SMALL ACTIVE PHASED ARRAY CHARACTERISTICS WITH GaAs IMPATT AMPLIFIER MODULES

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ABSTRACT

Application of pulsed GaAs IMPATT modules for phased array radiators is examined. Measured intrapulse phase and gain variations are presented. Module hardware and statistical pattern effects for a small-diameter phased array are discussed.

Introduction

Increasing the amount of power on target delivered by small missile-sized antennas is a matter of ongoing interest. Enhanced detection and tracking ranges result directly. These are key items for the system designer. Such an increase, in conjunction with the "inertia-free" characteristics of phased array operation, continues to have great appeal. This idea, while not new, deserves to be revisited from time to time as the technology evolves.

Recent advances in GaAs pulsed IMPATT diode power and efficiency suggest that radiated power levels might be increased by an order of magnitude over other system concepts employing tube or FET technologies. Diode peak power levels of 24 watts and efficiencies greater than 20 percent are currently state-of-the-art. Pulsed GaAs IMPATT diode measurements now indicate that such a final amplifier driven by a FET preamplifier may be feasible.

Phased array radiation characteristics, while understood in approximate detail for large arrays, are not so easily generalized in the small array domain. Intuitively, one would expect more stringent scan limitations to exist for broader main beam operation. Unwanted active impedance effects should accrue more rapidly with scan, but have not been carefully studied. In this instance random errors in the excitation coefficients due to differences in pulsed IMPATT behavior may have more serious impact than that observed for large arrays. The purpose of this work was, first, to characterize the intrapulse behavior of a particular IMPATT diode, then judge the effects of this behavior on small phased array performance.

Critical IMPATT Diode Module Parameters

For purposes of this work an IMPATT diode module was defined to be a pulsed IMPATT final amplification stage, driven by a relatively low power preamplifier, and terminated by a particular radiating element. All preamplifiers and radiating elements were assumed to be identical so that critical IMPATT diode parameters could be related directly to the antenna radiation characteristics.

Accurate calculation of the antenna pattern performance requires that we specify the element positions, relative excitation amplitudes and phases, and radiating characteristics (element factor). The main concern here was the relative amplitude and phase. In an active array, each radiator associates with a particular diode. Relative excitations are thus dictated by the complex output voltages of the diodes. For pulsed applications, then, the intrapulse complex output voltages must be considered. It follows that random variations among these output voltages will influence the pattern integrity of any given antenna and the mean performance of the ensemble.

Intrapulse IMPATT Diode Characteristics

The device used for the characterization was an MA 41602, manufactured by Microwave Associates, Inc. This is a GaAs single drift lo-hi-lo profile IMPATT diode. The device produced approximately 12 watts of peak power at 1/3 duty, with a D.C.-RF efficiency of 18%. Six diodes were examined. Each device was operated as an injection-locked oscillator in a fixed tuned circuit, at gains of both 7 and 10 dB.

The relative intrapulse amplitude and phase characteristics of the diodes were measured on the impedance bridge[1] shown in Figure 1. This bridge measured the dynamic characteristics of the IMPATT diodes. The system was capable of measuring relative and absolute amplitude and phase characteristics of CW or pulsed devices and amplifiers. Table I shows the waveforms used for this characterization.

TABLE I

Pulsewidth (μsec)	Duty Factor (%)
1.33	33.0
1.60	40.0
4.00	10.0

A sample of the MA 41602 phase and amplitude response versus time shown in Figure 2. In this figure it can be seen that the intrapulse amplitude and phase characteristics track similarly with time from device to device. Table II presents the intrapulse amplitude and phase slopes as a function of waveform and gain, averaged over the available IMPATT population.

TABLE II. INTRAPULSE SLOPE

Duty (%)	Gain (dB)	Amplitude Slope (ave. dB/μsec)	Phase Slope (ave. deg/μsec)
33.0	7.0	0.72	7.0
33.0	10.0	0.84	11.4
40.0	7.0	0.69	5.4
40.0	10.0	0.63	8.6
10.0	7.0	1.50	15.9
10.0	10.0	1.30	21.0

More immediately interesting were the intrapulse amplitude and phase variations that were observed from device to device. Maximum values for these parameters are listed in Table III.

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TABLE III. MAXIMUM INTRAPULSE VARIATION

Duty (%)	Gain (dB)	Amplitude Variation (dB)	Phase Variation (deg.)
33.0	7.0	1.80	59.0
33.0	10.0	1.70	59.0
40.0	7.0	1.50	55.0
40.0	10.0	1.30	75.0
10.0	7.0	2.30	56.0
10.0	10.0	1.60	46.0

Pattern Characteristics

A primary interest for a small active phased array is the degree of pattern degradation assignable to the IMPATT differences shown above. Speculation about compensating these differences by way of diode current and phase shifter bias is sometimes encountered. Such was not the principal purpose of this work. Because compensation is technically complex it was judged more valuable to see how tolerant such an array is to these kinds of errors.

A fourteen inch diameter, uniformly illuminated, aperture was used for this particular evaluation. Calculations showed that approximately 324 I-band IMPATT modules could be housed within such an aperture when arranged in a triangular lattice. Preliminary calculations showed that the desired polar scan angle of 60 degrees could not be tolerated. Instead, a reduced value of 45 degrees was employed.

Standard deviations of 0.1, 0.2, and 0.3 were selected after Elliott[2]. While this model makes the somewhat optimistic assumption of equally probable error phase on the range $-\pi$ to $+\pi$, a worst-case analysis indicates a doubling of the variance and surprisingly little change in the mean sidelobe level. Table III is too abbreviated to supply reliable statistics. However, it seems reasonable to assume that acceptable devices for this application might be normally distributed with zero mean over a diminished range of angle. One would expect this model to give results somewhere between the above limits.

Figure 3 shows the worst-case scan condition for this array, with $\sigma = 0.3$. Figure 4 indicates the degree of mean pattern degradation as a function pattern level between -20 dB and -40 dB, for this same standard deviation. The envelope distinguished by crosses in Figure 3 indicates the levels to which the mean sum pattern sidelobes will rise.

Conclusions

For small arrays larger amounts of power on target appears feasible by way of increased numbers of radiating elements and high power active devices. Measurements and calculations indicate that the uncompensated intrapulse amplitude and phase errors associated with GaAs IMPATT diodes are sizeable but do not cause a large reduction in array performance. Future effort is planned to provide more complete data and calculations of actual rise in particular sidelobe levels.

REFERENCES

1. R.L. Eisenhart, "Time Varying IMPATT Impedance Measurements," Proceedings of the 1976 International Microwave Symposium, June 14-16 1976, pp. 40-42.

2. R.S. Elliott, "Mechanical and Electrical Tolerances for Two Dimensional Scanning Antenna Arrays," IRE Trans., vol. AP-6, pp. 114-120, January, 1958.

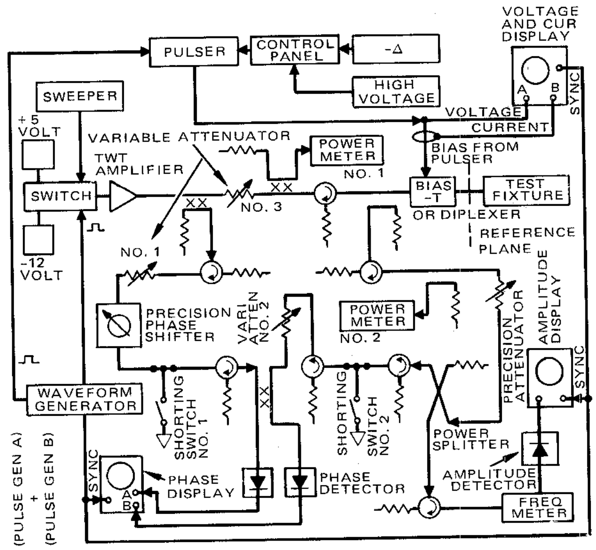
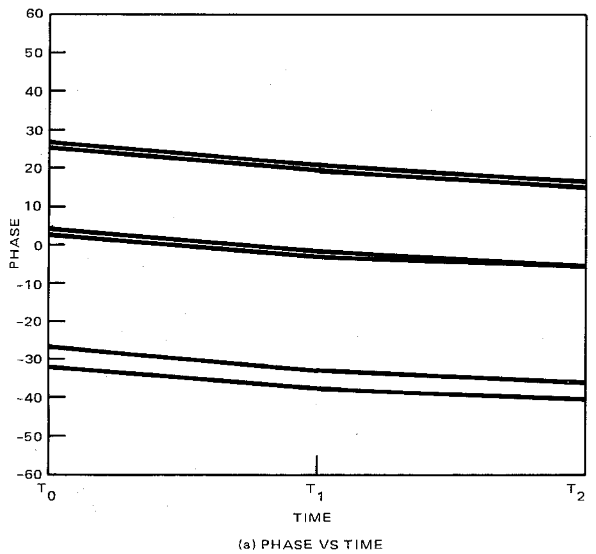


Figure 1. Impedance Bridge



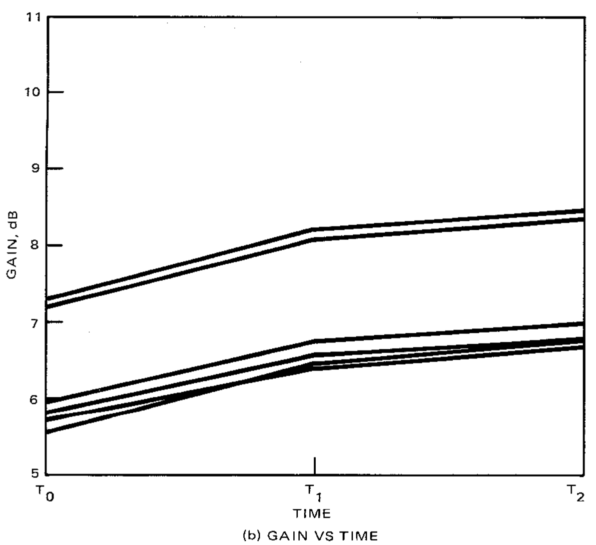


Figure 2. Output Phase and Gain Characteristics

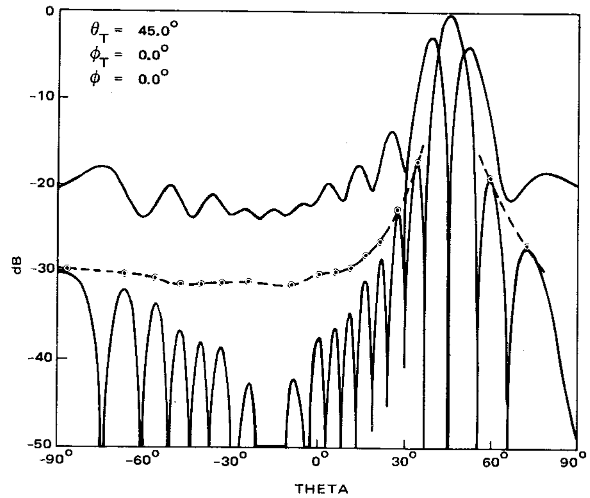


Figure 3. Ideal Pattern, Worst-Case Scan Condition

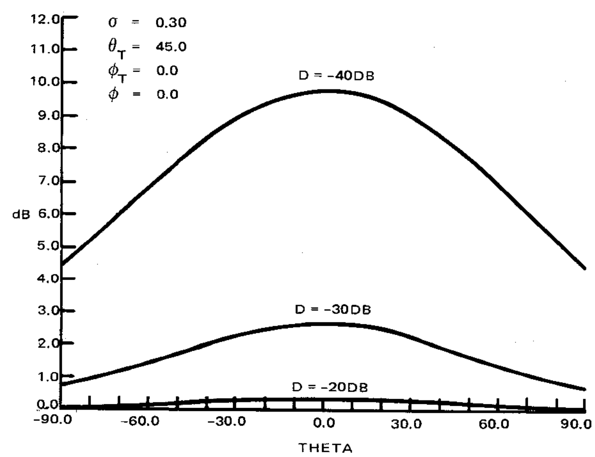


Figure 4. Mean Pattern Degradation, Worst-Case Scan Condition