C-BAND ANALOG MONOLITHIC VECTOR MODULATOR

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Abstract

A novel circuit structure for a MMIC C-Band analog vector modulator is described. It provides full 360 degree phase coverage with 50 dB amplitude range over an octave band. The MMIC die size is 70 x 70 mil.

Introduction

Vector modulators are circuits that provide both amplitude and phase control simultaneously. By holding the phase constant the amplitude can be varied to form an attenuator function. Also, by holding the amplitude constant the phase can be varied to form a phase shifter function. This combination of functionality makes the vector modulator very useful in a multitude of applications. Phased array antenna systems use amplitude and phase control on the radiating elements to provide beam steering. Vector modulators are commonly used in null steered arrays to provide isolation from jammers. Other applications include adaptive filters and M-ary modulators.

In the past, several approaches have been demonstrated. In 1983 E. Strid [1] developed the tapped delay line vector modulator. During the late 1980's several designers [2,3] used multi-order allpass networks with variable gain amplifiers to control quadrature vectors. In 1987, J. Selin [4] achieved great performance using four fixed phase shifters and variable amplifiers arranged between two four way power dividers.

The new implementation here is based upon and improved over a patent developed at ECI in 1992 by S. Bingham[5,6]. It consists of two artificial transmission lines that are connected by four cascode MESFET's. The MESFET's provide independently controllable amplitude vectors that are separated by 90 degrees. Different attenuation and phase levels are produced by controlling the amplitudes of two quadrature vectors. This new vector modulator includes balancing resistors for flat phase variation versus frequency.

Circuit Operation

The vector modulator can be understood simply by realizing that its function is to vary (or modulate) the amplitude and/or phase of a vector (in this case it is a C-band RF signal). The input RF signal is split off the low pass input filter via cascode connected MESFET's to the highpass output filter (see Fig. 1). The cascode MESFET's are used as variable gain amplifiers. The lowpass and highpass filters in combination with these cascode MESFET's produces four orthogonal vectors: 0,90,180, and 270 degrees. Each vector comes from one of the four cascodes. Each of the cascodes can be pinched off (max. loss condition) to turn the vector off. By turning on all the vectors the output RF signal would be canceled at the output. However, by turning on only two vectors, a signal is produced that is a vector sum. If the amplitude of one of these vectors is varied while the other is constant, then the resultant sum vector will have a different phase. By using any two of the four vectors at a time, the phase can varied from 0 to 360 degrees. Amplitude can also be changed by varying both vectors at the same time.

Circuit Design

The MMIC vector modulator was developed via the Triquint GaAs 0.5 um HA process. This is shown Figure 2. Circuit modeling was accomplished through the use of the HP MDS software utilizing the Triquint foundry library and measured data. Most of the modeling effort was concentrated upon the spiral inductors and the cascode connected MESFET's. The spiral inductors were kept to the minimal number of turns to maintain the largest Q. The cascode connected MESFET's were constructed

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from two 0.5 μm devices with 300 μm gate width. An RF shorting capacitor was used for the second gate termination to maximize the amplitude range while keeping the device stable. On chip Sample/Hold circuits provide simplified vector control. Off chip capacitors are required to insure stability as well as bias decoupling. Seven 18 pF single layer capacitors were required. Each capacitor is 15 x 15 mil and integrates directly into a MMIC package.

Measured Performance

The measured phase variation vs frequency for the uncompensated MMIC vector modulator is shown in Figure 3. The eight curves display each of the four independent vector phases as well as the four combinations. This vector modulator is uncompensated in the sense that no D/A circuitry was used. However, by controlling the voltages with a PROM and D/A, the phase may be set to within a few degrees at any frequency in the band. An example of this for one frequency is shown in Figure 4. Each point on the polar chart is either a single vector or a combination of two vectors. Orthogonality is well maintained. Accurate phase and amplitude control is possible via the large amplitude variation that is obtained from the cascode MESFET's. The measured data of Figure 5 shows a 50 dB attenuation characteristic. This data was taken by varying the second gate voltage of one of the cascode parts while in the vector modulator. The input return loss across the band is better than 15 dB. The output return loss across the band is better than 10 dB. Gain with any two vectors averaged 3.5 dB.

Conclusion

A novel C band vector modulator was developed. It combines the features of small size and broadband phase and amplitude control to provide an alternative to hybrid technology for phased array antenna systems. It also opens the door to applications involving null-steered arrays, adaptive filters, and advanced modulations schemes.

References

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[5] Steven D. Bingham, 'Broadband Phase Shifter and Vector Modulator,' U.S. Patent 5,168,250, Dec. 1992.

[6] Steven Bingham and Bob Krause, "Broadband 1.5GHz Analog Monolithic Vector Modulator," 1992 IEEE GaAs IC Symposium, pp. 33-36.

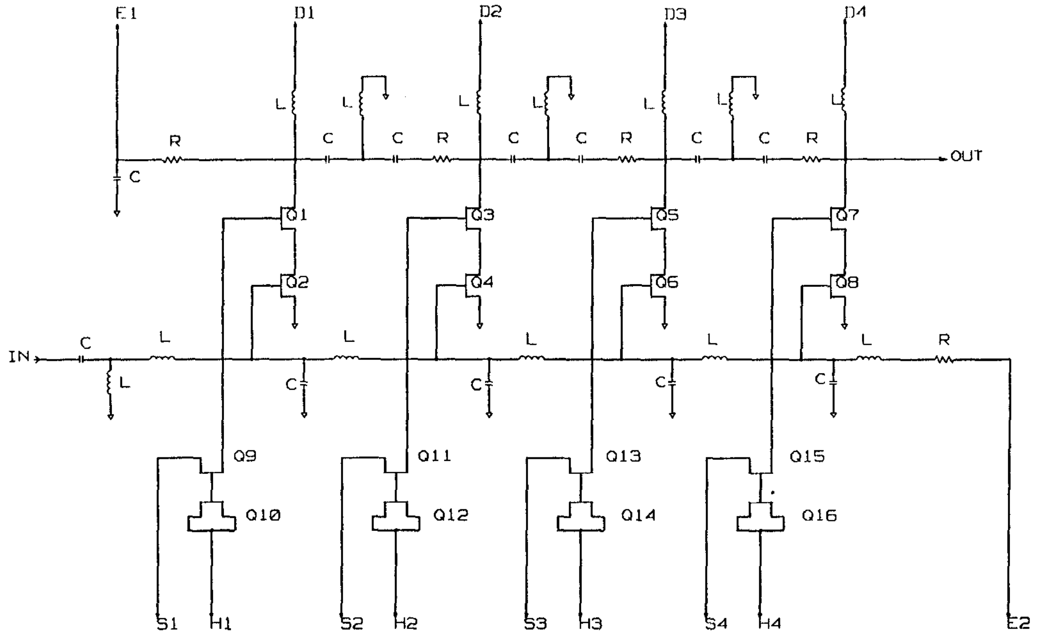

Figure 1: Circuit Schematic

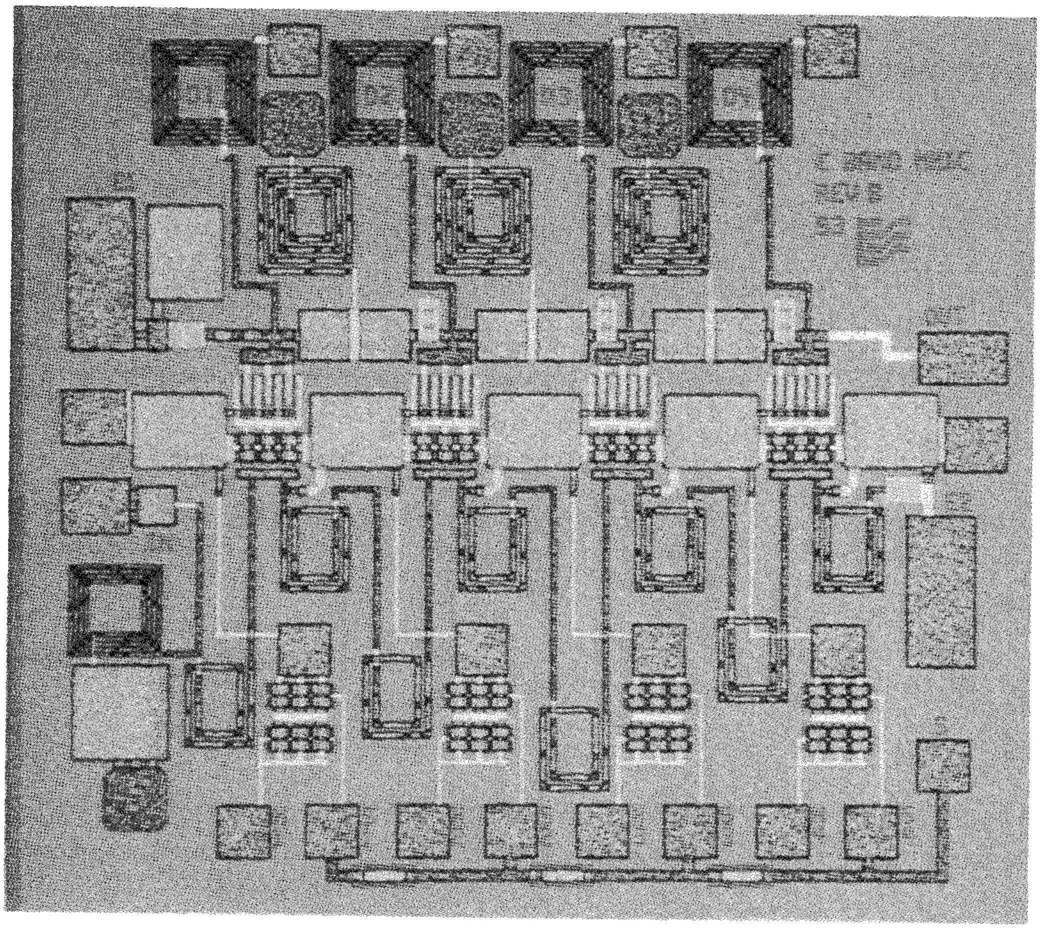

Figure 2: C-Band Vector Modulator MMIC Chip (70 x 70 mil)

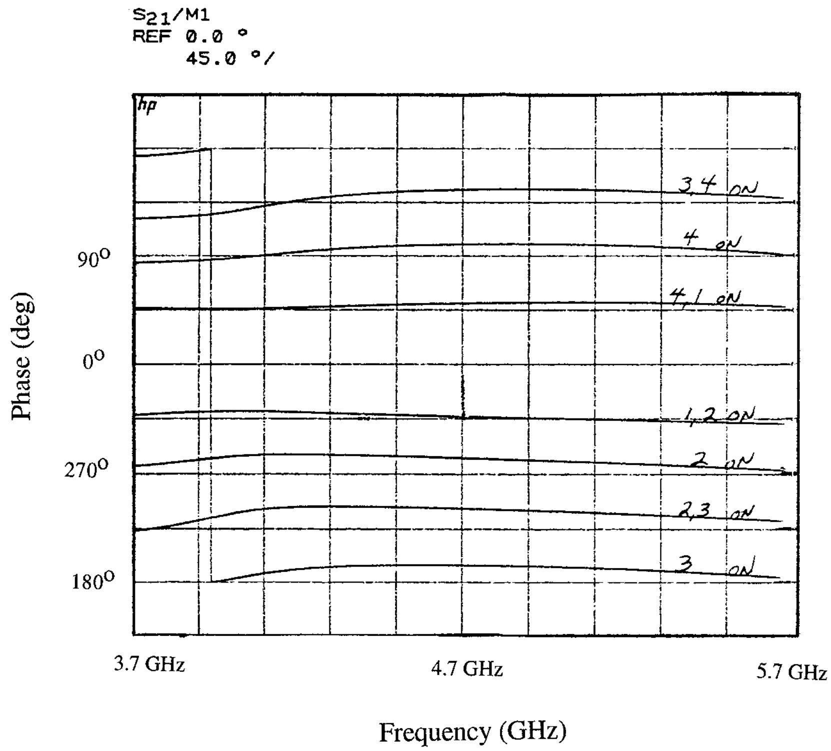

Figure 3: Measured Phase vs Frequency (four uncorrected quadrature vectors and combinations)

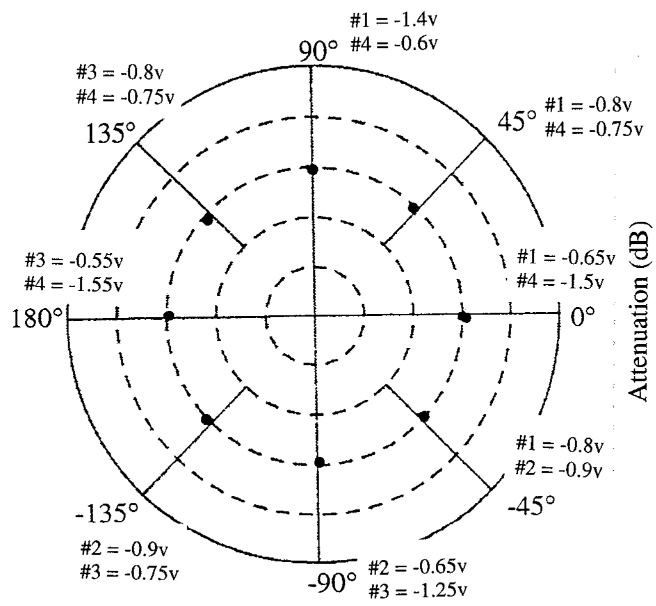

Figure 4: Measured Phase Vectors a 5 GHz (corrected)

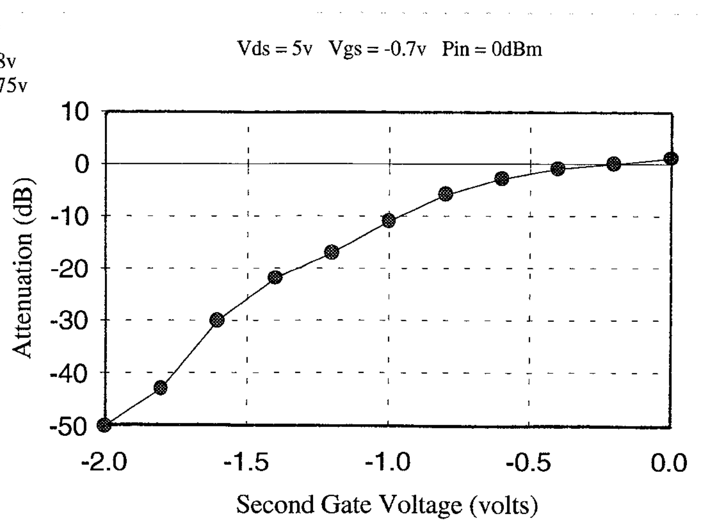

Figure 5: Measured Attenuation vs Second Gate Voltage