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Engineering Methodology for the Selection of a Composite Polymer Dielectric that Ensures the Absence of Electrostatic Discharges in the Design of the Onboard Electronic Equipment of the Spacecraft

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***Abstract* — an engineering technique for selecting a composite polymer dielectric with increased conductivity, ensuring the absence of electrostatic discharges, has been developed for radio electronic devices as part of the onboard equipment of spacecraft. On the basis of the developed methodology, at the stages of preliminary and technical design, calculations of the operability of the developed radioelectronic means are carried out in relation to the invariability of the operating characteristics specified according to the terms of reference, and at the same time there is no electrostatic discharges of the printed circuit board substrate - printed conductor. The method is based on comparison of the conductivity value of the composite dielectric of the printed circuit board of the developed radio-electronic apparatuses, at which its operating parameters are still unchanged, with the criterion conductivity value ensuring the absence of electrostatic discharges – 10^{-9} $\Omega^{-1}\cdot m^{-1}$. The method is intended for the developed avionics of space application, operating on board the spacecraft, operated in conditions of intense impact of space plasma.**

Keywords— electrostatic discharges, methodology, printed circuit board, dielectric material, computer modeling.

I. Introduction

Electrons and ions of cosmic plasma affect spacecraft, causing the electrization of their dielectric materials, including materials of printed circuit boards of on-board radio electronics. The result of the accumulation of charge is the occurrence of electrostatic discharges, leading to its failures. Due to this phenomenon, the duration of the active existence of spacecraft is significantly reduced [1,2].

One of the effective ways to solve this problem is the use of composite polymer dielectrics with increased conductivity as printed circuit board materials [3]. In this case, a certain amount of conductive material is introduced into the polymer dielectric. This increases the dark conductivity of the polymer, there is a drain and equalization of the accumulated charge and the conditions that determine the occurrence of electrostatic discharges (ESD) disappear.

For a number of promising polymer materials that are part of composite dielectrics with increased conductivity, studies have been conducted aimed at estimating the values of specific volumetric conductivities that make it possible to ensure the absence of electrostatic discharges [4]. The authors found that in the conditions of the space environment, with the value of the specific volume conductivity of the dielectric equal to 10^{-9} $\Omega^{-1}m^{-1}$, electrostatic discharges will not occur.

However, the use of dielectrics with such volumetric conductivity as a printed circuit board material can lead to a malfunction of on-board electronics devices due to the occurrence of parasitic current leaks.

Therefore, the task of modeling the functional output characteristics of avionics devices built on printed circuit boards with increased volumetric conductivity of the dielectric material is relevant.

The authors [5] theoretically and experimentally showed that when using composite polymer dielectrics with increased conductivity as a printed circuit board material for a typical digital electronics device - a low-frequency multivibrator - no change in its characteristics was observed up to the specific volume conductivity, $\gamma = 1.55 \cdot 10^{-7}$ $\Omega^{-1}m^{-1}$. This indicates the possibility of using such dielectrics in printed circuit boards to protect against the damaging effects of electrification factors.

Research in this direction led to the creation of models of a number of radio electronic devices (heterodynes and broadband amplifiers) and the study of their characteristics, taking into account the replacement of the traditional dielectric of the printed circuit board with a composite dielectric with increased specific volume conductivity [6].

The dielectric material with increased specific volumetric conductivity is taken into account in the model by introducing additional resistances into the electrical circuit (fig. 1 and 2), characterizing current leaks between the conductors of the device's printed circuit board and leaks to the zero conductor.

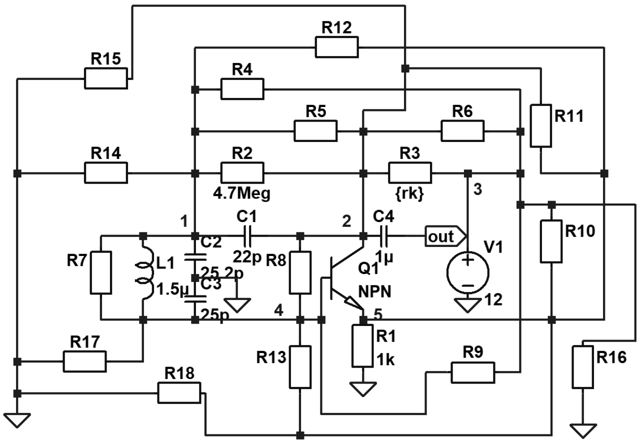

Fig. 1. A computer model of a heterodyne that takes into account software leaks between the nodes of the circuit

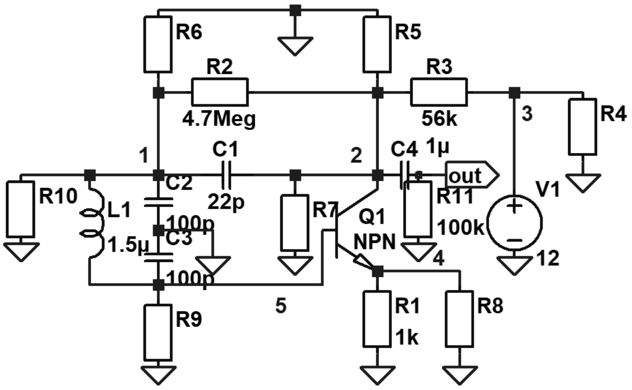

Fig. 2. A computer model of a heterodyne that takes into account leaks to a conductor of zero potential

The results of computer modeling and experimental study of the performance characteristics of the heterodyne showed that an increase in the specific volume conductivity of the printed circuit board material from 10^{-15} to $2 \cdot 10^{-9}\ \Omega^{-1}\text{m}^{-1}$ does not change the frequency and amplitude of the output voltage.

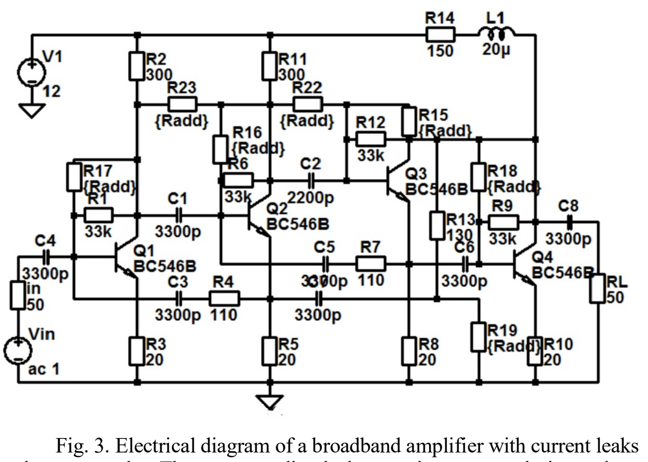

Fig. 3. Electrical diagram of a broadband amplifier with current leaks between nodes. The corresponding leakage resistances are designated as Radd.

Studies of the performance characteristics of a broadband amplifier, in which the printed circuit board material is a composite dielectric with increased specific volumetric conductivity (diagrams are shown in Fig. 3 and 4), have shown that an increase in conductivity in the range from 10^{-15}, to $1.2 \cdot 10^{-5}\ \Omega^{-1} * \text{m}^{-1}$ does not lead to a change in the bandwidth and gain of a broadband amplifier.

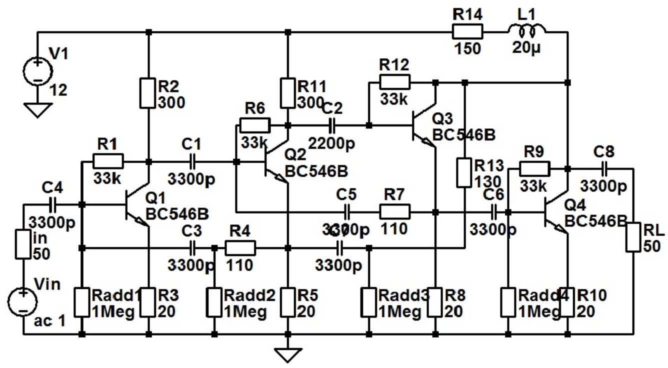

Fig. 4. A computer model of a broadband amplifier that takes into account leaks to a conductor of zero potential

Thus, the possibility of effective use of dielectrics with increased conductivity in radioelectronic devices for space applications to prevent the occurrence of electrostatic discharges and subsequent failures in operation is shown.

In addition, the validity and applicability of the developed models of current leakage between the nodes of devices and to the zero conductor for the above-mentioned classes of devices is shown. It is obvious that the leakage resistances caused by the increased conductivity of dielectrics depend on the geometry of printed conductors on printed circuit boards, and therefore they must be evaluated for each design of the printing unit. To do this, at the stages of preliminary and technical design, it is necessary to introduce a special operation for the selection of the dielectric material of the printed circuit board, which is based on the determination of the conductivity value at which the operating characteristics of functional units begin to change.

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II. ENGINEERING METHODOLOGY FOR THE SELECTION OF COMPOSITE POLYMER

An engineering technique for selecting a composite polymer of the corresponding value of the maximum value of the specific volumetric conductivity of the dielectric base of printed circuit boards, at which the operating parameters are still unchanged. In this case, the operability of the radio-electronic device, accompanied by the absence of an electrostatic charge, is determined by the fact that this permissible value should be greater than $10^{-9}\ \Omega^{-1}\text{m}^{-1}$.

In order to be able to attribute the beginning of changes in performance characteristics to a certain resistance, all leakage resistances are assumed to be the same.

The calculation of the maximum permissible specific conductivity, the maximum value of the specific volumetric conductivity of the dielectric base of the printed circuit board, at which, with an increase in which the operating characteristics of the device begin to change, is performed by the expression:

$$\gamma_m = \frac{\varepsilon_0 \cdot \varepsilon}{R_{mn} \cdot C} \quad (1)$$

Where R_{mn} is the minimum resistance of the dielectric base of the printed circuit board between the printed conductors, at which the operating characteristics begin to change;

C - is the capacitance of the dielectric base between the printed conductors; γ_m - is the maximum value of the specific volumetric conductivity of the dielectric base of the printed circuit board, at which the operating characteristics of the radio device begin to change; E_0 is the electrical constant; E is the relative permittivity of the dielectric base of the printed circuit board. There are a number of programs for calculating parasitic capacitances between printed conductors [7], which can be used to calculate “C”. Naturally, the calculation results in a set of several values that differ from each other. For use in expression (1), the maximum capacity is selected as corresponding to the worst case. The presence of a conductive component in a composite dielectric lead to a certain change in the relative permittivity [5,8].

Unfortunately, there are no data on the values of E for composite dielectrics. Therefore, for single-layer and multilayer printed circuit boards based on fiberglass, E = 4,5 is used, based on getinax E = 6, and for flexible printed circuit boards based on polyimide E = 3,4. These values also relate to the worst case (when a conductive filler is introduced into these materials, the relative permittivity increases, which leads to some increase in γ_m).

Below is a brief description of the main stages of the developed methodology, and the general scheme of calculations according to the methodology is shown in Figure 5:

1. At the first stage, after tracing printed conductors on a board with a dielectric base using a composite dielectric with increased conductivity, the tracing of printed conductors of the printed circuit board is analyzed to identify all possible current leakage options.
2. At the second stage, appropriate changes are made to the schematic diagram and modeling of the operating characteristics of the device is carried out to identify the leakage resistance Rm, at which these characteristics begin to change.
3. At the third stage, according to one of the methods [7], the capacitance from the dielectric base between the printed conductors corresponding to the worst case is calculated.
4. 4. Further, using the expression (1), using the values obtained in printed circuit boards 1-3, the maximum value of the conductivity of the dielectric base of the printed circuit board γ_m is calculated, at which its operating parameters remain unchanged.
5. 5. At the final stage, the obtained maximum conductivity value of the dielectric base of the printed circuit board γ_m is compared with the criterion value of conductivity, ensuring the absence of electrostatic discharges: 10^{-9} $\Omega^{-1}m^{-1}$.

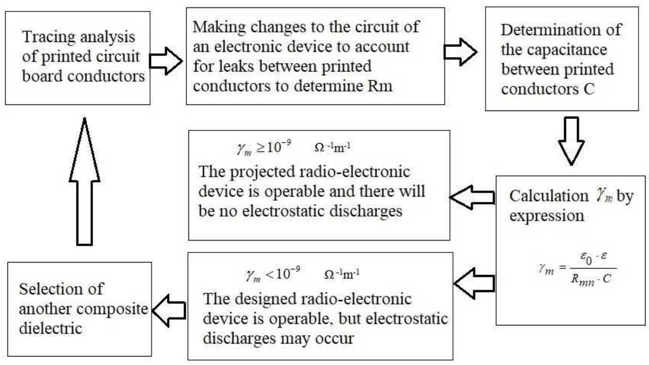

Figure 5. Scheme of the algorithm

Fig. 5. Scheme of the algorithm of the engineering methodology for selecting a composite polymer dielectric of the printed circuit board of the projected radioelectronic device for the onboard radioelectronic device of the spacecraft ensuring the absence of electrostatic discharges

If the calculated conductivity is greater than the criterion value:

$$\gamma_m \geq 10^{-9} \ \Omega^{-1}m^{-1} \quad (2)$$

the selected composite dielectric as part of the base of the printed circuit board of a radio-electronic device designed for operation in space conditions is operable, that is, its performance characteristics will correspond to the technical specification, and at the same time electrostatic discharges are excluded. the substrate of the printed circuit board is a printed conductor. Further, from a number of composite dielectrics, taking into account the necessary mechanical and thermal properties, the optimal one is selected.

If the calculated conductivity is less than the criterion value:

$$\gamma_m < 10^{-9} \ \Omega^{-1}m^{-1} \quad (3)$$

the composite dielectric of the base of the printed circuit board of a radio-electronic device designed for operation in space conditions does not ensure the absence of an electrostatic discharge, that is, its performance characteristics will correspond to the technical task, but at the same time electrostatic discharges of the printed circuit board substrate – printed conductor may occur.

Here it is necessary to use a composite dielectric with a lower value of specific volumetric conductivity and at the same time it is necessary to check for the absence of the physical possibility of the occurrence of electrostatic discharges.

III. Conclusion

An engineering technique has been developed for the selection of a composite polymer dielectric with increased conductivity, ensuring the absence of electrostatic discharge, for radio-electronic means as part of the onboard radio-electronic equipment of spacecraft. Based on the developed methodology, at the stages of preliminary and technical design, calculations of the operability of the developed radio–electronic means are carried out with respect to the immutability of the performance characteristics specified in the TOR, and at the same time the absence of electrostatic discharges is ensured by the printed circuit board substrate - printed conductor. The methodology is based on comparing the conductivity value of the composite dielectric of the printed circuit board of the developed radioelectronic means, in which its operating parameters are still unchanged, with the criterion value of conductivity, which ensures the absence of electrostatic discharges – $10^{-9}\ \Omega^{-1}\text{m}^{-1}$.

The technique is intended for the developed radio-electronic means of space applications operating on board a spacecraft operated under conditions of intense exposure to space plasma.

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References

[1] DeForest S.E. Spacecraft charging at synchronous orbit. J. Geophys. Res. 1972. Vol. 77. No. 4. P. 651–659: DOI:10.1029/JA077I004P00651

[2] Frederickson A.R. (1974) Radiation Induced Electrical Current and Voltage in Dielectric Structures. AFRL-TR-74 – 0583, 41 p.: DOI:10.21236/ada007670

[3] Pozhidaev E.D. Saenko V.S., Smirnov I. A., Babkin G.V., Tyutnev A.P. Povyshenie stojkosti kosmicheskih apparatov k vozdejstviyu porazhayushchih faktorov elektrizacii. Kosmonavtika i raketostroenie. 2003. № 1 (30). S. 32–35: eLIBRARY ID: 20376819.

[4] Abrameshin D.A., Pozhidaev E.D., Tumkovskij S.R. Modelirovanie radiacionnogo zaryazheniya korpusov mikroelektronnoj apparatury kosmicheskogo primeneniya. Informacionnye tekhnologii. 2021. T. 27. №2. S. 59-64. DOI: 10.17587/it.27.59-64

[5] V. Saenko, A. Tyutnev, A. Abrameshin, G. Belik. Computer Simulations and Experimental Verification of the Nanoconductivity Concept for the Spacecraft Electronics. 14th Spacecraft Charging Technology Conference. 04-08 April 2016, ESA-ESTEC. Noordwijk: DOI: 10.1109/TPS.2017.2688180

[6] D.A. Abrameshin, E.D. Pozhidaev, V.S. Saenko, S.R. Tumkovskiy. Computer Simulations and Experimental Investigation of the Heterodyne Employing Printed Circuit Board With an Increased Resistance to Electrostatic Discharges. IEEE Transactions on Plasma Science. 2019. Vol. 47. No. 8. P. 3653-3657: DOI: 10.1109/TPS.2019.2915522

[7] Suhodoliskij V.YU. Altium Designer. Proektirovanie funkcional'nyh uzlov RES na pechatnyh platah. SPb.: BHV-Peterburg 2010. S. 480. URL:https://radiohata.ru/textbook/1592-altium-designer-proektirovanie-funkcionalnyh-uzlov-res-na-pechatnyh-platah.html

[8] Abrameshin A. E., Chetverikov V. The Effective Dielectric Constant of a Composite with Conductive Nanoparticles, in: 2020 Moscow Workshop on Electronic and Networking Technologies (MWENT): DOI: 10.1109/MWENT47943.2020.9067401