A HIGH-GAIN DIRECTLY MODULATED L-BAND MICROWAVE OPTICAL LINK

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ABSTRACT

A directly modulated microwave optical data link, using an efficient lossless impedance matching approach to maximize the transducer gains in the laser and detector matching networks, has yielded high gain. The free-space optical link operates at 900 MHz with a peak gain of 3.7 dB over a 3 dB bandwidth of 90 MHz. The link also exhibits a wide dynamic range of 89 dB·MHz. This optical data link is the first to function without any active amplification.

INTRODUCTION

Directly modulated optical data links are increasingly being considered for a variety of analog communication applications such as satellite communications, local area networks, and active phased array harnesses. These applications, however, are currently limited by high insertion loss (-35 to -40 dB) and poor dynamic range (less than 60 dB·MHz at 1 dB compression) of the optical link. Recently, an optical link with lower insertion loss (-15 dB) was reported that used an impedance-matching approach at X-band (1). Yet another approach for improving the dynamic range of an optical link separated the microwave signal into a low frequency (500-1000 MHz) information channel and a high frequency (1-20 GHz) reference channel to optimize the dynamic range of the information channel at the low frequency range, where the insertion loss and noise figure of the link (which are dominated by the semiconductor laser diode) are low (2).

Most recently, our development of a directly modulated optical data link at L-band adopted an efficient impedance-matching approach to maximize the inherent transducer gains in the laser and detector matching circuits. This free-space optical link operates at 900 MHz with a peak gain of 3.7 dB over a 3 dB bandwidth of 90 MHz and features a dynamic range of 89 dB·MHz. This directly modulated optical link is the first to exhibit significant gain.

APPROACH

The schematic diagram of the experimental optical link and the equivalent circuit diagram are shown in Figure 1. The laser and detector modules were constructed using commercially available 1.3 µm InGaAsP lasers and InGaAs detectors from British Telecom & DuPont (BT&D). The responsivities of the laser diode (η_L) and photodetector (η_D) are 0.27 W/A and 1.0 A/W, respectively. Free-space optical coupling losses from the laser to the detector (η_{op}) measured 40%, resulting in a net current conversion efficiency from the laser to detector of 10%. Employing the conventional through-and-delay technique, the S-parameters of our standard 50 Ω test fixtures were de-embedded from the measured laser and detector S-parameters to determine the intrinsic device S-parameters. Subsequently, device models were extracted from the intrinsic device S-parameters using the SuperCompact^T CAD tool. The design for the optimum matching circuits to the laser and detector incorporated passive lumped elements, which are appropriate at the 1 GHz frequency range. Based on the circuit model parameters and the optical efficiencies listed above, the RF insertion gain was estimated to be 5.5 dB at 900 MHz.

RESULTS

Measurement of the input and output return losses of the laser and detector modules showed minimum S_{11} and S_{22} of -26 dB and -14 dB, respectively. However, the laser module showed a minimum input return loss at 1 GHz with a -10 dB bandwidth of 220 MHz, whereas the detector module showed minimum loss at 900 MHz with a -10 dB bandwidth of 30 MHz. The measured link gain is shown in Figure 2. The gain curve in the figure varies with the DC bias current of the laser diode. At 20 mA, the gain is low due to the poor quantum efficiency near the laser threshold of 18.8 mA. When the bias is increased to 27 mA, the maximum measured gain is 3.7 dB at 900 MHz. At biases higher than 27 mA, the optical power increases, but again quantum efficiency decreases, as well as gain. For all of the bias values, the 3 dB bandwidth is 90 MHz. The discrepancy in gain between the model and experimental results is due to parasitics unaccounted for in the laser and detector models.

Linearity of the optical link was assessed using the two-tone intermodulation method. The two tones were centered at 900 MHz and separated by 10 MHz. Figure 3 shows the results of the two-tone IM measurement. The maximum third-order intercept point was +17.5 dBm, and the output power at 1 dB compression was 6.1 dBm. To determine the dynamic range, a separate noise figure measurement was performed on the link. At a laser bias of 43.8 mA, the link exhibited a 30 dB noise figure, shown in Figure 4, for the frequency range of interest. At a lower bias of 27 mA, the link achieved its minimum noise figure of 27 dB.

It is worthwhile to note that the link gains obtained from the intermodulation and the noise figure measurements are within ±1 dB of the network analyzer value at a bias current of 43.8 mA. Based on the above results, the compression dynamic range and the corresponding spurious-free dynamic range are 89 dB·MHz and 66.3 dB·MHz, respectively, which are the highest values reported to date for directly modulated optical data links.

CONCLUSIONS

Optical links, particularly because of their small size and light weight, are extremely attractive alternatives for distributing data and control signals among phased array antenna elements. However, the advantages have heretofore been undermined by the high insertion loss and narrow dynamic range of most optical links. Methodical optimization of the transducer gains in our laser and detector matching networks eliminated the insertion loss of our free-space optical link, producing 3.7 dB of insertion gain at 900 MHz. The wide compression dynamic range (89 dB·MHz) exhibited by this directly modulated optical data link affirms its suitability for a variety of analog communication applications, including active phased array harnesses, local area networks, and satellite communications systems.

REFERENCES

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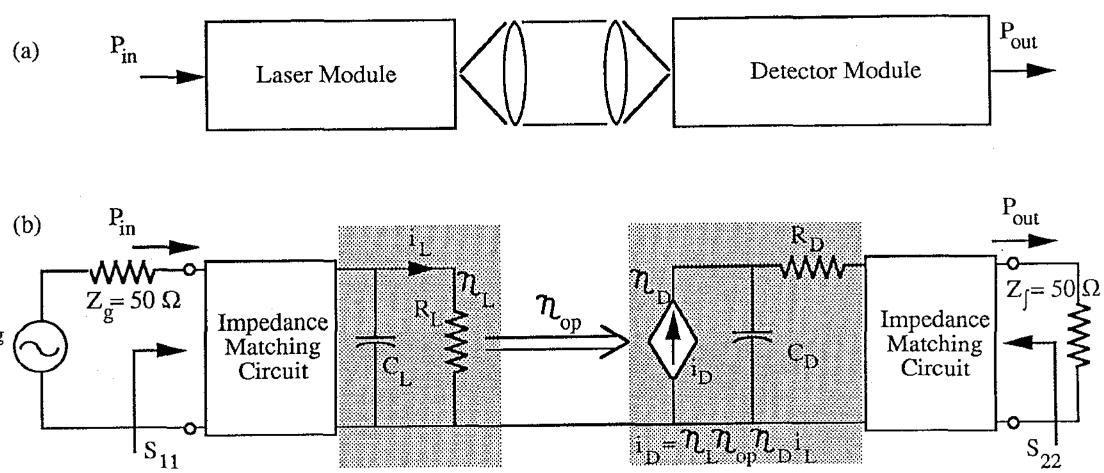

$$G = \frac{P_{out}}{P_{in}} = \frac{(1-|S_{11}|^2)\eta_L^2}{R_L}\ \eta_{op}^2\ \frac{\eta_D^2(1-|S_{22}|^2)}{4\omega^2 C_D^2 R_D}$$

Figure 1. (a) Schematic diagram of experimental optical link and (b) equivalent circuit model.

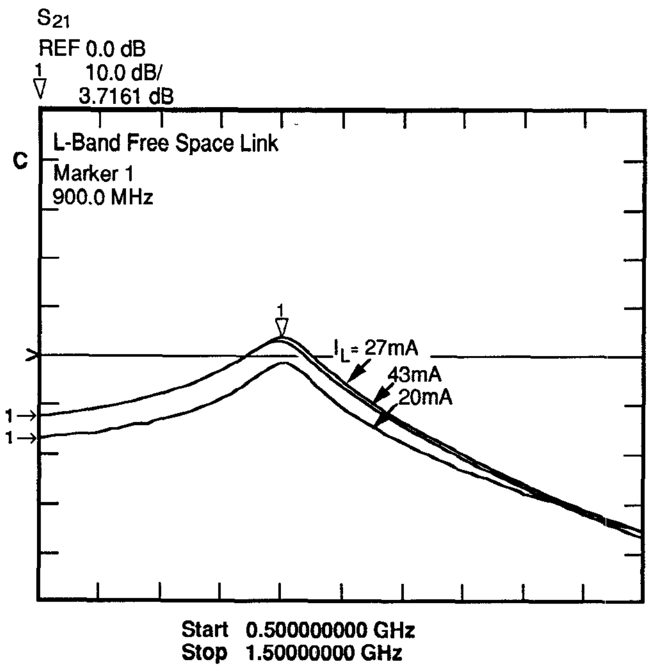

Figure 2. Measured insertion gain of L-band optical link under various laser diode biasing conditions.

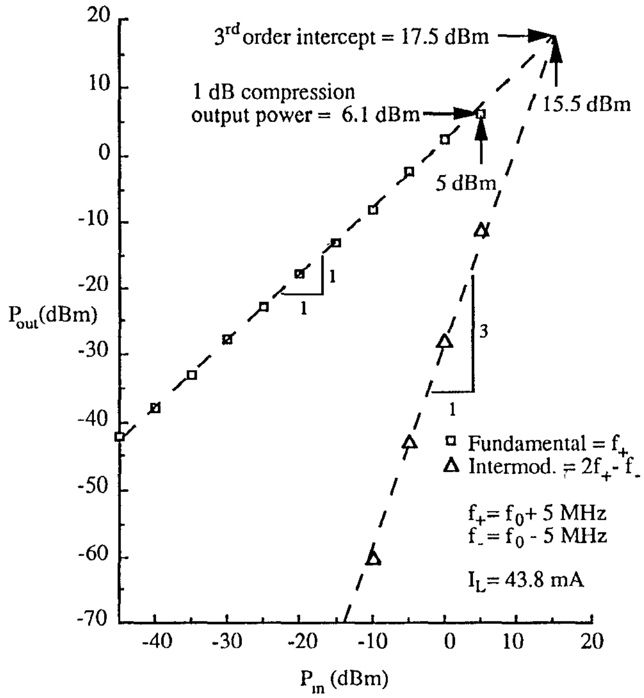

Figure 3. Results of a two-tone intermodulation distortion measurement, showing the link's 1 dB compression point and third-order intercept.

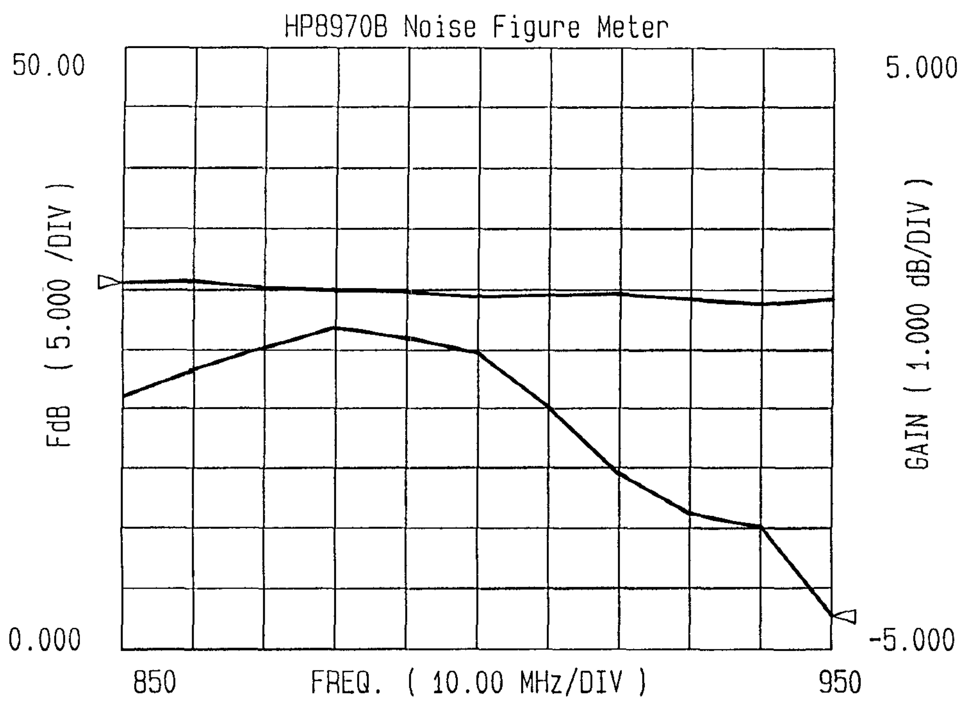

Figure 4. Measured noise figure of L-band optical link (laser bias current = 43.8 mA).