Radio Physics and Radio Astronomy, 2002, v. 7, No. 4, pp. 379-384

THE EXPERIMENTS ON RADIATION OF SHORT PULSE SIGNALS BY THE LARGE CURRENT RADIATORS OF DR. H.F. HARMUTH

G.P. Pochanin, I.E. Pochanina, P.V. Kholod, S.A. Masalov

A.Ya. Usikov Institute for Radiophysics and Electronics
of the National Academy of Sciences of Ukraine
12, Акad. Proskury-street, 61085, Kharkov, Ukraine
E-mail: gpp@ire.kharkov.ua

The report contains some designs and characteristics of studied by the author large current radiators (LCR) of Dr. H.F. Harmuth for radiation of pulse signals of the nanosecond duration range.

Introduction

The key problem restricting radar and radio communication capabilities of UWB/SP systems is lack of ultra wideband antennas, which are able to radiate and receive short pulse electromagnetic waves with high efficiency and without shape distortions. We consider the proposed by H.F. Harmuth the LCR approach [1] as a promising way to such antennas development.

Basic equations describing the strength of the electrical field $\vec{E}$ and the magnetic one $\vec{H}$ radiated by the small-sized electric dipole (Fig. 1), look like

$$\vec{E} = \frac{Z_0 \ell}{4\pi c}\left[\frac{1}{r}\frac{dI_{rad}}{dt}\frac{\vec{r}\times(\vec{r}\times\vec{\ell})}{\ell\cdot r^2} + \left(\frac{c}{r^2}I_{rad} + \frac{c^2}{r^3}\int I_{rad}\,dt\right)\cdot\left(\frac{3(\vec{\ell}\cdot\vec{r})\cdot\vec{r}}{\ell\cdot r^2} - \frac{\vec{\ell}}{\ell}\right)\right], \qquad (1)$$

$$\vec{H} = \frac{\ell}{4\pi c}\left(\frac{1}{r}\frac{dI_{rad}}{dt} + \frac{c}{r^2}I\right)\frac{\vec{\ell}\times\vec{r}}{\ell\cdot r}. \qquad (2)$$

Here I_{rad} – is the radiator current; ℓ – is the dipole length; $Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$ – is the free space wave impedance with permeability μ_0 and permittivity ε_0; $\vec{r}$ – is the observation point vector.

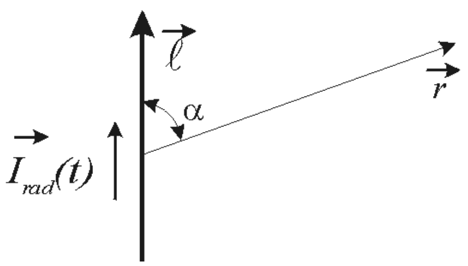

Fig. 1. *Electric dipole*

For large r it is possible to neglect components proportional to $1/r^2$ and $1/r^3$. Then the strength of the fields $\vec{E}$ and $\vec{H}$ is determined as follows

$$\vec{E} = \frac{1}{r}\frac{Z_0\ell}{4\pi c}\frac{dI_{rad}}{dt}\frac{\vec{r}\times(\vec{r}\times\vec{\ell})}{\ell\cdot r^2}, \qquad (3)$$

$$\vec{H} = \frac{1}{r}\frac{\ell}{4\pi c}\frac{dI_{rad}}{dt}\frac{\vec{\ell}\times\vec{r}}{\ell\cdot r}. \qquad (4)$$

Expressions (3) and (4) show that in the antenna far zone the time dependence of strengths of the radiated pulse electromagnetic field represents the derivative of current in the dipole with respect to time. Therefore, to radiate a field pulse the dipole would be driven by the step current. And the radiated pulse duration is equal to the current rise (drop) time in the antenna.

LCR represents (Fig. 2) a small-sized frame $ABCD$. The metal-ferrite shield S with permeability μ_S and ferrite permittivity ε_S divides the frame into the region containing the radiating element, and the region, in which is the return loop. Due to the shield S the return loop radiation doesn't interfere with the radiating element field, and owing to that we can achieve the dipole mode of radiation. As the wave impedance of the ferrite shield is $Z_S = \sqrt{\frac{\mu_0\mu_S}{\varepsilon_0\varepsilon_S}} > Z_0$, the reflectance from this shield has the positive sign. Therefore the field reflected by the ferrite shield does not compensate the field generated by the radiating element.

In view of the LCR design features and also because the radiator resistance is very low it is usu-

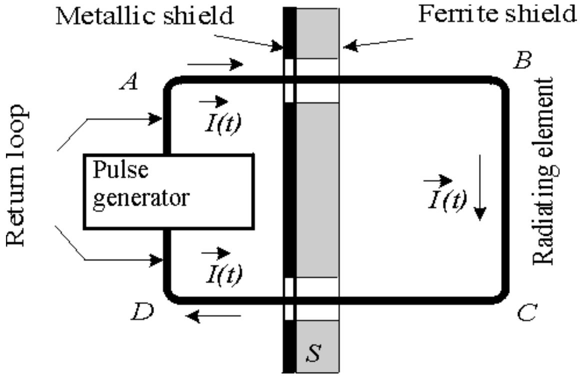

Fig. 2. *Schematic circuit of LCR*

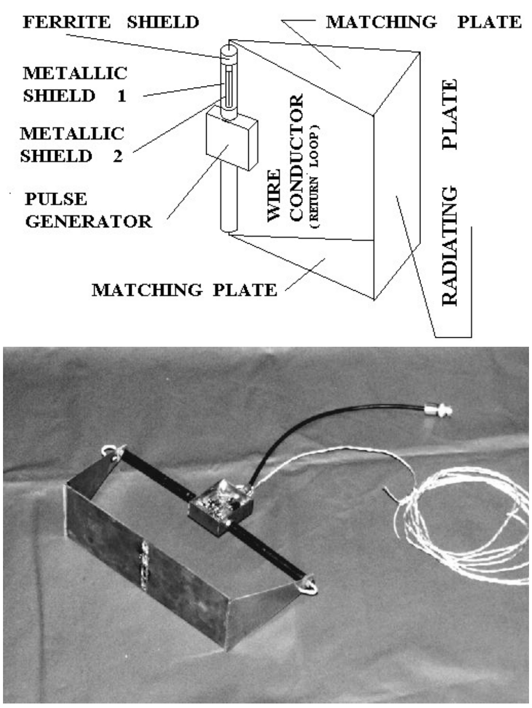

Fig. 3. *Antenna design*

ally connected as a load directly to the pulse generator output.

Due to the small resistance in LCR the large current arises just at small voltage of the drive signal. (Hence – the name “large current radiator.”)

Examples of LCRs studied in our laboratory and their performances are presented below.

LCR with Avalanche Transistor Switch

The LCR (Fig. 3) produces radiation of carrier-free pulse signals with a magnetic field strength $H = 4.2$ mA/m at a distance of 5 m for a current amplitude in the radiating plate of 0.7 A and a rise time of 1 ns [2].

Driving pulse parameters:

- Current amplitude 0,7 A;

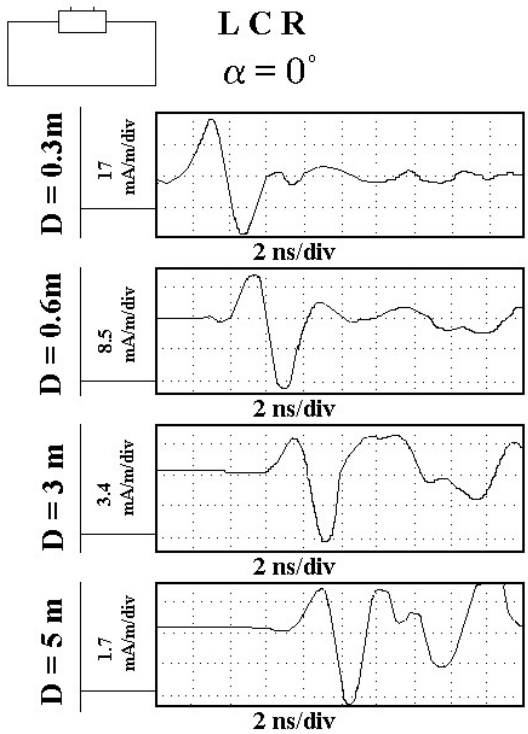

Fig. 4. *Spatial dependence of the radiated field strength*

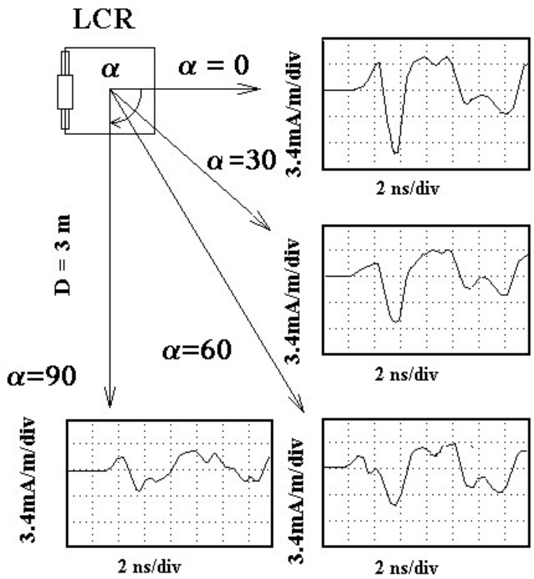

Fig. 5. *Angular dependence of the radiated field strength*

- Rise time 1 ns;
- Pulse duration 10 ns;
- Repetition rate 4·10-5 s;
- Power consumption < 0.2 W.

Spatial and angular dependences of the radiated field strength are shown in Fig. 4 and Fig. 5.

LCR with S-Diode Switch

The LCR with S-diode pulse generator (Fig. 6) allows increasing a radiated signal power [3].

The designed LCR has the following features:

- The peak current driven through the LCR is 12 A.
- The pulse repetition rate can be varied from 150 Hz to 1000 Hz.

The time variation of the radiated electric and magnetic field strength resembles one period of a sinusoidal oscillation (Fig. 7 and Fig. 8) with the following characteristics:

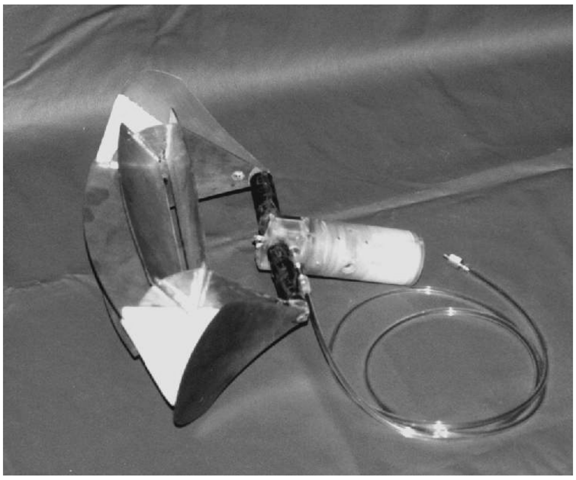

Fig. 6. *Antenna design*

The rise time of the electric field strength from 0.1 to $|E_{\max}|$ is 0.5 ns.

The duration of the first half period of the electric field strength measured at $|0.5E_{\max}|$ is 1 ns.

The total duration of first and second half period is 3.5 ns.

The peak amplitude of the electric field strength is about 56 V/m at a distance of 3 m from the radiator.

The beam width of the peak amplitude pattern:

- in the E-plane – 90°;
- in the H – 360°.

A power supply for nominally 5 V, or 4.5 to 6 V, and a current of 0.15 A is required.

The size of the LCR is $0.4\times0.3\times0.15$ m^3.

The weight is 1 kg.

The use of a relaxation pulse generator with an S-diode provides good energy efficiency. This made it possible to use a battery as the power supply. The use of a battery and the ability to trigger the S-diode via infrared radiation removed many sources of distortion from the vicinity of the radiator. Using a battery also permitted a reduction of size and weight of the LCR. A three-layer metal-ferrite-ferrite shield suppresses radiation from the return loop significantly. Two TEM-horns for impedance matching reduces distortion and increases the amplitude of the current pulses driving the radiator. The shield and the TEM-horns make it possible to achieve dipole rather than quadrupole radiation. The independent power

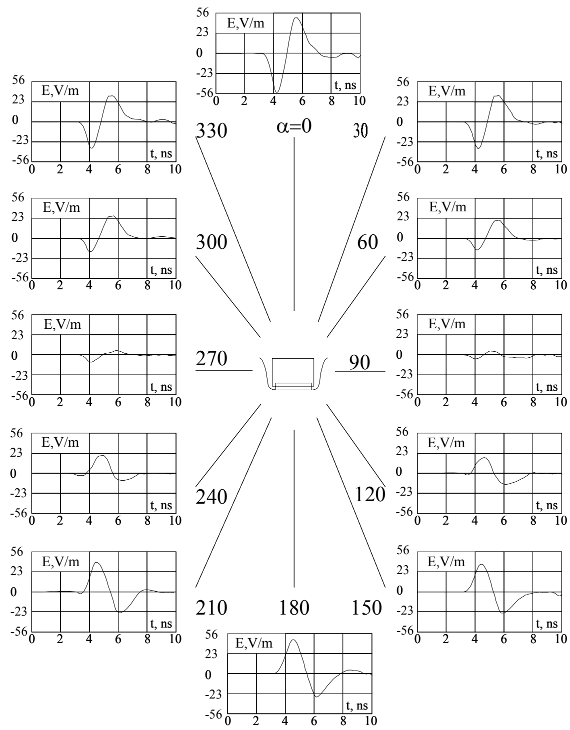

Fig. 7. *Angular dependence of radiated pulses shape. E-plane*

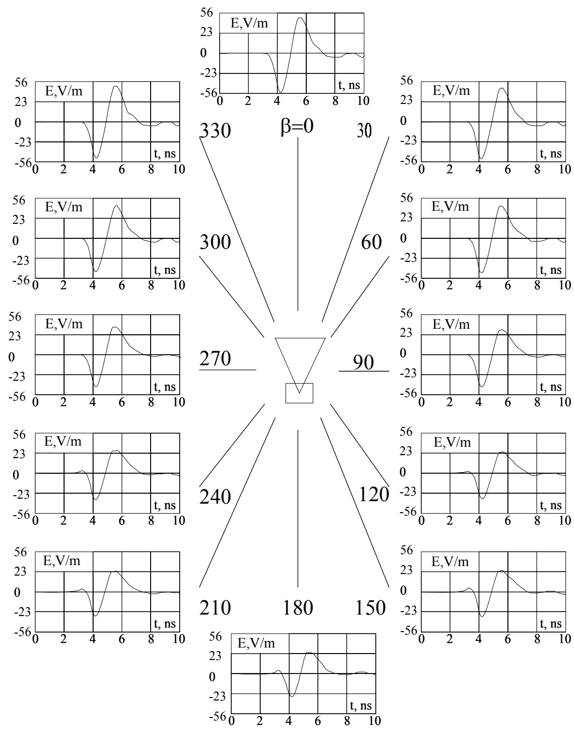

Fig. 8. *Angular dependence of radiated pulses shape. H-plane*

supply and the triggering of the radiation via infrared radiation make this LCR usable as element of an antenna array.

Small-Size Pulse LCR

The design of small-size pulse antenna Fig. 9 has been developed for possible use in UWB pulse communication systems and in radar. It may also be used as element of UWB antenna array.

Performance attributes.

Avalanche transistor switch is used to drive this antenna.

The power supply voltage 160 V and current – 5 mA.

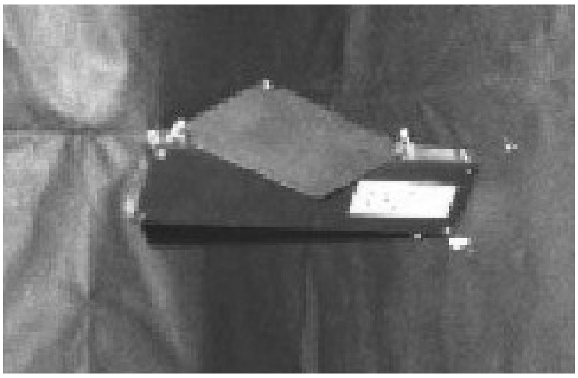

Fig. 9. *Antenna design*

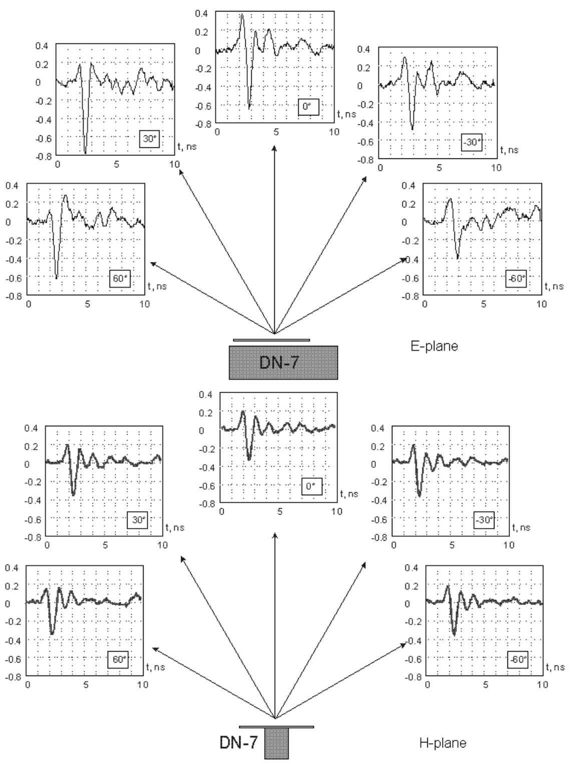

Fig. 10. *Angular dependence of radiated pulses shape*

The unit measures 0.12×0.04×0.04 m.

The weight – 0.2 kg.

LCR with "Traveling Wave" Pulse Generator

The generator consists of seven avalanche switches in series forming a "traveling wave" generator. The pulses forming go on from central (forth) switch. Timing of this switch realize with external timing generator. After switching on of third stage of the pulse generator two waves of currents with opposite polarity come from this switch to both sides. Each wave stimulates the switches on the next stages (and so on). The energy is stored in capacitors of avalanche switches add to the wave energy when the next stage switches on. Thus, we can obtain the increase the amplitude of current pulse when it travels to the radiator. At the same time this "traveling wave former" is the return loop in the design of LCR (Fig. 11).

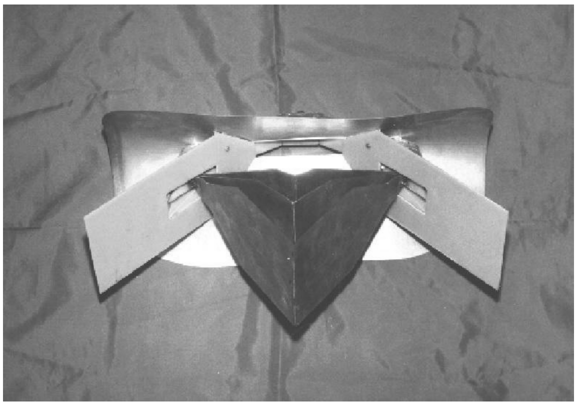

Fig. 11. *Antenna design*

Reflector is used to decrease backspace radiation.

Performance attributes.

Radiated pulse is the one period of sin oscillation with following amplitude and time-domain parameters:

- the rise time of pulse amplitude from 0.1 to $|E_{\max}|$ is 0.5 ns;
- the duration of the negative half-period at the $|0.5E_{\max}|$ level is 1.2 ns;
- common pulse duration (both of half-periods) is 2.5 ns;
- the amplitude of pulse of field strength at the 2 m from the radiator is about 0.2 A/m;
- the width of the pick amplitude pattern of the LCR at the $|0.5E_{\max}|$ level in
  - E plane – 60°,
  - H plane – 140°;

- the repetition rate of radiating pulses is in range up to 1 MHz;
- the jitter is less than 0.1 ns.
- The power supply voltage 160 V, current – 5 mA.
- The unit measures 0.4×0.3×0.2 m.

The LCR for Variable Pulse Width Radiation

The possibility to radiate the pulse signal of different duration is investigated with the following LCR (Fig. 12). The antenna is an array consisting of four radiating elements, which are excited by the pulse power amplifiers assembled with the use of powerful MOSFETs [4].

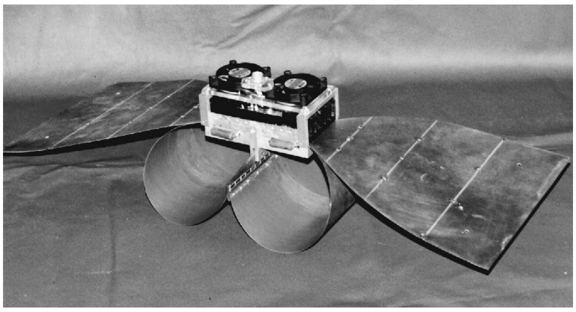

Fig. 12. *Antenna design*

Spatial distribution of pulses of the radiated electromagnetic field is similar to the one generated by an electric dipole. There is not any radiation directivity in one plane but there exist gaps and changes of polarity of strength of the radiated pulse field in the other plane.

We have analyzed LCR operation in the switch operation mode and pulse (linear excitation) operation mode. Listed below in Table 1 are the parameters of the signals at the power amplifier outputs with a connected antenna system.

Table 1.

Parameters	Mode	
	Switch	Linear amplification
Voltage pulse amplitude, V	45	20
Rise time, ns	2.5	3
Drop time, ns	4	3.5
Pulse overshoot	50%	5%
Pulse decay	10%	10%
Pulse duration, ns	50	50
Pulse repetition rate, ns	100	100

The switch operation mode allowed us to reach the higher strength of the radiated pulse field, but the radiated pulse duration is not a variable in this mode.

The experiments have shown very clearly that such an antenna design allows one to radiate various duration pulse signals (Fig. 14). For practical applications, it would be necessary to optimize the radiating element shape, and to develop an electric controllable damping element in the radiator to obtain a more efficient LCR.

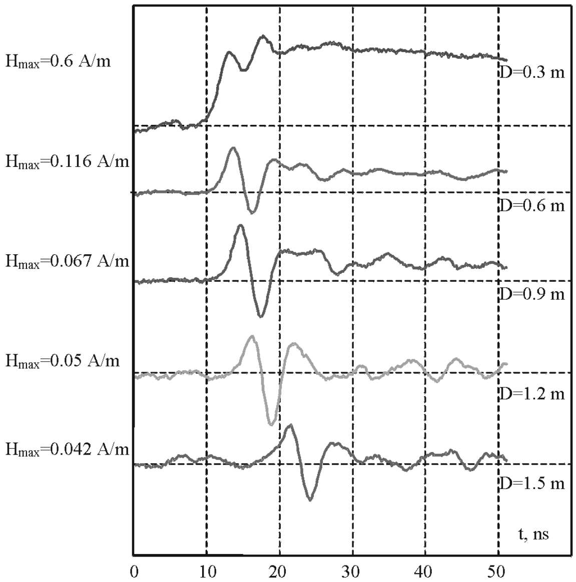

Fig. 13. *Range dependence of radiated pulse shape in switch mode demonstrates that the LCR is able to radiate "pure" pulses*

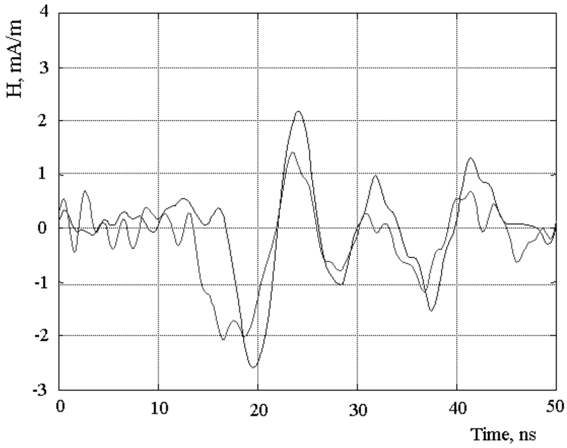

Fig. 14. *3 ns and 5 ns pulses radiation*

Conclusions

Experimental results on the short pulse signal radiation by the H.F. Harmut's large current radiator show clearly that LCR idea works. After corresponding improvement described above antennas will be usable for radar and radio communication systems and also to be a basis for the development of UWB antenna arrays.

Acknowledgment

This work is supported by Professor of Catholic University of America Henning F. Harmuth.

References

1. H.F. Harmuth. Sequency Theory. Foundations and Applications. New York: Academic Press, 1977.
2. K.A. Lukin, G.P. Pochanin, S.A. Masalov. IEEE Trans.on EMC. **EMC-39**, No. 2, 156-160 (1997)
3. G.P. Pochanin, P.V. Kholod, S.A. Masalov. IEEE Trans.on EMC. **EMC-43**, No. 1, 94-100 (2001).
4. G.P. Pochanin. Radiofizika i elektronika.– Kharkov: IRE NASU. **5**, No. 2, 118-127 (2000).

ЭКСПЕРИМЕНТЫ ПО ИЗЛУЧЕНИЮ КОРОТКИХ ИМПУЛЬСНЫХ СИГНАЛОВ АНТЕННАМИ БОЛЬШОГО ТОКА Х.Ф. ХАРМУТА

Г.П. Почанин, И.Е. Почанина, П.В. Холод, С.А. Масалов

Статья содержит описание ряда конструкций и характеристики антенн большого тока Хармута, предназначенных для излучения коротких импульсных сигналов наносекундного диапазона длительностей.

ЕКСПЕРИМЕНТИ ПО ВИПРОМІНЮВАННЮ КОРОТКИХ ІМПУЛЬСНИХ СИГНАЛІВ АНТЕНАМИ ВЕЛИКОГО СТРУМУ Х.Ф. ХАРМУТА

Г.П. Почанін, І.Є. Почаніна, П.В. Холод, С.О. Масалов

Стаття вміщує опис конструкцій і характеристики антен великого струму Хармута, призначених для випромінювання коротких імпульсних сигналів наносекундного діапазону тривалостей.