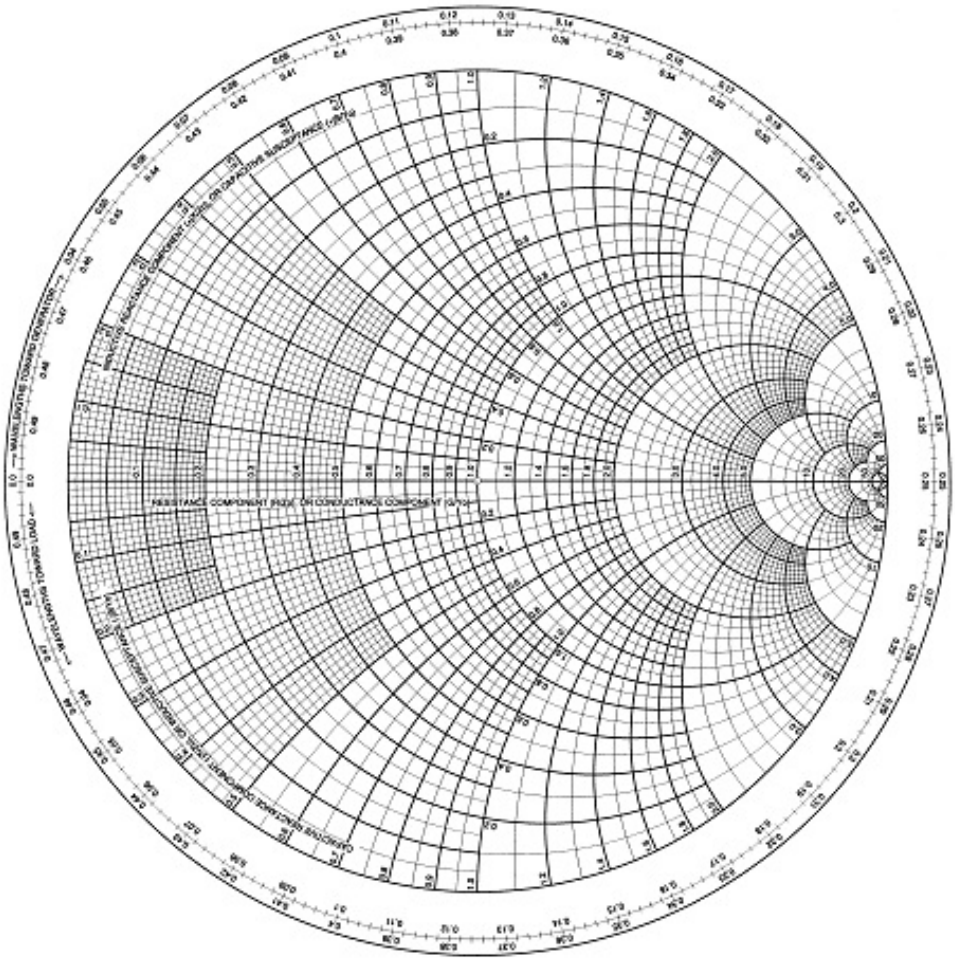
Microwave Engineering / Mikrovågsteknik

SK2814 Microwave Engineering, 7.5 credits

Older course code: IT2651

Course description for the academic year 22/23



Canvas: https://kth.instructure.com/courses/37912

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Introduction: Why study microwave engineering?

Microwave engineering is a subject that deals with phenomena that occur when the wavelength of an electromagnetic field becomes so short that the wavelength is comparable to the sizes of conductors and other structures that the field propagates across. There is no universal definition of the microwave frequency range, but the most common choice among textbook authors is 1-30GHz, which corresponds to between 1cm and 30cm wavelength in air or vacuum.

Microwave engineering as a subject brings together knowledge from several other subjects that are studied in undergraduate programs in e.g. electrical engineering. The relationships between currents and voltages from electrical circuit theory are combined with the electromagnetic fields studied in electromagnetics and optics, through the dependencies between flowing charges and propagating fields. An example of an important microwave phenomenon is that electrical signals propagating along conductors on a circuit board may be reflected by changes in the conductor geometry in a manner similar to the reflection of light at a water surface, and this causes practical consequences for the design of high-frequency electronics.

The history of microwave engineering is closely related to the development of radar during the second world war. Microwave devices were then mostly different types of vacuum tubes and hollow-pipe waveguides. Due to the development of semiconductor devices useful at high frequencies, the work in microwave engineering has gradually come to involve transistors and integrated circuits. Applications are today found in for example mobile communications, radar, heating, and also in electronics for high-speed fiberoptical communications (at ≥1Gbit/s).

Every engineer who works with electronics at frequencies of about 1GHz or higher needs to know at least the basics of microwave engineering. In modern electronics and electrical engineering an alternative to the term "microwave engineering" is therefore in practice "high-frequency electronics".

Languages

The microwave course is given in English since a majority of the participants are not Swedish speaking. The lectures and exercises will be in English. The labs will be either in English or Swedish depending on which students are present. The textbook is in English but the rest of the course material can be obtained in both English and Swedish. The examination will be in English from the academic year 2021/2022. Swedish translations will sometimes be used in brackets and hyphens to simplify for the Swedish students ("översättning till svenska").

Syllabus

Important subjects treated in this course are:

- Circuit theory
- Waveguides
- Scattering parameters
- Impedance transformation
- Matching
- Antennas
- Resonators
- Passive and active microwave devices
- Microwave communication systems
- Radar
- Microwave measurements

Aim

After the course the participants should be able to:

- Apply electromagnetic theory to calculations regarding waveguides and transmission lines
- Describe, analyze and design simple microwave circuits and devices e g matching circuits, couplers, antennas and amplifiers
- Describe and coarsely design common systems such as radar and microwave transmission links
- Describe common devices such as microwave vacuum tubes, high-speed transistors and ferrite devices
- Handle microwave equipment and be able to make measurements.

Prerequisites

The microwave course requires that the students have studied the compulsory courses of the E (CELTE) and F (CTFYS) programs at KTH in electromagnetics, or equivalent courses at other universities. The course starts with a very brief repetition of the most important parts of those courses, but each student must have a good knowledge of these previous courses in order to have a reasonable workload during the microwave course.

Course literature

The course literature consists of the following:

- **The textbook by Robert E. Collin, "Foundations for Microwave Engineering"**. The book was earlier available in a paperback version from McGraw-Hill, ISBN 0-07-112569-8, 2nd edition from 1992, but printing was discontinued in 2005. A hardcover version is available from Wiley-IEEE Press, ISBN: 0-7803-6031-1, since December 2000 and the book contains the same text as the McGraw-Hill 2nd edition from 1992. The book may also be found electronically on the KTH Library web site by searching for the book title in the KTH Library Catalogue. Only some parts of Collin are used in this course (the rest is studied in a graduate course). Exactly which parts are included may be found in the study notes at the end of this course description. The book contains many derivations which will not be explained in detail during the lectures, and it is thus important for the understanding of the subject to read the book. The exams contain a list of equations ("formelblad") with numbers that refer directly to Collin. You are advised to read the textbook during the course. Just reading solutions to examination problems can not give the same understanding of the subject. Answers to some of the essay problems in the exams can only be found in the textbook. **The examinations are designed assuming that the students have read the book by Collin in the manner described in the study notes by the end of this course description.**
- **"Problems Manual and Laboratory Instructions"** written by the lecturer Urban Westergren. This book of about 300 pages contains problems with solutions, lab instructions and appendices about measurements techniques, radar etc. It is also available in both English and Swedish ("Exempelsamling och laborationsanvisningar"). You can download the Problems Manual in pdf files from Canvas (see the front page of this course description).
- It may be helpful, but it is not necessary, to have access to an undergraduate book in electromagnetics containing the basics of antenna theory, e.g. the book by Cheng, Second Edition, Addison-Wesley, Reading, MA, 1989, which has been used in courses in electromagnetics at KTH. A summary of the most important aspects of antennas for this course is found in the Problems Manual, with references to Cheng.

Information during the course

If there is a need to spread information to the participants during the course, it will be done the following ways: Orally at lectures and exercises, via e-mail, and via Canvas.

The teaching: Lectures, exercises, and laboratories

The teaching is divided into 14 lectures, 8 exercises and three laboratories. Dates and preliminary contents may be found in the schedules in the appendices below. The teachers are:
Lectures: Urban Westergren, tel 790 4072, e-mail: urban@kth.se
Exercises and laboratories:
Richard Schatz, tel. 790 4069, mobile 073-6672485, e-mail: rschatz@kth.se

A student will only get a passing grade if results of the three laboratories have been accepted by the teaching assistant. The laboratories are awarded 1.5 credits. The labs will be performed in the Albanova building. There will be a separate lab schedule announced after the start of the course and each student has to book three separate lab times for the labs A, B and C.

A student who is absent from a booked lab time without notifying the teaching assistant in advance can not count on a new time being available this academic year. Before each lab, the instructions must be carefully studied and the preparatory problems solved. **A student who does not have correct solutions to 2/3 of the problems will not be admitted to the lab.** The teaching assistant may deny entrance for students who have not prepared for the labs. Observe that the times stated in the lab schedule are exact: no "academic quarter" is used for the labs.

Examination

The course ends with a written closed-book examination. Examiner is Urban Westergren. A passing grade on the exam is awarded 6 credits (hp) and the exam grade is the final grade for the course. The remaining 1.5 hp is awarded for the compulsory labs, see above, but these do not influence the grade for the course. The exam is 5 hours long. One re-examination is given in June each academic year (for dates see e.g. the timetables found via www.kth.se).

The microwave course contains both mathematical/analytical parts and descriptive brief-reading parts ("kursiva"). The mathematical parts are mostly examined through calculation problems in the exams. The descriptive parts are examined through essay problems. The level of difficulty in the problems is shown in earlier exams and in the Problems Manual where almost all problems are taken from old exams. Knowledge gained during exercises and labs may be useful also for the exam. There is a list of essay problems in the Problems Manual which contains most of the (types of) essay problems that can reasonably occur in an exam. The exam consists of:
- 4 calculation problems which can be awarded a maximum of 3 points each
- 3 essay problems which can be awarded a maximum of 2 points each

8 points are sufficient for a passing grade (E) provided that at least 2 points are for essay problems. The normal limits for the grades are:

Points	Grade
0-6.5	F=Failed
7-7.5	Fx=Failed with possibility of upgrading to E without new exam, see below
8-9.5	E
10-11.5	D
12-13.5	C
14-15.5	B
16-18	A

It should be possible to answer essay type problems in about one A4 page of text each, excluding possible drawings. If an answer to an essay problem contains variables, e.g. in an equation, all of these variables have to be defined in the answer. Answers only containing copies of equations from the list included in the exam ("formelblad") will naturally not be awarded any points.

The answers to the four calculation problems should be expressed in given quantities and natural constants. When grading a solution the examiner will give special attention to whether all steps in a calculation have been clearly motivated. A solution containing only a numerical answer, even if it is the right one, will not be awarded any points. Unreasonable answers without comment, reasonable answers with the comment that they are unreasonable, and solutions with incorrect use of equations from the list included in the exam will normally result in zero points for the problem.

The emphasis in the grading of the solutions is on the display of understanding of the subject rather than just the ability to perform calculations. The basic grading principle for a complete solution to a calculation problem (meaning that it includes a motivated calculation and an explicit answer) is to start at 3 points with a minimum reduction of 1 point for every major error in the solution and a maximum reduction of 0.5 points for every minor calculation mistake. Examples of major errors are the use of equations which are not relevant to the problem or using an equation in the wrong manner. Minor mistakes include simple calculation errors which are not directly related to the subject of microwaves. Incomplete solutions are graded proportionally.

These items are allowed during the examination:

- Mathematics handbooks such as Beta and similar, but no handbooks containing expressions for electromagnetic fields. Handbooks brought to the examination may not contain personal notes.
- Calculator. It may not contain information pertinent to the course, i.e. programmed information from the course literature that is not included in allowed handbooks. Calculators with QWERTY keyboards should be avoided since they may be removed from the student by the invigilators for check of the contents of the memory which may limit availability. Computers are not allowed.
- Handbooks in the English language. They may not contain notes relevant to the course. Electronic translators are not recommended since they may be removed from the students for check as for calculators with QWERTY keyboards.
- Each exam contains a four-page list of equations with references to the textbook by Collin. You do not need to bring your own copy of the list, and you are not allowed to bring a list containing notes. Questions regarding the list of equations are not answered by the examiner during the examination.
- It is recommended that you bring a ruler and a pair of compasses ("passare") to draw circles in Smith Charts.

The results of examinations will be announced 15 working days after the examination date. Appeals should be submitted in writing according to the rules of KTH.

Registering for the examination is compulsory for all students at all examinations. Deadline is two weeks in advance.

Students who receive the grade Fx (7-7.5 points) are offered the possibility of an additional examination to be upgraded to the grade E without attending a second full examination. This additional examination will be an individual take-home examination to be returned by e-mail within 24 hours after receiving it from the examiner. The examiner will offer students with the grade Fx the possibility of receiving a take-home exam, and the date and time for receiving the exam is then agreed on by the examiner and the student. The take-home examination will consist of problems of the same type as in the ordinary examination but may be more extensive. A minimum of 75% acceptable solutions will result in an upgrade to the grade E. Higher grades than E can not be acquired through this type of exam.

There is no limit to the number of re-examinations a student can take part in until a passing grade is acquired. After receiving a passing grade, a student may take part in one more exam to

attempt to improve the grade. If the grade then is lower, the student keeps the higher previous grade. If the grade E has been obtained through upgrading from Fx, no more attempts to improve the grade will be allowed.

Continued studies

Electromagnetic field problems are treated in an applied manner in the microwave course. Students who would like a deeper understanding of the theoretical aspects can attend the courses EI2420 Electromagnetic Wave Propagation and EI2410 Field Theory for Guided Waves. EI2400 Applied antenna technology provides a continuation of the antenna part in SK2814. The microwave course is also useful for those who plan to study SK2811 Fiberoptical communications and SK2403 Applied Photonics even if it is not part of the prerequisites for those two courses.

Questions

The written course information and the course material should usually be sufficient to answer all relevant questions regarding the course, so the students are asked to read everything carefully. If you still have questions you can contact the Urban Westergren who is examiner, lecturer, and responsible for the course: e-mail: urban@kth.se. Normal e-mail response time during ongoing courses is one working day but may be longer during travels.

I welcome all participants to the microwave course!

Stockholm, January 16, 2023

Urban Westergren

Preliminary schedule for lectures and exercises

The "academic quarter" is used which means that all lectures and exercises start 15 minutes past the hour, for example lecture #1 starts at 10:15. All halls are at main campus Valhallavägen.

Date and time	Location	Preliminary contents
Tuesday January 17, 13-15	E34	Lecture 1
Wednesday January 18, 10-12	Q24	Lecture 2
Thursday January 19, 08-10-12	D4448	Lecture 3
Friday January 20, 15-17	Lallerstedt (KTHB)	Lecture 4
Monday January 23, 08-10	D4448	Exercise 1
Tuesday January 24, 13-15	Hjärne (KTHB)	Lecture 5
Wednesday January 25, 10-12	Q24	Lecture 6
Wednesday January 25, 13-15	Hjärne (KTHB)	Exercise 2
Thursday January 26, 08-10	Hjärne (KTHB)	Lecture 7
Friday January 27, 15-17	Q11	Lecture 8
Tuesday January 31, 10-12	Lallerstedt (KTHB)	Exercise 3
Tuesday January 31, 13-15	Lallerstedt (KTHB)	Lecture 9
Wednesday February 1, 10-12	B23	Lecture 10
Thursday February 2, 08-10	D4448	Lecture 11
Friday February 3, 13-15	M23	Exercise 4
Tuesday February 7, 13-15	Hjärne (KTHB)	Exercise 5
Thursday February 9, 08-10	Hjärne (KTHB)	Exercise 6
Tuesday February 14, 13-15	M37	Exercise 7
Thursday February 16, 08-10	D4448	Exercise 8
Tuesday February 21, 13-15	Hjärne (KTHB)	Lecture 12
Wednesday February 22, 10-12	B24	Lecture 13
Thursday February 23, 08-10	D4448	Lecture 14
Monday March 13, 08-13	B2	Examination
Friday June 9, 08-13	V12	Re-examination

Please note that there may be changes regarding the scheduling. The schedule is also found here: https://www.kth.se/social/course/SK2814/subgroup/vt-2023-163/calendar/

Preliminary contents of the lectures and exercises

The table below may be subject to changes during the course.

	Preliminary contents	Relevant course material
Lecture #1	Introduction to microwaves	Collin ch 1
Lecture #2	Electromagnetic fields (repetition)	Collin ch 2
Lecture #3	Waves on transmission lines	Collin ch 3, part 1, PM
Lecture #4	Field analysis of transmission lines	Collin ch 3, part 1-2
Lecture #5	Waveguides	Collin ch 3, part 2-3
Lecture #6	Waveguides Impedance transformation and matching	Collin ch 3, part 3, Collin 4.1 Collin 5.1-5.6, PM
Lecture #7	Impedance transformation and matching	Collin 5.1-5.7, PM
Lecture #8	Broadband matching, S-parameters	Collin 5.10-5.12, 4.5-4.8
Lecture #9	S-parameters, passive devices	Collin 4.5-4.8, 6, PM
Lecture #10	Passive devices	Collin ch 6, PM
Lecture #11	Resonators, ferrites	Collin ch 6, 7, PM
Lecture #12	Microwave antennas, measurements	PM
Lecture #13	Active devices, circuit design	Collin ch 10, 12, Appendix to PM
Lecture #14	Applications, repetition and summary	Everything!
Exercise #1	Problems AF2, AF3, LS1, LS2	PM
Exercise #2	Problems LS3, LS5, LA6, LA7	PM
Exercise #3	Problems LA8, V1, V2, V4	PM
Exercise #4	Problems V6, LB2, S2, S4	PM
Exercise #5	Problems S5, S6, S10, S15	PM
Exercise #6	Problems S16, S18, RL2, RK1	PM
Exercise #7	Problems RK2, RK4, A1, A3	PM
Exercise #8	Example of an old exam	

Notes:
- PM = Problems Manual
- There are already printed solutions in the Problems Manual to all of the problems in the exercises, so the exercises will be devoted to the principles of solving different types of microwave problems, rather than just the mechanics of performing the calculations.

Schedule for labs

Each student has to book three separate lab time slots, one slot for each of the labs A, B and C.

The schedule for the labs will be discussed at the first exercise. The schedule is designed by Richard Schatz.

Notes:
- Each student has to provide acceptable results for all three labs to receive a passing grade on the course.
- **Booking of lab time slots is done in contact with Richard Schatz (via mail to rschatz@kth.se or SMS including name to 073-6672485). Make sure that you note which time slots you have booked in your own calendar! A student who does not appear for a booked time slot can not count on a new time being available this academic year.**
- The lab hall is in Albanova.
- Before each lab, the instructions must be carefully studied and the preparatory problems solved. **A student who does not have correct solutions to 2/3 of the problems, or who can not explain the solutions, will not be admitted to the lab.** The teaching assistants are authorized to deny entrance for students who have not prepared for the labs.
- The three labs are awarded a total of 1.5 credits (hp).

Study notes for the textbook by Collin

The course literature consists of one textbook and one Problems Manual ("Exempelsamling") with a collection of solved problems, laboratory instructions and appendices including some microwave applications. The textbook is called "Foundations for Microwave Engineering" by R.E. Collin, Second edition, McGraw-Hill 1992, ISBN 0-07-112569-8. Only some parts of Collin are studied fully or briefly in this course, and below is a list of different parts of the books divided into three categories. This list defines how the different parts of the literature are examined:

- **Category A:** Part that must be studied fully and which may be examined both with calculation problems and with essay questions in the examination.
- **Category B:** Part that may be studied briefly and which is only examined with essay questions in the examination.
- **Category C:** Part that may be omitted.

The numbers below refer to Collin unless something else is specified.

- **A. Parts that must be studied fully:**
    - Chapter 1
    - 2.1-2.9
    - 3.1-3.9, 3.11, 3.17-3.19
    - 4.1-4.2, 4.5 the part "Normalized Impedance and Admittance Matrices", 4.7-4.8
    - 5.1-5.3, 5.5-5.6, 5.9-5.12
    - 6.10 - Three-port Circulator
    - 7.1-7.2, 7.4
    - 10.1-10.2, 10.8
    - 12.1-12.3
    - The prerequisites pages ("förkunskaper") of the antenna part of the Problems Manual
- **B. Parts that may be studied briefly**
    - 5.7-5.8, 5.13, 5.16
    - 6.1-6.9
    - 7.3, 7.5
    - 10.4-10.5, 10.9, 10.12
    - 12.4-12.5
    - All appendices in the Problems Manual ("Exempelsamlingen")

- **C. Parts that may be omitted:**
  - 2.10-2.12
  - 3.10, 3.12-3.16, 3.20-3.21
  - 4.3-4.4, 4.5 the parts "Proof of Symmetry.../Proof of Imaginary Nature...", 4.6, 4.9-4.13
  - 5.4, 5.14-5.15, 5.17-5.19
  - 6.10 the part "Field Analysis of Three-Port Circulator", 6.11
  - 7.6-7.10
  - Chapter 8
  - Chapter 9
  - 10.3, 10.6-10.7, 10.10-10.11
  - Chapter 11
  - 12.6-12.11