Originally appeared in the **September 2008** issue of *Communications Technology*.

HOW FAST IS RF?

By RON HRANAC

Maybe a better question is, "What's the speed of an electromagnetic signal in a vacuum?" After all, what we call RF refers to signals in the lower frequency or longer wavelength part of the electromagnetic spectrum. Light is an electromagnetic signal, too, existing in the higher frequency or shorter wavelength part of the electromagnetic spectrum. One way to look at it is to assume that RF is nothing more than really, really low frequency light, or that light is really, really high frequency RF. As you might imagine, the numbers involved in describing RF and light can be very large or very small. For more on this, see my June 2007 CT column, "Big Numbers, Small Numbers" (www.cable360.net/ct/operations/techtalk/23783.html).

According to the National Institute of Standards and Technology, the speed of light in a vacuum, c0, is 299,792,458 meters per second (http://physics.nist.gov/cgi-bin/cuu/Value?c). The designation c0 is one that NIST uses to reference the speed of light in a vacuum, while c is occasionally used to reference the speed of light in some other medium. Most of the time the subscript zero is dropped, with c being a generic designation for the speed of light.

Let's put c0 in terms that may be more familiar. You probably recall from junior high or high school science class that the speed of light is 186,000 miles per second. Sorting out a more accurate number: 299,792,458 meters per second/0.3048 = 983,571,056.43 feet per second, and 983,571,056.43 feet per second/5,280 feet per mile = 186,282.397 miles per second. What's that in miles per hour? 186,282.397 miles per second x 60 seconds x 60 minutes = 670,616,629.39 mph.

Other media

So far I've discussed the speed of light in a vacuum, also known as the free space value of the speed of light. What happens when an electromagnetic signal propagates through a medium other than a vacuum? Its speed is less compared to what it is in a vacuum. Velocity of propagation is a parameter that describes, in percent, the speed of an electromagnetic signal propagating through some medium relative to its speed in a vacuum. For example, hardline coaxial cable used in trunk and feeder applications has a velocity of propagation of about 87 percent. In other words, RF signals travel through coax at about 87 percent of the free space value of the speed of light, or 299,792,458 meters per second x 0.87 = 260,819,438.46 meters per second.

The speed that light propagates in a medium such as glass - say, optical fiber - is less than the speed of light in a vacuum, too. The ratio of c0 to its observed phase velocity in optical fiber is the fiber's refractive index. If you know the refractive index of fiber (more accurately, its effective group index of refraction), you can calculate the fiber's velocity of propagation. Single-mode optical fiber has an effective group index of refraction of about 1.46 at 1,310 nm. That works out to a velocity of propagation of 1/1.46 = 0.68, or 68 percent. So, 299,792,458 meters per second x 0.68 = 203,858,871.44 meters per second. That's right, light travels through single-mode optical fiber more slowly than RF travels though coaxial cable! Of course, slowly is a relative term here. 203,858,871.44 meters per second is still really, really fast.

Want a good trivia subject for your next in-house training session? Ask attendees what the velocity of propagation is for coax, and then ask what it is for fiber. More often than not when I ask this question in technical seminars, the answer that comes back for fiber is usually in the 90 percent to 99 percent range. Not even close.

Now that we know the speed of light expressed in various metrics - meters per second, miles per hour, and so on - another good question for in-house training sessions might be, "How long does it take RF to travel through 1 foot of coax?" The simple answer is approximately 1 nanosecond (a billionth of a second, or 1 x 10-9 second). In a vacuum, the actual number is 1/983,571,056.43 feet per second = 1.02 nanosecond. For coaxial cable with a velocity of propagation of 87 percent, we can work out the propagation or transit time - also called transit delay - through a foot of that cable: 1/(983,571,056.43 x 0.87) = 1.17 nanosecond.

Transit delay

The DOCSIS Radio Frequency Interface Specification includes an assumed worst-case value for the transit delay between a cable modem termination system (CMTS) and the most distant cable modem: <=0.800 msec (millisecond or ms). This parameter is listed in both the "Assumed Downstream RF Channel Transmission Characteristics" and "Assumed Upstream RF Channel Transmission Characteristics" tables in the DOCSIS Radio Frequency Interface Specification. Keep in mind that each of the DOCSIS transit delay numbers is a one-way value, or 0.800 ms in each direction. Translation: It's not supposed to take more than 0.800 ms for a downstream RF signal transmitted by the CMTS to reach the most distant cable modem, and it shouldn't take more than 0.800 ms for the most distant cable modem's transmitted upstream RF signal to reach the CMTS.

You may have heard transit delay expressed as a 100 miles maximum one-way distance. Technically that's not correct, since transit delay is expressed in units of time, not distance. However, we can calculate a distance that is equivalent to the DOCSIS 0.800 ms transit delay number. Naturally, the answer will vary depending upon the medium through which the signal is transmitted. Here's how to figure it out.

First, start with the free space value of the speed of light c0, which is the previously mentioned 299,792,458 meters per second. Next, we have to know the velocity of propagation for the desired transmission medium. In this example, I'll show you the math for both coaxial cable and optical fiber. Recall that the typical velocity of propagation for hardline coaxial cable is about 87 percent, and for single-mode optical fiber it's about 68 percent.

If I've got my decimal points in the right spot, the DOCSIS 0.800 ms transit delay spec is 0.000800 second. Now the question becomes "How far does an electromagnetic signal travel in 0.800 ms?"

In free space, the distance is 0.000800 second x 299,792,458 meters per second = 239,833.97 meters. This is (239,833.97 meters/0.3048)/5,280 feet per mile = 149.03 miles. In coaxial cable that has a velocity of propagation of 87 percent, the distance is 208,655.55 meters (0.87 x 239,833.97 meters = 208,655.55 meters). This works out to (208,655.55 meters/0.3048)/5,280 feet per mile = 129.65 miles. Finally, in optical fiber that has a velocity of propagation of 68 percent, the distance is 0.68 x 239,833.97 meters = 163,087.10 meters, or 101.34 miles.

So the oft-quoted 100 miles figure actually is the approximate one-way distance through single-mode fiber that corresponds to 0.800 ms of transit delay.

What's the transit delay in a typical HFC network? Let's assume something like 11 miles (58,080 feet) of fiber between the headend and node and 1 mile (5,280 feet) of coax between the node and the most distant subscriber's cable modem. The coax's transit delay is [1/(983,571,056.43 feet per second x 0.87)] x 5,280 feet = 6.17 x 10-6 second, or about 6.2 microseconds (μs). The fiber's transit delay is [1/(983,571,056.43 feet per second x 0.68)] x 58,080 feet = 8.68 x 10-5 second, or about 86.8 μs. The sum of the coax and fiber is 6.2 μs + 86.8 μs = 93 μs. That's well within the DOCSIS 0.800 ms (800 μs) transit delay spec.

So, back to the question in the title of this month's column: How fast is RF? Really, really fast, any way you look at it!

Ron Hranac is technical leader, HFC Network Architectures, for Cisco Systems, and former senior technology editor for *Communications Technology*. Reach him at rhranac@aol.com.