Pill-box Cavity BPM for TESLA Cryomodule

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Abstract

A new cavity BPM with 10 μm resolution is designed and built to perform single bunch measurements at the TESLA linear collider. In order to have a low energy dissipation in the cryogenic supermodule, the inner surface of the cavity is copperplated. Cross-talk is minimized by a special polarisation design. The electronics, at 1.5 GHz, is a homodyne receiver normalized to the bunch charge. Its LO signal for down-conversion is taken from the same cavity.

THE PICK-UP STATION

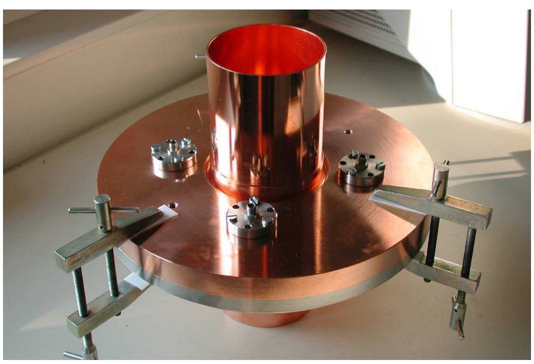

Figure 1: The pick-up station with four feed-troughs

A cylindrical pill-box cavity has been constructed as seen in figure 1. The pick-up station is fabricated from stainless steel. Dimensions and material properties of the structure are listed on table 1.

Table 1: Cavity dimensions and material parameters

type of stainless steel		1.4429
shrinkage from 293K to 2K	[%]	0.3
conductivity (293K)	$[\Omega^{-1}m^{-1}]$	$1.33 \cdot 10^6$
cond. (2K)	$[\Omega^{-1}m^{-1}]$	$1.88 \cdot 10^6$
Room Resistivity Ratio (copper)		6.9
conductivity (293K)	$[\Omega^{-1}m^{-1}]$	$3.569 \cdot 10^6$
cond. (2K)	$[\Omega^{-1}m^{-1}]$	$24.84 \cdot 10^6$
Cavity diameter	[mm]	222 (221.3 at 2K)
Beam-pipe diameter	[mm]	78 (77.8 at 2K)
Cavity length	[mm]	18 (17.9 at 2K)
Coupling antenna depth	[mm]	7.6

In order to decrease energy dissipations on the walls the cavity was copper plated.

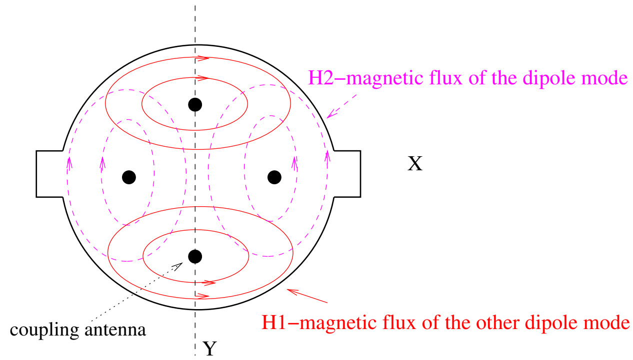

Figure 2: Cut of the cavity with two rectangular recesses

Two rectangular recesses were symmetrically eroded inside the cavity, in x-direction, see figure 2. It is done to get minimal cross-talk [2].

Fabrication tolerances result to changes in the anticipated TM_{110}-dipole mode frequency, see the following table. This results in a total error of

Table 2: Mechanical parameters sensitivity

dimension	target [mm]	sensitivity ±100 μm	tolerances [μm]	shrinkage [μm]
cavity radius	111	∓1.247 MHz	±10	-433
cavity length	18	±0.158 MHz	±100	-203
pipe radius	39	∓0.305 MHz	±50	-146

$$\Delta f = \sqrt{\Delta f(\delta R_{res})^2 + \Delta f(\delta l)^2 + \Delta f(\delta r)^2} \approx 252\,\mathrm{kHz} \qquad (1)$$

For simulations of the structure and resonant mode parameter computations the computer code GdfidL was used [1]. The signal which an antenna couples from the cavity on 1.512 GHz dipole mode frequency is

$$V^{out}(1.512\,\mathrm{GHz}) = V^{out}_{110} + V^{out}_{010} + V^{out}_{020} + V_N \qquad (2)$$

Where

- V^{out}_{110} is the coupled voltage of the dipole mode,
- V^{out}_{010} is the coupled voltage of the common mode on 1.512 GHz-dipole mode frequency,
- V^{out}_{020} is the coupled voltage of the second monopole mode on 1.512 GHz-dipole mode frequency, and
- V_N is the noise level, which is approximately -70 dBm (0.07 mV).

These values are computed theoretically, and for TESLA with a bunch charge of 3.2 nC and 10 μm beam-offset they are summarized in table 3.

Table 3: Voltages on 1.512 GHz frequency

signal	voltage
V_{110}^{out}	4.41 mV
V_{010}^{out}	2.77 mV
V_{020}^{out}	14.78 mV
V_N	0.07 mV

Frequency scan of the cavity

A frequency scan of the cavity by means of a Network Analyser results to S_{21} measurements, see figure 3.

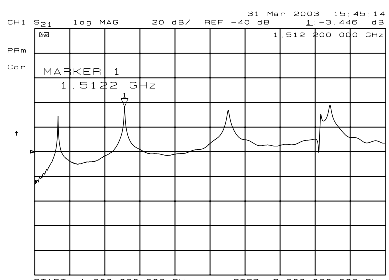

Figure 3: S_{21} against the frequency

The results are summarized in the follwoing table:

Table 4: Data of frequency scan

	measured (warm)	computed
Q_L^{110}	700	822
f_{110}^x	1.512 GHz	1.51 GHz
Q_L^{110}	760	839
f_{110}^y	1.522 GHz	1.522 GHz
Q_L^{010}	1133	1700
f_{010}	1.131 GHz	1.133 GHz

Cross-talk measurement

Cross-talk isolation measurements were performed as indicated in figure 4. At first, we generated and coupled the signal through the antennas in the same direction, as in figure 4a. The two remaining coupling ports were loaded by 50Ω. Left plot in figure 5 shows the result of this measurement. Here signal level is obtained as a function of frequency. A maximum at 1.522 GHz with a level of −1.8 dB is observed.

Next, we repeated the measurement using antennas in perpendicular to each other directions (figure 4b) and obtained the second plot in figure 5. Here two maxima are

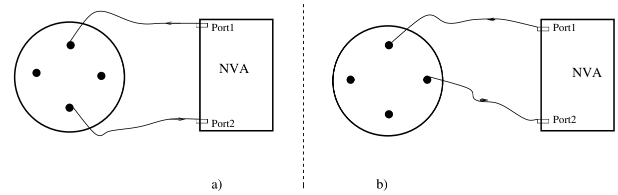

Figure 4: Layout of the cross-talk measurement

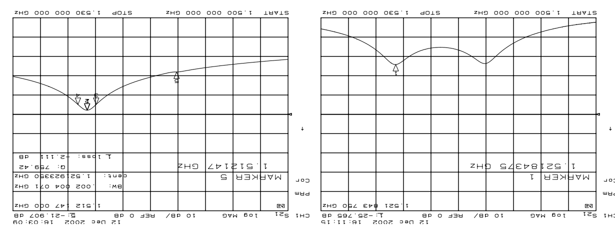

Figure 5: Signal level in [dB] against frequency. The signal level is graded by 10 dB. The reference 0 dB-line is the middle one

visible. The corresponding signal at the second maximum with the same frequency has a level of -25.8 dB. The first maximum on 1.512 GHz refers to the second dipole mode in the perpendicular plane.

The cross-talk isolation value is the 24 dB signal level difference between left and right plots in figure 5 on the same 1.522 GHz frequency. The cross-talk between the other ports was about the same.

ELECTRONICS

The parameters of the signals which should be handled by the electronics are:

Table 5: Signals from the pick-up station

bunch distance	337 ns (2.96 MHz)	
TM_{110} GHz	1.5 GHz	
TM_{010} GHz	1.14 GHz	
TM_{020} GHz	2.64 GHz	
Charge	3.2 nC	1.0 nC
V_{110}^{out} (δx = 10 μm)	−34.1 dBm	−44.2 dBm
V_{010}^{out} (10 μm)	−38.1 dBm	
V_{020}^{out} (10 μm)	−23.6 dBm	
V_{110}^{out} (δx = 2.5 mm)	13.8 dBm	

Comparing parameters such as *dynamic range*, *signal to noise ratio*, *amount of electrical components* (less components means cheaper electronics system) we have chosen a *homodyne* system of signal detection [3], which is shown in figure 6.

The electronics, at 1.5 GHz, is a homodyne receiver, which provides bunch charge normalized signals. It has 5 output channels: two for x-position detection; two for y-position detection, and one for charge detection (see figure 6). The LO signal is taken from the cavity itself. The IF

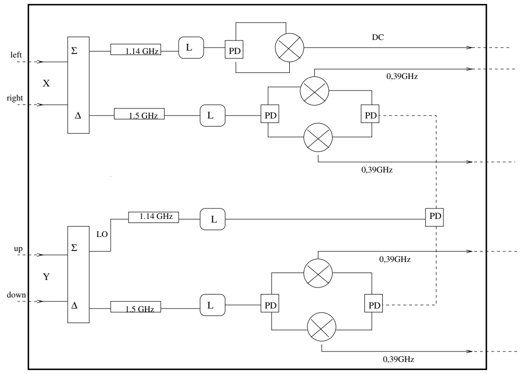

Figure 6: Electronics box

signal has a 0.4 GHz frequency. Before the signal digitizing we apply a Sample-Hold system, which selects the part of the IF signal of 2.9 GHz, the TESLA bunch repetition frequency.

RESOLUTION MEASUREMENTS

The test-measurements are performed at the DESY-Zeuthen laboratory. The generator-antenna was moved with a 10 µm step-size in x-direction (y-direction) over a range of ±1 mm. With the detected I_x and Q_x values we computed the V_x

$$V_x = \sqrt{I_x^2 + Q_x^2}. \tag{3}$$

Figure 7 illustrates the sensitivity of the BPM. The bigger slop means higher sensitivity. To valuate the resolution we

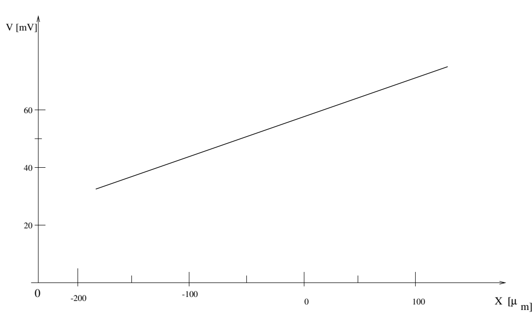

Figure 7: BPM sensitivity plot

compare the measured position with the real antenna positions, see figure 8.

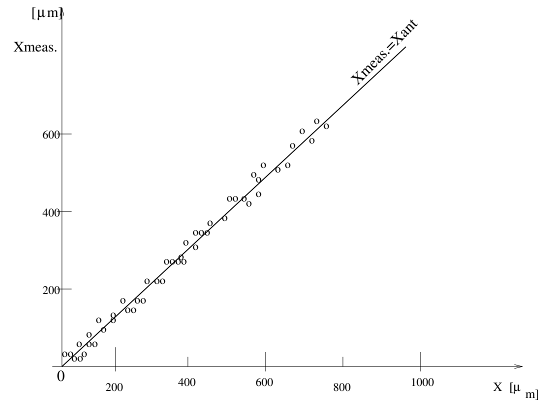

Figure 8: BPM resolution plot

The TESLA-bunch excites the cavity 10 times stronger than it was in laboratory conditions. Hence, we aspect 8 µm resolution performance.

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