3rd ILSF Advanced School on Synchrotron Radiation and Its Applications

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Introduction to Synchrotron Radio Frequency System

Khorshid Sarhadi
Head of ILSF RF Group

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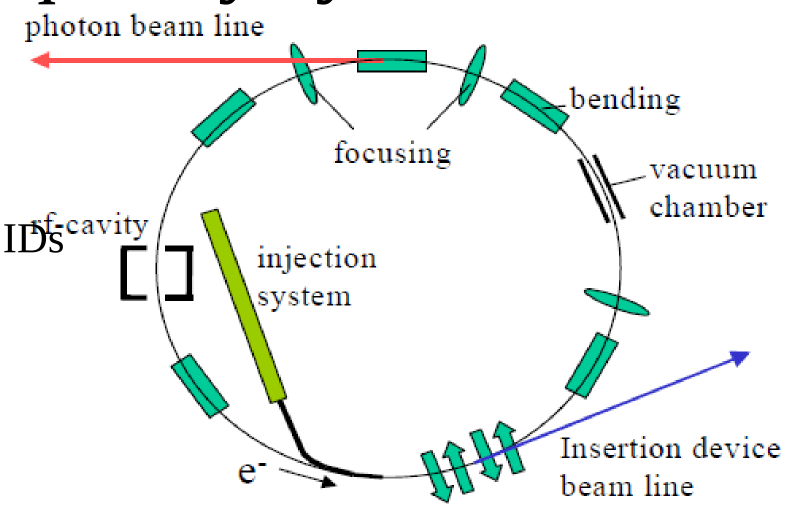
Outline

- Necessity of Radio Frequency system
- How the cavity works
- RF dependant parameters
- RF system components and functions
  - Cavity
  - High power RF Amplifier
  - Waveguide System
  - LLRF System
- RF System Design Procedure
- RF frequency selection
- Review of ILSF RF prototypes

1. Necessity of Radio Frequency system



- Goal of synchrotron facility?
  - Producing X-ray Radiation for research
- How?
  - High energy Electrons passage through dipoles & IDs
  - Momentum changes
  - Energy losses
  - Photon emission
- How to provide the energy of the electrons?
  - Electric field or Magnetic field for acceleration?
    - Lorentz force $\vec{F} = e\vec{E} + e(\vec{v} \times \vec{B})$
    - Work rate $F \cdot \vec{v} = eE \cdot \vec{v} + \underbrace{\cancel{e(\vec{v} \times \vec{B}) \cdot \vec{v}}}_{0}$ no work with magnetic field

→ Electric Field

  - DC or time varying electric field?
    - Maxwell equations: $\nabla \times \vec{B} - \frac{1}{c^2}\frac{\partial}{\partial t}\vec{E} = \mu_0 \vec{J}$ $\quad \nabla \cdot \vec{B} = 0$

$$\nabla \times \vec{E} + \frac{\partial}{\partial t}\vec{B} = 0 \qquad \nabla \cdot \vec{E} = \mu_0 c^2 \rho$$

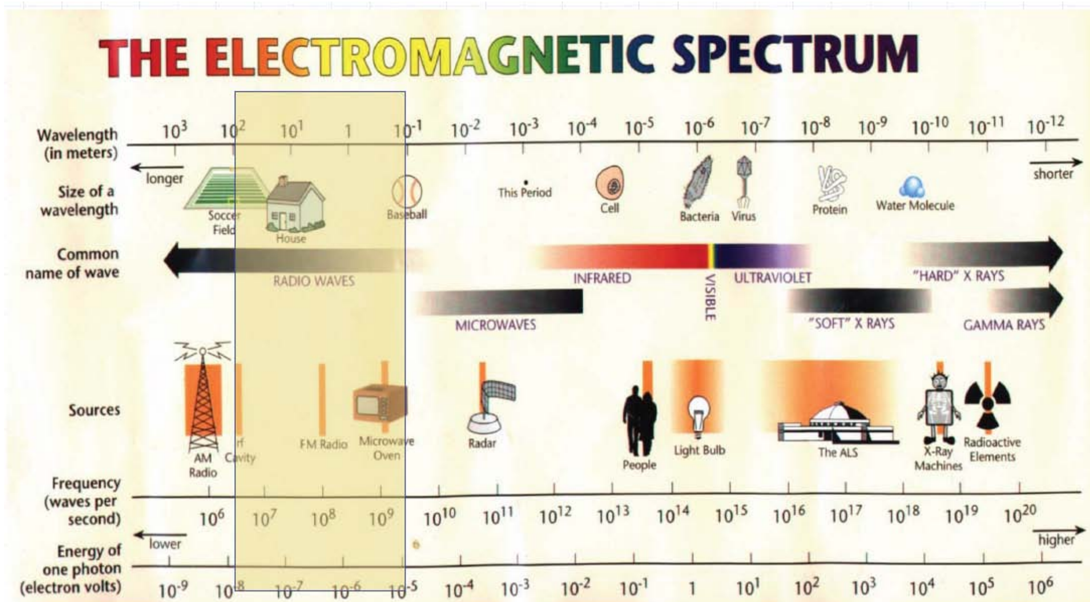
    - In circular machine: $\nabla \times \vec{E} = -\frac{\partial}{\partial t}\vec{B}$ $\quad \oint \vec{E} \cdot d\vec{s} = -\iint \frac{\partial \vec{B}}{\partial t} \cdot d\vec{A}$ => DC acceleration is impossible, $\oint \vec{E} \cdot d\vec{s} = 0$

→ Time-varying Field

    - In non-circular machine: DC acceleration is possible but limited by break down

1. Necessity of Radio Frequency system (Cont.)

- Which frequency the time-varying field oscillates with?



Frequency bands
HF: 3-30MHz
VHF: 30-300MHz
UHF: 0.3-1GHz
L : 1-2GHz
S: 2-4GHz
C: 4-8GHz
X: 8-12GHz
Ku: 12-18GHz
K: 18-27GHz
Ka: 27-40GHz

  - Structure size, power source availability, etc. ➡ Radio Frequency Field
- How to apply the field to the electrons?
  - Passing the electrons through a field resonator which is called cavity

2. How the cavity works

- Standing wave field

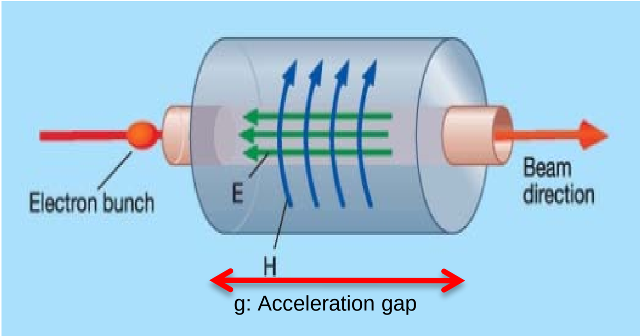
$$E_z(r,z,t) = E_z(r,z)\sin(\omega t + \phi)$$

- Electron energy gain on axis

$$\Delta E = e\int_{-g/2}^{g/2} E_z(0,z)\sin(\omega t + \phi)dz$$

$$\Delta E = eV_c \sin\phi \qquad V_c = \int_{-g/2}^{g/2} E_z(0,z)\cos\omega t dz$$

  - RF phase dependant



- How to adjust electron energy gain to compensate the energy loss?
  - Synch the particle arrival with RF phase
  - That's where synchrotron name comes from!

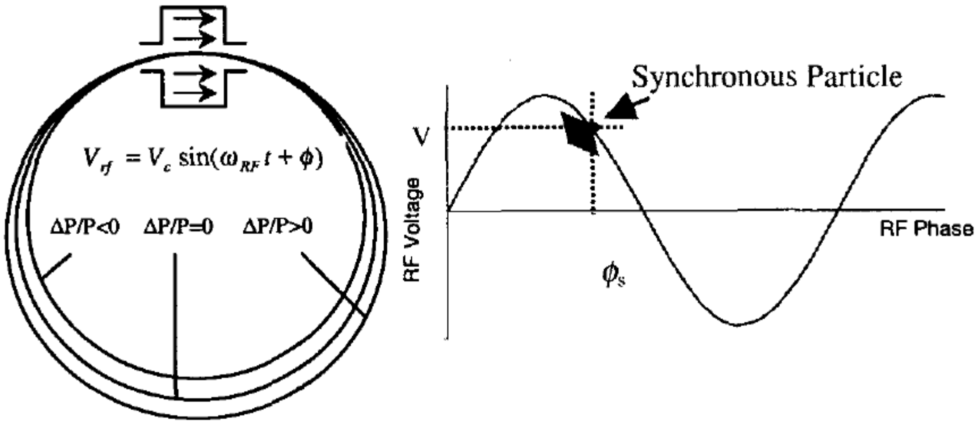
2. How the cavity works (Cont.)

- Synchronous phase
  - ϕ_s, RF phase which the ideal particle always sees passing the cavity

$$h = \frac{f_{RF}}{f_{rev}}$$ harmonic number

  - Energy gain=energy loss

$$\sin\varphi_s = \frac{U_o}{eV_{RF}} = \frac{V_r}{V_{RF}}$$



  - Phase focusing principle
    - ΔP/P >0 => electron arrives later => gain less energy => closer to ideal energy
    - ΔP/P <0 => electron arrives earlier=> gain more energy => closer to ideal energy

- Necessity of cavity phase and amplitude adjustment with the beam

3. RF dependant parameters

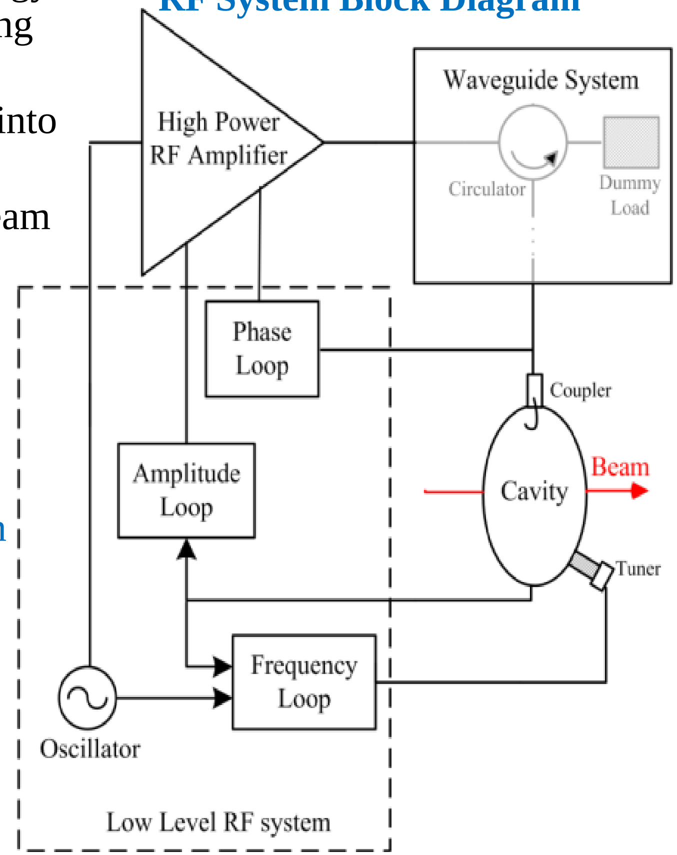
- Synchronous phase $$\sin\varphi_s = \frac{U_o}{eV_{RF}} = \frac{V_r}{V_{RF}}$$
- Synchronous frequency $$f_s = f_{rf}\sqrt{\frac{-e\alpha V_c h\cos\varphi_s}{2\pi E_0}}$$
- Over voltage factor $$q = \frac{V_{RF}}{V_r} = \frac{1}{\sin\varphi_s}$$
- Energy or momentum acceptance $$\delta_{RF}^2 = \frac{V_r F(q)}{\pi h\alpha E} = \frac{f_{rev} V_r F(q)}{\pi f_{RF}\alpha E} \quad , F(q) = 2\left[\sqrt{q^2-1} - \cos^{-1}(1/q)\right]$$
- Electron bunch length $$\sigma_L = \frac{c\alpha\sigma_\varepsilon}{2\pi f_s E_0}$$
- Touscheck lifetime $$\tau_T = \frac{8\pi\langle\sigma_x\sigma_y\rangle\sigma_s}{cr_e^2 ND(\chi)}\gamma^2\delta_m^3 \qquad \chi = \frac{1}{2\gamma^2}\frac{\langle\beta_x\rangle}{\varepsilon_x}\delta_m^2$$
- Bremsstrahlung lifetime $$\frac{1}{\tau_B(h)} = 3.23\times10^{-3}\left[\ln\left(\frac{1}{\delta_m}\right) - \frac{5}{8}\right]\frac{P(nTorr)}{T(K)}\sum_i \ln\left(\frac{183}{z_i^{1/3}}\right).z_i(z_i+\varsigma)N_i r_{pi},$$

4. RF system components and functions

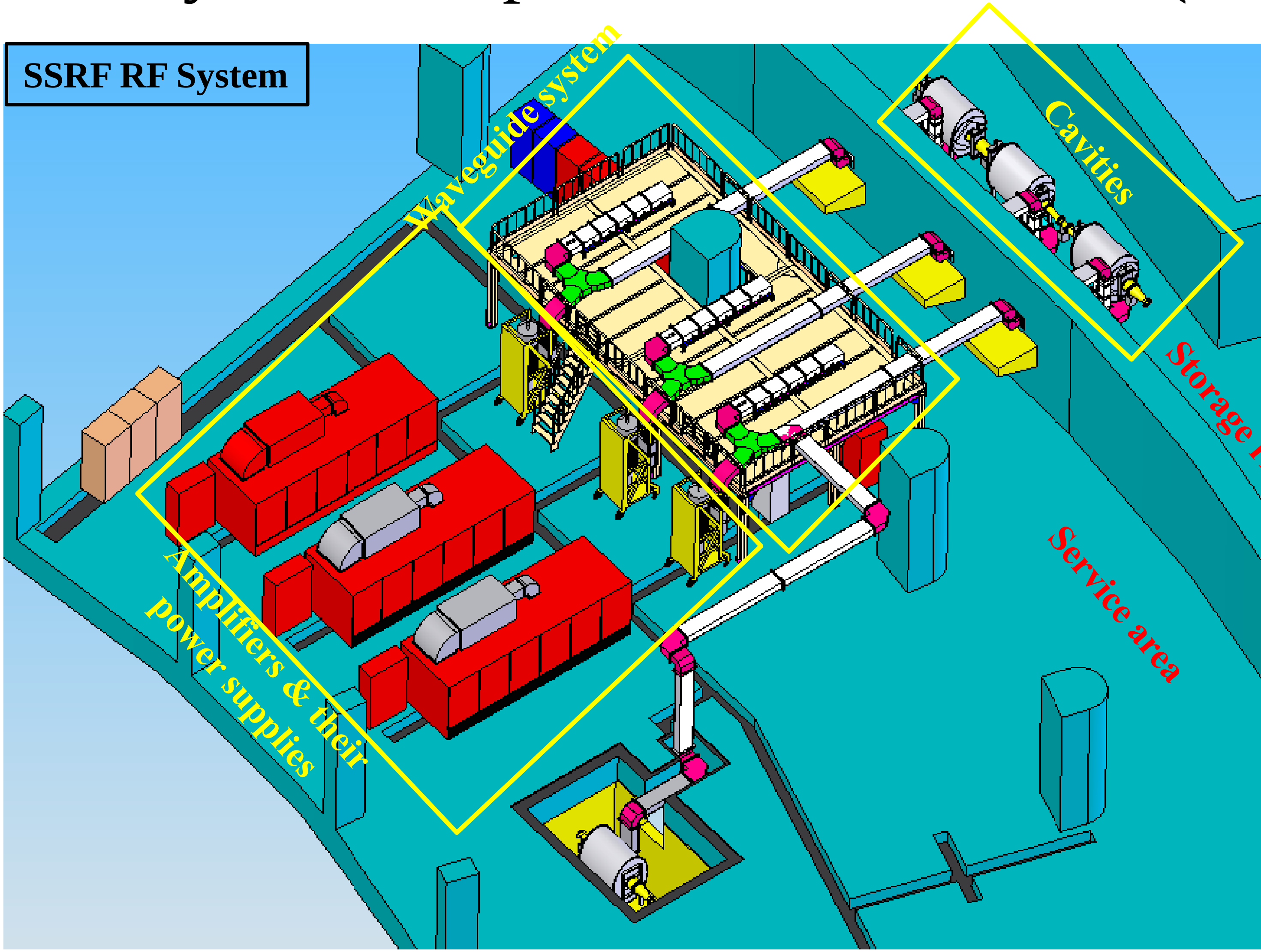
- Function of RF system:
  - Providing the energy to electrons for compensating the energy loss to continue photon radiation (in storage ring) or ramping to higher energies (in booster)
  - Establishing RF voltage to capture and focus the electrons into bunches
  - Controlling the beam parameters, such as bunch length, beam lifetime, etc.
  - Providing damping effects to the electron motions by synchrotron radiation and RF acceleration.

- RF System key components and their functions:
  - Cavity: establish RF voltage and transfer energy to electron beam
  - High power RF amplifier: generate the cavity required RF power
  - Waveguide system: transport the RF power to the cavity
  - LLRF system: perform cavity tuning, phase and amplitude stabilizing, suppress beam instabilities by RF and beam feedbacks, execute interlocks

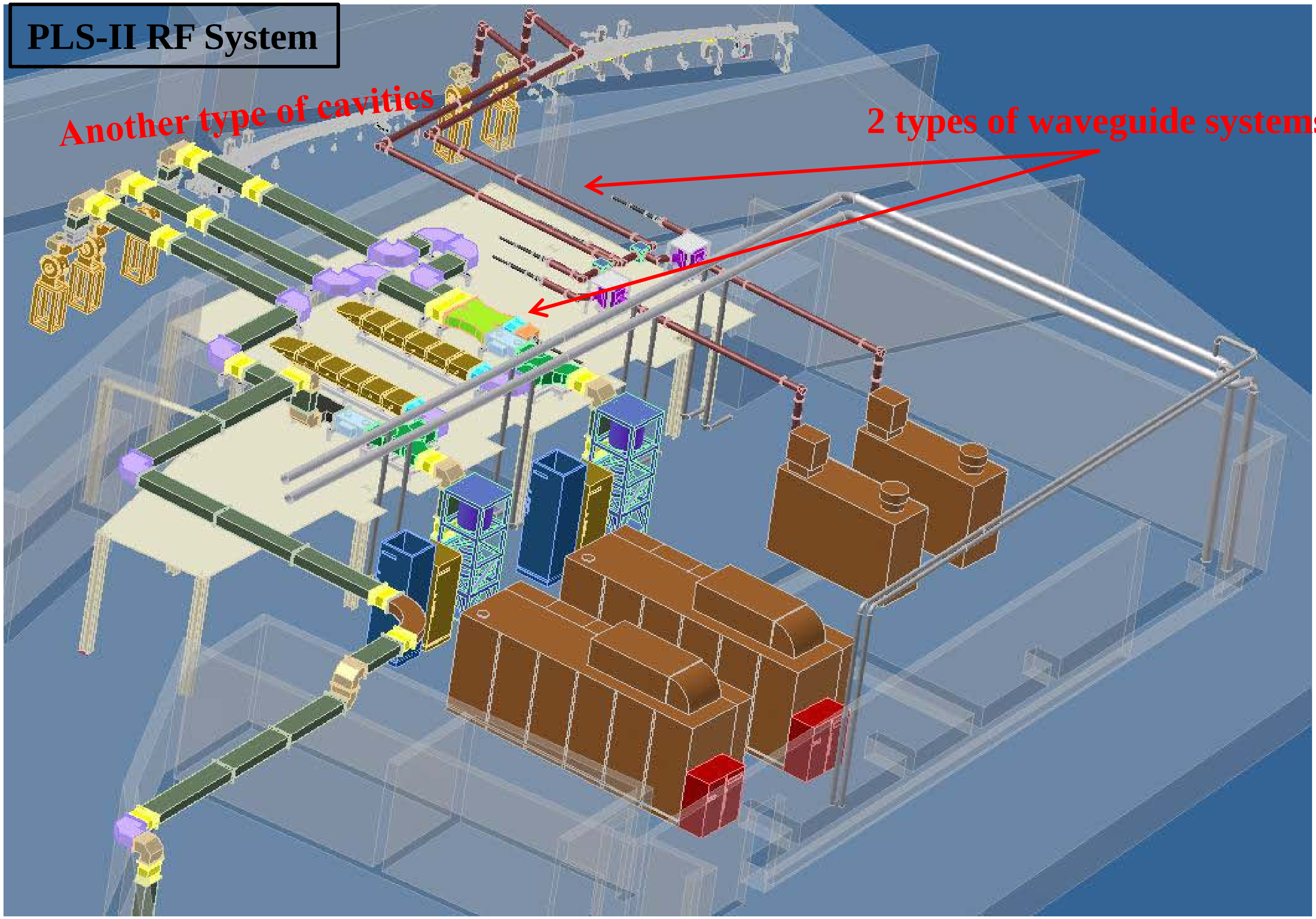
RF System Block Diagram



4. RF system components and functions (cont.)

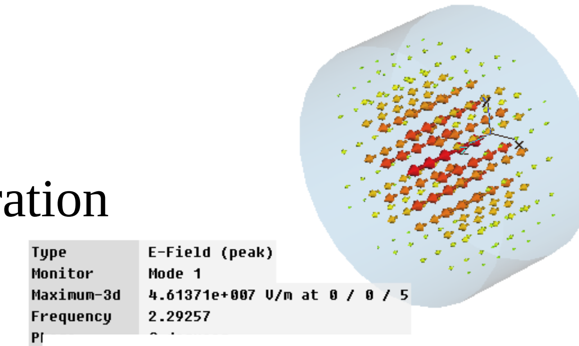


4. RF system components and functions (cont.)



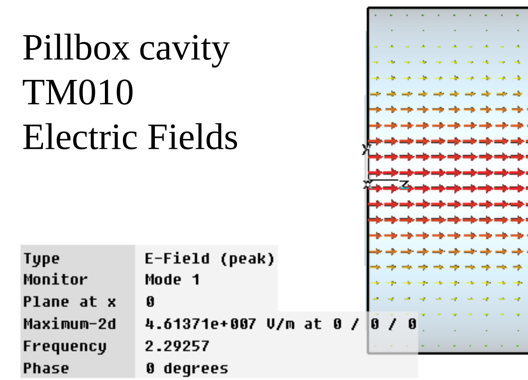
4-1. Cavity

- Simplest type: pillbox
- TM010 fundamental mode & best mode for acceleration

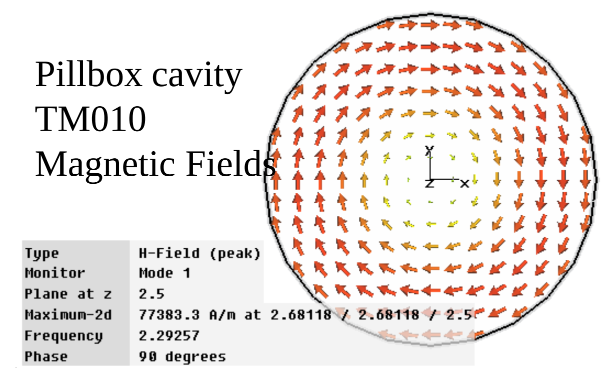


- Cavity figures of merit:
  - Shunt impedance $R_s = \dfrac{V_{RF}^2}{2P_{Diss}}$ $\quad P_{Diss} = \dfrac{1}{2} r_{surface} \int |H|^2 dS$
    - Higher, better
  - Quality factor $Q_o = \dfrac{\omega U}{P_{Diss}}$
    - Higher, better
  - Geometric factor or normalized impedance $\dfrac{R_s}{Q} = \dfrac{V_{RF}^2}{\omega U}$
    - Higher, better

Pillbox cavity
TM010
Electric Fields



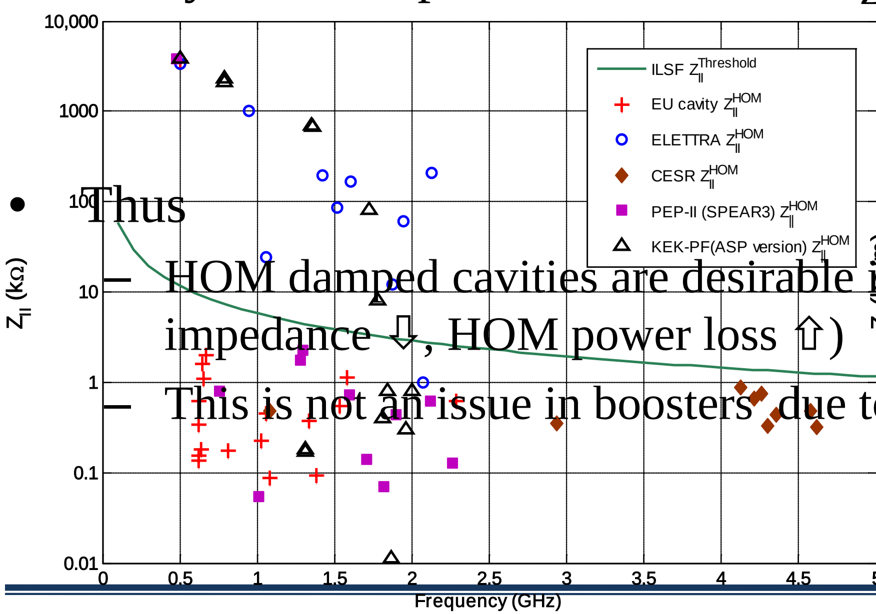
Pillbox cavity
TM010
Magnetic Fields

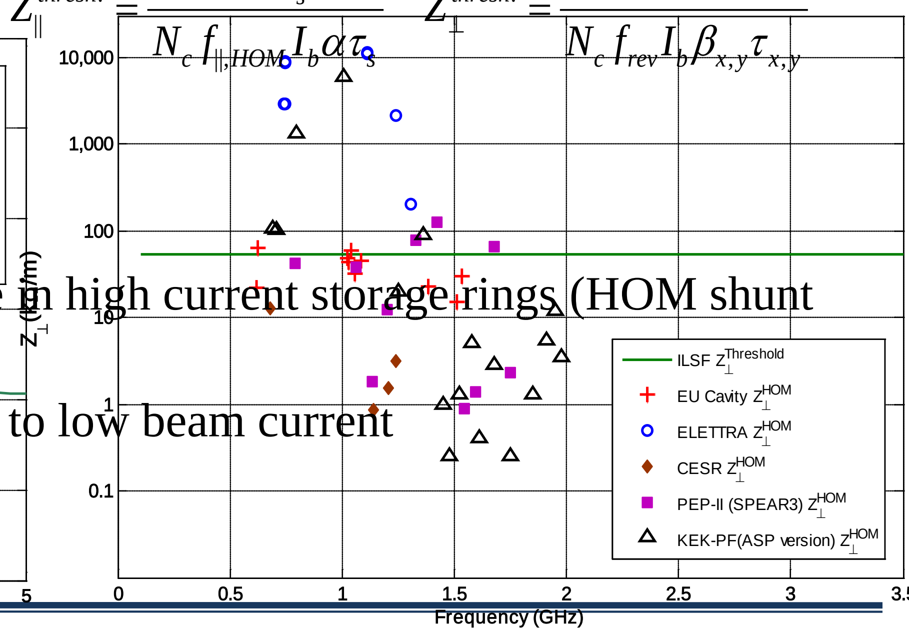


4-1. Cavity (cont.)

- Higher order modes (HOM) also exist in a cavity and can be excited by beam when the beam current is high
  - Electric field has longitudinal variation => accelerate & decelerate the beam
  - Electric field in other direction => kick the beam transversely
  - Causes beam instabilities
- Each lattice has the instability thresholds which should be higher than cavity HOM impedances

$$Z_{\parallel}^{thresh.} = \frac{2EQ_s}{N_c f_{\parallel,HOM} I_b \alpha \tau_s} \qquad Z_{\perp}^{thresh.} = \frac{2E}{N_c f_{rev} I_b \beta_{x,y} \tau_{x,y}}$$

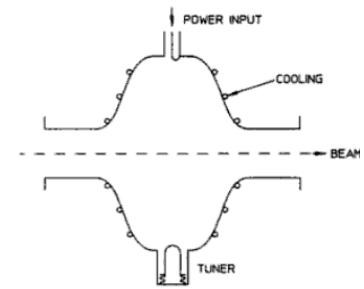




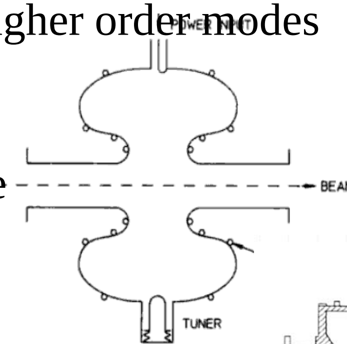
- Thus
  - HOM damped cavities are desirable in high current storage rings (HOM shunt impedance ⇩, HOM power loss ⇧)
  - This is not an issue in boosters due to low beam current

4-1. Cavity (cont.)

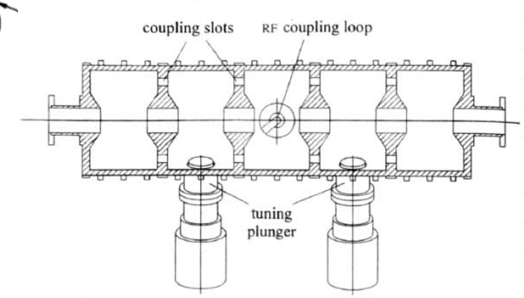
- Cavity design goal:
  - high gradient, high power, low loss (high fundamental shunt impedance), no/low HOM
- Cavity geometry evolution
  - Bell-shaped cavity => higher gradient, lower Higher order modes



  - Nose coned cavity => increase shunt impedance



  - Multi cell cavities
    - higher voltage, higher shunt impedance
    - Not HOM damped => suitable for boosters

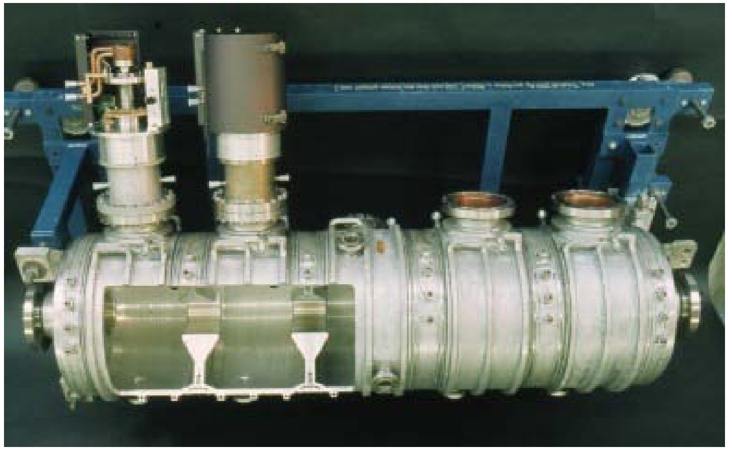


  - Various HOM damping methods
    - Adding antennas
    - Adding absorbers in the tube
    - Waveguide dampers
    - HOM shifting by temperature tuning
  - Super conducting cavities
    - Low loss
    - Low HOM impedances

4-1. Cavity (cont.)

- NC multi cell cavities

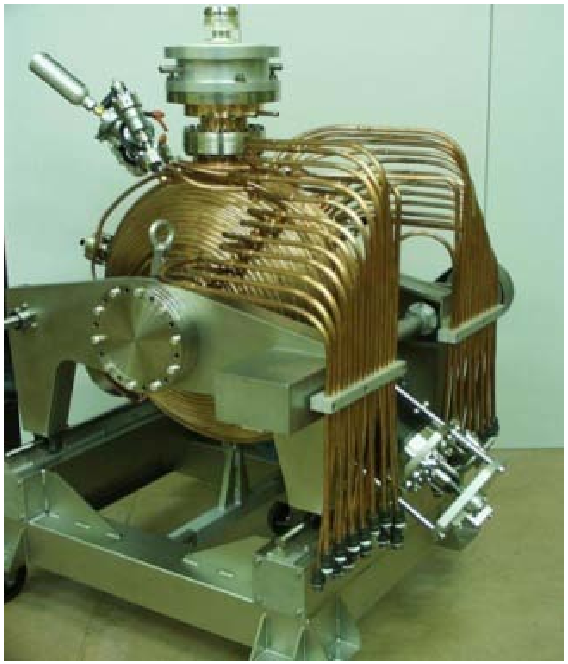
	5 cell Petra	7 cell Petra
π mode frequency (MHz)	499.67	499.67
Shunt impedance (MΩ)	15	23
Nominal accelerating voltage (MV)	1.34	1.67
Maximal accelerating voltage (MV)	1.94	3
Total length (mm)	1800	2200
Outside diameter (mm)	445	448



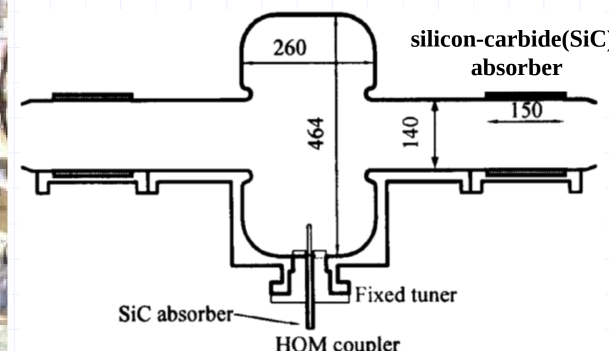
Petra 5 cell at SSRF booster

4-1. Cavity (cont.)

- HOM damped NC cavities



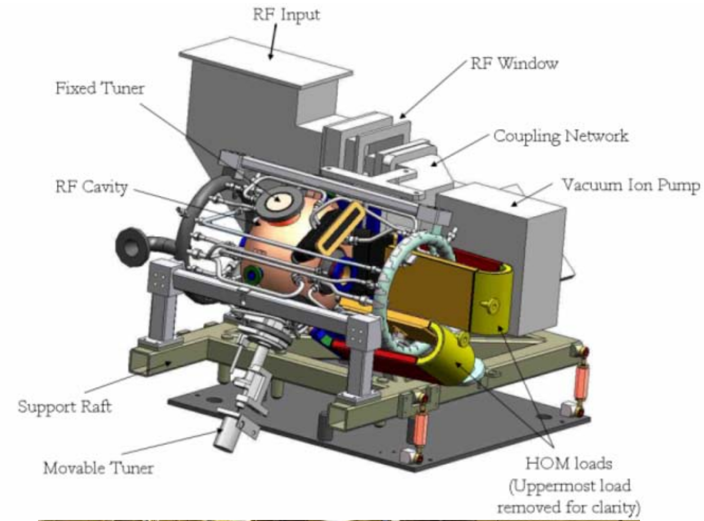
Elettra

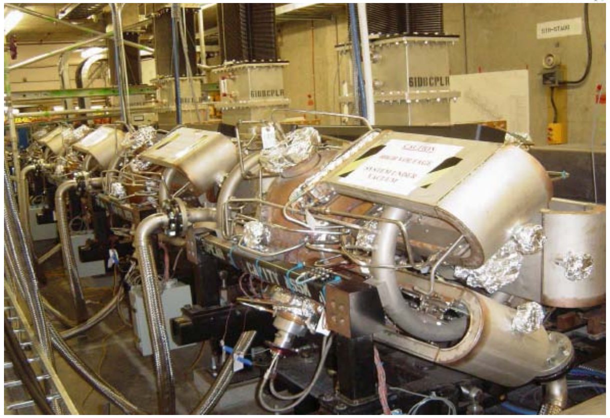


KEK-PF HOM-damped (ASP version)

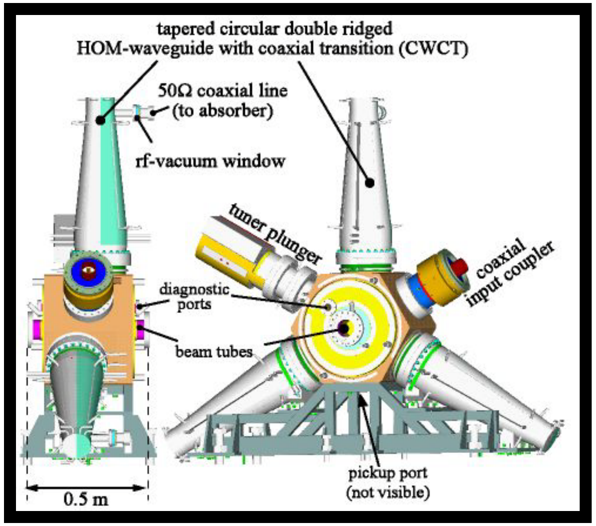
4-1. Cavity (cont.)

- HOM damped NC cavities





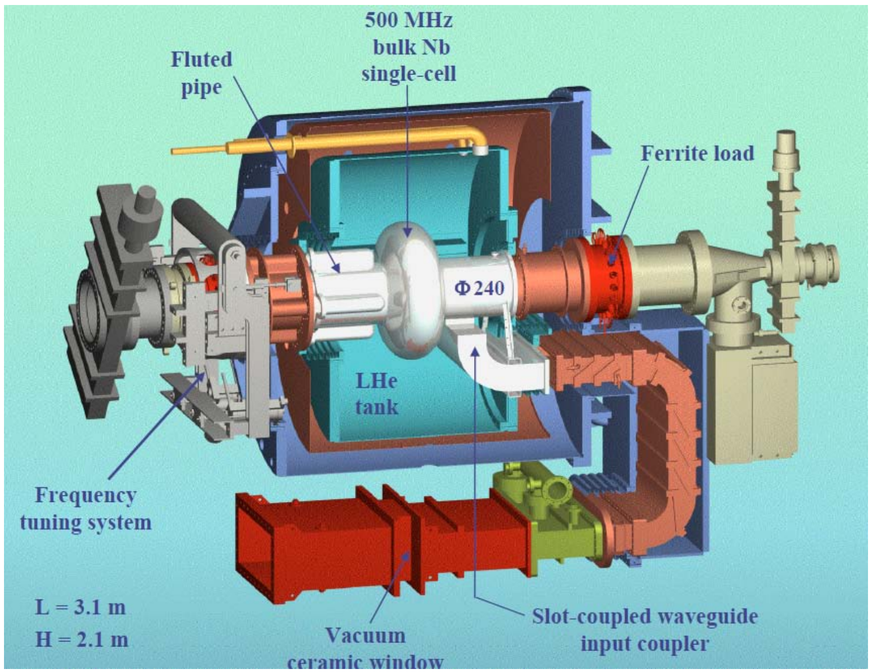
PEP-II



EU

4-1. Cavity (cont.)

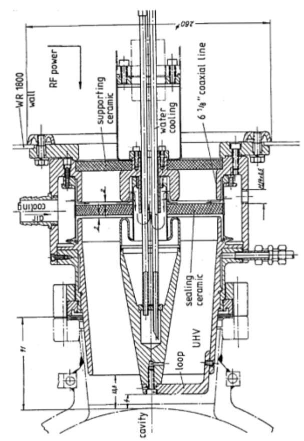
- Super conducting cavities

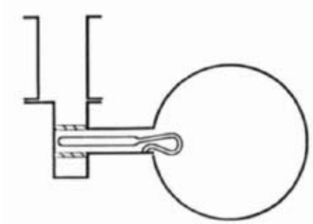


CESR cavity at SSRF storage ring

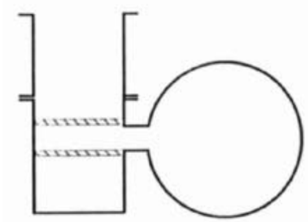
4-1. Cavity (cont.)

- Cavity Components
  - Coupler
    - Couple the input power from waveguide to cavity or pick up the cavity signal for monitoring
    - Types: loop & aperture
    - Power handling of the cavity is usually limited to the coupler structure



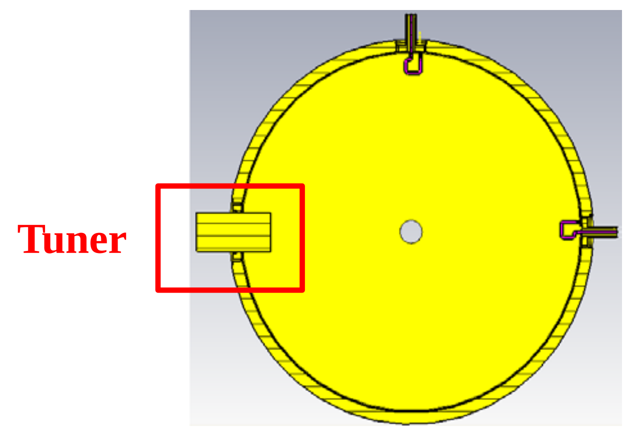


Ceramic cylinder with loop coupling



Ceramic cylinder with aperture coupling

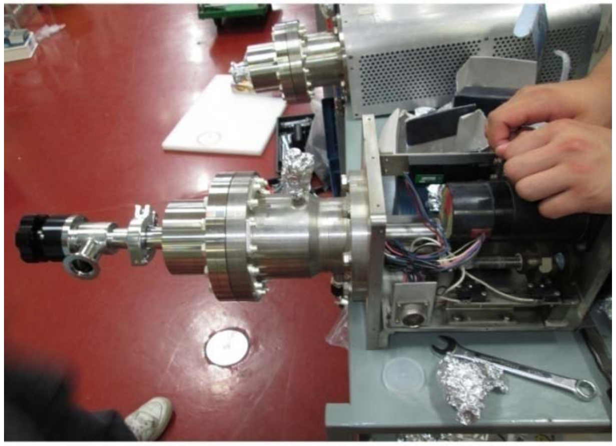
  - Tuner
    - Tuning and adjusting the cavity frequency

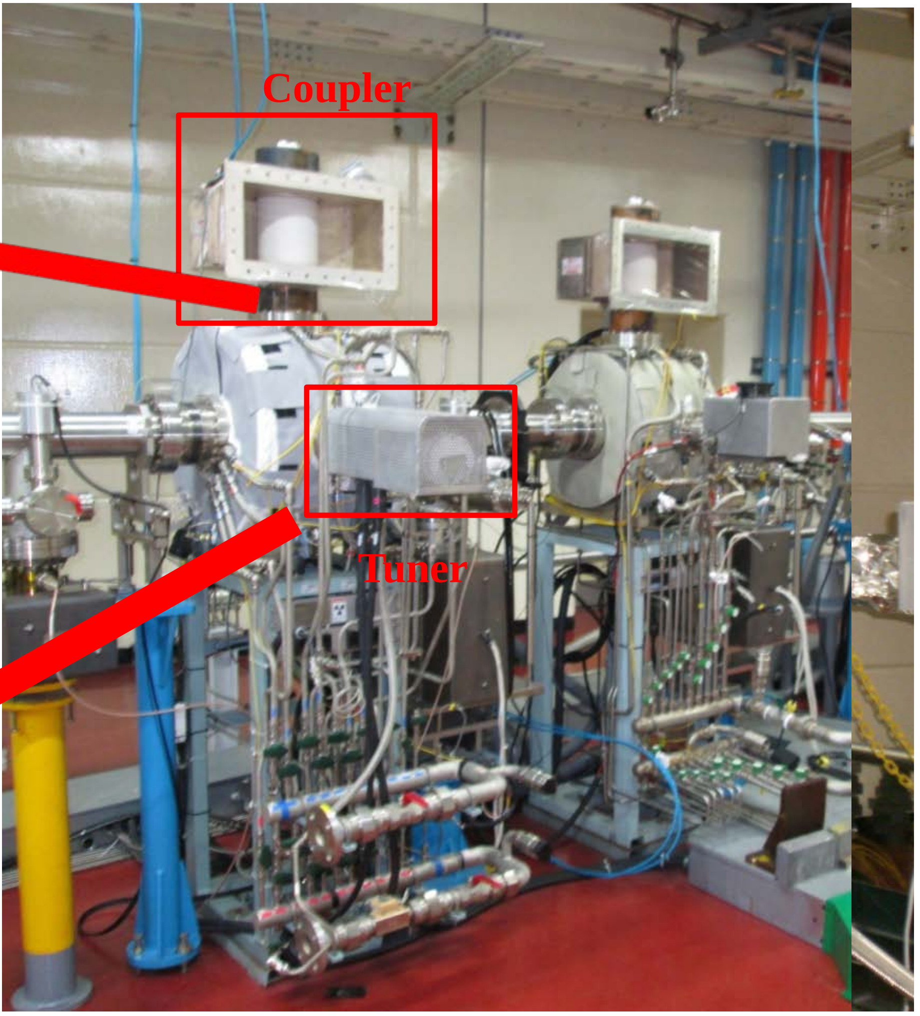


Iranian Light Source Facility

4-1. Cavity (cont.)

- Cavity Components on PLS cavity





PLS cavity under assembling

PLS cavity working in PLS-II ring

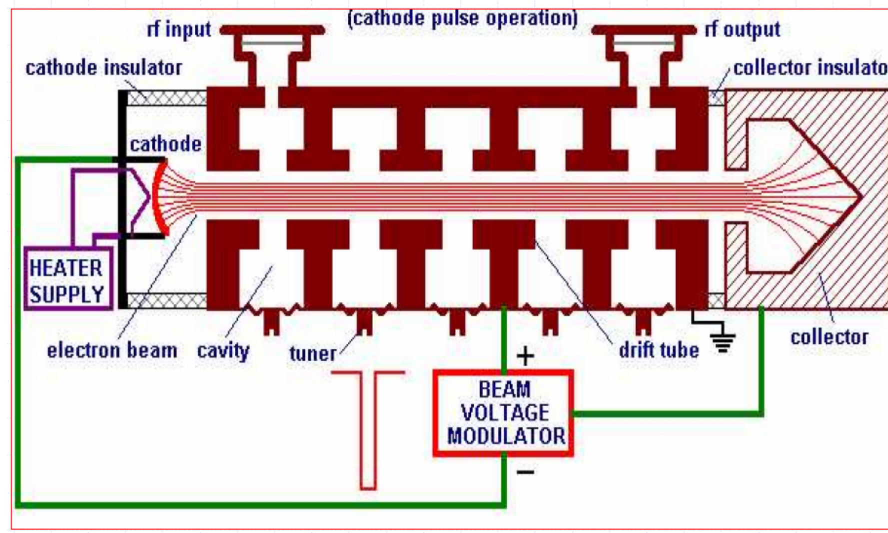
4-2. High power RF amplifier

- Function: generating the required RF power for the cavity
- Order of required power: few hundred kilowatts for storage ring
- High power Amplifiers Options:
  - Microwave tubes (Klystron, IOT (Inductive Output Tube), etc.)
    - Principle: reverse of Linac

Klystrons

Tetrode

IOT



4-2. High power RF amplifier (cont.)

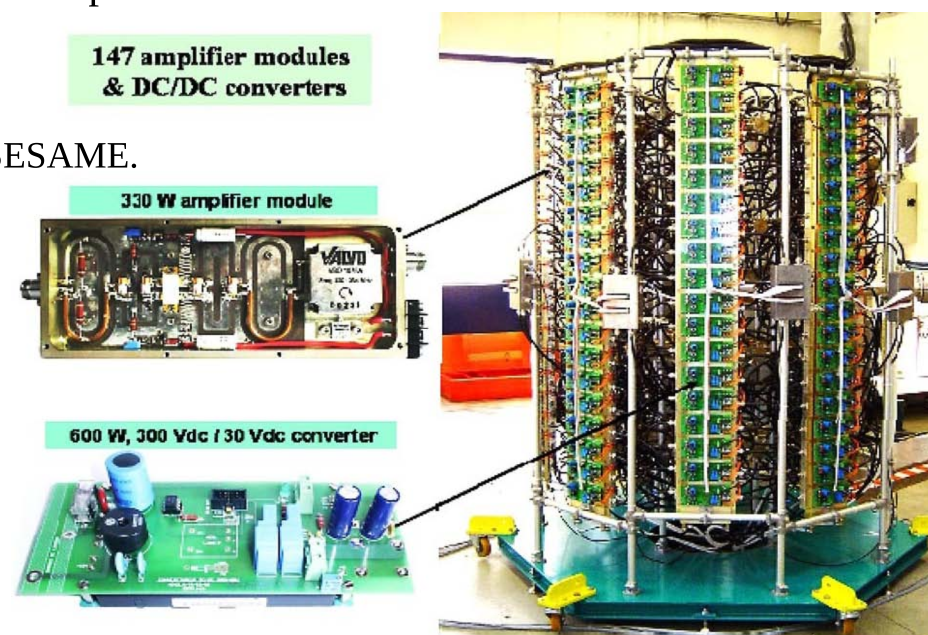
- Function: generating the required RF power for the cavity
- Order of required power: few hundred kilowatts for storage ring
- High power Amplifiers Options:
  - Microwave tubes (Klystron, IOT (Inductive Output Tube), etc.)

High-voltage power supply

300kw Klystron At PLS-II

4-2. High power RF amplifier (cont.)

- Function: generating the required RF power for the cavity
- Order of required power: few hundred kilowatts for storage ring
- High power Amplifiers Options:
  - Microwave tubes (Klystron, IOT (Inductive Output Tube), etc.)
  - Solid State Amplifiers
    - Principle: Combining the transistor amplifiers
    - Recently used in accelerators
      - First experience at Soleil.
      - Now in Brazil, Swiss, Taiwan ,SESAME.



4-2. High power RF amplifier (cont.)

Microwave Tubes (Klystron, IOT,…)

Solid State Amplifier

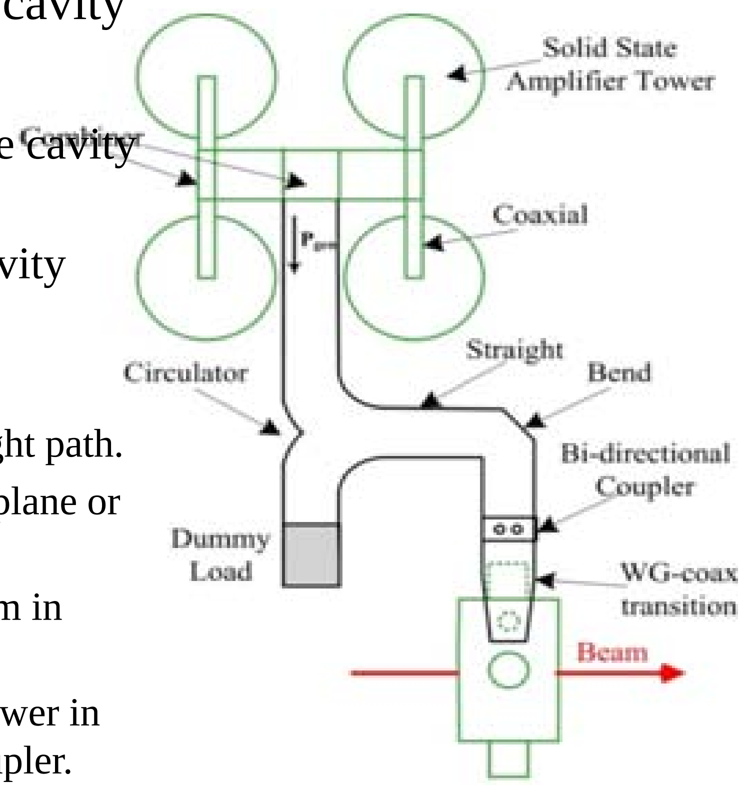
Comparison

- More experienced technology
- Cheaper than SSA but Difficult and expensive maintenance
- Few existing manufacturers
- Radiate X rays
- Work in High Voltage which has safety problems

- New technology (under improvement, not commercially available)
- Highly modular
- Good experience at SOLEIL
- No X rays
- Easier and quicker maintenance(In principle, it is possible to replace a broken module without interrupting the amplifier operation)
- Absence of high biasing voltages
- Possibility of reduced power operation in case of failure (Graceful degradation)
- Stable gain with aging

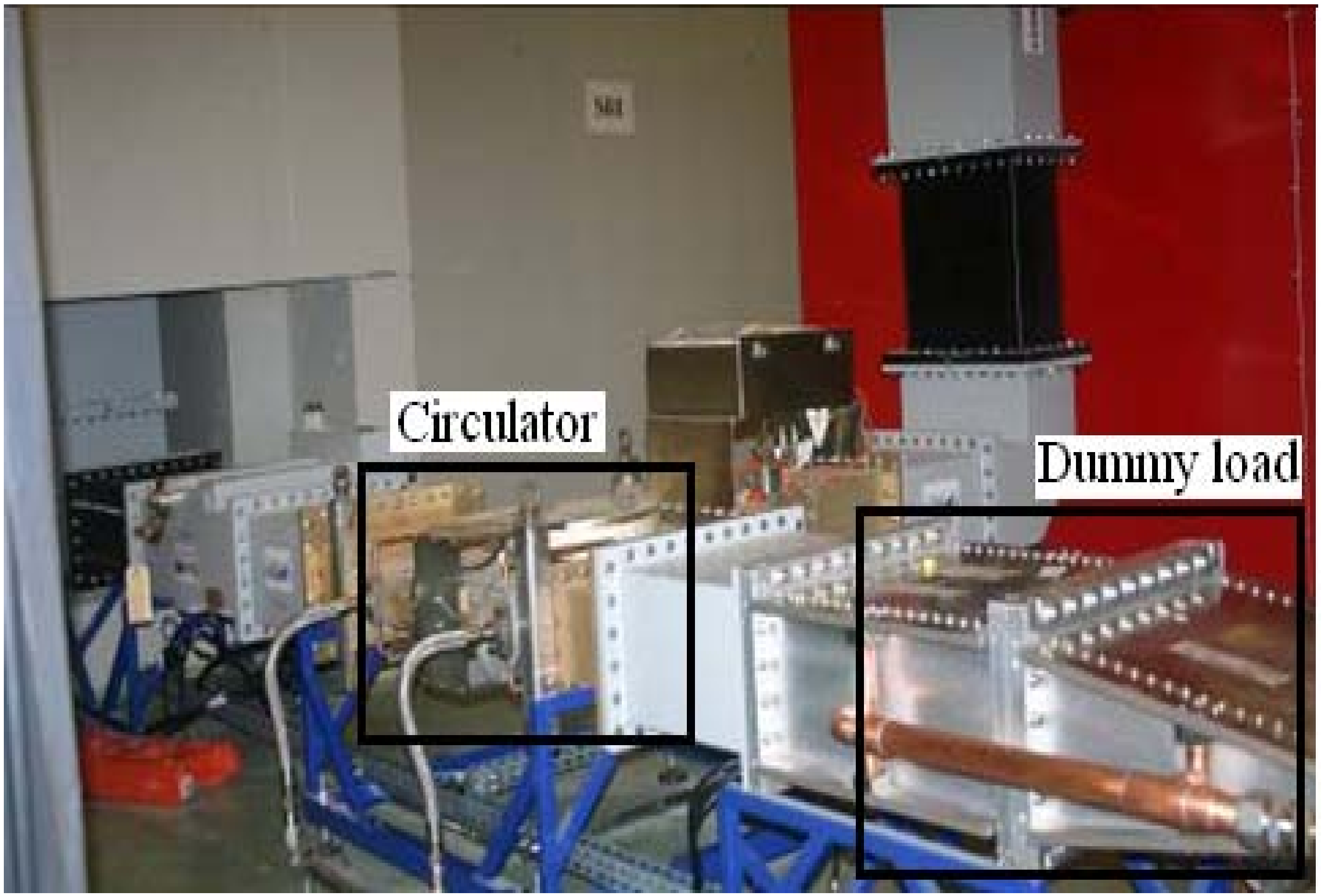
4-3. Waveguide System

- Function: transmit the energy from amplifier to cavity
- Waveguide System components:
  - Circulator : prevents the power reflected from the cavity go back toward the amplifier and cause damage.
  - Dummy load: absorbs any reflection from the cavity (installed in the third port of the circulator)
  - Transmission Lines:
    - Straight lines to transport the RF signal on a straight path.
    - Bends to turn the wave direction 90 degrees in E-plane or H-plane.
    - Bellows to give flexibility to the waveguide system in case of temperature changes.
    - Waveguide-coaxial transitions to match the RF power in the waveguide to the coaxial line of the cavity coupler.
    - Bi-directional couplers to couple the forward and reflected power out for measurement.
  - Other components: phase shifter, magic Tee, RF switch (might be necessary in some systems)



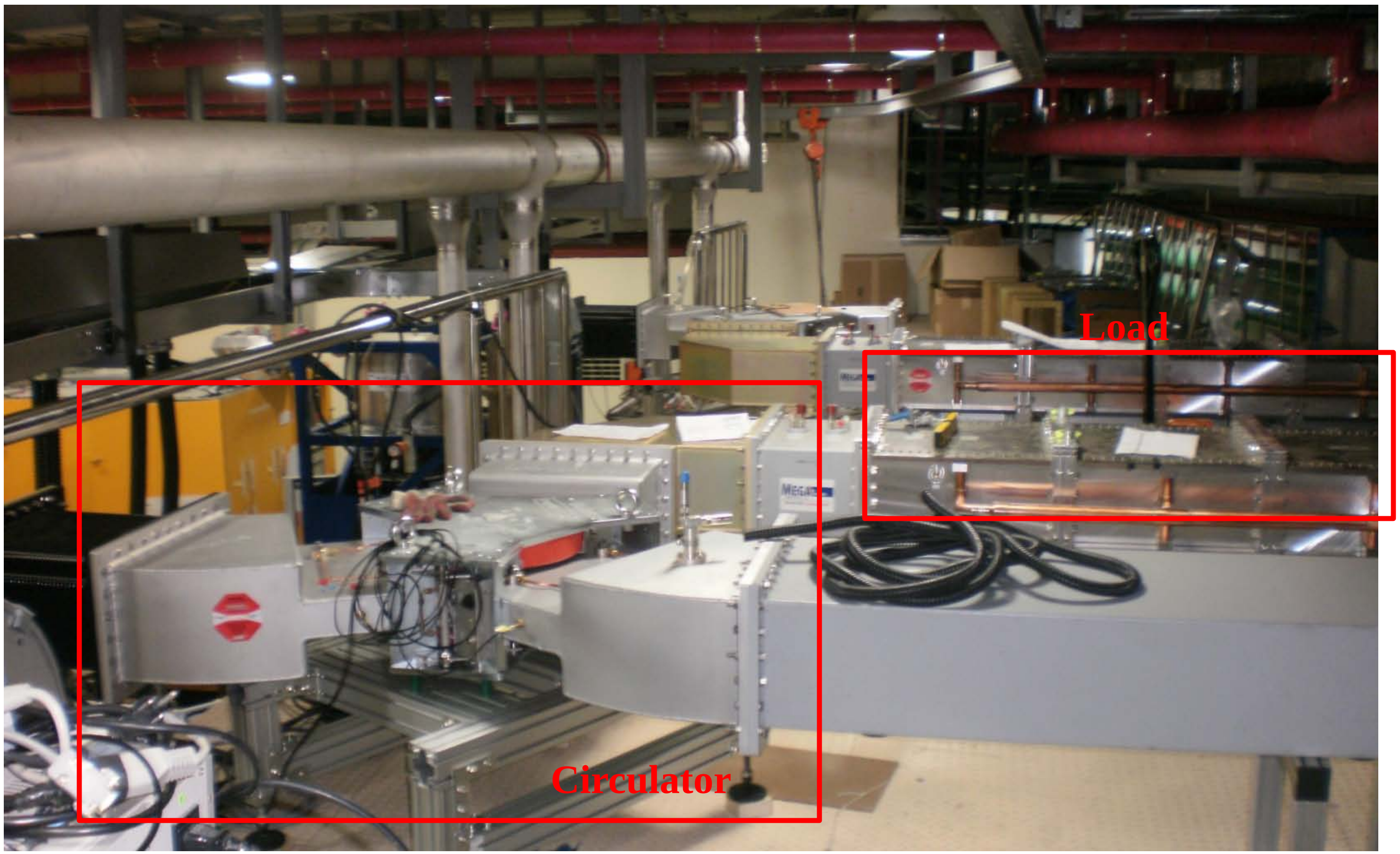
4-3. Waveguide System (cont.)

- Waveguide distribution at ALBA



4-3. Waveguide System (cont.)

- Waveguide distribution at PLS-II



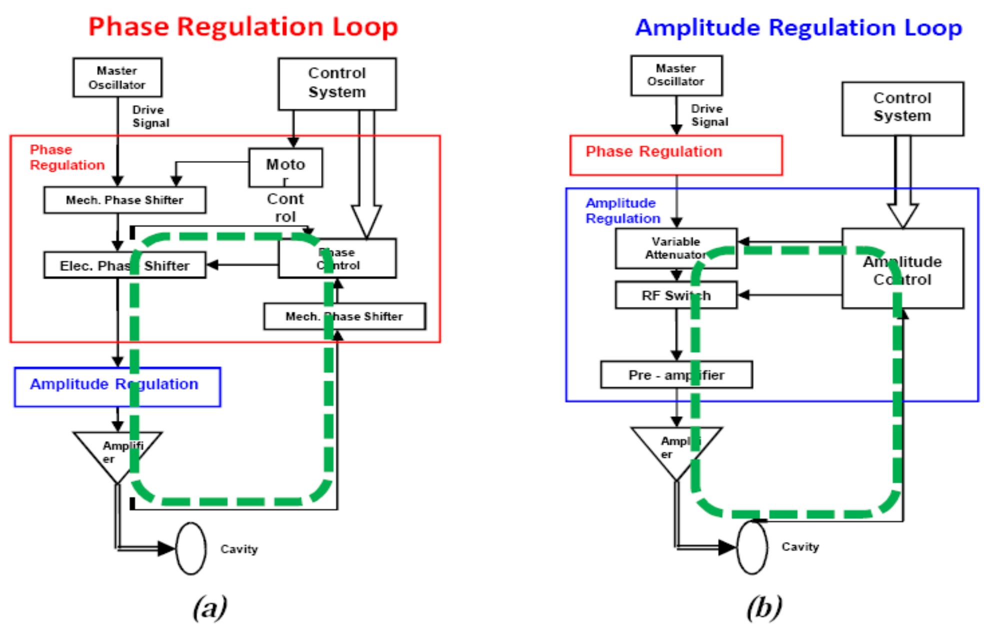
4-3. LLRF System

- LLRF: Low Level RF

- RF Control requirements
  – Amplitude and phase stability
    - Typically ±0.5 degrees on phase, ±1% on amplitude, and ±1 ppm
  – Cavity Tuning and beam loading compensation
    - Frequency loop is required
  – Suppression of beam instabilities

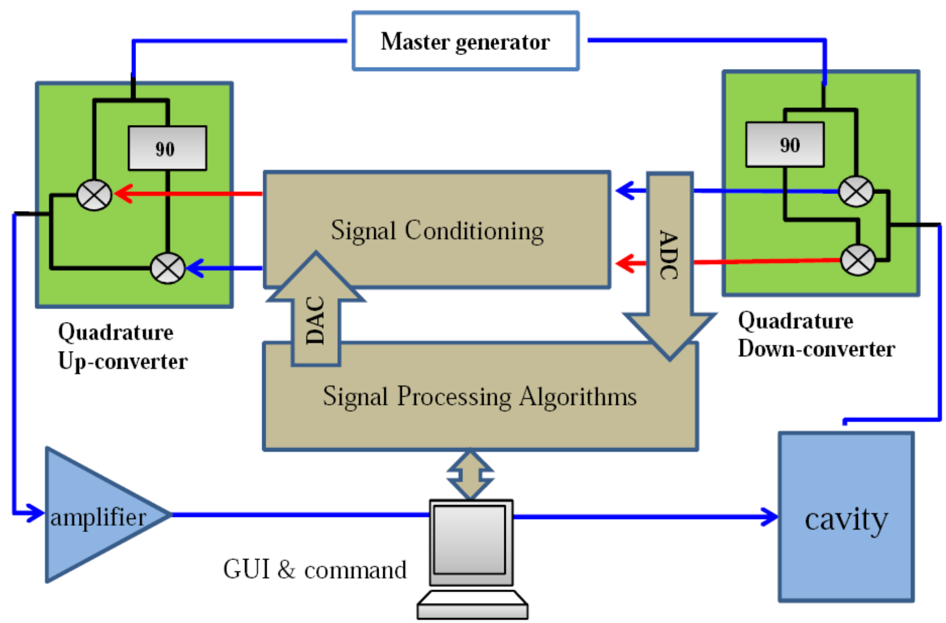
4-3. LLRF System

- Implementation options:
  - Fully Analogue
    - It directly uses cavity analog signal => very fast and relatively simple
    - Lack of flexibility => digital LLRF



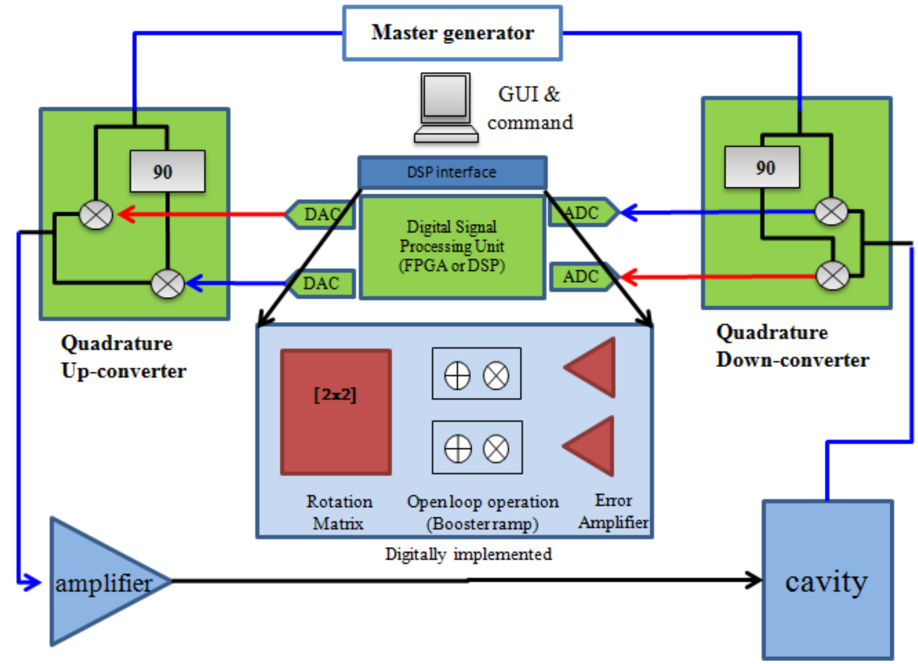
4-3. LLRF System (cont.)

- Implementation options:
  - Fully Analogue
  - Semi-digital
    - Signal conditioning: analogue
      By physical components
      (amplifiers &combiners)
    - Relatively fast & accurate
    - Moderately complex



4-3. LLRF System (cont.)

- Implementation options:
  - Fully Analogue
  - Semi-digital
  - Fully digital
    - Signal conditioning: digital
      By digital processors (FPGA&DSP)
    - Higher delay
    - Higher flexibility



5. RF System Design Procedure

- Step 0: RF frequency selection
  - Effects and selection arguments will be discussed in this presentation
- Step 1: RF voltage calculation
  - Goal: providing the desirable
    - momentum acceptance (typically 3% in recent lattices)
    - Lifetime (around 6 hours for top-up operation)
  - Required data:
    - Lattice parameters
    - Beam power (beam current×total radiation loss)
- Step 2: Cavity selection or design
  - Calculate:
    - Shunt impedance
    - Maximum tolerating voltage (due to cooling)
    - Maximum handling power (duo to coupler window)
  - Other Considerations
    - Lattice instability threshold & HOMs
    - Available straight sections in the lattice & cavity dimension
    - Cost

6. RF System Design Procedure (cont.)

- Step 3: determination of number of cavities
- Step 4: cavity dissipation power calculation
- Step 5: cavity required RF power calculation
  - Beam power/N + dissipation power

$$V_{cav} = \frac{V_{RF}^2}{2N^2 R_s} + \frac{P_{beam}}{N}$$

- Step 6: Amplifier power calculation
  - Cavity power + waveguide system loss (usually 10%)
- Step 7: Other components detail designs
  - Selection of component design option
  - Detail design of component
    - Amplifier and its components
    - LLRF blocks
    - All waveguide components
- Step 8: Other issues
  - Beam cavity interaction
    - Beam loading effect & RF matching
    - Robinson instability & cures
    - Higher order mode instabilities & cures

6. RF frequency selection

- RF frequency at other synchrotrons
  - 500MHz was used in most of the 3rd generation synchrotron light sources
    - Availability of high power klystrons
    - Utilizing the experience of other light sources

Synchrotron light source	Energy (GeV)	RF freq. (MHz)
ALBA	3	499.654
SOLEIL	2.75	352.2
SLS	2.4	500
TPS	3-3.3	499.654
NSLS-II	3	499.68
ESRF	6	352.2
CANDLE	3	499.654
PLS II	3	499.973
Diamond	3	500
ELETTRA	2.4	499.654
MAX IV	3	100
CLS	2.9	500
ANKA	2.5	499.66
Solaris	1.5	100
ASTRID 2	580	100

6. RF frequency selection (cont.)

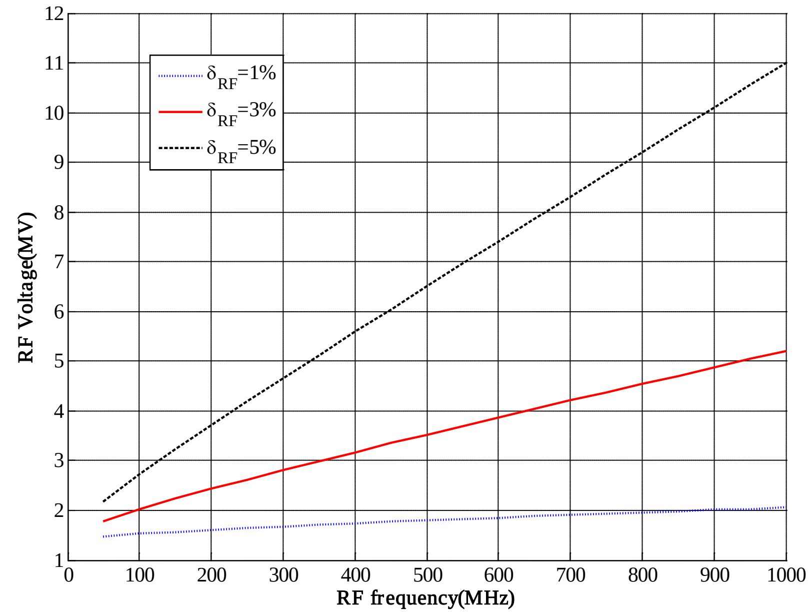
- Theoretical issues & practical concerns => selection (which may not necessarily be the universally optimum choice, but will be the optimum choice for the specific situation under consideration.)

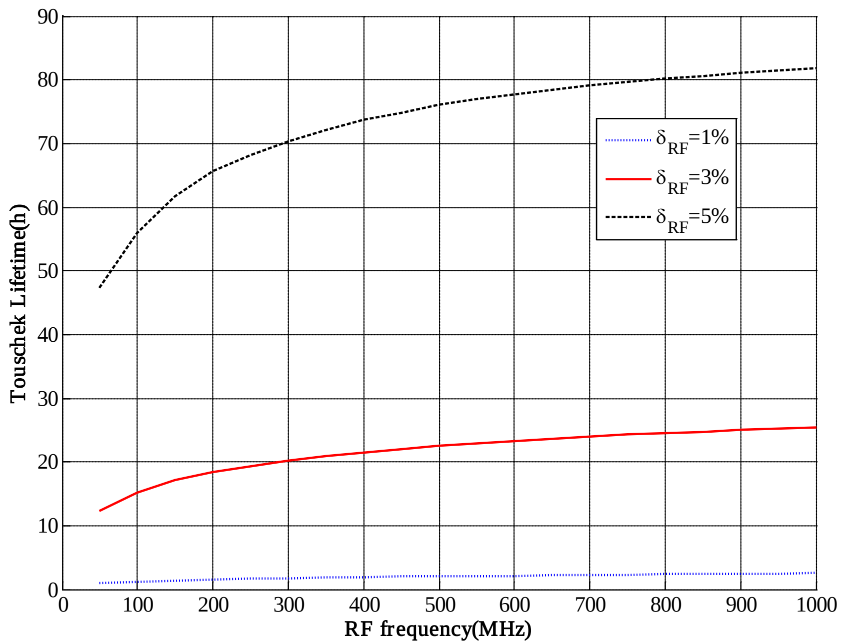
- Effects of RF frequency
  - Machine and beam parameters
  - RF system parameters
  - RF system components
    - Cavity
    - LLRF
    - Amplifier

6. RF frequency selection (cont.)

- Effects of RF frequency
  - Machine and beam parameters
    - RF voltage for 3% acceptance

      f⇩ , required RF voltage ⇩





- Touschek lifetime for a specific acceptance

  Not much dependent to frequency

6. RF frequency selection (cont.)

- Effects of RF frequency
  - Machine and beam parameters
    - Bunch length

      f⇩ , bunch length⇧

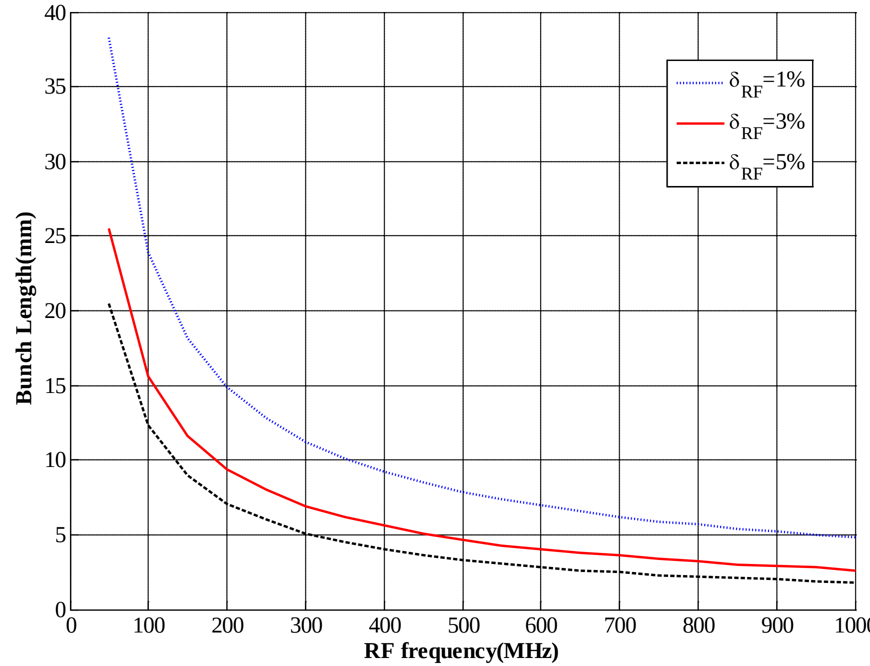
      4.7mm @ 500MHz

      15.6mm @ 100MHz

  - photon pulse width ⇧

    16psec @ 500MHz

    52psec @ 100MHz



Users need short pulse width for some time-resolved measurements. (can be also done in FEL laboratories.)

But that time resolution is in the order of 10fsec-1psec which cannot be produced by any of cases and micro-bunching or beam slicing methods should be used in both cases.

Thus, it seems the change of RF frequency won't affect users side.

6. RF frequency selection (cont.)

- Effects of RF frequency
  - Machine and beam parameters
    - Bunch length

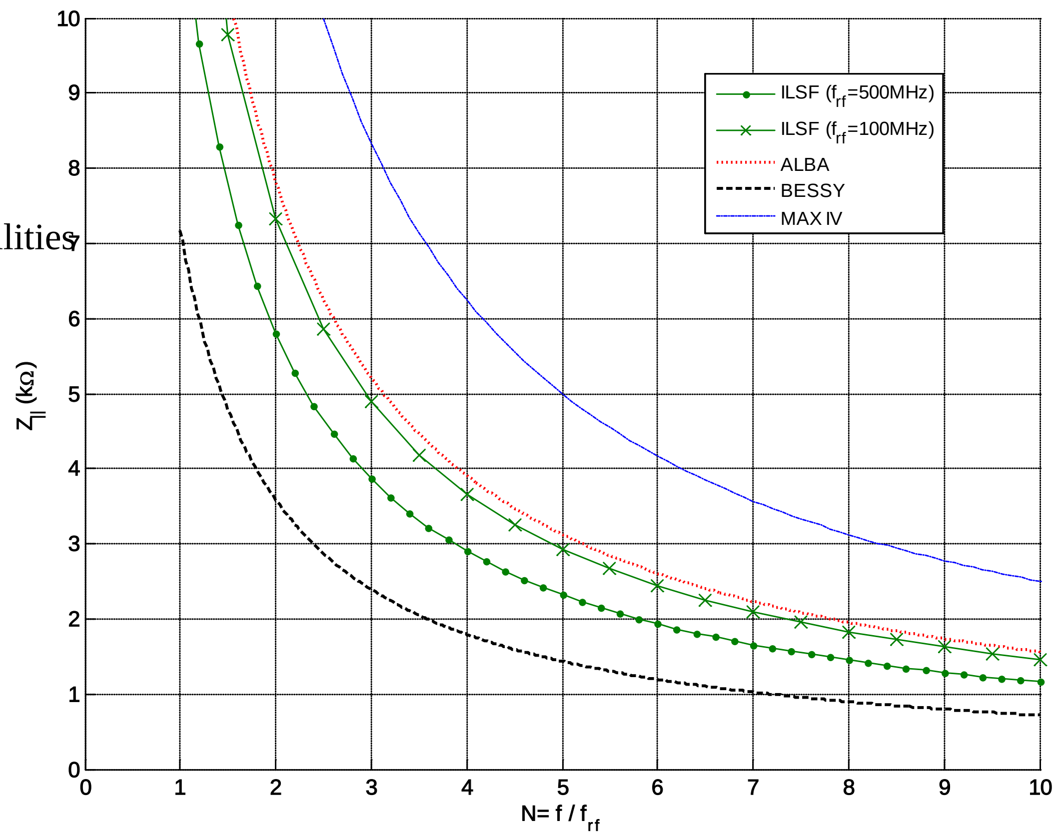
      f⇩ , bunch length⇧

      – Single bunch instability ⇩

    - Less buckets

      ⇒ higher threshold for beam instabilities

      ⇒ Less HOMs must be damped



6. RF frequency selection (cont.)

- Effects of RF frequency
  - RF system parameters
    - Storage ring RF parameters for
      - Beam power=560kW
      - 3% acceptance

Parameters	500 MHz based on EU cavity	100 MHz based on MAX cavity
Total RF voltage (MV)	3.5	2
Harmonic number	496	92
RF Voltage/cavity (kV)	588	286
Number of cavities	6	7
Cavity Insertion length	0.5 m	0.5 m
Cavity Insertion height (m)	1.6	0.9
HOM damping	√	√
Shunt Impedance (MΩ)	3.3	1.6
RF power/cavity (kW)	146 = (52+94)	106= (26+80)
Amplifier Power (kW)	161	117
Transmission Line	Waveguide	Coaxial line
Total RF power (kW) including 10% transfer loss	966	819
SR tunnel space	3 short straight sections	4 short straight sections

6. RF frequency selection (cont.)

- Effects of RF frequency
  - RF system parameters
    - Booster RF parameters
    @ extraction for
      - Max beam current 10mA
      - 0.7% acceptance @ extraction

Parameters	500 MHz based on 7cell Petra	100 MHz based on MAX cavity
Total RF voltage (MV)	1.454	0.99
RF Voltage/cavity (kV)	1.454	247
Number of cavities	1	4
Cavity Insertion length	0.5 m	0.5 m
Shunt Impedance (MΩ)	23	1.6
RF power/cavity (kW)	54 = (46+8)	27= (19+8)
Amplifier Power (kW)	59	30
Transmission Line	Waveguide	Coaxial line
Total max RF power (kW) including 10% transfer loss	59	120

6. RF frequency selection (cont.)

- Effects of RF frequency
  - RF system components (Availability / fabrication feasibility)
    - Cavity
      - More simple structure of MAX IV 100MHz cavity
      - Availability of dimension => easier to start the design
      - Possibility of fabrication in Iran ⇧
        - Wider tolerance range
        - No Ferrite absorbers, vacuum brazing are required
        - Electron beam welding instead of vacuum brazing
      - Better HOMs condition
        - First cavity HOM @4f0 instead of 1.4f0
      - Higher instability thresholds @ 100MHz => less damping is required
      - Less power on cavity, easier to handle
      - Lower cost due to less complicated fabrication process and absence of ferrite absorbers
      - Only one option for procurement in 100MHz
    - LLRF system
      - No difference @ 100MHz and 500MHz
      - Only the up/down converters and RF filters must be changed.

6. RF frequency selection (cont.)

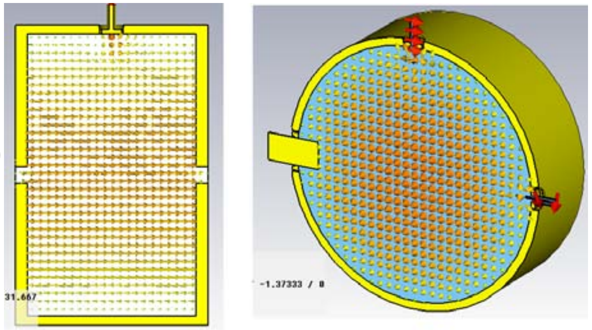
- Effects of RF frequency
  - RF system components (Availability / fabrication feasibility)
    - Solid State Amplifier
      - Higher power @ module output (around 1kW)
      - Lower price in some module components but higher in combiners fabrications
      - No appropriate circulator is available at this frequency and power
        - » Dimension of the only one exists : 19cm*19cm*8cm .
        - » Without circulator, the combiners should have isolation which is complicated to develop. Needs R&D.
      - Bulky combiners => bulky towers. Current configuration cannot be used. New design idea is needed!
      - There is no implemented system with this power @ 100MHz. But 10kW amplifiers are available => combining existing amplifiers is a better solution.
    - Tetrode
      - Applications: Military and FM transmitter (power range of 10-20kW), particle accelerators (>60kW)
      - Procurement might be not easy/possible due to political situation.
      - High power circulator is needed which cannot be easily procured.
      - Similar system (100kW tetrode with 10kW SSA driver @ 100MHz) is available inYazd.

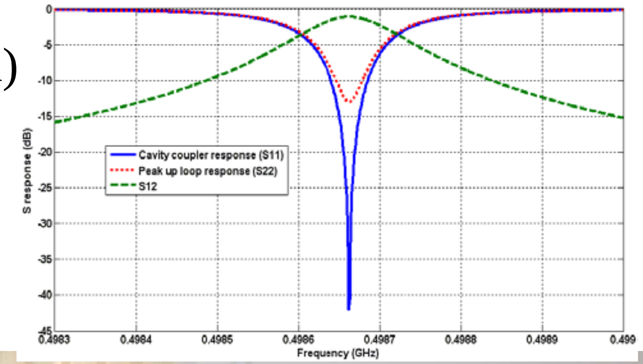
6. RF frequency selection (cont.)

- So far at ILSF
  - 500MHz was selected as RF frequency
    - Being used in most of the 3rd generation synchrotron light sources
    - Utilizing the experience of other light sources
    - Availability of several HOM damped cavities (several options => lower cost)
    - R&D in solid state amplifier fabrication
    - Short pulses (bunch length) requirements for some users' applications
- But now 100MHz is under exploration due to some practical concerns in procurement and fabrication feasibility.

7. Review of ILSF RF prototypes

- Cavity
  - 500MHz AL cavity (designed, fabricated and tested)
    - Useful for Cavity low power test, LLRF test
    - Will be discussed in next presentation
  - 100MHz NC cavity (under design and investigation)



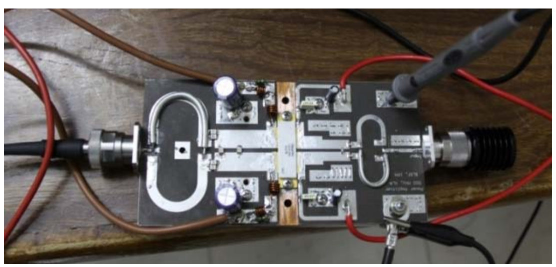


- Suitable Software for Cavity design:
  - 2D: Superfish
  - 3D: Electromagnetic Software:
    - CST (or Mafia)
    - HFSS

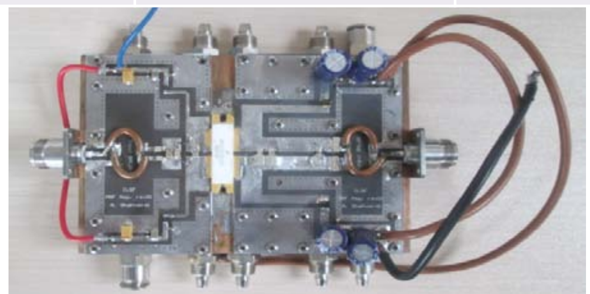
7. Review of ILSF RF prototypes (cont.)

- RF Amplifier
  - Solid State Amplifier is selected as a power source
  - 3 amplifier modules with different transistors are designed, fabricated and tested

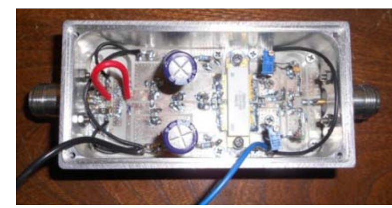
Transistor (UA)	BLF578	NXP Semiconductor	LDMOS, 10-500MHz, 1000W
	MRFE6VP1K25HR6	Freescale	1.8-600MHz, 1000W
	BLF888	NXP Semiconductor	470-860MHz, 600W



Module 1: using BLF578
Gain=17.8dB
Power =660w



Module 2: using MRFE6VP1K25HR6
Gain=18.4dB
Power=700W

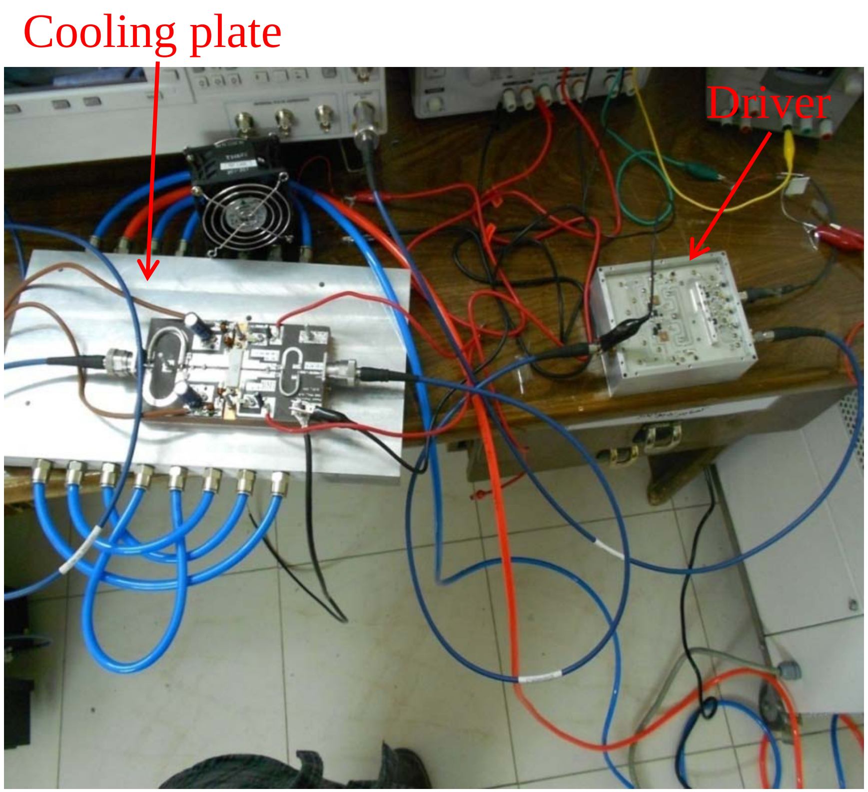


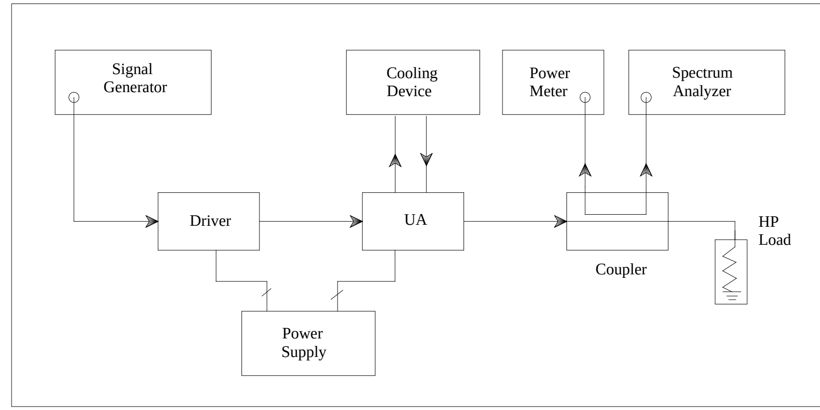
Module 3: using BLF888
Gain=20dB
Power =450w

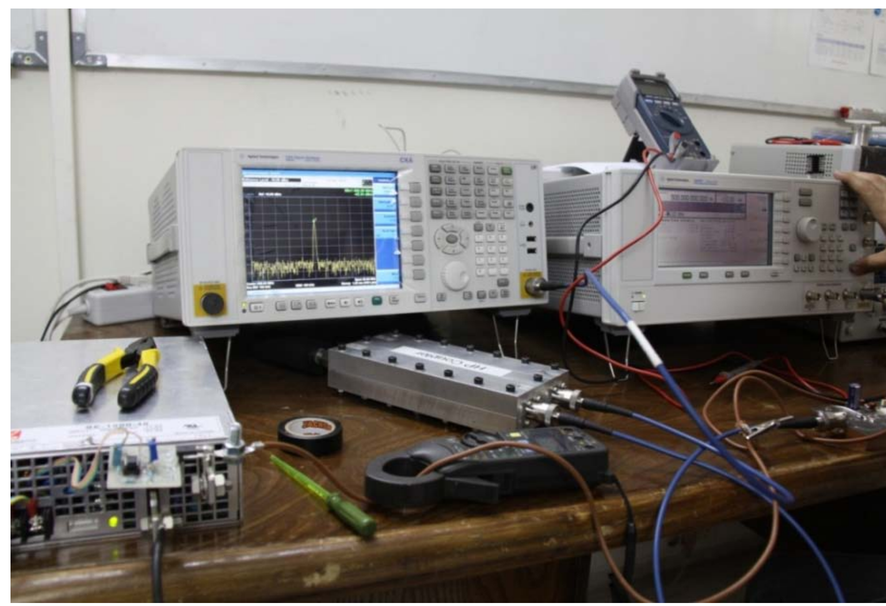
  - Suitable Software for transistor amplifier design:
    - ADS (Agilent Advanced Design System)
    - AWR Microwave office

7. Review of ILSF RF prototypes (cont.)

- RF Amplifier
  - Module under test

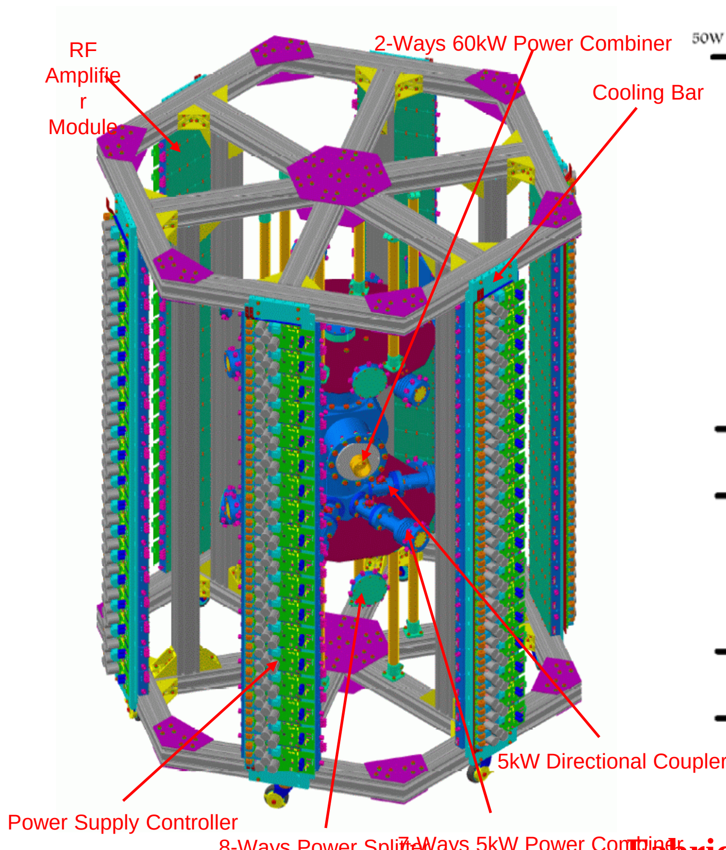


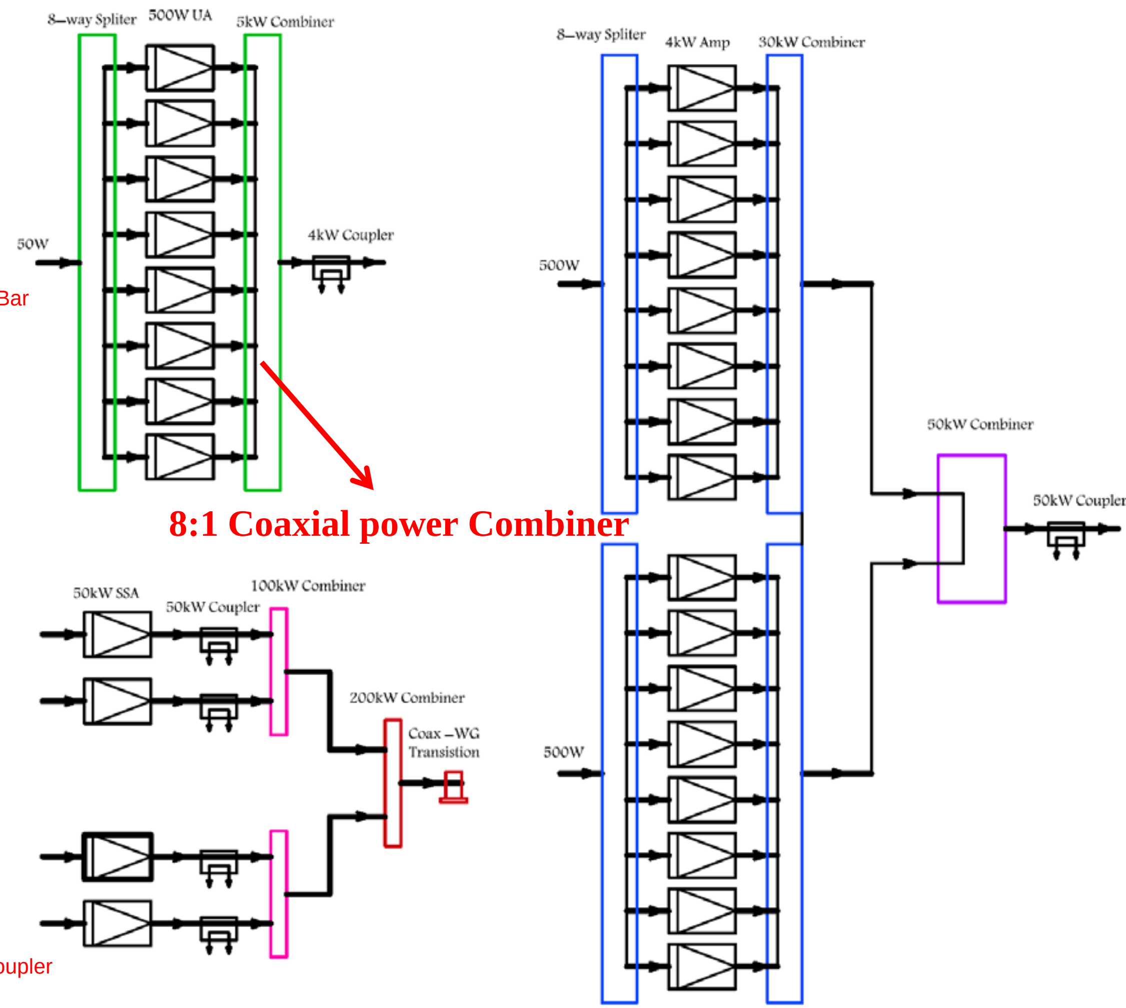




7. Review of ILSF RF prototypes (cont.)

- RF Amplifier
  - Combining network

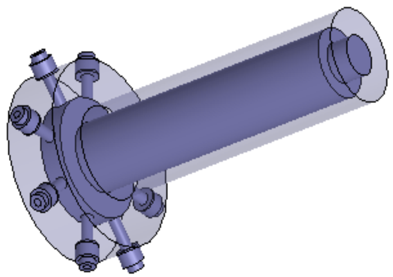


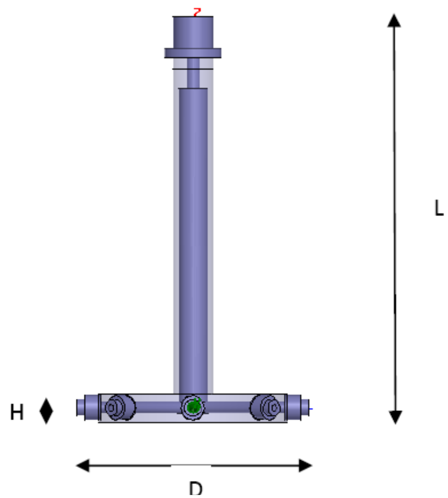


Fabrication of 4kW amplifier based on BLF578 is under progress

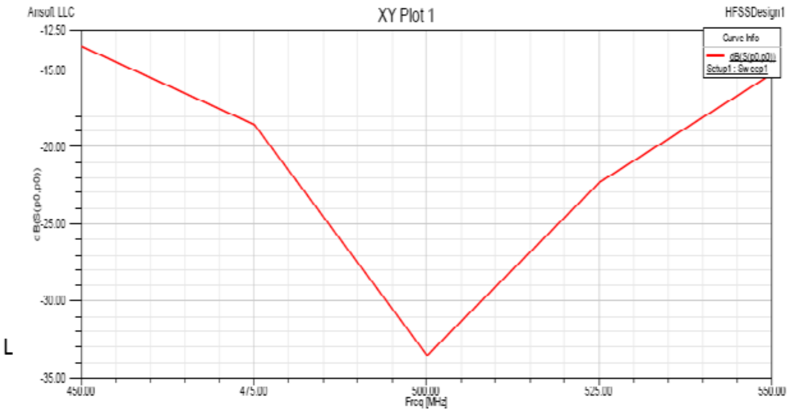
7. Review of ILSF RF prototypes (cont.)

- RF Amplifier
  - 8-1 combiner

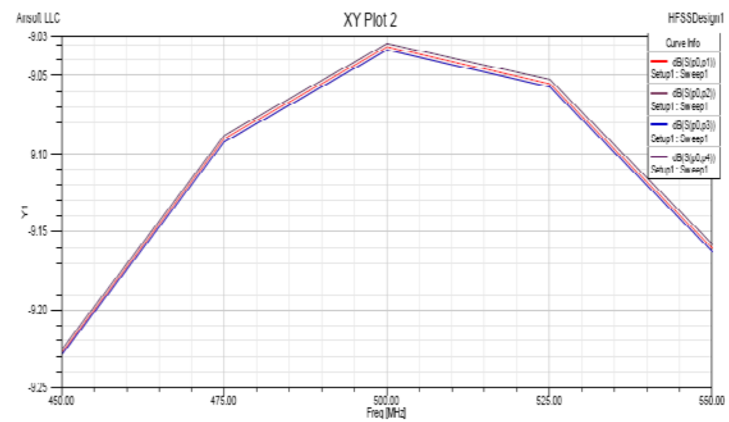




H	L	D	S_{11}	S_{1n}	Isolation (MIN)
12mm	161mm	95mm	-33 dB	0.04 dB	16 dB



Return loss

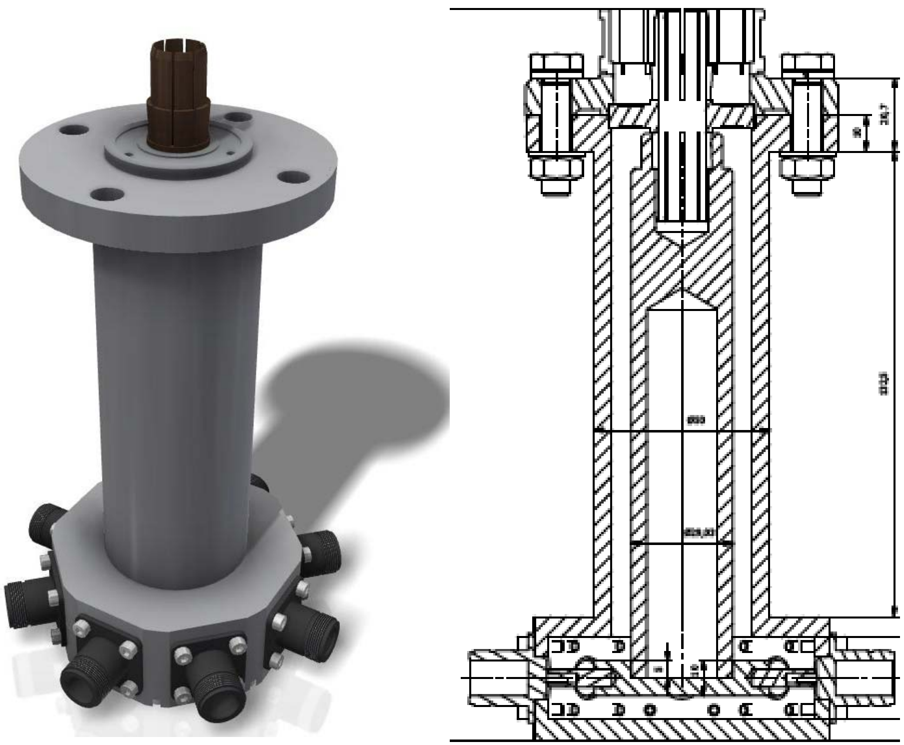


Insertion Loss

- Suitable Software for divider/combiner design
  - HFSS
  - CST

7. Review of ILSF RF prototypes (cont.)

- RF Amplifier
  - 8-1 combiner



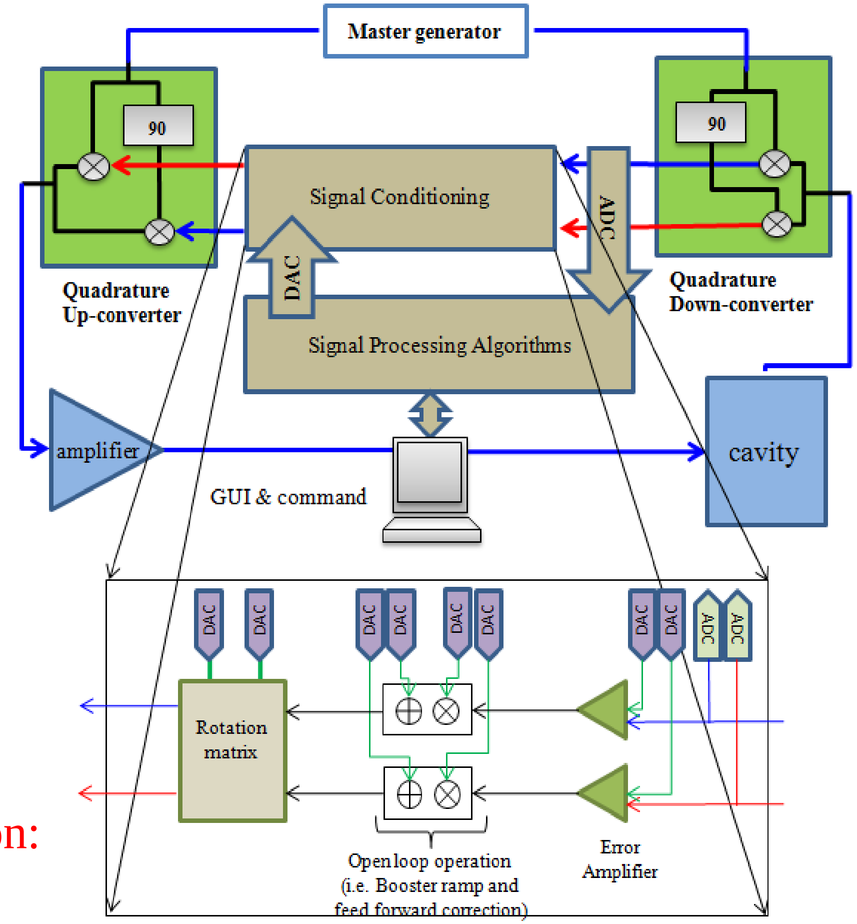
1st version of mechanical design

Fabricated combiner

-Cooling blades are added for about 200W dissipated power

7. Review of ILSF RF prototypes (cont.)

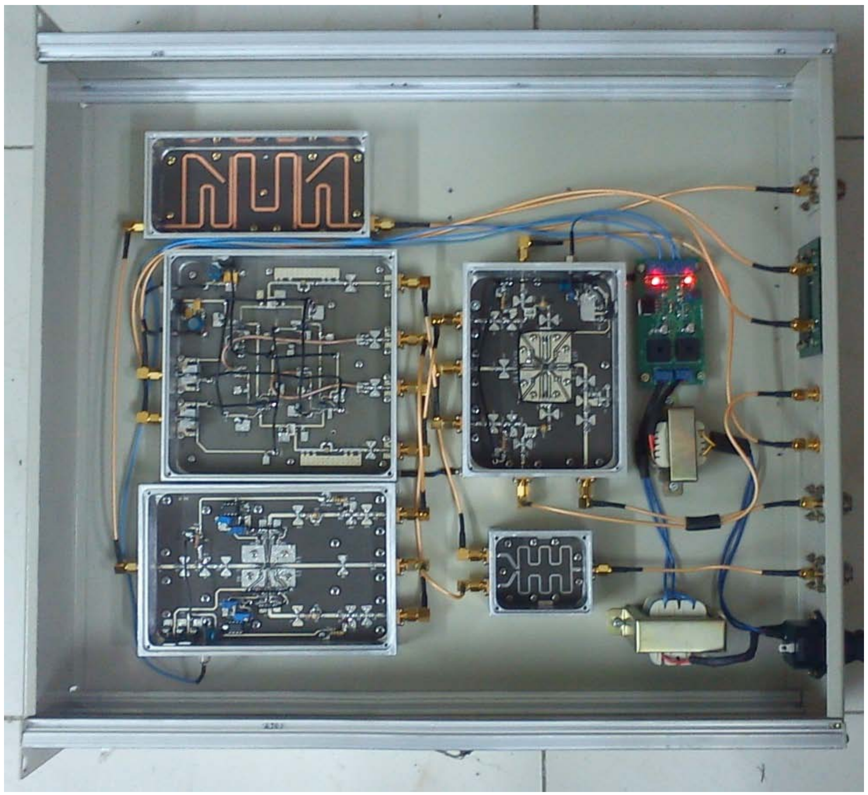
- Semi-digital prototype
  - IF frequency= 30MHz



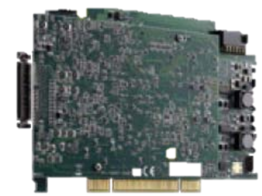
  - Suitable Software for RF control circuits:
    - ADS (Agilent Advanced Design System)
  - Suitable Software for PCB preparation:
    - Protel or DXP

7. Review of ILSF RF prototypes (cont.)

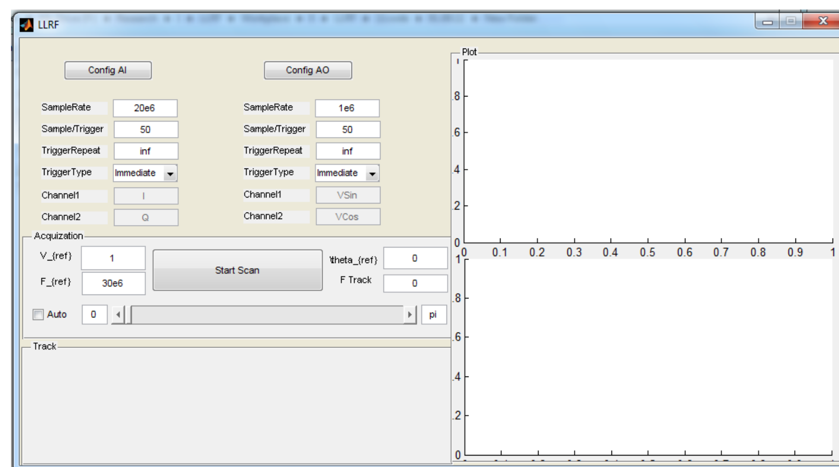
Analog Sections



Digital Sections

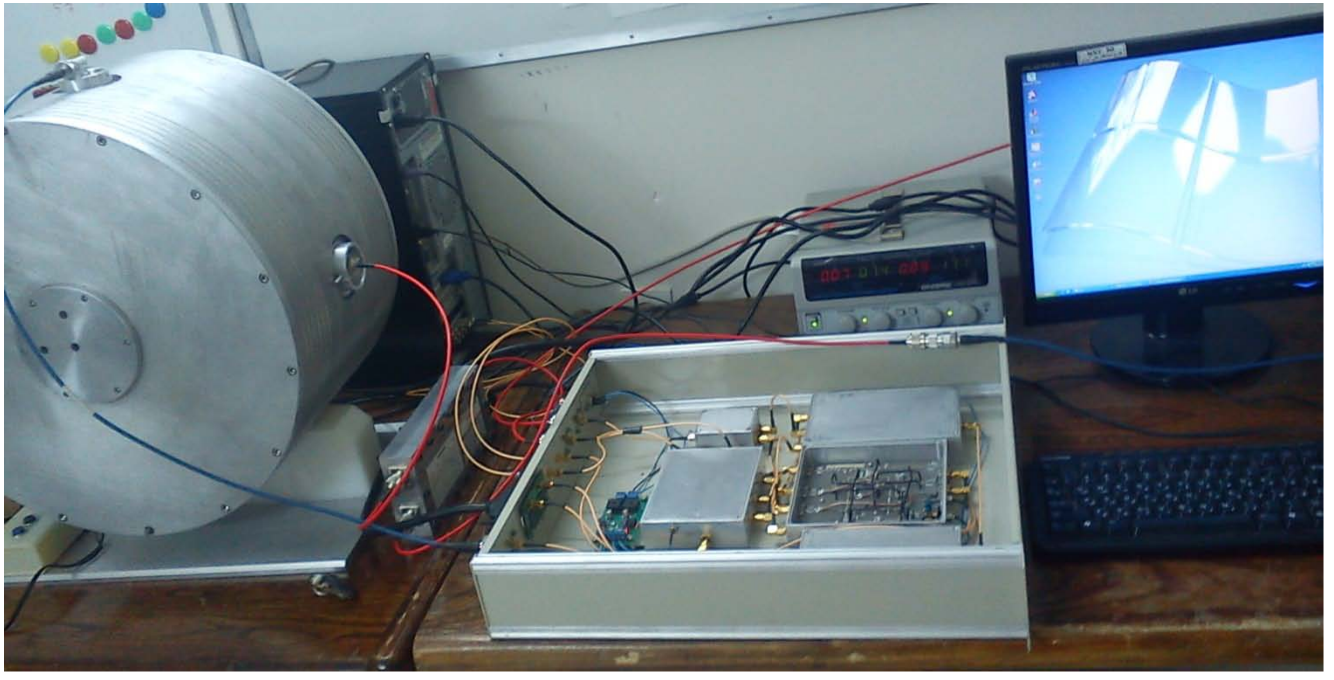


Software



7. Review of ILSF RF prototypes (cont.)

- The primary tests show that the LLF system is able to stabilize the phase and amplitude of the resonant field of the cavity
- Currently, we are developing more sophisticated controlling algorithms and finalizing test and operation routine of the LLRF system

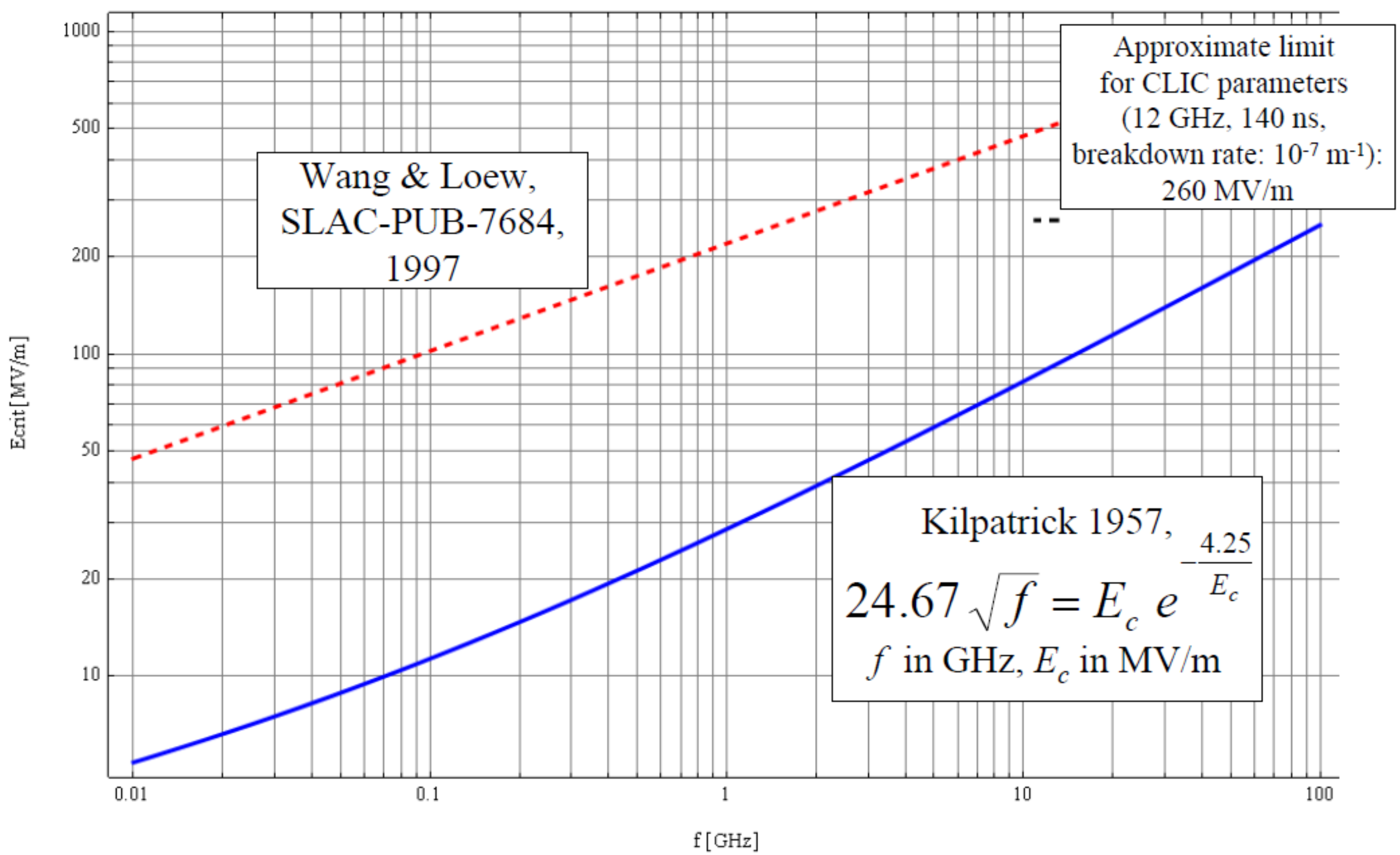


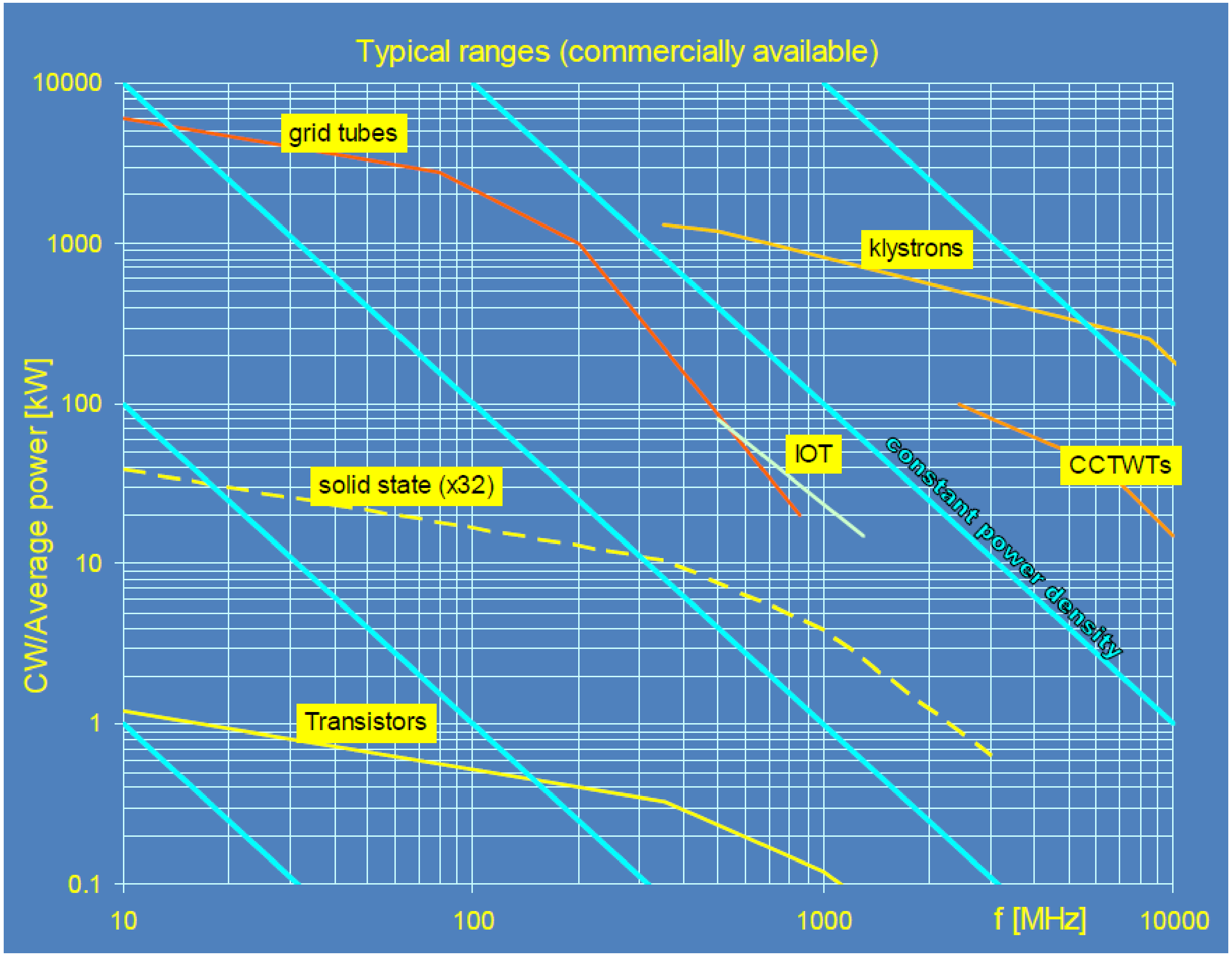
Thanks for your attention

Backup Slides

Another reason for RF: breakdown limit

surface field, in vacuum,Cu surface, room temperature





Typical ranges (commercially available)
10000
1000
100
10
1
0.1
CW/Average power [kW]
10
100
1000
f [MHz]
10000
grid tubes
klystrons
IOT
CCTWTs
constant power density
solid state (x32)
Transistors