C—1—2 TRANSIENT FIELDS OF LINEAR ANTENNA ARRAYS

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The transient electric field strength of a logarithmic-periodic dipole antenna as an example of a linear antenna array is theoretically investigated on the base of different degrees of approximation to discuss the separate influence of the element radii and the transient mutual coupling between neighbouring elements.

1. INTRODUCTION

The development of broad-band communication systems and the interest of EMP effects on them as well as a general interest in their principal physical behaviour leads to the investigation of their transient response. Concerning the pertinent antennas, several attempts have been started to calculate the transient behaviour of logarithmic-periodic dipole antenna arrays, which are either rather time consuming (Solman 1975), rather vague (Knop 1970; Stark 1977) or incorrect (Russegger 1976). Here, the transient transmitting and receiving case of such antennas is discussed theoretically firstly by assuming uncoupled infinitely thin elements using the basic pulsed linear antenna theory of Franceschetti and Papas (1974), secondly by investigating the influence of the uncoupled elements' radii using a recently presented extension (Langenberg and Rech 1978) of Marin and Liu's (1976) simplified singularity expansion. On the base of this approach the coupling influence of neighbouring elements can be calculated approximately and leads to a criterion whether the coupling can be neglected or not. In all cases simple analytical expressions are obtained for the transient real step-function response, that is to say assuming a finite rise time of the exciting voltage of a step-function generator as well as a finite rise time of step-function incident fields.

2. UNCOUPLED INFINITELY THIN ELEMENTS

We consider the logarithmic-periodic dipole antenna (LPDA) of Fig. 1 assuming infinitely thin elements ($a_m = 0$; $m = 1,\ldots,N$). We are interested in the transient electric field strength at some far-field point P in the plane of the antenna when the exciting voltage $V(t)$ (t = time) is given by a real step-function with finite rise time T according to

$$V(t) = U(t)(1-e^{-t/T})^3 \qquad (1)$$

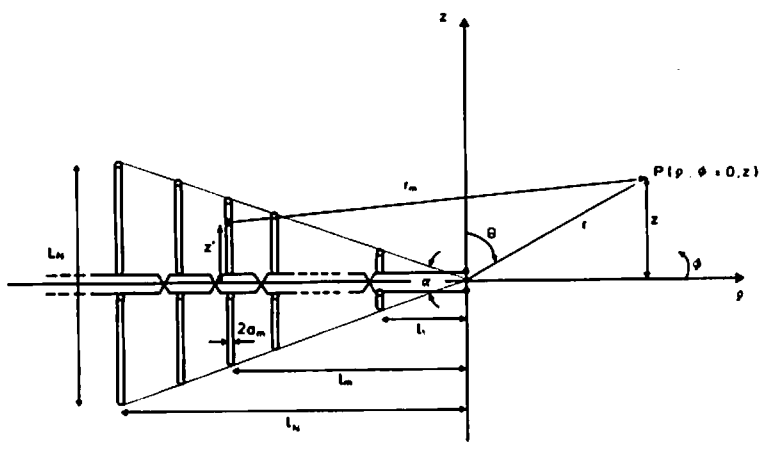


Fig. 1: Logarithmic-periodic dipole antenna

with U(t) being the unit step-function. Neglecting higher order interactions of the element feed points, which yields an error less than 10 % (Russegger 1976), the excitation of the m-th element is approximately supposed to be

$$V_m(t) = (-1)^{m-1} d_1^m \, V(t-t_{1_m}) \tag{2}$$

with the travel time $t_{1m} = l_m/c$ (c = phase velocity along the homogeneous lossless feeding transmission line of characteristic impedance Z_1) and the transmission coefficient $d_1 = 1+\gamma_1$; γ_1 denotes the reflection coefficient at each element's feed point; hence it is given by

$$\gamma_1 = \frac{\bar{Z}_0 \| Z_1 - Z_1}{\bar{Z}_0 \| Z_1 + Z_1} \quad , \tag{3}$$

where $\bar{Z}_0$ is a frequency averaged input impedance of the infinitely long thin dipole antenna according to Wu (King and Harrison 1969). On the base of (2) and the analytical expressions of the transient radiation field of infinitely thin linear antennas with time harmonic sinusoidal current distribution (Franceschetti and Papas 1974) the real step-function response of the LPDA can be calculated by superposition of the single elements' transient fields. The normalized result is shown by Fig. 2 as function of the retarded ($t_0 = l_1/c + r/c + l_1 \sin\Theta/c$) and normalized ($t_L = L_N/c$) time for an antenna with the following parameters: N = 13, $\alpha = 14^0$, $\tau = L_{m+1}/L_m = 0.9$, $l_1 = 0.1524$ m. The rise time T is chosen to be T = 0.025 ns. Generally the transient far-field of LPDAs is found to be an amplitude modulated carrier frequency pulse with decreasing instantaneous frequency; the detailed structure of this signal can be physically explained in a very intuitive manner (Langenberg 1978).

3. ELEMENTS WITH FINITE RADII

Assuming finite radii of the single elements with $\Omega_m < \infty$ and

$$\Omega_m = \Omega = 2 \ln L_m/a_m \quad , \quad m = 1,\ldots,N \tag{4}$$

we can use the Singularity Expansion Method (SEM)

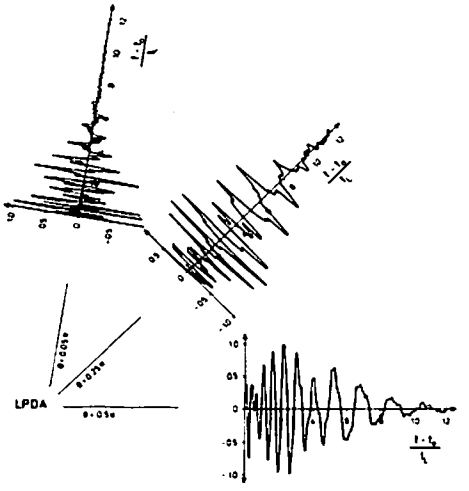


Fig. 2: Real step-function response of LPDA with infinitely thin elements

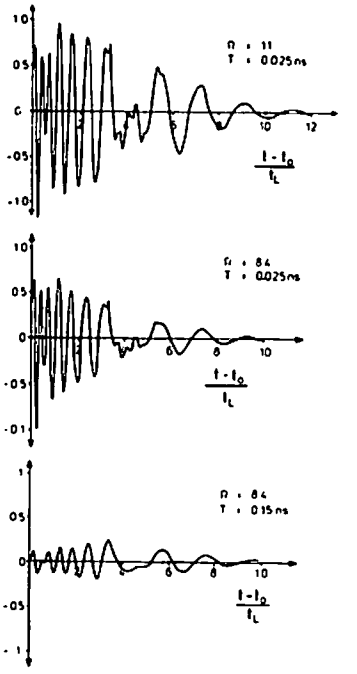
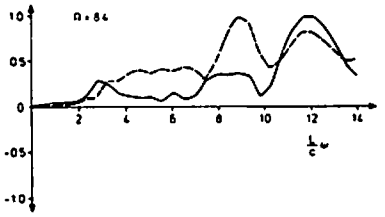


Fig. 3: Real step-function response of LPDA with finite radii elements

to calculate their transient far-fields to the excitation function (2). Recently given numerical SEM-data of high accuracy for non-zero generator impedance (Langenberg and Rech 1978) show how to extend Marin und Liu's (1976) approximate SEM-version to transmission line connected wire antennas. It is found that the natural modes are nearly unaffected by the generator resistance whereas the negative real part of the first layer poles increases, dependent on the pole number and the element's radius; their imaginary parts as well as the complex second layer poles are nearly unaffected. Based upon these results transmission line analogy in connection with Wu's input impedance theory yields very good approximate expressions for the pole shifting due to the generator's resistance or to the characteristic impedance of the feeding transmission line. Hence, analytic expressions for the real step-function response of the LPDA's transient far-field are presented, which can be easily evaluated numerically. Results are shown in Fig. 3 for $\Theta = \pi/2$; the main influence of the elements's finite radii consists in a slight reduction of the instantaneous frequency and in shifting the envelop's maximum to earlier times; these effects increase for decrasing Ω, whereas the opposite effect is observed for increasing T.
The receiving case of the LPDA can be treated in a similar manner; the corresponding real step-function response (T = 0.025 ns) is shown in Fig. 4. Generally, using SEM, it can be easily shown, that calculation of the transient response of any receiving antenna to any transient excitation means time-integration of the pertinent response of the same antenna to the same excitation in the transmitting case.

4. INFLUENCE OF COUPLING

The afore-mentioned extension of the approximate SEM-version can equally be used to compute time harmonic data. Fig. 5 shows the normalized absolute value of the frequency response of the LPDA under consideration ($L\omega/c$ is a normalized circular frequency). The practical bandwidth ranges from $3 \leq L\omega/c \leq 9$, where characteristic "fadings" are observed for decreasing Ω; this effect similarly occurs in the frequency dependence



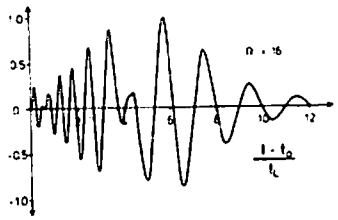


Fig. 4: Real step-function response of receiving LPDA

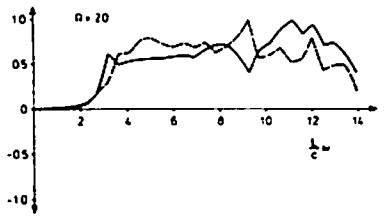


Fig. 6: Input admittance (solid lines: without coupling; dashed lines: with coupling)

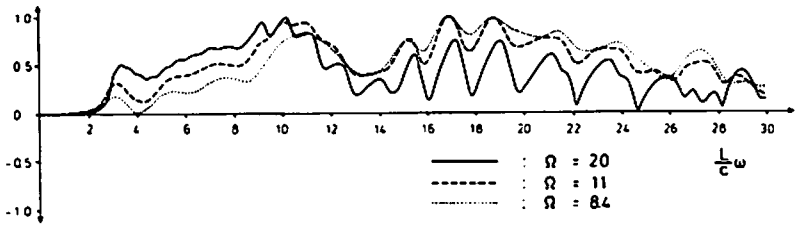


Fig 5: Frequency response

of the input admittance (Fig. 6, solid lines). It can be theoretically shown that this is due to the neglection of coupling, since our theory permits calculation of the transient coupling of neighbouring LPDA-elements by multiple interaction on the base of an appropriate near-field approximation. It is shown that the induced transient currents on neighbouring elements are proportional to Ω^{-2} and that their superposition to the current due to the transmission line excitation results in less radiation damping as if the array elements were thinner; hence, a characteristic influence of the coupling is observed in the frequency dependence of the input admittance (Fig. 6, dashed lines) as well as in the transient far-field; coupling can certainly not be neglected for $\Omega \lesssim 14$.

5. CONCLUDING REMARKS

The presented theory of calculating transient responses of wire antenna arrays to arbitrary excitation allows performance of parametric studies to determine the worst case of - for example - EMP effects. Furthermore, a straightforward procedure allows consideration of surface environment.

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