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RADIATION OF ULTRA-WIDEBAND (UWB) SIGNALS

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The radiation of short duration signals (or ultra-wideband – UWB signals) is significantly different from the long duration narrowband signals (see Table 1 below). Paper analyzed the processes in linear antennas and gives a physical interpretation these differences.

1. Introduction

The building of ultra-wideband (UWB) radars requires a theoretical basis for calculating the antenna design parameters and predicting the performance. This is particularly important for designing antenna systems that set up the performance of precision range and the direction measuring systems. Recent publications about UWB antennas do not present a comprehensive and systematic theory for calculating such antenna parameters. This is because the UWB signal radiation process in antennas is significantly different from the narrow-band signal case. Studying these differences and determining the causes helps to develop the design calculation methods for the UWB antennas. In this paper, we analyzed the radiation process occurring in linear UWB antennas and gave a physical interpretation.

Table 1.

Parameter	Signal	
	Narrowband	UWB
Radiation	All the aperture of antenna (one wave)	Only the center and edges of antenna's aperture (several waves)
The form of a radiation field in time	Derivative from form of current (signal)	Repeats the form of a current (signal)
Amplitude of a radiation field	Depends on angular coordinates only	Depends on angular coordinates and time
The form of a radiation field in space (antenna pattern)	Depends on angular coordinates only	Depends on angular coordinates, time and on form of current (signal)
Side radiation	Side lobes	Uniform decrease

2. The Processes in a UWB Antenna

2.1. A UWB Antenna Propagation Model

We consider a series excited antenna modeled as one branch of a symmetrical radiator of length L, and having a large number of the elementary radiators of size ΔL. By examining the radiation from each element ΔL we can sum up the results and provide the far field estimate at different angles from the antenna axis. The result shows that the field is a function of time and the angular position from the antenna, instead of the position, as in the narrowband case. For the given radiator size L, the radiation becomes axial for small values of $c\tau$. As τ has increased increases to a constant length, the pattern becomes normal to the antenna axis.

Fig. 1 shows the 1 representing one branch of a symmetrical radiator with length L consisting of a large number of elementary radiators with the linear size ΔL. In Fig. 1 we use the following notation: ΔL_j is the j-th elementary radiator, L_j is its coordinate, r is the distance to observation point M; Θ is the angle between the direction to observation point and the antenna axis. The pulse of current starts at point O which is the physical base of the antenna.

2.2. Derivation of the Equation

We consider the electromagnetic far-field, appearing

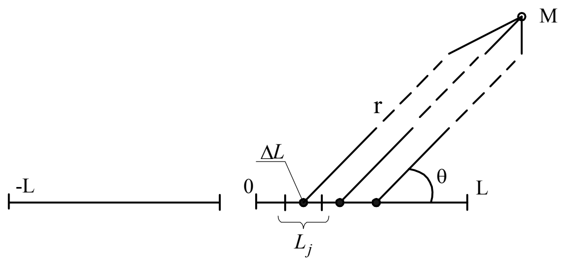

Fig. 1. *The symmetrical radiator model for the analysis*

as the pulse of current spreads along the radiator branch. The current pulse feeding to point O excites the first elementary radiator. The electromagnetic field appearing in the far field at time r/c has the following form:

$$E(t,\theta) = \frac{Z_0 \sin\theta}{4\pi c}\frac{1}{r}\frac{d}{dt}\left[i\left(t - \frac{L_1}{c_0} - \frac{r - L_1\cos\theta}{c}\right)\right]\Delta L\ ,$$

where Z_0 is the free space impedance; c_0 is the velocity of propagation of the current pulse in the radiator. To simplify calculations hereinafter we assume: $c_0 = c$.

In time $\Delta L/c$ the pulse of current enter the second elementary radiator and excite it. The second electromagnetic field is as in the equation as L_1 is changed to L_2.

As the current pulse moves along the branch it sequentially excites each elementary radiator. To get a clear physical knowledge we ignore the resistance and radiation losses and assume that the load absorbs the current pulse after exciting the last, or N-th radiator. The far field after the excitation of all the elementary radiators is as:

$$E_\Sigma(t,\theta) = \frac{Z_0 \sin\theta}{4\pi cr}\sum_{j=1}^{N}\frac{d}{dt}\left[i\left(t - \frac{L_j}{c} - \frac{r - L_j\cos\theta}{c}\right)\right]\Delta L\ ,$$

Now we can examine the continuous antenna. For this purpose we consider the length of the elementary radiator tending to zero $\Delta L \to 0$ and the number of elementary radiators tending to infinity $N \to \infty$. Then, in our equation the summation can be changed to integration so that

$$E_\Sigma(t,\theta) = \frac{Z_0 \sin\theta}{4\pi cr}\int_0^L \frac{d}{dt}\left[i\left(t - \frac{L}{c} - \frac{r - L\cos\theta}{c}\right)\right]dL.$$

This equation describes the electric component of the electromagnetic far field for symmetrical radiator branch excited by arbitrary current.

The field is determined by the derivative of current with respect to time and is formed by various points of the radiator as the pulse moves along the wire. In round brackets there is the expression which determines the current time of the system in view of this delay. We take the derivative of this time with respect to dL, and have the opportunity to introduce the replacement variable: $dt = \frac{\cos\theta - 1}{c}dL$. As a result we obtain the receive integral from the derivative function of the same variable, which is equal to this function. Then:

$$E_\Sigma(t,\theta) = \frac{Z_0 \sin\theta}{4\pi r}\frac{1}{\cos\theta - 1}\left[i\left(t - \frac{L}{c} - \frac{r - L\cos\theta}{c}\right)\right]_0^L = \frac{Z_0 \sin\theta}{4\pi r}\frac{1}{\cos\theta - 1}\left[i\left(t - \frac{L}{c} - \frac{r - L\cos\theta}{c}\right) - i\left(t - \frac{r}{c}\right)\right].$$

It is seen from this equation that the radiation of the symmetrical radiator branch in far field is a sum of two fields. One of which is radiated when the current pulse enters the point of radiator excitation, and the other at the moment when this pulse achieves the end of the radiator. In literature this process is often explained as the radiation from the excitation point and from the end of radiator. However, this interpretation is not correct.

Let us consider the example: the field created by radiator branch in the case when the exciting current pulse has the Gaussian form shown by the solid line in Fig. 2, and is expressed by

$$i(t) = \exp\left[-4\left(t/\tau\right)^2\right],$$

where τ is the duration of pulse on level 0,5.

This pulse creates the elementary radiator far field determined by its derivative. The result is the symmetrical bipolar pulse shown by the dotted line in Fig. 2. Having substituted equations and performing differentiation and integration, we obtain:

$$E_\Sigma(t,\theta) = \frac{Z_0 \sin\theta}{4\pi r}\frac{1}{\cos\theta - 1}\times \left\{\exp\left[-4\left(\frac{t - \frac{L}{c} - \frac{r - L\cos\theta}{c}}{\tau}\right)^2\right] - \exp\left[-4\left(\frac{t - r/c}{\tau}\right)^2\right]\right\}.$$

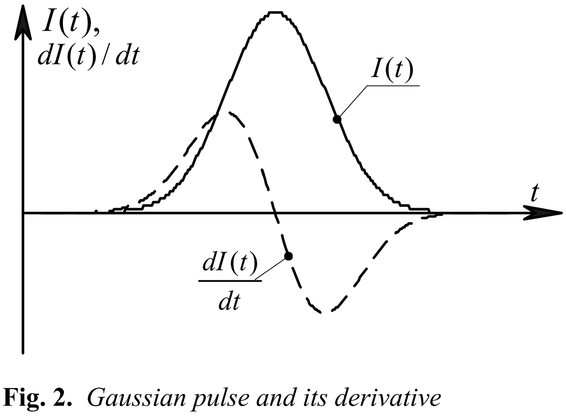

Fig. 2. *Gaussian pulse and its derivative*

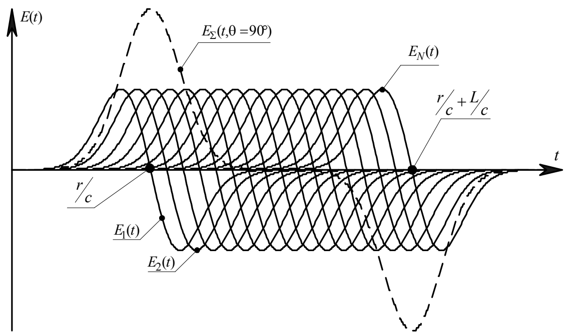

Fig. 3. *Fields excited by radiator branch when* $L \gg c\tau$

2.3. The Fields and Antenna Patterns during Radiation of a UWB Signal

We examine the far field formation for the case where the branch length L greatly exceeds the pulse duration in the space $c\tau$.

In Fig. 3 the fields exited by elementary radiators L_j in point M at the angle $\theta = 90°$ are shown with continuous line. These fields have the double polarity and time delay relative to each other. The far field result, at any angle and distance, is compensated by the addition or subtraction of the fields from different points along the radiator. There is the full compensation of the fields in the time interval $t = \tau$ and $t = L/c - \tau$. However, some part of the fields excited by the pulse of current at the initial and terminal areas of the radiator branch remain uncompensated. The sum of these remaining fields is shown in Fig. 3 with dotted lines. As a result the field created by the radiator branch under $L \gg c\tau$ consists of two parts, as if they were connected with the point of excitation and with the end of this branch.

This figure explains the apparently contradictory shape of the radiated short pulse because the field waveform follows the current instead of its derivative.

The degree of interaction and compensation between the elementary radiator fields depends on the antenna length and pulse duration. If the pulse duration τ increases and the antenna length L remains constant, then the time interval on which the compensation of the fields occurs will become less. Finally, under $L \ll c\tau$ the compensation practically stops, as shown in Fig. 4. The antenna radiates with the whole aperture simultaneously.

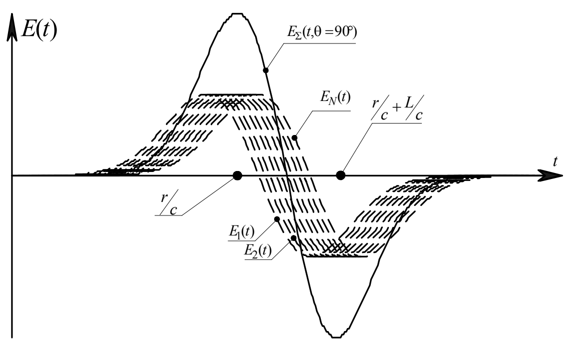

Fig. 4. *The fields excited by the radiator branch when* $L \ll c\tau$

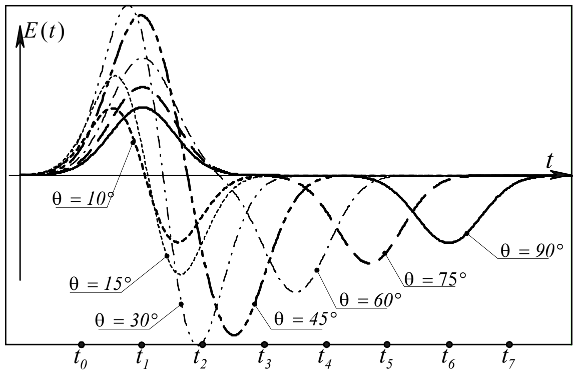

Fig. 5. *Variations of the summation field in the far zone for different angles*

With variations of the observation angle θ, the distances from the observation point to each elementary radiator L_j vary. As a result, the summation of far-fields for these radiators occurs in various ways and the form of the resulting field created by the radiator branch varies as shown in Fig. 5. Thus, if angle θ is reduced the amplitude of this field increases. This occurs because more of the elementary radiator fields do not fall into the compensation areas. The field amplitude increases until it is influenced by the multiplier $\sin\theta$, which defines the pattern of the elementary radiator. Note the radiation waveform changes with the angle from the antenna.

Let us consider the pattern of the radiator branch. For this, we use the above equations. Thus, the considered antenna pattern is non-stationary and depends on the time of the current pulse in the antenna. This pattern can be presented as a family of instant pat-

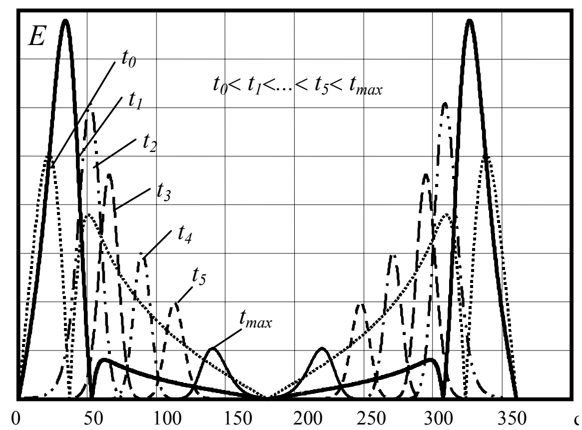

Fig. 6. *UWB radiator instantaneous field patterns for Gaussian pulse excitation*

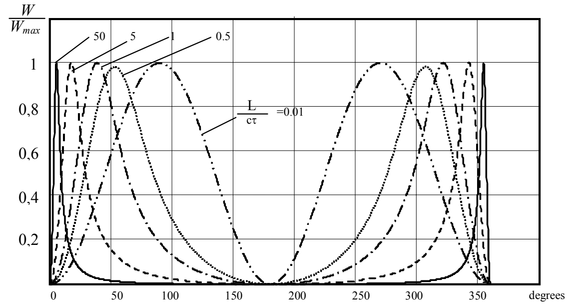

Fig. 7. *Family of the simple radiator field patterns for different ratios of* L *to* $c\tau$

terns, each of which corresponds to the instantaneous far field for some given waveform.

Fig. 6 shows the family of instant patterns in the field $E(\theta)$ for the Gaussian pulse exciting the radiator branch when the radiator length exceeds the signal spatial duration so that $L \gg c\tau$. As it can be seen from Fig. 6, the pattern maximum changes its direction during the time of the radiated field existence. At initial time this maximum is directed practically along the antenna axis. As the current pulse moves, the pattern shifts toward the antenna normal. The space pattern width and maximum value decrease as the pattern moves away from the axis.

The field pattern of time varying nature is difficult to use. We can determine a static pattern by averaging the radiator far field over the time of its existence. Such pattern is called the energy pattern $W(\theta)$. The family of such patterns for different relationships between the length of radiator branch L and the pulse duration in space $c\tau$ is shown in Fig. 7. The expressions for the energy pattern of a wire antenna are also given in Malek G.M. Hussain, Matthew J. Yedlin [2] for various values $L/c\tau$. When $L < c\tau$, this pattern coincides with the radiator branch pattern. If τ is reduced and L is held constant, the pattern shifts from normal position to the antenna and grows narrower. At values of $L \gg c\tau$, radiation becomes axial, as if the impulse source radiates directly into free space with no compensation from the antenna length.

The series excited antenna was considered above. We can obtain similar results for the parallel antenna excitation. For this purpose it is necessary to exclude from the equations term L/c determining delay of a current's pulse in the aperture. Fig. 8 and 9 show the instantaneous field patterns and energy patterns for the Gaussian pulse excitation of UWB radiator in this case.

3. Conclusion

In the conventional antenna theory, the radiated energy duplicates the exciting signal frequency and

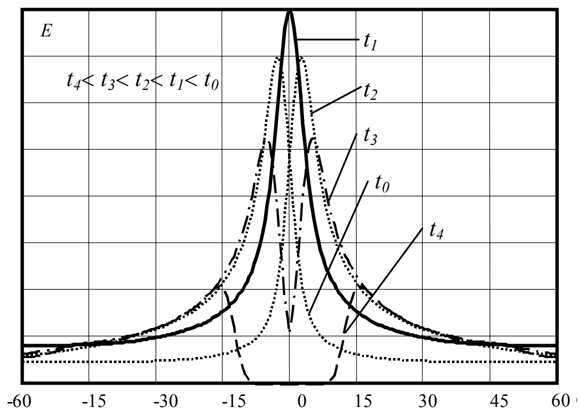

Fig. 8. *The UWB radiator instantaneous field patterns for the Gaussian pulse and parallel antenna excitation*

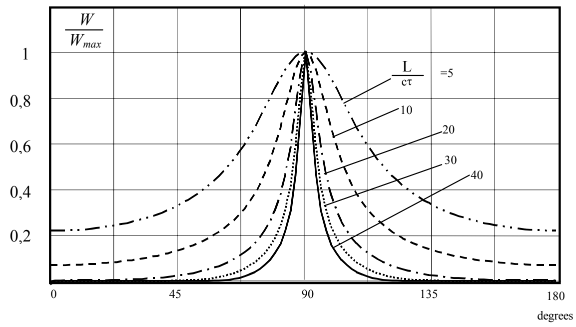

Fig. 9. *Family of the simple radiator field patterns for different ratios of* L *to* $c\tau$ *for parallel antenna excitation*

waveform. By examining the impulse radiator case, we find that the length of the antenna and the radiation direction with respect to the antenna axis produce different waveforms. Analyzing and predicting UWB signal radiation require a new approach to considering how electronic impulses interact and compensate in the far field.

This paper suggests that if antenna length $L \gg c\tau$, there will be a continuously varying signal spectrum in off-axis directions.

This could provide a method for the direction finding with respect to the antenna axis based on the signal waveform.

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ИЗЛУЧЕНИЕ СВЕРХШИРОКОПОЛОСНЫХ СИГНАЛОВ

И.Я. Иммореев, А.Н. Синявин

В статье анализируются процессы в линейных антеннах. Излучение сигналов короткой длительности (или сверхширокополосных) существенно отличается от излучения сигналов большой длительности (узкополосных). Приводится физическая интерпретация этих различий.

ВИПРОМІНЮВАННЯ НАДШИРОКОСМУГОВИХ СИГНАЛІВ

І.Я. Імморєєв, А.М. Синявін

У статті аналізуються процеси у лінійних антенах. Випромінювання сигналів короткої тривалості (або надширокосмугових) суттєво відрізняється від випромінювання сигналів з великою тривалістю (вузькосмугових). Наводиться фізична інтерпретація цих відмінностей.