PHOTONIC BAND GAP HIGHER ORDER MODE COUPLER FOR THE INTERNATIONAL LINEAR COLLIDER *

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Abstract

A photonic band gap (PBG) higher-order-mode (HOM) coupler is proposed as an Alternative Configuration Design (ACD) for the HOM coupler for the International Linear Collider (ILC). The PBG HOM coupler uses a two-dimensional triangular PBG structure with good axial symmetry. Simulation studies of a PBG HOM coupler show that it maintains the operating mode at 1.3 GHz with $Q > 10^{10}$. While a PBG HOM coupler provides superior damping for all the higher order modes, in principle, the effectiveness of HOM damping remains an open subject of future investigations.

INTORDUCTION

As reported in the ILC Base Configuration Design (BCD) [1], the accelerated ILC beam, if similar to the proposed in the TDR beam of the TESLA 500 GeV collider, will generate spectrum up to 0.4 THz. The beam-deposited power in a cryo-module housing 12 TTF-like 9-cell structures will be ~24 W if no synchronous excitation of parasitic modes takes place. A large fraction of the beam-deposited power (17.4 W) is in propagating modes above 5 GHz. The beam-deposited power must be removed from cryo-modules to avoid an additional heat load in 2K environment and to maintain the high quality of the accelerated beam (preserving the low emittance). This will be achieved by means of two kinds of devices: HOM couplers and beam line absorbers. Beam dynamics simulations showed that preservation of the low emittance demands suppression of high impedance dipoles to Q_{ext} of the order of 10^5. This suppression will also ensure stable operation if resonant excitation of some high impedance modes takes place.

The ILC BCD employs the suppression scheme as proposed in the TESLA TDR [2]. The careful studies of HOM suppression at TESLA test facility (TTF) linac showed that almost all dipole modes, but two, are well damped and satisfy the specification. Besides its ineffectiveness of damping the two dipole modes, the BCD HOM coupler has other two shortcomings: a) mode asymmetry, and b) high cost. Further improvement in the HOM coupler is still required.

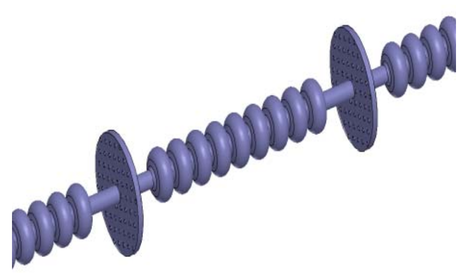
We propose a PBG HOM coupler as an Alternative Configuration Design (ACD) for the ILC HOM coupler. The PBG HOM coupler uses a two-dimensional triangular PBG structure which is composed of metalic rods. Such a structure has superior axial symmetry. It allows all unwanted high-order modes to leak out of the structure while preserving high Q of the operating mode. Potentially, the cost of building PBG HOM couplers can be reduced due to the simple geometry of the structure.

The goals of our HFSS simulation studies of the PBG HOM coupler are to determine the feasibility of confining the 1.3 operating mode in the PBG HOM coupler and to explore the effectiveness of HOM damping. The present paper reports the progress in achieving the first goal.

PBG HOM COUPLER DESIGN

The schematic layout of the PBG HOM coupler is shown in Fig. 1(a). The PBG HOM couplers are mounted to both ends of the 9-cell cavity. Use of a triangular superconducting lattice design with four rows of rods is chosen for the PBG HOM coupler as shown in Fig.1 (b). The radius of the rods is $a = 8.25$ mm and the spacing between the closest rods is $b = 55$ mm. A hole is opened in the center (not shown in Fig. 1(b)) of the structure which is connected to the beam tunnel. The material of PBG HOM coupler is chosen to be superconducting material.

(a)



(b)

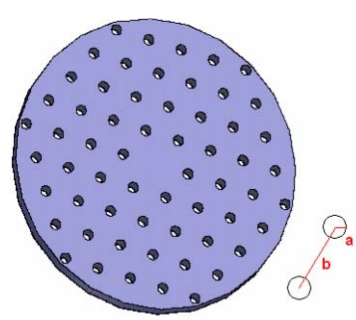


Figure 1: (a) Schematic layout of the PBG HOM coupler and (b) triangular superconducting PBG lattice design with $a = 8.25$ mm and $b = 55$ mm.

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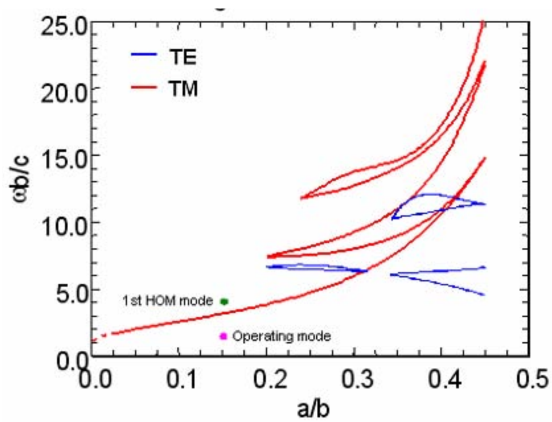


Figure 2: Plots of global band gaps for TM and TE modes as functions of a/b as obtained from PBG calculations for the triangular lattice in Fig.1.

The surface conductivity of 7.2×10^{18} S/m is used in our calculations.

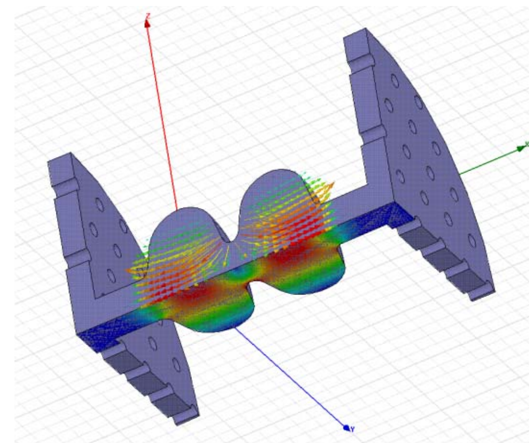
For triangular PBG lattices, the global band gaps are computed for TE and TM modes in [3], as shown in Fig.2 for different choices of lattice parameters. For TM modes, the modes in the region under the red curve are in a photonic band gap, where they cannot propagate in the transverse direction of the 2D PBG structure. By creating a defect, i.e., a missing rod in the center of the PBG structure, a TM mode in the photonic band gap can be confined in the center of the PBG structure. The TM modes which are not in the photonic band gap will propagate along the transverse direction outwards the structure.

For the PBG HOM coupler, the ratio $a/b = 0.15$ is chosen such that the operating mode with a frequency of 1.3 GHz is inside a photonic band gap and the first higher-order mode with a frequency of 5 GHz is outside the band gap. Therefore, the 1.3 GHz operating mode is confined in the center of the PBG lattice, whereas the higher-order modes propagate outwards the PBG lattice. The outer wall of the PBG coupler is made with absorbing materials such that all the high-order modes are damped at the outer wall.

The 3D electromagnetic simulation code, HFSS, is used to simulate the PBG HOM coupler in an effort to determine the feasibility of confining the 1.3 operating mode in the PBG HOM coupler. Since it is challenging to simulate the full 9-cell cavity model due to overmoding in the longitudinal direction and intensive computation, a 2-cell cavity model is developed to simulate the PBG HOM coupler with 2 cavities, as shown in Fig. 3. The cavity cell takes the TESLA design with the same geometry as in Ref. [2]. The 2-cell model proves to be effective in our HFSS simulations.

Using the 2-cell model with PBG HOM couplers on both sides, an operating frequency of 1.293 GHz is achieved in HFSS simulations. At 1.293 GHz, a quality factor of $Q = 8.53\times10^{9}$ is obtained for the two-cell model.

(a)



(b)

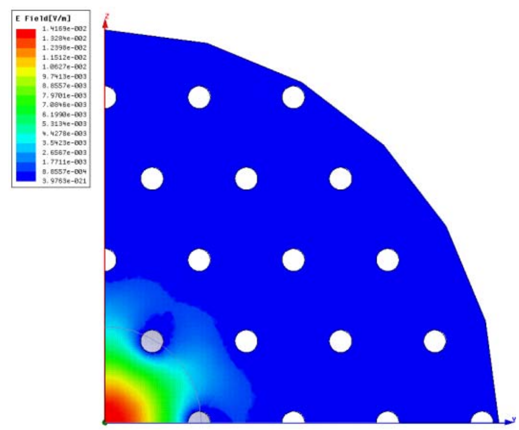


Figure 3: (a) 2-cell model with two TESLA cavities and two PBG HOM coupler; (b) the operating mode structure with a frequency of 1.293 GHz in the transverse plan of the PBG HOM coupler.

Since $Q = \omega U / P$, we expect the quality factor of the 9-cell model with PGB HOM couplers to be approximately 4.5 times as large, i.e., $Q = 3.84\times10^{10}$. Figure 3(b) shows the operating mode structure with the frequency of 1.293 GHz in the transverse plane of the PBG HOM coupler. There results show that the PBG HOM coupler meets the goal of maintaining the operating mode.

The operating mode is concentrated in the center of the PBG lattice, and therefore, it is insensitive to the radius of the PBG structure. The change of PBG HOM coupler size does not affect the operating mode. This is demonstrated by a study on the change of Q as a function of the radius. As shown in Fig. 4, Q is computed for various values of coupler radius. Compared with a pillbox coupler in which Q is quite sensitive to the coupler radius, Q of the PBG HOM coupler remains constant as the coupler radius varies.

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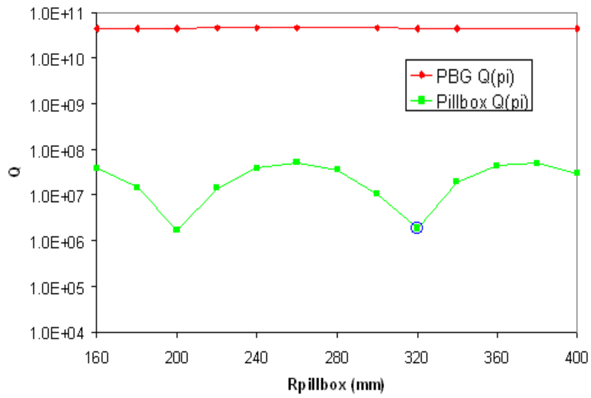

Figure 4: Plot of Q as a function of the coupler radius for the pillbox coupler and the PBG HOM coupler.

CONCLUSION AND DISCUSSION

The effectiveness of maintaining the operating mode of the proposed PBG HOM coupler is demonstrated by HFSS simulations. The PBG coupler is robust and realistic.

Although the PBG HOM coupler provides, in principle, superior damping for all the higher-order modes, a detailed HFSS simulation study remains to be carried out to ascertain whether the PBG coupler can provide the necessary HOM damping. For all the higher-order mode, the PBG coupler should provide Q less than 10^5. Positive outcome of such study will call for an experimental demonstration of the PBG HOM coupler as an ACD for ILC.

REFERENCES

[1] The International Linear Collider Global Design Effort Baseline Configuration Document (March 12, 2007).

[2] B. Aune, et al.; The Superconducting TESLA Cavities, *PRST-AB* **3** (9) 092001 (2000).

[3] E. I. Smirnova, C. Chen, M. A. Shapiro, et al., *J. of Appl. Phys.*, **91**(3), 960 (2000).

