Tech Notes

[Tech Notes seems the ideal forum for Rudy to present some supporting documentation regarding his earlier stance on using foil conductors in antennas. Are the benefits obtained by using a thin foil element outweighed by increased edge-current losses? Read on and then decide for yourself. We are always in need of short, interesting technical articles for future Tech Notes columns. If you have something that may be of interest, please contact us.—Peter Bertini, K1ZJH, *QEX* Contributing Editor, **k1zjh@arrl.org**]

Resistance of Foil Conductors For Antennas

By Rudy Severns, N6LF

In the Nov/Dec 2000[1] issue of *QEX,* I presented an overview of conductor resistance for antennas. One of the suggestions offered was to use foil conductors to reduce resistance for a given cross-section of copper. Obviously, just using round copper wire of larger and larger diameters would be a heavy and expensive way to reduce conductor loss in low-impedance antennas. The premise was that the resistance of a round wire (which is more than a few skin depths in diameter) will be reduced by rolling it out into a foil. Several readers challenged this, stating that "The current in a foil is concentrated at the edges, and so, in effect, you don't gain anything." This illustrates a very common misconception, which I will address.

Relative Loss in Wider Foils

While it's certainly true that current densities at the edges of a foil can be much higher than in other parts, this does not mean that you cannot substantially reduce losses for the same area of copper by going from a round to a foil conductor.

I ran a very simple model using Finite Element Modeling (FEM) software,[2] which allows the loss in a given conductor of arbitrary shape to be determined at high frequencies, while accounting for eddy current effects. I chose a foil thickness of 8 mils and a frequency of 14 MHz, with a constant current of 1 A rms. The skin depth in copper at 14 MHz is about 0.7 mils, so this represents a relatively thick conductor. I then varied the width from 125 mils (1/8 inch) to 1000 mils (1 inch) and computed the losses. If it were true that all of the current would be concentrated in the edges, then making the foil wider should have little effect on the losses. However, if this view is indeed incorrect, you would expect to see the loss decrease as the foil is made wider.

The results are shown in Fig 1. The loss is normalized to 1 for a strip width of 125 mils. As we increase the width, loss decreases, but not as quickly as it would if it strictly followed the area ratio or dc resistance. It is pretty clear that the current is probably not entirely—or even largely—flowing in the edges, but there is something going on that is probably related to edge effects. Time to take a closer look!

Current Distribution in a Foil

One of the nice things about FEM CAD software is that you can graph the current density in the conductor. Fig 2 is a plot of the current density in the foil; the lines represent constant current densities. The greatest current density is indeed at the outer edge, and in fact, at the outer corners as indicated. Nonetheless, it is also clear that there is current flowing elsewhere. Because the foil is about 11 skin-depths thick, we see that there is essentially no current inside the conductor. This is due to skin effect and comes as no surprise.

Now let's look more closely at the

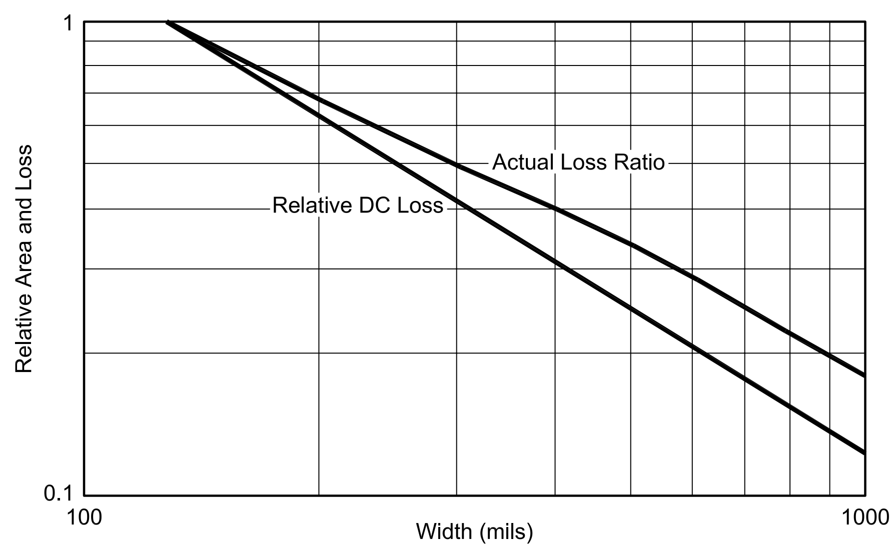

Fig 1—Comparison of dc and actual ac loss based on an increase of the 0.008-inch foil width.

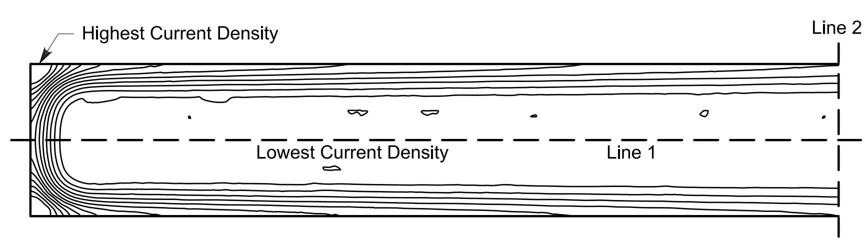

Fig 2—Current density distribution on the left half of the foil. By symmetry, the other half is a mirror image.

[1]Notes appear on page 64.

current density at the outer edge. Fig 3 is a graph of the current density along Line 1 defined in Fig 2. Sure enough, the current density at the ends is quite high, but the area of that region is relatively small so it represents only a portion of the total current in the entire conductor. There is significant current in other areas.

Fig 4 is plot of the current density along Line 2 in Fig 2, which is roughly at the middle of the foil. In line with what we know about skin effect, the current density is highest on the surface of the foil and decreases as we go inside. Yet, there is still significant current flowing on the surface of the foil away from the end edges. For this example, I chose a thick foil (11+ skin depths). Using a thinner foil would have shown that the edge effect was less pronounced, and in fact, thinner foils have less loss contributed by the edges.

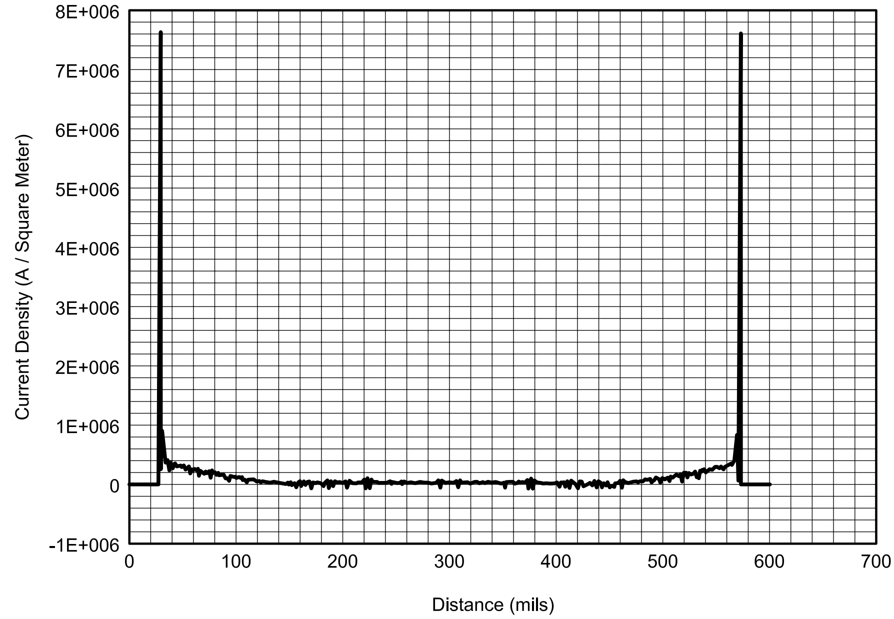

Fig 3—Current density in amperes per meter along line 1 (see Fig 2).

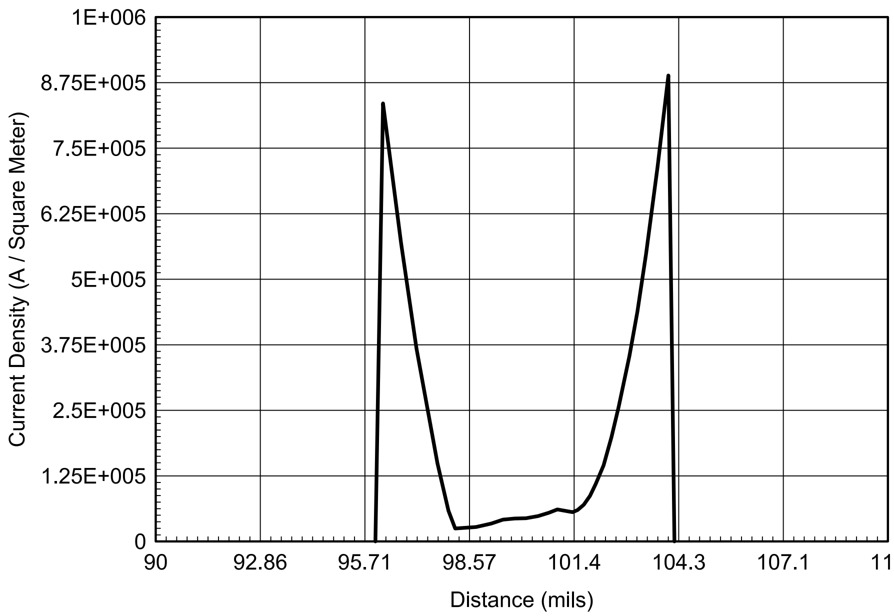

Fig 4—Current density in amperes per meter along line 2 (see Fig 2).

Summary

If a round wire is run through a roller so it flattens while keeping a constant cross-sectional area, we will discover that the HF resistance initially increases when the wire is formed into a square. It then begins to decrease as it is flattened further. As the conductor is made thinner, the resistance decreases, and when the thickness is about one skin depth, the difference between the ac and dc resistances will be small. There will also be little loss from the edges. All of this has been long known and experimentally verified in the early 20th century. Unfortunately, the idea that all the current flows in the edges is still part of our lore.

Another fact has been long known[3] but often forgotten: For a given external diameter (which is large compared to a skin depth), you can reduce the ac resistance by removing copper from the inside—that is, use a "thin-wall" tube. For a given diameter, the minimum ac resistance is reached when the wall thickness is roughly two skin depths.

Foil conductors do have disadvantages: They flutter in the wind, and very thin foils have little mechanical strength if the foil is unsupported. Several years ago, while building an antenna for my sailboat, I needed a low-loss and lightweight design to mount at the masthead. I bought some thin copper tape and applied it to a fiberglass fly-rod blank. It worked great and survived many thousands of miles of sailing across the Pacific. In effect, it was a "thin-wall" tube. Alternately, the foil could have been *inside* the fiberglass tube. Another time, losses in a stainless steel backstay antenna were reduced by bending a thin foil strip, with PVC tape on both edges, around the backstay in a U shape. This worked great. The copper tape was the conductor, and the stainless-steel backstay kept it and the mast supported.

I've noticed that the new motorized dipole being sold by Fluid Motion uses a copper-foil element inside a fiberglass tube. Reeling the foil in or out sets the length of the element. I think this shows that there is a practical use for foil conductors in some antenna installations.

Notes

[1]R. Severns, N6LF, "Conductors For HF Antennas," *QEX*, Nov/Dec 2000, pp 20-29.

[2]*Maxwell* software by Ansoft Corporation; **www.ansoft.com/products/em/max3d/index.cfm**.

[3]F. Terman, *Radio Engineers Handbook* (New York: McGraw-Hill, 1943), Fig 2, p 33. □□