Microwave chirped delay effect based on substrate thickness modulation

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Abstract: This paper deals the generation of chirped delay (CD) effect in microwave regime. For the purpose of achieving reflection dispersion, electromagnetic band-gap (EBG) structures with different rejection frequency are fabricated in different position by modulating the thickness of substrate. Microwave with different frequency will be reflected in different position, so non-flat reflected group delays responses can be obtained. One CD-EBG with 6–10 GHz operation frequency range is designed, fabricated and measured. Different group delay responses are obtained when feeding from different ports. Finally, temporal characteristic of the CD-EBG is studied by simulation and two chirped impulses are obtained.

Keywords: microwave, chirped delay (CD), dispersion, electromagnetic band-gap (EBG), group delay

Classifi cation: Electromagnetic theory

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1 Introduction

In recent years, real-time signal processing in microwave or millimeter wave regime have become an urgent topic due to the limitation of the digital signal processing technique [1, 2, 3, 4, 5]. In order to search an efficient way to deal with signals with high frequency, the researchers have turned their attention to analog signal processing technique which is based on physical mechanism of the components [1, 2, 3]. As the key component, the chirped delay line plays an important role in the real time waveform transmission system [3, 6]. There are several types dispersion delay line have been widely used and reported. The most common ones are dispersion fiber and surface acoustic wave dispersion delay line [7, 8, 9]. Both of them have the advantages in terms of large time-bandwidth product and compact sizes, however, these DDLs are not suitable for fully electromagnetic systems due to their operation frequency. Another transmission type dispersion component is the magneto-static wave dispersion delay line [10]. It works in microwave frequency and provides large time-bandwidth product. But the lossy and cumbersome peripheral equipment limits their applications in modern wireless systems. Therefore, it is necessary to develop a new kind of chirped delay line with low cost and compact size in microwave regime.

The microstrip line has the flexibility to fabricate various electromagnetic structures in microwave regime such as left-handed (LH) structure and Electromagnetic Band-Gap (EBG) [6, 11]. In 2003, width modulation technique of the microstrip is employed to fabricate quasi-periodic EBG structure to obtain linear reflection group delay [6]. Then the subsequent studies based on this structure have been reported [12, 13]. In 2009, a design method of reflection chirped delay line based on artificial substrate technique was reported to fabricate EBG structure [12]. The discontinuity is fabricated inside the entire structure to avoid back radiation and asymmetry of the scattering parameters.

In this paper, another approach to fabricate microstrip chirped delay line is proposed. The chirped delay line is realized by constructing EBG structures with different rejection frequency. The impedance discontinuity is controlled by mod-
ulating the thickness of the substrate. Compared with the method proposed in [12], this method provides not only the same advantages, but also reduce the cost of the fabrication processing. Moreover, the effective dielectric constant of each EBG unit is easier to calculate and fix by thickness modulation.

2 Principle

2.1 Basic theory

The equivalent transmission model of a CD-EBG with 3 varied periods is show in Fig. 1. As denoted in Fig. 1, the total physical length of the transmission line is $L$. In order to obtain band-gap effect, the characteristic impedances $Z_{01}$ and $Z_{02}$ of the adjacent units in one period should be different. According to Bragg condition [7], the band-gap frequency is,

$$f_{\text{gap}} = \frac{c}{2(n_1 l_1 + n_2 l_2)} \tag{1}$$

where $c$ is the speed of light in vacuum, $l_1$ and $l_2$ are the physical length of the adjacent units in one period which are related to the electrical length $\theta_1$ and $\theta_2$; $n_1$ and $n_2$ are the refraction indexes of the adjacent units in one period which can be determined by the permeability and permittivity of the medium,

$$n = \sqrt{\varepsilon_{\text{eff}}/\mu_{\text{eff}}} \tag{2}$$

When the physical lengths of the periods are different, according to (1), band-gaps with different frequencies will be distributed at different position along the transmission line. Therefore, the input microwave with different frequency will be reflected at different position which results in non-flat reflection group delay response. Finally, the dispersion delay effect is obtained. In Fig. 1, the physical length of the period is,

$$\Lambda_n = l_1 + [l_2 + (n + 1)\Delta l] \tag{3}$$

If the increment $\Delta l$ is larger than 0, according to (1), the band-gap frequency would be decreased and negative chirped delay would be achieved, otherwise, positive chirped delay response would be achieved. According to 1, there are several ways to achieve chirped delay effect.
2.2 CD-EBG structure design

According to (2), there are two obvious ways to change the refraction index of the medium, the first is to change the relative effective permittivity $\varepsilon_{\text{reff}}$, the other way is to change the relative effective permeability $\mu_{\text{reff}}$. For conventional microstrip structure, it is difficult to change its permeability. Therefore, we choose the first way to achieve the purpose.

The most direct way is to modulate the line width of the transmission line which can change the characteristic impedance, however, the loss of the structure fabricated using this way is large [6]. Another way is to change the dielectric constants between the adjacent unit [12]. This method can reduce the loss but will bring difficult in fabrication. Therefore, it is necessary to find a way to design the CD-EBG structure, which is easy to fabricate and avoid loss increasing.

The permittivity of the microstrip line $\varepsilon_{\text{reff}}$ depends on,

$$
\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(1 + \frac{12H}{W}\right)^{1/2} + F - 0.217(\varepsilon_r - 1) \frac{T}{\sqrt{HW}}
$$

where, where $\varepsilon_r$ is the relative permittivity of the substrate, $H$ is the thickness of the substrate, $W$ and $T$ are the width and thickness of the signal line, respectively. $F$ is a function related to $W/H$,

$$
F\left(\frac{H}{W}\right) = \begin{cases} 
0.02(\varepsilon_{\text{reff}} - 1)\left(1 - \frac{W}{H}\right) & \text{for } \frac{W}{H} \geq 1 \\
0 & \text{for } \frac{W}{H} < 1
\end{cases}
$$

In this case, to avoid such drawbacks, we choose modulating $H$ to vary $\varepsilon_{\text{reff}}$. Fig. 2 show the relationship between $\varepsilon_{\text{reff}}$ and $H$ of substrate with $\varepsilon_r$, when other parameters are fixed.

The schematic of the proposed method is shown in Fig. 3. Fig. 3(a) depicts the 3D view of the chirped delay line based on modulation of substrate thickness. As shown in this figure, the entire structure consists of two substrate layers. Between the two layers, there are some etched metal strips to isolate them and the metal strips are connected with the ground by metallic holes. Fig. 3(b) is the literal view of the structure. As shown in Fig. 2, the thicknesses of the substrates are $h_1$ and $h_2$.

![Fig. 2.](image-url) Equivalent transmission line model of the quasi-periodic electromagnetic band-gap.
respectively. When the metal strips exist, in this region, the effective thickness of the substrates H will be $h_1$. When there are no metal strips, the effective thickness of the substrates H in this region will be $h_1 + h_2$. According to (4), the relatively effective dielectric constants in the adjacent regions should be different. Once $\varepsilon_{\text{reff}}$ is fixed, it is easy to control the band-gap frequency along the direction of propagation of the microwave. Since $L_1$, $L_2$ and $L_3$ are linearly increased, an up-chirp response can be obtained if the signal is fed from the left port.

![3D view of the CD-EBG.](image)

(b) Literal view of the CD-EBG.

**Fig. 3.** Configuration of the CD-EBG

![Equivalent transmission line model of the quasi-periodic electromagnetic band-gap.](image)

**Fig. 4.** Equivalent transmission line model of the quasi-periodic electromagnetic band-gap.

### 3 Simulation and experiment validation

A chirped delay EBG has been designed and fabricated using the proposed method. The bottom substrate of the fabricated structure is shown in Fig. 4. Substrates with relative dielectric constant $\varepsilon_r = 6$ are selected to fabricate the chirped delay EBG. The thickness of the two substrates are $h_1 = h_2 = 1$ mm. The width of the micro-
strip line is 3 mm which corresponds to characteristic impedance of 50 Ω. The width of the metal strip is $L_a = 3$ mm. The length of the other part of the first period is $L_1 = 9$ mm. The length of the periods is,

$$\Lambda_n = L_a + [L_1 + (n - 1)\Delta L] \quad (i = 0, 1, 2, \cdots 17) \quad (6)$$

The radius of the metallic holes is 0.4 mm. In region I, because of the existence of the metal strip, the effective thickness of the substrate is $h_1 = 1$ mm, which corresponds to $\varepsilon_{\text{eff}} = 4.62$. In region II, the effective of the thickness of the substrate is $h_2 = 2$ mm, which corresponds to $\varepsilon_{\text{eff}} = 4.33$. According to (4), the longest period structure will generate the lowest band-gap frequency of the entire structure, while the shortest one will generate the highest band-gap frequency.

Numerical simulations and experiments are carried out to verify the principle. The simulation results are using commercial simulation software CST Microwave Studio. The S11 and S22 parameters are measured by Vector Network Analyzer 8730. As shown in Fig. 5, the simulation and experimental results are well matched. The CDL operates from 6 to 10 GHz.

![Fig. 5. Reflection parameters of the CD-EBG](image)

![Fig. 6. Equivalent transmission line model of the quasi-periodic electromagnetic band-gap.](image)

Fig. 6 shows the reflected group delay responses. As shown in Fig. 6, up chirp and down chirp responses can be obtained from different ports. As shown in Fig. 4, the Bragg periods gets shorter and shorter from left to right which leads to the rejection frequency of the bang-gaps getting higher and higher.
the left side of the structure, the microwave signal with the lowest frequency will be reflected firstly and the signal with the highest frequency will be reflected lastly. Therefore, the group delay increases with the increasing of frequency (the blue line shown in Fig. 6). The opposite group delay responses (the brown line shown in Fig. 6) can be obtained for the same reason mentioned before.

![Graph](image)

(a) Input pulse.

(b) Output signal. Feeding from the left port.

(c) Output signal. Feeding from the left port.

Fig. 7. Input and output signals

The time domain characteristics of the CD-EBG structure have been also studied using CST Microwave Studio. Fig. 7 shows the input and output signals. The signal with 4 GHz bandwidth and 8 GHz central frequency is fed into the CD-EBG from different ports. As shown in Fig. 7(b) and (c), compared with the input signal, the output signals are dispersed. Since the group delay of S11 and S22 are opposite, the output signals exhibit different dispersion characteristics.

4 Conclusion

In this paper, a new approach to obtain strong chirped delay effect in microwave regime is proposed. The discontinuity of the characteristic impedance of the transmission line is fabricated inside the structure by substrate thickness modulation. Compared with the method introduced in [12], the effective dielectric constant of each unit is easier to calculate and fix. Moreover, the less metallic holes can make the structure more firm than the one proposed in. Finally the scattering parameters of the CD-EBG structure are simulated and measured, and the time domain characteristics are studied by simulation.
Acknowledgments

This work was funded by the Fundamental Research Funds for the Central Universities (Grant No. ZYGX2015KYQD040), Project (9140C070403150C07003) and National Natural Science Foundation of China, (Grant No. 61601087.)