AN OCTAVE BAND GaAs ANALOG PHASE SHIFTER

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ABSTRACT

A GaAs variable gain analog phase shifter, which operates with high phase and amplitude resolution over an octave band has been demonstrated. The phase shifter, which consists of three GaAs MMIC chips in a hybrid package, exhibits greater than 10db gain and 100mW output power from 400MHz to 1400 MHz, with a phase/amplitude settling time of less than 100 nS. This paper addresses the design of the three MMIC chips contained in the module, and the performance of the module itself.

INTRODUCTION

Approaches to analog phase shifters abound in the literature. In making the transition from hybrid to monolithic integration at L-band however, existing circuits suffer from a number of disadvantages. First, most approaches require the use of 3 dB hybrids, which are too large to be fabricated in monolithic form at L-band. Approaches using lumped elements to approximate 3 dB hybrids invariably suffer from excessive loss, and narrow band performance. Approaches using high pass-low pass filters to provide a 90° phase split have been fabricated for S-band applications (1), but require large inductance values at UHF and L-band which consume valuable GaAs real estate. In addition, such circuits have not demonstrated an ability to cover the greater-than-octave bandwidths required by current programs.

The module discussed in this paper makes use of very wide-band MMIC phase shifters and amplifiers. The phase shifter chip is based on parallel all-pass networks, to enable octave band performance. The amplifier chips use feedback, and other special techniques to realize not only a wide bandwidth, but a wide attenuation range without a large phase shift with attenuation.

THE ALL-PASS ANALOG PHASE SHIFTER CHIP

The principles behind all-pass networks in forming phase splitting circuits are well known (2,3,4). Briefly, an ideal first order all-pass network (Figure 1) will shift an input signal in

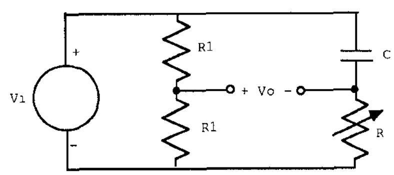

Figure 1 First Order All-Pass

phase from 0° to 180° as the frequency increases to infinity, while the amplitude of the signal remains constant. The rate at which the phase increases from 0° to 180° depends entirely on the values of R and C in the figure, but the amplitude remains unaffected. Therefore, an equal amplitude phase split may be realized by incorporating two all-pass networks in a circuit. In realizing the phase shifter chip, a differential amplifier was designed to a) take the difference voltage between the two output nodes of figure 1, and b) form two output voltages 180° out of phase with each other. By using parallel all-pass networks, and two differential amplifiers, a four quadrant phase split network was formed (figure 2).

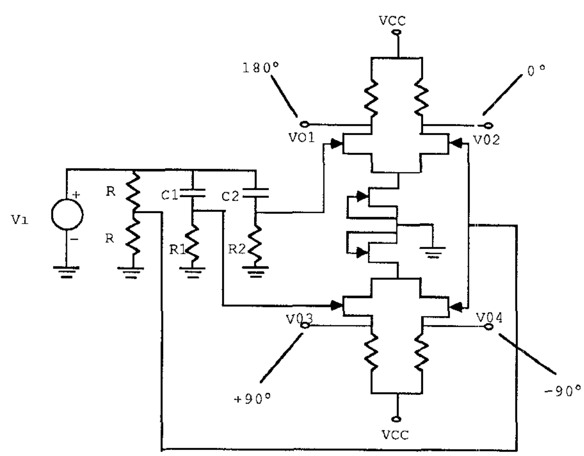

Figure 2 Formation of Quadrature Channels Using All-Pass Networks, and Differential Amplifiers

The addition of attenuating amplifiers (dual gate FETs) at each of the four outputs, allows each of the four vectors to be independently controlled. By subsequently combining the four channels, and continuously varying the second gate voltage on each of the four channels, a 0°-360° analog phase shift capability results.
Figure 3 shows the full schematic of the chip. A photograph of the chip is shown in figure 4. The chip size is 2500 microns X 2500 microns.

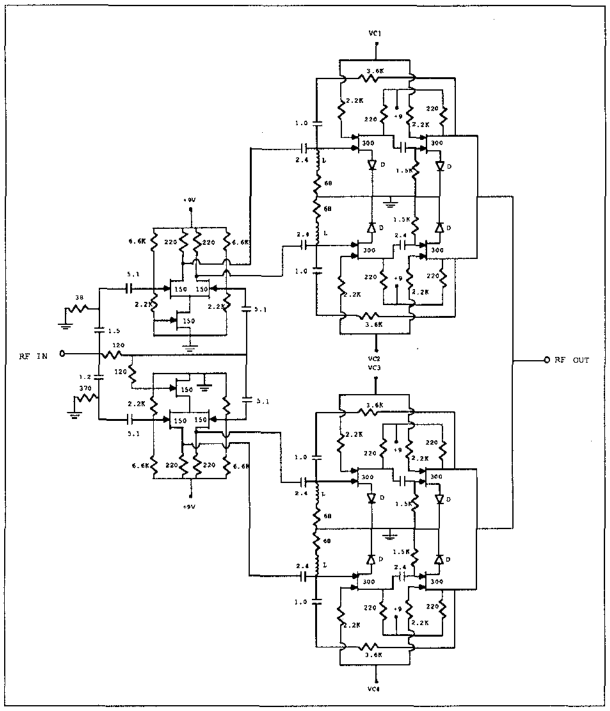

Figure 3 Schematic of Phase Shifter Chip

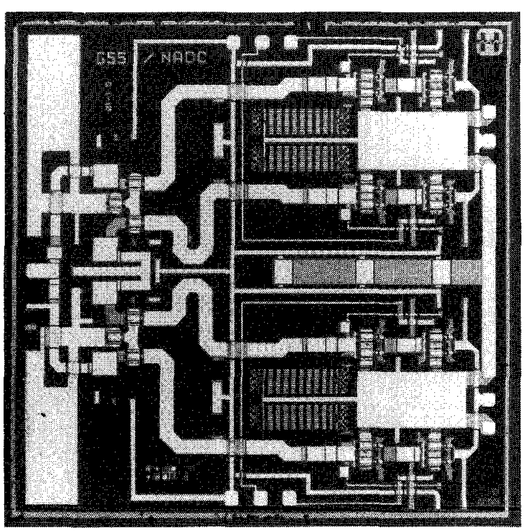

Figure 4 Photograph of Phase Shifter Chip

THE WIDEBAND FEEDBACK AMPLIFIER CHIP

This chip was developed independently as a general purpose cascadable gain block for use in MMIC subsystems.The design goals of broad bandwidth and high yield were obtained by utilizing feedback for both gain flatness and matching. Although a significant amount of available gain is sacrificed to accomplish this, the consistent high level of performance which results makes this approach quite viable. Employing two 600um gate perifery gain stages, this chip provides nominally 10.5dB gain across the 300 MHz to 5GHz frequency band. A schematic of this chip is shown in figure 5 and a photograph is shown in figure 6.

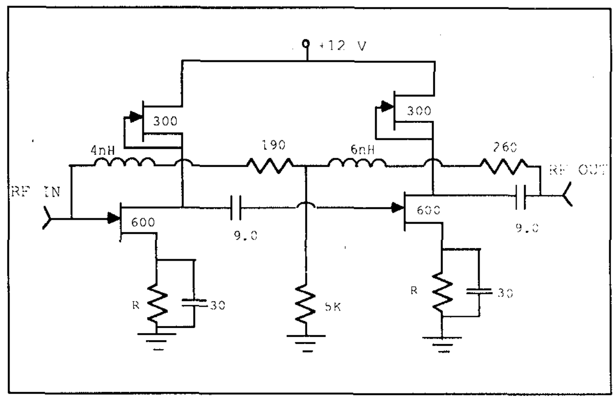

Figure 5 Schematic of Wideband Feedback Amplifier

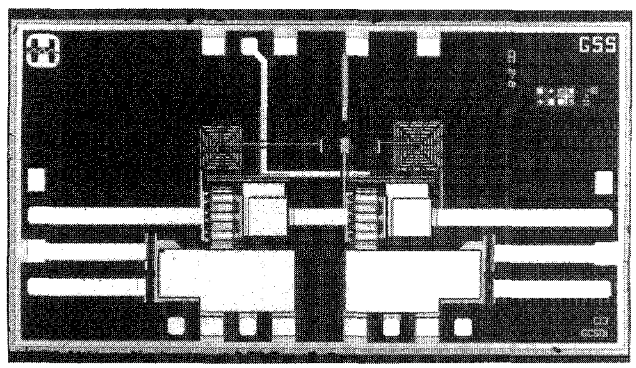

Figure 6 Photograph of Feedback Amplifier Chip

THE VARIABLE GAIN AMPLIFIER CHIP

Providing the bulk gain of the phase shifter module, the variable gain amplifier also provides amplitude control independant of phase setting. The variable gain portion of this chip consists of two dual gate FET amplifier stages as shown schematically in figure 7. Feedforward circuitry is utilized to compensate for the phase shift accompanying attenuation of dual gate FETs, resulting in less than 10 degrees phase shift over a 30 dB control range. The latter two stages of the amplifier consist of increasing gate perifery FETs to provide the desired power output. Nestled about the circuit and integrated into the bias arrangement are various lossy matching and feedback elements to provide broadband flat gain and excellent match. As with the wideband amplifier discussed previously, this approach provides the consistent performance and high yield required for production MMIC systems at the cost of some available gain. A photograph of the chip is provided in figure 8.

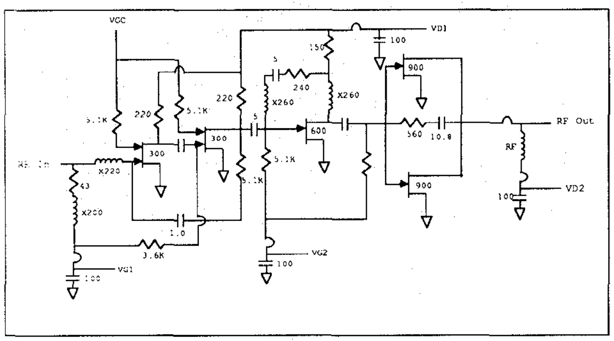

Figure 7 Schematic of Variable Gain Amplifier Chip

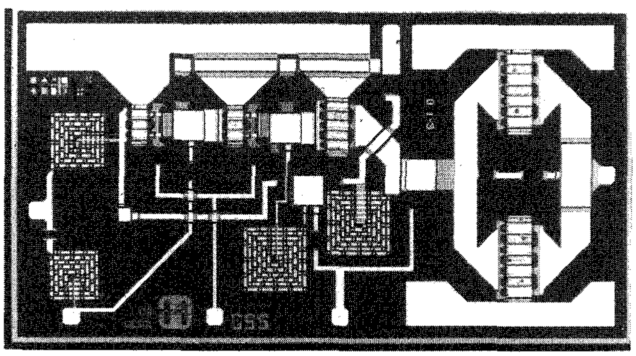
Figure 8 Photograph of Variable Gain Amplifier Chip

CHIP AND MODULE FABRICATION

The chips described above were fabricated at Harris Microwave Semiconductor in October 1986, using their standard Digi-1, one micron ion implant process. The three chips were then packaged in leadless chip carriers, and epoxied to the base of the module. A substrate of Duroid™ e-10 soft dielectric was used to provide the DC and RF connections from chip to chip, and from chip to module inputs and outputs. A photograph of the module with the lid removed is shown in figure 9. The module dimensions are 1.75" X 1.5" X .5".

TEST RESULTS

The phase shifter modules were subjected to a number of performance tests. The test results associated with

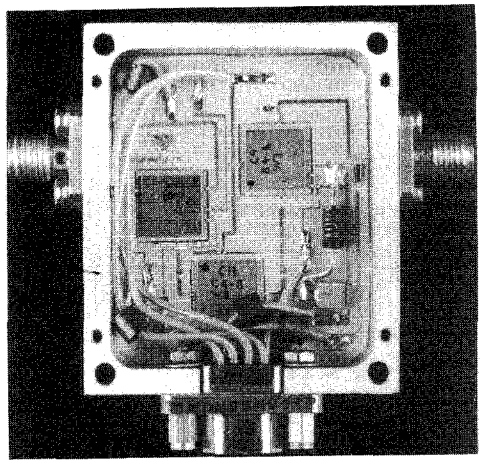
Figure 9 Photograph of One of Ten Delivered Modules

the following module characteristics are presented in this section:

1. Frequency response.
2. Phase shift control range.
3. Gain control range.
4. Output power.
5. Input/Output VSWR.
6. Response time.

The frequency response of the phase shifter module at +10 dB gain, and -10 dB gain, and at a number of phase settings is demonstrated by the family of $|S_{21}|$ curves shown in Figure 10. The broadband gain in this figure is shown at each value of gain for 8 phase states in 45° increments.

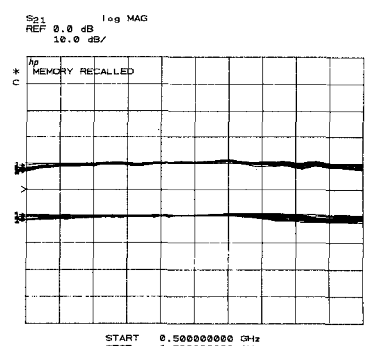

Figure 10 Gain of Phase Shifter Module at 8 Phase and 2 Amplitude Settings.

Figure 11 shows the phase shift capability of the module at a) 600 MHz, b) 1000 MHz, and c) 1400 MHz. Each phase plot was produced at 10dB gain over a 20 MHz instantaneous band. Similar measurements were made at -10dB gain. Although the phase shown is in 10° increments, phase resolution was <.5°, limited only by the resolution of the controlling Digital to Analog Converter (DAC).

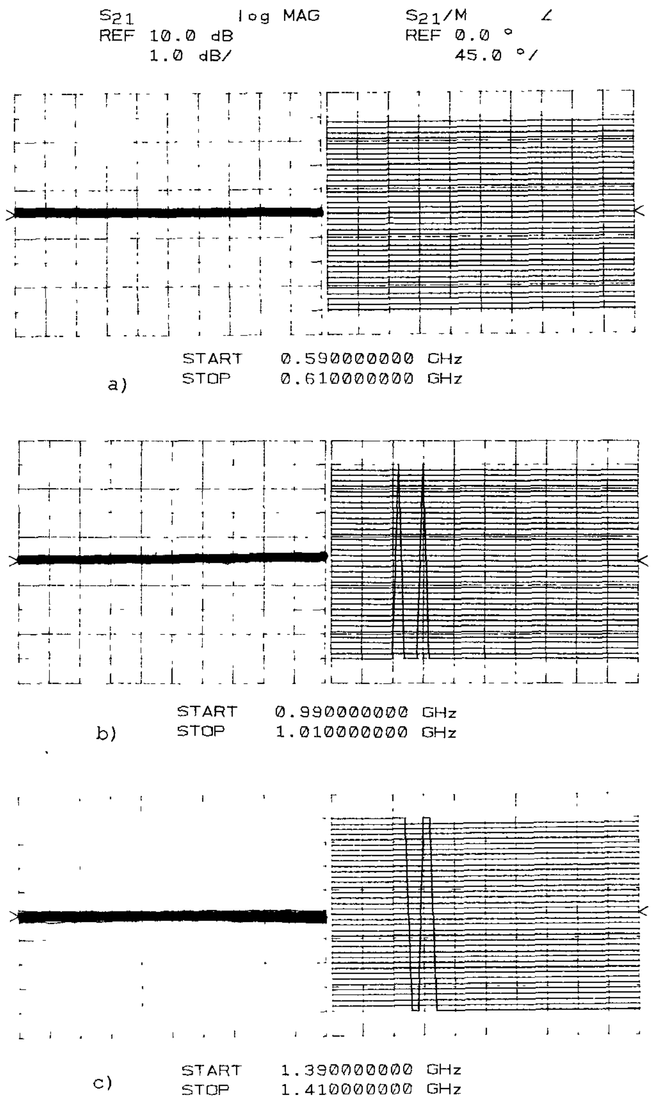

Figure 11 Amplitude and Phase Shift in 10° Steps over 20 MHz Instantaneous Bands at a) 600 MHz, b) 1000MHz, and c) 1400 MHz

Over 40 dB gain control was demonstrated by the module. Gain compression was measured at the four quadrant states to be greater than 22.5 dBm. Input VSWR was less than 1.5:1 across the band, with the output VSWR less than 2.2:1.

The response time of the phase shifter module was measured using a microwave bridge, functioning as a phase detector. The bridge circuit was balanced when the phase shifter was set to 0 db gain and 45° phase shift (optimized at 1 GHz). Upon application of a 500 kHz, 1V peak to peak square wave to the 90° channel's control voltage, the bridge becomes unbalanced, resulting in a square wave at the the output of the phase detector. The time scale of the oscilloscope was constrained to the positive leading edge of the square wave to show the step response of the phase shifter. The phase shifter reaches steady-state in less than 100 nS, as shown in Figure 12 (lower signal).

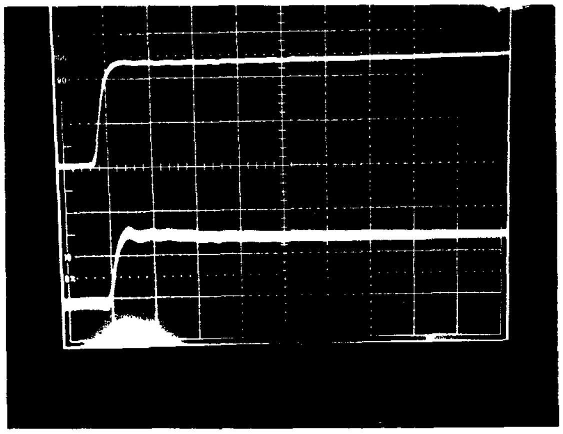

Figure 12 Phase Response Time (Horizontal Scale: 100nS/Div)

CONCLUSION

This paper has demonstrated that 0-360° phase shift over a broad bandwidth is achievable using GaAs monolithic technology. An all-pass approach to the phase shifter design eliminated the need for bulky hybrid couplers, and enabled better than .5° phase resolution over an octave band. 40 dB gain control has been demonstrated, with a phase/amplitude settling time of less than 100 nS.

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