HIGH SPEED FIBER OPTIC LINKS FOR SHORT-HAUL MICROWAVE APPLICATIONS

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ABSTRACT

An experimental and analytical comparison between the fiberoptic (FO) and the conventional coaxial interconnects are made. Experiments were conducted for two different fiber optic links, namely reactively matched and resistively matched. An approach based on the use of reactively matched optical transmit/receive modules in conjunction with an advanced fiber optic link architecture leads to a substantial improvement in the system performance of high speed FO links.

INTRODUCTION

The inherent advantages of fiber optic (FO) links over coaxial and waveguide transmission lines has led to their wide spread use for medium and long haul telecommunications and local area networks (LAN). These advantages include light weight, small size, low attenuation, low susceptibility to electromagnetic interference, large bandwidth capacity and compatibility with optical processing schemes. There is considerable interest to use FO links to interconnect distributed microwave components and subsystems in phased array antennas, phase interferometers for direction finding, multistatic radars, etc.(1). However, at the present the inherent advantages of FO links cannot be exploited for short distance microwave applications (~below 100 meters) where their performance is limited by the opto-electronics transducers. This paper will discuss a new approach which includes the use of reactively matched optical transmit/receive modules in conjunction with an advanced link architecture that leads to a substantial improvement in the performance of high speed FO links. Experimental and analytical results are given comparing FO and the conventional coaxial interconnects.

PERFORMANCE LIMITATIONS OF FO LINKS

The principal elements of a typical fiber optic link which includes a semiconductor laser, a photodetector, associated driving circuitry and optical fiber, are shown in Fig.1. Major limitations associated with such a link operating at microwave frequencies are gain-bandwidth, sensitivity and dynamic range.

Gain Bandwidth: The maximum operating frequency of a directly modulated FO link is limited by the relaxation oscillation frequency of the semiconductor laser diode. This frequency is 10 GHz for commercially available buried hetereojunction GaAlAs laser diodes. The relaxation frequency is determined by structural parameters such as the differential optical gain constant, the photon life time, and the internal photon density in the active region which is dependent on the pump current. At the proximity of the relaxation frequency the relative intensity noise (RIN) of the laser increase dramatically, and above it the attenuation becomes prohibitive. Since the frequency response of commercially available PIN photodetectors now exceeds 20 GHz, therefore the FO link operating frequency is predominantly curtailed by the laser.

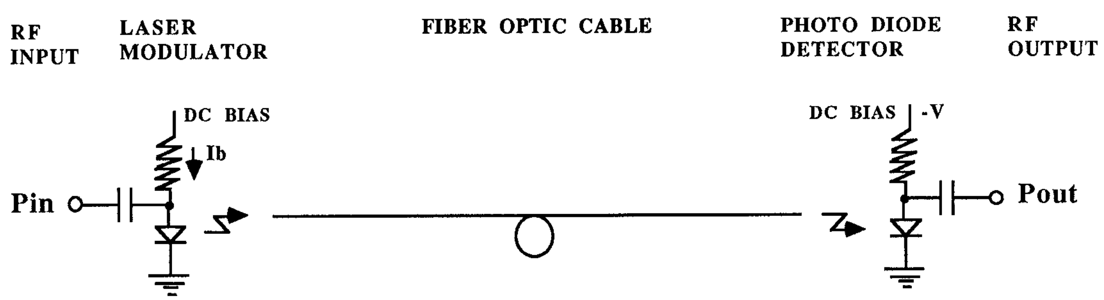


Figure-1 :Fiber Optic Link Components

1988 IEEE MTT-S Digest

The gain of a FO link at frequencies below the 3 dB bandwidth of laser and photodetector is given by:

$$G\,[dB] = 10 \log(L_{me}^2 L_{ro}^2 L_{mo}^2 L_{fo}^2 L_{co}^2) \qquad (1)$$

where:

$$L_{me}^2 = (1-|S_{11}|^2)\,(1-|S_{22}|^2)\,\frac{R_D}{R_L},$$

S_{11}, S_{22} : Reflection coefficients of laser and detector,

R_L, R_D : Laser and photodetector input resistance,

$L_{ro}^2 = \eta_L^2\, \eta_D^2$,

η_L , η_D: Responsivity of laser and detector,

$L_{mo}^2 = K_L^2\, K_D^2$,

K_L, K_D : Laser and detector coupling efficiency,

L_{fo}^2 : Fiber losses,

L_{co}^2 : Connector losses.

In Eq. (1) the microwave matching loss depends on the circuit as well as the operating frequency and bandwidth. The laser responsivity, of course, depends on the device structure and material. The coupling efficiency between the electrooptic components and the fiber, and connectors losses depend on mechanical alignment. The only loss term that is dependent on the link length is that of the fiber itself. Design and optimization of high speed FO links must take this factors into consideration.

For example let us consider a 50 meters FO link comprised of commercially available Ortel semiconductor lasers and photodetectors (SL-1020, PDO-25) modulated by a 2 GHz analog signal. The average loss will be 36 dB, distributed among the different components as shown in the accompanying pie chart:

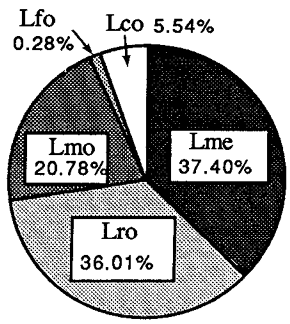
Lme (dB)=13.5

Lro (dB)=13.0

Lmo (dB)=7.5

Lfo (dB)=.01

Lco (dB)=2.0



It is clear that these losses must be significantly reduced before the full potential of optical interconnect of microwave systems can be realized.

Dynamic Range : The dynamic range of a link is determined by the difference between the 1 dB compression point input power (P_{1C}) and the minimum detectable signal (MDS) as described in Eq.-2.

$$CDR = P_{1C} - MDS \qquad (2)$$

where the MDS is given by:

$$MDS\,(dB) = -174 + NF + 10 \log BW$$

BW is the link bandwidth, 174 stands for the room temperature thermal noise contribution and NF is the link noise figure determined by the laser noise and the detector shot noise as described in the following equation.

$$NF = \frac{RIN(I_b,f)\,(I_b-I_{th})^2 R_L}{KT} + \frac{2e\,(I_b-I_{th})\,\sqrt{R_L R_D}}{\sqrt{G K T}}$$

Laser contribution — Detector contribution

The different parameters are: laser diode bias current, I_b, laser diode threshold current , I_{th}, and relative intensity noise of the laser diode, RIN. In short haul applications the FO link noise figure is dominated by the laser contribution. The laser noise is driven by the RIN which peaks at the relaxation oscillation frequency (4).

The link 1dB compression point input power (P_{1C}) is usually determined as 10 dB below the third order intercept point of the laser diode and depends on the laser structure and material.

The typical dynamic range measured for a system like the one shown in Fig.1 is 22dB (at 6GHz for a signal bandwidth of 0.5 GHz) which is inadequate for many applications. An examination of Eq. (1) leads one to conclude that the link noise figure must be reduced either by a redesign of the active devices internal structure or by developing an alternate FO configuration.

The problems of high speed FO links for microwave applications can be summarized as excessive system losses, poor dynamic range and limited frequency range. The challenge is therefore, to find ways to overcome these problems. The approach followed here is two pronged. First, we are systematically reducing system losses; second, we are exploring alternate FO link configurations which are both compatible with most applications and which circumvent some of the inherent problems discussed above.

ALTERNATE APPROACH

The conventional Fo configuration, referred to as *Central Data Mixing* (CDM), is shown in Fig. 2. In this architecture the FO link is directly substituted for the coaxial cable. The information or data is first upconverted by the reference signal at the CPU level and then transmitted to the remote element, such as a T/R module. This puts severe restraints on the laser as we expect it to be linear and free of noise very close to its relaxation oscillation frequency. This results in high attenuation and limited dynamic range. To reduce the link noise figure and thus increase the dynamic range, an alternate link architecture was developed (3). It is noted that most applications require a relatively narrow bandwidth information/data signal (typically 0.5-1.0GHz) modulating a high frequency carrier (10GHz or higher). By separating the information/data signal from the carrier, significant improvements can be achieved. The alternate configuration, called the *Remote data mixing* (RDM), is shown in Fig. 3. It uses two FO links , one for the data and one for the carrier, each of which can be independently optimized.

For the RDM configuration the carrier link provides essentially a synchronizing signal, typically a high frequency but very narrow bandwidth microwave signal. Since this link now does not carry data or information, one can exploit the nonlinearities of the laser to extend the operating frequency well beyond the laser relaxation frequency as demonstrated by Daryoush et al (5, 6). The use of a narrow band reactive matching circuit to the laser and photodetector greatly reduce system losses.

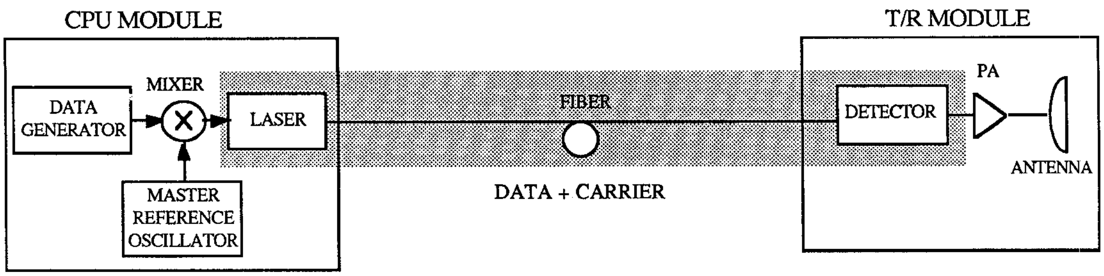


Figure-2 :Central Data Mixing Link Configuration

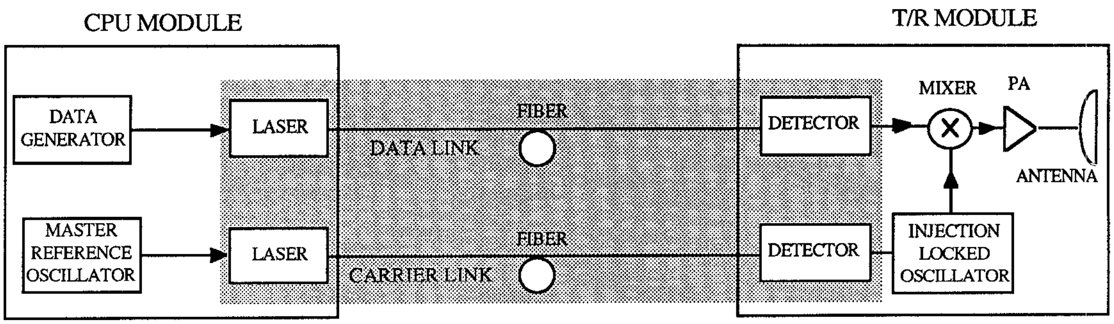


Figure-3 :Remote Data Mixing Link Configuration

Based on previous experimentation (5) coupled with improvements reported here, frequency synchronizing links up to 60 GHz are now feasible.

The data or communication link which operates at lower frequencies, usually well below the relaxation frequency, can be optimized as well. By designing new optical transmitter and receiver modules that are reactively matched to the microwave circuits an estimated reduction of ~13dB in the total system attenuation can be achieved. It should be noted that a 7 dB improvement in the system attenuation was experimentally demonstrated just by reactively matching the laser diode alone. The reactive matching of the photodetector, now under development, will reduce losses even more. A further reduction of 3 to 5 dB in the system total loss can be obtained by optimizing the optical alignment between the fiber ends at the laser diode and the photodetector active area. As a result of these improvements the total link attenuation can be reduced to the 20 dB region (2).

The dynamic range of the FO link is limited by the noise figure, which is dominated by the RIN. Since the data link in the RDM configuration operates at a lower frequency (relative to the CDM operating frequency) the RIN in this scheme will be lower and the dynamic range will be higher accordingly. An experimental improvement of 15 dB is reported in the following section.

EXPERIMENTAL SET-UP AND RESULTS

Attenuation measurements: Using an automatic network analyzer (HP8510) the attenuation of a resistively matched CDM system and of an RDM system in which the laser diode was reactively matched were measured and compared to coaxial cables including a semi rigid and a very high quality GORE cable (which cost $500/m). Selected results are depicted in Figs. 4 and 5. One can compare the link attenuation for these measurements in terms of the "crossover length", **L**, where the attenuation of the FO link and a conventional interconnect are equal, for a given frequency. This is shown in Table I.

	L -CROSSOVER LENGTH [m]		
	5 GHz	10 GHz	20 GHz
CDM Vs. coax	80	50	~
RDM Vs. coax	60	30	20
CDM Vs. Semi rigid	30	18	~
RDM Vs. Semi rigid	25	12	5

TABLE I

Dynamic range measurements: Selected results of dynamic range measurements for the *Central data mixing* and *Remote data mixing* configurations are summarized in Table II.

	DYNAMIC RANGE [dB] CDM	RDM
MEASURED	21.5	36
CALCULATED	23.8	35.9

TABLE II

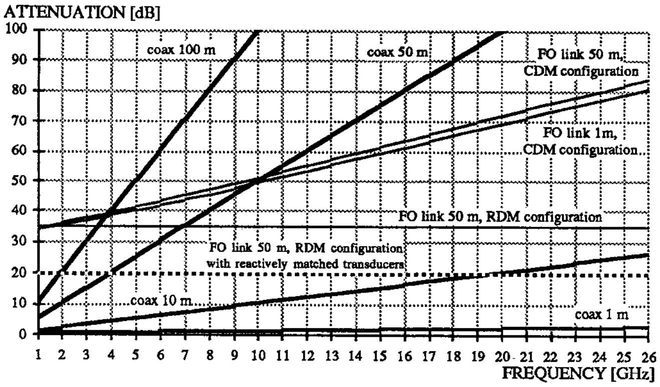


Figure-4: Attenuation of high quality coaxial lines compared to different FO link configurations

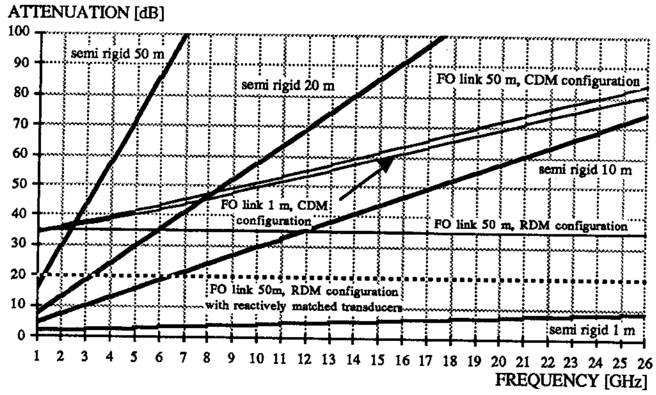


Figure-5: Attenuation of semi rigid coaxial lines compared to different FO link configurations

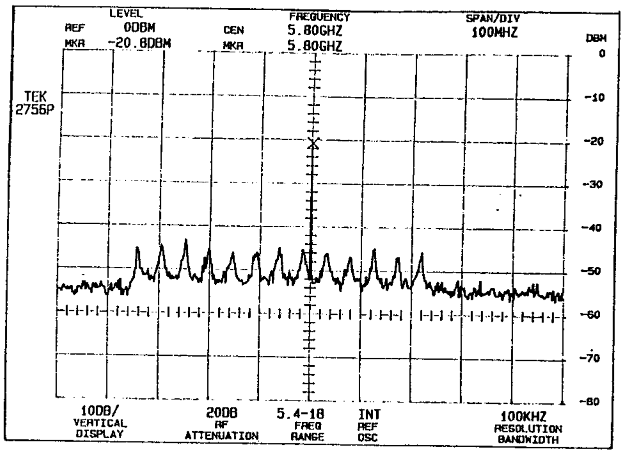


Figure-6: Central Data Mixing experimental results.

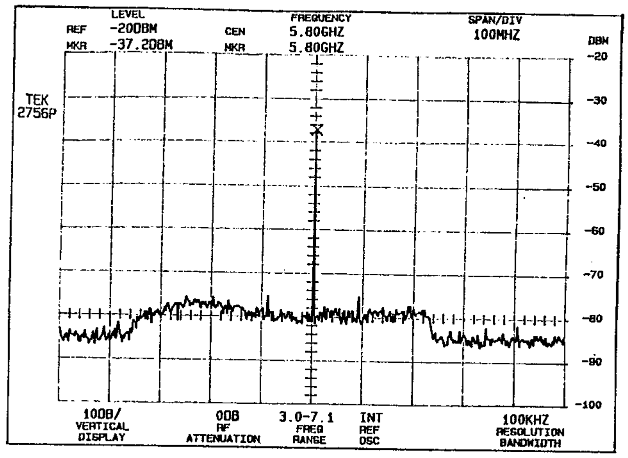


Figure-7: Remote Data Mixing experimental results.

We compared experimentally the performance of the two configurations, CDM and RDM. In this case the carrier frequency was 6.5 GHz and the information signal was 0.7 GHz. The experimental set-up was described elsewhere(3). Fig.s 6 and 7 show the detected signal and noise for the CDM and RDM systems, respectively. These figures clearly illustrate the advantages of the RDM configuration, particularly a 22 dB reduction in the noise floor of the fiber optic links indicates that the sensitivity has been improved by 22 dB.

SUMMARY

The combined approach that was described in this paper shows that the use of reactively matched transducers together with the *Remote data mixing* configuration can reduce the crossover length of fiber optic links when compared to coaxial lines from 40 to 60 meters at microwave frequencies to the 10 to 20 meters range.

This reduction of the crossover length the increased operating frequency and dynamic range achieved, has the potential to extend the use and application range of FO links in short haul distributed microwave systems.

REFERENCES

(1) J.J.Pan " Fiber Optics and Opto Electronics for Radar and Electronic Warfare Applications", Proc. SPIE Vol. 716, High Frequency Optical Communication (1986).

(2) M. de la Chapelle et. al. " Analysis of Low Impedance Matched Fiber-optic Transceivers for Microwave Signal Transmission ", Proc. SPIE Vol. 716, High Frequency Optical Communication (1986).

(3) I. Koffman et. al. "Comparison of Various Architectures of Microwave Fiber-Optic Links. A system level Analysis ", Proc. SPIE Vol. 840, Fiber Optic Systems for Mobile Platforms (1987).

(4) H.W.Yen et. al. " High Speed Modulation Techniques", SPIE Vol. 545, Optical Technology for Microwave Applications (1985).

(5) A.S.Daryoush et. al. " Phase and Frequency Coherency of Optically Synchronized 20GHz FET Oscillators " Proc. Int Microwave Symp. Las Vegas, NV, 1987.

(6) A.S.Daryoush et. al. " Comparison of Indirect Optical Injection-Locking Techniques of multiple X-Band Oscillators", IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-34, NO. 12, Dec. 1986.