Improved TEM-cell for EMC Tests of Integrated Circuits

Alexander V. Demakov, Maxim E. Komnatnov, *Member, IEEE*
Department of Television and Control
Tomsk State University of Control Systems and Radioelectronics, TUSUR
Tomsk, Russia

Abstract— **In this paper, the construction of TEM-cell, which can be used for tests on radiated susceptibility and emissions of integrated circuits in the frequency range up to 5 GHz, is presented. Constructional features and advantages of proposed TEM-cell compared with classic constriction are described. Electrodynamic simulation of construction is completed and results of the analysis of frequency dependencies of the magnitude of reflection $|S_{11}|$ and transmission $|S_{21}|$ coefficients are presented. Results of the simulation showed good matching with the 50 Ohm feeder ($|S_{11}| \leq$ -20 dB) and low losses ($|S_{21}| \geq$ -3 dB) in considered frequency range. Evaluation of nonuniformity of electric field strength in test volume is represented. Its value doesn't exceed ±3 dB in the test volume of 30×30×5 mm^3.**

Keywords—TEM-cell; electromagnetic compatibility; integrated circuit; tests

I. Introduction

Electromagnetic compatibility (EMC) of radioelectronic equipment (RE) is impotant for performance with required quality [1]. At the moment there is wide range of methods for characterization of radiated susceptibility and emission of RE of different assignment, which are described in international standards [2-5]. Due to evolution of analog and digital microelectronics the level of integration and operation frequencies are grown, whose values reach the order of 10 GHz. Application of some methods (TEM-cells, striplines) is impossible for testing in required exposure frequency and magnitude ranges. Using of CAD systems allows to obtain only approximate evaluation of noise immunity of an integrated circuit (IC), hereupon in-situ testing of real samples is obligatory. Therefore there is necessity in refinement of existing facilities for IC-testing, which suits the modern EMC requirements.

As of today, investigations are under way in this line of research. In [6] results of development of closed stripline for IC-testing on radiated susceptibility and emission are presented. For calculation of geometric parameters the equivalent scheme of stripline and response surface space-mapping technique (RSSMT) were used. Voltage stand wave ratio (VSWR) of developed stripline doesn't exceed the level of 1.25 ($|S_{11}| \leq 19$ dB) in frequency range up to 4.4 GHz. Meanwhile, it's desirable to increase the upper frequency limit of the measuring devices for testing over a wider frequency range.

Investigation was carried out at the expense of the Ministry of Education and Science of Russian Federation project No. 8.9562.2017/8.9.

TEM-cell is a ultra-high frequency device for EMC tests, which is intended for tests on radiated susceptibility and emission of IC [3]. Construction of the cell consists of regular waveguide with inner conductor, which connected with microwave connectors by pyramidal transitions (Fig. 1).

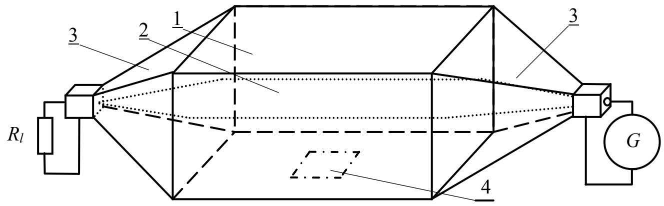

Fig. 1. Main view of TEM-cell (1 – case, 2 – inner conductor, 3 – pyramidal transitions, 4 – location of device under test)

For characterization of radiated susceptibility device under test (DUT) is placed into internal volume of the cell in the regular section, where the electromagnetic field is homogeneous. When a signal with specified characteristics (duration, amplitude, modulation factor) is applied to the cell input, due to the specific shape of the cell and the matched load a transverse electromagnetic wave (TEM wave) propagates in the regular part, impacts on the DUT and absorbed by the load. Emissions are characterized with a similar location of DUT by using of EMI receiver for measuring currents, which are induced by fields from the DUT in the inner conductor.

The main requirement for testing by TEM-cells is the uniformity of propagation of electromagnetic field in the volume under the DUT in the operating frequency range. According to the standard [2] the nonuniformity of the field in the location of DUT should not exceed ±3 dB. This condition is ensured by minimization of reflected electromagnetic wave at constructional elements and constancy of characteristic impedance in each cross-section of the cell.

Besides dominant TE_{10} mode inside the TEM-cell the higher-order modes can propagate. In this state TEM-cell work as radio-frequency cavity that can lead to uncontrolled impact on the DUT. In the classic design of TEM-cell according to method [7] for IC tests the upper frequency in operation range will not exceed 3 GHz. It can be not enough for researches of some currently used IC throughout their operating frequency range.

The purpose of this paper is present the results of development of improved TEM-cell, which can be used for test on radiated susceptibility and emission of IC in frequency range up to 5 GHz.

II. Description of Improved Construction

In the design of improved TEM-cell the height of the cell was reduced for tests of IC with height of 5 mm. According recommendations for designing of TEM-cells [7, 8], the height of DUT z_1 must be not more than 1/3 of distance between central conductor and lower base of cell's case d:

$$d \geq 3 \cdot z_1, \quad (1)$$

This condition is acceptable for minimization of stray impedance, which arises when DUT is located into the TEM-cell (Fig. 2).

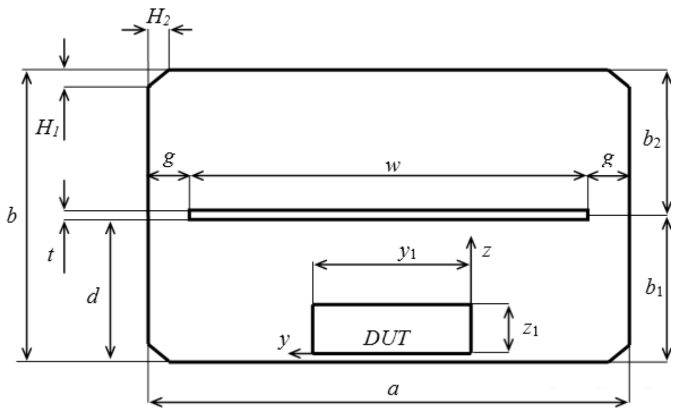

Fig. 2. Cross-section of TEM-cell in location of DUT

Thus the height of the cell b was chosen equal to 30 mm (1). Field strengh E_v in regular section of the cell, where the field is already excited, is determined as

$$E_v = \frac{V_c}{d}, \quad (2)$$

where V_c is the voltage, applied to the cell's input. For continuous exposure the limit value of the E_v is 223 kV/m, which is calculated based on the maximum operation voltage of the connector $V_c = 335$ V and the minimum distance between the central conductor and the case of the cell of 1.5 mm (2).

Calculation of other geometrical parameters of cross-section in regular part of the cell for characteristic impedance 50 Ohm was performed according to [5, 6] and using TALGAT system [9]. The following values were obtained: $a = 100$ mm, $t = 0.1$ mm, $w = 50$ mm, characteristic impedance $Z_0 = 49.92$ Ohm. Length of regular part L is 65 mm, while length of central conductor was calculated based on the criterion: $L_2 = 0.8\ldots0.9\,L$ (Fig. 3).

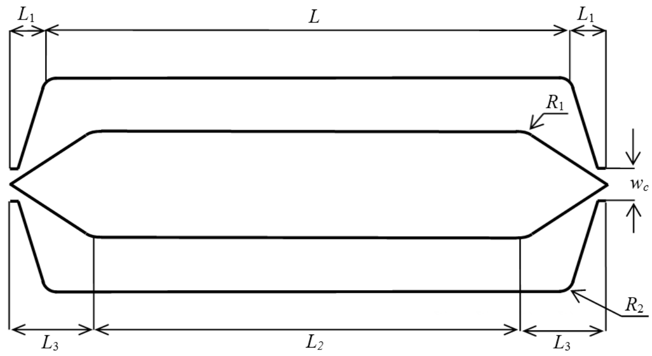

Fig. 3. Top view of longitudinal section of TEM-cell

For connection of regular part of the TEM-cell with microwave connectors it was decided to abandon the pyramidal transitions in favor of transitions, shown in Fig. 4.

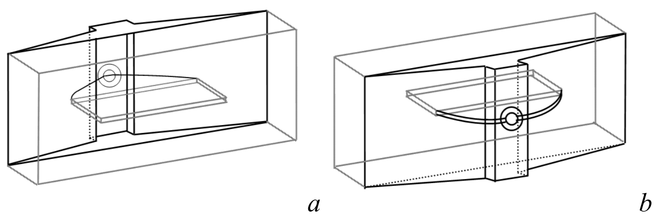

Fig. 4. Shape of transitions for matching the regular part of the cell with microwave connectors (*a* – view at the place of connection with regular part of cell, *b* – with microwave connector)

The height of transition is constant along their length $L_1 = 13$ мм, while their width w_c decrease to the value, which exceeds diameter of microwave connectors by 10 mm. In Section III will be shown that this shape of transition provides lesser mismatch at the joint with regular part of the cell and in the location of microwave connectors.

For EMC testing, IC is mounted on a specially designed PCB. On the IC side there is continuous ground, as it shown at Fig. 5 *a*. At side of the board ground without a solder mask is electrically connected through the vias with the TEM-cell case. On the back side of the board peripheral equipment (memory unit, quartz-crystal unit for synchro clock, input/output ports) is mounted for ensuring and evaluating the IC operation (Fig 5 *b*).

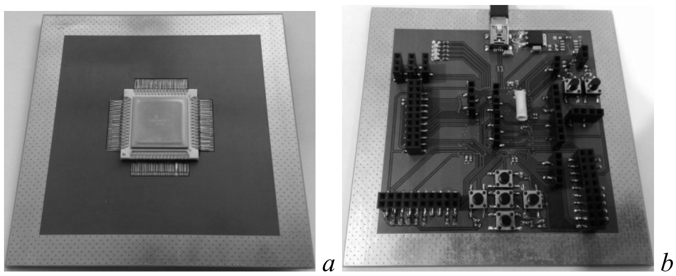

Fig. 5. PCB with IC and peripheral equipment, top (*a*) and bottom (*b*) views

In real construction a bottom wall of the cell's case will be removed, because PCB with mounted IC will be the bottom base of the case. At the stage of electrodynamic simulation, the test board is replaced by a ground plane.

III. Electrodynamic Simulation

Based on the calculated geometrical parameters the electrodynamic model of improved TEM-cell was created (Fig. 6) and its parametric optimization by the trust region method was performed.

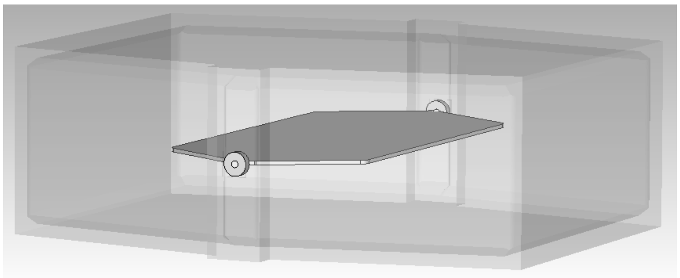

Fig. 6. Electrodynamic model of improved TEM-cell

The maximum of magnitude of reflection coefficient $|S_{11}|$ in the frequency range up to 5 GHz was chosen as goal function for minimization. The following parameters were subject to optimization: lengths L, L_1, L_2, width of the case a, width of central conductor w, length H_1 and width H_2 of chamfers and rounding radii R_1 and R_2. Height of the cell b remanded constant and defined by (2).

We compared the frequency dependences of reflection $|S_{11}|$ (Fig. 7 *a*) and transfer $|S_{21}|$ (Fig. 7 *b*) coefficients magnitude for improved and classic TEM-cells [10, 11].

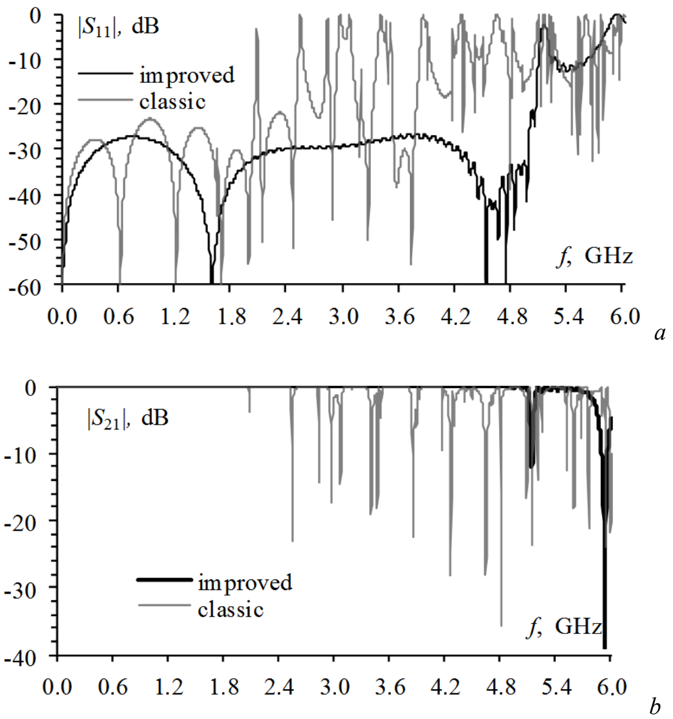

Fig. 7. Frequency dependencies of $|S_{11}|$ (*a*) and $|S_{21}|$ (*b*) for improved and classic TEM-cells

As can be seen from the Fig. 7, 8, the cutoff frequency of the improved TEM-cell is 5 GHz, while for cell of classic implementation this value is 2.1 GHz. Before cutoff frequency $|S_{11}|$ does not exceed the level -23 dB and $|S_{21}|$ is on the level of 0 dB, corresponding to the test standards [3, 4].

Estimation of the field strength in the DUT location was performed by lumped field monitors. The monitors were placed on a square grid of 30×30 mm in 15 mm increments at a height of 2 mm from the bottom wall of the cell (Fig. 9).

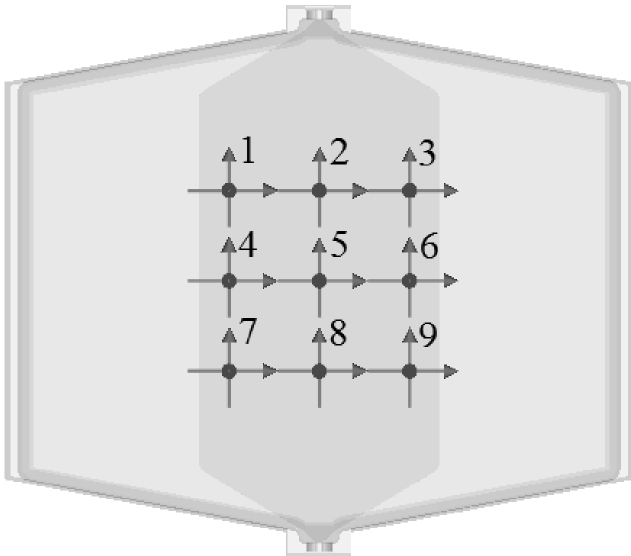

Fig. 8. Placement of lumped field monitors at the location of DUT (top view)

An analysis in the frequency domain of the magnitude of electric field strength showed that the nonuniformity of the field in the test volume does not exceed ±1 dB at frequencies up to 4 GHz (Fig. 10). At higher frequencies, a higher order waves propagate, which leads to an increase of field nonuniformity in the test volume (Fig. 11). Due to the symmetry of TEM-cell's construction results of calculation at the locations of monitors 3, 6, 9 coincide with 1, 4, 7 respectively, and therefore the repeated data are not shown.

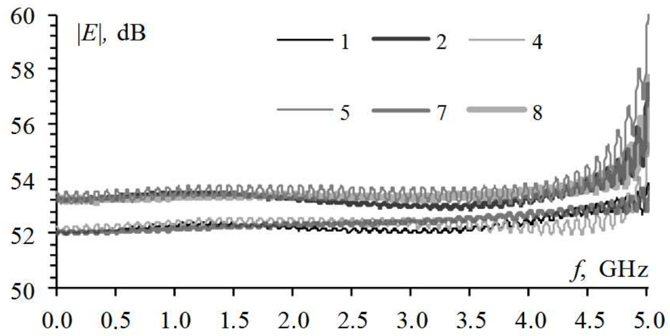

Fig. 9. Frequency dependencies of electric field strenght at the location of field monitors (1, 2, 4, 5, 7, 8) in frequency range up to 5 GHz

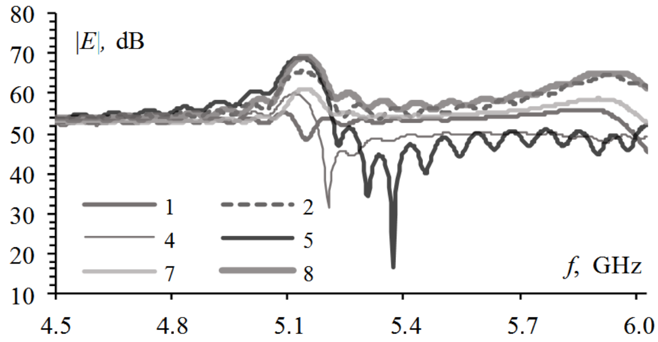

Fig. 10. Frequency dependencies of electric field strenght at the location of field monitors (1, 2, 4, 5, 7, 8) in frequency range 4.5-6 GHz

IV. CONCLUSION

Improved TEM-cell with $|S_{11}| \leq -23$ dB in the frequency range up to 5 GHz and height of DUT 5 mm was developed. The proposed design solutions will allow testing in a wider frequency range compared with the TEM-cell of classic implementation [10]. In the future, it's planned to create the prototype of the cell.

References

[1] Komnatnov M.E., Gazizov T.R. On joint climatic and electromagetic testing of radioelectronic equipment // Dokladi toms. gos. un-ta sistem upr. i radioelectr. – 2014. – №4(34). – P. 67-78.

[2] Integrated Circuits. Measurement of Electromagnetic Immunity. Part 2: Measurement of Radiated Immunity, TEM Cell and Wideband TEM Cell Method, IEC 62132-2, First Edition, 2010.

[3] Integrated Circuits. Measurement of Electromagnetic Emissions. Part 2: Measurement of Radiated Emissions, TEM Cell and Wideband TEM Cell Method, IEC 61967-2, First Edition, 2005.

[4] IEC 61000-4-21, Electromagnetic compatibility (EMC) – Part 4-21:Testing and measurement techniques – Reverberation Chamber Test Methods, 2003-08.

[5] IEC 61967-3, Integrated circuits - Measurement of electromagnetic emissions - Part 3: Measurement of radiated emissions - Surface scan method, 2014-08.

[6] Mandic T. Optimization of IC-Stripline Performance by Response Surface Space-Mapping Technique. / Mandic T., Gillon R., Baric A. // IEEE Trans. on Electromagn. Compat. – 2017. – Vol. 59, № 4. – P. 1232–1238.

[7] Crawford M.L. Generation of standard EM fields using TEM transmission cells // IEEE Trans. on Electromagn. Compat. – 1974. – Vol. 16, №4. – P. 189–195.

[8] Crawford M.L. Expanding the bandwidth of TEM cells for EMC measurements. / Crawford M.L., Workman J.L., Thomas C.G. // IEEE Trans. on Electromagn. Compat. – 1978. – Vol. 20, № 3. – P. 368–375.

[9] S.P. Kuksenko, T.R. Gazizov, A.M. Zabolotsky, R.R. Ahunov, R.S. Surovtsev, V.K. Salov, Eg.V. Lezhnin. New developments for improved simulation of interconnects based on method of moments. Advances in Intelligent Systems Research (ISSN 1951-6851). Proc. of the 2015 Int. Conf. on Modelling, Simulation and Applied Mathematics (MSAM2015). August 23–24, 2015, Phuket, Thailand, P. 293–301.

[10] Patent №2606173 RF. TEM-cell