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HIGH SIGNAL TO NOISE OPERATION OF FIBER OPTIC LINKS TO 18 GHz

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ABSTRACT

Very high signal to noise ratio transmission through a fiber optic link has been demonstrated for frequencies up to 18 GHz. To achieve this required good laser and photodiode frequency response, high laser and photodiode efficiency, low optical reflections, and a laser with good low frequency noise characteristics.

Fiber optic links offer many features which make them attractive for microwave signal transmission. Among these are extremely low transmission loss, small size and weight of components, and immunity of optic fibers from EMI. In recent years, tremendous progress has been made in developing high speed lasers and photodiodes[1-3]. In addition, many applications require high signal to noise transmission capability. In this paper, the dominant noise sources of fiber optic links will be reviewed and experimental results will be presented for a link with components selected for high signal to noise transmission at frequencies up to 18 GHz.

I. Noise Sources of Fiber Optic Links

The major noise sources of a fiber optic link can be categorized as due to laser noise, photodiode shot noise, or receiver amplifier noise. Photodiode shot noise and receiver amplifier noise are well understood and are easily characterized. Laser noise, however, depends in a complex fashion on the laser used and on the environment in which it is operated. For example, optical reflections can drastically increase the laser noise level. In this section, the noise sources will be briefly reviewed and expressions derived for characterizing these noise sources.

Because optoelectronic components have electrical inputs and optical outputs, or vice versa, they create unique problems in developing methods for characterizing their performance. We have found that the most useful approach to characterizing a link is in terms of equivalent input noise (EIN) and input distortion intercept points. For example, if a link had an EIN of -120 dBm/Hz, an input second harmonic intercept point of +50 dBm, and an input signal of 0 dBm, then the signal to noise ratio will be 120 dB/Hz and the second harmonic will be -50 dBc.

A. Laser Noise: As was mentioned previously, laser noise in general depends in a complex fashion on both the laser used and the operating environment. We have found that if care is taken to prevent optical reflections that the noise performance is much more predictable. However, the discussion that follows is only valid for single mode fiber links with low optical reflections, and which are short enough so that fiber dispersion is not significant. For 1300 nm systems, this is true for lengths up to at least several kms.

Laser noise in well behaved links consists of inherent laser intensity noise and upconverted low frequency intensity noise. Inherent laser noise refers to the light fluctuations that occur in the absence of any modulating signal. This can be characterized by a laser equivalent input noise, EIN_L. EIN_L is an easily measurable quantity. It is determined by modulating the laser with a small input signal and measuring the link signal to noise. If the laser is the dominant noise source, then EIN_L is directly determined. If photodiode and/or receiver amplifier noise is important, then corrections for these noise sources can be made by measuring the noise floor with the laser turned off. For a laser which has been impedance matched to 50 Ω, EIN is related to laser relative intensity noise (RIN) by:

$$EIN_L(\nu) = \frac{50RIN(\nu)\ (I_L-I_{th})^2}{S_L(\nu)}$$

where $S_L(\nu)$ is the laser frequency response.

When large modulation signals are used, it is often observed that the noise floor increases in the vicinity of the carrier. The presence of these noise wings is well correlated with the presence of low frequency laser noise. In practice, this often limits the S/N for large input signals. Beyond a certain input power level it is observed that the signal and noise floor increase together. To avoid this phenomenon, low frequency noise must be minimized.

This phenomenon has been analyzed using a laser rate equation model[4]. It has been found that due to nonlinearities in the dynamics of the laser response, that low frequency noise can be upconverted to the vicinity of the carrier. The upconverted noise can be described in terms of a noise translation factor, $T(\nu)$, as follows:

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$$EIN_{LF}(\nu) = \frac{RIN\ (\nu \approx 0) T(\nu) P(\nu)}{S_L(\nu)}$$

where $P(\nu)$ is the modulating signal power. $T(\nu)$ is maximum near the laser resonance frequency where it is found both theoretical and experimentally to be about 6 dB for 1300 nm buried crescent lasers. The calculated and measured frequency response of the noise translation factor is shown in Figure 1.

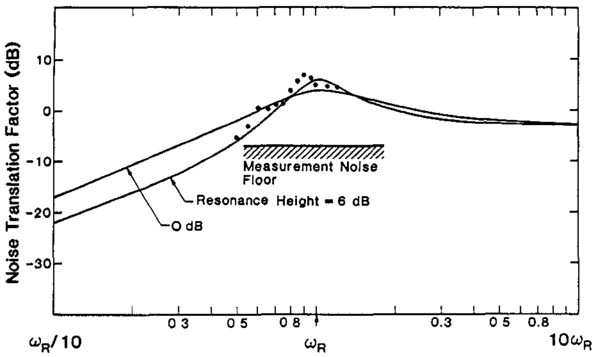

Figure 1. Frequency dependence of noise translation factor.

B. Photodiode Shot Noise: Photodiode shot noise produces a noise current at the output of the photodiode as given below.

$$\langle I^2 sn \rangle = 2eI_o$$

where I_o is the DC photocurrent. This noise current can be translated to the laser input by dividing by the DC link current transfer function, H_L, and correcting for the laser frequency response.

$$H_L = \frac{\Delta I_{PD}}{\Delta I_L}$$

which can also be expressed as

$$H_L = \eta_L \eta_{PD} \eta_F$$

where η_L and η_{PD} are the laser and photodiode DC efficiencies and η_F is the fiber transmission loss. The shot noise EIN is the translated noise current multiplied by 50Ω

$$EIN_{SN} = \frac{100eI_o}{H_L^2 S_L(\nu)}$$

since $I_o = H_L(I_L - I_{th})$,

$$EIN_{SN} = \frac{100e(I_L - I_{th})}{H_L S_L(\nu)}$$

EIN_{sn} therefore varies inversely with the link current transfer function.

C. Receiver Amplifier Noise: The receiver amplifier can be characterized by an equivalent input noise at the input to the amplifier of kTF, where F is the amplifier noise figure. To translate this to the input of the laser, we divide by the link RF insertion loss.

$$EIN_{AN} = \frac{kTF}{S_L(\nu) S_{PD}(\nu) H_L^2}$$

II. Experimental Results:

The components of the fiber optic link that was characterized are shown in Figure 2. The laser was a high speed buried crescent type 1300 nm laser (DP-1501C). It had a threshold ocurent of 10 mA and was operated at a bias current of 70 mA. The frequency response and noise characteristics of this laser are shown in Figure 3. The photodiode (DP-2501C) had a 3 dB bandwidth of 12 GHz and a response at 18 GHz of -8 dB. The fiber coupled laser efficiency was 0.06 mW/mA, and the photodiode responsivity was 0.6 mA/mW. For signal to noise measurements, several amplifiers covering .01-18 GHz were used. The link length for which measurements were made was 100 meters, but similar results are expected for link lengths up to several km. The link was connected by fusion splices and the photodiode had an optical return loss > 55 dB to eliminate enhanced noise due to optical feedback. The maximum S/N that could be achieved at various frequencies is shown in Figure 4. The RF input signal was limited to 20 dBm, which corresponded to nearly 100% modulation for frequencies below 10 GHz. Higher S/N ratios might have been possible above 10 GHz by further increasing the RF signal level.

The best S/N was achieved in the DC-3 GHz region where laser noise is lowest. The S/N steadily drops for frequencies out to the laser resonance frequency of approximately 10 GHz. From 10-16 GHz the link response is rolling off, but so is the laser noise, which results in a nearly constant link S/N. Beyond 16 GHz, receiver noise dominates. Improvements in the frequency response or efficiency of the laser or photodiode would push the frequency where receiver noise is dominant to beyond 18 GHz, resulting in improved S/N in the 16-18 GHz region. The key factors in obtaining these S/N levels is the use of a laser with good low frequency noise characteristics and the absence of optical reflections.

Acknowledgement

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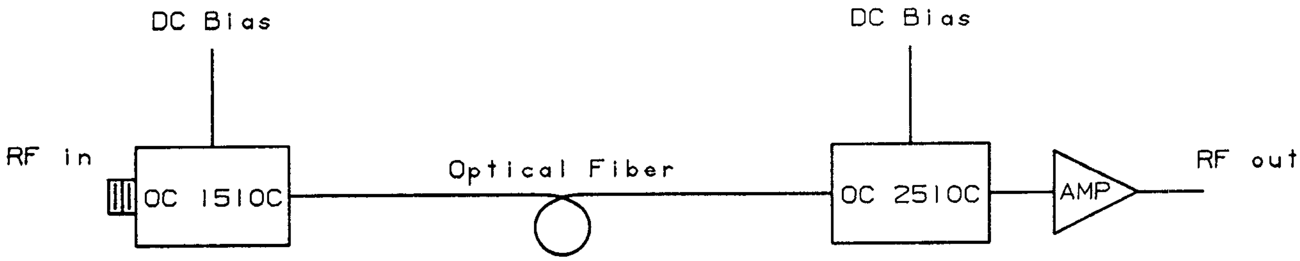

Figure 2. Components of high speed fiber optic link.

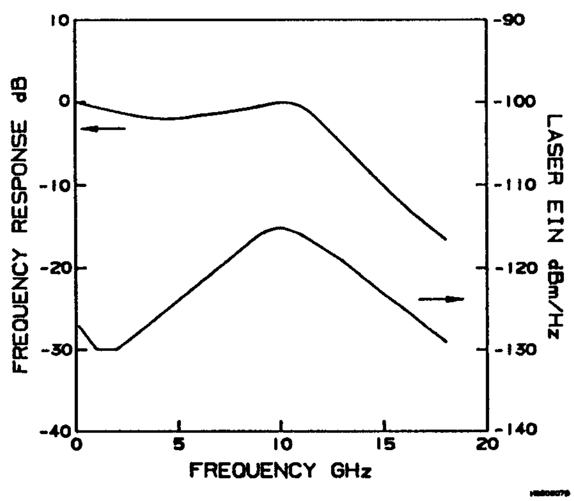

Figure 3. Frequency response and noise of high speed laser.

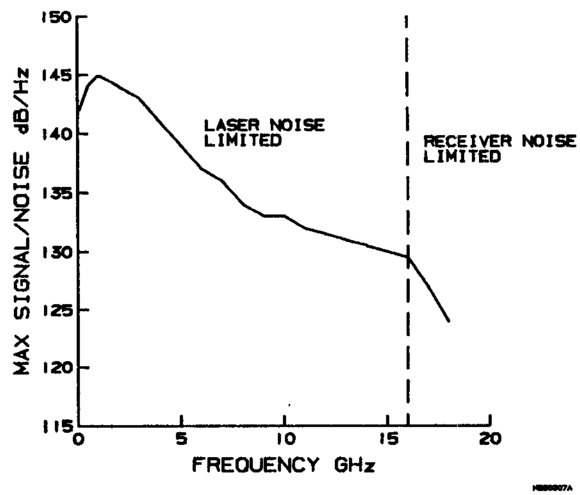

Figure 4. Dynamic range of high speed link.

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