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Abstract
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Keywords
Broad-band antenna, electromagnetic susceptibility, log-periodic dipole array, pulsed radiation, timedomain

Disciplines
Computer Engineering | Computer Sciences

An Independently Fed Log-Periodic Antenna for Directed Pulsed Radiation

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***Abstract*—The development of an antenna capable of radiating a band-limited pulse with minimal distortion, negligible loss, and significant directivity is reported. A design was derived by modification of the conventional log-periodic dipole array to permit independent feeding of each dipole. This was modeled with a time-domain integral equation program and iterated to find a design that minimized phase dispersion across the operating band. The optimal design was realized in hardware, using a printed structure to feed the dipoles independently; this was located in the normal plane to prevent distortion of the radiated fields. When tested, the antenna was found to give a good quality radiated pulse in the main beam direction, with weaker and dispersed waveforms in other directions, indicating significant directive gain.**

***Index Terms*—Broad-band antenna, electromagnetic susceptibility testing, log-periodic dipole array, pulsed radiation, time-domain integral equation method.**

I. Introduction

The use of standard log-periodic dipoles for electromagnetic compatibility (EMC) testing is well established and it has also been demonstrated [1] that arrays of them can be used to generate near-field plane-wave test zones over larger volumes than are possible with a single antenna. In view of the predominance of impulsive interference in many practical situations and the trend toward wide-band radio communications systems, an investigation into the extension of the concept for generation of plane waves with a pulsed time-domain waveform was initiated.

The log-periodic antenna is attractive for use in wide-band arrays since being an end-fire structure, its physical aperture (normal to the main-beam direction) is smaller than is the case for many other designs. However, it is intuitively obvious that the standard form of the antenna will cause severe dispersion of the frequency components in a pulsed waveform. This is because the antenna is excited at the "nose" (the front end nearest to the shortest dipole element) and low-frequency components of the signal have to travel down the antenna structure until they reach a dipole that is near resonance. They then have to travel back the same distance as radiated fields before they can combine with the high-frequency components radiated from short dipole elements near the nose. The result is that a time delay is imposed that is approximately proportional to the wavelength of the component.

Although it is somewhat counterintuitive, an earlier paper [2] had shown the feasibility of using log-periodic antennas to radiate pulses. However, this approach required the use of either a relatively long antenna with nonstandard element spacings or a chirped input signal to compensate for time-delays. The long antennas could pose difficulties in some circumstances and the generation of chirped input signals is difficult if a high-power test facility is desired, or if the antenna is required for wide-band communications. A search for smaller alternative designs capable of radiating a pulse without dispersion was thus undertaken.

II. Simulation Studies Using Time-Domain Integral-Equation Software

A. Trapezoidal Log-Periodic Antenna

A time-domain integral-equation (TDIE) program was used to model log-periodic antennas under pulsed excitation without the need for Fourier transformation, as would be required with traditional frequency-domain programs [3]. The first antenna investigated was a trapezoidal-type log-periodic dipole array (LPDA) with a taper angle (the included angle of the loci of the tips of the elements) of 23°, which, for a given bandwidth, gives a shorter antenna than those reported in [2]. The scale factor was 0.88 and the spacing factor 0.15—these values being chosen to give the antenna optimum conventional performance [4]. The resonant frequencies of the shortest and longest elements were 1 GHz and 500 MHz, respectively, and the angle between the two halves of the antenna was 30° (Fig. 1). When the antenna was excited with a 2 ns Gaussian pulse (Fig. 2), it was found that the radiated signal was much broader and contained several oscillations (Fig. 3), which are clearly the result of dispersion caused by the wavelength-dependent time delay in such a nose-fed antenna.

It was reasoned that if the exciting pulse at the input were replaced by a replica of the radiated waveform, but reversed in time, this would give a form of predistortion that would exactly compensate for the dispersive delays in the antenna. When this was tried in the software model a band-limited pulse of good quality resulted (Fig. 4). It should be noted that this radiating system is necessarily band-limited and, hence, radiation of pulses with a dc component is not possible: the radiated pulses should always have, at minimum, a positive and a negative swing to cancel the dc and the result in Fig. 4

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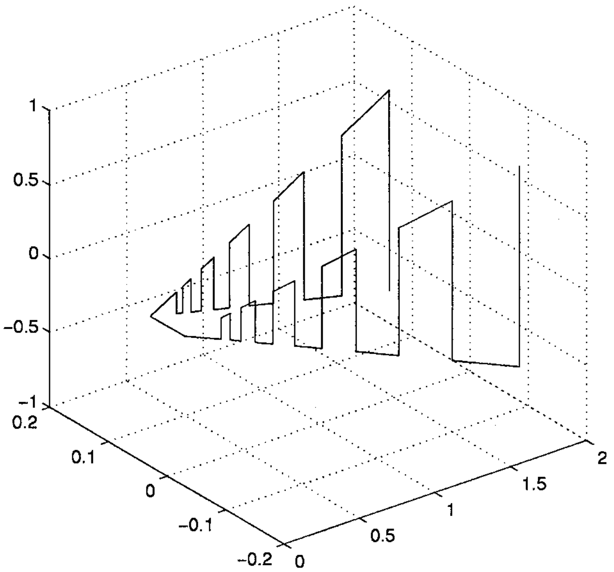

Fig. 1. The trapezoidal log-periodic antenna investigated with TDIE (the scales are in meters).

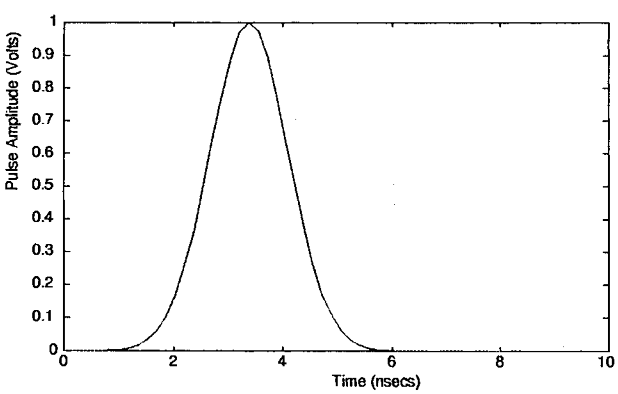

Fig. 2. The input pulse used in TDIE studies.

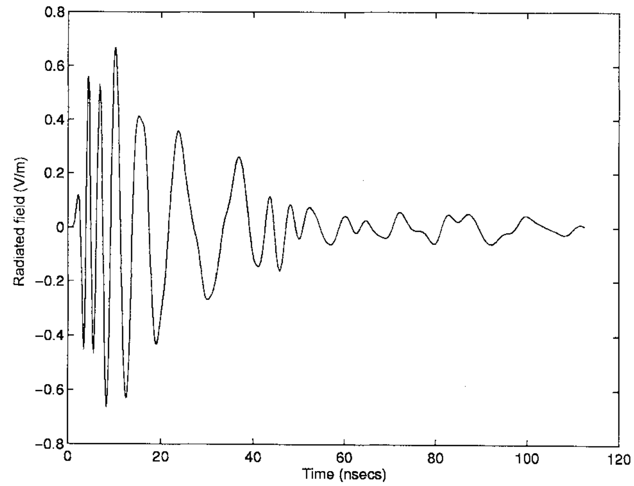

Fig. 3. TDIE predicted dominant component of electric field (i.e., vertically polarized in the sense of Fig. 1) radiated from the trapezoidal antenna at a distance of 10 m from the feed point in the main-beam direction when excited by the pulse in Fig. 2.

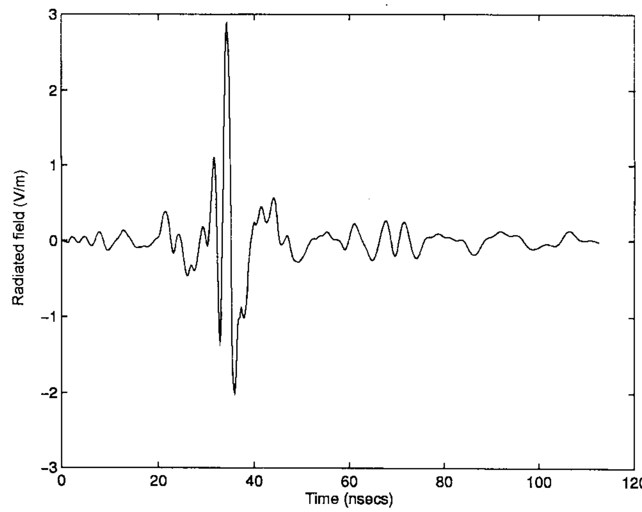

Fig. 4. TDIE predicted radiated pulse from trapezoidal antenna with predistorted input waveform. (Dominant component of electric field at a distance of 10 m from the feed point in the main-beam direction).

is a reasonable approximation to this. This approach could thus be used directly as a solution of the problem, but the cost of implementing the predistorted pulse could be substantial and the network to achieve it would be relatively inflexible (this solution is, in fact, closely similar to that of the chirped feed approach of [2]).

B. Independently-Fed LPDA

An investigation of further designs was thus instituted in an attempt to find a design that would accept a pulsed input and radiate it without dispersion, thus enabling the use of a simple pulse generator as the source. It was concluded that the traditional approach to feeding log-periodic antennas via a transmission line fed at the nose leads to unacceptable time delays in the elements more distant from the nose and that independent feeding of the elements should be tried. The standard practice of reversing the feed to alternate elements was retained as this gives the localized Yagi-like directive behavior of a LPDA.

A heuristic design procedure was adopted in which a standard log-periodic structure of eight solid rods was chosen for study (Fig. 5). The lengths of the longest and shortest rods were 300 and 123 mm, respectively, and their diameters were chosen to keep the length to diameter ratio approximately constant, as is required in an ideal LPDA. The excitation was, again, a 2 ns Gaussian pulse. In the first step, the field radiated was found when the shortest rod (number 1) was excited as a dipole with a voltage source at its center (Fig. 6). The same excitation was then applied simultaneously to a rod at the other end of the distribution (number 7), and the feed-point time delays for the two dipoles were adjusted to give maximized amplitude in the pair of superposed radiated pulses (Fig. 7). This procedure was continued for the full set of eight elements with several values of the included taper angle. After several iterations, a design was derived which showed relatively nondispersive radiation of a band-limited pulse from a 2 ns Gaussian input (Fig. 8). The optimum design was found to have a very small value of the spacing factor, giving an unusually large taper angle of 90°. The relative time delays in

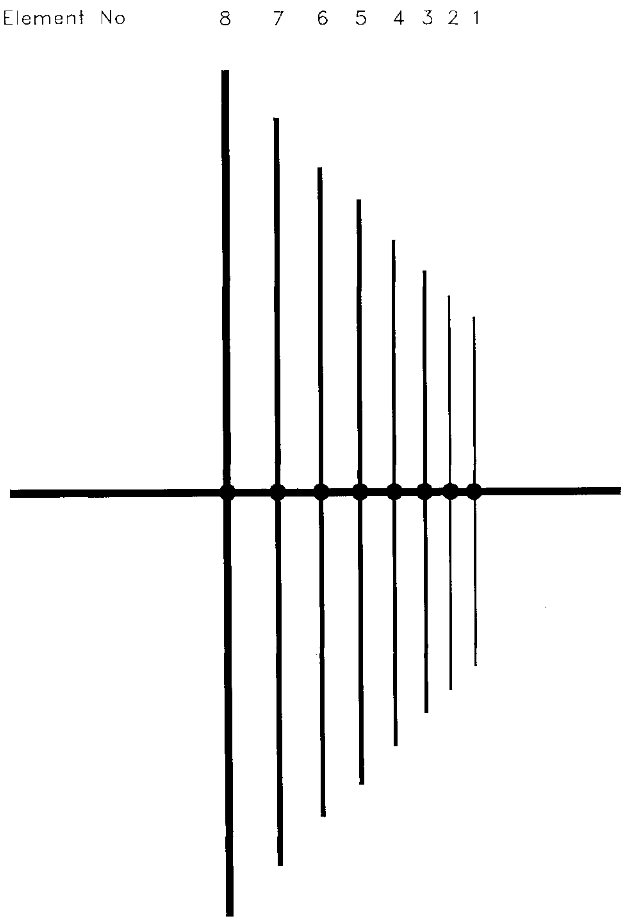

Fig. 5. The set of eight rods forming the independently-fed log-periodic antenna, as modeled by TDIE (for dimensions see Table I: the central support structure was not included in the model as it is normal to the electric field). The large taper angle used in the final design is shown here, although other values were tried in the course of iterative design.

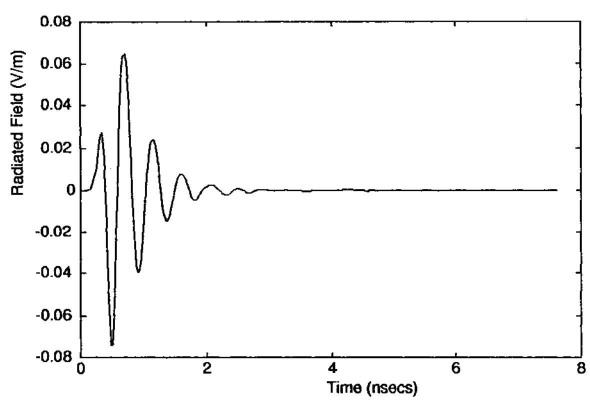

Fig. 6. Radiated dominant electric field component predicted by TDIE with 2 ns Gaussian input to element number 1 (the shortest) in the antenna shown in Fig. 5, at a distance of 2 m in the main-beam direction.

the feed network were substantially different from those that would be achieved with a traditional nose-fed LPDA (Table I).

The time delays appear somewhat counterintuitive, but they are less so if the "forward" and "reversed" driven dipoles are considered separately. Note that element number 7 has the minimum time delay: this is because number 1 was chosen as the reference element in the design process and this is in

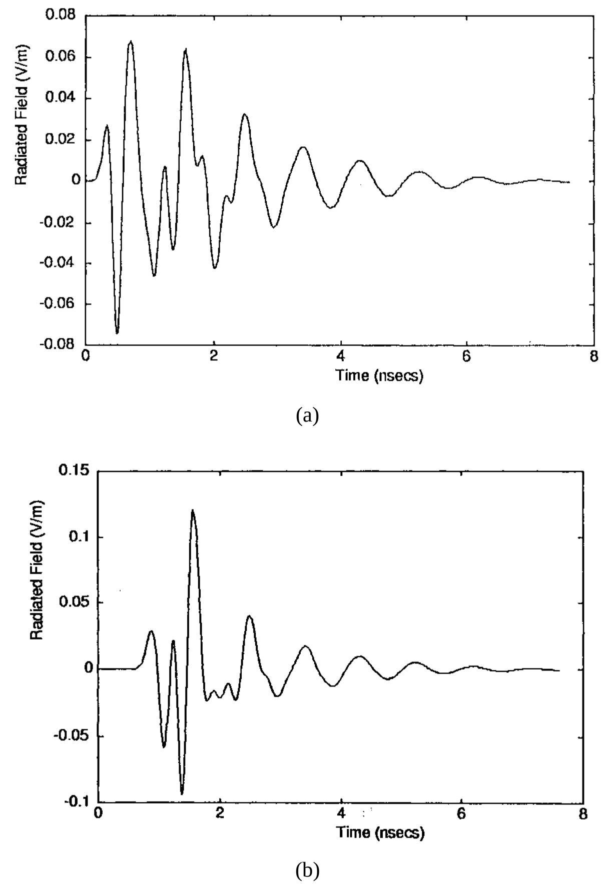

Fig. 7. Radiated dominant electric field component at 2 m from element number 1 in the main beam direction, predicted by TDIE. (a) With identical synchronized 2 ns Gaussian inputs to elements numbers 1 and 7 in the antenna shown in Fig. 5. (b) With the feed to element number 1 delayed to achieve coincidence of the two positive maxima in (a).

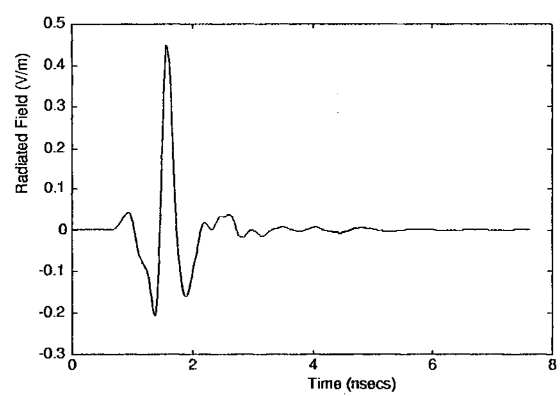

Fig. 8. Radiated dominant electric field component at 2 m from element number 1 in the main beam direction, predicted by TDIE with 2 ns Gaussian input to all elements in the antenna shown in Fig. 5, with time delays as given in Table I.

the "reversed" set. Number 7 is the member of this set that requires the least delay, while the whole of the "forward" set was found to require additional delay.

III. Realization of the Nondispersive Log-Periodic Antenna

Having devised this design, an attempt was then made to realize it in hardware. Two antennas were constructed—one

TABLE I
OPTIMIZED DIMENSIONS AND TIME DELAYS IN THE FEEDS FOR THE DIPOLES OF THE INDEPENDENTLY FED ANTENNA DESIGN (FIG. 5)

Element No.	Dipole length, mm	Spacing from next, mm	Feed direction	Time delay, ns
1	123	8.4	Reversed	0.6532
2	140	9.5	Forward	0.7821
3	159	10.8	Reversed	0.4299
4	180	12.3	Forward	0.6881
5	205	14.0	Reversed	0.2441
6	233	15.8	Forward	0.5735
7	264	18.0	Reversed	0
8	300	-	Forward	0.4034

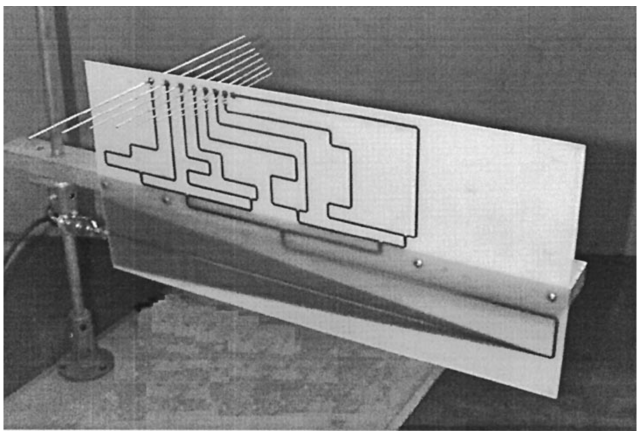

Fig. 9. The final antenna design, as realized with its normal-plane feed network.

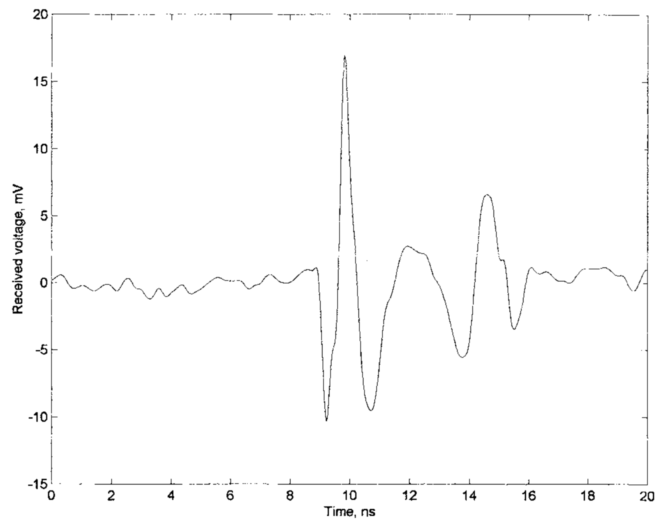

Fig. 10. Measured radiated electric field (dominant component) at 2 m from element number 1 in the main beam direction, with 2 ns Gaussian input to the antenna in Fig. 9.

according to the design derived above. The other had a more traditional value of the taper angle (23°) and with time delays in the individual feedlines chosen on an intuitive basis. In this case, the lengths of the separate element feed lines were arranged to be progressively reduced with increasing distance of the element from the nose such that the total time delay from the corporate feed point to each element and from that element to the nose was equalized.

Since the fields radiated by the antenna are everywhere normal to the plane that bisects the structure and is normal to the dipole elements, it was reasoned that a printed feed structure could be created in this plane that would not distort the fields and would not itself be disturbed by interaction with them. A sheet of printed circuit board material was thus used with the necessary transmission lines etched on both sides of the board to form balanced twin striplines. At the antenna elements requiring reverse-phase feed, two via holes were drilled and cross connections inserted at a break in the transmission lines. To enable the system to be fed from a coaxial transmission line, a broad-band balun was created by tapering one of the striplines so that it became very wide and, hence, gave the appearance of a ground plane. By using a long gentle taper it was found that a good broad-band performance could be achieved (Fig. 9). The effective permittivity of the stripline dielectric was taken into account in designing the length of the feedlines to achieve a given time delay. The lines were widened to give a halved characteristic impedance of 25 Ω in a short section before each power division.

In order to test these antennas, an avalanche-breakdown pulse generator was created as a source: this produced pulses with a rise-time of 400 ps. To probe the radiated fields, two bowtie dipole antennas were created with resistive end loading such that they were nonresonant [5]. Tests of these showed that they had a good deadbeat response with rise times much less than a nanosecond.

When the antenna designed by the procedure described above was tested it was found to give an excellent band-limited radiated pulse, the only corruption being a small time-delayed pulse about 5 ns later (Fig. 10). From its time delay, the latter is evidently a result of reflections at mismatches in the terminations of the feedline. The directive behavior of this antenna was investigated in a fully time-domain test and it was found that the antenna indeed showed directivity with much weaker and dispersed waveforms in directions away from the main beam (Fig. 11). When the second (intuitively-designed) log-periodic antenna was tested with the pulse generator and bowtie field probe dipole its pulsed performance was found not to be very satisfactory, with substantial dispersion of the frequency components (Fig. 12). This suggests either that some better paradigm for the intuitive design of such antennas is required or that intuitive design is infeasible.

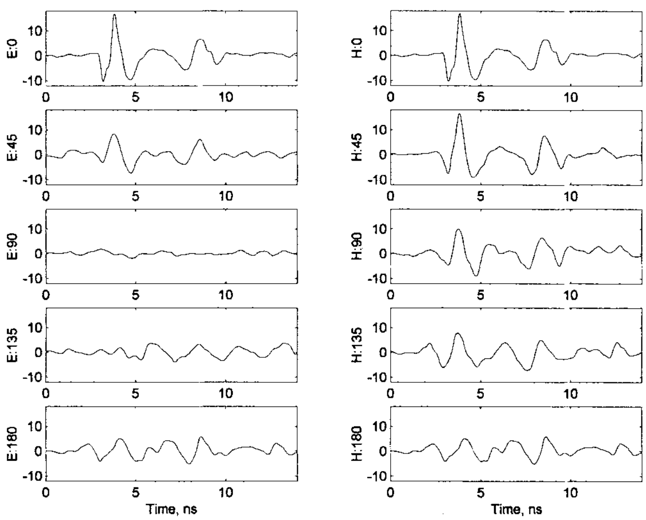

Fig. 11. Measured radiated electric field (dominant component) at 2 m from element number 1, demonstrating directive behavior in major selected directions. Vertical scale: V/m. Labels "E:θ" and "H:θ" refer to angle θ away from main beam direction in E-plane (containing the dipoles) and H-plane (normal to the dipoles), respectively. Only half of each plane shown as the other half is symmetrical.

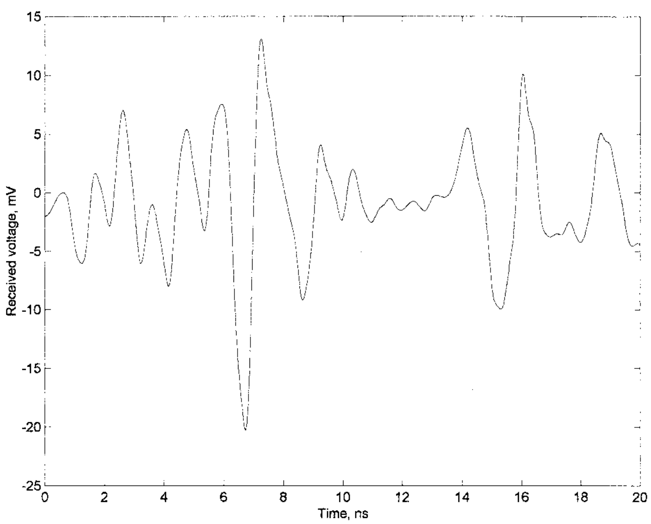

Fig. 12. Radiated electric field (dominant component) at 2 m from element number 1, predicted by TDIE with 2 ns Gaussian input to all elements in a more conventional antenna structure with time delays chosen to compensate for the delays in lower-frequency elements.

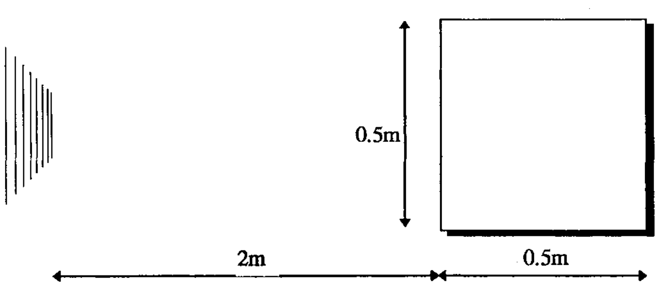

Fig. 13. Location of cubic test zone used to investigate quality of localized plane wave radiated from antenna.

It is considered that this novel nondispersive log-periodic antenna has many other applications, notably in wide-band ground-probing radar and in very wide-band communications,

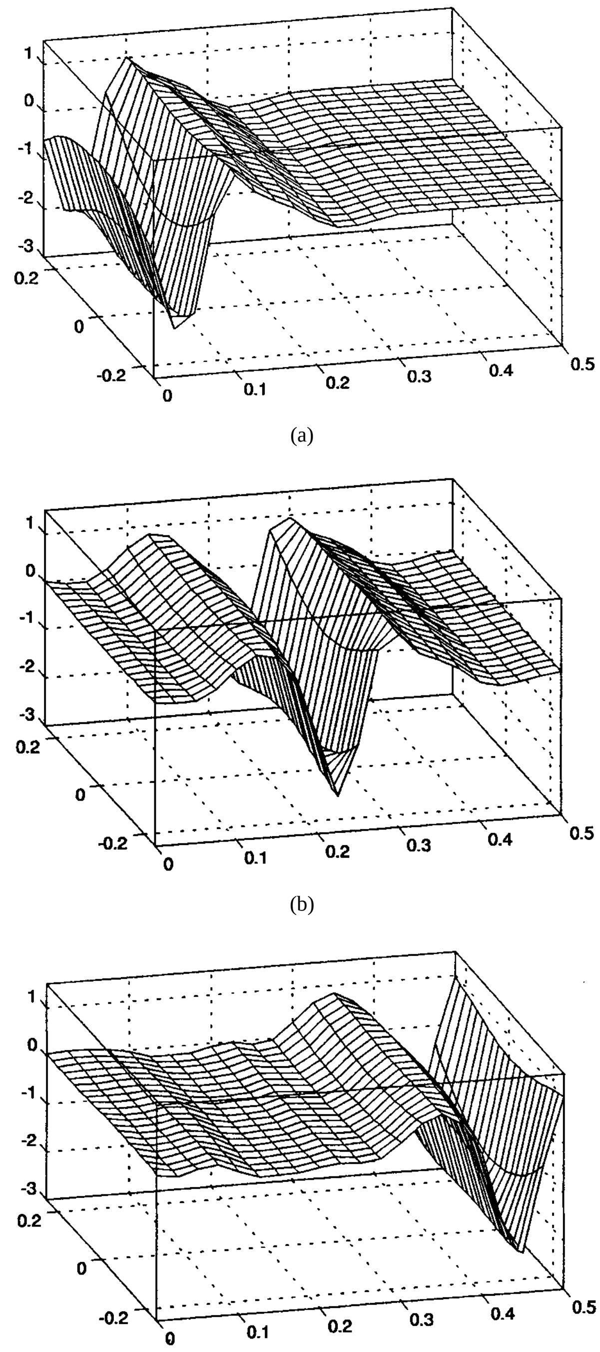

Fig. 14. Dominant component of a pulsed plane wave travelling across the test zone shown in Fig. 13, displayed at 0.7 ns intervals. Vertical scales: V/m; horizontal scales: m. (a) t_0. (b) $t_0 + 0.7$ ns. (c) $t_0 + 1.4$ ns.

where the dispersive nature of standard antennas would be unacceptable [6].

The arraying of the novel antenna design has not yet been tested, but computer simulation of the field distribution in a realistically sized test zone illuminated by the single nondispersive log-periodic antenna was undertaken (Fig. 13). The results (Fig. 14) show the dominant component of the electric field; the cross-polar component is inherently zero on the principal planes and will also be negligible for EMC purposes in off-axis directions within the zone examined. A plane wave of good quality is observed to be traveling through the zone: this demonstrates the potential for extension of the principle, e.g., by arraying to widen the zone.

IV. Conclusion

Time-domain integral-equation (TDIE) studies of a trapezoidal log-periodic antenna of relatively standard form showed substantial dispersion in the radiated waveform when it was fed with a wide-band pulse. A radiated waveform much closer to a band-limited version of the pulse was achieved when the antenna was fed with a time-reversed replica of the dispersed waveform found in the first case.

A heuristic iterative design procedure was developed for a simple log-periodic dipole array (LPDA), based on TDIE modeling, which enabled the development of a design which was predicted to radiate a band-limited version of the input pulse without significant dispersion. This design differed from a conventional LPDA in that each element was fed by a separate source, each with an independently adjustable time delay. This contrasts with the standard transmission-line feeding method for LPDA's, which imposes inappropriate time delays that are proportional to the wavelength of the frequency component. The design was also unconventional in having relatively closely spaced elements leading to a very large value of the taper angle between the loci joining the tips of the dipole elements.

The novel design was realized in hardware, using a printed feed structure in the normal (bisecting) plane to create the desired independently adjustable time delays. A resistively-loaded broad-band dipole antenna was used as a field probe and this showed that the novel LPDA could radiate a band-limited pulse that corresponded reasonably well with the TDIE prediction. Tests of the radiated signals in directions away from the main beam showed that the antenna had significant directive behavior, displaying reduced amplitude and increased dispersion in directions away from the desired main beam.

A simulation of the use of such an antenna in an EMC test facility showed it to be capable of radiating a pulsed plane wave of good quality over a near-field test zone of useful size.

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