Monolithic Millimeter Wave CPW Circuits

M. Riaziat, E. Par, G. Zdasiuk, S. Bandy, and M. Glenn

Varian Research Center
611 Hansen Way, Palo Alto, CA 94303

Abstract

Three monolithic circuits were designed and fabricated on GaAs substrates using CPW transmission lines. These circuits consist of two amplifiers and a frequency doubler, and demonstrate the application of CPW in the Ka band. The active device used in these circuits is a $0.25\mu m$ gate AlGaAs HEMT defined by E-beam lithography. Transmission line and substrate dimensions are chosen to avoid interaction with extraneous modes.

Introduction

The use of CPW in MMIC design is driven by the cost savings and process simplicity that it offers [1]. Wideband CPW circuits operating up to 20 GHz have been previously reported [2]. Higher frequency operation of coplanar waveguides poses the problem of potential interaction with extraneous substrate modes. The present work demonstrates that this problem can be avoided by choosing proper dimensions for both the waveguide and the substrate.

Circuit design

The first circuit to be reported is a lossy match cascode amplifier (Fig. 1a). The schematic diagram of the circuit is shown in Figure 1b. The cascode configuration is especially attractive in a CPW layout due to the possibility of low inductance RF grounding of the second gate.

The second circuit is a low current distributed amplifier (Fig. 2). Three capacitive elements are used in both the gate and the drain lines. The active devices constitute two of the capacitive elements. The third capacitance in each case is a passive element.

The third circuit is a frequency doubler using the cascode configuration (Fig. 3). The second gate of the cascode pair is terminated in a resonant section of transmission line whose resonance frequency is the frequency that will be doubled by the circuit. The input matching network is low pass with a cutoff frequency of 20 GHz. Output matching is done by a high pass structure with the same cutoff frequency.

The Active Device

The active device is an AlGaAs HEMT with a quarter micron E-beam defined gate (Fig. 4). This device has a maximum available gain of 8 dB at 40 GHz. For the distributed amplifier the layout of the active device is optimized for incorporation in a coplanar waveguide circuit. The drain and the gates fit in the ground to ground spacing of the CPW, minimizing source inductance caused by ground discontinuities.

Transmission Line Modes

The transmission line is designed to operate in the CPW mode [3]. The slotline mode is suppressed by periodic airbridge connections of the two side grounds. In order to avoid the excitation of microstrip modes the $400\mu m$ substrate is not thinned. Since the backside of the substrate is metalized, parallel plate waveguide modes can be excited (Fig. 5). The presence of these modes contributes to dispersion, power loss, and cross talk. These effects are strongest when the phase velocity of any of the substrate modes coincides with that of the CPW mode [4]. For TE_1/TM_1 modes this condition is satisfied at values of h/λ_d ranging from 0.15 to 0.2, corresponding to the frequency range of 32 to 42 GHz for a 400 μm thick substrate. This range coincides with our frequency band of interest. For this reason, either the substrate thickness had to be reduced, or the ground to ground spacing $(W + 2G)$ of CPW had to be small. We chose the later solution by selecting a $W + 2G$ of 50 μm for the line. Small ground to ground spacing results in small field overlap integrals between substrate modes and the CPW, ensuring a low level of interaction. The fact that this solution is indeed satisfactory in practice was verified by changing the boundary conditions on the bottom of the substrate. These changes did not have any measurable effect on the performance of the circuit.

Experimental Results

Figures 6 through 8 show the observed responses of the three circuits. The lossy match amplifier (Fig. 6) gives a small signal gain of 12 ± 2 dB over the frequency range of 22 to 40 GHz. The noise figure increases monotomically from 4 to 7 dB in the same frequency range. This amplifier operates at a drain bias of 6V and requires 14 to 24 mA of current.

Small signal gain of the low current distributed amplifier (Fig. 7) is 6 ± 0.5 dB from 15 to 40 GHz. The bias current required is less than 40 mA at 4.0 volts of drain bias.

The output response of the frequency doubler is shown in Figure 8. This is the output obtained by sweeping the input frequency from 13.3 to 20 GHz. The peak in the output response is close to 30 GHz and has 2 GHz of tunability by changing second gate bias. The conversion loss of the doubler is 8 dB.

CH2725-0/89/0000-0525$01.00

Conclusions

(1) The cascode configuration is shown to be a convenient gain element to be used with coplanar waveguide circuits where low inductance RF grounding of the the second gate is easily achieved. (2) In a distributed amplifier the capacitive elements of gate and drain artificial transmission lines do not need to be all active elements. Especially in a case where multi-octave bandwidth is not required, gain at low frequencies can be traded off with current consumption by replacing some FETs with passive capacitors. (3) In the cascode frequency doubler reported here, the quality factor of the resonator at the second gate affects both bandwidth and conversion loss. CPW with the dimensions used here yields a lower Q resonator than microstrip. Nevertheless the performance of the circuit indicates that the use of such CPW resonators is still feasible in circuit design. (4) Finally, this work shows that coplanar waveguides are well enough characterized to be usable in sensitive millimeter wave circuits.

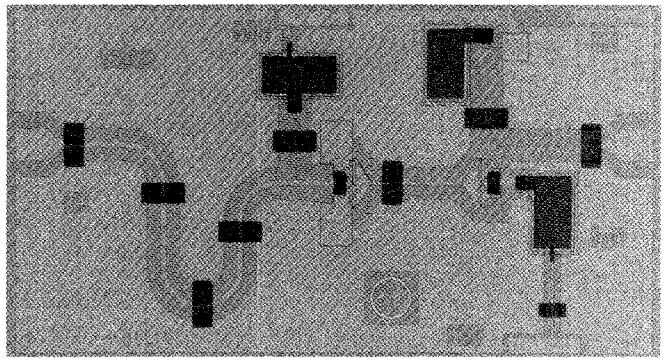
References

[1] M. Riaziat, S. Bandy, and G. Zdasiuk, *"Coplanar Waveguides for MMICs"*. Microwave Journal, Vol. 30, No. 6, June 1987.

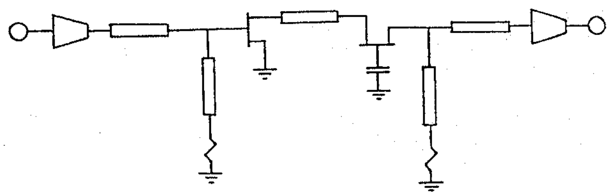
[2] M. Riaziat, I. Zubeck, S. Bandy, and G. Zdasiuk, *"Coplanar Waveguides Used in 2–18 GHz Distributed Amplifier."* in 1986 IEEE MTT–S International Microwave Symposim Digest, June 1986.

[3] M. Riaziat, I.J. Feng, R. Mjidi–Ahy, and B.A. Auld, *"Single Mode Operation of Coplanar Waveguides"*. Electronics Letters, Vol. 23, No. 24, November 1987.

[4] M. Riaziat, R. Majidi–Ahy, and I.J. Feng, *"Propagation Modes and Dispersion Characteristics of Coplanar Waveguides"*. to be published in IEEE Trans. Microwave Theory Tech.



(a)



(b)

Figure 1. (a) Photomicrograph and (b) schematic diagram of the lossy match cascode amplifier.

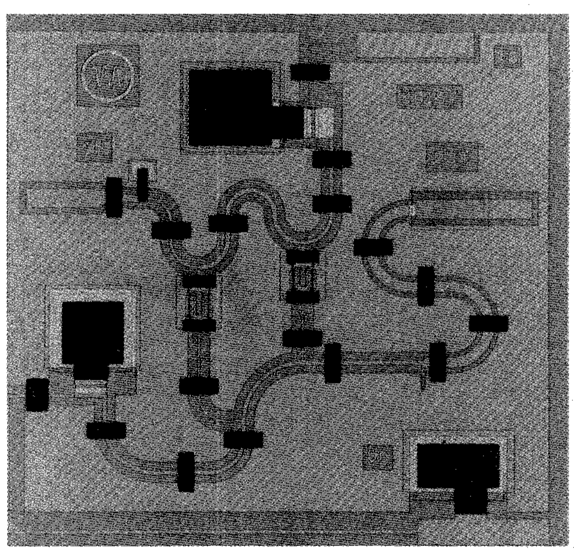


Figure 2. Low current distributed amplifier.

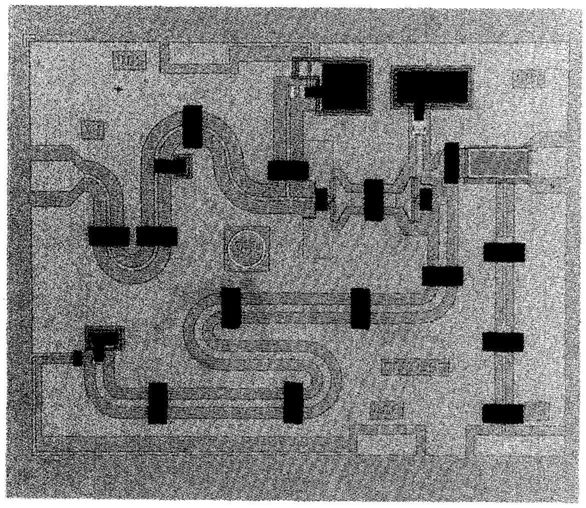


Figure 3. 15 to 30 GHz frequency doubler.

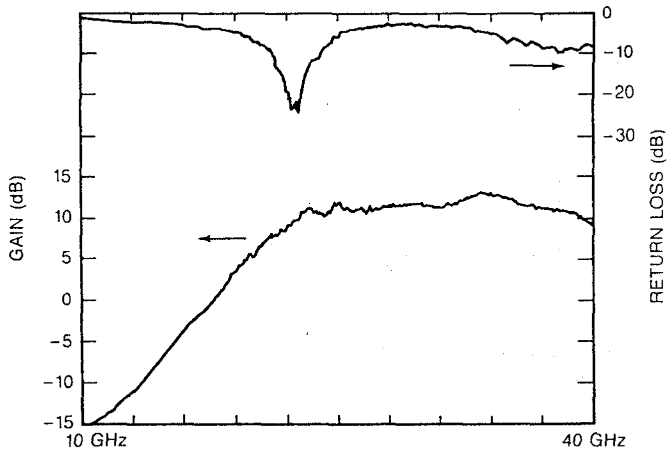


Figure 6. Gain and return loss of the lossy match amplifier.

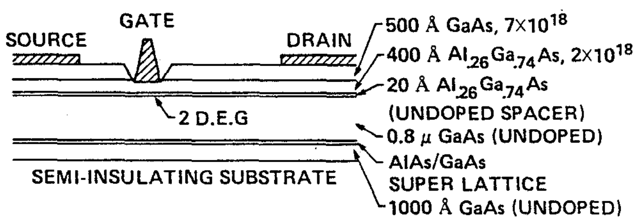


Figure 4. AlGaAs HEMT structure used in Ka band circuits.

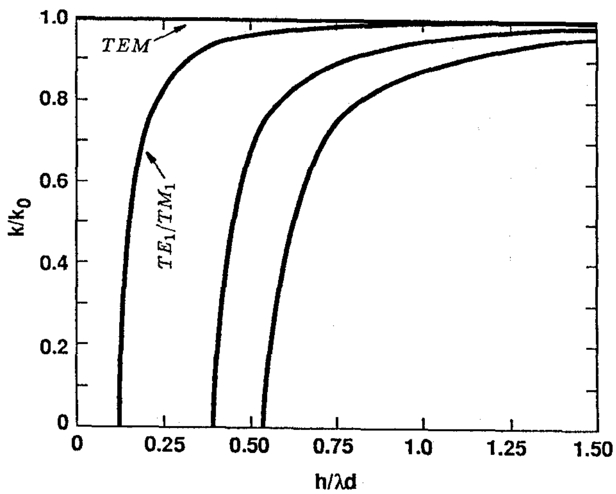


Figure 5. Parallel plate waveguide modes. Vertical axis is the propagation constant normalized to that of the TEM mode. Horizontal axis is the substrate thickness normalized with respect to wavelength in the dielectric.

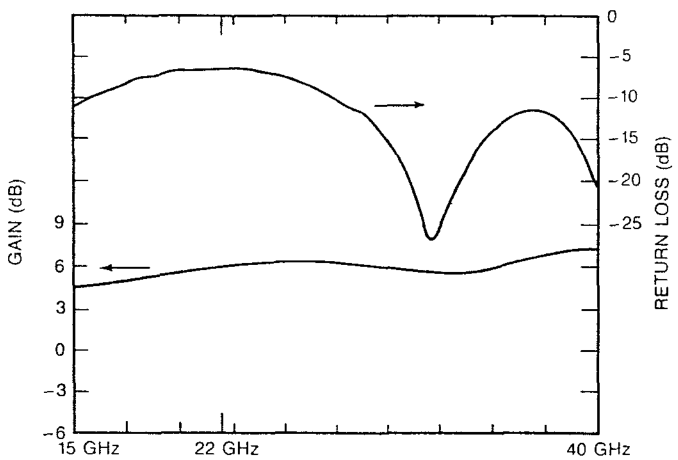


Figure 7. Gain and return loss of the low current distributed amplifier.

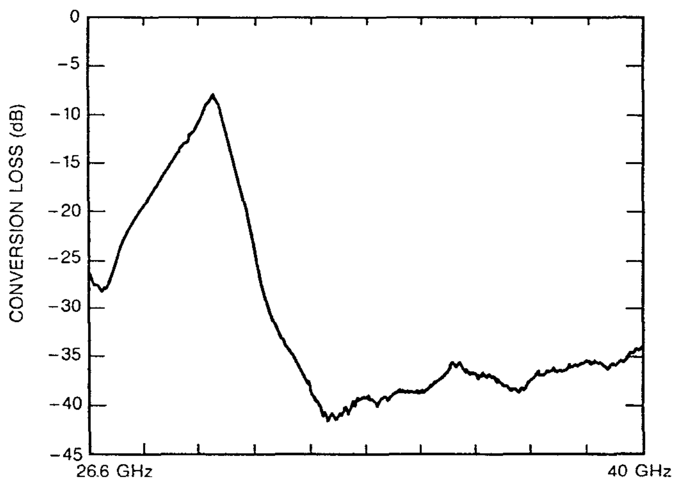


Figure 8. Output performance of the frequency doubler.