doi: 10.56761/EFRE2024.S3-P-044601

Research and development of a waveguide water-cooled power load

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Abstract. The design of a waveguide load intended to absorb up to 3 kW of continuous microwave power at 2.45 GHz is presented. The load comprises a short-circuited section of a rectangular waveguide with a cross-section of 90×45 mm, in which a flask of flowing water is located at a distance of approximately 1/4 of the wavelength from the shortening wall. A distinctive aspect of the aforementioned design is the utilisation of a preform, which is a billet employed in the fabrication of plastic PET bottles. Such blanks are a common standard component, facilitating the replacement of the flask, which is susceptible to overheating and the action of discharges at high electric field strength. The results of numerical modelling are presented, and the optimal bulb arrangement is found to ensure matching in the required frequency band. A sample of the waveguide load was made, and measurements of the reflection coefficient were carried out, which showed similarity with the results of calculations. Resource tests with a 2.5 kW magnetron showed no deformation of the plastic bulb at a flow of mains water from 0.5 litres per minute.
Keywords: waveguide load, microwave power absorption, PET preform.

1. Introduction

To test microwave devices, a test bench needs to be designed and assembled, which includes a power supply, input and output waveguide channel, and other components. One important component is the waveguide load, which absorbs microwave energy. In a functioning system, the load is usually coupled to the ballast arm of a ferrite circulator, where it absorbs power reflected from any issues in the waveguide, such as an increase or decrease in impedance. This helps prevent the reflected wave from reaching the output of the magnetron or semiconductor oscillator, ensuring their performance is not disrupted. Additionally, the waveguide load can be connected directly or through a directional coupler to the output of the microwave energy generator for debugging and adjusting power supply modes.

The frequency range for industrial, scientific, medical and household devices is determined by regulatory documents. According to GOST R 51318.11-2006, the frequency 2450 ±2.0%, i.e. the frequency band 2.4–2.5 GHz, is allocated for these purposes. Experiments with conventional magnetrons of household microwave ovens with a power of 700–900 W and available magnetrons of increased power of 2 and 3 kW showed that with a standard single-half-periodic circuit with voltage doubling, almost all magnetrons of different manufacturers have a frequency of output radiation 2.447–2.452 GHz. It is possible to get 1.8–2 kW of power from household microwave ovens when you switch them on in quasi-continuous mode from the three-phase power network and increase the average cathode current by 2.5 times relative to the passport values. This also means that the centre frequency in the emission spectrum has a spread up to 2.42–2.47 GHz.

To absorb microwave energy at 2.45 GHz, it is convenient to use a cooled load in which water itself is an absorbing element. An early version of such a load is presented in [1]. Further development led to modern high-power loads [2]. A significant influence on the wave reflection coefficient from the input of such loads is the conductivity of the water. A typical solution is to use a large volume of distilled water circulating in a closed loop, such as in the M3-13/1 absorbed power wattmeter. However, over time the water gets oxides of metals from which the parts of the device are made, so distilled water must be periodically replaced. Also, the disadvantage of such designs is the use of quartz glass or other specific materials for the manufacture of the flask with water in which the microwaves are absorbed. It is of interest to develop an absorbing load using maximally available components, suitable for connection to the running water of the municipal water supply system.

2. Waveguide load design

We have developed a load with a preform bulb, which is used as a blank in the manufacture of conventional plastic bottles. Such blanks are common standard parts that are very cheap and can be easily replaced in case of damage. Several sizes of preforms are available. A BPF/PCO 26 gram size with a standard 38 mm diameter screw part was selected. The bulb material, polyethylene terephthalate (PET), has a relative dielectric constant $\varepsilon = 2.6$ and a dielectric loss angle tangent tgδ of about 0.08. The disadvantage of the PET material is its low temperature resistance, usually it is used up to +80 °C, but the use of cooling circulating mains water should keep the bulb temperature within acceptable limits.

The design of the waveguide load is shown in Figure 1. A short-circuited section of a rectangular waveguide (1) with an internal cross-section of 90×45 mm houses a PET mold (2) with a diameter of 22 mm of cylindrical part and a wall thickness of 2.4 mm. The PET preform is located at a distance of approximately a quarter of a wavelength at the center frequency from the waveguide shorted wall. The depth of immersion of the flask affects the wave reflection and frequency characteristics of the load. The thickness of washer 3 adjusts the depth of immersion of the flask in the waveguide cavity in the range of 24–32 mm to adjust the minimum of the reflection coefficient in a given frequency band when using tap water with different degrees of salt hardness. The flask is filled with circulating water. The conical region (4) forms a smooth coaxial transition [3–4] with a central core made of a dielectric with high dielectric constant and weak conductivity.

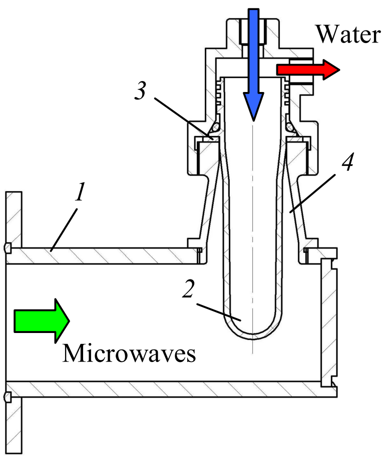

Fig. 1. Schematic representation of the water-cooled load design.

3. Numerical modeling of waveguide loading

The waveguide load was modeled in the CST Studio Suite software product. The following main parameters were varied: the depth of the bulb immersion in the waveguide cavity d and the distance from the short-circuited wall to the bulb axis s. The resonance frequency shift mainly depends on s, and for the center frequency of 2.45 GHz the optimum value of $s = 26$ mm was found. By varying d, a strong influence of the water model on the similarity of the calculation and measurement results was found. The most suitable water parameters were found to be as follows: $\varepsilon = 78$ and tg$\delta = 0.15$. When changing tgδ of water in the range of 0.12–0.2 by changing the value of d in the range of 24–32 mm, it is possible to keep the value of the reflection coefficient modulus $|S_{11}|$ below –15 dB near the frequency of 2.45 GHz. The frequency dependence of $|S_{11}|$ when changing d within 24–32 mm is shown in Figure 2.

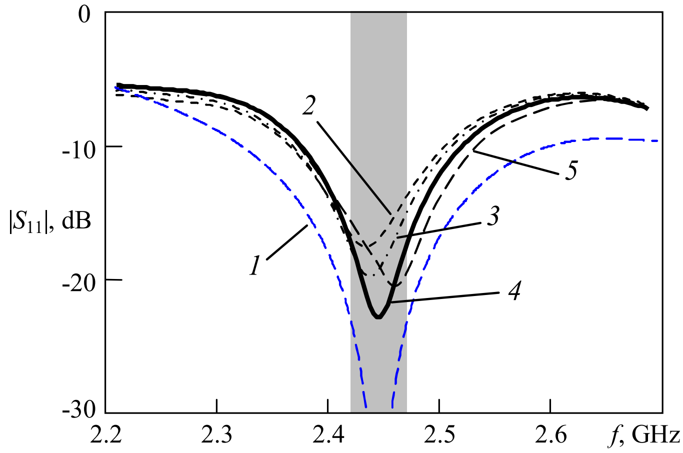

Fig. 2. Modulus of wave reflection coefficient from the waveguide load: 1 – calculation; measurements at d = 27, 28, 29 and 30 mm (curves 2–5, respectively).

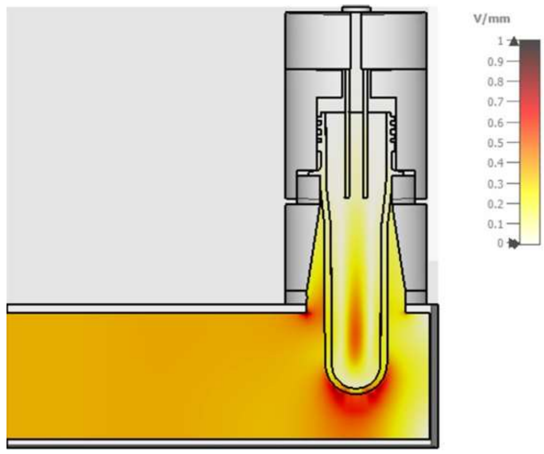

Fig. 3. Electric field strength distribution (effective value) at input power of 0.5 W.

During modelling, particular attention was paid to locating the electric field maximum near the centre of the water-filled piston to prevent overheating of the walls. The results of calculating the field strength when 0.5 W of power is applied to the waveguide input are shown in Figure 3. The maximum field strength is at the axis of the flask. It should be noted that to estimate the absorbed power, the value of ε air and water must be taken into account. To reduce the local field enhancement, the sharp edges are chamfered.

4. Measurement of the characteristics of the manufactured waveguide load sample

The fabricated load sample was measured using an Agilent PNA N5227A vector network analyzer. At $d = 29$ mm, the matching bandwidth was 2.37–2.51 GHz with $|S_{11}| < -10$ dB. A resource test of the load at a constant power from the magnetron generator was carried out. In Figure 4, the fabricated waveguide load 1 was excited by a magnetron 2 continuous power up to 2.5 kW. A directional tap 3 was used to control incident and reflected power. The tests showed that at a flow of mains water from 0.5 litres per minute, the outer surface of the bulb is heated to a temperature no higher than 60 °C, no deformation of the plastic bulb was observed.

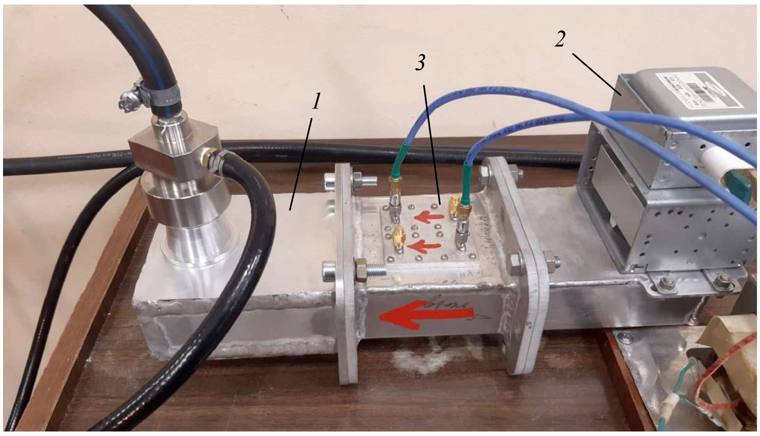

Fig. 4. Waveguide load life test facility.

5. Conclusion

A waveguide absorbing load cooled by flowing water has been developed and investigated. The matching bandwidth of the load is 2.37–2.51 GHz to the level $|S_{11}| < -10$ dB. At the operating flow rate of tap water of 2 litres per minute, the dielectric bulb does not overheat and there are no traces of microwave breakdown on the dielectric surface at the power of the microwave magnetron of 2.5 kW. The generated load is suitable for repair and testing of microwave equipment.

Acknowledgement

The work was supported by the Ministry of Science and Higher Education of the Russian Federation (FWRM-2021-0002).

The authors also thank the Regional Collective Use Center, Tomsk Scientific Center SB RAS, Tomsk, Russia, for the Agilent PNA N5227A network analyzer provided.

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