Highly Miniaturized RF components employing metamaterial structure on MMIC

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Abstract: In this study, we introduce highly miniaturized on-chip impedance transformer and Wilkinson power divider, which were fabricated using metamaterial structure on MMIC. Concretely, a microstrip line employing metamaterial was used for a fabrication of the RF passive components. The size of the impedance transformer and power divider were reduced to 2.3 and 6 % of the conventional one, respectively.

1. Introduction

RF components dealing with high frequency signals are most important in wireless communication system and the performance of communication system depends on them [1]-[8]. To realize highly miniaturized and fully integrated communication system, miniaturized RF passive components should be fabricated on MMIC (monolithic microwave integrated circuit). Until know, metamaterial structure employing periodic patterns such as PBG (Photonic Band Gap) have been recently reported for a development of miniaturized passive components, and it has been found that they are very efficient structure for a miniaturization of passive devices and an improvement of RF characteristics of filters [9]-[14]. However, they have not been employed as transmission line due to their low resonance frequency characteristics originating from their inherent LC parallel structure, and the characteristic impedance was strongly dependent on frequency. For this reason, the conventional PBG and metamaterial have been mainly applied for filters on hybrid ICs. For a size reduction of RF components, we proposed a metamaterial structure employing periodic structure [15]-[17].

In this study, we introduce highly miniaturized on-chip impedance transformer and Wilkinson power divider, which were fabricated using metamaterial structure on MMIC. Concretely, a microstrip line employing periodically patterned ground was used for a fabrication of the RF passive components. The size of the impedance transformer and power divider were reduced to 2.3 and 6 % of the conventional one, respectively.

2. Microstrip line employing metamaterial structure

Figure. 1 (a) shows a top view of the microstrip line employing periodically patterned ground, and Figure. 1 (b) corresponds to a cross-sectional view according to Y-Y direction of Figure. 1 (a). As shown in Figure. 1 (b), periodically patterned ground plane was inserted at the interface between SiN film and GaAs substrate, and it was electrically connected to backside ground metal through the via-holes.

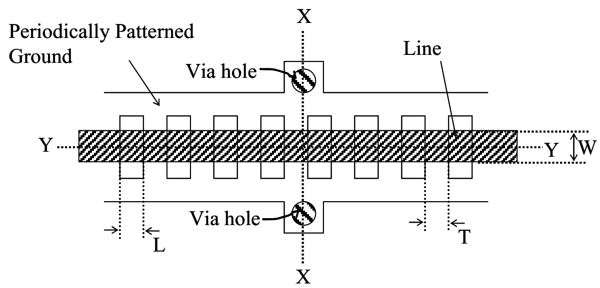

Fig. 1 (a) A top view of the microstrip line employing metamaterial structure with periodically patterned ground

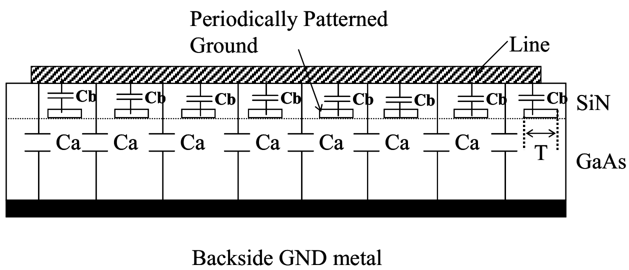

Fig. 1 (b) A cross-sectional view according to Y-Y direction of Figure. 1 (a)

As is well known, conventional microstrip line without PPGM has only a periodical capacitance C_a (C_a is shown in Figure. 1 (b)) per a unit length, while the microstrip line employing periodically patterned ground has an additional capacitance C_b as well as C_a due to periodically patterned ground. From this figure, we can see that the microstrip line with PPGM exhibits much lower characteristic impedance (Z_0) and shorter guided-wavelength (λ_g) than conventional one, because Z_0 and λ_g are inversely proportional to the periodical capacitance

$$Z_0 = (L/C)^{0.5} \quad (1)$$

$$\lambda_g = 1/[f \cdot (LC)^{0.5}] \quad (2)$$

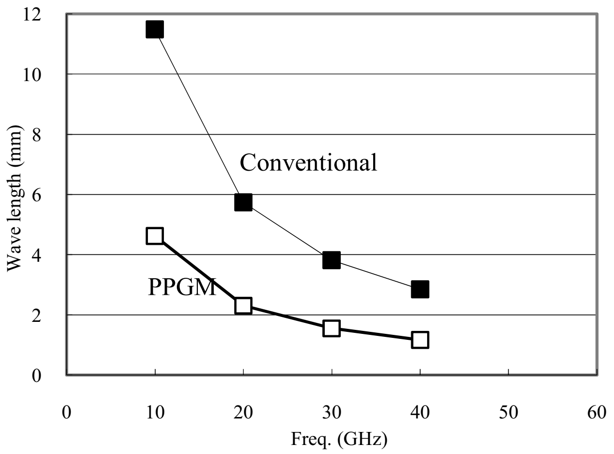

Fig. 2 Wavelength for conventional microstrip line and metamaterial structure employing periodically patterned ground.

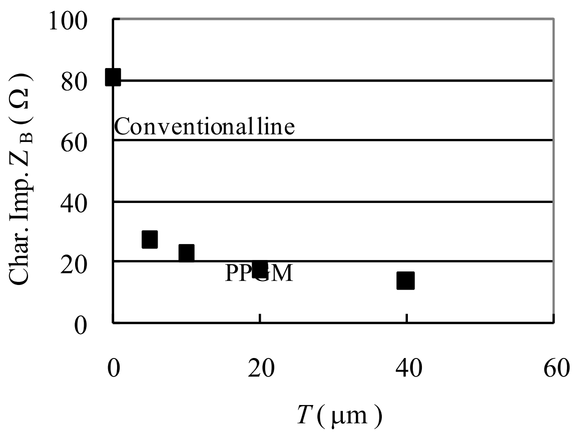

Fig. 3 Characteristic impedance for conventional microstrip line and metamaterial structure employing periodically patterned ground.

The wavelength (λ_g) for conventional microstrip line and periodically patterned ground structure on GaAs substrate with a height of 100 μm is shown in Figure. 2, where the thickness of SiN film and T for PPGM structure are 700 nm and 20 μm, respectively. As shown in this figure, the wavelength was highly reduced by using the PPGM structure. Figure 3 shows measured characteristic impedance Z_B, where T is the spacing between periodically perforated rectangular holes shown in Figure. 1 (a) and (b). Microstrip lines were fabricated by Au plating on GaAs substrate with a height of 100 μm. The width L for the holes and line width W, which are shown in Figure. 1 (a) and (b), were set to 20 μm, respectively. The thickness of the SiN layer was 700 nm. As shown in Figure. 3, characteristic impedance of the conventional microstrip line, which corresponds to the data at the spacing T = 0, is 80 Ω, and low Z_B can be obtained by increasing the spacing T because an increase of T causes an enhancement of periodic capacitance C_b. The value for Z_B can be easily controlled by only changing the spacing T. Above results mean that the metamaterial structure employing periodically patterned ground can be used for application to low impedance and miniaturized on-chip components on MMIC.

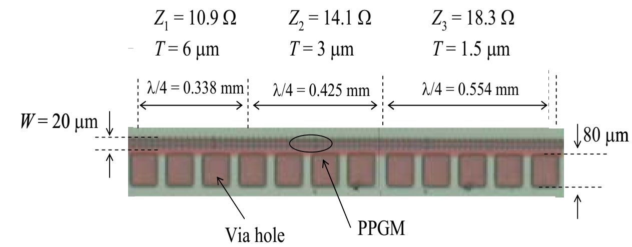

Fig. 4 A photograph of the impedance transformer employing metamaterial structure with periodically patterned ground

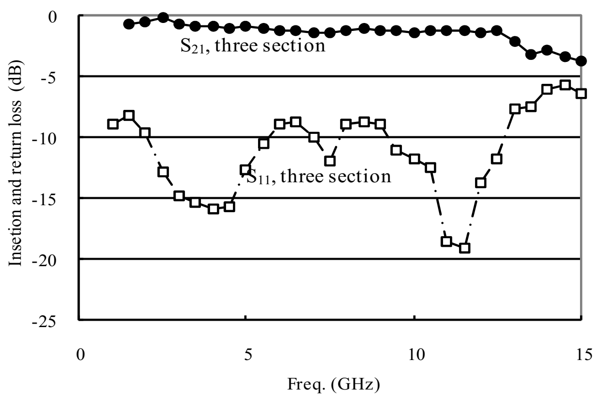

Fig. 5 Measured return and insertion loss of the impedance transformer employing metamaterial structure with periodically patterned ground

3. Miniaturized and low impedance on-chip transformer and Wilkinson power divider employing metamaterial structure on MMIC

For a development of a highly miniaturized on-chip broadband low-impedance transformer on a GaAs MMIC, we employed the microstrip lines with the metamaterial structure, which shows a much lower characteristic impedance and shorter guided wavelength than the conventional microstrip-line structure [15-17]. Figure. 4 shows a photography of the impedance transformer. Measured return loss S_{11} and insertion loss S_{21} are shown in Figure. 5. The three-section transformer exhibits return loss values lower than -9 dB from 2 GHz to 13 GHz, and insertion loss values lower than 1.2 dB in the above frequency range, which reveals that the three-section transformer can be applied for on-chip matching component between low impedance devices in a broadband including UWB.

Using the metamaterial structure employing periodically patterned ground, a highly miniaturized on-chip Wilkinson power divider with a low port impedance of 13 Ω was also developed. According to a measured wavelength for the conventional microstrip line and the metamaterial structure, line width and wavelength of the metamaterial structure with a characteristic impedance of 13 Ω are 20 ㎛ and 2.35 ㎜, respectively, while line width and wavelength of the conventional microstrip line with a characteristic impedance of 13 Ω are 640 ㎛ and 18.5 ㎜.

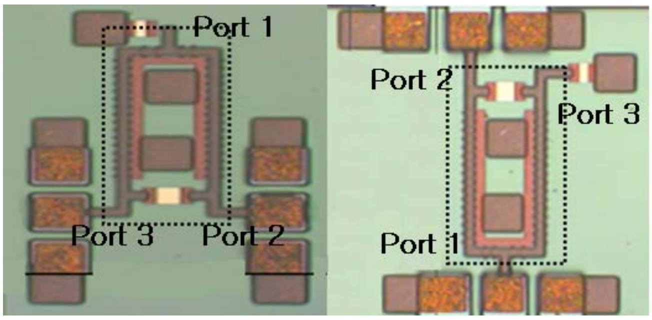

Fig. 6 A photograph of the Wilkinson power divider employing the metamaterial structure with periodically patterned ground on MMIC

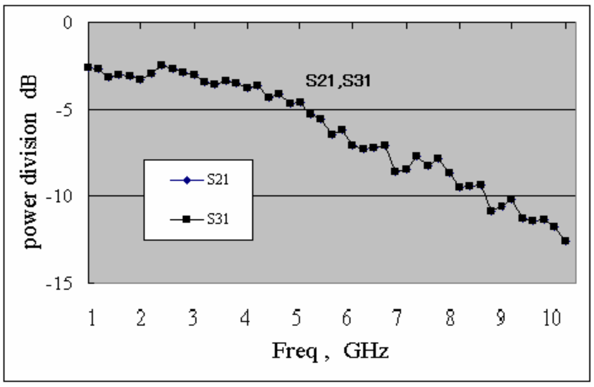

Fig. 7 Measured power division characteristic of the power divider employing the metamaterial structure with periodically patterned ground

A photography of the power divider is shown in Fig. 6. Actual size of the power divider corresponds to the part surrounded by dotted line because GSG pad was connected for on-wafer measurement. The size of the power divider employing PPGM structure on MMIC is 0.110 ㎟, which is 6 % of the size of the one fabricated by conventional microstrip line. Concretely, the size of the power divider employing conventional microstrip line on GaAs substrate with a height of 100 ㎛ is 1.82 ㎟ at 5 GHz. Figure. 7 shows measured power division (S_{21} and S_{31}) for the Wilkinson power divider employing the metamaterial structure with periodically patterned ground. As shown in Figure. 7, we can observe equal power division characteristics from 1 to 5 GHz. The power divider showed insertion loss values lower than -5.5 dB and isolations value better than -7.5 dB from 4.5 to 6 GHz.

4. Conclusion

In this study, we purpose a highly miniaturized on-chip impedance transformer and Wilkinson power divider, which were fabricated using metamaterial structure on MMIC. Concretely, a microstrip line employing metamaterial structure with periodically patterned ground was used for a fabrication of the RF passive components. The size of the impedance transformer and the power divider were reduced to 2.3 and 6 % of the conventional one, respectively. And the size of the power divider was 0.110 ㎟, which is 6% of conventional one.

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