X-Band Distributed Array Gunn Effect Transmitter

by

M. S. Stringfellow+, G. Bednar+, F. J. Rosenbaum++, K. L. Horn+

This paper describes the use of injection phase locked Gunn effect oscillators as module transmitters for distributed phased array applications. These devices are capable of direct dc to microwave conversion with reasonable efficiencies and useful power levels. However, certain problem areas must be investigated before they can be successfully employed. These areas include peak and average power output, sensitivity of output power and frequency to the microwave circuit and bias voltage, phase control, reproducibility and cost, driver requirements, and temperature and frequency stability.

In order to resolve some of these questions, the distributed 4-element array of Fig. 1 was constructed and tested using pulsed Gunn oscillators as the element transmitters. The devices used[1] were three layer epitaxial sandwich structures with a 12 micron thick active layer, and a doping-density length product of $N_oL = 10^{12}$ cm^{-2}. The devices were operated in low dielectric constant ($\epsilon_r = 2.5$) microstrip circuits at a 50Ω impedance level. They were shunt mounted across the line and tuned by a short circuit located approximately $\lambda_g/2$ behind the device. Peak power from these circuits was typically 250 mw with the devices biased at 25 volts. The operating pulse impedance was nominally 25Ω.

A block diagram of the array is shown in Fig. 2. The master phase locking oscillator is coupled to a four-way power divider through the master circulator. The outputs of the divider lock the individual oscillators through the element circulators and the locked outputs are radiated by half-wave colinear dipoles fed by coaxial slotted baluns. The received signals are coupled back through the element circulators, combined in the power divider and directed to the receiver through the master circulator. For this preliminary investigation phase shifters were not included and only broadside antenna patterns were measured.

+Emerson Electric Co., St. Louis, Missouri

++Electrical Engineering Department, Washington University, St. Louis, Missouri, Consultant to Emerson Electric Co.

NOTES

Phase control of oscillators by signal injection, is a well known technique[2-8]. Adler's linearized theory[2] is useful in interpreting experimental data and is an adequate description in most cases. In this formulation the frequency pulling range of the locked oscillator is given by

$$\frac{\Delta f}{f_o} = \frac{\sin \phi}{2\ Q_L} \left[\frac{P_i}{P_o}\right]^{1/2} \tag{1}$$

where

$\Delta f = f_o - f_i$

f_o = frequency of free running oscillator

f_i = frequency of injection signal

P_o = free running oscillator power

P_i = injection power

Q_L = loaded Q of free running oscillator circuit

ϕ = phase difference between output of locked oscillator and injected signal after locking.

In phased array applications phase errors due to line length differences and residual phase shift in element components will lead to beam steering errors and alterations in the anticipated beam shape. Thus the sources of phase errors in the system must be understood. When phase locked, the operating frequency of the Gunn oscillator is f_i. Equation (1) shows that a frequency difference Δf will produce a phase shift between the locked oscillator output and the locking signal. Experimental results for this phase shift are plotted in Fig. 3. This points up one of the inherent difficulties in the use of injection phase locking to control arrays with large numbers of independent oscillators which may run at difference frequencies. However, this same phase shift mechanism may be used to simplify the design of phase shifters for the array. By varying the locking power ratio (P_i/P_o) or by voltage tuning the Gunn device after it is locked, adjustable phase control may be obtained.

Experimental results of output power and frequency as a function of bias voltage will be presented as well as a discussion of pulser requirements, module design and other considerations.

Figure 4 shows the degradation of the pulse spectrum of a single Gunn oscillator when the driver pulse width is increased. This phenomenon is presumably due to frequency modulation caused by pulse heating. The power spectrum can be drastically improved by phase locking the devices to the master oscillator. Figure 5 shows the spectrum of the four element array measured in the far field. This indicates the output of the entire array is phase coherent when all elements are locked to the same signal.

Broadside antenna patterns were measured both on transmit and receive. The transmit pattern is shown in Fig. 6. Notice that the sidelobe levels are down approximately -14 db with respect to the main lobe which is in excellent agreement with the calculated pattern for this array. The main nulls are -20 db which indicates a high degree of phase coherence across the array. Mutual coupling between radiating elements did not prove to be a problem.

The results of this study demonstrate the feasibility of using Gunn oscillators as transmitters in modular type distributed phased array antennas.

REFERENCES

1. Experimental devices obtained from Monsanto Co., St. Louis, Missouri.
2. R. Adler, "A Study of Locking Phenomena in Oscillators", Proc. I.R.E., vol. 34, pp. 351 - 357, June 1966.
3. E. E. David, Jr. "RF Phase Control in Pulsed Magnetrons", Proc. I.R.E., vol. 40, pp. 669 - 685, June 1952.
4. R. C. Mackey, "Injection Locking of Klystron Oscillators", I.R.E. Trans. Microwave Theory and Techniques, vol. MTT-10, pp. 228 - 235, July 1962.
5. H. L. Stover and R. C. Shaw, "Injection-Locked Oscillators as Amplifiers for Angle Modulated Signals", International Microwave Symposium Digest, pp. 60 - 65, May 1966.
6. R. C. Shaw and H. L. Stover, "Phase-Locked Avalanche Diode Oscillators", Proc. IEEE (letters), vol. 54, pp. 710 - 711, April 1968.

7. H. Fukui, "Frequency Locking and Modulation of Microwave Silicon Avalanche Diode Oscillators", Proc. IEEE (letters), vol. 54, pp. 1475 - 1477, October 1966.

8. T. Isobe and M. Tokida, "Effects of Phase Locking and Modulation Characteristics", Proc. IEEE (letters), vol. 55, pp. 453 - 454, March 1967.

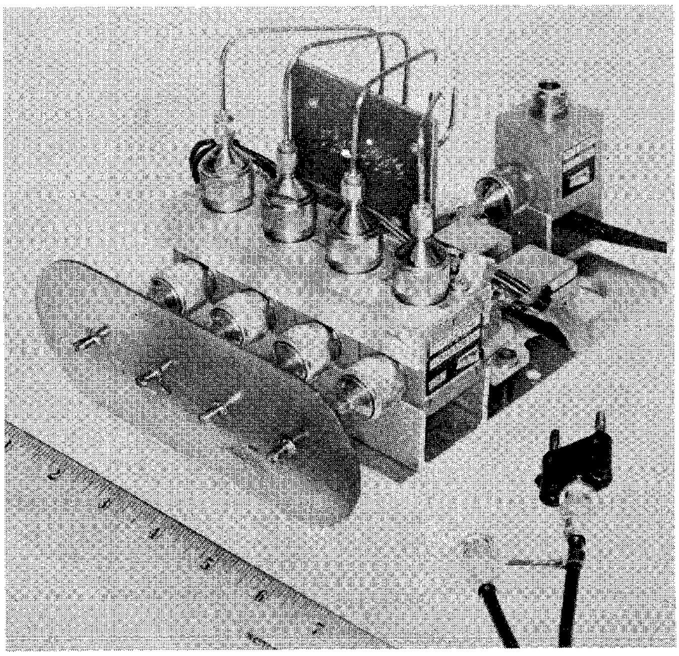
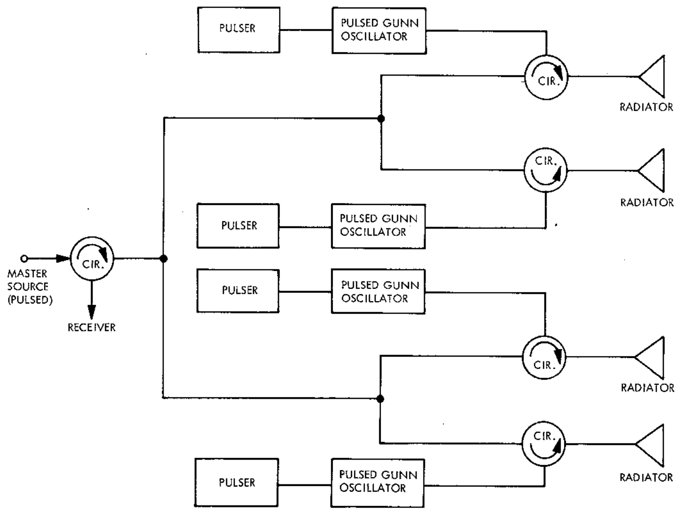
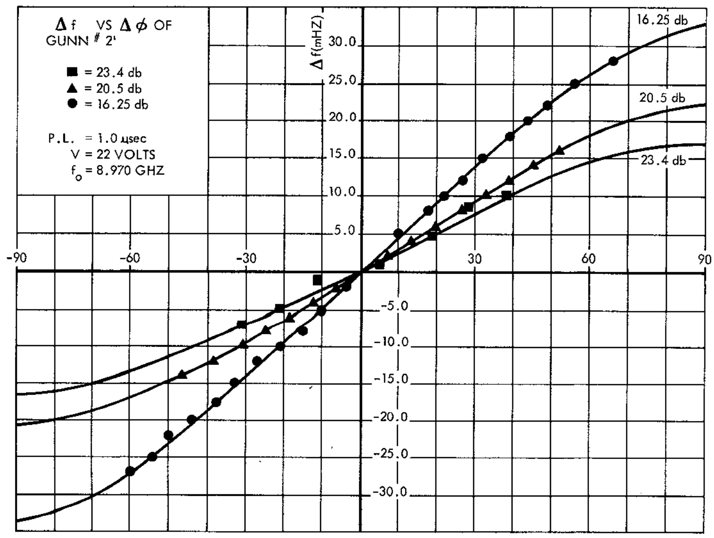


FIGURE 1

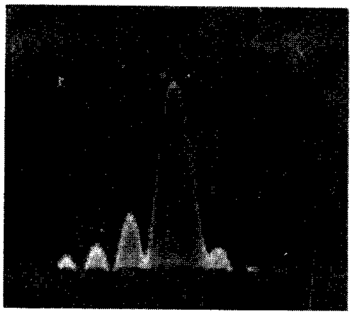
Front view of array



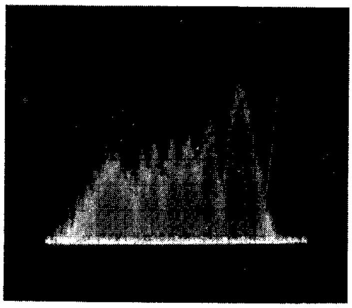
BLOCK DIAGRAM OF GUNN ARRAY



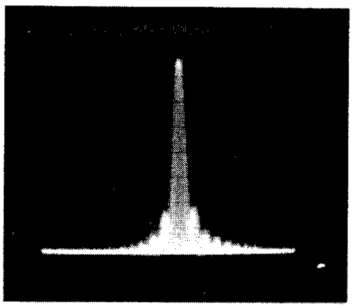
PHASE SHIFT AFTER LOCKING AS A FUNCTION OF FREQUENCY DEVIATION Δf=f o - f i WITH THE RATIO OF P o/Pi AS THE PARAMETER



Free running oscillator, pulse length 0.25 μsec.

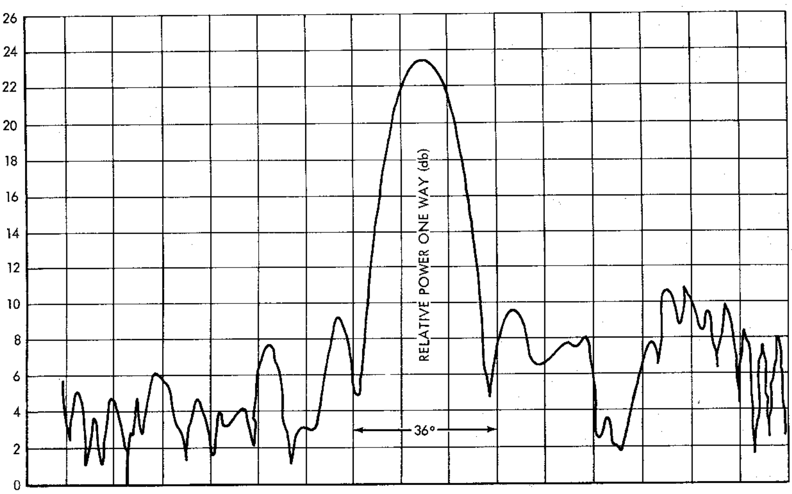


Free running oscillator, pulse length 0.8 μsec.



Injection locked oscillator, locking power 20 db below free running output (250 mw), pulse length 0.8 μsec.

FIGURE 4 - Spectral smearing vs. pulse length. Power spectrum of Gunn oscillator, with various pulse lengths. Oscilloscope dispersion 3 megahertz per division.



FOUR ELEMENT FAR FIELD TRANSMIT PATTERN IN THE E PLANE, GUNN DIODES PHASE LOCKED

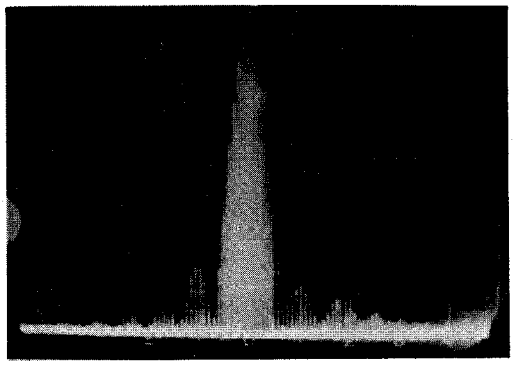


FIGURE 5

Spectrum of four element array phase locked to the same signal as measured in the far field