

MONOLITHIC GaAs INTERDIGITATED 90° HYBRIDS  
WITH 50- AND 25-OHM IMPEDANCES\*

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Abstract

This paper describes the design, fabrication and performance of two monolithic GaAs C-band 90° interdigitated couplers with 50-ohm and 25-ohm impedances, respectively. A comparison of the performance of these two couplers shows that the 25-ohm coupler has the advantages of lower loss, higher fabrication yield and needs fewer numbers of matching elements when it is used in the balanced amplifier configuration. The fewer number of matching elements results in great savings in the GaAs real estate for MMICs. 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-ohm and 25-ohm 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 ohms. We report here the first realization of a monolithic 25-ohm impedance coupler on GaAs substrate that has some distinct advantages of low loss and small amplifier size over the conventional 50-ohm 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 ohms. In a con-

ventional approach, the input and output impedances of the FET are matched to 50 ohms. To overcome such a large mismatch from a few ohms to 50 ohms, multi-section 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 frequency (e.g. mm-wave), high power (e.g. a few watts) and wide bandwidth are required. By selecting a lower than 50-ohm system such as 25-ohms, 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 matching circuits. Thus the 25-ohm coupler is useful in a multi-stage, 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 0.2 mm thick GaAs 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 mm 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-ohm, 6-line coupler for power combination at high frequencies is preferred.

The 25-ohm coupler has the width and spacing of 19.0  $\mu$ m and 11.0  $\mu$ m, respectively, as compared to 6.5  $\mu$ m and 7.0  $\mu$ m for a four-line, 50-ohm coupler on a 0.1 mm thick GaAs SI substrate. Thus, the 25-ohm coupler has two advantages over the 50-ohm, 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 section, 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-ohm and the 50-ohm couplers are 0.3 dB and 0.5 dB, respectively,

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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-ohm, four-line and 25-ohm, six-line interdigitated couplers were designed for operation over the 4-8 GHz frequency band. The length of

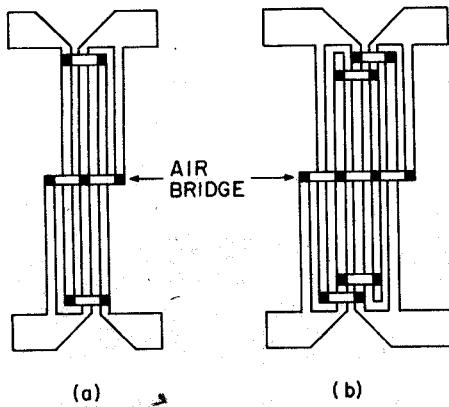


Fig. 1 Schematics of four-line and six-line couplers (a) four-line coupler, (b) six-line coupler

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 1.

Table 1

### 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	Conductor width (μm)	Conductor spacing (μm)
50-ohm, 4 line	6.5	7.0
50-ohm, 6 line	6.6	4.3
25-ohm, 4 line	47.3	4.3
25-ohm, 6 line	19.0	11.0

For a 25-ohm 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-ohm, four-line coupler are 47.3 μm and 4.3 μm, respectively, as compared to 19.0 μm 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-ohm coupler will present some difficulties in the fabrication of this coupler. At 6 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 easy to be realized. Because of this fabrication constraint, a six-line coupler was chosen for a 25-ohm 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 IC.

The initial semi-insulating GaAs substrate thickness is 0.3 mm (12 mils). A 3000 Å thick layer of Ti and 2000 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-ohm, four-line coupler

The photograph of the 50-ohm, four-line interdigitated coupler is shown in Fig. 2(a). The SEM micrograph of the air-bridge connection is shown in Fig. 2(b).

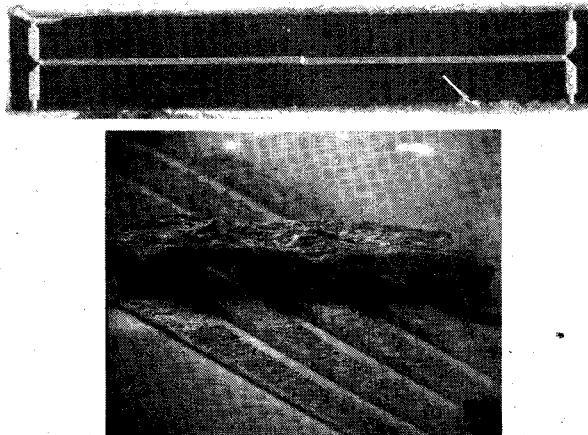


Fig. 2(a) Photograph of the four-line coupler,  
(b) SEM micrograph of the air-bridge connection

The coupler was tested in a test fixture which has 50-ohm lines on a 0.0254 cm thick alumina substrate on input and output side of the GaAs chip to connect the coupler ports to the 50-ohm 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-ohm coupler. The theoretical

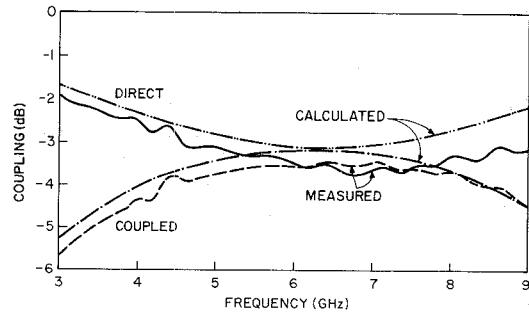


Fig. 3 Coupling as a function of frequency at coupled and direct ports of the four-line, 50-ohm coupler

results are also presented in the same figure. The measured performance is in close agreement with the theoretical prediction. The insertion loss and phase difference between the coupled and the direct port of the 50-ohm coupler as a function of frequency are presented in Fig. 4.

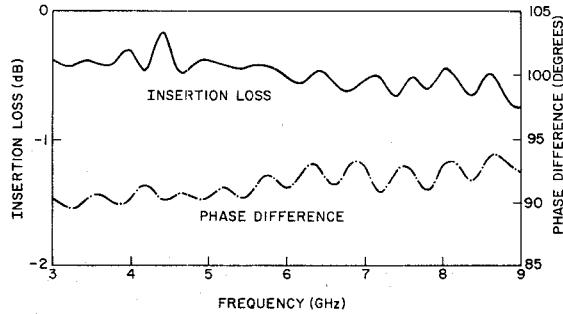


Fig. 4 Insertion loss and phase difference between coupled and direct ports of the four-line, 50-ohm coupler

The average insertion loss is 0.5 dB and the phase difference is  $90^\circ \pm 2^\circ$  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.

#### (b) 25-ohm, six-line coupler

Fig. 6 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 ohms, for testing in a 50-ohm

system, a four-section  $\lambda/16$ , 25 to 50-ohm 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. 7.

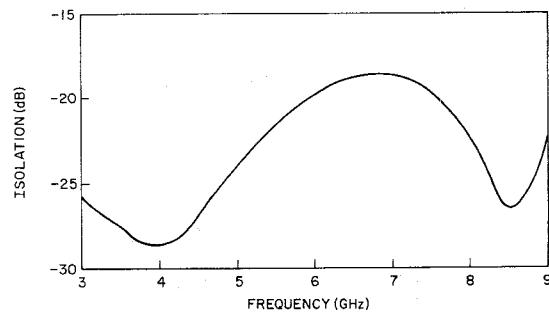


Fig. 5 Isolation between coupled and direct ports of the four-line, 50-ohm coupler

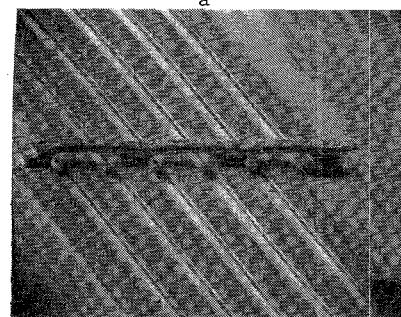
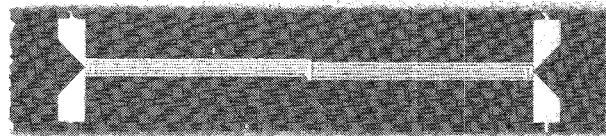


Fig. 6(a) Photograph of the six-line, 25-ohm coupler,  
(b) SEM micrograph of the air-bridge connection

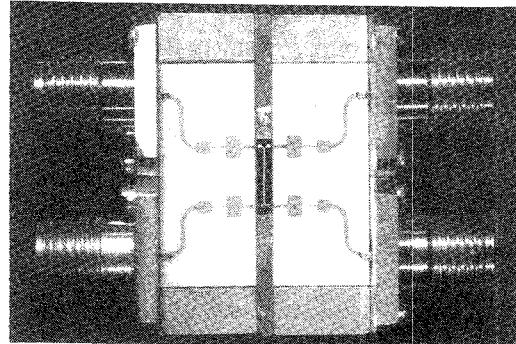


Fig. 7 Photograph of the test fixture (including coupler) used for measurement of six-line, 25-ohm coupler

The losses in the test fixture were calibrated and subtracted from the measured results to extract the true performance of the coupler. The theoretical and experimental results of coupling at coupled and direct ports of this 25-ohm coupler are shown in Fig. 8. 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. 9.

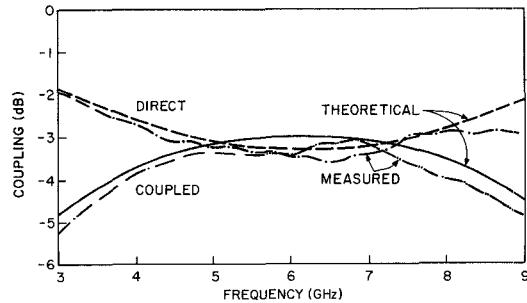


Fig. 8 Coupling as a function of frequency at coupled and direct ports of the six-line, 25-ohm coupler

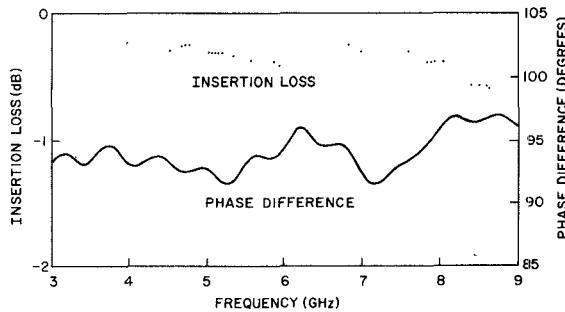


Fig. 9 Insertion loss and phase difference between coupled and direct ports of the six-line, 25-ohm coupler

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. 10 shows the isolation between the coupled and direct ports of the coupler. The isolation is better than 17 dB over the band.

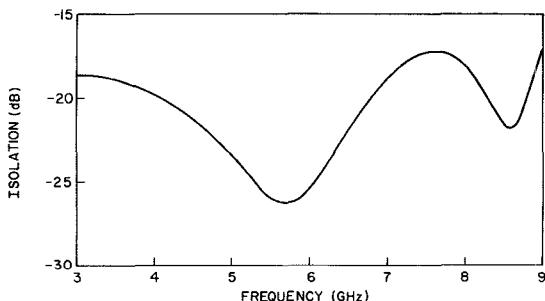


Fig. 10 Isolation between coupled and direct ports of the six-line, 25-ohm coupler

## V. Conclusions

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

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