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ALL-OPTICALLY CONTROLLED BEAM-SCANNING ARRAY FOR ANTENNA REMOTING APPLICATIONS

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ABSTRACT

In this work, a beam-scanning array for antenna remoting via an optical link is presented. Optical control over the main beam is accomplished through the use of a photosensitive resonator. Experimental data shows a total scan angle up to 36° can be achieved with this optical technique.

INTRODUCTION

Radar, missile guidance and communications systems typically have rigid spatial constraints. However, in conventional systems, large amplifiers and motors are required to transmit high power and scan the antenna main beam, respectively. Waveguide typically is used because it has low loss and high power capability, but is bulky and not easily routed. These obstacles have led to continuing research in system and component designs to produce integrated and compact designs.

One method that has shown promise in remedying these problems is the active antenna array, which integrates active components directly into the antenna platform. It has been shown that the main beam of an active antenna array can be electronically scanned by controlling the phase between adjacent antenna element [1]-[3]. Recently, an active phased array with optical input and beam-scanning capability was reported [4]. In [4], a microwave reference signal is provided through an optical fiber link, but array control signals are provided electronically by varying the bias of the active device.

In this work, we attempt to increase the merits of optical remoting of antennas by demonstrating additional optical control over an active antenna phased array. Previous researchers have shown that performance of MESFET devices can be altered by applying optical illumination [5]. Recently, direct illumination of oscillating devices was shown capable of achieving 20°-scan angle, but can only be scanned in one direction [6]. In this work, we present an optical resonator, which achieves ±18° of main beam scan control.

DESIGN

Figure 1. shows the basic architecture for an *n*-element linear beam-scanning array. To

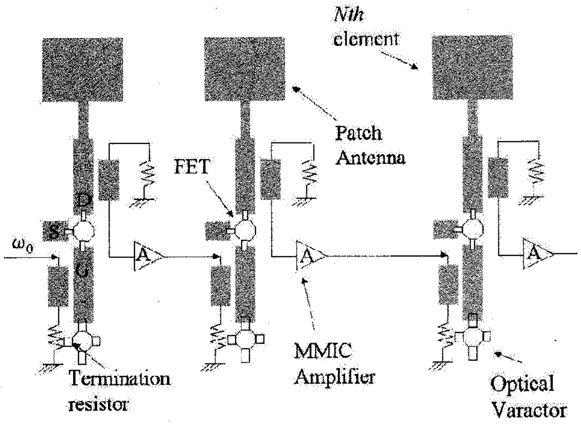

Figure 1. Archtecture of n-element array

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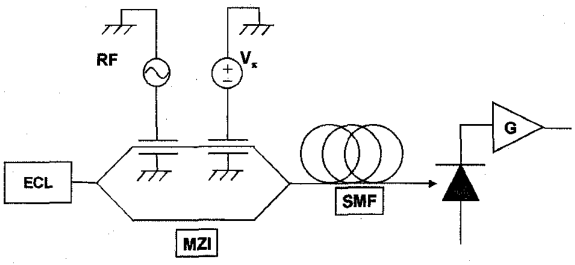

Figure 2. Optical link for antenna remoting.

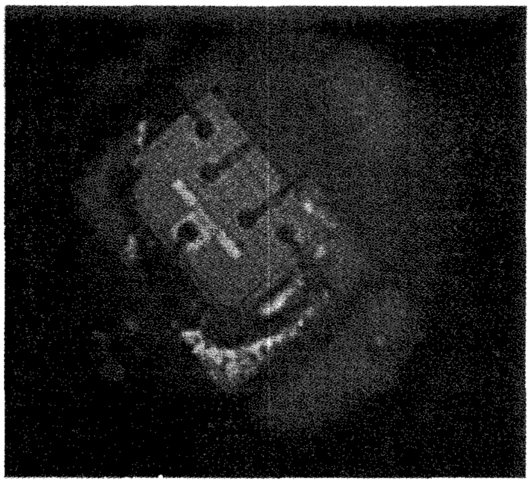

Figure 3. MESFET transistor mounted through circuit substrate for optical biasing.

achieve beam steering, a progressive phase shift is needed between adjacent elements. This is done by using unilateral injection locking and controlling the free-running frequency of the oscillating MESFETs.

Transmission type injection locking is provided at the gate of each oscillating MESFET. Two MESFETs are in each cell, one an oscillator and the second an optically controlled varactor. The source of the varactor MESFET is shorted to ground. The drain is "self-biased" through the device. DC Bias is applied at the gate. Microstrip from the gate of the varactor device to the gate of the oscillating device couples in the injection locking circuit and forms the remainder of the optical resonator circuit. Optical illumination then varies C_{gs} of the varactor MESFET as a function of illumination intensity. This varies the reactance of the MESFET to alter the oscillation condition and therefore change the free-running oscillation frequency.

For antenna remoting applications, the reference signal is applied by an optical delivery system. In this work, the system shown in Figure 2 is used. A microwave tone is generated on an optical carrier by external modulation with a Mach-Zehnder intensity modulator (MZI). An external cavity laser (ECL) at a wavelength of 1550 nm is used as the carrier. The modulator is biased at quadrature and driven by a RF tone at the injection locking frequency. A single-mode fiber carries the output of the MZI to the antenna site, where it is detected by a high-speed photodetector. The photocurrent is then amplified by low noise amplifier for injection into the phased array antenna.

In this work, a two-element active antenna array is tested. From Kurokawa [7], the phase between adjacent elements is given by:

$$\Delta\phi = \arcsin\left(\frac{\omega_f - \omega_0}{\Delta\omega_m}\right)$$

Note that ω_o is the injected signal frequency, $2\Delta\omega_m$ is the locking bandwidth and ω_f is the free-running frequency of the oscillator given by (for transmission-type injection locking):

$$\Delta\omega_m = \frac{\omega_0}{Q_{ext}}\sqrt{\frac{P_i}{P_0}}$$

Where Q_{ext} is the external Q of the resonant circuit, P_i is the injection locking power and

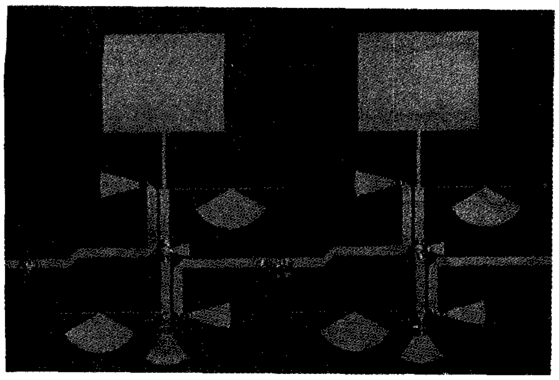

Figure 4. Fabricated array.

P_0 is the oscillator power. With the adjacent antenna radiating with phase difference $\Delta\phi$, the main beam can be scanned to an angle:

$$\theta = \arcsin\left(\frac{\lambda_0 \Delta\phi}{2\pi d}\right)$$

This theory is used to design a two-element array. The circuit is realized in microstrip and fabricated on a substrate with $\varepsilon_r = 2.33$ and substrate height of 31 mils. Element spacing is 0.7 λ_0 at 4.0 GHz, corresponding to a theoretical maximum beam-scan angle of ±21° at injection locking edge. GaAs MESFET transistors manufactured by NEC (part #NE76184A) are used as the active devices in the circuit. The package of the varactor transistor is removed to permit illumination by an optical source. The optical varactor is mounted through the substrate and illumination is applied from the rear of the circuit to prevent pattern disruption. Figure 3 and 4 show a mounted transistor and the completed circuit, respectively.

II. RESULTS

After fabrication, circuit performance is determined. Variable power optical illumination is provided a Cole Parmer Low Noise Illumination Source. The source is placed behind the optical transistor. No focal lens is used, and the optical power incident on the varactor is estimated to be on the order of μW. The oscillating MESFET is biased at V_{ds} = 3 V and I_{ds} = 20mA. Oscillating frequency is in the region of 4.0 GHz. By varying V_{gs} of the optical varactor, this can be adjusted by several hundred MHz.

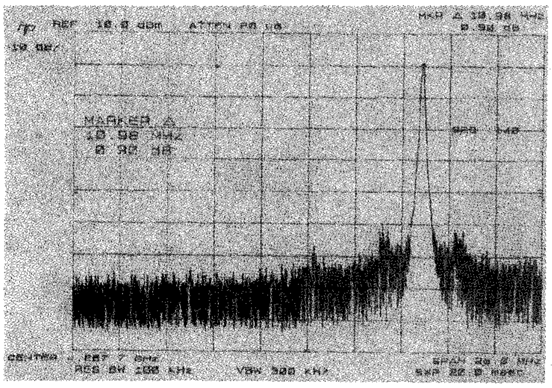

Figure 5. Optical locking bandwidth.

First, the optical link for antenna remoting is tested. The modulator is biased at 2.54 V and is driven by a RF tone of +10dBm at 4.3 GHz. At the antenna site, -10dBm output power is obtained for injection locking into the array. This is sufficient to injection lock the array over an 11 MHz range, as shown in Figure 5. Injection locking range can be increased either the gain of the amplifier in the optical link or the amplitude of the RF tone.

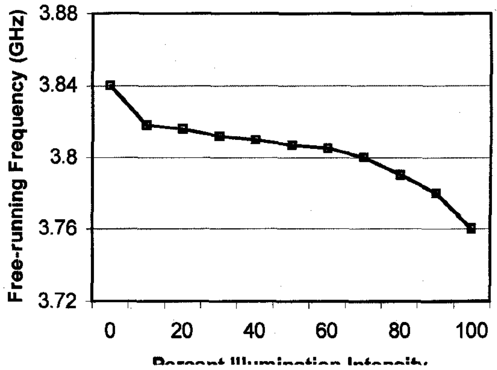

Figure 6. Free-running frequency vs. optical bias.

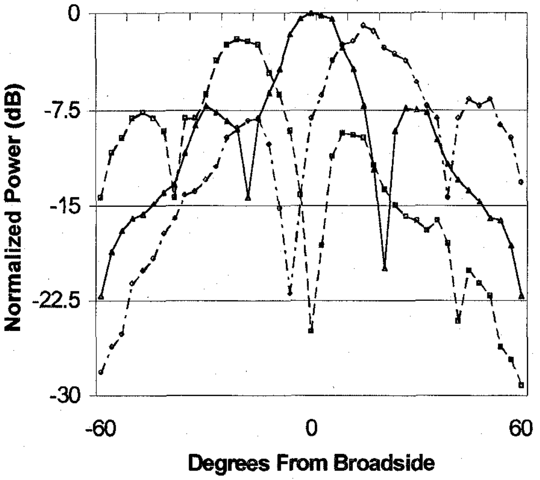

Figure 7. Measured scan patterns with optical control.

The MESFET varactor is then tested at a variety of values of V_{gs} for optimal photosensitivity. This is done by applying zero and maximum illumination to determine maximum deviation in free running oscillator frequency. No deviation is found for $V_{gs} = 0.0$. Response increases until maximum deviation of 70.0 MHz is found at $V_{gs} = -1.9V$. Figure 6 shows free-running frequency versus relative illumination. Output power changes by approximately –2dB over this frequency range. Note that once the illuminator is turned on, response is fairly linear.

Finally, beam patterns are measured. Beam-scan at broadside is obtained by adjusting optical bias so that the free-running frequency is equal to the injection frequency. Maximum beam scan is obtained by adjusting the optical bias until the upper or lower-locking edges are almost reached. Patterns are shown in Figure 7. Maximum scan of about ±18° is obtained, close to the theoretical limit of ±21°.

CONCLUSION

In this work, direct optical illumination and control of MESFET transistors in an active antenna oscillator is demonstrated. Direct optical illumination of a MESFET varactor is shown capable of scanning the main beam by ±18°. Previously, it was demonstrated that an optical fiber link could be used to convey a reference signal to the active antenna array, with the potential application of reducing spatial design constraint [6]. This work demonstrates that additional optical control of the array is possible which further increases the merit of using optical fiber links to control active antenna phased arrays.

ACKNOWLEDGEMENTS

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