Miniaturized Wilkinson Power Divider Using Three-Dimensional MMIC Technology

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***Abstract*— A miniaturized Wilkinson power divider using three-dimensional (3-D) monolithic microwave integrated circuit (MMIC) technology is presented. The new power divider utilizes stacked thin film microstrip (TFMS) lines that sandwich a ground plane with a slit between the TFMS lines. The slit effectively widens the upper and lower TFMS-line widths, which makes it possible to stack high-impedance lines with a reasonable conductor strip width and lower loss. The proposed structure also exhibits a coupling between the quarter-wavelength conductor strips of less than −15 dB, simplifying the design for each TFMS line. A fabricated 15–25 GHz Wilkinson power divider, the area of which is only 0.31 mm × 0.52 mm, exhibits a coupling of −4.5 ± 0.5 dB, isolation of greater than 15 dB, and a phase deviation of less than 3 degrees.**

I. Introduction

To SUCCESSFULLY construct multifunction monolithic microwave integrated circuits (MMIC's) such as single-chip receivers and transmitters, both miniaturization and high-level integration of MMIC's are required, and one of the important issues concerning this construction is reducing the size of dividers and combiners. Three-dimensional MMIC technology [1]–[6], incorporating thin-polyimide-film layers (2–3 μm each) on a wafer, has been demonstrated to be very effective for this purpose. The reasons for this are that miniature transmission lines, such as TFMS lines and inverted thin film microstrip (TFMS) lines, are designed with a narrow line-width and a spacing of less than 30 μm. The size of the Wilkinson power divider is still large, however, because 70-Ω quarter-wavelength TFMS lines are laid out on the top surface of the polyimide layers to achieve a low loss. Although stacking the 70-Ω lines above and below a ground plane reduces the size to possibly a half of the above configuration, an inverted TFMS line with a characteristic impedance of 70-Ω becomes particularly narrow (less than 3 μm) and lossy when a TFMS line is stacked above it.

This letter proposes a novel Wilkinson power divider configuration that stacks 70-Ω TFMS line above an inverted TFMS line separated by a ground metal plane which is sandwiched by two dielectric layers, and that effectively widens both lines using a slit in the ground metal plane between lines. This results in a line width of 13 μm for the upper TFMS line and 5 μm for the lower inverted TFMS line when the ground slit is 25 μm. These are values that are practical for fabrication. The very small coupling between the lines through the ground slit resulting from a large difference in the effective dielectric constants for the stacked lines also makes the design extremely simple.

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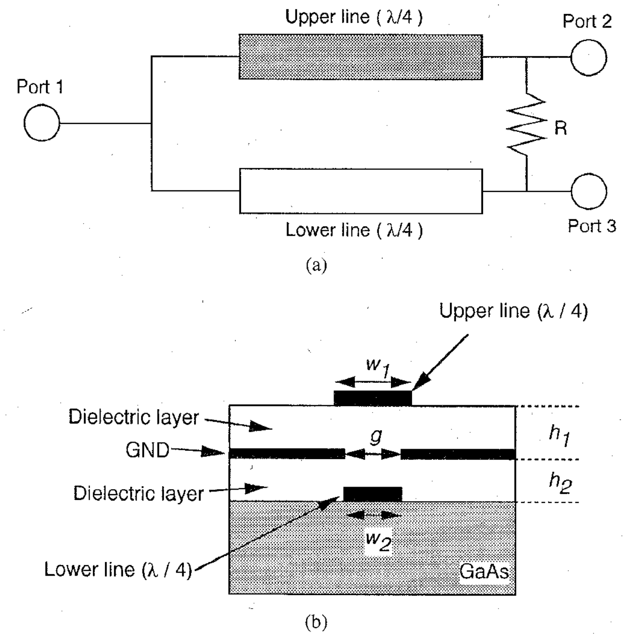

Fig. 1. Structure of the new power divider: (a) equivalent circuit and (b) cross-sectional view.

II. Circuit Structure

Fig. 1 shows the basic structure of a miniaturized Wilkinson power divider and its cross-sectional view. The most significant feature of the miniaturized Wilkinson power divider structure is that 70-Ω quarter-wavelength transmission-line strips constructed on the surface of the top polyimide layer and on the GaAs substrate are stacked above and below the common ground plane with a slit in the middle of the polyimide layers as shown in Fig. 1(b).

The isolation bandwidth is nearly constant when the coupling between the upper and lower lines is less than −15 dB, although it decreases as the coupling increases [7]. In addition, the characteristic impedance difference between the transmission lines with and without coupling is less than 3.8% under these conditions. This permits us to design separately the 70-Ω lines with ground slit. Fig. 2 shows the conductor strip widths, w_1 and w_2, for the TFMS and inverted TFMS lines in relation to the slit, g, where each polyimide film thickness, h_1

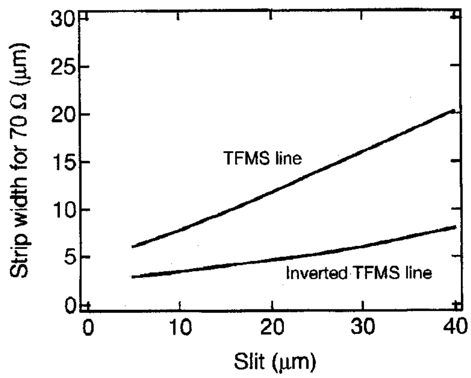

Fig. 2. Calculated strip width of a TFMS line and an inverted TFMS line with ground slit to obtain characteristic impedance of 70 Ω.

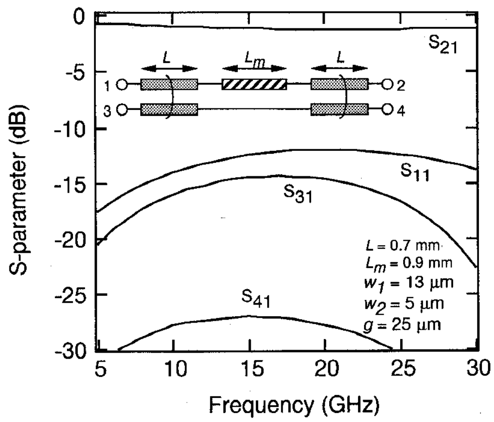

Fig. 3. Coupling effect between the TFMS lines through the slit.

and h_2, is 5 μm. The value of g is determined to be 25 μm to make the lower strip width, w_2, 5 μm. The upper strip width is 13 μm in this case. The other parameters for the upper 70-Ω line are: effective dielectric constant of 2.9, a loss per unit length of 0.21 dB/mm, and a quarter-wavelength of 2.3 mm at 20 GHz. The corresponding parameters for the lower one are 7.6, 0.40 dB/mm, and 1.4 mm, respectively. These parameters were calculated by full-wave FEM [8]. The loss values for the quarter-wavelength lines are close to each other. Using these parameters coupling between the lines was estimated. As shown in Fig. 3, both lines are stacked where the upper line exceeds the lower line by length L_m. The calculation was performed using *em* of Sonnet inc. and *Touchstone* of HP-EEsof. Coupling from port 1 to port 3 (S_{31}) is less than -14 dB over the calculated frequency range. This meets the above requirement for separately designing the lines. The coupling level is also low enough to achieve 90% or more of the isolation bandwidth for a divider using uncoupled lines.

III. Fabrication

Fig. 4 shows a microphotograph of a fabricated 15–25 GHz Wilkinson power divider. The quarter-wavelength conductor strips were formed in a meander-like configuration. The upper line length is 2.3 mm, and the lower line length is 1.4 mm. The ground slit in the middle of the polyimide layer runs along the upper and lower strips. Since the lower strip is shorter than the upper one by 0.9 mm, it takes shortcuts across the additional ground slits. The width of the ground metal between the slit edges is designed to be 40 μm to avoid coupling between the adjacent-line segments. A 110-Ω isolation resistor, fabricated by the GaAs FET process, was used for improving the isolation between the output ports. The lines running to ports 2 and 3 are normal TFMS lines, each of which has a conductor strip on the top surface and a ground metal in the middle of the polyimide-film layers. The intrinsic area of the divider is 0.31 mm × 0.52 mm, which is merely 0.16 mm^2.

Measured divider performance is indicated by the black curves in Fig. 5. The dotted curves are the calculated performance that was simulated without coupling effects between the upper and lower lines. Insertion loss for both coupling ports is as low as 1.5 ± 0.5 dB over the measured frequency range, and the coupling characteristics are well balanced due to the close transmission-losses for both quarter-wavelength lines. The bandwidth offering an isolation of greater than 15

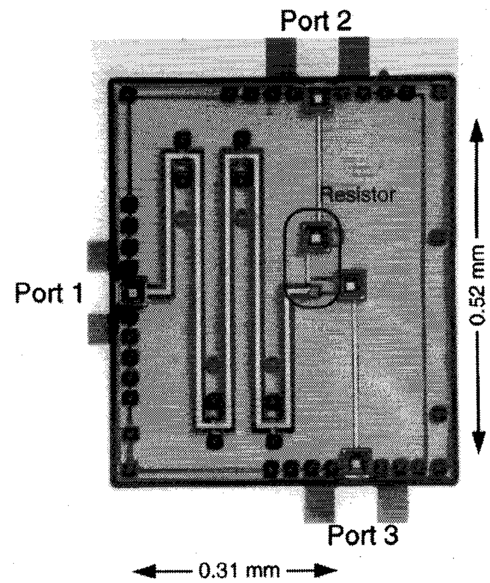

Fig. 4. Microphotograph of the power divider.

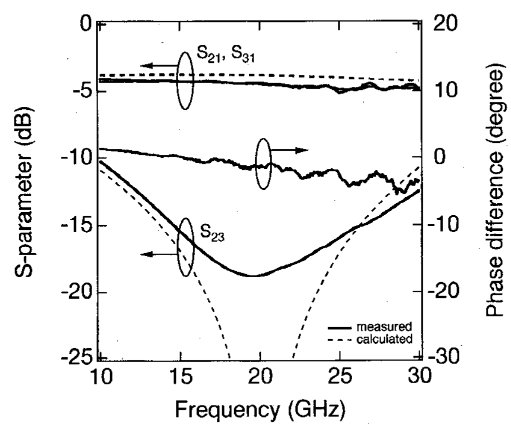

Fig. 5. Measured performance level.

dB is obtained from 15 GHz to 26 GHz; more than 90% of the bandwidth for the Wilkinson power divider is constructed with perfectly independent lines. Isolation at the center frequency is 18.8 dB. The phase difference between output signals on port 2 and port 3 is less than 3° over the frequency range. Return losses are better than -12 dB, where the values increases as frequency decreases.

IV. Conclusion

A very small Wilkinson power divider was proposed and fabricated in the 20-GHz band. The quarter-wavelength, 70-Ω lines were stacked above and below a ground metal plane with a slit in the ground plane, in a three-dimensional MMIC structure using polyimide layers and miniaturizing the circuit without significantly degrading the performance. The design was simplified based on a very small coupling between the conductor strips through the ground slit. The measured performance exhibited a close agreement to the calculated results. This result is effectively used to enhance the integration level of multifunction MMIC's.

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