Application of 3d technologies for microwave range electronic components creating

Kh Gadzhiev, S Gadzhieva and T Chelushkina

Dagestan state technical University, Imam Shamil Ave. 70, Makhachkala, 367000, Russia

E-mail: gadjiev.xad@mail.ru

Abstract. This paper presents the results of the study of microwave radio-electronic components electrophysical parameters manufactured on a 3D printer. Laser sintering technologies for metal semiconductor and ceramic powders were used as experimental research methods. The resonant properties of one-sided surfaces in the form of a Mobius sheet made on the 3D printer are analyzed. An explanation of a traveling and standing wave formation in the oscillatory contours of the microwave range of one-sided surfaces in the form of a Mobius sheet is presented. The possibility to create digital active phased antenna arrays based on one-sided surfaces in the form of a Mobius sheet is shown.

1. Introduction

In the radio-electronic industry are widely used 3D printers for the manufacture of metal or ceramic structural elements [1-3]. At the same time 3D technologies can be effectively used to create electronic components such as resistors inductors capacitors resonators and microwave antenna-feeder devices [4-6]. Existing 3D printers form structural elements as a rule from the same material [7]. It is possible to create electronic circuits in the form of metal structural elements on a ceramic basis, which limits the range of manufactured electronic components. It is advisable to manufacture electronic components in the same technological cycle from materials with different electrophysical characteristics. To solve this problem it is necessary to produce powder structures from different materials with similar sintering temperatures and weight and size characteristics. Alternate sintering of powders with different electrophysical properties in each layer will allow forming of electronic components with unique parameters that cannot be implemented using other technologies. For example it will be possible to produce digital active phased antenna arrays based on one-sided surfaces in the form of a Mobius sheet. Such antenna system will allow for direction finding of aircrafts in conditions of additive and multiplicative interference of natural and manufactured nature.

2. Materials and Experimental Methods

To produce digital active phased antenna arrays based on one-sided surfaces in the form of a Mobius sheet it is necessary to use a 3D printer with the ability to print products from different materials with electrophysical properties. Ceramics semiconductors and metal will be used as materials. Because of application of layer-by-layer laser sintering technology ceramic and metal powders can form a ceramic surface in the form of a one-sided surface of a Mobius sheet. This one-sided surface will be metallized in such a way that in the cross section it will have the capacitance properties in the form of two plates and a dielectric between them, and in the longitudinal section it will be two metal coils of the inductor.
As a result on the basis of capacitance and inductance a resonant oscillatory circuit of the microwave range is formed in which a traveling or standing wave can be formed depending on the geometric dimensions.

3. Results and Discussion

Figure 1 shows a 3D printer for printing products made of different materials by electrophysical properties. Instead of a single container with particles of powdered material for sintering with a movable bottom in the vertical direction are added several similar containers containing particles of powdered materials with different electrophysical properties which will be used in a given order to form each printing layer due to the horizontal movement of the mobile platform with containers over the working area for the product sintering.

After the formation of the particles sintering of one powdered material is completed all containers are simultaneously shifted to the side so that the container with particles of powdered material with other electrophysical properties can also apply the next layer to the working surface for sintering another material at the same level as the previously printed material. Thus in one layer it is possible simultaneously form several surfaces consisting of different materials with different parameters. At the end of the sintering process excess particles of powdered materials from this layer can simply be blown away or collected using a suction device to be placed into the same container from which these particles of powdered material were taken. To ensure high accuracy at the boundaries of the formed surfaces it is advisable to start sintering with those particles of powdered material that have the highest sintering temperature. It will avoid parasitic interference when sintering subsequent particles of the powdered material since the laser beam temperature for each subsequent particles of the powdered material will decrease and will not affect the parasitic melting at the boundaries of the previous material in this layer. After all the surfaces of one layer have been formed all free space in this layer must be filled with the most fusible material or other similar material that can be easily melted dissolved etc. when the product forming is finished or will be stored as a filling to increase water resistance strength or perform other auxiliary functions [8].

For the obtaining of ceramic semiconductor and metal powders for additive technologies can be used a plasmatron installation with ultrasound influence (figure 2). To obtain spherical powders and granules is used the cylindrical workpiece rotation around the horizontal axis and the workpiece end face is melted by a plasma jet of an arc plasmatron. The separation of molten particles from the end face edge under the action of centrifugal forces and the solidification of particles during flight in a gas environment will occur in contrast to known technical solutions under the influence of ultrasound on the separating molten particles. The standing wave inside the rotating cylindrical workpiece will determine not only size of the molten metal particle but the moment of its separation too. A similar effect will be synchronously exerted by a standing wave from an inert gas medium at the edge of the molten end face. Changing the frequency of ultrasonic vibrations allows to control the process of forming of certain size metal particles.

Thus, the method of forming metal semiconductor or ceramic powders for additive technologies in a plasmatron installation under the ultrasound influence solves the problem of powders forming with different electrophysical properties in the form of spherical particles of the same size for subsequent use in 3D printers.

On a 3D printer using metal and ceramic powders with different electrophysical properties can be made a microwave range resonator in the form of a one-sided Mobius surface for a digital active phased antenna array.

The ultra-high-frequency electromagnetic oscillations resonator in the form of a Mobius (figure 3) surface of metal-dielectric-metal structure is a closed microstrip structure with twisted plates for one 180-degree rotation. Figure 4 shows a Mobius ring section which shows the geometric dimensions as the cross-section radius r and is indicated half length of the inductor coil as l / 2. It is also shown how the metal plates 1 around the dielectric layer 2 forms the capacitive component of the contour, and how the outer plate passes into the inner one, and the inner one into the outer one.
Figure 1. 3D printer diagram for printing products made of different by electrophysical properties materials.

Figure 2. Method for forming powder structures with various electrophysical properties for additive technologies in a plasmatron installation under the influence of ultrasound.

In this case, two metal plates turn into one 1, which has the form of an inductance consisting of two turns closed on each other.

Figure 3. Resonator in the form of a closed surface of a Mobius strip.

Figure 4. Section of the Mobius ring:
1 – metal plates;
2 – dielectric layer.

Figure 5 explains the formation of an oscillating circuit from a capacitance and two-turn inductance and shows the thickness h and width d of the capacitance indicating the metal plate 1 and the dielectric layer 2.

Figure 5. Formation of an oscillating circuit from a capacitance and two-turn inductance:
1 – metal plates;
2 – dielectric layer.
The resonator works as follows: in any section of the resonator there is a capacitive component in the form of two metal plates 1 on opposite sides of the dielectric surface 2. The capacitance value depends on the dielectric permittivity of the insulator its thickness (the distance between the metal plates) width of the plates and length, and the length of the plate corresponds to the length of one circuit turn. And inductance is a construction of a two-turn short-circuited solenoid that induces a magnetic field depending on the magnetic permeability of the dielectric size of the circuit cross-section and length of the metal plate. Inductance and capacitance together form an oscillating circuit. Depending on the geometrical dimensions of the circuit, it generates either a traveling wave (if a whole wave of oscillation is placed along the length of the plate) or standing wave (if half of the oscillation wave is placed along the length of the plate).

The change in inductance will be accompanied by changes in the capacitance of the circuit too since all the inductance parameters are also parameters of the capacitance. Some capacitance parameters can be changed without affecting the inductance value, so when changing the width or thickness of the dielectric and plates the inductance parameters will be saved but the capacitance parameters will change. Thus, it is possible to independently select the frequency of electromagnetic oscillations in the resonator by changing the capacitance parameters separately.

The calculation of the resonator electrophysical parameters (inductance, capacitance, and frequency) can be performed using the following formulas:

\[ L = \mu_0 \mu \frac{N^2 \cdot S}{l}, \]  
\[ C = \varepsilon \cdot \varepsilon_0 \cdot \frac{l \cdot d}{h}, \]  
\[ f = \frac{1}{2\pi \sqrt{LC}}, \]  
\[ \lambda = \frac{c}{f} = \frac{c}{\frac{1}{h} \cdot \frac{1}{2\pi \sqrt{\varepsilon \cdot \varepsilon_0 \cdot \frac{l \cdot d}{h}}} \cdot \frac{1}{\mu \cdot \mu_0 \cdot \frac{l \cdot d}{h}}}. \]
Thus, it is possible to determine the wavelength of the oscillation and compare it with the resonator size to select either the traveling wave mode or the standing wave mode.

For a digital active phased antenna array is important the pulse mode of operation with discrete values of information signals, which can be implemented in the form of a code-pulse modulator of ultra-high-frequency electromagnetic oscillations in the form of a multilayer Mobius surface with p-i-n diodes.

The modulator is a closed Mobius surface formed by a multilayer structure in the form of metal-dielectric-metal-p-i-n-diodes-metal-dielectric-metal, where each section of such a surface has a capacitive component formed by a rectangular dielectric on two opposite sides covered with metal plates. Through p-i-n diodes it is possible to connect or disable the additional plate in such a way that the capacitance will increase or decrease discretely (the inductance will remain unchanged). The closure in the form of a one-sided Mobius surface from these two metal plates forms one metal plate in the form of two turns of short-circuited inductance.

The modulator of ultra-high-frequency electromagnetic oscillations, in the form of a Mobius surface of the multilayer structure metal-dielectric-metal-p-i-n-diodes-metal-dielectric-metal is a closed multilayer structure with twisted plates for one 180-degree rotation. Figure 6 shows a section of the Mobius ring which shows how the metal plates 1 around the dielectric 2 form the capacitance component of the circuit, and how the outer plate passes into the inner one, and the inner one into the outer one. In this case two plates turn into one which has the form of an inductance consisting of two short-circuited turns. In addition it shows how p-i-n diodes allow to connect or disable the additional plate. The Mobius strip can be narrower (diodes are closed) or wider (diodes are open) depending on the polarity of the DC voltage applied to the diodes between the internal main and external additional plates.

Figure 7 explains the formation of an oscillating circuit from the capacitance and two-turn inductance using p-i-n diodes to change the resonant characteristics in the traveling and standing wave modes by connecting or disabling of additional plates to the capacitance in the modulator using p-i-n diodes.

The modulator works as follows: in any section of the modulator there is a capacitive component in the form of two metal plates 1 on opposite sides of the dielectric surface 2. The value of the capacitor depends on the dielectric constant of the insulator, its thickness h (distance between the metal plates), plates width d and length l, and the length of casing corresponds to the length of one loop turn. With
open p-i-n diodes, the plate will be wider by the value of Δd, and the capacitance is greater. Inductance is a two-coil short-circuited solenoid construction that induces a magnetic field depending on the magnetic permeability of the dielectric, size of the circuit cross-section and the metal plate length. Since the width of the plate does not affect the inductance the open or closed p-i-n diodes also do not affect the inductance value. Inductance and capacitance together form an oscillating circuit. When changing the width or thickness of the dielectric and plates the inductance parameters will be preserved, and the capacitance parameters will change. Thus it is possible independently select the frequency of electromagnetic oscillations in the modulator. By connecting of additional plate using p-i-n diodes the capacitance can be discretely changed, which in its turn results in a change of the circuit resonant frequency and allows to implement code-pulse frequency modulation [9].

Oscillatory contours of the microwave range in the form of multilayer Mobius surfaces can be used in digital active phased antenna arrays for communication and radar systems [10].

4. Conclusions

As a result with the help of the developed construction digital active phased antenna arrays can be manufactured on the basis of one-sided surfaces in the form of a Mobius sheet, consisting of conductive metal surfaces and dielectric ceramics.

Errors when printing on a 3D printer are comparable to tens of microns, which is many orders of magnitude less than the wavelength of the microwave oscillation of the centimeter and millimeter range, so such defects will not practically affect the accuracy of digital active phased antenna arrays, for which details less than a quarter of the wavelength are indistinguishable.

The microwave range resonator can be implemented using only additive technologies, since the use of semiconductor powders with different types of conductivity allows for the implementation of adjustable microwave range resonators. The microwave resonator of electromagnetic oscillations in the form of a Mobius surface of the metal-dielectric-metal structure can be used in communication and radar systems. It is advisable to use a resonator in the input circuits of digital active phased antenna arrays. An important advantage is that the electromagnetic oscillations of such circuit can be perceived by a similar circuit, rather than traditional microwave range resonators, that will protect the transmitting and receiving information from interference and unauthorized access. Also in the low-frequency range it is possible to produce thermoelectric devices, semiconductor components, etc.

References

[1] Nikiforov S O, Markhadaev B E, Nikiforov B S and Sholokhov E S 2016 Bulletin of the Buryat scientific center of the Russian Academy of Sciences Siberian branch 4 156–163 (in Russian)
[2] Drovosekova T I Voronin A Yu and Zverko E K 2018 Forum of young scientists 4 452–460 (in Russian)
[3] Yakushin K E Romanova E B and Kirillov G R 2018 Fundamental and applied researches in the modern world 22 86–90 (in Russian)
[4] Dobychina E M Slatin M V and Solod A G 2018 Telecommunication 12 68–73 (in Russian)
[5] Slatin V V 2017 Aviation systems 7 3–9 (in Russian)
[6] Quaranta P 2016 Military technology 9 86–89 (in Russian)
[7] Vitsukaev AV Pavlovich O V Tsarkova Yu M and Maslennikova A A 2018 Electronics and Super high frequency microelectronics 1 58–62 (in Russian)
[8] Ismailov T A Gadzhiev H M Shkurko A S Chelushkina T A and Kablov E N 2019 3D printer for printing products consisting of materials with different electrophysical properties Patent RF no. 2702019
[9] Ismailov T A Gadzhiev H M Chelushkina T A Shkurko A S and Magomedova P A 2015 Bulletin of the Dagestan State Technical University 37 44–49
[10] Ismailov T A Gadzhiev H M Kryachko A S Chelushkin D A and Shkurko A S 2017 Code-pulse modulator of ultrahigh-frequency electromagnetic oscillations in the form of a multilayer Mobius surface with p-i-n diodes Patent RF No. 2616440