A Note on Wire Size and Material

L. B. Cebik, W4RNL (SK)

Recent discussions about the use of various materials in antennas posed some interesting questions about the advisability of using such materials as stainless steel and phosphor bronze in different types of antennas.

Initial models that I used to explore the question all used wire diameters that were relatively large for the wavelength involved. For example, I used 0.1" (3 mm) elements for a VHF (225 MHz) antenna. For a 3-element beam showed only about 0.17 dB less gain for a stainless steel model relative to an aluminum model.

Material	**Gain dBi**	**F-B dB**	**Source Z R ą jX Ohms**
6061-T6 Aluminum	**8.25**	**24.80**	**24.4 - j 0.8**
Stainless Steel Type 302	**8.08**	**23.65**	**25.0 + j 0.1**

If we use only such large wire diameters relative to wavelength, the large surface area can mislead us into thinking that perhaps phosphor bronze and stainless steel are satisfactory for all antenna applications.

Of course, the question here is the electrical properties of the material, not the physical and chemical properties. Weight, corrosion, and other such factors must be considered in addition to these notes on the electrical properties of certain kinds of wire in antenna applications.

Proper tests of antenna wire types should press them toward levels of thinness relative to a wavelength that begin to show their limitations. Hence, the low HF wire dipole become a better test vehicle. It can show to some degree at what point one is better off leaving some materials alone, even if they offer some good physical and chemical properties. Materials that offer good performance when fat often reach their limits of application when thinned down.

All runs were made with NEC-Win Pro a version of NEC-2. Exact numbers may vary in the last decimal place with other programs--or if you simply choose a different level of segmentation. 21 segments per dipole was the segmentation density used for these simple tests.

Test 1: #14 wire dipole for 7.0 MHz

In this test, I took a resonant dipole model using lossless wire and then changed materials (from the usual list of materials) to see what the effect might be. Here is data on free space gain, source impedance, and efficiency for a number of materials. 6063-T843 and 6061-T6 are common aluminum allows used mostly in tubing that we find in HF and VHF beam antennas. The "Ey" notation is common computereze for "x 10 to the y power." Note where the list changes from E7 to E6.

Conductivity S/m	**Material**	**Gain dBi**	**Source Z R ą jX Ohms**	**Efficiency %**
Perfect	**(lossless)**	**2.13**	**72.2 + j 0.1**	**100.00**
6.2893E7	**Silver**	**2.04**	**73.7 + j 1.4**	**98.09**
5.8001E7	**Copper**	**2.04**	**73.7 + j 1.5**	**98.01**
3.7665E7	**Pure Al.**	**2.02**	**74.1 + j 1.8**	**97.54**
3.0769E7	**6063-T832**	**2.01**	**74.3 + j 1.9**	**97.28**
2.4938E7	**6061-T6**	**2.00**	**74.6 + j 2.2**	**96.98**
1.5625E7	**Brass**	**1.96**	**75.2 + j 2.7**	**96.19**
9.0909E6	**Phosphor Bronze**	**1.91**	**76.2 + j 3.6**	**95.02**
1.3889E6	**Stnlss Stl 302**	**1.55**	**83.0 + j 8.8**	**87.53**

Note that even silver (untarnished) shows a 2% efficiency loss and a 0.1 dB gain loss relative to perfection. Even if silver were cheap, I would not waste it on a wire antenna of this kind, given the performance of copper. Also note the larger step drops as you move below pure aluminum on the list.

Test 2. 4 MHz Wire dipole

The second modeling test took a different approach. With a 4 MHz wire dipole, what is the minimum AWG wire size necessary to achieve 1.75 dBi free space gain? Each change of material brought about a re-resonating of the antenna. I chose 1.75 dBi as the threshold of acceptability because this value resulted in wire sizes on the available list of automated selections in the program used.

Material	**Source Z R ą jX Ohms**	**Effici- ency %**	**Gain dBi**	**Length Meters**	**AWG Wire Size**
Stls. Steel	**78.3 + j 0.1**	**91.64**	**1.75**	**36.36**	**# 8**
Ph. Bronze	**78.3 - j 0.4**	**91.75**	**1.75**	**36.46**	**#16**
Brass	**78.1 + j 0.1**	**92.06**	**1.77**	**36.50**	**#18**
6061-T6	**78.1 - j 0.0**	**92.08**	**1.77**	**36.52**	**#20**
6063-T832	**77.5 - j 0.6**	**92.85**	**1.81**	**36.52**	**#20**
Pure Alum.	**78.3 - j 0.5**	**91.88**	**1.76**	**36.53**	**#22**
Copper	**78.4 - j 0.5**	**91.76**	**1.75**	**36.55**	**#24**
Silver	**78.2 + j 0.4**	**92.08**	**1.77**	**36.57**	**#24**

First, the gain numbers are not exactly 1.75 dBi, but the value closest to it on the high side yielded by the smallest wire size that would yield at least 1.75 dBi.

Second, within those limits, notice that there is an equality of source impedance and efficiency for a specific gain level. What differs among the antennas is the length necessary for resonance and the wire size.

Third, notice the wide range of antenna sizes in the list. As the wire grows thin for a given wavelength, the material losses play an increasing role in performance. If we use a conservative minimum gain of 1.75 dBi free space as the limit of acceptability, stainless steel--the strongest of the wires--would require a #8 AWG size to meet the standard. The electrical performance is at odds with its physical advantages.

Phosphor bronze is marginal under this test, requiring a minimum size of #16 AWG. If we set the gain standard higher, perhaps at 2.0 dBi free space, then phosphor bronze might fail to meet the electrical standard at an acceptable diameter.

Whether phosphor bronze will meet a given standard or whether the gain level obtainable with an available diameter of phosphor bronze wire is acceptable to a user is not a decision that can be made here. Instead, this note and the tests reported in it yield the advice not to misapply test results, not even these.

The selection of wire material requires that you set standards of performance for a given application. Then, model (or build) your antenna using the range of possible materials to see if each material meets the standard. When the diameter of the wire becomes thin enough relative to a wavelength, you may encounter a threshold situation in which some materials simply fail the electrical test.

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