INSTRUMENTATION
TECHNOLOGIES

LIBERA

Low-Level Radio Frequency for Medical Acclerators

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July 18^{th}, 2024

WWW.I-TECH.SI

Outline:

- Introduction to Instrumentation Technologies
- Cancer Therapy Introduction
- Hadron Accelerators
- Introduction to Low Level Radio Frequency
- LLRF Specifications
- LIBERA LLRF
- X-Band and it's challenges

INSTRUMENTATION TECHNOLOGIES

Est. 1998

~50 employees

ISO 9001:2015 certified ISO

Headquartered in Solkan, Slovenia

Company Business Units

INSTRUMENTATION TECHNOLOGIES

LIBERA

SOLUTIONS FOR INDUSTRIES

redpitaya

Beam-diagnostics-and-control instrumentation

- Particle Accelerators
- Nuclear Research Reactors
- Nuclear Fusion

Custom data-acquisition products

- Transportation Industry
- Energy Industry
- Test and Measurement

Open-source general-purpose lab devices

- Universities
- Research
- Industry

> 6,000 instruments sold
to **> 80 laboratories** worldwide

Asia
Bhabha Atomic Research Center
Chinan Biomedical Technology
HiSOR
HUST
IBS—RISP
IHEP—BEPC II, ADS, CSNS
IMP-CAS—C-ADS, LEAF, SSC-LINAC, CSR, HIRFL
IMS—UVSOR
Inter University Accelerator Centre
ISSP
KEK—PF, PF-AR, LINAC, SUPER B, J-PARC, cERL
Nagoya University—Aichi Synchrotron
NewRT Medical Systems
NSRRC—TLS, TPS
PAL—PLS II, XFEL ITF
Peking University
RRCAT—INDUS, INDUS II
SACLA—SPring-8
SINAP—SSRF
SJTU
SLRI
Tokamak Energy
Tsinghua University
USTC, NSRL—HLS, HLSII

Australia
Australian Synchrotron

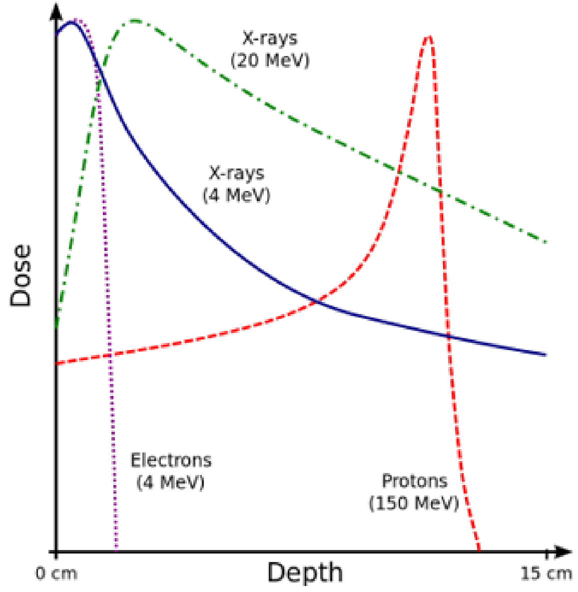
Europe
AVO-ADAM—LIGHT
CANDLE
CEA
CELLS—ALBA
CERN
CNAO
DESY—PETRA III, FLASH, DESY XFEL, DORIS III
Diamond Light Source
ELI - Extreme Light Infrastructure
ESRF—ESRF-EBS
Forschungszentrum Jülich—COSY
Fritz Haber Institute of the MPS
GANIL
GSI—FAIR
Helmholtz-Zentrum Berlin BESSY II
Helmholtz-Zentrum Dresden-Rossendorf —ELBE
IBPT—KARA
IJS
INFN—Daphne, ELI-NP, SPARC
IPNO
ISA—ASTRID II
Jagiellonian University—SOLARIS
JINR—NICA
LAL—THOM-X
Lund University—MAX III, MAX IV
MedAustron
Physics Institute of the University of Bonn
PSI—SLS, SwissFEL
Research Instruments
RRC Kurchatov Institute—SIBERIA II
ScandiNova
SCK-CEN
SDU—TARLA
SESAME
Sincrotrone Trieste—Elettra, FERMI
SOLEIL Synchrotron
STFC ASTeC—EMMA, CLARA
University of Twente

North America
ANL—APS, APS-U
Best Medical International
BNL—ERL, NSLS II, X-RAY ring
Canadian Light Source, CLS
Cornell University—CHESS, CESR
Idaho National Laboratory
LANL—LANSCE
LBNL—ALS
Michigan State University—FRIB
Northwestern University
NUSANO
Oak Ridge National Laboratory
RadiaBeam
SLAC—LCLS, SPEAR

South America
ABTLuS—LNLS

Radiation therapy

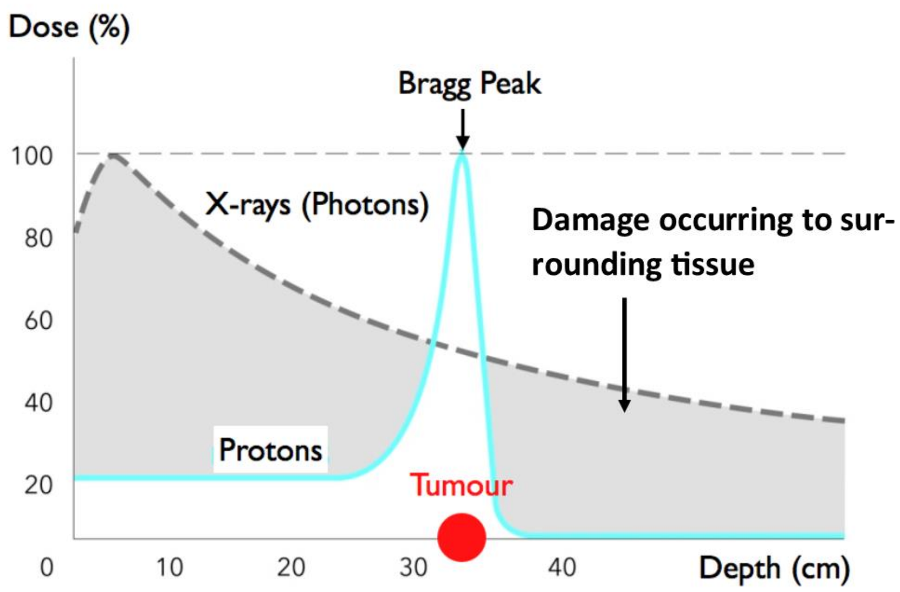
- ❑ Cancer treatment through ionizing radiation is acting on cancer cells DNA.
- ❑ Radiation therapy methods:
  - Electrons:
    Limited effects on surface
  - Photons (x-rays):
    Spread among different depths
  - Protons (or heavy ions, e.g. carbon):
    - ➢ Very focused with depth (Bragg peak).
    - ➢ Penetrate deeply (depth depends on beam energy).



Particle Therapy advantages

- High energy protons are applied to tumor tissue.
- Proton energy is increased through particle accelerators.

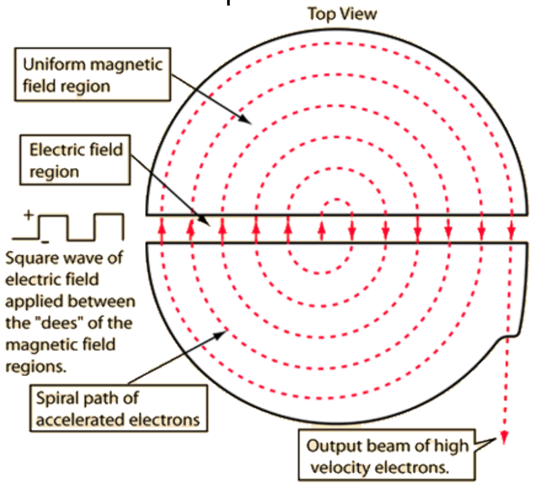
- Proton therapy advantages:
  - ✓ Radiation dose selectively deposited at beam energy dependent depth (70 MeV to 250 MeV).
  - ✓ Beam transversally more focused, less scattering (protons are heavy).
  - ✓ Protons reach tumors deeply in the body.
  - ✓ Minimized side-effects on surrounding tissue.



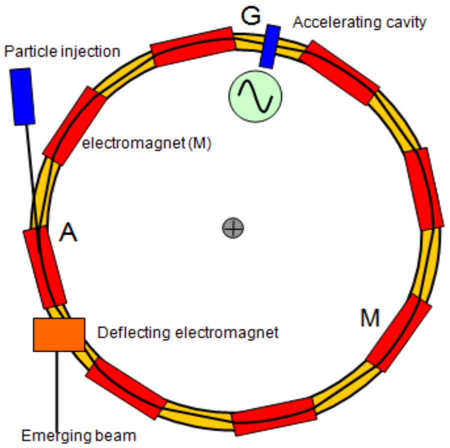
Hadron accelerators

Protons are accelerated by applying electro-magnetic field within RF cavities or dees.

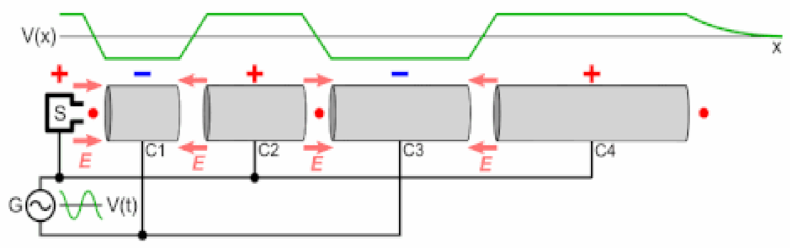
- Circular machines: cyclotrons and synchrotrons
  - beam energy is increased over many cycles and require accelerating RF frequency and deflecting magnetic field to be corrected accordingly. Cyclotron extract at full energy; degrader are used to reduce it. (radiation issues)
  - RF frequency ramping process may have implication on cavity tuning and transverse beam position control
- Linear machines: LINACs
  - More flexible in controlling beam energy and less complex to control
  - Dynamic control of beam energy (tracking patient movement)
  - More efficient as protons are accelerated to the required energy



Cyclotron



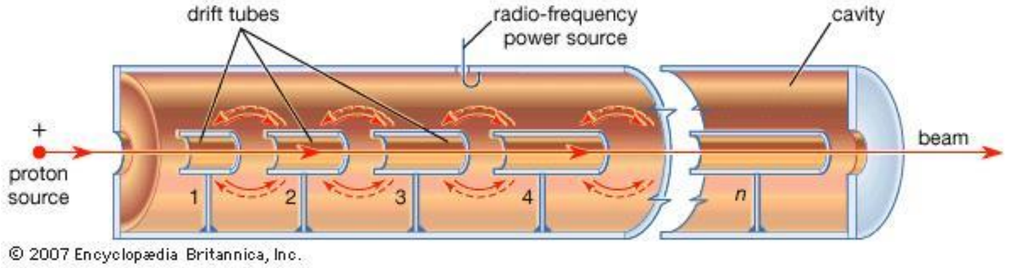
Synchrotron



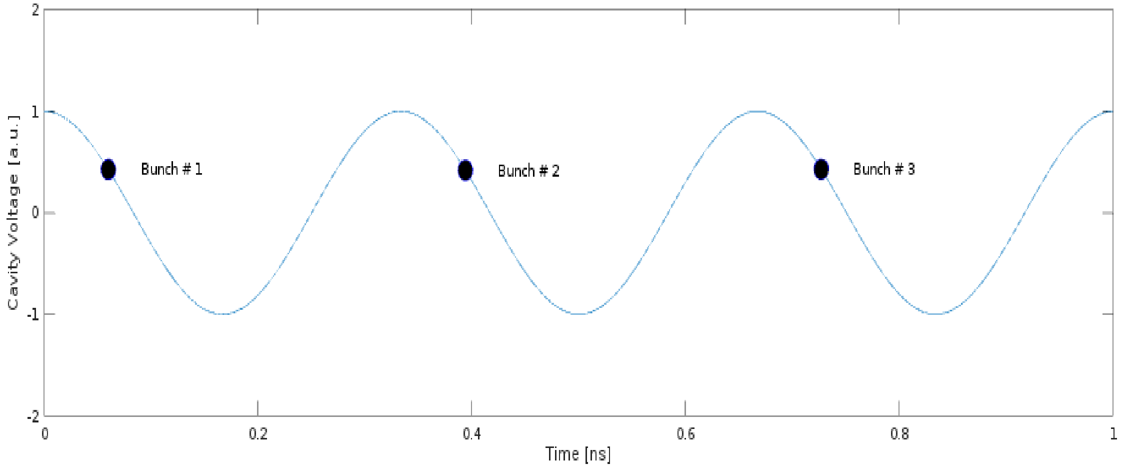
LINAC

Proton acceleration

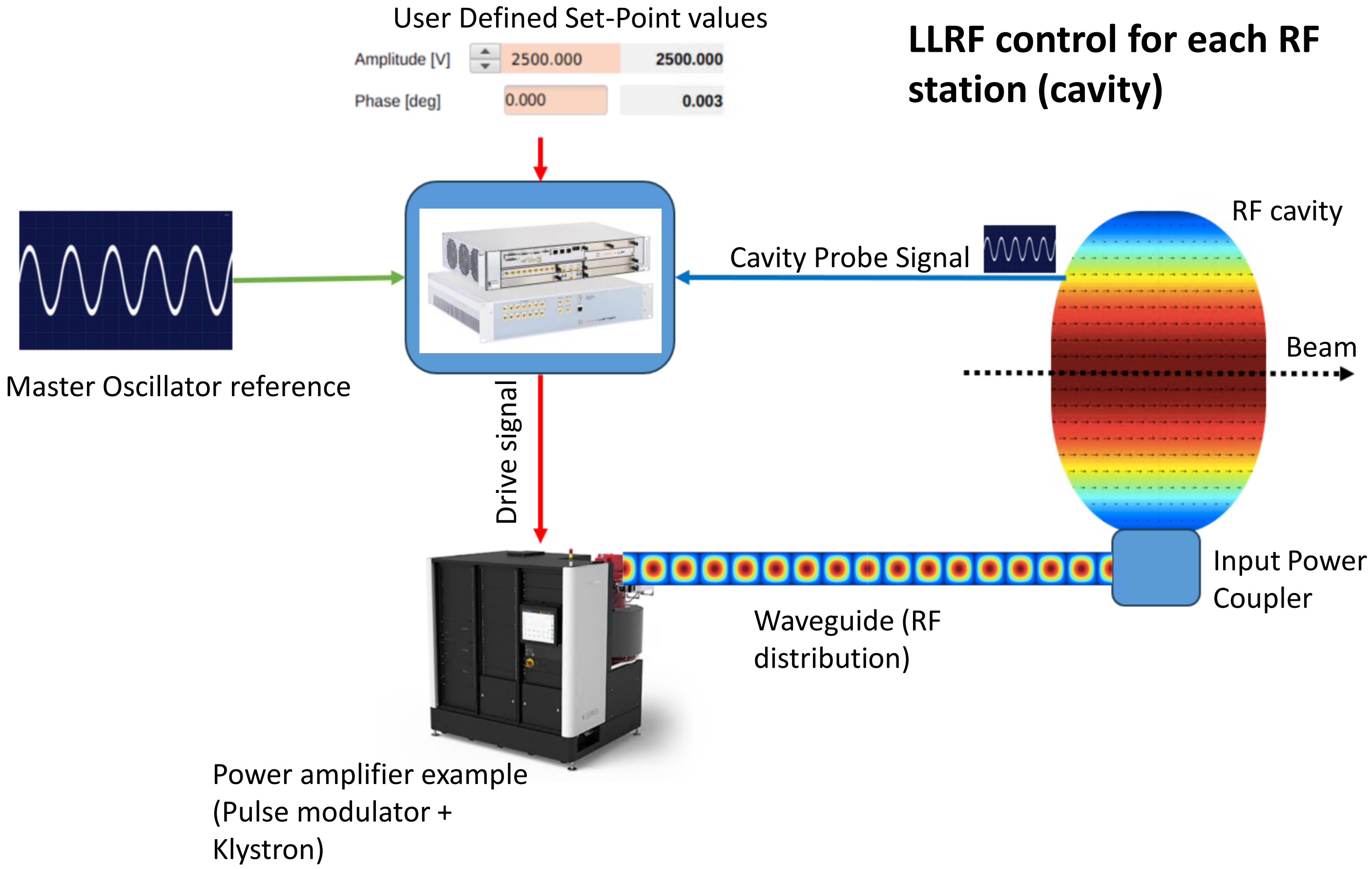
- Precise synchronization RF cavity field vs. Beam
- Cascaded RF stations: beam dynamics effects may spoil beam quality
- Sources of errors:
  - High power amplifier response
  - Cavity resonant frequency drifts (thermal expansion)
  - Amplifier working point (beam energy modulation)



There is the need to actively control cavity field amplitude and phase!

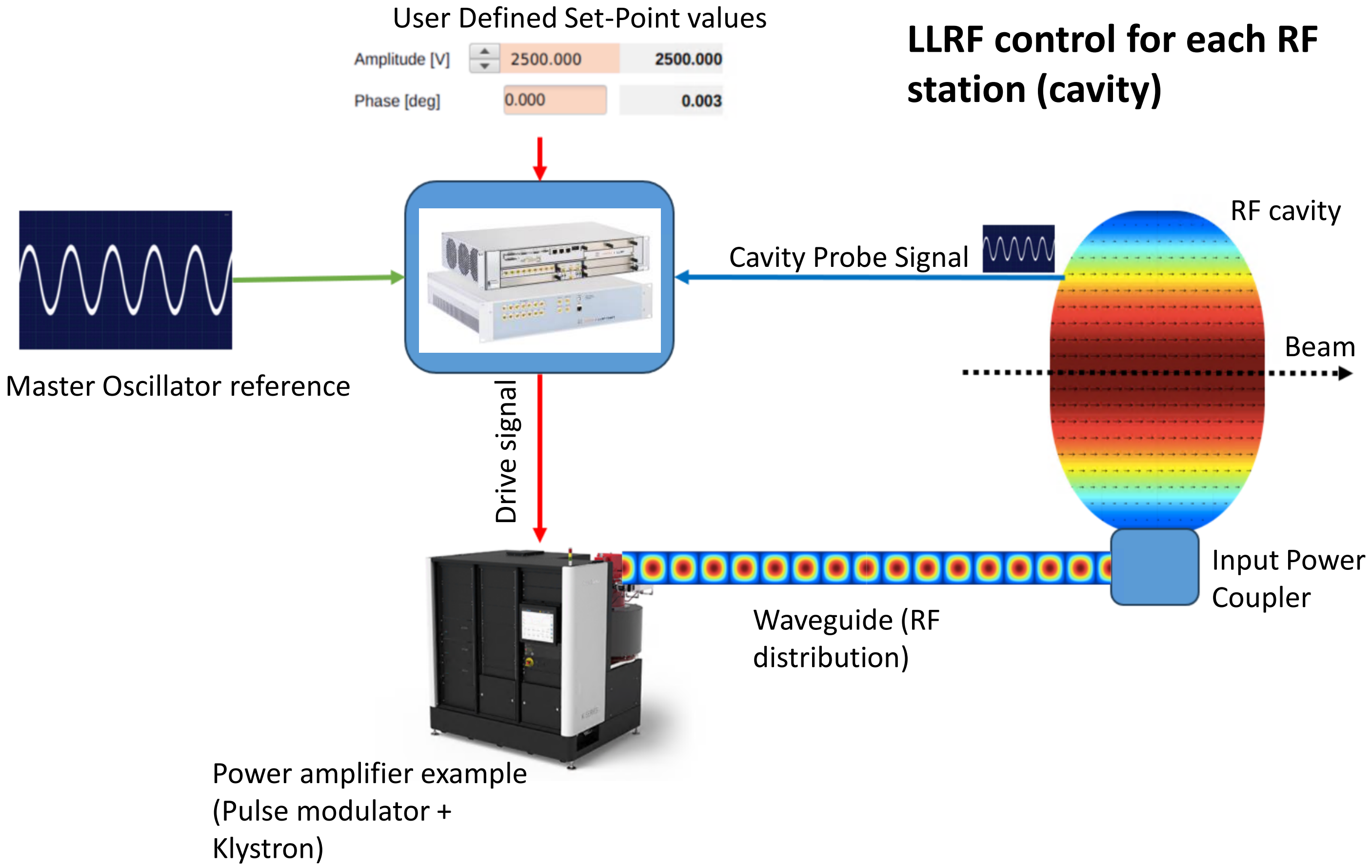


Introduction to Low Level Radio Frequency (I)



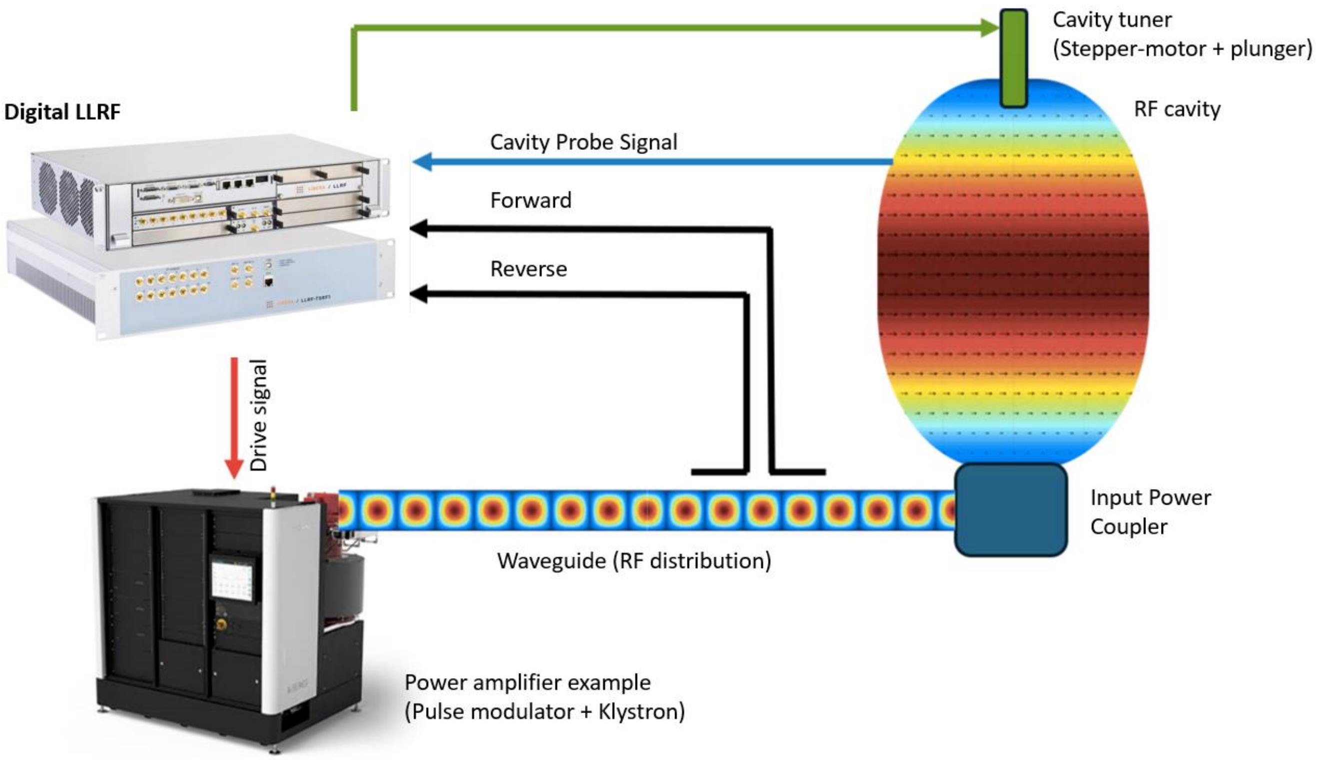
- Subsystem of Radio Frequency (RF) system.
- Maintain the stability and control of frequency, phase and amplitude.
- LLRF starts by measuring the characteristics of the RF signal. Detectors sample the amplitude and phase of the signal.
- The measured signal is then compared to a reference signal.

Introduction to Low Level Radio Frequency (II)



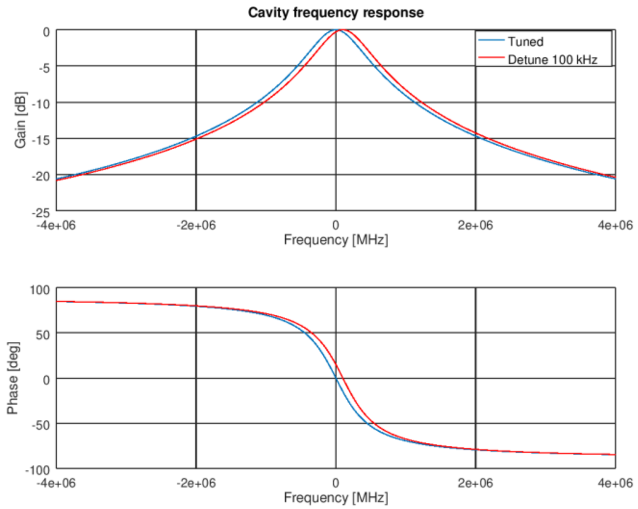
- Deviation between the measured signal and the reference compensated by feedback control system.
- This system brings the signal back into alignment with the reference.
- This feedback loop is continuous and rapid, to ensure the RF signal stays within the desired parameters.
- Operates in real time with sub-microsecond response times.

Introduction to Low Level Radio Frequency (III)

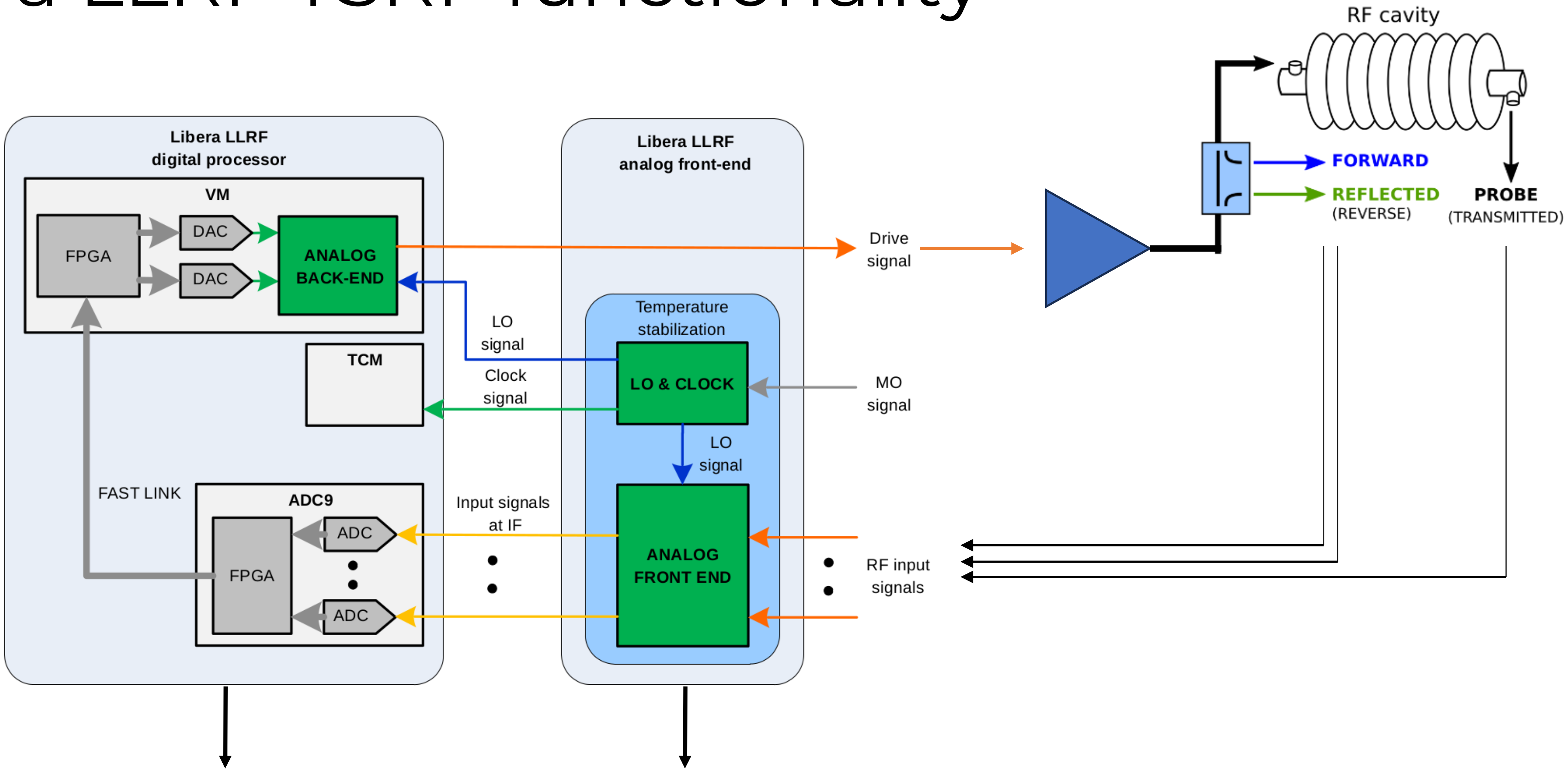


LLRF system purpose (continued):

- Measure the cavity resonant frequency and control the cavity tuning
- Trigger the machine protection system in case of unexpected signals in the cavity or in the RF distribution.



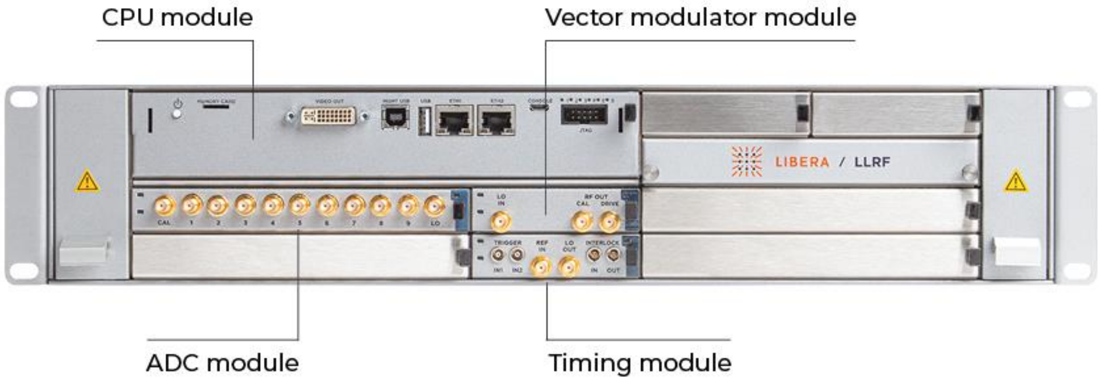
Libera LLRF TSRF functionality

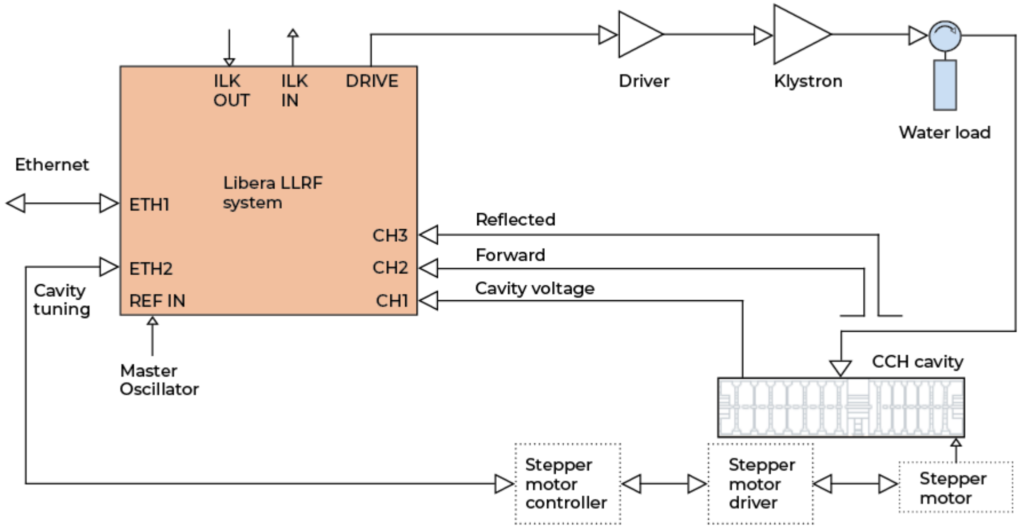


Important LLRF specifications

Physical interfaces:

- Number of RF inputs (8 or 16 or more) and expected signal levels
- Number of RF outputs (1 or 2) and signal levels
- Specific trigger signals (RF pulse, Beam pulse, Modulator signals)
- Machine Protection System interfaces (Interlock)





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- Machine Protection System interfaces (Interlock)

Machine specifications:
- RF frequency
- Type of cavity (NC, SC)
- Pulsed (pulse duration, injection frequency) vs CW
- Cavity tuning requirements
- Control system interface

RF Frequency band	Frequency range
L-band	1-2 GHz
S-band	2-4 GHz
C-band	4-8 GHz
X-band	8-12 GHz

The higher the frequency, the smaller is the size of the RF components and RF structures **-> more compact machines**!

Important LLRF specifications

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Machine specifications:
- RF frequency
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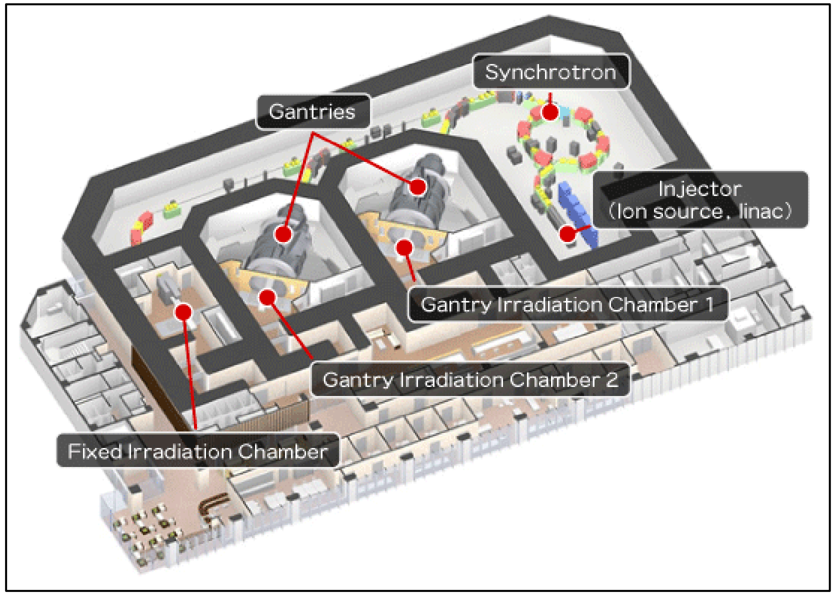
Performance specifications:
- Front-end and Back-end: Bandwidth, sampling rate, added noise
- Short term amplitude and phase stability
- Long term amplitude and phase stability

CNAO
Centro Nazionale di Adroterapia Oncologica

MedAustron

ADAM
an ADVANCED ONCOTHERAPY company

NUSANO



X-Band Low Level Radio Frequency

- Development of accelerator technology at higher frequencies up to X-Band allows high accelerating gradients [MV/m] and shorter accelerating structures (compact machines).
- Easier to install in Medical facilities (eg:- hospitals).
- Challenge of controlling RF parameters (amplitude and phase) at high frequencies and for very short pulses (100ns).
- LLRF system stability influenced by temperature drifts at higher RF frequencies.
- Instrumentation Technoloiges is currently developing a commericial LLRF system working in X-band.

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