# PHASED-ARRAY EFFECT IN ANTENNAS WITH TRANSIENT EXCITATION

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**Abstract**
In this work the phased array effect in linear antenna with transient excitation will be under theoretical and numerical analysis. This effect is realized inherently due to specific features of transient electromagnetic radiation in long linear and other antennas. The waveform of radiated electromagnetic field of those antennas includes separated in time the pulse signal replicas that produced by specific points on antenna like its boundaries as well as any point with "strong" charge disturbance of antenna. This waveform registered by a field probe in an arbitrary observation point depends on its spatial position. The last can be principally determined by processing of the registered waveform. This signal processing involves resolution in time of indicated signal components and is in fact a beam-forming procedure of phased array antenna with transient behavior.

## 1. Problem Background

In contrast to antennas and arrays with both sinusoidal and narrow frequency-band excitation the electromagnetic structures with transient excitation demonstrate quite different performances [1]. Such excited by pulse (video-pulse) signals antennas are employed widely in high-resolution radars, subsurface radars, EMP simulators etc. The theoretical and experimental time-domain approaches to study transient antennas are more adequate than traditional frequency-domain technique [2]. Besides known features of transient antennas [1-4] there is an inherent effect than can be treated as some phased array behavior. For simplicity, let consider a thin monopole antenna in the Cartesian coordinates as it is shown in Fig. 1a. The two boundaries of antenna are located at *x=0* (source termination) and *x=La* (end point). The radius of antenna is enough small so that only the x-direction component of the vector potential function Ax should be treated that resulted in the principal component $E_x(t,x,y)$ for single-passing excitation mode [1]:

$$E_x(t,x,y) = k\left\{\int_0^{La}\frac{U'(t-(R+l)/c)}{R}dl + \int_0^{La}\frac{U(t-(R+l)/c)}{R^2}dl\right\} \qquad (1)$$

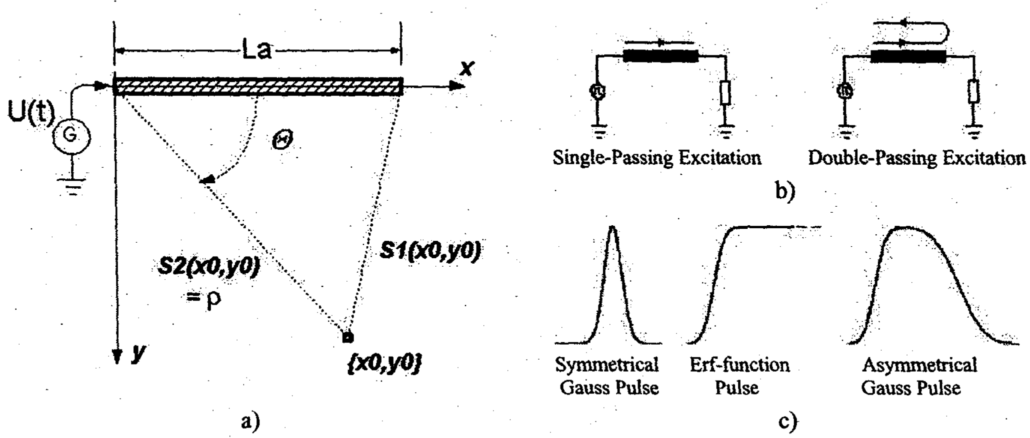



Fig. 1. Schematic presentation of linear monopole antenna in the Cartesian coordinates (a) excited in single- or double-passing mode (b) by driving signal *U(t)* of definite waveforms (c).

Where in (1) $c$ is the light velocity; $k$ –coefficient; $l$ – local auxiliary coordinate along antenna axis with the origin at $x = 0$; $R \equiv R(x,y,l)=((x-l)^2 + y^2)^{1/2}$ is a distance on the plane $xy$ from the point on antenna $x \equiv l$ to observation one with coordinates $\{x,y\}$ in Fig 1a. The expression (1) has been obtained under the following assumption. The antenna is excited by pulse signal with waveform $U(t)$ like ones in Fig. 1c. Current distribution along the antenna is initially presented like traveling wave $U(t-(l+R)/c)$ until this current reaches the boundary at $x = La$. Then there are two main scenarios of antenna excitation (Fig. 1b), i.e. single-passing excitation due to matched antenna end loading or double-passing one due to boundary effect at $x=La$ with the following current disappearance on matched impedance of the driving source. Generally both modes are implemented by means of antenna distributed resistive loading.

Note that the first term in the left part (1) corresponds to the radiated far-field component while the second one is the near-field [1]. Expression for far-field radiation can be obtained analytically from (1) by noncomplex math manipulations. Thanks to axial symmetry of problem it is easy to present the electric far-field under the single-passing excitation in the polar coordinate system $\{\Theta,\rho\}$ on the plane (Fig. 1):

$$E_\Theta(t,\Theta,\rho) \cong k_1 \frac{\sin\Theta}{1-\cos\Theta} \cdot \left\{ U(t-\frac{\rho}{c}) - U(t-\frac{\rho}{c}-\frac{La}{c}(1-\cos\Theta)) \right\} \quad (2)$$

where $k_1$ is normalized coefficient. The expression (2) reflects that radiation of transient antenna is produced by antenna's boundary points at x=$\{0,La\}$ [3,4]. There is some physical sense in that statement because electromagnetic radiation is originated due to acceleration or deceleration the charges on antenna [5]. Evidently rapid appearance or disappearance of charges takes place on the antenna boundaries. In fact energetic and pattern features of transient radiation depends on antenna total length and its geometrical structure [1,4], which are not considered in detail here.

### 2. Phased Array Effect in Transient Linear Antenna

Let analyze the basic geometrical relations in antenna arrangement in Fig. 1a in accordance to introduced above a "discrete-point" model of transient radiation. Starting from evident geometrical properties in Fig. 1a one has the following expressions for time intervals that are necessary to reach the observation point from the antenna boundaries in process of pulse propagation along antenna excited in the double-passing mode (right part of Fig. 1b):

$$T1(x,y) = S1(x,y)/c \quad (3a) \qquad T2(x,y) = (La + S2(x,y))/c \quad (3b) \qquad T2(x,y) = (2La + S2(x,y))/c \quad (3c)$$

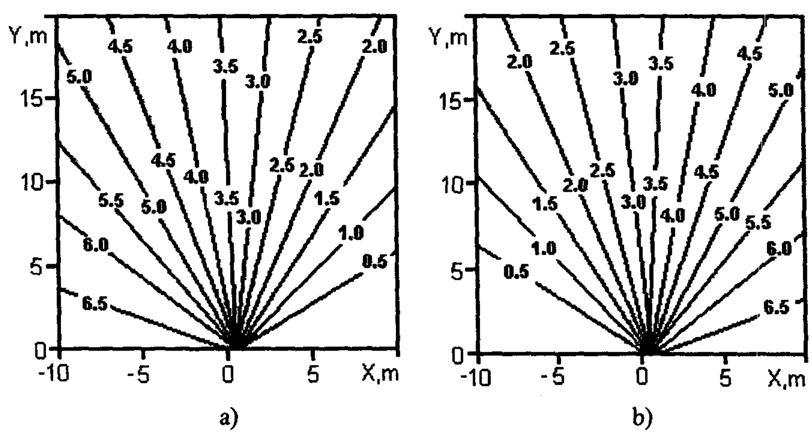



Fig. 2. Contour plots for $\Delta T1(x,y)$ (a) and $\Delta T2(x,y)$ (b) quantities terminated in nanosecond (ns) unit. These figures have been computed for linear antenna La = 1.0 m in the Cartesian coordinates (Fig. 1a) for square area limited by inequalities: $-10 \le x \le 10$ and $0 \le y \le 20$. Both x and y are terminated in meters (m).

Next it is reasonable to express time differences between the field events characterized by $T1,2,3(x,y)$

$$\Delta T1(x,y) = T2(x,y) - T1(x,y) \quad \text{(4a)} \qquad \Delta T2(x,y) = T3(x,y) - T2(x,y) \quad \text{(4b)}$$

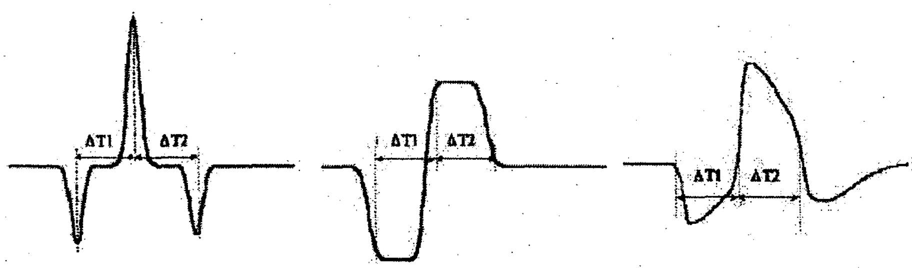
Then one is able computing $\Delta T1$ and $\Delta T2$ by (4) and presenting the final results by contour plots like in Fig. 2 where is seen that there is mutual dependence between quantities $\Delta T1$ and $\Delta T2$ and spatial coordinates $\{x,y\}$ of the observation point. Such dependence establishes the one-to-one correspondence between $\{\Delta T1,\Delta T2\}$ and $\{x,y\}$ excepting only narrow domain where $x \approx La/2$.

Now let consider the problem starting rather from expressions like (1) and (2) then geometrical properties discussed above. Reaching this goal one can specify quantities $\Delta T1$ and $\Delta T2$ versus $\{x,y\}$ by computing simulated waveforms. The double passing excitation mode of antenna and set of excitation signals (Fig. 1c) are involved in simulation. The typical simulated waveform can be obtained like ones in Fig. 3 where aforementioned quantities $\Delta T1$ and $\Delta T2$ are shown. In fact exact time evolution of signal depends on correlation of antenna length La and signal electrical lengths $Ls=Ts*c$ [4] where Ts is equivalent signal duration. The array effect under investigation becomes apparent for long antenna when $La > Ls$.

In what follows one computes $\{\Delta T1,\Delta T2\}$ for chosen points $\{x,y\}$ inside the square domain $-10 \le x \le 10$ and $0 \le y \le 20$ (Fig. 2). This computation involves the specification of wanted magnitudes from simulated waveforms as shown in Fig. 3. Acting in such way one can receive total coincidence of results of presented above geometrical analysis and electromagnetic modeling as it follows from Fig. 4. In this Fig. 4 one can observe the changing of signal waveform and corresponding $\Delta T1$ and $\Delta T2$ figures versus the Cartesian coordinates of observation point inside the indicated domain. The effect of the near-field electromagnetic radiation is visible in Fig. 4 when $y \le 5*La$ and can be employed for some goals too.

## Summary

Due to the fact that transient electromagnetic events are considered in time-domain each component of electromagnetic field connected with antenna's boundaries is registered in proper time that depends on geometrical relations of task. For the sample of linear antenna with double-passing excitation considered above there are three separated replicas of radiated electromagnetic field, which are connected with pulse radiation produced by the antenna's end points. As it was shown early the features of the registered waveform depend on the coordinates of observation points $\{x,y\}$ and the general geometry of antenna. Such dependence is mostly a single-valued function excepting position $x \approx La/2$ that in turn is valuable too, for instance, to solve pointing or navigation tasks etc. Generally for implementation of radar signal processing one should solve three consequence problems, i.e. (1) target detection, (2) coordinate measurement and (3) recognition. For pulse radar operating in time-domain the problems (2) and (3) are closely matched together due to the fact that observed waveform of scattered signal is a function of both the spatial position and shape of target. The presented study gives a model of array behavior of pulse antenna that can be employed for implementing time-domain beam forming in transient antennas.




a) b) c)

Fig. 3. Radiated waveforms due to double-passing excitation by (a) symmetrical Gauss pulse, (b) Error-function pulse and (c) asymmetrical Gauss pulse with $\Delta T1$ and $\Delta T2$ characteristic values.

Note that in practice for navigation and positioning tasks the measurement of spatial mutual position of receiver in observation point and transmitter with transient array can be implemented in asynchronous modes. Such working is based on estimation of the *ΔT1* and *ΔT2* characteristics without necessity for mutual synchronization of transmitter and receiver in time.

## References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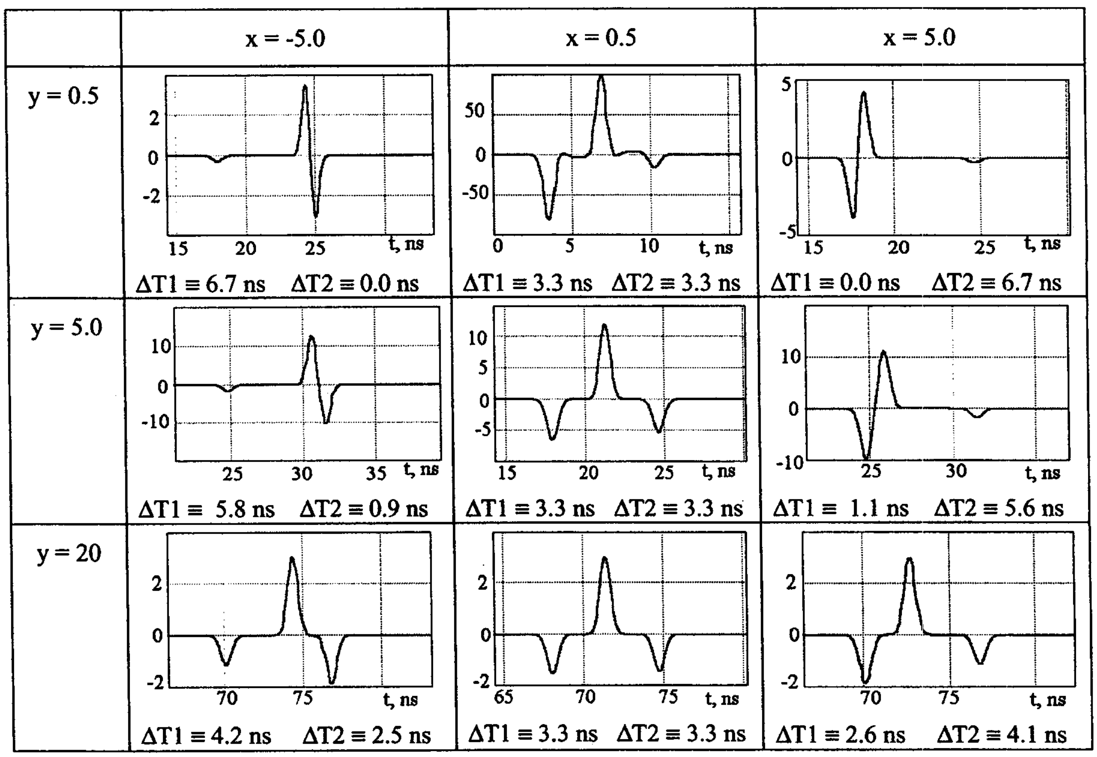


Fig. 4. Waveforms of principal electrical component of radiated electromagnetic field and magnitudes of ΔT1 and ΔT2 quantities computed for linear monopole antenna of the 1-m length. This antenna is located like one in Fig. 1a and excited in the double-passing mode by the current pulse source with the Gauss symmetrical waveform and pulse duration of 0.5 ns at the amplitude level 0.5 (-6dB).