PHY 693 (High Power RF Engineering)
Fall 2022

Syllabus

1. Instructor

Instructor: Jayant P. Parekh
jayant.parekh@stonybrook.edu
Light Eng. 225

2. Course Description

The course starts with an essential review of the properties of low and medium power RF waves and components including transmission lines, waveguides and cavities, and then proceeds to highlight the properties and limitations under high power RF conditions. The principal deleterious effects taking place at high power levels are caused by arcing (a high peak power effect) and the ohmic dissipation in the metal walls (a high average power effect). Exceeding the power handling capacity of the RF components can result in expensive repairs. Methods of mitigating or avoiding these expensive repairs are discussed. Important applications of high power rf are discussed in depth. Finally the students are given an extended project on implementing a particle accelerator using the traditional method of placing cylindrical cavities in tandem and using the longitudinal electric field in the TM_{010} cavity mode to pump RF power into a particle beam and cause the desired acceleration of the charge particles.

Full Course title: High Power RF Engineering
Course catalog # and section: ESE 593
Credit hours: 3
Contact hours: each class 1.5 hours, twice per week.
Semester: Fall semester, once in two years
General education designation(s) (SBC) (senior undergraduate and graduate): Graduate course
Prerequisites: A basic course in microwaves
Office hours: TBD
TA Information: N/A

3. Textbook

None. Class notes and references will be provided by the instructor

4. Course Learning Objectives

Upon completion of the course, students will have

- refreshed their background and learning of low and medium power RF waves and components;
- learnt about the important limitations of using RF components at high power levels, and methods of mitigating the deleterious arcing and ohmic dissipation overheating problems which cause expensive repairs;
- learnt about high-power RF amplifiers and oscillators
- learnt about important application of high power RF; and
- learnt about how high RF particle accelerators are implemented in practice

5. Topics

1. **ESSENTIAL REVIEW OF LOW AND MEDIUM POWER RF:**
   - Lorentz force equation, cyclotron motion of charged particles
   - Maxwell Equations, electromagnetic wave equation, uniform plane EM waves in dielectrics and conductors, power flow
   - Transmission lines (TLs): wave behavior of voltage and current on a TL arising from the distributed circuit nature of TLs, voltage reflection coefficient Γ, VSWR S, Smith Chart, impedance matching techniques. Derivation of time-average power flow in the TEM mode in a coaxial TL, and its dependence on the geometry of the TL and the peak or amplitude value of the electric field. High power handling capability of coaxial TLs and the limitations imposed by arcing or dielectric breakdown taking place when the electric field between conductors of a coaxial TL exceeds a threshold value, and also the propagation loss arising from ohmic dissipation. Derivation of the propagation loss in TEM wave propagating in a coaxial TL in dB/m.
   - Waveguides (WGs): TE and TM modes, dominant modes in rectangular and circular WGs, electric and magnetic field expressions in the dominant modes, derivation of time-average power flow in the TE_{10} mode in a rectangular WG and sample calculation of the maximum value of this power in the TE_{10} mode before arcing occurs, derivation of the attenuation in dB/m of the TE_{10} mode due to Ohmic dissipation
   - RF Cavities: properties of rectangular and circular cavities, resonant frequencies, Q factor, field profiles in cavities, TM_{010} mode of cylindrical cavity used in accelerators because of the longitudinal rf electric field which imparts the accelerating force to the charged particle beam, equivalent resonant LRC circuit
   - Scattering parameters for multi-port RF components and their use in computing reflection and transmission coefficients and power flow in RF circuits components such as isolators, circulators, directional couplers, phase shifters, the Riblet coupler, the magic tee, etc.

2. **HIGH POWER RF:**

   High-power RF components (TLs, WGs, cavities, etc.) are dimensionally the same as their low or medium power counterparts.
   - Two main problems exist in using RF components at high RF power levels:
     i) High peak power kills hardware through dielectric breakdown (arcing), and
     ii) High average power kills hardware through excessive heating due to ohmic dissipation in the metal walls

     Some mitigation of the arcing problem is achieved by placing gaseous or solid dielectrics with higher dielectric constants, thereby raising the threshold electric field above which arcing takes place.

     Some mitigation of the excessive heating problem is achieved by using a heat sink implemented using cooling methods.

     Exceeding the power handling limitations of RF components can result in expensive repairs.

- High power RF amplifiers: tetrode amplifiers, solid-state amplifiers, traveling wave tube (TWT) amplifiers (popular in high-power RF transmitters, satellite transponders, radars, etc.)
- High power RF generators: klystrons, magnetrons, solid-state oscillators

3. **APPLICATIONS OF HIGH POWER RF AND HOW THEY WORK:**
   - The ubiquitous microwave oven
   - Broadband jamming
   - Electronic warfare
   - Pulsed radar
   - RF transmitters and receivers
   - Food processing industry
   - Industrial heating and drying applications
   - Plasma generators (used in the production of integrated circuits, solar cells, batteries, fuel cells, flat panel displays, etc.)
   - Particle accelerators

4. **EXTENDED PROJECT ON USING HIGH POWER RF IN PARTICLE ACCERATORS:**
   - Cylindrical RF cavities placed in tandem and connected via drift tubes through which a particle beam accelerates
   - TM_{010} mode of cylindrical cavity used in transferring power into the beam via its longitudinal electric field and thereby accelerating the particles
   - Students to submit a detailed report on the design of a particle accelerator using high power longitudinal electric field in the cavities

6. Assignments

7.1. Homework Assignments

Homework Assignments will be issued once every week. All homework solutions must be submitted on the Blackboard by the midnight of the assigned day. No late submission of homework is accepted except under extenuating circumstances.

7.2. No makeup Exams or Homeworks:

There will be no “make-up” exams or homeworks except under absolutely extenuating or exceptional circumstances.

7. Questions on grading:

Any questions on grading of homeworks must be brought to the attention of the instructor and resolved within ten days of the return of the homeworks to the students. Late queries will not be entertained.

8. Academic Honesty:

Cheating of any kind is considered a serious offence, and will be treated according to the university rules of academic dishonesty, which provide for failure, suspension, and/or dismissal of the students involved. Regarding homework assignments and test preparation, you may freely interact with other students. But when you do the actual homework assignment or exam, you are to work alone and your work is to be yours alone.

9. Student Accessibility Support Center Statement:

If you have a physical, psychological, medical, or learning disability that may impact on your course work, please contact the Student Accessibility Support Center, 128 ECC Building, (631) 632-6748, or at sasc@stonybrook.edu. They will determine with you what accommodations are necessary and appropriate. All information and documentation is confidential.

10. Grading:

1. 1 Term Exam @25%	25%
2. Homework	25%
3. Final Exam	25%
4. Project	25%

11. Syllabus subject to change:

This syllabus is subject to change in terms of course content or any other way as dictated by progress in or needs of the class.