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Receiving and Detection of Ultra-Wideband Microwave Signals Radiated by Pulsed Excitation of Monopole Antennas

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Pulsed excitation of small size monopole antennas for generating wideband electromagnetic pulses was used. The monopoles were excited by electrical pulses having rise times of 600 ps, 200 ps, 70 ps and voltages 100 V, 15 V, and 0.4 V respectively. Antennas spanning (0.3 – 26) GHz bandwidth, including broadband horns with coaxial outputs, were employed to receive signals, which were investigated using (0 – 26) GHz passband sampling oscilloscope.

It was found that waveforms of signals, received by the antennas, mostly depend on the pulse rise time and on the details of geometry of monopoles. The electromagnetic pulses have relatively long duration of about 30 ns and spectral harmonics up to 22 GHz. Therefore they can be attributed to pulses with large base. The results show that the upper frequencies of the spectrum most probably are cut off by existing arrangement. Usage of such pulses can find wide practical application when they are received after transmission trough different media by a number of antennas having different operational frequency ranges, followed by digital signal processing.

Keywords: pulsed excitation, monopole antennas, UWB signals, long duration signals, wideband antennas.

1. INTRODUCTION

Recent creation of digital oscilloscopes, having passband up to 50 GHz, allows recording of different ultra-wideband signals and of their bursts, which are received by wideband antennas, in digital format. Corresponding software not only simplifies manipulations with the signals but also allows avoid interferences caused by parasitic reflections.

If earlier ultra short electromagnetic (EM) pulses were defined as ultra-wideband (UWB) signals, then, after two and a half decades of intensive investigations, variety of signals that can be related to UWB were discovered. Properties of these signals are different and therefore it is a possibility of a choice when applying them to solve specific problems. EM wideband signals of (20 – 30) ns in duration have properties that may be very useful when searching objects behind covers or placed into media having strong frequency-dependent losses [1]. Due to this, continuous theoretical studies [2] and experimental research [3] keep reveals new types of ultra-wideband signals having relatively long durations.

Investigation of EM pulses radiated by plane rectangular, monopole antennas was carried out in work [4]. Short pulses with sub nanosecond rise time were used for pulsed excitation of the antennas. The EM pulses were received by wideband antennas and obtained signals of short duration were characterized as ultra-wideband (UWB) signals. However usage of sampling oscilloscope with (0 – 5) GHz passband prevented precise definition of their spectral characteristics in high frequency range.

In this work experimental investigation of EM pulses radiated by different plane antennas is done. The antennas include those, which were designed using fractal geometry. Monopoles were attached to the open end of coaxial cable and were excited by fast rising pulses of different amplitudes. Radiated pulses were received by six antennas spanning (0.3 – 26) GHz bandwidth and (0 – 26) GHz bandwidth sampling oscilloscope was used for visualization of the received signals. The aim of the work is to determine upper limit of the signals spectra and more precisely define their pulse duration, therefore to make more exact conclusions about the EM pulses generated by the pulsed excitation.

2. EXPERIMENTAL

Schematic of the experimental setup is presented in Fig.1. Multifunctional pulse generator (1) transmits pulses through the cable (2) to plane monopole antenna (3). EM pulse radiated by antenna (3) should be received by broadband antennas. In this case we placed broadband horn with coaxial output (4) and broadband TV dipole (5) antennas. Further manipulations with the signals are done after recording them by the digital oscilloscope having passband of (0 – 26) GHz (10).

Three types of radiating monopole antennas were used in the experiment. Their forms and dimensions one can see from Fig. 2. Some of them are designed by applying fractal geometry. The monopoles were attached to the open end of the coaxial cable and excited by electrical pulses with rise time of 600 ps, 200 ps, 70 ps and amplitude 40 V, 15 V and 0.4 V respectively.

Six receiving antennas with bandwidth spanning from 0.3 GHz to 26 GHz were used for investigation of the EM pulses. Broadband TV ((0.3 – 1) GHz) and logoperiodic ((1 – 1.7) GHz) antennas cowered lower part of the spectra. Two horn antennas with coaxial outputs have (2 – 5.64) GHz and (8.24 – 12.05) GHz operational frequency bands. The signals formed by these two

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antennas have low amplitude values and usage of the amplifier (7) is recommended. Remaining antennas were broadband dipole antenna and super broadband horn having operational frequency band of (0.3 – 4) GHz and (1 – 26) GHz, correspondingly. The distance between the monopoles and the receiving antennas depends on the amplitude of the excited pulse.

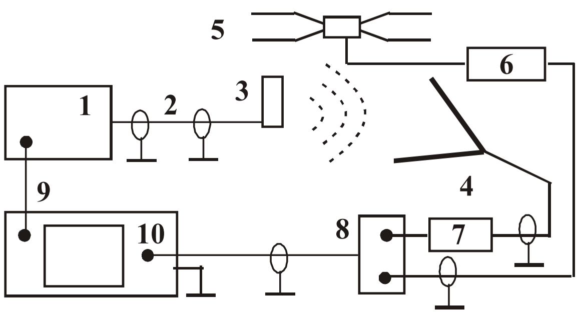

Fig. 1. Schematic diagram of experimental setup. 1 – multifunctional fast rise time pulse generator, 2 – coaxial transmission line, 3 – monopole antenna, 4 – receiving horn antenna, 5 – receiving TV-range antenna,6 – (75 – 50) Ohm transition unit, 7 – broadband amplifier, 8 – sampler, 9 – synchronizer, 10 – (0 – 26) GHz passband digital sampling oscilloscope

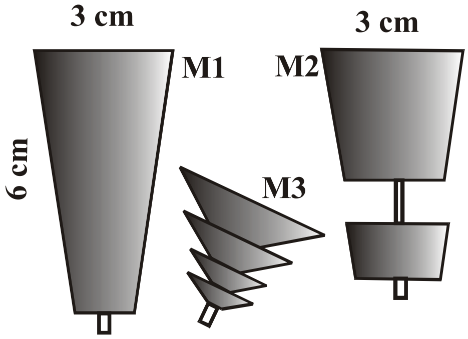

Fig. 2. Three plane antennas were used in experiment as monopoles. The antennas denoted as M1, M2, and M3

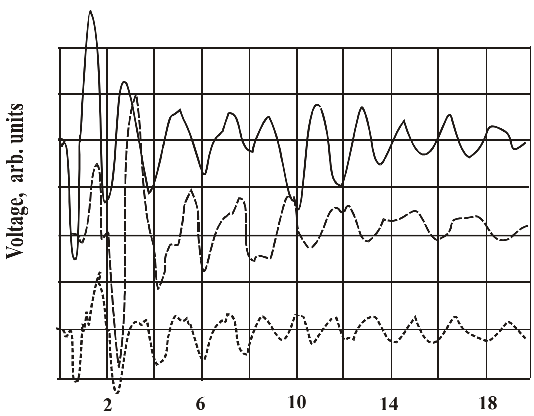

Fig. 3. Three waveforms of signals received by the broadband dipole antenna. They correspond to 600 ps, 200 ps, 70 ps rise times (from top to bottom). The EM pulses were radiated by antenna M3

The view of the pulses, received by the broadband dipole antenna, radiated by antenna M3 when excited by 600 ps, 200 ps, 70 ps electrical pulses is given in Fig. 3. The waveforms from other monopoles only slightly differ and therefore these waveforms are common to all monopoles.

Fig. 4 presents waveforms of signals received by TV range antennas. The wave forms from the logoperiodic antenna consist of several wave trains varying by peak amplitude. Usually wave trains of such signals last from 5 ns to 15 ns and average period of oscillations is 1.5 ns. Total duration of the wave train chain is about (25 – 30) ns. The waveform from broad band TV antenna indicates the signal having no carrier frequency. The signal waveforms of the same EM pulses as in Fig. 3, but received by the (2 – 5.64) GHz band horn antenna, are presented in Fig. 5. The signal wave forms from the (8.4 – 12.05) GHz band horn (not shown) consist of several sinus-like wave trains and their duration last from 1.5 ns to 2 ns with average period of 0.14 ns. The total duration of wave train chain is about (3.5 – 4) ns.

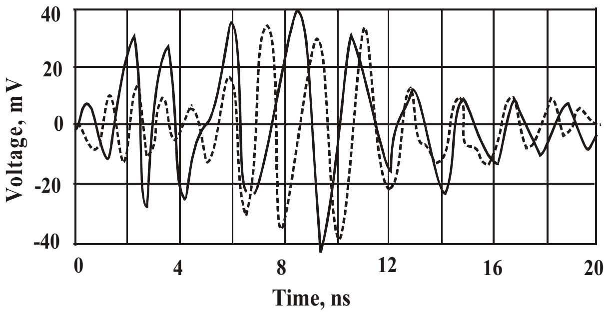

Fig. 4. Two waveforms received by the logoperiodic (dotted) antenna and by the broadband TV range antenna (solid). The EM pulses were radiated by antenna M2. The exciting pulse had rise time of 200 ps and amplitude of 15V

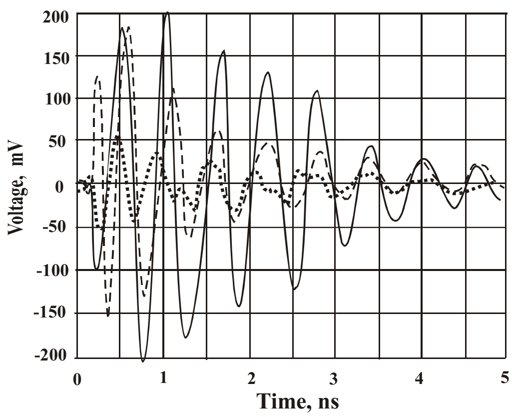

Fig. 5. Three waveforms received by the (2 – 5.6) GHz horn. The EM pulses were radiated by antenna M3. The waveforms correspond to 600 ps, 200 ps, 70 ps rise time pulses. The shorter rise time corresponds the smaller oscillation amplitude

Fig. 6 presents signal waveform of the pulse radiated by the antenna M1 and its spectral density when received by the ultra-wideband horn antenna. Exiting pulse has 200 ps rise time. The waveform can be seen as consisting of two parts – initial 5 ns part which has no carrier frequency and the remaining 25 ns low amplitude part which can be discarded as interference. The figure also shows that spectral resolution of our arrangement reaches (20 – 22) GHz.

Registration of a signal can be also performed using detectors that is especially relevant for practical applications. Oscillograms of the one of the signals presented in Fig. 5 are obtained using two types of broadband detectors and are presented in Fig. 7. One can see that depending on detector sensitivity and power of signal, the oscillograms obtained in such a way can be sufficiently different.

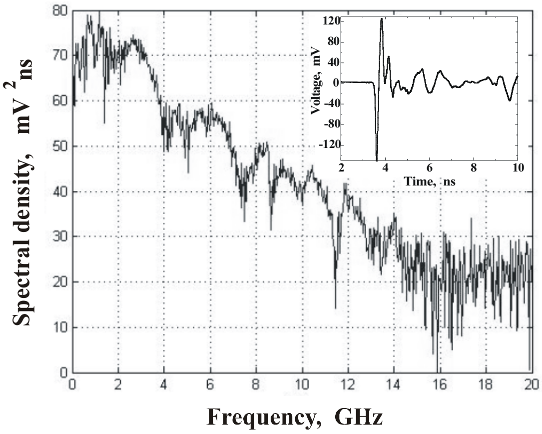

Fig. 6. Spectral density of pulse radiated by antenna M1. The exciting pulse has 200 ps rise time and receiving antenna is the ultra-wideband horn. The signal waveform in insertion

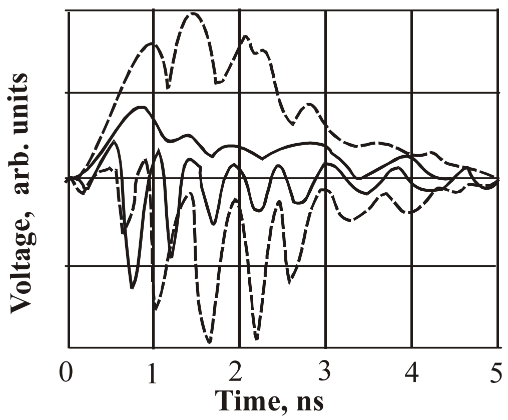

Fig. 7. Detection of signal using 2 detectors. The signal waveform shown in Fig. 5 with exciting pulse of 200 ps rise time. Oscillograms obtained without (solid) and with (dashed) amplification

3. DISCUSSION

The most complete waveforms of broadband electromagnetic signal were visualized using the broadband dipole receiving antenna (see Fig. 3). As one can see the waveforms differ on the front rise time of excited pulse. Truth to say here the tail part of the waveforms is not shown. The whole duration of the signals is (25 – 30) ns. The lower frequency of the spectrum can be defined as 0.3 GHz.

We will use the definition of UWB signal [4]: signal is UWB if $0.25 \le \eta \le 1$ and $\eta = (f_{up} - f_{low})/(f_{up} + f_{low})$, where f_{up}, f_{low} are upper and lower frequencies of the signal spectra. Base B of long duration signal is equal to $(f_{up} - f_{low}) \cdot T$, where T is signal duration and signals with $B >> 1$ are called large bandwidth and long duration signals (LB-LD). So for the signals in Fig. 3 η is equal to 0.86 and $B = 92.5$ and they can be referred both as UWB and LB-LD signals.

Taking in mind waveform that was received by logoperiodic antenna, one can determine if the waveform corresponds to UWB signal. One calculates that the logoperiodic antenna $\eta = 0.45 \cdot 10^9 / 1.1 \cdot 10^9 = 0.41$. This index value indicates the UWB signal, however the train's maximal $B = 0.65 \cdot 10^9 \cdot 15 \cdot 10^{-9} = 9.75$, so for the train condition $B >> 1$ is not sufficient. Therefore signals from TV range antennas are chains of trains which are UWB signals.

For waveforms in Fig. 4 $\eta = 3.64 \cdot 10^9 / 7.64 \cdot 10^9 = 0.476$ and $B = 3.64 \cdot 10^9 \cdot 5 \cdot 10^{-9} = 18$ and, therefore they are also rather UWB signals.

Taking in mind description of waveform from (8.4 – 12.05) GHz band antenna, one calculates the antenna $\eta = 3.64 \cdot 10^9 / 20.44 \cdot 10^9 = 0.178$. This index value have no indication on UWB signal, the train maximal $B = 3.64 \cdot 10^9 \cdot 2 \cdot 10^{-9} = 7.25$, so for these trains condition $B >> 1$ is also not sufficient. Therefore signals from the antennas are no UWB signals and have no large B.

For signal from super wideband horn beginning part without carrier frequency have very high $\eta = 25 \cdot 10^9 / 27 \cdot 10^9 = 0.926$ that indicates on UWB signals and residual part could be referred as interference.

As seen from Fig. 6 upper spectrum frequency of the EM pulse is about (20 – 22) GHz which is also the limit of existing experimental arrangement. Therefore B of the investigated EM pulse is about 600. The beginning parts of the waveforms differ as seen from Fig. 3 and Fig. 5 which is conditioned both by the front rise time and by the radiating antenna geometry. This relation is confirmed by reflectograms from monopoles and could widen higher harmonics of spectral density. This data obtained from the oscilloscope indicates that the EM pulse spectrum most probably even exceeds 26 GHz and could contain harmonics up to 40 GHz. This especially can be applied for M3 fractal monopole.

Naturally we can only receive certain part of the spectrum of the EM pulse that is supported by the antenna. Therefore it would be more desirable to perform broadband detection. As an example we provide detection of the signal radiated by M3 excited by electrical pulse with 200 ps rise time (see Fig. 7). One detector gives the envelope. Another detector performs rectification in small signal regime which remains unchanged even when using amplifier. One should pay attention to matching network of broadband rectifying and choose the parameters of charge pump circuits properly. Also, when using amplifiers their amplification coefficient should be constant in the supported by the antenna's frequency range.

4. CONCLUSIONS

Results of the experiments show that pulsed excitation of monopoles antennas of 6 cm in height by electrical pulses of different amplitudes and rise times leads to generation of LB-LD EM pulses. Each of the receiving antennas transformed the radiated EM pulses into different UWB and LB-LD electrical pulses according to its own different bandwidth. The radiated EM pulses have wide spectrum in (0.3 – 20) GHz frequency range and their base B is about 600. The registered frequency range limit of (20 – 22) GHz is also the maximum capacity of our measuring arrangement. Spectral density of radiated signals depends on the rise time of exciting electrical pulses and influenced by monopole's geometry. The results indicate that spectral harmonics of the investigated EM pulses could exceed 20 GHz but to establish this precisely additional investigation employing measuring arrangement with higher frequency resolution is required. Indeed, they have properties that can be very effective when searching objects behind covers or placed into media having strong frequency-dependent loss.

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