

# ABSOLUTE BEAM POSITION MONITORING USING HOM-DAMPER SIGNALS<sup>\*</sup>

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## Abstract

To preserve the required beam quality in an  $e^+/e^-$ -collider it is necessary to have a very precise beam position control at each accelerating cavity. An elegant method to avoid additional length and beam disturbance is the usage of signals from existing HOM-dampers. The magnitude of the displacement is derived from the amplitude of a dipole mode whereas the sign follows from the phase comparison of a dipole and a monopole HOM. To check the performance of the system, a measurement setup has been built with an antenna which can be moved with micrometer resolution to simulate the beam. Furthermore we have developed a signal processing to determine the absolute beam displacement. Measurements on the HOM-damper cell can be done in the frequency domain using a network analyser. Final measurements with the nonlinear time dependent signal processing circuit has to be done with very short electric pulses simulating electron bunches. Thus, we have designed a sub nanosecond pulse generator using a clipping line and the step recovery effect of a diode. The measurement can be done with a resolution of about 10 micrometers. Measurements and numerical calculations concerning the monitor design and the pulse generator are presented.

## 1 INTRODUCTION

To explain the principle of operation, we take a look to the modes of a single pillbox resonator. On the one hand, the monopole modes have a nearly constant longitudinal electrical field near the axis. Therefore their excitation by a bunch of charged particles does not depend on the displacement. The amplitude after a passing of a bunch is proportional to the charge of the bunch, the starting phase is independent of the displacement. On the other hand, the dipole modes have no longitudinal electrical field on the axis. Off-axis the field rises with the first Bessel function. Near the axis, the amplitude after a passing of a bunch is proportional to the magnitude of displacement and the charge, the starting phase ( $0^\circ/180^\circ$ ) depends on the sign of the displacement.

So we can use the complex amplitude of a dipole mode to measure the absolute beam position in one azimuthal direction. A higher monopole mode serves as a phase reference to detect sign of bunch displacement. The accelerating mode is not useful for this purpose since amplitude is dominated by the klystrons.

One possibility for the choice of a suitable monopole mode is the  $TM_{011}$  pillbox mode. Due to the fact of different frequencies of the  $TM_{011}$  and  $TM_{110}$  mode phase comparison of both modes is very difficult. This method was described in a preceding paper [1].

To simplify the method it is desirable to have the same frequency for both modes. This would simplify the synchronisation with the bunch and reduces the number of intermediate frequency stages which leads to a considerable reduction of costs. Thus one needs an additional monopole-like mode with the frequency of the  $TM_{110}$  dipole mode. This is ensured by the presence of reflections in waveguide corners of the HOM-damping system attached (see for example the SBLC [2] HOM-damping system).

One suitable mode was found by a MAFIA-simulation (eigenmode solver) of the coupler cell closed by electrical boundaries within the iris and waveguide flanges. The mode on the left hand side of Figure 1 is the desired mono-

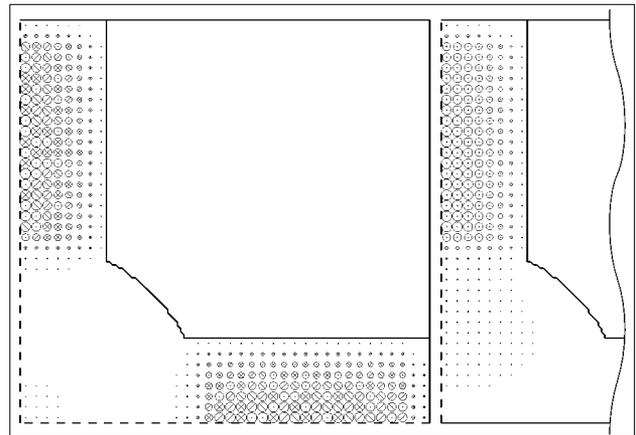


Figure 1: MAFIA[3]-simulation of the coupler cell: monopole-like waveguide mode at 4.1682 GHz and dipole mode at 4.1115 GHz.

pole mode with electrical field on axis. On the right hand side one sees the dipole pillbox mode geometry changed by the damping system attached. Due to the strong damping effect on both modes, the resonance curves are widely overlapped. Thus one can choose a frequency near both resonances. To proof the existence of the monopole mode and their coupling to the beam a MAFIA time domain simulations have been done.

<sup>\*</sup> Work supported by DESY/Hamburg and BMBF under contract 06OF841

## 2 FREQUENCY DOMAIN MEASUREMENTS

For the measurements the beam was simulated by a movable antenna nearby the axis. Therefore a positioning system has been build with a mechanical resolution of 1.23 micrometers. As long as all components of the signal processing electronics are linear and time invariant, the measurements can be done in frequency domain. During the measurements the RF-source was connected to the movable antenna. The signals of the modes were detected by two pick-up antennas mounted in the waveguides of the damping system. The separation of monopole and dipole signals were done by a  $180^\circ$  ring hybrid which delivers the sum and the difference of the signals. Figure 2 shows mag-

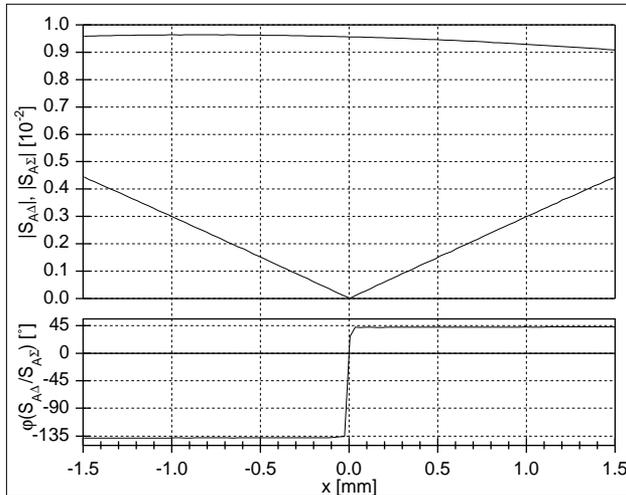


Figure 2: Transmission from antenna to  $\Sigma$ - and  $\Delta$ -Port at 4.198 GHz in dependence of the displacement.

nitude and phase of the transmission from the movable antenna (A-Port) to the  $\Sigma$ - (monopole signal) and the  $\Delta$ -Port (dipole signal) of the hybrid depending on the position of the input antenna. As expected, the dipole signal rises linearly with the magnitude of displacement and the phase between monopole and dipole signal jumps by  $180^\circ$  at zero displacement. Furthermore the result shows a much stronger coupling to the monopole than the dipole mode. Even at positions far off axis (1.5 mm) the monopole transmission is two times the dipole transmission. Thus it is clearly shown that the  $180^\circ$  ring hybrid is necessary.

Figure 3 shows the ratio of dipole to monopole transmission in magnitude and phase with the maximum resolution of the positioning system. This measurement was performed at optimum frequency of 4.197 GHz. We found a phase jump within 1.23 micrometers on axis. Apart from the optimum frequency the minimum is flatter and is further away from zero. Due to the fact of mechanical tolerances of the damping system, the electrical axes of the monopole and the dipole modes are different (Figure 2). Thus the electrical field of the monopole mode is not constant near the axis of the dipole mode. Together with the

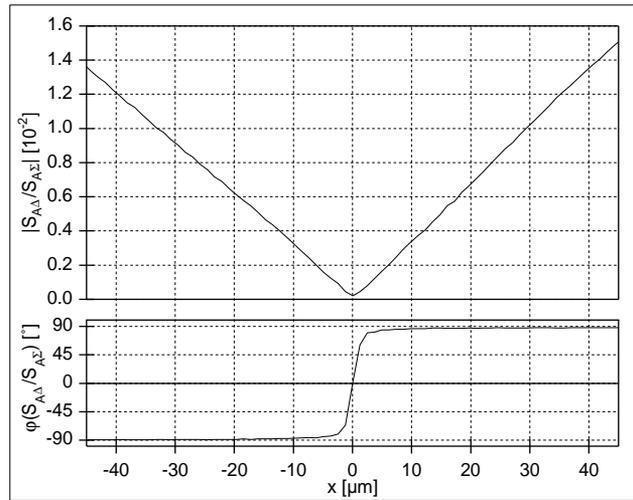


Figure 3: Transmission ratio at 4.197 GHz in dependence of the displacement.

limited isolation of the hybrid the signal is not symmetric, which causes a relative inaccuracy of 6 % of the beam displacement.

Further measurements with the nonlinear time dependent signal processing circuit have to be done with very short electric pulses simulating electron bunches.

## 3 BEAM SIMULATIONS BY SHORT PULSES

The requirements to produce a short pulse are small transition time and small pulsewidth. A 10 MHz oscillator pulse is shaped by a clipping line and the transition time is shortened by a step recovery diode. The pulse generator is realized on a single microstrip line printed circuit board completely. The schematic configuration is shown in Figure 4.

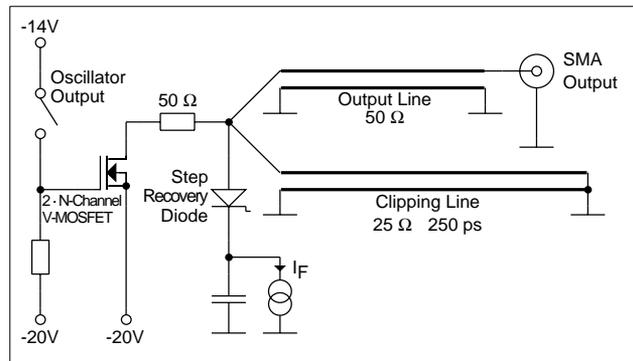


Figure 4: Schematic of a fast pulse generator (simplified).

The step recovery diode can be described as fast switch reducing the fall time of the oscillator pulse. A forward bias  $I_F$  stores charge and the negative oscillator pulse, powered by two V-MOSFETs, causes a reverse bias  $I_R$  which depletes this charge, and when fully depleted the step recovery diode ceases to conduct current. The action of turning

off takes place within 100ps or less depending on forward and reverse bias and the specific carrier life time of the diode.

The clipping line changes the falling edge into a pulse, and pulse length is given by two times the delay of the clipping line which has to be longer than two times the rise time of negative edge. Otherwise the resulting pulse height decreases. To avoid multiple reflections the entrance of the clipping line, seen from the short end, should be matched. But due to presence of the diode capacity and parasitic inductances of the MOSFETs perfect matching is impossible. The effect of multiple reflections on the resulting pulse can be seen in Figure 5, after the desired negative pulse,

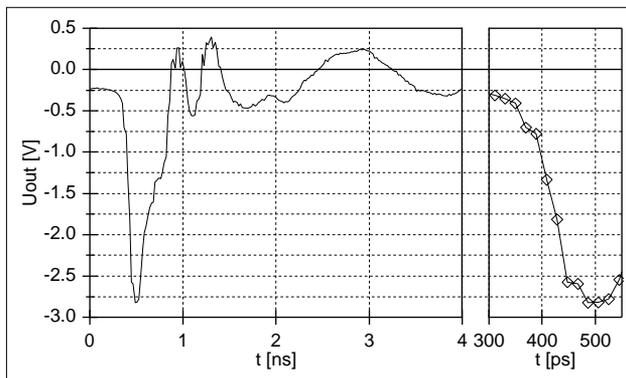


Figure 5: Measured output signal of the pulse generator in Figure 4.

which ends around 800 ps, the signal is oscillating around zero.

One possibility to get rid of the undesired multiple reflections caused by the mismatch of the clipping line is to connect the diode directly to the common drain of the MOSFETs. The disadvantages are now the parasitic inductances and capacities of the MOSFETs which influence the pulse stronger than before. On the other hand due to the inductances the pulse height is increased. Additionally length and impedance of the clipping line were optimized to achieve a more proper pulse. This is ensured by destructive interferences eliminating the parasitic oscillations. Furthermore leading parasitic oscillations can be minimized using a second line with an open end. All these precautions were verified numerically with the program SPICE [4] and are not yet realized experimentally. The configuration is shown in Figure 6 and the results are presented in Figure 7.

#### 4 CONCLUSION

The resolution of the HOM-damper beam position monitor is limited by strongly excited monopole modes. It has been shown that a resolution of 10  $\mu\text{m}$  seems possible. The relative inaccuracy caused by the axes offset of the monopole mode, which is in the order of 6 %, can be decreased by the construction of a new HOM-damping system which can be machined more precisely. Furthermore an inaccuracy due

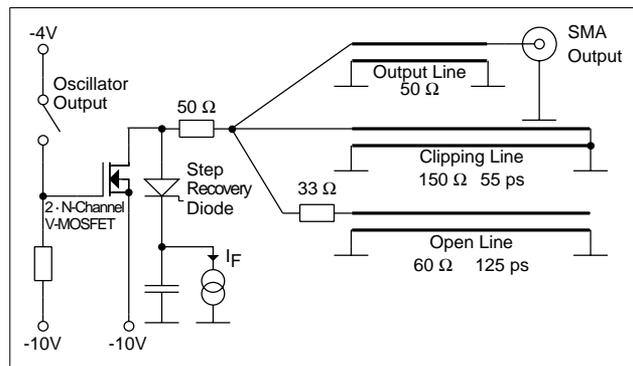


Figure 6: Schematic of an optimized pulse generator (simplified).

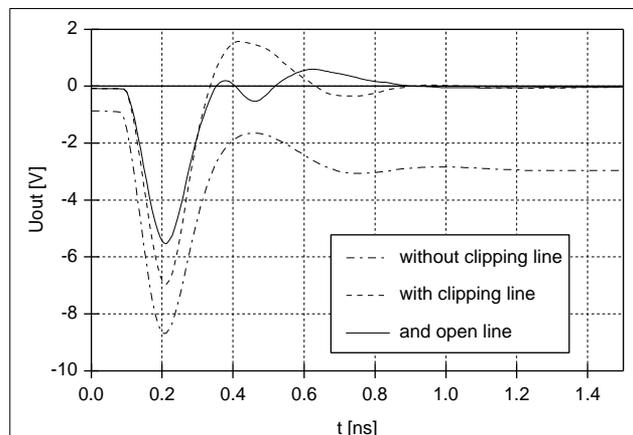


Figure 7: Calculated output signals of the pulse generator in Figure 6.

to the evanescent accelerating mode in the HOM-damping waveguides is expected. But this influence depends strongly on the signal processing electronics and has not yet been proven. For measurements with the pulse generator the new proposed setup (Figure 6) will be built and tested.

This concept of a beam position monitor can be applied to any high energy cavity type linac with symmetric HOM-damping system. Due to the synchronisation with a higher monopole mode, external synchronisation to the timing system of the linac is not necessary. Thus beam position monitoring is also possible in non accelerating cavities.

#### 5 REFERENCES

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