ inch pipe-cap filter response with varying probe length at 8.2 GHz

Upper Frequency Limit

Finally, Zack, W9SZ, wondered how high in frequency the ½" pipe-cap would work. Just a matter of turning the screw out. The highest frequency curve, just below 14 GHz, is with the tuning screw removed completely.

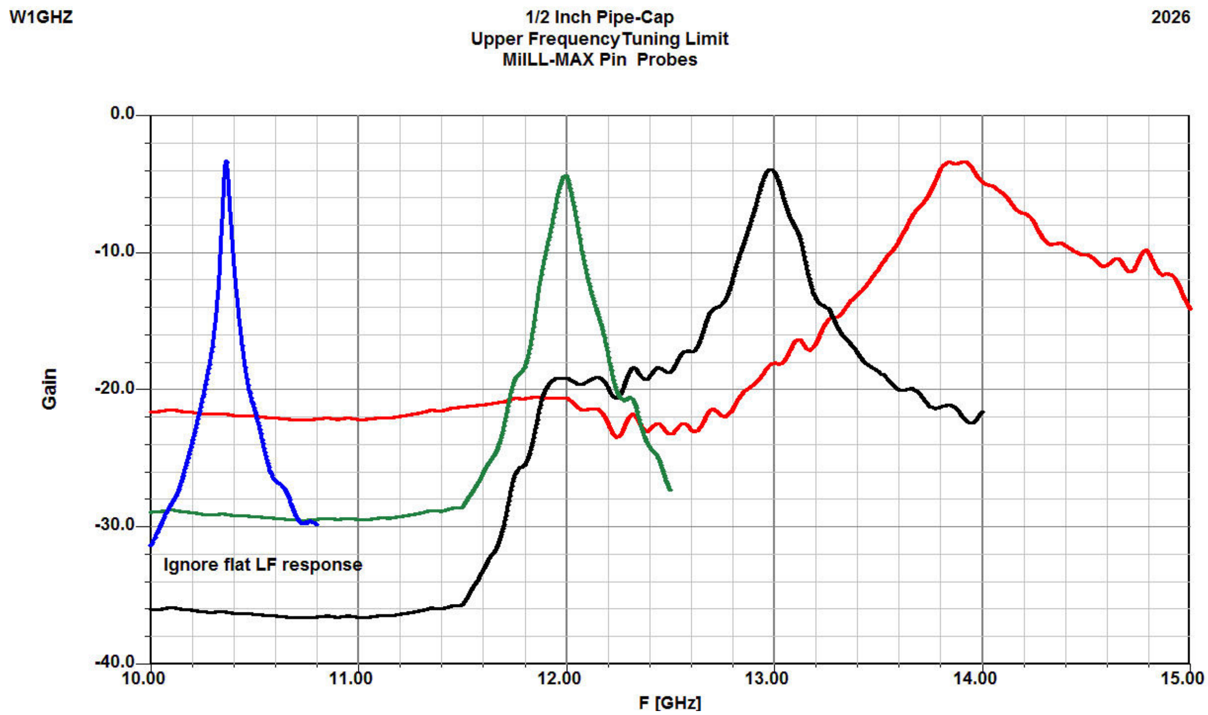

Figure 6 – ½ inch pipe-cap filter response at higher frequencies

Pre-tuning the ½" pipe-cap filters

The pipe-cap filters are quarter-wave resonators, with the tuning screws acting as the resonator. Setting the tuning screws in the pipe-cap filters to approximately the right depth will make transverter tuneup easier. I recorded the following screw lengths inside the pipe-cap. Then setting the screws is just adjusting the length outside the cap to the screw length minus the inside length and wall thickness.

Frequency	Length inside
5.76 GHz	0.375 inch
10.368	0.165
12	0.150

Absorber

All microstrip transmission lines have some radiation. When they are enclosed in a metal enclosure, this creates coupling between stages, so that the filters are not as effective and LO and image rejection is not as good. Most of the effect is from the metal surface above the transmission lines. Tom tried putting expensive microwave absorber material on all surfaces of a metal box with good results. Looking for an available affordable alternative, he found some EMI Absorber material on ebay from TOJOIN.   The stuff has adhesive backing, and adding it on just the metal surface above the transmission lines is as effective at 10 GHz as doing the whole box. Two sheets of 2mm thick absorber for about $20 should last most of us a lifetime.

Longer Pins

The 10 GHz Mill-Max pins are too short to use at 5760 MHz with the ½ inch pipe-caps – tuning is too sharp and critical. Lower frequencies and larger pipe-caps also need longer pins, though the length is probably less critical. I previously used capacitor leads as longer probes, ideally with the same lead spacing as the hole spacing for the probes. To set the length, I measure the distance needed from the capacitor body to the PC board that would produce the desired probe length, and use a drill bit of that diameter to set that distance, as shown in Figure 7.

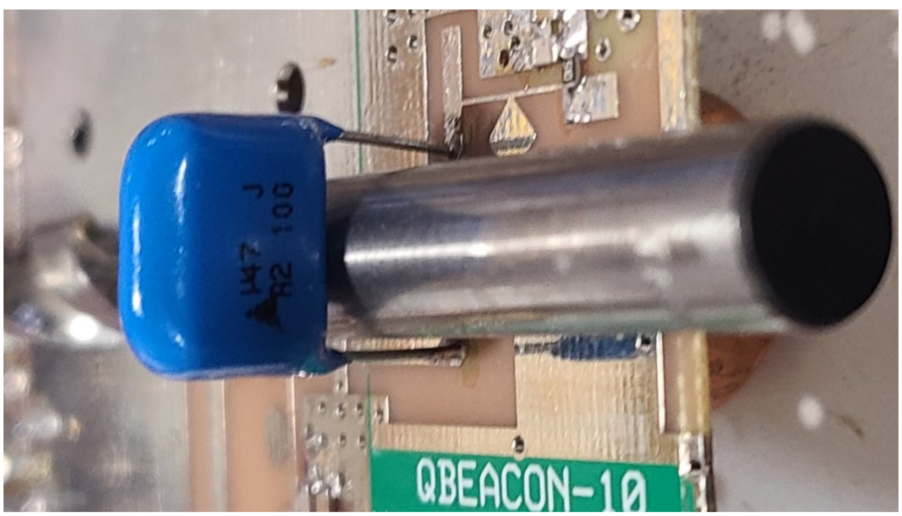

Figure 7 - Setting probe depth by using a drill bit as precision spacer

The longer Mill-Max pins with pin length = 0.211 inches are available – see Table 1. With a 0.031" thick PC board, these have a probe length inside the pipe-cap of 0.180 inches, with performance in Figure 4 comparable to the 0.175' probes in Figure 4. They should be ideal for a 5760 MHz Qbeacon board with ½ inch pipe caps.

Other longer Mill-Max pins are available which work well in transverters for bands below 10 GHz. Table 1 lists the pins that we have been able to find available at Mouser and Digikey

¾ Inch Pipe Cap Filters

The ¾ inch pipe caps are used over a range of frequencies: in the 5760 MHz transverter, as in intermediate-stage at 3456 MHz in the 10 GHz Personal Beacon, and in the Multiplier and Personal Beacon board for 5760, 3400, and 2304 MHz, at frequencies as low as 2.8 GHz. I have specified 8-32 tuning screws for all of them.

At 5.76 GHz, I started with the longer Mil-Max pins: 0.300" long pins which result in 0.235' (measured) probes inside the pipe cap, and the 0.475' long pins, which relust in 0.406' probes inside. As shown in Figure 8, the 0.235" probes produce a rather sharp filter response while the 0.406' probes produce a broad response with little rejection. Some intermediate length is needed, and Mill-Max probably makes one, but we couldn't find any in the Mouser or Digikey catalog.

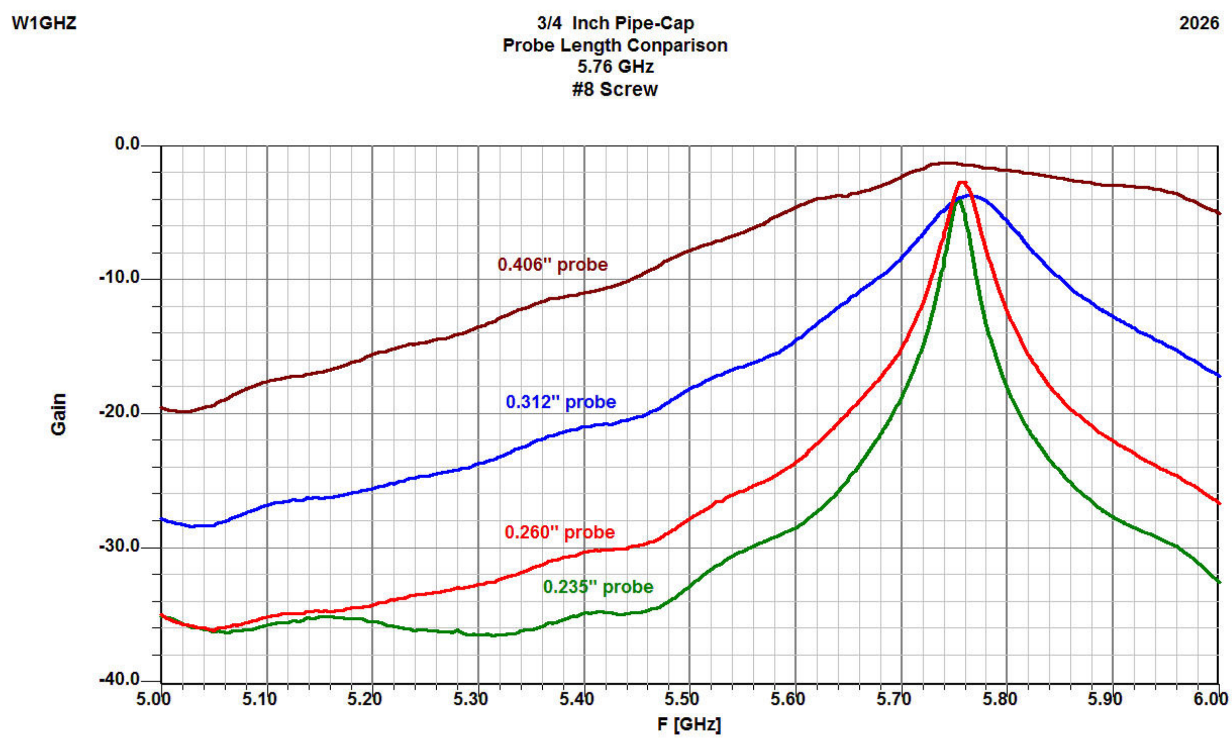

Figure 8 – ¾ inch Pipe-Cap at 5.76 GHz – Probe length comparison

To make an intermediate length pin, cut a longer one to the desired length, as shown in Figure 9. Make a shim for the desired length using Post-it notes, peeling off sheets until the desired length is reached. Insert the pin into the transverter board, or a scrap board if you have already started assembly, and cut it to length using a flush cutter with the Post-it pad controlling the length.

Figure 9 – Cutting Mill-Max pins to length using Post-It spacer

I made pins with length of 0.312", halfway between the available Mill-Max pins, which still seem to produce a somewhat broad response. Then I trimmed shorter pins, 0.260" long, slightly longer than the shorter one. These provide a nice curve, with the LO frequency of 5616 MHz about 20 dB down,

At 3.4 GHz, I made plots with the same probe lengths. Figure 10.. The short probe, 0.235" inside the pipe cap, is rather sharp, while the long probe, 0.406", is again rather broad. The intermediate 0.312" length looks about right for this frequency, about 20 dB down at the LO frequency, 3256 MHz.

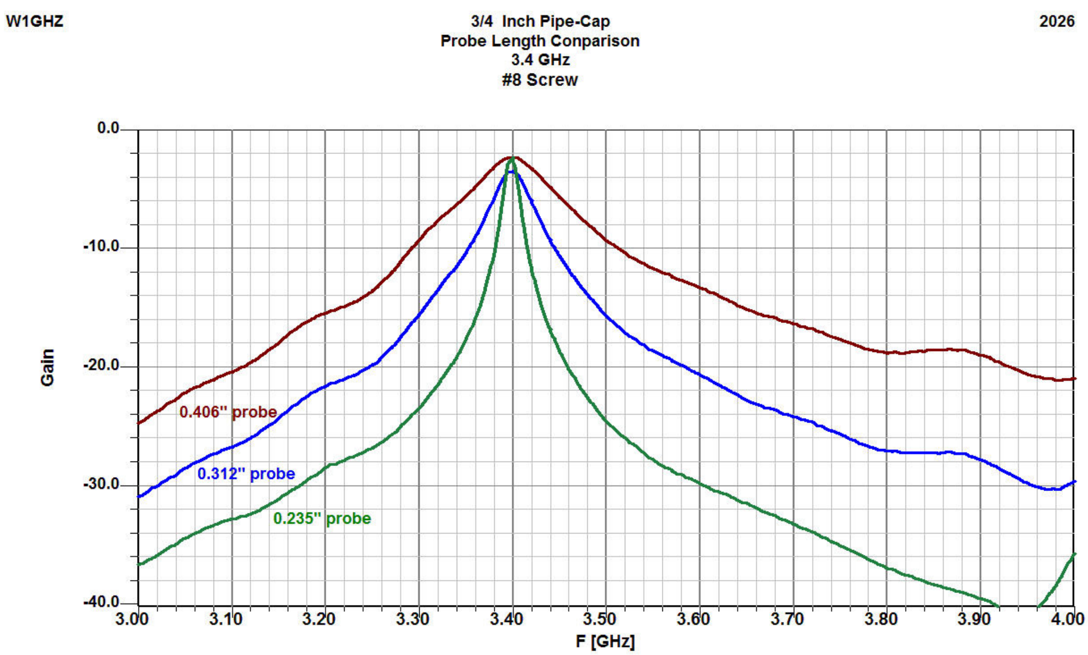

Figure 10 - ¾ inch Pipe-Cap at 3.4 GHz – Probe length comparison

At 2.8 GHz, in Figure 11, the long Mill-Max probe, 0.406" long inside the pipe cap, is about right, especially in a multiplier chain where harmonics probably have wider spacing so filtering is easier. If a sharper response is needed, the shorter pin lengths should be adequate.

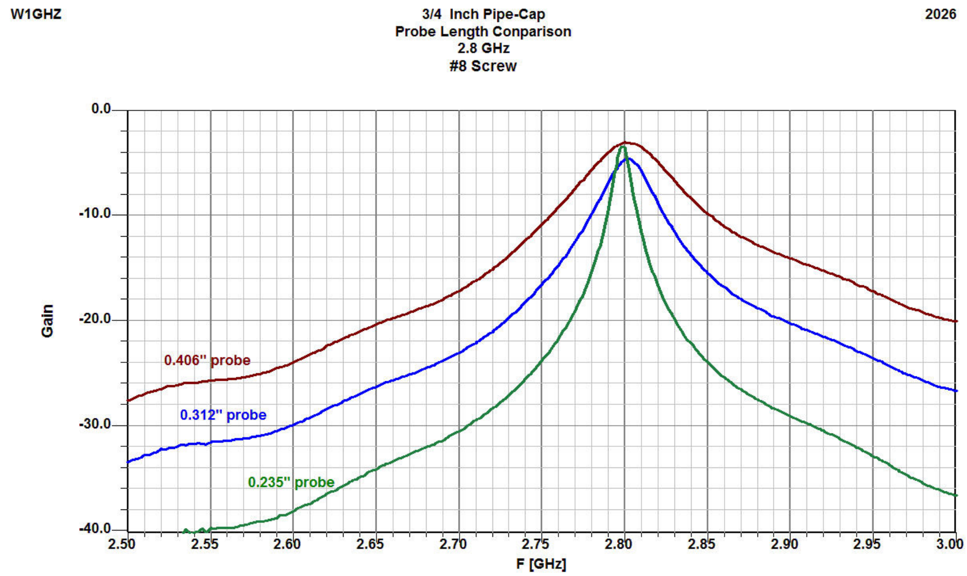

Figure 11 - ¾ inch Pipe-Cap at 2.8 GHz – Probe length comparison

What we can see in Figures 8 thru 11 is that longer probes are needed at lower frequencies for the same bandwidth. The whole tuning range for a ¾" pipe cap tuned with an 8-32 screw is plotted in Figure 12 with probe lengths that I would consider good for each frequency. If another frequency within the tuning range is desired, it should be possible to interpolate for a usable probe length.

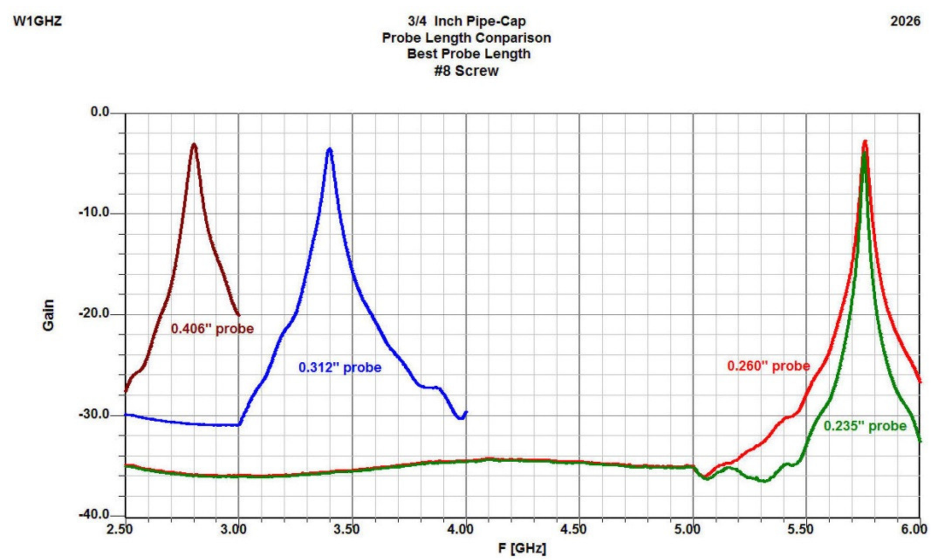

Figure 12 – ¾ inch Pipe-cap tuning range with best probe lengths

¾ inch Pipe Cap Filter with 6-32 screw

While I was rounding up pieces for these experiments, I found a ¾" pipe cap threaded for 6-32. Since some folks might have difficulty sourcing an 8-32 and perhaps use a metric approximation, I tested with this version also. The pipe cap is clamped in place in the test fixture so it was an easy swap.

The 3/4" pipe cap with 6-32 tuning screw tuned to 5760 MHz response is shown in Figure 13. Bandwidth for each probe length is comparable to the 8-32 tuning screw in Figure 8, but the curves fall off a little more slowly at frequencies above resonance. Losses with shorter probes appear significantly higher.

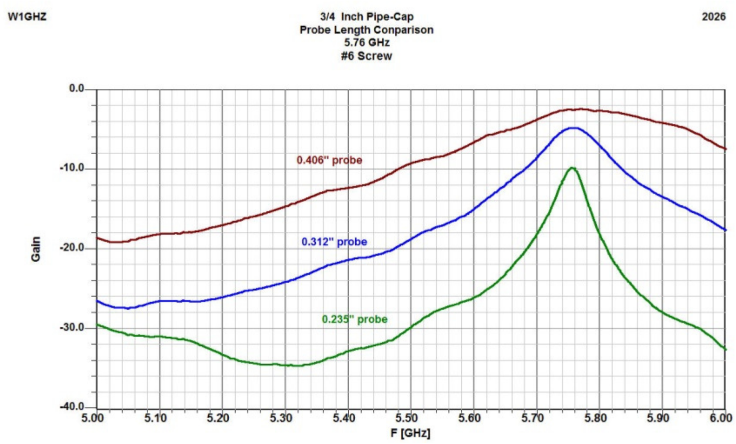

Figure 13 - ¾ inch Pipe-Cap with 6-32 screw at 5.76 GHz – Probe lengths

The 3/4" pipe cap with 6-32 tuning screw tuned to 3400 MHz response is shown in Figure 14. Response for each probe length is comparable to the 8-32 tuning screw in Figure 10, so the tuning screw size is not critical in this frequency range.

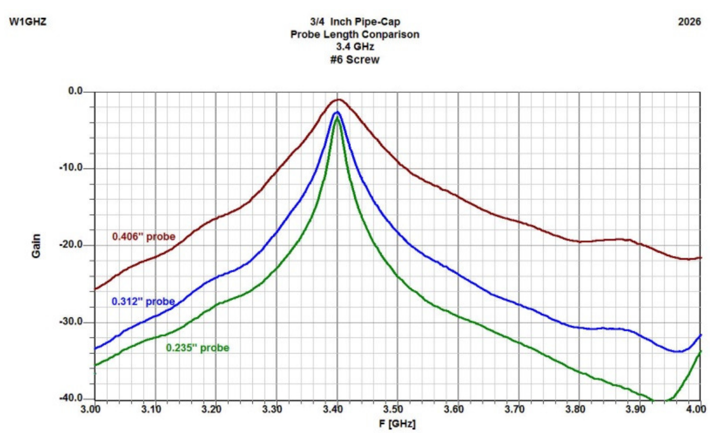

Figure 14 - ¾ inch Pipe-Cap with 6-32 screw at 3.4 GHz – Probe lengths

With the 6-32 tuning screw, a ¾" pipe cap would not tune down to 2.8 GHz

1-inch Pipe Cap Filters

1 inch pipe cap filters area used in the transverters for 2.3 and 3.4 GHz and tuned with a 10-32 brass screw. I started with the longest Mill-Max pin, for a 0.406" probe. The response at 3.4 GHz looks just about right, 20 dB down at the LO frequency, 3.256 MHz.

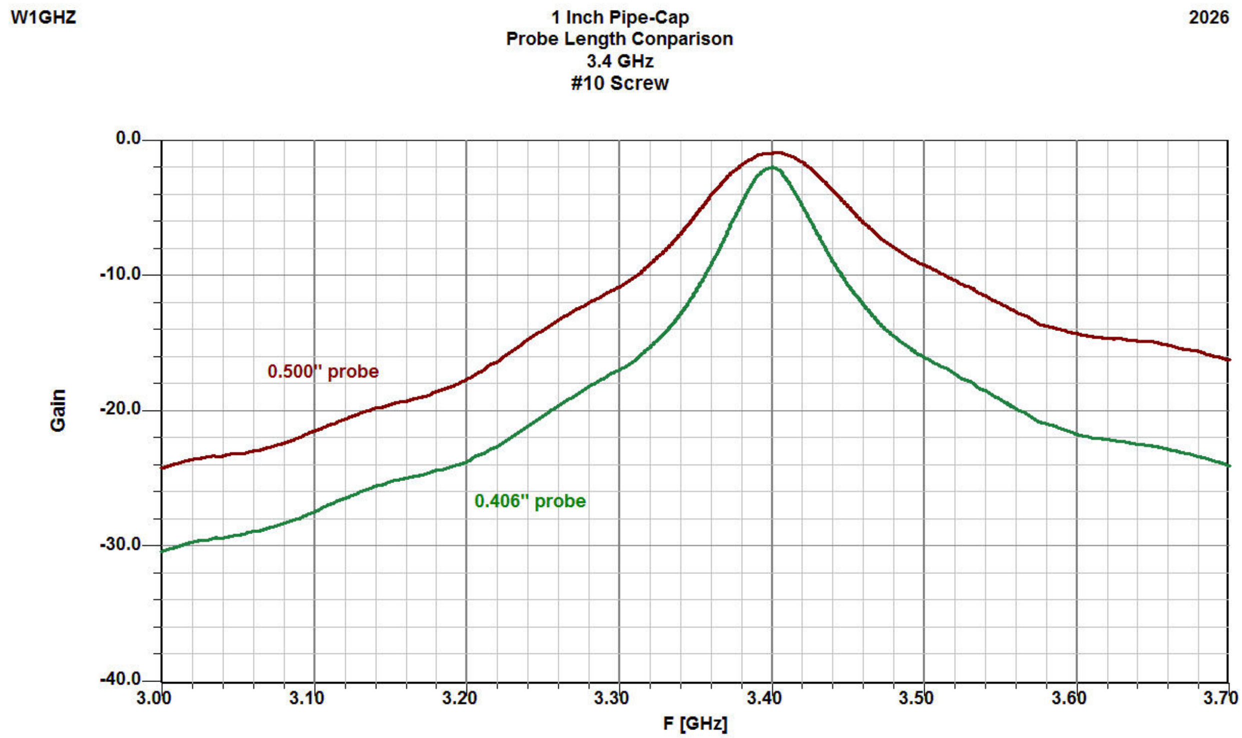

Figure 15 – 1 inch Pipe-Cap at 3.4 GHz – Probe length comparison

The response at 2.3 GHz in Figure 16 is rather sharp with the 0.406" probe, so I tried a longer 0.500'" probe as well. The longer probe is a capacitor lead, with length set as shown in Figure 7. The response is still pretty sharp, but it tunes smoothly, and narrow bandwidth is important in this band with all the WiFi crap.

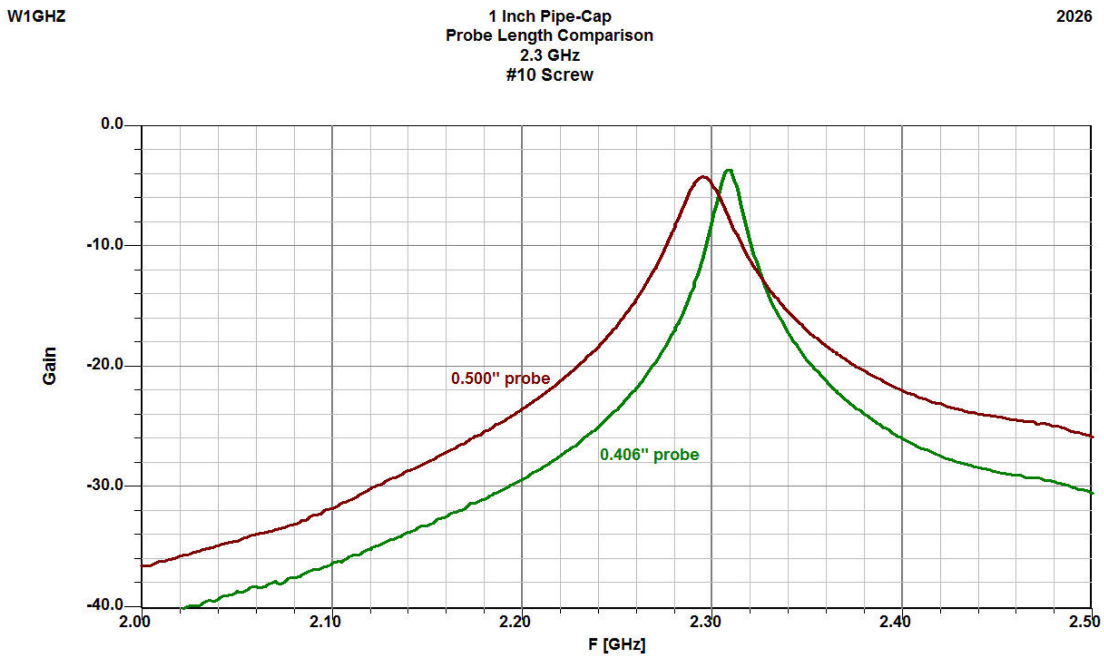

Figure 16 – 1 inch Pipe-Cap at 2.3 GHz – Probe length comparison

The 1" pipe caps might be useful for some future possibilities like LO multipliers, so I also measured the response at 2.1 GHz, in Figure 17, and 2.8 GHz, in Figure 18. The response at 2.1 GHz seems a bit sharp with some loss, so it would probably benefit from a somewhat longer probe.

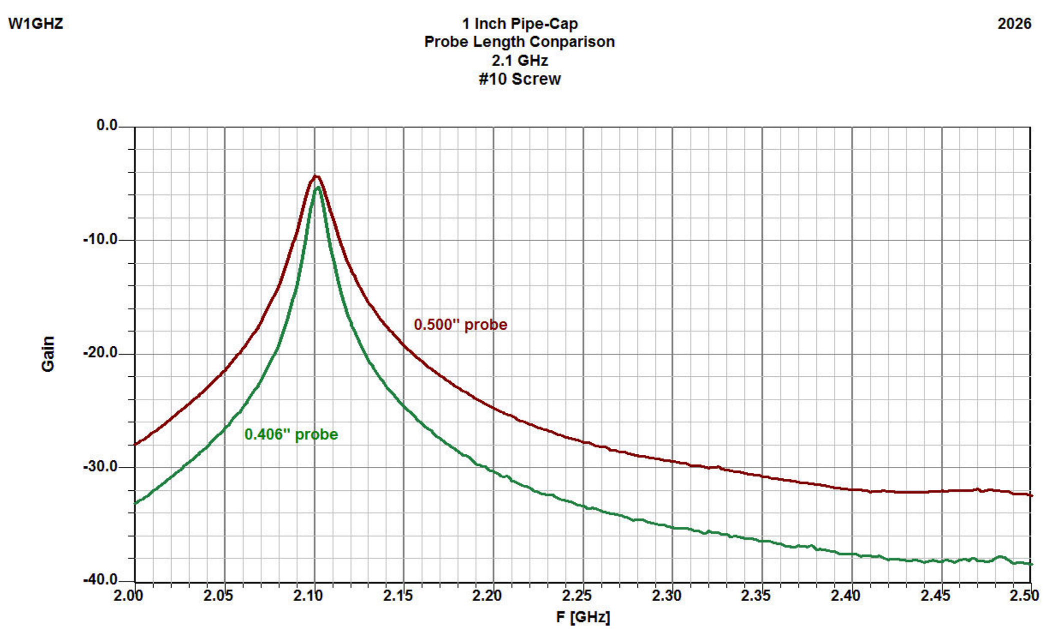

Figure 17 – 1 inch Pipe-Cap at 2.1 GHz – Probe length comparison

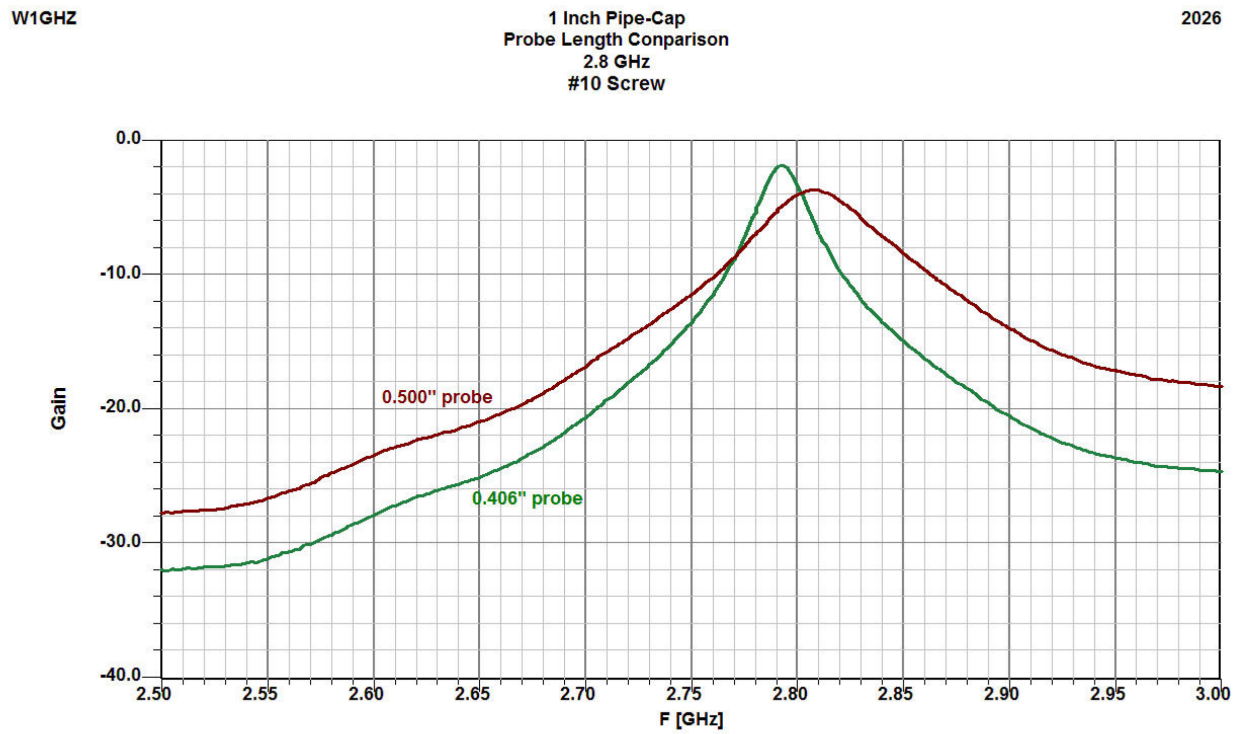

Figure 18 – 1 inch Pipe-Cap at 2.8 GHz – Probe length comparison

Measurements and Test Fixture

The pipe caps were tested on an HP8722C VNA using the test fixture shown in Figure 19. The pipe cap is clamped to a small section of PC board cut from the appropriate transverter, so the configuration is the same as the transverter, with the probes projecting through small holes at the end of transmission lines. The transmission lines are separated from the fixture with foam for minimal effect on RF performance. A spacer block at the other end keeps the top and bottom of the fixture parallel for even clamping on the pipe cap, and a small clamp applies pressure. The tuning screw is accessible so different frequencies may be tested with one setup.

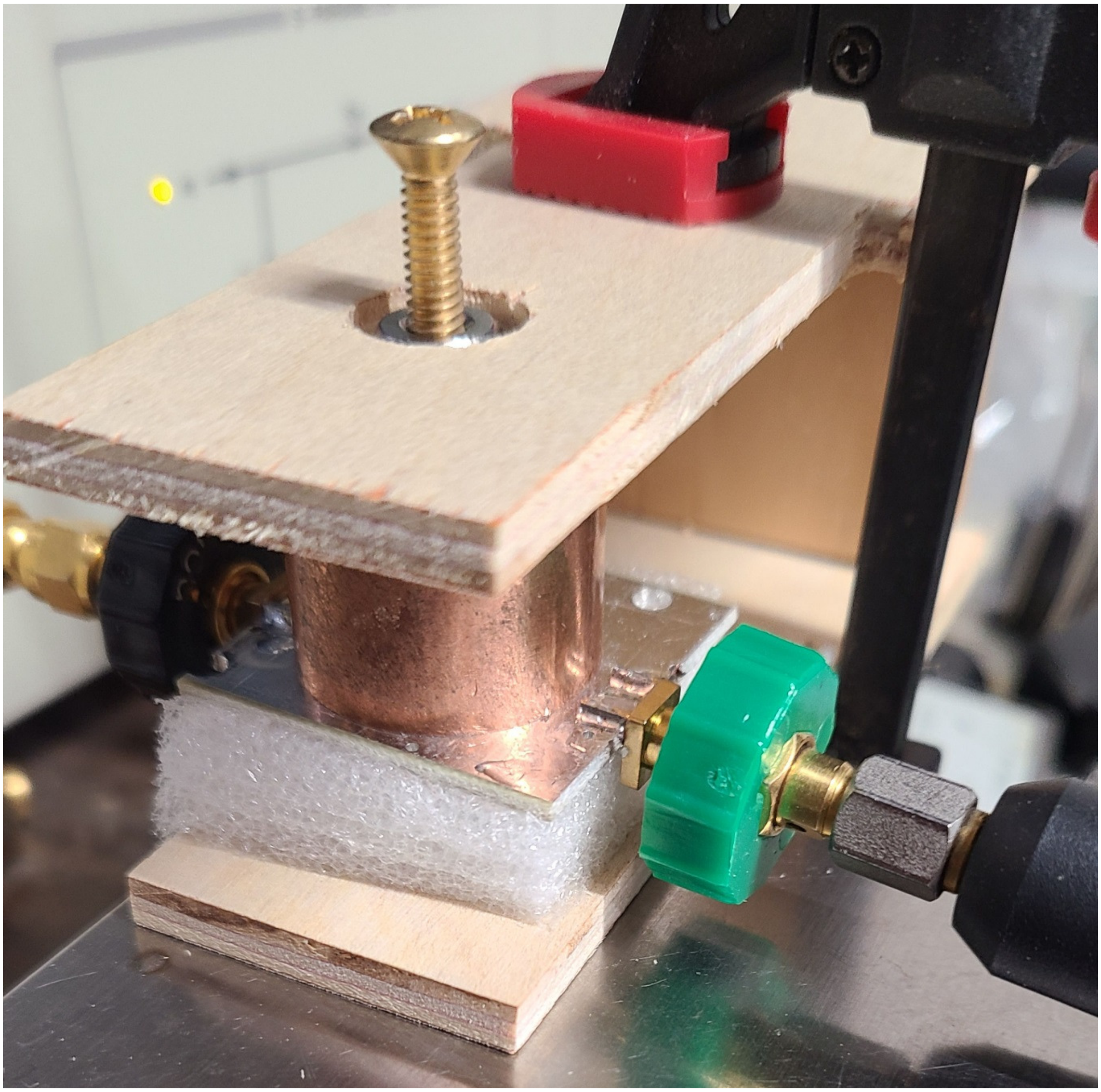

Figure 19 – VNA Fixture for measuring Pipe-Cap filter bandwidth

Measurements were made with small frequency steps to accurately capture filter bandwidth. The ancient VNA does not have enough memory for full calibration over a wide frequency range, so insertion loss is compared to an SMA F-F through connector. Thus, losses shown in the response curves are approximate and differences of a dB or two can be ignored; again, the goal is to capture the bandwidth with various probes.

Special thanks are due to John Miles, KE5FX. His KE5FX VNA Utility[4] is the only way to get meaningful amounts of data out of the ancient VNA, through the GPIB bus. The VNA doesn't even have a floppy disk drive.

Loss in the pipe-cap filters is not very important. The transverters all have alternating amplifiers and pipe-cap filters, which helps both work well. The amplifiers isolate the filters from each other, so that there is little tuning interaction, and all can be tuned to the same frequency or stagger-tuned for more bandwidth – this was called a synchronous amplifier in the TRF receiver days. The pipe-caps provide a bit of loss between the amplifiers, reducing interaction and impedance mismatch, and making them more stable – Rick, KK7B, pointed this out. Remember: *Gain is Cheap*.

Tuning Screws

All the tests use brass screws threaded directly into the pipe caps, locked down with KEP nuts (integral lock washer). The KEP nuts allow easily adjusting tension on the screw: firm to allow smooth tuning and tighter to lock.

Some hams have gone to the trouble of soldering nut on top of the pipe-cap for stronger threads. I have not found this necessary – the threaded copper works fine even with multiple tuning during these tests. And Down East Microwave has sold hundreds of transverters with threaded pipe caps.

Summary

The Mill-Max pins have a nail head so the head sits flat on the board for perfect alignment, and the diameter slips nicely into the plated-thru hole in the board. They are gold plated for easy soldering and the flat head also eliminates a solder bump over the probe that adds a bit of loss.

Using the Mill-Max pins as probes makes transverter assembly easier and better controlled, with more predictable performance, and pre-tuning should make tuneup easier at the higher frequencies, particularly for those hams without extensive test equipment. The data here should allow you to choose the best probes for your transverters. Let's get them on the air.

Notes

1. Paul Wade, W1GHZ, & Tom Williams, WA1MBA, "Qbeaon Board," https://www.newsvhf.com/conference/conf2026/PresPapers/W1GHZ&WA1MBA-Qbeacon_Board.pdf

2. Paul Wade, W1GHZ, "Pipe-Cap Filters Revisited," https://w1ghz.org/filter/Pipe-cap_Filters_Revisited.pdf

3. Paul Wade, W1GHZ, "Simple and Cheap Transverter for 10 GHz, https://www.w1ghz.org/xvtr/Simple_and_Cheap_Transverter_for_10GHz-2024_update.pdf

4. John Miles, KE5FX, GPIB Toolkit – available at http://www.ke5fx.com/gpib/readme.htm