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A QUASI-OPTICAL BEAM POSITION MONITOR

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Abstract

There is a strong demand for non-destructive electron Beam Position Monitors (BPMs) for non-perturbative diagnostics of the electron beam position. Challenges are related to the shortness of the electron beam and the noisy chamber environment that are typical for modern RF-driven and plasma-driven accelerators. We propose using a pair of identical high-quality quasi-optical resonators attached to opposite sides of the beam pipe. The resonators can introduce Photonic Band Gap (BPM) structures. These open resonators sustain very low numbers of high-quality modes. We intend to operate at the lowest mode among the others that are capable of being excited by the bunches. The mentioned mode has a coupling coefficient with the beam that depends on the distance between the bunch and the coupling hole. The lower this distance, the higher the coupling. Therefore, comparing the pick-up signals of both resonators with an oscilloscope, we can determine the beam position.

INTODUCTION

For a classical Bunch Position Monitor (BPM) based on a proximity effect ultrashort bunches become inevitably shorter than the length of the capacitor antenna. In this case the capacitor must be considered as a broadband RF antenna. Such antenna sees lots of noise including the noise generated far from the BPM. These challenges can be approached by the excitation of resonator modes within a so-called cavity BPM shown in Fig. 1 [1-2]. Our idea is to develop the cavity BPM concept and to design a quasi-optical BPM (QBPM).

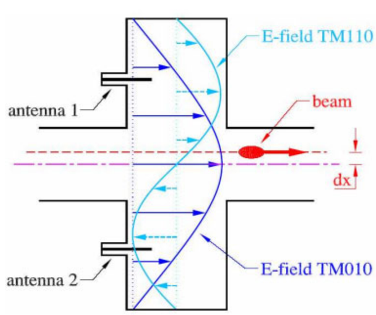

Figure 1: Pillbox cavity BPM.

We suggest using a pair of identical high-quality quasi-optical resonators attached to opposite sides of the beam pipe. The resonators, for example, can introduce Photonic-Band Gap (PBG) structures [3–4]. These open PBG resonators sustain a very low number of high quality factor modes or even only one mode. We intend to operate in the lowest order mode among those that are capable of being excited by the electron bunches. The mode that we plan to use has a coupling coefficient with the beam that depends on the distance between the bunch and the coupling hole. The lower this distance, the higher the coupling coefficient will be. Therefore, by comparing the pick-up signals of the two resonators with an oscilloscope, we can determine the position of the beam. Unlike the mentioned cavity BPM in Fig. 1 our QBPM uses highly selective resonators that allow to suppress the noise. The frequency of our open resonator is below cutoff for the beamline where the QBPM installed. Therefore, the noise at the operating frequency generated far from the QBPM cannot spoil the received signal.

DESIGN OF QBPM

We suggest using a pair of identical high-quality open resonators attached to opposite sides of the beam pipe. These pairs of resonators operate as a quasi-optical bunch position monitor (QBPM) that can retrieve the beam position along one of the transverse coordinates. Figure 2 illustrates one such resonator. It consists of a periodically perforated rectangular cross-section waveguide. Such waveguides can work as a Bragg reflector for radiation that is below the cut off for the perforation holes.

The Q-factor of the operating mode depends on size of the coupling hole, and should be high enough to allow for receiving a sufficient number of oscillations of the 10–100 ns pick-up signals. Of course, the measurement procedure requires some calibration.

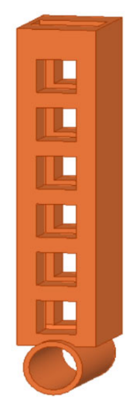

Figure 2: Open BPG resonator for QBPM based on Bragg reflector.

First, we simulated a 10-GHz rectangular cross-section Bragg reflector. Figure 3 represents the E-field distribution in the Bragg reflector that consisted of 6 periods. The S-parameters of this Bragg reflector are shown in Fig. 4.

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Note that the reflector's bandwidth is located between 9 GHz and 11 GHz. Each perforation hole has dimensions of 13 mm×14 mm, so that all modes at frequencies higher than 11.53 GHz can leak into the free space and, therefore, their Q-factors cannot be high.

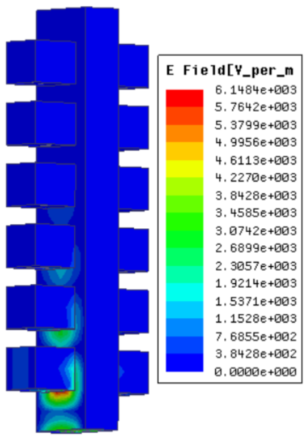

Figure 3: E-field structure of Bragg reflector at 10 GHz.

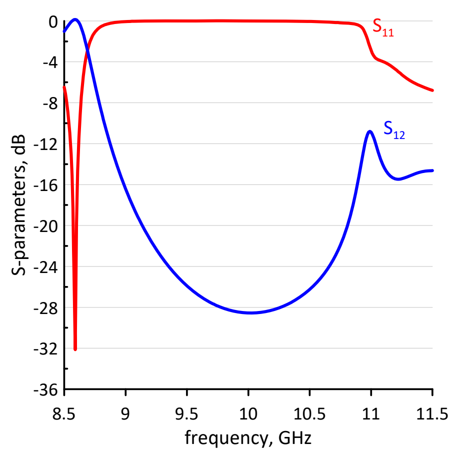

Figure 4: S-parameters of the reflector vs. frequency.

The HFSS eigenmode model is shown in Fig. 5. Here, we have inserted absorbers to model the open ends. The absorbers have parameters to provide less than -30 dB reflection at frequencies near the operating frequency. Two H_τ=0 symmetry planes were used to reduce the computation volume and to exclude modes that do not have E_x field components and thus cannot be excited. The operating eigenmode is shown in Fig. 6. The fields of this mode are concentrated near the coupling hole. This mode has the highest Q-factor among the modes between 0 GHz and 13 GHz. The tendency is that the higher the frequency of a spurious mode, the lower a Q-factor it has.

As was predicted, in the beam pipe the E_x-field of the operating mode decreases along the z-axis, being a maximum at the coupling hole and being zero at the opposite side of the beam pipe (Fig. 7). Therefore, bunches located closer to the coupling hole will generate higher operating mode fields in the resonator compared with those bunches that move at a larger distance from the coupling hole.

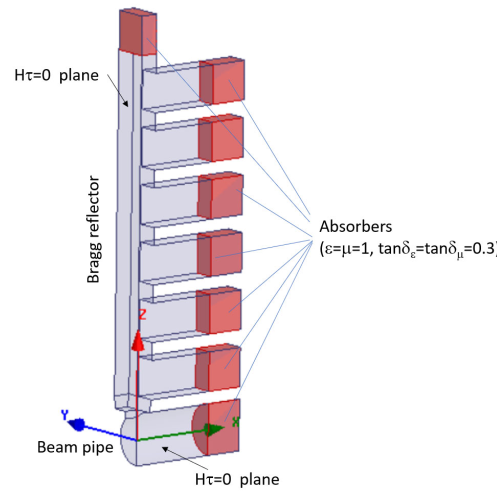

Figure 5: HFSS model for the open PBG resonator of QBPM.

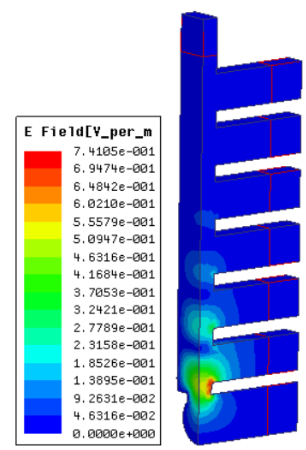

Figure 6: *E*-field structure of the operating eigenmode.

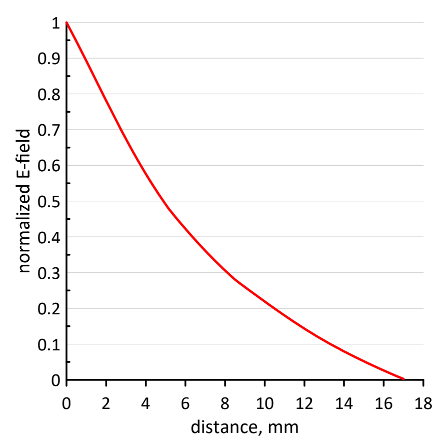

Figure 7: E_x-field component near the coupling hole across the beam line.

SIMULATIONS

In order to simulate the excitation of the operating eigenmode in the time domain, we used CST Particle Studio. In this model, we investigated the wakefields produced

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by a single bunch. For the preliminary simulation, the bunch length was set as 10 ps, which allowed us to carry out the calculations with a personal computer. We plan to carry out calculations by means of a multi-node cluster to see the wakefields excited by a femtosecond bunch. The results of simulations with a 10-ps, 1-pC bunch traveling exactly on the beam pipe axis are presented in Figs. 8–10. In Fig. 8, the wake is shown for a bunch that has not yet reached the coupling hole. In Fig. 9, the bunch has already passed by (t = 10 ns), the field structure in this case accurately corresponds to the operating mode field structure (Fig. 6).

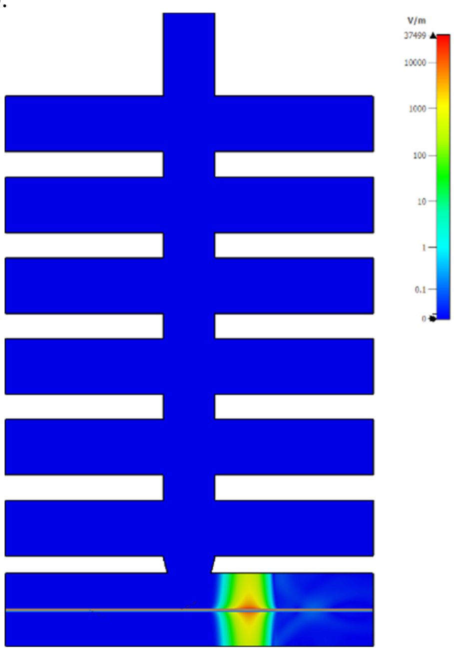

Figure 8: Instantaneous field when the bunch approaches to the resonator.

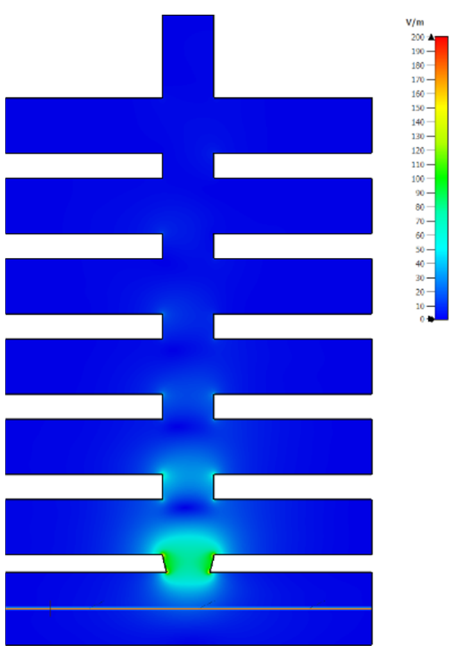

Figure 9: Instantaneous field distribution 10 ns after the bunch has passed.

The Fourier spectrum for the signal seen by a point probe in the resonator is shown in Fig. 10. One can see that there is a high peak at the operating frequency only. Note that the field amplitude under steady-state conditions is equal to about 80 V/m. If we assume that an SMA pickup will be used, we can expect measurable signals as high as hundreds of millivolts.

Let us now consider the excitation of the resonator with offset bunches. In Fig. 11, the field in the resonator is shown for the case of a bunch traveling along the z axis with a shift of –1 mm from the x-axis, so that it is further away from the coupling hole (pink curve). The field of the same bunch, but shifted 1 mm closer to the coupling hole is shown by blue curve in the Fig. 11. In the second case, the field is 30 V/m higher than in the first case. Figure 11 confirms that both signals in steady state have the same frequency, and can be summarized as the coherent signals that are required for the QBPM concept.

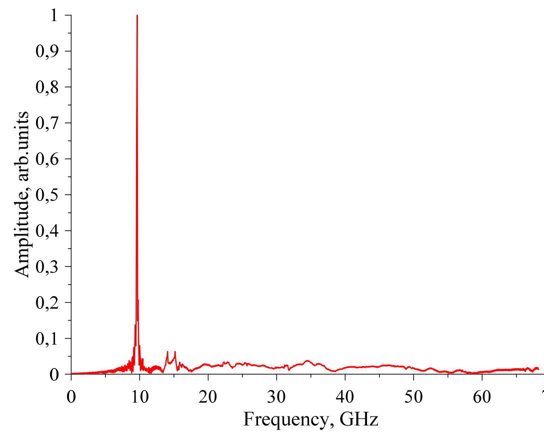

Figure 10: Fourier spectrum for the field excited in the PBG resonator.

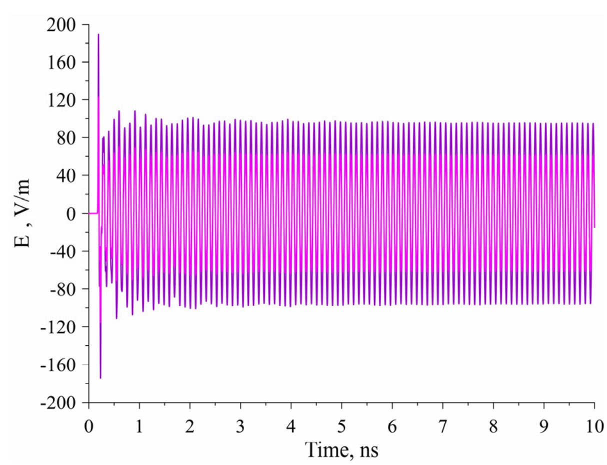

Figure 11: E_x-field components at the PBG resonator when excited by a bunch shifted by $\Delta z = -1$ mm from the x axis (pink) shifted by $\Delta z = -1$ mm (blue).

CONCLUSION

The QBPM can become an efficient tool for diagnostics of short bunches.

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