MICROSTRIP ACTIVE ANTENNAS AND ARRAYS

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ABSTRACT

Microstrip active antennas and arrays have been designed at X-band using patch antennas and Gunn diodes. Injection locking experiments were carried out to achieve frequency coherency and to calculate the circuit Q-factor. Over 9 percent electronic tuning range has been achieved for the single active patch element. The power outputs from two elements have been successfully combined in free space. The advantages of low cost and wide bandwidth should offer many applications.

Two of these active antennas were combined to form an array. Received output power was approximately doubled indicating a combining efficiency of over 90 percent. The tuning range is much lower compared to a single active patch antenna due to a higher Q-factor. Experimental results also showed that the array antenna pattern suffered an unlocking phenomena. The phenomena occured when the antenna broke from a single beam into two separate beams as the DC bias voltage of one of the antennas was varied. The breakup limits the practical tuning range.

INTRODUCTION

Recent developments in solid-state devices and microwave integrated circuits have made it possible to implement active devices directly on planar antenna element. Many active elements can be combined to form an active array, a spatial power combiner [1] or a quasi-optical power combiner [2]. These techniques are compatible to monolithic implementation by fabricating both active devices and antennas on a single semiconductor substrate. The circuits can be made at very low cost and should have many applications in radar, communication, and EW systems.

Microstrip active patch antennas have been reported by Thomas et. al.[3] and Perkins [4] using Gunn and IMPATT diodes. Injection locking the antenna elements through space has also been demonstrated. However, no attempt was made to measure the loaded active antenna Q-factor or to electronically tune the active antenna element. Furthermore, no attempt was made to form an array out of the active antenna elements.

This paper reports the design and measurements of a single active patch antenna with a Gunn diode mounted directly on the patch. The Q-factor was measured using the spatial injection locking technique. The output power was found comparable to that from a waveguide circuit using the same Gunn diodes.. The active antenna can be made tunable over a 9 percent bandwidth by varying the DC bias. This wide tuning range compared to a passive patch antenna is attributed to a lower loaded Q-factor.

DESIGN CONSIDERATIONS

Both the single patch antenna and the two element array were constructed on Duroid 5870 substrate with a thickness of 1.524mm. The circuit configurations are shown in Figure 1.

The antenna dimensions were determined by the equation given by James et.al [5]. The antenna length was chosen to be

$$L = \frac{\lambda_g}{2} - 2\triangle l_{eo}$$

and the antenna width is

$$W = 0.3\lambda_o$$

where λ_g= guided wavelength

$\triangle l_{eo}$= equivalent length to account for open end fringing capacitance

λ_o= free space wavelength

The placement of the active device was chosen such that the device impedance was matched to the input impedance of the patch. The diode placement location D is given by

$$D = \frac{\lambda_g}{2\pi}\cos^{-1}[Z_{in}\ G_r(1 - \frac{G_m}{G_r})]^{1/2}$$

where G_r= radiation conductance

G_m= mutual conductance of the two edges of the antenna

D= the distance from either antenna edge to the feed position

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Z_{in}= the input impedance to the antenna at the diode location

For a rectangular patch of $W = 0.3\lambda_o$, G_r and G_m can be found from James et.al [5].

$$G_r = (\frac{W^2}{90\lambda_o^2})$$

$$\frac{G_m}{G_r} = 0.32$$

The input impedance Z_{in} is set equal to the active device resistance which is assumed to be 8 ohms [6].

The two element active array is also shown in Figure 1. Each element was designed to have the same dimensions as the single antenna. The two antenna elements were separated by one-quarter of the guided wavelength. The Gunn diode is a package pill type diode from M/A COM. It produced 10-25 mW output power at 10 GHz in an optimized waveguide circuit.

RESULTS FOR A SINGLE PATCH ANTENNA

The output power from the active patch was measured using a standard antenna located at a known distance from the patch. The maximum output power is about 15mW at 10.1 GHz. This power is calculated using the radar equation based on a 15.4μW received power. The output power and frequency as a function of DC bias is shown in Figure 2. A 3 dB tuning range of 839 MHz was achieved from 9.278 to 10.117 GHz. This tuning range is equivalent to a 9 percent bandwidth which is much wider than to that of a single passive patch.

The antenna patterns for several bias voltages are shown in Figure 3. This shows a beamwidth of $\pm$45 degrees. The large peak present at -60^o is most likely due to experimental setup. The plot also shows that the pattern changes very little as the bias voltage (and thus the frequency and power) is varied.

The single active patch antenna can be injection locked to an external signal incident on the patch. Figure 4 shows the frequency spectrum before and after the injection-locking. The frequency stabilization and noise suppression provided by injection locking are evident. Figure 5 shows the injection locking bandwidth vs. locking gain. The external Q can be found from the equation by Adler [7]. For the results shown in Figure 5, the external Q value is about 20. This low Q-value explains why a wider tuning range was achieved for a single active patch antenna. The Q-factor measured here compares favorable with those previously reported for microstrip oscillators [8,9].

RESULTS FOR TWO ELEMENT ACTIVE ARRAY

The two active devices in the two element array will injection-lock each other through mutual coupling. An external signal can also be used to lock the array.

The measured pattern for the array is shown in Figure 6. Also shown are the patterns with either antenna "off". It can be seen that when both antennas are "on", the beamwidth is narrower and the gain is higher. A received boresight power of 31 μW was achieved at 10.42 GHz. This received power level is about twice of that from a single patch active antenna. This demonstrated a good combining efficiency. The boresight power and the operation frequency of the array has a severe drop at a bias voltage of 15.44 volts. It was found that the radiation pattern broke from a single beam into two separate beams above this bias voltage. The tuning range is much narrower compared to that of the single active patch antenna.

CONCLUSIONS

Active antennas and arrays using microstrip patch antennas and Gunn diodes have been studied. A single active patch was tested and the results showed a 3 dB beamwidth of 90 degrees and an external circuit Q of approximately 20. Over 9 percent tuning range was achieved using bias tuning.

A two element active array was also developed. The output power levels from the two elements were combined in free space resulting in higher power in the main beam. The tuning range is much narrower and the antenna pattern broke from a single beam into two separate beams as the DC bias voltage is varied.

The active antennas and arrays can be made at very low cost. The wide tuning range for the single active patch antenna is very attractive. The results should have many applications in radar, communication, and EW systems.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. J.L. Klein for many helpful discussions and technical assistance. This work was supported in part by a grant form TRW, Inc.

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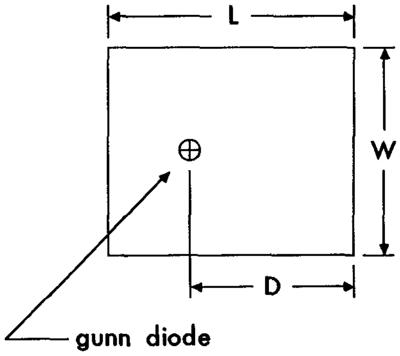
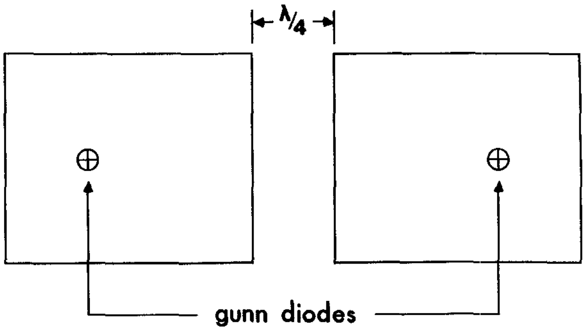


(a) Single active patch antenna



(b) Two-element array

Figure 1 Circuit configurations for a single active patch antenna and a two element active array

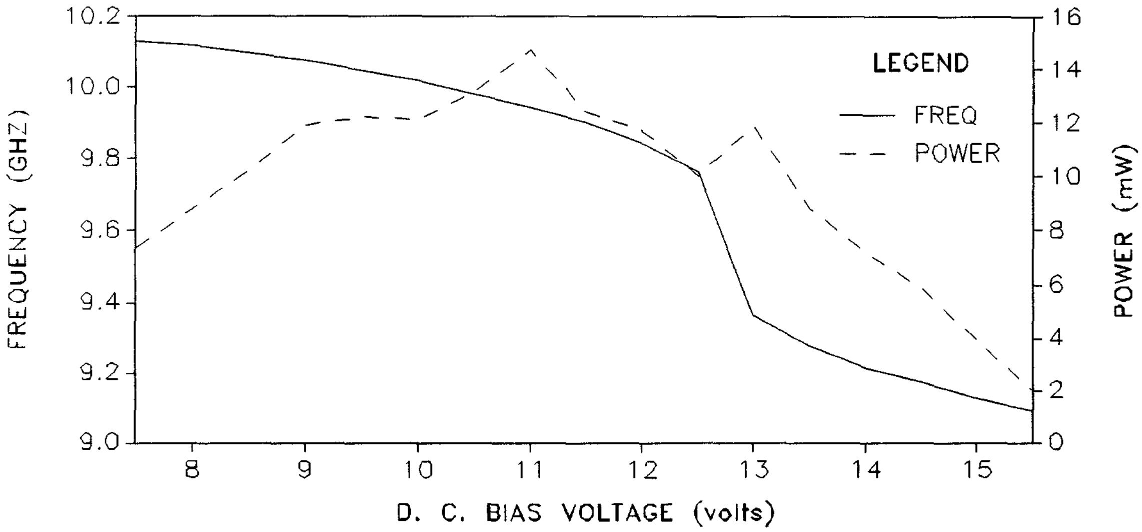


Figure 2 Output power as a function of frequency and bias voltage for a single active antenna

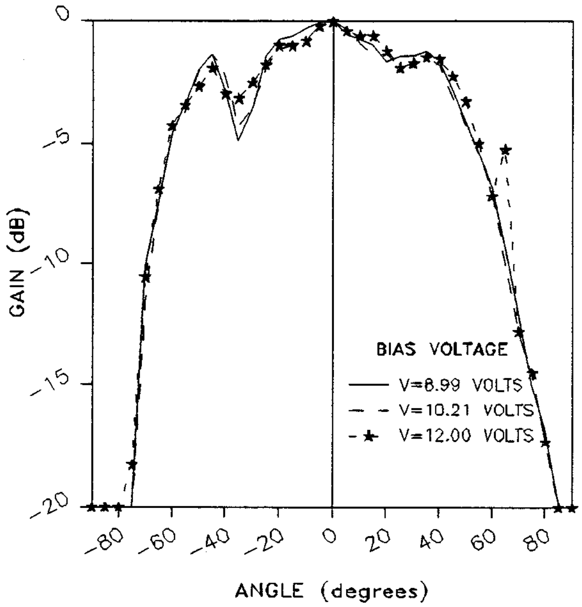


Figure 3 Antenna patterns for several different bias voltage levels for a single active antenna

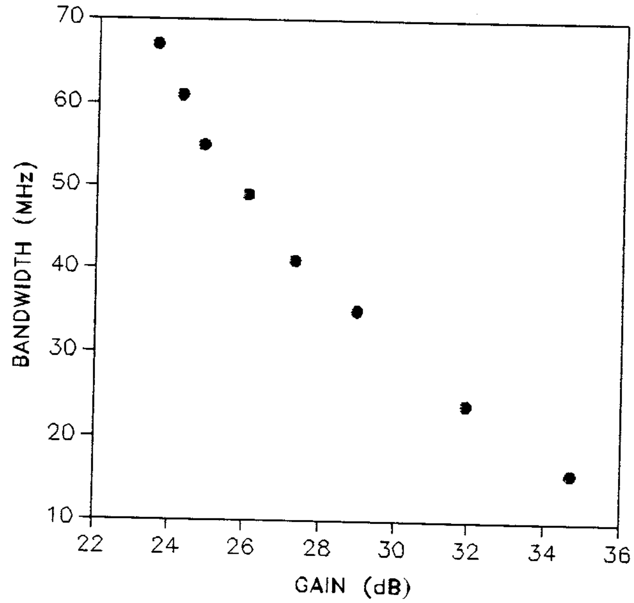
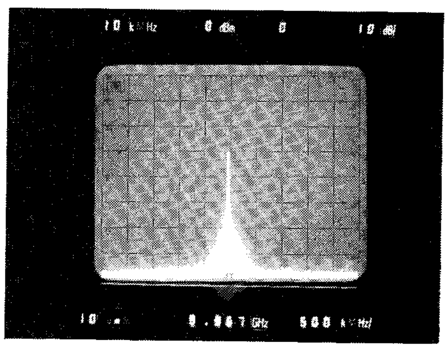
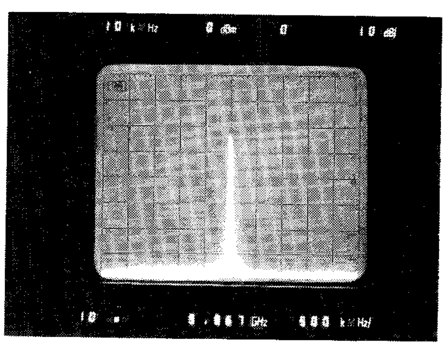


Figure 5 Injection locking bandwidth as a function of locking gain



(a)Free running signal



(b)Injection-locked signal

Figure 4 Signal spectrum before and after the injection-locking

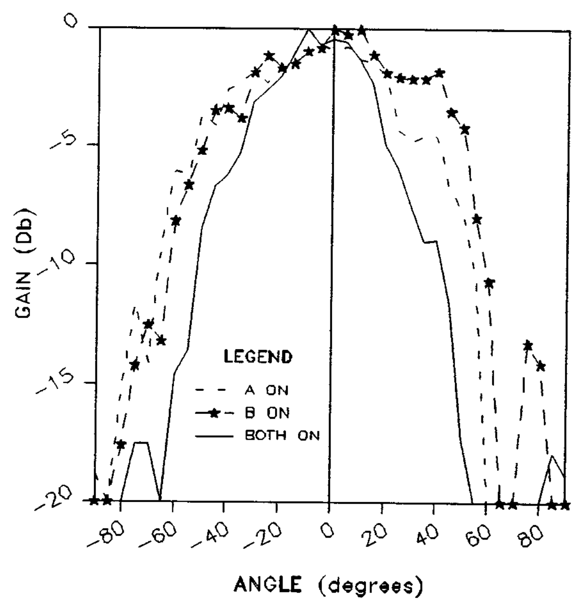


Figure 6 Measured patterns for two-element array.