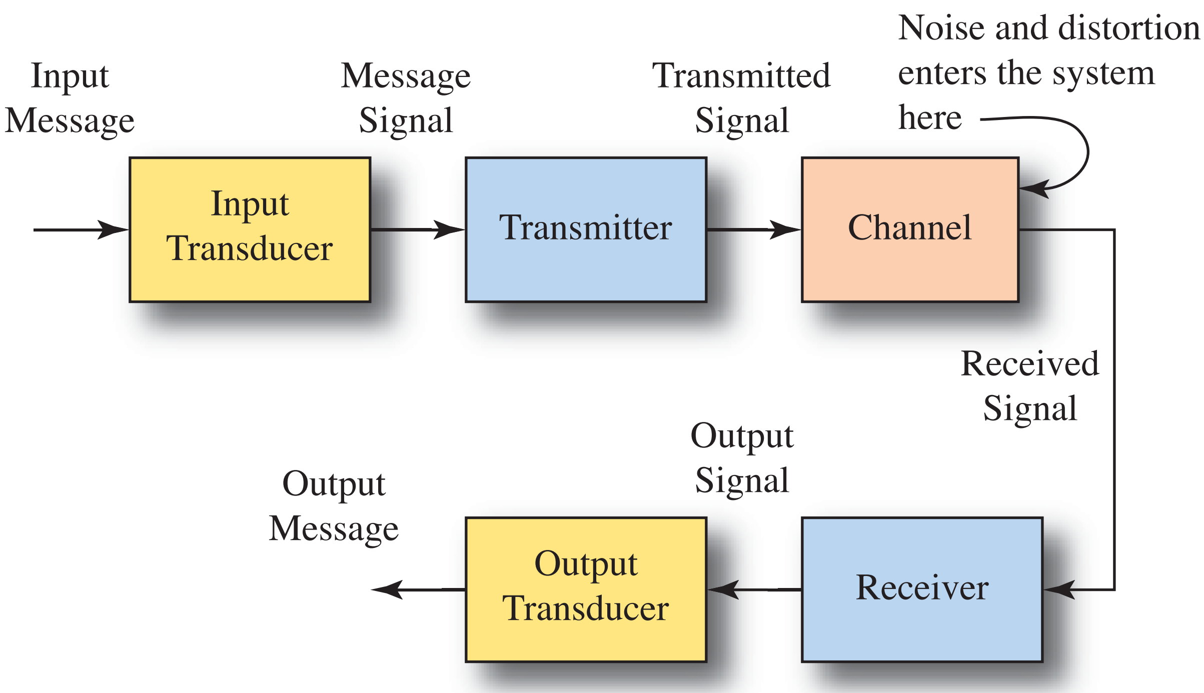
# Communication Systems I

## ECE 5625/4625 Lecture Notes

## Spring 2026





Mark A. Wickert

Chapter 1

# Course Introduction/Overview

## Contents

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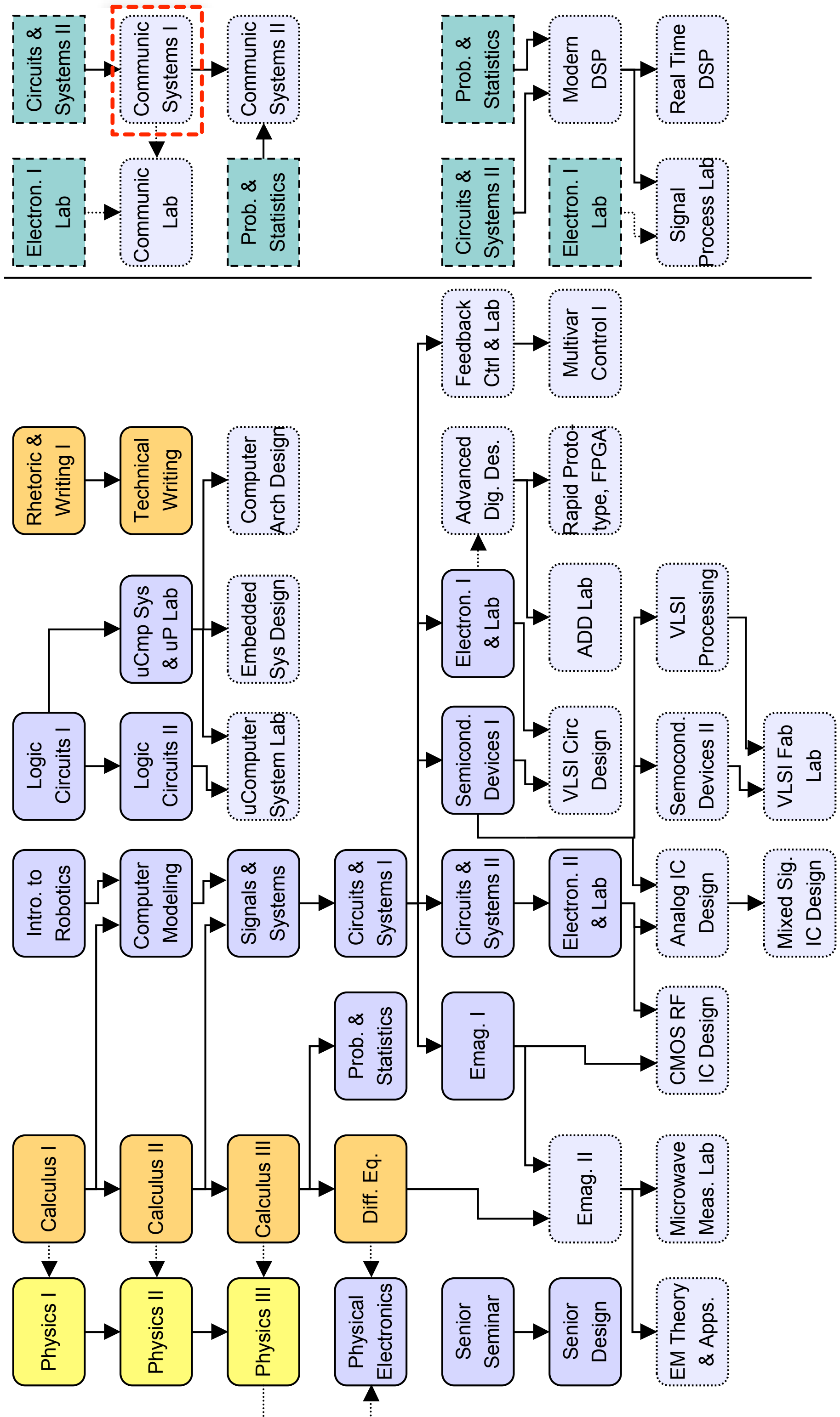
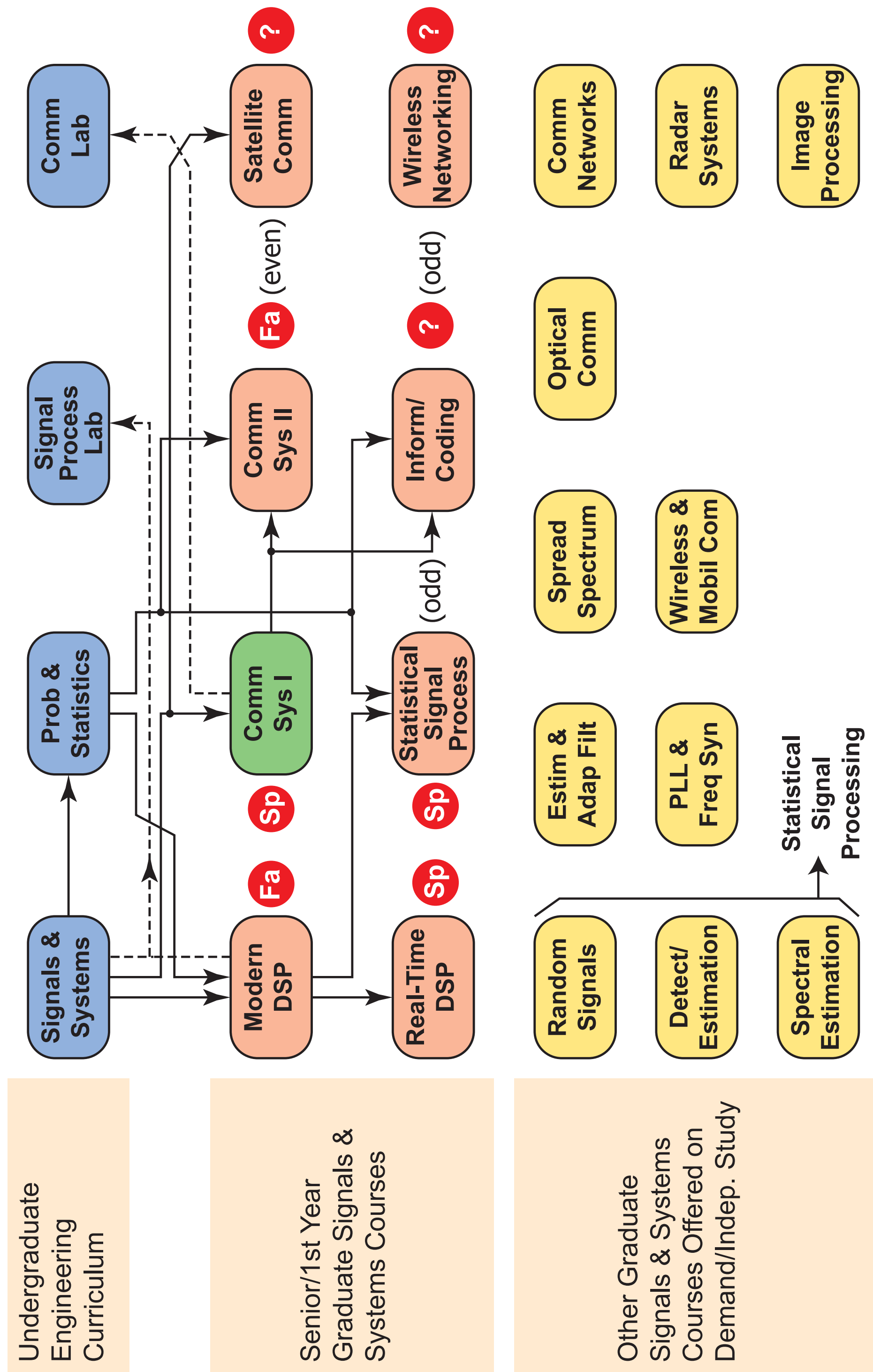
## 1.1 Introduction

- 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?



## Where are we (cont.)?



## 1.3 Course Syllabus

# ECE 5625/4625
# Communication Systems I

Spring Semester 2026

**Instructor:** Dr. Mark Wickert **Office:** AEC-3xx **Phone:** 719-332-6996
mwickert@uccs.edu, https://faculty.uccs.edu/mwickert/

**Office Hrs:** Tue 10:40-11:30AM + other times by appointment (initiate on Slack)

**Required Text:** R. Ziemer and W. Tranter, *Principles of Communications*, seventh edition, Wiley, 2014 (ISBN-13: 978-1118078914). I recommend the e-book version to save money. I have full course notes available on the course Web Site.

**Optional Text:** M.A. Wickert, *Signals and Systems for Dummies*, Wiley, 2013. Useful for Fourier theory review and worked examples, including the use of Python.

**Modeling Software:** Python and Julia Jupyter notebooks and wxMaxima. Consider Julia using Pluto *reactive* notebooks. A Web Site document will explain the install details.

**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%.

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

**Important**: If you are a student with a disability and believe you will need accommodations for this class, it is your responsibility to register with Disability Services and provide them with documentation of your disability. They will work with you to determine what accommodations are appropriate for your situation. To avoid any delay, you should contact Disability Services as soon as possible. Please note that accommodations are not retroactive and disability accommodations cannot be provided until a Faculty Accommodation Letter has been given to me. Please contact Disability Services for more information at Main Hall, 3rd floor, Room 324, (719) 255-3354, or dservice@uccs.edu.

# Syllabus continued...

**Slack** We will be using Slack *Channels* for group discussions and Slack *Direct Messaging* for audio and screen sharing. You will receive an invite to join the *DSP Comm Courses* Slack workspace. Download is under *Resources*.

**Setting up Python via miniconda** To set up Python alone but with the advantage of virtual environments, miniconda works very well (on Windows install for Powershell). The helper document new_python_virtual_environment.pdf is provided. To run real-time DSP code in Jupyter Lab or vs code using pyaudio_helper. pyaudio_helper runs under Python 3.13.

**vs code** Microsoft Visual Studio Code (vs code) is great for writing and debugging Python and Julia code source code files or Jupyter Lab notebooks. *Extensions* are available for Python, Julia, and Jupyter Lab, and many others. See the Julia_with_Python_Setup doc linked below for vs code setup info

**Julia and Python, with Jupyter Lab together** Documents linked on the course Web Site provide details on how to install both Python and Julia along with various Julia and Python packages (Julia_with_Python_Setup.pdf). Under Jupyter Lab you create notebook documents (.ipynb) for either Python of Julia.
**Note**: Jupyter Lab is the perfect place to write code, document code, write text using markdown, import figures, and typeset math equations using LaTeX syntax. Julia makes a significant step in solving the *two language problem* (Python for rapid prototyping and C/C++ for execution speed). You will also see the *reactive* Julia Pluto notebook in action in class.

**wxMaxima** Similar to Mathematica, as it is a computer algebra system (CAS), but open-source. Simpler to use than Python, but not as fast at numerical DSP type operations. I will be showing off the new DSP package in class.

**Typst**

- Typst is a new writing tool, similar to LaTeX, but it has a very nice cloud-based interface with real-time preview and one click PDF export. Why? To allow you to create documents that are a hybrid of scanned hand written solutions, typed out problems with text and math, and code with plots. I will supply a homework template and examples and you can decide if you want to try it.

## 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:
  - RF spectrum analyzer and network analyzers (to experience with RF/microwave masurement techniques and practice)
  - Spectrum Analysis
  - Mixers and Amplitude Modulation
  - FM Radio Receivers for Analog and Digital Modulation
  - Software defined radio and the RTL-SDR
  - FieldFox measurement campaign with a log-periodic antenna (not implemented yet)
- 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 (and perhaps Pluto) Notebooks for writing up solutions to homework and computer projects (HTML and screenshots OK too)

- In writing you will become familiar with 3 elements: Markdown, LaTeX math mode, and code cells

- Analysis and Simulation:

  - Python and/or Julia will be used (Jupyter Notebook with Python or Julia and Pluto notebook with Julia)
  - Both are free and open source with instructions for download and installation available on the Web Site
  - In particular I recommend Anaconda distribution scientific Python
  - Julia is available directly from `julialang.org/` and keeping it updated is easy using the built-in package manager, and `juliaup`
  - Both have extensive libraries for numerical computing, signal processing, and plotting/visualization; Python has the edge here
  - Don't forget about your calculator (good practice for quizzes and exams)
  - Additional tools that I may use in class include wxMaxima for CAS type calculations, including the signal processing for `wxmaxima` package I published on GitHub Fall 2025.

## 1.7 Comm 1/Comm 2 Course Sequence

- Communication systems 1, 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

- Both projects 1 and 2 in this course will expose you to some digital communications concepts that will be expanded upon in Comm 2

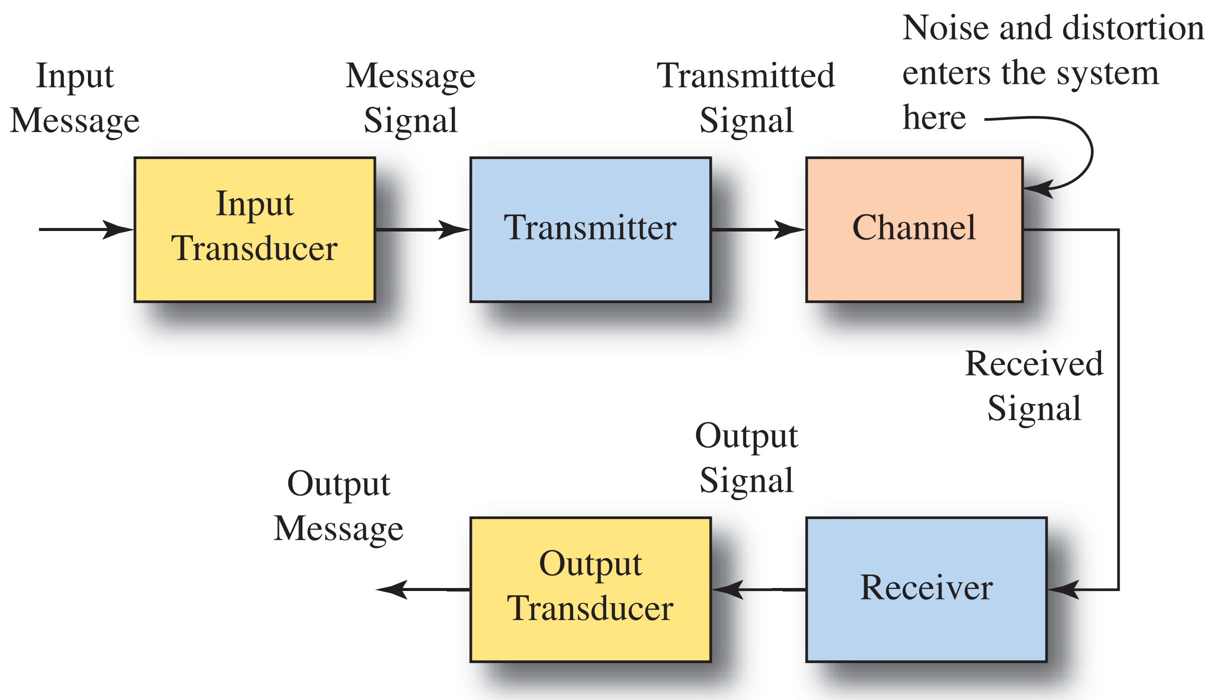
## 1.8 Course Introduction and Overview

- *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:

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

# 1.9 A Block Diagram

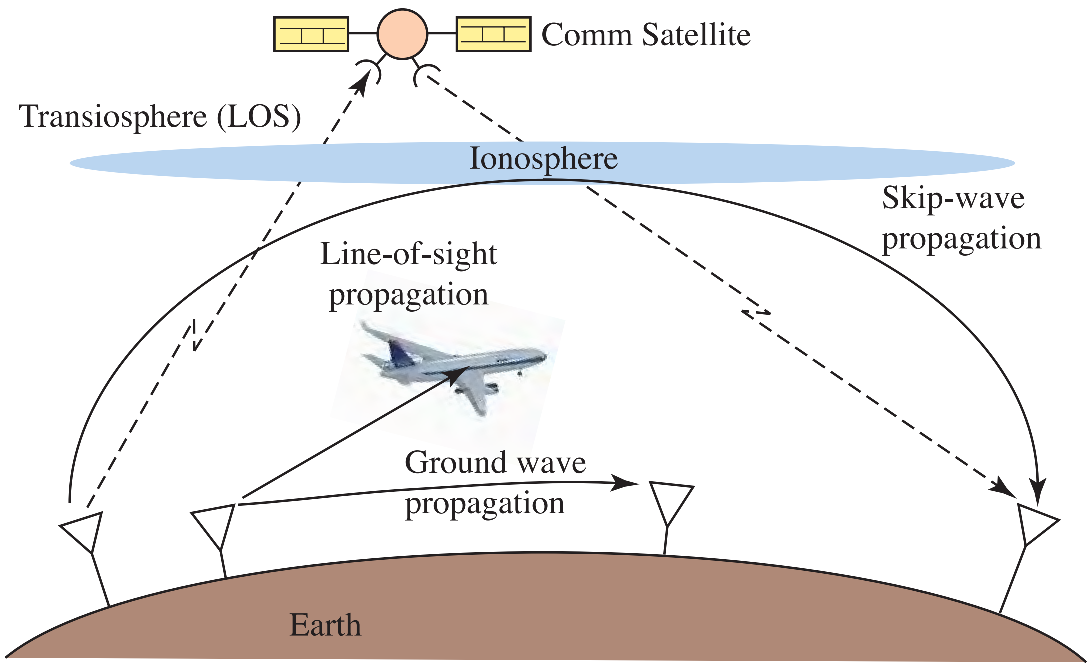
- A a high level communication systems are typically described using a block diagram




- 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 may 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 earths 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**

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

[a]Abbreviations: kHz = kilohertz = $\times 10^3$ hertz; MHz = megahertz = $\times 10^6$ hertz; GHz = gigahertz = $\times 10^9$ hertz; THz = terahertz = $\times 10^{12}$ hertz; $\mu$m = micrometers = $\times 10^{-6}$ meters.

- Examples of public (commercial) and government (military applications and the frequency bands they operate in

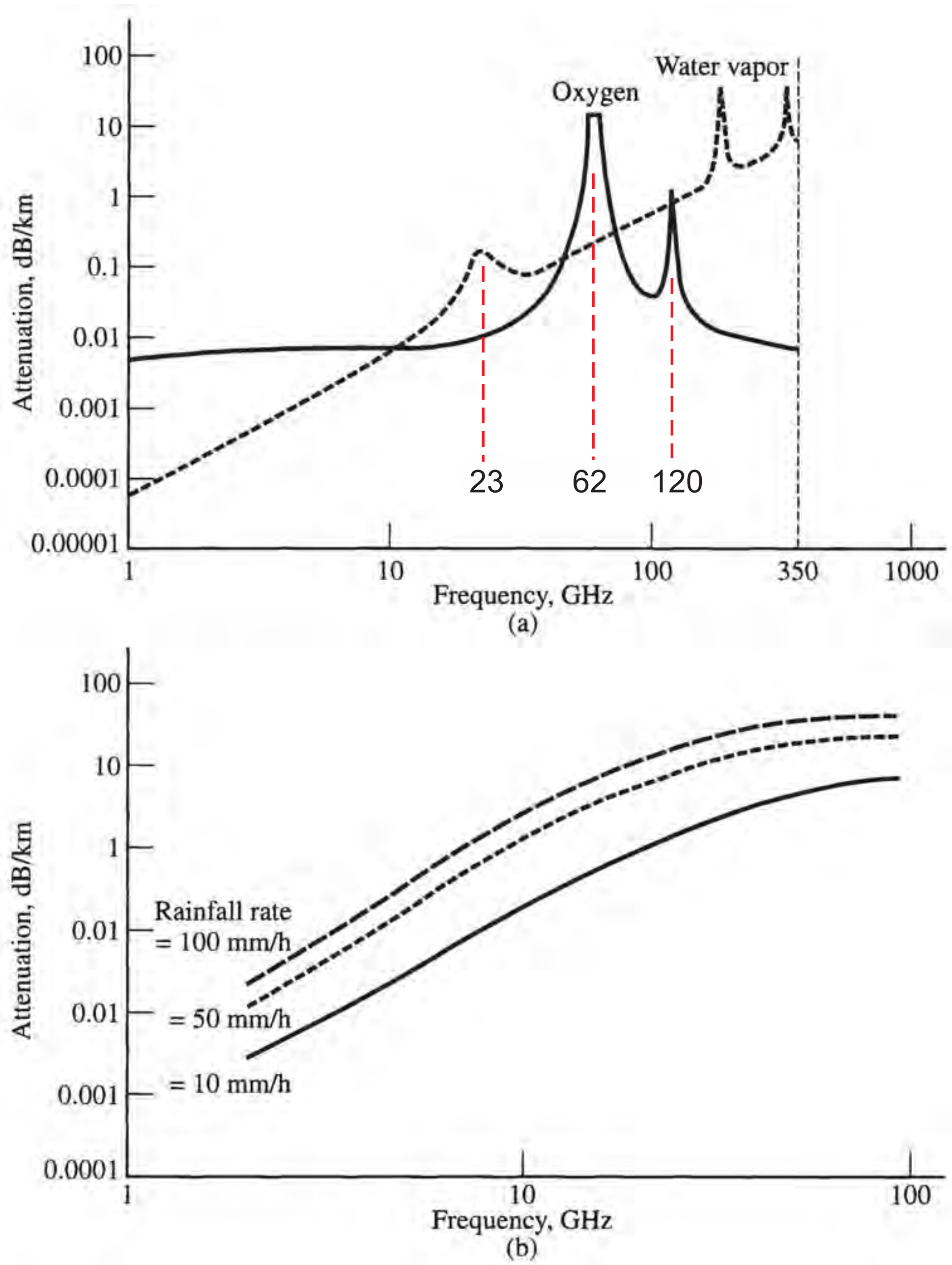
**TABLE 1.3 Selected Frequency Bands for Public Use and Military Communications[5]**

| Use | | Frequency |
|---|---|---|
| Omega navigation | | 10–14 kHz |
| Worldwide submarine communication | | 30 kHz |
| Loran C navigation | | 100 kHz |
| Standard (AM) broadcast | | 540–1600 kHz |
| ISM band | Industrial heaters, welders, etc. | 40.66–40.7 MHz |
| Television | Channels 2–4 | 54–72 MHz |
| | Channels 5–6 | 76–88 MHz |
| FM broadcast | | 88–108 MHz |
| Television | Channels 7–13 | 174–216 MHz |
| | Channels 14–83 | 420–890 MHz |
| Cellular mobile radio | Mobile to base station | 806–821 MHz |
| | Base station to mobile | 851–866 MHz |
| | Mobile to base station | 896–901 MHz |
| ISM band | Older microwave ovens; medical | 902–928 MHz |
| Cellular mobile radio | Base station to mobile | 935–940 MHz |
| Point-to-point microwave | | 2.11–2.13 GHz |
| Personal communication services | CDMA cellular in No. Amer. | 1.8–2.0 GHz |
| Point-to-point microwave | Interconnecting base stations | 2.16–2.18 GHz |
| ISM band | $\mu$-ovens; unlicensed SS; medical | 2.4–2.4835 GHz |
| | | 23.6–24 GHz |
| | | 122–123 GHz |
| | | 244–246 GHz |

- 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*




Water vapor and oxygen attenuation

Rainfall rate attenuation

### 1.10.2 Guided EM-wave propagation

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

### 1.10.3 Magnetic recording channel

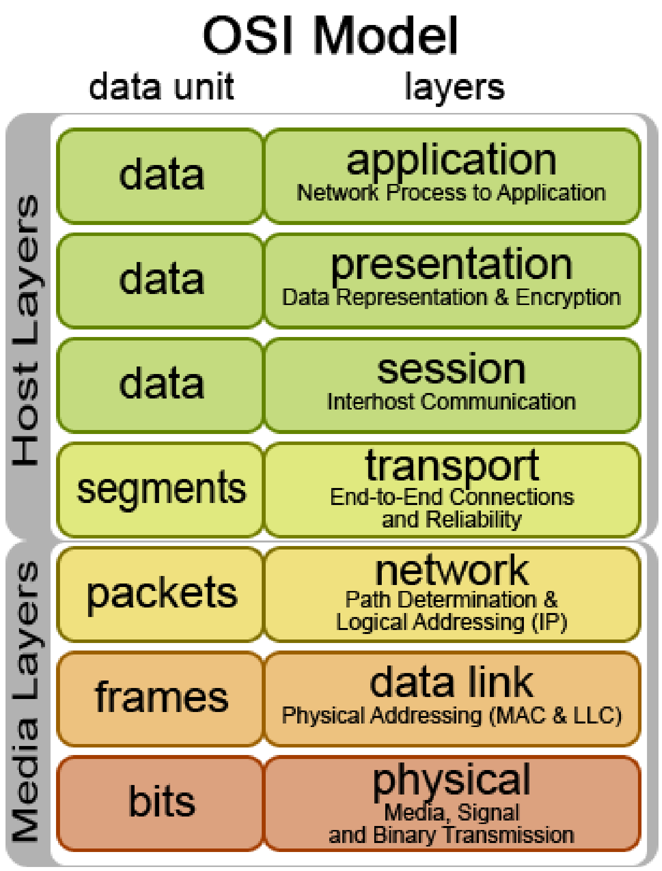
- Disk drives, fixed (at one time flexible too)
- Video and audio

### 1.10.4 Optical channel

- Free-space
- Fiber-optic
- CD, DVD, HD-DVD, etc.

## Example 1.1: Open Systems Interconnect (OSI) Model

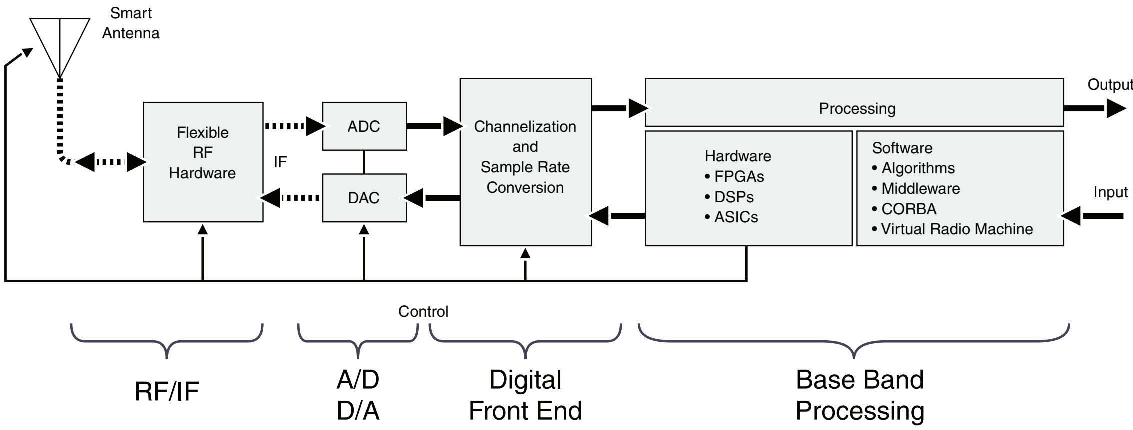
- When dealing with data communications (as in bits/s) the OSI model of interest
- Both ECE and CS majors have an interest in this




- In this course we are focused on the physical layer

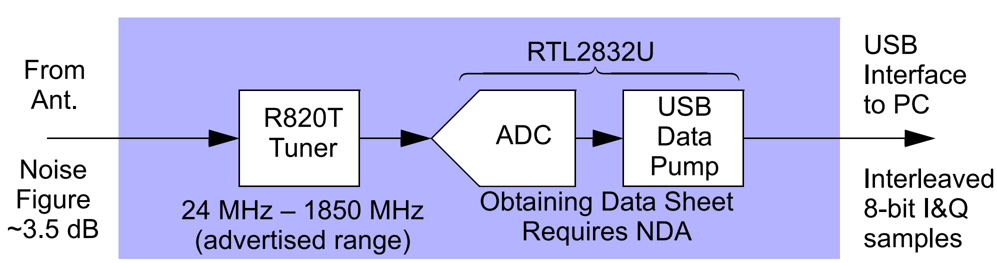
## Example 1.2: Lowcost Software Defined Radio

- Software defined radio (SDR) is an exciting merger of digital signal processing and wideband radio hardware [1]
- The basic elements of a practical SDR transceiver are shown below:




The SDR transceiver concept in block diagram form

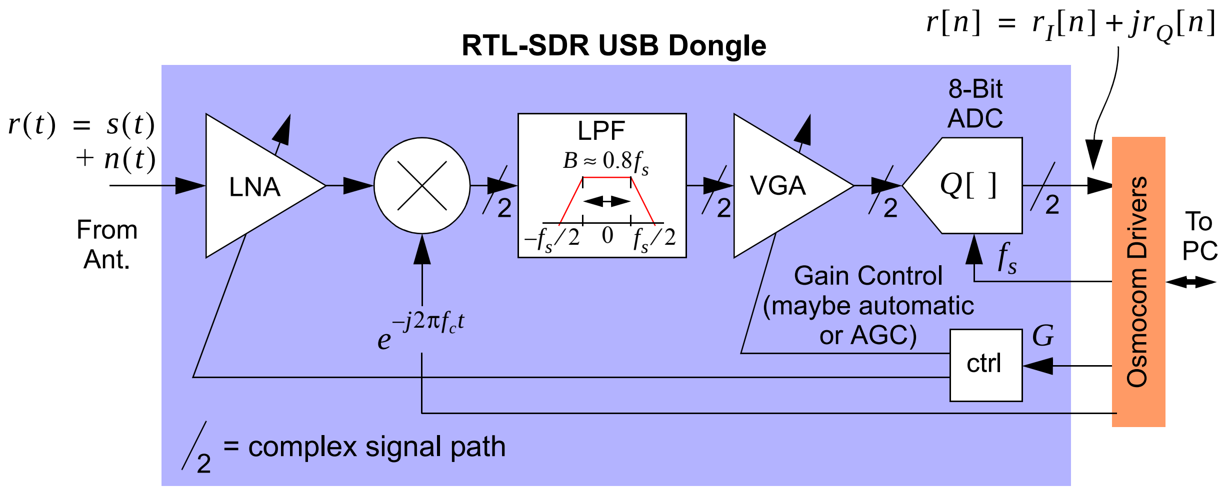
- A very popular platform at \$20, with a very active user community, is the RTL-SDR[2]
- The original RTL-SDR dongle contains two primary chips: (1) the Raphael Micro R820T radio tuner and the Realtek RTL2832U which contains an 8-bit ADC and USB *data pump*




[1] http://en.wikipedia.org/wiki/Software-defined_radio

[2] http://rtlsdr.org/

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

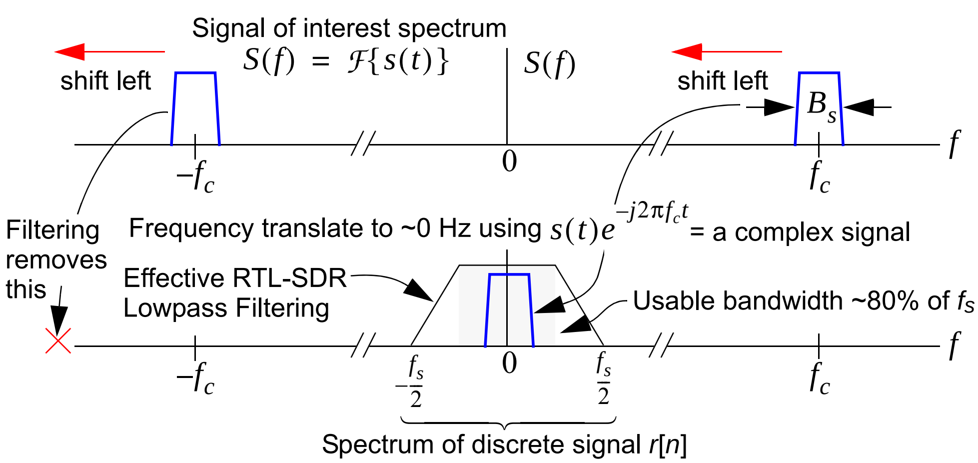



A behavioral level model of the RTL-SDR.

- 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

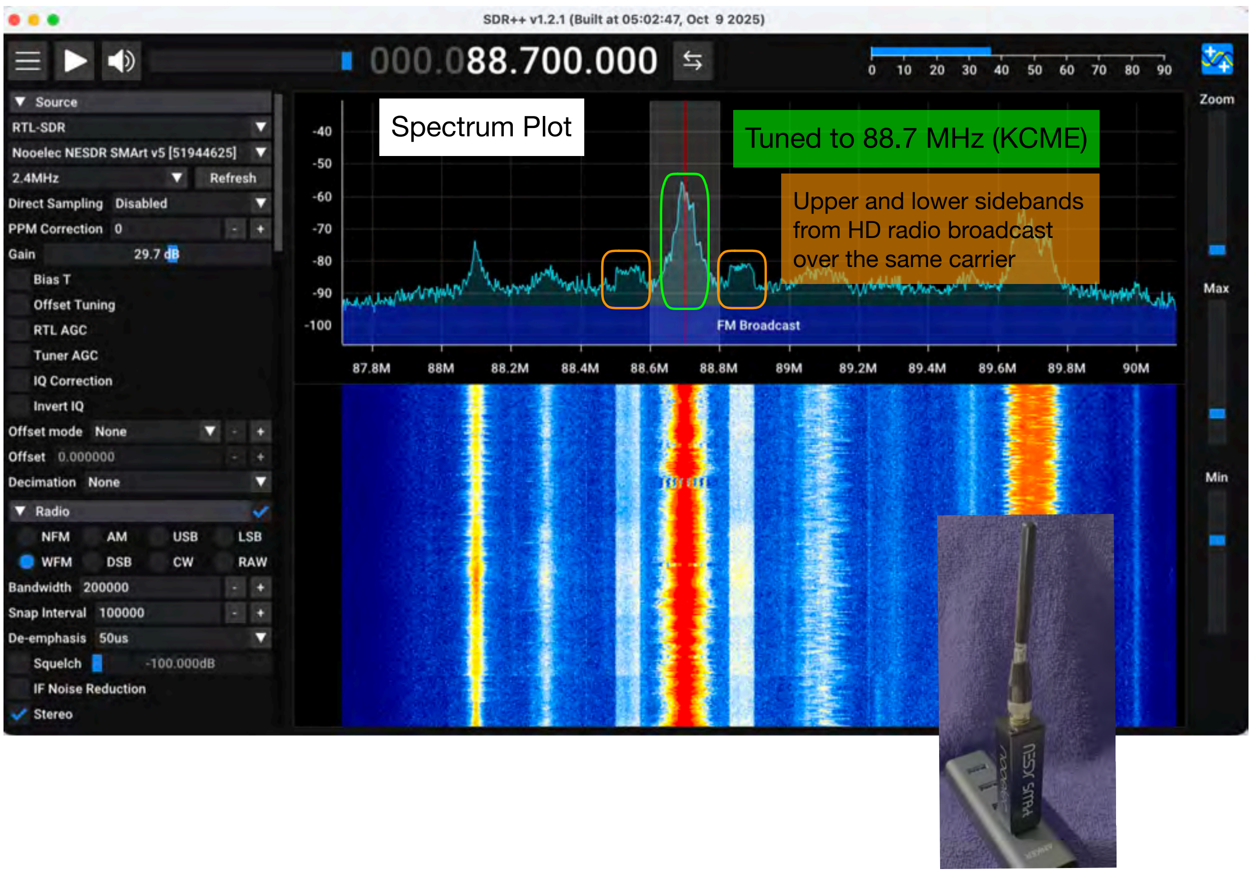
- In picture form consider:




A frequency domain view of the RTL-SDR

- A fun way to exercise the RTL-SDR is using the free app *SDR#* or *SDR++* as shown below

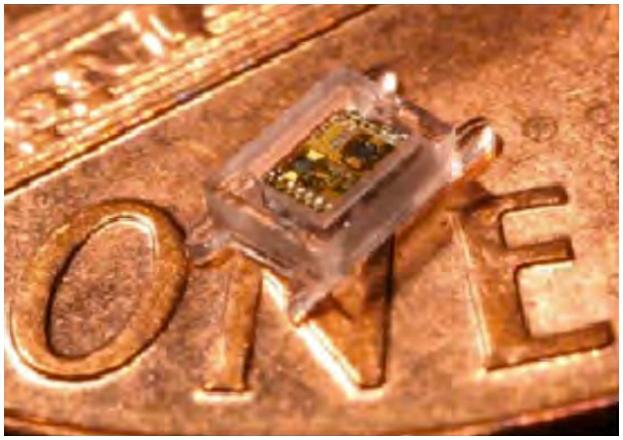
- Both apps provide a GUI interface to control the SDR and display the received signals




The SDR++ GUI and a photo of the newer nooelectric *neSDR SMArt*

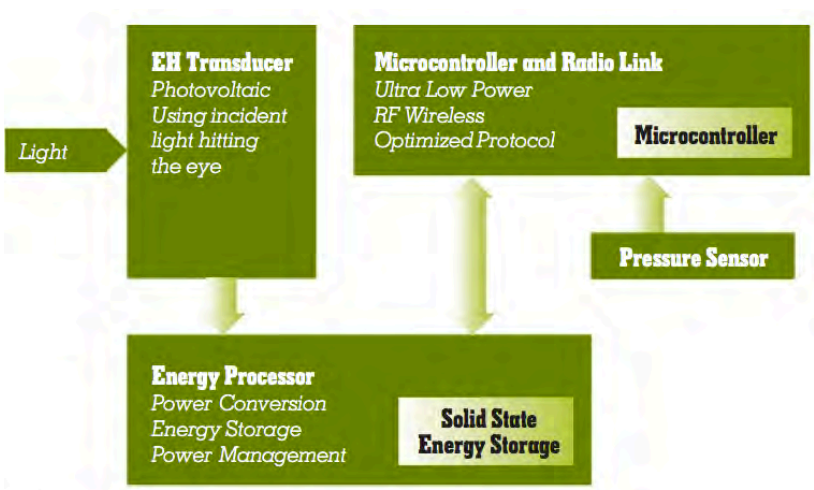
## Example 1.3: Wireless in the Eye

- A recent publication[3] describes a wireless sensor for intra-ocular pressure monitoring in the eye



The wireless sensor

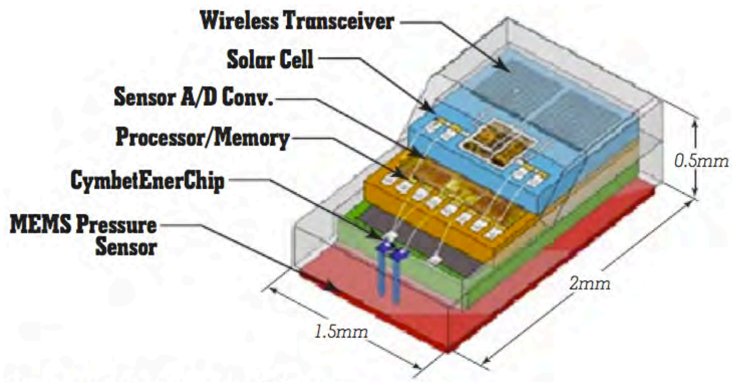
- The device is powered using ambient energy (light in this case) via a rechargeable thin film Li state battery

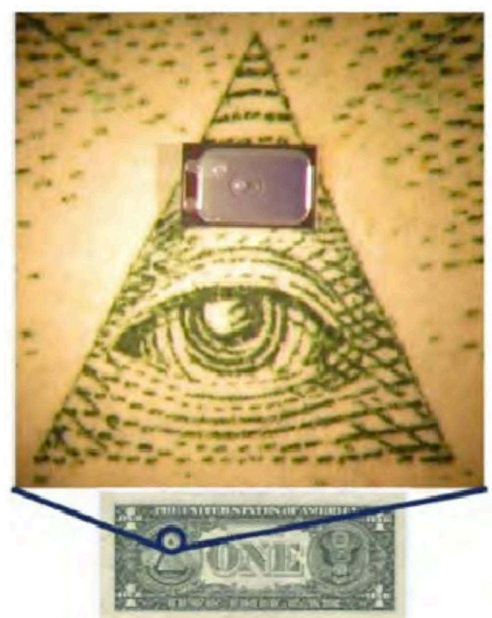



The system block diagram

[3]"Millimeter Scale Energy Harvesting," *EEPulse*, Issue 27, `http://www.eeweb.com/`

- The space constraint is 1.5 $mm^3$
- The energy chip stores 1 $\mu$Ah, 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 1$\mu$Ah battery