work. By using CSRRs, a very large insertion loss was obtained in the stopband. Because the bandgap characteristic is the behavior of the CSRR itself, not because of the array of the periodic structure, the dimensions of the structure can be made much smaller than in the case of a microstrip line with a periodic perturbation of square pattern on the ground plane. The sub-wavelength resonator is proved to find practical applications in band reject structures with small size. The attenuation and propagation constants of unit cell of this structure were extracted and a physical behavior of stopband of this CSRR loaded microstrip line has been demonstrated.

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VARIABLE $Z_c$ TRANSMISSION LINE AND ITS APPLICATION TO AN IMPEDANCE TRANSFORMER

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ABSTRACT: This paper presents a novel transmission line with variable characteristic impedance. A tunable impedance transformer using this line is fabricated and measured. The impedance transformer can be electronically varied from 10 $\Omega$ to 65 $\Omega$ in a 50 $\Omega$ environment at the center frequency of 900 MHz. © 2005 Wiley Periodicals, Inc.


Key words: transmission line; impedance transformer; characteristic impedance

1. INTRODUCTION

As the demands for wireless communications increase and become complex, RF front-ends need multiband or wideband circuits to satisfy several standards of wireless systems, which makes a tunable circuit essential. An adaptive controlled system which can enhance the performances of a wireless system also requires tunable devices and circuits. For instance, a high-performance transmitter with good efficiency or a multiband transceiver needs a good impedance match between antenna and amplifiers or filters. A wideband antenna, however, does not have an impedance of 50 $\Omega$ and neither does a power amplifier, in general. As this may decrease the efficiency of overall system, many authors have reported methods to improve the impedance match and enhance the performances by means of a tunable transformer [1–3]. For a specific purpose, such as performing measurements, a wide range of tunable impedance is needed, as in [4–6]. In this case, more complicated structures and control units are also required. Especially, most of the published papers use more than two bias inputs to control the impedance of the tuner. For a practical RF front-end system, more convenient way of implementation will make a more efficient system.

A variable capacitor, such as a varactor diode, is the most frequently used device as a tuning element, but it has a limitation to meet every requirements. This is mainly caused by the lack of variable inductance devices or circuits. As an alternative way to realize a tunable circuit, we propose in this paper a variable $Z_c$ transmission line which can be used as a distributed tuning circuit. Moreover, a new method is proposed to implement a variable characteristic impedance $Z_c$ line that is controlled by a single bias. As an application, a tunable impedance
transformer can be constructed with the proposed line when its electrical length is around 90° over an operating frequency band. A demonstrator for such a tunable impedance transformer has been designed, fabricated, and tested. Both the simulated and experimental results are presented.

2. VARIABLE \( Z_C \) TRANSMISSION LINE

The new type of transmission-line structure is shown in Figure 1(a). We have added a metal layer between the signal line and ground as the third metal, which is connected by a switch with the ground layer. Assume that the dielectric constants \( \varepsilon_1 \) and \( \varepsilon_2 \) have the same value and the equivalent capacitance per unit length between the signal line and the inserted metal, \( C_1 \), is significantly larger than \( C_2 \), which originates from the inserted metal and ground. When the switch is on, the equivalent circuit can be expressed as shown in Figure 1(b), and the line can have a low \( Z_C \) value. On the other hand, when the switch is off, the equivalent circuit can be expressed as shown in Figure 1(c), and the line can have a high \( Z_C \) value. As shown in Figure 1(d), we substitute a varactor for the switch, by which the circuit has continuous values of \( Z_C \) with the bias voltages. Its higher \( Z_C \) limit is determined by the structure shown in Figure 1(c) and the lower one depends on the structure shown in Figure 1(b).

3. TUNABLE IMPEDANCE TRANSFORMER

Based on the new variable \( Z_C \) transmission line, we have designed a tunable impedance transformer. In general, the input impedance of a transmission line with a load, \( Z_L \), as shown in Figure 2, is expressed in Eq. (1), where \( \beta \) is the propagation constant and \( l \) is the length of the line; if the line has a quarter-wavelength, the input impedance has the relation of Eq. (2) and operates as an ideal impedance transformer:

\[
Z_{in} = Z_C \left[ \frac{Z_L + jZ_C \tan \beta l}{Z_C + jZ_L \tan \beta l} \right]. \tag{1}
\]

\[
Z_{in} = \frac{Z_C^2}{Z_L}. \tag{2}
\]

For practical implementation with a conventional substrate and hybrid elements, we modify the vertical structure of a variable \( Z_C \) transmission line in Figure 1(d) into a uniplanar structure using CPW-like transmission line. In Figure 3, we used coupled CPW lines which represent the signal line and the third metal in Figure 1(a). This figure shows a unit cell of a variable \( Z_C \) transmission line, of which the characteristic impedance varies when the bias to a diode is adjusted. In order to achieve tight coupling between the signal line and the inserted third-metal layer, lumped capacitors, \( C_S \) and \( C_{SE} \), are added, which enlarge the tuning range. Also, \( D_{var} \) represents a varactor diode, which is connected between the inserted metal and ground metal. This modeling and simulations were performed using Agilent ADS.

Figure 4 shows the block diagram of the designed tunable impedance transformer while Figure 5 is a photograph of the fabricated circuit board. \( Z_C \) is controlled by a single bias voltage to the varactors, which makes the control circuit and algorithm simple. For the supply of dc bias to varactors and the suppression...
of parasitic anti-resonance (which comes from the length of the inserted third metal), we cut the RF path and insert a chip resistor $R_S$ with a high value. We used a dielectric substrate with a relative dielectric constant $\varepsilon_r$ of 3.05 and the height of 1.524 mm in order to implement a CPW line with high $Z_C$. The varactor, which has capacitances of 0.5 to 9.5 pF with respect to the bias voltage of 0 to 30 V, is an Infenion BB833, denoted as $C_{var}$ in Figure 4. The fabricated impedance transformer in Figure 5 has an overall dimension of $2.9 \times 1.0$ cm$^2$.

The simulated result, shown in Figure 6, indicates that the impedance transformer can be electronically varied from 19Ω to 65Ω in a 50Ω environment at the center frequency of 900 MHz, and it has a bandwidth of 200 MHz when the bias supply varies from 0 to 16 V. The input impedance of an impedance transformer has a parasitic-reactance element due to the lumped elements, such as varactors and chip capacitors, while the control voltage varies. This is based on the difference of the propagation constants for the different bias conditions. However, its level is quite low within a specific frequency band. The scattering-parameter measurements were performed using an Agilent 8753D network analyzer over the frequency range from 0.8 to 1 GHz. Figure 6 also shows the measured responses of the impedance transformer in which the tuning range was found to be 10Ω to 69.5Ω. This agrees well with the simulated result, except for the minor discrepancy due to the parasitic of varactors.

4. CONCLUSION

This paper has proposed a new type of variable $Z_C$ transmission line and its application to a tunable impedance transformer in order to enhance the efficiency of an RF front-end. It is promising for high-performance transceiver and reconfigurable antenna systems. The measurement of the experimental demonstrator has shown that the proposed impedance transformer has a broad tuning range with single bias voltage. This tunable impedance transformer can be easily constructed by applying conventional MMIC techniques. It is especially promising for RF MEMS applications when switches are used for the digitally controlled impedance transformer.

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