Design of a Tapered Stripline Fast Faraday Cup for Measurements on Heavy Ion Beams: Problems and Solutions

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Abstract. The design of a tapered stripline fast Faraday cup (TSFFC) to perform the impedance matching between the fast cup itself and the signal line (connector, cable, and amplifier) is reported here. The frequency response of the TSFFC as a high-pass filter is analyzed from a theoretical point of view and some solutions to achieve a broadband response are given.

INTRODUCTION

The design of a fast Faraday cup has to respect some rules regarding the required bandwidth and the characteristic impedance (1).

If only the TEM (or quasi-TEM) mode has to be transmitted along the line, the cut-off frequency is an important parameter. Using a stripline fast Faraday cup with a thickness between 0.5 and 1 mm, a bandwidth over 50 GHz can be reached.

The characteristic impedance, in planar geometry, given a dielectric medium, is proportional to the ratio between the dielectric thickness and the strip width. For instance, if the dielectric is teflon and its thickness is 0.5 mm, a width of 10 mm or more implies a characteristic impedance of 10 Ω or less, so a problem of impedance-matching with 50 Ω has to be worked out.

One solution is to use a resistor network to match the impedances (2). In our case, we sought to avoid resistor weldings on the strip by designing a tapered stripline fast cup. On the other hand, one can regard this as a high-pass filter, so other problems have to be solved. They will be shown in the next sections with the possible solutions.

THEORY OF THE TAPERED STRIPLINE

An exhaustive study of the tapered transmission line theory is given in Reference 3. In the analysis of a tapered stripline, the starting point is to consider it as a transmission line with characteristic impedance changing continuously along the longitudinal direction as a result of the changes in the strip width.

These changes produce a change in the total reflection coefficient at the input as an addition of the same infinitesimal variations. The formula is the following:

$$\Gamma_{\mathrm{i}} = \frac{1}{2}\int_0^L e^{-2jz\beta}\frac{d}{dz}(\ln \mathrm{Z})dz \tag{1}$$

where Γ_i is the total reflection coefficient at the input of the taper, L is the total taper length, z is the longitudinal coordinate, β is the inverse of the wavelength ($\beta=2\pi/\lambda$) and $\underline{Z}$ is the normalized impedance, as a function of the distance z along the taper. If the variation in $\underline{Z}$ with z is known, Γ_i may be evaluated from the above equation.

This was done for the fast cup. The strip width changes linearly with z, so the characteristic impedance is inversely proportional to the longitudinal coordinate (the dielectric thickness remains unchanged). The resulting integral does not have an analytical solution and was worked out numerically, taking β as parameter.

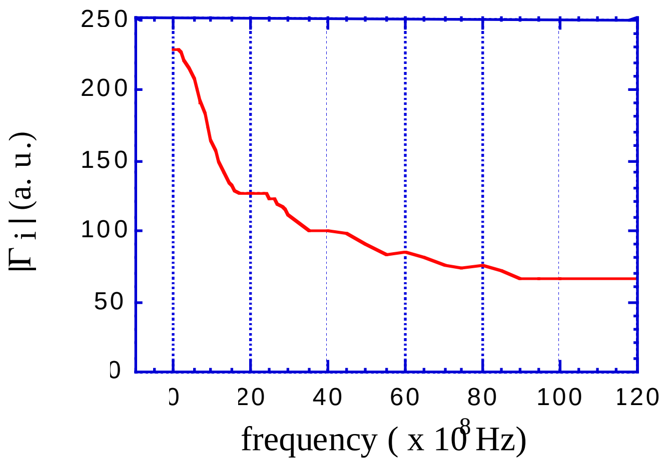

FIGURE 1. Calculated reflection coefficient vs. frequency

Figure 1 shows the calculated reflection coefficient magnitude vs. frequency . The high-pass effect is visible.

The tapered stripline was simulated using an HP program named “High Frequency Structure Simulator,” and the plot of the transmission coefficient vs. frequency is reported in Figure 2, showing a similar high-pass filter effect.

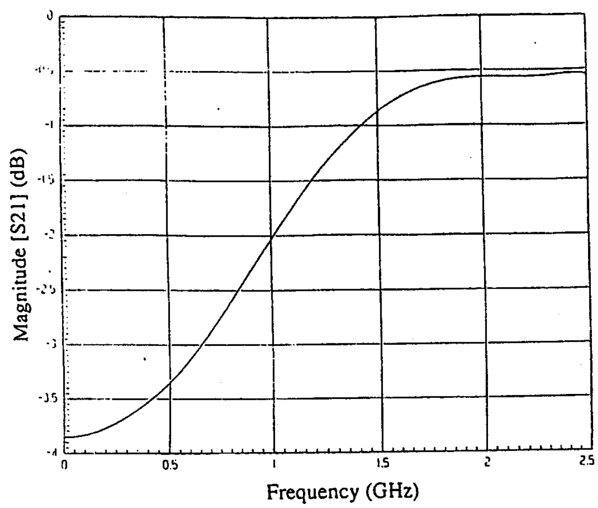

FIGURE 2. Simulated transmission coefficient vs. frequency

ANALYSIS OF THE ACTUAL TAPERED STRIPLINE

A drawing of the tapered stripline is shown in Figure 3. At the extremities, the width of the strip is matched with a 50 Ω characteristic impedance, but after a few millimeters it becomes larger to reach a width of 14 mm in the central region, which corresponds to an impedance of 7 Ω. This central region is the impact zone for the beam. The cup is 0.5 mm in thickness and the dielectric is teflon.

The frequency response between 0 and 6.5 GHz was analysed with a spectrum analyser, putting a signal into the 50 Ω matching section and looking at the other extremity, and the result is shown in Figure 4. In contrast with the simulation, where only half of this actual stripline was analyzed (from the 50 Ω matching strip to the center of the cup), the frequency response here shows an attenuation of 10 dB between 40 MHz and 1 GHz.

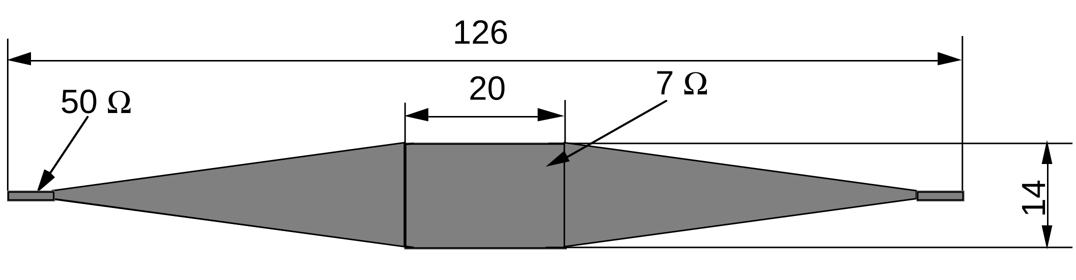

FIGURE 3. Fast Faraday Cup dimensions (in mm).

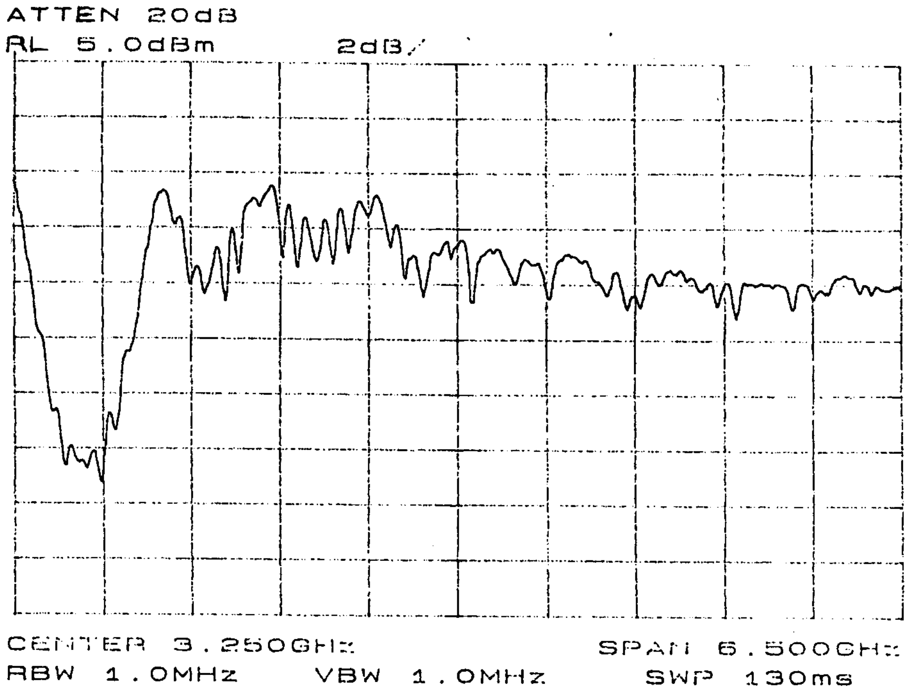

FIGURE 4. Frequency response of the TSFFC (range 0–6.5 GHz)

This kind of transfer function gives different responses at different input signal widths. However, for the beams involved, the cup must, be able to measure bunch widths between 10 ns down to 100 ps, so it is mandatory to have a broadband device. This has led to a more widespread problem of reconstructing the input signal, knowing the output signal and the transfer function of the intermediate device.

SIGNAL RECONSTRUCTION

The frequency response of the designed TSFFC can be approximated with a transfer function having two poles and two zeroes. These four points determine the 10 dB attenuation hollow mentioned before. By means of the "LAPLACE" function in the PSPICE code, the transfer function was successfully simulated. This is illustrated in Figure 5, where, using the same input signal, (actual in "A" and simulated in "B"), the output signal from the 20 GHz HP sampling oscilloscope is compared with the simulated output signal from PSPICE.

Once the transfer function is so characterized, the deconvolution of the output signal may solve the problem, but at present this is not useful, as the signal reconstruction cannot be done in real time.

Two different methods have been considered, neither yet realized, to achieve a result in real time: 1) the use of a Digital Signal Processor (DSP) to do a software reconstruction, 2) to carry out the transfer function inversion using a hardware filter with resistors and capacitors.

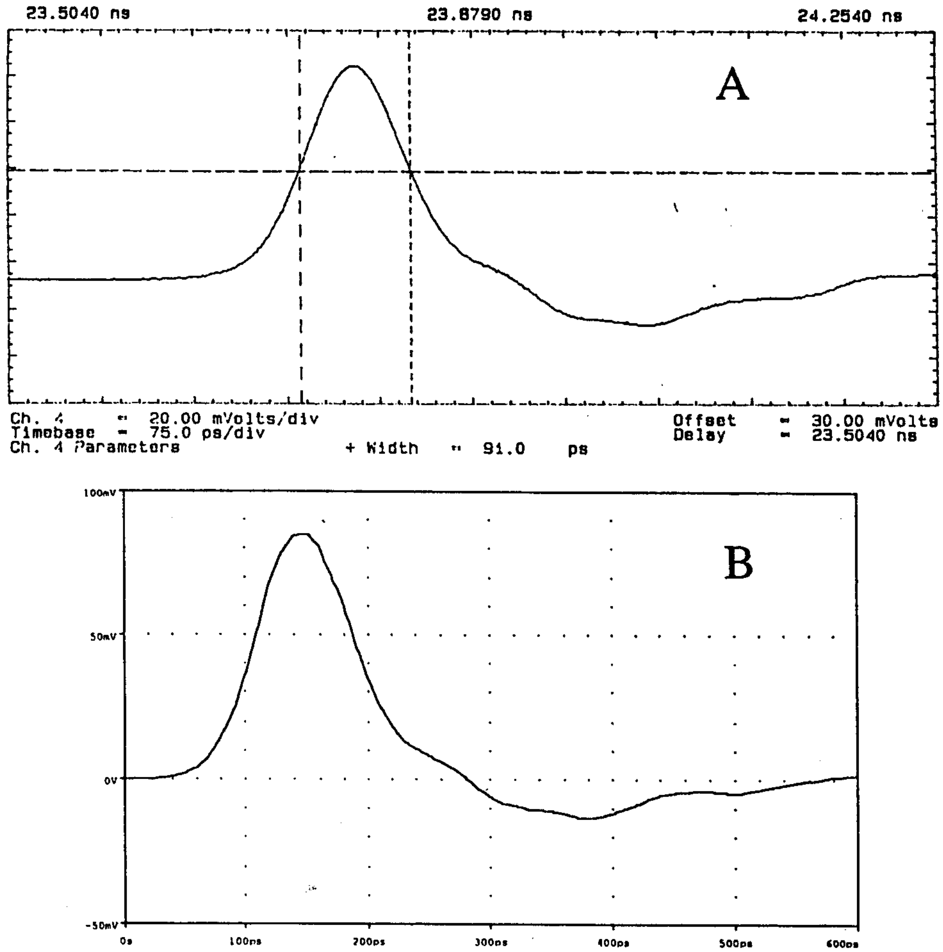

FIGURE 5. Signal reconstruction using PSPICE: “A” from the oscilloscope, “B” from PSPICE with simulated transfer function.

The first method implies taking the data from the HP oscilloscope with the HP-VEE program, working on them with a DSP, which performs the deconvolution with the inverse of the transfer function, and then displaying that processed data. The second method was simulated with PSPICE code. The inverse of the transfer function was approximated with only one zero and one pole at 20 dB/decade slope. The result is shown in Figure 6. With this second method there is a problem of signal attenuation due to the passive resistor and capacitor network.

CONCLUSIONS

Until now the problem of the input signal reconstruction has been successfully analyzed with simulations. The fast cup was implemented but has not yet been put in the beam. In a few months, a test with the hardware reconstruction will be performed. In the future, we hope to be able to do also the software reconstruction.

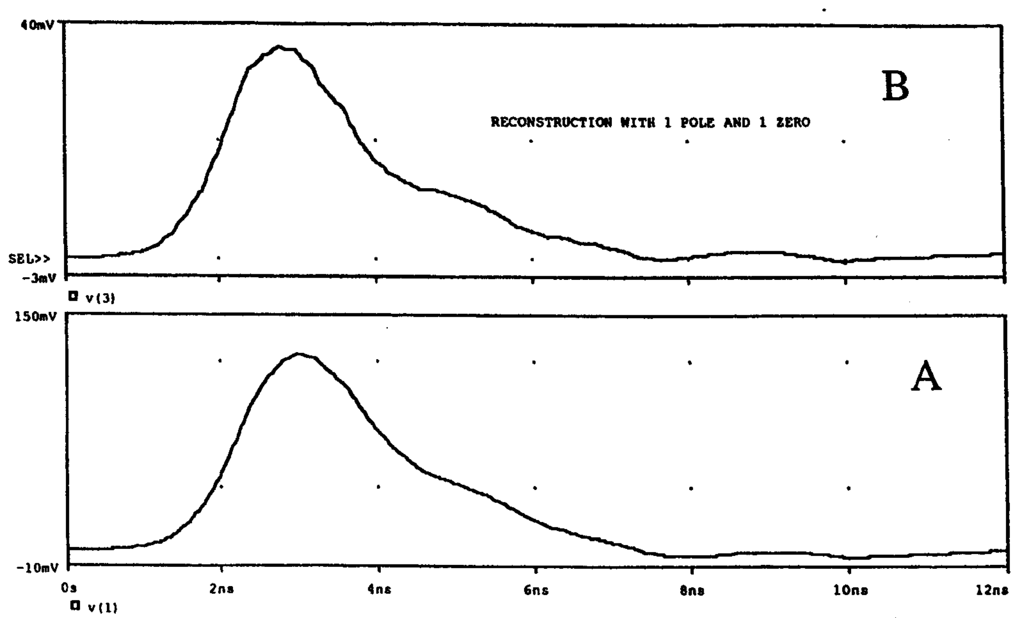

FIGURE 6. Signal reconstruction simulation using PSPICE with the "hardware" filter: "A" input signal, "B" output signal after simulated transfer function and filter.

ACKNOWLEDGMENTS

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