# A New Type of Active Antenna for Coupled Gunn Oscillator Driven Spatial Power Combining Arrays

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***Abstract*—A new type of active antenna appropriate for coupled Gunn oscillator driven spatial power combining arrays was developed. The active antenna uses a ring stabilized oscillator coupled to a slot antenna. The circuit should be useful in communications, radar, and sensor systems.**

## I. Introduction

In recent years, spatial power combining technology has received extensive attention due to its potential applications in solid-state radar or communication systems in microwave bands or millimeter wave bands [1]. As it is widely implied or accepted, spatial power combining is such a concept that by exciting the elements of an antenna array with signals of certain phase relationship directly from solid-state RF power oscillators or amplifiers, a desired beam (usually a broadside beam) which contains most of the radiated RF power will be formed. This method can achieve higher RF power than traditional circuit level combiners which can accommodate only a small number of solid-state devices.

In spite of their low efficiency, Gunn diodes are widely used in microwave and millimeter wave frequencies due to its low noise, simple peripheral circuit design, etc. They are also used in many spatial power combining applications. Several successful designs of the active antennas and spatial power combiners using Gunn diodes were reported, among them are microstrip patch antenna [2]–[5], notch antenna [6], and inverted stripline circular patch antenna [7]. In most of these circuits, the bias lines of the Gunn diodes would cause certain spurious radiation, thus, deteriorate the pattern of the active antennas.

To overcome the shortcomings of the previous designs, a new type of active antenna appropriate for the coupled Gunn oscillator driven spatial power combining arrays was proposed. The circuit uses a ring stabilized oscillator coupled to a slot antenna. The bias circuits and Gunn diodes are hidden behind the metallization. This active antenna has advantages of low spurious radiation, low cross polarization, good heat sinking, ease of integration, etc. A design in $C$-band demonstrated good performance.

## II. Circuit Configuration

The configuration of the new active antenna is shown in Fig. 1. A circular microstrip ring is used as the resonant element of the oscillator. A slot on the ground plane of the substrate coupled with the circular microstrip ring serves as the radiating element. A Gunn diode is mounted between the ring and the ground plane of the substrate at either side of the ring. A metal mirror block is introduced one quarter wavelength behind the ring to avoid any back scattering.

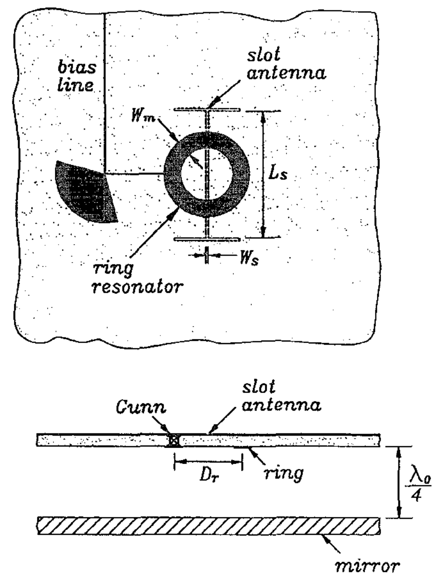


Fig. 1. Circuit configuration.

The operating frequency of the active antenna is expected to be close to the first resonant frequency of the circular microstrip ring. At this frequency, the circumference of the circular microstrip ring is equal to one guided wavelength of the microstrip line meaning that the diameter of the circular microstrip ring is equal to 0.318 guided wavelength of the microstrip line. This active antenna is compact and , thus, can be readily used in a coupled Gunn oscillator driven spatial power combining array.

## III. Design Example

An active antenna of this type was designed, fabricated, and experimentally optimized at 5.5 GHz with Gunn diodes of model number MA49135 from M/A-COM and RT/Duroid 5880 dielectric substrate of $\epsilon_r = 2.20$ and thickness $h = 1.57$ mm. This frequency was chosen as our design frequency $f_0$ only for convenient fabrication. The passive portion of the active antenna was designed in the following procedure:

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1) The width $W_s$ of the slot antenna was set at 0.50 mm. The effective dielectric constant $\epsilon_{\text{eff}}^s$ of the slot was calculated to be 1.34 at 5.5 GHz.
2) The length $L_s$ of the slot was chosen greater than the average diameter $D_r$ of the resonant ring and less than half of the design wavelength in free space (to avoid grating lobes when the active antenna is arranged along this direction to form a coupled Gunn oscillator driven spatial power combining array). That is

$$D_r < L_s < \frac{\lambda_0}{2}(= 27.3 \text{ mm}). \quad (1)$$

3) The average diameter $D_r$ of the resonant ring was determined by the condition that the first resonance of the microstrip ring occurs when the circumference of the ring is equal to one guided wavelength. Thus

$$D_r = \frac{\lambda_0}{\pi\sqrt{\epsilon_{\text{eff}}^m}} = \frac{0.318\lambda_0}{\sqrt{\epsilon_{\text{eff}}^m}} = \frac{17.3 \text{ mm}}{\sqrt{\epsilon_{\text{eff}}^m}} \quad (2)$$

where $\epsilon_{\text{eff}}^m$ is the effective dielectric constant of the microstrip line.
4) The width $W_m$ of the microstrip line was determined by an optimum characteristic impedance $Z_C$ of the microstrip line. This optimum $Z_C$ was found experimentally to match the impedance of the Gunn diode.

With a Gunn diode mounted on this ring resonator/slot radiator, the whole circuit forms an active antenna. A simplified equivalent circuit of this active antenna is as shown in Fig. 2, where $Z_s(\omega)$ denotes the radiation impedance of the slot seen by the microstrip line, $Y_D(\omega, V)$ and $Y_{\text{in}}(\omega)$ denote the admittance of the MA49135 Gunn diode and the input impedance of the whole passive portion seen by the Gunn diode, respectively. The operating frequency $f$ and voltage magnitude $V$ of this active antenna will be the stable solution

$$-Y_D(\omega, V) = Y_{\text{in}}(\omega) = G_{\text{in}}(\omega) + jB_{\text{in}}(\omega). \quad (3)$$

The output power of this active antenna will be

$$P = \frac{G_{\text{in}}(\omega)V^2}{2}. \quad (4)$$

Given a specific Gunn diode, the output power of this active antenna is mainly a function of the radiation impedance $Z_s(\omega)$ of the slot and the characteristic impedance $Z_C$ of the microstrip line of the resonant ring and, ultimately, a function of the slot length $L_S$ and the microstrip width $W_m$ of the resonant ring, i.e.,

$$P = P(L_s, W_m) \quad \text{for a given Gunn diode.} \quad (5)$$

The optimum design with the maximum output power was found experimentally.

## IV. Experimental Results

First, the length $L_S$ of the slot was set at 24 mm which satisfies conditions (1) and (2). To increase the coupling between the slot and the resonant ring, the slot was cut into a $T$ shape at its both ends with the length of the head of the $T$ being fixed (12 mm, about one quarter guided wavelength of the slot). In this way, a more uniform electric field distribution along the slot, thus, a greater gain of the antenna will result. To optimize the circuit, three different $W_m$'s were considered which yielded three different active antennas as shown in Table I.

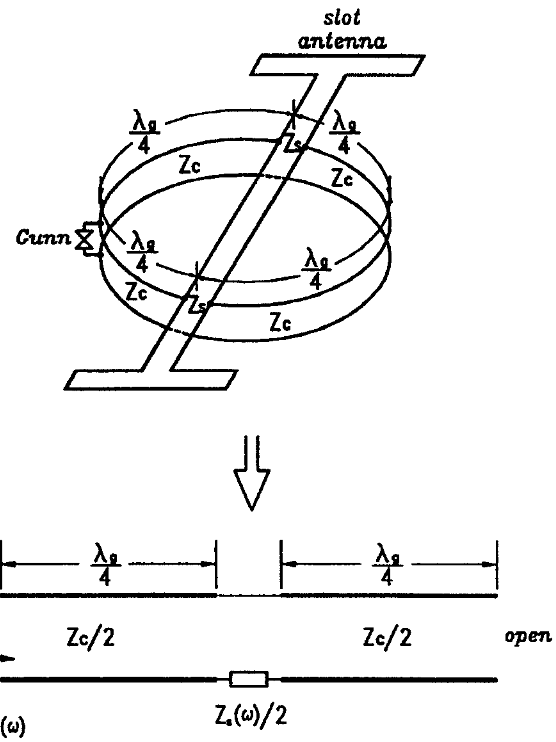


Fig. 2. Equivalent circuit.

TABLE I
Three Different Designs

| $Z_C$(ohms) | $W_m$(mm) | $\epsilon_{\text{eff}}^m$ | $D_r$(mm) |
|---|---|---|---|
| 50 | 4.8 | 1.91 | 12.6 |
| 67 | 3.1 | 1.87 | 12.7 |
| 100 | 1.4 | 1.78 | 13.0 |

An MA49135 Gunn diode was mounted onto each of the three circuits to form a single active antenna. Then, the radiation patterns, radiated powers, as well as the operating frequencies of the three different designs were measured. Of the three, the 67 ohm ring resonator/slot radiator circuit displayed the optimum performance with

1) the highest radiation power level along the direction of the maximum radiation of the active antenna
2) good $E$- and $H$-plane patterns
3) stable oscillation with the widest bias voltage tuning range

Figs. 3 and 4 show the patterns of the optimum active antenna observed in the experiments. Further inspection of these patterns revealed that this optimum active antenna had a directivity of 8.4 dB which was estimated with Kraus' formula [8], and a cross polarization level lower than −10 dB. A reasonable phase noise level (−92 dBc/Hz at 100 KHz offset from its central frequency), a frequency shift of 89 MHz, and

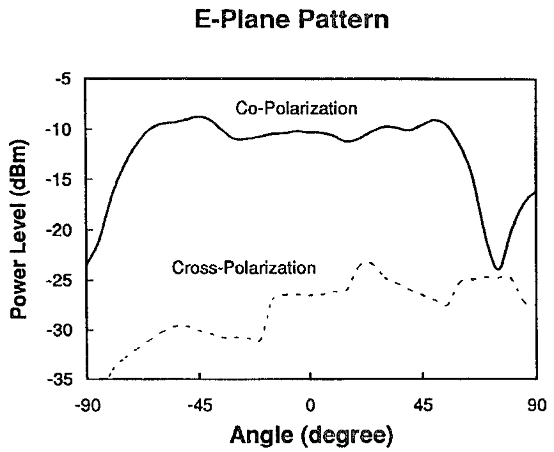


Fig. 3. $E$-plane pattern of the active antenna.

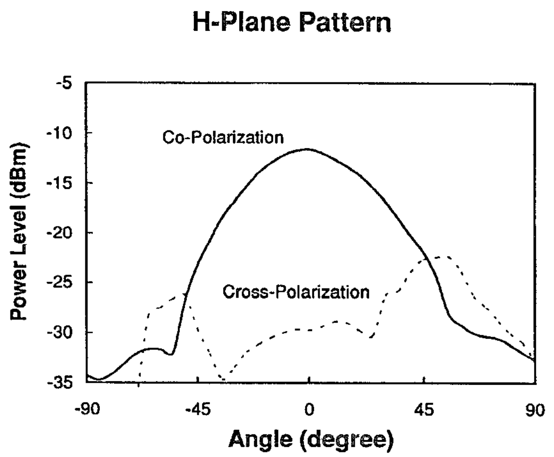


Fig. 4. $H$-plane pattern of the active antenna.

a power fluctuation of less than 0.79 dB were observed when its bias voltage was changed from 10.0–14.0 V. The radiated power of this optimum active antenna was estimated by means of Friis transmission equation [3]. A radiated power of 16 dBm occurred at the bias voltage of 12.6 V. Experiments also showed that the ground plane of the substrate is a good heat sink for the used Gunn diode which consumed dc power of up to 2.5 W.

## V. Conclusion

A new type of active antenna appropriate for the coupled Gunn oscillator driven spatial power combining arrays was proposed. An active antenna of this type was designed and experimentally optimized in $C$-band. The satisfactory performance of the optimum active antenna indicated that this type of Gunn active antenna is practicable. In addition to its potential applications in the coupled Gunn oscillator driven spatial power combining arrays, this active antenna itself can be used as the front end of a compact Doppler sensor or frequency-modulated transmitter.

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