Estimating Characteristic Impedances of Transmission Lines

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Ever thought of building your own feed line but didn't know where to start? Or maybe figure out what an unknown cable's impedance is? It's usually printed on the transmission line or is commonly recognized but what if it's not. How can you figure this out the layman's way having no knowledge of the line itself? With a tape measure, a sharp eye, and a calculator of course! If you happen to have a micrometer handy you should, by all means, use it for these measurements!

Note: Make the math easier by measuring in 1/16th inches (or better), then convert to decimal.

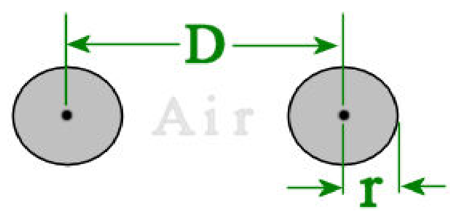
Open-Wire Transmission Line

Open-wire calculations are pretty straight forward. The following equation sums up the characteristic impedance of open wire transmission lines (with air as the dielectric). The dielectric constant of air (1.0006) has been factored out of this equation because it is a square root function in the denominator of a fraction resulting in $\frac{276}{\sqrt{1.0006}}$. This is very negligible and need not be included for the purpose of estimation.

$$Z_o = 276 \log \frac{D}{r}$$

Where

Z_o = characteristic impedance
D = distance between conductors
r = radius of one conductor



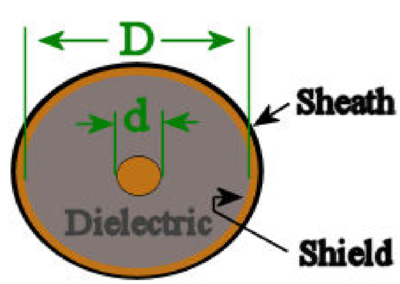
Example: You come across some homebrew open-wire that has the following physical properties.

Measuring the distances you discover that D is $\frac{3}{8}$ inches (or .375") and the diameter of the conductor is $\frac{1}{16}$ inches (or 0.0625"). You must **half** the diameter of the conductor because we need the radius (.03125"). So $\frac{D}{r}$ is $\frac{.375}{.03125}$ and gives us a $\frac{D}{r}$ ratio of 12. To calculate the log you enter 12 on your calculator and then press the log key. Your result should be 1.079. So….

$Z = 276 \log 12 \rightarrow 276\,(1.079)$
$Z = 297.85\ \Omega$
Safe to say this is 300 Ω line!

Coaxial Cable Transmission Line

The math behind coaxial characteristic impedance is one step harder because we are dealing with a dielectric that is based on something *other* than air. It could be any number of non-conductive materials. A vacuum has a dielectric constant of 1.0 whereas Teflon is 2.0. Generally the dielectric constant for commonly used materials in coax is between 1.2 and 2.8. The following is the equation to determine the characteristic impedance of coaxial cable. You'll notice a slight change to the equation as well as an additional variable to compensate for the dielectric material.



$$Z_o = \frac{138}{\sqrt{\mathcal{E}r}} \log \frac{D}{d}$$

Where

Z_o = characteristic impedance

$\mathcal{E}r$ = relative dielectric constant of the insulating material

D = inside diameter of the outer conductor (shield)

d = outside **diameter** of the center conductor

This equation differs from open-wire primarily because it takes into account dielectric constants. If the coax is air dielectric the equation can be simplified to $Z_o = 138 \log \frac{D}{d}$ since $\mathcal{E}r$ would be near 1. With an air dielectric the equation begins to resemble the open wire equation.

Example: You find some unknown coax and it appears to have a foam dielectric inside. You look up the specs on some foam dielectrics and decide the dielectric constant is likely around 1.4. Measuring the distances you discover that D is $\frac{8}{16}$ inches (or .50") and the diameter of the center conductor is $\frac{3}{16}$ inches (or 0.1875"). So $\frac{D}{d}$ is $\frac{.50}{.1875}$ and gives us a $\frac{D}{d}$ ratio of 2.67. To calculate the log you can enter 2.67 on your calculator and then press the log key. Your result should be .4265. So….

$$Z_o = \frac{138}{\sqrt{1.4}} \log \frac{.50}{.1875} \quad \rightarrow \quad \frac{138}{\sqrt{1.4}} \log 2.67 \quad \rightarrow \quad \frac{138}{\sqrt{1.4}} (.4265) \quad \rightarrow \quad (116.949)(.4265)$$

$Z_o = 49.88\ \Omega$

Nice find, some 50 Ω feed line!

This is a quick and easy way to estimate the characteristic impedance of a transmission line. This is also a severely abridged version of transmission line impedance. Entire books have been written on this subject but the quick and dirty know-how can be handy.

Approximate dielectric constants of materials

Vacuum	1.0	Air	1.0006	Teflon	2.0
Paraffined Paper	2.5	Rubber	3.0	Mica	5.0
Glass	7.5	Polyethylene	2.5	Distilled Water	75.0
Soil (dry)	2.8	Wood (dry)	2.7	Styrofoam	1.03

Conclusion

The resultant impedance of feed lines, whether they are open wire or coaxial, depends greatly on the separation and size of the conductors as well as what's between them. In open wire it's feasible to male 600Ω feed line with a distance of 6 inches between wires if you use AWG 12 or 14 wire[1]. In fact you could construct your own open wire with your own impedance and a maybe use a balun[2]. AWG charts can be found online for wire diameter if you know the gauge[3].

For coax the same considerations are made to ratio except coaxial cable is typically made with a dielectric other than air and it becomes necessary to account for the dielectric mathematically.

[1] A good article on 600Ω feed line construction can be found in QST - December 2006, Pg. 55, ACØAX

[2] N5ESE constructs 450Ω feed line for portable/QRP portable: http://www.io.com/~n5fc/openfeed.htm

[3] Wikipedia's chart for determining wire diameter: http://en.wikipedia.org/wiki/American_wire_gauge