Low Energy Faraday Cup

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Abstract

The RadiaBeam Technologies Low Energy Faraday Cup is a beamline diagnostic that is used to measure the charge of a pulsed beam. The Faraday Cup (FC) is mounted on a BNC vacuum feedthrough with a 6 inch nipple. The FC is impedance matched to 50 Ω. The output reading of the FC on an oscilloscope yields information proportional to the beam charge. The FC will accurately operate with electron beams up to 35 MeV.

Figure 1: RadiaBeam Low Energy Faraday Cup Part No. FARC-02-300

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1 Introduction

A Faraday Cup is a beamline diagnostic that is used to measure the total charge of pulsed beams.

The term "Faraday Cup" (FC) is used in two contexts throughout this document. Sometimes, it refers to the conducting cup used to capture the electrons (cylindrical shape), i.e. the individual component which is the main feature of the complete assembly. It may also refer to the total assembly, sold as a complete product (i.e. the diagnostic instrument). The usage is apparent and explicitly stated where ambiguity may arise.

This document specifically refers to the RadiaBeam Low Energy Faraday Cup, Part No. FARC-02-300. This document is not an owner's manual (Please see Instruction Manuals). Distribution of this document is prohibited.

2 Operation

The RadiaBeam FC is used as a charge diagnostic and a beam stop. It is **NOT** radiation shielded; adequate measures should be taken by the operator to shield for emitted radiation.

As a charge monitor, the FC must be impedance matched (the RadiaBeam FC is matched to 50 Ω) to provide useful information. When the output signal is terminated to 50 Ω (e.g. with a BNC T-connector) the signal on the oscilloscope is integrated and divided by the termination to give a reading of the charge. For example, if the integrated scope signal reads 25 nV s, then the charge is,

$$Q = \frac{Vt}{R} = \frac{25\text{ nV s}}{50\Omega} = 500\text{ pC} \tag{1}$$

The FC should be installed by a qualified vacuum technician. It is mounted inside a standard 6" nipple with a 2.75" Conflat flange. The BNC feedthrough flange should not be removed unless troubleshooting is required. All standard vacuum techniques and procedures should be followed when installing the FC.

3 Design Considerations

There are two main design considerations for the FC: impedance matching and stopping range. Each will be addressed individually.

3.1 Impedance Matching

The impedance of a coaxial line is,

$$Z_0 = \frac{1}{2\pi}\left(\frac{\mu}{\epsilon}\right)^{1/2} \ln\left(\frac{a}{b}\right), \tag{2}$$

where Z_0 is the impedance of the coaxial line, μ is the permeability of the medium between the conducting cylinders, ϵ is the dielectric constant, and a/b

is the ratio of the diameters of the outer and inner cylinders respectively. For an impedance of 50 Ω, the ratio, a/b, for a coaxial line in free space is 2.30.

The RadiaBeam FC uses the vacuum nipple as the outer cylinder and a custom machined aluminum cylinder for the inner. The inner diameter of the outer nipple is 1.37” (3.48 cm). To achieve the proper ratio for 50 Ω impedance matching, the corresponding diameter of the inner aluminum cup is 0.595” (1.51 cm).

The aluminum cup is electrically isolated from the grounded outer cylinder by a ceramic washer.

3.2 Stopping Range

The RadiaBeam FC is designed to stop a 35 MeV electron beam. The stopping range is calculated using the following,

$$R_s = \frac{A}{Z\rho}\left(.285E - .137\right), \tag{3}$$

where A is the atomic weight, Z is the atomic number, ρ is the density in units of [g cm^{-3}], and E is the electron beam energy in units of [MeV]. Using the parameters for aluminum (Table 1), the stopping range for a 35 MeV electron beam is 3.0” (7.6 cm).

Material	Al	Cu
Atomic Number (A)	13	29
Atomic Weight (Z)	27	63.5
Density (ρ) [g cm^{-3}]	2.7	8.92

Table 1: Physical properties of Aluminum and Copper.

A quick shortcut to calculate the stopping range for low Z materials is given by,

$$R_s = \frac{0.6}{\rho}E, \tag{4}$$

which also yields 3.0” for a 35 MeV beam.

The aluminum cylinder face is conically shaped (45 deg) to capture any secondary emissions. Also, aluminum is used to minimize activation.

4 Useful Constants

Magnetic Constant:	$\mu_0 = 4\pi \times 10^{-7}$m kg s^{-2} A^{-2}
Electric Constant:	$\epsilon_0 = 8.85 \times 10^{-12}$m^{-3} kg^{-1} s^4 A^2

5 Summary of Important Points

- The RadiaBeam FC is **NOT** radiation shielded and provides no protection from x-rays and gammas. The operator should assume all shielding responsibilities based on the parameters of the beam being used.
- The RadiaBeam FC is impedance matched to 50 Ω with the assumption that the outer cylinder (vacuum nipple) and the inner aluminum cup are separated by vacuum, or free space. Insertion of any materials between the two cylinders will effectively change the impedance and the accuracy of the measurement.
- The RadiaBeam FC has a 3" aluminum cup that is capable of stopping a 35 MeV beam with a conical face to capture secondary emissions.
- The RadiaBeam FC works best with an oscilloscope with an integrating function.

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References

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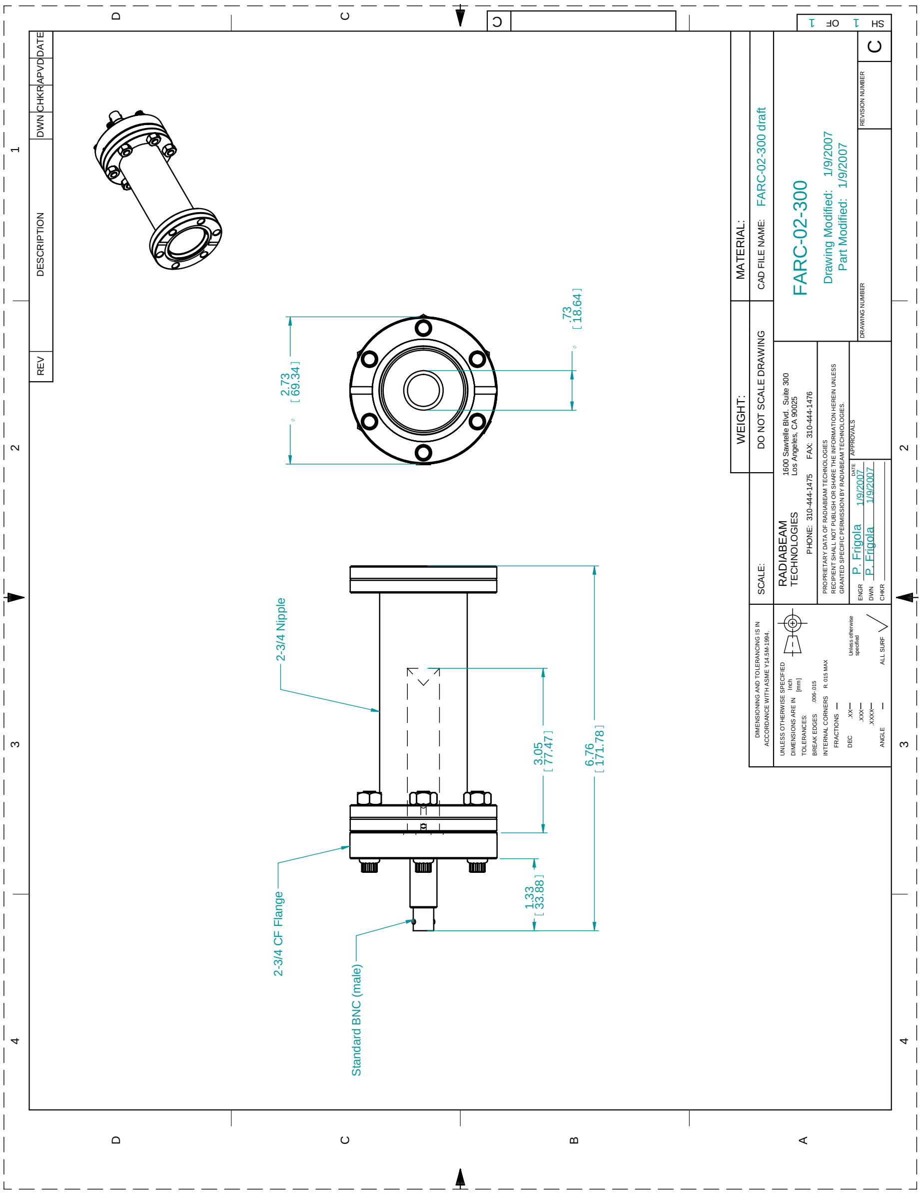

Figure 2: Technical Drawing for Faraday Cup.