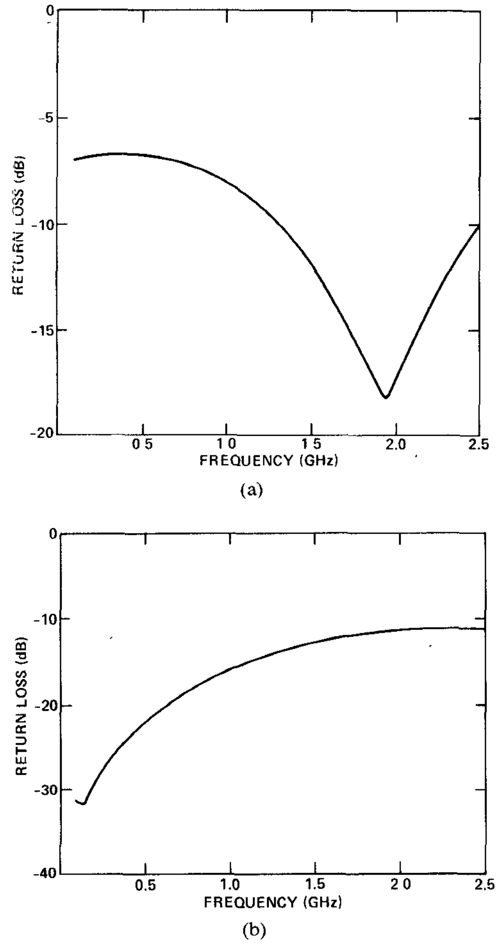

Fig 6. (a) Measured input match (b) Measured output match.

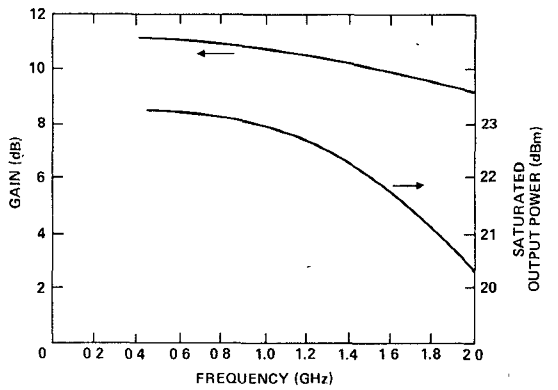

Fig. 7 Measured small-signal gain and saturated power at power bias.

Output return loss is better than 12 dB across the band and is better than 16 dB below 1 GHz. Measured input and output match are shown in Fig. 6. When the amplifier is biased for maximum gain, the output match remains excellent and the input return loss is better than 10 dB across the band due to higher transconductance. Gain shape remains the same, but the gain is increased slightly. At this bias point, saturated power in excess of +20 dBm is obtained across the band while +23 dBm is obtained below 1 GHz, as shown in Fig. 7.

VI. Conclusion

In conclusion, the application of negative resistive feedback around a 1200-μm-wide GaAs FET has led to the fabrication of a low-noise wide-band amplifier suitable for use as a utility amplifier or an IF amplifier. The high dynamic range amplifier is useful as both a discrete component and part of a larger monolithically integrated circuit. Potential future enhancements of the circuit include higher frequency performance, active loads for higher large signal efficiency, and a level shifting circuit to enable dc cascading of the amplifiers.

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Monolithic GaAs Interdigitated Couplers

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***Abstract* —This paper describes the design, fabrication, and performance of two monolithic GaAs *C*-band 90° interdigitated couplers with 50- and 25-Ω impedances, respectively. A comparison of the performance of these two couplers shows that the 25-Ω coupler has the advantages of lower loss and higher fabrication yield. The balanced amplifier configuration using 25-Ω couplers will require a fewer number of elements in the input–output matching circuit of the FET amplifier. The fewer number of matching elements results in great savings in the GaAs real estate for microwave monolithic intergrated circuits (MMIC's). Both the couplers have been fabricated on a 0.1-mm-thick GaAs SI substrate. The measured results agree quite well with calculated results. The losses of the 50- and 25-Ω couplers are 0.5 and 0.3 dB, respectively, over the 4–8-GHz frequency band.**

I. Introduction

A monolithic interdigitated 90° coupler is an important passive component for microwave monolithic integrated circuit (MMIC) applications such as balanced amplifiers, mixers, discriminators, and phase shifters [1]. The monolithic interdigitated 90° hybrids reported in the literature [2], [3] thus far are confined to the conventional input and output impedances of 50 Ω. We report here the first realization of a monolithic 25-Ω impedance coupler on GaAs substrate that has some distinct advantages of low loss and small amplifier size over the conventional 50-Ω design.

The thickness of GaAs substrate used for most medium-power MMIC applications is 0.1 mm because of considerations in device thermal resistance and circuit loss [4]. The input and output impedances of a GaAs power FET are, in general, only a few ohms, which is much less than 50 Ω. In a conventional approach, the input and output impedances of the FET are matched to 50 Ω. To overcome such a large mismatch from a few to 50 Ω, multi-element matching networks have to be used. This leads to a high loss in the matching network and a relatively large matching network which consumes a large area of GaAs real estate. This problem becomes more severe when high power (e.g., a few watts) and wide bandwidth are required. By selecting a lower than 50-Ω system, such as 25 Ω, the matching circuits will result in fewer numbers of matching elements, leading to savings in the GaAs substrate area and reduction in the losses in the

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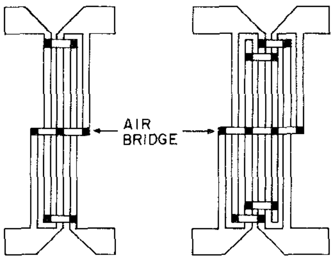

Fig 1. Schematics of (a) four-line and (b) six-line couplers.

TABLE I
DIMENSIONS OF VARIOUS COUPLERS ON A 0 1-mm-THICK GAAS SI SUBSTRATE
(The length of coupling region is 4 39 mm for 4–8 GHz band.)

Coupler	50-ohm, 4-line	25-ohm, 4-line	25-ohm, 6-line
Conductor width (μm)	6.5	47.3	19.0
Spacing (μm)	7.0	4.3	11 0

matching circuits. Thus the 25-Ω coupler is useful in a multistage, balanced amplifier aiming for high-frequency and high-power applications.

The conductor loss in a coupler is inversely proportional to the metallization line width for a given metallization thickness. The line width of the coupler is in turn determined by the coupler impedance and the GaAs substrate thickness. Brehm and Lehmann [3] have used a 0.2-mm-thick GaAs semi-insulating (SI) substrate for obtaining wider conductor width to reduce the conductor losses. The conductor losses can be reduced by a factor of two if the width and spacing of the interdigitated lines are doubled by increasing the substrate thickness from 0.1 to 0.2 mm. For the case of the power FET, however, the thermal consideration dictates that the GaAs substrate thickness be about 0.1 mm or less [4]. Therefore, the choice of a 25-Ω six-line coupler for power combination at high frequencies is preferred.

The 25-Ω coupler has the width and spacing of 19.0 μm and 11.0 μm, respectively, as compared to 6.5 μ and 7.0 μm for a four-line 50-Ω coupler on a 0.1-mm-thick GaAs SI substrate. Thus the 25-Ω coupler has two advantages over the 50-Ω four-line coupler, namely, better matching to FET impedances and larger interdigitated conductor width resulting in lower loss and higher fabrication yield.

In the following sections, the design, fabrication, and performance of the couplers are presented. The method of measurement and the correction for fixture loss are discussed. The measured results agree quite well with the theoretical calculations. The losses for the 25- and the 50-Ω couplers are 0.3 and 0.5 dB, respectively, over the 4–8-GHz frequency band, with an isolation better than 18 dB for both couplers.

II. DESIGN OF THE COUPLERS

The four-line and six-line interdigitated 90° couplers are schematically shown in Fig. 1. The 50-Ω four-line and 25-Ω six-line interdigitated couplers were designed for operation over the 4–8-GHz frequency band. The length of both couplers is 4.39 mm. The design was done using CAD techniques based on the published theory [5], [6]. The dimensions of the two couplers are summarized in Table I.

For a 25-Ω coupler, the six-line interdigitated coupler was selected instead of the four-line interdigitated coupler for the following reason: the width and spacing of a 25-Ω four-line coupler are 47.3 and 4.3 μm, respectively, as compared to 19.0 and 11.0 μm for a six-line coupler on a 0.1-mm-thick SI GaAs substrate. The small spacing of 4.3 μm between interdigitated conductors of a four-line 25-Ω coupler will present some difficulties in the fabrication of this coupler. At 4 GHz, the skin depth is about 1 μm and, therefore, the conductor thickness has to be at least 3–4 μm to reduce the conductor loss. The spacing-to-conductor-thickness ratio of almost 1 to 1 is, in general, difficult to achieve with high yield. The dimensions of the six-line coupler, on the other hand, are easily realized. Because of this fabrication constraint, a six-line coupler was chosen for a 25-Ω coupler.

III. COUPLER FABRICATION

The fabrication process described here for interdigitated couplers is compatible with monolithic microwave integrated circuits fabrication technology. These couplers can be integrated with other active elements and passive components to form a monolithic GaAs integrated circuit.

The initial SI GaAs substrate thickness is 0.3 mm (12 mils). A 3000-Å-thick layer of Ti and 200-Å-thick layer of Au were evaporated on to the GaAs substrate to facilitate the plating of the interdigitated conductors. The interdigitated conductors were defined using thick photoresist (4–5 μm) and the gold was plated to a thickness of 4 μm (more than three times the skin depth). The interconnections between the interdigitated conductors were provided by thick (3 μm) gold-plated air-bridges. After removing the photoresist, the Ti–Au layer outside the gold-plated area was etched off. The substrate was then lapped to 0.1-mm thickness and a thick layer of Ti–Au (5–6 μm) was evaporated on the back side to form the ground plane.

IV. PERFORMANCE

A. 50-Ω Four-Line Coupler

The photograph of the 50-Ω four-line interdigitated coupler is shown in Fig. 2(a). The SEM micrograph of the air-bridge connection is shown in Fig. 2(b). The coupler was tested in a test fixture which has 50-Ω lines on a 0.0254-cm-thick alumina substrate on input and output side of the GaAs chip to connect the coupler parts to the 50-Ω SMA connectors. The losses in the test fixture were calibrated and later subtracted from the measured results to determine the true coupler performance. Fig. 3 shows the coupling at the coupled and the direct port as a function of frequency for the 50-Ω coupler. The theoretical results are also presented in the same figure. The measured performance is in close agreement with the theoretical prediction. The insertion loss and phase differences between the coupled and the direct port of the 50-Ω coupler as a function of frequency are presented in Fig. 4. The average insertion loss is 0.5 dB and the phase difference is 90±2° over the 4–8-GHz frequency band. The variation of isolation between coupled and direct ports is shown in Fig. 5. The isolation is better than 18 dB across the 4–8-GHz band. The variation of the return loss with frequency at one of the ports of the coupler is shown in Fig. 6. The typical return loss is better than 16 dB.

B. 25-Ω Six-Line Coupler

Fig. 7 shows the photograph of the coupler and the SEM micrograph of the air-bridge connection. Since the coupler has input and output impedances of 25-Ω, for testing in a 50-Ω system, a four-section λ/16, 25–50-Ω step transformer [7] on a 0.0254-cm-thick alumina substrate was used. The photograph of the coupler in the test fixture is shown in Fig. 8. The losses in the test fixture were calibrated and subtracted from the measured

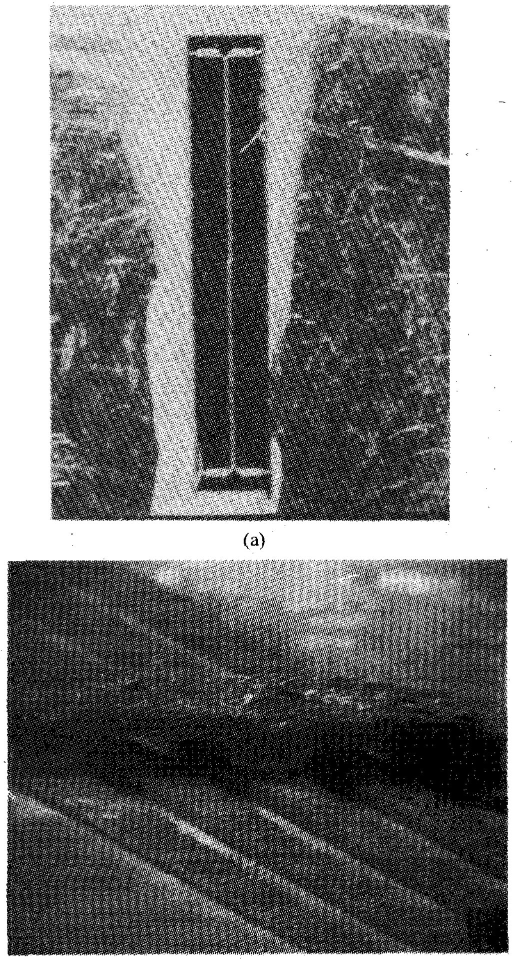

Fig. 2. (a) Photograph of the four-line coupler. (b) SEM micrograph of the air-bridge connection.

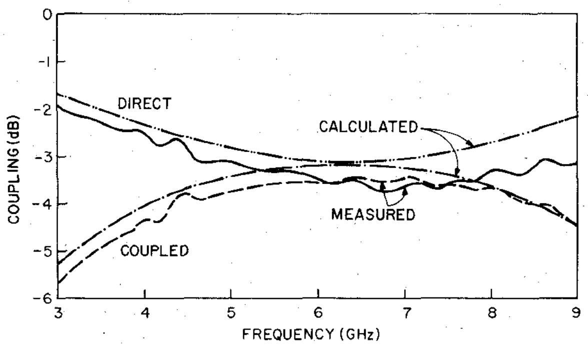

Fig. 3. Coupling as a function of frequency at coupled and direct ports of the four-line 50-Ω coupler.

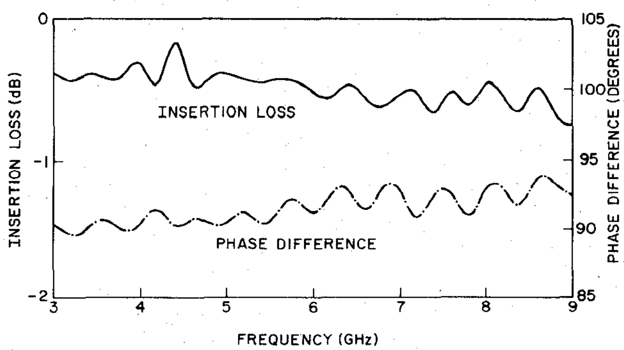

Fig. 4. Insertion loss and phase difference between coupled and direct ports of the four-line 50-Ω coupler.

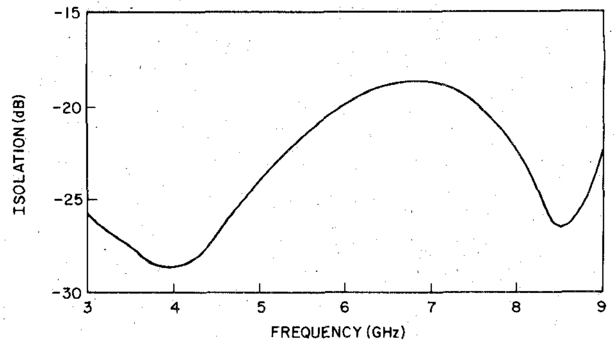

Fig. 5. Isolation between coupled and direct ports of the four-line 50 – Ω coupler.

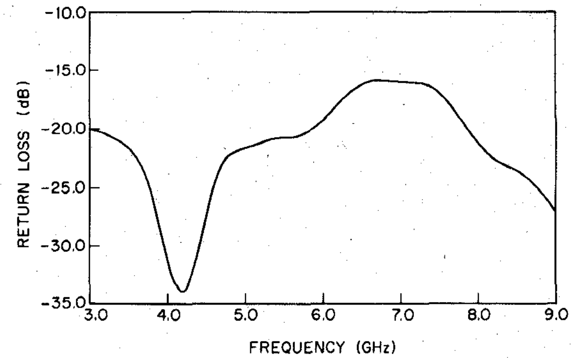

Fig. 6. Typical return loss at one of the ports of the six-line 25-Ω coupler.

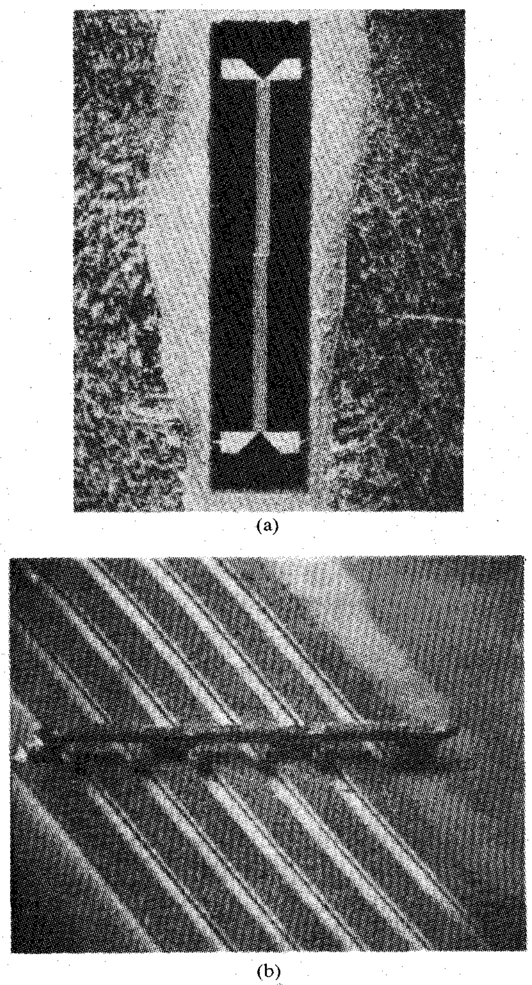

Fig. 7. (a) Photograph of the six-line 25-Ω coupler. (b) SEM micrograph of the air-bridge connection.

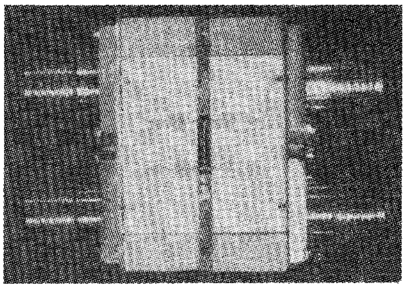

Fig. 8. Photograph of the test fixture (including coupler) used for measurement of the six-line 25-Ω coupler.

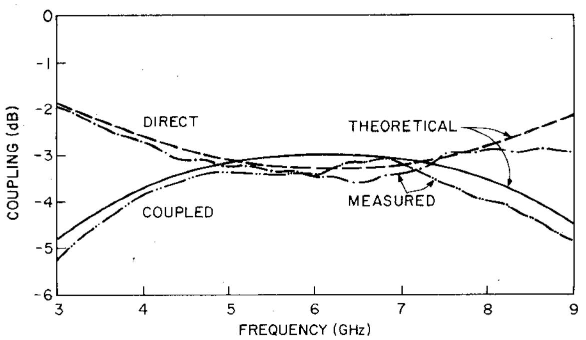

Fig. 9. Coupling as a function of frequency at coupled and direct ports of the six-line 25-Ω coupler.

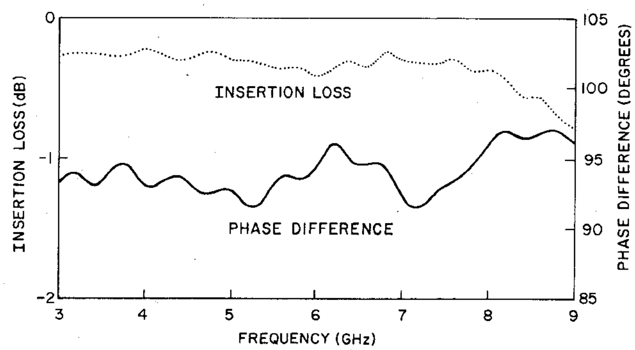

Fig. 10. Insertion loss and phase difference between coupled and direct ports of the six-line 25-Ω coupler.

results to extract the true performance of the coupler. The theoretical and experimental results of coupling at coupled and direct ports of this 25-Ω coupler are shown in Fig. 9. There is a close agreement between the theoretical and experimental results. The variation of insertion loss and phase difference between coupled and direct ports with frequency is presented in Fig. 10. The average insertion loss of the coupler over the 4–8 GHz-band is 0.3 dB, which is a significant improvement over the insertion loss of the four-line coupler. Fig. 11 shows the isolation between the coupled and direct ports of the coupler. The isolation is better than 17 dB over the band. The variation of the return loss with frequency at one of the ports of the coupler is shown in Fig. 12. The typical return loss is better than 17.4 dB over the 4–8-GHz band.

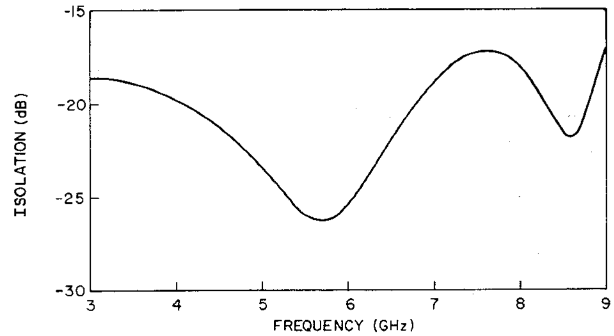

Fig. 11. Isolation between coupled and direct ports of the six-line 25-Ω coupler.

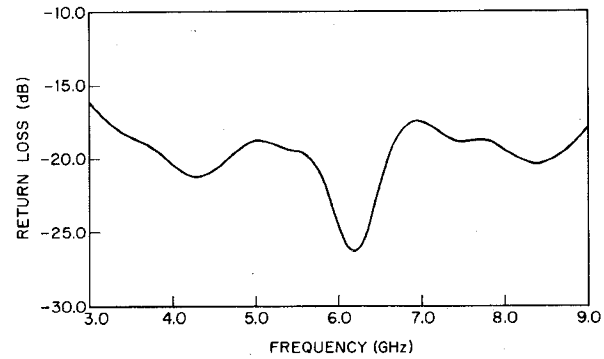

Fig. 12. Typical return loss at one of the ports of the four-line 50-Ω coupler.

V. Conclusions

Interdigitated 90° couplers for monolithic integration with other active and passive circuits on GaAs for MMIC applications have been presented. The 25-Ω coupler has the two-fold advantage over a 50-Ω coupler, namely, reduced loss and better matching to the impedance of the active devices. The loss of the 25-Ω coupler is 0.3 dB over the 4–8-GHz band. The experimental results agreed well with the theoretical results.

Acknowledgment

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