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The study of microwave range energy harvesting device

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The study of microwave range energy harvesting device

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Abstract. The paper is devoted to the development of the energy harvesting system of microwave range. The block diagram of the system was developed and stands for measuring antenna patterns and study of the transmission voltage dependence from distance were made. To perform the study were selected six types of antennas: dipole, wire dipole, stripline, horn, parabolic and stripline antenna array. The study revealed that the parabolic antenna has the advantage in distance of energy transfer out of the six considered antennas. The achieved value of the potential on the receiving device is about 23 mV at the distance of 9 m. The obtained results allow realizing the energy harvesting system in a small industrial premise or room.

1. Introduction

Currently, the most widely used devices are wireless charging devices, which use inductive coupling for energy transfer. Initially, devices were developed based on the Magnetic induction (MI) method, and recently a number of companies are preparing to start manufacturing devices that use the magnetic resonance method (Magnetic Resonant – MR).

The energy intensity of the energy harvesting device is not limited by anything from the outside, because only an energy environment is needed for its operation. Standalone wireless sensor systems are one of the new concepts. The problems of increasing the reliability and stability of wireless data transmission channels under conditions of RF interference in most cases are solved separately. The essence of the new concept is that the autonomy of the power supply of individual nodes will allow wireless sensors to work without fear that the battery will be discharged or disconnected from the power plant [1, 2].

There is the possibility of combined use of various available energy sources, for example, mechanical and thermal, wireless power transmission (power supply of the node over the air).

The energy harvesting device is designed to power an electronic circuit with electrical energy that is stored in a battery or capacitor. Energy harvesting devices can not yet compete with batteries in systems where they are easy to change, and with wires as a reliable and inexpensive means of modern communication, if they harmoniously fit into the system. Wireless monitoring evolves as a complement or replacement for wired connections, and energy harvesting devices are part of such a system.

In recent years, international industry associations have been created to develop and promote specifications, as well as components and equipment for wireless charging - this is the Wireless Power Consortium (WPC), as well as the Power Matters Alliance (PMA) and Alliance for Wireless Power (A4WP). The WPC consortium, founded in 2008, includes more than 200 companies, including

Fairchild Semiconductor, Foxconn, Freescale Semiconductor, Huawei Technologies Co., Ltd., Infineon Technologies AG, Integrated Device Technology (IDT), Qualcomm Incorporated, Renesas Electronics Corporation, Rohm Co., Ltd., Sony Corporation, Samsung Electronics Co., Ltd., ST Microelectronics International NV, TDK Corporation, Texas Instruments, Toshiba Corporation. The consortium's task is to develop specifications for low-power wireless power and battery charging devices, as well as related technology. At the end of 2010, the consortium introduced the first specifications for wireless transmission of electricity up to 5 watts. The specifications are called Qi 1.0 (Quality Interface) [3].

In paper [4] a device for transmitting and collecting radio energy at a frequency of 2.44 GHz was considered, a block diagram of a transmitter and a receiver was developed, and an experimental setup was described. The purpose of this article is to show the capabilities of an energy harvesting device for transmitting microwave power to a distance of 9 meters and converting a microwave signal to direct voltage, the level of which will be sufficient to convert and store energy in a battery, the charge of which can then be used in various electronic circuits.

2. Investigation of the dependence of voltage transmission on distance

A fundamental aspect of energy recovery in energy harvesting systems is to determine the power of the energy flow depending on the distance between the transmitting and receiving antennas. Thanks to the obtained and studied antenna directivity patterns (DP), voltage measurements were made at the points of maximum energy radiation.

Figure 1 shows the dependence of voltage on transmission distance.

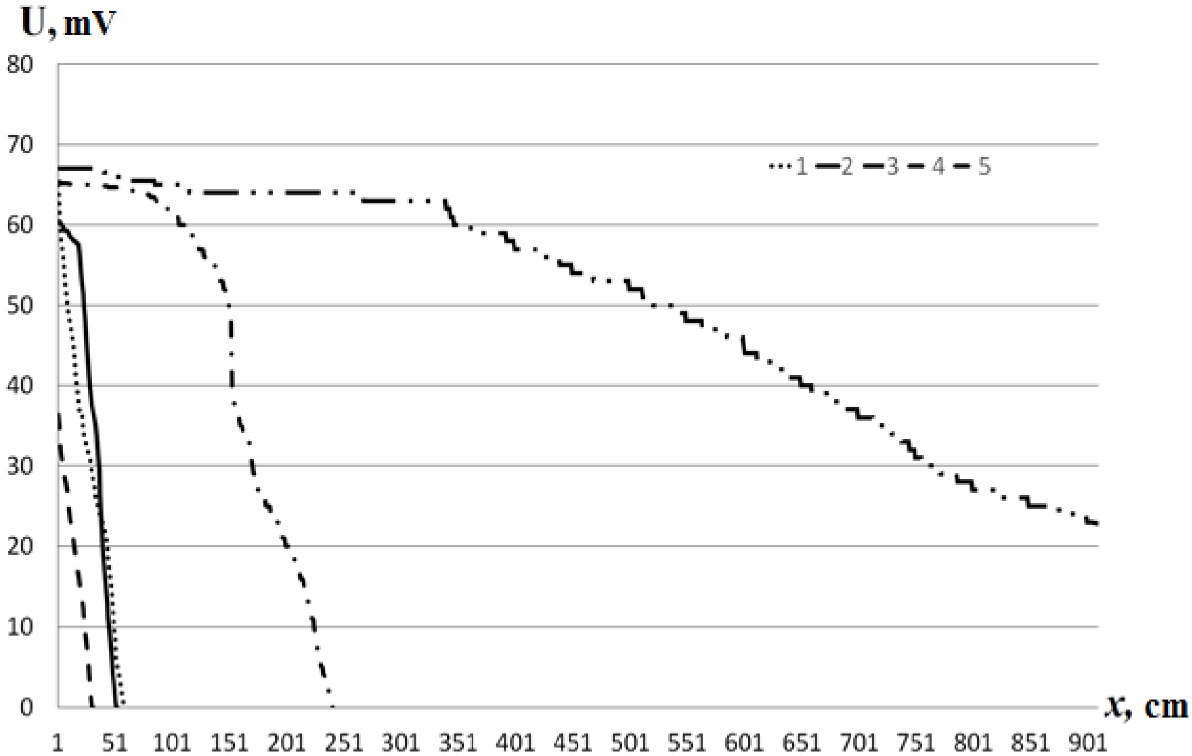

Figure 1. 1 – dipole and dipole wire antennas, 2 – stripline antenna, 3 – stripline antenna array, 4 – horn antenna, 5 – parabolic antenna.

Figure 1 shows that the parabolic antenna has an advantage in the range of energy transmission.

When measuring the output voltage at the detector when a parabolic antenna is connected to the stand, a maximum voltage value of about 23 mV is obtained at a distance of 9 m. We also measured the propagation of energy into the space by a parabolic antenna, and measured the dependences of the voltage along the direction of the maximum of the transmission coefficient S21 on the coefficient of amplification at a distance of 1, 2 and 3 m. The voltage dependences on the distance at different amplification factors are presented in figure 2.

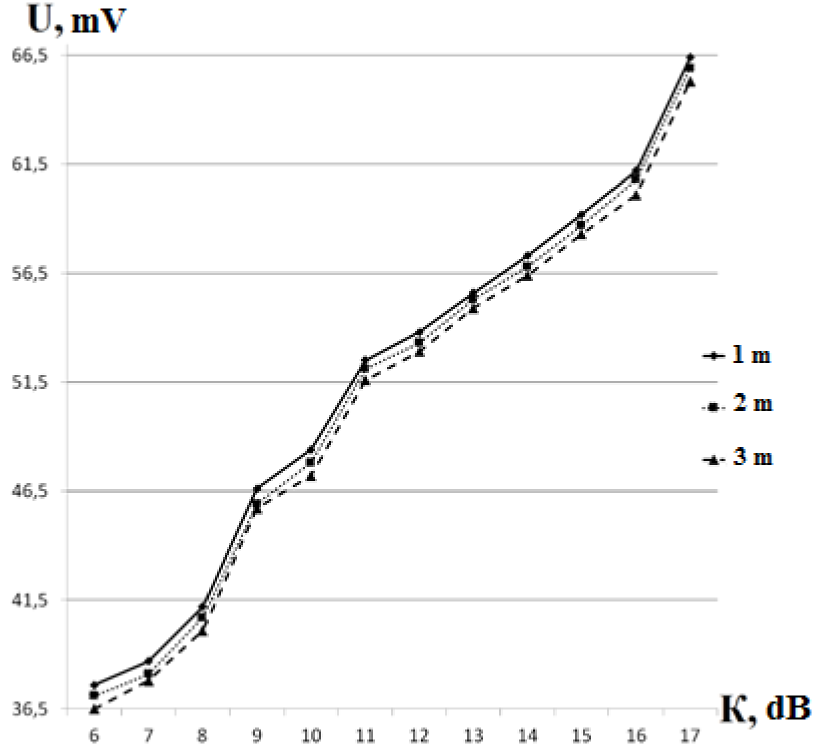

Figure 2. Dependence of the removed voltage on the gain of a parabolic antenna.

Figure 2 presents three graphs: 1 – dependence of the voltage on the gain at a distance of 1, 2 and 3 m. From the graphs it can be seen that the voltage is inversely proportional to the distance between the transmitting and receiving antennas at any gain.

3. Antenna directivity pattern measurement

It is necessary to know along which direction the energy is distributed in each of the studied antennas to extract the maximum amount of energy. You can determine the direction of the distribution of the maximum energy using directivity patterns. Thus, obtaining the directivity patterns of the studied antennas is one of the research priorities.

It is necessary to measure the antenna patterns in order to determine the direction of the maximum radiated power. Six types of antennas were chosen for the study: dipole, dipole wire, stripline, antenna stripline array, horn and parabolic antennas. All studied antennas were tuned to a resonance at a frequency of 2.44 GHz. Calculation and development of antennas are discussed in articles [4–8].

To measure the DP of the antennas of the microwave energy harvesting device, measuring stands were developed and assembled. A measuring stand for measuring directivity patterns of microwave energy harvesting devices according to the first measurement method is shown in figure 3 [8].

A transmitting antenna mounted on a tripod is supplied with a 5 W signal at a frequency of 2.44 GHz from the first port of the MCTRC Obzor-804 through a microwave power amplifier. A receiving antenna located at a distance of 2 meters from the receiving antenna is mounted on a second tripod equipped with an angle meter. TP-LINK TL-ANT2408CL dipole antenna was used as the receiving antenna [4]. Using the second port of the Obzor-804 complex transmission and reflection coefficient (MCTRC) meter, the transmission coefficient S21 was measured by changing the angle of the transmitting antenna relative to the receiving antenna in 10-degree increments using an angle meter on the second tripod. The

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measuring stand for measuring directivity patterns of microwave energy harvesting devices according to the second measurement method is shown in the figure 4 [8].

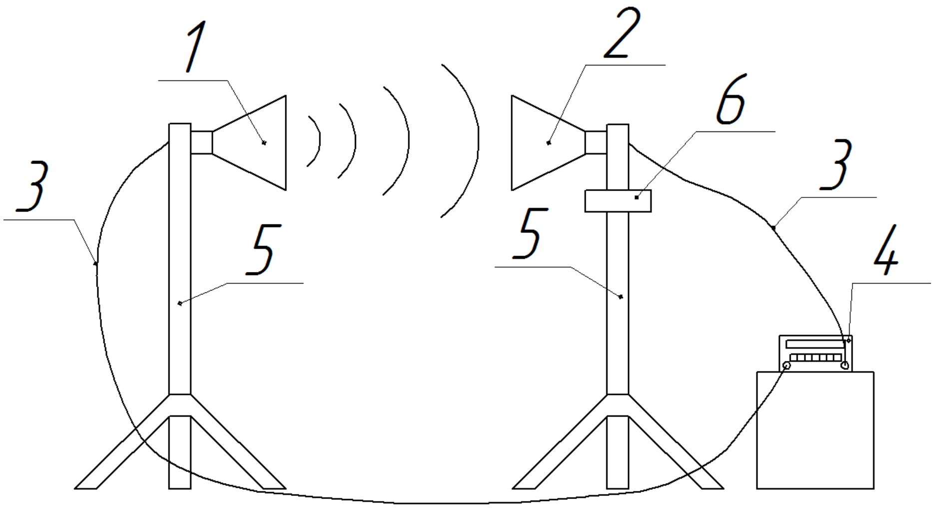


Figure 3. - Layout diagram of measurements of directivity patterns for a device for collecting microwave energy in the first way: 1 – transmitting antenna; 2 - receiving antenna; 3 – microwave cable; 4 – meter for complex transmission and reflection coefficients (MCTRC) "Obzor – 804"; 5 – a tripod; 6 – angle meter.

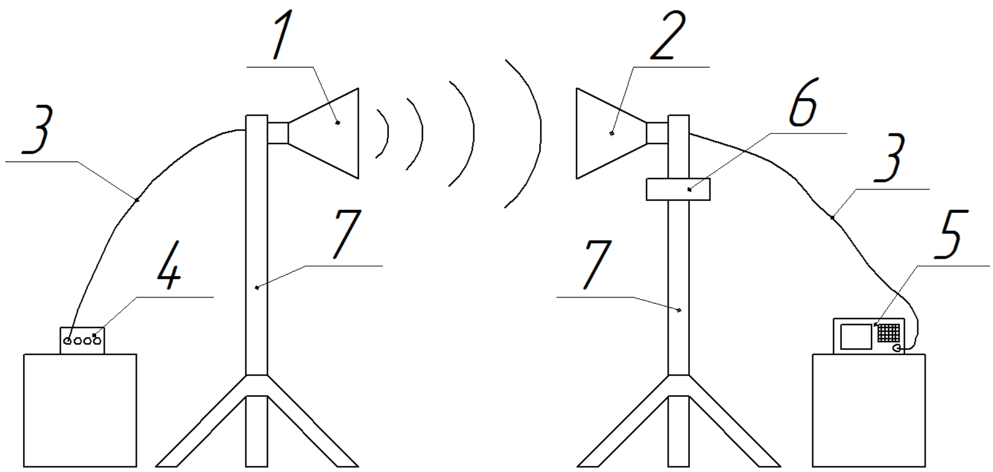


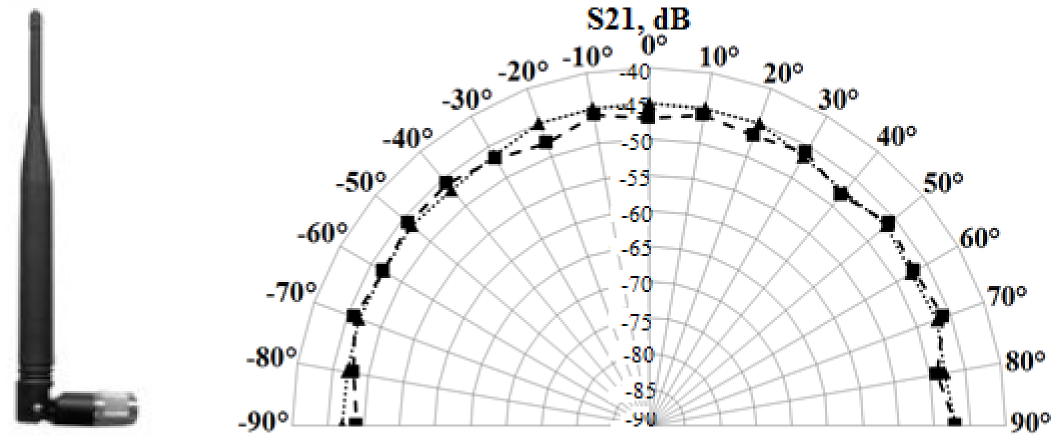
Figure 4. Layout diagram of measurements of directivity patterns for a device for collecting. microwave energy in the second way: 1 – transmitting antenna; 2 – receiving antenna; 3 – microwave cable; 4 – signal generator "Obzor-804"; 5 – spectrum analyzer "SIGLENT AKIP-4205"; 6 – angle meter; 7 – tripod.

A 5 W signal at a frequency of 2.44 GHz was transmitted through a microwave power amplifier to the transmitting antenna using the transmitting part of the UHF energy collection system used as the signal generator. A receiving antenna mounted at a distance of 7 meters from the transmitting antenna is mounted on a second tripod equipped with a protractor. The same dipole antenna TP-LINK TL-ANT2408CL was used as the receiving antenna. Using the SIGLENT AKIP-4205 spectrum analyzer, the directivity pattern (DP) was measured by changing the angle of the transmitting antenna with respect to the receiving antenna in increments of 10 degrees using an angle meter on a second tripod.

A significant difference in the measurement methods is the distance between the receiving and transmitting antennas. At a frequency of 2.44 GHz, the wavelength in space will be approximately 0.123 m. For the correct measurement of the directivity pattern, distances from the point of radiation to the point of reception of at least 10 wavelengths are required, which in our case will be about 1.23 m. The first method using only the Obzor-804 panorama for measurements is located on the edge of the near measurement zone (16 wavelengths), but nevertheless, such measurements can be carried out according to the recommendations given in [3]. This method requires only one measuring device, the receiving and transmitting channels of which are well calibrated. The second method is widely used and does not cause any doubts (57 wavelengths), it uses two devices - a generator and a spectrum analyzer. The distance factor is significant in laboratory conditions. Therefore, verification of the measurement method at short distances is essential for devices such as energy harvesting devices. In these devices, the receiving and transmitting antennas are usually located at small distances - from a few centimeters to several meters, which makes it relevant to conduct research in the way of measuring the directivity pattern at short distances.

Below in the figures, the dashed line with squares shows the directivity pattern taken by the first method, and the dots with triangles show the directivity pattern taken by the second method. The figures below show the measurement data of the transmission coefficient S21 at a distance of 2 m between the antennas.

Figure 5 (a) shows a standard dipole antenna for Wi-Fi transmitters. Figure 5 (b) shows the measured directivity pattern of the dipole antenna. This antenna was used as a receiving antenna. From the directivity pattern it is seen that the maximum of the DP is not expressed.



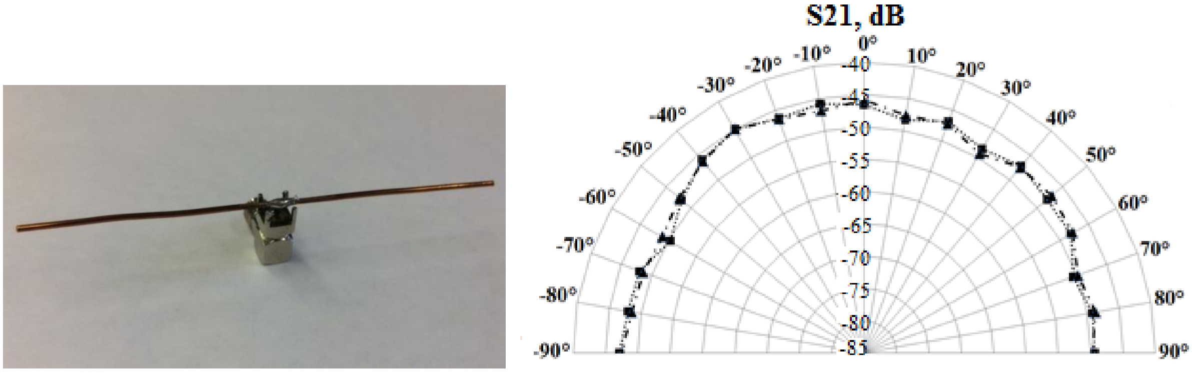
(a) (б)

Figure 5. a – dipole receiving antenna, b – directivity pattern of the dipole receiving antenna.

Figure 6 (a) shows the studied dipole transmit antenna for a frequency of 2.44 GHz, which has an SWR <1.3. Figure 6 (b) shows the resulting directivity pattern for a given antenna. It is seen that the maximum of the DP is not expressed from the directivity pattern.

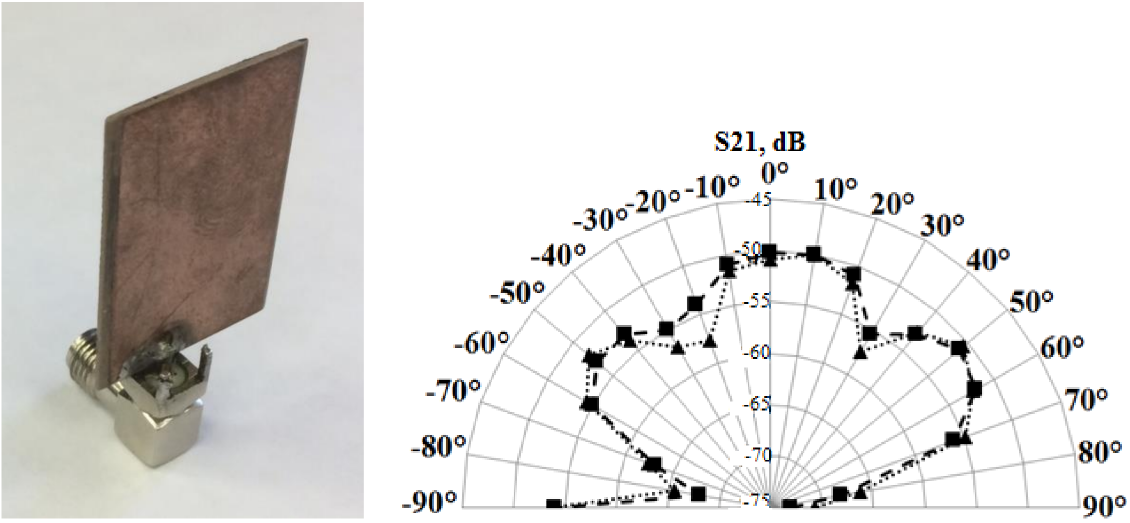
Figure 7 (a) shows a stripline antenna with dimensions of 25.2×18.7 mm with a strip length from the excitation point to the plate of 19.1 mm. The substrate is made on the material FLAN-10 ($\varepsilon = 10$), with dimensions of 30× 39×1 mm. Metallization is applied below the substrate. Figure 7 (b) shows the radiation pattern of a stripline antenna.

Figure 8 (a, b) shows the design of the pyramidal horn. Corrugated cardboard glued with aluminum foil was used as a material for the bell of the antenna. A hole for an SMA connector is cut out in one of the antenna walls, located at a quarter wavelength (in our case, 33 mm) from the narrow side in one of the four horn trapezes. All four trapezes are glued in such a way as to ensure continuous conductivity of the entire area of the foil coating. Figure 8 (b) shows the directivity pattern of an experimental sample of a pyramidal horn antenna.



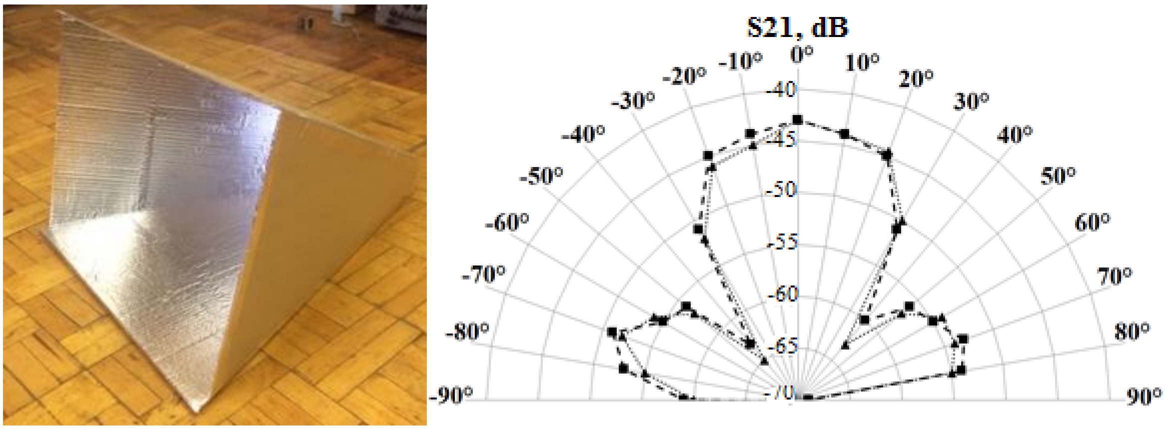
(a) (б)

Figure 6. a – dipole antenna, b – directivity pattern of the dipole antenna.



(a) (б)

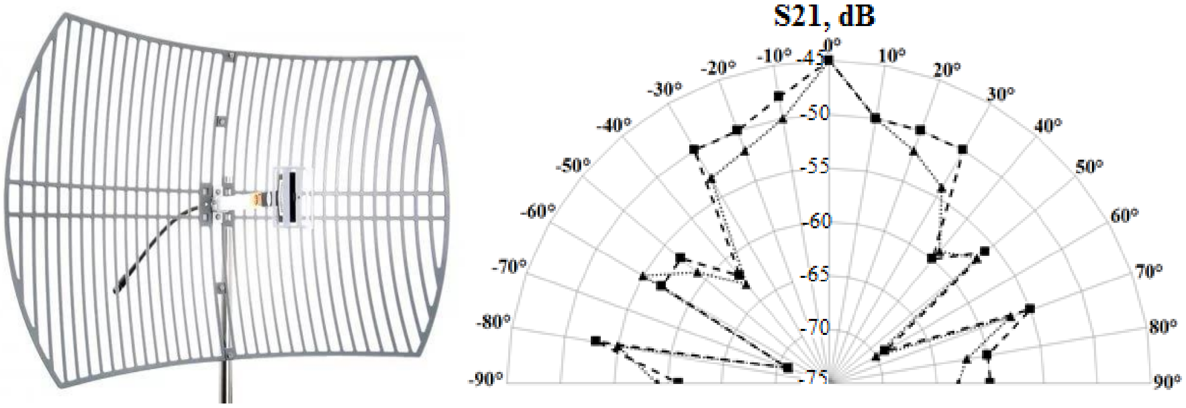
Figure 7. a – stripline antenna, b – directivity pattern of the stripline antenna.



(a) (б)

Figure 8. a – pyramidal horn antenna, b – directivity pattern of the pyramidal horn antenna.

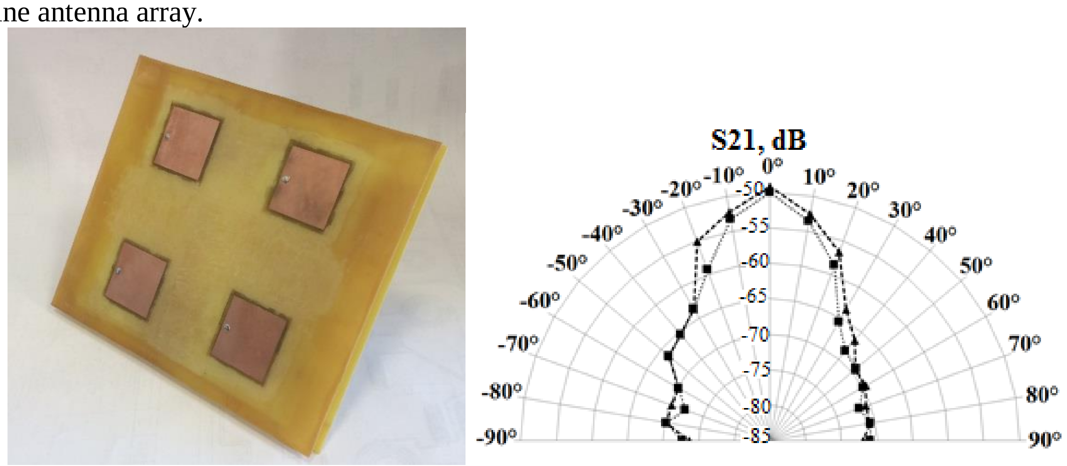
Figure 9 (a) shows the TL-ANT2424B 24 dB 2.4 GHz parabolic antenna. Figure 9 (b) is the measured directivity pattern of a parabolic antenna.



(a) (б)

Figure 9. a – parabolic antenna, b – directivity pattern of a parabolic antenna.

Figure 10 (a) shows the stripline antenna array. Figure 10 (b) is the measured directivity pattern of the stripline antenna array.



(a) (б)

Figure 10. a – stripline antenna array, b – directivity pattern of the stripline antenna array.

4. The structure and design of a microwave energy harvesting device

The microwave energy harvesting device under study consists of a generator, a preliminary amplifier (PA), an attenuator, an amplifier, transmitting and receiving antennas, a detector (mixer), and an RF to DC converter. The structural diagram of this system is shown in figure 11 [5].

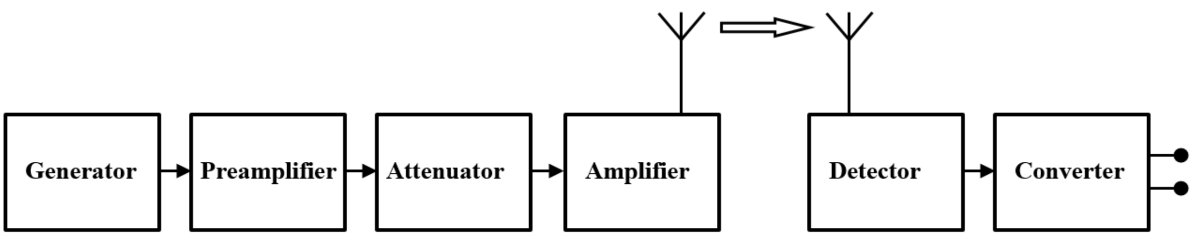


Figure 11. Structural diagram of the experimental setup.

The ZX95-253C + generator was used to generate a signal at the input. With a supply voltage of 5 V, the output power is 3.71 mW. The ZX60-272LN preliminary power amplifier and the Szhuashi microwave power amplifier of the Hs2405Mn model with an output power of 5 W were included in the circuit to obtain the required signal level at the transmitting antenna. A ZX05-43MH + S mixer was used in the circuit, which has a conversion loss to a signal at a frequency of 2440 MHz equal to 5.12 dB as a radiation detector. The converter for the energy harvesting system was developed on the basis of Linear Technology's LTC3108 chip and CoilCraft LPR6235- 752SML transformer. This chip can convert the input voltage from 20 mV to 500 mV at the input to the voltage from 2.5 to 5 V at the output. The circuit of the developed converter and its output characteristics are given in [7].

We will calculate the characteristics of the radiation device for the far zone. Suppose that the radiating antenna is non-directional, then the radiated power on a sphere of radius R is evenly distributed over the surface $4\pi R^2$. Then, a power flux density will be created in the area of the receiving antenna:

$$\Pi_D = \frac{P_C}{4\pi R^2}. \quad (1)$$

Where P_c is signal strength.

In our case, due to the directivity of the antenna, the power flux density at the receiving antenna will be K_A times higher:

$$\Pi = \frac{K_A P_C}{4\pi R^2}. \quad (2)$$

where K_A is a coefficient of directional action.

The energy of the direct wave is partially absorbed, and partially reflected from the object. Since the receiving antenna is an antenna with an effective area of S_{effAo}, the power at the input of the radio signal detector will be equal to:

$$P_{CO} = \Pi S_{effAo} = \frac{P_C K_A S_{effAo}}{4\pi R^2}. \quad (3)$$

The signal power at the input of the P_{CO} detector decreases with increasing distance to the object and reaches a minimum threshold P_{Comin} at $R = R_{max}$:

$$P_{COmin} = \frac{P_C K_A S_{effAo}}{4\pi R_{max}^2}. \quad (4)$$

Because:

$$S_{effAo} = \frac{K_{Ao}\lambda_o^2}{4\pi}, \quad (5)$$

where K_{Ao} – receiving antenna directional coefficient, λ_o – emitted signal wavelength, then:

$$D_{\max} = \sqrt{P_C K_A K_{Ao}\lambda_0^2 / 4\pi P_{CO\min}} \quad (6)$$

It is also possible to calculate the minimum power required for registration of the received signal. It is known [1] that for a detector matched with an antenna, the minimum signal power at the input is:

$$P_{CO\min} = m_P P, \quad (7)$$

where m_p is a distinguishability coefficient, $m_P = E_C/N_0$ equal to the minimum excess energy of a single input signal E_s over the spectral noise density N_0, at which the receiver has the ability to detect the received signal; P_n is a total noise power of the receiver and antenna connected to the input of the receiver. Then:

$$P_{COmin} = m_p k T_0 K_n \Delta f_{eff}, \quad (8)$$

where k = 1,38×10^{-23} J/K is Boltzmann constant; T_0 = 290 K is room temperature; K_n is a receiver noise figure; Δf_{eff} is an effective receiver noise bandwidth.

The power of the signal supplied to the transmitting antenna is about 5 W.

We will determine the power at the output of the receiving detector, provided that the receiver and transmitter are at a distance of 9 m. We choose a parabolic antenna as the transmitting antenna. We make the assumption that the losses in the medium of passage of the electromagnetic wave are negligible.

From expression (7) we find the power at the input of the receiving antenna:

$$P_{CO} = \frac{P_C K_A K_{Ao} \lambda_0^2}{4\pi D^2} \quad (9)$$

Then the signal power at the mixer output will be equal to:

$$P_{out} = \frac{P_{CO} K_{Amp}}{N_{Loss}} = \frac{P_C K_A K_{A0} \lambda_0^2}{(4\pi D)^2 N_{Loss}} = \frac{5 \cdot 11 \cdot 1 \cdot 0{,}123^2}{(4\pi \cdot 9)^2 \cdot 3{,}25} \approx 24{,}2[\text{мкВт}]$$

Further, by calculating the output power, it is possible to calculate the electric potential that will occur at the output of the mixer and to assess whether this voltage level is sufficient for the converter to convert and the battery charge. Taking into account that the resistance of the transmission line is 50 Ohms, we calculate the voltage at the output of the mixer, which in this case will be 24.6 mV, which is in good agreement with experimental data. This voltage is enough to charge a small, for example, lithium battery, and then power a small electronic circuit. Thus, experimental data and theoretical calculations confirm the possibility of remote power supply of electronic circuits using a microwave energy harvesting device.

5. Conclusion

The article presents the results of a study of the characteristics of the microwave energy harvestingdevice. Six types of antennas were chosen for the study: dipole, dipole wire, stripline, horn, parabolic antenna, stripline antenna array. Directivity patterns were measured for all types of antennas, for which measuring stands were developed. The antenna transmission coefficients were measured as a function of the distance between the transmitting and receiving antennas and the output voltage of the detecting device. As a result of the study, it was revealed that a parabolic antenna has an advantage in the range of energy transfer of the antennas under study. The experimental value of the potential at the output of the receiving device was about 23 mV at a distance of 9 m.

Acknowledgments

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References

[1] Sysoeva S A 2011 Devices for wireless and batteryless power autonomous nodes *Electronic components* **6** 42–45

[2] Ohrimenko V A 2014 Wireless charging technology *Electronic components and systems* **7** 17–24

[3] 2013 System Description Wireless Power Transfer Low Power Vol **1** *Interface Definition Version 1.1.2* Part **1**

[4] Kuzmin E V, Platonov S V, Bichurin M I, Khavanova M A and Petrov R V 2017 Study of a device for harvesting radio-frequency energy Vestnik NovSU Ser.: Technical sciences **6 (104)** 72–76

[5] Khavanova M A, Yukhno I M, Petrov R V, Kuzmin E V and Lobekin V N 2018 Study of the characteristics of a printed antenna based on magnetoelectric composites *Proceedings of the 28th international conference KryMiKo* (Sevastopol, RF)

[6] Kuzmin E V and Khavanova M A 2018 Design of a stripline antenna array with an air dielectric *Materials of student reports from the XXV scientific conference of teachers, graduate students and students of NovSU*

[7] Kuzmin E V, Platonov S V, Khavanova M A and Petrov R V 2017 Microwave energy harvesting system *Vestnik NovSU. Ser.: Technical sciences* **7 (105)** 52–58

[8] Kuzmin E V, Platonov S V, Petrov R V and Khavanova M A 2018 Measurement of radiation patterns of antennas of energy harvesting devices *Vestnik NovSU Ser.: Technical sciences* **4 (110)** 33–39