Q-Band Monolithic Phase and Amplitude Weights

Jeffrey A. Lester, K. Nakano, and Y.C. Ngan

TRW Electronics and Defense
One Space Park
Redondo Beach, CA 90278

ABSTRACT

Monolithic variable amplitude and phase weight components have been developed for applications at Q-band. The amplitude weight consists of a three-stage variable gain amplifier using 0.25 um HEMT devices. Variable gain was acheived by adjustment of the bias voltages. The variable phase shifter is based on the I/Q design and utilizes two of the variable gain amplifiers in quadrature. Continually variable phase shift between 0 and 90 degrees was achieved with 2 dB insertion loss.

INTRODUCTION

The development of phase shifters at 44 GHz has potential application for communications phased array systems. TRW's involvement with amplifier design utilizing High Electron Mobility Transistors (HEMT) [1,2] has given us a baseline approach for these circuits. The I/Q phase shifter approach was chosen to give a continuously variable phase shift between 0 and 90 degrees.

DESIGN

Figure 1 shows the completed three-stage variable gain amplifier that is used as the amplitude weight and as the building block of the phase shifter. The cicuit includes input, output, and interstage matching networks as well as gate and drain bias circuitry. The matching networks consist of series transmission lines and transmission line stubs gounded by means of backside via holes. The bias networks consist of quarter-wavelength high impedance lines, bypass capacitors, and 50 ohm thin film resistors. There are also DC blocking capacitors between all devices and at the shorted stubs. A schematic of the amplifier is shown in Figure 2.

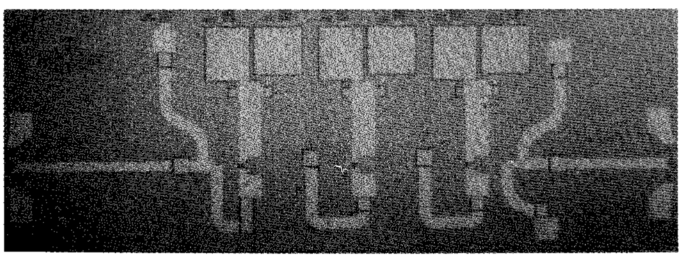


Figure 1. HEMT Monolithic Three-Stage Variable Gain Amplifier

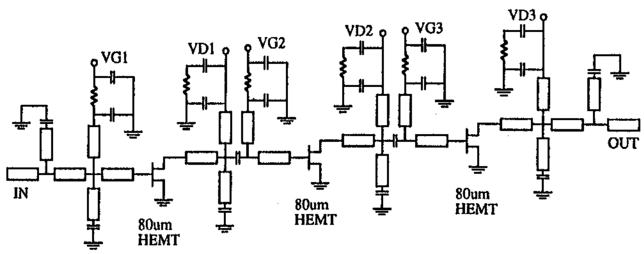


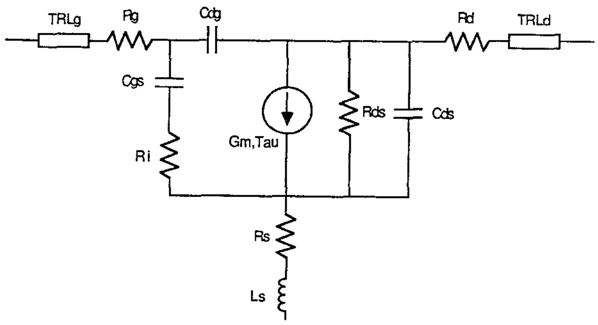
Figure 2. Amplifier Schematic

The HEMT device used in the circuits has two 0.25um x 40um gate fingers. A circuit model for the HEMT device was generated by first measuring the S-parameters of a discrete device from 1-26 GHz. Because of the variable gain nature of the amplifier design, the S-parameters were measured at different bias points. The model shown in Figure 3 represents the device in its peak gain bias condition. Each of the bias dependent models were optimized using TOUCHSTONE and were then used in analysis at Q-band to develop the matching networks for the amplifier. The matching networks were optimized to give the best possible match over the range of bias conditions while keeping the gain flat and within the desired range for its particular bias.

The variable phase shifter is based on the I/Q design, in which and RF signal is split into quadrature, amplified, and recombined in phase. By choosing different amplitude combinations in the paths, the phase of the output signal can be continuously varied over a 90 degree range. The phase shifter circuit consists of two variable gain amplifiers and input and

CH2848-0/90/0000-1231$01.00 © 1990 IEEE

80um HEMT CIRCUIT MODEL



80um HEMT Circuit Model Elements From Chip E1 of Wafer 3114			
TRLg	.25um x 20um	Rs	1.11 ohms
Rgs	9 ohms	Ls	0.011 nH
Cgs	0.048 pF	Rds	487 ohms
Ri	2.01 ohms	Cds	0.01725 pF
Cdg	0.0104 pF	Rd	7.11 ohms
Gm	19.75 mS	TRLd	8um x 15um
Tau	1.8 ps		

Figure 3. 80um HEMT Device Model

output Wilkinson splitters. The Wilkinson design was also optimized using TOUCHSTONE and includes coupled line effects. The quadrature required for the phase difference between the arms is acheived by a 120 degree length of transmission line.

FABRICATION

The monolithic circuits were processed using TRW's baseline HEMT approach. After device isolation is acheived by oxygen ion implantation, ohmic metals are deposited in the sequence: Ni-AuGe-Ag-Au. The metals are alloyed by use of a rapid thermal anneal system to acheive contact resistance on the order of .1 ohm/mm. The beam lithography using a Philips Beamwriter system. After the recess is etched the titanium-gold gate metal is evaporated into the recess. Figure 4 shows an SEM photo of the 0.25um gate finger. Thin-film resistors are then processed using a nichrome alloy. First level metal is deposited to define transmission lines and the bottom plates of the MIM (metal-insulator-metal) capacitors. Silicon dioxide is deposited and acts as the insulator for the capacitors as well as passivation over the thin-film resistors. Air-bridges to the capacitors are created and top metal is evaporated into the spaces in the airbridge resist. The backside is then thinned to 4 mils, via holes are etched, and

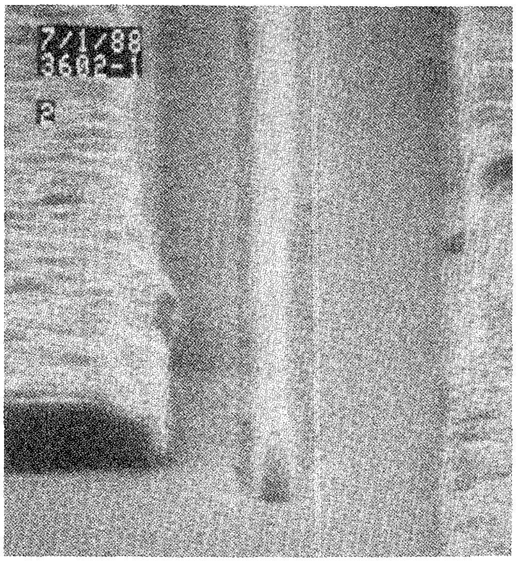


Figure 4. 0.25um EBL Gate Finger

metallization is performed. The wafer is then diced to yield the final chips. Figure 5 shows a completed phase shifter chip.

MEASUREMENT RESULTS

The circuits were tested on an HP8510 network analyzer with a Q-band extension kit. Test structures for measuring the performance of the Wilkinson splitter were added to the mask and the layout for these is shown in Figure 6. These structures were tested using the network analyzer and 50 GHz probe heads from Cascade Microtech.

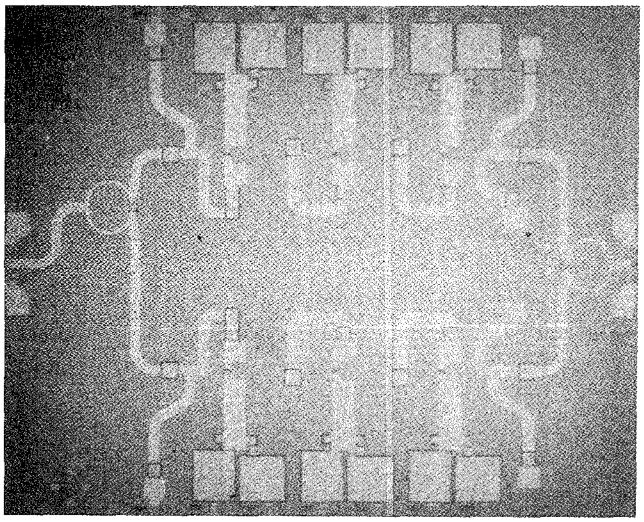


Figure 5. HEMT Monolithic Phase Shifter

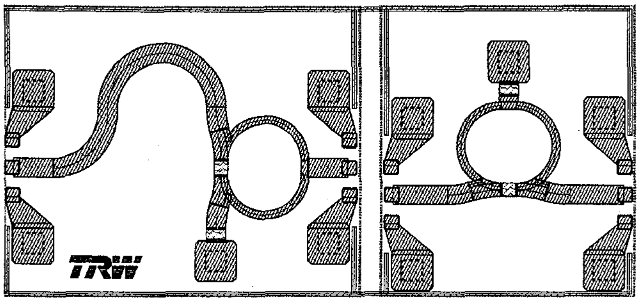


Figure 6. Layout of Wilkinson Splitter Test Structures

The insertion loss (S21) of the Wilkinson was 4 dB and is shown in Figure 7, along with the isolation (S23) between the output ports, which was about 12 dB. The input (S11) and output return loss (S33) of the Wilkinson splitter are shown in Figure 8. The monolithic 50 ohm load that terminated the unused port of each test structure had a measured return loss between 15 and 20 dB. For testing the monolithic circuits in waveguide, finline transitions were used for the conversion from waveguide to microstrip. Figure 9 shows the performance of a pair of back-to-back transitions. The insertion loss was .7 dB and the return loss was better

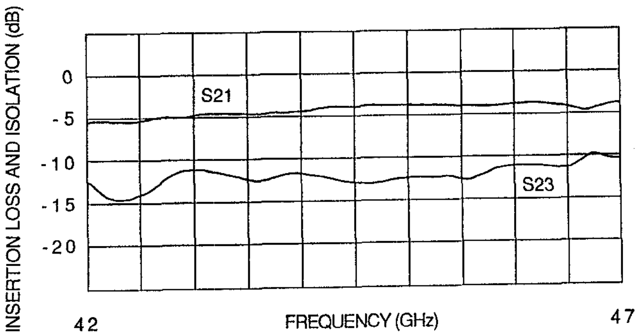


Figure 7. Insertion Loss (S21) and Isolation (S23) of Wilkinson Splitter

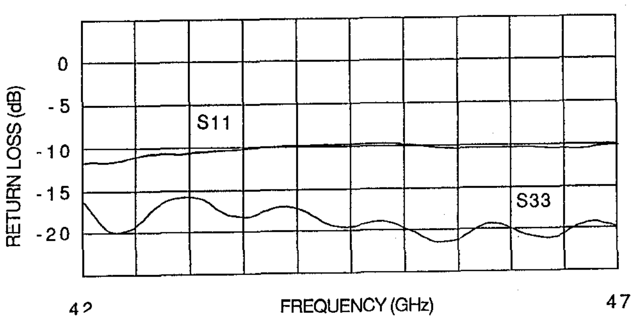


Figure 8. Input (S11) and Output (S33) Return Loss of Wilkinson Splitter

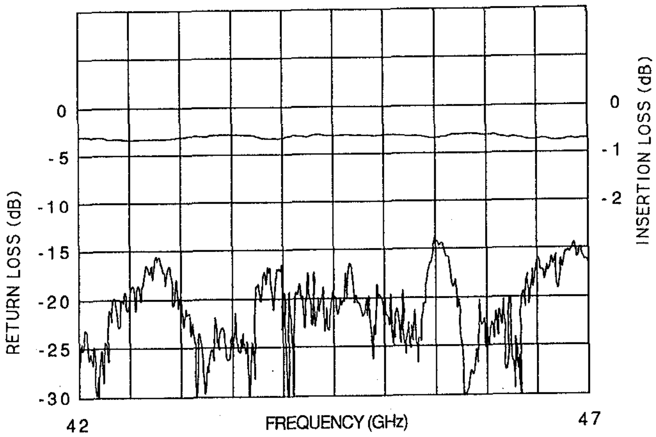


Figure 9. Performance of Finline Waveguide-to-Microstrip Transitions

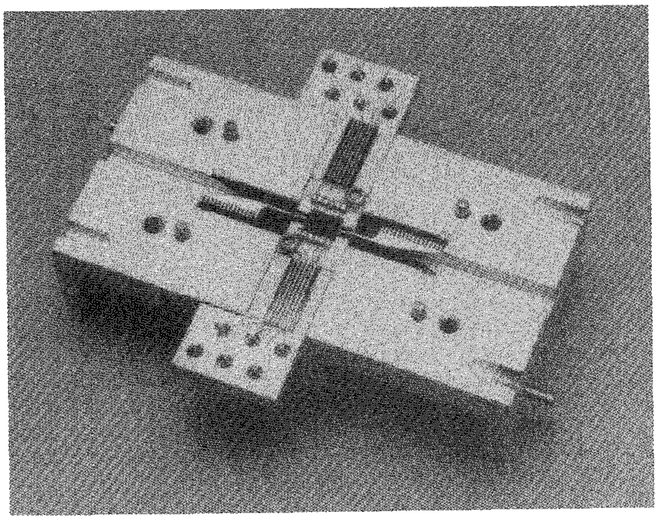


Figure 10. Monolithic Phase Shifter Mounted in Waveguide Test Fixture

than 15 dB. Figure 10 shows the phase shifter mounted in its test fixture and assembled with the finline transitions.

Figure 11 shows the variable gain characteristics of the amplifier biased at 4 different bias voltages. The gain can be varied anywhere within a 9 dB range by adjustment of the drain voltage to each of the three HEMT devices and the input return loss is better than 10 dB for all states. Although the magnitude of the transmission can be lowered further, the change in insertion phase becomes too great. Over this 9 dB of gain control, the phase changes by a total of 4 degrees.

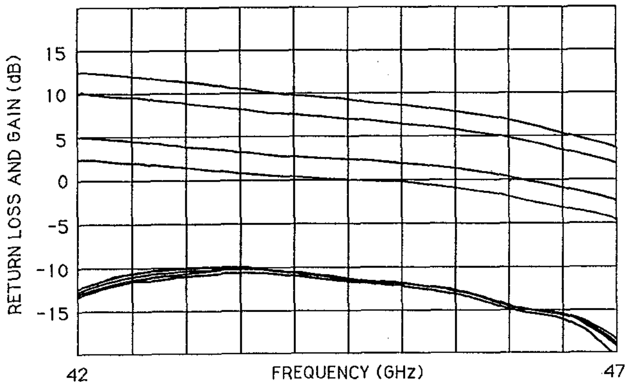


Figure 11. Amplitude Weight Performance

Figures 12 and 13 present measured results for the monolithic phase shifter. Figure 12 shows the relative insertion phase shift in 5 degree steps from 0 to 95 degrees. Figure 13 shows the input return loss and S21 characteritics for these 20 phase states. The 20 phase states were obtained through adjustment of the bias voltages such that the desired phase shift was achieved while the magnitude of the state was a close as possible to that of the reference phase state. The magnitude variation between states is better than 1 dB over most of a 5 GHz bandwidth.

CONCLUSION

A continuously variable phase shifter has been developed at Q-band using a HEMT three-stage variable gain amplifier. The phase shift can be varied between 0 and 90 degrees with 2 dB loss and minimal amplitude variation from state to state. The amplifier can also stand alone to be used as an amplitude weight.

ACKNOWLEDGEMENTS

The authors wish to thank Mike Aust and Jim Yonaki for their suggestions, Linda Klamecki for processing, and Laurie DeLuca and Teresa Cazares for assembly. The work decribed was sponsored by the Rome Air Development Center (RADC) under Contract No. F19628-86-C-0223.

REFERENCES

[1] J. Berenz, et al., "44 GHz Monolithic Low Noise Amplifier," 1987 IEEE Microwave and Millimeter-Wave Monlithic Circuits Symposium Digest, Las Vegas, NV, pp 15 - 17.

[2] J. Yonaki, et al., "A Q-Band Monolithic Three-Stage Amplifier," 1988 IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest, New York, NY, pp 91-94.

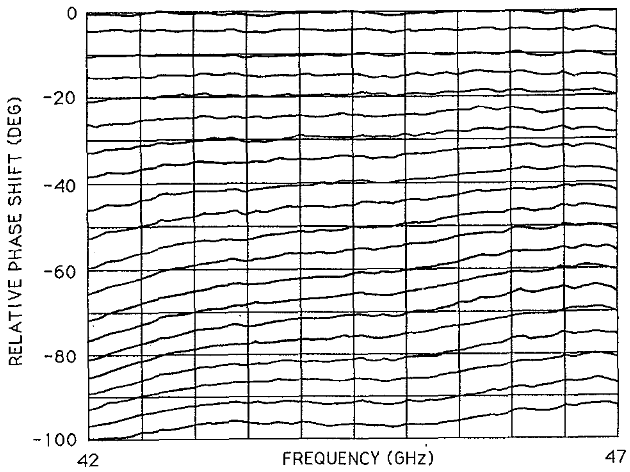


Figure 12. Phase Shift Measurement of Monolithic Phase Weight

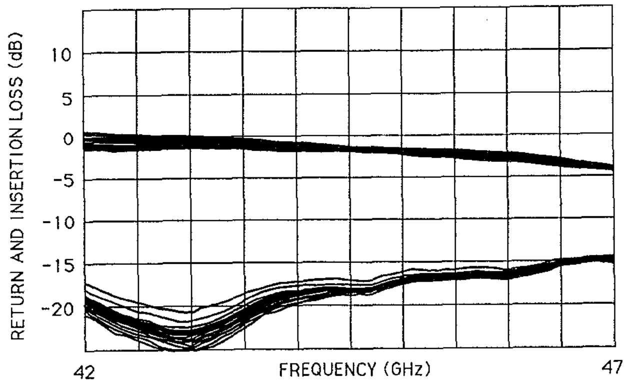


Figure 13. Insertion Loss and Return Loss of Monolithic Phase Weight