Ultra-Wideband Scattering Performance of Log-Periodic Dipole Antenna

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Abstract:In this letter, the ultra-wideband scattering performance of a log-periodic dipole array(LPDA) element is numerically demonstrated. Numerical simulations clarify that the LPDA element has a 3 dB-gain bandwidth of 1:2.7. Moreover, it is shown that the phase of reflection coefficient of the LPDA element linearly varies over 500^o.

Keyword: Log-periodic dipole antenna, reflectarray, scattering property

1. Introduction

A planar reflectarray has much attention as an attractive alternative to a conventional parabolic reflector [1][2]. The planar reflectarray has various advantages e.g., low-profile, low-mass, low-volume and low-cost for fabrication. On the other hand, one of the disadvantages of the planar reflectarray is inherently narrow bandwidth. In previous studies, reflectarrays using various wideband elements have been proposed but their bandwidth is at most 15〜25 % [3]-[5]. Therefore, ultra-wideband reflectarray elements are desired to enlarge the bandwidth of reflectarrays. On the other hand, ultra-wideband antennas have been used for a radar or satellite communications. In previous studies, various ultra-wideband antennas, e.g., a bowtie antenna[6], a tapered slot antenna [7], a spiral antenna[8], and a log periodic dipole array antenna[9][10], have been proposed. These ultra-wideband antennas have been studied and their radiation performance is well-known; however, to the best of our knowledge, the scattering performance of these ultra-wideband antennas has not been reported. In this letter, the scattering performance of a LPDA element is reported. Results of numerical simulation using a method of moments (MoM) shows that the bandwidth of the LPDA element strongly depends on the polarization of a incident wave. Moreover, the effect of a ground plane to the bandwidth and directivity of the LPDA element is shown. Phase of reflection coefficient of the LPDA element is evaluated and it is shown that the LPDA element is a promising candidate of a ultra-wideband reflectarray element.

2. Geometry of LPDA Element

The geometry of the LPDA element is shown in Fig.1. The length of a dipole element and element spacing are determined using Eq. (1).

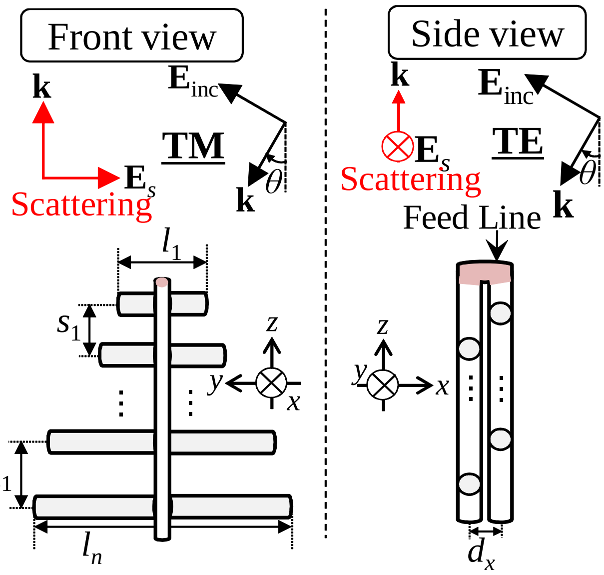

Fig. 1: Log-periodic dipole array element.

$$\alpha = \frac{l_{n+1}}{l_n} = \frac{s_{n+1}}{s_n}, \qquad (1)$$

where l_n is the length of the nth element and s_n is spacing between the nth and the $n+1$th element. The bandwidth of the LPDA element is determined by the ratio of l_n to l_1. In this letter, the LPDA element which covers bandwidth from 600 MHz to 1.4 GHz is designed.

3. Scattering Performance of LPDA Element

The scattering performance of the LPDA element is compared with the radiation performance of the LPDA element. The simulated directivity is shown in Fig.2. The directivity D is calculated using Eq. (2).

$$D = \frac{4\pi R^2 |\mathbf{E}_s(\theta_s)|^2}{Z_0 P_r}, \qquad (2)$$

where R is the distance from the LPDA, Z_0 is the characteristic impedance of free space, $\mathbf{E}_s(\theta_s)$ is scattering field from the LPDA element in the direction of θ_s and P_r is radiation or scattering power. From Fig.2, it is found that bandwidth of the LPDA element as a scatterer strongly depends on the polariation of the incident plane wave. When the plane wave of TE incidents to the LPDA element, it is excited in the same way

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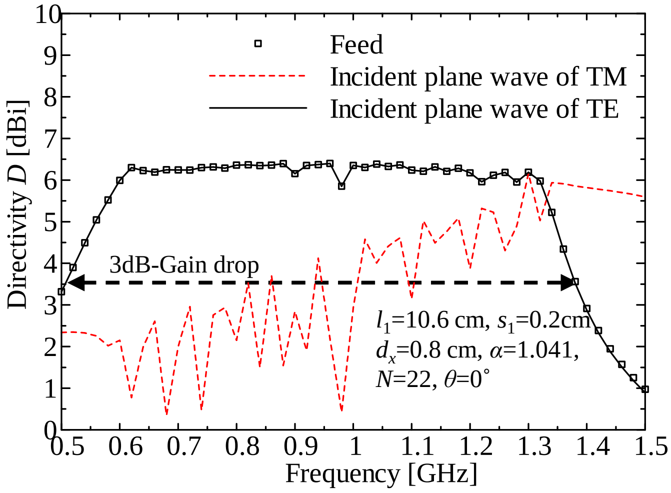

Fig. 2: The radiation and scattering performance of the LPDA element.

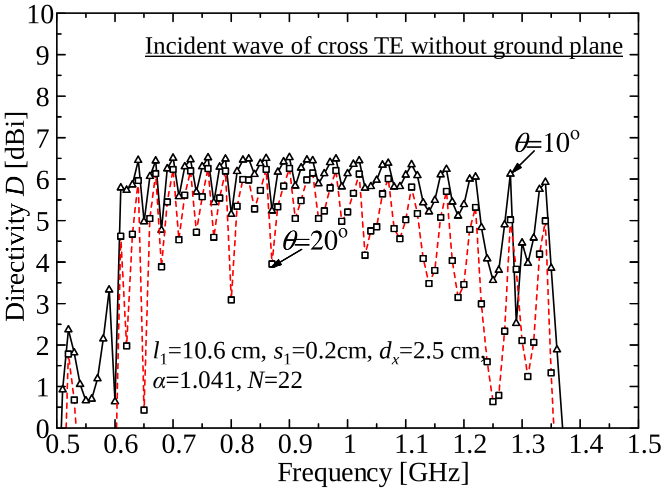

Fig. 4: The effect of incident angle to directivity.

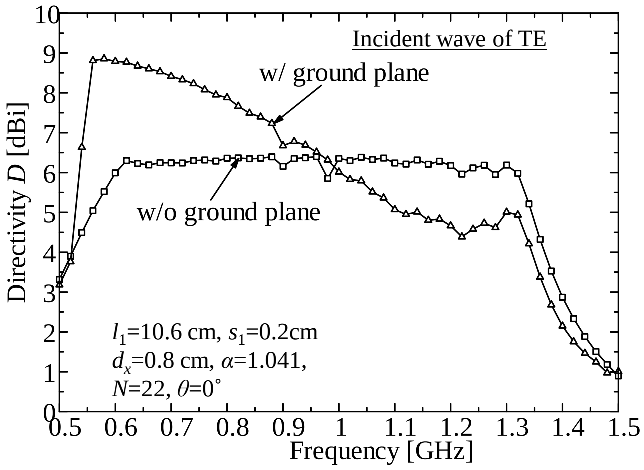

Fig. 3: The effect of ground plane to directivity.

as the radiation. Therefore, the scattering performance of the LPDA element shows the ultra-wideband characteristics when the LPDA element is illuminated by the incident plane wave of TE. A 3-dB gain bandwidth of around 1:2.7 is achieved. Based on the above discussion, the plane wave of TE is used as a incident wave to the LPDA element in the following.

The simulated directivity of the LPDA element backed by ground plane is shown in Fig.3. A 3 dB-gain bandwidth of the LPDA element backed by a ground plane is around 1:1.9 on frequency band of 0.54-1.0 GHz. The maximum directivity increases about 3.5 dB of 0.6 GHz when the LPDA element is backed by the ground plane. But it can be seen that the bandwidth of the LPDA element backed by the ground plane becomes narrow and its the directivity decreases at the frequency beyond 1 GHz compared with the LPDA element without the ground plane.

The effect of angle of incidence to the bandwidth of the LPDA element is confirmed. When the angle of incidence is 10^o and 20^o, the directivity of the LPDA element is shown in Fig.4. A 3 dB-gain bandwidth of the LPDA element is 1:2.1 when the angle of incidence is 10^o and is 1:1.8 when the angle of incidence is 20^o. Fig.4 indicates that the directivity and bandwidth of the LPDA element decrease when the angle of incidence θ increases.

4. Phase of reflection coefficient LPDA Element

In this section, the desired phase characteristics of the LPDA element as a ultra-wideband reflectarray element is discussed. A configuration of reflectarray is shown in Fig.5. The phase Φ_m of reflection coefficient Γ_m of the mth element is expressed by using Eq. (3).

$$\begin{aligned}-k_0|r_m - r_1| + (m-1)k_0 d\sin\theta + [\phi_m(l_m, f) \\ -\phi_1(l_1, f)] = \Phi_m,\end{aligned} \qquad (3)$$

where f is the design frequency, k_0 is the wavenumber of free space, ϕ_m is the phase of reflection coefficient of the mth element, d is array spacing and r_m is the distance between the primary source and the mth element. The size of elements $l_1, l_2, ...l_M$ is decided to satisfy $\Phi_1 = \Phi_2 = ...\Phi_M$ in the main beam direction θ_s. The reflectarray satisfies $\Phi_m = \phi_c + 2\beta\pi$ where ϕ_c is constant and $\beta = 0, \pm1, \pm2...$. Substituting $k_0 = \frac{2\pi}{\lambda} = \frac{2\pi f}{c}$ and $\Phi_m = \phi_c + 2\beta\pi$ to Eq. (3), Eq. (4) is obtained.

$$c_m f + [\phi_m(l_m, f) - \phi_1(l_1, f)] = \phi_c + 2\beta\pi, \qquad (4)$$

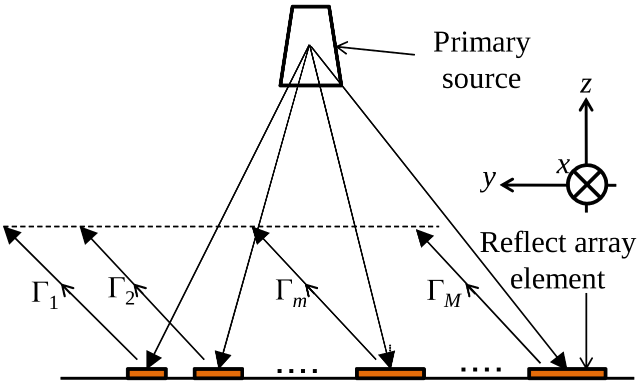

Fig. 5: Configuration of reflectarray.

where c_m is constant and ϕ_c is phase of reflection coefficient of reflectarray. When f changes to $f+\Delta f$, the Eq. (4) is transformed into Eq. (5).

$$c_m(f+\Delta f)+[\phi_m(l_m,f+\Delta f)-\phi_1(l_1,f+\Delta f)] \\ =\phi_c+2\beta\pi. \tag{5}$$

Submitting $\phi_m(l_m,f+\Delta f)=\phi_m(l_m,f)+\Delta\phi_m$ and $\phi_1(l_1,f+\Delta f)=\phi_1(l_1,f)+\Delta\phi_1$ into Eq. (5), Eq. (6) is derived.

$$c_m f+[\phi_m(l_m,f)-\phi_1(l_1,f)]+c_m\Delta f \\ +[\Delta\phi_m-\Delta\phi_1]=\phi_c+2\beta\pi. \tag{6}$$

Eq. (6) equals to the Eq. (4) except for additional terms $c_m\Delta f+[\Delta\phi_m-\Delta\phi_1]$ corresponding to frequency defference Δf. In general, the additional term $c_m\Delta f$ shows non-linearlity when the operating frequency chang-es. As shown in Fig. 6(a), the additional terms $[\phi_m-\Delta\phi_1]$ also show non-linearlity when the conventional microstrip element is used. Therefore, the reflectarray can not form a main beam to the designed direction when the operating frequency changes. On the other hand, as shown in Fig. 6(b), the non-linearlity of the additional terms $[\Delta\phi_m-\Delta\phi_1]$ can be alleviated when the reflectarray element with linear phase variation is used. As a result, the reflectarray shows ultra-wideband characteristics. Phase of reflection coefficient versus the length of dipole element l_1 of the LPDA element is shown in Fig.7. Variation of phase of the designed LPDA element is over 500^o. It is clear that the curve is almost linear and in parallel when the operating frequency changes. Therefore, the designed LPDA element satisfies the condition of wideband reflectarray element.

5. Conclusion

In this report, the scattering performance of the LPDA element was confirmed. It can be said that the bandwidth of the LPDA element strongly depends on the polarization of a incident wave. The bandwidth of the LPDA element deteriorated when the LPDA element was backed by the ground plane. The large angle of incidence to the LPDA element caused narrow bandwidth. The LPDA element was suitable for the wideband reflectarray element because the curve of phase of reflection coefficient to the size of element is almost linear and in parallel when the operating frequency changes.

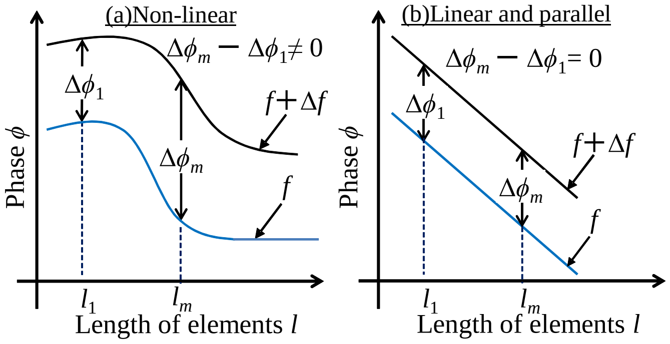

Fig. 6: (a) Conventional microstrip element(Narrow band). (b) Ultra-wideband reflectarray element.

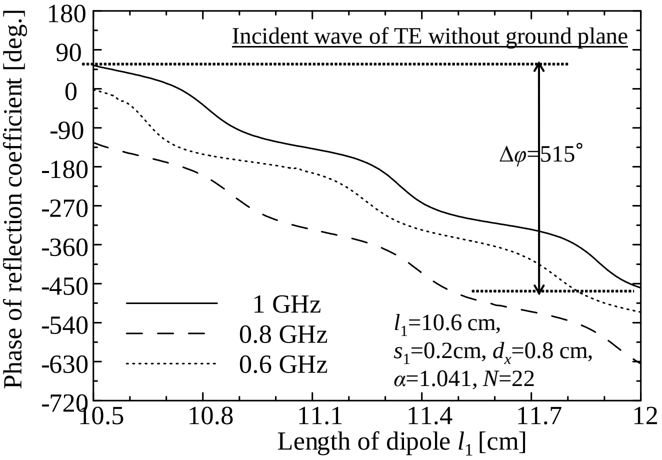

Fig. 7: Phase of reflection coefficient versus length of dipole element l_1.

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