A Linear Antenna Array for UWB Applications

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1 Introduction

The design of UWB antennas requires special considerations, for example the control of emission level over the entire UWB bandwidth in all directions, which make the antenna design challenging [1]. The single UWB antenna element has been studied extensively [2], and it is the time to work on the UWB antenna array, which has many potential applications in both radio and radar systems. Recently, the radiation from a linear UWB antenna array has been reported [3], and a time-domain array factor proposed [4]. In this paper, a uniformly spaced linear array comprising planar UWB dipole antennas is studied. First, time-domain waveforms due to the superposition of ten radiating antenna elements are examined. Next, the antenna geometry as well as the array configuration are presented. The characteristics of a single antenna element, and the coupling between two adjacent elements are examined with Finite difference time domain (FDTD) method and Method of Moments (MOM). After that, a source pulse is optimized for the UWB antenna array in order to comply with the Federal Communications Commission (FCC)'s regulation. Lastly, the radiation of the array excited by the optimal source pulse is investigated in terms of three different patterns.

2 Time-domain waveforms due to a UWB antenna array

In a UWB antenna array, each antenna element radiates short pulses. The superposition of these signals in free space is determined by both the waveform of each signal, and their relative time-delay. Figure 1 plots the superposition of 10 identical short pulses in the form of (1) where $\sigma = 91$ ps and $f_c = 6.85$ GHz, with identical time-delay between every neighboring pulses.

$$g(t) = \exp[-(\frac{t}{\sigma})^2] \sin(2\pi f_c t) \quad (1)$$

Such pulse parameters are selected to make the pulse's -10 dB bandwidth exactly covers the UWB band from 3.1 to 10.6 GHz, which is allocated by the FCC. It can be seen that the superposition of the pulses varies a lot with the relative time-delay, in both magnitude and waveform. The superposition of the pulses could be a single pulse for 0 ps delay, two separated pulses for 60 ps delay, a truncated sinusoidal-like pulse for 100 ps delay, and a train of separated pulses with the number of antenna elements for 360 ps delay. In an antenna array, the time-delay that determines the final waveform depends on both the element spacing and scan angle.

3 Antenna geometry and array configuration

A planar dipole is selected to form a uniformly spaced linear array as shown in Figure 2, where the dipoles are placed in the y-z plane, with a spacing of d. Each dipole is excited by a voltage source with an internal resistance, $R_o = 100\Omega$. A -10 dB isolation between two neighboring antenna elements over the entire UWB band

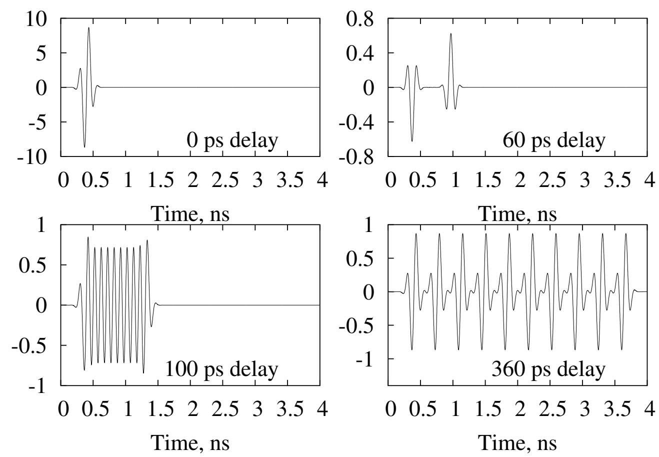

Figure 1: Waveforms for different delay

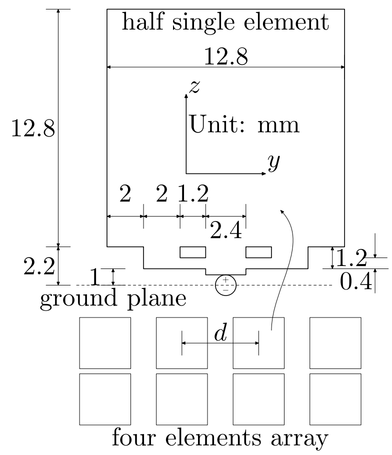

Figure 2: Antenna geometry

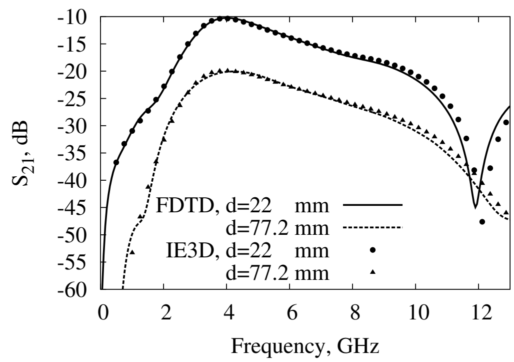

Figure 3: Antenna isolation

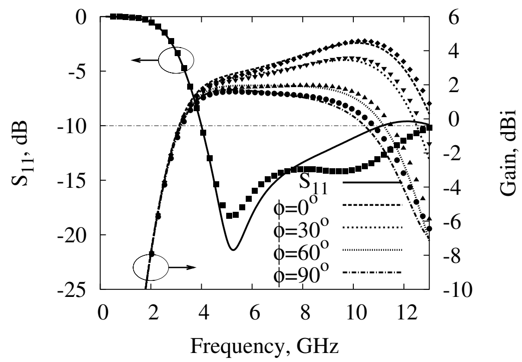

Figure 4: Antenna characteristics, θ=90°

can be achieved by choosing $d = 22$ mm, and -20 dB isolation by choosing $d = 77.2$ mm, as shown in Figure 3, where the results are obtained by FDTD method and a commercial software package IE3D with an MOM method. The single element S_{11} and gain responses in the x-y plane are plotted in Figure 4, where the curves with lines are obtained by the FDTD method, and those with points by the IE3D.

4 Equivalent isotropically radiated power (EIRP) and emission limits

For a uniformly spaced linear antenna array with elements excited by identical sources, the far field time-domain waveform ($s(t,\phi)$) can be obtained in (2), where N is the number of antenna elements, "$*$" is the convolution operator, $f(t,\phi)$ is the radiated waveform from a single element in the ϕ direction, c is the light speed, and τ_n is the exciting delay for the nth element. No mutual coupling is assumed in (2).

$$s(t,\phi) = f(t,\phi) * \sum_{n=0}^{N-1} \delta(t - n\Delta t - \tau_n) = \sum_{n=0}^{N-1} f(t - n\Delta t - \tau_n, \phi),\ \Delta t = \frac{d \sin\phi}{c} \quad (2)$$

The EIRP from the array radiation can be obtained from (3), where $F(\omega,\phi)$ is the spectrum of $f(t,\phi)$.

$$S(\omega,\phi) = F(\omega,\phi) \sum_{n=0}^{N-1} \exp[-j\omega(n\Delta t + \tau_n)] \quad (3)$$

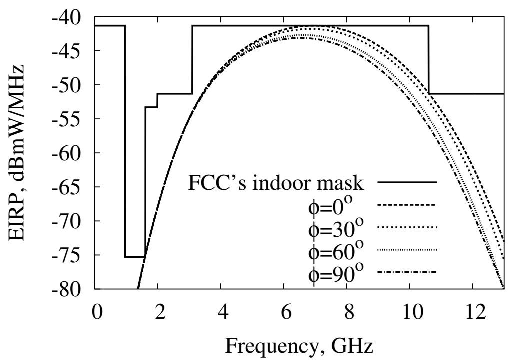

Figure 5: EIRP, $\theta = 90°$

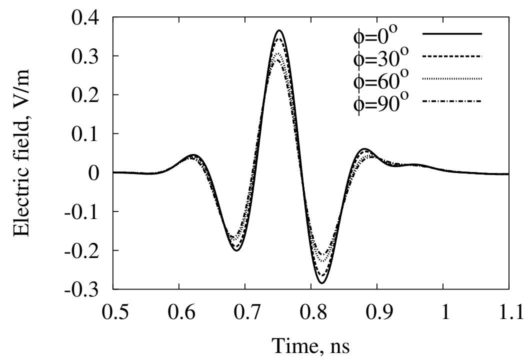

Figure 6: Radiated pulses, $\theta = 90°$

With the inequality of $\left|\sum_{n=0}^{N-1} \exp[-j\omega(n\Delta t + \tau_n)]\right| \leq N$, we have $|S(\omega, \phi)| \leq N \times |F(\omega, \phi)|$, and the equality is obtained in the steering direction. Therefore, the same source pulse designed for a single UWB antenna element to meet the FCC's regulation could be used for the corresponding array, and the resulting EIRP will comply with the emission limits automatically. Furthermore, this conclusion is valid for an arbitrary array with identical antenna elements. With *PULSE-KIT* [5], the optimal source pulse exciting the planar dipole is obtained in the form of (1), with $\sigma = 91.531$ ps and $f_c = 6.661$ GHz. The resulting EIRP from the radiation of a single element in the x-y plane is plotted against the FCC's indoor emission limits in Figure 5, where about 95.5% bandwidth efficiency is observed in the broadside direction. Clearly, the planar dipole is not ideally omnidirectional over the UWB band, thus leading to different radiated waveforms in the x-y plane, as shown in Figure 6.

5 Radiation patterns

As the radiated signal is no more in the continuous sinusoidal form, and the waveform changes a lot with the scan angle, the conventional pattern calculated from power density may be of little practical meaning. Based on different schemes to capture the electromagnetic energy, three types of radiation patterns, namely energy pattern defined in (4), peak value pattern in (5), and cross correlation pattern in (6), are investigated for the array. Particularly, $b(t)$ in (6) is a reference pulse to correlate the radiated pulse, and is selected to be the radiated pulse in the steering angle. The steering angle $\phi = 0°$ assumes that all the antenna elements are excited by the optimal voltage source simultaneously by enforcing $\tau_n = 0$ ps in (2).

$$P_{energy}(\phi) = \int_0^\infty |s(t, \phi)|^2 dt \tag{4}$$

$$P_{peak}(\phi) = \text{Max}\{s(t, \phi)\} \tag{5}$$

$$P_{cross}(\phi) = \int_0^\infty s(t, \phi) b(t) dt \tag{6}$$

The array with four or ten elements are studied in terms of the above three radiation patterns in the x-y plane, and plotted in Figures 7 and 8, respectively. For each case, different element spacings of $d = 22$ mm or 77.2 mm, corresponding to the

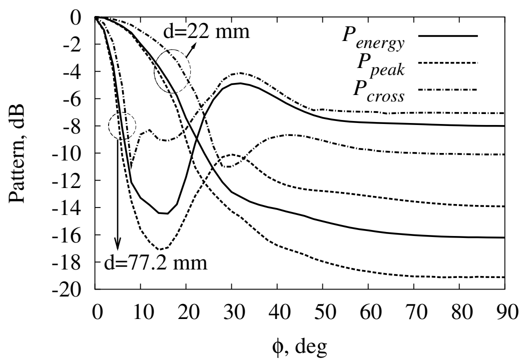

Figure 7: Patterns of 4 element array

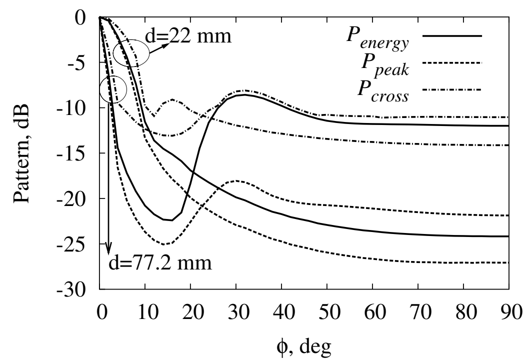

Figure 8: Patterns of 10 element array

−10 dB and −20 dB isolation between the adjacent elements, are selected. Three observations can be made from the results. (1) The beam width of the main lobe for each pattern will be narrowed by increasing the number of antenna elements, or the element spacing. (2) Given an array configuration, the peak value pattern has the narrowest beam width for the main lobe, and the lowest sidelobe level, while the cross correlation pattern has the widest beam and the highest sidelobe level. (3) The sidelobe level increases with element spacing. Specially, there is no sidelobe for the energy and peak value patterns when $d = 22$ mm.

6 Conclusions

A uniformly spaced linear antenna array was investigated for UWB applications. A planar UWB dipole antenna was selected as an array element, and simulated with both the FDTD and MOM. A source pulse was optimized to fully make use of the FCC's allocated UWB bandwidth. It was proven that the pulse optimized for a single antenna element could also be applied to an array in the sense of complying with emission limits. Three different radiation patterns were examined for the array with different number of elements, and element spacing. For all the three patterns, a narrow beam width of the main lobe was achieved by increasing the array size, either by increasing the number of elements or the element spacing. However, the later rises the sidelobe level. Among all the patterns for a given array configuration, the peak value pattern gave the narrowest beam width of the main lobe, and the lowest sidelobe level.

References

[1] Z. N. Chen, X. H. Wu, H. F. Li, N. Yang, M. Y. Chia: 'Considerations for Source Pulses and Antennas in UWB Radio Systems', *IEEE Transactions on Antennas and Propagation*, 2004, 52, (7). pp. 1739-1748.

[2] X.H. Wu, Z. N. Chen: 'Comparison of Planar Dipoles in UWB Applications', *IEEE Transactions on Antennas and Propagation*, accepted for publication.

[3] W. Soergel, C. Waldschmidt, W. Wiesbeck: 'Transient Radiation from a Linear UWB Antenna Array', *URSI EMTS*, Pisa, Italy, May. 23-27, 2004, pp. 1254-1256.

[4] S. Foo, S. Kashyap: 'Time-domain array factor for UWB antenna array', *Electronic Letters*, 2003, 39, (18), pp. 1304-1305.

[5] X. H. Wu, Z. N. Chen: 'Design and Optimization of UWB Antennas by a Powerful CAD Tool: PULSE KIT', *IEEE International Symposium on Antennas and Propagation* , Monterey, California, USA, Jun. 20-26, 2004, pp. 1756-1759.