

Accelerator Physics

# Photonic Band Gap Higher-Order Mode Coupler for International Linear Collider

(New Proposal)

Accelerator Physics

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Institution(s)

Massachusetts Institute of Technology

Funds Awarded (DOE)

FY06 Request: \$40,000

FY07 Request: \$40,000

# Research Proposal

## Project Title

Photonic Band Gap Higher-Order Mode Coupler for International Linear Collider

## Project Leader

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## Project Overview

Control of wakefields or higher-order mode (HOM) excitations is a very important design issue in the International Linear Collider (ILC) program. The electron beam in the main linac is expected to generate 7 Watts of wakefields in each of 24000 superconducting cavities. The wakefields are in the frequency range of 2.8 to 7 GHz, and dipole-like HOM.

Wakefields give rise to the parasitic energy loss and energy spread in the successive bunches propagating in the main linac. They also introduce transverse forces that tend to increase the beam emittance. Worse, the wakefield-induced transverse forces could be sufficiently strong to deflect the entire beam. In order for the machine to operate, wakefields must be sufficiently damped.

The leading candidate for Basic Configuration Design (BCD) is a conventional HOM coupler of the TESTA type. Two such conventional HOM couplers are present in each superconducting cavity.

However, there are two potential issues with the BCD HOM coupler choice:

- a) Both the conventional HOM coupler and its installation is not axisymmetric, which has the potential to induce dipole-like perturbations on the electron beam, degrading and/or destabilizing the electron beam;
- b) BCD HOM couplers may not provide sufficient damping for non-dipole-like HOM modes which might be excited by the beam;
- c) Cost of a conventional HOM coupler is estimated to be \$20K, \$480M total for a 0.5 TeV machine.

We propose to explore a photonic band gap (PBG) HOM coupler as a promising alternative configuration design (ACD) for a HOM coupler for ILC.

## Project Description

In the PBG HOM coupler, the distinctive feature of properly designed PBG structure is used. In particular, a PBG structure can support one or more global band gaps, such that for a certain range of frequencies, electromagnetic waves cannot propagate in the structure in any direction. By removing some elements of the PBG structure, i.e., creating a defect, we form a PBG cavity for a PBG HOM coupler. The remains of the PBG structure will then form a PBG wall around the defect. On one hand, a wave with the frequency in the global band gap cannot propagate in the PBG wall of the cavity, and therefore it is confined at the defect. On the other hand, the PBG cavity can be designed to be frequency selective, so that the operating mode will be confined inside the defect and all the higher order modes will not be confined by the cavity.

A comparison between the conventional HOM and PBG HOM coupler is shown schematically in Fig. 1. Our PBG HOM coupler consists of a triangular lattice of metallic (possibly superconducting) rods in vacuum sandwiched between two metal plates with an absorbing wall. The side and cross sectional views of our PBG HOM coupler are shown on Fig. 2.

The PBG HOM coupler has the following advantages over the conventional HOM coupler:

a) Because the PBG HOM coupler is more azimuthally symmetric than the conventional HOM mode coupler, we anticipate the benefit of mitigating the non-axisymmetric issue in the BCD for HOM couplers.

b) The PBG HOM coupler permits all higher-order modes, including dipole-like and non-dipole-like modes, to leak through the PBG coupler and be absorbed by the absorbing wall.

c) The PBG HOM coupler is simple to build. We anticipate that the PBG HOM couplers will cost considerably less than the conventional HOM couplers, resulting in saving for the ILC construction.

We anticipate that these advantages would help the ILC community to address the potential issues of the conventional HOM coupler.

For the operating mode with frequency 1.3 GHz, the estimated quality factor of the 9-cell cavity with the PBG HOM coupler is found to be of the order of  $10^{10}$  (Samokhvalova and Chen, 2005), which meets the ILC requirement. Our preliminary studies (Samokhvalova and Chen, 2005) indicate good prospect that all the higher order modes leak through the PBG wall,

We propose to carry out a detailed feasibility study of the PBG HOM coupler and develop a cost proposal for experimental demonstration of the PBG HOM coupler concept.

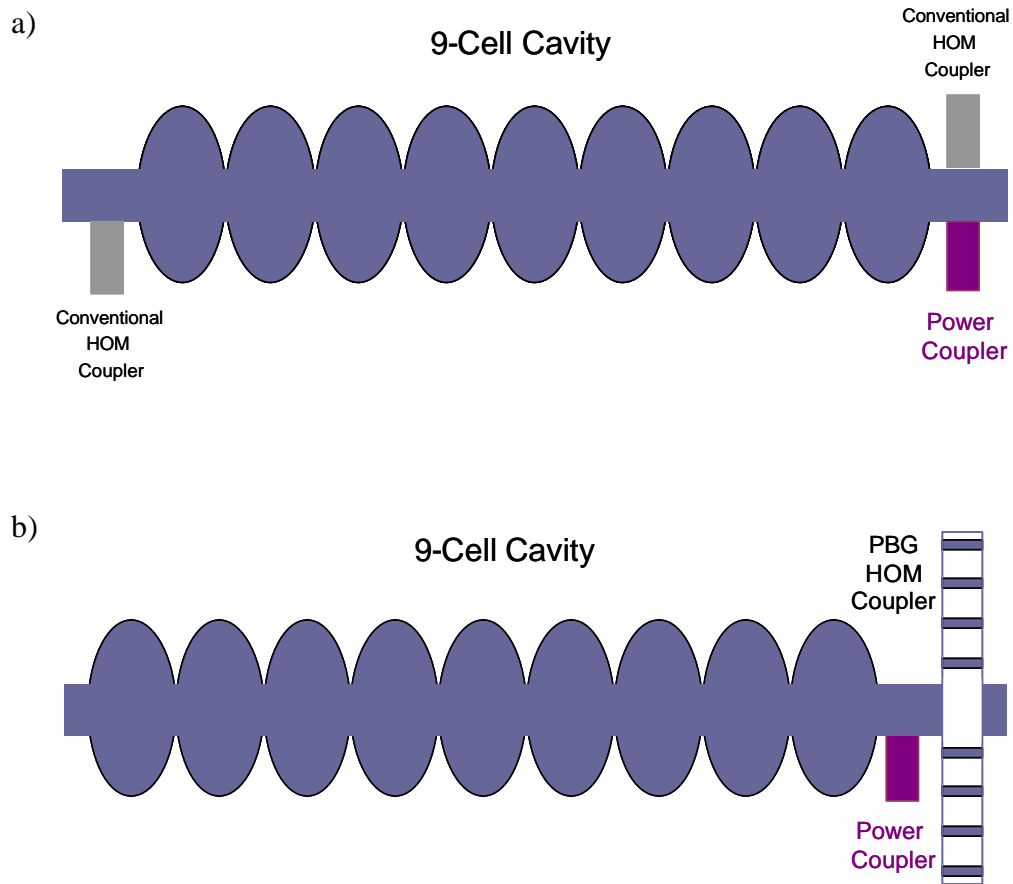


Fig. 1 Schematic of 9-cell cavity for the main linac with (a) conventional HOM coupler design and (b) PBG HOM coupler design.

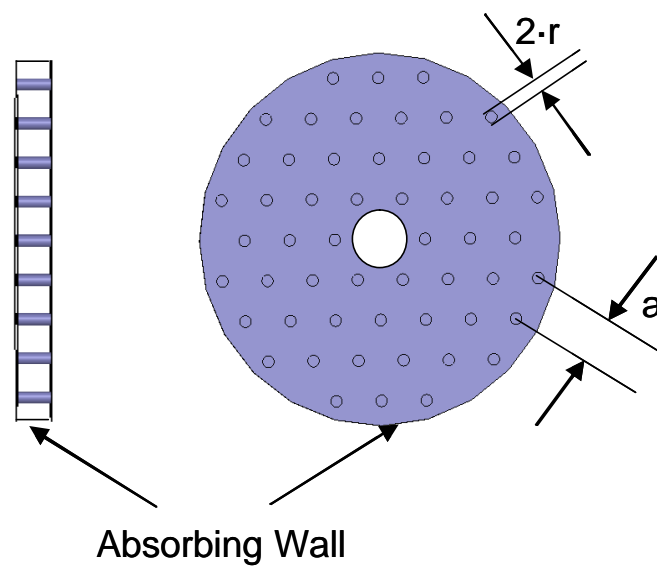


Fig.2. Side view and cross sectional view of the PBG HOM coupler.

Our work tasks are:

- a) We will perform HFSS simulations to determine the quality factor of the operating mode.
- b) We will design the PBG cavity for PBG HOM coupler using both analytical tools (Smirnova and Chen, 2003; Smirnova, Chen, Shapiro, et al., 2002) and HFSS simulations.
- c) We will engage other laboratories and/or industries in the ILC consortium for possible participation in the experimental demonstration of the PBG HOM coupler concept.
- d) We will further establish the cost savings if the PBG HOM couplers are selected for ILC.

### **Budget**

Funds of \$40K are requested for FY2006 and for FY2007. An approximate breakdown of the budget is summarized in Table 1 for the 2-year period.

Table 1. Approximate breakdown of the budget

Item	FY06	FY07	Total
Chiping Chen (PI)	\$13,000	\$13,000	\$26,000
2 Graduate Students	\$24,800	\$24,800	\$49,600
Travel	\$2,200	\$2,200	\$4,400
Total	\$40,000	\$40,000	\$80,000

This budget is modest for the proposed research efforts.

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# CURRICULUM VITAE

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### Personal Data

Born: June 14, 1962, Yichang, Hubei, People's Republic of China  
U. S. Citizen

### Education

Ph.D., Physics, Stevens Institute of Technology, Hoboken, New Jersey, 1987  
M.S., Physics, Stevens Institute of Technology, Hoboken, New Jersey, 1985  
B.S., Physics, Beijing University, Beijing, P.R. China, 1982

### Professional Experience

President, Director, and Chief Technology Officer, Since 2003  
Beam Power Technology, Inc.  
Group Leader, Since 1995  
Intense Beam Theoretical Research Group, Plasma Science and Fusion  
Center, Massachusetts Institute of Technology  
Principal Research Scientist, Since 1998  
Plasma Science and Fusion Center, Massachusetts Institute of Technology  
Research Scientist, 1990-1998  
Plasma Fusion Center, Massachusetts Institute of Technology  
SRS Postdoctoral, 1988-1990  
Plasma Fusion Center, Massachusetts Institute of Technology  
Postdoctoral Research Fellow, 1987-1988  
Department of Physics, Stevens Institute of Technology

### Awards

Outstanding Graduate Publication Award, 1987  
Stevens Institute of Technology  
Outstanding Graduate Research Award, 1987  
Department of Physics, Stevens Institute of Technology

### Professional Societies

Member of the American Physical Society, Since 1985

### Research Interest

Physics and applications of particle beams and plasmas, generation of coherent electromagnetic waves, and nonlinear dynamics and chaos.

## PUBLICATIONS IN REFEREED JOURNALS

- Chiping Chen -

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13. "Equilibrium of Self-Organized Electron Spiral Toroids," W. C. Guss and C. Chen, *Phys. Plasmas* **9**, 3303 (2002).
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15. "Ideal Matching of Heavy Ion Beams," C. Chen, R. Pakter and R. C. Davidson, *Nuclear Instruments and Methods in Physics Research A* **464**, 518 (2001).
16. "Equilibrium and Stability Properties of Electron Spiral Toroids," C. Chen, R. Pakter, and D. C. Seward, *Physics of Plasmas* **8**, 4441 (2001).

17. "Mechanisms and Control of Beam Halo Formation in Intense Microwave Sources and Accelerators," (Invited Paper) C. Chen and R. Pakter, *Physics of Plasmas* **7**, 2203 (2000).
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**PUBLICATIONS IN CONFERENCE PROCEEDINGS**  
**- Chiping Chen -**

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9. "Analytical and Numerical Calculation of 2D Dielectric Photonic Band Gap Structures," K. Samokhvalova, C. Chen, and B. L. Qian, Advanced Accelerator Concepts, AIP Conference Proceedings, in press (2004).
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12. "Three-Dimensional Modeling of Intense Bunched Beams in RF Accelerators and Sources," R. Bhatt, M. Hess, and C. Chen, Proceedings of the 2003 Particle Accelerator Conference (2003), p. 2643.
13. "Image-charge effects on the envelope dynamics of an unbunched intense charged-particle beam," Qian, B. L., J. Zhou, and C. Chen, Proceedings of the 2003 Particle Accelerator Conference, (2003) p. 3302.

14. "Beam Halo Formation and Loss Induced by Image-Charge Effects in a Small-Aperture Alternating-Gradient Focusing System," Zhou, J., B. L. Qian, C. Chen, E. Henestroza, S. Eylon, and S. Yu, Proceedings of the 2003 Particle Accelerator Conference (2003), p. 2646.
15. M. Hess and C. Chen, "Confinement of High-Intensity Bunched Beams in High-Power Periodic Permanent Magnet Focusing Klystrons", Proceedings of 2001 Particle Accelerator Conference, Vol. 5, 3302 (2001).
16. "Influence of velocity spread on cyclotron masers driven by spatiotemporally gyrating electron beams," Intense Microwave Pulses VIII, edited by H. E. Brandt, SPIE Proc. **4371**, 39 (2001).
17. "Bunched Annular Beam Equilibrium and Confinement," Intense Microwave Pulses VIII, edited by H. E. Brandt, SPIE Proc. **4371**, 57 (2001).
18. "Intense corkscrewing and wobbling elliptic beams in a piecewise uniform magnetic field," to appear in Proc. 2001 Part. Accel. Conf. (2001).
19. "New Method for Ultrahigh Frequency Cyclotron Maser at Low Magnet Field," J. A. Davies and C. Chen, Intense Microwave Pulses VII, edited by H. E. Brandt, SPIE Proc. **4031**, 19 (2000).
20. "Electron Beam Halo Formation in Periodic Permanent Magnet Focusing Klystron Amplifiers," C. Chen, M. Hess, and R. Pakter, Intense Microwave Pulses VII, edited by H. E. Brandt, SPIE Proc. **4031**, 34 (2000).
21. "Improved photonic bandgap cavity and metal rod lattices for microwave and millimeter wave applications," M. Shapiro, W. J. Brown, C. Chen, V. Khemani, I. Mastovsky, J. R. Sirigiri, and R. J. Temkin, Microwave Symposium Digest, 2000 IEEE MTT-S International, Vol. 1, p. 581.
22. "Confinement of Bunched Beams," M. Hess and C. Chen, Advanced Accelerator Concepts, edited by P. L. Colestock and S. Kelley, American Physics Institute Conference Proceedings **569**, 415 (2000).
23. "Space Charge Effects in Rectilinear Motion: Emittance Compensation, Pulse Shortening, and Halo Formation," C. Chen and M. Ferrario, Proceedings in the Second ICFA Advanced Accelerator Concept Workshop on the Physics of High-Brightness Beams, edited J. Rosenzweig and L. Serafini (World Scientific, 2000), p. 167.
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