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Simple Faraday cup with subnanosecond response

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A small Faraday cup of coaxial design for use in plasma physics experiments is presented. The construction permits an approximately 50-Ω geometry to be maintained, allowing direct coupling to coaxial cable. The detector rise time is less than 0.4 ns, and is designed for beam currents of between 0.1 and 100 A. The design is well screened to reject spurious electrical noise.

In recent years the development of high-voltage pulsed power sources has placed stringent new requirements on passive probes of all types. In the course of research into a pseudo spark gas discharge driven by a fast Marx generator, it became necessary to measure fast-rising pulses of intense electron beams having rise times of the order of nanoseconds and currents in the range of amps to hundreds of amps.[1,2] Although much has been published on passive probes for beam diagnostics,[3–5] the simple design presented here provides a new contribution in the fabrication of Faraday cups with subnanosecond response time.

The probe described in this paper is of small size, approximately 15 mm long and 12 mm overall diameter. It maintains approximately 50-Ω geometry from the output cable right to the detector surface, and as a result the response time is less than 0.4 ns. The design is vacuum tight and may be easily adapted to fit any port diameter from a few millimeters upward.

A schematic of the design is shown in Fig. 1. The design is based on a commercial semirigid coaxial cable of 0.141 in. external diameter. The solid copper outer conductor of the 50-Ω cable is soldered to a brass disk D_1. The central conductor and insulator pass through the disk and terminate on the front conducting surface of disk D_2. The central conductor is soldered with a low-melting-point solder to D_2.

Between D_1 and D_2 there is the current viewing resistor, which is a cylinder of Poco graphite with an interior diameter the same as the outer diameter of the coaxial cable insulator, preserving the 50-Ω geometry to the detecting surface. The outer diameter of the graphite cylinder is machined such that the resistance between D_1 and D_2 is 0.22 Ω. Electrical contact and structural support between the Poco graphite and D_1 and D_2 are provided by using a silver-loaded epoxy. The outer surface of the Poco graphite is covered by a thin layer of standard Araldite epoxy, which is in turn covered by aluminum foil, Al, which is glued to the ground plane disk D_1, with conducting epoxy.

Coating of the exterior of the cylinder with a uniform thin layer of standard Araldite contributed to assure good vacuum tightness. In situations where the solid coaxial cable will be subject to varying stress and bending, some form of external reinforcing sleeve, Sl, will be needed. This may be part of an external BNC connector, or a simple structural support, according to individual design needs. The silver-loaded epoxy has proven to be rugged, and the electrical contact between the graphite and the disks is good.

To test the response time of the circuit, a coaxial reed relay pulse generator with an estimated rise time of less than 200 ps[6] was connected through a low-inductance matching resistance to the front surface disk. The output pulse was measured on a Tektronix 7834/7A19 oscilloscope with an intrinsic rise time of 600 ps at 2 cm vertical deflection. The input and output waveforms are shown in Fig. 2. The input waveform has a measured 10%–90% rise time of 550 ps, reflecting the negligible contribution from the input pulse compared with the rise time of the measuring system. The output waveform is very similar to the input waveform, as may be appreciated from the photograph. There is no measurable distortion on the rising edge of the waveform. The rise time of the Faraday cup is 350 ps assuming that the measured total rise time represents the root-mean-square value.

It was found that keeping the layers of epoxy adhesive as thin as possible was important to achieve good probe response bandwidth. In one construction in which the epoxy thickness was about twice as thick as the thickness used on the Faraday cup, whose response is shown in Fig. 2, the rise time increased to 1.2 ns.

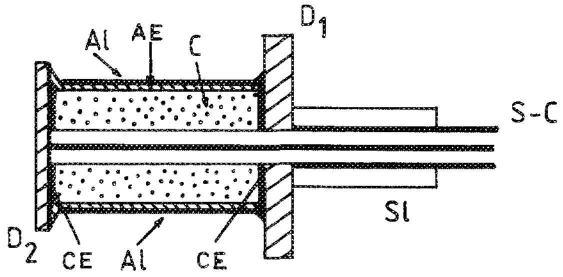

FIG. 1. Schematic of the coaxial Faraday cup construction; S-C, semi-rigid coaxial cable; Sl, supporting sleeve; D_1, brass disk; D_2, copper disk; C, carbon resistor; AE, Araldite epoxy coating; CE, conducting silver-loaded epoxy; Al, aluminum foil.

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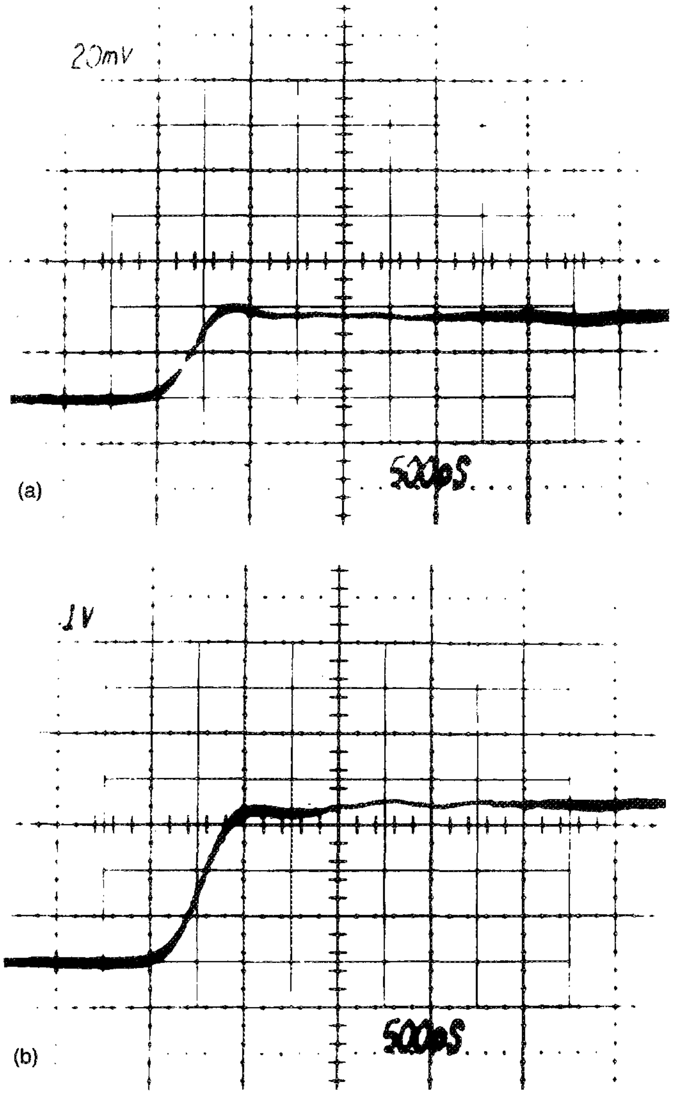

FIG. 2. Step response of Faraday cup: (a) input signal; (b) output signal. Vertical scale arbitrary, horizontal scale 500 ps/small division.

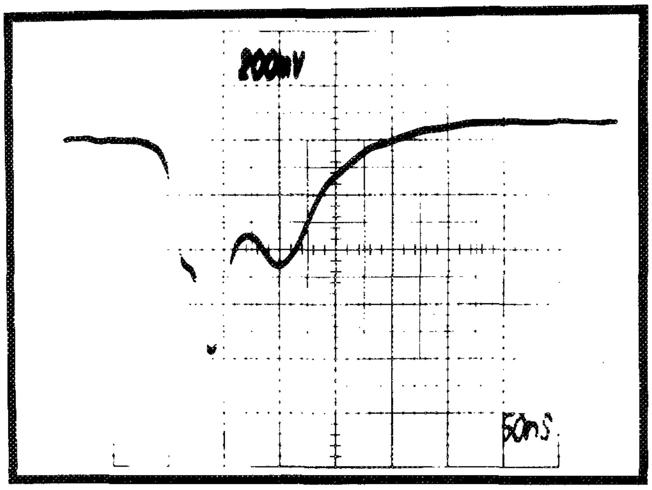

FIG. 3. Current pulse measurement using the Faraday cup. 50 ns/div.

In Fig. 3 a typical output voltage pulse is shown when an electron beam of approximately 10 keV is incident on the probe. The sensitivity of the probe may be altered by changing the thickness or length of the cylinder of graphite without affecting the pulse response significantly. This is an advantage of this scalable design.

In conclusion, a simple but high-performance design for a fast Faraday cup has been presented. Its performance has been demonstrated to be suitable for measurements of energetic electron beams in fast-discharge plasma physics experiments.

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