

# Measurements of Parameters of X-band High Power Microwave Pulses

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**Abstract – Techniques developed in the Institute of High Current Electronics for measurement of the parameters of X-band microwave pulses with a peak power as high as  $10^8 - 10^9$  W is described in the manuscript.**

## 1. Introduction

Evolution of high current electron beams and high power microwaves production techniques have lead to the creation of devices capable to produce X-band nanosecond electromagnetic pulses with a peak power up to  $10^8 - 10^9$  W [1]. Complication of measurement of these microwave parameters is due to their short duration, a relatively wide spectrum and a high peak power of the pulses as well as a strong electromagnetic noise of microwave devices.

## 1. Antenna measurements

A receiving horn antenna is a very convenient, technique in the field of low microwave power flow density. Unfortunately, these antennas cannot be used in the field of high power microwaves where power flow density as high as tens to hundreds watts per square centimetre is a usual value. This is the main reason why it is more suitable to use a section of the waveguide as receiving antenna rather than horn for the measurement of the high power microwave pulse characteristics. The design of the waveguide antenna is shown in Fig. 1.

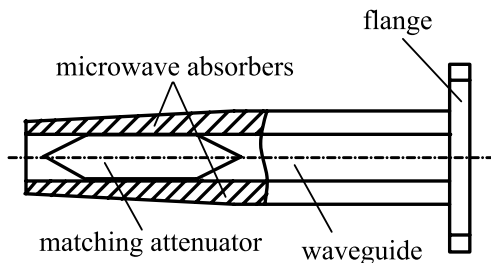


Fig. 1. Schematic drawing of the waveguide antenna.

There are absorbing cover plates in the form of “wedges” on the wide walls outside the waveguide as well as a fixed matching attenuator on the narrow wall inside the waveguide in order to reduce the influence of standing waves. The standing wave inside

the antenna arises due to reflections between the open end of the waveguide and the detector connected to the antenna [2]. The quality of matching of the antenna with the waveguide and detector influences strongly the results of measurement of its effective surface and results of measurements of high power microwaves as well. Waveguide antennas have both a rather wide frequency band, which allows avoiding a significant distortion of the receiving microwave pulse waveform and rather a low effective surface that determines the input power level acceptable for the detectors described below.

The effective surface of a receiving antenna was measured using the three antenna method and the main radiolocation equation [2]

$$P_R / P_T = G_R G_T / (4\pi / \lambda^2), \quad (1)$$

where the value with index  $T$  relates to the transmitter and the value with index  $R$  corresponds to the receiver;  $P_{R,T}$  is the microwave power;  $G_{R,T} = 4\pi S_{eff,R,T} / \lambda^2$  is the antenna gain coefficient;  $S_{eff}$  is the effective surface of the antenna;  $r$  is the distance between the transmitter and the receiver. Distance  $r$  must satisfy the far field condition:  $r \gg 2D^2/\lambda$ ; where  $\lambda$  is the wavelength in vacuum,  $D$  is the largest aperture size of the receiving and transmitting antennas.

Agilent 8719ET network analyzer was used in the measurement (Fig. 2). As the first step we measured the effective surface of two identical rectangular horns that had output sizes 449 cm. These horns were considered standard antennas. For this measurement the following ratio was used

$$S_{eff} = \lambda r \sqrt{P_R / P_T}, \quad (2)$$

derived from (1). The value  $P_R/P_T$ ,  $\lambda$  and  $r$  were measured. Then the receiving horn was replaced by the waveguide antenna and the deviation of the transmitting coefficient  $\Delta(P_R/P_T)$  was measured that allowed determining the waveguide antenna effective surface in the required frequency band.

Calculation of the effective surface of the antennas was accomplished according to the formulae based on the Huygens-Kirchhoff ratio [3].

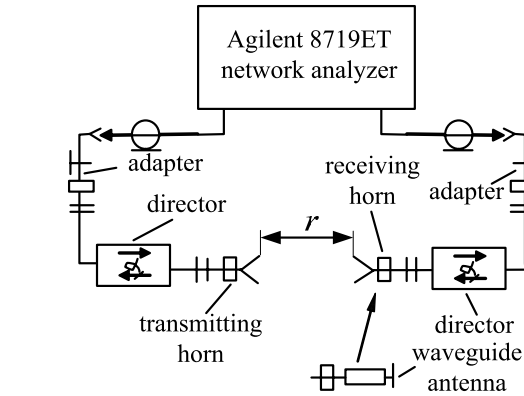


Fig. 2. Scheme of measurement of the antenna effective surface.

The results of the measurement and calculation of the effective surfaces of the rectangular horns and one of our waveguide antennas are shown in Fig. 3 and 4, respectively.

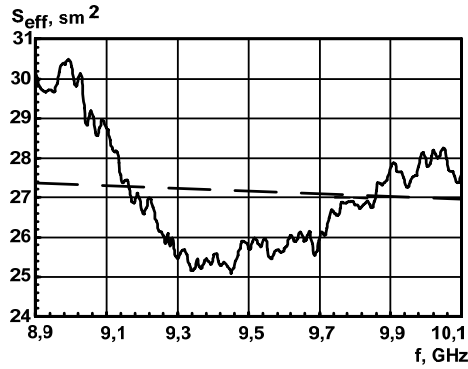


Fig. 3. The calculated (dotted curve) and measured (solid curve) dependences on frequency of rectangular horn (4Ч9 cm) effective surface.

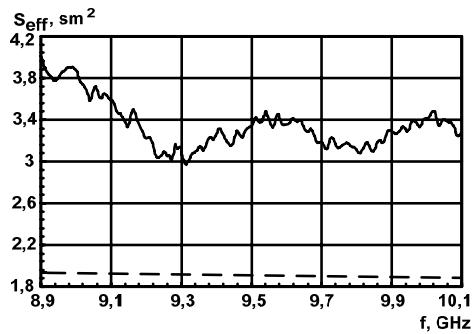


Fig. 4. The calculated (dotted curve) and measured (solid curve) dependences on frequency of waveguide antenna effective surface.

The difference between the measured and calculated effective surfaces is the result of inaccuracy of the formulae [3] that do not take into account the influence of the high frequency current flowing outside the antenna near its aperture and some diffraction effects. The difference increases when the ratio of the aperture size to wavelength decreases. It is easy to

see that it has the most significance for the waveguide antenna.

## 2. Detector measurements

We use semiconductor detectors to detect high power microwave pulses. The design of the detector is shown schematically in Fig. 5. Crystal of Ge of the p-type placed in the middle of a standard 23Ч10 mm waveguide is used as a detecting element.

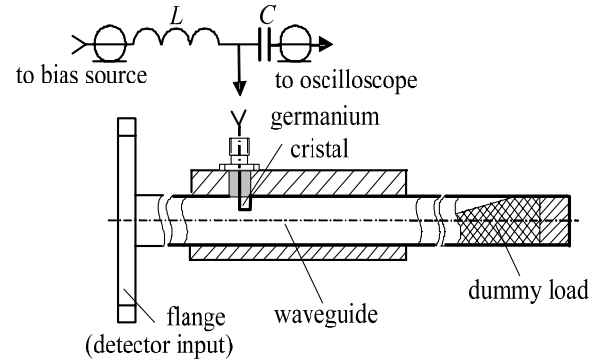


Fig. 5. Microwave detector based on the hot electron effect.

Microwave detection is based on the hot electron effect in a semiconductor [4]. It is known that mobility of electrons heated by a high frequency field can drop. Operation of the detector is as follows. A bias voltage is applied across the crystal via inductance  $L$ . The inductance is chosen according to the condition  $L / R \gg \tau$ , where  $R$  is the resistance of the crystal exposed to the microwaves with duration  $\tau$ . Under this condition the current flowing through the crystal becomes constant during the pulse. The crystal resistance increases under microwave exposition due to the hot electron effect and the crystal voltage increases too. The voltage increase is, in fact, the detected (output) signal. The output signal is transmitted through the low-pass filter and the coaxial cable to the oscilloscope. The minimum time resolution is determined by the hot electron relaxation and can be as low as  $\sim 5 \cdot 10^{-12}$  s [4]. The real time resolution of the detector is determined by the parasitic parameters of the crystal electrical circuit. So in this work we used a crystal with the characteristic resistance that equaled 5 Ohm·cm. The crystal size was rather small: it was 1 mm thick, 3 mm high and 5 mm long. Initial resistance of the crystal was about 43 Ohm. The conductor connecting the crystal with the output connector was of a minimum length in order to minimize as much as possible the reactive impedance of the circuit.

The volt-watt characteristic and the frequency response of the detector were investigated according to the scheme shown in Fig. 6. The scheme includes a Russian frequency tunable pulsed magnetron МН505.

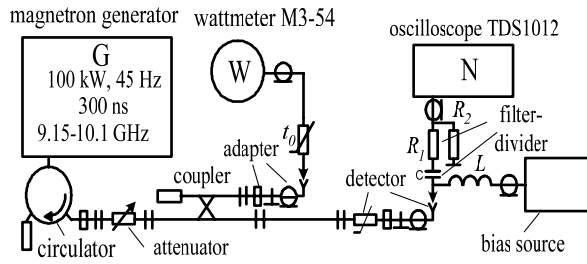


Fig. 6. Scheme of detector calibration.

The magnetron microwave pulses  $P(t)$  with different carrier frequencies between 9.15 and 10.1 GHz were input to the detector. The peak power  $P_0$  of the pulses was varied with an attenuator and could reach  $\sim 100$  kW. The pulse duration  $\tau$  was  $\sim 300$  ns and the pulse repetition rate  $f_{rep} \approx 45$  Gz. The output signal  $U(t)$  of the detector was registered by the oscilloscope TDS1012. The average microwave power was measured with a Russian power meter M3-54 and a waveguide directional coupler. The coupling coefficient  $k_c$  of the coupler was  $\approx 19 - 20$  dB in the frequency band mentioned above. It is not difficult to show that the following ratio between the peak power  $P_0$  and the average power  $P_{av}$ , is valid

$$P_0 = k_m P_{av} 10^{0.1k_c} / (f_{rep} \tau k_\phi),$$

where  $k_m$  is the coefficient taking into account an error due to the microwave reflection and microwave transformation in the power meter adapter,

$$k_\phi = \frac{1}{P_0 \tau} \int_0^\infty P(t) dt = \frac{1}{U_0 \tau} \int_0^\infty U(t) dt - \text{is the waveform}$$

coefficient that was determined at a low power level when the condition  $U(t) \sim P(t)$  of square-law detection is valid. Fig. 7 shows the volt-watt characteristic of the detector. It is seen that the high output signal of the detector allows making to do measurements even at a rather strong electromagnetic noise of the pulsed power set up of the relativistic microwave generator. Frequency response of the detector (Fig. 8) is determined by the standing wave that arises as a result of the reflection of microwave radiation from a dummy load and Ge-crystal. Investigation of the frequency response showed that the microwave power corresponding to a fixed output signal decreased approximately two times when the frequency increased from 9.15 to 10.1 GHz. That means that the output signal (and sensitivity) of the detector increased with a frequency increasing in this frequency band.

Beside the detector described above waveguide detectors based on thermionic tube diode, for example, like Russian miniature 6Д16Д-diode, can be used successfully to register high power microwaves.

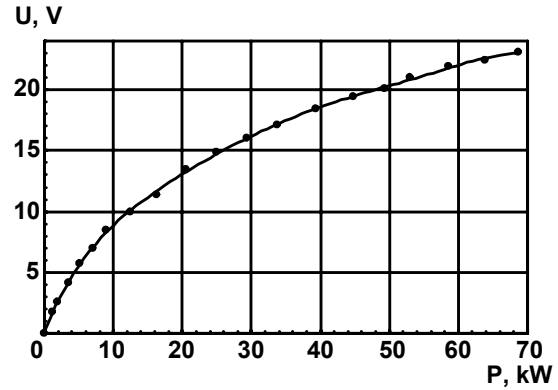
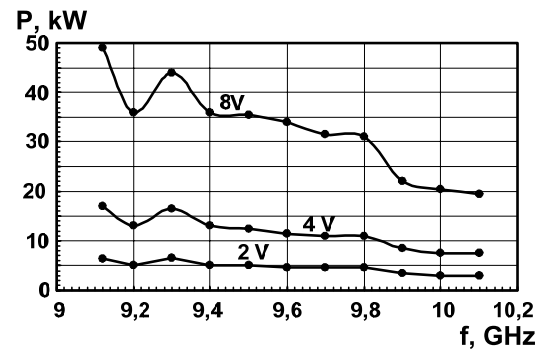

 Fig. 7. Volt-watt characteristics of a detector based on the hot electron effect,  $f = 10$  GHz.


Fig. 8. Frequency response of a detector based on hot electron effect.

The detector (Fig. 9) is based on a standard waveguide with a cross-section of  $23 \times 10$  mm. A 6Д16Д-diode is installed in the middle of the waveguide perpendicular to its wide wall. A detected signal passes through the low-pass filter to the oscilloscope circuit. There is a dummy load at the end of the waveguide and a matching attenuator at the

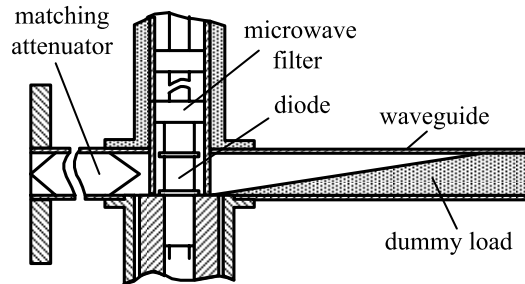


Fig. 9. Thermionic tube diode detector.

detector input in front of the diode. Sensitivity of the detector is determined by electron emission of an indirectly heated cathode of the diode. The electron emission depends on the power of heating. Therefore, stabilized DC power supply is used for heating the cathode. These detectors are capable to detect microwave pulses with a peak power as high as tens kW and an output signal can equal to tens of volts which is quite

enough for microwave measurement at rather strong electromagnetic noise.

These detectors have no problems related to second harmonics of carrier frequency [4] or a problem that arises due to heating of detecting element in pulse-periodic regime. These problems are typical for detectors based on the hot electron effect [4].

Calibration of the detector was accomplished according to the scheme shown in Fig.6. The calibration procedure of was like that of the detector based on hot electron effect. The volt-watt characteristic of the detector is shown in Fig. 10.

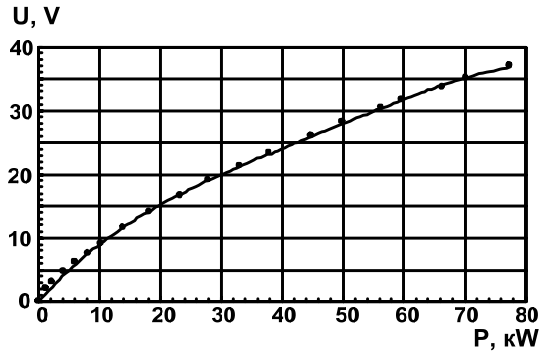


Fig. 10. Volt-Watt characteristic of the thermionic tube detector,  $f = 10$  GHz.

The measurements showed that the frequency response of input power (Fig. 11) was  $\pm 35\%$  corresponding to output signals different but fixed in frequency band 9.15 – 10.1 GHz.

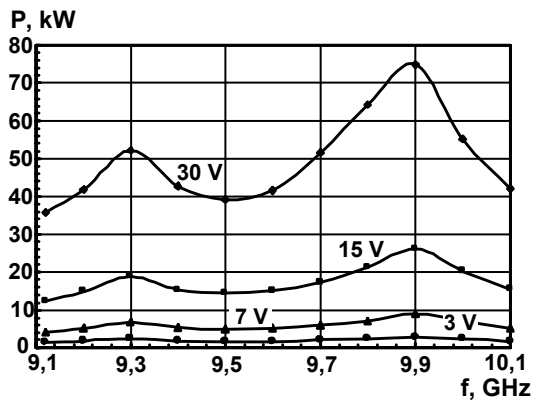


Fig. 11. Frequency response of the thermionic diode detector.

The Ge-detector and the thermionic tube detector were used in the experiments with relativistic BWO that operated at 10 GHz in a super radiance regime like that described in [5]. Fig. 12 shows a typical waveform of the output pulse of a Ge-detector based on the hot electron effect.

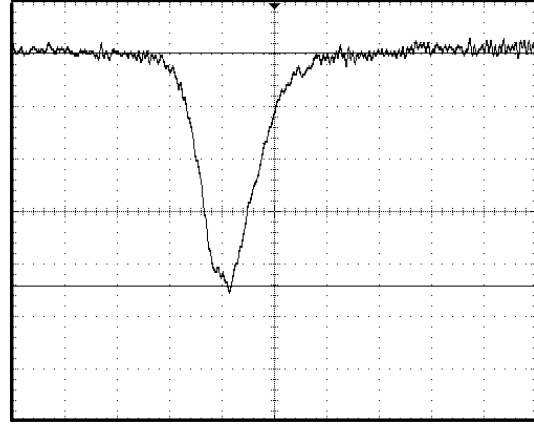


Fig. 12. Signal of the Ge-detector based on hot electron effect with horizontal scale being equal to 1.25 ns/div.

The thermionic diode detector waveforms were very similar to those of the Ge-detector. Both of the detectors registered a microwave pulse edge  $\leq 400$  ps., which characterizes their time resolution.

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