Short Electric Dipole Antennas for HPM Pulse Detection

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Abstract – The paper describes S-and short electric dipole antennas designed for measuring the parameters of nanosecond high-power microwave pulses. A method is proposed for flattening the frequency response of the microwave measuring circuit.

1. Introduction

S-band high-power microwave (HPM) sources [1] are capable of producing microwave power of density as high as tens of kilowatt per square centimeter. For receiving of HPM pulses in the S-band, waveguide antennas, e.g., like those used in the X-band [2] can be employed. However, the dimensions and weight of the waveguide circuit connected to the antenna are rather large. That makes the measuring system inconvenient to use in the S-band. A short electric dipole antenna connected to a coaxial cable is apparently much more suitable and efficient in this case. An example of this measuring system is shown in Fig. 1.

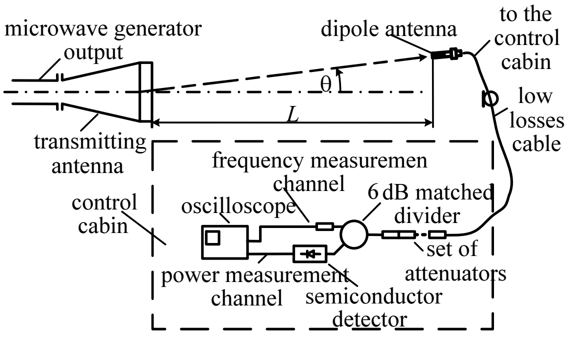

Fig. 1. Schematic of the microwave measuring system

The microwave power is received by the dipole antenna and is then transmitted to the control cabin via a low-loss flexible coaxial cable. In the cabin, the microwave power is attenuated by a set of coaxial attenuators and can be divided in two parts, of which one is used for spectrum measurements and the other for power measurements. The both types of measurements can be made using a digital oscilloscope, e.g., like a TDS 6604 oscilloscope. The allowable microwave peak power at the cable input with no microwave discharge in the microwave measuring circuit is normally ~ 10 kW [3]. Hence, the antenna must have the effective absorbing area of ~ 1 cm^2 or even much less. This can be attained using the short electric dipole as the receiving antenna.

2. Short dipole design and characteristics

Fig. 2 shows schematic of the antenna. A photo of the antenna is shown in Fig. 3. This antenna is a mere resonant dipole antenna with zero-length "mustache". The zero length is needed for minimizing the effective absorbing area of the antenna. The antenna has two symmetric slots in the outer conductor. The antenna resonance closely corresponds to the slot length $l = \lambda/4$, where λ is the wavelength in vacuum. The geometry of the coaxial conductors of the antenna corresponds to the characteristic impedance equal to 50 Ω. At the Institute of High Current Electronics, a set of this type of antennas were developed for measuring HPM pulses in the frequency band from 2 to 4 GHz.

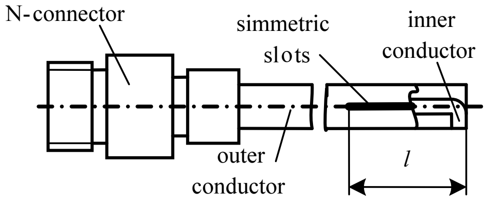

Fig. 2. Schematic of the short dipole antenna

Fig. 3. Photo of the short dipole antenna

The effective area of the receiving antenna can be measured using the three-antenna method and the ratio derived from the receiving-transmitting equation [4]:

$$\frac{P_R}{P_T} = \frac{S_{eff.R} S_{eff.T}}{\lambda^2 L^2}, \tag{1}$$

where the value with the index T relates to the transmitter and the value with the index R corresponds to the receiver. $P_{R,T}$ is the microwave power, $S_{eff.}$ is the effective absorbing area of the antenna, L is the distance between the transmitting and the receiving antennas. The scheme of the measurement is shown in Fig. 4.

The condition of far field must be valid

$$L >> 2D/\lambda,$$

where D is the largest aperture size of the receiving and/or transmitting antennas. In the measurements, Agilent 8719ET network analyzer is used. First, the effective absorbing area $S_{eff.T} = S_{eff.R} = S_{eff.}$ of two identical half-wave dipole antennas is determined according to the relation that follows from (1):

$$S_{eff.} = \lambda L \sqrt{\frac{P_R}{P_T}}.$$

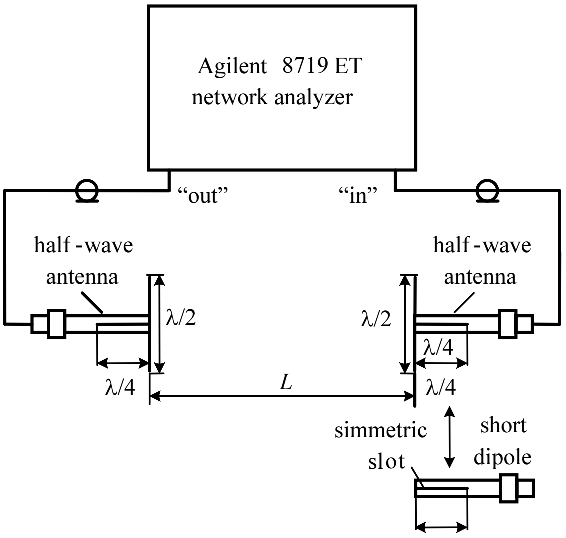

Fig. 4. Scheme of measurement of the antennas effective absorbing area

These antennas are actually the standard antennas used in this measurement. The antennas are resonant and we can estimate their effective absorbing area at the resonance frequency [5] according to the ratio:

$$S_{eff.} = 1.64\,\lambda^2/(4\pi).$$

The results of measurement can be compared with the estimation to improve the reliability of the method. Next, the short electric dipole antenna is installed instead of the receiving half-wave antenna.

The measured deviation of the value P_R/P_T allows one to determined the dipole effective absorbing area. The ratio P_R/P_T is measured using Agilent 8719ET network analyzer.

The effective length of the half-wave antenna is $h_{eff.} = \lambda/\pi$ [5]. Hence, the far field condition in this case takes the form:

$$L >> 2D^2/\lambda = 2h^2_{eff.}/\lambda = 2(\lambda/\pi)^2/\lambda \approx 0.2\,\lambda.$$

This means that the distance between the antennas of about λ is possible. If so, the transmitted signal can be much higher than the standing wave signal, compared to the case with $L >> \lambda$, which is typical of waveguide antenna measurements [2].

Figures 5–7 show the measured frequency dependence of the effective absorbing area $S_{eff.}(f)$ for short dipoles with different lengths of symmetric slots.

The measurement error for the effective absorbing area of the short dipole antenna may range to ± 2% mainly due to the measurement error for P_R/P_T (± 7%), the measurement error for the effective absorbing area of the half-wave antenna ± (6–8)%, the error due to the presence of the standing wave (± 15%), and the antenna polarization error (± 5)%.

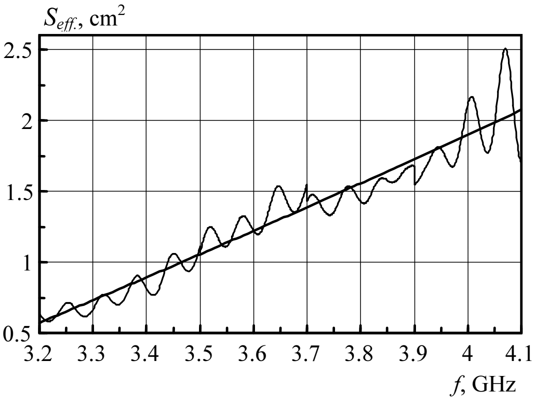

Fig. 5. Frequency dependence of the effective absorbing area of the short dipole antenna with symmetric slots of length l = 16 mm

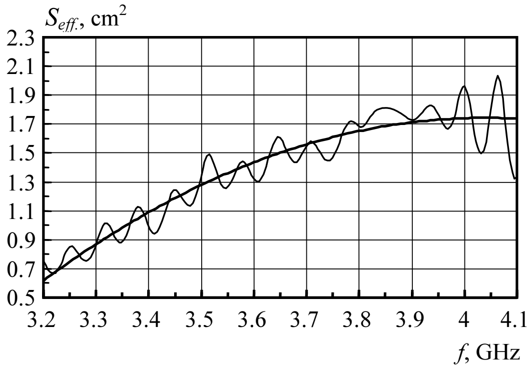

Fig. 6. Frequency dependence of the effective absorbing area of the short dipole antenna with symmetric slots of length l = 17 mm

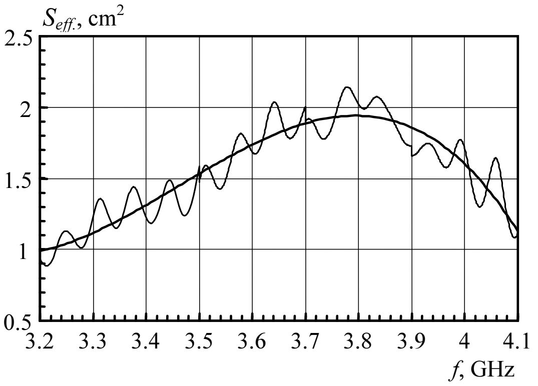

Fig. 7. Frequency dependence of the effective absorbing area of the short dipole antenna with symmetric slots of length l = 18 mm

3. Frequency response of the microwave circuit

A very important point in microwave measurements is the reduction of the distortion of the received microwave pulse in the measuring circuit (Fig. 1). By way of example, Fig. 8 shows the frequency dependence of the transmission coefficient of RK50-4-47 low-loss coaxial RF cable.

It is easily seen that the signal distortion is due to the increased losses in the high-frequency region of the signal spectrum. The distortion increases if the short dipole antenna is connected to the cable with the frequency dependence of the effective absorbing area similar to that shown in Fig. 7.

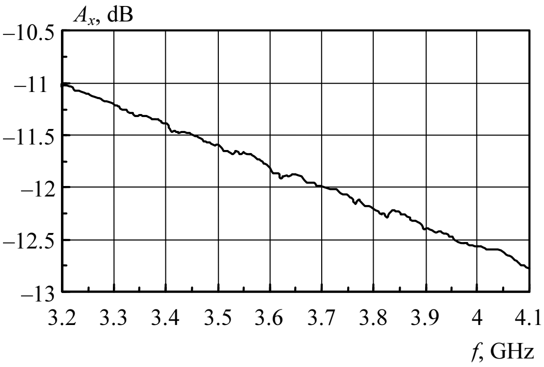

Fig. 8. Frequency dependence of the transmission coefficient for the RK50-4-47 cable. The cable length is 25 m

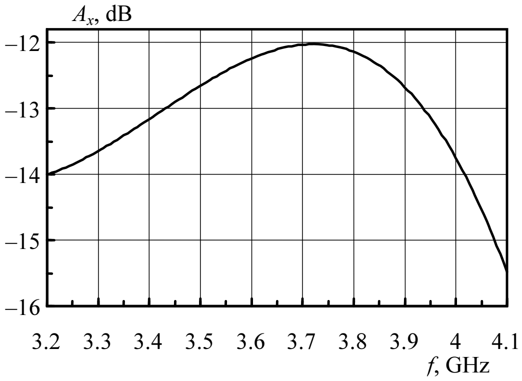

Fig. 9. Frequency dependence of the total transmission coefficient of the cable and the short dipole antenna, l = 18 mm

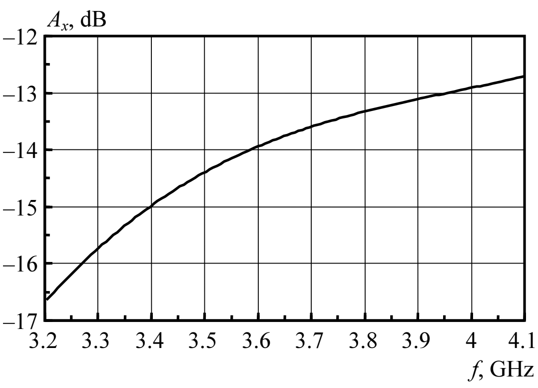

Fig. 10. Frequency dependence of the total transmission coefficient of the cable and the short dipole, l = 16 mm

Figure 9 shows the frequency dependence of the total transmission coefficient of the microwave circuit including the antenna with l = 18 mm and the cable. This dependence is actually the frequency response of the circuit. For calculating the frequency response, the frequency dependence of the effective absorbing area of the short dipole was divided by the maximum value of the area, the ratio was calculated in dB and was added to the transmission coefficient of the cable (Fig. 8).

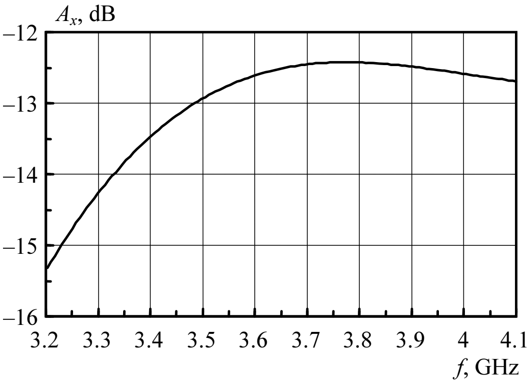

Fig. 11. Frequency dependence of the total transmission coefficient of the cable and the short dipole, l = 17 mm

Flattening the frequency response of the microwave circuit requires a short dipole with an appropriate dependence $S_{eef.}(f)$ This can be attained by varying the length of the symmetric slots l. Figs. 10 and 11 show the frequency dependences of the total transmission coefficient of the cable and the short dipole aantenna for l = 16 mm and l = 17 mm , respectively. It is readily seen that the antenna with the slot length l = 17 mm provides a more uniform (within 3 dB) total transmission coefficient of the circuit in the frequency band from 3.2 to 4.1 GHz.

It should be noted that the transmission coefficient nonuniformity within 3 dB complies with standard requirements imposed on measuring systems [6].

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