Modeling Insulated Wire

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Insulated Wire

Amateur antennas often incorporate insulated wire, i.e., wire that is covered with a dielectric or magnetic material. Some programs, notably NEC-3 and later versions, feature insulated wire capability in their calculating engine. Most thin-wire calculating engines do not have the capability to model insulated wire. In some cases, an aftermarket user interface GUI program provides insulated wire capability that the main calculating engine lacks. It is therefore important to know how to model insulated wire both for using programs that lack the capability and for getting an independent check on those programs that do. The simplest approach to modeling insulated wires is to replace them with *equivalent* uninsulated wires. Three different methods for specifying equivalent wires are given. The methods have different accuracies.

Method 1: The first method is due to L.B. Cebik, W4RNL, and is used in *4nec2* with the NEC-2 engine. Given an insulated wire having conductor radius *a* and insulation outer radius *b*, the equivalent wire is an uninsulated wire having the same radius *a* plus distributed inductive loading in the amount

$$L = \frac{\mu_0}{2\pi}\left(\frac{b}{a}\varepsilon_r\right)^{\frac{1}{12}}\left(1-\frac{1}{\varepsilon_r}\right)\ln\left(\frac{b}{a}\right) \text{ henries per meter}$$

where

- L is the distributed inductance in henries per meter
- ε_r is the dielectric constant of the insulation
- μ_0 is the magnetic permeability of vacuum in henries per meter
- b is the outer radius of the dielectric insulation
- a is the outer radius of the metal wire
- ln(·) is the natural (base *e*) logarithm function

The equivalent wire has the same length and conductivity as the wire it replaces. This method is not based on electromagnetic theory but comes from an ad hoc curve fit to the insulated wire correction inside NEC-4. Absolute accuracy has not been established.

Method 2: The second method is due to A.S. Yurkov, RA9MB, and is used in *MMANA* with the MiniNEC engine. According to this method, the equivalent wire is an uninsulated wire having radius *b* (instead of *a*) plus distributed inductive loading in the amount

$$L = \frac{\mu_0}{2\pi}\left(1-\frac{1}{\varepsilon_r k_{abs}^2}\right)\ln\left(\frac{b}{a}\right) \text{ henries per meter}$$

The equivalent wire has the same length and conductivity as the wire it replaces. This method is based on electromagnetic theory and is believed to be more accurate. However, this method has the disadvantage that the distributed inductance depends on k_{abs}, which is neither a physical constant nor a geometric dimension, but rather an intermediate variable for which no formula is given.

Method 3: The third method is due to S.D. Stearns, K6OIK. According to this method, the equivalent wire is an uninsulated wire having an intermediate outer radius a' plus distributed inductive loading and modified conductivity. The radius and loading are given by

$$a' = a\left(\frac{b}{a}\right)^{\left(1-\frac{1}{\varepsilon_r}\right)}$$

$$L = \frac{\mu_0}{2\pi}\left(1-\frac{1}{\varepsilon_r}\right)\ln\left(\frac{b}{a}\right) \text{ henries per meter}$$

Skin effect loss is accounted for by decreasing the metal conductivity to

$$\sigma'_{effective} = \sigma\left(\frac{a}{b}\right)^{2\left(1-\frac{1}{\varepsilon_r}\right)} \text{ siemens per meter}$$

The radius lies between those of the other methods, i.e., $a < a' < b$. So, the diameter of the equivalent wire lies between the diameter of the conductor and the diameter of the insulation of the insulated wire. Distributed inductance and metal conductivity are less than in the other methods. The adjustments to wire diameter, loading and conductivity depend only on geometry and are frequency independent. The K6OIK method is based on electromagnetic theory. Its adjustments are exact in the quasi-static case, i.e., at frequencies for which the diameter is very small compared to a wavelength assuming the wire is in vacuum or air.

Table A. Equivalent Wire Replacements for Insulated Wire.

Method	Radius	Distributed Inductance	Conductivity	Accuracy	Insulation
W4RNL	a	$\frac{\mu_0}{2\pi}\left(\frac{b}{a}\varepsilon_r\right)^{\frac{1}{12}}\left(1-\frac{1}{\varepsilon_r}\right)\ln\left(\frac{b}{a}\right)$	σ	Good	Dielectric
RA9MB	b	$\frac{\mu_0}{2\pi}\left(1-\frac{1}{\varepsilon_r k_{abs}^2}\right)\ln\left(\frac{b}{a}\right)$	σ	Better	Dielectric
K6OIK	$a\left(\frac{b}{a}\right)^{\left(1-\frac{1}{\varepsilon_r}\right)}$	$\frac{\mu_0}{2\pi}\left(1-\frac{1}{\varepsilon_r}\right)\ln\left(\frac{b}{a}\right)$	$\sigma\left(\frac{a}{b}\right)^{2\left(1-\frac{1}{\varepsilon_r}\right)}$	Best	General

Table A summarizes the three methods of modeling insulated wire. The methods can be used with any thin-wire program. Indeed, the first method is built into *4nec2*, and the second method into *MMANA*.

The W4RNL method defines equivalent wires by adding distributed inductance alone. Conductor diameter and metal conductivity are not changed.

The RA9MB method defines equivalent wires by adding distributed inductance and increasing the conductor diameter to that of the insulation, but adjustment to metal conductivity to account for increased diameter is absent. Additionally, the method has an undetermined parameter.

The K6OIK method defines equivalent wires by (1) adding distributed inductance; (2) increasing the conductor diameter to a value between the diameter of the conductor and the diameter of the insulation; and (3) reducing the metal conductivity. The three-part correction gives the equivalent wire the same distributed capacitance, inductance, and resistance as the original insulated wire. This method, based on electromagnetic theory, expresses the parameters of equivalent wires in terms of physical constants and geometric dimensions with no undetermined variables. Moreover, K6OIK's method can be extended beyond simple dielectric insulation to wires covered by magneto-dielectric material.

The reader is referred to the work of Lee and Balmain, and Popović, et al., listed in the Bibliography.