# OPTICAL CONTROL OF A GaAs MMIC TRANSMITT/RECEIVE MODULE

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## ABSTRACT

This paper reports on experimental results of an optical gain control and optical pulse code modulation of a GaAs Microwave Monolithic Integrated Circuit (MMIC) distributed amplifier. The control signal was generated by a low cost LED and a multifinger MESFETwas utilized as a photodetector. The amplifier gain was varied by 15 dB as a function of the optical intensity over the frequency range of 5 to 8 GHz. Pulse code modulation was obtained using a semiconductor laser. The work has relevance to reconfigurable phased array antennas.

## INTRODUCTION

One of the prime utilizations of the newly developed MMIC components will be for active aperture phased array antennas employed in communications and radar. To provide more radiating power, more agility and higher sensitivity, this new generation of phased array antennas will require a large number of closely-spaced MMIC T/R modules. The access and control of these elements by conventional means presents a problem and alternate approaches need to be explored[1,2]. Fiberoptic distribution networks can be used to route control and information signals providing phase, frequency, and modulation information to the independent T/R modules. Distributing the various signals by optical fibers has desirable features, such as high speed, large bandwidth, good electrical isolation, and elimination of grounding problems. Also, the fiber is lightweight, has a small size, and most significantly, it is immune to electromagnetic interference (EMI) and electromagnetic pulses (EMP). Furthermore, if the phase and/or gain of the MMIC T/R elements can be controlled by light intensity, then beamforming may be implemented by the use of high speed, parallel optical processors, such as spatial filters. The purpose of this paper is to demonstrate how MMIC T/R modules can be optically controlled. We report on two areas of optical control, namely, the gain control of distributed MMIC amplifiers and optical pulse code modulation of MMIC circuits.

## BACKGROUND

For a one dimensional phased array, with N nondirectional elements, the field strength in the far field is given by

$$E_T=E_o\sum_{n=0}^{N-1}K_n e^{j\theta_n}$$

where $K_n$ is current to the $n^{th}$ element, and $\Theta_n$ is the phase angle. In an active array antenna the current to each individual element is controlled, allowing for amplitude tapering. In a T/R module the current to each antenna element is a function of the amplifier gain; and in an optically controlled T/R module this gain is controlled by light:

$$K_n=K_oG_n= K_o\, G_n(\Phi_n)$$

where $K_o$ is the input to each amplifier in the array, $G_n$ is the amplifier gain of the $n^{th}$ element and $\Phi_n$ is the optical intensity to the $n^{th}$ amplifier. If in fact an efficient optical gain controller can be developed, then the antenna beam pattern can be manipulated by an electronically variable optical spatial filter with a transfer function T(x,y) ,

$$\Phi_n=T\,(x,y)\Phi_o$$

where $\Phi_o$ is the uniform input optical power illuminating the spatial filter[3]. Our task was to develop a simple, low-cost approach to control the gain of an amplifier resident in a MMIC T/R module, optically. (More recently the optical control of phase shifters was also demonstrated and will be reported elsewhere[4]).

Several investigators [5,6,7] attemted to control the performance of microwave devices, particularly HEMTs, lateral PIN diodes and MESFET's by direct optical illumination. The MESFET is of particular interest because of its sensitivity to light and its prominence as the basic element in MMIC.

Earlier studies [5,7] focused on high speed MESFET devices by injecting light into the active region between the gate and the source, and the drain. The photons absorbed in the GaAs generate electron hole pairs which alter the device characteristics. The optical port acts as an additional terminal. Specifically, the excess carrier density created by the optical illumination manifests itself by decreasing the effective thickness of the depletion region under the gate of the MESFET, resulting in an increase of the gate-to-source voltage as observed by DeSalles and others[7,8].

In general, the difficulty with previous experimentation has been the poor coupling of the light into the active region of the device. The geometry of high speed, high frequency MESFET, namely, its relatively large gatewidth (of the order of several hundred micrometers) and very short gatelength (of the order of a micrometer or less) is fundamentally incompatible with the typical cylindrical light spot emerging from a fiber. This reduces the effectiveness of the single gate MESFET as a detector.

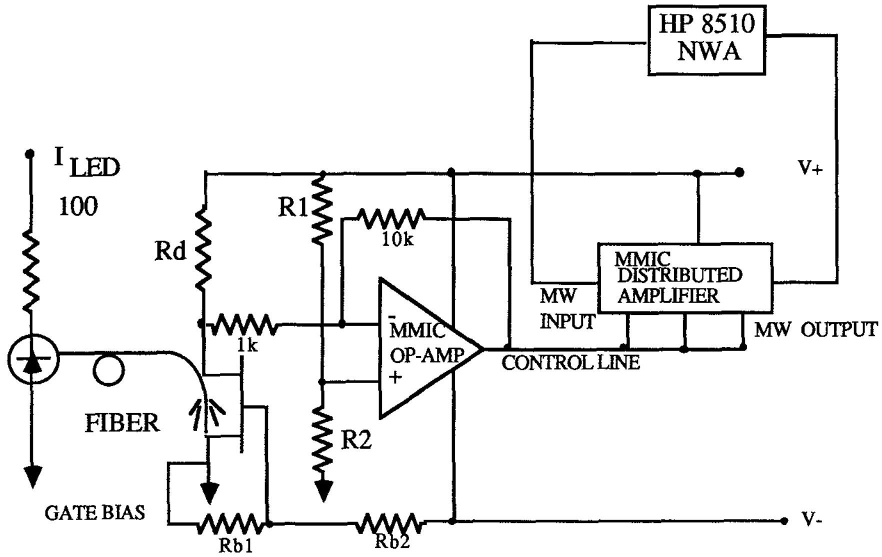


Fig.1 Experimental set up for the optical control of a GaAs MMIC Distributed Amplifier.

To circumvent this limitation, a different approach is presented in this paper. Rather than controlling the high frequency MESFETdirectly, we controlled the biasing circuitry of a microwave distributed amplifier operating in the the 5-8 GHz range (see Fig.1). The optical sensing element was a multi-finger MESFET, which has an enhanced exposed active area when compared to a single-finger MESFET. It was illuminated by a LED source operating at 835 nanometers, whose characteristics are shown in Fig.2.. The optical injection effectively varied the gate-to-source voltage of the low frequency MESFET and the change in this voltage was amplified by a MMIC operational amplifier, and then used to control the bias voltage of the distributed amplifier. By using the multi-fingered MESFET in our experiments, the effective illuminated area increases yielding a larger change in drain-to-source voltage over the single-finger MESFET, as seen in Fig.3.

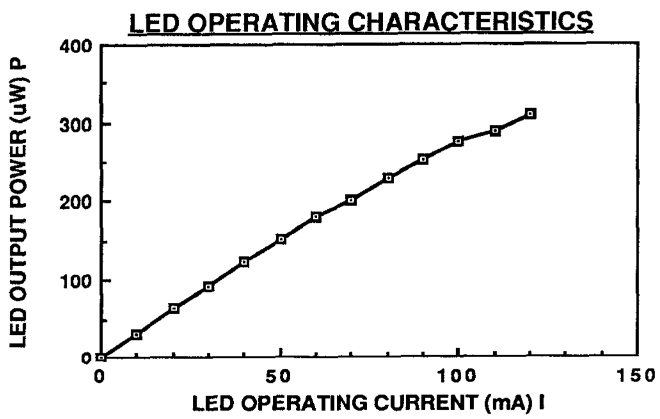


Fig. 2. Operating characteristics of the pig-tailed LED at a wavelength of 835 nanometers.

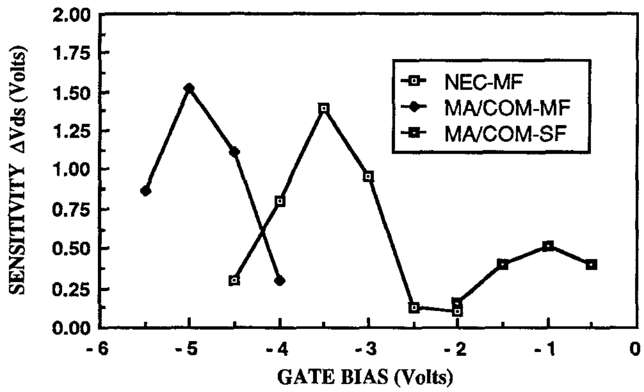


Fig. 3. Optical sensitivity of two different muli-finger FET, made by MA/COM and NEC, and a single gate MESFETproduced by MA/COM, as a function of gate bias. The change in drain to source voltage(ΔVds) is due to optical illumination of the device.

## EXPERIMENTAL SET UP

The experimental setup for gain control and pulse modulation were similar. The circuit for gain control, shown in Fig. 1, consists of four main sections; the LED light source with a pigtail, a light sensitive FET, a d.c. amplifier, and a distibuted microwave amplifier. The hybrid MMIC was assembled from three seperate GaAs MMICs which are commercially available and which can be integrated into a single chip. The multi-finger MESFETdetector (made by MA/COM) was selected because it has more exposed GaAs for light absorption than a typical single gate FET. The second chip, providing d.c. amplification, is a GaAs MMIC Operational Amplifier by ANADIGICS. The third chip is a GaAs MMIC distributed amplifier manufactured by MSC,which has four FETs that are tied to a common d.c. bias.

All of the three components described above are compatible with GaAs MMIC fabrication methods and can be integrated into a single MMIC chip.

Referring to Fig.1, the gain control circuit operates in the following manner. The MESFETis biased at or near pinch-off where it appears most sensitive to light.Gate biasing is obtained from the voltage divider resistors Rb1 and Rb2. The drain-to-source voltage of the FET, which is a function of light intensity is connected to the op-amp circuit. The op-amp is in the inverting configuration with 10 dB of gain. The resistors R1 and R2, which can be adjusted to accomodate the particular microwave circuit, provide voltage level shift for the control line.

The light is directed to the MESFETby positioning the fiber end a few hundred µm from the surface which produces a spot size safely covering all 14 gate fingers. The exposed GaAs surface (between the sources and drains) is approximately 2-3% of the total illuminating area of the beam pattern which is an estimated 3 to 5 times greater than one could acheive with a single gate MESFETas corroborated by the measurement shown in Fig.3. Varying the light intensity gives rise to a change in the drain-to-source voltage (Vds), which is amplified and controls the line voltage and hence the gain of the distributed amplifier.

For the pulsed operation of the circuit the LED is replaced by a semiconductor laser with a bandwidth of 1Gbit. The optical pulses effectively control the amplifier gain resulting in a pulse code modulation of the T/R module.

## EXPERIMENTAL RESULTS

The measurement consisted of monitoring the gain of the distributed amplifier over a frequency range of 5 to 8 GHz on a HP 8510 automatic network analyzer (ANA) as a function of light intensity on the MESFET detector.

A plot of the MESFET optical response to light versus gate bias is given in Fig. 3. The change in Vds was due to illumination of the MESFET at 250 µw of optical power at a wavelength of 835 nm. A maxium change in Vds of 1.52 volts was obtained at a gate bias of -5.0 volts for the multi-finger device (MA/COM-MF) as compared to a change of 0.5 volts for the single-finger device(MA/COM-SF). A change in gain of the distributed amplifier from +5 dB ±1.5 dB to -12 db ±1.5 dB was achieved when the gate bias varied from 0.0 volts to -4.0 volts. The lower limit of gate voltage(-4.0) determines the voltage level shift required from the op-amp in the absence of light.This is accomplished by setting the divider resistors R1 and R2 with the biased MESFET connected to the op-amp.

The parameter |S21| of the amplifier in the frequency range of 5.0 to 8.0 GHz at different light intensities is depicted in Fig.4. It is appearent that the response remains flat across the band with optical gain control. The amplifier gain as a function of optical intensity at 6.2 GHz is shown in Fig.5. It is seen that the gain of the amplifier can be controlled over a range of +6.0 dB to -10 dB with a maximum optical power of 250 µw.

For the pulse code modulation studies a semiconductor laser (ORTEL SL-620) with a modulation bandwidth of 6 GHz was used in place of the LED. The measurements were performed in two steps. First, the response of the MESFET to high speed sinusoidal optical modulation and short optical pulses was established. The multi-fingered MESFET displayed a flat response up to 1 GHz to a cw optical stimulus. Next the laser was excited by a 1 GHz signal, coded by a 1 microsecond pulse. The response of the MESFET to this optical input was monitored on a Textronics 2756P spectrum analyzer with the result shown in Fig.6. As the figure indicates the MESFET performs well as a high speed detector.

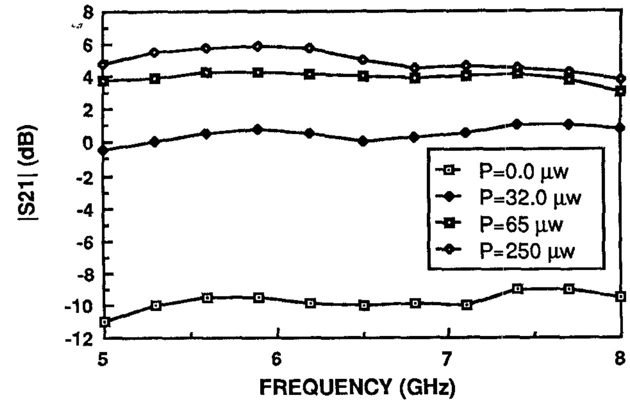


Fig. 4. Magnitude of the forward transmission parameter( S21) of the MMIC distributed amplifier over the frequency range of 5 to 8 GHz as a function of light intensity .

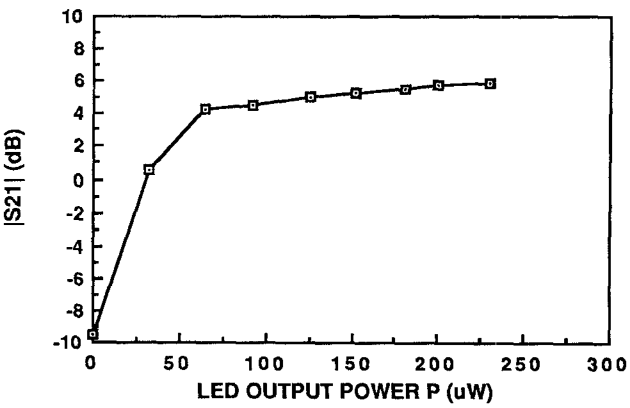


Fig. 5. Magnitude of the forward transmission parameter( S21) at 6.2 GHz of the MMIC distributed amplifier as a function of light intensity.

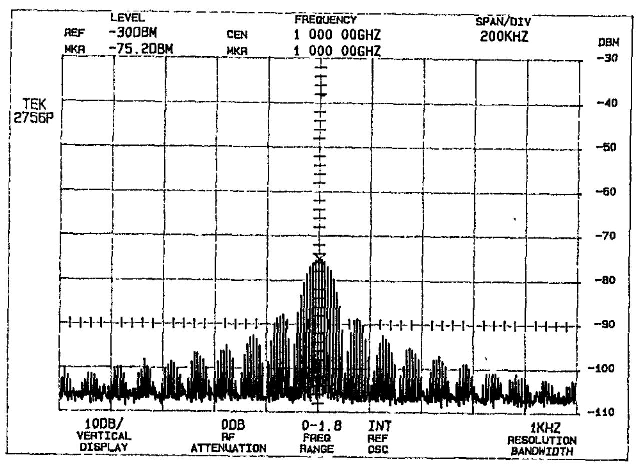


Fig. 6. Frequency spectrum of the MESFET response to optical pulse modulation.

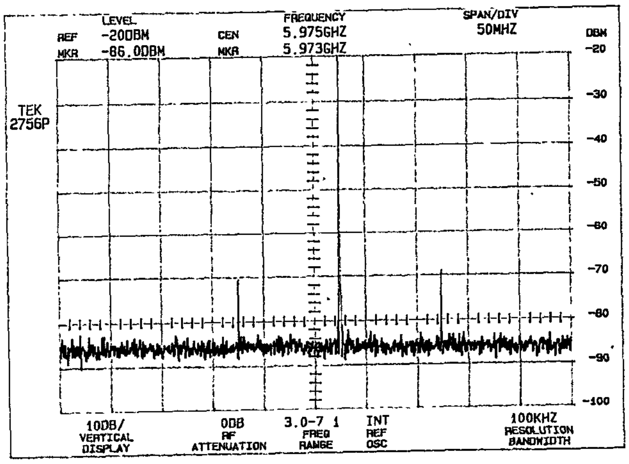


Fig. 7. Frequency spectrum of the distributed amplifier at 6.0 GHz, modulated optically by a 100 MHz signal.

In the second, experiment the laser was modulated by a 100 MHz signal and the optical signal was then transmitted to the remotely located MESFET by a multimode fiber. The optical signal detected by the MESFET was amplified by the op-amp and fed to the distributed amplifier as described earlier. The distributed amplifier was operated at a carrier frequency of 6.0 GHz, and observed on the spectrum analyzer as displayed in Fig. 7, whch clearly shows the carrier and the modulation sidebands.The modulation can be extended to higher frequencies, 1 GHz or higher, by substituting for the present op-amp a similar unit with higher bandwidth.

## DISCUSSION

We have presented a technique for gain control and modulation of MMICs by optical means that has produced encouraging results. The experimental setup was assembled from available, off the shelf MMIC components, including the MESFET used as a photodetector. The circuit as well as the components could be optimized and tailored to specific applications. The approach has several important attributes such as:

- it is independent of the operating frequency of the microwave components thus it can be extended to the millimeter range,
- it is totaly compatible with GaAs MMIC fabrication processes,
- it can be extended to other control functions of MMICs such as switching, limiting, and phase shifting [4]
- it is cost effective because it uses a low cost, low power LED and standard MMICs.
- it is compatible with emerging optical signal processing schemes with application toward advanced reconfigurable antennas.

## ACKNOWLEDGEMENTS

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