FIBER OPTIC FED C-BAND ACTIVE PHASED ARRAY ANTENNAS

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ABSTRACT

Experimental results are presented demonstrating operation of optically controlled phased array antennas at C-band. More specifically we present experimental results of optically controlled 2x4 MMIC based active T/R modules over the frequency of 5.5 to 5.8GHz. Custom designed fiber optic links have been employed to provide distribution of data and frequency reference signals to phased array antennas used in *T/R Level Data Mixing* architecture system.

INTRODUCTION

Fiber optic links play an important role in the distribution of signals in active phased array antennas consisting of a large number of transmit/receive (T/R) modules. Conceptual block diagram of fiberoptic based distribution networks is presented in Fig. 1, providing distribution of control and modulated carrier signals from CPU to two subarray modules in the transmit mode of operation (cf. Fig. 1). At each sub-array, a modulated carrier is obtained by mixing a coding/data signal with a stabilized LO. Two separate fiberoptic (FO) links are used for this purpose. One FO link is used for distribution of frequency reference to stabilize remotely located local oscillators and the second for coding/data signals.

Similarly in the receive mode of operation the received signals from the subarrays are down-converted at the subarrays with the same stabilized LO and returned back to the CPU, for further processing, using the coding/data FO link. This approach is called *T/R Level Data Mixing* architecture [1] and has a better system performance over the standard *CPU Level Data Mixing* architecture.

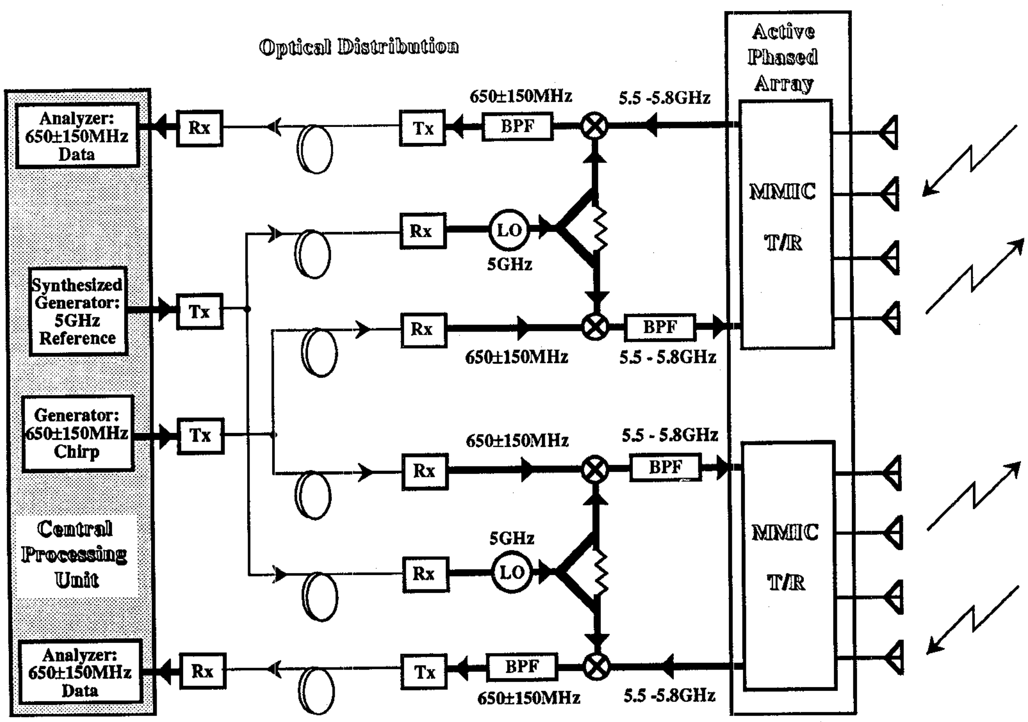

Fig. 1. Experimental setup for the optical control of 2x4 MMIC active phased array.

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This paper presents experiments leading to full optical control of two C-band MMIC subarrays, consisting of 1x4 MMIC T/R modules. For MMIC based T/R modules, operating best at 5.5 to 5.8GHz, fiber optic links at 5GHz (for frequency reference) and at 650±150 MHz (for coding/data signals) were selected. The narrow band fiber optic link at 5GHz provides distribution of the frequency reference to synchronize the two isolated, subarray based local oscillators to the same reference frequency of 5GHz. The reference FO link is designed for low FM noise degradation characteristics. The stabilized local oscillators are used to up-convert (down-convert) the IF (RF) signals. The coding/data signals are provided to and from subarrays using 650±150MHz FO links, designed for low loss and high dynamic range.

FIBER OPTIC LINK AT 650±150MHZ

To achieve low loss, low noise, and high dynamic range fiberoptic data links, custom designed optical transmitter and receiver modules were developed. Since our long range goal is to integrate optical T/R modules with GaAs MMICs, lasers and detectors operating at 850nm (Ortel's SL300H and PDO50C) have been selected.

To develop efficient optical/microwave interfaces over the required 500-800MHz frequency range, reactive and active impedance matching techniques have been considered for the laser and pin photodiode, respectively [2]. Measured return losses of the optical transmitter and receiver modules are measured to be 11dB and 4dB respectively. The optical transmitter and receiver were coupled using straight cleaved fibers. Gain of the complete link has been measured to be -27dB as shown in Fig. 2.

Much higher link gains of -9dB and -15dB have been measured for custom designed single mode lensed fibers and are also shown in Fig. 2. However, use of a lensed fiber has two disadvantages. First, the amount of light coupling from the laser to the lensed fiber is very position sensitive. (Position tolerances for lateral and transverse movements of the fiber are ±0.6μm and ±0.5μm, respectively, for a 1dB power drop). Second, the

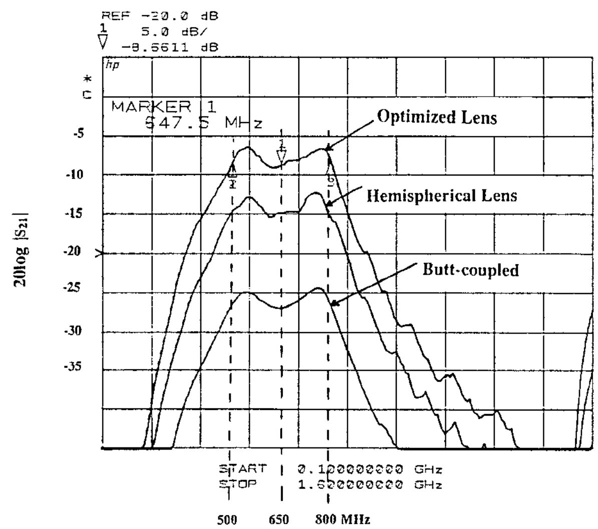


Fig. 2. Measurements of the 650±150MHz coding/data FO link using three different coupling factors of lensed single mode optical fibers coupled to the laser [4].

large coupling factor from the laser to the fiber makes the laser performance very much sensitive to the coherent light feedback from any scattering point. Strong reflections back into the laser result in large reflection induced noise peaks in the noise spectrum of the link. This reflection induced noise can be made negligible by inserting an optical isolator between the laser and the lensed fiber.

From the above discussion we can observe that by using a straight cleaved multi-mode fiber, to couple the laser's light to the detector, results in a lower gain, but a much reduced noise level and consequently a more acceptable dynamic range can be obtained. We have performed noise figure and two tone intermodulation distortion measurements for the link. The measured noise figure of the FO link at 650MHz is 45dB. The link exhibits a 1dB compression dynamic range of 65dB over a 1MHz bandwidth and a spurious-free dynamic range of about 50dB•MHz$^{2/3}$.

5GHZ INDIRECT OPTICALLY INJECTION LOCKED LOCAL OSCILLATOR

The block diagram of the local oscillator at 5GHz is shown in Fig. 3. The design concept of this oscillator is described by Berceli et. al. [3]. A dielectric disc resonator is incorporated to provide free running oscillations at approximately 5GHz. The spectra of the free running oscillators are shown in Fig. 4, which indicates high close-in FM noise and instability of the oscillators, at output power levels of ~13dBm. To synchronize the two local oscillators, a reference signal at 5GHz has been optically distributed (cf. Fig. 1), which after detection is electrically injected to the two local oscillators to provide stabilized oscillations at 5GHz. Note that with the present design of the oscillators no circulator is required for electrical injection locking; hence this design is quite compatible with MMIC circuit design techniques.

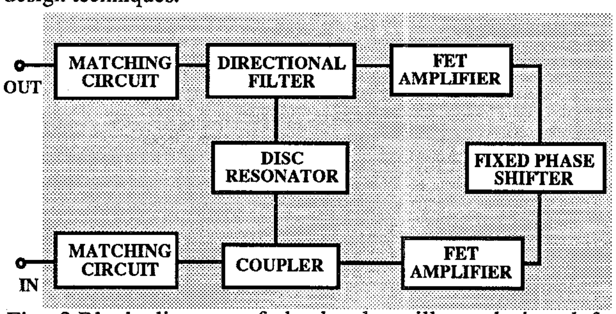
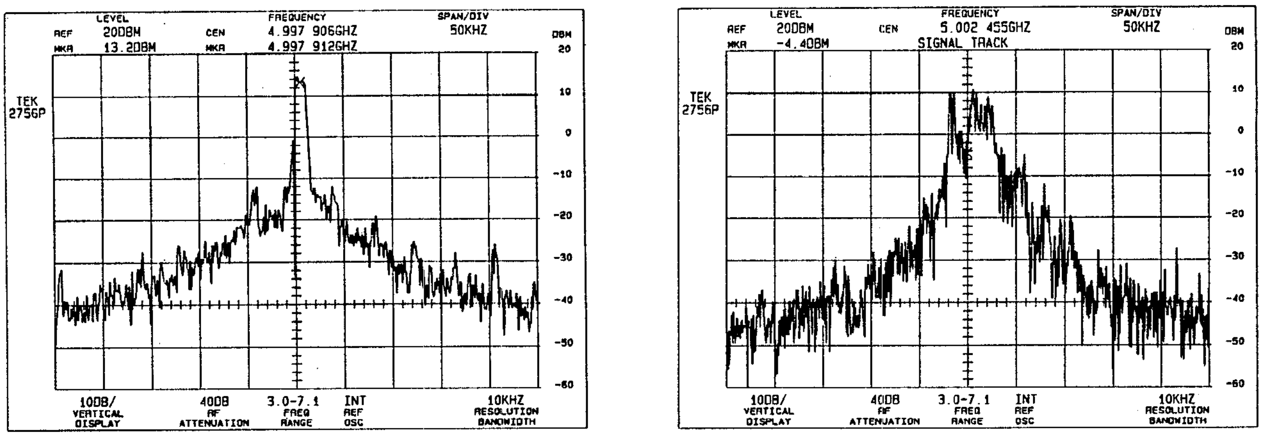


Fig. 3.Block diagram of the local oscillator designed for optically controlled injection locking.

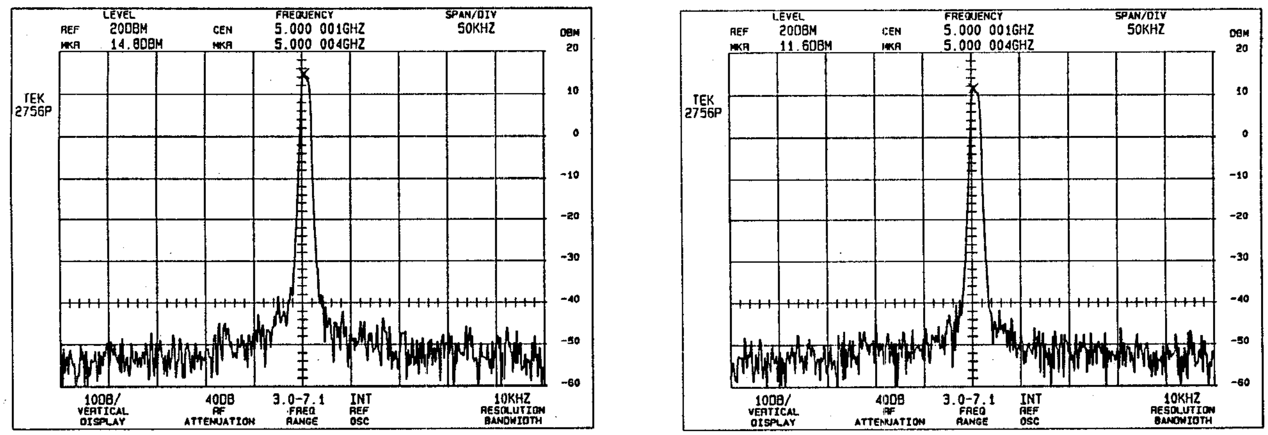
The optical distribution of 5GHz reference signal has been accomplished using custom designed optical transmitter and receiver modules with a 3dB optical coupler from Canstar (Model PC3-C-050) having coupling factors of -3dB and -6dB. The optical transmitter and receivers are based on the reactively matched AlGaAs laser diode (Ortel's SL1000H) and AlGaAs pin photodiodes (Ortel's PDO-25C). The link gains in the respective branches of the distribution network are measured to be -28dB and -38dB.

Injection locking of oscillators considerably improves the spectral purity of the oscillators as compared to that of free running oscillators, as shown in Fig. 5. Furthermore, this figure shows synchronization of the two local oscillators to a 5GHz frequency reference. The locking range increases with injected power level and is measured to be as high as 5MHz for a power gain of 22dB.



(a) (b)

Fig. 4. Spectra of two free running local oscillators providing oscillations at approximately 5GHz; (a) oscillator#1 operating at frequency of 4.997912GHz; and (b) oscillator#2 operating at frequency of 5.002455GHz. (Horizontal scale of 50kHz/div., vertical scale of 10dB/division and reference level of 20dBm).



(a) (b)

Fig. 5. Spectra of two local oscillators injection locked by the reference FO link distribution network providing frequency stabilized oscillations at 5.000004GHz; (a) oscillator#1; and (b) oscillator#2. (Horizontal scale of 50kHz/div., vertical scale of 10dB/division and reference level of 20dBm.)

TRANSMIT MODE OF OPERATION: UP-CONVERTED SIGNAL AT 5.5 - 5.8GHZ

An experimental setup similar to Fig. 1, has been established to examine the fiber optic distribution performance for the transmit mode of operation. A modulated carrier over 5.5 to 5.8GHz has been achieved by mixing signals from the data and the synchronizing FO links. In our experiment this up-conversion has been achieved by mixing the power conditioned coding/data signal from the 650±150MHz link with the stabilized 5GHz output of the injection locked local oscillator using a commercial balanced mixer (Avantek DBX-72L).

The dynamic range of the transmit mode of operation has been measured using two tone intermodulation and noise figure measurements at carrier frequency of 5.650GHz. Results of these measurements are depicted in Fig. 6. The measured compression dynamic range (CDR) of the system is 58dB in a 1MHz bandwidth and the measured spurious free dynamic range (SFDR) is 45dB•MHz$^{2/3}$. The dynamic range is almost the same as that of the coding/data link. This is due to the fact that the mixer has a higher third order intercept point than the FO link. In comparison with the two tone intermodulation measurements of the coding/data FO link, it has been observed that for the transmit mode the fundamental signal, the third order intermodulation product, and the noise floor of the system are scaled by the conversion gain of the mixer, which is measured to be about -7dB. The up-converted signal output of the mixer is injected to the MMIC subarray for amplitude and phase control before radiation.

RECEIVE MODE OF OPERATION: DOWN-CONVERTED SIGNAL AT 500 - 800MHZ

In the receive mode of operation, shown in Fig. 1, a signal from the MMIC sub-array is down-converted to IF frequency. This procedure is the reverse of the transmit mode technique. To simulate receive mode of operation, a signal of 5.5 to 5.8GHz from generator has been down-converted by the stabilized LO and the coding/data signal at IF frequency of 500 - 800MHz has been extracted. The IF signals from 500 - 800MHz are returned

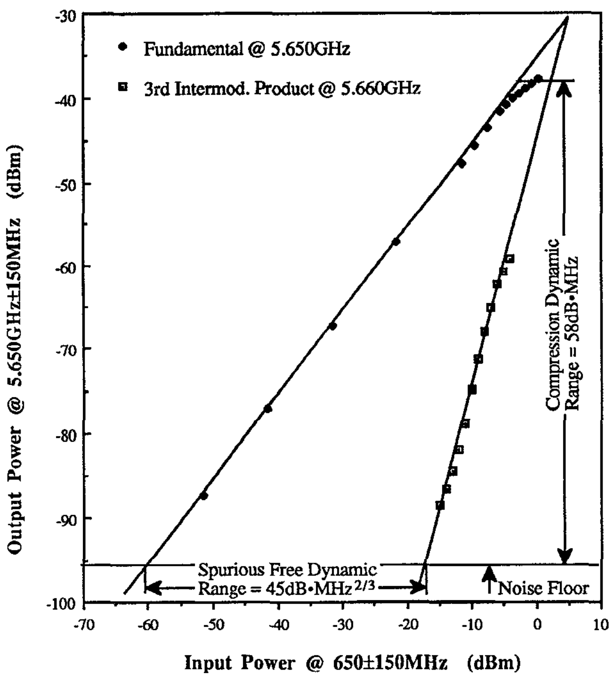


Fig. 6. Measurement of two tone intermodulation distortion showing gain, third order intermodulation product, noise figure, compression and spurious free dynamic ranges over a 1MHz bandwidth in the transmit mode of operation. Input IF powers are at f_1=650MHz and f_2=655MHz and RF output powers are at the fundamental frequency of 5.65GHz and at the third order intermodulation product frequency of 5.66GHz.

to the analyzers using the coding/data FO links. A high gain, low noise and high dynamic range MMIC based amplifier (LNA) is used at the input of the mixer to increase the sensitivity of the receive mode.

The dynamic range of the system without the LNA has been measured using two tone intermodulation and noise figure measurements, which are shown in Fig. 7. The measured compression dynamic range of the receive system is 64dB•MHz whereas a spurious free dynamic range of 50dB•MHz$^{2/3}$ has been measured. Dynamic range in the receive mode, is also limited by the coding/data FO link performance.

CONCLUSION

Experimental results of T/R level data mixing for a C-band active phased array antenna are presented. The mixing of the data and reference signal are achieved using fiber optic links in each stage. In the actual receive mode operation of the system the LNA plays the critical role of increasing the sensitivity of the receiver. The high gain and low noise figure of the MMIC LNA reduce the overall noise figure of the system. If the third order intercept of the LNA is higher than that of the data FO link, then receive mode of operation of the system with the amplifier will have an enhanced sensitivity without any degradation to the overall receive mode system dynamic range.

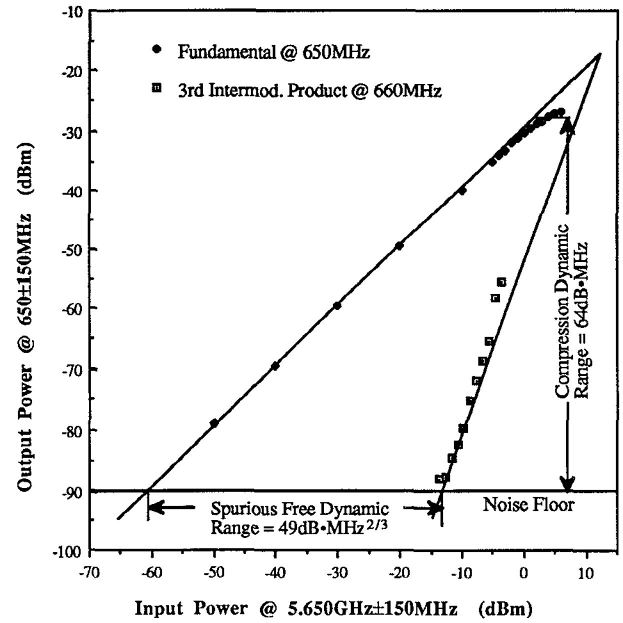


Fig. 7. Measurement of two tone intermodulation distortion showing gain, third order intermodulation product, noise figure, compression and spurious free dynamic ranges over a 1MHz bandwidth in the receive mode of operation. Input rf powers are at f_1=5.650GHz and f_2=5.655GHz and the output IF powers are at the fundamental frequency of 650MHz and at the third order intermodulation product frequency of 660MHz.

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