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# STRIPLINE DESIGN OF A FAST FARADAY CUP FOR THE BUNCH LENGTH MEASUREMENT AT ISOLDE-ISRS*

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*Abstract*

In order to measure the bunch length of the beam after Multi Harmonic Buncher (MHB) of ISOLDE Superconducting Recoil Separator (ISRS) [1] and characterize the longitudinal structure of bunches of MHB, installation of a Fast Faraday Cup (FFC) is foreseen. Several possible structures of the fast faraday cup are studied and due to timing characteristics of the beam, a microstrip design is selected as the first option. The beam is collected on the biased collector of the microstrip with a matched impedance and transferred to the RF wideband amplification system. The amplified signal then can be analysed on the wideband oscilloscope or acquisition system to extract the bunch length and bunch timing structure with precision. The design of the microstrip FFC and primary RF measurement of the prototype are discussed in this paper.

## INTRODUCTION

ESS-Bilbao is designing a Multi Harmonic Buncher (MBH) for the ISOLDE-ISRS [2]. In order to measure the functionality and characteristics of the MBH bunches, some diagnostics have been foreseen. They include ACCT current measurement, energy measurement, and a Fast Faraday Cup (FFC) for bunch length measurement. Prior to delivery of MHB to its final location at ISOLDE-ISRS, it will be tested with ion source beam at ESS-Bilbao with a β equal to 0.00328. The operational RF frequency of MHB is 10.126 MHz and the low velocity bunch length after MHB could converge down-to 1 ns. The maximum proton energy is 50 keV, the beam current could reach up to 40 mA and the maximum pulse width is 3 ms. The beam repetition rate varies from 1 to 30 Hz. It should be mentioned the beam species, energy and current at ISOLDE-ISRS are different than ESS-Bilbao injector.

## BUNCH LENGTH MEASUREMENT PRINCIPLES

The measurement of bunch length involves capturing the temporal distribution of charged particles within a bunch. There are methods which rely on the interaction of the bunch with a transverse radiofrequency (RF) field, leading to longitudinal deflection, which is then measured using downstream diagnostics. A commonly used instrument for bunch length measurements is the Feschenko bunch shape monitor (BSM), which relies on the time-to-space conversion of electrons emitted when the beam interacts with a wire [3]. However, there are also methods which can interact directly with the beam and measure the bunch induced signal temporal distribution directly. In the latter case the fast faraday cups (FFC) are developed and inserted in the beam trajectory in order to collect the signal and transmit it via coaxial cable to the broadband amplifiers before acquisition system.

The performance of these fast faraday cups mainly affected by the bandwidth of the overall system, from the FFC signal to amplification and acquisition system. The required bandwidth of FFC usually depends on the bunch longitudinal size and its frequency spectrum.

## FAST FARADAY CUP DESIGN

Two types of fast faraday cups are studied namely coaxial type and stripline type. In both cases the bunch incident signal is collected and propagated in the FFC structure, which is matched to the cables and amplification system. However, for the required operational frequency range of the MBH, a coaxial type also can be realized without problems, but foreseeing future projects we decided to design a stripline type with higher frequency bandwidth. The main advantage of the stripline type FFC is the high frequency bandwidth, and its main drawback is the reduced beam thermal capacity.

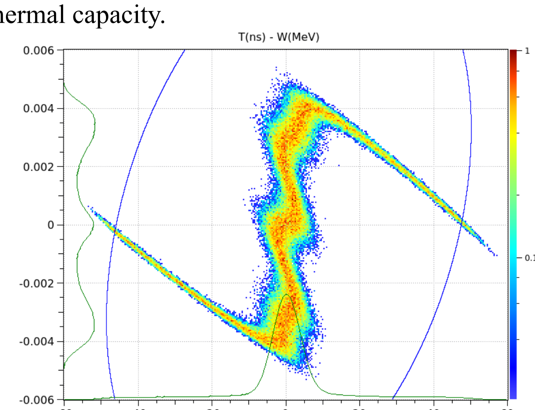


Figure 1: Bunch formation development at a distance of 1m from MHB. Horizontal axis corresponds to time (ns) and vertical axis to energy (MeV).

Figure 1 shows a TRACEWIN simulation of a specimen with β=0.00328 at a distance of 1m after MHB. Figure 2 shows the estimated shortest Gaussian bunch temporal distribution and the frequency spectrum of the bunches after MHB in the location of FFC. The Gaussian bunch has a

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sigma of 1 ns and the lower graph shows the bunch frequency components up to 1 GHz. Since the FFC will be implemented in other future projects with shorter bunch lengths, the current design of the FFC provides a bandwidth of 7.5 GHz which is much higher than required 1 GHz of MHB.

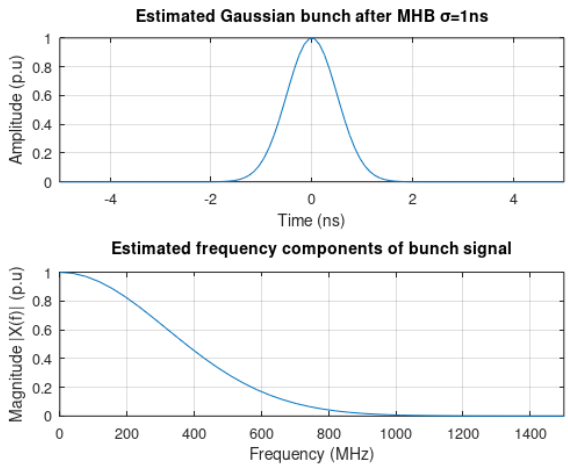


Figure 2: Expected shortest bunch temporal distribution and frequency spectrum after MHB in the FFC location.

## FFC GEOMETRY AND ANALYSIS

Striplines FFC provide a direct way to capture the charge distribution within a bunch by measuring the transient electric field induced by passing particles. In order to transmit accurately the induced signal, the RF structure of FFC should be matched to the adjacent structures such as connector, coaxial cable and the low noise amplifier [4,5]. The FFC can be customized for different beam energies and bunch lengths. Modelling approximation can be used to calculate the microstrip trace. Considering a microstrip with trace thickness of W and substrate height of H, one can calculate the characteristics impedance with equation (1):

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{H}+1.39+\frac{2}{3}\ln\left(\frac{W}{H}+1.44\right)\right]} \quad (1)$$

In which $\varepsilon_{eff}$ is the effective substrate dielectric. Using the computer codes and analysing the scattering parameters, the geometry of the FFC microstrip was defined in order to match the impedance to cables and amplifier. For the prototyping, we used standard FR-4 substrate with a substrate thickness of 1.5 mm and various trace thickness from 2.5 mm to 3.6 mm. After fabrication of prototypes with the same substrate height, but with different traces, their specifications including scattering parameters were measured. Figure 3 shows a screenshot of the induced bunch signal propagation in the FFC at 6 GHz. It shows the occupied space around the signal path for the signal transmission.

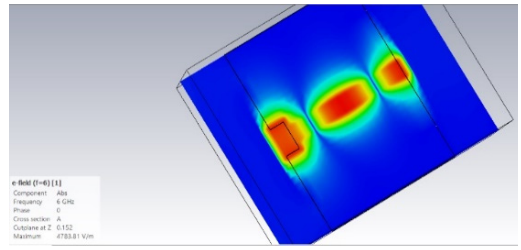

Figure 3: Screenshot of the 6GHz signal component propagation in the FFC mid-plane.

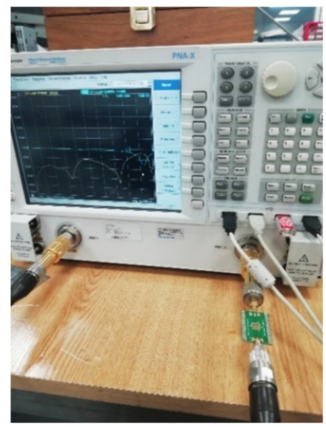

Figure 4: FFC microstrip PCB without collector during measurements of scattering parameters.

The fabricated prototypes have been checked with network analyser PNA-X for their RF characterizations with two-ports tests (see Fig. 4). The FFC microstrip connectors are SMA type for both the load and signal ports.

In the Fig. 5 the measured scattering parameters S12 for various trace thickness of prototypes are provided. In all cases the frequency bandwidth is higher than 6.5 GHz, while it shows at this stage the minimum losses for the trace thickness of 3.4 mm and a bandwidth of 8 GHz.

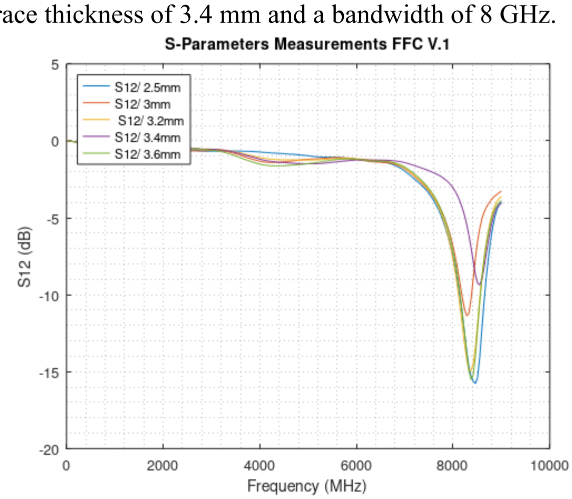


Figure 5: Measured $S_{12}$ parameters for different trace thickness of microstrips.

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## MEASUREMENT WITH GAUSSIAN PULSE SIGNAL

A setup has been installed in the laboratory to check the transient response of the FFC in the presence of a fast signal. The fast Gaussian signals with a rise time of 1 ns and 115 ps have been generated in order to check the possible deformation of the temporal distribution of the bunch signal. The pulse with rise time of 1ns is very similar to the bunch length at ISOLDE-ISRS, while the pulse with 115 ps is used to test the upper band of the bandwidth. To generate these pulses, we developed two different types of fast pulsers. The 1 ns rise time Gaussian pulser is based on avalanche diode technology which generates relatively high amplitude voltage, but limited rise time.

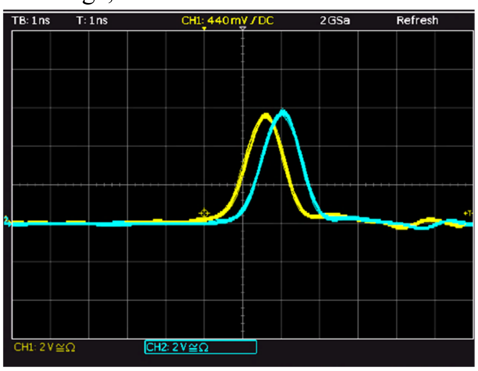


Figure 6: The incident 1ns rise time pulse (yellow) and after passing through the FFC (blue). Ver: 2 V/div, Hor.: 1 ns/div.

Figure 6 shows the incident signal and FFC output signal for a Gaussian pulse of 1 ns rise time. For the 115 ps rise time, we developed a pulser based on Step Recovery Diode (SRD), which can provide faster rise time. In both cases the signal is split into two channels. One is going directly to the oscilloscope and the second one is connected to the load port of the FFC. The signal port of the FFC then is connected to the oscilloscope. In this setup, one can measure the effect of the FFC on the incident signal.

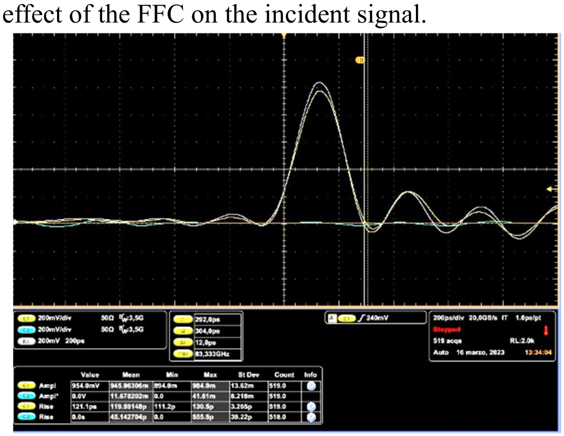

Figure 7: The incident 115ps fast rise time pulse variation before and after passing through the FFC microstrip.

In the Fig. 7, having a 115 ps rise time signal in the load port, will be deformed of about 12 ps. This is an indication of bandwidth effects of the FFC microstrip on the bunch temporal distribution measurement.

## ELECTRONICS AND DATA AQUISITION

In order to reduce the thermal heat on the FFC microstrip, the portion of beam which is collected on the FFC collector is reduced by a collimator in front of the FFC. The collimator opening aperture diameter is 0.8 mm and the stop range of hydrogen and nitrogen ions in the collector is less than a few µm. In this configuration, the signal amplitude at the signal port of the FFC is very weak with a power of less than -35 dBm. For that reason, we will use a broadband low noise amplifier (LNA) to amplify the signal before transmitting it via coaxial cable to the acquisition system. In addition, a DC bias voltage is placed on the signal port in order to supress the secondary electrons emission from collector. For the acquisition system, it is expected to use a wideband oscilloscope or acquisition card with sampling rate of higher than 50 GS/s being able to observe the bunch transients.

## NEXT STEPS

The first prototyping of FFC microstrip shows reasonably promising results for fast pulses. For the final design, we will make some modifications in particular the length of traces from load port to signal port in order to reduce the losses and increase the overall temporal accuracy for future projects with very shorter bunch length than ISOLDE-ISRS. Further effects of coaxial cables and amplification system will be investigated. Furthermore, the whole system including the vacuum vessel, mechanical parts, collimator, actuator, cooling system and local control system will be implemented.

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