35 GHz ACTIVE APERTURE

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ABSTRACT

Characteristics of a millimeter wave active array are described. Injection-locked pulsed IMPATT oscillators providing 36 watts peak transmitter power are integrated with a stripline-fed image array having a gain of 29 dBi. Performance of the transmitter, antenna and integrated active aperture are discussed.

Introduction

In recent years, considerable effort has been directed toward development of solid-state millimeter wave transmitters having sufficient power output for use in short range radars. Most of this work has concentrated on circuit techniques for combining the power from a number of solid-state sources. In many applications, however, additional benefits can be realized by integrating solid-state sources with the antenna and combining their powers in space. Such an approach eliminates most of the RF losses in connecting transmission lines. This paper describes a 35 GHz active array that spatially combines the power from pulsed IMPATT oscillators that are integrated with a printed circuit antenna.

Design Concept

A block diagram of the 35 GHz active aperture is shown in Figure 1. The antenna array consists of 32 image radiating elements[1] in a 5.5-inch diameter aperture. The image array concept greatly reduces the number of radiators required and simplifies the array feed network. The array is divided into quadrants for monopulse operation, and each quadrant is fed by an injection-locked pulsed IMPATT oscillator. A two-stage exciter provides the injection locking signal that is distributed to the aperture oscillators through the monopulse comparator.

Antenna Array

The antenna array for the 35 GHz active aperture utilizes image radiating elements. The image effect is created by placing a partially reflecting planar surface above the plane of the array and parallel to it. A sheet of high dielectric constant ceramic is used in this case. Energy reflected from the ceramic surface is again reflected in the antenna ground plane. These

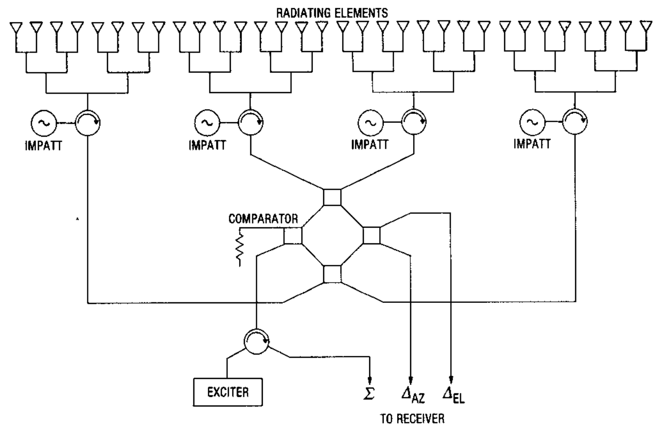

FIGURE 1: ACTIVE APERTURE BLOCK DIAGRAM

multiple reflections form a series of images in the ground plane that are phased in accordance with the spacing between the ceramic and the ground plane. Spacing the ceramic one-half wavelength above the ground plane results in proper phasing for radiation normal to the plane of the antenna. The radiation pattern formed for each element is that of an end-fire array phased for radiation along its axis. Using this directive, high gain radiator, only 32 radiating elements are required in the 5.5-inch aperture compared to hundreds in a conventional array design of the same size. The simplified array feed network keeps losses in the 35 GHz printed circuit antenna to a minimum.

The 32 element array is implemented in balanced stripline. The circuit layout is shown in Figure 2. The image elements are excited by radiating slots in one ground plane. The modular IMPATT oscillators are integrated with the array feed circuit by means of coupling slots in the rear ground plane. Connection to the monopulse comparator terminals are also made by coupling slots.

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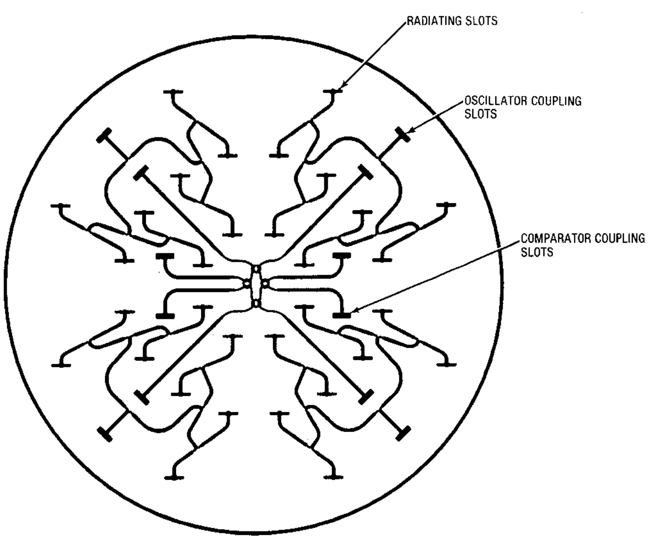


FIGURE 2: ANTENNA ARRAY CIRCUIT LAYOUT

Typical sum and difference radiation patterns of the passive antenna array are shown in Figures 3 and 4. Sum pattern sidelobes are down at least 20 dB in the E-plane and 18.5 dB in the H-plane. The beamwidth is less than 4.3 degrees. A gain of 29.13 dBi is provided for the active aperture transmitter. Difference pattern null depths are at least 28 dB below the sum peak.

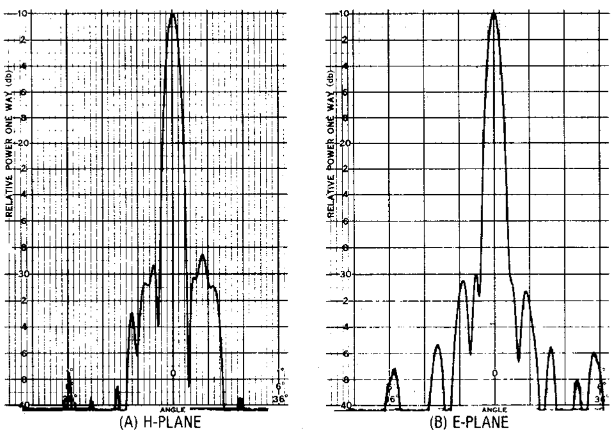


FIGURE 3: SUM CHANNEL RADIATION PATTERNS

Transmitter

The transmitter block diagram is shown in Figure 5. Four IMPATT oscillators serve as aperture power sources, one in each quadrant of the array. These are injection-locked by a two-stage exciter consisting of one Gunn oscillator and one IMPATT oscillator. The three oscillator stages of the transmitter are timed such that the pulse of each stage lies within the pulse of the preceding locking stage. Stability for the Gunn oscillator is provided by an external Q of 100 and 60 dB of load isolation.

An injection signal acts in a manner that reduces the real part of the load on a diode oscillator. Each

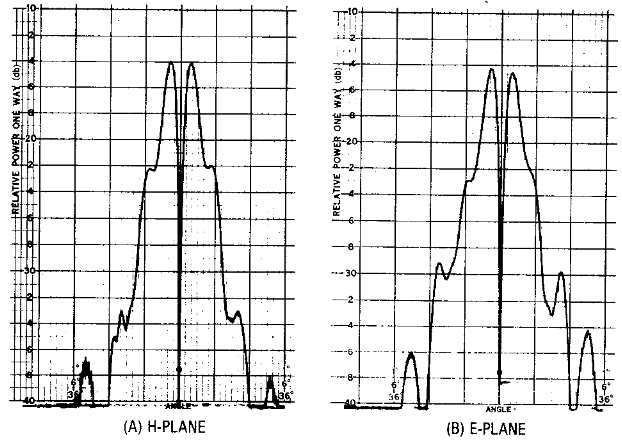


FIGURE 4: DIFFERENCE CHANNEL RADIATION PATTERNS

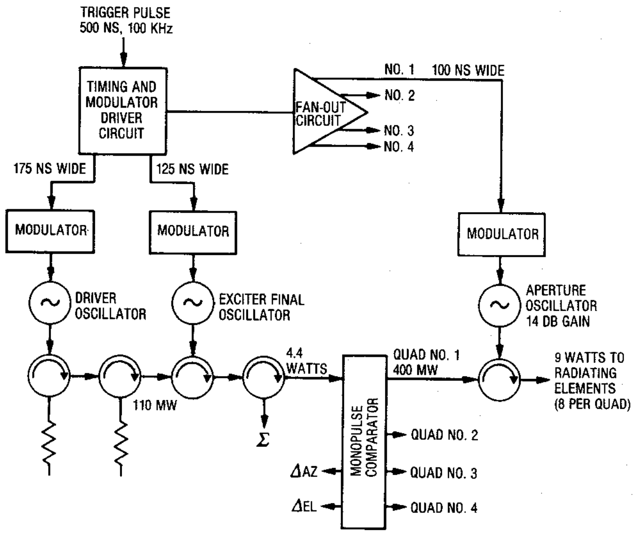


FIGURE 5: TRANSMITTER BLOCK DIAGRAM

aperture oscillator is tuned so that the addition of the locking signal loads the diode to the peak of its power curve. The output power of each oscillator and the locked gains of the IMPATT oscillators are indicated in Figure 5. Performance of the transmitter is summarized in Table I. A total of 36 watts peak transmitter power is provided by approximately 9 watts from each of the four aperture oscillators. The pulsewidth of the individual oscillators is 100 nanoseconds.

TABLE I. TRANSMITTER PERFORMANCE

EXCITER	
Power Output	4.4 watts peak
Pulse Length	125 ns
Pulse Repetition Frequency	100 kHz
Duty Factor	1.25 percent
Phase Chirp	10 degrees
APERTURE OSCILLATORS	
Power Output	9 watts peak (nominal)
Pulse Length	100 ns
Pulse Repetition Frequency	100 kHz
Duty Factor	1 percent
Phase Chirp (Absolute)	45 degrees
Phase Chirp (Relative)	20 degrees between oscillators

To obtain maximum radiated power from the active array, it is necessary that the four aperture oscillators track each other in phase during the transmit pulse. There are two sources of errors that can result in phase offsets between the aperture oscillators. The first is path length variations in passive components such as the array feed circuit, monopulse comparator and circulators. This type of error can be minimized by mechanical adjustments. The second source of phase errors results from differences in injection-locked phase offsets between the IMPATT oscillators. This type of error may be caused by differences in the free-running frequency of the oscillators or by differences in the chirp characteristics of the oscillators.

The free-running frequency of the oscillators can be adjusted by tuning. Frequency chirping during the pulse is caused by an increase in the diode temperature and can be minimized by shaping the bias current pulse. Using this technique, the transient phase error between the four aperture oscillators has been reduced to a maximum of 20 degrees.

Active Aperture Performance

Figure 6 shows the stripline antenna array and transmitter subassembly prior to integration. The antenna and transmitter were mated and tested as an integrated active array. After integration with the antenna, the changed conditions of impedance match and isolation between oscillators caused a reduction in the injection signal level. The four aperture oscillators were readjusted to obtain proper transmitter performance, and this reduced the oscillator outputs. Due to this factor, the measured radiated power was 1.6 dB below the maximum expected with a transmitter output of 36 watts. All of the IMPATT oscillators exhibited noise during the first 5 nanoseconds of the pulse. This noise effectively defocused the space combined output at the start of the pulse and reduced the transmitted pulse length to 95 nanoseconds.

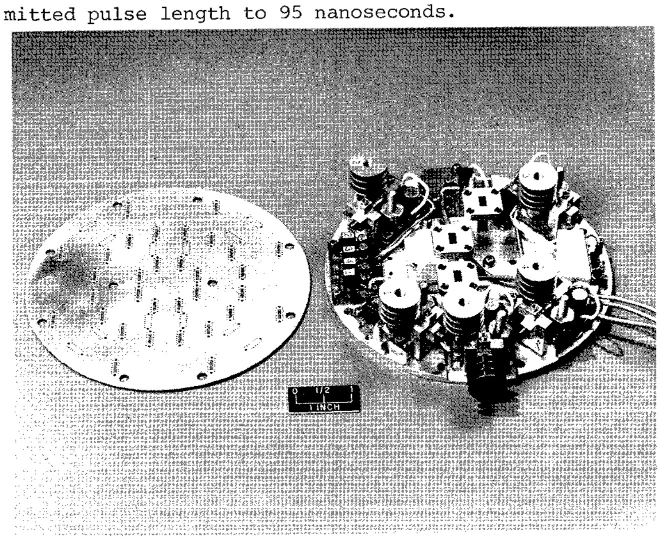
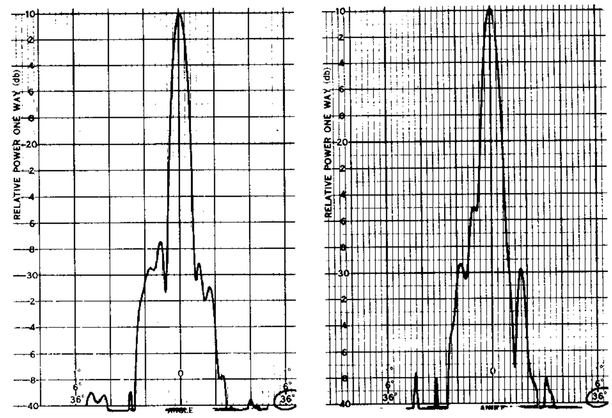


FIGURE 6: ANTENNA AND TRANSMITTER BEFORE INTEGRATION

Transmitted radiation patterns for the active aperture are shown in Figure 7. Sidelobes in the H-plane are down at least 17.5 dB. The E-plane pattern shows some asymmetry caused by uncompensated phase error, and the highest sidelobe is down 15.1 dB. However, the phase error is not large enough to have a significant effect on the combined power output. The boresight error between the monopulse null position and the transmitted sum peak is less than 0.5 degree.



(A) H-PLANE (B) E-PLANE

FIGURE 7: TRANSMITTED RADIATION PATTERNS

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References

1. Sasser, B.H., "A Highly Thinned Array Using the Image Element," presented at the 1980 IEEE International Symposium on Antennas and Propogation, June 1980.