10-4

A Circularly Polarized Active Antenna Array Using Miniature GaAs FET Amplifiers

H. C. Johnson, R. E. Marx, A. Sanchez and E. Mykietyn

RCA Laboratories
David Sarnoff Research Center
Princeton, NJ 08540

Abstract

An active antenna sub-array that inlcudes a miniature two-stage batch processable amplifier driving clusters of circularly polarized patch resonator antenna elements is described. The resulting lightweight, low profile structure provides an efficient source of radiated microwave power that can become the building block for a high power solid state transmitter array.

Introduction

A significant effort has been expended throughout the industry to develop power combining circuits that use hybrids, radial, or traveling wave circuitry. An active antenna array can efficiently produce high power microwave signals through the post radiation combining of a large number of amplifiers. It is the objective of all of these approaches to obtain the lowest loss circuitry. For all types of power combiners including the active antenna arrays, the effect on the overall efficiency of the input distribution circuitry losses can be reduced by using high gain amplifiers. However, the effects of the output combiner losses are fixed and must, therefore, be minimized. Placing high gain amplifiers in a transmitting antenna close to the radiating aperture so that each amplifier excites its own portion of the antenna results in virtual elimination of the combining losses. The resulting structure efficiently generates and transmits large rf powers using moderate power amplifiers that are performance optimized.

This paper describes a lightweight circularly polarized planar active antenna sub-array including a multi-stage amplifier constructed using batch processing techniques.

Multi-Stage Amplifier

A practical active antenna that generates high rf power requires a large number of efficient amplifiers that provide reproducible performance. A batch circuit fabrication technology that combines the reproducibility feature of monolithics with the power handling capability of hybrids has been developed[1]. This miniature beryllia circuit (MBC) technology which is ideal for the active array application results in a single substrate that includes all of the thin film lumped element matching circuitry for as many devices as requried. This technology also allows for the inclusion of discrete devices that meet minimum requirements based on dc probe tests.

The two-stage amplifier developed for the demonstration array is shown in Fig. 1. The circuit includes both a flip-chip and up-side-up mounted device. The number of device matching elements is intentionally kept to the minimum required for the desired bandwidth performance. This procedure reduces the circuit losses. The power output and efficiency vs. power input for this circuit is shown in Fig. 2 at the center of the operating frequency band of 12.45 GHz. The peak power added efficiency of 40% occurs for a device biasing condition that results in a strong current dependeance on the rf power input. This class AB or B operating mode, which has previously been reported[2], is determined by both the matching circuitry and bias condition. These conditions tend to limit the high performance bandwidth. Figure 3 shows the performance of this same circuit using different bias conditions. The power added efficiency has reduced to 35 ± 2% over a

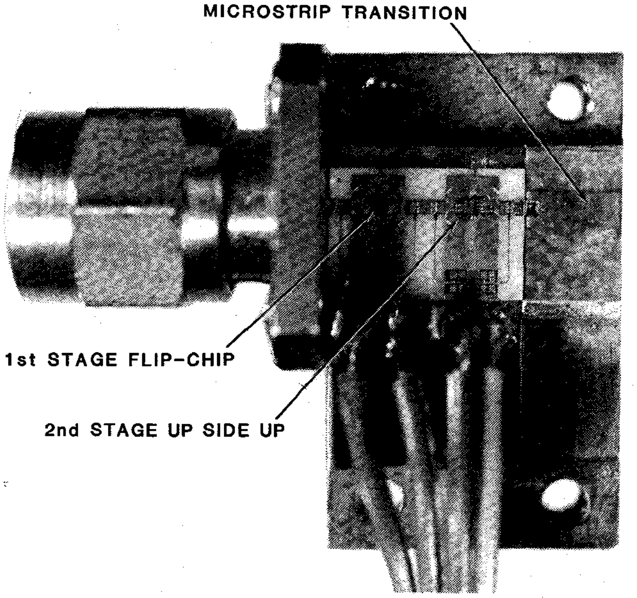

Figure 1. Two Stage MBC Amplifier.

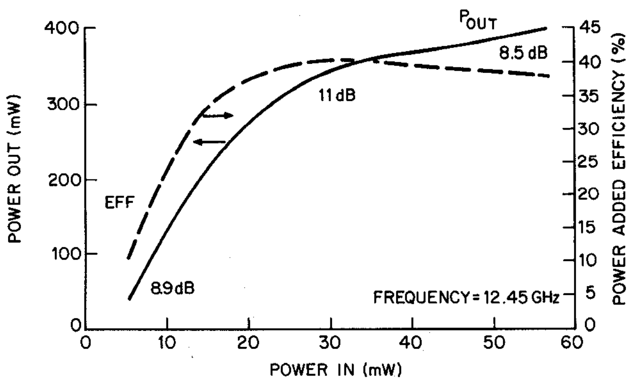

Figure 2. Two Stage MBC Amplifier Performance.
Tuned for Peak Efficiency

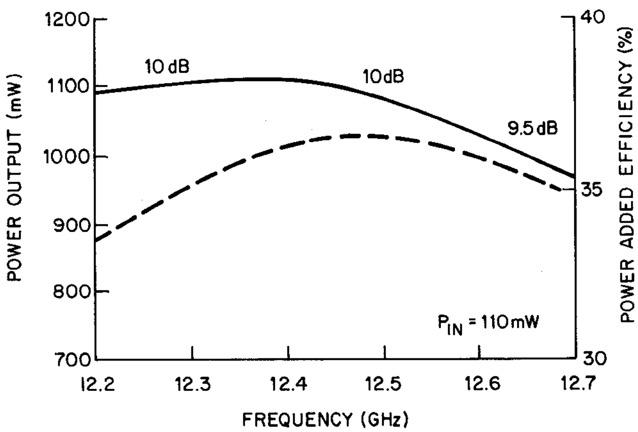

Figure 3. Two Stage MBC Amplifier.
Tuned for Full Band

500 MHz bandwidth for a constant input power level of 110 mW. A quarter wavelength section of 50 ohm line on Duroid substrate is placed at the output of the amplifier structure. This short length of Duroid line provides a graceful transition between the beryllia circuit and stripline distributor. The amplifier's output connector is removed for direct connection to the distributor.

Circularly Polarized Antenna

Circularly polarized (CP) antennas provide many advantages over linear polarization for communications systems that require mobility and weather penetration. They are not as adversely affected by the depolarization caused by rain and do not require careful angular orientation of the recieve antennas. Microstrip antennas are ideal for use in lightweight active antenna arrays due to their planar construction and ability to be divided into clusters for local illumination. The choice for the radiator geometry was limited to single feed patches with the feed located within the same plane as the radiator.

Various single feed element shapes were considered with the most promising results obtained from a corner fed rectangular patch. The two different dimensions of the rectangle provide two orthogonal linearly polarized electromagnetic fields that resonate at two distinct frequencies. The separation is, to the first order, proportional to the dimensional differences. Operating between the two resonances produces a phase offset of 90 degrees between the two orthogonal linearly polarized fields.

A four element array with a corporate feed fabricated on Duroid is used as a cluster of the 4x4 array as shown in Fig. 4a. Duroid material was selected for this demonstration array antenna mainly on the basis of it's dimensional stability. Another lighter weight, lower loss material that is difficult to use in small quantities has been successfully included in linearly polarized arrays[3] and will be used in a future circularly polarized model. The match and polarization purity of the Duroid 2x2 cluster over the 12.2 to 12.7 GHz band is shown in Fig. 5. The cluster is fed from below through a 50 ohm coaxial rf connection. A peak purity of 32 dB and minimum purity across the 500 MHz band of 15 dB was measured.

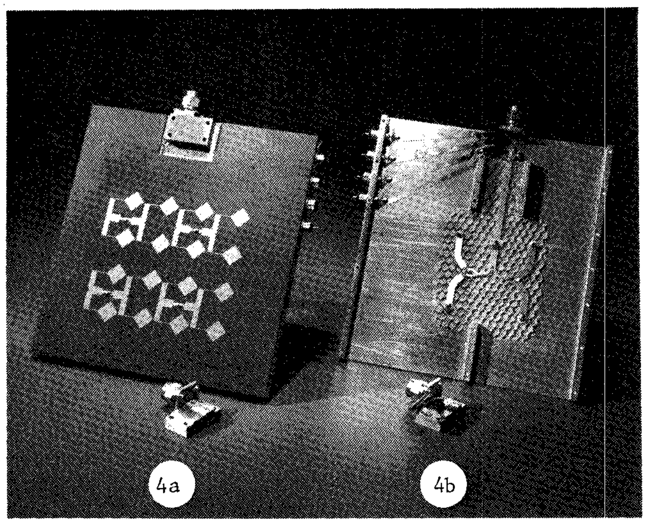

Figure 4(a and b). Active Antenna Sub Array.

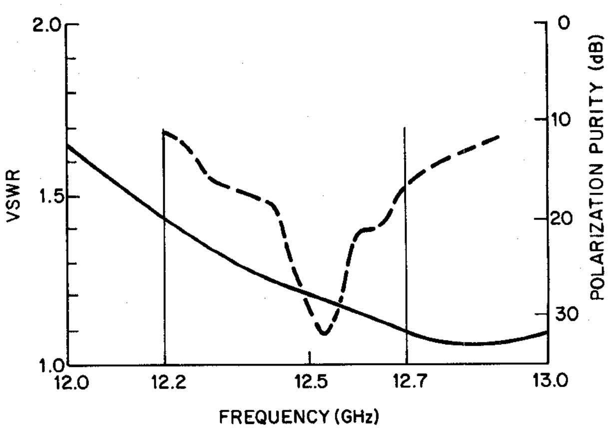

Figure 5. Duroid 2x2 Element Antenna.

Active Antenna Sub-Array

The active antenna sub-array combines the two-stage MBC amplifier with four of the corporate fed 2x2 element clusters to form the 4x4 element active sub-array as shown in figure 4. The structure is designed to use lightweight materials that also contribute to the mechanical rigidity. The sub-array consists of a total of five layers for a combined final thickness of 0.7 cm.

The four, four-element antenna clusters are each fed from the underlying rf distribution network through four short sections of coaxial lines that pass through the antenna ground plane. The one-to-four rf stripline distribution network (Fig. 4b) is mounted on a low loss, low dielectric material. The power split is accomplished in two stages. The first split from the amplifier is reactive, proceeding from one 50 ohm to two 100 ohm lines. The second split uses Wilkinson dividers that transform into 50 ohm feeds for each antenna cluster. This technique improves the match of each feed to a 1.4:1 VSWR while presenting a 1.2:1 VSWR to the amplifier. The antenna structure can be tested using either a 50 ohm feed or the demountable amplifier both shown in figure 4. Bias to the amplifier is supplied through conductors that are etched from metallized mylar film. A total of four bias lines are required: two for gate biasing and two for drain biasing.

The input match of the amplifier when driving the antenna and the polarization purity of the 4x4 element array are shown in figure 6. A peak polarization purity of 35 dB corresponding to an axial ratio of 0.13 dB occurs at 12.8 GHz. An antenna pattern measured at this frequency is shown in figure 7. The data for this curve is obtained by axially rotating a linearly polarized antenna that transmits energy to the sub-array antenna which is slowly rotating in the azmuthal plane. The 3 dB beamwidth of 19 degrees and average side lobe level of 12.5 dB for this unfformly illuminated array agree closely to the theoretical values.

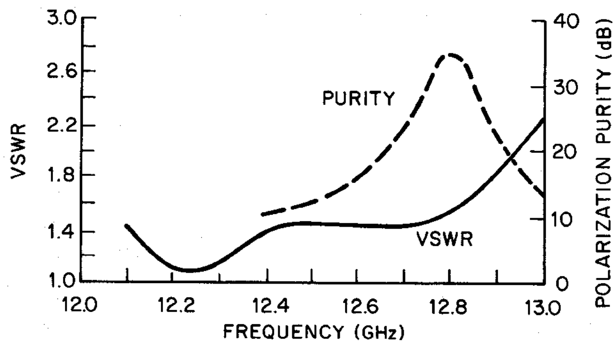

Figure 6. 4x4 Antenna Array.

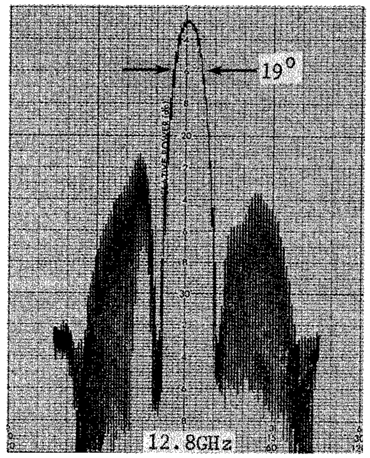

Figure 7. Antenna Pattern.

Conclusion

Active antenna arrays can be used to efficiently generate high rf powers for communications and radar systems applications. The realization of practical active arrays requires the inexpensive batch fabrication of large numbers of efficient multi-stage amplifiers. Amplifiers fabricated using the MBC technology were combined with a circularly polarized antenna array in a lightweight active sub-array structure. Full arrays of this type are expected to find use in many communications and radar systems applications that require mobility, efficiency and light weight.

Acknowledgements

The authors are indebted to L. Mackey for his skillful assembly and test work and to E. Belohoubek for the many useful discussions.

References

1. F. N. Sechi, R. Brown, H. Johnson, E. Belohoubek, E. Mykietyn, and M. Oz, "Miniature Beryllia Circuits - A New Technology for Microwave Power Amplifiers," RCA Review, Vol. 43, pp. 363-374, 1982.
2. M. Cohn, et al, "Class B. Openation of Microwave FETs for Array Module Applications," 1982 IEEE MTT-S Symposium Digest, pp. 169-171.
3. H. C. Johnson, M. Oz, R. E. Marx, J. Rosen, and E. Mykietyn, "A Lightweight Active Antenna Array Using Miniature Beryllia Amplifiers," 1983 IEEE MTT-S Symposium Digest, pp. 477-478.