# A NOVEL OSCILLATING RECTENNA FOR WIRELESS MICROWAVE POWER TRANSMISSION


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## Abstract

A new concept for solid state wireless microwave power transmission is presented. A 2.45 GHz rectenna element that was designed for over 85% RF to dc power conversion efficiency has been used to oscillate at 3.3 GHz with an approximate 10/0 dc to RF conversion efficiency. The RF radiation was obtained from the same circuit by supplying the dc output with reverse polarity dc power.


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## I. Introduction

The rectenna is a rectifying antenna operating in a receiving mode for reception of microwave power and subsequent conversion to dc by a diode rectifier. However if an IMPATT diode is used to rectify microwave power, the same diode can also operate in the avalanche region to generate and radiate RF power in the same circuit. Thus, the circuit can convert RF to dc and vice versa but not concurrently. The polarity of the dc voltage determines the operating mode. The dc current flow is in the same direction for either mode of operation.

The chief significance of this concept is that microwave solid state devices can in theory and in practice, work both ways as regards to power conversion. This fact is generally not known by members in the microwave community, whereas those in the 50/60 Hz power community do both dc-ac and ac-dc regularly with the same solid state devices [1]. Klystron and magnetron tubes can also be operated as RF to dc conversion devices [2]. Their inverse conversion efficiencies have not been optimized either, however.

The cost of wireless microwave power transmission systems can therefore be reduced if similar devices and circuits are able to be used on either end of the power link. Also, for intercontinental load-leveling where microwave power is transported via intermediate mirrors, the same equipment on either end of the link would allow both transmission or reception [3].

Based upon the conjecture of one of the authors ( Dickinson) [4], the concept is realized using a rectenna element obtained from the JPL Goldstone microwave power transmission experiment in 1975 [5]. The Goldstone rectenna array consisted of 4,590 elements that ~~operated~~ DELIVERED up to 34 kW of output dc power from a2.388 GHz microwave beam. This rectenna array demonstrated an average 82.5% collection and conversion efficiency whereas selected rectenna elements were tested at a 87°/0 conversion efficiency level [6].

## II. Rectenna Element Design

Figure 1 shows a photograph of the rectenna element used in this experiment. Two aluminum strips form the dipole and balanced transmission line. An added aluminum piece, located at the diode, is shown for heat sinking and securing the element to a support that suspends the element above a reflecting plane. As seen in Figure 2, the rectenna consists of a half wave dipole antenna, a two section input low pass filter, a GaAs IMPATT diode, and an output 30 pF capacitor for shorting RF power and tuning the diode. A 165 Ω dc resistive load is also connected in parallel at the output to complete the dc circuit and achieve a conversion efficiency of greater than 85°/0. More details on the rectenna design are given by Brown in [7] and [8].

As a rectifier, the received microwave power is converted into dc power and measured across the 165 Ω load. As an oscillator, bias is applied with reversed polarity and the RF power radiates from the dipole. The nominal characteristic impedance of the low pass filter is 120 Ω, and the cutoff frequency is 3.7 GHz for attenuating harmonic signals generated by the diode. The entire circuit is placed approximately 0.2 $\lambda_o$ horizontally above a reflecting plane.

## 111. Measurements

Figure 3 shows the measured oscillation frequency and EIRP as a function of diode bias voltage. The breakdown voltage for this particular IMPATT diode is -52 V. A standard gain horn is used to measure the radiated power, and EIRP is calculated by

$$EIRP = \frac{P_{rec}}{G_{rec}}\left(\frac{\lambda_o}{4\pi R}\right)^{-2}$$

*where* $P_{rec}$ *is* the power received by the horn, $G_{rec}$ is the gain of the horn, and *R* is the separation distance between the horn and rectenna. Using an estimated gain of the horizontal dipole to be 6.5 dBi, the calculated dc to RF efficiency of the IMPATT diode is approximately 10/O. Measurements were also taken with the 165 Ω load removed, and no changes were observed in the oscillation frequency and output power.

The oscillation frequency is dependent on the diode structure and circuit impedance. Also, the IMPATT doping concentrations and layer thicknesses influence the dc to RF efficiency. IMPATT microwave oscillators are low impedance devices with typical diode impedances of- 1 Ω to -10 Ω [9], [10]. The impedance presented to the diode in this circuit is approximately 120 Ω which explains the low measured efficiency. Figure 4 shows the measured spectrum where the oscillation frequency occurs at 3.305 GHz. Sideband oscillations occurring at 560 MHz off the carrier frequency also occurred but were eliminated by slightly moving the output capacitor away from the IMPATT diode.

Pattern measurements were also taken of the oscillating rectenna as shown in Figures 5 and 6. E-plane and H-plane cross polarization levels are also shown. The sidelobe occurring in the E-plane pattern of Figure 5 is a result of the diffraction from the finite reflector plane (60 cm x 60 cm).

## IV. Conclusion

A microwave circuit that can either rectify or oscillate has been demonstrated. As a rectifier, the rectenna element had been previously tested with greater than 85°/0 RF to dc conversion efficiency. In this work, the same circuit has been shown to generate RF power at 3.3 GHz. Although the oscillating circuit has a low dc to RF conversion efficiency, circuit optimization is needed to improve its performance without altering the RF to dc efficiency.

## REFERENCES


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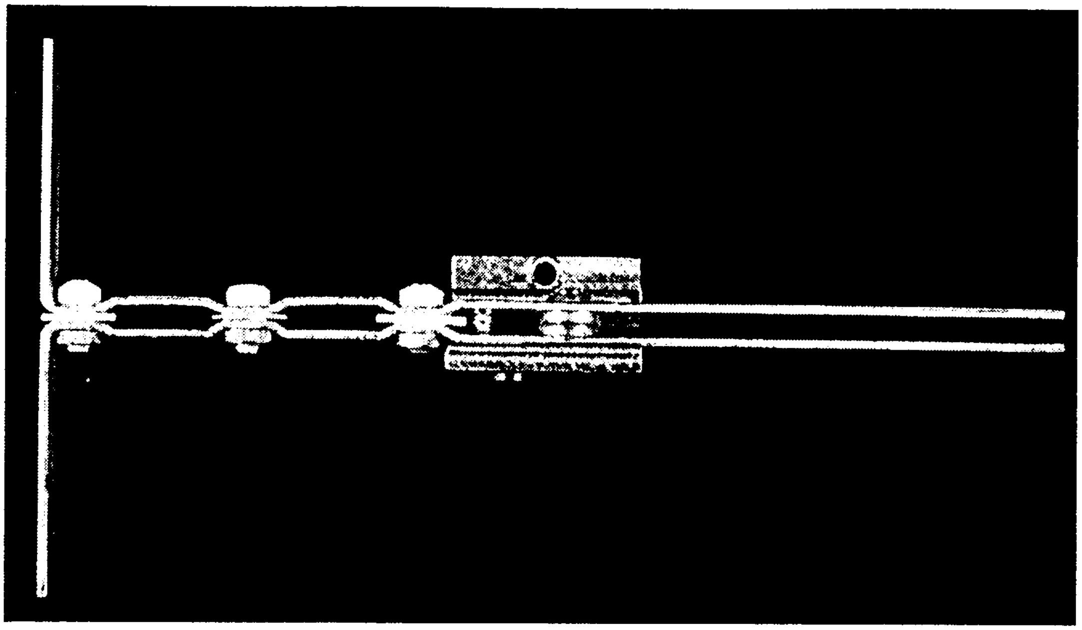

Fig 1. Photograph of rectenna element.

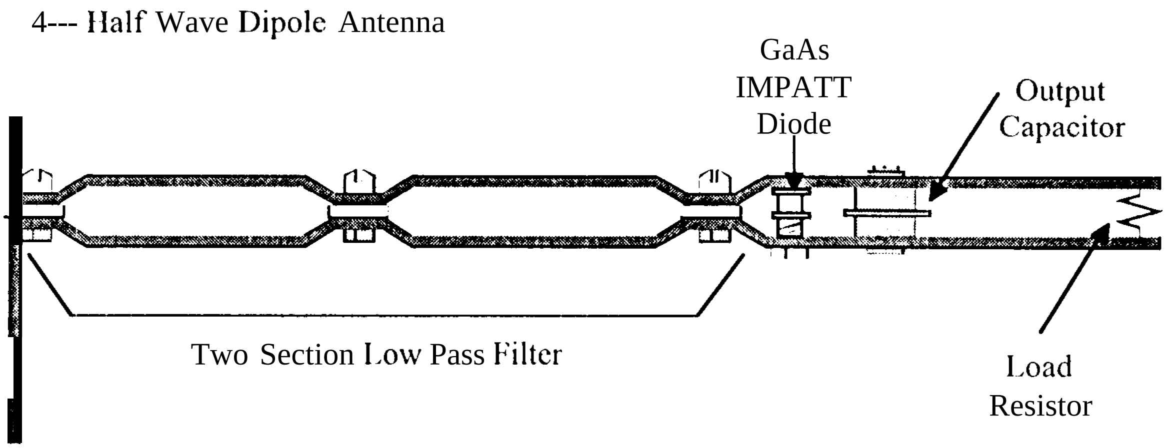


Fig 2.

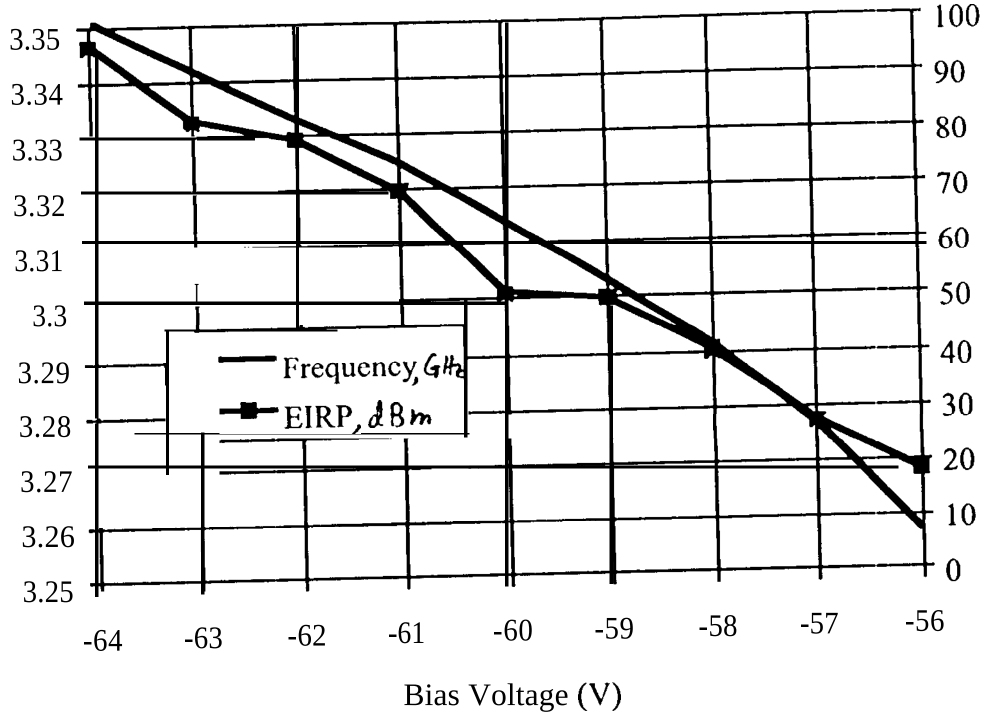


Fig 3. Oscillation frequency and EIRP vs. IMPATT bias voltage.

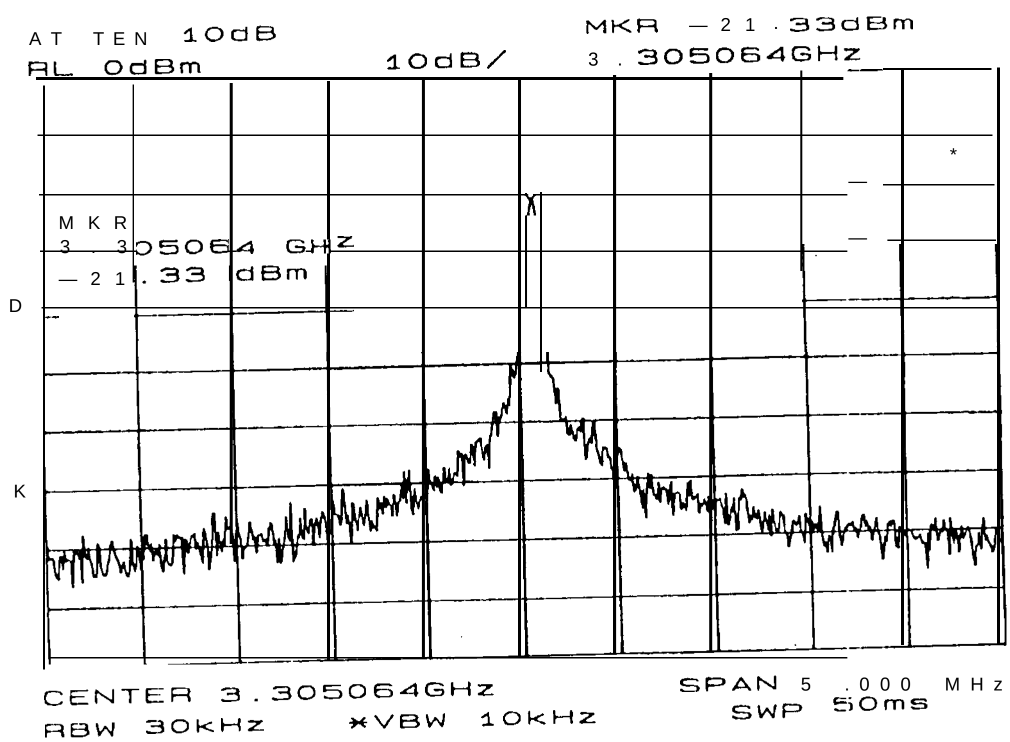


Fig 4. Measured spectrum of the oscillating rectenna.

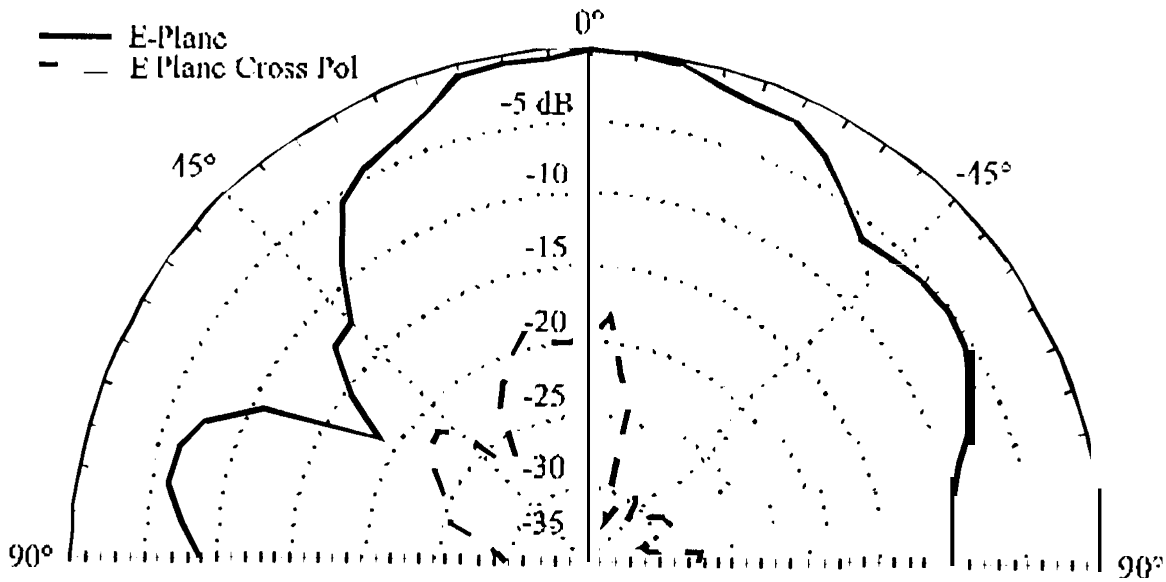


Fig 5. Measured E-plane and cross-pol patterns of the oscillating rectenna at 3.3 GHz.

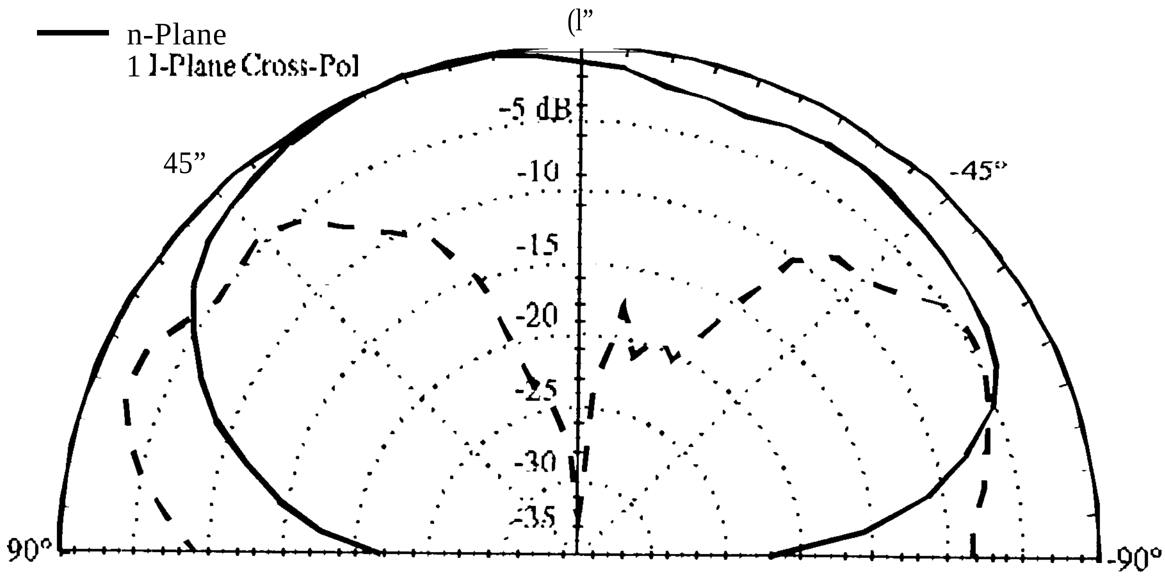


Fig 6. Measured H-plane and cross-pol patterns of the oscillating rectenna at 3.3 GHz.