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# FAST EXTRACTION KICKER FOR THE ACCELERATOR TEST FACILITY\*

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## Abstract

We present the results of a study for the design of a fast extraction kicker to be installed in the Accelerator Test Facility ring at KEK. This activity is carried on in the framework of the ATF2 project, which will be built on the KEK Tsukuba campus as an extension of the existing ATF, taking advantage of the world's smallest normalized emittance achieved there. ATF2's primary goal is to operate as a test facility and establish the hardware and beam handling technologies envisaged for the International Linear Collider. In particular, the fast extraction kicker object of the present paper is an important component of the ILC damping rings, since its rise and fall time define the minimum distance between bunches and ultimately the damping rings length itself. Building on the initial results presented at EPAC '06, we report on the present status of the kicker design and define the minimum characteristics for pulsers and other subsystems. In addition to the original scheme with multiple stripline modules producing a total deflection of 5 mrad, we also investigated a scheme with a single kicker module for a reduced deflection of 1 mrad placed inside a closed orbit bump, which takes the electron closer to the extraction septum.

## INTRODUCTION

We have already calculated the fundamental parameters of a kicker for single bunch extraction in the ATF [1]. Given the space limitation in the ring, we chose to operate with three stripline modules placed in two different locations, each 65 cm long. To minimize the kicker's impact on the beam impedance we chose to have a 24 mm distance between electrodes as our target. This distance is equal to the beam pipe diameter, so that discontinuities from the bunch wake field point of view are minimized as possible. The coverage angle was chosen equal to 120 for each stripline electrode. This is a classic configuration for stripline kickers, since smaller angles reduce the kicking field, while larger angles increase the beam coupling impedance and require larger beam pipes to obtain a 50  $\Omega$  characteristic impedance, although they don't result in a substantial reduction of the required voltage.

In Tab.1 we summarize the calculated kicker parameters for the chosen configuration, together with the main specifications of the project.

In the following section we show our computer simulation using the EM modeling suite Microwave Studio [2], where we studied the electromagnetic fields time evolution in correspondence of a complete cycle, from the beginning of a pulse to the passage of the next

trailing bunch through a kicker's module.

We also studied the uniformity of the kicking field and calculated the kicker's S-parameters, its coupling and transfer impedance.

In the third section, we then repeat the calculations for a different kicker configuration utilizing a single 50 cm long module for a 1 mrad deflection inside a closed orbit bump.

Finally, we discuss some critical aspects concerning the kicker's pulsers and feedthroughs.

Table 1: Relevant ATF parameters and fast kicker specifications (3-modules configuration).

Beam energy $E_b$	1.28 GeV
Beam pipe radius $r_p$	12 mm
Bunch spacing $t_b$	5.6 ns
Deflection angle $\theta_k$	5 mrad
Kick repetition rate $f_{rep}$	3 MHz
Total kicker length $L_T$	1.4 + 0.8 m
Kicker field at $t=t_0 + t_b$ $E(t_0 + t_b)$	$<7 \cdot 10^{-4} E(t_0)$
Required stripline voltage $V_k/2$	21 kV
Shunt impedance $R'_s$	250 k $\Omega$
Peak power $P_k$	7 kW
Average power (at 3 MHz) $P_{avg}$	100 W

## COMPUTER 3D ELECTROMAGNETIC MODELLING OF THE KICKER

Following the analytical calculation and 2D electromagnetic modeling, we undertook a careful three-dimensional computer model of our kicker module to described in [2]. Figure 1 shows a view of our Microwave Studio 3D model of a 650 mm long stripline module with 5:1 tapers. We designed some simple 50  $\Omega$  feedthroughs, with Teflon dielectric and standard N-Type connector dimensions. It will be discussed in a later section how, in fact, the choice of an appropriate high-power, high-voltage feedthrough is one of the critical points in the kicker design. We used this simple connector in order to be able to proceed in the analysis described in the following. Once a suitable feedthrough is identified the striplines will be optimized to ensure good impedance matching. Also, in Fig.1 one can see the 5:1 ratio tapers, which are used to reduce the kicker impedance,

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connecting the 22 mm radius kicker chamber to the 12 mm beam pipe.

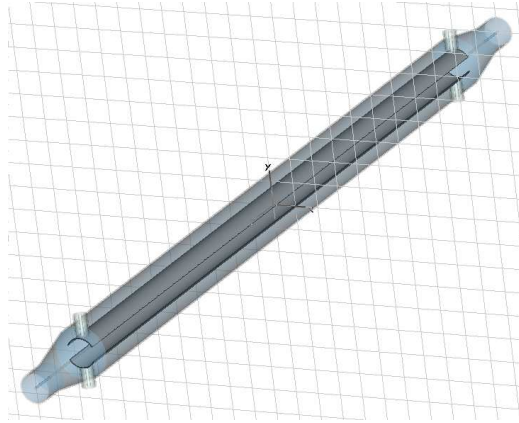


Fig.1. View of the kicker CAD model (Microwave Studio) with tapers, feedthroughs and coaxial wire.

Finally, Fig.1 also shows a coaxial wire of 2 mm diameter running through the module. This is of course no part of the kicker, but we used it to measure coupling and transfer impedance, by realizing a “virtual” measurement of the S-parameters, the same way as this is done in “hardware” with the classic coaxial-wire method for bench measurements.

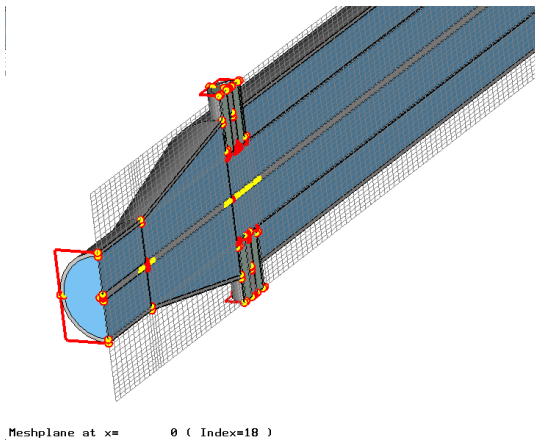


Fig.2. Detail of the simulation mesh in correspondence of one of the kicker extremities.

Figure 2 shows the automatically generated mesh on the module mid-section. We choose a minimum of 15 meshpoints per wavelength, which are increased in correspondence of critical points.

Microwave Studio is an FDTD based code and therefore especially well suited for analyzing the transient behaviour of the kicker in correspondence of a given excitation waveform. We used an excitation voltage with a  $t_{fl}=5.45$  ns long flat top which allows for an extra 1 ns filling time, compared to the theoretical 4.34 ns (2 times kicker length divided by the speed of light), in order to reach a more uniform deflecting field. Rise time  $t_r=150$  ps and fall time  $t_f=300$  ps were chosen according to the current state of the art for fast pulsers [3]. The simulation was extended to 11.3 ns, corresponding to the passage through the module of the trailing bunch.

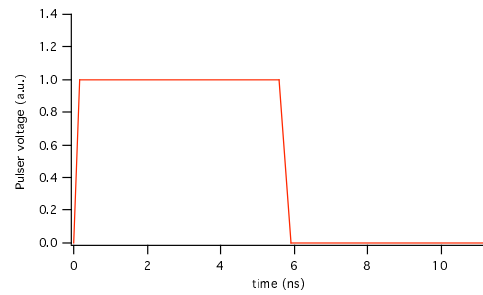


Fig.3. Pulser waveform.

The pulser waveform is shown in Fig.3.

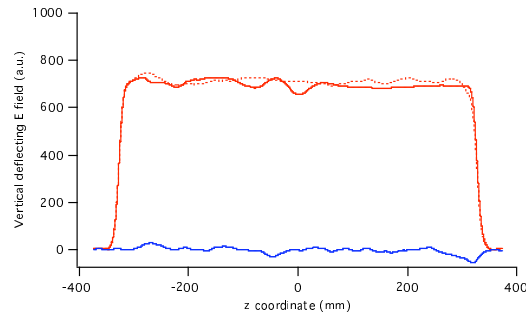


Fig.4. Vertical electric field ( $E_y$ ) along the nominal orbit when the bunch enters module (solid red); bunch is at module mid-length (dashed red); trailing bunch enters module (blue).

Figure 4 shows the vertical deflecting field  $E_y$  calculated along the bunch ideal orbit. By comparing the solid red curve to the dashed one, taken with the bunch at  $z=-350$  (1 ns after the pulser firing) and  $z=0$  mm (2.1 ns after pulser firing) respectively, we can evaluate how 1 ns pre-firing of the pulser is sufficient to have the deflecting field reach a reasonably good flatness already when the bunch enters the module. The blue curve shows how much the field value has decayed when the trailing bunch reaches the module’s mid-length, its average value being reduced to  $5 \cdot 10^{-3}$  times.

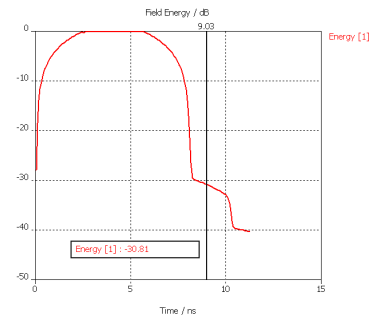


Fig.5. Normalized energy stored in a stripline module.

Residual field levels can also be evaluated by looking at the time evolution of the energy stored in the module (Fig.5), which we calculated to be at least 30 dB below it’s peak value. In addition, one has to consider that this is a free oscillating field and the residual level in a real kicker will be lower due to ohmic losses.

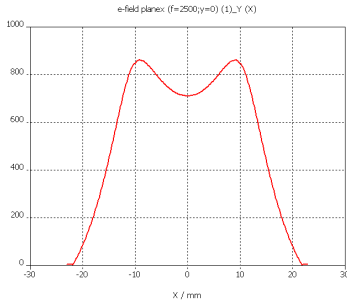


Fig.6. Transverse distribution of deflecting field at kicker's mid-length.

Figure 6 shows the transverse distribution of the kicking field calculated in correspondence of the kicker mid-length. The field variation is below 1% of its central value over an excursion of 5 mm across the bunch nominal orbit.

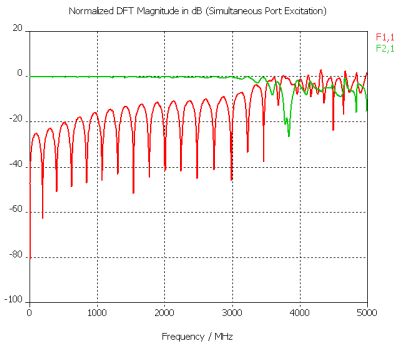


Fig.7. Calculated S-parameters between upstream and downstream feedthroughs: reflection (red) and transmission (green).

In Fig. 7 we show the calculated S-parameters between the two stripline ports, to verify impedance matching of the feedthroughs to the striplines. Even with our simple design there is an acceptable matching below 3 GHz, which will be improved after choosing the actual feedthroughs.

### Coaxial wire simulations

We also calculated the kicker longitudinal impedance simulating the classic coaxial wire method using Walling's formula for distributed impedances [4]

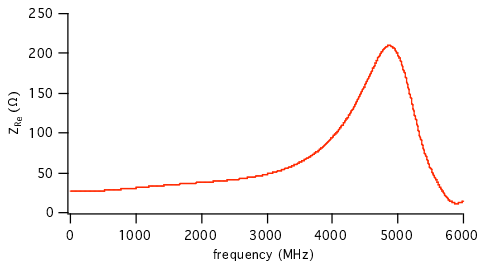


Fig.8. Real part of the longitudinal impedance.

With the data in Fig.8 it is possible to calculate the power deposition on the striplines and the beam energy loss (loss

factor). We analogously calculated the transfer impedance on both up and downstream ports.

## SINGLE KICKER MODULE WITH CLOSED ORBIT BUMP

We substantially repeated the calculations shown in [1] for a different extraction configuration where only 1 mrad deflection is required, but the kicker length has to be less than 60 cm. Table 2 shows those kicker's parameters, which are different from the original configuration.

Table 2: Relevant ATF parameters and fast kicker specifications (3-modules configuration).

Deflection angle $\theta_k$	1 mrad
Total kicker length $L_T$	0.6 m
Required stripline voltage $V_k/2$	16.5 kV
Shunt impedance $R'_s$	150 k $\Omega$
Peak power $P_k$	1.8 kW
Average power (at 3 MHz) $P_{avg}$	30 W

One can notice how, due to the lower average power it would be possible in principle to use in-vacuum ferrite loads in case a shorter field decay time is desired.

We run a 3D computer simulation for the transient response for this kicker as well and calculated its impedance. Our results don't suggest any additional problems.

## CONCLUSIONS

From the results presented in this paper we can recognize the two critical aspects in the realization of a fast extraction kicker, namely: pulser time response and maximum repetition rate, and feedthroughs power handling capabilities. Both aspects are strictly correlated to the 3 MHz repetition rate chosen, since pulsers with even higher voltage than needed and sufficient wavefronts steepness are already available on the market for lower repetition rates. Also, the feedthroughs, which in our case have to withstand powers above 100 kW, could be bought off the shelf. Nonetheless, the design of a 3-6 MHz 10kV pulser is underway and we have identified a possible solution for the feedthrough, which we are planning to test in early 2008.

## REFERENCES

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