A CONTINUOUSLY VARIABLE KU-BAND PHASE/AMPLITUDE CONTROL MODULE

by

Yehoshua Gazit and Henry C. Johnson
RCA Laboratories
Microwave Technology Center
Princeton, NJ 08540

ABSTRACT

A Ku-band microstrip phase shifter capable of continuous phase and amplitude control is described. Three dual-gate FET amplifiers provide variable amplitude vectors that are separated by 120° and summed through an arrangement of quadrature couplers. The described phase shifter provides a full 360° shift with an amplitude weighting capability of more than 20 dB.

Introduction

There is an increasing number of electronic warfare applications for adaptive phased arrays having tight illumination tolerances for both shaped and low side lobe beams. Continuous phase and amplitude control capability can reduce the individual circuit tolerance requirements by providing in situ circuit trimming through the use of automated near field measurements. Continuous phase shifters using dual-gate FET amplifiers [1] or variable PIN attenuators [2] for vector amplitude control have been described in the literature [3].

Each of these approaches requires four or more active devices with their associated circuitry. A potentially compact phase/amplitude control module using only three active devices is described.

Circuit Description

In previously reported continuously variable phase shifters the full 360° shift has been obtained by vector manipulation of four vectors with the vector angular separation being derived from mixers or quadrature couplers. Here we present a phase shifter using only three vectors, with the advantages of lower parts count and ultimately smaller size and lower cost. Figure 1 shows the respective vector amplitudes for the three vector case necessary to obtain any desired resultant phase with constant amplitude. The 120° vector separation can be achieved by adding 30° transmission line lengths to the quadrature coupler outputs as shown in Fig. 2.

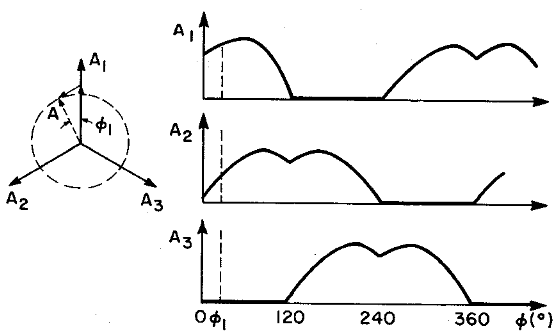

Fig. 1. Three vector phase and amplitude control diagram.

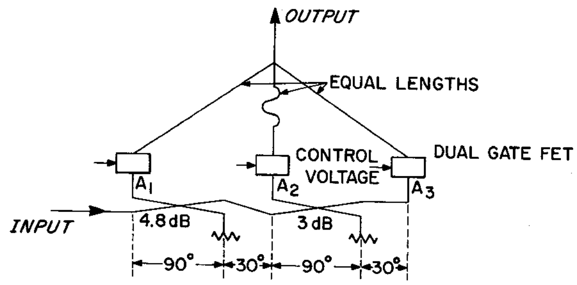

Fig. 2. Phase shifter using in-phase direct combiner.

The vector amplitudes are controlled by the variable gain amplifiers whose outputs are in-phase combined. Direct drain combining of the three dual-gate amplifiers has the advantage of making the entire unit very compact. Preliminary computer simulation showed the feasibility of this approach.

For the first experimental unit we selected the symmetrical circuit configuration as shown in Fig. 3.

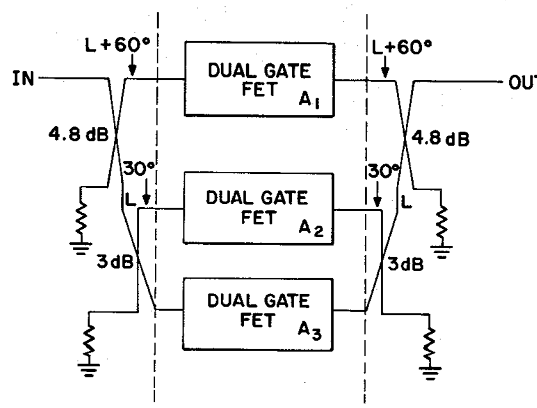

Fig. 3. Continuous phase and amplitude control.

In this arrangement, the power from the direct port of a 4.8 dB quadrature coupler is further divided by a 3 dB quadrature coupler [4,5] to provide the three equal power inputs to the amplifiers. The interconnecting line lengths are chosen to provide 60° output separation. Each of the three transmission paths includes the same number of right angle bends to help

0149-645X/81/0000-0436$00.75

maintain phase tracking. A mirror image of the coupler assembly is used for amplifier output combining and to add the additional 60° separations for the 0, 120° and 240° vectors. The coupler assembly provides only 0.3 dB coupling variation and 3.5° phase tracking error between all three ports from 16 to 16.5 GHz.

A dual-gate FET amplifier was designed around the nominal S-parameters of the NEC 46300 device. Numerous devices were characterized and a design tolerant to typical parameter spreads was developed. This approach results in very consistent unit-to-unit performance. Typical gains for six constructed amplifiers are 10 dB with variations of less than ±0.5 dB over the 15.8 to 16.7 GHz band. This performance is obtained without individual circuit tuning. Each amplifier has a noise figure of approximately 6 dB and provides greater than 30 dB gain adjustment as shown in Fig. 4.

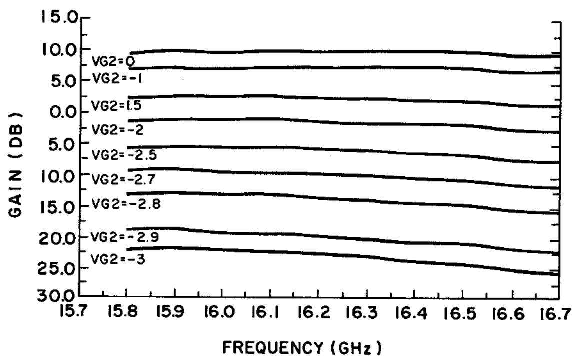

Fig. 4. Ku-band Dual-Gate FET gain control characteristics.

Experimental Results

The phase/amplitude control module consists of two dual-coupler assemblies and three dual-gate FET amplifiers as shown in Fig. 5. Phase tuning as a function of the amplifier second-gate gain control voltages (V_{G2}) is shown in Fig. 6.

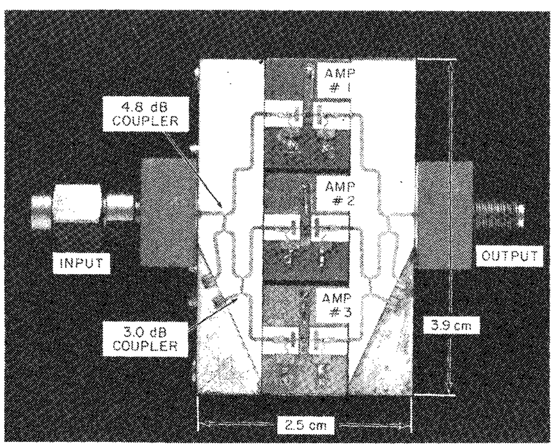

Fig. 5. Photograph of the continuous phase shifter.

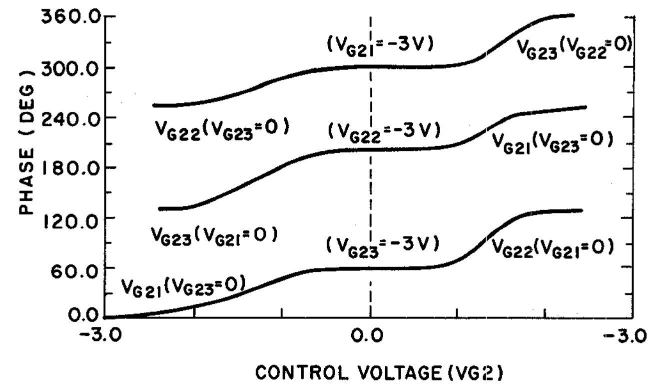

Fig. 6. Phase vs. control voltage of the phase shifter.

Here one gate voltage is kept at 0 V, one at -3 V, while the third one is varied between 0 to -3 V to cover in each case approximately 60° phase shift. Under these conditions the amplitude varies by about 7.5 dB over the full tuning range from 0° to 360°. Control voltage functions were developed and used to demonstrate constant amplitudes over the full 360° phase shift. Two of the three gates are controlled to attain any desired phase and amplitude while the third gate is set for minimum gain. Any constant insertion loss from 6 to greater than 28 dB can be achieved for all phases. The minimum 1 dB and 3 dB bandwidths for all phases is 125 and 450 MHz respectively. The output phase for all phase settings is maintained within 7° over a 200 MHz band. The noise figure varies as expected with insertion loss and ranges from 14 dB at 6 dB loss to 25 dB at 22 dB loss. These numbers include the 4.8 dB input coupling losses.

Conclusion

A breadboard Ku-band module having continuous 0 to 360° phase and -6 to -28 dB gain control was demonstrated. The module uses only three RF devices that can be controlled by D/A converters that determine the gains of the three dual-gate FET amplifiers. This approach when realized in hybrid integrated circuitry with direct device drain combining will result in an extremely compact phase/amplitude control module with very low parts count suitable for a variety of adaptive phased array applications.

Acknowledgment

The authors wish to thank Dr. Erwin Belohoubek for his many contributions to this work including the three amplifier phase shifter approach, Richard Brown for his circuit processing expertise, and Edward Mykietyn and Paul Czajkowski for their skilled circuit assembly.

References

1. C. A. Liechti, "Performance of Dual-Gate GaAs MESFET's As Gain Controlled Low-Noise Amplifiers and High-Speed Modulators," IEEE Tran. MTT, Vol. 23 No. 6, June 1975, pp. 461-469.

2. W. J. Parris, "PIN Variable Attenuator With Low Phase Shift," IEEE Trans. MTT Vol. 20, 1972, pp. 618-619.

3. M. J. Fitnian, "Two Microwave Complex Weighting Circuits," International Microwave Symposium, May 1980.

4. J. Lange, "Interdigitated Stripline Quadrature Hybrid," IEEE Tran. MTT, Vol. 17, Dec. 1969, pp. 1150-1151.

5. D. D. Paolino, "Design More Accurate Interdigitated Couplers," Microwaves, May 1976, pp. 34-38.