High-Dynamic Range Fiberoptic Links For Antenna Remoting Applications[1]

C. M. Gee, T. R. Chen, P. C. Chen, and J. Paslaski
Ortel Corporation, 2015 W. Chestnut St., Alhambra, CA 91803

K. Y. Lau
University of California, Berkeley, CA 94720

R. T. Logan, M. D. Calhoun, and G. Lutes
Jet Propulsion Laboratory, California Institute of Technology,
Pasadena, CA 91109

INTRODUCTION

In recent years, the performance and cost effectiveness of analog fiberoptic communication systems have improved so that many applications including antenna remoting which requires high dynamic range can now benefit from the many advantages of fiber optics[1].

The high speed microwave fiberoptic systems on the market today can be classified into two categories - those using directly modulated laser transmitters and those using external modulators in conjunction with diode-pumped solid state lasers. In almost all cases below 3 GHz, the direct modulation approach using distributed feedback (DFB) lasers, outperforms external modulator systems when all aspects of transmission performance including noise, linearity, simplicity and cost are taken into account. **[2] Figure** 1 compares the third order spurious-free dynamic range for the two techniques,

Within the category of direct modulation links, the achievable dynamic range depends upon the type of laser (DFB or Fabry-Perot), the link length and the photodiode linearity. In this paper, we examine these components, demonstrating how low frequency noise can be translated up to a higher modulation frequency and how fiber dispersion enhances noise. These phenomena make DFB lasers the choice laser type for systems demanding high dynamic range.

DFB versus FABRY-PEROT LASERS

A DFB laser is a special type of laser diode designed to lase in a single longitudinal mode (optical frequency), as compared to a conventional Fabry-Perot (FP) laser which typically lases in many longitudinal modes. Central to the issue of comparing DFB and FP lasers is a mechanism of noise generation known as "signal-induced noise". Traditionally, signals and noise are considered independent quantities which can be separately

---

[1] The research described in this paper was carried out by the Jet Propulsion Laboratory and Ortel Corporation and was partially sponsored by the National Aeronautics and Space Administration and the United States Air Force's Rome Laboratories.

Reference herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise does not constitute or imply its endorsement by the United States Government, or the Jet Propulsion Laboratory, California Institute of Technology.

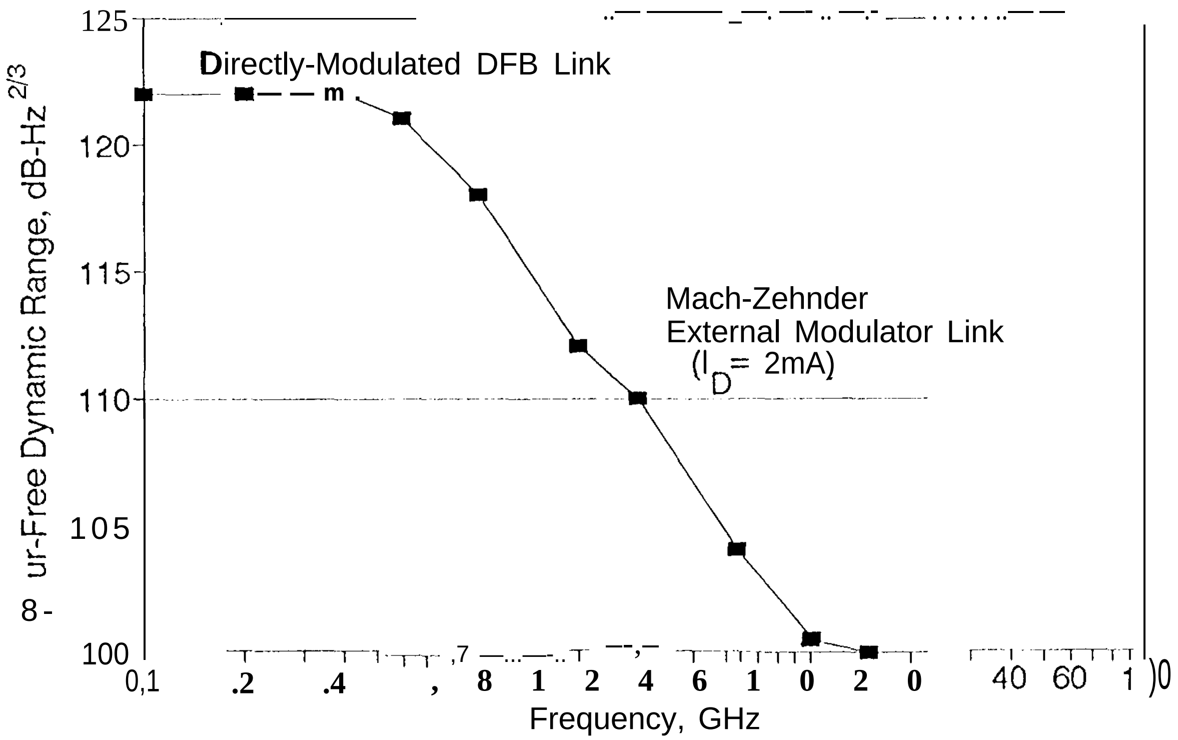


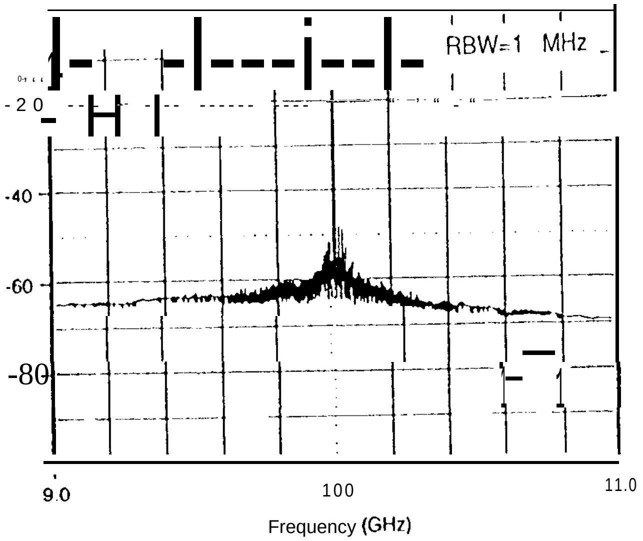
Figure 1. Spurious-free dynamic range as a function of frequency for a directly-modulated DFB laser link and for a Mach-Zehnder external modulator link.

considered. In a fiberoptic link using FP lasers, there exists a certain amount of low frequency noise in the frequency range well below 1 GHz, which is often not even specified by the manufacturer. However, it has been shown that the low frequency noise can be translated to the neighborhood of the microwave carrier[2], which can be several GHz and is evident only in the presence of a modulation carrier. This source of signal-induced noise for FP lasers can become quite serious at high frequencies and longer fiber links. It is therefore misleading to measure the system noise level at high frequencies without any applied modulation to the laser, and then to calculate the anticipated signal-to-noise ratio (SNR) based on these measurements, as if the signal and the noise are independent entities.

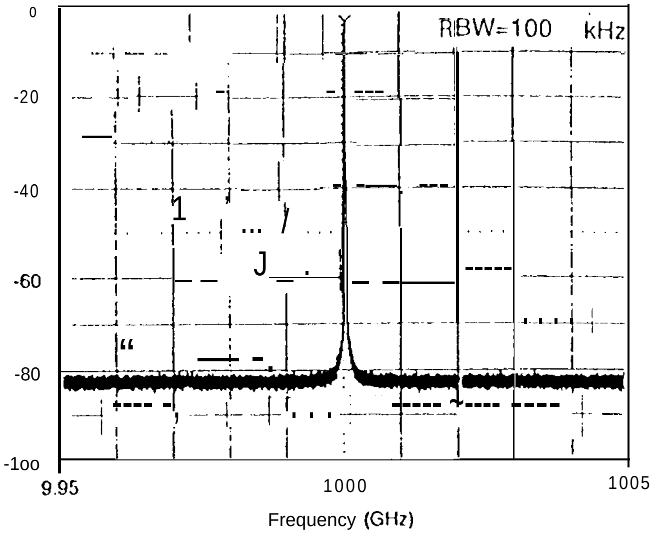
The mechanism for generation of low frequency noise in FP is primarily that of "mode-partitioning". Since there are multiple modes in a FP laser, there are constant exchanges of power between these modes, in such a way that the total power remains relatively constant. Therefore, when one detects the total optical power, little noise is present in the signal. However, when propagated in a fiber, dispersion causes the modes to "walk-off" in time relative to one another. The fluctuation in each mode now no longer compensates for one another and the total optical power shows fluctuations originating from the power exchange process. It so happens that this type of power exchange occurs at low frequency, hence the low frequency nature of mode-partition noise [3]. Besides

SIGNAL INDUCED NOISE

(a)

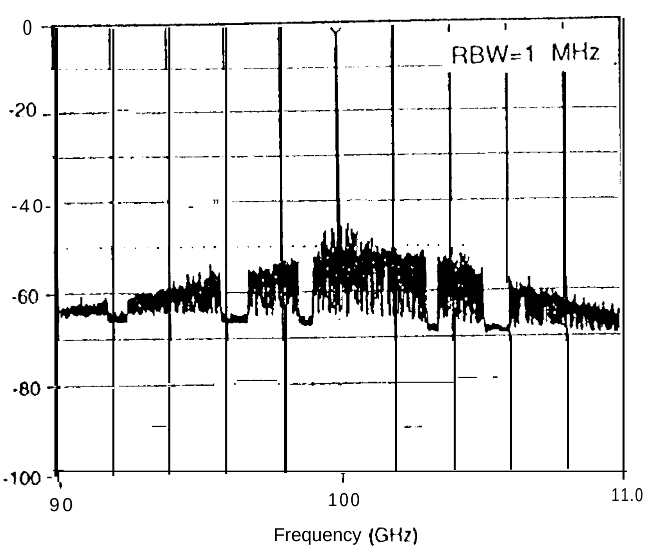


(d)

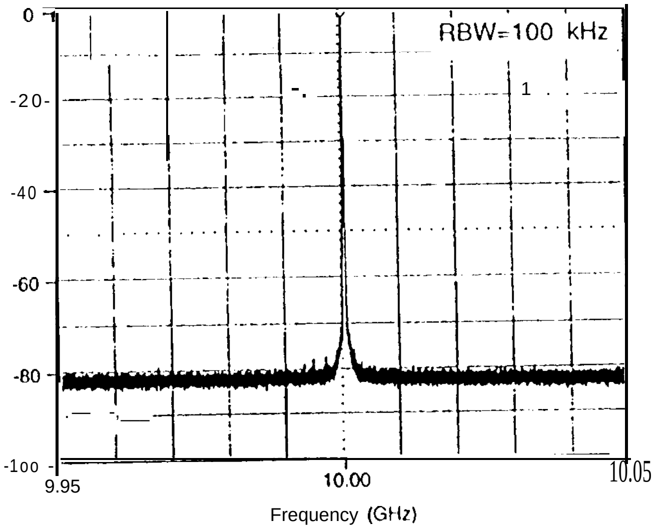


1 km

(b)

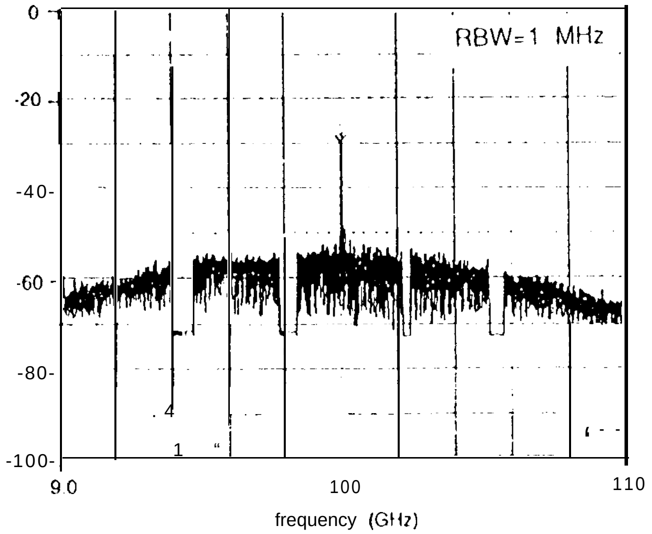


(e)

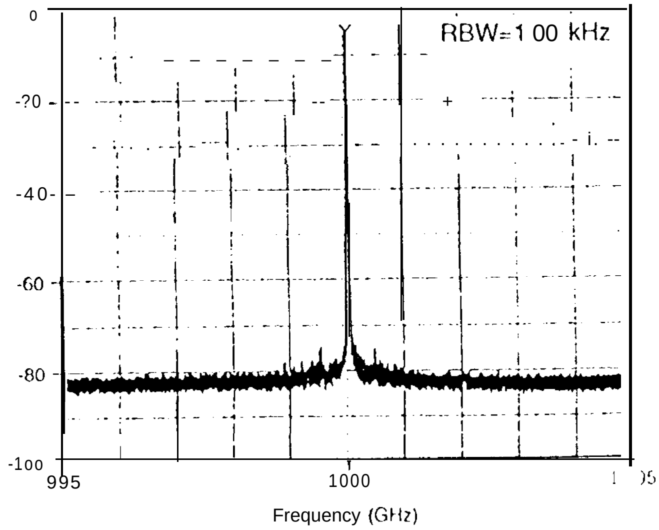


6 km

(c)



(f)



20 k m

mode-partition noise, low frequency "mode-hopping" noise in Fabry-Perot lasers can manifest itself in the laser diode output alone without the presence of fiber dispersion.

For single frequency lasers such as DFB lasers, mode-partition and mode-hopping noise are absent. The dominant source of low frequency noise comes from double reflections along the fiber length which converts the laser phase noise to intensity noise[4]. In general, this effect is much less severe than that for FP lasers, provided proper optical connectors and splices are employed.

To illustrate how the low frequency noise is translated to the neighborhood of the microwave carrier upon applying a high frequency modulation to the laser, Figure 2 shows measured results for links consisting of (a) a 1.3 μm FP laser and (b) a 1.3 μm **DFB** laser, modulated at frequencies of 10 GHz, and propagating through 1 km, 6 km and 20 km lengths of single mode fiber. Both high speed lasers have 3 dB modulation bandwidths well beyond 10 GHz. The measurements were done with an input RF drive level into the lasers of 10 dBm. The received photocurrent was 1 mA in all cases, except where noted. Angled polished optical connectors (APC) were used whenever an optical connection was required. The clean blanks in the noise traces for FP lasers in Figures 2(a)-(c) were measured by turning the RF signal off so that the low frequency noise was not unconverted. These plots illustrate that the low frequency noise and its translation are very significant. The drop in the RF signal level at longer fiber lengths for the FP laser (Figure 2(c)) is due to fiber dispersion. One should contrast the above results with those obtained with the DFB laser, Figures 2(d)-(f). Only a very slight degradation is observed for 20 km fiber length, while the FP laser is all but nonfunctional at this distance. Note also from Figures 2(b) that even at a relatively short distance of 6km, the actual signal-to-noise ratio (SNR) of the **high** speed FP laser is approximately 15 dB worse than that predicted from a conventional RIN measurement which is made without any applied modulation signal.

The superior performance of the DFB laser is also evident in better phase noise as shown in Figure 3. The phase noise was measured with an 8 GHz carrier frequency. The phase noise measurement was limited by the measurement equipment for offset frequencies less than 5 kHz.

PHOTODIODE LINEARITY

The dynamic range for both direct and external modulation improves with higher received photodiode current for systems that are shot noise limited. However, due to reliability concerns, present photodiodes can handle only approximately 2 mW. Besides this practical limitation, a misaligned photodiode can degrade the linearity of the overall link system. Figure 4 plots the output third order intercept point as a function of received photodiode current. The performance improves with increasing received current, but is dramatically degraded if the light coupled into the photodiode is even slightly misaligned. Alignment becomes even more critical at high frequencies because the photodiode active area is small.

CONCLUSIONS

We have made a quantitative comparison of signal-induced noise in a high frequency, single mode fiberoptic link using direct modulation FP and DFB lasers. It is clear that the common procedure of evaluating the signal-to-noise performance in a typical fiberoptic link, treating the various sources of noise independently of the modulation signal, is quite inadequate in describing the performance of such systems under real situations. This type of signal-induced noise arises from mode-partitioning in FP lasers, and interferometric phase-to-intensity noise conversion in DFB lasers, the former induced by fiber dispersion and the later by fiber reflections such as Rayleigh scattering. The former is considerably more significant than the latter. Both of these effects increase with fiber length, and concentrate at low frequencies so that a casual observation might lead to the conclusion that they are of no relevance to high frequency microwave systems. Narrow band transmission at high frequencies through even moderate lengths of fiber, high speed FP lasers are limited not just in the transmission bandwidth due to fiber dispersion, but also from the detrimental effect of signal-induced noise due to mode-partitioning. With DFB lasers, there is little degradation of the performance for transmission at 10 GHz up to 20 km. We also showed how photodiode misalignment can reduce its linearity.

1. G. Lutes, Jet Propulsion Laboratory, Pasadena, CA 91109 "Current Applications of Analog Fiber Optics in the NASA/JPL Deep Space Network, " Union of Radio Science Meeting, Boulder, CO, Jan. 1993.

2. C.M. Gee, H.A. Blauvelt, P.C. Chen, L.A. Stark, I.Ury, "Directly modulated lasers achieve wide dynamic range for high-fidelity analog signal transmission, " Microwaves & RF, November 1992,

3. K.Y. Lau and H. Blauvelt, "Effect of low-frequency intensity noise on high frequency direct modulation of semiconductor lasers, " Appl. Phys. Lett., 52, 694-696, 1988.

4. K. Petermann, **Laser diode modulation and noise,** Kluwer Academic Publishers, 1988.

5. R.T. Logan, Jr. and L. Maleki, "Influence of Modulation on Noise in Semiconductor Lasers, " Fourth Annual DARPA Symposium on Photonic Systems for Antenna Applications (PSSA-IV), Monterey, CA, Jan. 1993.

6. S.W. Wu, A. Yariv, H. Blauvelt and N. Kwong, "A theoretical and experimental investigation of conversion of phase noise to intensity noise by Rayleigh scattering of optical fibers", Appl. Phys., 59, 1156-1158 (1991).