Fullwave Analysis of Planar Microwave Transmission Lines as High-Frequency Pickup and Kicker Devices for Stochastic Cooling *

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Abstract

This paper presents the behaviour of microstrip lines working both as pickup and kicker devices in stochastic cooling systems. Based on a field-theoretical fullwave analysis the interaction between beam and signal electrodes is discussed.

1 INTRODUCTION

Pickup and kicker devices are key-components in stochastic cooling systems, since they are responsible for the direct interaction with the particle beam. The most commonly used electrodes are so-called loop couplers. Since their length has to be adjusted to approximately a quarter wavelength at system midband frequency, they tend to be the shorter the higher midband frequency rises. Due to the 3d-nature of these couplers this leads more and more to mechanical problems regarding their construction. In order to overcome those difficulties developments are in progress which apply planar transmission lines instead of loop couplers [1,2]. In the planar concept the transmission lines are fixed on a substrate. Fabrication techniques like e.g. photolithography have been well developed with very high accuracy due to their extensive application in high-frequency circuits. In this paper, as an example of the planar concept, the microstrip line is investigated as pickup and kicker device (see Fig. 1). The main difference with respect to common loop couplers is that this electrode supports waves propagating perpendicularly to the beam direction.

Both for kicker and pickup calculations, the beam is simulated by means of a single charge q travelling with arbitrary velocity $v_b = \beta c$ along the y-axis.

2 MICROSTRIP AS KICKER

For kicker operation the microstrip line under consideration is fed at each termination by voltage sources which differ only in phases. Thus, in this case the microstrip works as a Transverse Standing Wave System (TSWS [1]). The main feature of kicker devices for the application in stochastic cooling systems is the possibility to time three different directions of particle deflection (i.e. x, y, z) only by means of different signal phases. This leads for the microstrip to general relations between the phases $\varphi_1, \varphi_2, \varphi_3, \varphi_4$, and $k_z l$, where k_z denotes the wave propagation constant and l is the electrode length. However, for the particular case

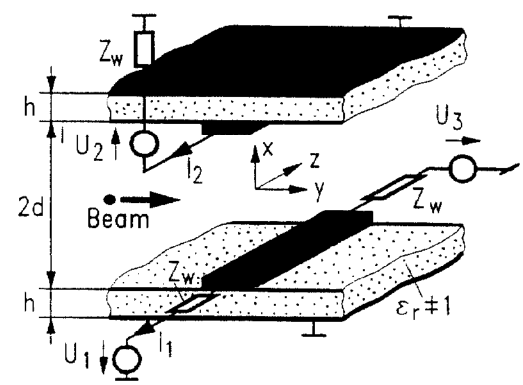

Figure 1: Microstrip line with stripwidth w as electrode

$k_z l = 3\pi/2$ the phases of the voltage sources are given in table 1 for each mode of kicker operation. Herein it is provided that the particle arrives at the time $t = 0$ at the location $z = 0$.

mode	φ_1	φ_2	φ_3	φ_4
x-kick	$-\frac{\pi}{2}$	$-3\frac{\pi}{2}$	$-\frac{\pi}{2}$	$-3\frac{\pi}{2}$
z-kick	0	0	π	π
y-kick	0	0	0	0

Table 1: The source voltage phases φ_i of each kicker mode for $k_z l = 3\pi/2$

For characterization of coupling between the particle beam and the respective deflecting electromagnetic fields the kicker constants [4] $K_i, i \in (x, y, z)$, resulting from the integration of the Lorentz force along the particle path is calculated. Hereby the field problem is solved by means of a fullwave finite-difference method in frequency domain [3].

$$K_i = \Re\left\{ \int_{-\infty}^{+\infty} \left[E_i(x,y,z,\omega) + (\vec{v}_b \times \vec{B}(x,y,z,\omega))_i\right] e^{j\omega y/v_b}\, dy \right\} \tag{1}$$

with $i \in (x, y, z)$.

2.1 Frequency Dependence of Beam Coupling

The dependence of kicker constants on frequency is shown in Figs. 2–4, for the respective mode of operation and for particles with different velocities travelling at x=z=0.

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Each constant generally tends to zero if frequency varies

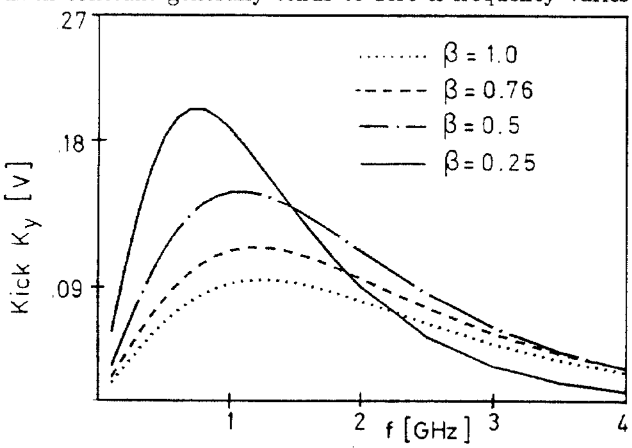

Figure 2: Long. kick K_y with h=2.5mm, w=2.25mm, d=15mm, ϵ_r=9.8, input power p=1/(30π)W; ($Z_w \approx 50\Omega$)

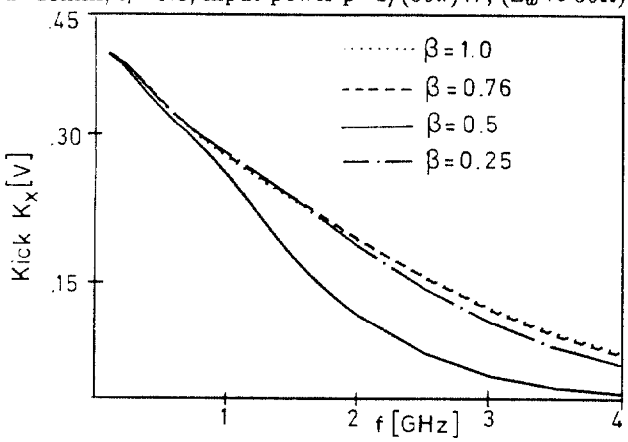

Figure 3: Vertical kick K_x with h=2.5mm, w=2.25mm, d=15mm, ϵ_r=9.8, input power p=1/(30π)W; ($Z_w \approx 50\Omega$)

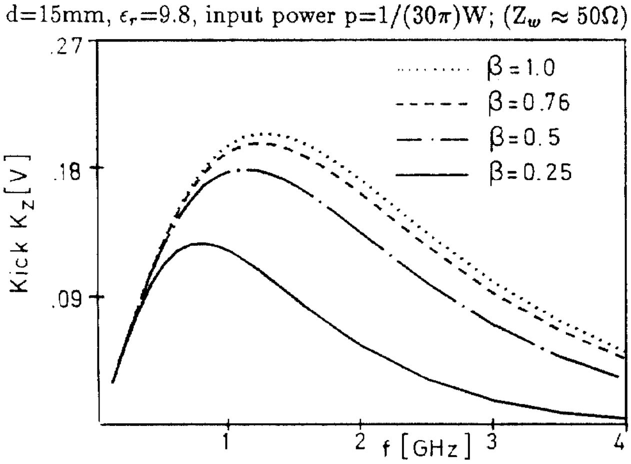

Figure 4: Horizontal kick K_z with h=2.5mm, w=2.25mm, d=15mm, ϵ_r=9.8, input power p=1/(30π)W;($Z_w \approx 50\Omega$)

up to ∞, since in that case the particle receives along a very short distance Δy two kicks of almost the same value, but into opposite directions. Due to the symmetry of the microstrip mode regarding y=0, both the longitudinal (K_y) and horizontal kick (K_z) vanish while the vertical kick (K_x) reaches its maximum as frequency approaches zero. Between these limits K_y and K_z reach maximum values for a particular frequency f_{max}, which depends on microstrip dimension, beam velocity and field distribution. If the dielectric material is completely removed the wave along the line is of TEM-type and the field distribution does not depend on frequency. In that case the frequency for maximum kicks K_y and K_z reads

$$f_{max}/\mathrm{GHz} \approx \beta \frac{d}{w+h}. \tag{2}$$

With inserted permittivity, however, the field strongly depends on frequency and the formula given in Eqn. 2 is to be considered only as a very rough estimation, which gets the worse the larger β is.

In comparison to the common loop coupler it should be pointed out that frequency behaviour differs significantly. For the envisaged cooling system at GSI (frequency range 0.9 – 1.6GHz, $\beta = 0.76$) with two loop couplers combined by means of a transmission line [6] the dependence on frequency regarding K_y and K_z is much stronger than for the TSW-coupler. While these coupling coefficients of the presently used GSI electrodes vary in the system range up to 50% with respect to their maximum at midband, the TSW-electrode suffers only approx. 10%.

Furthermore, the vertical kick K_x varies only very little for different beam velocities. Due to the dielectric substrate, both the electric and magnetic field contribute to the kick. However, although these contribution themselves depend on frequency and beam velocity their superposition cancels the velocity dependence.

2.2 *Limitation of Horizontal Beam Dimension*

Due to the standing wave each kicker constant behaves $\sim \cos(k_z z)$. Therefore, the dimension of the beam with respect to z-direction has to be limited to

$$A_{hor} = \pi / k_z \tag{3}$$

in order to ensure that each particle in the transverse (x, z) plane receives a kick into the same direction. As can be taken from Fig. 5 this aperture mainly depends on the choice of the dielectric material.

For possible application of this kicker device in the stochastic cooling system of the Experimental Storage Ring (ESR) at GSI an aperture of at least 11cm is required. Since the dielectric material Al_2O_3 which is commonly used in an UHV-environment leads only to an aperture of approx. 5cm, it can not be applied in the same way as shown in Fig. 1. One possibility to overcome this restriction is to remove as much as possible permittivity below the line and to use Al_2O_3 only as supporting posts at discrete locations z_i.

Furthermore, it has to be mentioned that this particular limitation generally also exists if other planar lines are used. However, in the case of slot-lines instead of microstrip [1] the aperture is about the same range.

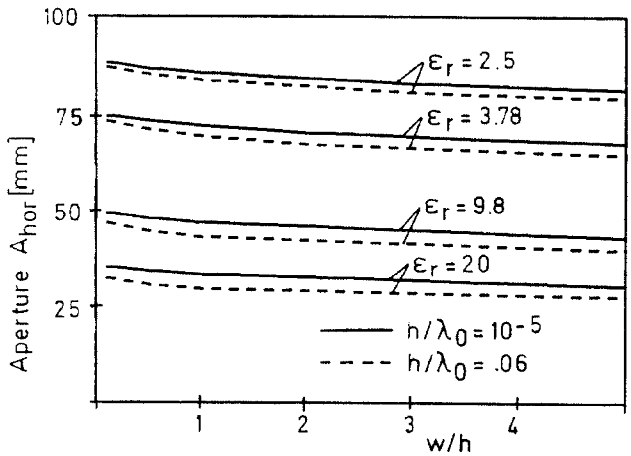

Figure 5: The beam aperture A_{hor} into z-direction with respect to frequency f, permittivity ϵ_r and geometry w,h

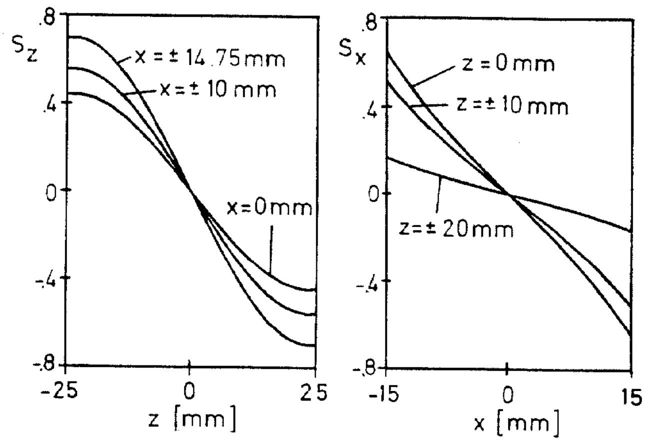

Figure 6: Vertical (S_x) and horizontal (S_z) pickup sensitivities with h=2.5mm, w=2.25mm, d=15mm, ϵ_r=9.8, β=0.76 and f=1.25GHz

2.3 *Parasitic Kicks*

As mentioned above the ideal kicker for stochastic cooling systems should allow to time the different modes of operation merely by means of the feeding voltage sources. Furthermore, if the ideal kicker works in a particular mode each particle in the cross section of the beam has to be kicked solely into one direction.

However, it can be shown that the TSW-coupler behaves ideal in that way only with respect to the 'y-mode' (i.e. kick into y-direction). But due to symmetry of field distribution particles travelling at positions x≠0 receive in x- and z-mode operation a parasitic kick $\sim \sin(k_x z)$ into z- and x-direction, respectively.

3 MICROSTRIP AS PICKUP

Working as a pickup the lines are not anymore fed with voltage sources, but the currents I_i induced by the beam are measured at the terminating impedances Z_w. The main requirement of a pickup is to deliver information about the beam position by means of combining the output signals. Thus, as a measure of pickup performance the sensitivities S_x and S_z which are defined as

$$S_z = \frac{(I_1+I_2)-(I_3+I_4)}{-I_0} \quad S_x = \frac{(I_1-I_2)+(I_3-I_4)}{-I_0} \tag{4}$$

are taken into account (I_0 denotes the beam current).

However, applying reciprocity theorem [5] the induced currents can be calculated based on the field computations which were earlier performed for kicker characterization (in section 2).

As shown in Fig. 6 this coupler concept generally does not allow to definitly identify the beam position. Hence, it owns the same drawback as the loop coupler configuration used at GSI [6].

Furthermore, also in the application of the microstrip as pickup the cross section of the beam has to be limited regarding z-direction in order to detect at least the correct sign of beam offset.

4 CONCLUSION

For the application of the microstrip line given in Fig. 1 both as pickup and kicker device the following features can be comprehended:

- In the operation as TSW-kicker only the y-mode behaves ideal, while parasitic kicks are produced both in x- and z-mode, depending on the particle path.
- The cross section of the beam has to be limited with respect to z-direction. This limitation mainly depends on the dielectric material.
- Applied as pickup it is only possible to determine the direction of beam offset, but not the definite beam position.
- Coupling depends less on frequency in comparison to common loop couplers.
- Due to well established fabrication techniques many microstrips can easily be combined.

5 REFERENCES

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