

Impedance-Matching-Transformer for Capacitive Pick-Ups

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Abstract

The transfer lines from GSI's heavy ion synchrotron (SIS) to the experimental set ups are equipped with segmented capacitive pick-ups for beam position measurement. This beam position measurement will be designed for single-bunch evaluation. Best choice for taking measurements with maximum sensitivity is a high-impedance tap at the pick-up referring to the bunch length of 50...500 ns. Therefore the feeding of 50 Ω coaxial cables will be realized by an impedance-matching transformer located close to the pick-up. It should have an impedance > 10 k Ω on the primary side and 50 Ω matching on the secondary side with a foreseen bandwidth of 200 MHz. So it is possible to use low noise amplifiers with 50 Ω input in a radiation save environment without loading the pick-up with 50 Ω .

INTRODUCTION

Many capacitive pick-ups at the GSI's synchrotron are used as position and phase pick-ups. Normally, high impedance head-amplifiers with an input impedance of 1 M Ω amplifies the plate signals close to the vacuum feed trough. Looking at the equivalent circuit of pick-up and amplifier explains why a high impedance signal tap is useful. This configuration behaves as a high pass filter as specified in [1]. Three different cases have to be taken into account as shown in figure 2.

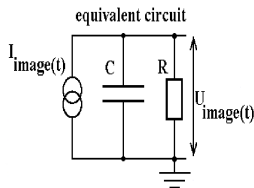


Figure 1: Equivalent circuit of one pick-up plate and amplifier

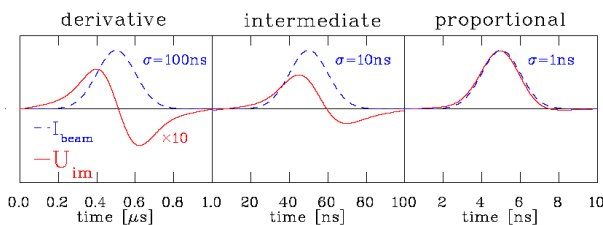


Figure 2: Theoretical bunch shaping

$$U_{\text{image}} = \frac{A}{\beta\pi\epsilon_0 C} \cdot \frac{j\omega RC}{(1 + j\omega RC)} I_{\text{beam}}(\omega) \quad (1)$$

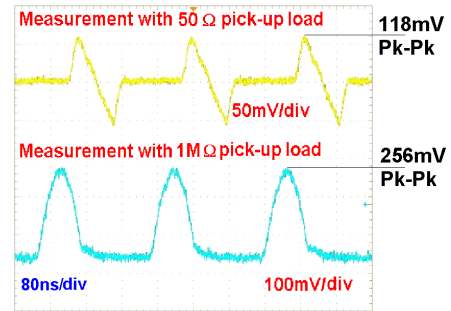


Figure 3: Measured bunch signals

Highest gain can be achieved in the proportional case. Measurements have approved the theoretical predictions (3). Figure 4 gives an information about the voltage gain of an 1 M Ω amplifier compared to a 50 Ω configuration.

It shows the calculated absolute value of the longitudinal transfer impedances ratio of a 1 M Ω and a 50 Ω amplifier.

In the range up to 1 GHz a 1 M Ω amplifier provides a higher gain. In practice, reflections will be generated due to the discontinuity of pick-up capacitance and amplifier input. But in the case of the used head amplifiers with its short cable length of a few centimeters this effect is negligible.

For beam position monitoring, at the high energy transfer lines from the SIS to the experimental area, it is necessary to use high impedance amplifiers to get a gain in position signals and a higher sensitivity. With a look to the future project of the GSI and its higher intensities it is important to make the maintenance at the beam diagnostics easier and saver. This means to get away from the beam tube into a radiation poor region of the plant.

$$U_{\text{image}} = 20000 \frac{\sqrt{1 + \omega^2 \cdot (50\Omega \cdot C_{\text{pickup}})^2}}{\sqrt{1 + \omega^2 \cdot (1M\Omega \cdot C_{\text{pickup}})^2}} \quad (2)$$

Furthermore some cryogenic regions at the new accelerator parts are provided. In this parts it is absolutely fatal to use head amplifiers with any power dissipation.

To work with 50 Ω coaxial cables is the best way to get away from the beam tube in an adequate manner. But

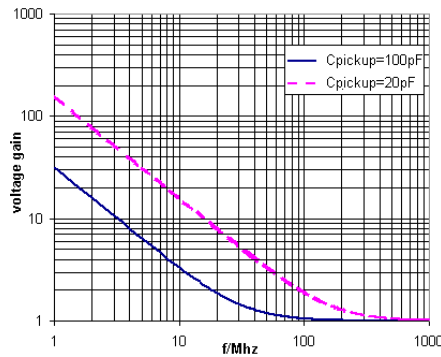


Figure 4: Calculated voltage gain (equation 2)

this causes reflections due to the mismatch to pick-ups high impedance to the 50 Ω coaxial cable. So the need of a broadband matching transformer is given. In consequence of its transforming properties the transformer can realize a high impedance at the primary side and a low at its secondary.

REALIZATION

It was necessary to accomplish preliminary inspections at air chokes, double hole-core inductors and toroids for an appropriate choice of the transformer configuration.

The choice of an air choke is the most invitingly transformer structure, because the medium air is everywhere available and has no saturation effects. Variations in temperature are not critical. But measurements showed, that it is not possible to reach a good coupling coefficient in due to leakage inductances. A loss in signal amplitudes is the result.

Particularly high coupling coefficients are reachable with ferrite double hole-cores and ferrite toroids. An accomplished power sweep up to +30 dBm shows no saturation effects.

The coupling coefficient for the used toroid sample is $\kappa = 0.995$. The dimensions of the core are 5.8 mm outside diameter, 3 mm inner diameter, a core thickness of 3 mm and an AL-value of 500 nH. The transformer windings are evenly distributed over the toroid core and the used Cu-wire has a diameter of 0.1 mm. With 45 windings on primary and 3 windings on the secondary side, its theoretical transformation ratio is $N = 15$. This means that the input impedance of the primary side with its 45 windings should have a value of

$$Z_{in} = 15^2 \cdot 50 \Omega = 11.25 \text{ k}\Omega \quad (3)$$

That is in the range of the desired 10 k Ω . But the measurements in figure 5 with a Z_{in} of only 5.8 k Ω do not approve this input impedance value.

The transfer function and the time domain signal shows, that the theoretical transformation ratio is not reached (fig. 5). The reason is the non-ideal behavior

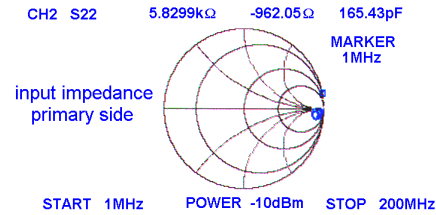


Figure 5: Smith diagram of the input impedance at the primary side with 45 windings

of the transformer in the rf-case, the measured transformation ratio is not equal to the theoretical. For a real transformer the following equivalent circuit and calculations are obtained. The calculations are based on measured data.

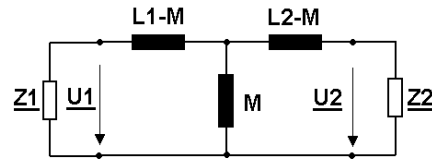


Figure 6: Equivalent circuit of the real transformer [3]

CALCULATIONS

The following calculations refer to the sample in test. The scattering factor is calculated by

$$\sigma = \frac{L_1(L_2 = \text{shorted})}{L_1(L_2 = \text{opened})} \quad (4)$$

and evaluates to

$$\sigma = \frac{9.5 \mu\text{H}}{1 \text{ mH}} = 0.0095$$

The coupling factor

$$\kappa = \sqrt{1 - \sigma} \quad (5)$$

evaluates to $\kappa = 0.995$.

The mutual inductance

$$M = \kappa \sqrt{L_1 L_2} \quad (6)$$

evaluates to $M = 98.5 \mu\text{H}$.

The transformation ratio

$$\frac{U_1}{U_2} = \frac{L_1}{M} + j\omega \frac{M\sigma}{\kappa^2 Z_2} \quad (7)$$

evaluates to

$$\frac{U_1}{U_2} = 10.1$$

The frequency depending term of equation 7 is negligible. This calculated transformation ratio is equal to the

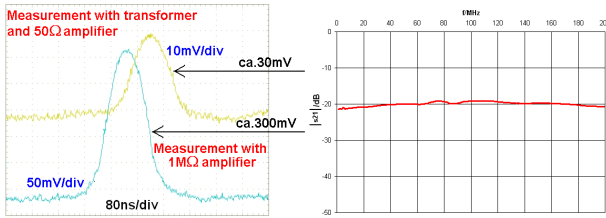


Figure 7: Measured bunch signals and transfer function of the transformer sample

observed ratio of the measurements (fig. 7) and also corresponds to the impedance value measured in fig. 5.

The fact, that the signal voltage is transformed down causes not automatically a loss in sensitivity, because the noise voltage is also transformed down. The use of 50 Ω amplifiers reduces the influences of the amplifier noise voltage in comparison to the 1 M Ω amplifier. So the dominant factor for the sensitivity is only the signal to noise ratio. The combination transformer and 50 Ω amplifier brings actually a gain up to 15 MHz. Figure 9 bases on the same calculation as figure 4. Only $R = 10\text{k}\Omega$ and the result is divided to the transformation ratio of 10. Furthermore galvanic isolation of the primary

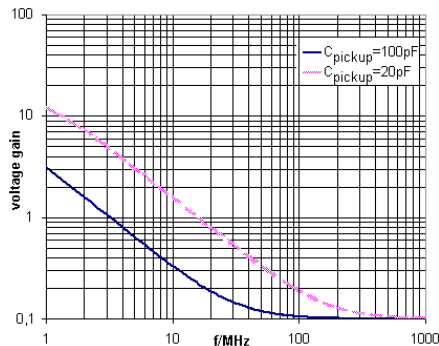


Figure 8: Calculated voltage gain with transformer

and secondary transformer sides reduces ground couplings and rejects disturbances. As the measurements of the secondary transformer side shows, there is a mismatching between transformer and 50 Ω . To avoid reflections at this discontinuity an additional passive matching network is necessary. The following matching network bases on a so called Zobel-network. The circuit was simulated and optimized with the rf simulation tool APLAC. Since a basic demand of circuitry is to make circuits as

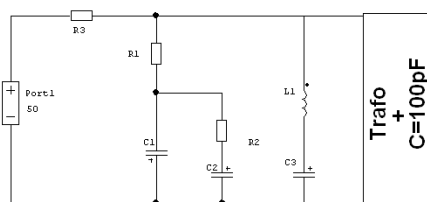


Figure 9: Zobel matching network the transformer sample

easy as possible another solution will be discussed in the optimization part.

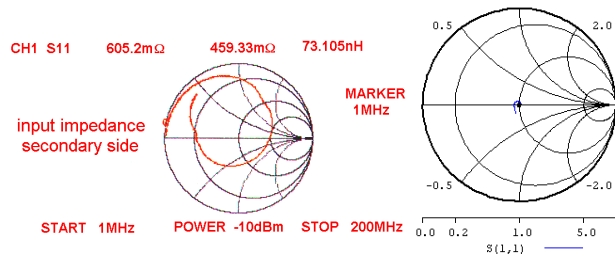


Figure 10: Smith diagram of the input impedance at the secondary side with 3 windings and matched transformer

OPTIMIZATION

In spite of the non-ideal transformation ratio of 10:1 the signal has an acceptable quality. There is no need to come up to the proposed transformation ratio of 15:1. So the prior aim of optimization should be the matching of the transformer secondary side to 50 Ω . Besides the described additional matching network the choice of a right ferrite core is another possibility to achieve a good matching to 50 Ω .

One of the ferrite material properties are a decreasing of permeability versus an increasing of the frequency. For a fixed output impedance the permeability of the core has to be proportional to $1/f$, but such a behavior is not available. Due to parasitic effects, it is necessary to get a low total number of windings. So a high permeability at low frequencies is required. This is very important, because at low frequencies the highest voltage gain is to anticipate (fig. 4, 9).

A test series with toroids from "Amidon" showed that not any of the materials type 43, 61, and 77 fitted these rules. But an approximation can be done by the combination of different ferrite materials. As a result, a stack of toroid slices from different ferrite materials will be given.

REFERENCES

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- [2] J. von Parpart, „Breitbandige Ferrit-Hochfrequenztransformatoren“, Hüthig Verlag, 1997
- [3] H. Freitag, „Einführung in die Vierpoltheorie“, Teubner Studienskripte, 1975