BEAM POSITION MONITORING FOR SBLC USING HOM-COUPLER SIGNALS[1]

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Abstract

To preserve the required beam quality in the proposed S-Band-Collider it is necessary to have a very precise beam position control at each accelerating structure. To avoid additional insertions the usage of the HOM-coupler signals would be advantageous. We present a conceptional design of the signal processing scheme capable to detect both sign and magnitude of a transversal beam displacement as well as the beam current. The magnitude information is derived from a dipole mode amplitude whereas the sign follows from the phase comparison of the dipole and a monopole HOM. Both signals are taken from a pair of pickups at the waveguide HOM-couplers.

1 INTRODUCTION

The longitudinal electrical field E_z of a TM_{mnp}-mode in a pillbox resonator is given by:

$$E_z(r, \varphi, z, t) = E_0 \cdot J_m\left(\frac{x_{mn}}{R} r\right) \cdot \cos(m\varphi) \cdot \cos\left(\frac{\pi p}{L} z\right) \cdot e^{i\omega z} \quad (1)$$

(r, φ, z is the position in cylindrical coordinates, t the time and E_0 the Amplitude)

For small displacements r, the E_z-field of dipole-modes is proportional to the displacement and the E_z-field of monopole-modes is constant. Therefore the amplitude of a monopole-mode excited by a particle is proportional to its charge and can be used for beam current measurements. The amplitude of a dipole-mode is proportional to the charge and the magnitude of the displacement and thus can be used for beam position measurement. To get the sign of the displacement, it is necessary to determine the phase between the monopole- and the dipole-mode at the time of particle passing. The start phase of the monopole-mode is independent of the displacement. On the other hand the start phase of the dipole-mode changed by 180˚ at the axis.

For a small displacement the energy loss of the particles into distinct modes is very different. Figure 1 shows the energy loss of a bunch, passing a six-cell resonator with a displacement of 100 µm (numerically calculated by MAFIA [1]).The highest energy loss is observed for the (TM_{010}-like $2\pi/3$) acceleration mode. The strongest excited dipole-mode is the TM_{110}-like $5\pi/6$-mode whereas the TM_{011}-like $4\pi/6$-mode is the most excited monopole-mode. The energy loss ratio between monopole- and dipole-mode is approximately four orders.

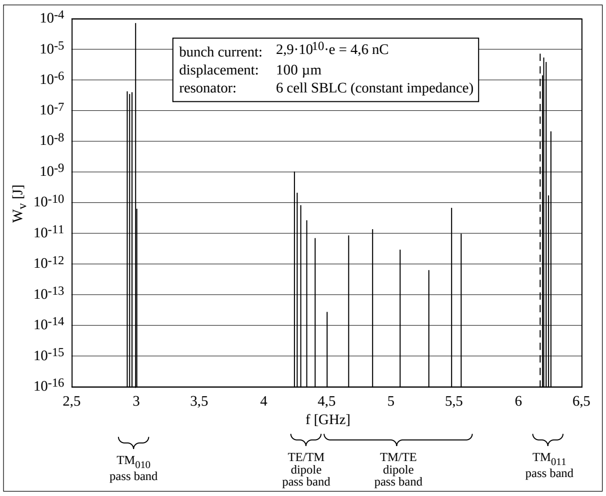

Figure 1: Energy loss of a bunch, passing a 6 cell cavity

In order to get a good resolution of the position measurement, we need high sensitivity and selectivity for the dipole-mode.

2 HOM COUPLER

To get the required higher-order-mode signals without the additional insertion in the beam line, we can use the HOM couplers for beam position measurement.

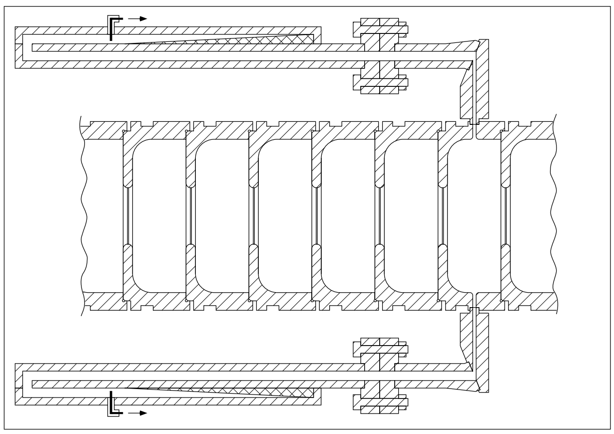

Figure 2: Cross sectional view of the SBLC main accelerator structure with HOM-couplers for one direction

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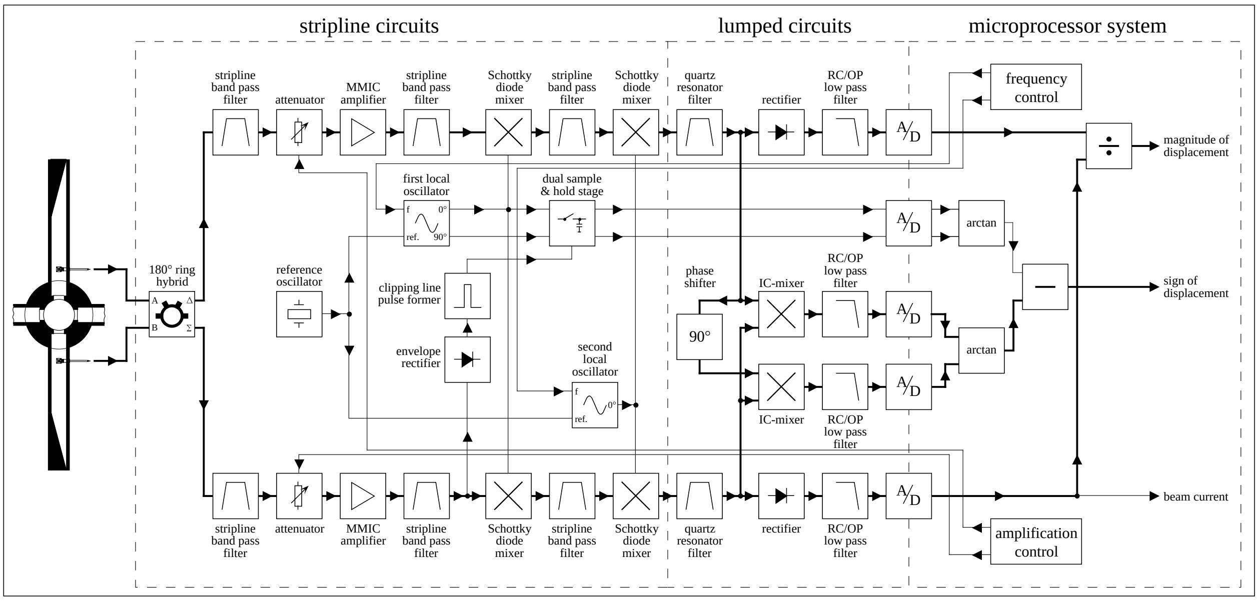

Figure 3: Signal processing scheme for beam position monitoring using HOM coupler signals

The HOM coupler shown in Figure 2 uses azimuthal wall slots for coupling. The slots and the rectangular waveguides have a width of 37.5 mm and thus a cut-off frequency of 4 GHz. The acceleration mode at 3 GHz is beyond the cut-off frequency of the waveguides and will vanish exponentially along the waveguide. The HOMs are above cut-off frequency. For good rejection of the acceleration mode, the pickup antenna (for the signal) is mounted as far as possible away from the slot.

For HOM damping and to prevent disturbing reflections it is desirable to have a wide band microwave absorber at the end of the waveguide.

3 SIGNAL PROCESSING

Signal processing is needed to measure the amplitudes of the monopole- and the dipole-mode and the phase between both during the time of bunch passage. Figure 3 shows a possible scheme to process the signals from the coaxial pick-ups for one direction [2].

The first stage is a 180˚ ring hybrid. The dipole signals from the HOM couplers have opposite phase at the two pick-ups, so they are transmitted to the Δ-port. The monopole signals have the same phase and go to the Σ-port. The hybrid will be designed to reject monopole signals at the Δ-port and the frequency of the dipole signal due to the finite Q of the cavities. The first pair of stripline filters has a bandwidth of a few tenth of a Mhz and rejects modes of the wrong passband. A filter with a small bandwidth at this position has the disadvantage that it becomes impossible to tune the monitor to a different mode. Too the phase shift, which is frequency depent, of the frequency offset and therefore also in depend of the temperature of the filter become too high. The variable amplifiers (variable attenuators and amplifiers) are for the adaption to different operating situations. For the fine tuning or pilot bunches we need higher amplification than for coarse adjustment and full current bunch trains. The filters behind the amplifiers are needed to reject the harmonics produced by the non-linearity of the amplifiers. The first local oscillator is tuned to the half of the frequency difference of the dipole- and the monopole-mode:

$$\omega_{LO1} = \frac{\omega_{mono} - \omega_{dipol}}{2} \qquad (2)$$

With this frequency the monopole signal is mixed downward and the dipole signal is mixed up to the common frequency:

$$\omega_{IF1} = \frac{\omega_{mono} + \omega_{dipol}}{2} \qquad (3)$$

The common frequency is needed for the phase comparison after the second mixer. The filter behind the mixers select the correct side band of the mixer signal. The second mixer stage mixes downward both signals to an frequency of 70 MHz for the final filtering.

All components up to here are stripline circuits. This allows to integrate the ring hybrid, the filters and the phase shifters inside the mixers as line structures on a singe PTFE printed circuit board. The following lower frequency components are lumped circuits on an unmatched PCB.

The two quartz SAW filters have a narrow bandwidth and separate a single mode of each signal. The following rectifiers and low pass filters extract the amplitude of the signals. The magnitude of displacement and the beam current is determined by this two signals. The phase difference between the two second intermediate frequency signals are measured by the complex mixer between the two pathes. Due to the scheme of the first mixer pair (up-/down-mixing) the phase difference between the monopole- and the dipole-signal cannot determined only by measuring the phase difference of the IF2s.

The signals are given by:

$$u_{IF2mono} \sim u_{mono} \cdot \cos(\omega_{IF2} t + \varphi_{LO1} + \varphi_{LO2}) \quad (4)$$

$$u_{IF2dipol} \sim u_{dipol} \cdot \cos(\omega_{IF2} t + \varphi_{dipol/mono} - \varphi_{LO1} + \varphi_{LO2}) \quad (5)$$

The measured phase difference depends on the phase of the first local oscillator at the time of the bunch passage. To get this phase we detect the leading edge of the monopole signal. A diode rectifies the envelope of the this signal. We do this at a point with wide bandwidth, so we have a sharp rising edge. From the envelope a clipping line pulse former produces a short pulse to drive a dual sampling bridge sampling the complex signal of the first local oscillator to allow the determination of his phase at this time.

After an A/D-conversion of all resulting signals a microprocessor does the non real time signal processing and the control and regulation of the LO frequencies and amplifications. An frequency offset of the first local oscillator results in linear ramps instead of a constant signal for the phase. The frequency of this ramps is equal to the offset. A frequency offset of the second local oscillator results in an frequency offset of IF2.

The information about the displacement and the beam current will be transmitted digitally from the μP to the position control system of the structures.

4 OUTLOOK

The first step in the realization of an beam position monitoring system with HOM signals is to design the pick-ups from the HOM coupler waveguides to the coaxial line and measure the transmission for the different modes. The second step is the development of the measurement receiver for the dipole mode to determine the magnitude of the displacement. In a third step we will add the components for the monopole channel and the phase measurement. This receiver is not time invariant, so time domain measurements with short pulses to simulate the bunches will be required. The fourth step is the test of the whole assembly at the SBLC test facility. If it works properly the electronics could be integrated to a cheap dual PCB device for the usage at SBLC.

5 REFERENCES

[1] T. Weiland et al.: "Solution of Maxwell's Equations using the Finite Integration Algorithm"; Version 3.2; Darmstadt, 1993

[2] P. Hülsmann, C. Peschke: "Signal Processing for the BEAM Position Monitoring using HOM Coupler Signals", Summary of the S-band Linear Collider Meeting of December 7th and 8th, 1995