COMPARISON OF CPU LEVEL DATA MIXING TO T/R LEVEL DATA MIXING ARCHITECTURES IN OPTICALLY CONTROLLED PHASED ARRAYS

R. Saedi, J. Wen, N. Samant, and A. Daryoush
Dept. of E.C.E., Drexel University, Philadelphia, PA
D. Sturzebecher
US Army Research Lab., ESPD, Ft. Monmouth, NJ
P. Herczfeld
F&H Applied Science Associates, Philadelphia, PA

ABSTRACT

Directly modulated fiber optic links are employed to control the active T/R modules of large aperture phased array antennas. The viable architectures considered for distribution of the modulated carrier are CPU level data mixing and T/R level data mixing. In this study, custom designed fiberoptic links were developed for distribution of the modulated carrier at 5.5-5.8GHz operating at 1300nm, whereas fiberoptic links operating at 5GHz and 650±150MHz were employed to provide the carrier and data separately, to the T/R modules generating the modulated carrier over 5.5 to 5.8GHz. These two architectures were used in optical control of a C-band 2x4 phased array antennas. The experimental comparison of fiber optic link performance is presented in this paper. Compression dynamic range of fiber optic link operating at 1300 nm was measured to be 72 dB.MHz over 5.5 to 5.8 GHz using the CPU level data mixing compared to the 77dB.MHz for the T/R level data mixing.

INTRODUCTION

We have demonstrated recently that an optically controlled phased array antennas operating at C-band can be implemented using the T/R level data mixing architecture [1]. In these experiments, fiberoptic links provide the frequency reference to synchronize distributed local oscillators operating at 5GHz and the 650±150MHz data signal to or from the T/R modules [1]. This architecture, called the T/R level data mixing architecture, is shown in Fig. 1a. A competing architecture, called the CPU level data mixing architecture, is shown in Fig. 1b. Because of the poor dynamic range performance of the directly modulated fiberoptic links at 20GHz and above, it is clear that the T/R level data mixing architecture is the only method by which to achieve high dynamic range in optically controlled phased array antennas operating at high microwave frequencies [2].

However, it is not clear that the benefits gained from T/R level data mixing at lower frequencies are as pronounced as those gained at millimeter wave frequencies; therefore, this question arises: How practical is it to realize the T/R level data mixing architecture at lower frequencies?

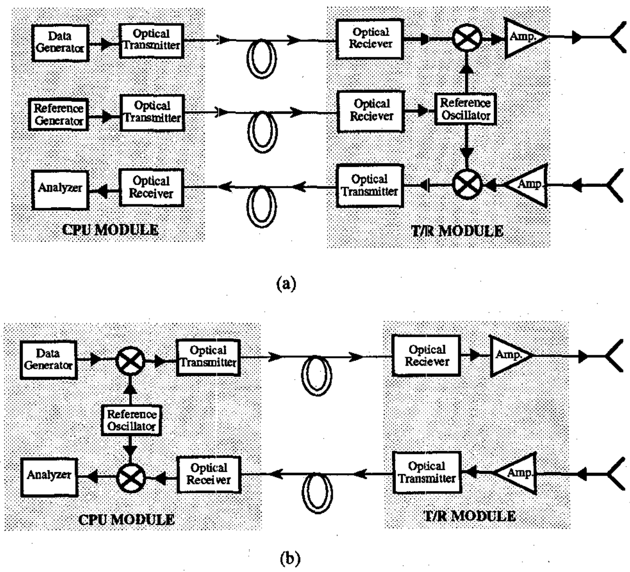

Fig. 1 Fiberoptic links for control of phased array antennas; a) T/R level data mixing architecture; b) CPU level data mixing architecture.

This paper compares the experimental performance of these two viable architectures in an optically controlled 2x4 phased array antenna operating at C-band. First we present the results of a CPU level data mixing followed by the analytical and experimental results of the T/R level data mixing. The performance criteria for comparison of these two different schemes of distributing a modulated carrier are the standard fiberoptic link parameters. More specifically, the performance of these two architectures are compared in terms of insertion loss, noise figure, distortion, and dynamic range.

DESIGN APPROACH

Design of the high dynamic range fiberoptic link is based on selection of the appropriate devices and their operating points in a custom-designed, reactively matched optical transmitter module and the actively matched optical receiver modules [3]. In the design of optical transmitter module, a 1300 nm quantum well InGaAsP laser diode was selected as the optical source [4], with a matching PIN photo-diode (Lasertron's QDE-35C) as the basis for the optical receiver module. The input impedance of the laser diode and PIN photodiode was measured and then fitted to equivalent circuit models over the bandwidth of 0.5-10.5 GHz to identify the best design techniques for the input /output matching circuits.

Our design topology takes advantage of a reactive matching network to match the laser diode impedance to the standard 50Ω system; an actively matched optical receiver design matches the high impedance of the reverse biased PIN photo-diode to amplifier input and amplifies the detected signal in the optical receiver [5]. In the design of the optical transmitter, a high pass filter configuration was employed as a dc blocking capacitor. A 0.375 pF capacitor separated the dc level of the laser diode from the RF input and compensated for the reactance of the laser diode at center frequency of 5.65 GHz. The circuit layout of the optical transmitter matching network is shown in Fig. 2.

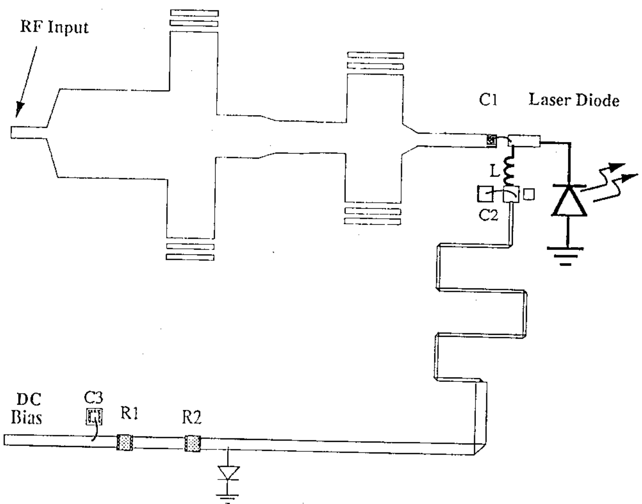

Fig. 2. The circuit layout of the reactively matched optical transmitter module.

The design block diagram of the optical receiver is shown in Fig. 3. In the design of the actively matched optical receiver, a common source configuration of a GaAs MESFET was used because of its high gate-to-source (input) impedance and low drain-to-source (output) impedance. Therefore, it is much easier to design a filter with fewer poles to match the PIN photo detector to the high input impedance of FET.

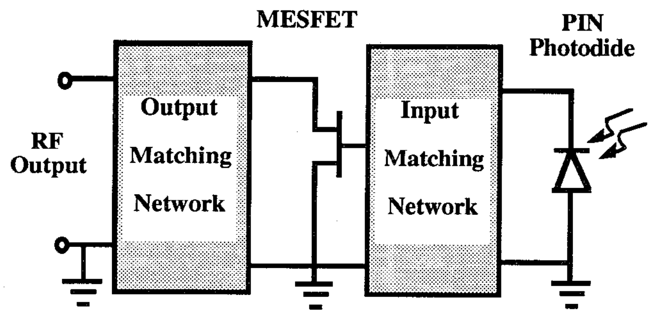

Fig. 3. The block diagram of the actively matched optical receiver module.

The fiber optic link, consisting of a reactively matched optical transmitter module, an optical fiber, and an actively matched optical receiver, was simulated on a custom designed microwave photonic CAD program[6]. The goal of this simulation was to optimize the gain and flatness of the link, while maintaining amplifier stability. By use of a layout program, the circuit layout was plotted for realization using thick film processing techniques. Both circuits were fabricated on a 25 mils thick RT/Duroid substrate, and all of the components were then mounted on the substrates. Return losses ≤ -10dB for the optical transmitter and receiver modules were accomplished over the bandwidth of 5.5-5.8 GHz.

EXPERIMENTAL RESULTS

The 5.5-5.8 GHz fiberoptic link was characterized in terms of frequency response, noise figure and inter-modulation distortion. The frequency response of the fiberoptic link is shown in Fig. 4, where a gain of -11.3dB with flatness of ±0.5dB was measured over the bandwidth of 5.5-5.8 GHz. For a hemispherical lensed fiber coupling to the laser diode, an insertion loss of ≈ 11 dB was achieved over the bandwidth of 5.5-5.8 GHz. However, a lensed fiber is more sensitive to vibration caused misalignment and imposes greater restriction on the mechanical tolerance of fiber aligning system. Therefore butt-coupled fiber was employed in the optical module, resulting in an insertion loss of 15 dB.

The fiber-optic link has a noise figure of 46-48 dB over the bandwidth of 5.5-5.8 GHz, which was primarily dominated by the RIN noise of the QW laser diode. The third order intercept point was identified through a two tone intermodulation distortion measurement at frequencies of 5.65GHz and 5.66 GHz. The output power of the fiber-optic link was measured at the fundamental frequency of 5.65 GHz and 5.66 GHz and third intermodulation frequencies of 5.64GHz and 5.67GHz. The plots of the received power as a function of input power is shown in Fig. 3, where the intermodulation signal at frequency of 5.64 GHz is displayed. From this figure, a 1dB gain compression point of ≈ 7 dBm at the input fundamental frequency of 5.66 GHz is achieved. The intermodulation intercept point for this link is at the input power of 15 dBm. As shown in Fig. 3, the designed fiberoptic link has a compression dynamic range of 72 dB.MHz and spurious free dynamic range of 53 dB.MHz$^{2/3}$.

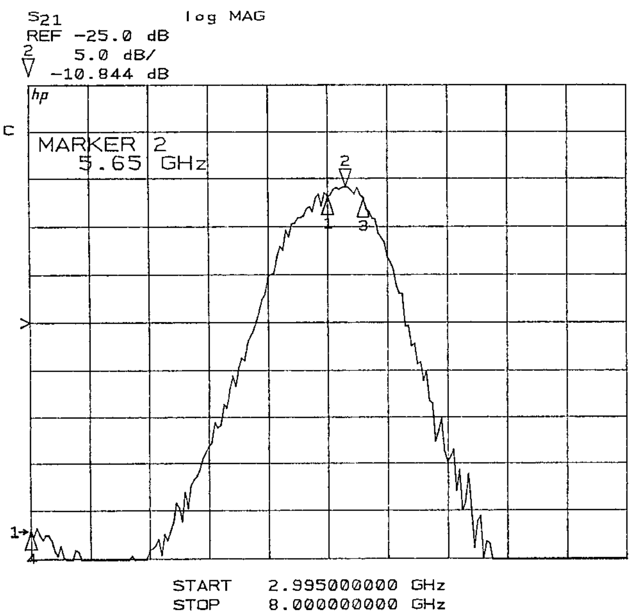

Fig. 4. Insertion loss (|S_{21}|) of the 5.5-5.8 GHz fiber optic link. (Vertical scale of 5dB/div, and the reference value of -20dB)

COMPARISON

To put in perspective performance of the CPU level data mixing architecture against the T/R level data mixing, we have compared these results with those reported for optically fed C-band phased array antennas [1], based on the AlGaAs components, from Ortel Corp. In the transmit mode, a compression dynamic range of 58 dB.MHz and spurious free dynamic range of 45 dB.MHz$^{2/3}$ was measured; whereas in receive mode a compression dynamic range of 64 dB.MHz and spurious free dynamic range of 45 dB.MHz$^{2/3}$ was accomplished over the same bandwidth [1]. In both modes, the dynamic range is limited by the data fiberoptic link performance. The obtained dynamic range results of the system operating at 850nm is lower than the CPU level results reported in this work. However, this superior performance is primarily as results of the better characteristics of the 1300 nm electro-optic components over the 850 nm components used in the design of those T/R level fiberoptic links.

Therefore, for a true performance comparison of these two architectures, the same type of QW laser diode for the optical transmitter and the lasertron PIN photodiode for the receiver module should be considered. We have proceeded with the design of a reactively matched optical transmitter and reactively matched optical receiver modules over the bandwidth of 650±150 MHz. Simulation of the link using our photonics CAD [6], indicated that the system can have a 48 dB noise figure, a 1 dB compression point of 8.5 dBm at the input , and a third order intercept point of +18dBm. We have proceeded with fabrication of the design to experimentally verify the simulation predictions.

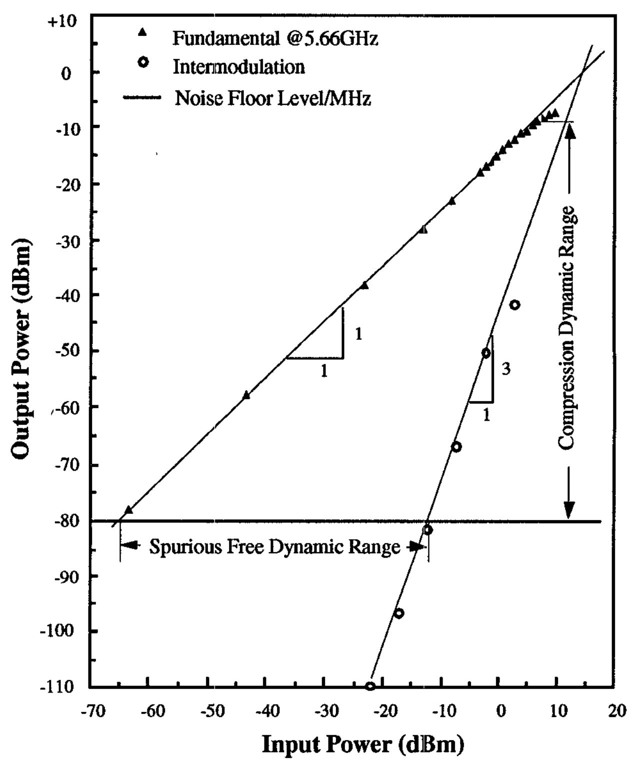

Fig. 5. Output power as a function of input power of the 5.5-5.8 GHz fiberoptic link at frequencies of 5.65 and 5.66 GHz, showing the linearity, third order intermodulation distortion and dynamic ranges.

The fiber optic link constructed for transmission of the data link over 650±150MHz was constructed and characterized in terms of gain, noise figure, and intermodulation distortion. Experimental results are insertion loss of ≈19 dB and noise figure of 45±2 dB over this bandwidth.

A plot of the output power as a function of input power is shown in Fig. 6, at the center frequency of 650MHz. As this figure shows, the fiberoptic link has an input 1 dB compression point of +8 dBm, a third order intercept point of +18dBm, a noise floor level of -88 dBm/MHz, a compression dynamic range of 77 dB/MHz, and a spurious dynamic range of 57dB.MHz$^{2/3}$.

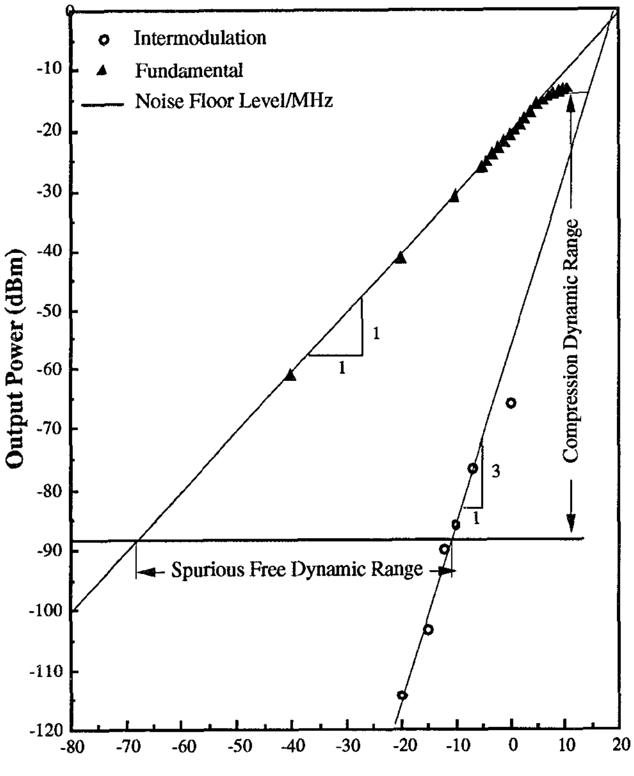

Fig. 6. Output power as a function of input power of the 0.5-0.8 GHz fiberoptic link at frequencies of 0.65 and 0.66 GHz, showing the linearity, third order intermodulation distortion and dynamic ranges.

CONCLUSION

In this paper we have presented performance comparison of a CPU level data mixing architecture versus a T/R level data mixing at C-band. The fiberoptic link used for transmission of the modulated carrier at 5.65±0.15 GHz has demonstrated insertion loss of ≈ 11 dB, compression dynamic range of 72 dB.MHz and spurious free dynamic range of 53 dB.MHz$^{2/3}$.

The achieved results for the CPU level data mixing architecture using InGaAsP/InP based components is higher than the results obtained out of the AlGaAs/GaAs based components for the T/R level data mixing architecture. This difference is as result of advances in the 1300nm based components as opposed to the components available at the obsolete wavelength of 850nm. In fact when a T/R level data mixing architecture was constructed using the same type of devices used in the CPU level data mixing, a higher dynamic range was attained. More specifically, we have achieved for the fiberoptic data link operating at 650 ± 150 MHz, an insertion loss of 19 dB, a compression dynamic range of 77 dB/MHz, and a spurious dynamic range of 57dB.MHz$^{2/3}$.

As result of this comparison, it appears that even at low microwave frequencies the T/R level data mixing architecture has a higher dynamic range over the CPU level data mixing; however, a few decibels of improvement in dynamic range would not warrant the cost of the additional components needed. We are currently evaluating the cross over point below which a T/R level data mixing architecture is not cost effective for an optically controlled phased array antennas.

REFERENCES

[1] A.S. Daryoush, et al., "Fiber Optic Fed C-Band Active Phased Array Antenna" The 1992 *IEEE International Microwave Symposium Digest*, Vol. I, pp. 437-440, Albuquerque, NM, June 1992.

[2] A. S. Daryoush, et al., "Fiberoptic Links for Millimeter Wave Communication Satellites" *IEEE International Microwave Symposium Digest,* New York, May 1988.

[3] A. Daryoush, N. Samant, E. Ackerman, and D. Kasemset, "Interfaces for High Speed Fiberoptic Links: Analysis and Experiment" *IEEE Trans. Microwave Theory Tech.,* vol. MTT 39, no. 12, pp. 2031-2044, 1991.

[4] R. Huang, D. Wolf, W. Cheng, C. Jiang, R. Agrawal, D. Renner, A. Mar, and J. Bowers, "High-Speed, Low-Threshold InGaAsP Semi-Insulating Buried Crescent Lasers with 22 GHz Bandwidth", IEEE *Photonics Technology Lett.,* vol. 4, no. 4, pp. 293-295, April 1992.

[5] N. Samant, *Experimental and Analytical Study of Actively Impedance Matched Fiber Optic Links,* M. S. Thesis, Drexel University, Philadelphia, PA, 1992.

[6] A.S. Daryoush, N. Samant, D. Sturzebecher, D. Rhodes, "Photonic CAD For High Speed Fiberoptic Links" , Microwave J., vol.36, no.3, p58, March 1993