A Miniaturized Wide Band Impedance Transformation Circuit Employing Periodic Ground Structure on RFIC

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Abstract

In this work, using a coplanar waveguide employing periodic ground structure (PGS) on silicon substrate, a highly miniaturized impedance transformer was developed for application to wide band communication system. Concretely, the multi-section transformer was designed using Chebyshev polynomials design technique for ultra broadband operation. Its size was 0.026 m^2 on silicon substrate, which was 8.7 % of the one fabricated by conventional coplanar waveguide on silicon substrate. The impedance transformer showed a good RF performance over ultra broadband from 8 – 49.5 GHz.

Keywords : Impedance transformer, RFIC (radio frequency integrated circuit), PGS (periodic ground structure), UWB (ultra wide band)

1. Introduction

In broadband communication system such as ultra wide band (UWB), low impedance transformation is required for impedance matching between active devices because the input and output impedances of the FETs are much lower than 50 Ω in RF band [2]. Therefore, for an efficient impedance matching of radio frequency integrated circuit (RFIC) in broadband communication system, a broadband and low impedance transformer performing low impedance transformation between active and passive devices is indispensable, and it should be highly miniaturized for integration on RFICs. λ/4 impedance transformers have been widely used for comparative broad bandwidth [3].

In this work, in order to realize highly miniaturized on-chip transformer, the multi-section impedance transformer was fabricated using periodic ground structure (PGS) [1, 4] on silicon substrate. For ultra broadband operation, it was developed using Chebyshev polynomials design technique.

2. A Coplanar Waveguide Employing PGS

Coplanar waveguide employing slow wave structure was fabricated on GaAs substrate for the first time [7]. Recently, a slow-wave structure on silicon substrate has been reported for application to passive components[1, 4, 8]. Figure 1 shows a structure of coplanar waveguide employing PGS, and figure 2 (a), (b) shows cross sectional view of PGS structure. As shown in Fig. 1 and 2, PGS exists at the interface between SiO_2 film and silicon substrate, and it was electrically connected to top-side ground planes (GND planes) through the contacts. Therefore, PGS was grounded through GND planes. As is well known, conventional coplanar waveguide without PGS has only a periodical capacitance C_a (C_a is shown in Fig. 2) per a unit length, while the coplanar waveguide employing PGS has additional capacitance C_b as well as C_a due to PGS. As shown in Fig. 2, C_b is a capacitance between line and PGS. In other words, a total capacitance (per unit length) of the coplanar waveguide employing PGS corresponds to $C_a + C_b$, but, it corresponds to C_a for a conventional coplanar waveguide without PGS.

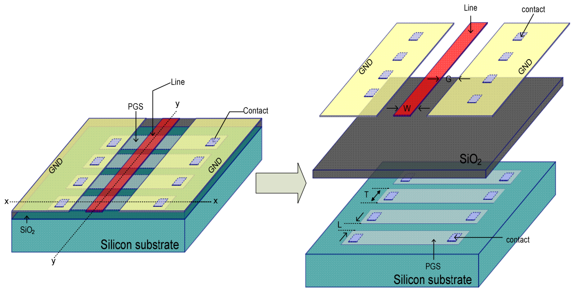
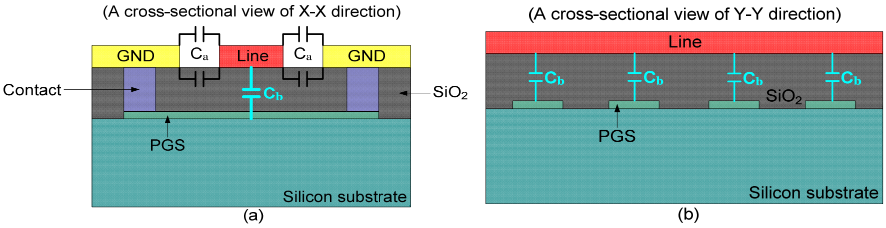


Figure 1: A Structure of Coplanar Waveguide Employing PGS.



(a)

(b)

Figure 2: (a) A Cross Sectional View of PGS Structure's X-X Direction.
(b) A Cross Sectional View of PGS Structure's Y-Y Direction.

Therefore, we can see that the coplanar waveguide employing PGS exhibits much shorter guided-wavelength (λ_g) and lower characteristic impedance (Z_0) than conventional one, because λ_g and Z_0 are inversely proportional to the periodical capacitance, in other words, $\lambda_g=1/[f\cdot(LC)^{0.5}]$ and $Z_0=(L/C)^{0.5}$ [1]. Concretely, as shown in Fig. 3, the wavelength of conventional coplanar waveguide on silicon substrate is 2.95 mm at 40 GHz, while it is 1.86 mm for coplanar waveguide employing PGS. In addition, λ_g and Z_0 can be easily controlled by only changing the spacing T (T is shown in Fig. 1), because an increase of T results in a reduction of λ_g and Z_0 due to an increase of C_b.

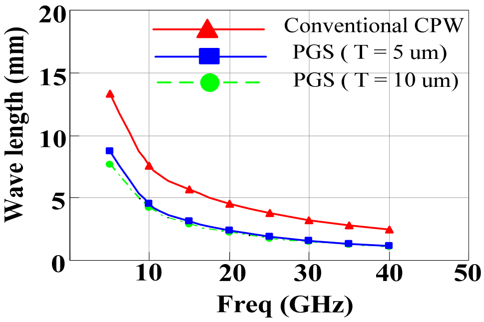


Figure 3: Measured Wavelength of The Coplanar Waveguide Employing PGS and Conventional One.

3. A Highly Miniaturized Impedance Transformer Employing PGS on Silicon RFIC

Using the coplanar waveguide employing PGS, a highly miniaturized and low impedance on-chip transformer employing multi-section lines was developed for broadband applications. For broadband operation, we designed a broadband multi-section transformer using the Chebyshev function. Figure 4 is a photograph of multi-section transformer employing PGS structure. For broad bandwidth, the reflection coefficient should be Chebyshev function response, and the following equations should be satisfied [2].

$$\Gamma(\theta)=2e^{-jN\theta}[\Gamma_0\cos N\theta+\Gamma_1\cos(N-2)\theta+....+\Gamma_n\cos(N-2n)\theta \\ +...+\frac{1}{2}\Gamma_{N/2}]=\Gamma_m e^{-jN\theta}T_N(\sec\theta_m\cos\theta),\quad for\ N\ even \tag{1 a}$$

$$\Gamma(\theta)=2e^{-jN\theta}[\Gamma_0\cos N\theta+\Gamma_1\cos(N-2)\theta+....+\Gamma_n\cos(N-2n)\theta \\ +...+\Gamma_{(N-1)/2}\cos\theta]=\Gamma_m e^{-jN\theta}T_N(\sec\theta_m\cos\theta), \quad for\ N\ odd \tag{1 b}$$

$$\sec\theta_m=\cosh\left[\frac{1}{N}\cosh^{-1}\left(\frac{1}{\Gamma_m}\left|\frac{Z_L-Z_0}{Z_L+Z_0}\right|\right)\right] \tag{2}$$

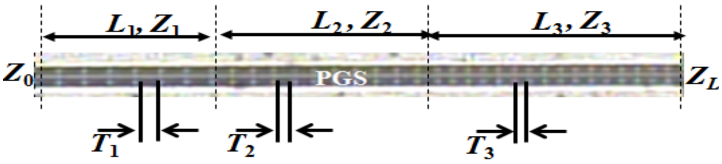


Figure 4: A Photograph of Multi-section Impedance Transformer Employing PGS on Silicon RFIC.

where Γ_m and T_N are a maximum value of reflection coefficient and nth order Chebyshev polynomial, respectively. N and Γ_n are number of section and reflection coefficient of multistage transformer shown in Fig. 4. If N, Γ_m, Z_L and Z_0 are determined, we can obtain secθ_m from Eq. (2). In this work, we designed three-section transformer to match a 50 Ω load to 19 Ω line, with Γ_m = 0.05. From Eq. (3) and (1b) with N = 3, we can obtain Eq. (4).

$$T_3(\sec\theta_m\cos\theta)=\sec^3\theta_m(\cos3\theta+3\cos\theta)-3\sec\theta_m\cos\theta \tag{3}$$

$$\Gamma(\theta)=2e^{-j3\theta}[\Gamma_0\cos3\theta+\Gamma_1\cos\theta]=\Gamma_m e^{-j3\theta}T_3(\sec\theta_m\cos\theta) \\ =\Gamma_m e^{-j3\theta}[\sec^3\theta_m(\cos3\theta+3\cos\theta)-3\sec\theta_m\cos\theta] \tag{4}$$

We obtain the characteristic impedances Z_1 = 26 Ω, Z_2 = 35 Ω, and Z_3 = 43 Ω from the with N = 3, Z_L = 50 Ω and Z_0 = 19 Ω. The photograph of the three-section transformer is shown in Fig. 4. The length of each section of the λ/4 transformer, L_1, L_2 and L_3 are 0.38, 0.44 and 0.485 mm, respectively. Therefore, the size of the transformer including via holes is 0.261 mm^2, which is 8.7 % of the size of the transformer fabricated by conventional coplanar waveguide (if we fabricate the three section impedance transformer using the conventional coplanar waveguide on silicon substrate, the size of the impedance transformer is 0.3 mm^2). Measured return loss S_{11} (Γ of Fig. 4) and insertion loss S_{21} of the three-section transformer are shown in Fig. 5, respectively. The three-section transformer exhibits return loss values lower than -10 dB from 8 GHz to 49.5 GHz, and insertion loss values are -1.5 ± 1 dB in the above frequency range, which is -1.15 ± 0.76 dB/mm for a length of 1 mm (the length of the multi-section transformer is 1.305 mm). Considering that silicon substrate is loss due to its high conductivity [6,7], the above insertion loss is comparatively small, and it is sufficiently low for application to silicon RFIC. Above results indicate that the highly miniaturized multi-section impedance transformer is a promising candidate for application to low impedance transformation in ultra broadband.

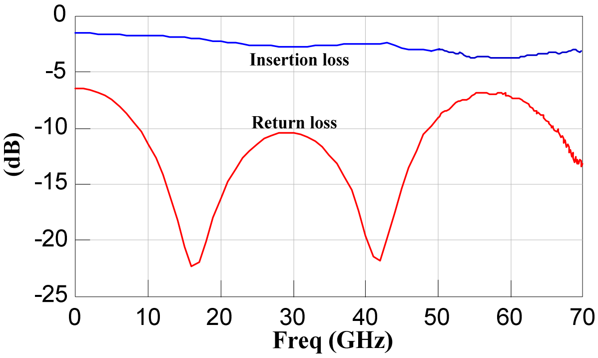


Figure 5: Measured Return Loss and Insertion Loss of The Multi-section Impedance Transformer Employing PGS.

4. Conclusion

In this work, using a coplanar waveguide employing PGS on silicon substrate, we developed a highly miniaturized impedance transformer for application to wide band. For ultra broadband operation, we designed the multi-section transformer using Chebyshev polynomials design technique. Concretely, impedances of three section transformer were determined so that the reflection coefficient of the transformer would be Chebyshev function response. The three-section transformer exhibited return loss values lower than -10 dB from 8 GHz to 49.5 GHz, and insertion loss values are -1.15 ± 0.76 dB/mm in the above frequency range. Its size was 0.026 m^2 on silicon substrate, which was 8.7 % of the one fabricated by conventional coplanar waveguide on silicon substrate. Above results reveal that the highly miniaturized multi-section impedance transformer is a promising candidate for application to low impedance transformation in ultra broadband.

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Acknowledgments

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