Research Report

Left-handed Dipole Antennas

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Abstract

A new concept to form a dipole antenna using a left-handed transmission line is proposed. The antenna is composed of a ladder network periodic structure of unit cells having series capacitors and shunt inductors. Placing capacitors into one side of the network leads to out of phase currents with different amplitudes that allow strong radiation. The antenna has a unique feature of reduced wavelength with decreasing frequency. The concept is applied for three antennas. The first one is a small dipole, whilst working in an $n = -1$ mode, based on conventional resonance numbering. The dipole with a length of 0.18 wavelengths can have an input impedance of 50 Ω. The second one is an orthogonally polarised dipole. A left-handed meandered dipole using higher order mode gives a polarisation orthogonal to that of a conventional right-handed one. The third one is an omnidirectional loop. The loop has a one wavelength circumference and gives an omnidirectional pattern in the plane of the loop, whilst using the zeroth mode. In contrast, a conventional right-handed loop has a figure of eight pattern. It is confirmed by the numerical analysis that the proposed concept significantly extends the design degrees of freedom for wire antennas.

Keywords: Dipole antennas, Left-handed materials, Metamaterials, Periodic structures, Moment methods

1. Introduction

Left-handed concepts have been applied to microstrip transmission lines,[1)] and some microwave circuits.[2, 3)] With regard to antennas, leaky wave antennas consisting of microstrip transmission lines have been demonstrated.[4)] The concept of left-handed transmission lines has been also extended to small antennas constructed on a ground plane.[5-7)] Those antennas are based on microstrip transmission lines, and hence need a ground plane. An infinitesimal dipole antenna immersed in left-handed material has been studied theoretically.[8)] Beyond this there have been no other publications, to the authors knowledge, on use of left-handed materials for a dipole antenna. In this research report, the use of a left-handed parallel line to form a dipole antenna is proposed. The concept is applied for three antennas. A small dipole,[9)] an orthogonally polarised dipole,[10)] and a loop[11)] are presented with numerical analysis in **Secs. 2**, **3** and **4**, respectively. This report is concluded in **Sec. 5**.

2. Left-handed small dipole

The new configuration of dipole antenna using a left-handed parallel line is shown in **Fig. 1**. The antenna has a ladder network periodic structure composed of unit cells of series capacitors C_{SL} and shunt inductors L_{SL}. The capacitors C_{SL} are put on the fed side of the ladder network, which results in the currents I_1 and I_2 on the vertical wires, being out of phase and having significantly different amplitude, which results in radiation. This radiation mechanism of the left-handed dipole antenna is very different from those of previous left-handed antennas based on microstrip lines. The operating frequency and input impedance are controlled by C_{SL} and L_{SL}, independent on the length of the antenna. Thus, the antenna can achieve the small size and good impedance matching.

The performance of the antennas is investigated numerically, using the commercial simulator "FEKO",[12)] which is based on the method of moments. Lossless LC lumped elements and wires are assumed. The parameters were specified so that the operating frequency of the antenna would be approximately one third of that of a half wavelength dipole antenna. Based on conventional resonance numbering, Eq. (1) gives relationship between the resonance number n, the length L_S of dipole, and the wavelength λ_a of the standing wave on the dipole.

$$L_S = |n| \frac{\lambda_a}{2} \quad \cdots\cdots (1)$$

The number, n, is a negative integer, which decreases with decreasing frequency. **Figure 2** shows near field distributions in the zx plane at n = -3, -2 and -1, where three, two and one standing wave peaks, respectively, can be seen, although less clearly in Fig. 2 (a). This reduced wavelength, λ_a, with decreasing frequency is a unique feature of the left-handed operation. It can also be seen that the field contours are widely spread at n = -1, indicating strong radiation, whilst at n = 3, out of phase currents on the three standing wave peaks reduce radiation. An n = -1 mode is suitable for small antenna operation, although the antenna could also

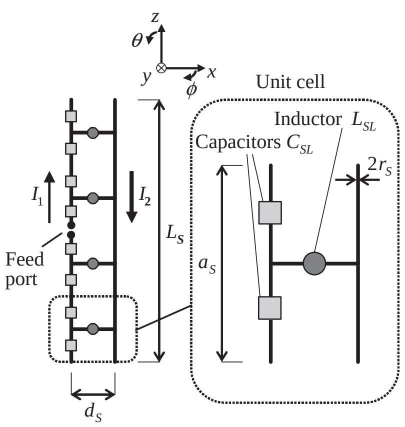

Fig. 1 Configuration of the straight left-handed dipole antenna. L_S = 100 mm, a_S = 25 mm, d_S = 10 mm, r_S = 0.44 mm, C_{SL} = 0.45 pF, L_{SL} = 140 nH.

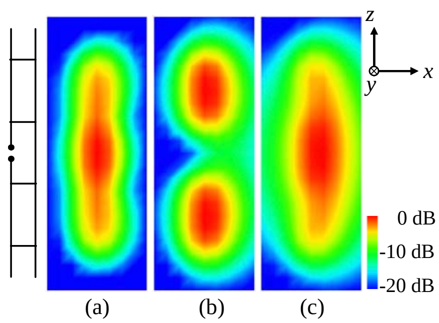

Fig. 2 Near field distributions of straight left-handed dipole antenna. (a) 395 MHz, n = -3, (b) 452 MHz, n = -2, and (c) 547 MHz, n = -1.

work in an $n = 0$ mode with appropriate CL values and shorted terminals at both ends. However the operating frequency in the $n = 0$ mode will be higher than that in the $n = -1$ mode. The dipole has a figure of eight radiation pattern of E_θ in an $n = -1$ mode at 547 MHz, as expected from the near field distribution of Fig. 2 (c).

Figure 3 shows the relationship between the wavelength, λ_a, and frequency. The wavelength, λ_a, of current induced on the dipole agrees with that of current of infinite transmission line by circuit theory. The unique feature of opposite relationship between the frequency and wavelength, λ_a, is clearly observed.

Reflection characteristic is shown in **Fig. 4**. One resonance for $n = -1$ was observed. An input impedance with a real part close to 50 Ω was achieved at $n = -1$. Bandwidth of $|S_{11}| < -10$ dB is 0.43 %. In the case of $n = -2, -3$, no resonance was observed due to mismatching at the feed point.

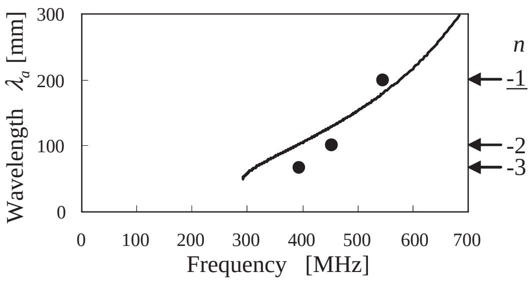

Fig. 3 Relationship of straight left-handed dipole antenna between wavelength, λ_a, and frequency in the left-handed region.
(● : Antenna by the MoMs, ▬: Infinite transmission line by circuit theory)

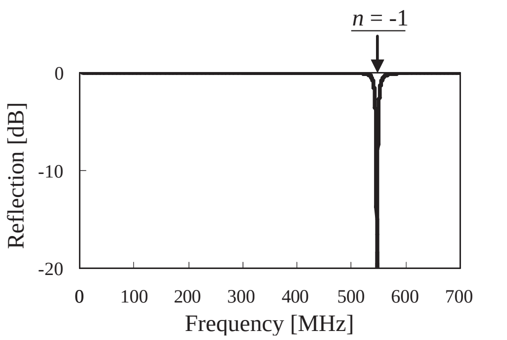

Fig. 4 Reflection characteristic of straight left-handed dipole with respect to 50 Ω.

3. Orthogonally polarised dipole

The unique feature of a reduced wavelength, λ_a, with decreasing frequency is applied to build an orthogonally polarised dipole antenna in this section. **Figure 5** shows the configuration of the meandered left-handed dipole antenna. The fundamental structure of the ladder network is the same as the straight left-handed dipole of Fig. 1. The meander structure has 18 unit cells and enables opposite polarisation to be obtained compared to a right-handed dipole.

Figure 6 (a) shows near field distribution of the meandered left-handed dipole. It can be observed that the nine peaks of the standing wave occur on the horizontal wires and the nulls on the vertical wires. The meandered left-handed dipole works in an $n = -9$ mode at 498 MHz, based on the resonance numbering of Eq. (1). In contrast, a meandered right-handed dipole having the same dimensions has only one peak in the middle of the dipole in Fig. 6 (b), at 505 MHz, while working in an $n = +1$ mode. The dominant polarisation can be understood as follows. The current distribution of the meandered left-handed dipole of Fig. 6 (a) results in the currents induced on wires along the x axis (or horizontal in

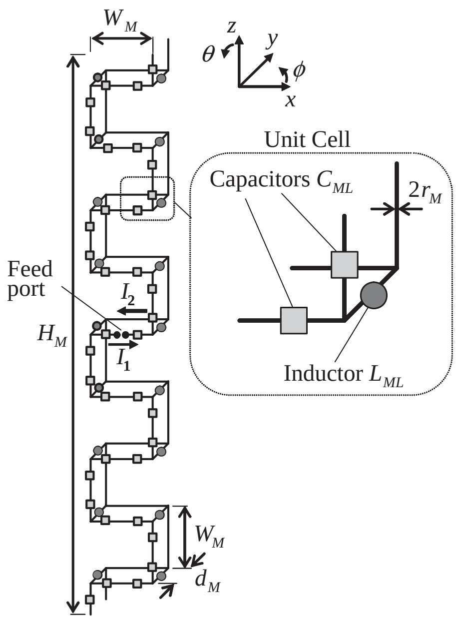

Fig. 5 Configuration of the meandered left-handed dipole antenna.
(H_M = 180 mm, W_M = 20 mm, d_M = 5 mm, r_M = 0.25 mm, C_{ML} = 0.75 pF, L_{ML} = 95 nH)

Fig. 6 (a)) being in phase and along the z axis (or vertical) being out of phase. Thus, radiations from the vertical currents cancel, whilst those from the horizontal currents reinforce and form an array of 9 small horizontal dipole antenna sources, with the spacing of 20 mm. These sources will have a radiated field polarised in the E_ϕ direction. In contrast, the meandered right-handed dipole of Fig. 6 (b) has the currents induced on wires along the x and z directions being out of phase and in phase, respectively, which is opposite to the left-handed dipole. Thus, this right-handed dipole has a dominant polarisation in the E_θ (or vertical direction) direction.

Radiation patterns of the meandered left-handed dipole in the n = -9 mode are shown in **Fig. 7** (a) and (b). It can be seen that the dominant polarisation is the E_ϕ component.

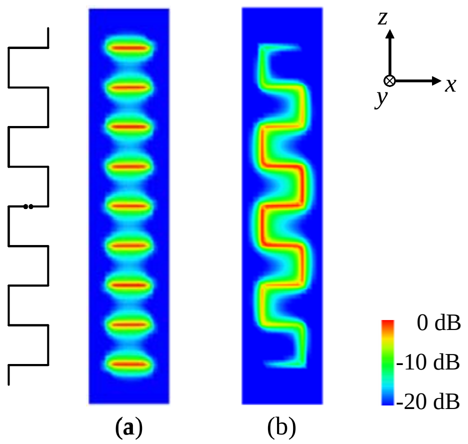

Fig. 6 Near field distributions of meandered left-handed and conventional dipole antennas.
(a) Left-handed dipole at 498 MHz
(b) Conventional dipole at 505 MHz

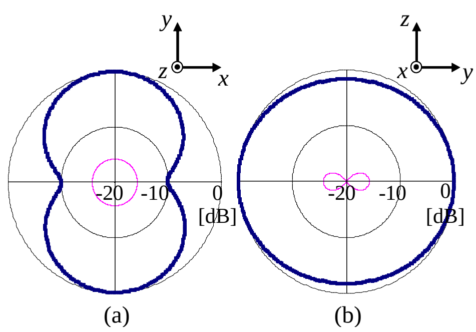

Fig. 7 Radiation patterns of meandered left-handed dipole antenna at 498 MHz, n = -9.
(a) xy plane and (b) yz plane. (—— : E_ϕ, —— : E_θ).

4. Omnidirectional loop

A right-handed loop having a one wavelength circumference gives a figure of eight radiation pattern in the plane of the loop. In this section, a left-handed loop antenna having an omnidirectional radiation pattern is built using a unique feature of the zeroth mode. **Figure 8** shows the configuration of left-handed loop antenna. The fundamental structure of the ladder network is also the same as the straight left-handed dipole of Fig. 1. The left-handed loop has a one wavelength circumference at 500 MHz.

Figure 9 (a), (b) and (c) show near field distributions of the left-handed loop. It can be observed, in Fig. 9 (b), that the field intensity is the same along the circumference at 509 MHz. This indicates that the wavelength of the induced current is infinite and that the left-handed loop works in the

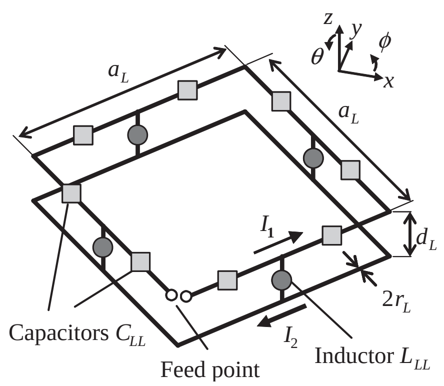

Fig. 8 Configuration of the left-handed loop antenna. a_L = 150 mm, d_L = 20 mm, r_S = 0.25 mm, C_{LL} = 1.1 pF, L_{LL} = 220 nH.

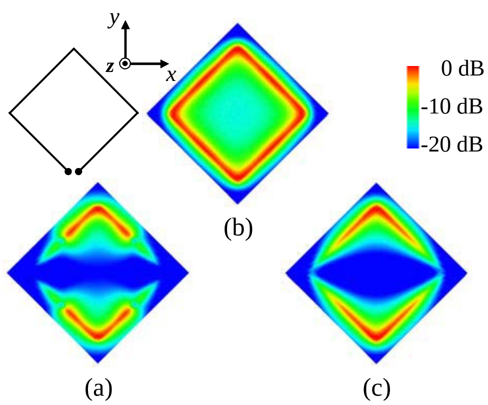

Fig. 9 Near field distributions of left-handed loop antenna. (a) 148 MHz, n = -2, (b) 509 MHz, n = 0, and (c) 763 MHz, n = +2.

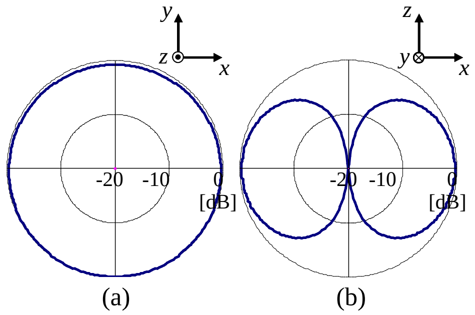

Fig. 10 Radiation patterns of left-handed loop antenna at 509 MHz, n = 0. (a) xy plane and (b) zx plane. (—: E_ϕ, E_θ is below -20 dB).

unique mode of n = 0, based on the conventional resonance numbering. In the case of Fig. 9 (a) and (c), the left-handed loop works in an n = -2 mode at 148 MHz and n = +2 mode at 763 MHz.

Radiation patterns of the left-handed loop are shown in **Fig. 10** (a) and (b). It can be seen that the omnidirectional pattern is obtained in the plane of the loop.

5. Conclusions

The use of a left-handed transmission line to form a dipole antenna has been proposed. The concept was applied for a small dipole, an orthogonally polarised dipole, and an omnidirectional loop antennas. It was confirmed by the numerical analysis that the three antennas worked, using the unique features of left-handed materials. The proposed concept significantly extends the design degrees of freedom for wire antennas.

It was reported from the experimental study that loss remained a problem in the left-handed wire antennas.[11] The establishment of low loss designs for loaded inductors and capacitors is an important further study.

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