RECENT PROGRESS IN POWER RECEPTION EFFICIENCY IN A FREE-SPACE MICROWAVE POWER TRANSMISSION SYSTEM

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Abstract

Recent improvements in rectifier devices in the form of specially designed GaAs Schottky-barrier diodes have been combined with rectifier circuit technology to produce receiving elements complete with low pass filtering at the microwave input and filtering at the output that operate in the 82-86 percent efficiency region. The combining of these elements in a rectenna array should produce an overall collection and rectification efficiency of over 80 percent.

Introduction

In a free-space microwave power transmission system, an efficient device for capturing and rectifying the microwave power at the receiving point is the "rectenna." In one form the rectenna[1, 2] consists of a large array of half-wave dipoles each terminated in its own rectifier. The outputs of the rectifiers can then be combined into one or several loads without loss of efficiency. Handling the reception and rectification problem in this manner eliminates a large number of problems associated with large receiving aperture in which the microwave energy is fed to a common terminal before rectification.

The capability of the rectenna to absorb the incident radiation approaches 100 percent efficiency so that the overall efficiency of the rectenna array is critically dependent upon the efficiency with which the received microwave power is converted into DC power within the rectenna element itself. The overall efficiencies which are now being obtained from these elements are in the 82-86 percent efficiency region. The rectenna element consists of a half wave dipole, a low-pass microwave filter to reject radiation of harmonic power in the input, one or more rectifying diodes, and a means of smoothing the output of the rectifier so that it appears as a pure DC voltage at the output of the device.

The basic rectifier circuit configuration in the rectenna element can take a variety of forms ranging from the two-diode full-wave rectifier, the four-diode bridge full-wave rectifier which has been the basis of most previous work, to the single-diode half-wave rectifier which is the principle subject matter of this paper. Currently the single-diode half-wave rectifier circuit is believed to represent the best compromise between efficiency, power handling capability, cost, and topological adaptation to printed circuit and strip line techniques which may be used in the future. This situation exists because of the availability of GaAs diodes which are capable of individually supplying from five to ten watts of DC power output when used in a rectenna element without auxiliary cooling, and considerably more with auxiliary cooling. For most rectenna applications five to ten watts of power output per rectenna element is adequate.

The losses in the rectenna element are made up of losses which occur within the diode itself and losses which occur within the rest of the circuit. The losses that occur within the diode are essentially those associated with the voltage drop of the Schottky barrier, and the series resistance of the diode. The series resistance of the diode is a source of loss in the conduction portion of the cycle and also in the non-conduction portion of the cycle because of the relative low reactance of the diode junction capacitance which allows displacement current to flow when the diode is reverse biased. A considerable reduction in the series resistance of the diode can be made by proper care in the design of the substrate and the active epitaxial region of the diode and in the contacts that are made to the diode. The series resistance associated with the GaAs substrate can be made minimal with a newly developed process called "PHS," for "plated heat sink." The substrate thickness may be reduced to 5-10 microns from the present 70 to 80 microns. The predominant losses are in the epitaxial region which can be made low in GaAs because of the very high mobility of this material. At the power levels of current interest, this low resistivity more than compensates for the forward conduction loss associated with the Schottky-barrier itself. In recently developed GaAs diodes these total losses are less than 8 percent.

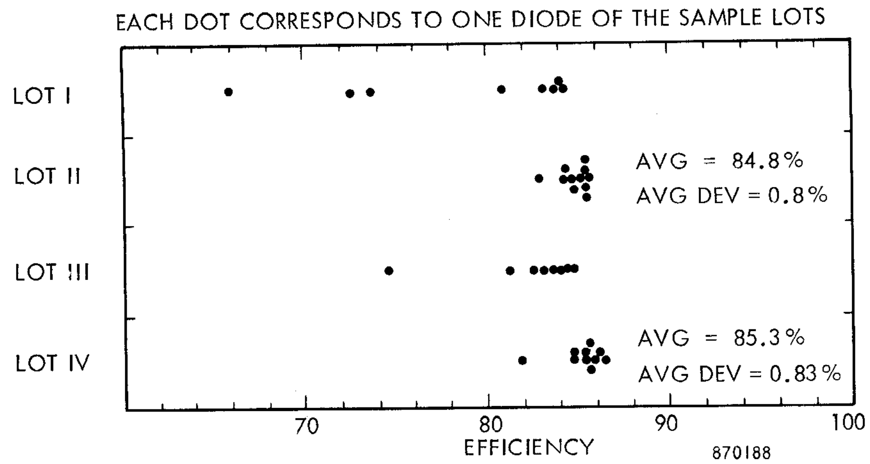
The other losses in the rectenna element are associated with the losses in the microwave input filter which are typically of the order of two or three percent, and in the rectifier circuit excluding the diode which represent an equal amount.

A plot of overall rectenna element efficiency for typical lots of flip chip diodes is shown in Figure 1. To obtain accurate test data on efficiency, rectenna elements are inserted into the end of an expanded section of waveguide which serves to approximate the cell area which the rectenna elements will occupy in the complete rectenna. (Figure 2)

References

1. W. C. Brown, "The Receiving Antenna and Microwave Power Rectification," J. Microwave Power, vol. 5, no. 4, pp. 279-292, 1970

2. W. C. Brown, "The Technology and Application of Free-Space Power Transmission by Microwave B ›m," Proceedings of the IEEE, Jan. 1974.



TEST CONDITIONS:

FREQUENCY = 2.45 GHz

RF INPUT = 4.6 WATTS

STANDARD RECTENNA ELEMENT WITH INPUT AND OUTPUT WAVE FILTERS
AUXILLIARY MATCH INSERTED TO ASSURE 4.6 WATTS ABSORBED BY
RECTENNA ELEMENT

Fig. 1. Overall rectenna element efficiency for sample lots of flip-chip diodes prepared in 1973.

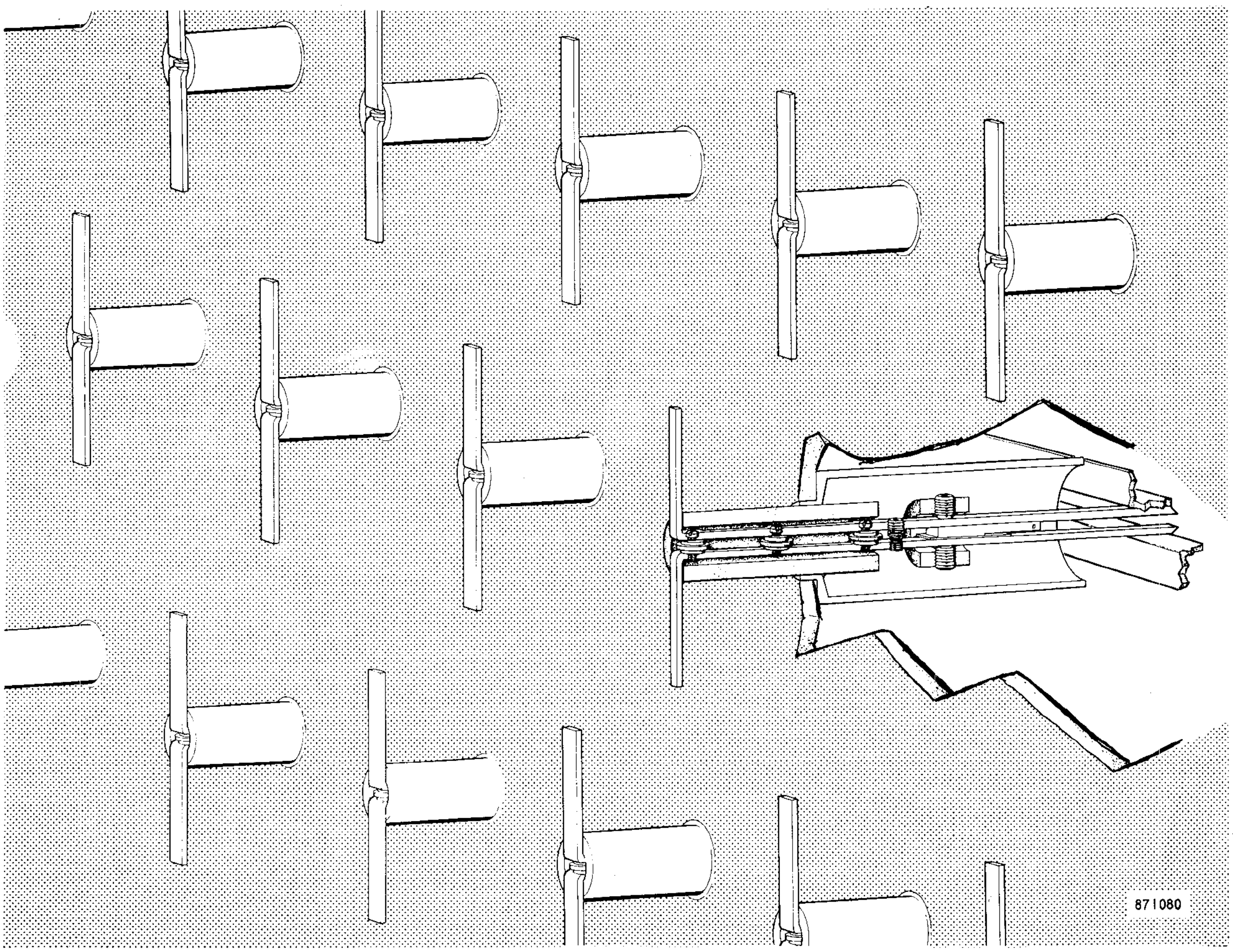


Fig. 2. Cutaway view of rectenna element showing its position in rectenna array. Each element consists of dipole, low pass input filter, Schottky barrier diode, and rectifying circuit. Power handling capability of each element is 5 to 10 watts.