SELECTION OF FIBEROPTIC COMPONENTS FOR RF COMMUNICATION

Part II

by Todd Olson.

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Part I of this two-part series discussed the primary choices and issues relating to fiberoptic transmitters for sending RF signals on optical fiber in cable television distribution systems, satellite antenna links, wireless dark zones and fiber to the premise (FTTP) passive optical networks (PON). This Part II will focus on the factors after the transmitter, namely noise at the receiver and fiber-induced noise and distortion.

NOISE MEASURED AT THE RECEIVER

As mentioned previously, the type of components used in fiber transmitters play a significant role in the amount of noise and distortion that RF signals experience when transmitted through an RF fiber link. When the transmitter has been optimized, the noise at the receiver then becomes the limiting factor for the signal to noise ratio (SNR). In this case, three main factors contribute to the noise measured at the receiver: laser noise, shot noise and receiver amplifier noise. The relative contribution of these three depends strongly on the amount of optical power absorbed by the receiver (Rx), as shown in figure 1.

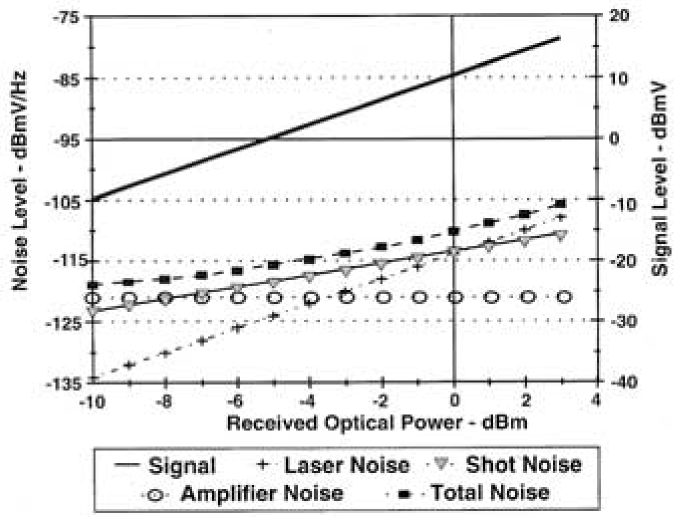

Figure 1. **Signal and noise levels in an RF fiberoptic link.**

Now we will discuss each factor in greater detail. "Laser noise" in figure 1 includes both the amount of noise produced directly by the laser plus any subsequent degradations generated as the light travels down the full length of the fiber (discussed later). Most engineers specify this laser noise as Relative Intensity Noise (RIN), which is the ratio of the total optical power divided by the random fluctuations (or "optical noise"). Both direct laser noise and fiber degradations can be improved significantly, primarily by changing various items discussed in Part I.

In contrast, for a specific amount of DC current at the Rx, shot noise cannot be changed. Because light is made up of a continuous stream of discrete packets of energy called "photons," each one arrives at the Rx somewhat randomly. When the photodiode in a Rx converts these photons to electrical current, the resulting RF signal is somewhat random, or noisy, as well. However, the relative contribution of shot noise to the overall SNR can be improved by increasing the amount of DC electrical current from the photodiode, thus better averaging this quantum noise. This DC current can be increased either by improving the photodiode's responsivity (the ratio of mA of electrical current divided by the mW of optical power) or by simply hitting it with more optical power. Virtually all optical receivers used for RF applications use PIN type photodiodes due to their good responsivity and exceptional linearity. (An alternate Avalanche Photodiodes (APD) type is quite popular for digital applications due to its outstanding responsivity and small signal sensitivity, but distorts the signal too much to be appropriate for more RF applications.)

Receiver amplifiers contribute the third category of noise impairments to RF links. Like shot noise, amplifier noise (sometimes called "thermal noise") improves with higher DC current, although at a rate even faster than with shot noise. Receiver designers therefore use various techniques to passively boost the electrical signal as much as possible before it hits the first amplifier, as well as select RF amplifiers with low noise.

RF SIGNAL LEVEL AND DISTORTION

A fourth factor also affects SNR, although to first-order does not affect the three noise contributors from figure 1. This fourth factor is the signal power itself. As shown in figure 2, in RF fiber applications the electrical signal is converted to an analog variation of the light proportional to this electrical signal, but always with a certain amount of DC light present. Hitting the Tx with a stronger RF signal increases the Depth Of Modulation (DOM) and hence SNR, but hits an extreme upper bound if the optical signal "clips" the 0 mW point, at which point the signal becomes extremely distorted.

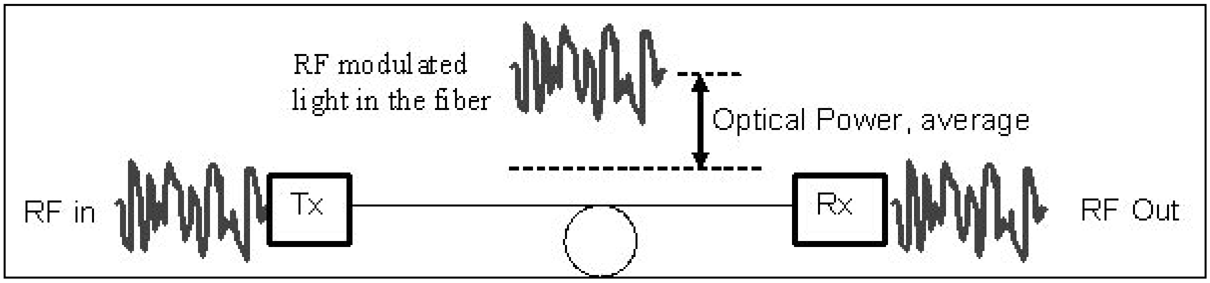

Figure 2. In an RF fiberoptic link, the electrical signal modulates the light around a constant average optical power.

Even for RF signals with power below the clipping level, driving the transmitter too hard may create intermodulation products in a way similar to the linearity limits of RF electrical amplifiers. Additionally, as noted in Part I of this series, modulating a signal also modulates the optical wavelength. For signals traveling down long lengths of fiber with high optical dispersion, this modulation creates distortion in the RF output, primarily as second-order intermodulation products. These clipping and other distortion limits related to RF signal level are usually specified with terms such as Composite Second Order (CSO), Composite Triple Beat (CTB), Carrier to Intermod (C/I), Third-order Intercept (TOI), or 1 dB compression. System designers will therefore pick an intermediate RF level optimize between noise and distortion.

STIMULATED BRILLOUIN SCATTERING

As noted above, higher optical power on the receiver improves SNR, so it is interesting to consider what limits this power at the upper end. First, the laser itself can only produce so much power, which then decreases as it passes through the various optical splitters, connectors, and long lengths of fiber to the receiver. Although with the introduction of Erbium-Doped Fiber Amplifiers (EDFA) for 1550 nm systems achieving powers of 14-27 dBm, and very recently 30-35 dBm, the availability of the raw power itself became less of an issue.

Instead, nonlinearities in the fiber itself became the second limit. It turns out that when light is sent down long lengths of single mode fiber (SMF), much of the power above a certain threshold bounces back in the opposite direction, in a phenomenon known as Stimulated Brillouin Scattering (SBS). Not only does this SBS limit the power that reaches the receiver, but more importantly it contributes significantly to the “laser noise” factor of figure 1.

Several techniques can be used to increase the SBS threshold of a given system. Primarily they include circuitry and optical devices in the optical transmitter that spread the optical signal over a wide range of optical frequencies (or “colors”). Because the SBS threshold value only applies to the light in a very narrow optical bandwidth, the total power can be much higher in bandwidth-widened transmitters before the optical power in each sub-band reaches the SBS limit. Careful calculation of the optical power at all points down a fiber by considering and optimizing the relative placement of transmitters, splitters, fiber and EDFA’s also should be used to effectively reduce SBS.

BACKSCATTERING NOISE

Another smaller, although measurable, degradation that occurs as the light travels down the fiber is double-backscattering (DBS) or interferometric noise. This phenomenon results from small amounts of light that reflect throughout the full length of a SMF. Light that reflects first back and then forward again combines with light that was always heading in the primary direction, as shown in figure 3. The interference of this small amount of re-reflected light generates noise on the RF signal. Although it is difficult to reduce the total amount of DBS noise, special techniques in the design of the optical transmitter can be used to ensure that this noise occurs in RF frequencies outside of those that matter to the signals being sent.

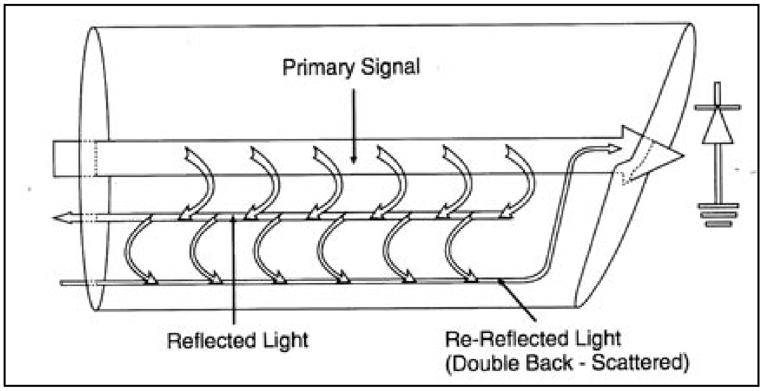

Figure 3. **Double backscattering in fiber creates a delayed optical signal that combines with the primary signal at the photodiode.**

Discrete reflections from various optical components, such as connectors and receivers, can contribute significantly to DBS and at certain levels can even create additional noise from the laser itself. For that reason, RF links typically require components with very good optical reflection performance. The most common technique is use optical components with angled interfaces so that reflected light scatters off to the side and never makes it back into the fiber.

CONCLUSION

As discussed in this article, there are a number of important factors to consider when selecting transmitters and receivers and optimizing the design of fiberoptic links for RF signals. In so doing, good RF performance can be achieved, enabling improved network reliability, reduced installation and maintenance costs, and most important, customer satisfaction. ■