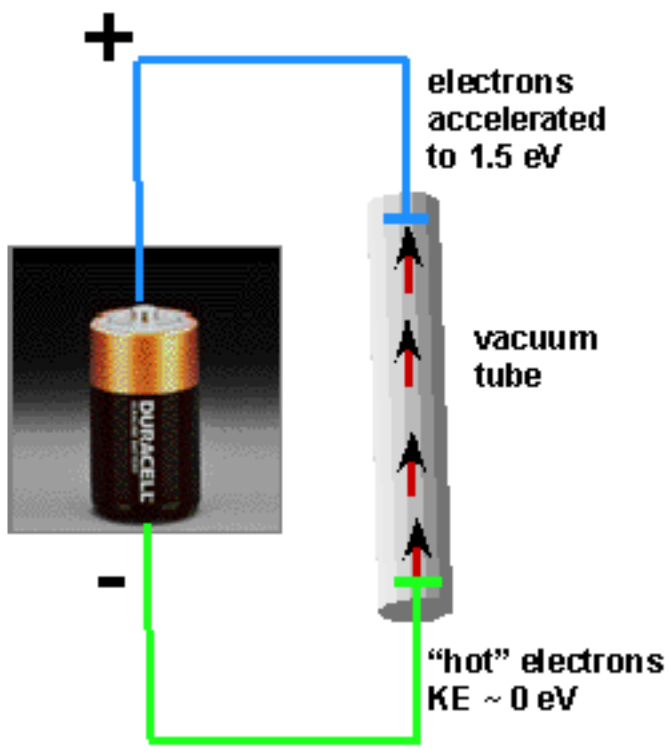
Fermilab

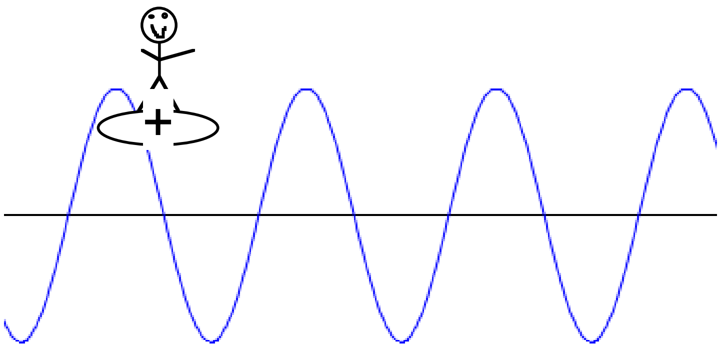
Design of an Accelerator RF System

Ralph J. Pasquinelli

Basic 1.5 eV accelerator



Basic Principle of Acceleration



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Building Blocks of a RF System

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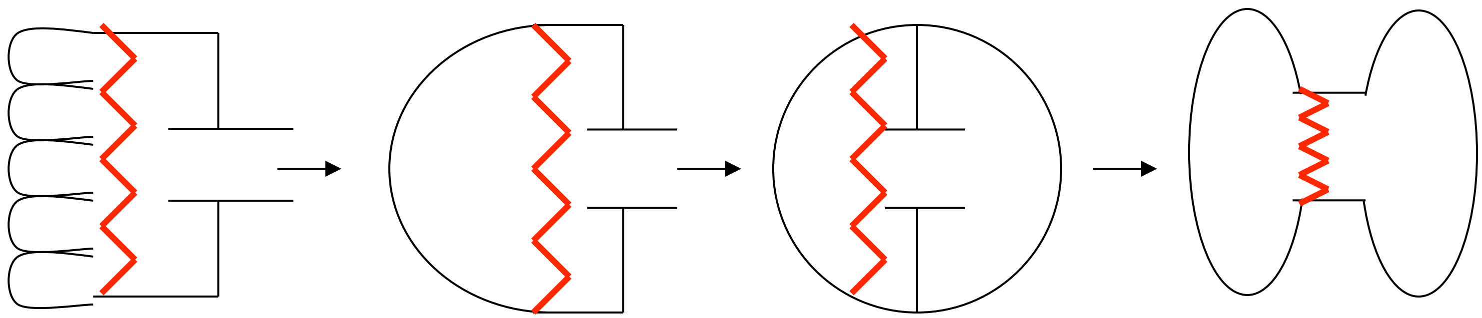
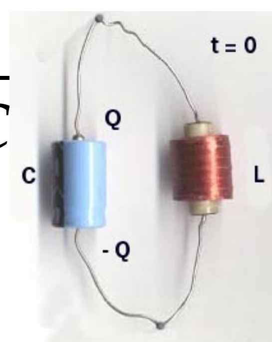
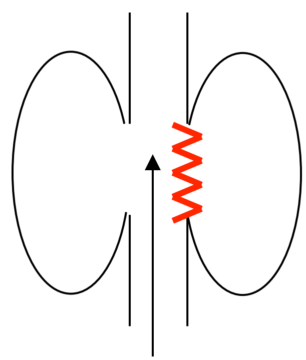
RF Cavity transformed from a LC circuit



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





Beam

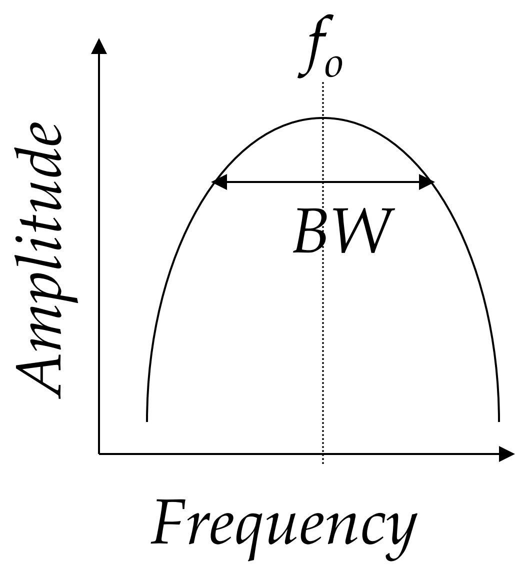
Shunt Impedance

Cavity Q or Quality Factor

Q=Energy Stored/Energy Lost (per cycle)

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

-3 dB +/- 45 degrees



BW~Information

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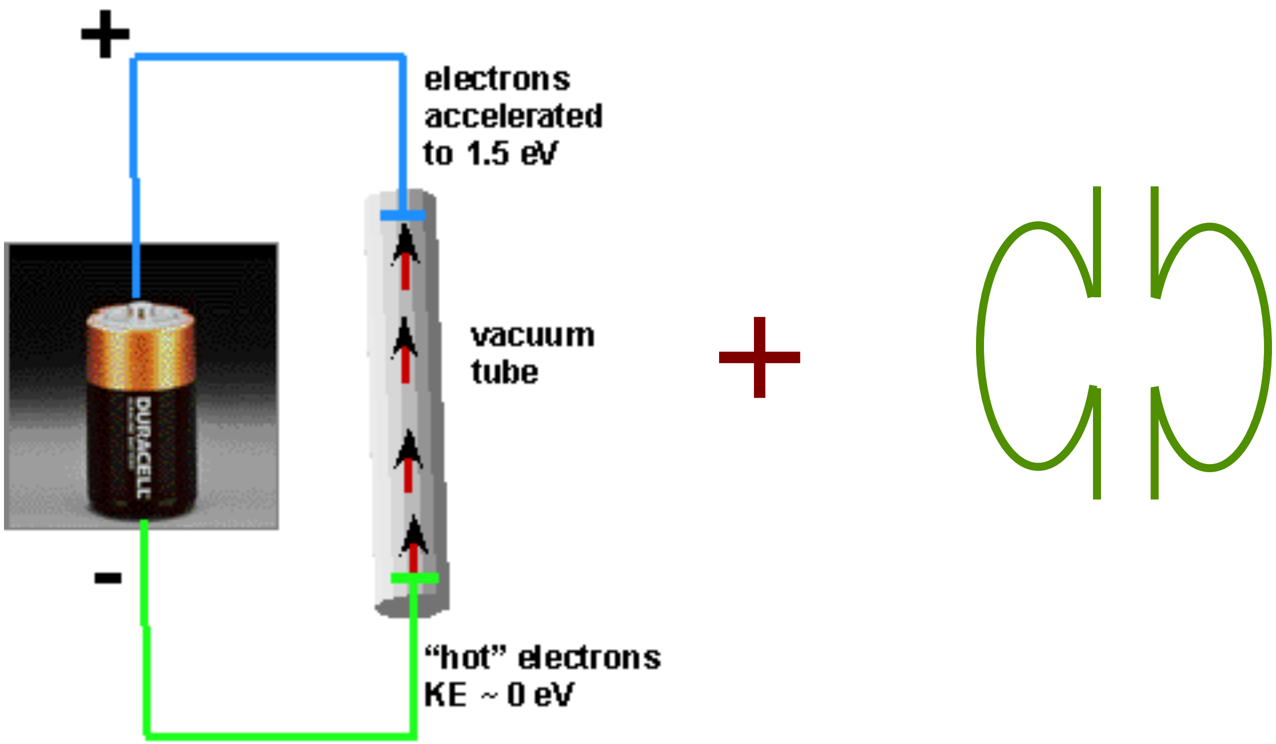
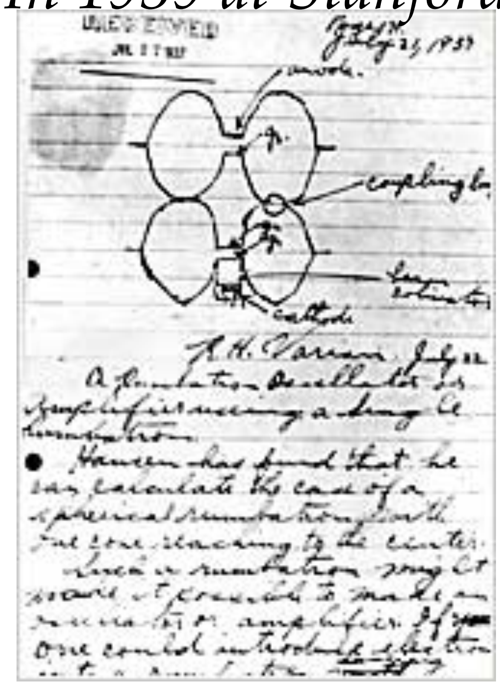
Klystrons, IOT, Solid State Provides the RF Power



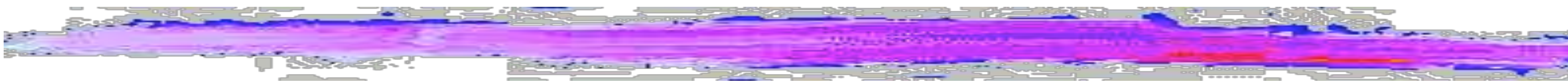
Invention of the Klystron

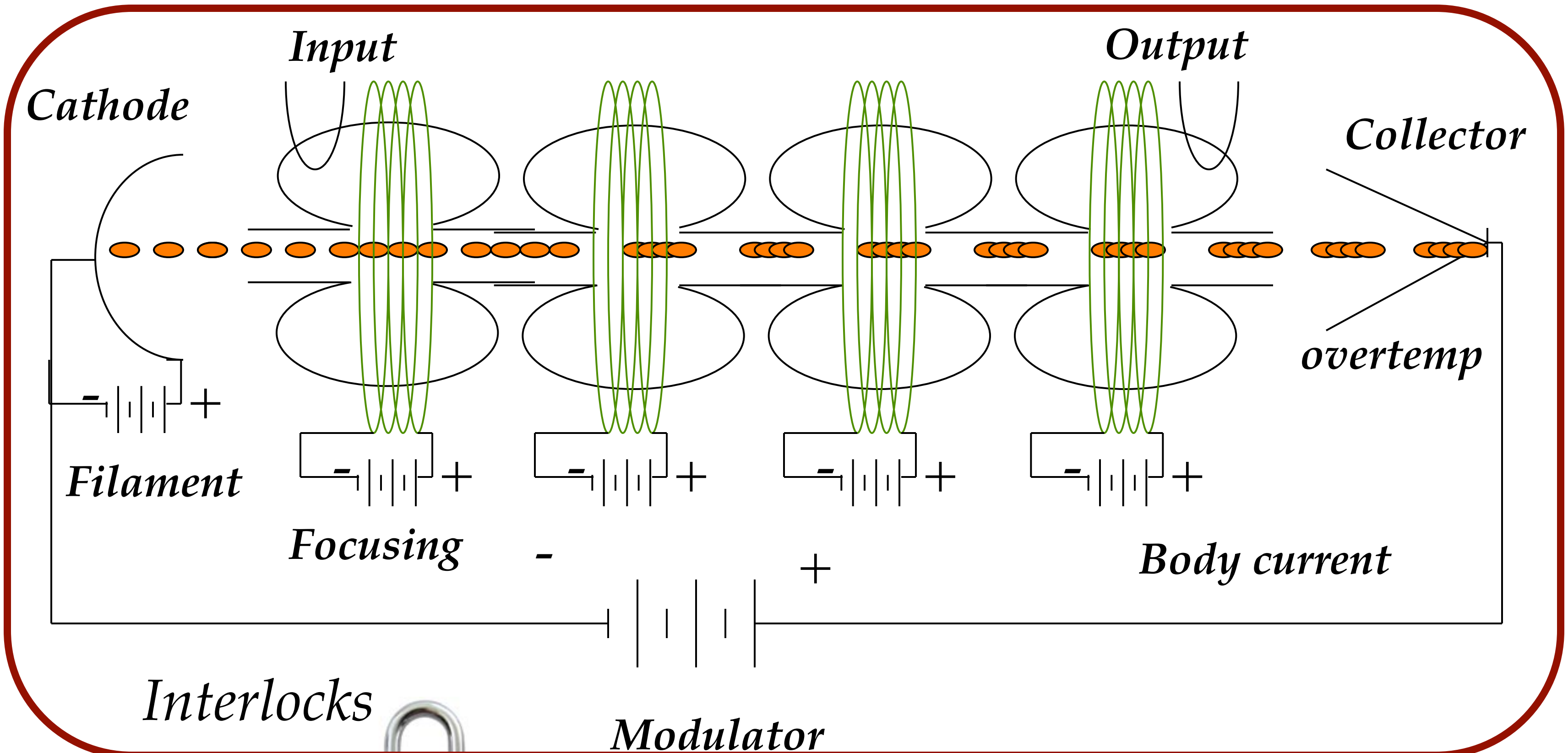
Varian Brothers Russell and Sigurd Develop Klystron In 1939 at Stanford



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

Klystron Operation
Electron Beam Velocity Modulation





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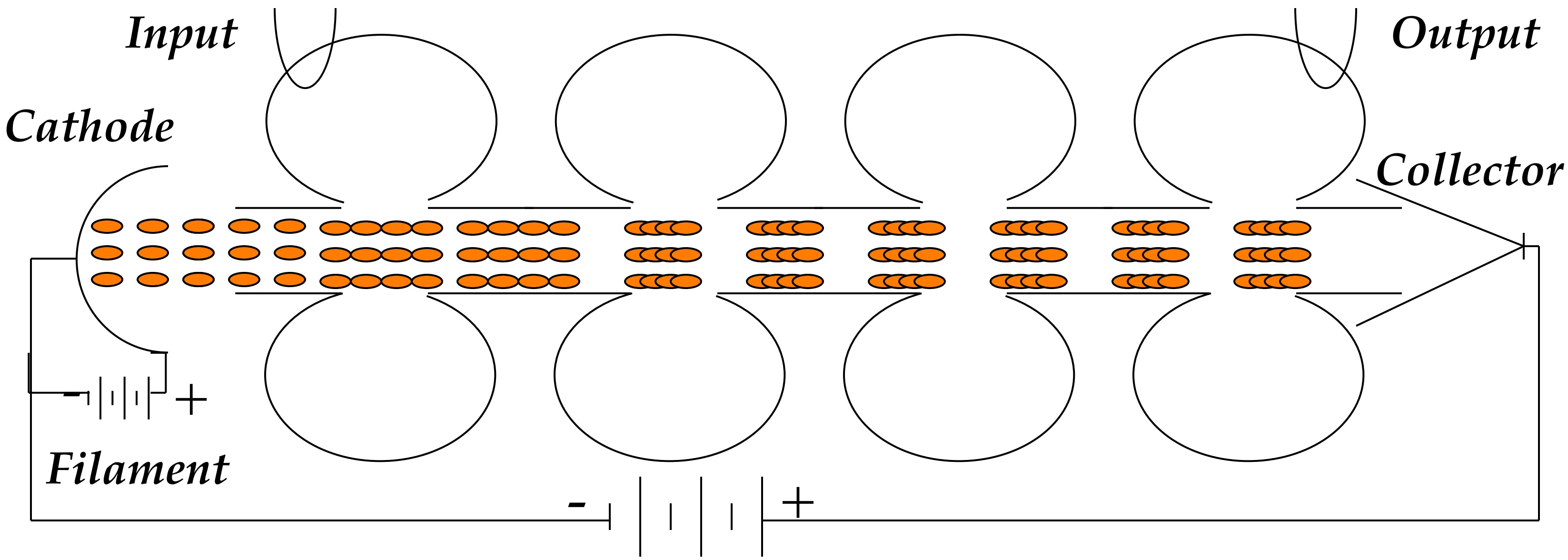
Multi-Beam Klystron Operation
Power Conversion Efficiency & Reduced Space Charge



Power = Electron Current x Cathode Voltage

Megawatts   10's of Amps   50-120 of Kilovolt

Modulator

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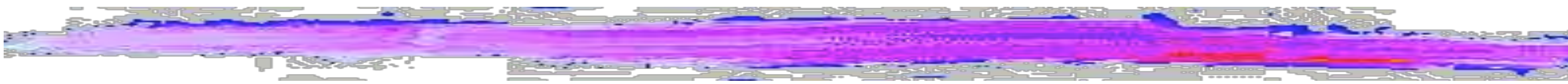
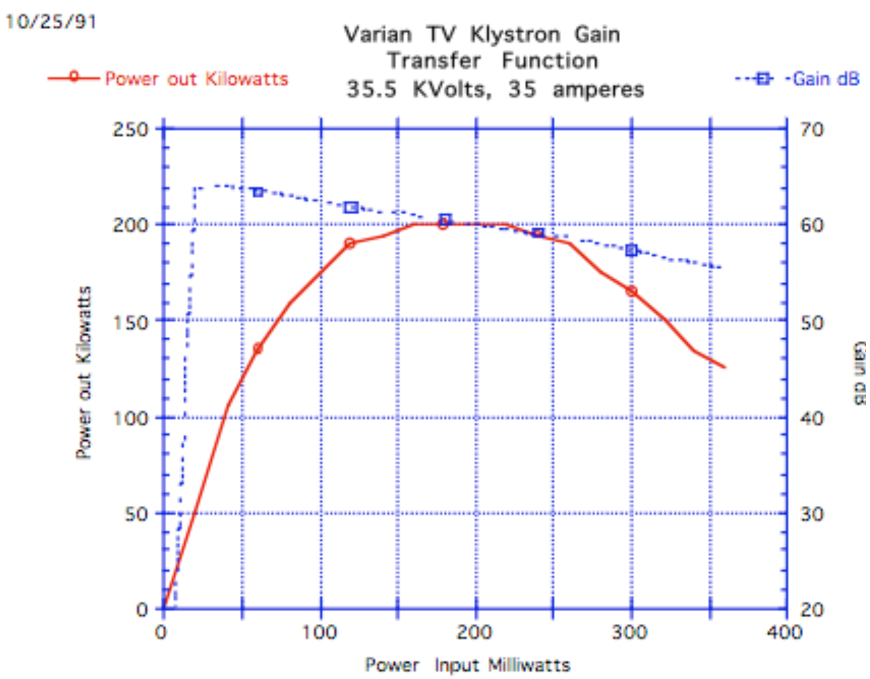
Typical Klystron Parameters

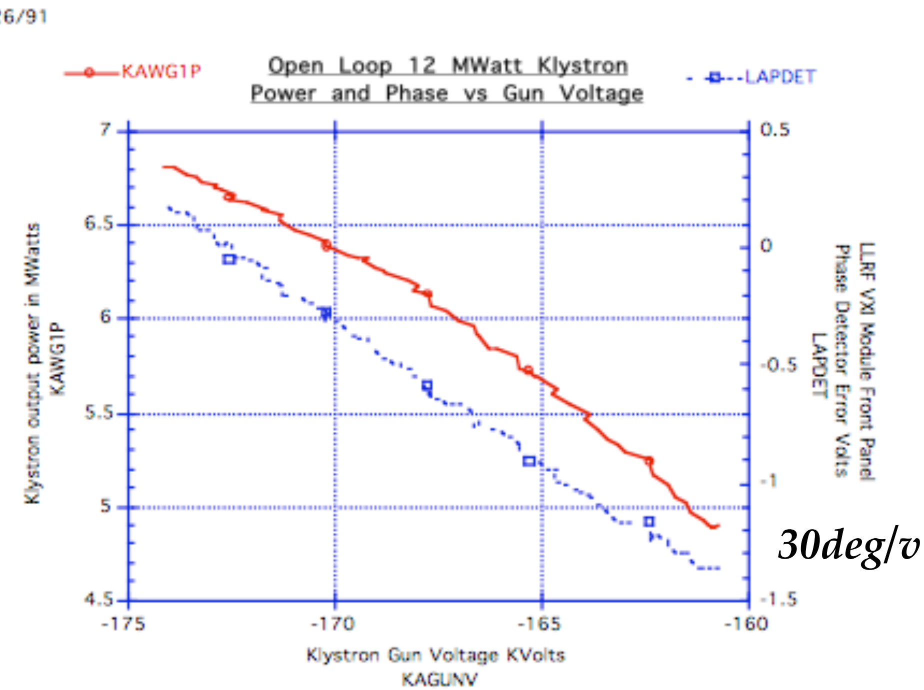
Power Gain	40-60 dB (10^4-10^6)
Power	10^3 to 10^7 Watts
Duty Cycle	Continuous or Pulsed
Frequency	Hundreds MHz to Tens GHz
Bandwidth	1%
Efficiency	50%
Cathode volts	10's to 100's of kilovolts
Klystron Life	10,000-100,000 hours

Klystron Characteristics





Power Gain Curve



Gain/Phase vs Gun Volts

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Klystron Photos

CPI VLK8301

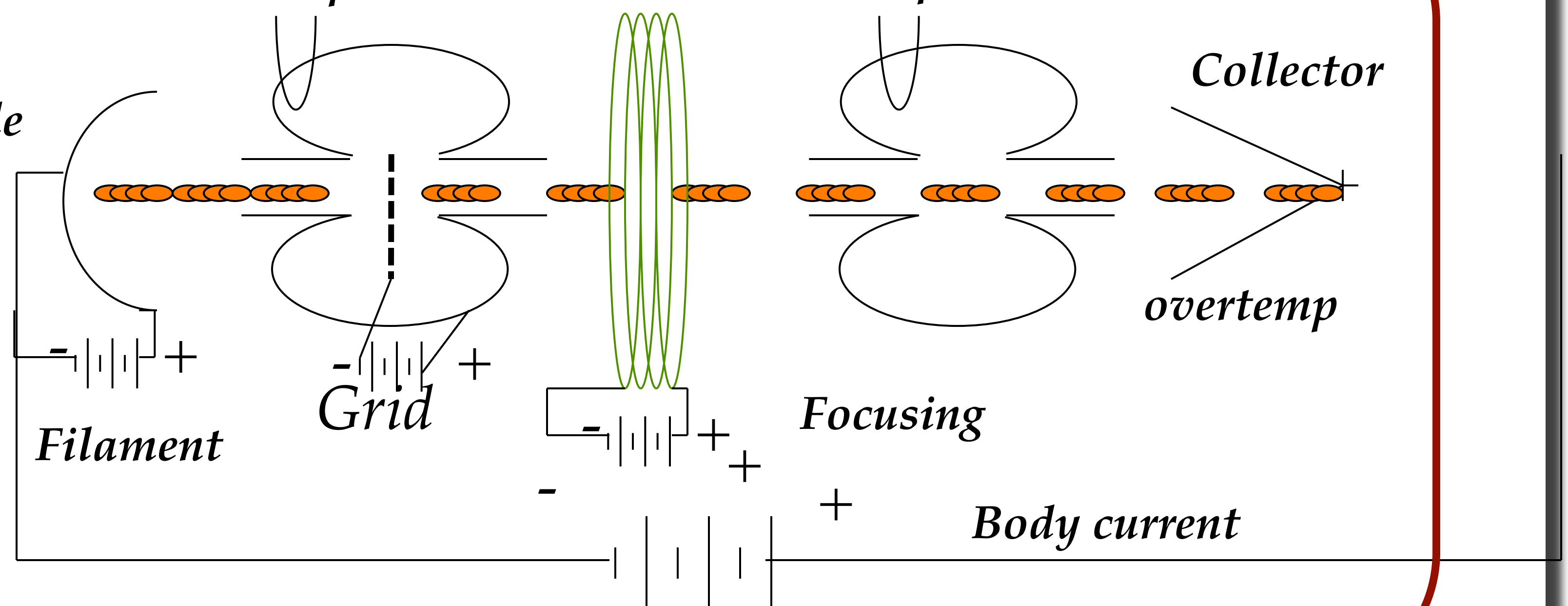
Toshiba

TH 1801
Multi-Beam Klystron

10 MW peak - 150 kW av.
at 1.3 GHz

THALES

Inductive Output Tube (IOT) Operation
Electron Beam Grid Gated



Interlocks

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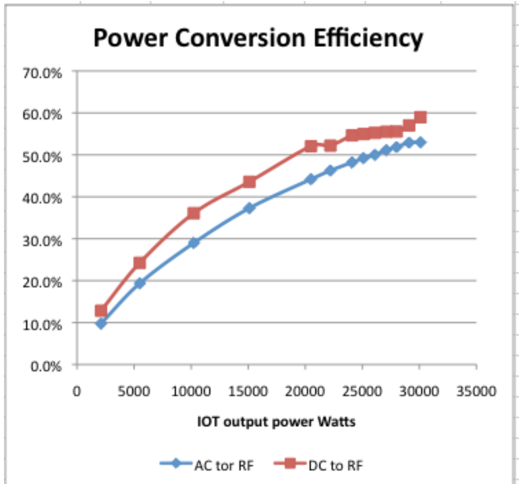
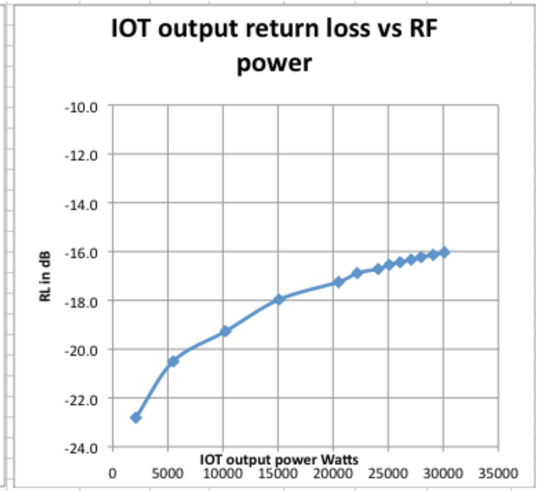
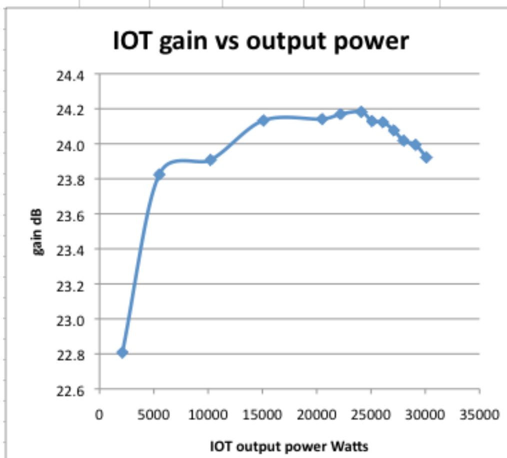
Typical IOT Parameters

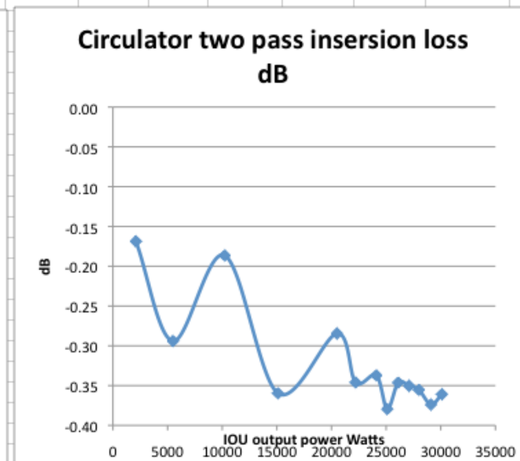
Power Gain	*20-25 dB*
Power	*10^4 to 10^5 Watts*
Duty Cycle	*Continuous or Pulsed*
Frequency	*Hundreds MHz (UHF)*
Bandwidth	*1%*
Efficiency	*60-65%*
Cathode volts	*10's of kilovolts*
IOT Life	*10,000-50,000 hours*

IOT Characteristics









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IOT Photos

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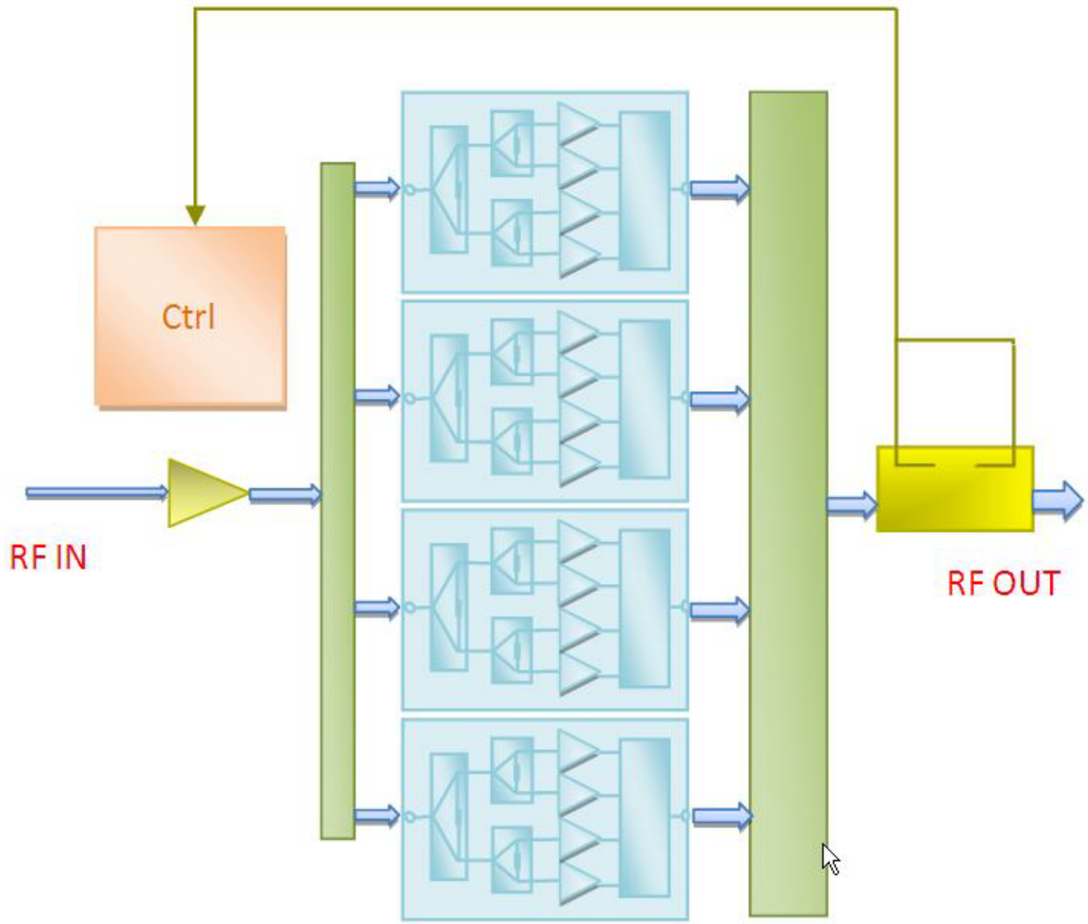
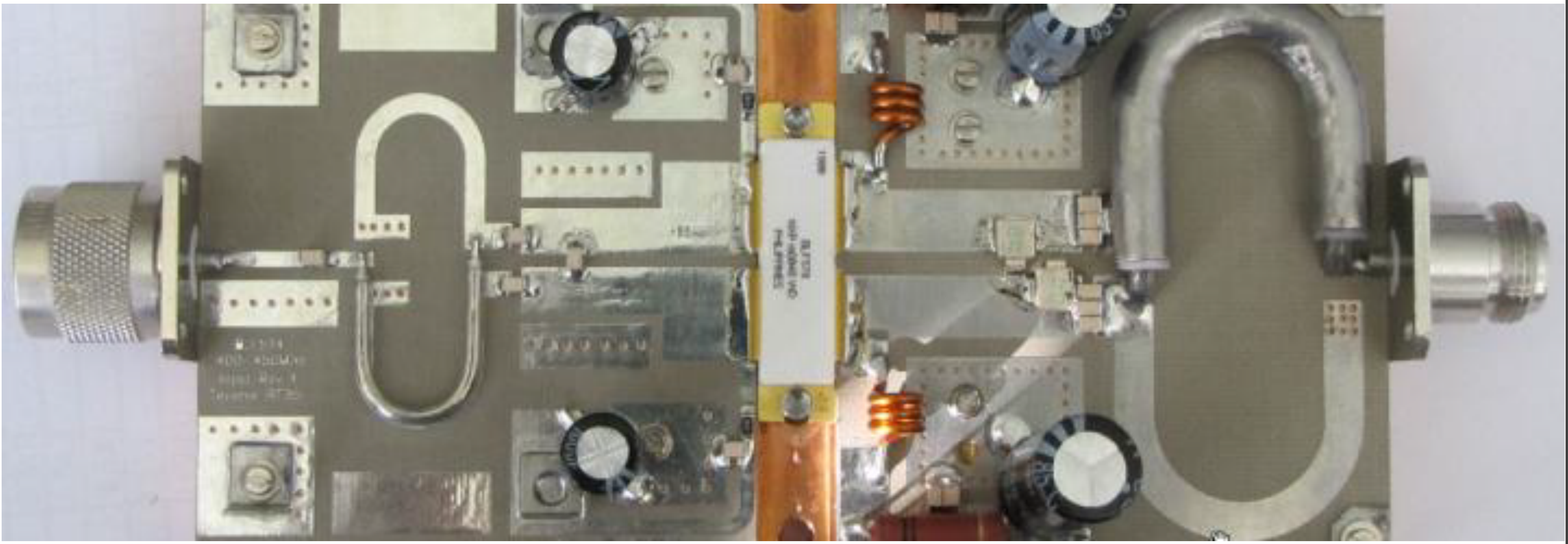
Solid-State Topology



Typical Solid-state Parameters

Power Gain	*20-70 dB (10^2-10^7)*
Power	*10^3 to 10^5 Watts*
Duty Cycle	*Continuous or Pulsed*
Frequency	*1 MHz to 2 GHz*
Bandwidth	*few % to decades*
Efficiency	*10-50%*
Voltage	*20-50 volts DC*
Life time	*10,000-200,000 hours*

Typical Amplifier Module



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Bruker Solid-state 10 KW Amplifier

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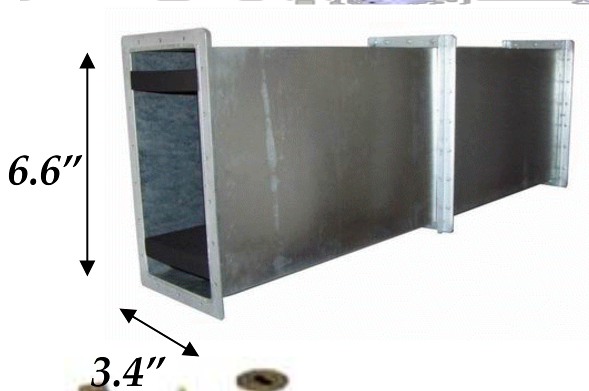
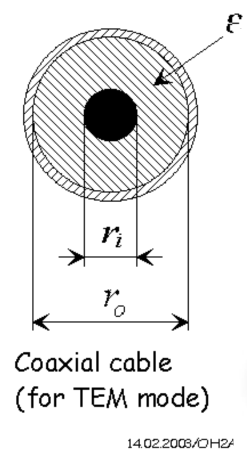
Power Transmission



@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

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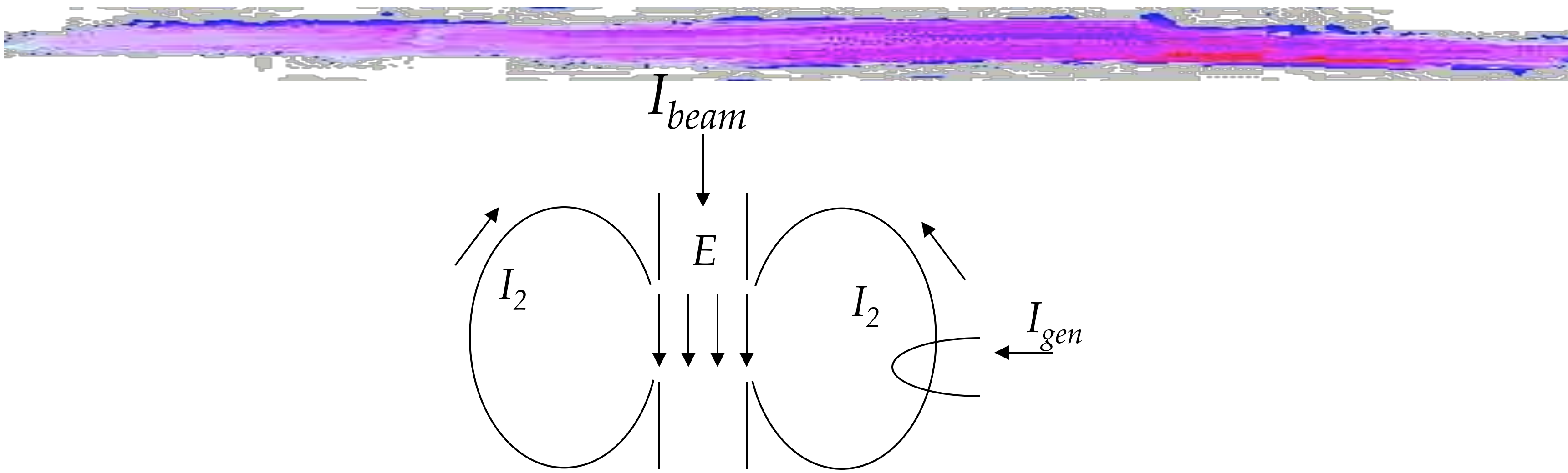
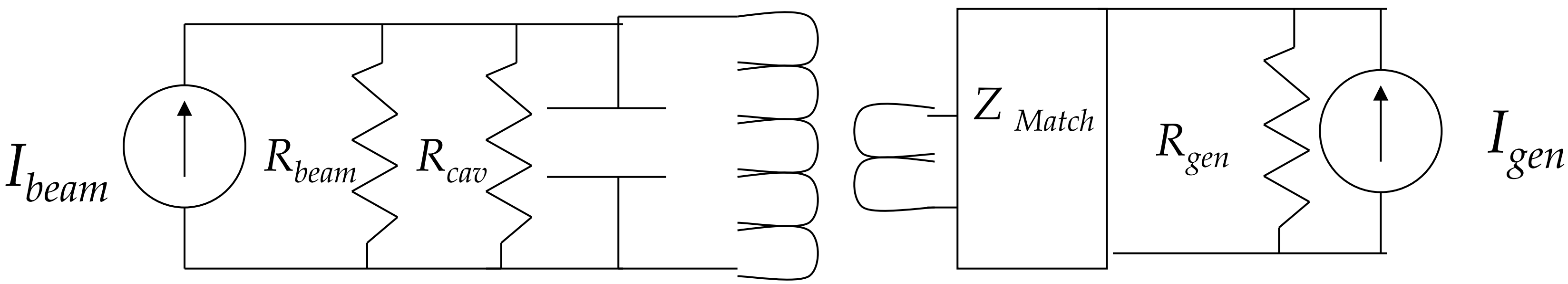
To inject or extract energy
A coupling loop is used.





Equivalent
Circuit model

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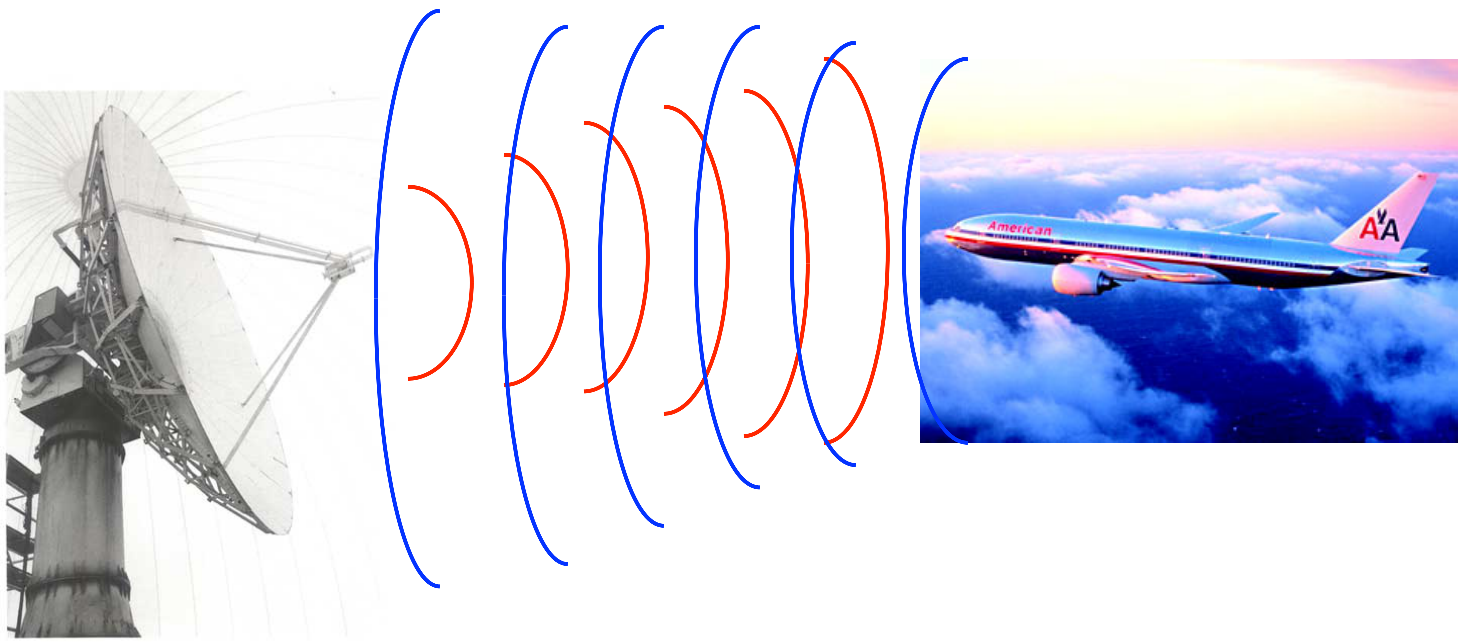
Importance of Matching



Radar works due to poor matching

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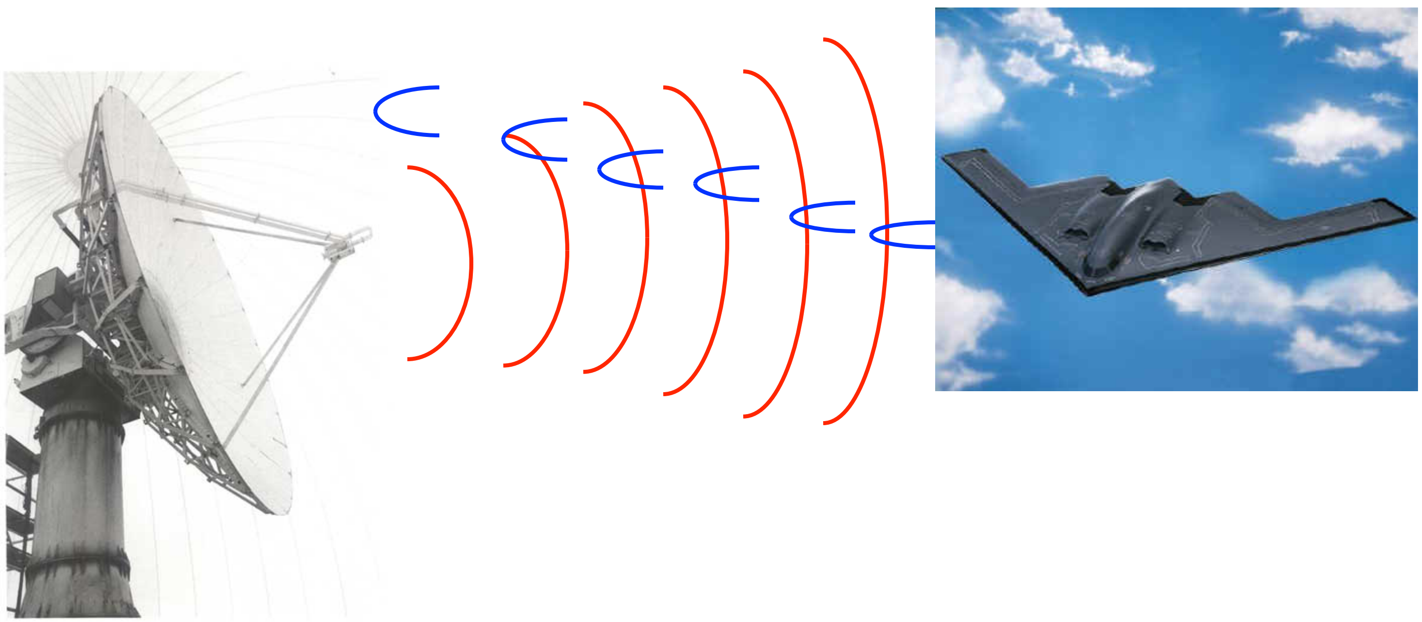
Importance of Matching



Better matching with the B2 harder to detect!

Microwave Matching Gizmos

Directional Coupler

Three Stub Tuners

Circulator/Isolator

Waveguide Load

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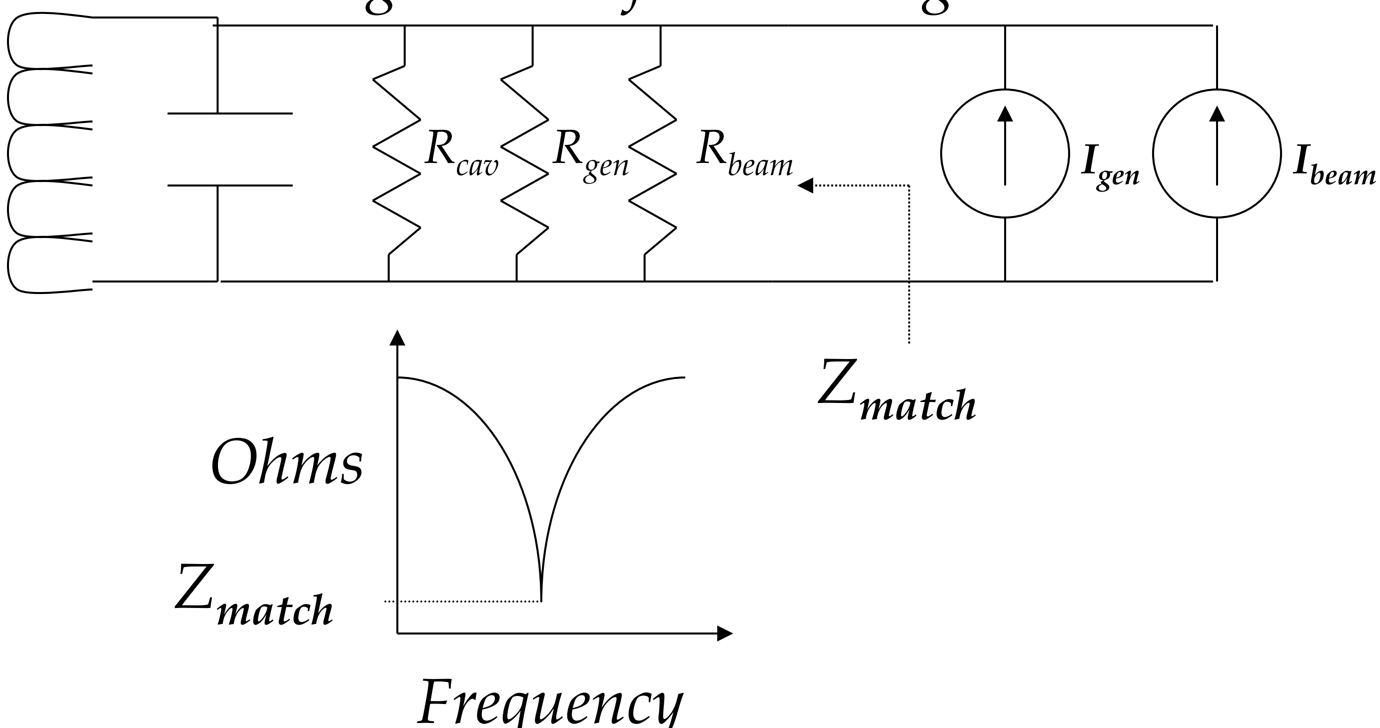
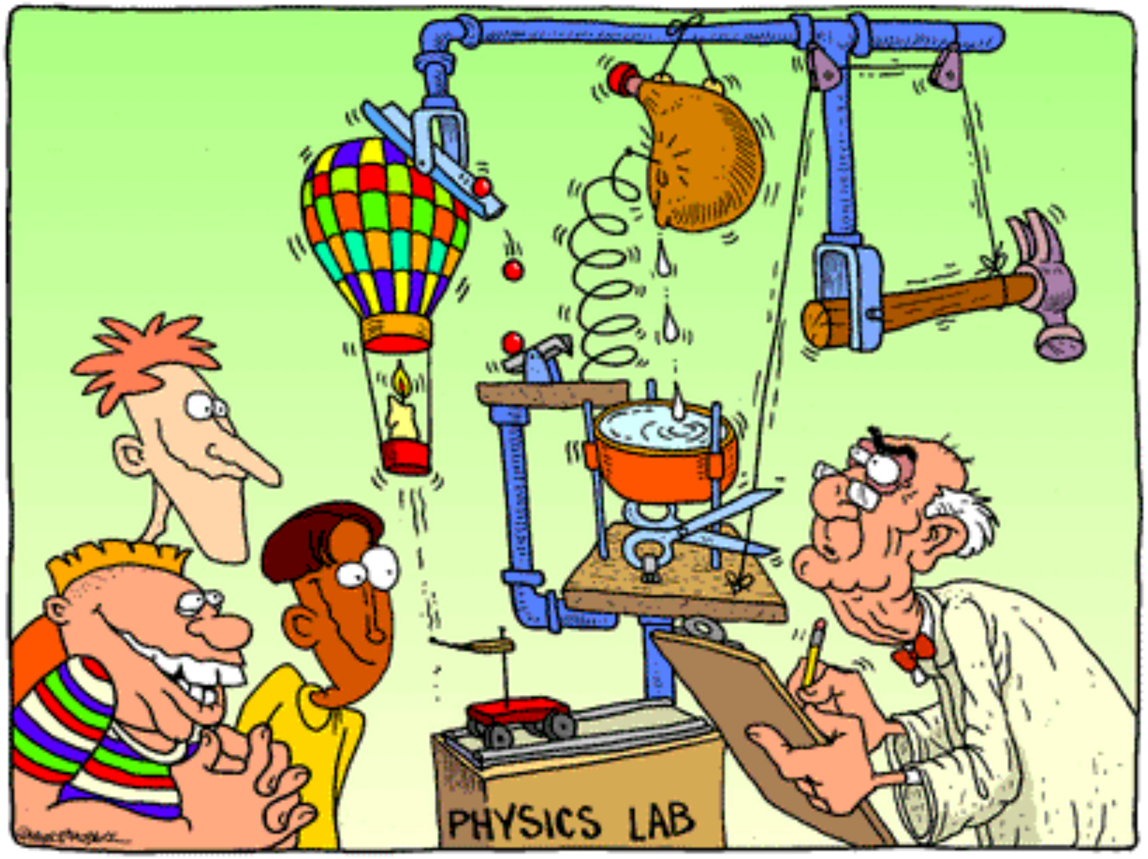
Cavity Model

Further circuit simplification and assign values for modeling



Design of a RF System



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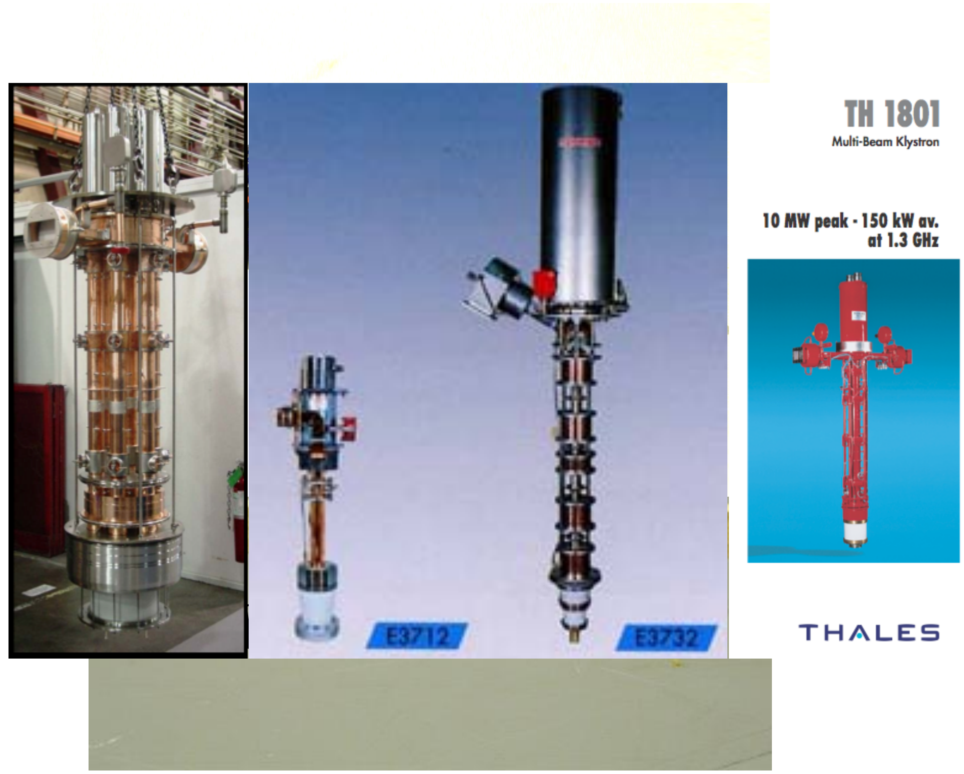
Questions to Ask

Duty Cycle?

Gradient possible?

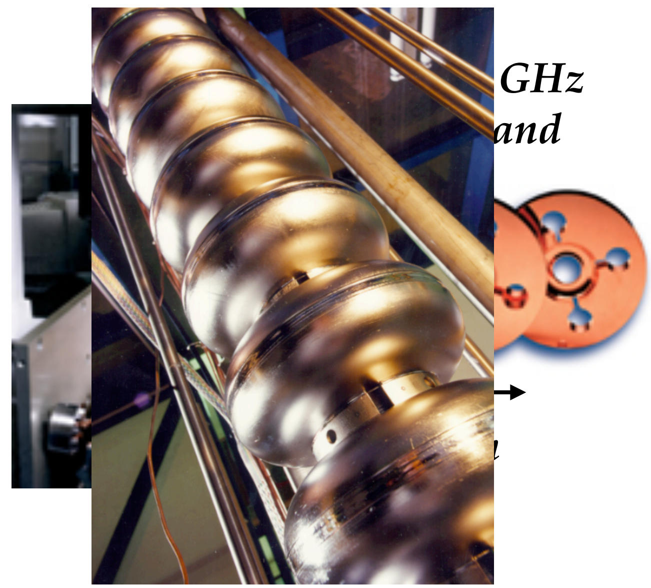
Power source available?



Need to Choose Frequency of Operation

Size Limitation?

Goldie Locks "just right!"



1.3 GHz 9 cell SRF Cavity 70mm iris

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Issues with Superconducting RF (SRF):

Narrow bandwidth due to high Q of 10^9

Pulsed RF fields exert mechanical detuning forces

Microphonic sensitivity

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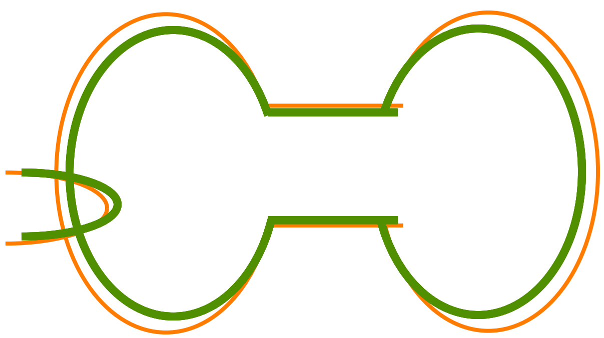
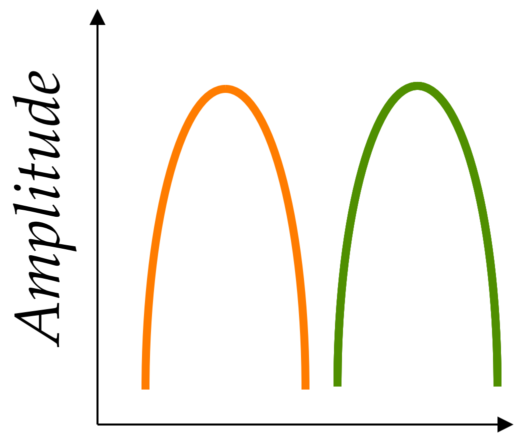
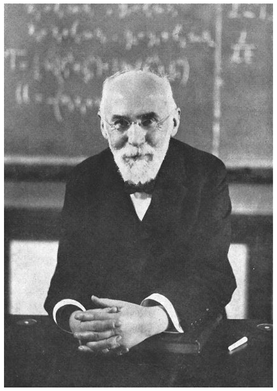
Lorentz Force Detuning







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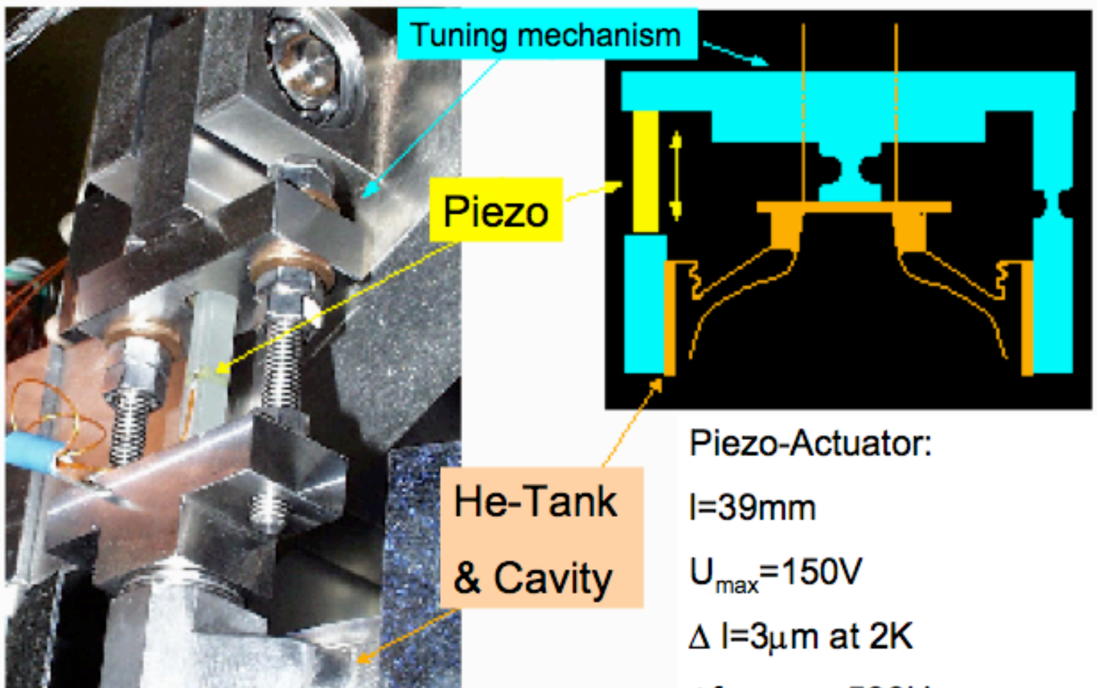
Dynamic Resonance Control

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

Lutz Lilje DESY TESLA 26/01/2004

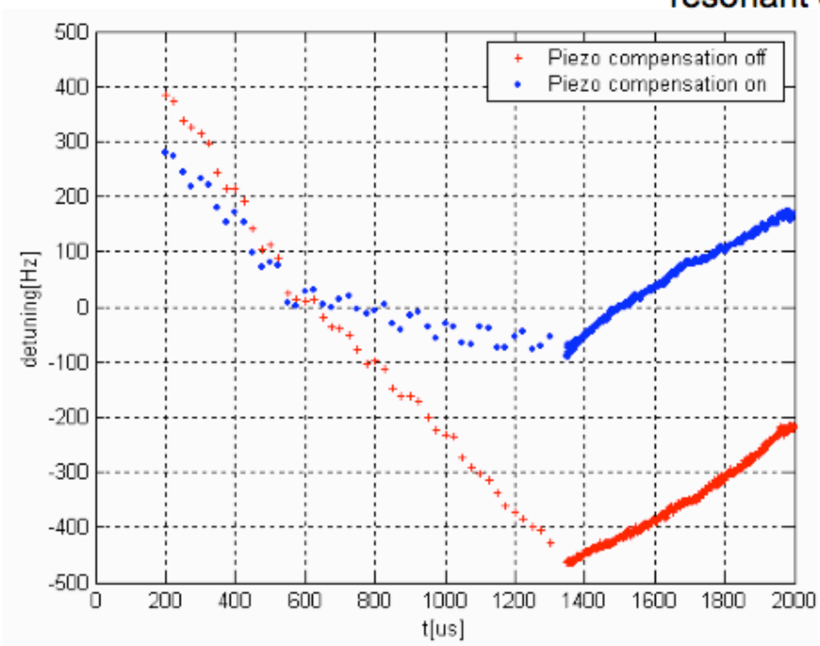
Piezo Tuner Response

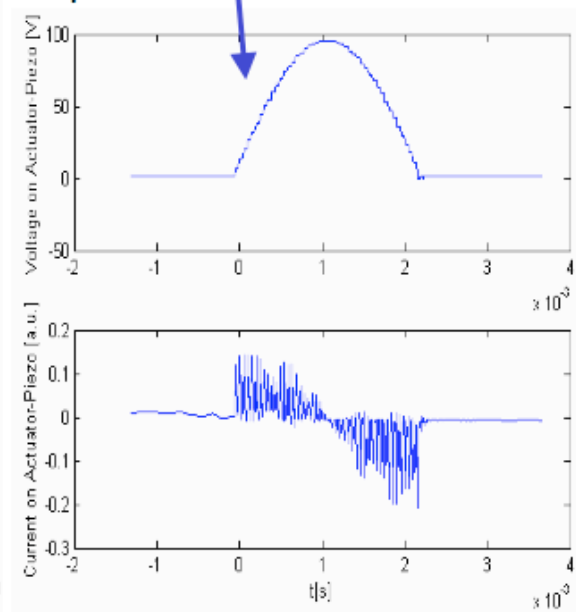
Frequency stabilization during RF pulse using a piezoelectric tuner

Blue: With piezo

Red: Without piezo

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



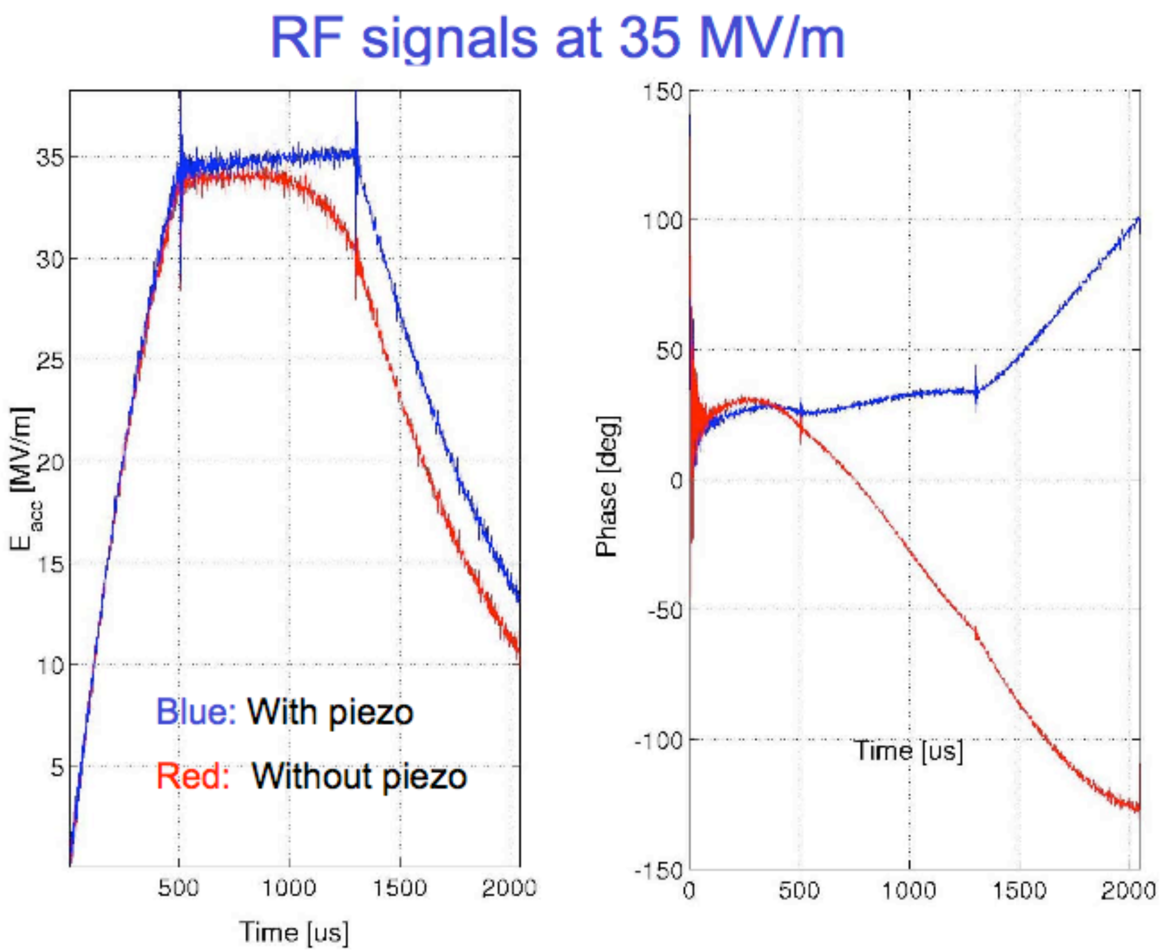


Lutz Lilje DESY

TESLA

26/01/2004

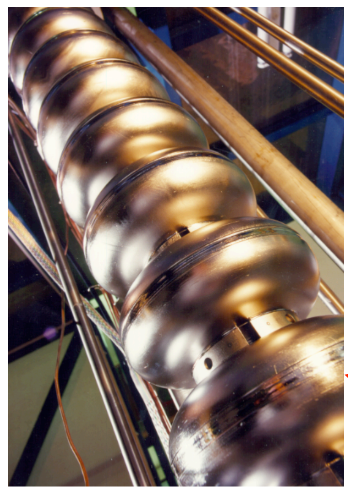
Cavity Amplitude and Phase Response



Lutz Lilje
DESY

Sources of Microphonic Noise

Cultural Noise



Earthquakes

Vacuum Pumps

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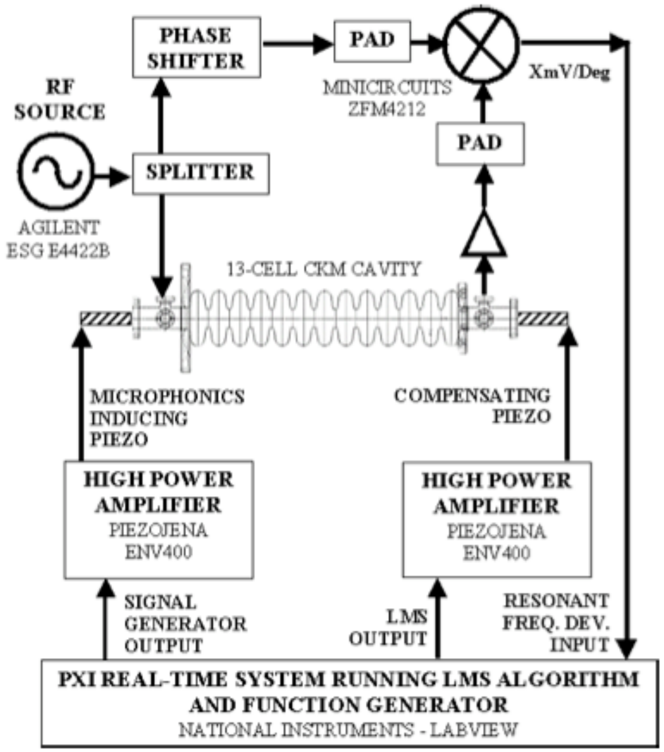
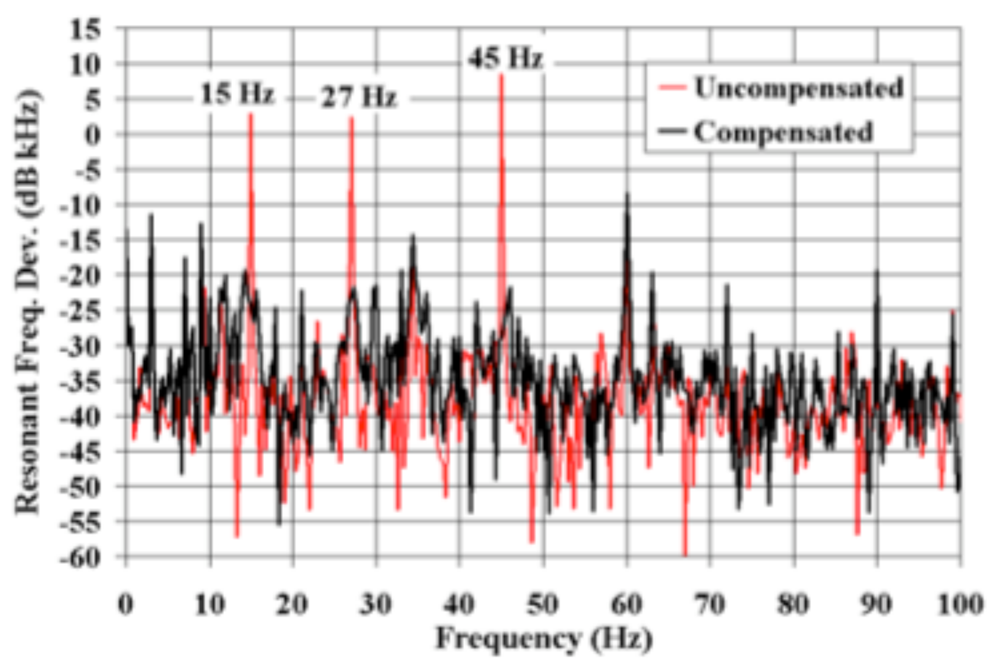
Microphonics Compensation





Ruben Carcagno et al Fermilab

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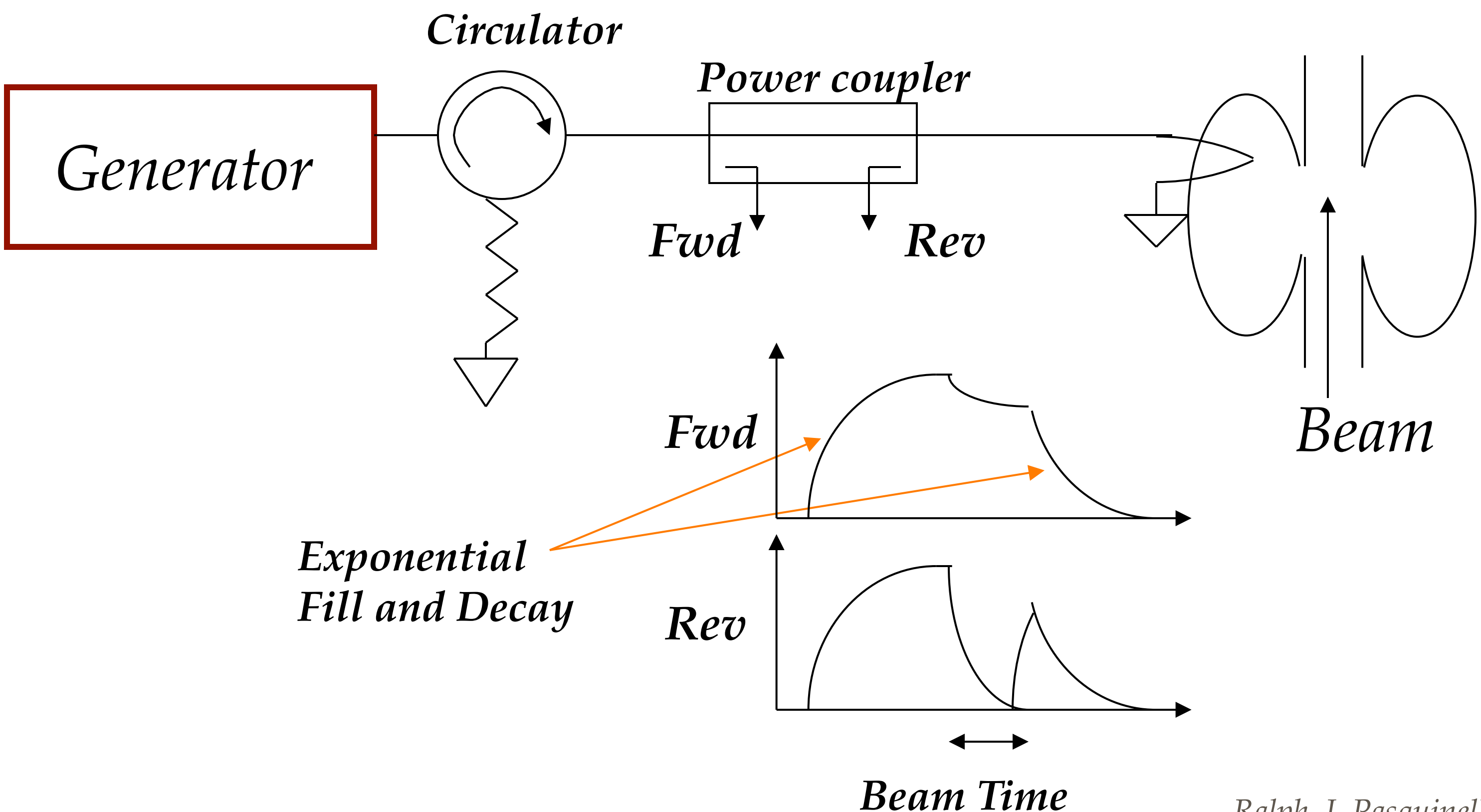
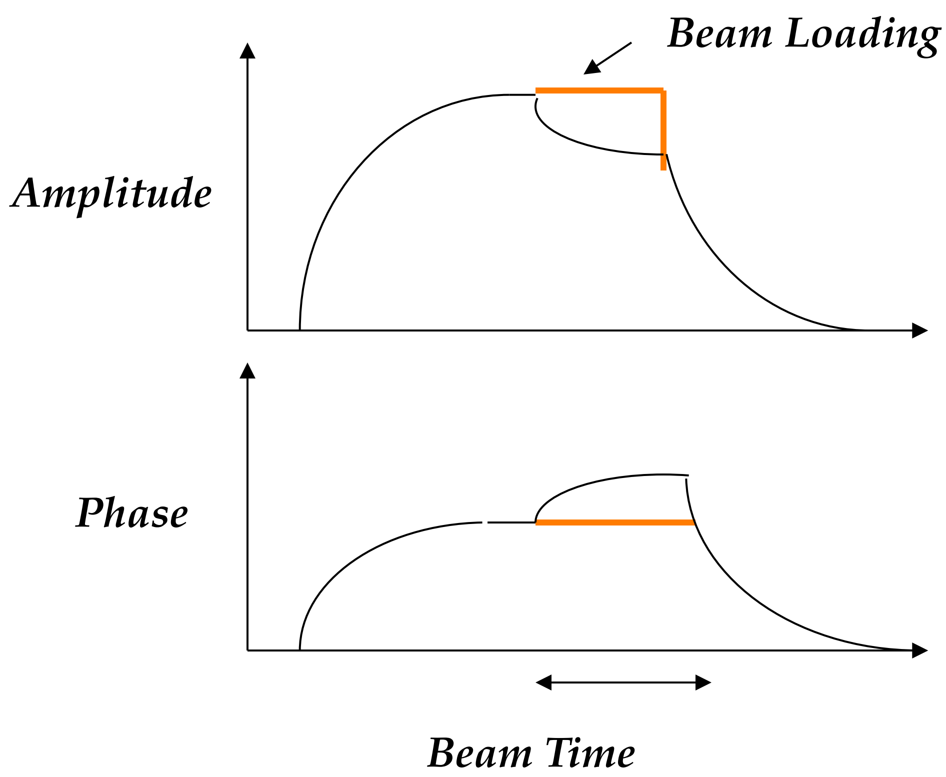
Beam impedance loads SRF cavity

Drive to cavity is only matched when beam is present



Low Level RF (LLRF)

Provides feedback and feed forward to improve gradient stability



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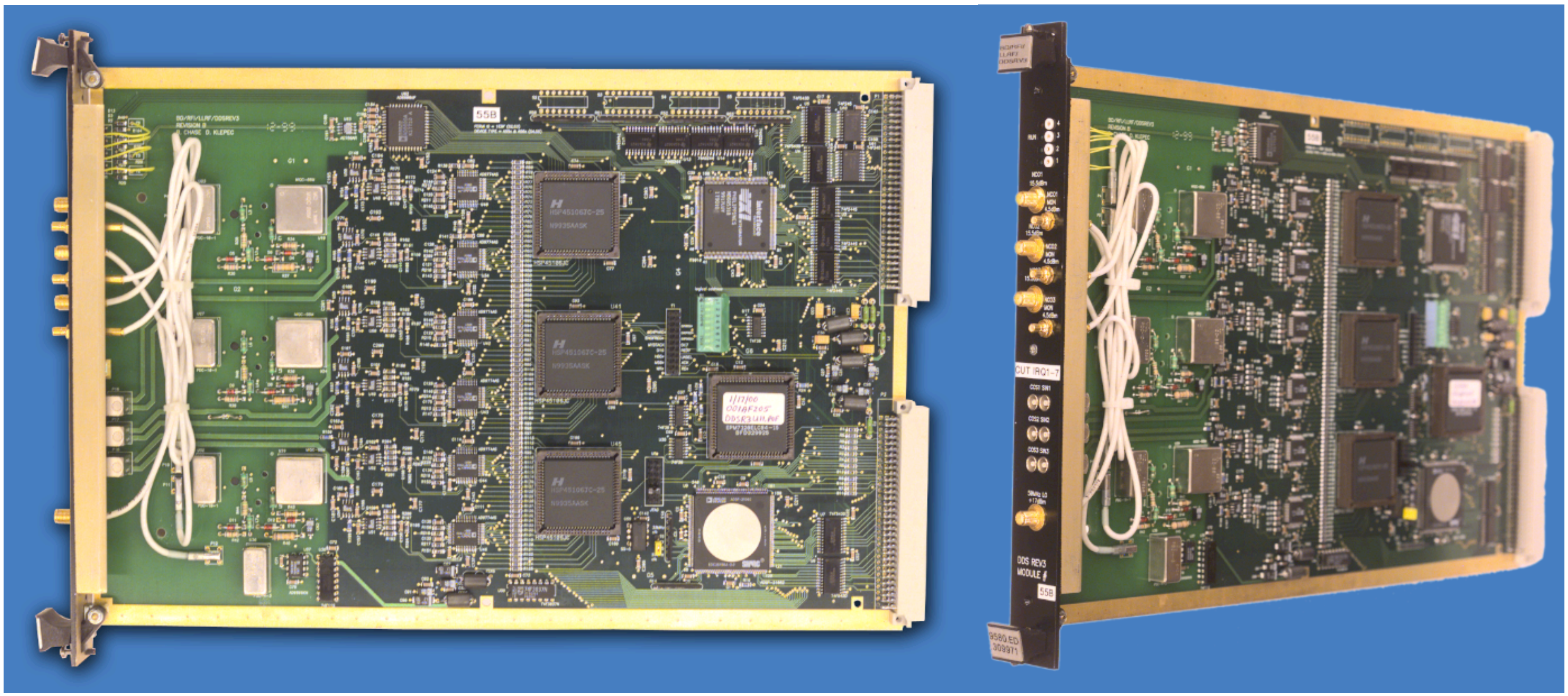
Typical LLRF Hardware



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Main Injector, Recycler, and Tevatron LLRF at Fermilab

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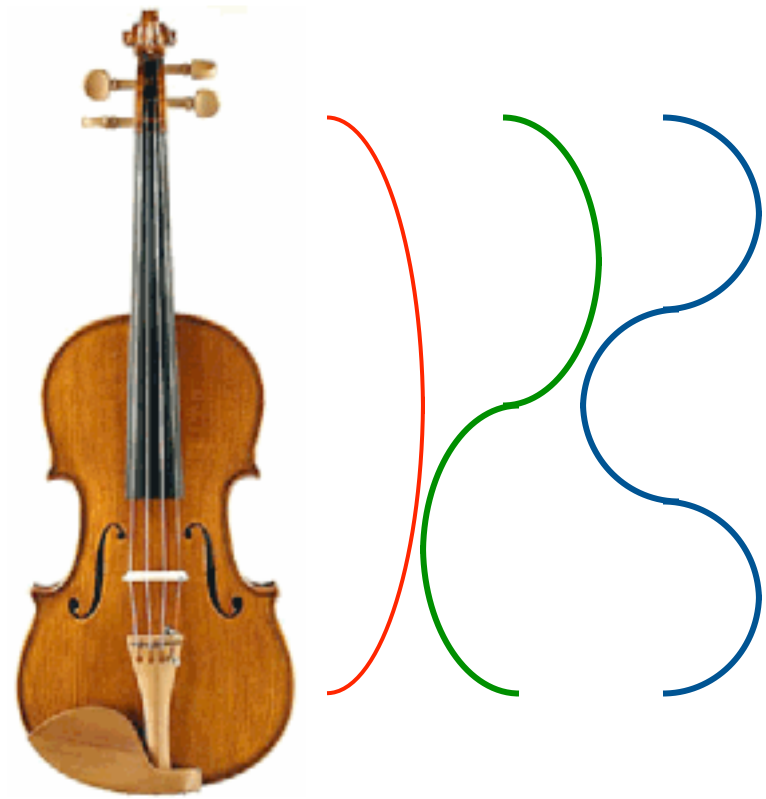
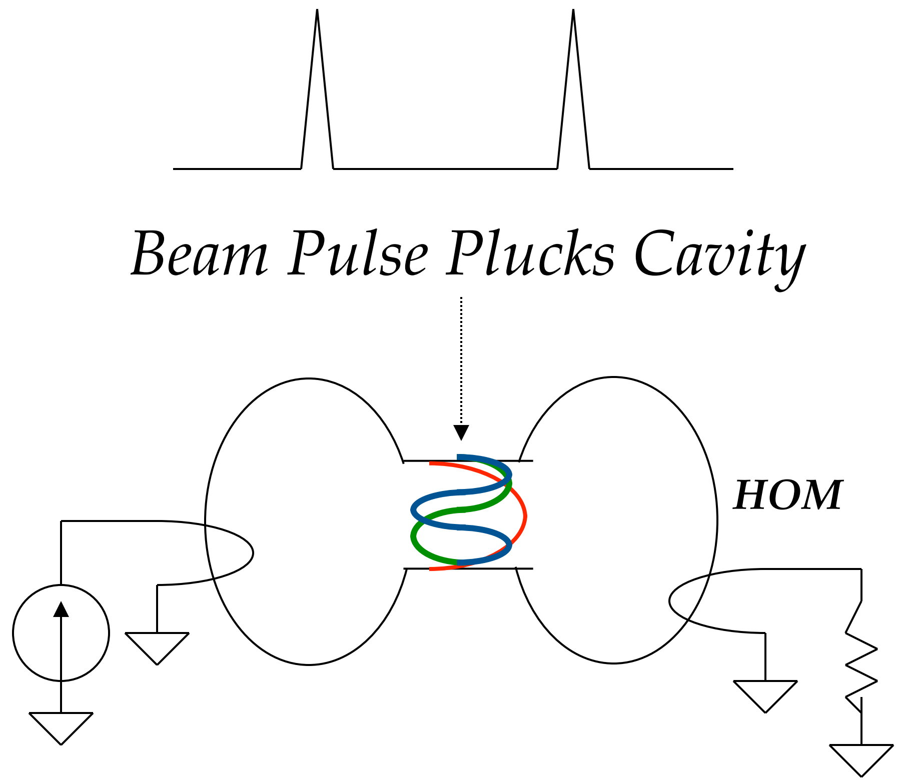
Cavity Higher Order Modes (HOMs)





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More choices….

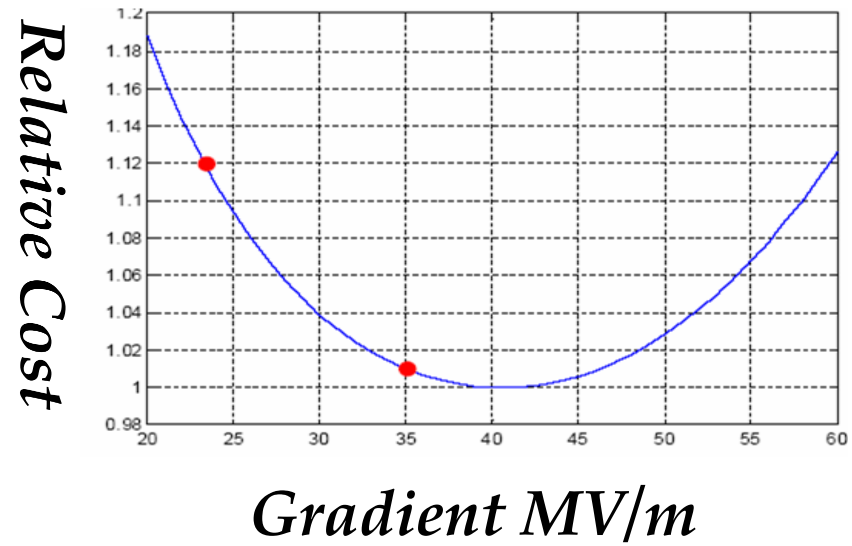
Energy of the accelerator?

Gradient of cavities?

Duty cycle and repetition rate?

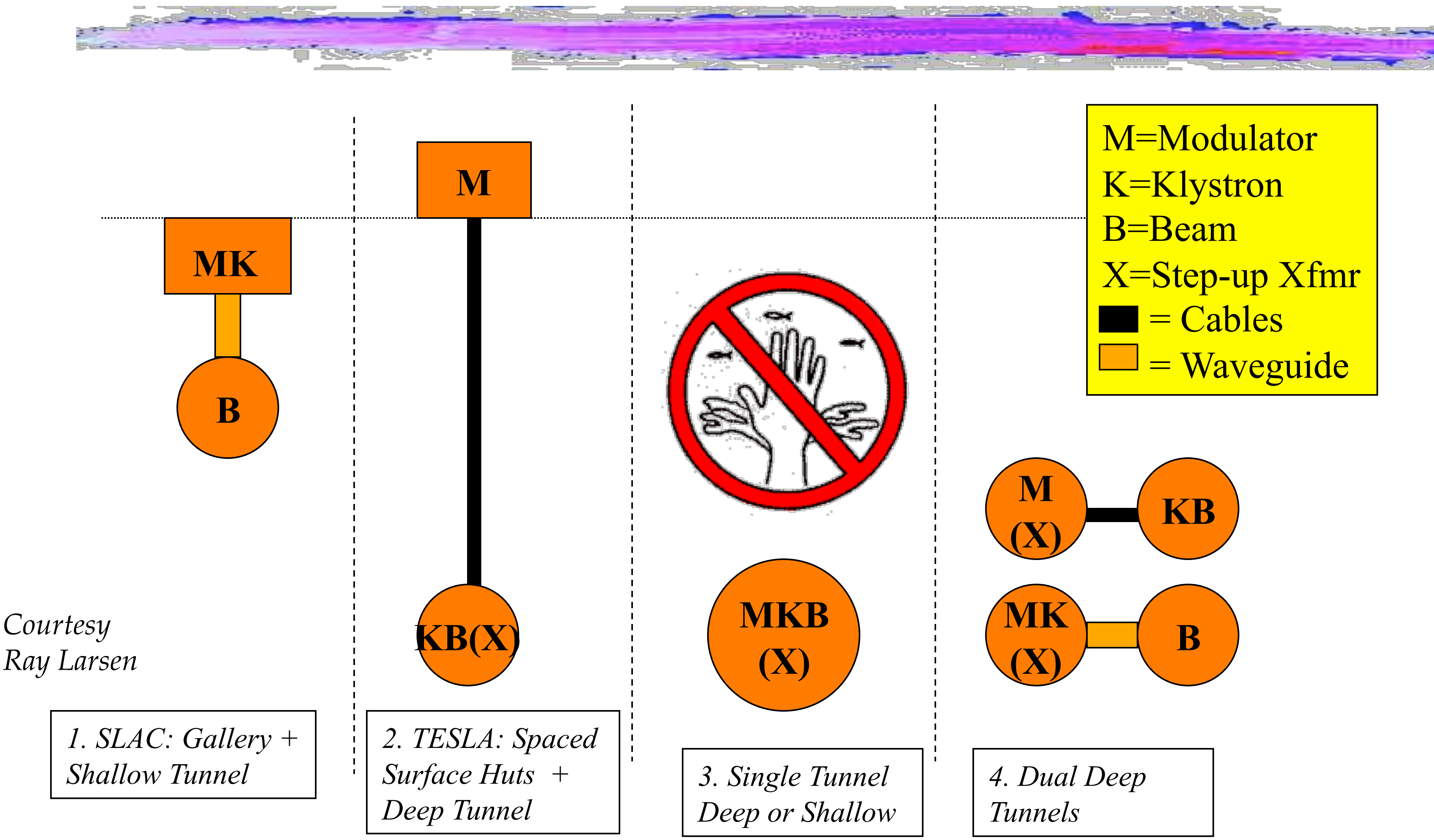
Location of hardware?

SRF cost vs gradient



C. Adolphsen (SLAC)

Tunnel Topology Options



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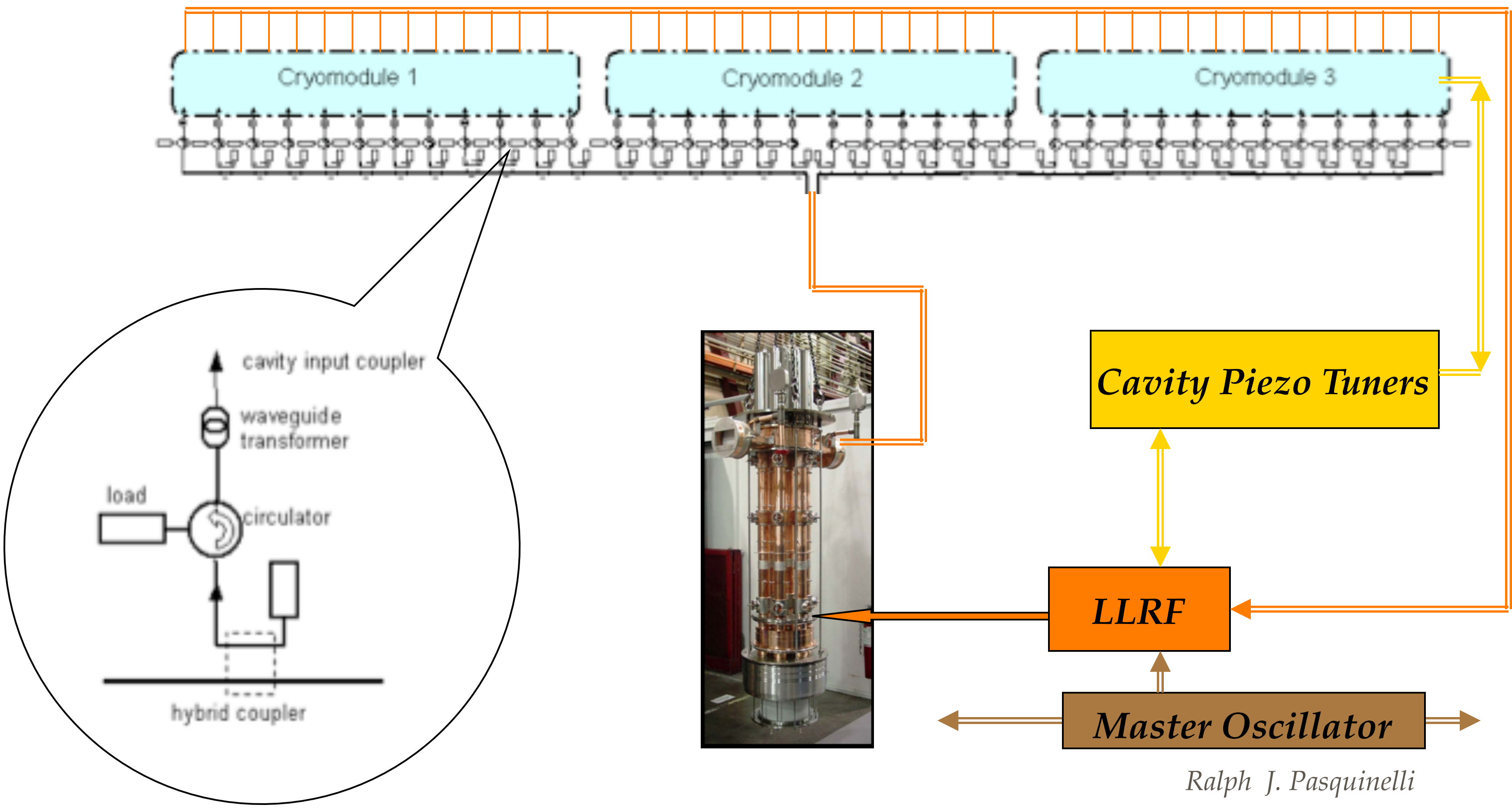
Typical RF Station



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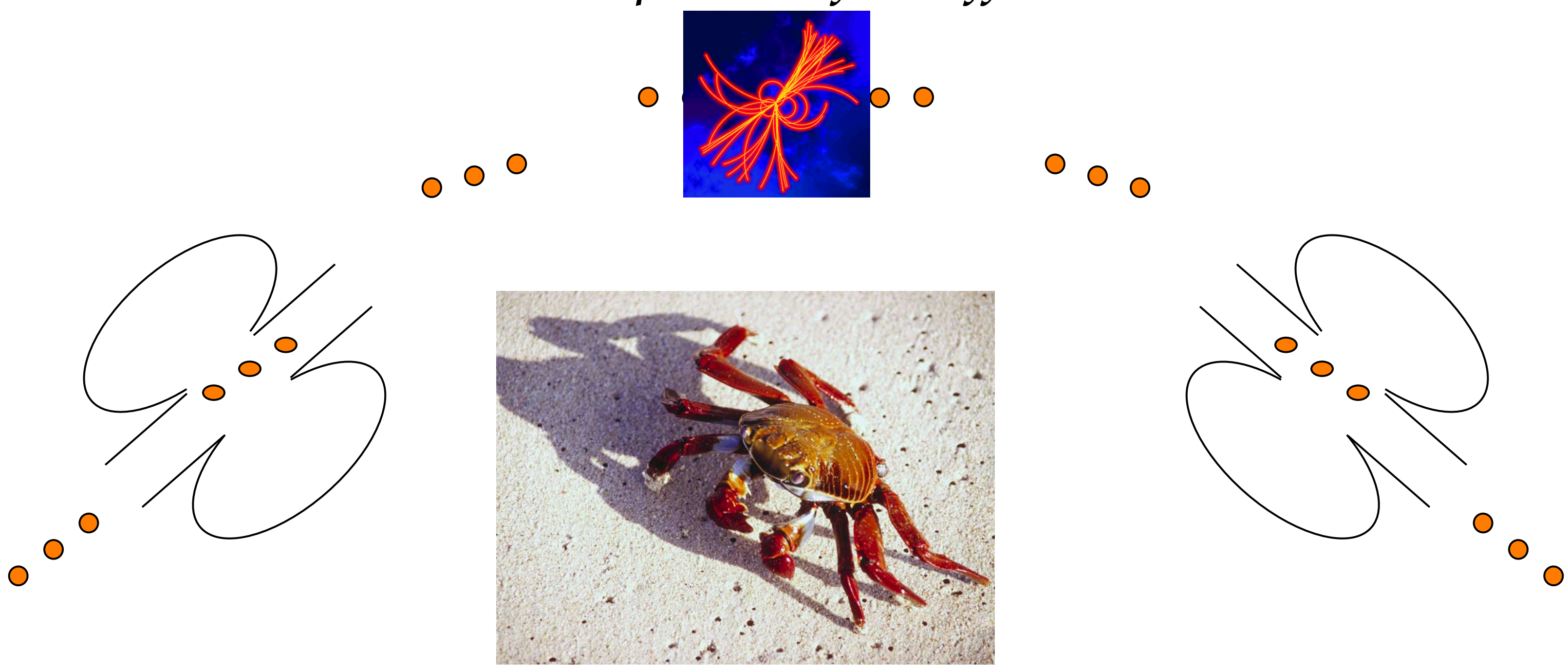
Crab Cavities

RF Used to Compensate for Off Axis Collisions



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Overall RF Power Conversion Efficiency

37%-48%

Wall Plug

AC to DC Power Converter

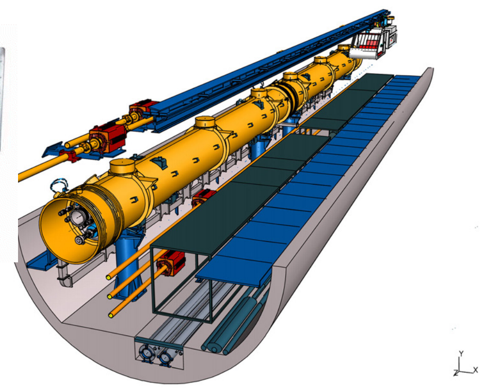
78%

RF Power Source

50%-65%

Transmission Line

95%



Beam

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Cost of RF Power

RF Power Source
AC to DC conversion
LLRF & Interocks
Power distribution
\+ Controls

$0.25 to $15 per RF Watt

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This Concludes Microwave Measurements 101 Lectures!

Ralph J. Pasquinelli