A FIBER-OPTIC LINK UTILIZING SUBCARRIER TRANSMISSION AND RECEPTION OF MICROWAVE SIGNALS

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ABSTRACT

A novel fiber-optic system utilizing subcarrier transmission and reception of microwave signals is demonstrated. Error free transmission of a 50 Mbit/s amplitude shift keyed signal over 9 and 16 GHz microwave subcarriers is demonstrated for received optical powers ≥ -30.5 and -28.5 dBm, respectively.

I. INTRODUCTION

Transmission of microwave signals over an optical fiber offers the advantages of low-loss and immunity to electromagnetic interference. Some applications of fiber-optic links (FOL) for microwave signal transmission include: satellite communications systems [1], subcarrier multiplexed (SCM) systems [2] and optically controlled beam-steering of phased-array antennas [3]. Recently, several different FOL architectures have been proposed for subcarrier transmission of microwave and millimeter-wave (mm-w) signals. Narrowband mm-w transmission has been demonstrated [4]–[5] by resonantly enhancing a semiconductor laser, and 3-18 GHz microwave subcarrier transmission has been demonstrated [6] with phase-locked distributed feedback lasers. Here, while the techniques of Refs. [4] and [5] are inherently narrowband, the bit rates in technique [6] are limited by the electronics of the phase-locked loop. In contrast, Ti:$LiNbO_3$ traveling wave (TW) external electro-optic modulators with low (< 5-V) half-wave voltages (V_π) and with performance from DC to 40 GHz [7]–[8] have been reported. Recently, the performance of such devices has also been extended to 75 GHz [9]. Hence for applications in mm-w FOLs, external modulation is a very attractive alternative.

Furthermore, at the receiver end of a FOL, the received microwave/mm-w subcarrier signals (RF) are mixed with a local oscillator (LO) and downconverted to a lower intermediate frequency (IF) towards recovery of the baseband information. Therefore FOLs typically employ a high-speed photodetector (PD) to detect the microwave/ mm-w signal, which is then applied to a microwave mixer to accomplish downconversion. High-speed PDs have small active areas and may saturate at relatively low (< 2 mW) optical power levels, resulting in significant non-linearities [10]. To circumvent the need for high-speed PDs and microwave mixers, it would be advantageous to design links that can concurrently detect and downconvert microwave signals using inexpensive, low-speed PDs. Recently [11], we demonstrated that a pair of external interferometric modulators, cascaded in series, both biased at quadrature could act as a microwave mixer. In this paper, we apply this approach to demonstrate a novel fiber-optic system, for digital data transmission over a microwave subcarrier.

II. EXPERIMENTS

Illustrated in Fig. 1 is a block diagram of the FOL and the associated test equipment. The link is comprised of a 15 mW, 1.5 μm diode laser, a pair of serially cascaded Ti:$LiNbO_3$ external modulators separated by a few meters of polarization preserving fiber (PPF), and a commercial 300 MHz bandwidth PIN-FET photo-receiver. The modulators [7]–[8] were packaged with PPF pigtails, and exhibited a V_π of ≈ 5-V. A 50 Mbit/s amplitude shift keyed (ASK) signal was transmitted over the FOL. A non-return-to-zero (NRZ), $(2^{23} - 1)$ pseudo-random bit stream from the data transmitter of a bit error rate (BER) test set was applied to the IF port of a microwave mixer. This data was then upconverted to the microwave frequency band by applying a microwave signal from an RF synthesizer to the RF port of the mixer. The upconverted signal is transmitted over the FOL, and is downconverted to an IF (200 MHz in our experiments) by applying a LO pump signal from a LO synthesizer to the second modulator [11]. The detected IF at the receiver is then passed through a 150 MHz high-pass filter (HPF) and is amplified by ≈ 30 dB. To recover the baseband data, the IF is mixed down to baseband with a third synthesizer operating at the IF frequency (200 MHz). The baseband signal is then low-pass filtered with a 50 MHz low-pass filter (LPF) and is applied to the error detector of the BER test set. To avoid subcarrier and clock recovery in this initial experiment, all three synthesizers were phase locked to a 10 MHz reference source. A data rate of 50 Mbit/s was chosen for this experiment since both the IF (200 MHz) and the baseband signal had to fall within the bandwidth (300 MHz) of the photoreceiver.

The BER as a function of received optical power is shown in Fig. 2 for two different carrier frequencies (9 and 16 GHz). Error free transmission (corresponding to a BER of better than 10^{-9}) was achieved at received optical powers of $\geq$ -30.5 dBm at 9 GHz and $\geq$ -28.5 dBm at 16 GHz. As shown in Fig. 2, when the carrier frequency is increased from 9 to 16 GHz, there is a power penalty of $\approx$ 2 dB in achieving error free transmission. We attribute this to roll-off in the frequency response of the modulator. The eye diagrams for error free transmission are shown in Fig. 3 for both carrier frequencies, where good eye opening is observed in both cases.

We also measured the BER of a FOL employing just one modulator for direct baseband transmission; i.e., the ASK baseband signal was applied directly to the modulator and was not upconverted to the microwave band. We show in Fig. 4 the measured BER as a function of received optical power for data rates of 155 and 500 Mbit/s. We attribute the power penalty for the 500 Mbit/s data to roll-off in the response of photo-receiver. Comparing Figs. 2 and 4 reveals that there is little penalty to transmitting the ASK data over a microwave subcarrier.

III. DISCUSSION

Since external modulators with performance to 75 GHz have already been demonstrated [9], the technique advanced here could easily be extended to higher subcarrier frequencies. Hence unlike previous approaches which are inherently narrowband, this is a truly broadband technique. As demonstrated in Fig. 2, there would only be a marginal power penalty (proportional to the roll-off in the frequency response of the modulators) associated with scaling up the subcarrier frequency . Furthermore, by employing serially cascaded modulators, the transmitted microwave subcarrier can be concurrently downconverted [11], allowing for circumvention of problems associated with high-speed PDs [10]. However, if the data rate is increased, a higher speed photo-receiver will have to be employed to accomodate the faster the data rate. Also, several subcarrier channels could be simultaneously transmitted, and the LO signal applied to the second modulator can be tuned to select the desired channel.

Serially cascaded modulators are also attractive for data upconversion in SCM systems [2]. Here the baseband signal is applied directly to the first modulator and is upconverted by applying the RF subcarrier signal to the second. Since the modulators are capable of very broadband performance, very high data rates (> 10 Gbit/s) can be transmitted over a mm-w subcarrier.

IV. CONCLUSIONS

A novel fiber-optic system utilizing subcarrier transmission and reception of microwave signals is demonstrated. Error free transmission of a 50 Mbit/s ASK signal over 9 and 16 GHz microwave subcarriers is demonstrated for received optical powers $\geq$ -30.5 and -28.5 dBm respectively. The system has potential for extremely broadband operation and allows for transmission and reception of multiple microwave subcarriers.

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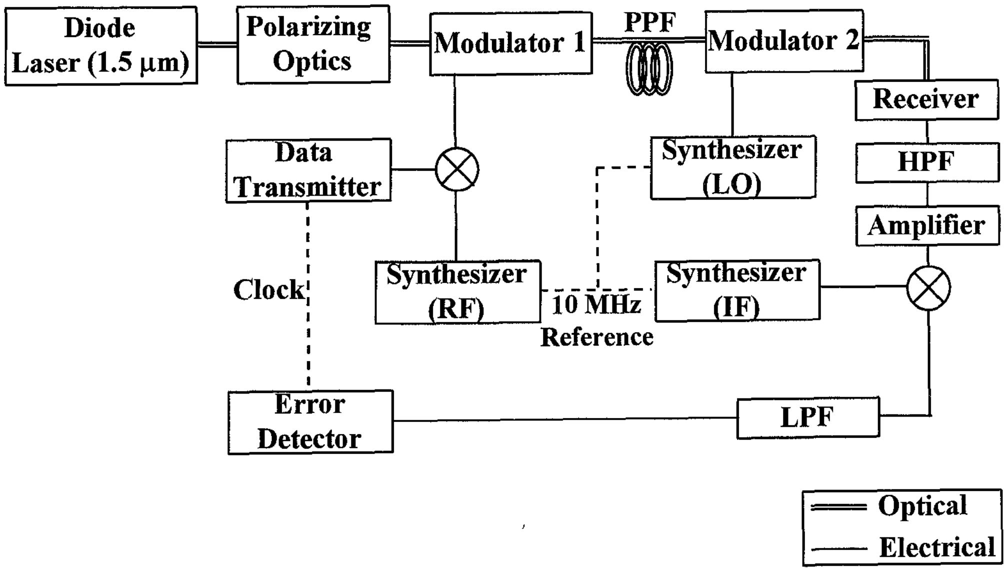


Fig. 1. Block diagram of test setup.

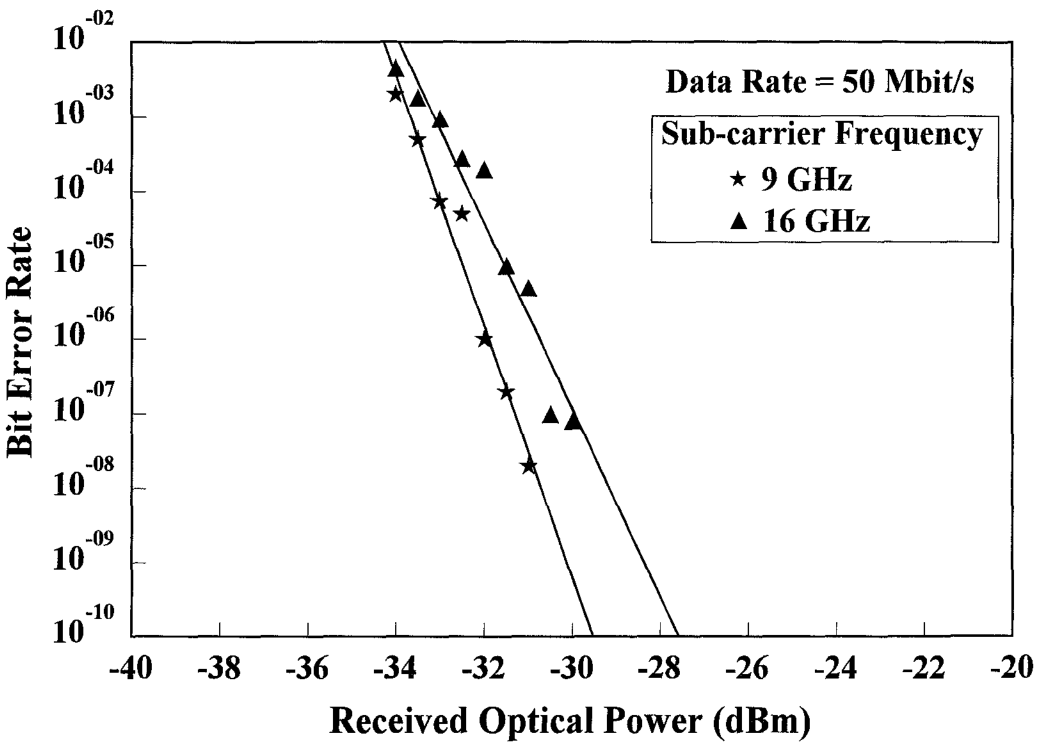
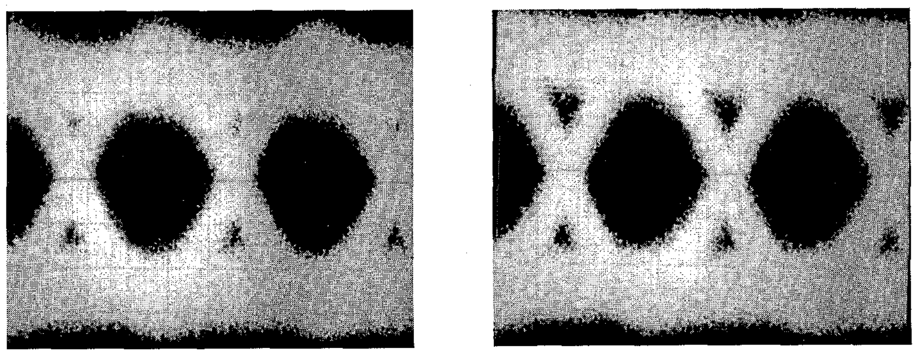


Fig. 2. Bit error rate vs received optical power for transmission of an ASK signal at 50 Mbit/s over microwave subcarriers at 9 and 16 GHz.



a b

Fig. 3. Eye diagrams of the recovered baseband signal transmitted over (a) 9 GHz and (b) 16 GHz subcarriers.

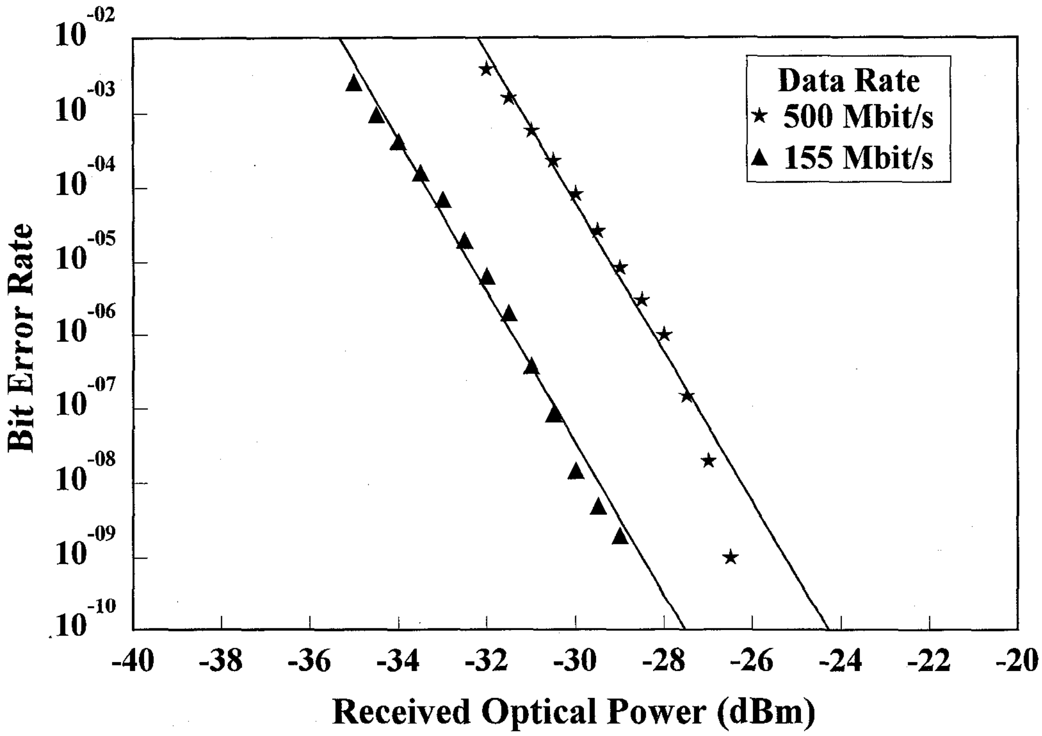


Fig. 4. Bit error rate vs received optical power for direct baseband transmission of ASK signals at 155 and 500 Mbit/s.