THEORETICAL AND EXPERIMENTAL COMPARISON OF AN ULTRA-HIGH-SPEED LASER DATA TRANSMISSION SYSTEM

Mona Tycz

The performance of a digital optical data transmission system is specified by the probability that the system erroneously decides a signal has or has not been transmitted. Two factors which induce signal fading and thereby decrease system performance are atmospheric scintillation and transmitter pointing inaccuracy.

We can see in the first figure that a known signal, having been tranmitted through the atmosphere, becomes a random signal at the receiver. Depending upon the physical model chosen to represent the atmosphere, it can be shown that the received signal intensity obeys log-normal, or the square of Ricean or Rayleigh, statistics.

We likewise see that if we couple transmitter pointing jitter with the far-field Gaussian intensity profile of a laser beam, then the received signal intensity will vary randomly, as the beam randomly jitters about the receiver. If we assume that the tracking-error signals at the transmitter are random, zero mean, Gaussian, and of equal variance on two orthogonal axes, then the received signal intensity will obey beta statistics. This received signal intensity can be completely described by the beta distribution, the ratio of the Gaussian intensity half-power, half-beam width, and the rms tracking error.

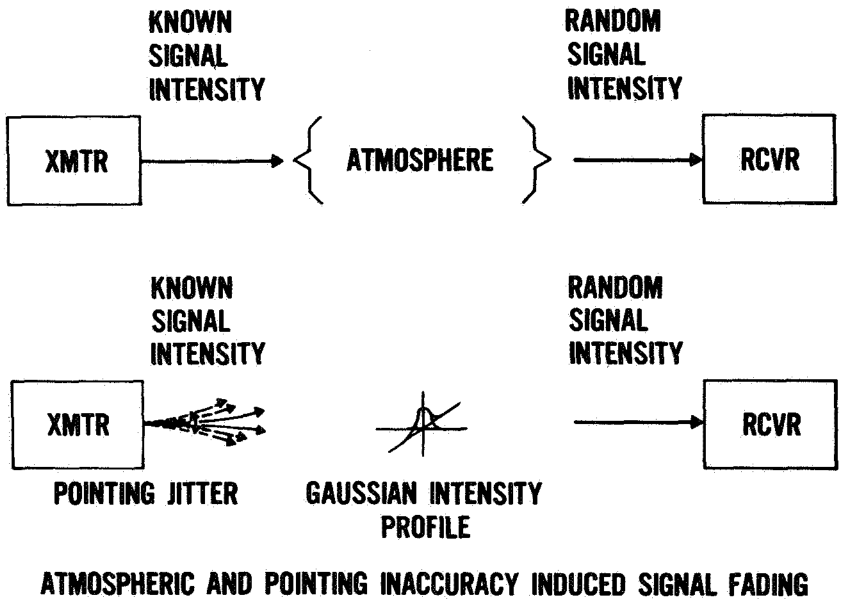

Figure 1. Optical communication system channels.

We currently have operating in-house a 400 megabit per second Neodymium-Yag Optical Data Transmission System. Since this system obeys or is governed by Poisson statistics, its performance cannot be specified by the well known signal-to-noise ratio. We have therefore conducted a theoretical analysis, in-house, of the system performance when subject to these types of perturbations. As to be expected, large families of performance curves are generated by varying such things as modulation format, receiver design, background noise levels and modulation extinction ratio. Therefore, we shall present only some typical results.

We have plotted in the second figure, for both curves, the system performance, or bit error probability, versus the average received signal when a binary 1 is transmitted for zero background and infinite modulation extinction ratio. The on-off key modulated signal in the figure to the right has been subjected to varying degrees of atmospheric scintillation; in the figure to the left, to varying degrees of relative tracking error. In both cases, the receiver incorporates adaptive thresholding techniques. That is, as the average received signal varies, the decision level which determines if a binary 1 or 0 has been transmitted will also vary.

Again, in both cases, the left most curve represents the system performance in free-space channel and is therefore a theoretical limit for the chosen parameters.

If we desire to maintain a system performance or probability of error of 10^{-16}, and assume that the system is subject to atmospheric scintillation of log-amplitude variance 0.01, or a

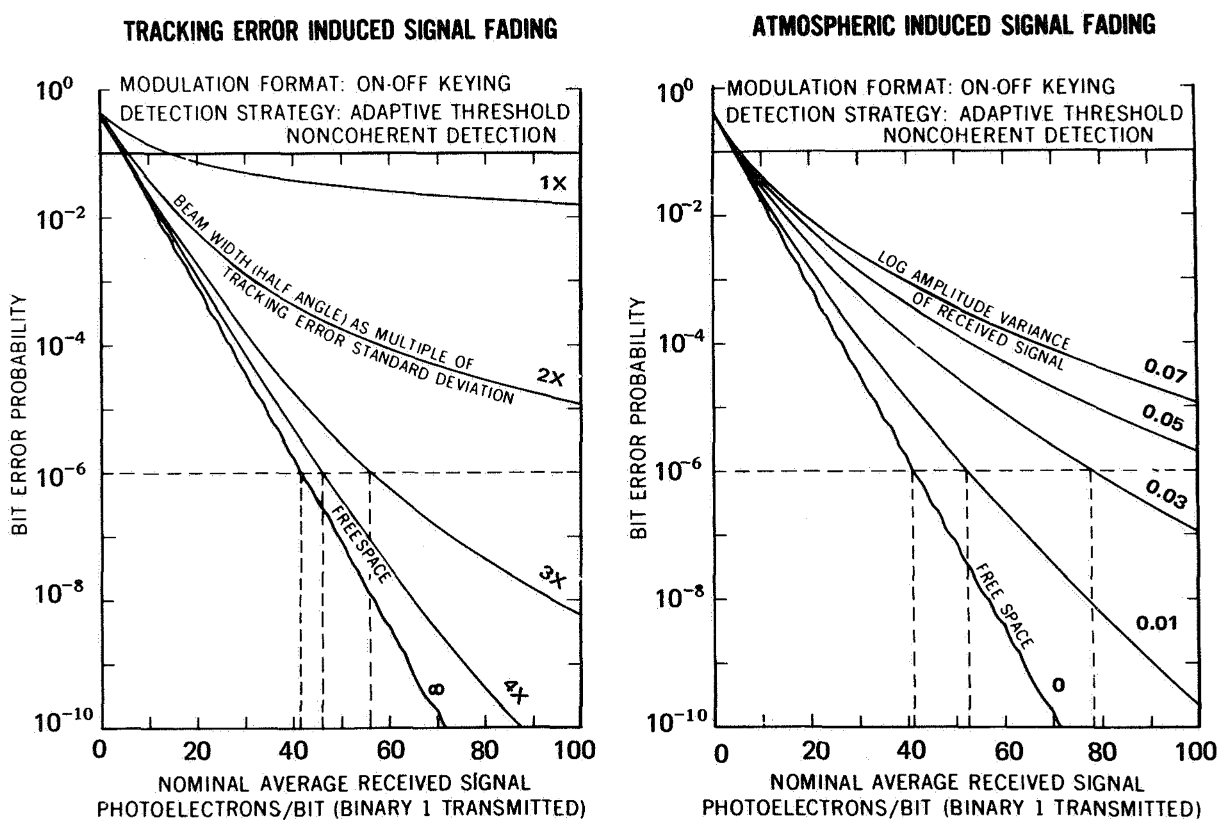

Figure 2. Binary optical communication system performance.

transmitter beam width to rms tracking error ratio of 3, then we must increase the received power by approximately one dB. This can be achieved in various ways; for example, by increasing the transmitter power or the receiver aperture diameter. This is obviously a trade-off between such things as system complexity and transmitter power requirements, or receiver weight.

In the development of any data transmission system, one needs not only an in-depth theoretical understanding of the system performance, but also a firm experimental basis upon which to proceed. We have therefore developed in-house a channel simulator, capable of producing the effects of both atmospheric scintillation and the transmitter pointing problem. Figure 3 demonstrates to us the functions of the channel simulator we currently have operating. It consists of a Gaussian noise source which is fed into analog processing electronics, which in turn drive a linearized acousto-optic modulator. The intensity transmitted through the modulator obeys the same statistics as the applied voltage. The processing electronics are capable of providing log-normal, Ricean, Rayleigh, or chi-squared random voltages for simulating atmospheric scintillation. The beta random voltages are for simulating the pointing inaccuracy induced signal fading.

The electronics consist simply of analog modules, multipliers, and the like, which perform the appropriate mathematical operations to generate the desired random voltages. The performance of the channel simulator is measured in terms of its ability to accurately simulate the desired channel. In Figure 4 we will look at the performance of the log-normal channel. We see there a comparison of data taken from the modulated intensity of a beam having been transmitted through the channel simulator, as compared to actual experimental data taken from the GEOS-B experiment.

The GEOS-B experiment consisted of an argon laser beam that was transmitted through the

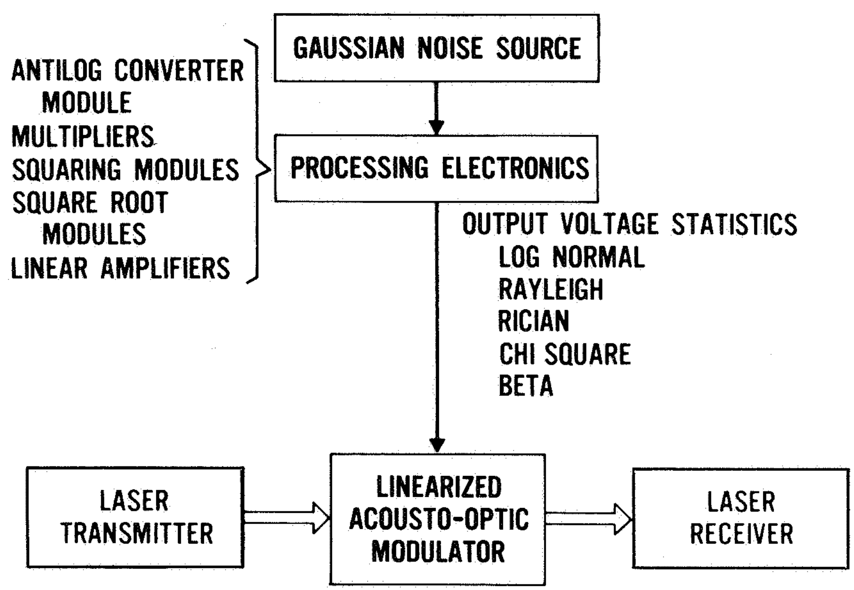

Figure 3. Channel simulator system.

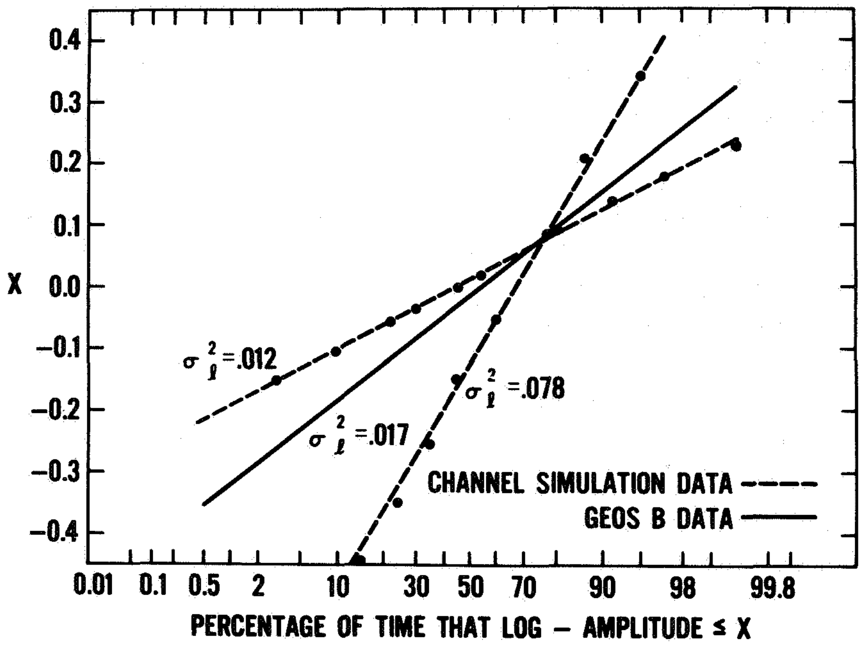

Figure 4. Comparison of channel simulator log-normal statistics with GEOS-B data.

atmosphere to a low earth-orbiting satellite. The received analog signal was then telemetered to ground. On ground, a statistical analysis was performed on the atmospheric scintillated intensity, and we see the resulting data plotted as the bold line.

We have plotted the range of values that the log-amplitude can take on versus the percentage of time that it is actually less than or equal to those values. The dotted or dashed lines represent data taken from the channel simulator. The linearity of the data indicates that the modulated signal intensity is indeed log-normal. The slope of the lines is indicative of the degree of atmospheric scintillation, which we can vary here from a log-amplitude variance of 0.01 to 0.08.

Similar tests, as well as the chi-square distribution test, will be performed for all channels of the channel simulator. Having completed this analysis, the channel simulator is to be incorporated into our 400 megabit per second Neodymium-Yag Data Transmission System. The performance of the composite system will then be evaluated and compared with the theoretical predictions.