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THE GROUNDING EFFECTIVENESS AT RF

By RON HRANAC

Various codes such as the National Electrical Safety Code (NESC) and National Electrical Code (NEC) - which are often adopted into law by local, county or state governments - mandate grounding and bonding of cable networks. The fundamental purpose of grounding and/or bonding is safety of people and equipment. From time to time, I'm asked if better grounding and bonding of the outside plant also will improve signal leakage and ingress performance.

Well, do they?

Do grounding and bonding help signal leakage and ingress? While there are some exceptions, in most cases the answer is no. Signal leakage occurs when a shielding defect allows signals inside the cable to leak out into the over-the-air environment. Ingress is the opposite: Over-the-air signals leak into the cable network through a shielding defect.

Common mode currents play a role in ingress. Over-the-air electromagnetic energy is coupled onto the metallic support strand and outer surface of the coax shield largely by conduction and induction. The first occurs via a physical connection to other conductors, such as the code-required bonds to the power company neutral conductor. With the second, over-the-air signals induce currents on the outer surface of the coax shield. The shield (and support strand) acts like a long-wire antenna of sorts.

The common mode currents travel along the strand and outer surface of the coax shield until they either dissipate or reach a shielding defect. When the latter happens, we have ingress. Won't good grounding and bonding of the cable network "ground" the common mode currents on the strand and outer surface of the coax shield and reduce the ingress? The grounds and bonds are effective at DC and low frequency AC, but are in most cases poor RF grounds!

Reasons

Why? If we think of each ground wire as a transmission line, the ground wire will be a quarter wavelength (λ/4) or an odd multiple of a quarter wavelength long at some frequencies. According to The ARRL Antenna Book, 18th Ed., "a λ/4 line is, in effect, an impedance transformer, and in fact is often referred to as a quarter-wave transformer." Even if the ground rod end of the ground wire is a very low impedance, the impedance transformation action of the λ/4 transmission line often will cause the ground wire's input impedance to be very high. The low impedance end of the ground wire at the bottom of the pole won't be "seen" by common mode currents on the strand and coax shield, depending in part on the frequencies of those common mode currents.

As just mentioned, a λ/4 (or odd multiple of λ/4) long transmission line behaves as an impedance transformer. Mathematically, this is described with the formula Zi = Z02/ZL, where Zi is the transmission line's input impedance and ZL is a resistive load impedance. If ZL is a pure resistance, Zi also will be a pure resistance. Rearranging the equation gives Z0 = sqrt(Zi * ZL).

This property of λ/4 transmission lines is commonly used in radio communications for impedance matching. For example, to match a 50 ohm transmission line to a 300 ohm load, a λ/4 transmission line whose impedance is 122.47 ohms inserted between the 50 ohm line and the 300 ohm load will do the trick: Z0 = sqrt(50 * 300) = 122.47 ohms.

Modeling

To understand one of the reasons why the ground wire won't be an effective RF ground, we need to model the strand, outer surface of the coax shield, and the ground wire as transmission lines. Let's look at the strand and cable first. The impedance Z0 of a single wire transmission line is calculated with the formula Z0 = 138log(4h/d), where h is the height of the conductor above a ground plane, and d is the conductor diameter. We can model the combination of the 0.25 inch diameter support strand and outer surface of a single 0.500 inch diameter coaxial cable as a 0.75 inch diameter single wire transmission line located, say, 20 feet (240 inches) above a "perfect" ground:

Z0 = 138log[4(240)/0.75]
Z0 = 138 * log[960/0.75]
Z0 = 138 * log[1280]
Z0 = 138 * 3.11
Z0 = 428.79 ohms

Modeling a 20-foot long No. 6 AWG (0.162 inch diameter) ground wire from strand level to ground level is a bit more difficult. We first need to calculate the self-inductance of the stand-alone ground wire, followed by its inductive reactance at the desired frequency, and the impedance from that.

One formula for determining self-inductance of a straight wire with a circular cross section is Lac = 2L[ln(2L/r) – 0.75], where Lac is the wire's self-inductance in nanohenrys (nH); L is the wire's length in centimeters (cm); ln is natural logarithm; and r is the wire's radius in cm. The 20-foot ground wire is 609.6 cm long, and the wire's radius is 0.21 cm.

Lac = 2*609.6[ln(2*609.6/0.21) – 0.75]
Lac = 1219.2[ln(1219.2/0.21) – 0.75]
Lac = 1219.2[ln(5805.71) – 0.75]
Lac = 1219.2[8.67 – 0.75]
Lac = 1219.2[7.92]
Lac = 9652 nH

A 20-foot ground wire is a λ/4 long at about 12 MHz: 245.9/20 ft = 12.29 MHz. (Note: 12.29 MHz is the free-space λ/4 value. Assuming an estimated velocity of propagation [VP] of 95 percent, the frequency would be 11.68 MHz. Given the complexity of determining the actual VP of a straight ground wire at RF, the λ/4 value has been rounded to 12 MHz for this example.) Inductive reactance is calculated using the formula XL = 2πfL, where XL is inductive reactance in ohms, f is frequency in Hz, and L is inductance in henrys.

XL = 2 * 3.1416 * 12,000,000 * 0.000009652
XL = 727.7 ohms

To calculate the ground wire's impedance, we have to know both its resistance at 12 MHz and its inductive reactance at 12 MHz. Taking into account skin effect, the AC resistance of No. 6 AWG wire at 12 MHz is about the same as the DC resistance of No. 23 AWG wire (20.36 ohms/1000 feet), or 0.41 ohm at 12 MHz. The complex impedance (r + jx) of the 20-foot length of No. 6 AWG ground wire is Z0 = 0.41 + j727.7 ohms. Converting complex impedance to a format we're more used to is done as follows:

Z0 = sqrt(r2 + x2)
Z0 = sqrt(0.412 + 727.72)

Z0 = sqrt(0.17 + 529,547.29)
Z0 = sqrt(529,547.46)
Z0 = 727.7 ohms

We now know the characteristic impedance Z0 of the 20-foot ground wire. Let's assume that the ground rod end of the wire at the bottom of the pole represents a nice, low load impedance ZL of something like 2 ohms. What's the input impedance Zi at the top of the ground wire, as "seen" by 12 MHz common mode currents traveling along the strand and outer surface of the coax shield? For that, we use the formula Zi = Z02/ZL:

Zi = 727.72/2
Zi = 529,547/2
Zi = 264,774 ohms

Because of the impedance transformation action of the λ/4 long ground wire, the 12 MHz common mode currents on the strand and outer surface of the coax shield will see a very high impedance of 264,774 ohms at the input end of the ground wire - not the low 2 ohms impedance of the grounded end of the ground wire. The 20-foot ground wire may work well at DC and low frequency AC, but it's not effective at 12 MHz! Things get worse at higher frequencies, in part because skin depth decreases (which increases the ground wire's AC resistance at the frequency of interest) and inductive reactance increases, both of which make the ground wire's Z0 higher. Other factors also come into play, but those are beyond the scope of this month's column.

Bottom line? Ground and/or bond for safety and code compliance, and keep the plant tight for leakage and ingress.

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