MULTILAYER MMIC BRANCH-LINE COUPLER AND BROAD-SIDE COUPLER

I. Toyoda, T. Hirota, T. Hiraoka, T. Tokumitsu

NTT Radio Communication Systems Laboratories
1-2356 Take, Yokosuka-shi, Kanagawa 238-03, Japan

ABSTRACT

Very small, multilayer MMIC couplers are newly proposed. New methods for size reduction, i.e., a quasi-lumped elements approach and a newly-developed multilayer coupled-line structure, are also described. A 24–26 GHz band branch-line coupler and a 20–30 GHz band broad-side coupler are implemented in very small areas of less than 0.4 mm × 0.4 mm and 0.2 mm × 0.2 mm, respectively.

Introduction

Directional couplers and hybrids are essential elements in microwave circuits, and are most commonly used in amplifiers, frequency converters, modulators, etc. for power dividing and combining. However, the quarter-wavelength transmission lines conventionally used make the hybrids very large and expensive when they are incorporated into MMICs, and this can be a major drawback when designing an MMIC subsystem. Some approaches have been proposed to overcome the problem in size reduction [1, 2]. In this paper, very small, multilayer MMIC couplers are proposed as new approaches to this problem, a branch-line coupler and a broad-side coupler. The branch-line coupler, which incorporates quasi-lumped elements [3], consists of 70 Ω TFMS (thin film microstrip) lines [4, 5] with parallel capacitors on both sides and is only 0.4 mm × 0.4 mm in the K-band. The broad-side coupler is constructed with two strip conductors on different layers and ground metal below the strips, and effectively provides a tight coupling (3 dB) between the strip conductors. It operates in the frequency range between 20 GHz and 30 GHz, and is merely 0.2 mm × 0.2 mm in size. Both couplers employ a meander-like TFMS lines configuration to achieve more drastic size reduction.

Branch-Line Coupler

A K-band branch-line coupler, which incorporates quasi-lumped elements, and its circuit diagram are shown in Fig. 1. A quasi-lumped element method [3] gives the following equations:

$$Z = Z_0/\sin\theta$$
$$\omega C = (1/Z_0)\cos\theta,$$

where Z_0, Z, θ, and C are, respectively, the characteristic impedance for the conventional quarter-wavelength line, the characteristic impedance, electrical angle and capacitance for the capacitor loaded line. ω is angular frequency. With these equations, we obtain

$Z = 70\,\Omega$, $\theta = 45°$ for $50\,\Omega$ lines
$Z = 70\,\Omega$, $\theta = 30°$ for $35\,\Omega$ lines.

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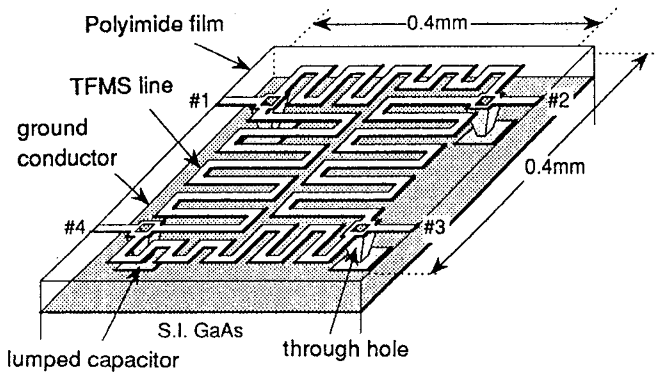
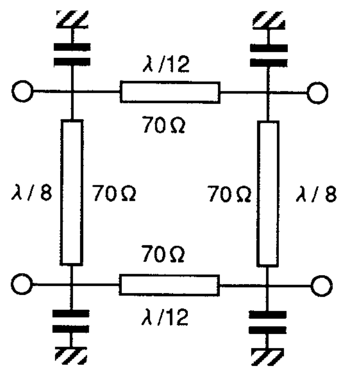


(a) Configuration



(b) Circuit diagram

Fig. 1: Branch-line coupler using capacitor-loaded high-impedance TFMS lines

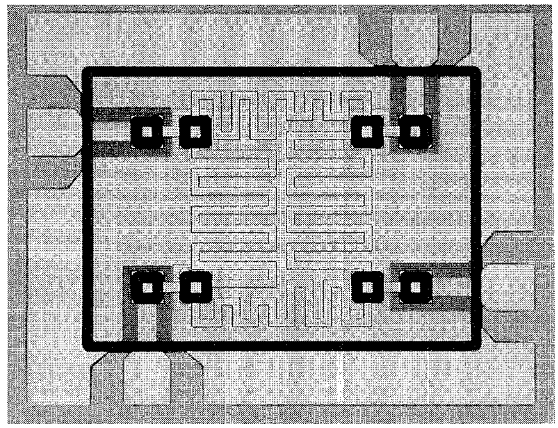


Fig. 2: Photograph of the branch-line coupler

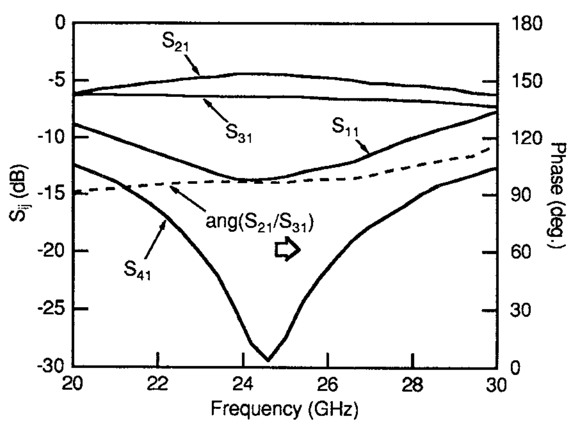


Fig. 3: Measured performance of the branch-line coupler

Thus the quasi-lumped element method effectively reduces the length of the transmission lines. 70 Ω TFMS lines of 1/8- and 1/12-wavelength and MIM capacitors are employed instead of the quarter-wavelength, 35 and 50 Ω transmission lines required for conventional branch-line couplers. The MIM capacitors are formed on the surface of the GaAs wafer and the upper conductors are connected vertically to the TFMS lines via through holes. The lower metal conductors are part of the base metal (ground) on the GaAs wafer surface. 10 μm thick polyimide film coated on a GaAs wafer is used for the substrate of the TFMS lines, where the 70 Ω TFMS lines' width is only 12 μm. TFMS lines are very narrow and allow us a meander-like configuration, where the line-space is only 18 μm. Therefore, the capacitor-loaded high-impedance TFMS line approach, as well as the meander-like configuration, provide more effective size reduction in the multilayer MMIC structure. A photograph of the newly developed branch-line coupler is shown in Fig. 2. The intrinsic area of the branch-line coupler is merely 0.4 mm×0.4 mm, about half the area of the recently reported TFMS branch-line couplers [5] and 1/20 that of conventional MMIC couplers. Figure 3 shows the measured performance of the newly developed branch-line coupler. Cou-

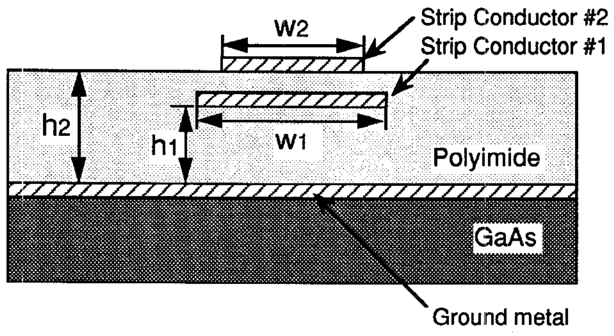


Fig. 4: Cross-sectional view of the broad-side coupler

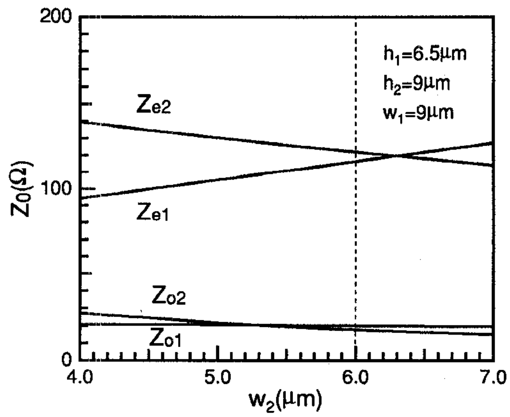


Fig. 5: Calculated characteristic impedance

pling loss of 5.5 ± 1 dB, return loss of better than 12 dB and isolation of better than 20 dB (30 dB at the center frequency) have been obtained over the 24–26 GHz frequency band.

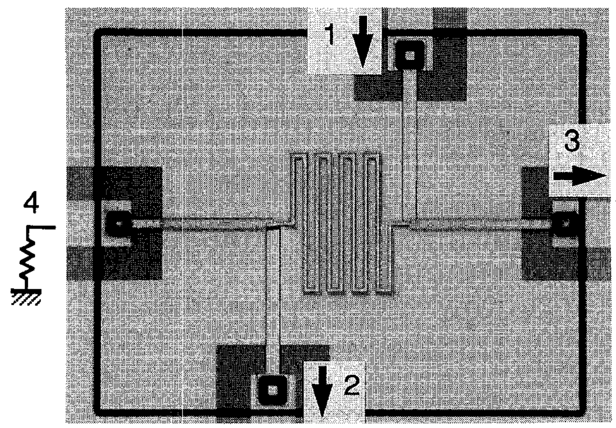


Fig. 6: Multilayer MMIC broad-side coupler. Port #1 is an input port, #2 and #3 are coupling ports and #4 is an isolation port.

Broad-Side Coupler

A cross-sectional view of a broad-side coupler is shown in Fig. 4. The coupler is constructed with two strip conductors on different layers and ground metal below the strips, and effectively provides a tight coupling (3 dB) between the strip conductors. In the figure, w_1, w_2, h_1 and h_2 are, respectively, the width and the height of strip conductors #1 and #2. Two orthogonal modes, corresponding to even- and odd-modes, propagate in the structure shown in Fig. 4. These modes are not exactly equivalent to even- and odd-modes because the two strip conductors are not symmetric to each other. However, the characteristics of the modes can be made electrically symmetric by adjusting the width and height of the strip conductors. If they are electrically symmetric, the conventional even- and odd-mode design method is available. For a 3 dB coupler with characteristic impedance $Z_0 = 50\,\Omega$, $Z_{0e} = 121\,\Omega$ and $Z_{0o} = 21\,\Omega$ are required, where Z_{0e} and Z_{0o} are the characteristic impedance of even- and odd-mode, respectively.

A finite element method (FEM) [6] is adopted to calculate the propagation constant and the characteristic impedance of each mode. Figure 5 shows the calculated characteristic impedance, when $h_1 = 6.5\,\mu m$, $h_2 = 9\,\mu m$, and $w_1 = 9\,\mu m$, where Z_{e1}, Z_{e2}, Z_{o1}, and Z_{o2} are, respectively, the even- and odd-mode characteristic impedance of microstrip lines #1 and #2. From the figure, the solution "$w_2 = 6\,\mu m$" is obtained. A meander-like configuration, shown in Fig. 6, is used to reduce the chip size drastically. The intrinsic area of the broad-side coupler is

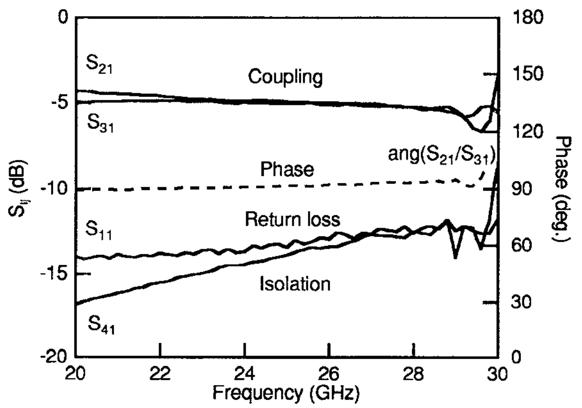


Fig. 7: Measured performance of the multilayer MMIC broad-side coupler

merely 0.2 mm $\times$ 0.2 mm, about 1/10 the area of conventional MMIC couplers. Figure 7 shows the measured performance of the newly developed broad-side coupler. Coupling loss of 5 $\pm$0.1 dB, and return loss and isolation of better than 12 dB have been obtained over the 20–30 GHz frequency band.

Conclusions

Very small, multilayer MMIC couplers, a branch-line coupler and a broad-side coupler, have been demonstrated. In the couplers, a quasi-lumped element, a multilayer coupled-line structure, and a meander-like configuration, based on the TFMS line, have been used for size reduction. These couplers can be effectively used in MMICs such as mixers and many other types of RF processing circuits.

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