TECHNICAL COLUMNS

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BIG NUMBERS, SMALL NUMBERS

By RON HRANAC

Ours is a world of numbers, and in cable we tend to use a lot of really big and really small numbers. Fortunately, there are several ways to simplify how we describe those numbers, which I'll get to shortly.

In reality, it's hard to grasp just how big or small numbers can be. Consider the number 1,000,000. When discussing an RF signal, 1,000,000 might be the signal's frequency, as in 1,000,000 Hertz (Hz). It also might represent data rate - say, 1,000,000 bits per second. But just how big is 1,000,000?

If you were to count to 1,000,000, how long would it take? If we assume the average person needs 1 second per number, and you count nonstop (no sleeping, eating, drinking, or …) to 1,000,000, it will take a million seconds. That's just over 11-1/2 days. From that perspective, a million is a pretty big number. It's generally inconvenient to deal with large numbers like that, which is where the International System of Units (SI) - specifically SI prefixes (http://physics.nist.gov/cuu/Units/prefixes.html) - can help. Our 1,000,000 Hz frequency becomes 1 megahertz (MHz), and 1,000,000 bits per second is 1 megabit per second (Mbps).

Too many zeroes

Have you ever wondered why we use the decibel to express signal levels? Why not just use the signal's actual voltage or power? One reason is the very small numbers that make up typical cable network signal levels. Think about the minimum per-channel input to a subscriber terminal, as defined in Part 76 of the FCC's Rules: 1 millivolt (75 ohms), or 0.001 volt. 0.001 volt isn't too cumbersome as far as the number of zeros to the right of the decimal point, but how about the same signal level expressed as power, or 0.00000001333 watt (13.33 nanowatts)? A line extender's typical per-channel input level is 0.010 volt (10 millivolts) or 0.000001333 watt (1.33 microwatt), and its per-channel output is 0.251189 volt (251.189 mV), or 0.000841276 watt (841.276 μW). Can you imagine dealing with numbers like these on a daily basis? The decibel allows us to express these same levels as 0 dBmV, +20 dBmV and +48 dBmV respectively, using the formula dBmV = 20log(signal level in mV/1mV). Nice mathematical shorthand!

Speed of light

One measure that we deal with, often indirectly, is the speed of light. In a vacuum, light - or any electromagnetic signal, for that matter - zips along at 299,792,458 meters per second, or 186,282.397 miles per second. That's really, really fast. How fast? Let's imagine a beam of light that could somehow travel unimpeded around the Earth's equator. For this example, I'm ignoring terrain obstructions, reflection, atmospheric refraction, the atmosphere's slightly different velocity of propagation compared to a vacuum, and the fact that light prefers to travel in a straight line,. In one second, that beam of light will go around the Earth nearly 7-1/2 times!

How far will light travel in the blink of an eye? Normal eyeblink duration is typically 150 to 200 milliseconds (ms), so for this example let's call it 175 ms. In a blink of an eye, then, our light beam will have traversed 32,599 miles, or roughly one-and-a-third trips around Earth's equator. In case you were wondering, Earth's equatorial circumference is about 24,900 miles, or 256,948,534 dollar bills laid end to end.

How long does it take for RF signals to travel through 1 foot of hardline feeder coax? Assume the cable's velocity of propagation is 87 percent, which means that RF signals travel through the coax at 87 percent of the free space (vacuum) value of the speed of light. Eighty-seven percent of 186,282.397 miles per second is 162,065.685 miles per second - still really fast! It takes a mere 0.00000000117 second (1.17 nanosecond) for RF to travel through a foot of coax. A nanosecond is a billionth of a second!

While I'm on the subject of light, how far does light travel through space in one year? The answer is about 5.879 trillion miles, which we call a light year. No, a light year isn't a measure of time; it's a measure of distance. A really long distance. Do you remember NASA's Voyager 1 and 2 spacecraft from the late 1970s? They're headed out of our solar system at about 40,000 miles per hour. At that speed, it will take 16,766 years to travel one light year. If the Voyagers were headed directly to the nearest star beyond our solar system - Proxima Centauri, just 4.22 light years away - it would take them 70,752 years to get there. Where is warp drive when we need it?

Optics

OK, let's get back down to Earth. The cable industry has been using single-mode optical fiber in HFC network architectures since the late 1980s. A common optical wavelength for transporting signals from headend to node is 1,310 nanometers (nm). 1 nm is 0.000000001 meter, or a billionth of a meter - another really small number. The light inside the fiber is an electromagnetic signal, not unlike the RF inside of our coaxial cables. Well, except for the fact that it's a lot higher in frequency. How high? How about 228,849,204 MHz? That's a lot of megahertz, so we can whittle it down with the SI prefix tera (terahertz or THz), which makes our number 228.85 THz. Light at 1,550 nm has a frequency of 193.41 THz.

Going the other way, why not refer to RF signals in our cable networks by wavelength rather than frequency? 5 MHz is 59.96 meters, 42 MHz is 7.14 meters, 50 MHz is 6 meters, and 860 MHz is 0.35 meters. In the old days, radio signals were expressed in terms of wavelength. Ham radio operators still use wavelength to describe the spectrum allocations for two-way communications: The 80 meter ham band is 3.5-4.0 MHz, 40 meters is 7.0-7.3 MHz, and so on.

Before I get too far away from single-mode optical fiber, here's an interesting tidbit. The diameter of the fiber's core through which most of the light travels is about 0.0000083 meter (8.3 µm), or 8.3 microns. That's roughly the same size as the Giardia protozoa, a nasty little germ familiar to backpackers that can cause great tummy discomfort if, say, one drinks unfiltered or untreated water from some mountain streams.

Shorthand

SI prefixes and the decibel are two mathematical shorthand methods we use to deal with very large and very small numbers. Another mathematical shorthand for large and small numbers is scientific notation. The latter is commonly used for bit error rate (BER) - sometimes called bit error ratio - which, by definition is the ratio of errored bits received to the total number of bits transmitted. For example, if we transmit 1,000,000 bits, and three bits are received in error at the receiver, the BER is 3/1,000,000 = 0.000003. In scientific notation, this BER is 3 x 10-6, or 3.00E-6.

Scientific notation can be confusing if you're not careful. Which of the following is a higher (worse) BER: 1.00E-6 or 1.00E-9? This one's not too difficult: 1.00E-06 is 0.000001, and 1.00E-9 is 0.000000001, so 1.00E-6 is the worse of the two because there are more errors. How about 1.00E-6 and 3.72E-6? Here we're comparing 0.000001 and 0.00000372, or 1 errored bit out of a million bits transmitted vs. 3.72 errored bits out of a million bits transmitted. So 1.00E-6 is a better (lower) BER than 3.72E-6.

One last question

Let me leave you with this question: What are the biggest and smallest numbers you deal with regularly?

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