Power Couplers for the ILC

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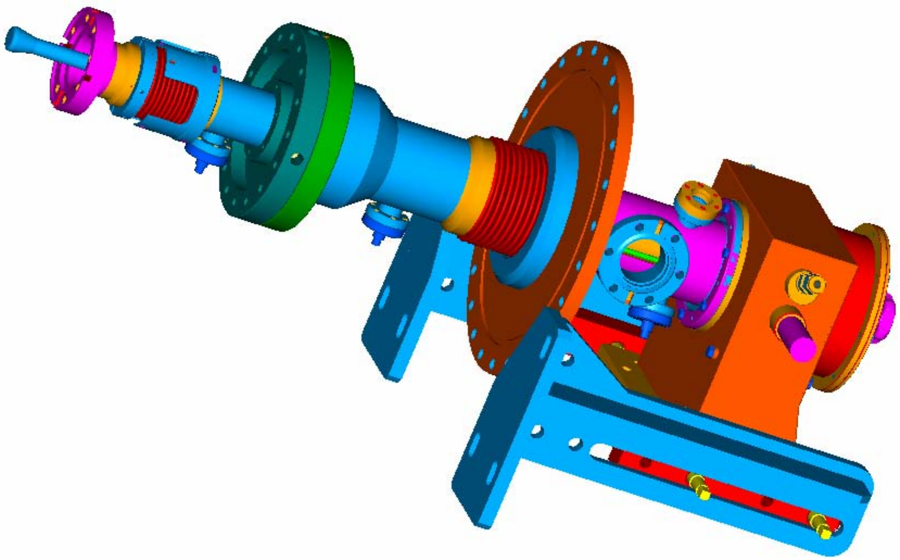
Outline of Talk

- Fundamental Power Couplers Defined
- Summary of Power Couplers Built by CPI
- Industrial Manufacturing Capabilities Developed at CPI for Power Couplers
- Highlights of ILC Power Coupler Cost Study
- Challenges Building Couplers for the ILC
- Summary

Power Couplers

- The main function of a power coupler is to efficiently transfer the RF power from the source to the cavity and ultimately the particle beam
- ILC Reference Design Report specifies the TTF3 or XFEL power coupler for the ILC
- TTF3 power coupler has three main functions
  - Transmits 250 kW - 500 kW through two cylindrical ceramic windows
  - Acts as an interface between room temperature parts of accelerator and cold parts at cryogenic temperature
  - Provides interface between atmospheric pressure in waveguide and ultrahigh vacuum in the SRF cavity
- XFEL power coupler is a slightly simplified version of the TTF3 power coupler shown at right



CPI Power Couplers for Superconducting Accelerators

Model	Accelerator Application	Frequency (MHz)	Peak Power (kW)	Avg. Power (kW)	Cooling	Status
VWP 1133	Spallation Neutron Source (SNS)	805	1000	60	water or air	Qualified at JLAB
VWP 1162	Rare Isotope Accelerator (RIA) prototype	805	1000	10	air	Qualified at JLAB
VWP 1137, VWP 3049 (TTF3)	Tesla Test Facility	1300	1110	7.2	air	Delivered 32, 42 currently in production
VWP 1136	Tesla Test Facility	1300	1110	7.2	air	Delivered in 2004
VWP 3032	Cornell ERL Injector Cavity	1300	75	75	air	Qualified at Cornell, 10 currently in production
VWP 1185/86	Free Electron Laser Injector	748	1000	500	water, helium	Delivered in 2006
VWP 3038	Fermi Lab Third Harmonic Accelerating Cavity	3900	45	12.5	air	Delivered in 2006

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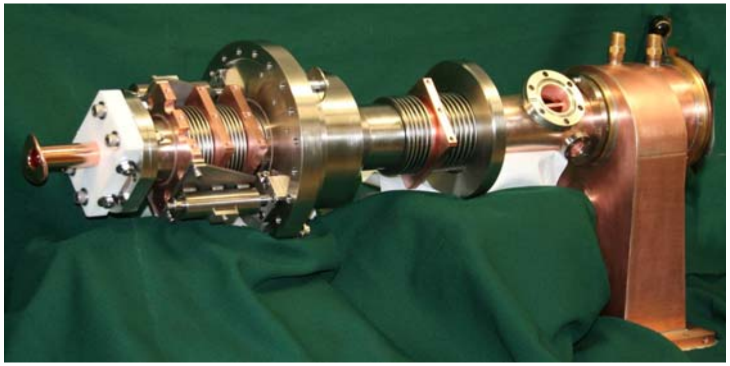
CPI Power Couplers for Superconducting Accelerators

VWP-3032 Power Coupler
Power Couplers for Cornell ERL currently in production
1.3 GHz
75 kW peak, 75 kW average power

VWP-1137, VWP-3049 Power Couplers
TTF3 Power Couplers in Production for DESY and Fermi Lab
over 70 will have been manufactured by end of 2007
1.3 GHz
1 MW peak, 7 kW average power



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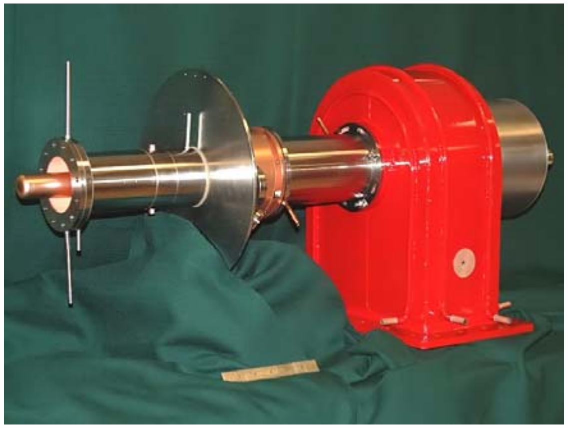
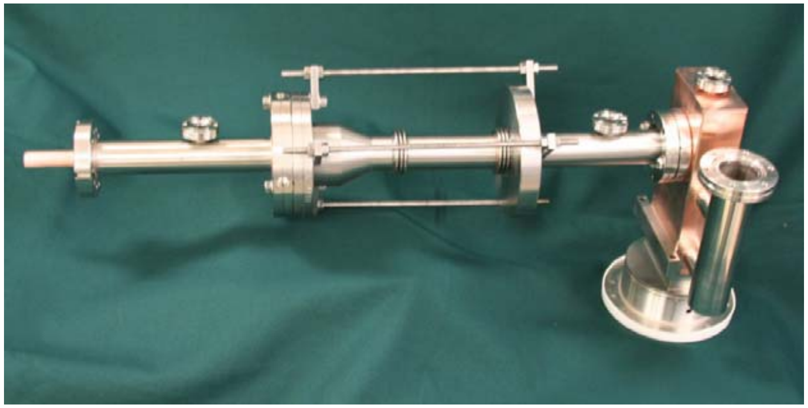


VWP-1185/86 Power Coupler
FEL Injector
748 MHz
1 MW peak, 500 kW average power
Designed and built in collaboration with AES



VWP-3038 Power Coupler
Fermi Lab Third Harmonic Accelerating Cavity
45 kW peak, 12.5 kW average power
Designed and built in collaboration with Fermi Lab

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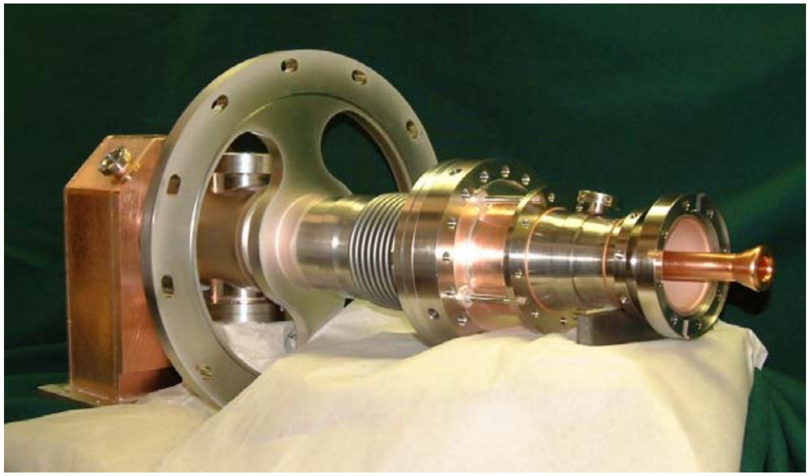

VWP-1133 Power Coupler

Spallation Neutron Source

805 MHz

1 MW peak, 60 kW average power

VWP-1162 Power Coupler

Rare Isotope Accelerator

1 MW peak, 10 kW average power

VWP-1136 Power Coupler

Tesla Test Facility

1300 MHz

1 MW peak, 7 kW average power

Designed and built in collaboration with AMAC Intl.

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Key Process Technologies

- Key process technologies qualified by DESY, CNRS-Orsay, and / or Cornell
- TIG welding of stainless steel components
- Vacuum brazing
  - Metal to metal seals
    - Stainless steel to stainless steel
    - Copper to stainless steel
  - Ceramic to metal joints
    - Alumina to copper
- E-beam welding of copper cylinders
  - 100% penetration depth required
  - Complex fixtures required to protect ceramic surfaces from spattered material
- High RRR-copper plating of stainless steel
  - Thickness and RRR carefully controlled
- TiN coating of alumina windows for multipactor suppression
  - Thickness and composition carefully controlled
  - Secondary yield less than unity

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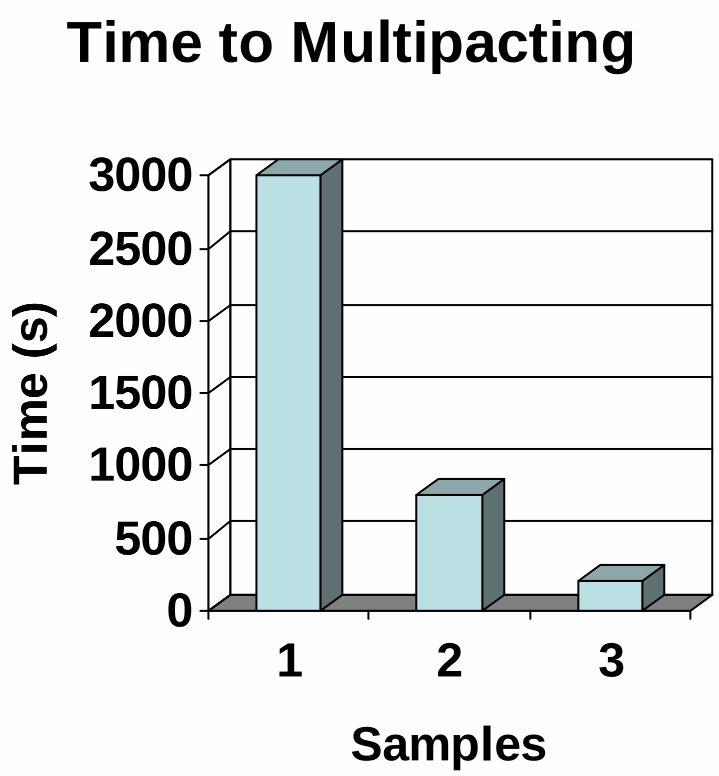
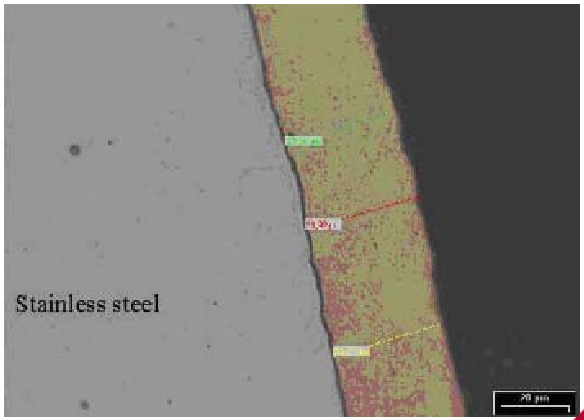
Industrial Capabilities Developed for Power Couplers

- TTF3 Couplers have two cylindrical alumina windows requiring TiN coating to suppress multipactor
  - Warm window (T~300 K) at waveguide to coax transition
  - Cold window (T~70 K) near opposite end
- TiN coating process developed at CPI
  - Modeled process after DESY process
  - Titanium vapor deposition in ammonia atmosphere
- Process qualified at DESY
  - Multipacting measured by A. Brinkmann using 500 MHz resonator
  - Stable multipacting is established if the secondary yield is greater than 1
  - CPI provided TiN-coated copper samples to DESY
  - Samples 1 are uncoated copper, ultrasonically cleaned, rinsed with isopropanol, blown dry with nitrogen
  - Samples 2 are TiN-coated copper, as received
  - Samples 3 are TiN-coated copper, treated as Samples 1 and baked at 200°C for 12 h
- TiN coating composition and thickness are sufficient to suppress multipacting



Industrial Capabilities Developed for Power Couplers

- Copper plating of various stainless steel components is required to reduce heat loads to the refrigerator at 2 K, 4 K, and 70 K
- Plating specifications trade off minimal thermal conduction vs. minimal RF heating
  - RRR greater than 30 required after baking at 400 °C in a vacuum furnace
  - tight tolerance is required on thickness of copper plating
  - 10 μm ± 5 μm and 30 μm ± 10 μm on outer and inner conductors, respectively
- High RRR plating process developed at CPI
  - In-house electroplating process with proprietary process parameters, plating bath composition, electrode profiles
- Process qualified at CNRS-Orsay*
  - Sample 1, RRR = 20, as received
  - Sample 1, RRR = 113, after annealing at 400 °C for 1 hour
  - Two other samples, RRR = 24 and 46, as received



*M. Fouaidy and N. Hammoudi, "RRR of copper plating and low temperature electrical resisitivity of material for TTF couplers," Physica C 441 (2006) 137-144.

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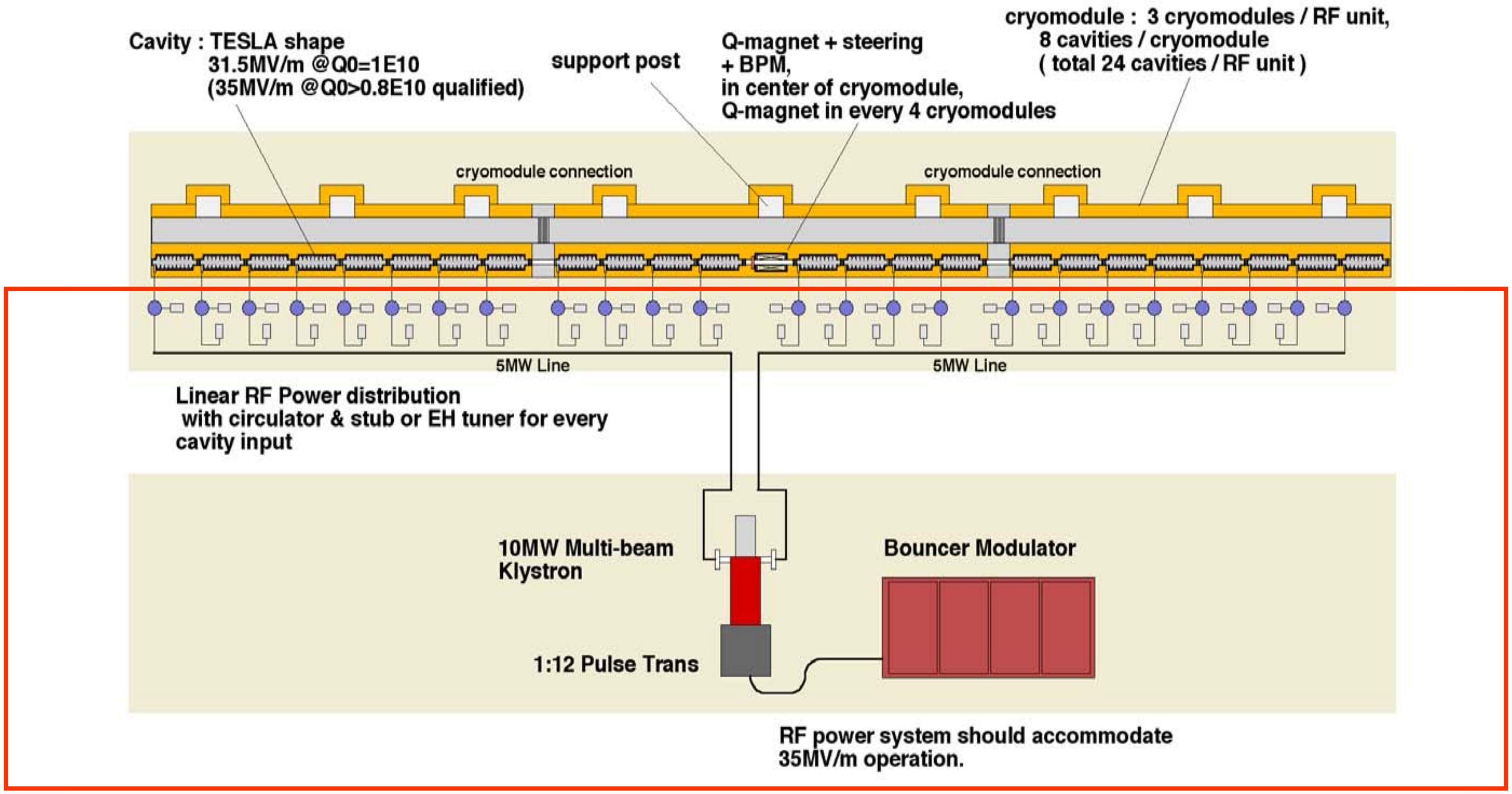
ILC RF Unit Industrial Cost Study

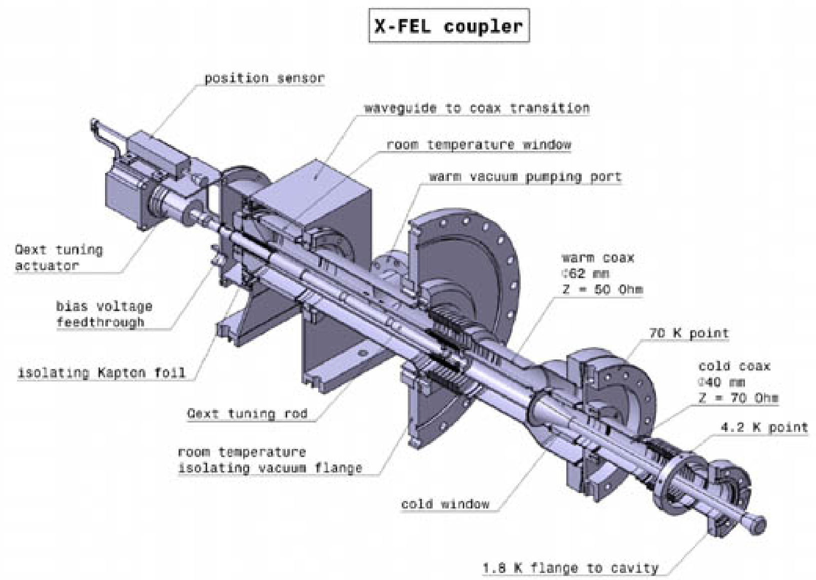
- AES, Meyer Tool, and CPI performed an industrial cost study for Fermi Lab for the ILC RF Unit
- CPI was responsible for costing all RF system components
  - Modulator (Titan L3)
  - Klystrons (CPI Microwave Power Products Division)
  - Circulators and waveguide components (Ferrite)
  - Couplers (CPI Beverly Microwave Division)
  - Low Level RF (CPI Beverly Microwave Division)

ILC RF Unit Configuration



Highlights of ILC Cost Study - Couplers

- CPI estimated costs to fabricate, clean, assemble in a class 10 clean room, and condition 24, 6000, and 18,000 XFEL power couplers
- Basis of fabrication cost estimate
  - 5 ¼ year production at CPI Beverly facility
  - Initial ramp up of production during first ¾ year then stable production rate
  - All processes established beforehand
  - Multiple vendor quotes solicited for all materials
  - Labor estimated for all fabrication steps (to 0.1 h)
  - History from 32-coupler production run used as guide
  - Final review by cross-functional team
  - Results provided to Fermilab and GDE in March 2007
  - Cost details proprietary to CPI
  - Fidelity within ± 20%



- Summary for 6000 couplers
  - Materials: 45% of total cost
  - Labor: 50% of total cost
  - Other (capital equipment procurement, fixtures, shipping containers): 5% of total cost

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Highlights of ILC Cost Study - Couplers

- Basis of clean room assembly and conditioning cost estimate
  - 5 ¼ year production at CPI Beverly facility
  - Initial ramp up of production during first ¾ year then stable production rate
  - Industry acquires experience with assembly and conditioning prior to ILC production
  - Labor estimates based on report provided by CNRS-Orsay
  - Couplers conditioned in pairs
  - 90% learning curve assumed, less aggressive learning curves also modeled
  - 20 hours average conditioning time assumed, higher conditioning time also modeled
  - Typical monitoring levels associated with vacuum electron devices assumed
  - Results provided to Fermilab and GDE
  - Cost details proprietary to CPI
  - Fidelity within ± 20%

- Summary for 6000 couplers
  - Clean room assembly and conditioning costs 26% of the total cost of power couplers
  - 30 hours average conditioning time increases overall cost of couplers by only 2.5%
  - 2 RF test stands required

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Challenges Building Couplers for the ILC

- Quantity of 1000 per year (20 per day) for 5 years is obviously challenging but not daunting
- Similar in scope and duration to very large military vacuum electron device program
- Low rate initial production required over several years to ramp up to full scale
  - Will enable documentation and process validation at representative manufacturing rates
  - Will enable hiring and training of appropriate personnel
  - XFEL program may act as substitute
- Optimum production ramp up rate needs to be determined
- Sufficient time needs to be accommodated for equipment purchase, installation, and verification
- Design needs to be refined for manufacturability to minimize costs
- Industry needs experience with clean room assembly and conditioning of couplers

Summary

- CPI has built over 50 power couplers over the last 7 years
- CPI will build an additional 50+ power couplers this year for Fermi, DESY, and Cornell
- With significant help from DESY, CNRS-Orsay, and Cornell, CPI has qualified its key processes for the fabrication of power couplers
- Through CPI's participation in the ILC RF Unit Cost Study, we have identified what is required for XFEL and ILC quantity production
- We believe that US Industry (CPI) is qualified to manufacture power couplers for the XFEL and the ILC