STAND FOR ELECTROMAGNETIC COMPATIBILITY TESTS USING A SIGNAL OF ULTRASHORT DURATION WITH A COMPLEX SPECTRAL COMPOSITION

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The possibility to create the stand for tests of electronic equipment on electromagnetic compatibility based on TEM cell and high voltage nanosecond pulse source with a complex spectral composition has been considered. The pulse formation occurs in a nonlinear transmission line with saturated ferrite. In comparison with high voltage source using spark switches, this device has several advantages: the possibility to vary spectral composition of the test impulse, the design simplicity, and the output signal stability. The matching element between the coaxial feeder and TEM cell, which provides high efficiency of power transfer in a wide frequency range: from zero to about 1.6 GHz, has been developed and numerically analyzed.

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INTRODUCTION

The modern electromagnetic environment (EME) is determined by a number of interfering external factors (IEF) dangerous for electronic and digital facilities (EDF). In many cases, the IEF level is sufficient for functional upset or total disruption of their operation [1]. The object operation stability checks to certain IEF can be carried out either within the manufacture process or by periodic tests. The tests of EDF on electromagnetic compatibility and resistance (EMC&R) are realized with the use of test equipment that simulates the IEF with a set of parameters. In the case of EMC&R tests for impact of electromagnetic short- and ultrashort pulses (USP), great complexity and high cost of high-voltage pulse-formers, measurement equipment, and preparation and protection means of the test area makes each of the IEF simulators unique [2].

Usually, the test area of the USP IEF simulator is created on the base of the TEM cell (indoor tests) or the antenna system specially prepared in the testing ground (outdoor tests). An object under test (OUT) when located in the TEM cell is exposed to the IEF created by the former of the pulse of a certain shape. Thus, the pulse former and TEM cell provide a set of certain IEF parameters. In regard with the investigating affect of the USP IEF with ultra-wide or narrow frequency spectrum the generators of nano/subnanosecond, the video- or mw signals of separate waveform can be used. In cases when critical EMC&R characteristics of an OUT are required, the USP IEF simulators use high-voltage impulse formers with the voltages up to hundreds of kilovolts or high-power mw facilities with the impulse power up to hundreds of megawatts – relativistic magnetrons, klystrons, vircators [3].

Investigations of recent years in the field of pulse-power electronics have been associated with creation of unique devices capable to provide direct conversion of the energy of impulse signals into mw oscillations. It have been shown that the electric pulse with a sharp rise-time traveling down the transmission line, which is made of lumped nonlinear elements or is filled with a dielectric medium having nonlinear properties, can produce at the line output a shock wave with or without HF oscillations of the type of a damped sinusoid [4, 5]. The pulse parameters at the nonlinear transmission line (NLTL) output are strongly dependent on the properties of the line elements and the parameters of the initial pulse. In the experiments with NLTL based on lumped nonlinear reactive elements (capacitances and inductances), the output USP signals with the amplitude up to hundreds of kilovolts, pulse rise-time of hundreds of picoseconds, and frequency of mw component of hundreds of MHz have been obtained [6, 7]. The use of microstrip line technology made it possible to achieve the pulse rise-time of tens of picoseconds and to obtain HF oscillations with the frequency up to hundreds of GHz [8]. Relatively small impulse power of experiments [8] corresponded to the limiting electrical characteristics of the lumped elements and heterostructures. A significantly larger output impulse power (up to hundreds of megawatts) was demonstrated in the experiments with the NLTL, where a ferromagnetic medium and high-voltage insulation were used. In NLTL of this type, which had a coaxial design and used a NiZn based ferroceramic and liquid high-voltage dielectric, the formation of shock waves and high-frequency oscillations with the amplitude up to hundreds of kilovolts was demonstrated. In this case, the oscillation frequency varied from 0.6 to 5 GHz [9].

In a number of our experiments, it was demonstrated the possibility to combine a NLTL and impulse antenna with a large electrodynamic potential for radiating high-power impulse quasiharmonic HF signals of the type of a decaying sinusoid within the frequency range of 0.8…2.5 GHz [10]. In the present work, we investigate the possibility to use the NLTL as a source of the high-power USP signal with a wide-ranged spectral composition for feeding a test TEM cell, which can be used in the EMC&R test stand TS-6 [11].

1. DESCRIPTION OF THE TEST STAND

As a prototype for creating the EMC&R simulator, the structural design of the TS-6 described in [11] was taken, Fig. 1. As before, new stand uses a strip line with grounded bottom electrode, where the traveling TEM wave with ultra-wide spectral composition can be formed with the help of a high-voltage USP source. The general view of the test stand TS-6 is shown in Fig. 2. The operation area used for disposing the OUT is located in the homogeneous part of the strip line – in the TEM cell with the dimensions $L \times H \times W = 1.1 \times 0.7 \times 1.0$ m.

In the alternative construction of the TS-6 the high-voltage impulse former (HVIF) based on the double forming line creating the unipolar USP is substituted for the HVIF based on the NLTL [10] creating the combined USP – the unipolar pulse with quasiharmonic HF component, Fig. 3. Since the NLTL with saturated ferromagnetic makes it possible to form a shock wave with adjustable rise time, there is no need for a spark switch. Thus, this ensures the simplicity of design, and increases the reliability and durability of the HVIF. Under certain conditions [10], the shock wave traveling down the NLTL generates damped HF oscillations. Variation of the bias magnetic field H_0, which saturates the ferromagnetic medium of the NLTL, tunes the frequency and amplitude of the oscillations (Fig. 4), and therethrough the spectral composition of the signal at the line output. Thus, it is possible to test the equipment with the use, both the unipolar pulse and the quasi-harmonic signal.

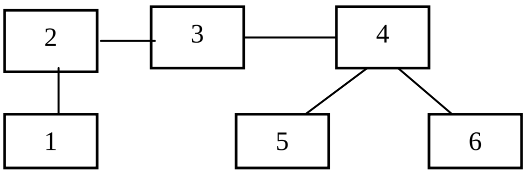

Fig. 1. Structural diagram of TS-6: 1 – starting unit; 2 – HVIF; 3 – transmission strip-line; 4 – test TEM cell; 5 – shielded room with measuring equipment; 6 – shielded equipment box

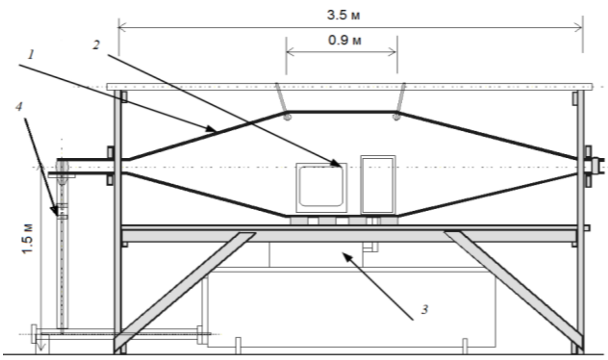

Fig. 2. General view of the stand TS-6: 1 – strip-line with homogeneous operation area; 2 – OUT; 3 – shielded equipment box; 4 – USP forming system

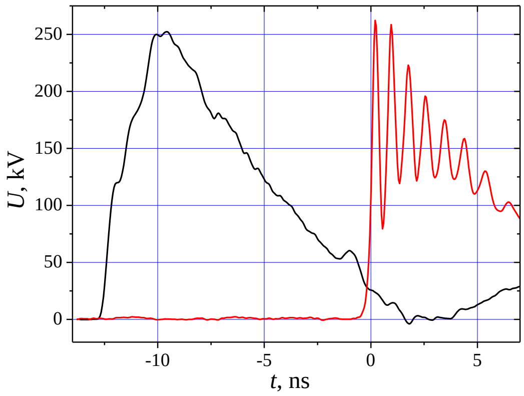

Fig. 3. Pulse waveforms at the NLTL input (left) and output (right)

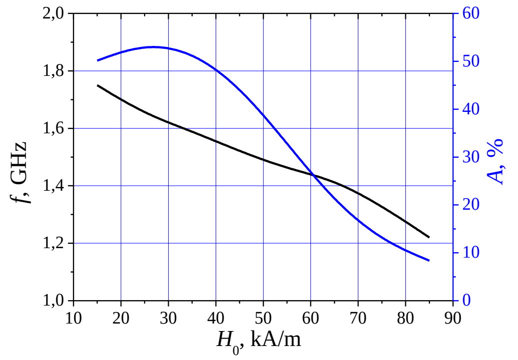

Fig. 4. Dependence of the HF oscillation frequency and relative amplitude on the bias magnetic field

2. SIMULATING THE USP TEST SIGNAL DYNAMICS IN THE TEM CELL

Calculation of electromagnetic properties of the stand test cell was carried out with the help of CST software Microwave Studio Suite [12]. It was assumed that the power supply of the TEM cell was performed with the use of the coaxial feeder (Z = 75 Ω) filled with transformer oil, and the electrode diameters of 8 and 51 mm. The TEM cell (general view of the model and its dimensions are shown in Fig. 5) was tested by a signal generated by the HVIF based on the NLTL. The signal had combined structure: the triangular unipolar pulse with the amplitude of 100 kV, width of 10 ns, rise-time of ~ 0.5 ns, and the damped sinusoid with the amplitude of 55 kV, frequency f_0 = 0.5…2.2 GHz [10].

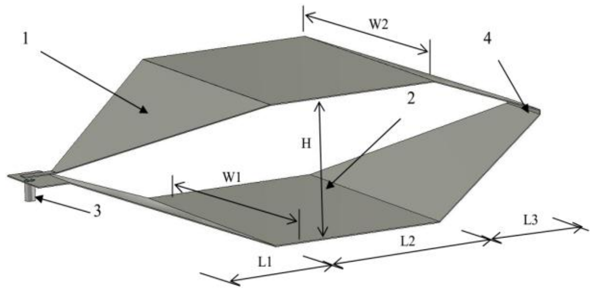

Fig. 5. The TEM cell model and its dimensions: 1 and 2 – upper and lower electrodes of the transmission line; 3 – coaxial feeder; 4 – resistive load. W1 = 1.6 m; W2 = 1 m; L1 = 0.94 m; L2 = 1 m; L3 = 0.94 m; H = 0.7 m

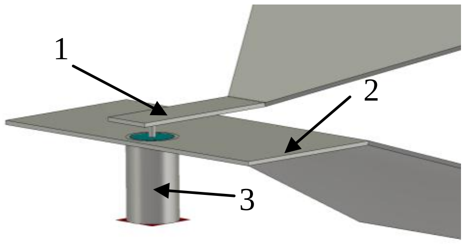

Fig. 6. Matching interface between the TEM cell and vertically disposed feeder: 1 and 2 – upper and lower electrodes of the transmission strip-line; 3 – coaxial feeder

First, the matching conditions between the TEM cell and the coaxial feeder located vertically (Fig. 6) was investigated. This configuration is similar to the TS-6 stand [11]. As it developed (Fig. 7), this design has low efficiency due to high-level reflections in the area of signal input of the TEM cell. For example, at f_0 =

1.5 GHz, more than half of the signal energy reflects back into the fiber, while the voltage amplitude in the center of the TEM cell hardly exceeds half the voltage created by the HVIF.

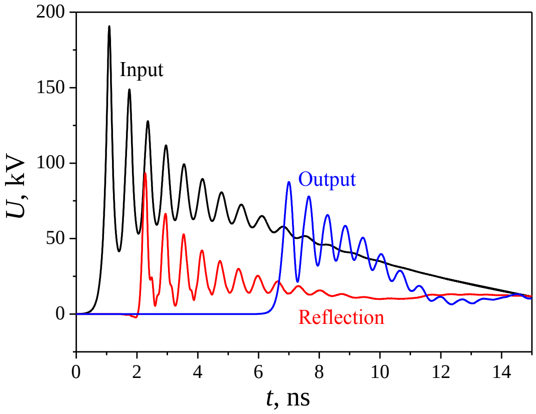

Fig. 7. Matching conditions for the case of vertically disposed feeder. The input (black), and reflected (red) signals, and the signal at the center of the TEM cell (blue), f_0 = 1.5 GHz

In this regard, another matching configuration was proposed – a variant with horizontal disposition of the coaxial feeder. In this case, to improve the matching, it was envisaged also to change the dimensions of the potential electrode at the input. In addition, to increase the electrical strength, the input section of the potential electrode was protected by the oil envelope (Fig. 8).

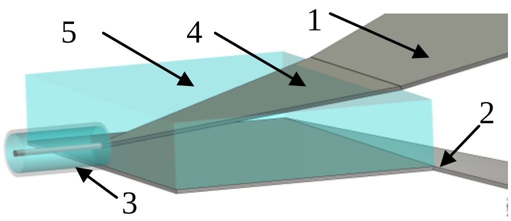

Fig. 8. Matching interface between the TEM cell and horizontally disposed feeder: 1 – potential upper electrode; 2 – grounded lower electrode; 3 – coaxial feeder; 4 – input section of the potential electrode; 5 – transformer oil envelope

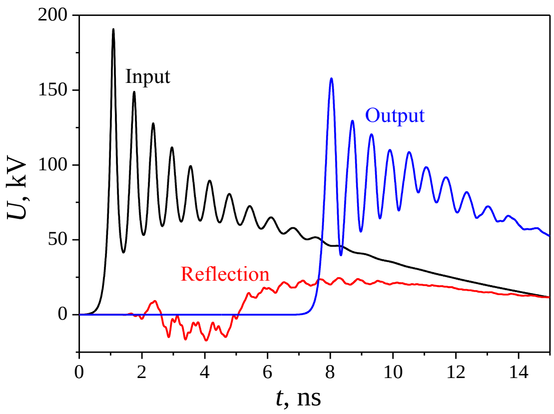

Fig. 9. Matching conditions for the case of horizontally disposed feeder. The input (black), and reflected (red) signals, and the signal at the center of the TEM cell (blue), f_0 = 1.5 GHz

As one would expect, the maximum electric field strength corresponds to the edges of the electrodes, while the electric field strength is close to homogeneous in the center of the TEM cell (Figs. 9 and 10).

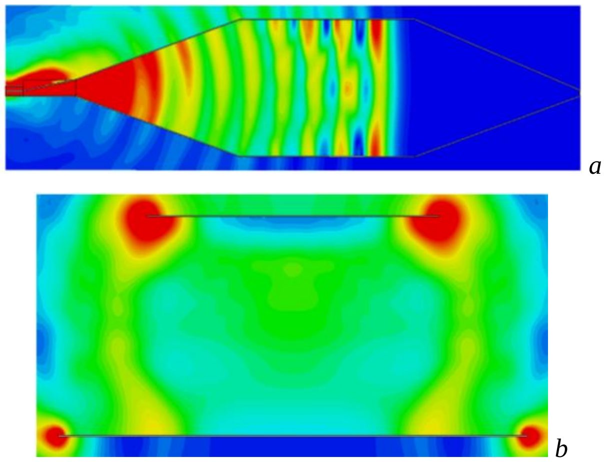

Fig. 10. Module of the electric field strength in the center of the TEM cell in (a) longitudinal and (b) transverse cross-sections

The simulation results obtained for the TEM cell fed by the video pulse, which correspond to the HVIF operation mode without generating the quasiharmonic oscillations, are shown in Figs. 11 and 12.

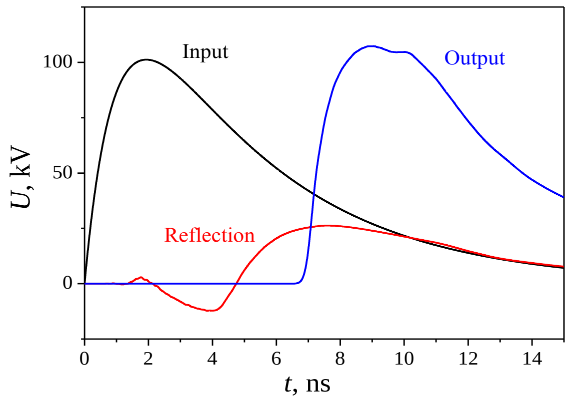

Fig. 11. The simulation results for the case of horizontally disposed feeder when tested by a video pulse: the input signal (black), the reflected signal (red), and the signal in the center of the TEM cell (blue)

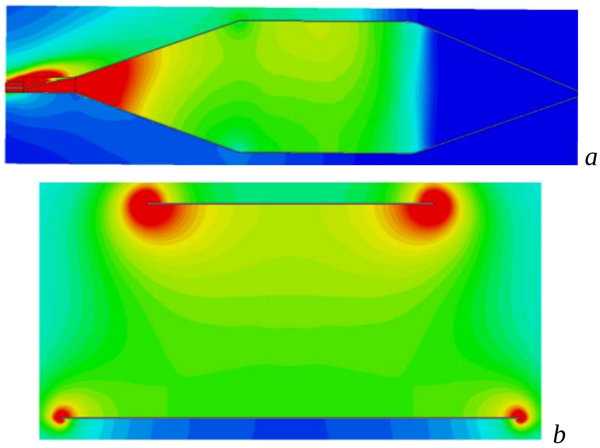

Fig. 12. Module of the electric field strength in the TEM cell fed by a video pulse in (a) longitudinal and (b) transverse cross-sections

It is evident that in the range of low frequencies, the matching between the feeder and the TEM cell is quite efficient: the reflected signal amplitude is at a 25% level of the original signal, while the amplitude of the signal propagating in the TEM cell is almost constant. Small voltage excess above the level of the original signal in the center of the TEM cell can be explained by slight increase of the TEM cell impedance over the feeder impedance.

More detailed study of the TEM cell electrodynamic properties was carried out with the use of a monochromatic test signal (Fig. 13) with different frequencies f_0.

From Fig. 14 it can be seen that part of the signal energy (f_0 = 1.3 GHz) radiates from the feeder – TEM cell interface and from the TEM cell in side directions. The radiation losses of the signal at high frequencies are accompanied by the reflection losses due to the impedance mismatch between the feeder and the TEM cell.

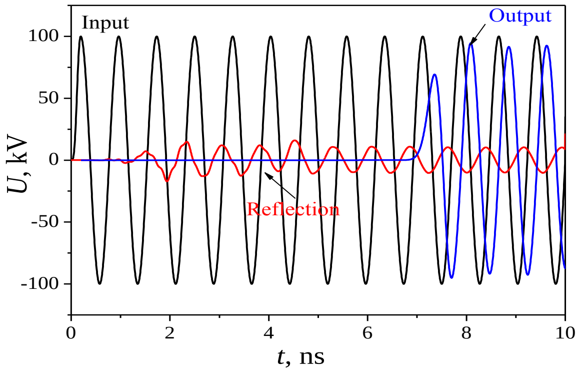

Fig. 13. The simulation results for the horizontally disposed feeder when tested by a harmonic signal with the frequency of 1.3 GHz: the input signal (black), the reflected signal (red), and the signal in the center of the TEM cell (blue)

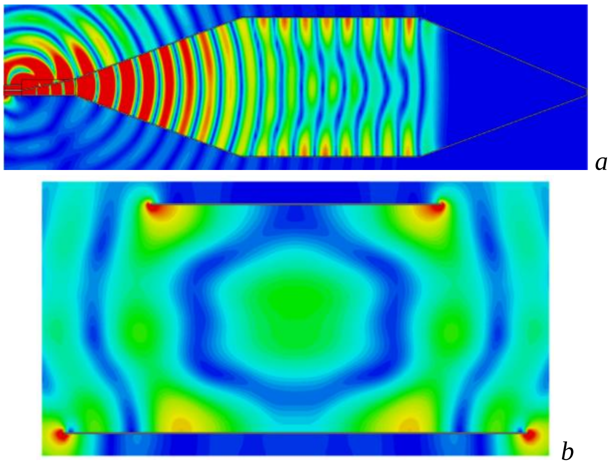

Fig. 14. Module of the electric field strength in the TEM cell fed by a harmonic signal at f_0 = 1.3 GHz in (a) longitudinal and (b) transverse cross-sections

The efficiency of the monochromatic signal transmission from the feeder to the TEM cell is illustrated in Table. It can be seen that the level of the reflected signal with respect to the signal at the cell input does not exceed 25% in the whole range of the investigated frequencies. At the same time, as the frequency increases, the signal level at the center of the TEM cell decreases due to growing radiation losses. In the frequency range up to 1.6 GHz, the energy transfer efficiency from the feeder to the TEM cell is quite high – the wave amplitude decrease in the center of the cell does not exceed 25%.

The values of the reflected and transmitted monochromatic signals compared with the input signal at different frequencies

Frequency, GHz	Reflected signal, %	Signal in the center of the TEM cell, %
0.5	15	106
0.7	25	111
1	22	98
1.3	15	89
1.6	16	78
1.9	18	64
2.2	15	50

In order to minimize the reflection and radiation losses, the cell model geometry was optimized. In particular, it was determined that the optimum pitch angle of the upper and lower electrodes is 20°, and the optimal pitch angle of the input section of the potential electrode of the strip-line with horizontally disposed feeder (see Fig. 8) is 12°.

It was studied also the dependence of the electromagnetic energy transfer efficiency to the TEM cell, depending on the transverse dimensions of the upper and lower TEM cell electrodes. Variation of the lower electrode width *W*1 within 800…2000 mm and the upper electrode width *W*2 within 400…1200 mm demonstrate that the signal amplitude at the center of the TEM cell changes no more than 5%. Therefore, the selection of the overall dimensions of the TEM cell is quite arbitrary and can be performed assuming only engineering considerations.

The *E*-field distributions in the transverse direction of the lower electrode surface in the center of the TEM cell (where OUT is usually located) for the signals of various waveforms are shown in Fig. 15. It can be seen that for all signal waveforms the electric field strength within 200 mm of the TEM cell center is uniform with the accuracy of ~10%.

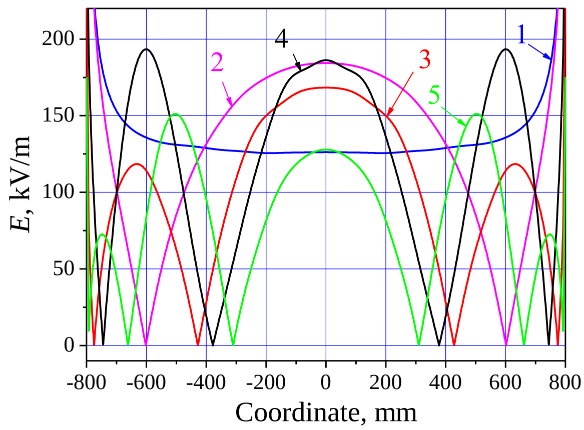

Fig. 15. The E-field distribution in the transverse direction in the center of the cell TEM for different signals: 1 – video pulse, and harmonic signal with the frequencies; 2 – 0.7 GHz; 3 – 1.0 GHz; 4 – 1.3 GHz; 5 – 1.6 GHz

CONCLUSIONS

On the basis of numerical simulation of 3D model, which uses variety of the USP signal waveforms (and spectral composition, accordingly), a possibility of creation and studying the characteristics of the facility for electromagnetic compatibility tests of the electronic equipment, are considered. The source of the high-voltage signal is the nonlinear transmission line, which uses a magnetized ferromagnetic. The discussed test facility has several advantages in comparison with traditional stands that use spark switches:

• the ability to test equipment with the use either unipolar pulse or the quasi-harmonic signal;

• the possibility of an instrumental control of the signal waveform (spectral composition);

• the simplicity of design and stability of signal parameters, due to the absence of spark switches in the HVIF.

Optimization of the feeder – TEM cell interface of the stand ensures high transmission efficiency of the USP signal with combined waveform in wide frequency range of 0…1.6 GHz.

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СТЕНД ДЛЯ ТЕСТИРОВАНИЯ НА ЭЛЕКТРОМАГНИТНУЮ СОВМЕСТИМОСТЬ СИГНАЛОМ СВЕРХКОРОТКОЙ ДЛИТЕЛЬНОСТИ СО СЛОЖНЫМ СПЕКТРАЛЬНЫМ СОСТАВОМ

С.Ю. Карелин, И.И. Магда, В.С. Мухин

Рассмотрена возможность создания стенда для тестирования электронной аппаратуры на электромагнитную совместимость на базе ТЕМ-ячейки и источника высоковольтных импульсов наносекундной длительности со сложным спектральным составом. Формирование импульсов происходит в нелинейной передающей линии с намагниченным ферритом. По сравнению с источником высоковольтных импульсов на основе искровых коммутаторов данное устройство имеет ряд преимуществ: возможность варьирования спектрального состава тестирующего импульса, простота конструкции, стабильность формируемого сигнала. Разработан и численно исследован элемент сопряжения коаксиального фидера и ТЕМ-ячейки, обеспечивающий высокую эффективность передачи энергии в широком интервале частот: от нулевых до 1,6 ГГц.

СТЕНД ДЛЯ ТЕСТУВАННЯ НА ЕЛЕКТРОМАГНІТНУ СУМІСНІСТЬ СИГНАЛОМ НАДКОРОТКОЇ ТРИВАЛОСТІ ЗІ СКЛАДНИМ СПЕКТРАЛЬНИМ ВМІСТОМ

С.Ю. Карелін, І.І. Магда, В.С. Мухін

Розглянута можливість створення стенда для тестування електронної апаратури на електромагнітну сумісність на базі ТЕМ-комірки і джерела високовольтних імпульсів наносекундної довжини зі складним спектральним вмістом. Формування імпульсів відбувається в нелінійній передаючій лінії з насиченим феритом. У порівнянні з джерелом високовольтних імпульсів на основі іскрових комутаторів цей пристрій має ряд переваг: можливість варіювання спектрального складу тестового імпульсу, простота конструкції, стабільність сигналу, що формується. Розроблений і чисельно досліджений елемент сполучення коаксіального фідера і ТЕМ-комірки, який забезпечує високу ефективність передачі енергії в широкому інтервалі частот: від нульових до частот біля 1,6 ГГц.