Lecture 1

Introduction

1 Overview

Welcome to "EE432 RF Engineering for Telecommunications." This is a course concerned primarily with analysis and design of systems for wireless communications. We will refer to this as "RF engineering" (RF stands for Radio Frequency). RF engineering also commonly refers to the design of high-frequency circuits. In this course we are not much concerned with things at the circuit or component level. Our focus is mostly on the way in which radio waves are used to transmit information in a wireless system, system issues such as modulation and coding, and the way all of this is put together to form standardized systems such as GSM, BlueTooth and WiFi.

1.1 Prerequisites

At WSU the prerequisites for this course are EE341 Signals and Systems, and EE351 Distributed Parameter Systems. Equivalent courses can be substituted but you do need to have been exposed to the basic material. The important concepts we will use from those courses are:

- Impulse response and transfer function
- Fourier transform and spectra
- Maxwell's equations and the wave equation
- Plane and spherical waves

1.2 Course goals

This course aims to provide a rigorous introduction to the types of issues faced by RF engineers working in the cellular and wireless industries.

1.3 Programming

EE students are required to take programming early in their studies. This is an essential skill and you will be disadvantaged in the job market if you cannot program. You will be required to write programs in this course, for homework and for exams. If you feel your programming is rusty, now is the time to start reviewing. Programming may be done in C, C++, Matlab or Scilab.

1.4 Grading

Grades are based on a combination of homework, labs, quizzes, and exams. To the best of my ability your grade will represent the extent to which you have mastered this material. No late homework, or make-up labs, quizzes, or exams will be allowed. I realize that people get sick, have emergencies, have bad days and so on, and that they may be forced to miss a lab, quiz, or exam, or might just "blow it." For that reason I will drop the lowest score in each category so that you are not penalized.

1.4.1 Homework 10%

Homework is due on the dates listed in the syllabus. No late homework is accepted for any reason, period. I will drop the lowest homework score from your final grade. Note that homework is graded based on effort. If there are signs of a sincere effort, then you get full credit, even if your answer is wrong. Homework should be turned in as hardcopy during class.

Homework assignments exist for you to work with and learn the material. You are encouraged to study and do homework with other students if that suits you. You can also collaborate on homework assignments, but you should try to do your own work so that you can learn the material. Homework solutions are available “up front” for some assignments.

It is up to you to decide how best to collaborate with others and utilize the solutions. My suggestion is to first work on the problems alone. If you get stuck on a problem, then refer to the solutions or talk to other students. Finally, check your answers against the solutions and go back and rework any problems that you got wrong. Remember that the goal is to learn the material in whatever ways works best for you. You will be expected to demonstrate your mastery of the material on quizzes and exams.

1.4.2 Labs 25%

There is a lab assignment most weeks (but not the first week). For each assignment you are required to turn in a lab report describing your analysis and results. You can talk with other students about the labs, but you should do your own work, i.e., write your code, do your own analysis, and come to your own conclusions. If two or more students turn in essentially the same lab report, then I will divide the score for that single report equally amongst them. No late lab reports are accepted for any reason, period. I will drop the lowest of your lab scores from your final grade.

1.4.3 Quizzes 25%

There will be four in-class, multiple-choice quizzes. These are designed to test your grasp of general concepts without you necessarily having to crank out exact numerical answers. The lowest one of the four scores will be dropped from your final grade. Quizzes are open-book, open-notes, and you can use a calculator. You may not use a laptop computer.

1.4.4 Exams 40%

There will be a midterm and a final. Each will have an in-class component and a take-home component that will count for ½ the total, so there will be four components in all. Exams will test your ability to apply theory, both on paper and in computer programs, and derive quantitatively correct results. The lowest of the four exam components will be dropped from your final grade. Exams are open-book, open-notes, and you can use a calculator. You may not use a laptop computer on the in-class component. You may use a computer on the take-home components. Indeed, these typically involve computer programming.

2 A Time-Line of Radio Communication

Let’s get started on the content of the course and put things in perspective by considering some of the historical developments in the field of wireless communications.

- 1820 Oersted discovers that electrical current generates a magnetic field. In modern notation we express this as $\nabla\times\mathbf{H}=\mathbf{J}$.
- 1821 Faraday discovers electrical induction, i.e., that a time-varying magnetic field produces an electric field. In modern notation we express Faraday's Law as $\nabla\times\mathbf{E}=-\frac{\partial\mathbf{B}}{\partial t}$. Farday was also responsible for the "field" concept.
- 1865 Maxwell publishes one of the most important scientific papers of all time: "The Dynamical Theory of the Electromagnetic Field." This paper presents "Maxwell's equations" to the world. Maxwell develops the idea of magnetic induction, i.e., that a time-varying electric field produces a magnetic field in the same manner that a current does. In modern notation we express the resulting Ampere's Law as $\nabla\times\mathbf{H}=\mathbf{J}+\frac{\partial\mathbf{D}}{\partial t}$. Combined with Faraday's Law this predicts electromagnetic waves traveling at a speed $c=1/\sqrt{\mu_0\epsilon_0}$, or 300 meters per microsecond.
- 1887 Hertz generates and detects radio waves in his laboratory.
- 1897 Marconi transmits Morse code via radio across the English Channel.
- 1901 Fessenden patents the heterodyne detector.
- 1906 Fessenden achieves voice transmission using an alternator at about 100KHz for the RF source.
- 1907 De Forrest invents the vacuum tube triode. This makes possible electronic amplification and generation of RF signals.
- 1911 WSU radio club forms.
- 1912 As it sinks, RMS Titanic uses radio to call for help.
- 1920 KDKA Pittsburgh becomes the first licensed radio station in USA.
- 1927 New York to London commercial SSB radio service begins.
- 1928 "Motorola" car radio is introduced.
- 1935 FM is demonstrated by Armstrong.
- 1946 First public mobile phone service comes online.
- 1983 Analog cell phone service (AMPS) starts in the USA.
- 1993 Digital cell phone service (PCS) is introduced in the USA.

3 Radio Bands

There is a wide range of frequencies that can be used for wireless communications. These are grouped into decade-wide "bands" and given designations are shown in the table below. Recall that for a frequency *f*, the wavelength is $\lambda=c/f$.

LF, MF, and HF stand for "low frequency," "medium frequency," and "high frequency." These were coined in the early years of the 20th century when 10 MHz seemed like a "high frequency." Since that time technological advances have enabled us to work at ever-higher frequencies, and we have had to introduce ever-more intense adjectives to describe the new bands. VHF is "very high frequency," UHF is "ultra high frequency", SHF is "super high frequency," and EHF is "extremely high frequency." For our purposes the UHF band is the most important as both the cellular and PCS services and most wireless LANs operate at these frequencies. However, there is a lot of development concerned with new services in the SHF band, so that band will become increasingly important. There is also a lot of point-to-point wireless activity in the EHF band, for example 38 GHz.

Band	Frequencies	Wavelength	Some Applications
ULF	300-3000Hz	1000-100km	
VLF	3-30kHz	100-10km	Submarines
LF	30-300kHz	10-1km	Navigation beacons
MF	300-3000kHz	1000-100m	AM radio
HF	3-30MHz	100-10m	CB, wireless local loops
VHF	30-300MHz	10-1m	FM radio, TV, police/fire, cordless phones
UHF	300-3000MHz	100-10cm	Cellular, PCS, FRS, UHF TV, wireless LAN, cordless phones, GPS
SHF	3-30GHz	10-1cm	Satellites, point-to-point
EHF	30-300GHz	10-1mm	Point-to-point, 60GHz is particularly attractive for local area wireless networks

4 Communication Link Model

Fig. 1 shows a simple block diagram of a communication link. The goal is to move information from one place to another – tele-communication. The information might be voice (telephony), digital computer data, or measurements of the state of some system (telemetry). We may put the information through some sort of processing. For example, for digital data we might apply compression algorithms or add error-correcting codes. In a simple analog radio system we might skip this step. We then "modulate" the information to put it in a form suitable for the channel. Examples are AM and FM for analog signals, and various phase- and frequency-shift methods for digital signals.

Then we transmit the modulated information over the physical channel. Up to this point we have more or less had control over the system. We are free to change the algorithms and/or hardware to suit our needs, to within our technological limitations, of course. But the physical channel is often a given that we cannot control. For wireless communication the physical channel consists of radio propagation in the generally complex environment near the surface of the earth. Since it is unlikely that anyone will re-engineer the earth or atmosphere or cities and so on to make life easier for RF engineers, this is an environment that we must live with. As we'll see in this course it can be an extremely troublesome environment. Lots of effort with regards to systems and components is directed to dealing with these troubles.

Upon reception, we basically undo the modulation and processing from the transmitter and arrive at, hopefully, the desired information. However, if the physical channel has messed up the signal we might not be able to obtain the information reliably. Designing a communication system involves numerous trade offs to achieve an acceptable signal, in an acceptable amount of time, with an acceptable cost, complexity, and effort.

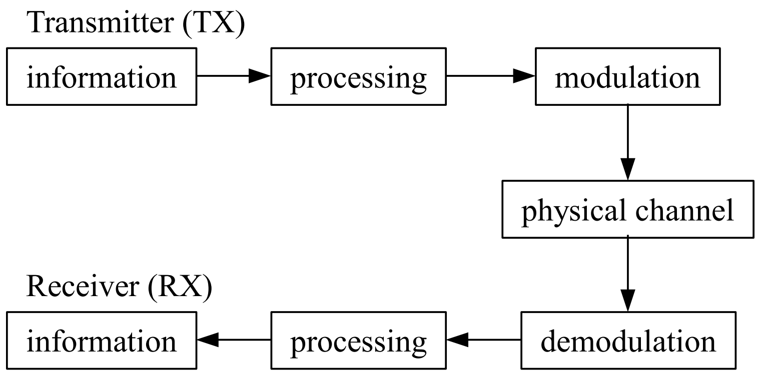

Fig. 1: Communication link model.

5 References

1. Nahin, P. J., *The Science of Radio*, AIP Press, 1996, ISBN 1-56396-347-7.