Lecture course: RF technology for fundamental physics

MicroWaves (MW) and Radio Frequency (RF) Technology were the breakthrough of modern particle physics in the 20th century, by realising particle accelerators for direct discovery of new physics (quarks, leptons, vector bosons and the Higgs boson) and RF spectroscopy for precision tests of Quantum ElectroDynamics (QED; Lamb shift, g-2, etc). Until very recently, the MW/RF community have been somewhat decoupled from the other domains of particle physics due to its distinct technical requirement and infrastructure to pursue MW/RF experiments. However, emergence of new research fields in physics beyond the colliders has opened new opportunities in MW/RF technology for fundamental physics, such as Cosmic Microwave Background (CMB), Gravitational Waves (GW), and in particular, dark matter axion and dark photon physics. This school aims to provide basic knowledge and skills for the students and early-career researchers to be able to follow the language spoken in this new research field based on MW/RF engineering.

The school will cover practical aspects of solving Maxwell equations beyond what students in physics department typically learn in the bachelor education, including non-plain wave solutions, resonant cavities, numerical methods, calibration methods, mean to measure electromagnetic fields, engineering devices and convention to express MW/RF as complex fields. We will particularly focus on the applications of MW/RF technology for the fundamental physics, such as axion experiments and brief introduction to particle accelerators. The student will follow lectures, theoretical exercises, hands-on experiments, and playing with commercial codes typically used in the MW/RF community.

[Prerequisite to the students]

- Passion to learn new things
- Basic knowledge on classical electrodynamics (Maxwell equation and vector analysis)
- Basic knowledge on complex analysis and Fourier transform
- Basic skill in plotting data in some program language (python, julia, C++, ROOT, MATLAB, etc)

[Lectures]

Lecture 0: Introduction

- New research field in the post-LHC era: particle physics with microwaves
- How can a researcher with particle physics background learn microwaves? Physics vs Engineering
- Narrative of Akira Miyazaki from quantum electrodynamics to superconducting radiofrequency

Lecture 1: RF in free space

- From Maxwell equation to the Helmholtz equation
- Gaussian beam: eigenmode of free space propagation
- Integral form and Fourier transform

Lecture 2: RF in confined space

- Material and boundary conditions
- Waveguide modes and coaxial lines
- Resonators

Lecture 3: Equivalent circuit

- From (E, B) to (V, I) in a circuit model
- Transmission line theory

- Circuit representation of resonators

Lecture 4: Basic of RF measurement

- Analog and digital circuits
- Our weapons
- RF noise

Lecture 5: RF Applications for various physics fields

- Particle accelerator
- Axion experiments
- Gravitation waves
- Cosmic microwave background

[Hands-on]

Hands-on 1: RF simulation in COMSOL

- RF cavity modeling
- Electromagnetic field distributions
- RF ports and S-parameters
- Antenna modeling

Hands-on 2: RF measurement with Vector Network Analyzer

- Short / Open / Load / Through 2-ports calibration
- S21 to Q_L
- Coupling from S11
- Q0 and Qext
- Time domain analysis

Hands-on 3: Cavity field measurement with beads-pulling method and VNA

- Perturbation of beads to the RF fields
- Characterization of the field distribution along one beam axis
- Comparison to the simulated field distribution prepared in Hands-on 1
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Hands-on 4: RF measurement with Spectrum Analyzer

- Power spectral density
- Resolution bandwidth
- Low noise amplifier
- Y-factor calibration method

[Site visit]

We will visit ALPS-II for the Fabry-Pérot resonators and superconducting facility for RF cavities

	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	Lecture 1	Lecture 3	Hands-on 1/2	Hands-on 3/4	Site visit
afternoon	Lecture 2	Lecture 4	Hands-on 2/1	Hands-on 4/3	Lecture 5