Broadband choke structure using composite right/left-handed coaxial line

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Abstract: The composite right/left-handed (CRLH) coaxial line (CL) is applied to the broadband choke structure. Because the choke structure uses an electromagnetic bandgap (EBG), broadband operation is realized. To obtain the wide bandwidth of the EBG, the CRLH CL is redesigned and applied to the choke structure. The proposed choke structure is attached to the coaxially fed monopole antenna, whose characteristics are simulated. The simulated results show that the proposed choke structure operates in broadband.

Keywords: electromagnetic bandgap, sleeve antenna, choke structure, leakage current

Classification: Antennas and Propagation

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1 Introduction

When a monopole antenna without a ground plane is fed by a coaxial line (CL), a leakage current flows through the outer conductor of the CL because the CL is unbalanced. The leakage current radiates undesired waves and the radiation pattern is deformed. To suppress the leakage current, a coaxial choke structure is attached to the outer conductor of the CL. A coaxially fed monopole antenna with the choke structure is referred to as a sleeve antenna [1]. The choke structure is able to suppress the leakage current when the length of the choke structure is equal to a quarter-wavelength because the input impedance of the choke structure becomes infinite. Since the leakage current is suppressed, the radiation pattern of the sleeve antenna in the vertical plane is shaped as the figure 8, which is similar to that of the dipole antenna. However, the quarter-wavelength choke structure is able to suppress the leakage current only at a single resonant frequency.

Some sleeve antennas with a wideband choke structure have been proposed. A double choke structure has been proposed in [2]. Each choke structure resonates at different frequencies and the leakage current can suppress from 3.3 to 3.7 GHz. A choke structure with variable capacitors has been proposed in [3]. The variable capacitors are inserted into the choke structure to control the current rejection band. The antenna operates from 0.47 to 0.77 GHz by varying the impressed voltage to the variable capacitors. Since these choke structures use resonance, the operation bandwidth is fundamentally narrow.

Electromagnetic bandgap (EBG) structures have been proposed in [4, 5, 6, 7]. The EBG structure does not operate at a single frequency but in a frequency bandwidth that can be designed. Therefore, the EBG structure has been applied for the suppression of noise on the dielectric substrate [4], reduction of mutual coupling between antennas [5], and the filter with ultrawide band [6]. A composite right/left-handed (CRLH) transmission line (TL) has the EBG frequency region, whose bandwidth can be designed by the transmission line theory [7, 8]. Hence, the CRLH TL is often used as the EBG structure. To enhance the bandwidth of the
EBG of the mushroom structure, multi-via structure has been proposed in [9, 10]. The EBG structure has already been applied to the sleeve antenna in [11]; however, in this reference, the EBG structure has been used for a reflector of an artificial magnetic conductor. Therefore, it has not been clarified that the EBG structure suppresses the leakage current through the outer conductor of the CL.

A CRLH CL has been proposed and applied to the choke structure of the sleeve antenna for miniaturization [12]. The choke structure using the CRLH CL is composed of five unit-cell structures. The negative resonance of the left-handed mode of this wavelength is significantly compressed when compared with that in free space, so that the length of the choke structure is miniaturized by only 0.06 wavelength. However, this choke structure using CRLH CL can suppress the leakage current in narrow frequency as it also uses resonance.

In this paper, the CRLH CL proposed in the reference [12] is applied to the broadband choke structure. The choke structure uses the EBG; therefore, the mechanism to reduce the leakage current is completely different from that in reference [12] and the other resonant-type conventional choke structures. To obtain the wide bandwidth of the EBG, the CRLH CL is redesigned. The CRLH CL is applied to the choke structure and attached to the coaxially fed monopole antenna. The antenna characteristics are simulated and the broadband operation of the choke structure is described.

2 Antenna configuration and principle

Fig. 1(a) shows a configuration of the coaxially fed monopole antenna with the proposed choke structure. The antenna is composed of a feeding CL whose characteristic impedance is 50Ω, an extended inner conductor as a monopole antenna, and the choke structure is composed of the CRLH CL with n cells. Fig. 1(b) shows the configuration of the CRLH CL when the number of vias per unit cell are 4. The CRLH CL is a coaxial structure and is composed of split outer conductors, an inner conductor that corresponds to the outer conductor of the feeding CL, and vias. Each split outer conductor is connected to the outer conductor of the feeding CL through the vias.

The configuration and the structure parameters are based on that in the reference [12] and $d_{ce} = 50.0 \text{ mm}$, $d_{cc} = 14.0 \text{ mm}$, $l_{ce} = 4.5 \text{ mm}$, $l_{vc} = 18.0 \text{ mm}$, $p_{c} = 5.0 \text{ mm}$, $d_{vc} = 0.5 \text{ mm}$, and $g_{c} = 0.5 \text{ mm}$, respectively. However, the number of vias are increased to expand the EBG bandwidth as shown in Fig. 1(c). In the frequency region of the EBG, the magnitude of the leakage current flowing through the outer conductor of the feeding CL decreases exponentially along the CL. This is because the propagation constant of the EBG is purely real.

The dispersion relations of the CRLH CL for the choke structure are shown in Fig. 1(d). When the number of via is 1 per unit cell, which corresponds to the reference of [12], the relative bandwidth of the EBG is 73%. When the number of vias are 2, the relative bandwidth of the EBG is expanded and 99%; this is because the lowest frequency of the right-handed mode, which is the shunt resonance of the CRLH CL, increases. When the number of vias are 4, the relative bandwidth of the EBG is 123%. The CRLH CL with 4 vias are applied to the choke structure.
Therefore, this choke structure has the potential to suppress the leakage current with broadband.

3 Simulated antenna characteristics

Fig. 2 shows the $|S_{11}|$ characteristics of the proposed antenna. The structure parameters are $n = 20$ cells, $h_c = 100\, \text{mm}$, $l_{cc} = 200\, \text{mm}$, and $h_m$ is varied. The EBG bandwidth of the dispersion relations, which is in Fig. 1(d), is also described in the figures. When $h_m = 40\, \text{mm}$, three resonances exist as shown in Fig. 2(a). The lowest resonance at 1.2 GHz is not in the EBG but in the left-handed region of the dispersion relations. The second resonance at 2.1 GHz is the quarter-wavelength resonance of the monopole. The length of the monopole $h_m = 40\, \text{mm}$ is almost equal to $\lambda_0/4 = 36\, \text{mm}$, where $\lambda_0$ is the wavelength in free space. The third resonance at 5.4 GHz is the $3/4\lambda_0$ resonance of the monopole because $3/4\lambda_0 = 41.7\, \text{mm}$ and is almost equal to $h_m$. In this paper, we focus on the second resonance which is the quarter-wavelength resonance of the monopole.
The resonant frequency can be shifted to vary $h_m$. When $h_m = 40, 26,$ and $18 \text{ mm}$, the second resonances are at 2, 3, and 4 GHz as shown in Fig. 2(a). When $h_m = 14, 12,$ and $10 \text{ mm}$, the resonances are at 5, 6, and 7 GHz and the resonance in the left-handed region disappears.

The radiation patterns in the $zx$-plane at each resonant frequency are shown in Figs. 3(a) and (b). At 2 GHz, the radiation pattern is completely shaped as the figure 8. At 3, 4, and 5 GHz, the radiation toward lower direction is slightly deformed but almost shaped as an 8. At 6 and 7 GHz which are higher than EBG, the radiation patterns are more deformed than the lower frequency, though still shaped as an 8.

The radiation patterns in $xy$-plane at each resonant frequency are shown in Figs. 3(c) and (d). At all frequencies, the radiation patterns are omnidirectional. The maximum gain in the $xy$ at 2, 3, 4, 5, 6, and 7 GHz are 1.1, 1.0, 1.1, 0.3, 0.7, and 0.4 dBi, respectively.

**4 Conclusion**

The broadband choke structure using the EBG bandwidth of the CRLH CL has been proposed. The operation mechanism of the proposed choke structure is completely different from that of the conventional resonant-type choke structures. The proposed choke structure uses the EBG of the CRLH CL, so that the operation frequency range of the proposed choke structure is much wider than that of the conventional quarter-wavelength choke structures using the resonance. The dispersion relations of the CRLH CL are designed. The bandwidth of the EBG is broadband and 123%. The coaxially fed monopole antenna with the choke structure using the CRLH CL has been simulated. The resonant frequency has been able to design from 2 to 7 GHz by adjusting the length of the monopole. The radiation patterns at each resonant frequency have been omnidirectional in the horizontal direction and shaped as the figure 8 in the vertical plane.
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Fig. 3. Radiation patterns in the $zx$-plane (a) at 2, 3, and 4 GHz and (b) at 5, 6, and 7 GHz and radiation patterns in the $xy$-plane (c) at 2, 3, and 4 GHz and (d) at 5, 6, and 7 GHz.