PICK-UP ELECTRODE SYSTEM FOR THE CR STOCHASTIC COOLING SYSTEM*

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Abstract

The collector ring (CR) of the FAIR project will include a fast stochastic cooling system for rare isotope beams ($\beta = 0.83$) and antiprotons ($\beta = 0.97$). To reach a good signal to noise ratio of the pick-up even with a low number of particles, a cryogenic movable pick-up electrode system based on slotlines is under development. The sensitivity and noise properties of an electrode array has been calculated using field-simulation and equivalent circuits. For three-dimensional field measurements, an electric near-field probe moved by a computer controlled mapper has been used.

SLOTLINE PICK-UPS FOR THE CR

The pick-ups must have a large bandwidth, a high S/N ratio and a large aperture. A new planar electrode is developed [1] to meet these requirements. The electrodes consist of a slotline perpendicular to the beam and a microstrip circuit on the rear side of a planar Al_2O_3 substrate (Fig. 1, top, left). The mirror currents induce traveling waves in both directions of the slotline. At approx. $\lambda/4$ from the end of the slotline, the signal is coupled out to the microstrip line. The $\lambda/4$-section at the beginning of the microstrip is a virtual short to one of the two conductors of the slotline. The exact length of these sections has been used to optimize the frequency response. The two signals are coupled out to $110\,\Omega$ microstrip lines and are combined in a $100\,\Omega$ to $50\,\Omega$ Wilkinson combiner. The position of the $110\,\Omega$ to $100\,\Omega$ transition has also been optimized.

The figure 1 (top, left) shows the layout of an eight slot pick-up board on a scale of 1:3. A pick-up tank will consist of two times eight modules. The modules will be cooled down to 30 K using cold heads and will be movable. The two figures below show a simplified design of a module. The right figure shows a cut across the first module prototype. Beside the PU board, the module also contains vertical connection boards. On these Al_2O_3 boards, a cryogenic low noise amplifier is foreseen. A small antenna can be used to test all connections and amplifiers of the module
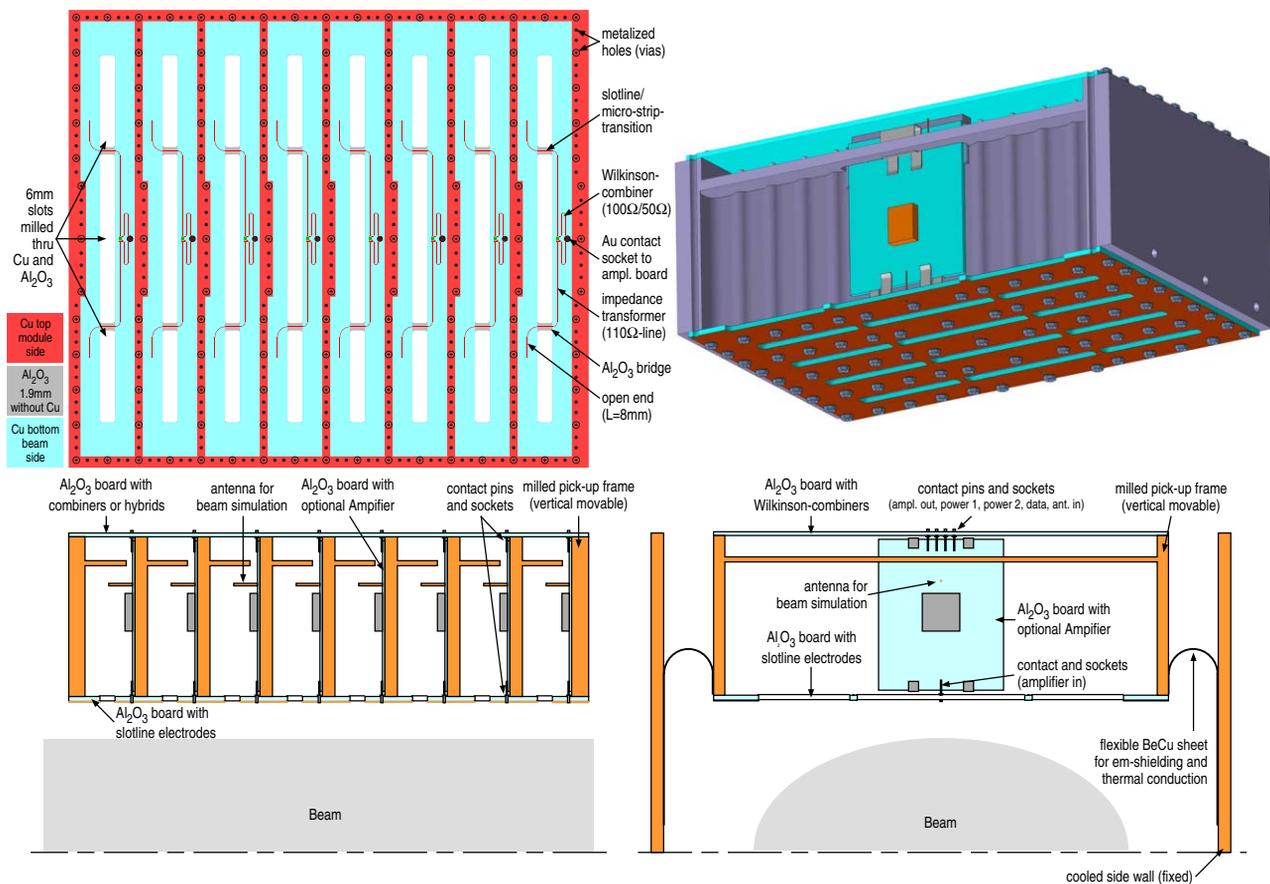
Figure 1: Layout of eight slot pick-up module prototype on a scale of 1:3.

without beam. The board on top of the module contains the phase-correct signal combination for $\beta = 0.97$. The signals of the eight modules will be combined outside the tank with switchable delays for $\beta = 0.83$ and $\beta = 0.97$.

The layout of the pick-up board is the result of numerical field calculations and an equivalent circuit based optimization. Compared to the unoptimized precursor, the position of the Al_2O_3 bridges over the slots and the dimensions of the microstrip lines have been modified. The equivalent circuit, including the first combiner and an additional $110\,\Omega$ line has been optimized with respect to maximum voltage and flatness. The diagram in figure 2 is a result of the optimization. It shows the magnitude and phase of the voltage over the center of the slotline versus the frequency.

Figure 3: Computer controlled E-field mapper with near field probe (detail).

Figure 4 shows a two-dimensional example of a field measurement. The single slot test pick-up for the equivalent circuit based optimization with 0.2 mm bridge and 10 mm open end has been fed with a 1.5 GHz signal at both ports. The diagram shows the magnitude of the E-field in z-direction, 5 mm above the surface. The sensitivity is relatively flat in the x-direction. The bridges with the microstrip tansitions are at ± 30 mm and the slot ends at ± 75 mm. In z-direction, the field decreases very fast. The next slots in a pick-up module would be at z=± 25 mm.

Figure 2: Voltage and phase over one slotline of Fig. 1 (simulated with equivalent circuit).
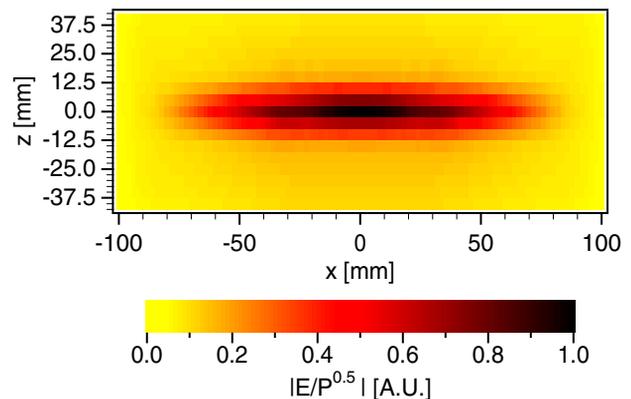
Figure 4: $|E_z|$-field 5 mm above the test structure.

A prototype of a module with this layout is under construction in order to compare the equivalent circuit with measurement results.

Suitable integration with β=0.97 over z gives the voltage over the particle trajectory. The diagram in figure 5 shows measured voltages at x = 0 in dependence of the frequency for different lengths of the open end. The peak at 1.1 GHz is an unwanted resonance of the measurement setup and will be avoided in the next measurements. The results of this measurements have been used for the optimization.

FIELD MEASUREMENTS

To perform four-dimensional (x,y,z,f) field measurements, a computer controlled E-Field mapper has been built. A small dipole (8 mm) is used as a near field probe. Figure 3 shows from left to right the controlling PC, the network analyzer, the CNC-machine which has been abused to move the probe over the test object, and the stepper controller. The detail shows the dipole at the end of the probe with small terminators. The feed line consists of two 1.2 mm semi-rigid cables.

EQUIVALENT CIRCUIT BASED OPTIMIZATION

To optimize the frequency response of the pick-up in detail, an equivalent circuit based approach has been chosen. To come close to a realistic behavior of the equivalent
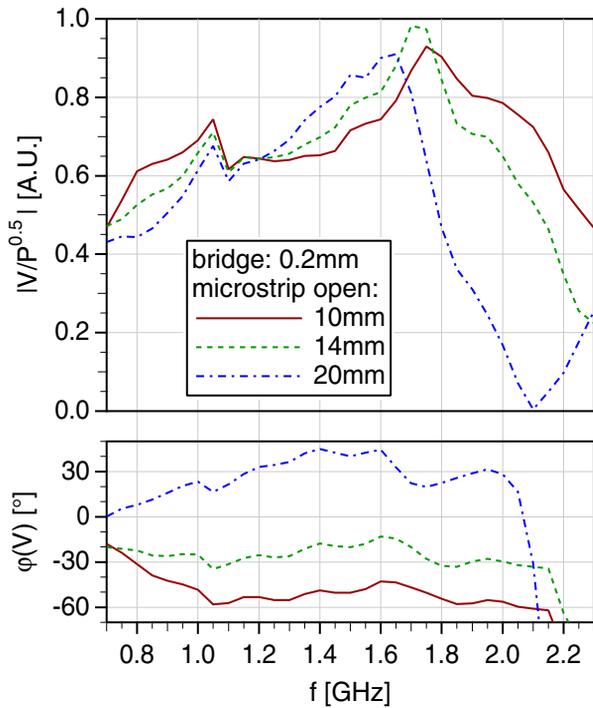
Figure 5: Voltage 5 mm above the slot of the test pick-up structure with three different lengths of the microstrip open end.

circuit, a simple test structure (Fig. 6) has been built and measured with the field mapper. The voltage, 5 mm above the slot, and the S-parameters between the two ports have been measured with six different lengths from 10 mm to 20 mm of the micro-strip open end and with two different widths of 0.2 mm and 2 mm of the microstrip lines on the Al_2O_3-bridges.
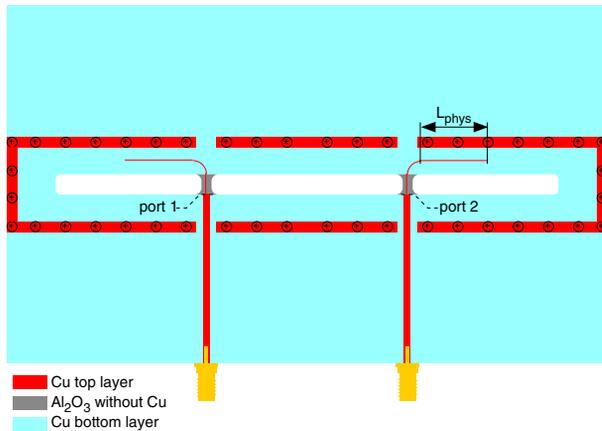
Figure 6: Layout of the test pick-up structure.

The circuit diagram (Fig. 7) shows the equivalent circuit of the test structure. The circuit has been simulated using Microwave Office [3]. The green underlined values are the fit parameters. The slotlines have been modeled by transmission lines with a frequency dependent impedance Z_{slot} and relative dielectric constant ε_{slot}. The losses of the slot-

lines have been modeled by the two attenuators with a voltage damping of D_{slot}. The main contribution to the losses comes from electromagnetic radiation. The resistive and dielectric losses are much lower. The parameters for the slotline have been derived from a numerical field calculation [2] of the slotline in the module using Microwave Studio [4]. The microstrip lines have been modeled by a Microwave Office model. The transition between slotline and microstrip line have been modeled by an ideal transformer and two suspended ground microstrip line, H_2 above the groundplane. The fit parameters for these components have been derived from the 12 field and S-parameter measurements.
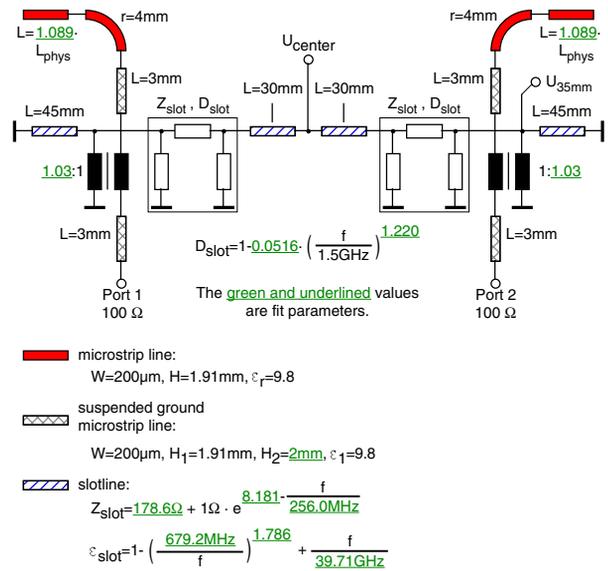
Figure 7: Equivalent circuit of the test pick-up structure in Fig. 6.

The diagrams in figure 8, 9 and 10 show a comparison of the final equivalent circuit results with the measured data. All the measurement equipment has an impedance of 50 Ω, whereas the pick-up is a 100 Ω device. The interfaces are at the dashed lines (port 1 and 2) in figure 6. The influence of this reflection, all cables and connectors as well as the frequency response of the near-field probe, has been eliminated from the measurement data in the diagrams. Figure 8 shows the transmission and figure 9 the reflection on port 1. Figure 10 shows the voltage above the center of the slot. The diagrams show a good agreement between the equivalent circuit and the measurements.

After the "calibration" of the equivalent circuit, it has been used to optimize the pick-up by varying the lengths of the slots and microstrips and the widths of the microstrips. The first result is the pick-up layout in figure 1 with the frequency response in figure 2.
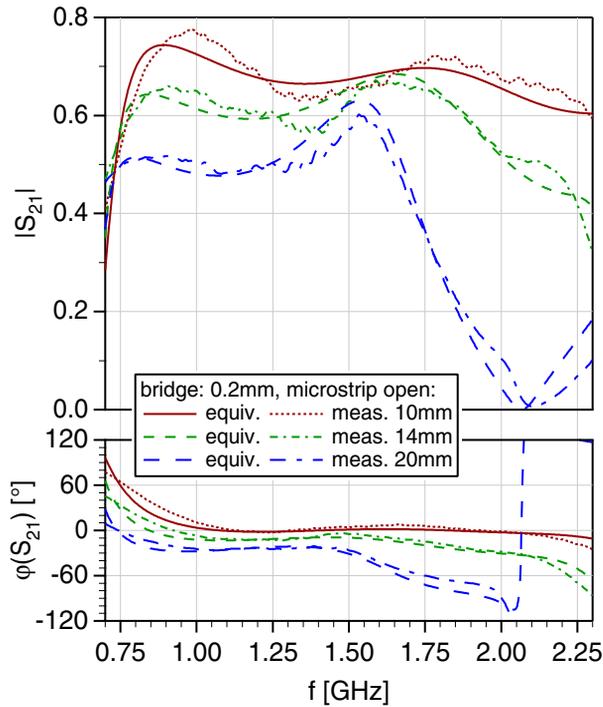
Figure 8: S_{21} of equivalent circuit and test structure.
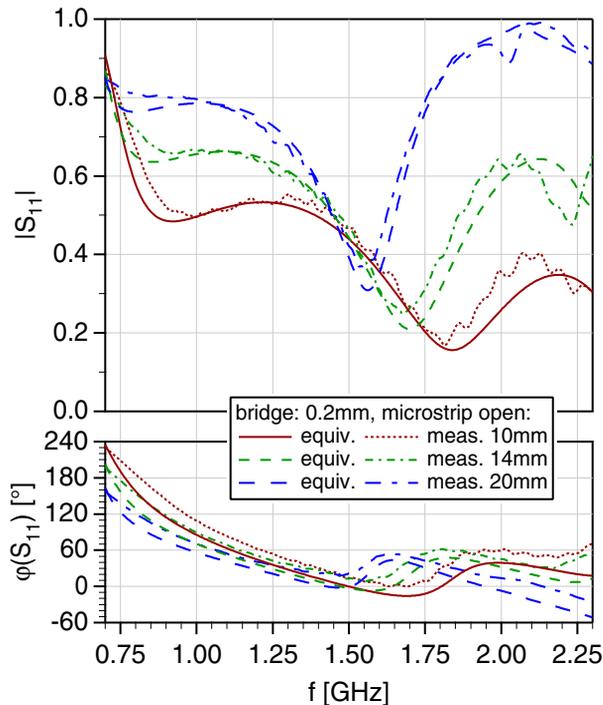
Figure 9: S_{11} of equivalent circuit and test structure.

SUMMARY AND OUTLOOK

The developed planar pick-up electrode has a large bandwidth and is suitable for a large aperture. The field measurement shows, that even the test structure (Fig. 6) has a relatively flat amplitude and very flat phase versus the frequency over one octave. The field measurements of the test structure together with S-parameter measurements pro-
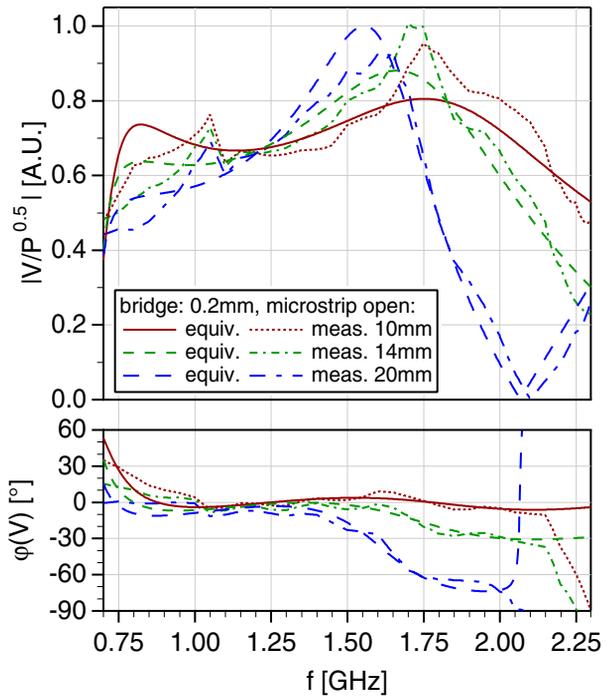
Figure 10: Voltage over the slot of equivalent circuit and test structure.

vides data to construct an adequate equivalent circuit. This circuit has been used to optimize the layout. The result of the simulation (Fig. 2) in promising.

The next step will be a field measurement of a complete module using the field mapper and the middle wire method.

REFERENCES

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[3] Program "Microwave Office", Applied Wave Research Inc., 1960 E. Grand Avenue, Suite 430, El Segundo, CA 90245, http://www.appwave.com

[4] Program "Microwave Studio", CST GmbH, Bad Nauheimer Straße 19, D-64289 Darmstadt, Germany, http://www.cst.de