

Dispersion-Compensation Technique for Log-Periodic Antennas using C-section All-Pass Dispersive Delay Structures

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Abstract

A general technique to compensate for pulse distortion induced in log-periodic antennas, due to their frequency dispersive response, is presented and demonstrated by full-wave simulations for the case of log-periodic dipole array (LPDA). A C-section based all-pass dispersive delay structure (DDS) exhibiting a dispersion profile opposite to that of an LPDA is used as a pre-distorter before the antenna. A faithful reconstruction of the pulse is demonstrated using time-domain simulations.

Keywords : Log-periodic antennas, all-pass networks, dispersion engineering

1. Introduction

Log-periodic antennas are well-known for wide bandwidth operation and unidirectional narrow beam. They are based on the principle of scaling or similitude and exhibit adjacent element impedance and radiation characteristics repeating as a logarithmic function of the excitation frequency [1]. Despite their attractive wideband performance, these antennas are notorious for their highly dispersive characteristics leading to time spreading, frequency chirping and amplitude reducing of radiated pulses, all of which are highly undesirable in communication systems. Several attempts have been made to compensate the dispersion of such antennas. For example, in [2] the antenna is loaded with resonant lumped elements to dispersion-engineer the response of a log-periodic dipole array (LPDA). However, this technique affects the overall antenna behaviour and requires design corrections. Other techniques either require redesigning the antenna or altering the inherent properties of a log-periodic antenna [3].

In this work, a new technique, based on dispersive delay structures (DDSs), is proposed for dispersion compensation of log-periodic antennas and a demonstration is presented for the case of a LPDA. The technique uses DDSs as a dispersion compensation component which is *external* to the antenna, and allows therefore a much simpler, more flexible and less invasive design.

2. Log-Periodic Dipole Arrays (LPDAs)

Fig. 1(a) shows a typical configuration of a printed LPDA. An LPDA antenna consists in a transmission line loaded by several radiating dipoles of different lengths and with different spacing radiating an end-fire beam in the plane of the antenna. The printed configuration consists of a line with an array of alternating dipole strips on both side of the substrate. The lengths of the successive dipoles are scaled by a constant factor Γ , and the spacing between the adjacent dipoles depends on a factor σ as

$$L_n = \Gamma L_{n-1} \quad \text{and} \quad D_n = D_{n-1} + 2\sigma L_n. \quad (1)$$

The LPDA design procedure is widely reported in literature, and is based on the choice of Γ and σ , which in turn determine the required antenna gain and frequency band of operation [4]. An LPDA can be matched in a wide frequency range. A typical matching response is shown in Fig. 1(b).

To assess the amount of distortion incurred to a wideband signal by an LPDA, a Gaussian pulse with full-width half maximum of 200 ps and modulated by wave of 3.5 GHz is fed to the antenna of Fig. 1(a). The corresponding radiation field in the time-domain is shown in Fig. 1(c). As can be clearly seen, the time domain pulse spreads in time with a frequency chirp (i.e. instantaneous frequency variation within the pulse envelope with higher frequencies appearing at earlier times). This frequency dependent phase distortion introduced by the LPDA has been extensively studied and is given by [3]:

$$\Phi(\omega) = \pi \frac{\ln(\omega/\omega_1)}{\ln \Gamma}, \quad (2)$$

where ω_1 is the frequency corresponding the smallest dipole of the LPDA. The group delay variation versus frequency, $\tau_g(\omega) = -d\Phi(\omega)/d\omega$, can be obtained from Eq. (2). It is plotted in Fig. 1(b), which ideally should be a constant as a function of frequency for a dispersion free pulse profile.

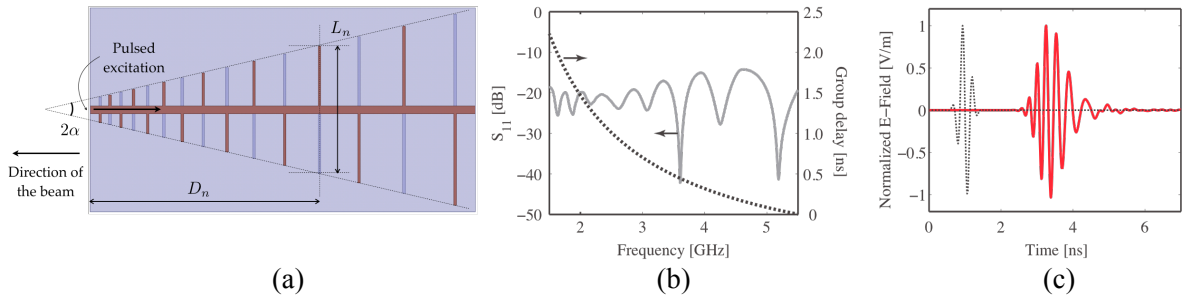


Figure 1: Log-periodic dipole array antenna. (a) Typical planar printed configuration. (b) Computed reflection coefficient magnitude ($|S_{11}|$). (c) Chirped radiated E-field (solid curve) in the far-field of the dipole array when excited with a broadband modulated pulse (dotted curve). The results are computed using FDTD based CST Microwave Studio.

3. Dispersion Compensated Log-Periodic Dipole Array

3.1 LPDA Dispersion Compensation Technique

We propose to compensate for phase distortion in log-periodic antennas by connecting an external dispersive structure (DDS) at the input of the antenna, as shown in Fig. 2(a). In such a configuration the DDS acts as a signal pre-distorter which properly adjusts the temporal phase of the original input pulse $x(t)$ by producing a chirped signal $y(t)$ which is fed to the dipole array. By appropriately designing the group delay characteristic of the DDS (positive slope in this case) to be exactly opposite to that of the dipole array (negative slope as shown in Fig. 1b), the phase distortion induced by the LPDA in the radiated pulsed signal can be completely cancelled. Thus, the radiated signal $z(t)$ is dispersion-compensated, i.e. it is exactly identical to original transmitted pulse $x(t)$, as desired.

3.2 C-section based All-Pass Dispersive Delay Structure (DDS)

A DDS exhibits a frequency dependent group velocity (and thus group delay). Several techniques have been reported in the literature to implement them in the microwave regime, including surface-acoustic wave devices [5] and microstrip chirped delay lines [6], to name a few. These dispersive structures are fundamentally of two types – reflective-type or transmission-type. Recently, a new transmission-type C-section based all-pass dispersive network has been proposed in [7], where an arbitrary phase response can be achieved.

A microwave C-section all-pass structure is a 2-port network obtained by connecting by a short transmission line section the two end ports of a coupled-line coupler. A generalized

N -coupled line configuration can be formed by cascading C sections. By connecting the i^{th} port with the $(i + 1)^{\text{th}}$ port using a short transmission line, except the 1^{st} and N^{th} port, the $2N$ -port network is transformed into a 2-port all-pass network, as shown in Fig. 2(b). Due to the different lengths of the C sections, such a configuration is called a *non-commensurate* coupled-line network. This structure can be modeled by computing its per-unit-length capacitance and inductance matrix \mathbf{C} and \mathbf{L} , respectively, using the method-of moment (MoM) technique [6]. By varying the length of individual coupled line pairs and line couplings, an *arbitrary group delay response* can be easily realized in this configuration. Due to its design simplicity, transmission-type operation and wide bandwidth characteristic, this structure is particularly suitable for phase compensation of an LPDA as the DDS component in Fig. 2(a).

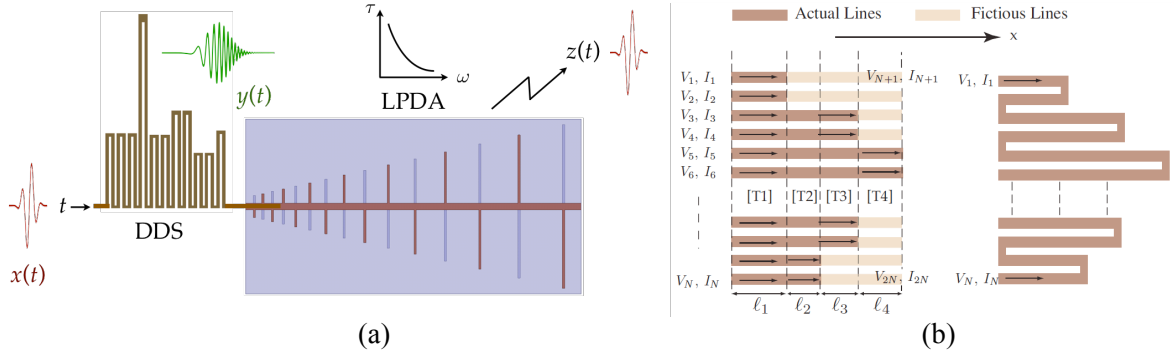


Figure 2: Proposed dispersion-compensation technique for LPDA. (a) Dispersive delay Structure (DDS) connected at the input of the LPDA as a pre-distorter. (b) C-Section based all-pass DDS.

3.3 Benefits and Features

Compared to conventional techniques, the proposed technique of dispersion compensation for log-periodic antennas offers distinct benefits. Firstly, the DDS acts as an external and independent element to the antenna, and therefore is a plug-and-play component that may be easily connected to the antenna. As a result, the inherent properties of the antenna such as directivity and matching are unaffected. This makes the overall design of the system simple without requiring any modification of the antenna itself. Secondly, the C-section based DDS is inherently broadband, planar, flexible and frequency scalable, and can therefore be easily adapted to wide variety of log-periodic antenna designs, without requiring any lumped components.

3.4 Results

In order to compensate for the dispersion of the LPDA, the DDS should exhibit dispersion opposite to that of the antenna. This requires a group delay design target for the DDS: $\tau(\omega) = \tau_0 - \tau_g(\omega)$, where τ_0 is an arbitrary constant such that $\tau(\omega) > 0$ for the entire bandwidth of operation. To illustrate the dispersion compensation mechanism, consider the dispersion profile $\tau_g(\omega)$ of Fig. 1(b) corresponding to the LPDA of Fig. 1(a). For this case, the target group delay profile of the DDS is shown as a dotted curve in Fig. 3(a). To achieve this group delay design, a C-section based all-pass network of Fig. 2(b) is designed in a strip-line configuration and its corresponding group delay is shown as a solid curve in Fig. 3(a). The DDS is reasonably matched ($|S_{11}| < -20$ dB) over the entire bandwidth of operation (not shown here). The total dispersion $[\tau(\omega) + \tau_g(\omega)]$ is also shown. As can be seen, an overall desired flat group delay response is achieved.

Next, a modulated Gaussian pulse, identical to one in Fig. 1(c), is used as $x(t)$. The DDS output $y(t)$ is then computed using the Fourier transform relation, $Y(\omega) = X(\omega)S_{21}(\omega)$, where $X(\omega)$ and $Y(\omega)$ are the Fourier transforms of the $x(t)$ and $y(t)$, respectively, and $S_{21}(\omega)$ is the transfer function of the DDS. Next, the DDS output $y(t)$, is fed to the LPDA of Fig. 1(a). The radiated fields in time domain are then computed using commercial software CST Microwave Studio, as shown in Fig. 3(b). As can be seen, the dispersion of the LPDA has been cancelled and the original input $x(t)$

is faithfully radiated from the antenna, thereby validating the proposed dispersion compensation principle.

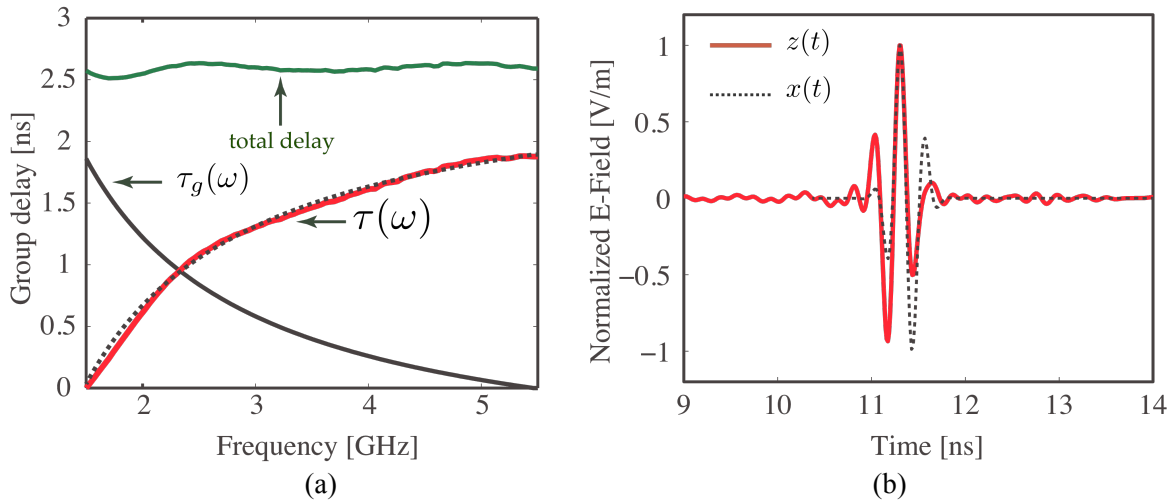


Figure 3: Dispersion compensation of a LPDA using a C-section based DDS. (a) Group delay response to compensate for the frequency dispersion of the LPDA of Fig. 1(b) computed using the MoM technique of [6]. (b) Radiated far-fields when the LPDA is excited with a broadband modulated pulse computed using FDTD based CST Microwave Studio, compared to the original input signal. A lossless DDS is designed in a strip-line configuration using a substrate of permittivity 6.15 with a total thickness of 50 mil, line- and gap-width of 16 mil and the structure configuration $(n_i, L_i) = [(18, 210), (6, 510), (4, 275), (4, 360), (2, 254), (20, 210)]$, where n_i is the number of line pairs of length L_i in mils.

4. Conclusion

A general technique to compensate for the frequency dependent phase shift of log-periodic antennas has been presented and demonstrated by full-wave simulations for the case of an LPDA. A C-section based all-pass DDS exhibiting the opposite dispersion compared to that of a LPDA is used as a signal pre-distorter before the antenna. A faithful reconstruction of the pulse has been demonstrated in the far-field validating the proposed concept. The experimental validation of this principle is currently under investigation where the practical issues such as losses and antenna performance will be studied in greater details.

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