# STOCHASTIC COOLING ELECTRODES FOR A WIDE VELOCITY RANGE IN THE CR

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*Abstract*

The CR storage ring is part of the FAIR project at GSI. It serves as a first stage of stochastic cooling for secondary rare isotopes at v/c=0.83 as well as for antiprotons at v/c=0.97. To avoid the installation of dedicated structures for each kind of beam, electrodes have been developed which are usable for both beams. They are based on slotline structures mounted perpendicular to the beam. They are shorted at the ends, and their signal is extracted by two striplines on the rear side, placed a quarter wavelength away from the open ends. The width of the structures can be adjusted to the initial betatron oscillation amplitudes. Their length is 25 mm, and the signal from many of these structures mounted in a row can be combined. The signal combination can be matched to the different beam velocities. The paper shows results from field calculations, prototype tests, and estimates of the signal combination efficiency. The beam impedance of the novel structures is compared with the superelectrodes applied in the former CERN AC and with the slow-wave structures currently installed in the FNAL Debuncher.

## PURPOSE AND SCOPE OF THE TECHNICAL DEVELOPMENT

The CR storage ring is part of the FAIR project at GSI (see [1], [2] and references therein). Its main purpose is stochastic precooling of antiproton (pbar) beams at 3 GeV ($\beta = 0.97$) and of secondary rare isotope (RI) beams at 740 MeV/u ($\beta = 0.83$). In order to accomplish these tasks without having to exchange stochastic cooling hardware components, it is desirable to dispose of a type of electrodes with the following properties:

- sufficiently high coupling impedance per installation length at both beam velocities (see below for definitions)
- high bandwidth
- usability as pick-up and kicker (with minor modifications)
- applicability in a high vacuum environment ($10^{-9}$ mbar)
- ease of manufacturing

In this article we describe the layout of a structure which is suitable as a vertical kicker for a beam chamber with a full vertical size of $\pm 53\mathrm{mm}$.

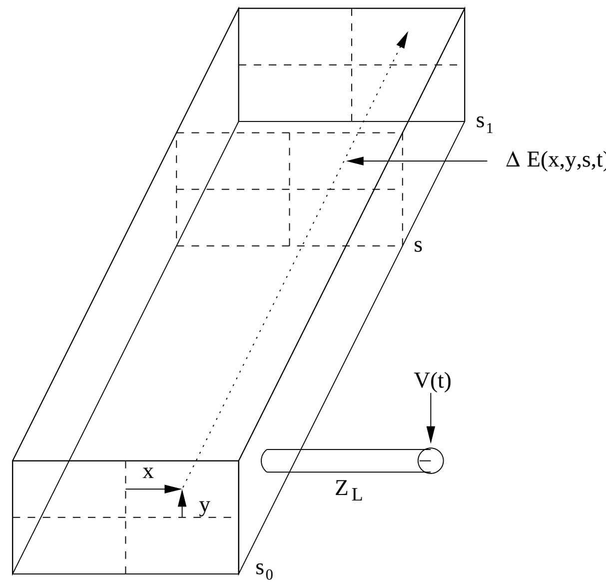


Figure 1: Basic Description of Pick-up or Kicker

## SENSITIVITY AND BEAM IMPEDANCE

The electrical properties of pick-ups or kickers with respect to a single particle with charge $Qe$ are usually parametrized either by a sensitivity $S$ or by an impedance $Z$. both descriptions are equivalent. If the device is operated at frequencies below the cut-off frequency of the beam chamber such that no waves can propagate, then it is reasonable to assume that the the reciprocity theorem holds. If the geometrical and electrical layout of pick-ups and kickers is the same, then both kinds of device can be described by the same impedance or sensitivity. In the following, we shall shortly characterize these properties quantitatively.

A kicker can be visualized (Fig.1) as a device which is fed through a (coaxial) input port where an input voltage $U_{in}$ and a line impedance $Z_L$ are well-defined. In the vacuum chamber, this voltage gives rise to an electric field, of which we are only interested in the longitudinal component. If the kicker is a linear device, then the voltage $V$ seen by a particle and the input voltage $U_{in}$ are related by

$$\frac{V(x,y,\Omega)}{U_{in}(\Omega)} = S(x,y,\Omega) = \sqrt{\frac{Z_{ki}(x,y,\Omega)}{Z_L}}$$

The sensitivity $S$ describes therefore how effectively the input voltage is translated into an accelerating voltage. $Z_{ki}$ is called kicker impedance. As $V$ is the integrated electric


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field along the path of the particle, $S$ and $Z_{ki}$ depend on the particle velocity. If the same device is used as a pick-up and if reciprocity holds, then a single particle passing the structure with an angular revolution frequency $\omega$ gives rise to an output voltage

$$U_p(\Omega) = \sum_{m=-\infty}^{\infty} \frac{Z_L Q e \omega S(x,y,\Omega)}{2} \delta(\Omega - m\omega)$$

These relations are written in terms of Fourier transforms, where frequencies of both signs occur. If reciprocity holds, one can define the pick-up impedance of the structure by

$$Z_{pu}(x,y,\Omega) = \frac{Z_{ki}(x,y,\Omega)}{4}$$

and for a circulating particle with revolution frequency $f = \omega/2\pi$ the single particle output power measured by a spectrum analyzer at each (positive) revolution harmonic is $P = Z_{\mathrm{pu}} I_{\mathrm{eff}}^2$, where $I_{\mathrm{eff}} = \sqrt{2}Qef$ is the effective single particle current.

## ELECTRODYNAMIC LAYOUT OF THE STRUCTURE

### *Concept of the Structure*

The slotline electrode is a novel electrode structure which was originally proposed with a somewhat different geometry by one of us in 1987 [3]. The coupling mechanism is provided by a slotline which is mounted transversely to the beam. In case of a pick-up, the mirror current of the beam has to cross the slots, inducing travelling waves into both directions of the slotline. The slotline is shorted at both ends. The waves are coupled out by a microstrip line mounted on the rear side of the structure, crossing the slotline a quarter wavelength before the shorted ends. The microstrips have open ends a quarter wavelength away from the crossing point. To minimize impedance jumps the microstrip couplers are broadened below the slotline.

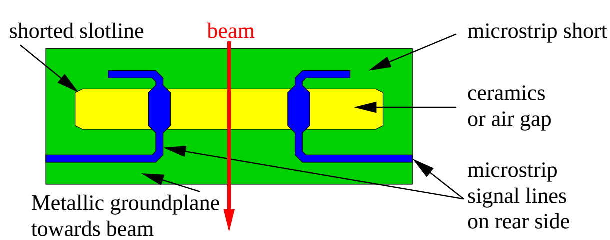


Figure 2: Conceptual Layouut of Slotline Electrode

Due to the short length of the slotline in the beam direction, the sensitivity of the device tends to be independent of the beam velocity. Moreover, many of these single electrodes can be mounted in the beam direction.

### *Field Calculations*

The geometrical layout of the structure was performed by using electromagnetic field models [4], [5], [6], [7], [8]. A quadratic beam chamber with a height of 106 mm was assumed and the calculations were performed for operation in a band 1-2 GHz. The studies were made for a longitudinal kicker. In a first step, the geometrical parameters of a single structure were optimized in order to optimize its sensitivity-bandwidth product. Several structures in a row were studied to achieve a high impedance per installation length. It turns out that 25 mm in the beam direction are sufficient for a single electrode. The effective width (inside which the sensitivity does not drop off too much) spanned by the electrode can be enlarged by thin ceramics in the slot or even by replacing the ceramics completely by an air gap.

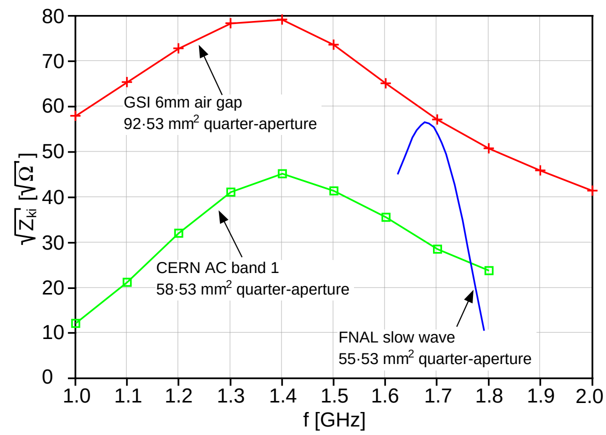


Figure 3: Comparison between different longitudinal kicker electrodes for $\beta = 0.97$ and a vertical distance of 53 mm to the beam

Detailed calculations were performed by one of us (L.T.) to relate the behaviour of long arrays of slotline electrodes to other, well-estalished structures. Fig. 3 shows a comparison of the slotline structure with quarter-wave structures formerly installed in the CERN AC and with an adapted slotted waveguide structure like the ones presently used in the FNAL Debuncher [9]. The calculations were made with a full installation length of 2 m, containing either 80 slotline electrodes, 23 quarter-wave superelectrodes, or a scaled slotted waveguide with 80 cells at a length of 32.5 cm without coupler. With respect to the quarter-wave structure, the impedance is clearly superiour, and it is competitive with the slotted waveguide. The latter one, however, is difficult to optimize for different beam velocities as required for the FAIR Collector Ring, because its usable frequency band depends on particle velocity. Furthermore, due to the strong field coupling with the beam chamber, plunging the slotted waveguide does not seem to be practicable. However, the required final beam parameters at the CR appear to be attainable only with plunging electrodes.

### *Model Measurements*

The field theoretical calculations were tested with models. Fig.4 shows the beam side of a model with four slotlines in a row. Fig.5 displays the rear side with microstrip

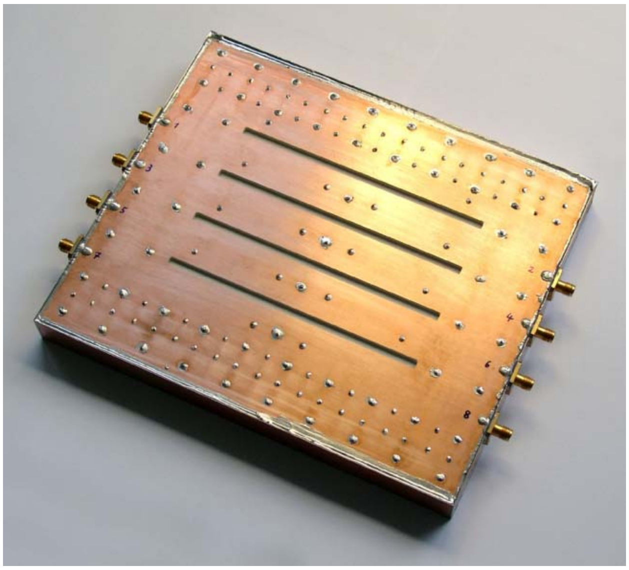

Figure 4: Slotline Electrode Model Beam Side

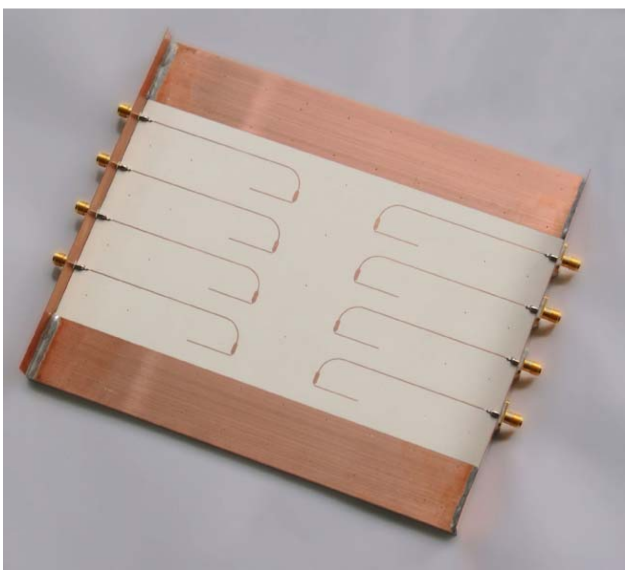

Figure 5: Slotline Electrode Model Rear Side

lines ending at the left and right sides of the model. A combiner was used in the measurements in order to get the sum signal from both ends. The fields were measured using a computer-controlled E-field mapper.

Fig.6 shows the amplitude and phase of the transmission from the field probe to the output port of the combiner at one of the central slotlines. The remaining microstrip lines were terminated. The field probe was mounted 5 mm above the slot. The transmission was measured at several horizontal positions parallel to the slotline. Position 0 corresponds to the slotline center, the microstrip lines cross the slotline at $\pm 19$ mm, and the slotline ends at $\pm 60.5$ mm. The transmission is proportional to the longitudinal sensitivity of the device. The measurements display:

- a reasonably flat amplitude and phase characteristics over nearly one octave,
- an almost position-independent phase,
- high sensitivity across a large width. Even beyond the microstrip crossings, a useful signal appears and the sensitivity drops to about one half of the central value at roughly 2/3 of the distance from the center to the end of the slotline.

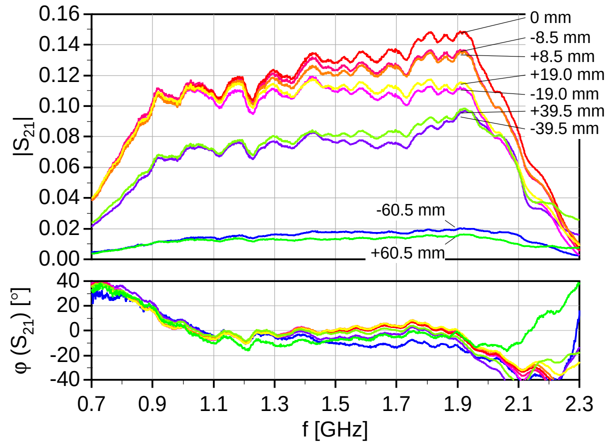


Figure 6: Results of Model Measurements

## CONCLUSIONS AND OUTLOOK

The slotline has turned out to be the structure which seems to fit best to the requirements of the CR stochastic cooling system. It features high sensitivity or coupling impedance with a sufficiently good versatility with respect to particle velocity. It is therefore favoured for installation into the CR.

In a next step, a longer model has to be designed with 8 slots in a row including signal combination.

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## REFERENCES

[1] P. Beller, K. Beckert, A. Dolinskii, B. Franzke, F. Nolden, C. Peschke, M. Steck, Proc. EPAC 2004, 1174-1176

[2] A. Dolinskii, K. Beckert, P. Beller, B. Franzke, F. Nolden, M. Steck, Proc. EPAC 2004, 1177-1179

[3] F. Caspers, Proc. PAC 1987, 1866-1868

[4] M. Balk, T. Weiland, F. Nolden, GSI annual report 2002, 205

[5] M. Balk, T. Weiland, F. Nolden, GSI annual report 2003, 260

[6] M. Balk, T. Weiland, F. Nolden, GSI annual report 2004, in the press

[7] F. Nolden, C. Peschke, L. Thorndahl, GSI annual report 2004, in the press

[8] C. Peschke, F. Nolden, M. Balk, Nucl. Inst. Meth A 532 (2004) 459-464

[9] D. McGinnis, Proc. PAC 1999, 1713-1715

 0-7803-8859-3/05/$20.00 ©2005 IEEE