

# Synthesis of ultrawideband radiation of combined antenna arrays excited by nanosecond bipolar voltage pulses

V I Koshelev, V V Plisko and E A Sevostyanov

Institute of High Current Electronics SB RAS, Tomsk, Russia

E-mail: koshelev@lhfe.hcei.tsc.ru

**Abstract.** To broaden the spectrum of high-power ultrawideband radiation, it is suggested to synthesize an electromagnetic pulse summing the pulses of different length in free space. On the example of model pulses corresponding to radiation of combined antennas excited by bipolar voltage pulses of the length of 2 and 3 ns, the possibility of twofold broadening of the radiation spectrum was demonstrated. Radiation pulses with the spectrum width exceeding three octaves were obtained. Pattern formation by the arrays of different geometry excited by the pulses having different time shifts was considered. Optimum array structure with the pattern maximum in the main direction was demonstrated on the example of a  $2 \times 2$  array.

## 1. Introduction

The spectrum width of high-power ultrawideband (UWB) electromagnetic pulses is determined by characteristics of radiator and exciting voltage pulse. To broaden the radiation spectrum, it was suggested in [1] to synthesize an electromagnetic pulse through the summation in free space of the pulses of different length (frequency band) radiated by an array of combined antennas. The possibility of synchronous operation of four independent bipolar pulse formers (BPF) exciting a 4-element array of combined antennas has been presented in the investigation [2]. The amplitude of voltage pulses, the length, and the time instability  $\sigma$  were equal to 50 – 60 kV, 3 ns, and 50-70 ps, respectively. The summation of fields from separate antennas in the array was realized in the far-field zone. Using the independent BPF, it is possible to create high-power UWB sources with combined antennas excited by bipolar voltage pulses of different length and, as a result, to increase the frequency band of the electromagnetic pulse. It will allow increasing the possibility of UWB radar as well as the study of susceptibility of electronic systems to the influence of strong electromagnetic fields.

At the first stage of the study, an UWB source based on a 4-element array of combined antennas excited by bipolar pulses of the length 2 and 3 ns has been developed. Below, the results of the numerical simulation of the antenna array for this type of radiation source are presented.

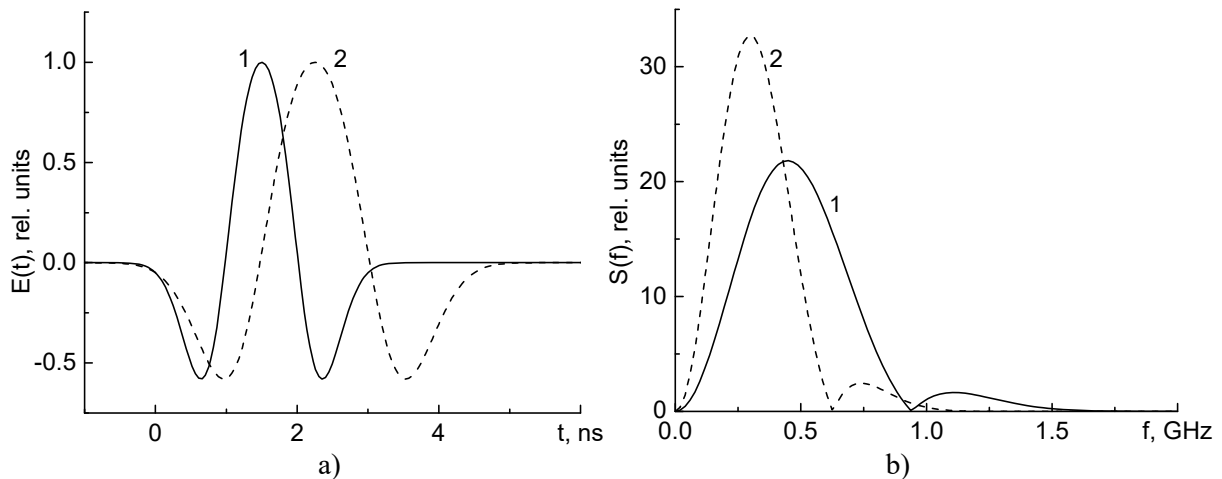
## 2. UWB pulses and their spectra

We will consider the increase of the spectrum width of a synthesized pulse using an example of pulses radiated by the previously developed antennas excited by the bipolar voltage pulses of the length 2 [3] and 3 ns [4]. To simulate the pulse radiated by the combined antenna, we will use the derivative of the sum of two Gaussian functions:



$$E(t, \tau) = \frac{8}{\tau} \left( \frac{4t}{\tau} - 2 \right) e^{-\left( \frac{4t}{\tau} - 2 \right)^2} - \frac{8}{\tau} \left( \frac{4t}{\tau} - 4 \right) e^{-\left( \frac{4t}{\tau} - 4 \right)^2}, \quad (1)$$

where  $\tau$  is the length of the bipolar voltage pulse exciting the antenna by the level of 0.1 of the amplitude. In [5], it is shown that formula (1) allows a reasonably good simulation of the real pulses  $E(t)$  radiated by the combined antennas as well as their spectra  $S(f)$ . Fig. 1a presents the pulses calculated by the formulae (1), while Fig. 1b presents their spectra.



**Figure 1.** Radiation pulses (a) at the antenna excitation by bipolar voltage pulses of the length 2 ns (1) and 3 ns (2) calculated by the formula (1) and the spectra corresponding to these pulses (b).

### 3. Summation of radiation pulses

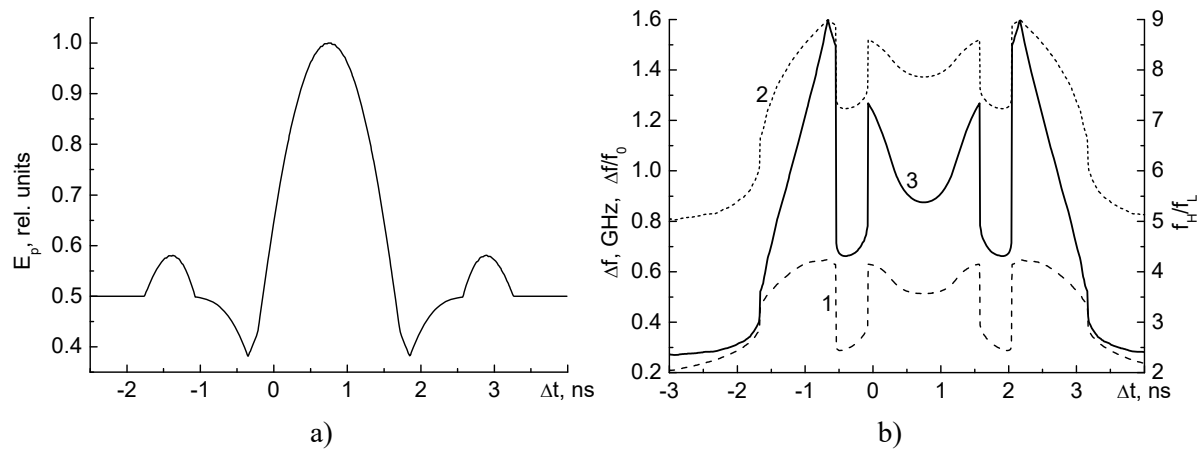
The result of summation of radiation pulses is determined by both the pulse characteristics and their time delays relative to each other. Thus, changing the delay between the radiation pulses of different length (spectrum width), we can obtain pulses with different characteristics: the amplitude and the spectrum width.

We will optimize the synthesized pulse by two parameters: peak amplitude of the field and the maximum spectrum width. Note that the pulse spectrum can be characterized by the following parameters:

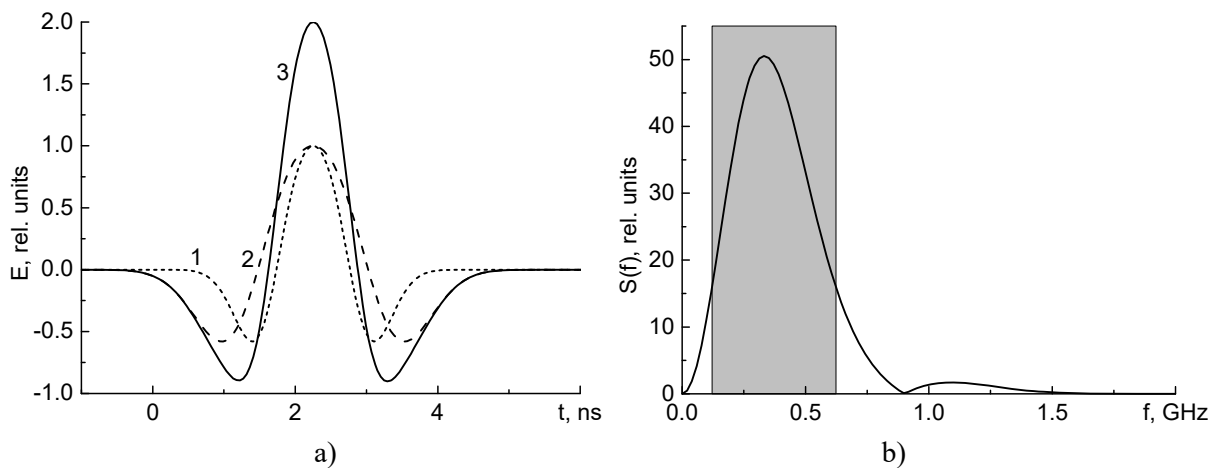
- 1) the spectrum width  $\Delta f = f_H - f_L$ , where  $f_L$  is the lower and  $f_H$  is the upper boundary frequency of radiation spectrum by the level of -10 dB;
- 2) the relative spectrum width  $\Delta f/f_0$ , where  $f_0 = (f_H + f_L)/2$  is the central frequency of radiation spectrum;
- 3) the ratio of the upper and the lower boundary frequencies  $f_H/f_L$ .

To analyze the characteristics of a synthesized pulse, we will plot the peak strength of the field  $E_p$  and the spectrum width  $\Delta f$  by the level of -10 dB versus the time delay  $\Delta t$  between the pulses (Fig. 2).

Maximum peak field strength is realized at the delay  $\Delta t = 0.76$  ns which corresponds to the synchronization of the pulse amplitudes (Fig. 3). Herewith, pulse amplitudes are summed but the ratio of the upper and the lower boundary frequencies of the total pulse increases insignificantly, approximately by 10%, in comparison with the pulses radiated at the antenna excitation by bipolar pulses of the length 2 and 3 ns.



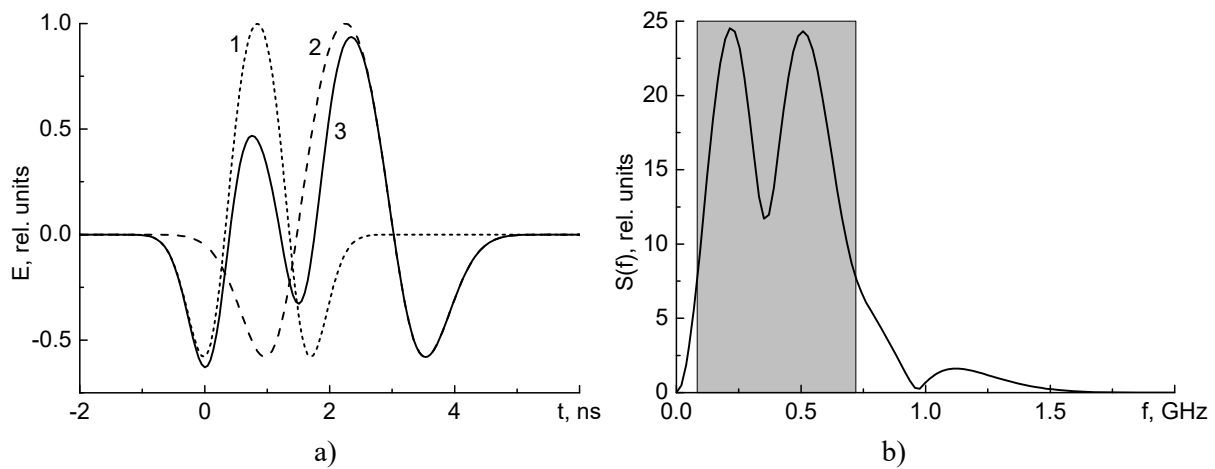
**Figure 2.** Peak field strength (a) and total pulse spectrum by the level of -10 dB (b) versus the delay between the pulses. 1 – spectrum width  $\Delta f = f_H - f_L$ , 2 – relative spectrum width  $\Delta f/f_0$ , 3 – ratio of the upper and the lower boundary frequencies  $f_H/f_L$ .



**Figure 3.** Pulse synchronization by the amplitude maximum. a) 1 – radiation pulse at the antenna excitation by a bipolar pulse of the length 2 ns, 2 – radiation pulse at the antenna excitation by a bipolar pulse of the length 3 ns, 3 – total radiation pulse. b) total radiation pulse spectrum.

Fig. 2 (b) demonstrates that the maximum values for all three parameters characterizing the pulse spectrum are accounted for the delays of -0.66 and 2.16 ns. Fig. 4 presents the total pulse for the delay  $\Delta t = -0.66$  ns and its spectrum. In comparison with a single pulse, the ratio of the upper and the lower boundary frequencies of the total pulse increased by a factor of 1.85 amounting to more than three octaves. Herewith, the field amplitude of the total pulse decreased by 7% relative to the amplitude of the initial pulses.

Table 1 presents the frequency characteristics for the singular (Fig. 1) and total pulses for the delays of 0.76 and -0.66 ns (Fig. 3 and 4). The Table demonstrates that the shift of the lower boundary frequency  $f_L$  up to 83.5 MHz. makes the substantial contribution into the bandwidth widening of the total pulse with the delay of  $\Delta t = -0.66$  ns.



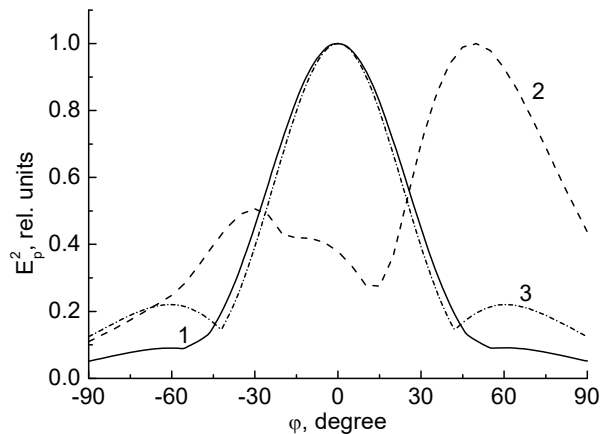
**Figure 4.** Summation of the pulses with the delay of -0.66 ns. a) 1 – radiation pulse at the antenna excitation by a bipolar pulse of the length 2 ns, 2 – radiation pulse at the antenna excitation by a bipolar pulse of the length 3 ns, 3 – total radiation pulse. b) total radiation pulse spectrum.

**Table 1.** Parameters of radiation pulses

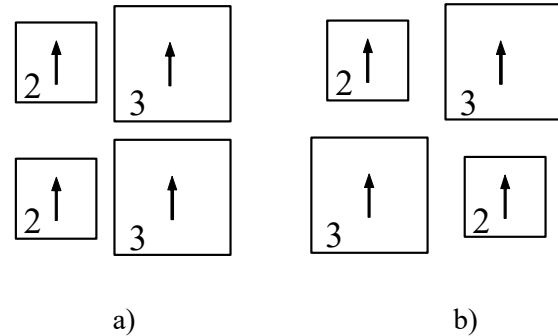
UWB radiation pulse	$f_L$ (GHz)	$f_H$ (GHz)	$f_0$ (GHz)	$\Delta f$ (GHz)	$\Delta f/f_0$	$f_H/f_L$
2 ns	0.1658	0.7686	0.4672	0.6028	1.290	4.636
3 ns	0.1104	0.5125	0.3115	0.4021	1.291	4.643
2+3 ns, max amplitude	0.1209	0.6232	0.3721	0.5023	1.35	5.153
2+3 ns, max spectrum	0.0835	0.72	0.4017	0.6364	1.584	8.618

#### 4. Patterns

Similar to [3, 4], we will use the pattern by the peak power  $E_p^2$  for antennas and arrays radiating ultrawideband pulses. When the pulses of the length 2 and 3 ns are synchronized by the field maximum ( $\Delta t = 0.76$  ns), their pattern will not differ from the array pattern that is excited synchronously ( $\Delta t = 0$ ) by the pulses with equal length (Fig. 5, curve 1). However, for the total pulse with maximum spectrum width ( $\Delta t = -0.66$  ns), the direction of the pattern maximum depends on the array configuration. Here, we consider the array of  $2 \times 2$  combined antennas, in which two elements are excited by a bipolar voltage pulse of the length 2 ns, while another two elements are excited by a bipolar voltage pulse of the length 3 ns. Figure 6 demonstrates two possible configurations. Numbers 2 and 3 mark the array elements excited by the bipolar pulses of the length 2 and 3 ns, respectively. We will calculate the array patterns by the peak power of radiation in the H-plane by means of direct summation of the pulses radiated by the array elements assuming that the element has a cardioid pattern and the radiation pulse waveform is independent of the angle. For the array configuration depicted in Fig. 6a, the pattern maximum is shifted by the angle of  $50^\circ$  (Fig. 5, curve 2). To return the pattern maximum to the initial direction (perpendicularly to the array plane), it is necessary to use the array configuration presented in Fig. 6b. In this case (Fig. 5, curve 3), the pattern does not practically differ from the pattern for the radiation pulses synchronized by the field maximum.



**Figure 5.** Patterns of the 2x2 arrays in the H-plane. 1- at synchronous excitation ( $\Delta t=0$  ns) by the pulses of equal length; 2 – at excitation by the pulses of 2 and 3 ns with  $\Delta t = -0.66$  ns (variant 6a); 3- at excitation by the pulses of 2 and 3 ns with  $\Delta t = -0.66$  ns (variant 6b).



**Figure 6.** Variants of configuration of a 2x2 array. The arrows indicate the polarization plane of vector E.

## 5. Conclusion

By means of numerical simulation, we have shown a possibility to broaden the spectrum of ultrawideband radiation using the summation of the pulses of different length (frequency band) in a free space. In case the antennas are excited by the bipolar voltage pulses of the length 2 and 3 ns, it becomes possible to obtain radiation pulses with the spectrum bandwidth up to three octaves. To obtain the pattern with the maximum in the main direction, the array elements should be located diagonally.

## Acknowledgment

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## References

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