A Rocky Mountain Chapter White Paper: “Coax Attenuation-Versus-Temperature Revisited”

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The following is adapted from an article I wrote about coaxial cable attenuation versus temperature, which originally appeared in the April 2002 issue of *Communications Technology*.

Consider a length of ordinary coaxial cable. That cable has certain properties which are well-understood. For instance, as a signal pass through the cable, the signal’s power is reduced, a characteristic known as attenuation. Signals at higher frequencies are attenuated or weakened more than signals at lower frequencies.

Most of us also are familiar with the relationship between coaxial cable attenuation and temperature. That is, cable attenuation in decibels varies about 1 percent per 10 °F of temperature change. But have you ever wondered just *why* the attenuation varies as the temperature changes? I thought so, and I’m glad you’ve asked. Grab a fresh cup of coffee and your calculator, then follow along as we explore “So, that’s how it works!”

First, I’d like to explain what *isn’t* the cause. Over the years I’ve heard the following explanation a number of times, and while it appears at first glance to make sense, it’s not correct.

We all know that cable expands when it’s hot, and contracts when it’s cold. Who among us hasn’t experienced trunk or feeder cable pulling out of a connector – or sometimes pulling the connector out of an active or passive device’s housing – when it’s really cold outside? Heck, if the cable expands, or gets longer when the weather is warm, that might explain why the attenuation increases. More loss because there is more cable for the signal to go through, right? Based on that reasoning, it seems to be perfectly logical that cold weather means less attenuation because the cable contracts, or gets shorter. In other words, there is less cable for the signal to go through, so the attenuation is less.

Nope. Not even close.

Let’s look at an example of why this is not true.

Consider a level span of .750 cable between two utility poles spaced 200 feet apart. Assuming two feet of sag at midspan when the temperature is 60 °F, the actual length of the cable in that span will be just a tad more than the distance between the poles: 200.05333 feet. (By the way, some of these numbers come from Times Fiber Communications’ Technical Note 1006-A, “Mechanics of Aerial CATV Plant.” The app note details the math to calculate span sag, cable length in a given span with a certain amount of sag and so forth.)

Assume our hypothetical span of .750 cable has 1.48 dB of loss per 100 feet at 750 MHz (68 °F), so our hypothetical span – in which the cable length will be about 200.06 feet at 68 °F – has 2.96 dB of loss. Let’s further assume the lowest temperature the cable will see is 50 °F and the highest is 110 °F. Based on the 1 percent attenuation change per 10 °F temperature change, the span’s attenuation will vary 6 percent, or 0.18

dB over that 60 °F temperature range. At 50 °F the attenuation will be 2.91 dB, and at 110 °F it will be 3.08 dB.

What .750 cable lengths have 2.91 dB and 3.08 dB of loss at 750 MHz? If the cable's attenuation spec is 1.48 dB per 100 feet, then 2.91 dB of loss corresponds to just under 197 feet of cable [(2.91 dB/1.48 dB) x 100 = 196.62 feet] and 3.08 dB is a tad more than 208 feet [(3.08 dB/1.48 dB) x 100 = 208.11 feet]. Do you think the cable between those two utility poles will actually vary in length from 197 feet to 208 feet over a 60 °F temperature swing?

Not a chance.

According to the previously mentioned TFC app note, the cable's actual length in that 200 foot span will be 200.04768 feet at 50 °F and 200.09026 feet at 110 °F. Hmmm, the cable's physical length changes a whopping 0.04258 foot, or about half an inch, which is nowhere close to the 11 feet required to give us the calculated attenuation change.

Okay, if the cable's varying length doesn't cause the attenuation to change, what does?

To understand what's happening here, we have to understand what causes attenuation in the first place (for more on this, see pages 429-434 in *Modern Cable Television Technology, 2nd Ed.*). There are four fundamental reasons why cable has attenuation: signal leakage out of the cable because of less-than-ideal shielding; resistive losses in the cable's metallic conductors; signal absorption in the dielectric; and signal reflections caused by impedance mismatches.

Without getting too deep, the majority of attenuation is caused by resistive losses in the cable's metallic conductors (the dielectric plays a larger role at higher frequencies). What's of interest here is the conductors' resistivity, which is temperature dependent. Resistivity – which is not the same thing as resistance – is a term with which you might not be familiar. Here's an explanation: Resistivity is a "bulk property of material describing how well that material inhibits current flow. This is slightly different from resistance, which is not a physical property. If one considers current flowing through a unit cube of material (say, a solid metal cube that measures 1 meter on each side), resistivity is defined as the voltage measured across the unit cube length (V/m) divided by the current flowing through the unit cube's cross sectional area (I/m^2). This results in units of ohm m^2/m or ohm-m." [University of British Columbia Geophysical Inversion Facility]

In case you were wondering, the resistivity of copper is 1.673^{-8} ohm-m, and aluminum is 2.650^{-8} ohm-m, both at 68 °F. Each of these metals has a temperature coefficient of resistivity of about 0.22 percent/°F. Conductor resistance varies as the square root of resistivity, so the resistance of the .750 cable's center conductor and shield (and the attenuation), changes about 0.11 percent/°F.

Yeah, but *why*?

Well, it's because the electrical resistance of a conductor such as copper or aluminum is dependent upon collisional processes within the metallic conductor. A closer look at conductivity shows it to be proportional to the mean free path between collisions (d). For temperatures above about 15 K (that's kelvin…), d is limited by thermal vibration of atoms.

Huh?

Let’s look at electrical conductivity ($\sigma = 1/\rho$, where σ is conductivity and ρ is resistivity – see, all this stuff is related!). Many metals make good conductors because they have lots of free charges – usually electrons – in them. When a voltage difference exists between two points in a metal, it creates an electric field that causes electrons to move – in other words, current! The electrons bump into some of the metal’s atoms, and this “frictional resistance” slows the electrons down. The greater the distance the electrons can travel without bumping into the metal’s atoms, the lower the resistance and the greater the conductivity. The average distance an electron can travel without bumping into an atom is known as the previously mentioned mean free path.

How does temperature play a role in all of this? The higher the temperature, the more the metal’s atoms jiggle around and get in the way of the electrons, causing the resistance to increase. At lower temperatures the metal’s atoms jiggle around less, so they don’t get in the way of the electrons quite as much. The resistance decreases.

That’s kind of a simplistic explanation of the mathematical formula $R = R_0[1 + \alpha(T - T_0)]$, where R is the new resistance, R_0 is the initial resistance, T_0 is the initial temperature, T is the new temperature, and α is the temperature coefficient. But jiggling atoms are much more intuitive than mathematical formulas!