Chapter 1

Course Introduction/Overview

Contents

1.1 Introduction ................................................. 1-3
1.2 Where are we in the Curriculum? ....................... 1-4
1.3 Where are we (cont.)? ................................. 1-5
1.4 Instructor Policies ....................................... 1-8
1.5 Communications Lab Connection ...................... 1-9
1.6 Software Tools ............................................ 1-10
1.7 Comm I/Comm II Course Sequence .................... 1-11
1.8 Course Introduction and Overview .................... 1-12
1.9 A Block Diagram ......................................... 1-13
1.10 Channel Types ........................................... 1-14
    1.10.1 Electromagnetic-wave (EM-wave) propagation 1-14
    1.10.2 Guided EM-wave propagation .................... 1-18
    1.10.3 Magnetic recording channel .................... 1-18
    1.10.4 Optical channel .................................. 1-18
1.1 Introduction

- Where are we in the ugrad and grad curriculum?
- Course Syllabus
- Instructor policies
- Relationship to the communications lab, ECE 4670
- Software tools
- The Comm I/Comm II course sequence
- Communication systems overview
1.2 Where are we in the Curriculum?
1.3 Where are we (cont.)?

[Diagram showing course offerings and schedules]

ECE 5625 Communication Systems I
ECE 5625/4625
Communication Systems I
Spring Semester 2018

Instructor: Dr. Mark Wickert  Office: EN292  Phone: 255-3500
mwickert@uccs.edu  Fax: 255-3589
http://www.eas.uccs.edu/wickert/ece5625/

Office Hrs: Tue/Thurs 2:15–3:00 PM + 4:20–5:00 PM + other times by appointment


Optional Software: Scientific Python via the Jupyter Notebook (installed with https://anaconda.org/anaconda/python). The ECE PC Lab also has Anaconda installed and Pandoc and MikTeX for PDF output from the notebook. See the second page of the syllabus. Mathematica, available to UCCS students (see course Web Site), is also very useful.

Grading: 1.) Graded short quizzes and/or homework assignments total 20%.
2.) Computer project(s) worth 20%.
3.) Two “Hour” exams at 15% each, 30% total.
4.) Final exam worth 30%.

<table>
<thead>
<tr>
<th>Topics</th>
<th>Text Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction and Course Overview</td>
<td>Notes</td>
</tr>
<tr>
<td>2. Signal and linear system review and introduction to new topics including generalized Fourier series, autocorrelation function, power spectrum, Hilbert transform and sampling theory</td>
<td>2.1–2.8, 2.10</td>
</tr>
<tr>
<td>3. Basic modulation techniques: DSB, AM, SSB, and digital-pulse modulation and multiplexing</td>
<td>Chapter 3 + Notes</td>
</tr>
<tr>
<td>4. Basic modulation techniques: FM, PM, analog pulse modulation, and more multiplexing techniques</td>
<td>Chapter 4 + Notes</td>
</tr>
<tr>
<td>5. Baseband digital data transmission and an overview of digital modulation techniques</td>
<td>Chapter 5 + Notes</td>
</tr>
<tr>
<td>6. Noise sources and calculations</td>
<td>Appendix A</td>
</tr>
</tbody>
</table>

Drop Date: The last day to drop is March 30, at the end of Spring break week.
Installing Python & scikit-dsp-comm

Download and Install the Anaconda Python 3.6 Distribution: [https://anaconda.org/anaconda/python](https://anaconda.org/anaconda/python).

Jupyter Notebook and QT Console will be installed with the Anaconda distribution, but more formation can be found at: [http://ipython.org/](http://ipython.org/).

Download and Install the distributed version control application git: [https://git-scm.com/](https://git-scm.com/) on Windows systems (included on macOS and Linux).

Optionally Download and Install a code development environment that also integrates git version control such as Visual Studio Code (VS Code): [https://code.visualstudio.com/](https://code.visualstudio.com/) or PyCharm Community Edition IDE for Python: [https://www.jetbrains.com/pycharm/](https://www.jetbrains.com/pycharm/).

Clone and Install the package scikit-dsp-comm by following the GitHub README page at: [https://github.com/mwickert/scikit-dsp-comm](https://github.com/mwickert/scikit-dsp-comm).

Maintain scikit-dsp-comm using git pull origin master (see the information in the GitHub link).

Optional Jupyter Notebook to PDF Conversion

The Jupyter notebook is the perfect place to write code, document code, write text using markdown, import figures, and typeset math equations using LaTeX syntax. To render a Jupyter notebook as a PDF document a few more open source software components are needed:

- **Install Pandoc** for file conversion to LaTeX and other formats: [https://pandoc.org/index.html](https://pandoc.org/index.html)
- **Install MikTeX** for converting LaTeX documents to PDF on Windows: [https://miktex.org/](https://miktex.org/)
- When installing MikTeX be sure to choose the option to automatically download needed LaTeX packages on-the-fly
- **Install TeXLive** for converting LaTeX documents to PDF on macOS and Linux: [https://www.tug.org/texlive/](https://www.tug.org/texlive/)
- **Install Inkscape** for converting embedded SVG graphics in Jupyter notebooks via Pandoc to LaTeX and then PDF: [https://inkscape.org/en/release/0.92.2/](https://inkscape.org/en/release/0.92.2/). This gives you the ability to have nice looking graphics in the notebook and easily convert to a PDF, using just the File: Download Notebook menu item. On macOS you just install Inkscape. On Windows you may have to manually tweak the registry to get Inkscape to launch by the build script.
1.4 Instructor Policies

- Homework papers are due at the start of class

- If business travel or similar activities prevent you from attending class and turning in your homework, please inform me beforehand

- Grading is done on a straight 90, 80, 70, ... scale with curving below these thresholds if needed

- Homework solutions will be placed on the course Web site in PDF format with security password required; hints pages may also be provided
1.5 **Communications Lab Connection**

- The labs are fairly tightly coupled with the lecture topics
- The communications hardware experience should enhance your understanding of communications theory and analysis
- Lab topics:
  - Linear System Characteristics
  - Spectrum Analysis
  - Amplitude Modulation and Demodulation
  - FM Superheterodyne Receivers for Analog and Digital Communications
  - Frequency Modulation and Demodulation, including Phase-Locked Loops
  - Software defined radio (RTL-SDR)
  - Wireless sensor radio network to relay GPS data
- Both circuit and subsystem level designs are dealt with, as well as pre-built radio circuits
- The spectrum analyzer and vector network analyzer are introduced to extend measurement capabilities into the frequency domain
1.6 Software Tools

- The Jupyter Notebook with PDF export via LaTeX is very good for writing up solutions to homework and computer projects (HTML and screenshots OK too)

- Analysis aids:
  - Python/PyLab (Jupyter Notebook or QT console command line interface) with NumPy and matplotlib (PyLab), and SciPy very powerful, and free
  - Calculator (good practice for exams)
  - Additional tools include Mathematica and MATLAB both freely available to UCCS students

- Block Level System simulation
  - Keysight ADS (used in ECE 4670), MATLAB/Simulink

- Circuit simulation (for lab only?):
  - Agilent ADS for circuits, baseband, radio frequency (RF) and systems
  - LTspice
1.7 Comm I/Comm II Course Sequence

- Communication systems I, this course, continues into a second semester when ECE 4630/5630 is offered alternate fall semesters.

- The second semester course focuses on digital communications:
  - An introduction to random signals is provided
  - Amplitude, Phase, and frequency shift-keyed modulation schemes are studied in considerable detail
  - Coherent versus non-coherent modulation
  - The Mobile radio channel is introduced
  - Satellite communications is introduced
  - Coding theory is introduced
1.8 Course Introduction and Overview

- *The theory of systems for the conveyance of information*

- Communication systems must deal with uncertainty (noise and interference)
  
  - The uncertainty aspects of noise require the use of probability, random variables, and random processes
  
  - In this first course deterministic modeling is used for the most part

- Some important dates:

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1915</td>
<td>Transcontinental telephone line completed</td>
</tr>
<tr>
<td>1918</td>
<td>Armstrong superheterodyne radio receiver perfected</td>
</tr>
<tr>
<td>1938</td>
<td>Television broadcasting begins</td>
</tr>
<tr>
<td>WW II</td>
<td>Radar and microwave systems developed</td>
</tr>
<tr>
<td>1948</td>
<td>Transistor invented</td>
</tr>
<tr>
<td>1956</td>
<td>First transoceanic telephone line completed</td>
</tr>
<tr>
<td>1960</td>
<td>Laser demonstrated</td>
</tr>
<tr>
<td>1962</td>
<td>First communications satellite, Telstar I</td>
</tr>
<tr>
<td>1970’s</td>
<td>Commercial relay satellites for voice and data</td>
</tr>
<tr>
<td>1977</td>
<td>Fiber optic communication systems</td>
</tr>
<tr>
<td>1980</td>
<td>Satellite <em>switchboards in the sky</em></td>
</tr>
<tr>
<td>1990’s</td>
<td>Global positioning system (GPS) completed</td>
</tr>
<tr>
<td>1990’s</td>
<td>Cellular telephones widely used</td>
</tr>
<tr>
<td>1998</td>
<td>Global satellite-based cellular telephone system</td>
</tr>
<tr>
<td>2000s</td>
<td><em>Smart phones</em></td>
</tr>
<tr>
<td>2011/2</td>
<td>Long Term Evolution (LTE) 4th-gen. cellular</td>
</tr>
</tbody>
</table>
1.9 A Block Diagram

- A high level communication systems are typically described using a block diagram

- There is an information source as the input and an information sink to receive the output

- The block diagram shown above is very general
  - The source may be digital or analog
  - The transmission may be at baseband or on a radio frequency (RF) carrier
  - The channel can take on many possible forms
1.10 Channel Types

1.10.1 Electromagnetic-wave (EM-wave) propagation

- When you think wireless communications this is the channel type most utilized
- The electromagnetic spectrum is a natural resource
- The above figure depicts several propagation modes
  - Lower frequencies/long wavelengths tend to follow the earth's surface
  - Higher frequencies/short wavelengths tend to propagate in straight lines
- Reflection of radio waves by the ionosphere occurs for frequencies below about 100 MHz (more so at night)
### Table 1.2 Frequency bands with typical uses

<table>
<thead>
<tr>
<th>Frequency band(^a)</th>
<th>Name</th>
<th>Microwave band (GHz)</th>
<th>Letter designations</th>
<th>Typical uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–30 kHz</td>
<td>Very low frequency (VLF)</td>
<td></td>
<td></td>
<td>Long-range navigation; sonar</td>
</tr>
<tr>
<td>30–300 kHz</td>
<td>Low frequency (LF)</td>
<td></td>
<td></td>
<td>Navigational aids; radio beacons</td>
</tr>
<tr>
<td>300–3000 kHz</td>
<td>Medium frequency (MF)</td>
<td></td>
<td></td>
<td>Maritime radio; direction finding; distress and calling; Coast Guard comm.; commercial AM radio</td>
</tr>
<tr>
<td>3–30 MHz</td>
<td>High frequency (HF)</td>
<td></td>
<td></td>
<td>Search and rescue; aircraft comm. with ships; telegraph, telephone, and facsimile; ship-to-coast</td>
</tr>
<tr>
<td>30–300 MHz</td>
<td>Very high frequency (VHF)</td>
<td></td>
<td>P R C R E U R V I O N S T</td>
<td>VHF television channels; FM radio; land transportation; private aircraft; air traffic control; taxi cab; police; navigational aids</td>
</tr>
<tr>
<td>0.3–3 GHz</td>
<td>Ultrahigh frequency (UHF)</td>
<td>0.5–1.0</td>
<td>VHF C</td>
<td>UHF television channels; radiosonde; nav. aids; surveillance radar; satellite comm.; microwave links; airborne radar; approach radar; weather radar; common carrier</td>
</tr>
<tr>
<td>3–30 GHz</td>
<td>Superhigh frequency (SHF)</td>
<td>1.0–2.0</td>
<td>L D</td>
<td>radio altimeters;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0–3.0</td>
<td>S E</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0–4.0</td>
<td>S F</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0–6.0</td>
<td>C G</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.0–8.0</td>
<td>C H</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.0–10.0</td>
<td>X I</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.0–12.4</td>
<td>X J</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.4–18.0</td>
<td>Ku J</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>18.0–20.0</td>
<td>K J</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20.0–26.5</td>
<td>K K</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>26.5–40.0</td>
<td>Ka K</td>
<td></td>
</tr>
<tr>
<td>30–300 GHz</td>
<td>Extremely high frequency (EHF)</td>
<td></td>
<td></td>
<td>Railroad service; radar landing systems; experimental</td>
</tr>
<tr>
<td>300 GHz–3 THz</td>
<td>(0.1–1 mm)</td>
<td></td>
<td></td>
<td>Experimental</td>
</tr>
<tr>
<td>43–430 THz</td>
<td>Infrared (7–0.7 (\mu m))</td>
<td></td>
<td></td>
<td>Optical comm. systems</td>
</tr>
<tr>
<td>430–750 THz</td>
<td>Visible light (0.7–0.4 (\mu m))</td>
<td></td>
<td></td>
<td>Optical comm. systems</td>
</tr>
<tr>
<td>750–3000 THz</td>
<td>Ultraviolet light (0.4–0.1 (\mu m))</td>
<td></td>
<td></td>
<td>Optical comm. systems</td>
</tr>
</tbody>
</table>

\(^a\)Abbreviations: kHz = kilohertz = \(x 10^3\) hertz; MHz = megahertz = \(x 10^6\) hertz; GHz = gigahertz = \(x 10^9\) hertz; THz = terahertz = \(x 10^{12}\) hertz; \(\mu m\) = micrometers = \(x 10^{-6}\) meters.
Examples of public (commercial) and government (military) applications and the frequency bands they operate in

<table>
<thead>
<tr>
<th>Use</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omega navigation</td>
<td>10–14 kHz</td>
</tr>
<tr>
<td>Worldwide submarine communication</td>
<td>30 kHz</td>
</tr>
<tr>
<td>Loran C navigation</td>
<td>100 kHz</td>
</tr>
<tr>
<td>Standard (AM) broadcast</td>
<td>540–1600 kHz</td>
</tr>
<tr>
<td>ISM band</td>
<td>40.66–40.7 MHz</td>
</tr>
<tr>
<td>Television Channels 2–4</td>
<td>54–72 MHz</td>
</tr>
<tr>
<td>Television Channels 5–6</td>
<td>76–88 MHz</td>
</tr>
<tr>
<td>FM broadcast</td>
<td>88–108 MHz</td>
</tr>
<tr>
<td>Cellular mobile radio</td>
<td>806–821 MHz</td>
</tr>
<tr>
<td>ISM band</td>
<td>851–866 MHz</td>
</tr>
<tr>
<td>Cellular mobile radio</td>
<td>896–901 MHz</td>
</tr>
<tr>
<td>ISM band</td>
<td>902–928 MHz</td>
</tr>
<tr>
<td>Cellular mobile radio</td>
<td>935–940 MHz</td>
</tr>
<tr>
<td>Point-to-point microwave</td>
<td>2.11–2.13 GHz</td>
</tr>
<tr>
<td>Personal communication services</td>
<td>1.8–2.0 GHz</td>
</tr>
<tr>
<td>Point-to-point microwave</td>
<td>2.16–2.18 GHz</td>
</tr>
<tr>
<td>ISM band</td>
<td>2.4–2.4835 GHz</td>
</tr>
<tr>
<td>ISM band</td>
<td>23.6–24 GHz</td>
</tr>
<tr>
<td>ISM band</td>
<td>122–123 GHz</td>
</tr>
<tr>
<td>ISM band</td>
<td>244–246 GHz</td>
</tr>
</tbody>
</table>

There is a hierarchy of organizations that regulate how the available spectrum is allocated

- Worldwide there is the International Telecommunications Union (ITU), which convenes regional and worldwide Administrative Radio Conferences (RARC & WARC)
- Within the United States we have the Federal Communications Commission (FCC)

Cellular telephony, wireless LAN (WLAN), and HDTV broadcasting, are examples where the FCC continues to make allocation changes
- At frequencies above 1–2 GHz oxygen and water vapor absorb and scatter radio waves

- Satellite communications, which use the microwave frequency bands, must account for this in what is known as the *link power budget*
1.10.2 Guided EM-wave propagation

- Communication using transmission lines such as twisted-pair and coax cable

1.10.3 Magnetic recording channel

- Disk drives, fixed (at one time flexible too)
- Video and audio

1.10.4 Optical channel

- Free-space
- Fiber-optic
- CD, DVD, HD-DVD, etc.
Example 1.1: Open Systems Interconnect (OSI) Model

- When dealing with data communications (as in bits/s) the OSI model of interest

- Both ECE and CS majors have an interest in this

- In this course we are focused on the physical layer
Example 1.2: Lowcost Software Defined Radio

- Software defined radio (SDR) is an exciting merger of digital signal processing and wideband radio hardware.

- The basic elements of a practical SDR transceiver are shown below:

The SDR transceiver concept in block diagram form

- A very popular platform at $20, with a very active user community, is the RTL-SDR.

- The RTL-SDR dongle contains two primary chips: (1) the Raphael Micro R820T radio tuner and the Realtek RTL2832U which contains an 8-bit ADC and USB data pump.

---

1 http://en.wikipedia.org/wiki/Software-defined_radio
2 http://rtlsdr.org/
1.10. CHANNEL TYPES

- To better understand the functionality of the RTL-SDR consider the behavioral level model shown below:

![RTL-SDR USB Dongle](image)

A behavioral level model of the RTL-SDR.

- Using your signals and systems background, with an emphasis on Fourier theory, even now you can make some sense of how the receiver works.

- The complex multiply by $e^{-j2\pi f_c t}$ and the lowpass filter are the two most important system blocks.

- In picture form consider:

![Frequency domain view of the RTL-SDR](image)

A frequency domain view of the RTL-SDR.

$$r[n] = r_I[n] + jr_Q[n]$$
A fun way to exercise the RTL-SDR is using the free app *SDR#*:

![SDR# GUI](image)

The SDR# GUI (older version)
Example 1.3: **Wireless in the Eye**

- A recent publication\(^3\) describes a wireless sensor for intra-ocular pressure monitoring in the eye.

  ![The wireless sensor](image.png)

- The device is powered using ambient energy (light in this case) via a rechargeable thin film Li state battery.

---

- The space constraint is 1.5 mm³

- The energy chip stores 1 μAh, but the device needs 10nW on average and 3.65nW when in standby

- Pressure is measured every 15 minutes (needed for Glaucoma patients)

- Energy autonomy is achieved with 10 hours of indoor lighting or 1.5 hours of sunlight per day

The chip layers and the 1μAh battery