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10 GHz RF FIBER OPTIC LINKS

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ABSTRACT

A 10-GHz direct laser modulation and an external modulation link were demonstrated. Signal-to-noise ratios of 130 dB/Hz and 115 dB/Hz have has been measured for the external modulation link at 1.3 μm wavelength and for the direct modulation link at 0.83 μm wavelength, respectively.

INTRODUCTION

Analog transmission of microwave signals through optical fibers offers the potential advantages of lower loss, less weight and larger bandwidth over conventional coaxial cable system. Due to a series of recent breakthroughs, key components for microwave fiber optic links are becoming available. Semiconductor lasers, $LiNbO_3$ traveling-wave modulators, and GaAs and InGaAs photodetectors with bandwidths in excess of 10 GHz have been demonstrated (1)-(5) in several laboratories.

In this paper, we present the results of our experimental studies of two X-band (10 GHz) fiber optic links: one uses direct modulation of the semiconductor laser source, the other uses an external modulator. We have measured signal-to-noise ratios (S/N) of 115 dB/Hz and 130 dB/Hz at 10 GHz for the direct modulated and the indirect modulated systems, respectively. Noise in the frequency

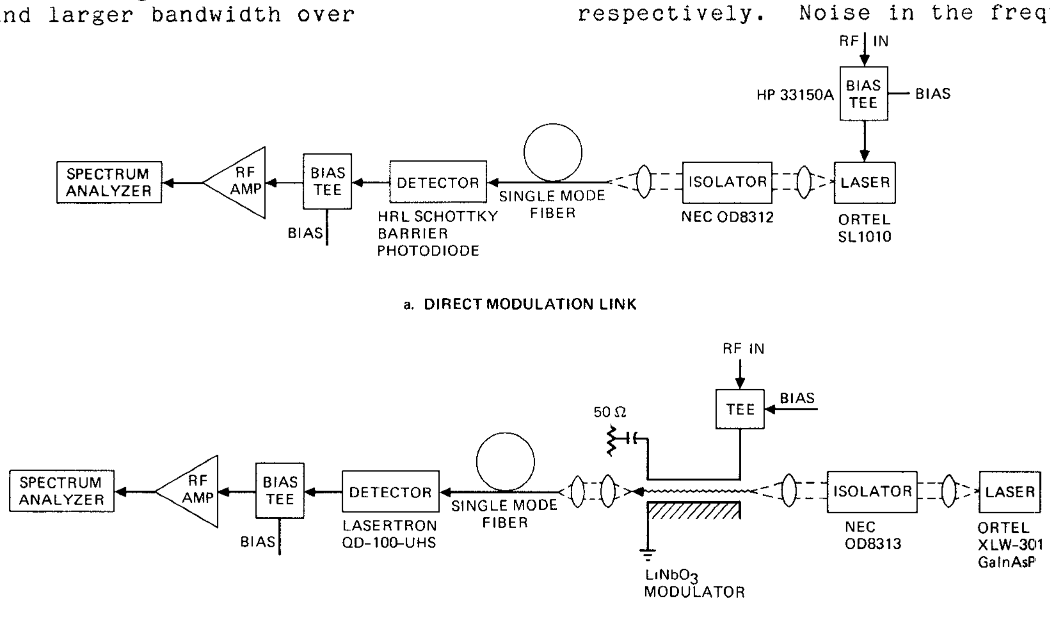

Fig. 1 Link configurations using (a) direct modulation at 0.8 μm wavelength and (b) external modulation at 1.3 μm wavelength.

range close to the rf carrier is important for doppler radar applications. An X-band noise test set was used to measure a carrier to noise ratio of 115 dB/Hz at 1 kHz away from the carrier for the 0.8 μm wavelength link. These results demonstrate for the first time, that rf fiber optic links are a viable approach to long range guided signal transmission at X-band frequencies.

EXPERIMENTAL RESULTS

Figure 1 illustrates the two link configurations under study. We used the best high-speed components available either commercially or through our own laboratory. The essential components of the 0.8 μm wavelength direct modulation link included a wideband GaAlAs window structure laser, an optical isolator, 1 km single-mode fiber, and a high-speed GaAs Schottky photodiode. The external modulation link included a 1.3 μm CW laser, an optical isolator, a $LiNbO_3$ traveling-wave modulator, 1 km single mode fiber, and a high speed InGaAs photodiode. Optical isolators were used to reduce spurious laser noise caused by reflection feedback. Since the isolators require a collimated beam, additional optics were necessary to couple the light from the laser through the isolator and into the fiber.

In the direct modulated link, the rf power was coupled to the laser through a bias tee. The detector output was coupled to a wideband amplifier and displayed on a spectrum analyzer. When the laser was

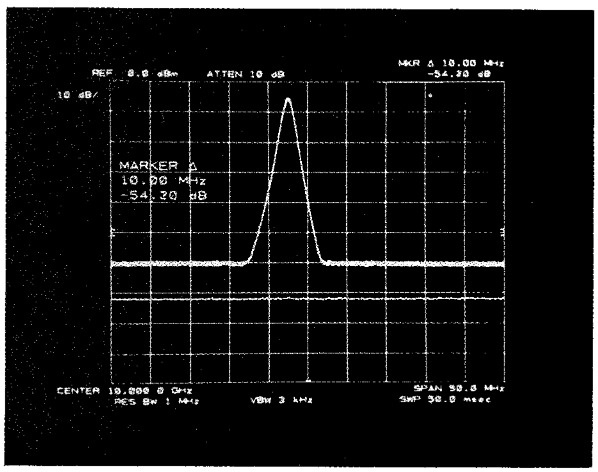

Fig. 2 Optical output for direct modulation 0.8 μm wavelength link under 10 GHz modulation into 1 MHz bandwidth (10 dB/div).

biased at 40 mA (I/I_{th} = 3.3), the 3-dB bandwidth of the link was measured to be 10 GHz, limited by the laser frequency response. The best S/N achieved was 115 dB/Hz at 10 GHz with 3 dBm of rf drive power (Figure 2). Driving the direct modulation link beyond 3 dBm did not significantly improve its S/N. Instabilities due to optical feedback reflections were observed in spite of > 25 dB isolation provided by the optical isolator. Noise spikes at frequencies corresponding to the round trip path length from the point of reflection were observed.

The noise floor of this link was dominated by the intrinsic intensity noise of the laser. This noise arises from shot noise processes associated with carrier injection and recombination inside the laser active layer.[1] These noise generating processes result in an intensity noise spectrum which is characterized by a broad resonance near the laser relaxation frequency, which for our laser biased at 40 mA was about 9.5 GHz. Besides this broad noise spectrum, when the laser was modulated, the low frequency laser noise appeared to mix with the rf modulation signal to produce rf noise sidebands on the carrier. The noise sidebands were strikingly similar to the noise structure observed at lower frequencies.

The AM and FM noise close to the rf carrier were measured with a relative noise test set for the 0.8 μm wavelength link. The phase noise measurement was made by applying the output from the rf signal generator which drives the link and the output of the link to a mixer used as a phase detector. The AM noise was measured with a microwave crystal detector. The output of the phase detector or AM detector was measured with a spectrum analyzer and compared to a calibration signal. Figures 3(a) and 3(b) display the AM and FM noise of the link when optical feedback was minimized. The top curves (lines) are calibration inputs that are at -60 dBc. Both AM and FM noise levels are approximately equal to -115 dBc/Hz, suggesting random noise. The AM and FM noise measurements are also consistent with the total noise measurements far from the carrier measured using only the spectrum analyzer.

Although direct modulation has advantages in its simplicity and lower drive power requirements, indirect modulation does not require that both low noise and high frequency response be satisfied by the same laser. In addition, external modulation is free from direct interaction of the rf modulation signal with the low frequency laser noise components. The indirect modulated link

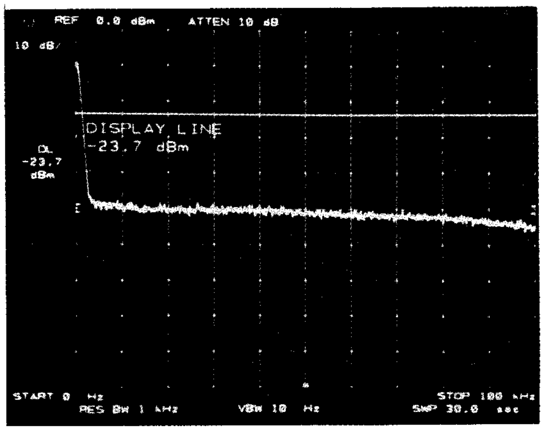

Fig 3(a) Amplitude noise of 0.8 μm wavelength system from dc to 100 kHz in 1 kHz bandwidth (10 dB/div). The top line is the -60 dBc calibration signal.

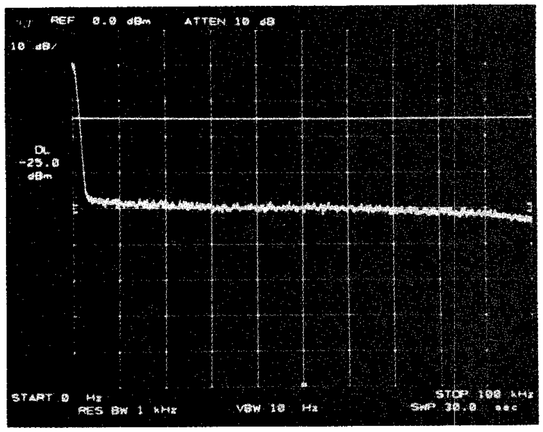

Fig 3(b) Phase noise of 0.8 μm wavelength system from dc to 100 kHz in 1 kHz bandwidth (10 dB/div). The top line is the -60 dBc calibration signal.

was performed at 1.3 μm because of the superior power handling capability of $LiNbO_3$ modulators at this wavelength. The rf power was coupled to the modulator through a bias tee, allowing a dc bias voltage to be applied to the modulator for selecting the proper operating point (V_π for the modulator was 15 V).

The 3-dB bandwidth of this link was measured to be 11 GHz, limited by the detector response. Figures 4(a) and 4(b) display the link output signal at 10 GHz. The peak signal level is at 0 dBm and the noise level is -70 dBm in a 1 MHz resolution bandwidth, giving a S/N of 130 dB/Hz for this link. The noise level in Figure 4(a) is that of the spectrum analyzer. The CW optical power from the laser was 28 mW and the rf drive power in this case was 280 mW. Slightly better S/N could be achieved with driving the external modulator harder. Like the direct modulated link, the S/N of the indirect modulated link noise was laser noise limited.

DISCUSSION

We have demonstrated the operation of X-band microwave fiber optic links with both direct modulation and external modulation configurations. The external modulation link exhibited better signal-to-noise compared to the direct modulation link primarily because the noise level of the 1.3 μm wavelength laser was lower than that of the 0.8 μm wavelength laser. In addition, a fairly large rf signal was applied to the external modulator. Hence, the performance of the links depends stongly on the components and the test parameters used. In general, though, the

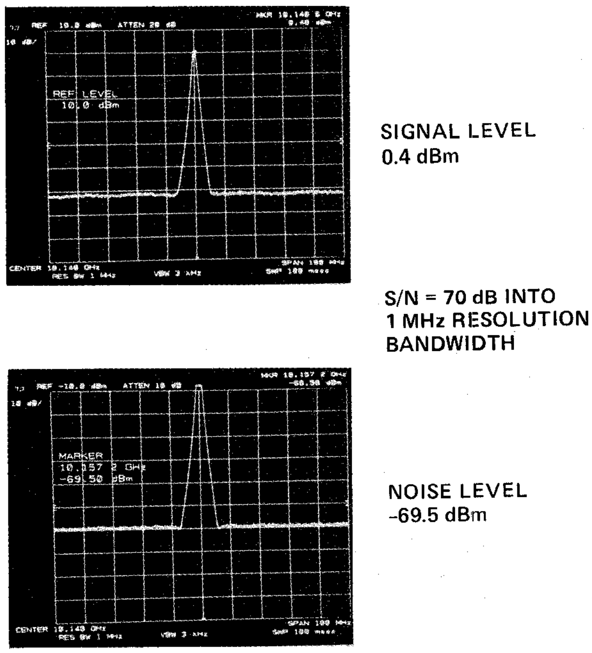

Fig. 4 Optical output of 1.3 μm wavelength external modulation link (10 dB/div) at 10 GHz with 280 mW input rf drive. The noise level of the top curve is the spectrum analyzer noise level.

1.3 μm wavelength laser seemed to be less sensitive to optical feedback reflections, and consequently the S/N of the 1.3 μm system was more stable. Recent efforts have demonstrated 1.3 μm wavelength lasers with frequency response in excess of 10 GHz.[2,3] It is anticipated that these type of lasers may provide an improved direct modulation link at X-band frequencies.

Direct modulation offers simplicity, low drive power and less overall link loss. However, laser wavelength chirping under high-speed modulation might prevent their use in some systems. On the other hand, the use of external modulators relaxes the demand for high frequency lasers and provides flexibility in selecting a low noise laser. The disadvantages, though, are additional coupling loss, higher drive power requirements and more distortion. Both techniques need to be evaluated for their applicability to specified system requirements.

In conclusion, with the rapid advancement of opto-electronic components, we expect to soon realize X-band rf fiber optic links in long range guided signal transmission systems.

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