A 4×4 Active Array using Gunn Diodes

R. A. York and R. C. Compton*
School of Electrical Engineering
Cornell University, Ithaca, NY 14853

Introduction

As the operating frequency of semiconductor devices is increased, their output power decreases rapidly. As we shall demonstrate in this paper, large powers can be achieved by combining the outputs of a number of devices. Traditional power combining using modified Wilkinson combiners are limited in the number of channels that can be combined [1]. More recently, attempts have been made to combine the output powers of Gunn diode oscillators using a planar quasi-optical approach [2,3], in which the diodes are integrated directly into an antenna array. These efforts were largely unsuccessful because low DC to RF efficiencies of Gunn diodes lead to overheating problems. This prompted an investigation into building oscillators using transistors because of their lower heat dissipation requirements [4,5]. Equivalent isotropic radiated powers (EIRP) of 25 Watts have been achieved with a 100 element transistor array [4]. In this paper we present results from a new 16 element active array incorporating Gunn diodes. The Gunn diode heating problem previously encountered was overcome by using patch antennas in which the ground plane serves as a diode heat sink. An EIRP of 22 Watts was measured for this array.

Design

Commercially available low-power MA/COM packaged Gunn diodes were used in this work. The threaded end of the diode package is screwed through the substrate and into the ground plane, leaving the anode end-cap in contact with the patch [6]. The precise location of the diode within the patch is found semi-empirically, and corresponds to a feed impedance equal to the diode negative impedance. Bias is applied to the center of a non-radiating side of the patch, at an RF null. The array consists of a 4 by 4 array of patch antennas spaced a half free space wavelength apart. The array design features individual bias to each device, enabling a variety of individual and

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multiple biasing schemes. This has proved valuable in investigations of injection locking, degradation, frequency stability, and adaptive control. The array design is illustrated in figure 1.

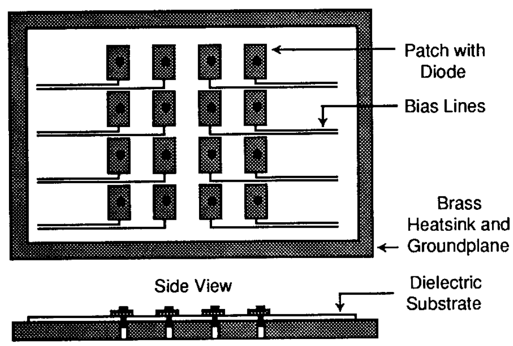

Figure 1. Diagram of Gunn diodes mounted into a 4×4 array of microstrip patches. The brass block serves as a groundplane, heatsink, and DC bias return. Bias is applied at an RF null.

Results

Initial investigations focused on a single diode/patch element. From these experiments we determined the correct diode placement and patch sizes for 10 GHz oscillations. Linear polarization and measured antenna patterns were consistent with expected patch behavior. Two patches were then fabricated to verify the concept of quasi-optical injection locking. Once this was achieved, the array shown in figure 1 was built and tested. Each diode was first biased, one at a time, to establish a common operating frequency. These individual biases were then applied simultaneously. Single frequency operation was verified with a spectrum analyzer, and in-phase oscillations were verified by measuring the E- and H-plane patterns using the set-up illustrated in figure 2. Slight differences in diode characteristics and diode placements made the simultaneous injection locking a delicate operation. The addition of a dielectric slab ($\varepsilon_r = 4.0$) above the array provided the necessary feedback to make the injection-locking routine.

The individual elements exhibited a frequency tuning from 9.5 to 10.0 GHz versus bias voltage. The best results for the array were obtained at a frequency of 9.6 GHz, which is within 4% of the design frequency. Sharp patterns in both the E- and H-plane corresponding to a directivity of 18 dB were measured at this frequency (figure 3). Some frequency tuning was observed by adjusting the position of the dielectric slab, but this effect is limited to

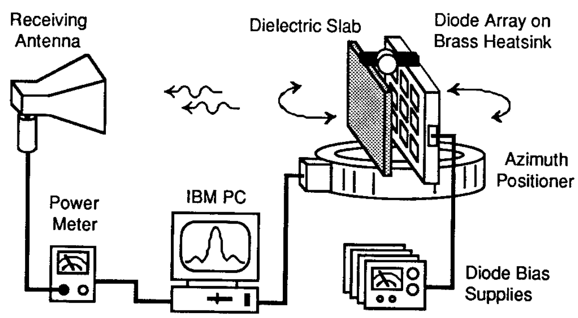

Figure 2. Experimental setup for antenna pattern measurements. Also depicted is the dielectric slab which facilitates simultaneous injection-locking of the diode oscillators.

the locking range of the array ($\approx$ 100 MHz). A maximum received power of 9.6 mW was obtained at a distance of 1.1 meters away from the array, using a 19.3 dB pyramidal horn. The total radiated power, estimated from the measured patterns, was 320 mW, or roughly 20 mW per device. This is consistent with the 25 mW rating of the diodes — considerably more power could be obtained using higher-power devices. This above data corresponds to an EIRP of 22 Watts. The DC to RF conversion efficiency was low, typical of Gunn diodes, around 0.7%.

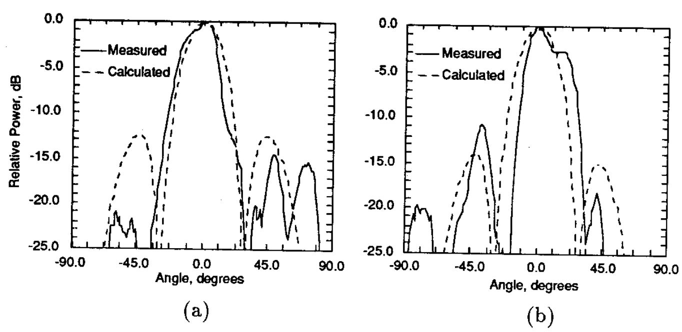

Figure 3. E-plane (a) and H-plane (b) patterns for the active array of fig 1. The theoretical results are calculated by combining the pattern of a single patch with a 4×4 array factor. The dielectric slab ($\varepsilon_r = 4$) has a small effect on the patterns.

Conclusions

We have presented results for a simple planar array of Gunn Diodes. By increasing the number of elements, and using higher power diodes EIRP of several hundred watts may be possible. Future work will focus on higher powers and steering of the beam.

Acknowledgments

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References

[1] W. Yau and J. M. Schellenberg, "An n-way broadband planar pwoer combiner/divider," *Microwave Journal*, November 1986, pp. 147-151.

[2] J. W. Mink, "Quasi-Optical Power Combining of Solid-State Millimeter-Wave Sources," *IEEE Trans. on Microwave Theory Tech.*, **MTT-34**, February 1986, pp. 273–279.

[3] Z. B. Popovic and D. B. Rutledge, "Diode-Grid Oscillators," *1988 IEEE AP-S International Symposium, Proceedings*, pp. 442–445.

[4] D. B. Rutledge, Z. B. Popovic, R. M. Weikle, M. Kim, K. A. Potter, R. C. Compton, and R. A. York, "Quasi-Optical Power-Combining Arrays" *submitted to the 1989 IEEE MTT International Symposium*

[5] J. Birkelan and T. Itoh, "Quais-Optical Planar FET Transceiver Modules," *1989 IEEE MTT-S Symposium Digest*, pp. 119–122.

[6] K. Chang, K. A. Hummer, and J. L. Klein, "Experiments on Injection-Locking of Active Antenna Elements for Active Phased Arrays and Spatial Power Combiners," *IEEE Trans. on Microwave Theory Tech.*, **MTT-37**, July 1989, pp. 1078–1084.