ACTIVE ENDFIRE ANTENNA ELEMENTS AND POWER COMBINERS USING NOTCH ANTENNAS

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ABSTRACT

A Gunn device has been integrated with a planar, endfire notch antenna. A simple transmission-line model has been developed to optimize the passive and active circuit parameters. An electronic tuning bandwidth of 275 MHz centered at 9.33 GHz with a maximum power output of 37.5 mW was accomplished. Two active notches in a broadside array configuration were injection-locked at 9.484 GHz with a 30 MHz locking bandwidth and well over 90% power combining efficiency.

I. INTRODUCTION

The notch antenna has many desirable characteristics including broad-impedance matching bandwidth, planar nature, good reproducibility, and ease of integration to passive components[1] and active devices. Furthermore, the length of the notch can be increased to create a travelling-wave antenna like the linear-tapered slot antenna(LTSA)[2]. The main design parameter of the notch antenna is the actual taper of the flare of the slot as given by Gibson's exponentially-tapered vivaldi antenna[3]. Other important work has been reported in solving for the fields along the antenna, impedance and radiation characteristics[4]-[6]. The flexibility of this type of antenna makes it ideal for many diverse applications.

Active solid-state devices have been successfully integrated in resonant broadside radiating elements such as the microstrip patch antenna [7]-[10]. However, the integration of the active devices with the wide-band endfire radiating notch has only received sparse attention [11]. This paper reports a novel circuit configuration of an active notch antenna. The active element used is the Gunn diode. Two of these active notches were successfully injection-locked and their power combined with well over 90% efficiency.

The notch antenna was integrated with a two-terminal device to demonstrate a low-cost, compact RF power source that can make use of injection-locking and power-combining techniques for low-cost, modular active arrays. The results are directly applicable to LTSA's and vivaldi antennas as well as the use of other active devices such as the IMPATT and FET to replace the Gunn. The importance of using the notch antenna is in the versatility of the design. The notch can serve as an element for a wide-bandwidth, wide-angle scanning phased array. Extending the length of the notch or increasing the dielectric constant to create a travelling-wave antenna increases the directivity for higher-gain applications and wide-bandwidth, narrow-angle scanning phased arrays.

Furthermore, other solid-state devices such as varactors and PIN diodes can also be integrated with the active notch antennas or arrays for frequency agile systems. The advantages of the element's low-cost, reproducibility, compactness, and planar nature combined with injection-locked power-combining techniques and monolithic circuit integration make this a feasible RF-power source at microwave and millimeter-wave bands.

II. THE SINGLE NOTCH ANTENNA

Figure 1 shows the novel active antenna configuration and equivalent circuit consisting of an active device placed in a planar resonator coupled to the radiating element. The circuit consists of a notch antenna coupled to a coplanar waveguide(CPW) resonator via slotline. A Gunn diode is placed in a heat-sink at at the open terminals of the resonator. The notch is formed by many step transformers which match the slotline impedance to free space.

The essential design element for improved oscillations and stability is the resonator. Considering the planar nature, Q-factor, and ease of integration with active devices, CPW was chosen over slotline for the resonator. The CPW slots where chosen to be 0.3 mm with a 3.5 mm separation. This arrangement provides a 50 Ω characteristic impedance and mates well with the 3.5 mm cap of the Gunn diode. The length of the resonator was chosen to be approximately 0.5λ accounting for the extra length on the shorted end. A dc block needed to be incorporated at the shorted end for biasing purposes. The CPW formulas used for the transmission line design can be found in [12].

The notch antenna design was accomplished using slotline transmission line formulas[13]. The impedance was increased by steps from a lower limit of 93Ω to free-space impedance. The steps are essentially sequential quarter-wave transformers that enable a very large impedance bandwidth. The low dielectric constant of 2.3 was chosen to allow efficient antenna radiation. The input impedance of the notch was matched to the resonator at a convenient point, approximately the center.

Matching from free space to the resonator was optimized using a transmission line model. Touchstone software was used to optimize the lengths of the transformer sections at discrete impedance values of the slotline for minimum return-loss throughout X-band. The circuit was fabricated on a 60 mil thick RT-Duroid 5870 substrate. To test the passive circuit, an SMA connector was soldered on to the CPW resonator and the measurements were performed on the HP-8510 Network Analyzer. The theoretical and measured return-loss (S11) agree fairly well.

The passive notch was then tested in the anechoic chamber to determine its radiating characteristics and gain from 9.0 to 10 GHz. Figure 2 shows the typical E and H field patterns of the configuration as well as the cross-polarization measurements(Ec, Hc). The high cross-polarization at broadside angles is due to the radiating characteristics of the CPW resonator. This is being improved with another design.

A Gunn diode from M/A COM (model 49106) was integrated with the notch antenna. This Gunn diode produced 72 mW in an optimized waveguide circuit. Figure 3 shows the spectrum of the active notch antenna. The bias voltage vs. frequency and power output is shown in Figure 4. The 3 dB electronic tuning bandwidth was 275 MHz centered at 9.33 GHz with a maximum power output of 37.5 mW at 9.328 GHz. A change in Gunn diode position in the heat-sink increased the maximum output power to 62 mW at 9.426 GHz with a decrease in electronic tuning bandwidth to 117 MHz centered at 9.445 GHz. The E and H-field patterns of this active notch antenna are shown in Figure 5. The patterns are similar to those given in Figure 2 for the passive notch circuit. E-plane asymmetry can be attributed to the heat-sink used.

III. Injection-locking & Power Combining

The purpose of injection-locking and power-combining techniques is to create a stable, high-power RF source from many low-cost, low-power RF sources. The output signal of the array of sources can only be as stable as the most stable source in the array. Injection-locking allows the use of a single, stable, low-power source to lock the signals of all the other sources in the array. The power combination that occurs is due to all the oscillating sources locking in phase at a particular frequency. Due to the different characteristics of each Gunn diode and capacitive effects of the mounting and positioning, injection-locking and power-combining is optimized using electronic bias tuning on each element.

The single active notch antenna has been successfully injection-locked to an external source to achieve spectral purity and stability. The maximum locking-gain was measured to be 33.5 dB at 9.373 GHz.

Two active notch antennas were brought together to a separation of 0.5λ at 9.484 GHz to form a broadside injection-locked two-element array or power combiner. The two antennas were injection-locked to each other due to mutual coupling. The output power of the two active antennas was combined in broadside with a combining efficiency of more than 90%.

IV. CONCLUSIONS

Active notch antenna elements and power combiners have been developed with good performance for the first time. The circuit design was based on a simple transmission line circuit model which describes the passive and active operating characteristics of the design accurately.The results should enable the combination of MMIC techniques, two and three-terminal active devices and planar antennas with injection-locking and power combining techniques so that low-cost,high-power RF systems can be designed through the use of many low-cost, low-power sources.

V. ACKNOWLEDGEMENTS

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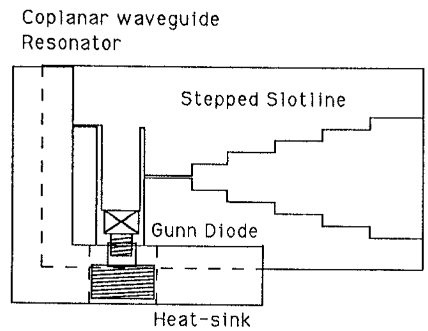
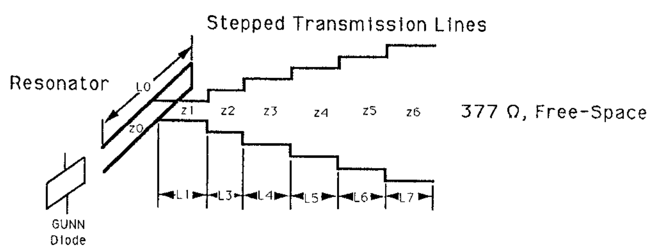
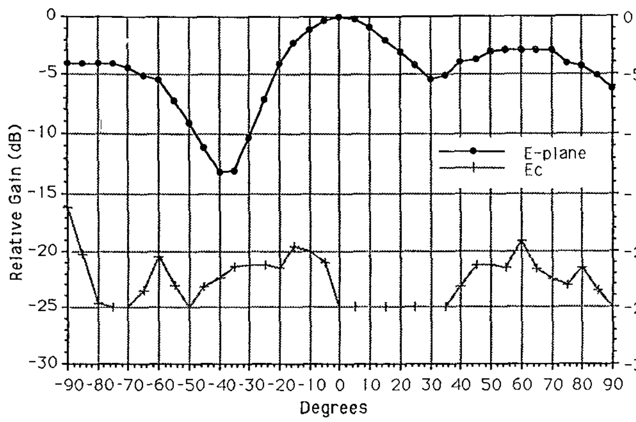


(a) Active Notch Antenna Configuration

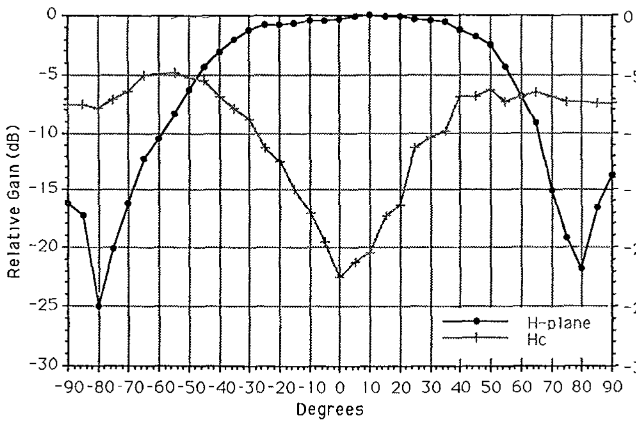


(b) Transmission Line Equivalent Circuit Model

Figure 1 (a) Active Notch Antenna Configuration
(b) Transmission Line Equivalent Circuit Model



(a) E-plane and Cross-polarization Measurement



(B) H-plane and Cross-polarization Measurement

Figure 2. Field Patterns of a Single Passive Notch Antenna Element

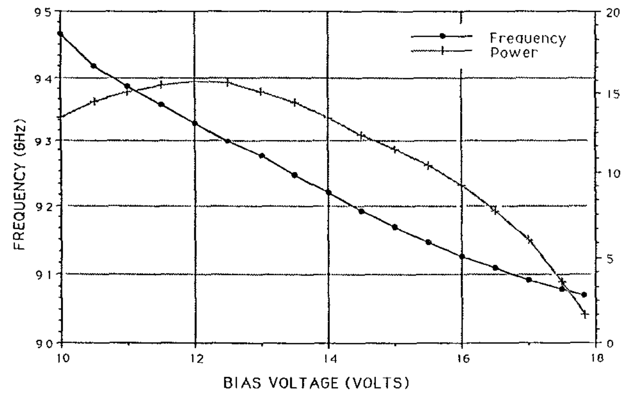


Figure 4 Frequency and Power Output vs Bias Voltage for a Single Active Notch Antenna Element

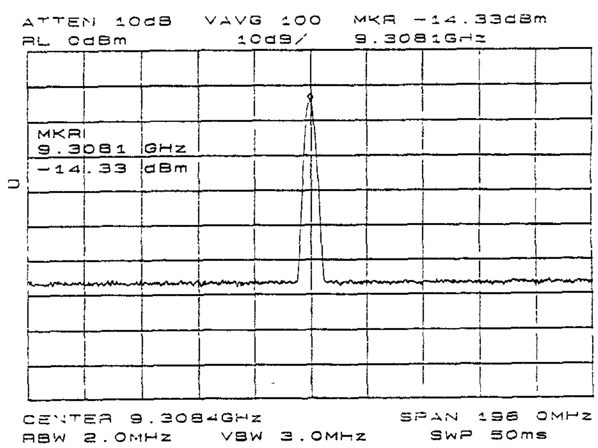
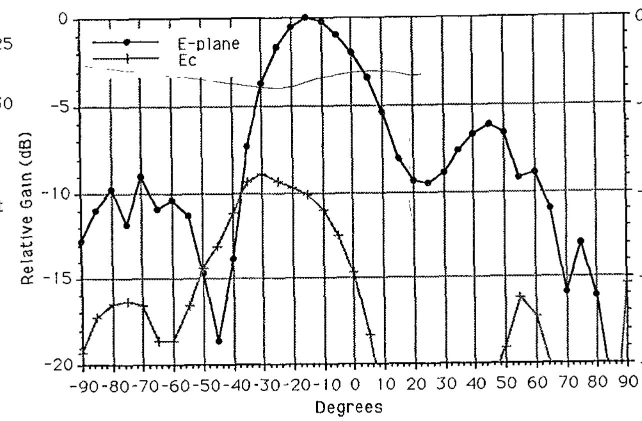
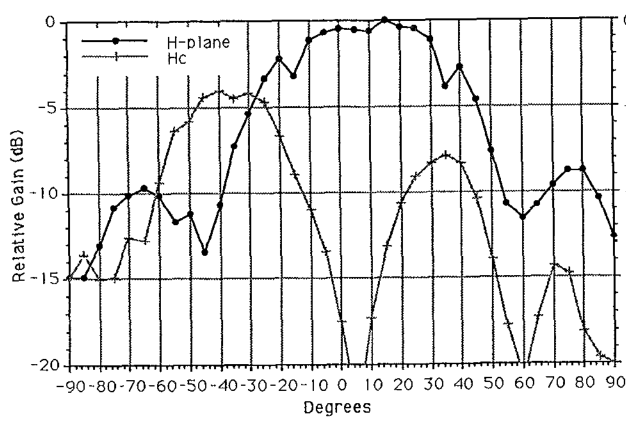


Figure 3. The Spectrum of Single Active Notch Antenna Configuration



(a) E-plane and Cross-polarization Measurement



(b) H-plane and Cross-polarization Measurement

Figure 5. Field Patterns of a Single Active Notch Antenna