A 2X2 BEAM-SWITCHING ACTIVE ANTENNA ARRAY

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ABSTRACT

An electronic beam-switching active antenna array is designed. The sum and difference patterns can be switched bi-directionally without additional switching devices. The required phase relationship is obtained through injection-locking. The transmitted power is combined quasi-optically. The measured patterns are in agreement with that of theory.

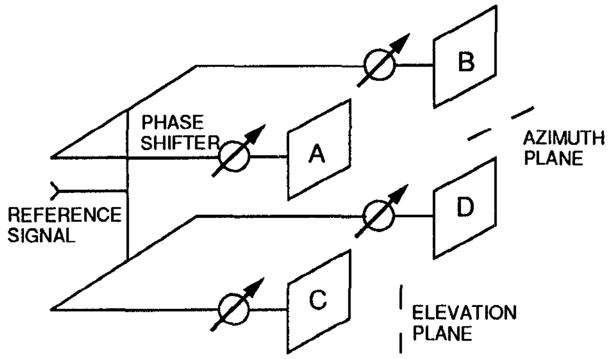

Figure 1 : Array with designated quadrants.

INTRODUCTION

In monopulse radar system, complex waveguide structure is required to feed the planar phased array. This feed provides the necessary phase and power relationships for the synthesis of the sum and difference patterns. However, such feed is bulky and adds weight to the antenna platform. Attempts have been made to realize this beam switching using mode-switch in active antenna [1,2]. However, both designs do not allow bi-directional electronic switching of the patterns.

In this paper, a transmitter with beam-switching capability is designed using active antenna phased array. The necessary phase shifts are synthesized via injection locking. Transmitted power is combined quasi-optically. Switching is bi-directional.

THEORY

A. Phased Array

To form a difference pattern in the azimuth and elevation planes, a planar phased array with even number of row and column elements must be used, as shown in Fig. 1. When all four quadrants are fed in-phase with respect to each other, a sum pattern is formed. However, when A and C quadrants are kept in phase at $+90^{o}$ with respect to the reference signal, and B and D are kept in phase at -90^{o} , difference and sum patterns are formed in the azimuth and elevation planes respectively. Different combinations of phase relationship resulting in various patterns in both planes can be synthesized and are tabulated in Table 1.

Table 1 : Relationships between antenna patterns and the phase conditions.

PHASE CONDITIONS	AZIMUTH PLANE	ELEVATION PLANE
$A=B=C=D=0^{O}$	SUM	SUM
$A=B=90^{O}$, $C=D=-90^{O}$	SUM	DIFFERENCE
$A=C=90^{O}$, $B=D=-90^{O}$	DIFFERENCE	SUM

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B. Phase shift via injection-locking

When a reference signal, whose frequency is close to that of the free-running oscillator, is injected into the oscillator, injection-locking phenomenon occurs. The oscillating signal is locked to the reference frequency, but exhibits a phase difference with respect to that of the reference signal. Based on Kurokawa's theory [3], this phase difference, $\Delta\phi$ is related by the following equation,

$$\Delta\phi = \sin^{-1}\left(\frac{\omega_f - \omega_o}{\Delta\omega_m}\right), \quad (1)$$

where ω_f is the free-running angular frequency, ω_o is the injected angular frequency, and $2\Delta\omega_m$ is the locking bandwidth. From Eqn. 1, $\Delta\phi$ can be tuned to a maximum of $\pm 90^o$ by varying the ω_f. $\Delta\omega_m$ increases with higher injected power.

In this design, a continuous variation of the phase is not required. The phase states of interest are $+90^o$, -90^o and 0^o. These states are realized by tuning the free-running frequency using Eqn. 1.

DESIGN

The whole active antenna array is fabricated on Duroid substrate with dielectric constant 2.33 and thickness 30 mils.

Rectangular patch antenna is used in this design. The size of the patch is 750 mils by 595 mils. The antenna is edge-fed with a microstrip line. The input impedance of the patch is measured using TRL calibration technique on HP8510B. The measured resonance of the (1,0) mode is at 6.2 GHz.

A Wilkinson power divider is designed for the power division of the injected signal. The reflection coefficients at all three ports are better than 20 dB. The maximum power and phase imbalance, and isolation between the two output ports are 0.2 dB and 1.5^o, and 18 dB respectively.

Each patch antenna is fed by an oscillator. NEC72084 GaAs MESFET is used as the active element, self-biased at V_{ds} = 3V and I_{ds} = 30 mA. A coupler is integrated to cater for injection-locking. The oscillating frequency is about 6.62 GHz and can be varied independently by at least 40 MHz via their respective drain bias.

The schematic diagram of the array is shown in Fig. 2. The upper quadrants and the lower quadrants are fed on the opposite sides of their respective patches, resulting in 180^o excitation. There are two reasons for such a layout. Firstly, there is a space constraint. Secondly, the critical performance of this circuit lies in its ability to have a deep and well-defined null at broadside for the difference pattern. A difference pattern is formed when the free-running frequencies of the oscillators are tuned to the injected signal. This is a very stable operating point. As was noted in [4], when operating at locking band-edge, instability results. Thus, the free-running frequencies are tuned close but not at the edge of the band. This causes the sum pattern to have a lower power level with possible offset in the position of the main beam. Due to layout constraint, the above-mentioned feature is implemented in the elevation plane only.

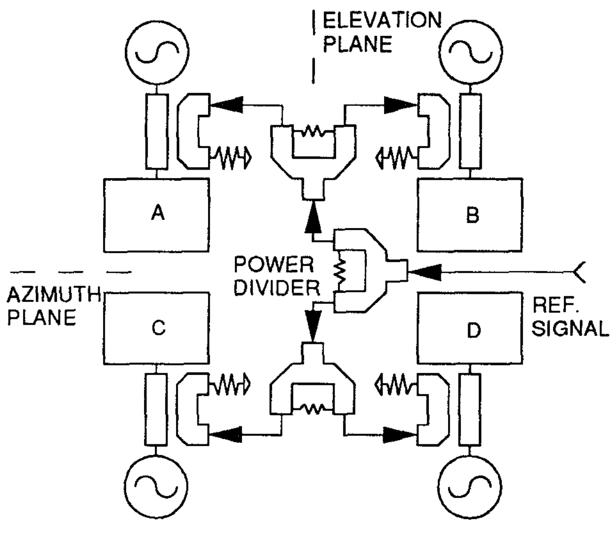

Figure 2 : Schematic diagram of the beam-switching array.

RESULTS

The active antenna array is measured with phase conditions as tabulated in Table 1. Since the antennae are fed on the opposite side of their respective patch antennae, the phase relationship in Table 1 must be offset with 180^{o} in the elevation plane. A comparison is made with the theoretical patterns, calculated from a transmission-line model [5].

The measured sum pattern in the azimuth plane is shown in Fig. 3. The measured ERP of this pattern is 30 dBm. The measured difference pattern in the azimuth plane is shown in Fig. 4. The null at broadside is better than -30 dB. There is asymmetry in the difference pattern. This is due to the difference in output power level of the oscillator for different free-running frequency. Both plots in Fig. 3 and 4 are in close agreement with the theoretical results. In the elevation plane, the sum and difference patterns are shown in Fig. 5 and 6 respectively. The null in the difference pattern is better than -35 dB. However, these plots do not match the theoretical results very well. This may be due to radiation from the rest of the circuit. Nevertheless, the patterns agree well in general.

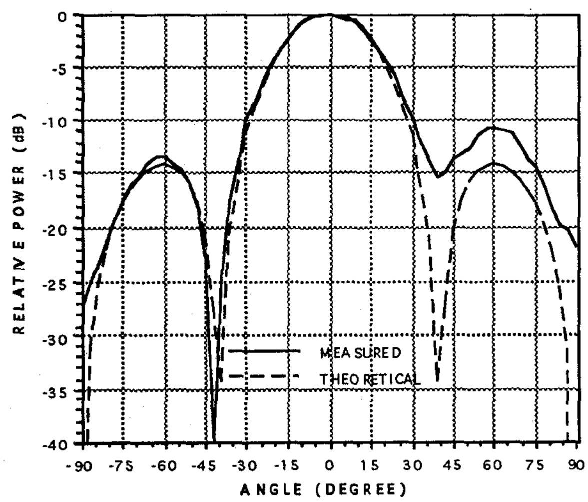

Figure 3 : Sum pattern in the azimuth plane.

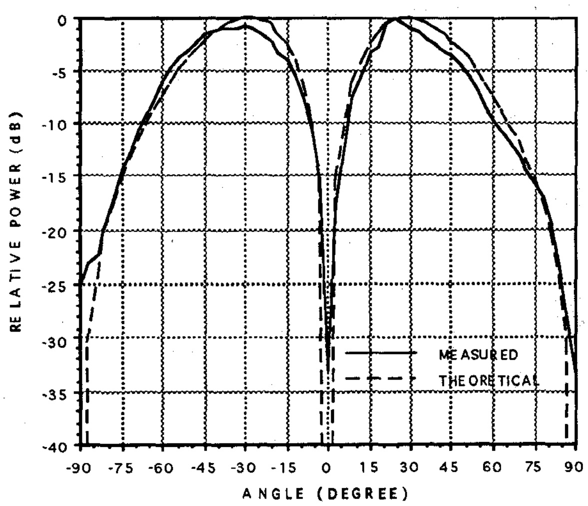

Figure 4 : Difference pattern in the azimuth plane.

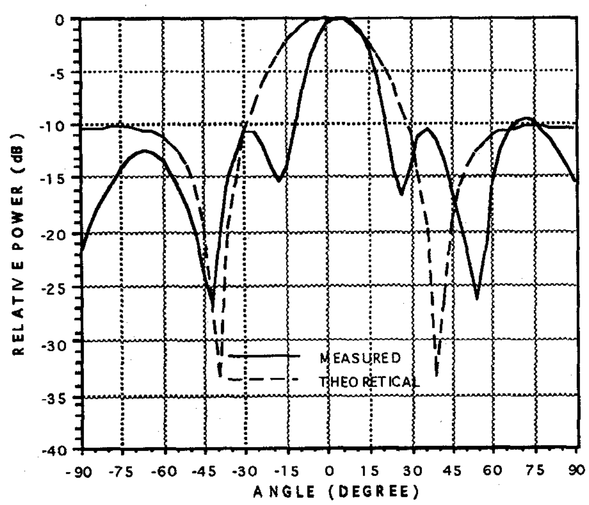

Figure 5 : Sum pattern in the elevation plane.

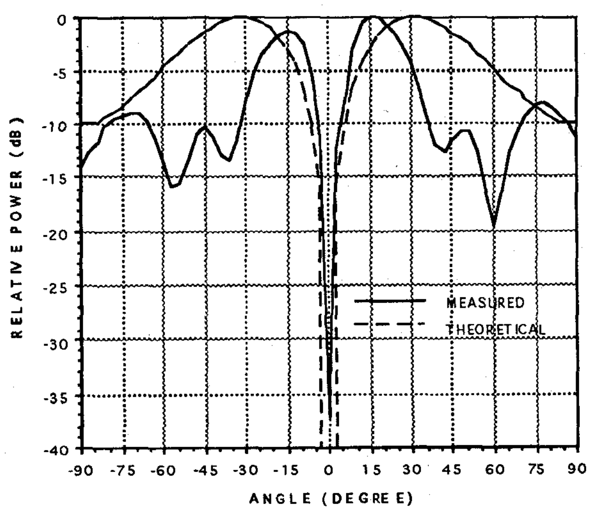

Figure 6 : Difference pattern in the elevation plane.

CONCLUSION

An active antenna planar array is designed with beam-switching capability without conventional switching devices. The phase variations amongst antennae are achieved through injection-locking. Switching is done electronically and is bi-directional. The measured patterns are in good agreement with that calculated from a transmission-line model for the antenna.

ACKNOWLEDGMENT

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