30dB Attenuating RF Sampler Build

I took it into my head that I needed to build something, as it had been a while since I had done so. I wanted something that would be useful, relatively simple to build, and easy to explain for duplication by other Club members, if so desired. One of the items that I had in mind was an inductive attenuating RF sampler, so I decided to build one of them, the CMS 30dB RF Sampler (Figure 1).

Figure 1 – CMS 30dB RF Sampler

This is an incredibly simple design. The total parts list is as follows:

- Hammond LU1144 enclosure;
- 3/8" square self-adhesive rubber feet (four needed) [BUD Industries F-3581 or equivalent];
- RG-316 coaxial cable – 6-inch length (will be cut to size later);
- 22AWG enameled magnet wire – about 36 inches;
- heat-shrink tube to fit coaxial cable – 2-inch length;
- T50-43 ferrite toroid;
- SO-239 connector, flange mount (2 needed);
- BNC 50-ohm female connector, flange mount;
- #4 solder lug;
- #8 solder lug;
- 4-40 x 1/2" machine screws (4 needed);
- 8-32 x 1/2" machine screws (8 needed);
- 4-40 KEPS nut; and
- 8-32 KEPS nut.

The SO-239 and BNC connectors do not need to be flange mount types; that is just what I had on hand and so they are what I used. This sampler can easily be built with standard panel-mount connectors, and doing so will eliminate the need for all of the machine screws, solder lugs, and KEPS nuts, and so may be the better way to go. It would also make the layout much simpler, as no screw holes need to be laid out or drilled; only a single large hole is needed for each connector. As the enclosure is of sheet metal construction, this is extremely easily done.

The schematic is shown in Figure 2. The SO-239 connectors are installed to the two end panels of the enclosure. The coaxial cable will be installed between the SO-239 connectors, but will only be grounded at the input end. Therefore, if using standard panel-mount SO-239 connectors, install the ground lug only on the input or left side connector.

Before soldering the second side of the coaxial cable to the SO-239 connector, the wound toroidal pickup coil must be slipped onto the coaxial cable and positioned at the center of the span. If the wound coil does not fit the coaxial cable tightly enough to keep it in position, a heat-shrink tube sleeve can be installed to increase the outer diameter of the center of the coaxial cable. It is almost certain that this will be needed, as it was in my build.

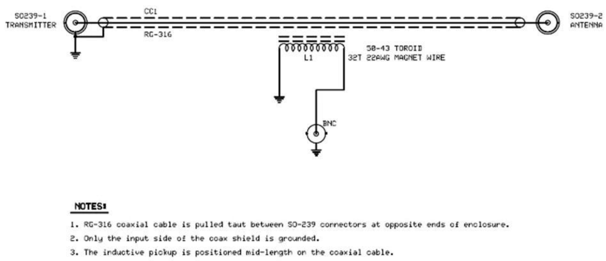

Figure 2 - RF sampler schematic diagram

There are some important points to keep in mind when winding the pickup coil. First, before beginning to wind the wire onto the form, prepare the toroid by easing the edges of the core by rounding them over slightly, if they are not already rounded. This is important so that the hard edges do not scrape the enamel off the wire as the wire is pulled through the core and wrapped over the form. The edges can be killed using a file, a knife edge, or a piece of sandpaper or some other abrasive sheet. If the core is small enough, a countersink bit can also be used. I cheated and used my Dremel tool with an abrasive drum in the chuck.

Another important point to remember is that you will need to leave wire tails of about three and a half or four inches on the finished pickup coil. This permits easy assembly of the finished sampler, as the SO-239 connectors will be in the enclosure lower half, while the BNC will be installed in the upper half. These two halves need to be brought together after everything is soldered up. The wire tails permit room for soldering to the BNC connector and ground lug, and then for assembling the enclosure halves.

Wind the appropriate number of turns for the attenuation level desired in your sampler. I built mine to be approximately -30dB of attenuation, or a one in one thousand signal sample. This would mean that a 100W signal passed through the RF path of the sampler would produce a 100mW signal at the BNC connector. A table of common attenuation levels and the turns count needed to produce that attenuation is shown at Table 1. The basic calculation for the turns count is the square root of the desired fractional sample level. For example, if a one in one thousand sample is desired, as I built mine, the turns count needed would be the square root of one thousand, or 31.6 turns. Thus, I wound 32 turns on the toroid in my build. A power ratio of 1:1000 is equivalent to -30dB.

Table 1 - Attenuation levels and associated turns counts

Power Ratio	Attenuation Level	Calculation	Turns Count
$1/1$	$-0dB$	$\sqrt{1}$	1
$1/10$	$-10dB$	$\sqrt{10}$	$3.16\ (3)$
$1/50$	$-17dB$	$\sqrt{50}$	$7.07\ (7)$
$1/100$	$-20dB$	$\sqrt{100}$	10
$1/1000$	$-30dB$	$\sqrt{1000}$	$31.6\ (32)$

The greatest attenuation level that can comfortably be reached using the toroid size specified above is -30dB. Beyond that, we have trouble fitting the wound pickup coil onto the coaxial cable. However, for most of us, -30dB is plenty of signal reduction for our needs, which would most likely be the introduction of that signal sample into an oscilloscope or a spectrum analyzer.

There is nothing saying that we cannot have multiple layers of magnet wire wound on a toroid, but the inside diameter of that toroidal form is a governing factor in how many turns we can wind thereon. However, in this instance, we also have to ensure that the wound coil can fit onto the coaxial cable. As a result, we are stuck with staying as close to one layer of wire as we can. Thirty-two turns, as I installed, is pushing that limit, with some minor overlap occurring as the final turns are laid in place. The finished and assembled pickup coil in fact actually forms a transformer with its primary winding having only a single turn and its secondary having thirty-two turns.

Purely as a point of interest, I am sure that many of my readers wonder just how to determine how much wire is needed to wind some given number of turns onto a toroidal form of a certain size. As with just about everything we do in electronics, there is an equation for that. Be sure to add any additional length needed for mechanical connection of the completed coil into its working circuit. For example, in the case of the pickup coil used in this build, we would have to add an additional eight inches or so. The length of wire required to wind some toroidal coils can be calculated as follows:

$$\sqrt{\left(n(4r + 2H + 2B - 2A)\right)^2 + \left(\pi(A + B)\right)^2}$$

where:

n is the number of turns of wire to be wound (32 in our case),

r is the radius of the wire to be used (0.014" in our case),

H is the height of the *torus,* or toroidal form (0.186" in our case),

A is the inner radius of the torus (0.140" in our case), and

B is the outer radius of the torus (0.250" in our case).

If we plug in our values as shown above, we get:

$$\sqrt{\left(32(0.056 + 0.372 + 0.500 - 0.280)\right)^2 + \left(\pi(0.140 + 0.250)\right)^2} =$$

$$\sqrt{\left(32(0.648)\right)^2 + \left(\pi(0.390)\right)^2} =$$

$$\sqrt{(20.736)^2 + (1.225)^2} =$$

$$\sqrt{415.18 + 1.500} =$$

$$\sqrt{416.68} =$$

$$20.41''$$

If we then add in the additional eight inches for the two wire tails, we get 28-1/2" of wire needed as a minimum. I rounded that up to three feet in the parts list above.

This equation is used for toroidal forms having a rectangular cross-section rather than a circular cross-section. The cross-section of the toroid in this case is rectangular. Of course, there is

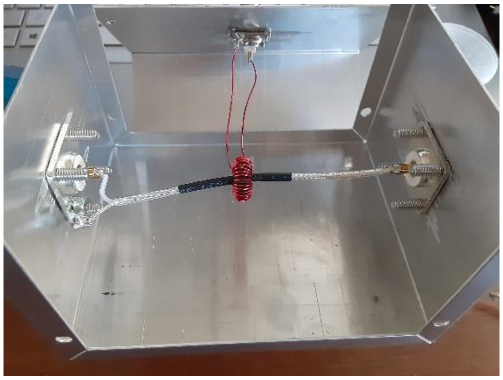

Figure 3 - Coaxial cable installed

another equation for calculating the wire length needed for winding a given number of turns onto a toroidal form having a circular cross-section, or a *torus*. There is also an equation for calculating the maximum number of turns that can be wound on a toroidal form of a given size in a single layer without any overlap. I have posted an article dealing with these topics in their entirety on my website at www.ad2cs.com for those who may be interested in reading further.

Going back to the build, it is also important that the coaxial cable be pulled fairly taut (Figure 3) between the SO-239 connectors when soldering the second end of that cable. This is to prevent any bending of the cable and the resultant bending and overlapping of the magnetic field surrounding that cable. While not of a critical nature in that the device will still operate if the coaxial cable bends, the best accuracy is derived with that cable held taut.

If using the flange-mount connectors, the solder lugs and the KEPS nuts for securing them are used to provide a solder point for each of the two ground connections. One of these connections is made at the RF input connector. Place the #8 solder lug onto one of the mounting screws and secure it there with an 8-32 KEPS nut (Figure 4). The second solder lug (#4) will go onto one of the four mounting screws used to secure the BNC connector to the enclosure upper section. Again, secure that solder lug there with a 4-40 KEPS nut.

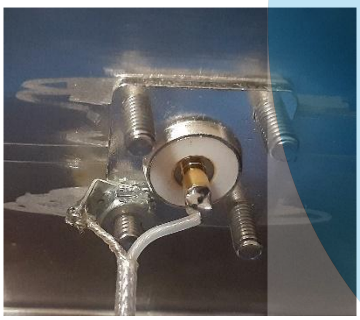

Figure 4 - Input SO-239 jack

I should explain that I chose to tap the holes in the mounting flanges of the connectors so that I would not have to deal with a full set of nuts and lock washers when assembling the sampler. Of course, you may not want to do the same, in which case you will need nuts for all of the mounting screws. As it turned out, the SO-239 connectors ended up tapped for 8-32 screws, and the BNC connector got tapped for 4-40 screws. Because these screws were secured directly into the connector flanges, which of course were installed from the inside of the enclosure, the KEPS nuts were required to secure the solder lugs.

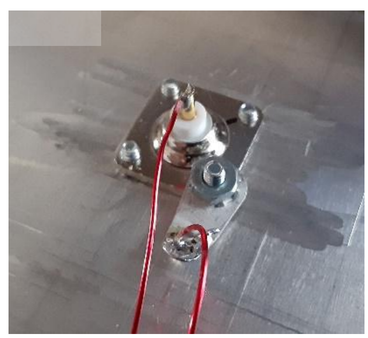

Figure 5 - BNC jack

The shield braid of the coaxial cable is to be soldered to the ground lug at the RF input side of the enclosure, while the coaxial cable center conductor is soldered to the SO-239 connector center terminal. When preparing the RG-316 coaxial cable, leave about an inch and a half of braid length twisted together for the ground connection, and then strip off the last quarter-inch to three-eighths of an inch of the center conductor for connection to the SO-239 center pin.

The two wire tails of the pickup coil are soldered to the BNC connector and the ground lug at that connector (Figure 5). It makes no difference which wire is soldered to which point, but it does make a huge difference if the enamel is not removed from the wire before attempting to solder it. In some cases, the enamel can be melted off using a ball of molten solder, which tends to tin the wire at the same time. In other cases, the enamel must be removed either by scraping the wire with the edge of a knife blade or through the use of some abrasive cloth or paper. Just be sure that you have removed the enamel all the way around the wire so that it will take solder properly.

As can be seen in the photo in Figure 1, I printed a simple self-adhesive label for my sampler. This can be done if desired, or some other marking method can be used. I had planned to make water-slide decals for the unit, but I got lazy and took the easy way out.

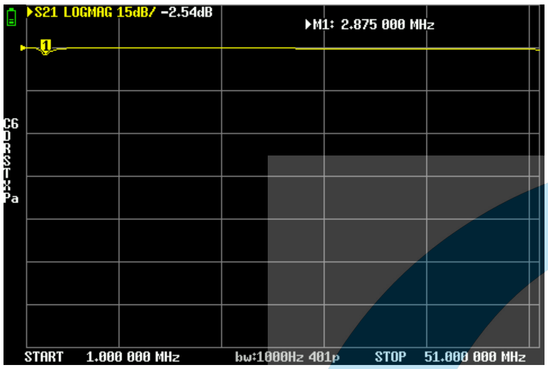

Figure 6 - Insertion loss dip at 2.875MHz

As this device could potentially be used by anybody wanting to monitor their outgoing RF signal, it is important that it not present any significant signal loss if placed in line after the transmitter on a permanent basis. To that end, I set up the equipment and measured the insertion loss presented by this sampler. I tested it from 1MHz all the way up to 520MHz in the popular band segments. The results were as I had thought they would be. The insertion loss in the HF bands ranged from a minimum of -0.02dB at 1.250MHz to -0.22dB at 28.625MHz, ending up at -0.58dB at 50.00MHz. There was, however, an unusual dip to -2.53dB right at 2.875MHz (Figure 6). That entire dip is in the dead space between the 160m and the 80m bands, so it is non-critical. The VHF band showed an insertion loss of -0.79 across the entire band, while the 1.25-meter band came in at a steady -3.98dB from 222MHz through 225MHz. On the other hand, the UHF range from 430MHz up to 520MHZ came out much differently. Here, we showed a start at -22.67dB at 430MHz, a gradual sag down to -25.99dB at 462.175MHz, and then a steady improvement to -17.57dB at 519.100MHz. As a result of this testing, I would have no problems with inserting the sampler full-time for HF, would think twice about leaving it in line for 2 meters, and would certainly not do so for the 1.25m or the 70cm band. It would be fine for testing, however, especially when testing as one really should, which is into a dummy load.

This insertion loss would logically be a direct result, and is very illustrative, of the effect of cable losses, even in short lengths. According to published data, RG-316 cable has a cable loss at least three times greater at 500MHz than it is at 10MHz. Add to that any losses in the pair of SO-239 connectors and the solder joints. It all adds up to some considerable losses, that as always, increase with frequency. Thus, it is very logical that the insertion loss would be much higher at UHF than at the low HF range.

The entire build, including laying out and drilling the holes and printing and attaching the label took about an hour and a half. It took about ten minutes to wind the toroidal pickup coil. This sampler will find a good amount of use on my bench, and it makes a good addition to my equipment set. It will be equally useful to anyone wishing to monitor their outbound RF signal via a monitoring oscilloscope. The extremely low insertion loss at HF makes it suitable for full-time installation in the feedline at HF frequencies. Go ahead… build one and see for yourself!