International Linear Collider Communication

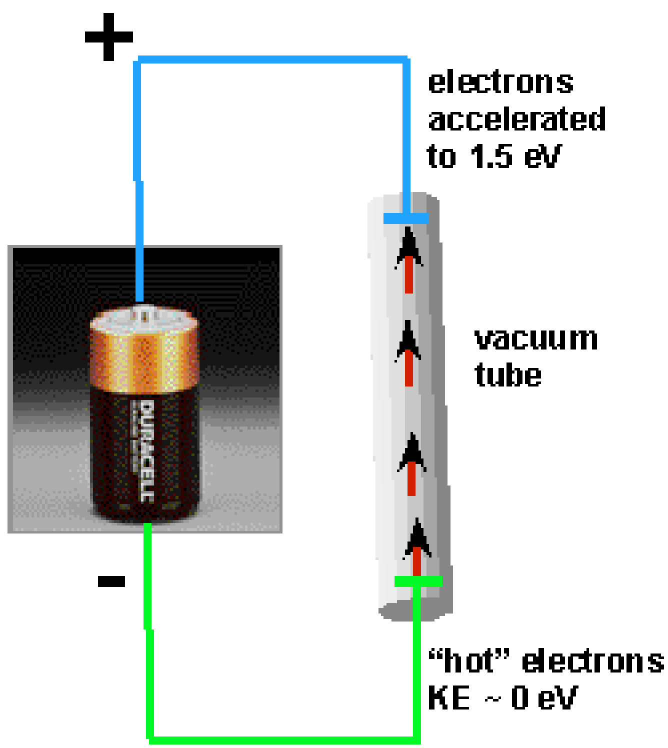
Radio Frequency (RF) Systems for the ILC

Ralph J. Pasquinelli

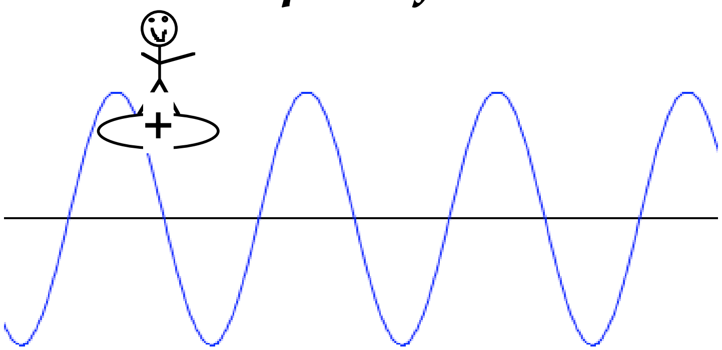
Fermilab

August 23, 2005

Basic 1.5 eV accelerator



Basic Principle of Acceleration



Building Blocks of a RF System

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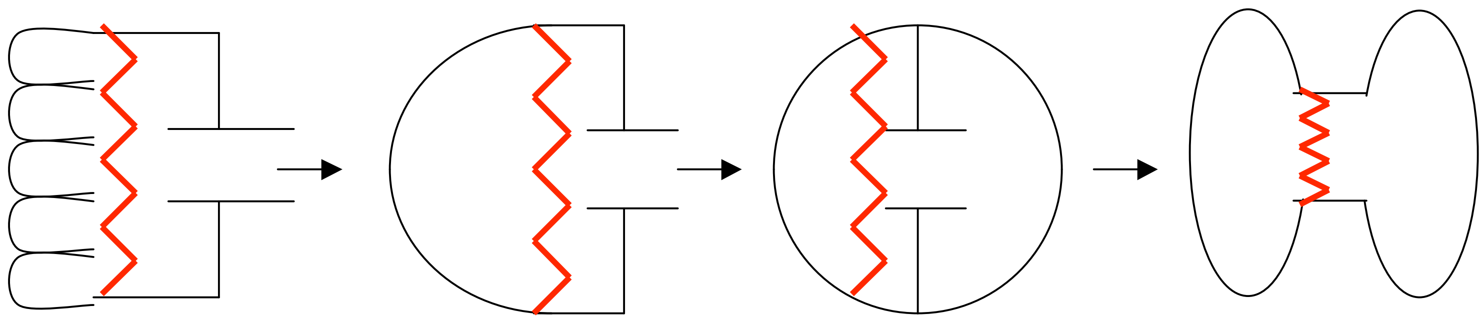
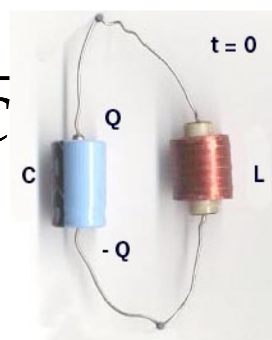
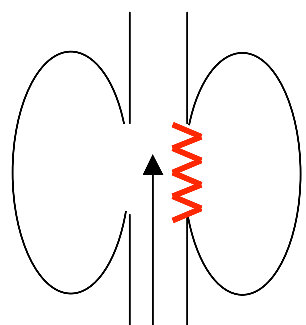
RF Cavity transformed from a LC circuit

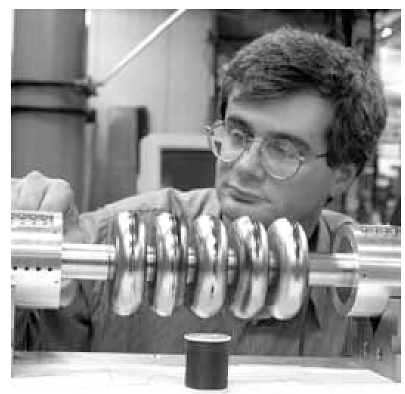


$$w_o = 2\pi f_o = \sqrt{\frac{1}{LC}}$$





Beam

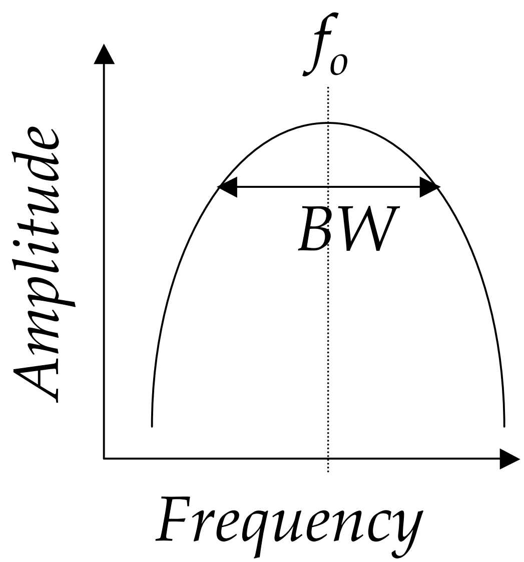


Shunt Impedance

Cavity Q or Quality Factor

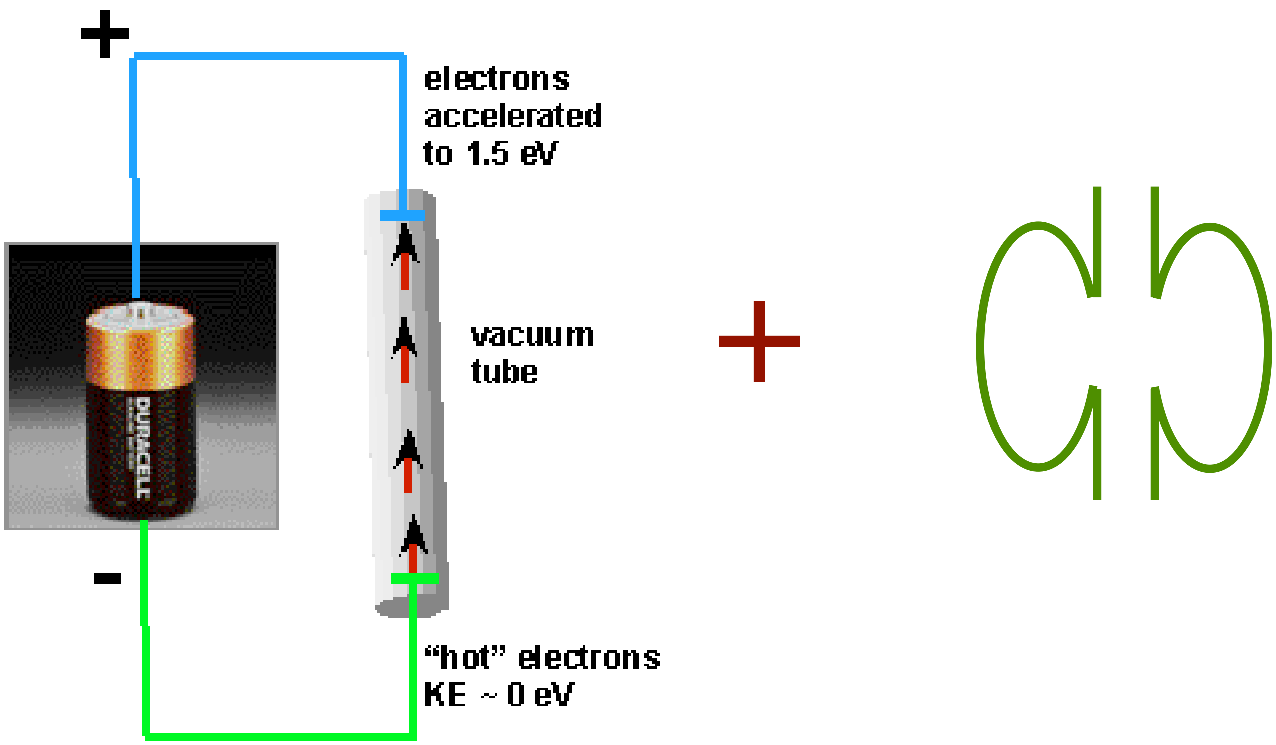
Q=Energy Stored/Energy Lost (per cycle)

$Q=f_o/BW$ (Center Frequency/Band Width)

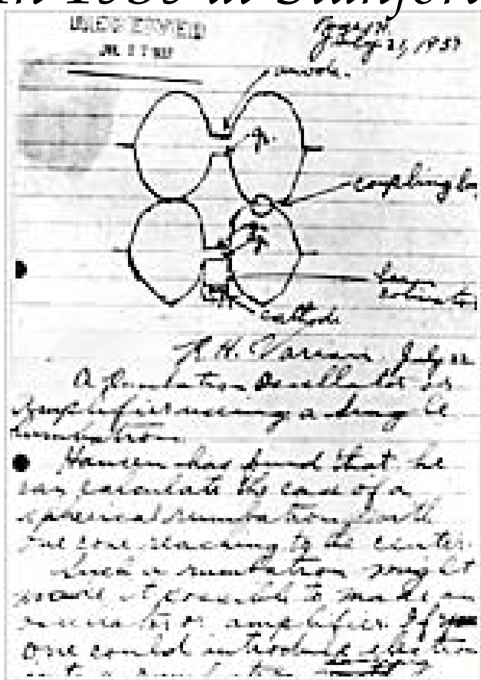


BW~Information

Klystrons Provide the RF Power

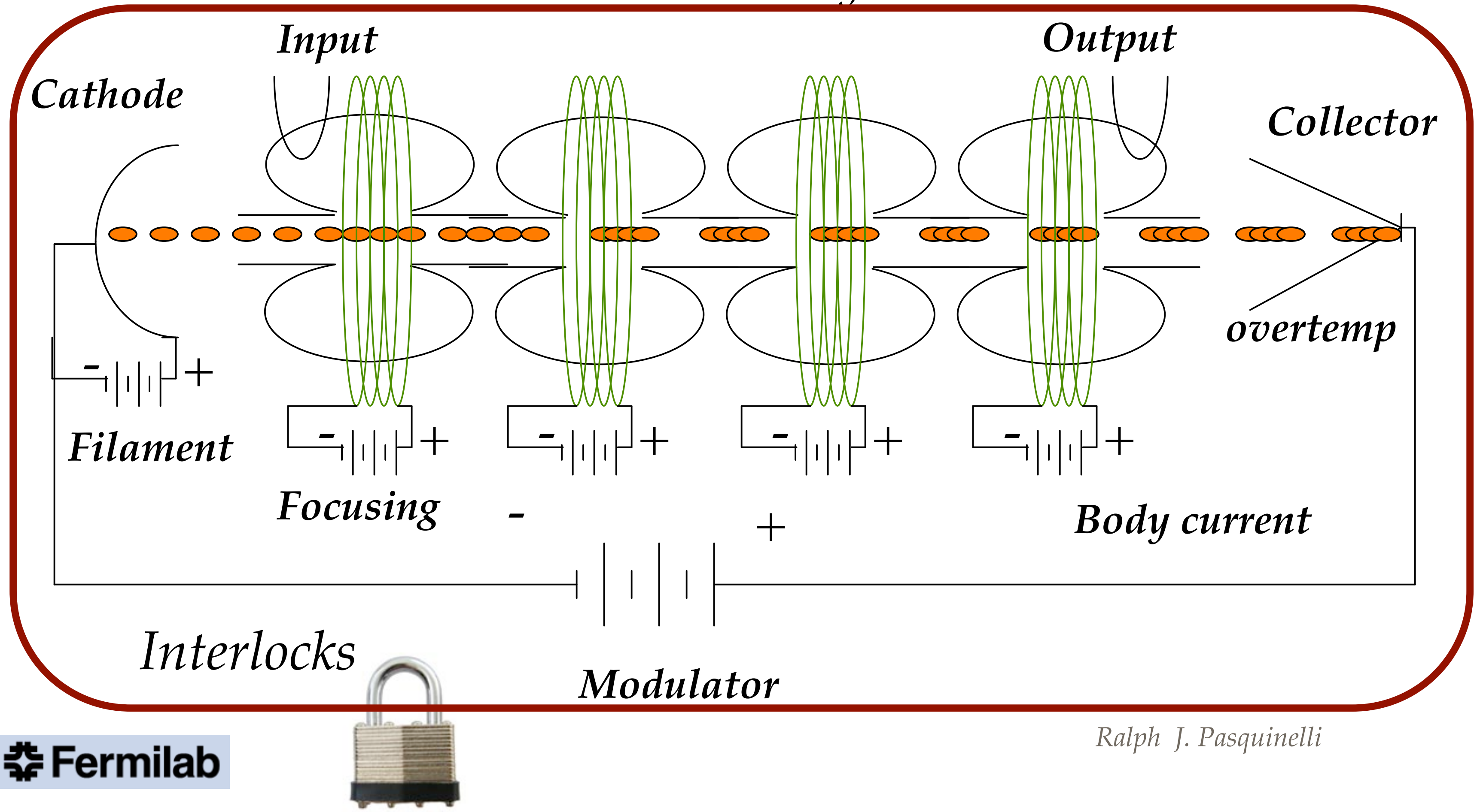


Varian Brothers Russell and Sigurd Develop Klystron In 1939 at Stanford

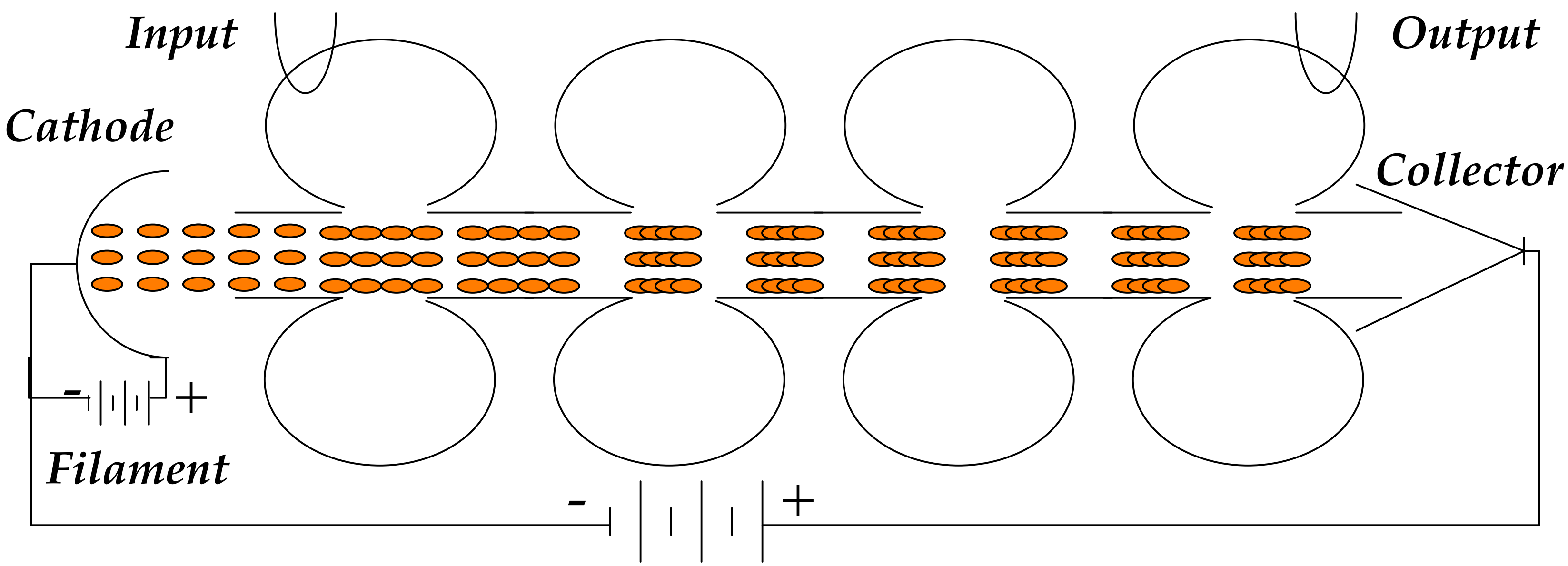


Named Klystron after Greek verb klyzo which expresses the breaking of waves on the beach

Klystron Operation
Electron Beam Velocity Modulation



Multi-Beam Klystron Operation
Power Conversion Efficiency & Reduced Space Charge



Power = Electron Current x Cathode Voltage

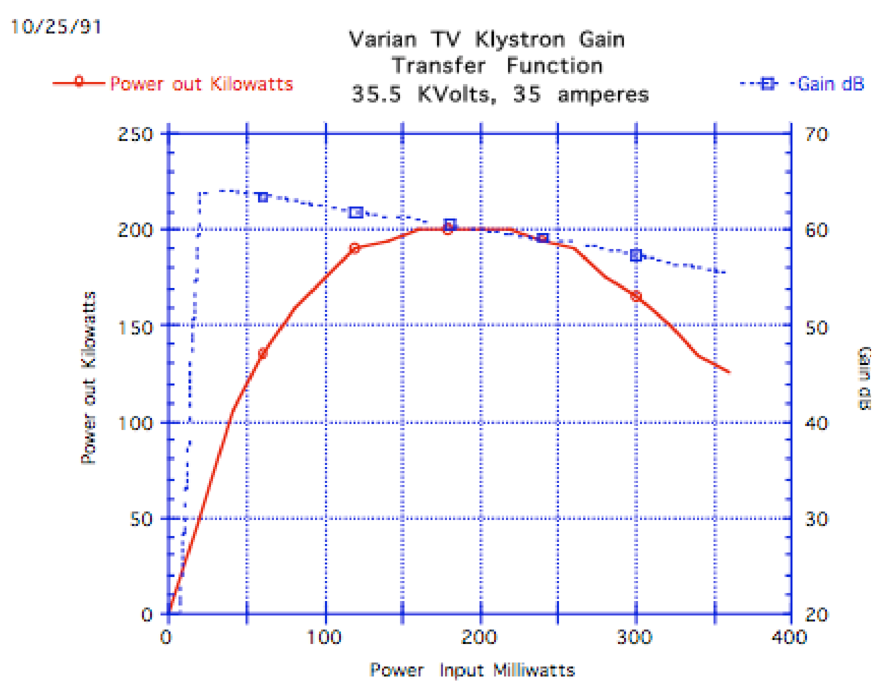
Megawatts   10's of Amps   100's of Kilovolts

Modulator

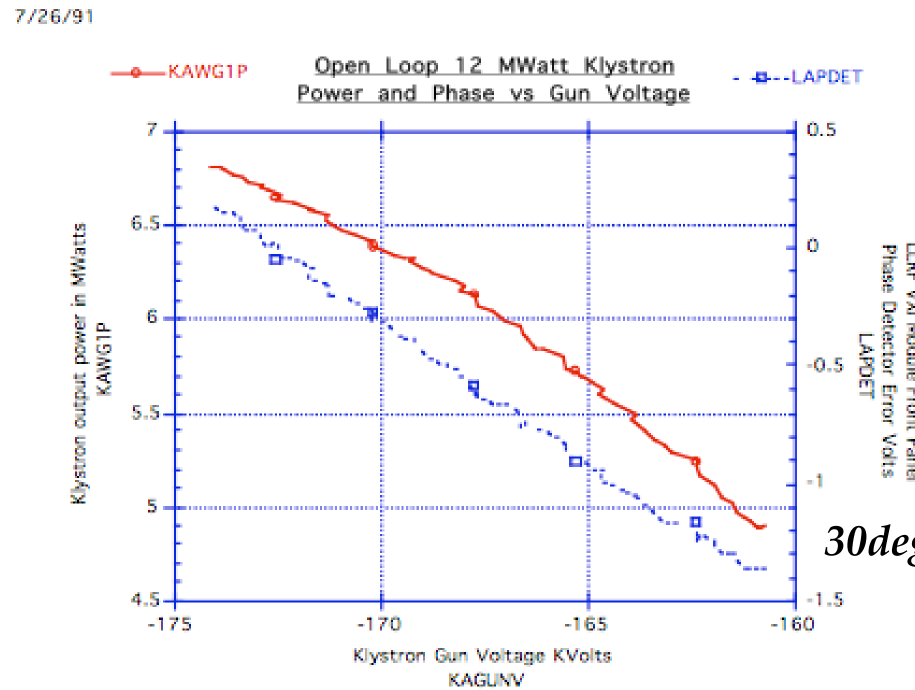
Typical Klystron Parameters

Power Gain	*40-60 dB (10^4-10^6)*
Power	*10^3 to 10^7 Watts*
Duty Cycle	*Continuous or Pulsed*
Frequency	*Hundreds MHz to Tens GHz*
Bandwidth	*1%*
Efficiency	*50%*
Cathode volts	*10's to 100's of kilovolts*
Klystron Life	*10,000-100,000 hours*

Klystron Characteristics



Power Gain Curve



30deg/v

Gain/Phase vs Gun Volts

CPI VLK8301

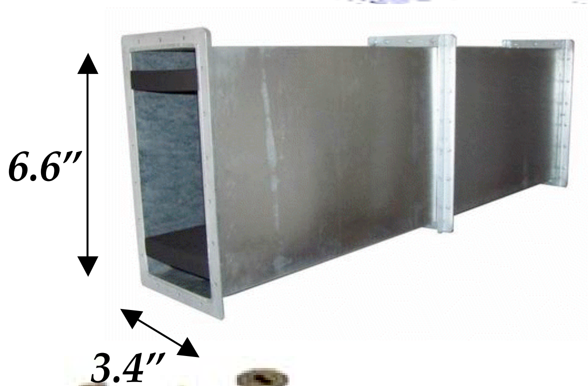
Toshiba

TH 1801
Multi-Beam Klystron

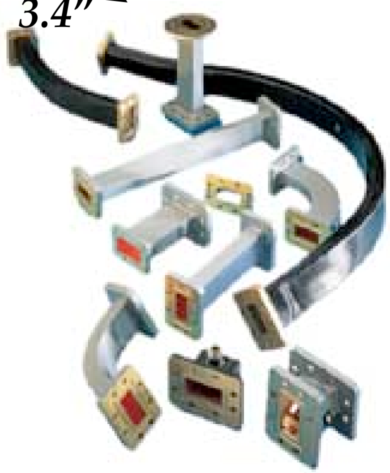
10 MW peak - 150 kW av. at 1.3 GHz

THALES

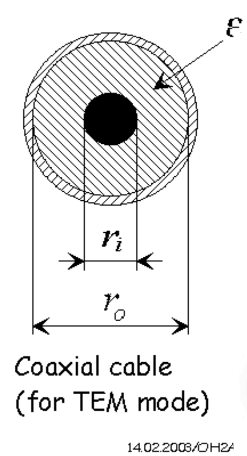
Power Transmission



@1.3 GHz
3″coax has 0.7dB/100ft 85%   0.64 Mwatts peak
WR-650 waveguide 0.25dB/100ft 95% 13 Mwatts

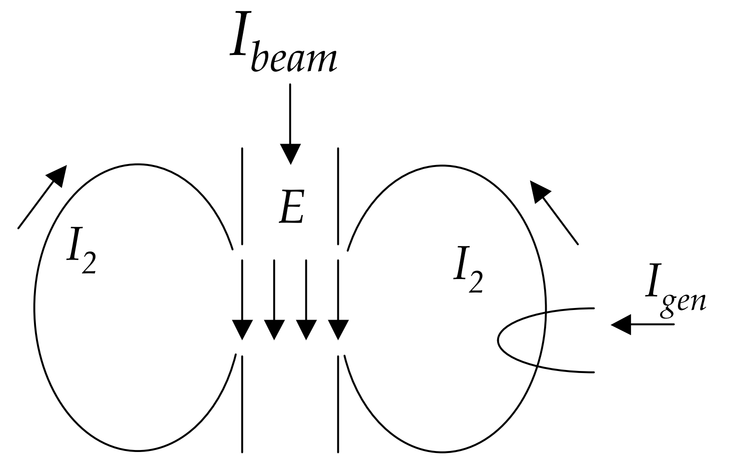


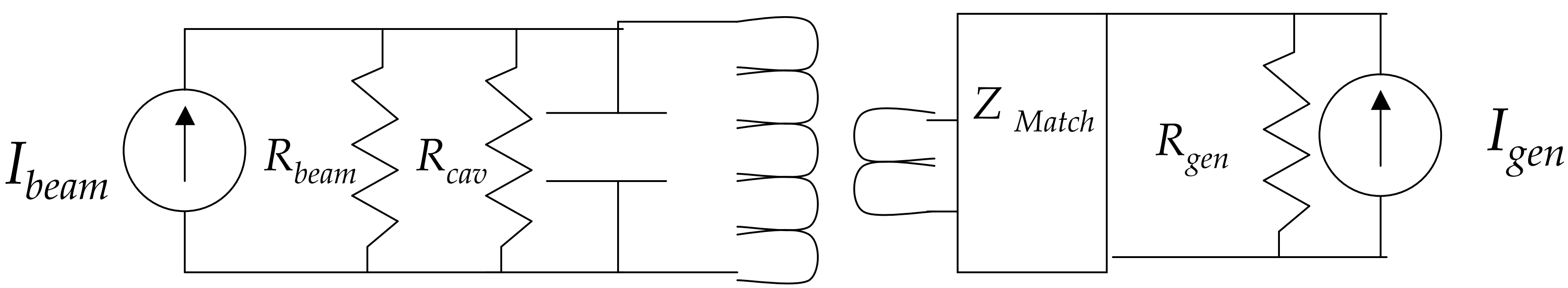
Waveguide



Coaxial Cable

To inject or extract energy
A coupling loop is used.





Equivalent
Circuit model

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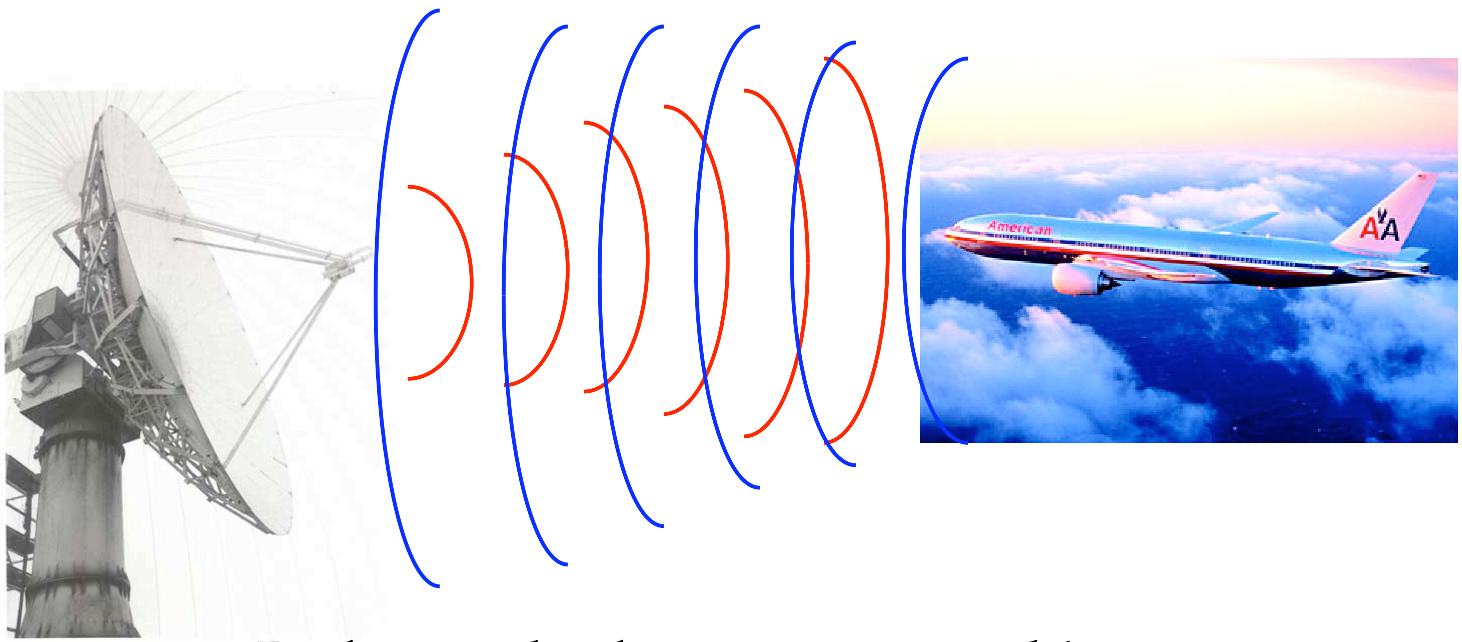
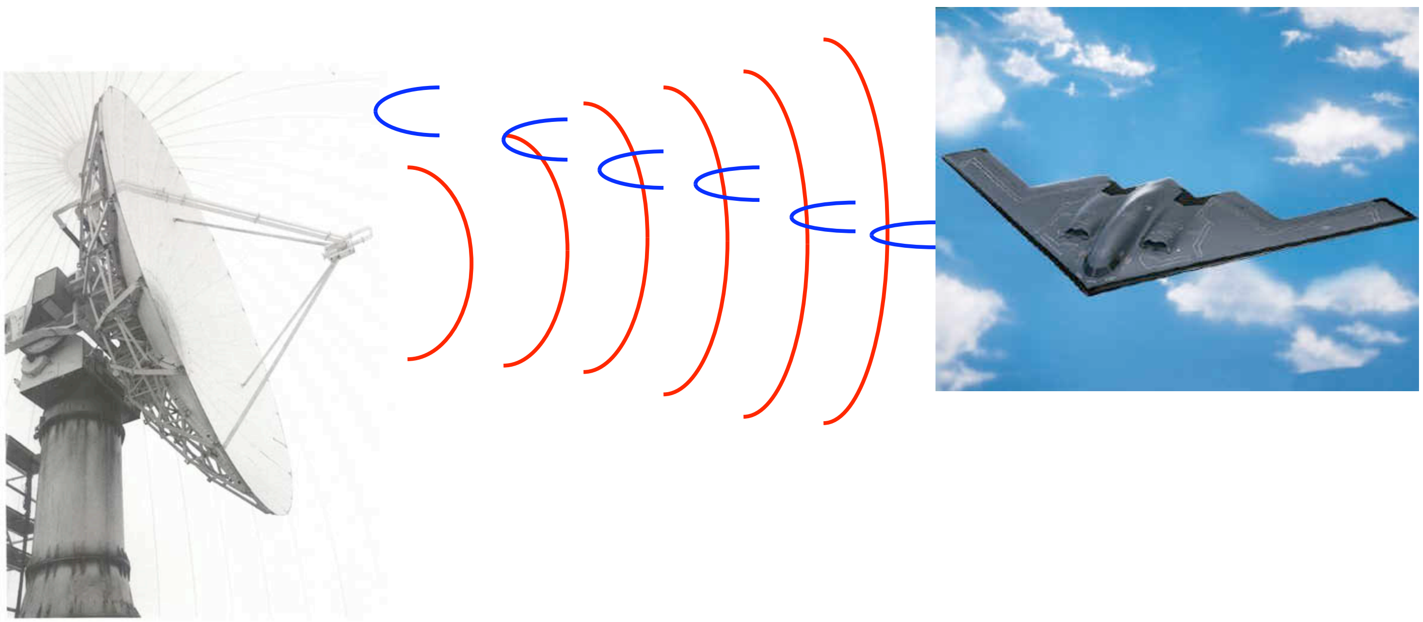
Importance of Matching



Radar works due to poor matching

Importance of Matching



Better matching with the B2 harder to detect!

Microwave Matching Gizmos

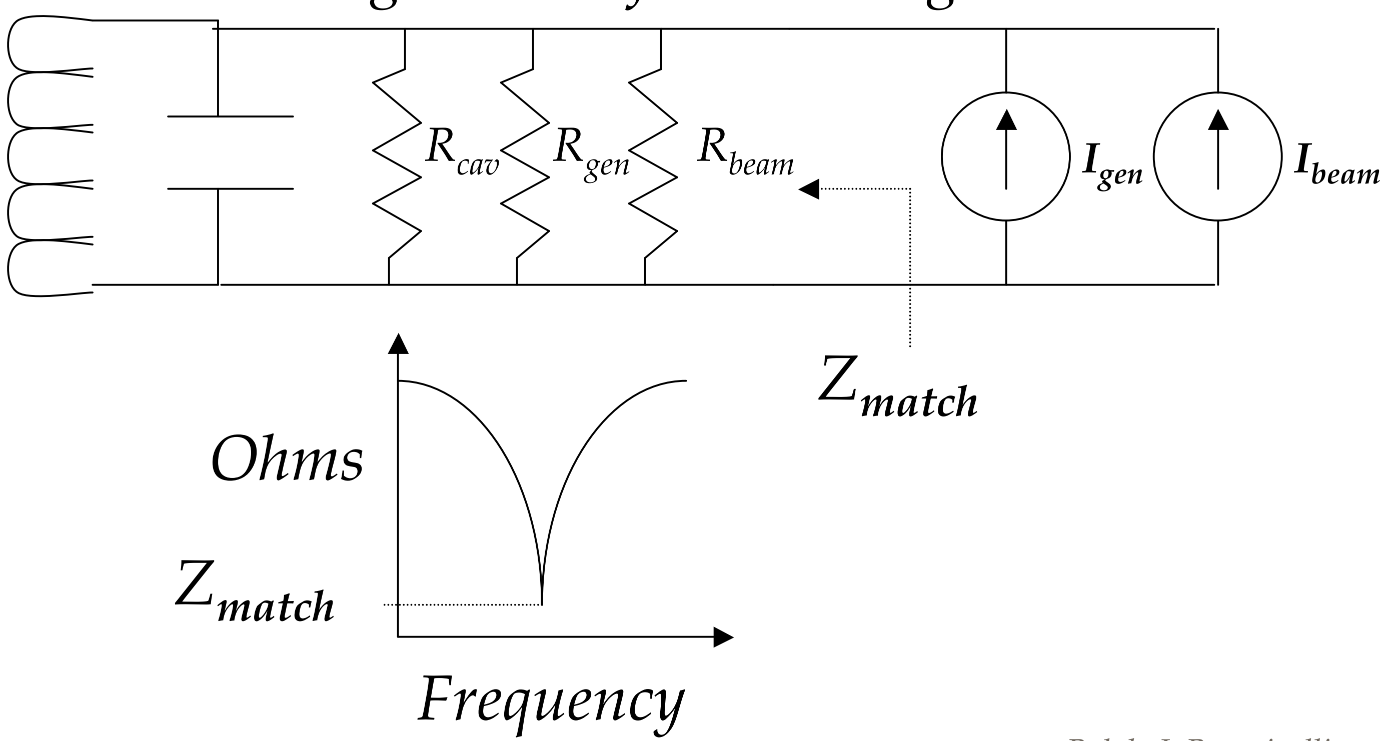
Directional Coupler

Three Stub Tuners

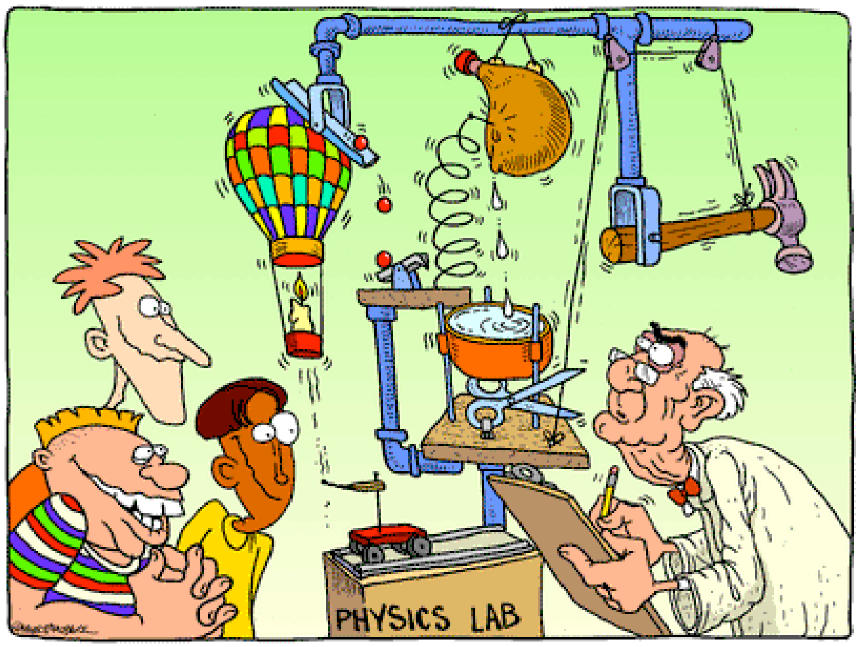
Circulator/Isolator

Waveguide Load

Further circuit simplification and assign values for modeling



Design of a RF System



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Questions to Ask

Duty Cycle?

Gradient possible?

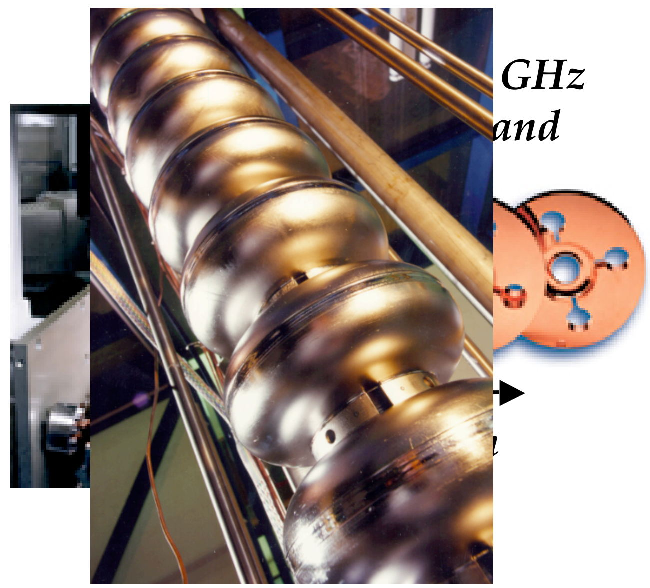
Power source available?

Need to Choose Frequency of Operation

Size Limitation?

Goldie Locks "just right!"

GHz
and



1.3 GHz 9 cell SRF Cavity 70mm iris

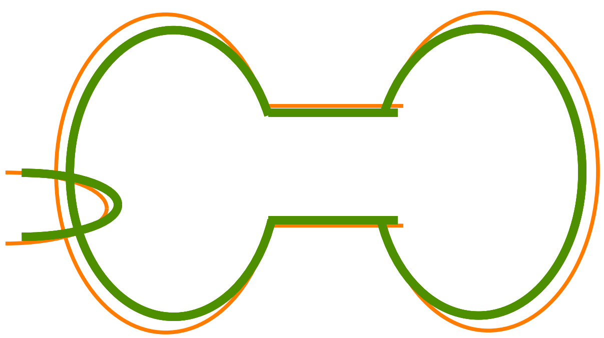
Issues with Superconducting RF (SRF):

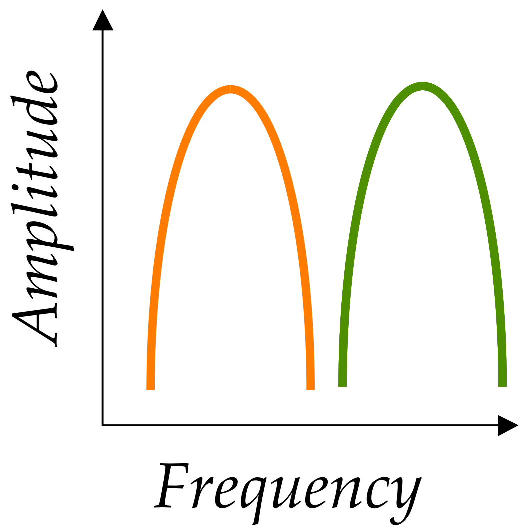
Narrow bandwidth due to high Q of 10^9

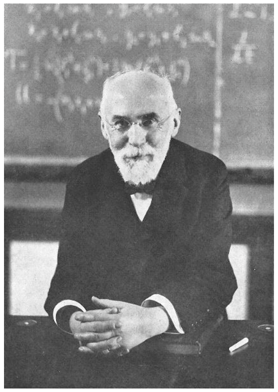
Pulsed RF fields exert mechanical detuning forces

Microphonic sensitivity

Lorentz Force Detuning

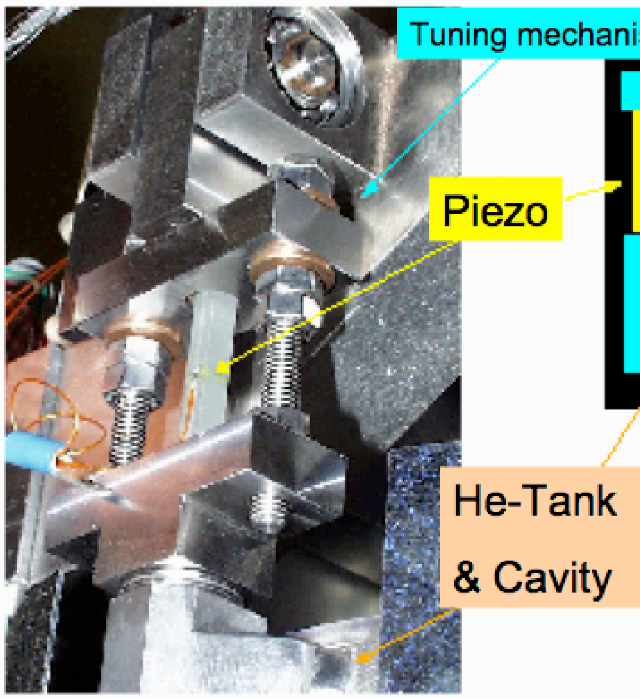


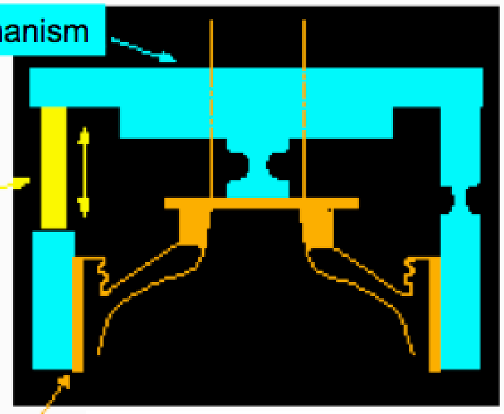




Piezoelectric tuner

M. Liepe, S. Simrock, W.D.-Moeller





Piezo-Actuator:

l=39mm

U_{max}=150V

Δ l=3μm at 2K

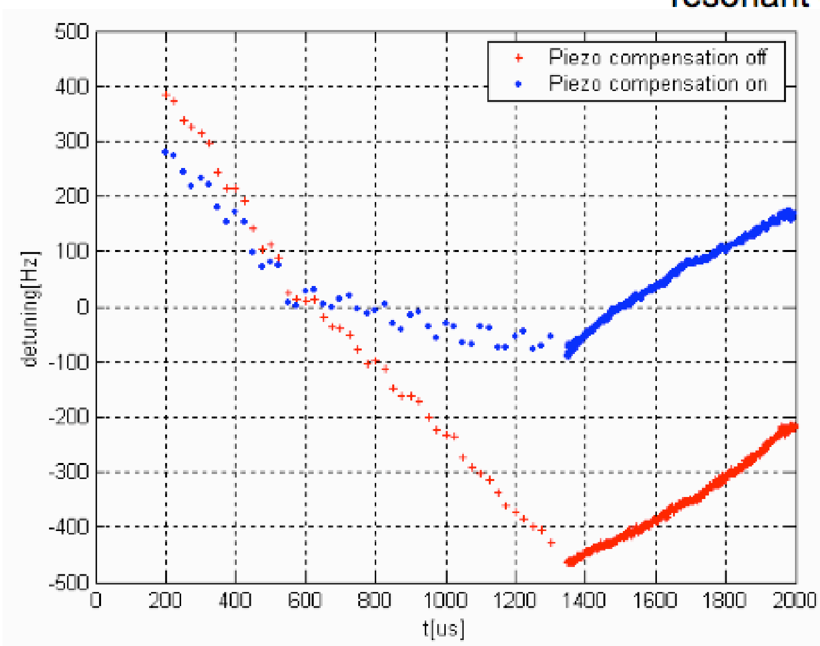
$\Delta f_{max,static}$=500Hz

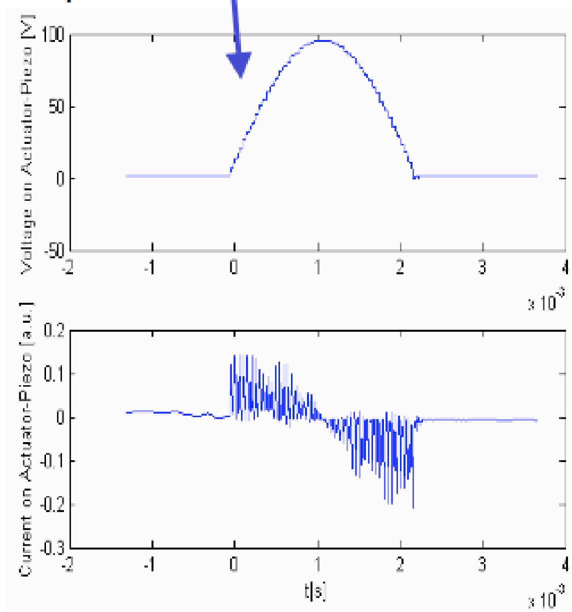
Frequency stabilization during RF pulse using a piezoelectric tuner

Blue: With piezo

Red: Without piezo

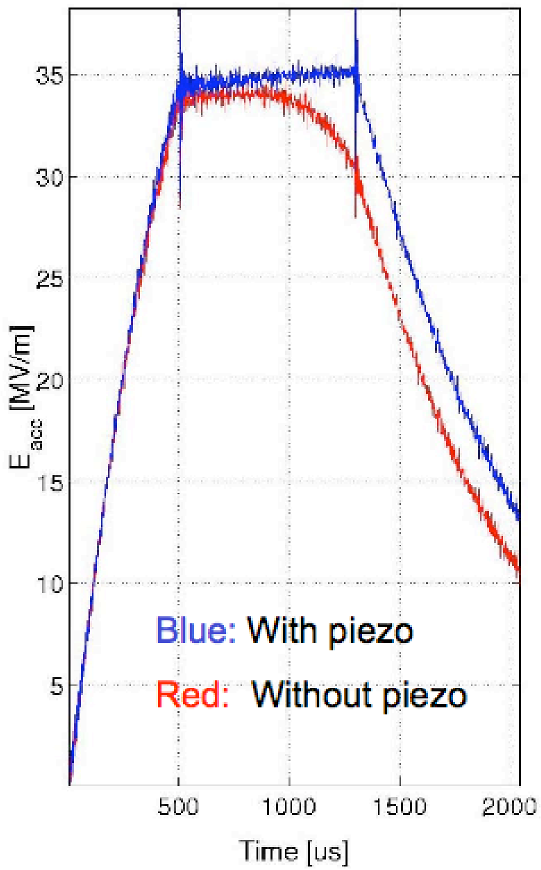
Frequency detuning of 500 Hz compensated voltage pulse (~100 V) on the piezo. No resonant compensation

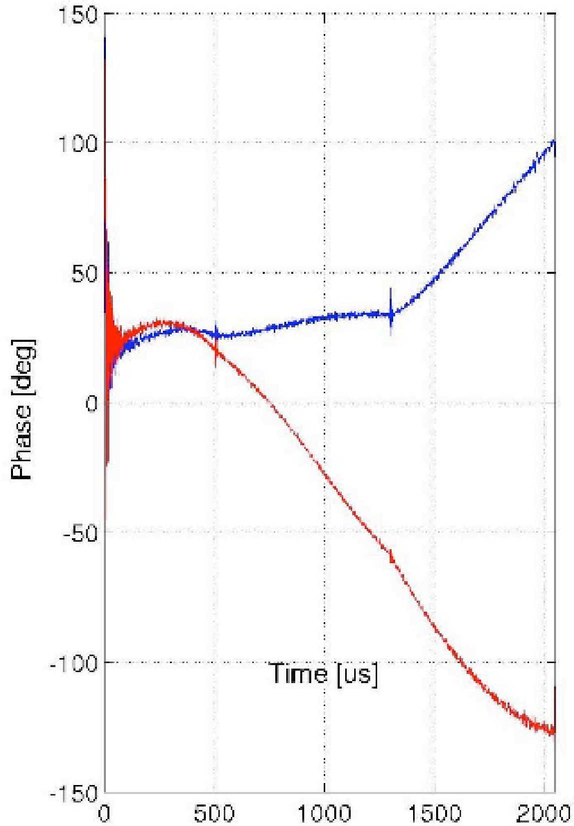




Lutz Lilje DESY TESLA 26/01/2004

RF signals at 35 MV/m

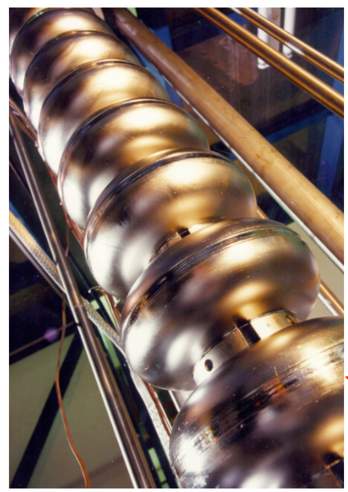




Lutz Lilje
DESY

Sources of Microphonic Noise

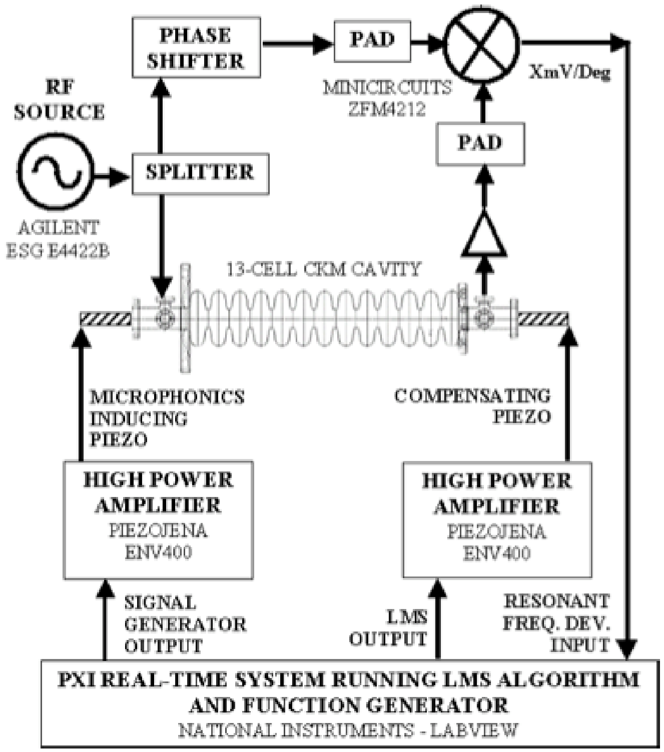
Cultural Noise

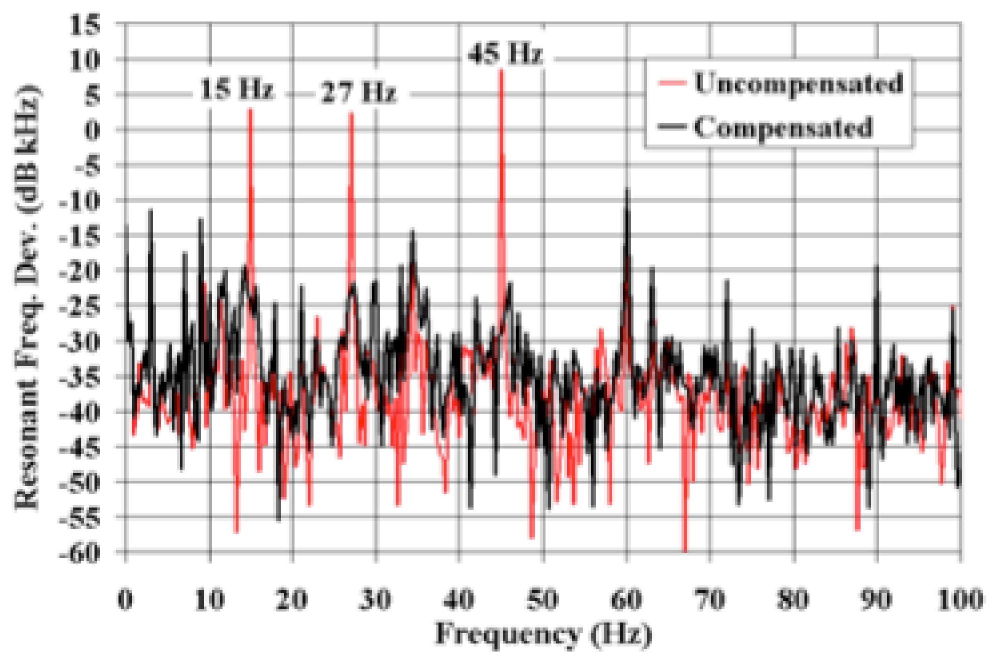


Earthquakes

Vacuum Pumps

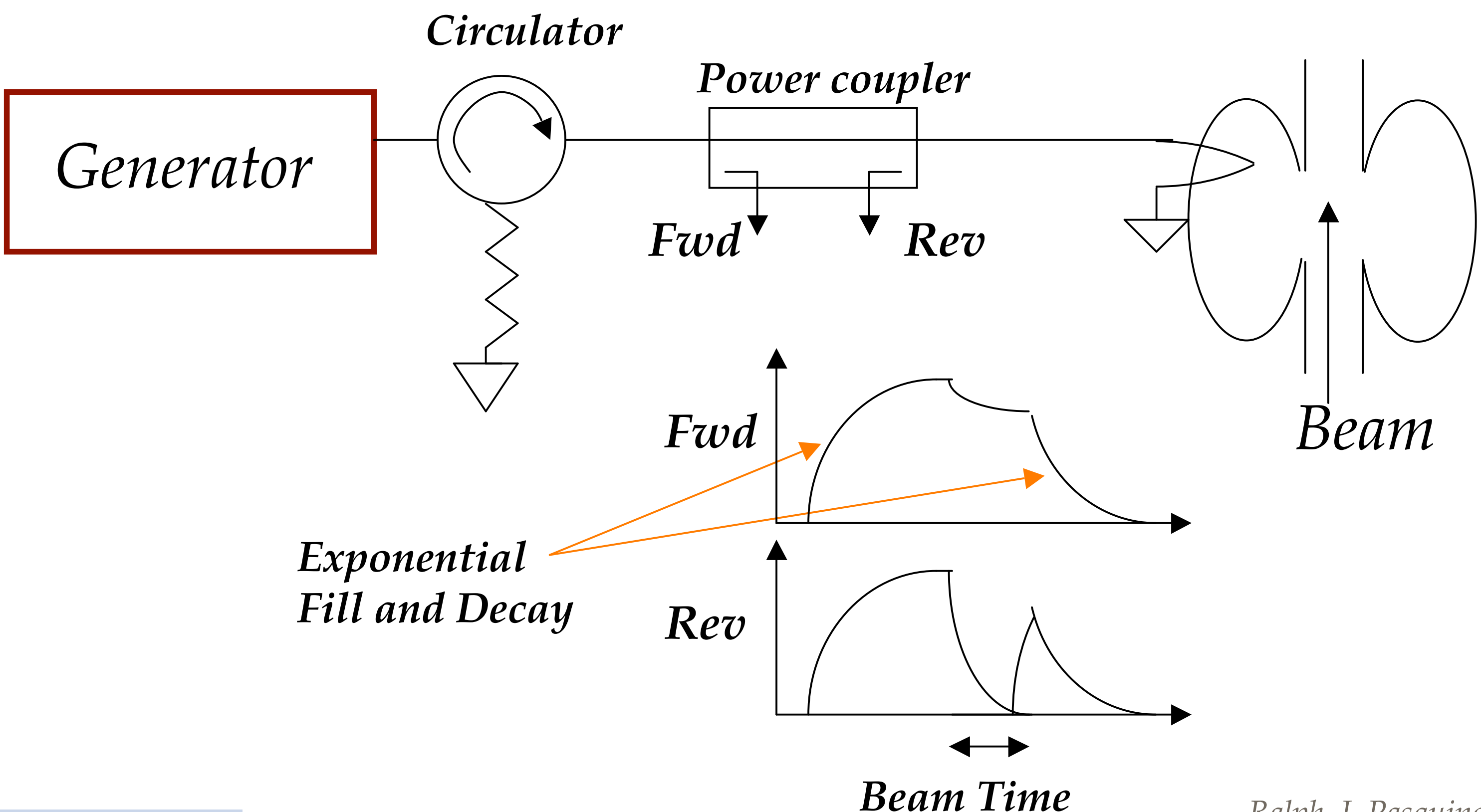
Microphonics Compensation





Ruben Carcagno et al Fermilab

Beam impedance loads SRF cavity
Drive to cavity is only matched when beam is present



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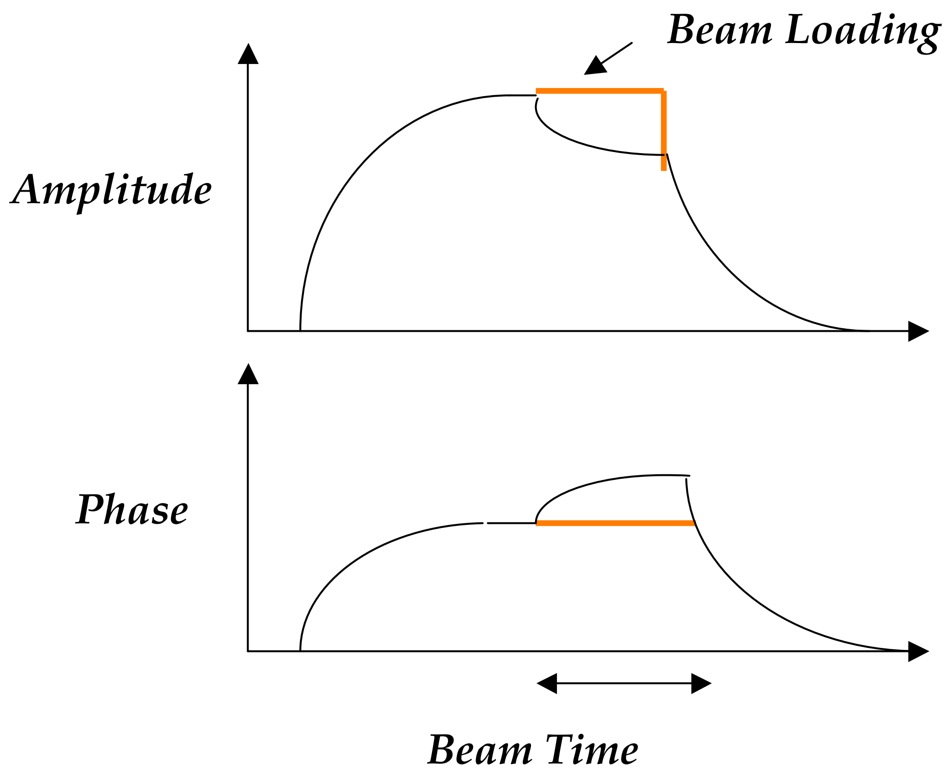
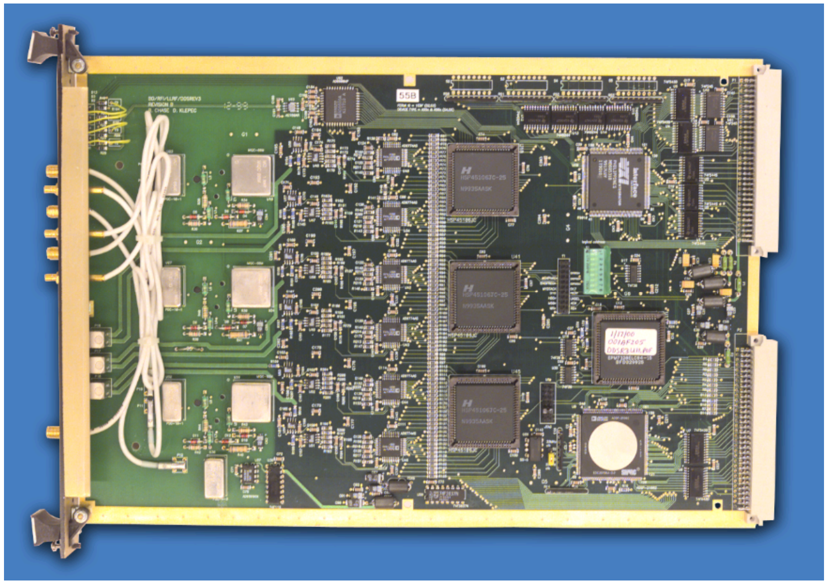
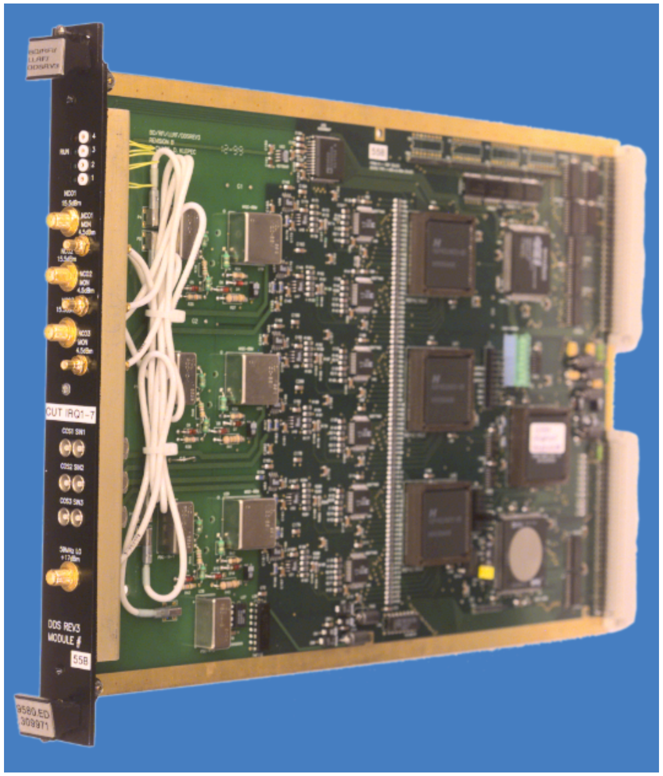
Low Level RF (LLRF)

Provides feedback and feed forward to improve gradient stability







Typical LLRF Hardware

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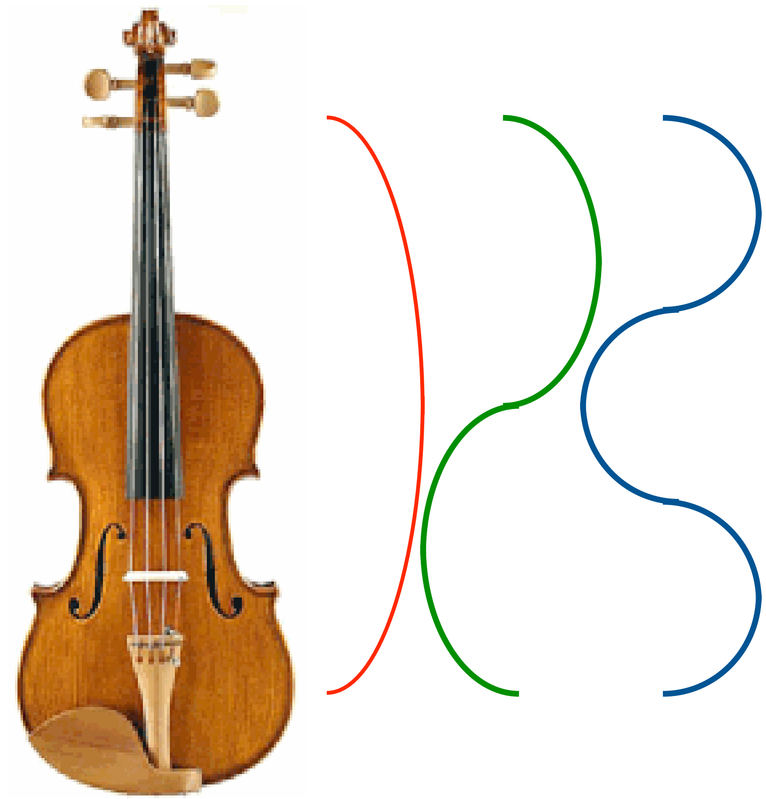
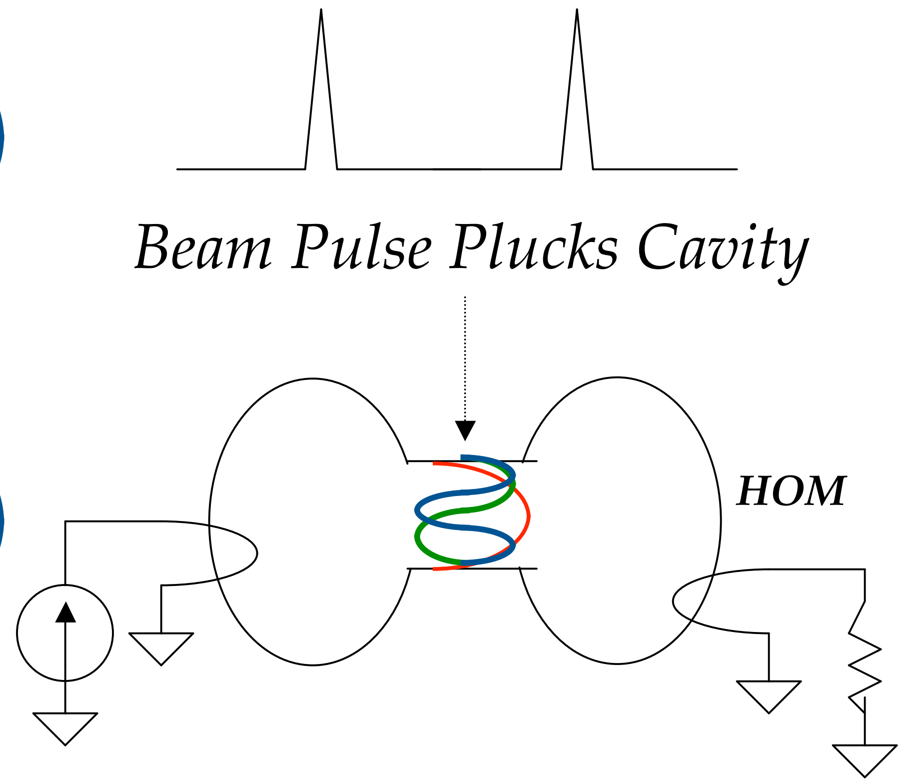
Main Injector, Recycler, and Tevatron LLRF at Fermilab

Fermilab

Ralph J. Pasquinelli

Higher Order Modes





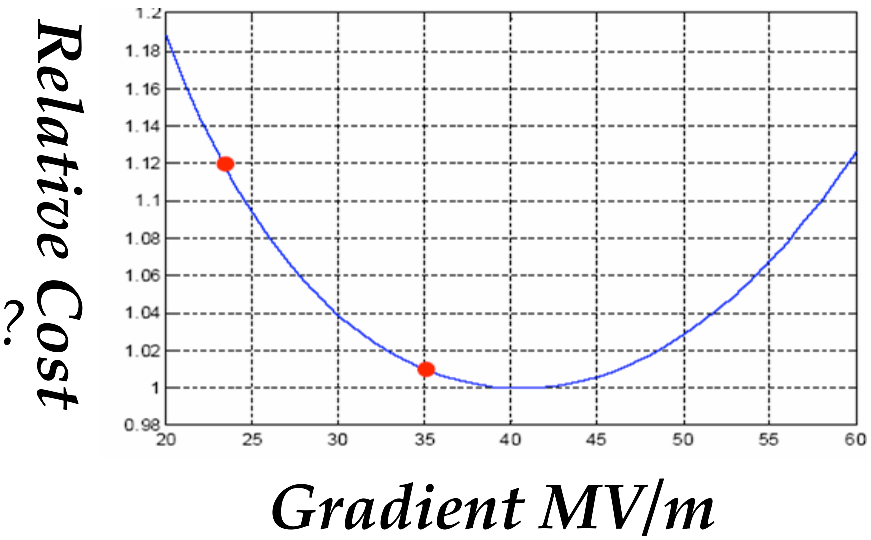
More choices….

Energy of the accelerator?

Gradient of cavities?

Duty cycle and repetition rate?

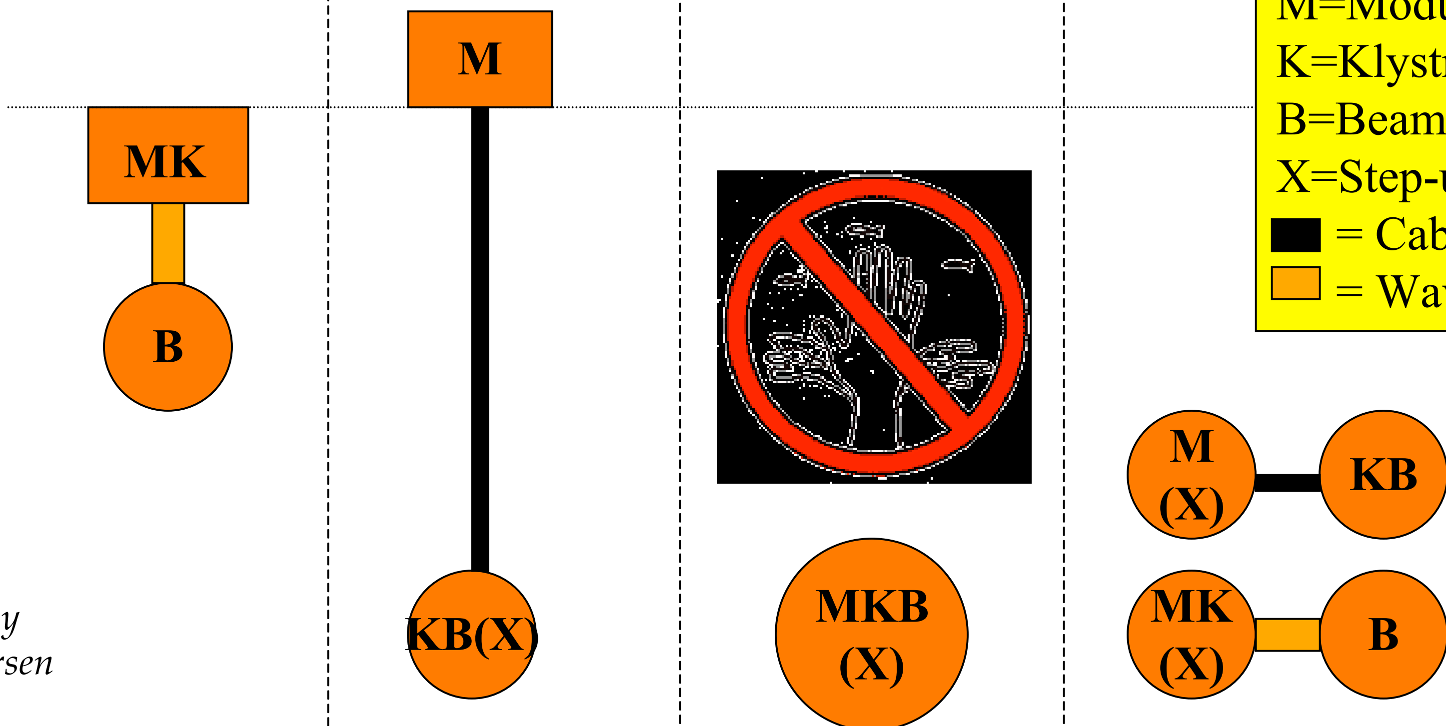
Location of hardware?



C. Adolphsen (SLAC)

Tunnel Topology Options

M=Modulator
K=Klystron
B=Beam
X=Step-up Xfmr
= Cables
= Waveguide



Courtesy
Ray Larsen

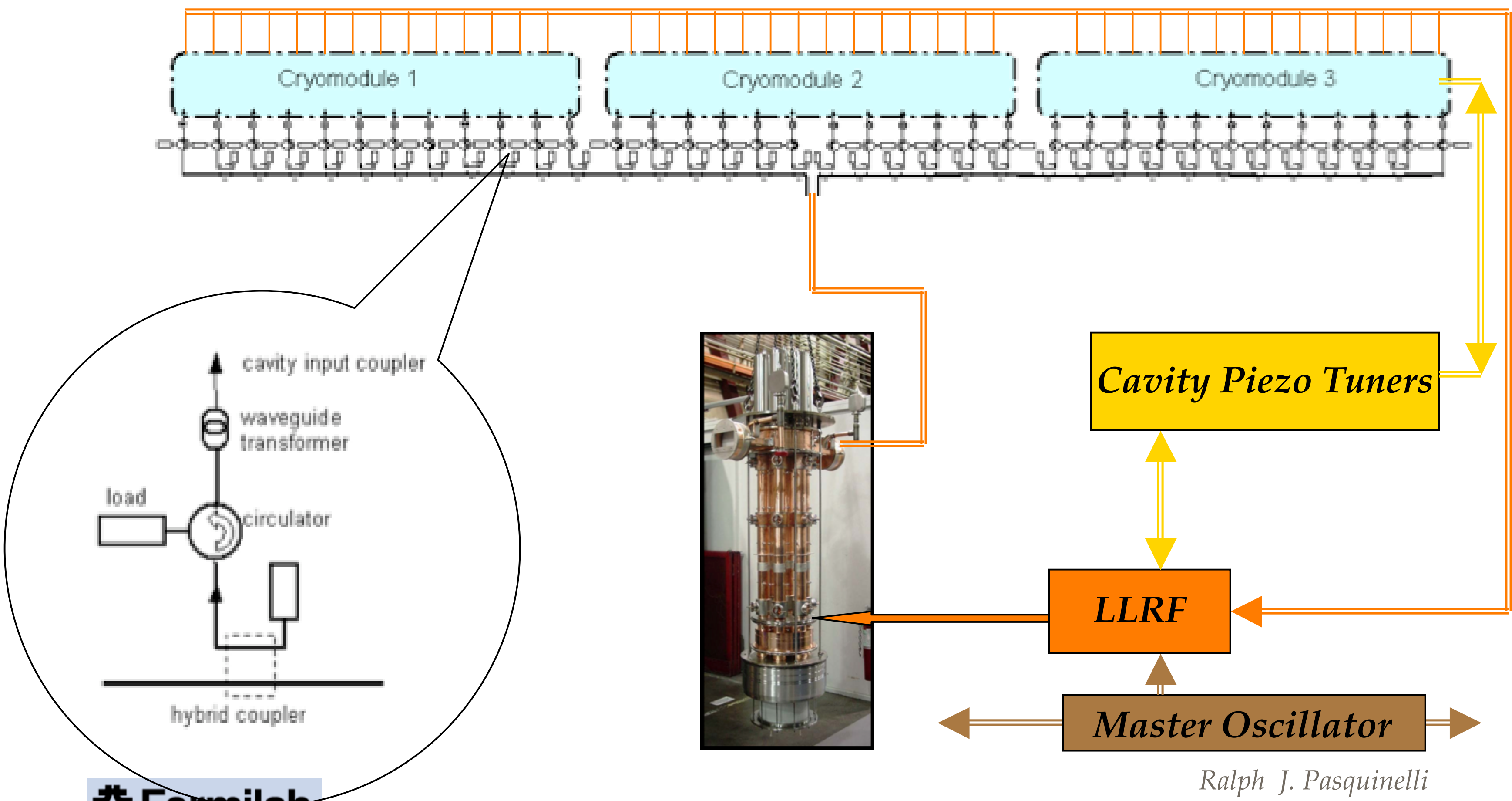
1. SLAC: Gallery + Shallow Tunnel

2. TESLA: Spaced Surface Huts + Deep Tunnel

3. Single Tunnel Deep or Shallow

4. Dual Deep Tunnels

Typical RF Station



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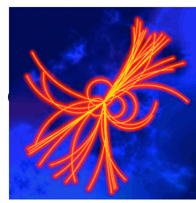
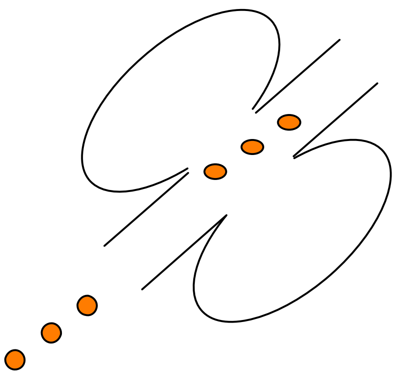
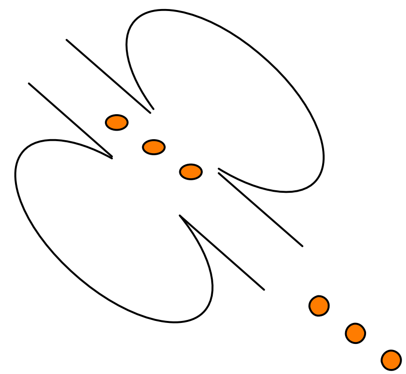
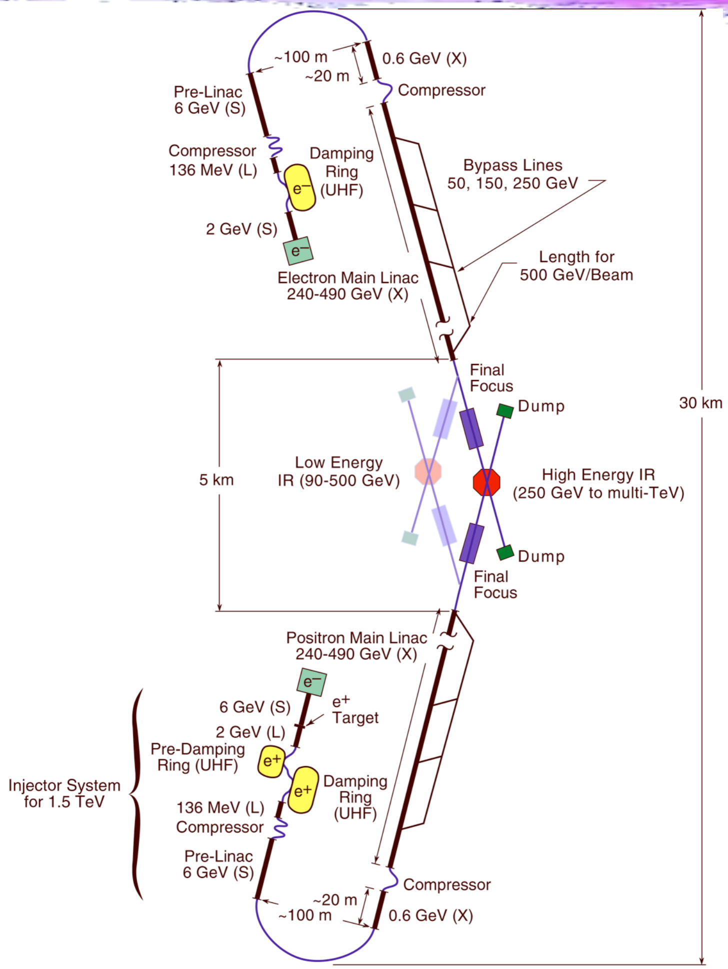
RF Used to Compensate for Off Axis Collisions



Crab Cavities







The Hardware

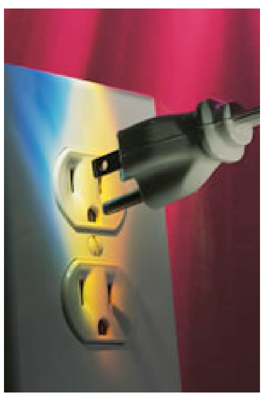
Over 500 Klystrons, Modulators LLRF stations

Driving

Over 20,000 9-cell RF cavities in 1500 plus cryomodules

And that is just the Main Linacs!!!

Overall RF Power Conversion Efficiency **37%-48%**



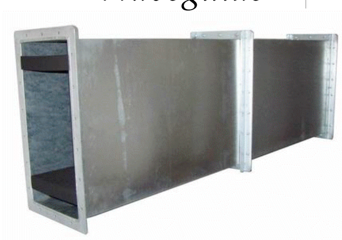
Modulator

78%

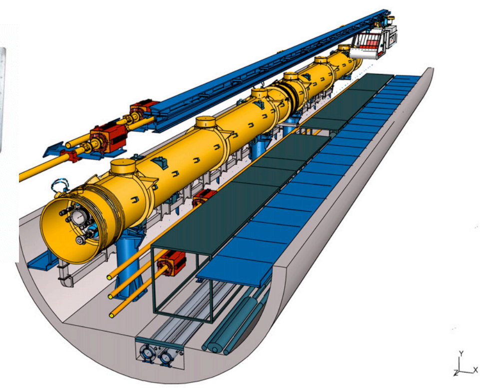
Klystron

50%-65%

Waveguide



95%



Cost of RF Power

Klystron
Modulator
LLRF
Power distribution
\+ Controls

$0.25/Watt

But….there are a lot of Watts!
About 5 Gigawatts
$1.25Billion

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