RF ANTENNA LEAD

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Abstract

RF antenna lead is described. This lead is used for RF power input to high voltage electrodes. The device consists of receiving and transmitting antennas realized as symmetrical parts of coaxial cavity with dielectric disk between the parts. Main operating characteristics are the following: high voltage is over 60 kV, coefficient of transmission S_{21} at the operating frequency is over 0.97, bandpass is over 70% (at the level of S_{21} = -3dB). The scheme of device, the principles of operation and measured results are presented in the paper.

INTRODUCTION

Antenna leads for the supply of RF signals into isolated high-voltage electrodes are used in the microwave and accelerator technology [1-3].

RF antenna lead was developed for current management of high voltage gun for electron accelerator. The operating frequency is 2450 MHz. The lead must have both high breakdown strength and low microwave losses.

The requirements for the device are following:
1) the transmission coefficient at the operating frequency of 2450 MHz must be more than 0.85;
2) the reflection coefficient at the operating frequency must be less than 0.1;
3) the breakdown voltage must be not less than 60 kV;
4) the leakage currents must be less than 10 µA;
5) the bandwidth of the transmission coefficient on the level -3 dB should be not less than 30 MHz;
6) the power flux density at 1 m from the lead should not exceed 10 µW/cm^2.

DESIGN AND PRINCIPLE OF OPERATION

Figure 1 shows the scheme of the lead. The lead presented consists of two symmetrical parts of coaxial half-wave resonator. The resonator is spitted along the perpendicular to the longitudinal axis plane of symmetry and solid dielectric disk is located between the halves.

The operating scheme is following. Microwave signal from a generator feeds the resonator by coaxial line. The excited mode of electromagnetic field is *TEM*-type. Taking into account the dielectric disk, the cavity length is chosen so that the resonator length fits a half of wavelength.

According to the structure of the *TEM* mode standing wave, the radial electric field has maximum at the location of the dielectric disc; angular components of the magnetic field, longitudinal currents on the inner and outer conductors of the coaxial line have minimum.
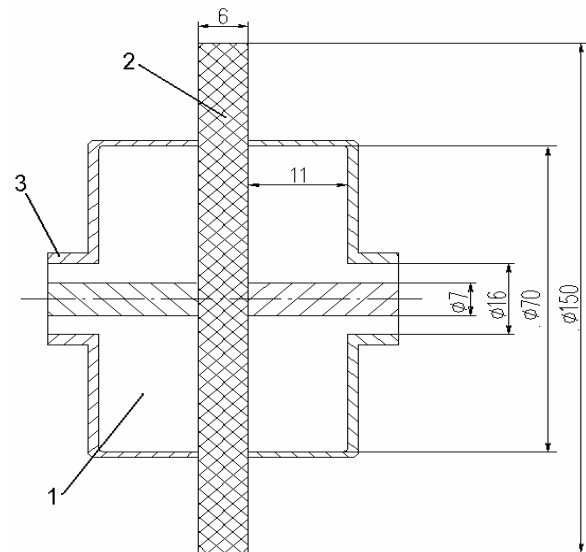

Figure 1: RF antenna lead design: 1 – half of coaxial resonator, 2 – dielectric disk, 3 – coaxial feed line.

The gap of coaxial line, which is set between the dielectric insulating discs, does not rupture the longitudinal currents and does not violate the cavity field structure. For these reasons, the reflected and radiated waves are not formed and the microwave signal passes the cavity without losses.

The breakdown strength of the device is determined by the breakdown voltage of the insulating dielectric. In our case, the dielectric material is formed from ceramics VG-4. The ceramic parameters at the operating frequency of 2450 MHz are following: the relative dielectric constant is 9.6, dielectric loss tangent is $<5 \cdot 10^{-4}$, the breakdown voltage is >150 kV/cm.

NUMERICAL SIMULATION

Ansoft HFSS [4] was used to calculate the basic characteristics of the device. Sizes of the resonator and thickness of dielectric disk were varied. The purpose of the calculations was to minimize the transfer attenuation and the amplitude of the reflected wave at the operating bandwidth in terms of the transmission coefficient S_{21} = -3dB. Also, the internal losses and radiation losses into the environment at the operating frequency were minimized.

Figure 2 shows the near field at a distance of 1 m from the lead (Y-axis coordinate is directed along the resonator axis). To calculate the characteristics of the device, the following parameters of the microwave signal were used: pulse duration – 5 µs, duty cycle – 1000, pulse power – 1 kW and frequency – 2450 MHz.
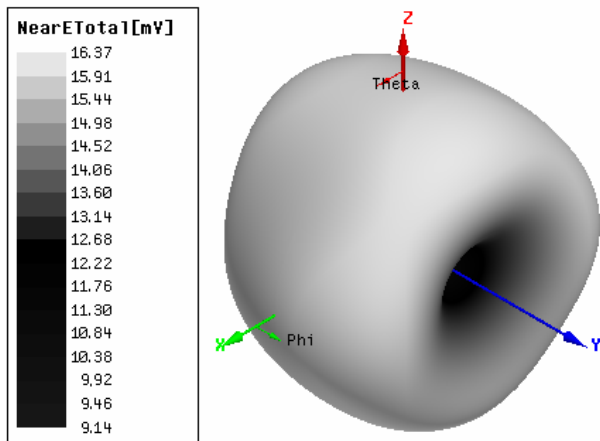
Figure 2: The flow of the electric field vector at a distance 1 m from the lead.

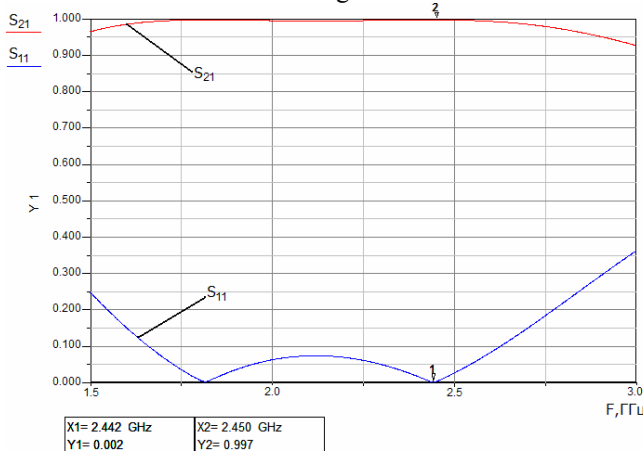The amplitude-frequency characteristics of the calculated lead are shown in Figure 3.

X1= 2.442 GHz	X2= 2.450 GHz
Y1= 0.002	Y2= 0.997

Figure 3: Dependence of the reflection coefficient S_{11} and the transmission coefficient S_{21} on frequency.

The transmission coefficient at the operating frequency is $S_{21} = 0.997$ and the reflection coefficient is $S_{11} = 0.002$.

To estimate the value of RF field radiation from device to environment we can use the following expression. The level of radiation power into the environment is equal to [5]:

$$P_r = P\left[1 - \left(S_{21}^2 + S_{11}^2\right)\right] \qquad (1)$$

where P is the power in supplying line.

Taking into account the near field (Fig.2) one can see that the intensity distribution is close to a spherically uniform one, so the power density can be estimated by the equation:

$$p_r = \frac{P_{rad}}{S_{sph}}, \qquad (2)$$

where $S_s = 4\pi R^2$ is area of a sphere which are limited the volume around the device, R is the radius of the sphere. Taking into account (1), S_{21}=0.997 and S_{11}=0.002 the losses of RF power radiation at the operating frequency does not exceed 0.5% of the generator power. The density of the pulsed flux power calculated by (2) at a distance

1 m from the antenna is equaled to 0.042 mW/cm². The density of the average flux power is 0.042 µW/cm².

Figure 1 shows the geometry of the main elements of the device corresponding to the characteristics obtained in numerical simulation. These dimensions were used in manufacturing of the device.

MEASUREMENTS

The reflection and transmission coefficients of manufactured device were measured in a wide range of frequencies. The leakage currents were measured with applying voltage of 60 kV. The maximum of the leakage current was 10 µA. Under high voltage the current quickly increased and the breakdown occurred.

Figure 4 shows the measured bandpass characteristics. The reflection coefficient at the operating frequency is 0.098 and the transmission coefficient is 0.976.
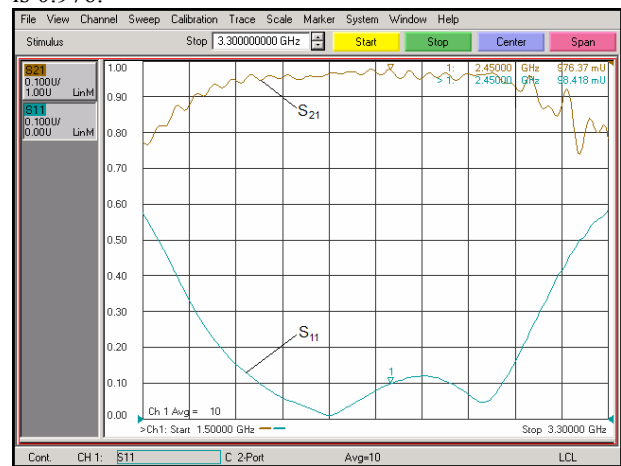

Figure 4: The transmission S_{21} and reflection S_{11} coefficients in a wide frequency range.

The bandwidth at attenuation level -3 dB is more than 1800 MHz (73%). Figure 5 shows a comparison of measured and calculated transmission characteristics of the device. Near the operating frequency the difference between measured and calculated values is less than 3% and the unevenness of the experimental curve is about 1.5%.

The level of radiated power calculated by (1) is not more than 6%. Accordance (2) the flux density of radiated power at the distance of 1 m from the lead is 0.48 µW/cm².

Table 1 lists the main parameters to be met by the device, the results of calculation and measured results of the device developed.

Differences between measured and calculated characteristics are present due to non-ideal RF components such as connectors, cables and transitions that introduce additional reflections and attenuations. In simulation, the effect of insulating plexiglas body around the device was not taken into account.
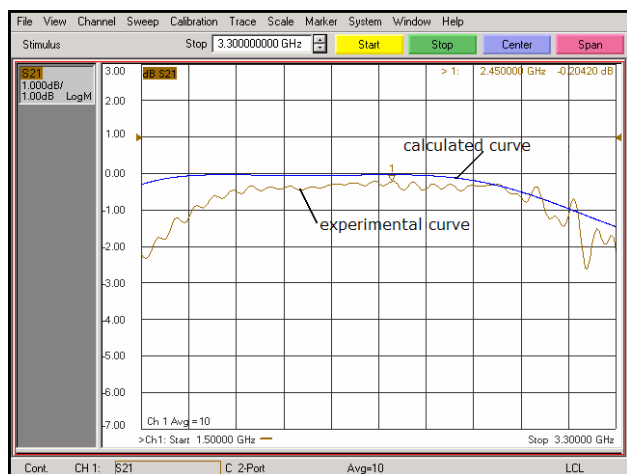
Figure 5: Frequency dependence of the transmission attenuation (S_{21}, dB). Comparison of calculated and experimental curves.

Also deviations from the actual geometry such as, for example, rounding sharp edges and corners of the electrodes of the resonator were not taken into account. The unevenness of transmission curve is probably due to the presence of standing waves in the measuring cables.

Table 1: Main parameters of RF lead

Parameter	Require-ment	Calcu-lation	Experiment
Breakdown voltage, kV	>60	>60	>60
Leakage current, μA	<10	-	<5
Transmission coefficient S_{21} at 2450 MHz	>0.85	>0.997	>0.97
Reflection coef-ficient S_{11} at 2450 MHz	<0.1	<0.002	0.098
Bandpass (at level S_{21}= -3 dB), MHz	>30	>1800	>1800
Radiation den-sity at 1 m dis-tance, μW/cm^2	<10	<0.05	<0.5

CONCLUSIONS

RF antenna lead was developed and designed by numerical simulation. Device parameters satisfy all requirements. The experimental results show good agreement with calculations and confirm high dielectric strength, low RF losses with wide bandpass. The device (Fig.6) is used in the injection current control of three-electrode electron gun to study parameters of the accelerator with parallel coupled accelerating structure [6].
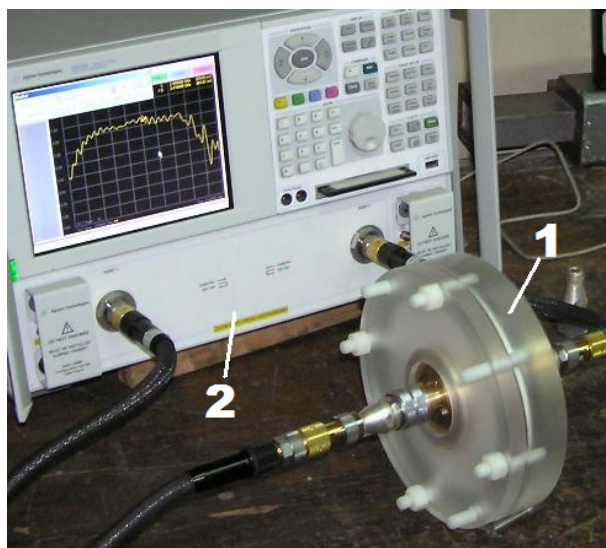
Figure 6: RF antenna lead. The measuring stand: 1 – the lead, 2 – measuring circuits Agilent N5230A.

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