High Power Microwave Detector with Improved Frequency Response

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Abstract – The paper describes an X-band thermionic tube detector with improved characteristics. The detector was designed for measuring superradiation pulses.

1. Introduction

X-band waveguide detectors based on a 6D16D thermionic tube diode are very efficient devices for detection of relativistic microwave pulses [1]. A schematic of the detector is shown in Fig. 1. The detector is based on a standard waveguide of cross section 23 × 10 mm. The 6D16D-diode is placed at the center of the waveguide and is perpendicular to its wide wall. A dummy load and a matching attenuator are located at the end and input of the waveguide, respectively.

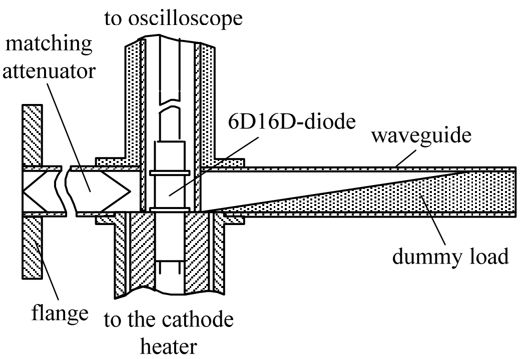

Fig. 1. Schematic of the 6D16D-diode detector

The detector sensitivity is determined by the electron emission from the indirectly heated cathode of the diode and the electron emission depends on the heating power. Therefore, a stabilized dc power supply is used for heating the cathode, making possible stabilization of the detector sensitivity. This detector is capable of detecting microwave pulses with a peak power of tens of kilowatt and its output signal can range to tens of volts, which quite suffices for microwave measurements under the conditions of rather high electromagnetic noise of HPM sources. The volt-watt characteristic of the detector may display a reasonably weak nonlinearity and normally allows calculations of the time dependence of the input microwave power. In this detector, no problem arises with respect to the second harmonic of the carrier frequency or to heating of the detecting element in the repetitive mode of a microwave source. These problems are typical for an alternative kind of high-power detectors based on the hot carrier effect [2]. Previous investigations [1] show that the detector based on a 6D16D diode can provide much better time resolution than that based on the hot carrier effect. The time resolution of a detector is critical for detection of superradiative microwave pulses [3] with a length less than 1 ns and with a spectrum width ranging to over ~ 1 GHz. Hence, the detector frequency response must be flat enough to preclude significant distortion of the detected microwave pulse.

Most of the microwave power penetrated into the detector waveguide is reflected by the 6D16D diode. Therefore, the frequency response is determined by the standing waves originated between the matching attenuator and the diode as well as between the diode and the dummy load (Fig. 1). The distortion of the microwave pulse may be amplified by the reflection of the waves between the attenuator and the waveguide antenna connected to the detector. The resulting standing wave amplitude depends on the decoupling of the matching attenuator and on the standing wave ratio (SWR) of the attenuator and of the dummy load.

This work deals with the development of attenuators and loads that allow more uniform frequency response and rather easy manufacture in laboratory conditions.

2. Design of the attenuators and loads

The designed attenuators are plates with tapered ends pasted on the narrow wall of the detector waveguide. The characteristic dimensions of the plates are shown in Fig. 2. The dummy loads are tapered wedges that gradually transform into a parallelepiped along the waveguide and "fill" its cross-section at the end (Fig. 2 and Fig. 3). The attenuators and the loads

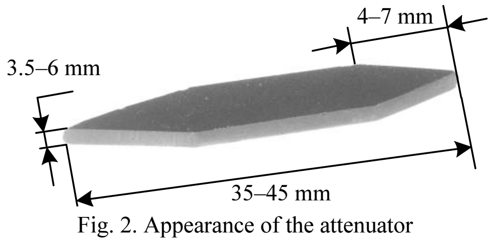

Fig. 2. Appearance of the attenuator

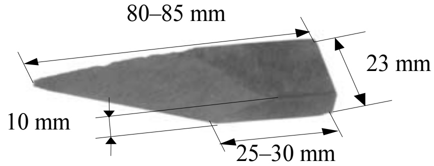

Fig. 3. Appearance of the dummy load

are made of special material. The material is actually a mixture of epoxy resin with graphite (soot) or with graphite and aluminum powder mixed in some proportion. The proportion was optimized in special investigations. The mixture was degassed in a vacuum volume and was placed in casting molds. When solidified, the attenuator and load castings were machined to a shape required to provide the desirable SWR (normally less than 1.6) and attenuation (normally from ~ 5 to 7 dB) of the attenuators and the desirable SWR (less than 1.3) of the loads. The attenuation and the SWR were measured with a R2-61 network analyzer in the frequency band from 8.5 to 11.5 GHz.

Tables 1 and 2 show the characteristics of the designed dummy loads and attenuators, respectively. Our studies show that with a soot content of 10, 20, 30, and 40%, it is possible to develop a dummy load with an SWR no greater 1.4 in the frequency band between 9 and 10 GHz and that the minimum SWR is determined by the load shape. However, it was found that with the load dimensions (Fig. 3) determined by the detector dimensions, the microwave absorption is incomplete. As the soot content is further increased, the number of air bubbles in the mixture increases and mixing and air pump-down become difficult. Therefore, some amount of aluminum powder was added in the mixture to increase its conductivity. It was found that the dummy loads made of Al-powder-containing material completely absorb the microwaves and display a more uniform frequency dependence of the SWR. The optimum mixture was epoxy resin with 20% of soot and 5–20% of aluminum powder. For the soot-powder content greater than 40%, many bubbles appear in the mixture and their pumping out of the material becomes difficult. Moreover, the material, when solidified, became inhomogeneous and brittle.

Table 1. Parameters of the designed dummy loads. The frequency band is between 8.5 and 10.5 GHz

Graphite (soot) content, %	Aluminum powder content, %	SWR_{max}	SWR_{min}
10	0	1.32	1.09
20	0	1.21	1.09
30	0	1.21 1.15	1.06 1.06
40	0	1.15 ~ 1.32	1.05 1.08
20	5	1.18 1.14	1.06 1.08
20	10	1.32 1.09 1.14 1.12	1.06 1.05 1.06 1.06
20	20	1.1 1.16 1.16	1.06 1.09 1.06
35	10	1.12	1.08

Table 2. Parameters of the designed attenuators. The frequency band is between 9 and 10 GHz

Graphite (soot) content, %	Aluminum powder content, %	Maximum attenuation, dB	Minimum. attenuation, dB
10	0	0.4 0.8	0.7 1.4
15	0	3.5 1.7	5.5 3.3
20	0	8.2 6.6 7.6 6.2 6.1	9.6 8.4 8.6 7.7 7.5
20	20	11.3 8.9	13 11.1
0	10	4.1	5.6
0	20	4.1	5.3
0	30	8.6 5.1	9.6 6.5

As for the attenuators, the frequency dependence of their attenuation with nonuniformity within 2 dB and with a SWR less than 1.6 could be obtained only within the frequency band no greater than 1 GHz (Table 2). It is readily seen from Table 2 that increasing the conducting matter content in the attenuator volume increases the attenuation. In the case where only soot was used in the mixture, a rather uniform attenuation up to 10 dB in the given frequency band could be obtained. For the soot content greater than 20%, the frequency dependence of the attenuation became nonuniform. With this soot content, it was possible to manufacture an attenuator with rather uniform frequency dependence of attenuation, but this required quite different geometrical dimensions of the attenuator, compared to those shown in Fig. 2. The use of only aluminum powder in the mixture made possible attenuators with a rather uniform frequency dependence of attenuation in the frequency band between 9 and 10 GHz. Increasing the powder content to over 30% resulted in nonuniform frequency dependence in the given frequency band (from 9 to 10 GHz). In this case, the material after solidification also became brittle and inhomogeneous. For higher attenuation to be attained, a quite different shape of the attenuators, compared to that shown in Fig. 2, was required. It follows from Table 2 that a small additional increase in attenuation is possible if the mixture contains 20% of soot and 20% of aluminum powder.

The volt-watt characteristic of the thermionic tube detector and its frequency response were measured using a pulsed generator based on a MI505 frequency-tunable magnetron. The procedure of measurements is described in [1, 4]. Fig. 4 and Fig. 5 show the volt-watt characteristic and the frequency response of the detector, respectively. Fig. 6 shows the frequency dependence of the detector SWR.

The improved detector design allows deviation of the detector input power no greater than ± 25% in the frequency band within 9.12–10.1 GHz for the fixed output signal. The SWR at the detector input was no greater than 1.5 in the frequency band from 9 to 10.8 GHz.

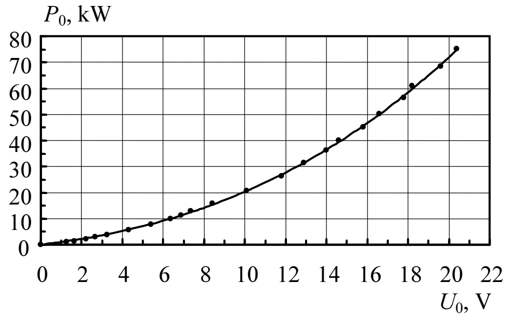

Fig. 4. Volt-watt characteristic of the detector at f = 9.7 GHz

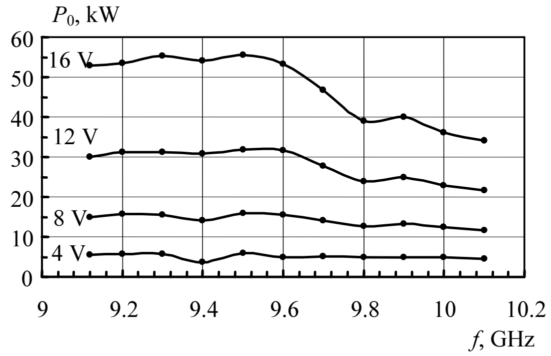

Fig. 5. Frequency response of the detector for different output signals

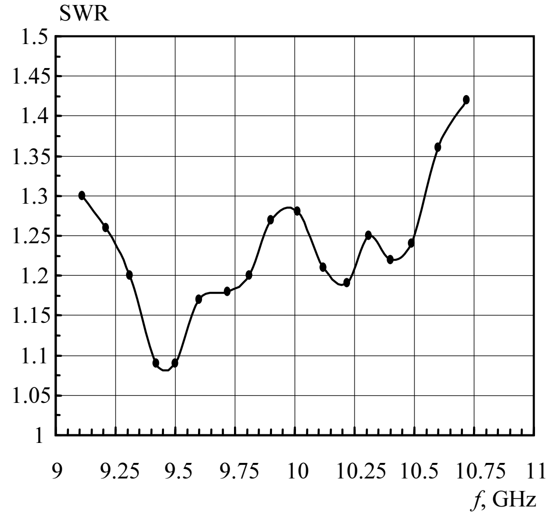

Fig. 6. Frequency dependence of the SWR at the detector input

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