Electronics for Wireless
ECEN 2420

Prof. Zoya Popovic

- analog circuits and their components
- signal generation, modulation, filtering, amplification, control, reception, down-conversion, demodulation
- not much point without some lab work
Class organization

- NorCal 40A 7-MHz superheterodyne transceiver
- Homework lab session: Monday 6:15-9:15pm
- Instructor: Prof. Zoya Popovic, ECOT 252, do not email me please
- Lectures: MWF 1 – 2pm, Benson BESC 185
- Office hours: M, W 2-3pm and by appointment
- Undergraduate assistants: Andrew Wylde, Matthew Cullen

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Homework (in lab session)</td>
<td>40%</td>
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<tr>
<td>Final exam</td>
<td>30%</td>
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<tr>
<td>Midterm</td>
<td>15%</td>
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<tr>
<td>Participation</td>
<td>25%</td>
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<tr>
<td>Total</td>
<td>110%</td>
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Class work

Homework for this class is structured as follows:

• One homework session per week will be held on MONDAYS at 6:15pm in the circuits lab. You will receive a printed set of exercises to fill out as you are doing the lab.

• Every student needs to hand in their own writeup at the end of each homework session. If you turn in one for the group, you will each receive 1/N of the credit, where N is the number of group members.

• I will plan on finishing by 9:15pm, but sometimes we will be done earlier and sometimes a bit later. The first homework session is on January 18th.

• You are expected to spend another few hours per week reading the book or other material I give you.

• To summarize, there is no formal homework. The classwork consists of building a functional 7-MHz radio and understanding how it works.

This week’s homework assigned January 11, due January 13:

– List all applications of wireless technology that you can think of, and bring the list to class for participation credit.
First 2420 class

All radios worked!
The world is wireless
50 Cell Phones Sold Per Second!

Economy
- Apple iPhones $50 billion in Q1 2015

Lifestyle
- >40% Americans make several calls per hour

Energy
- Telecom is 2% of carbon emission (same as aviation)

The number of mobile phones exceeded the number of people on planet Earth in October 2014
By the end of 2015, 7 billion mobile phone subscriptions

Earth population ~7.2 billion
Outline for today

• Where is wireless/radio technology used
• How we got here (smart people and hard work)
• What are the current technical challenges
• What your professor works on
Wireless – radio – applications

Communications with no tethers

Radio

Electronics

Antenna

Digital electronics
Processing
Power management
Antennas everywhere...
The story of a text message

Type message to a friend

Your phone modulates the RF carrier (2GHz wave) and transmit through antenna to base-station

Sends message through a fiber by modulating an optical wave

Message sent to Wireless Access Point for routing

Call routed to backhaul (wired or wireless)

This happens in $\frac{1}{20}^{\text{th}}$ of a second!

Another base-station sends a radio signal to your friend’s phone.

The friend’s phone radio receives the signal, demodulates it and types the message
The Electromagnetic Spectrum

Our work
Wireless – radio – applications

RFID

Localization

GPS

Navigation

Weather
Wireless – radio – applications

Defense and Security

Synthetic aperture radar image of the Pentagon
Wireless applications

**Medicine**
- Wearable sensors
- Hyperthermia
- Tumor ablation
- MRI

**Cooking**
- Smart solid-state ovens

**Industrial**
Wireless – radio – applications

Physics and Astronomy

Wilson and Penzias
Nobel, 1978

VLA measures Einstein gravitational lenses

Archeology / Geology

Zoya Popovic, University of Colorado, Boulder, 2016
Deep Space Network

Jet Propulsion Laboratory | California Institute of Technology

DEEP SPACE NETWORK NOW

NHPC  MMS2  DAWN

MADRID
SEP 14
7:55 PM

63  65  54  55

MVN  MRO  MOM  MEX  DSN  ROSE

GOLDSTONE
SEP 14
10:55 AM

14  15  24  25  26

GTL  NSYT

CANBERRA
SEP 15
3:55 AM

43  45  34  35

ROSETTA

SPACECRAFT
NAME
Rosetta
RANGE
266.62 million km
ROUND-TRIP LIGHT TIME
29.64 minutes
ANTENNA
NAME
DSS 26
AZIMUTH
+ more detail
Magellan Mission to Venus: Radar planetary mapping

Highest peak: Maxwell Mons (11km)

False-color radar image of Ma’at Mons
History of Wireless = Electromagnetics and Circuits

- started in ~600b.c. in ancient Greece (Thales from Miletus)
- in the 18th, 19th and 20th century:
  - Coulomb (unit for charge)
  - Volta (unit for voltage)
  - Ampere (unit for current)
  - Faraday (unit for capacitance)
  - Henry (unit for inductance)
  - Hertz (unit for frequency)
  - Oersted (formerly unit for magnetic flux)
  - Tesla (unit for magnetic field)

Maxwell (no unit!), but very important.
Electricity

Thales of Miletus (600 B.C) observed separation and attraction of electric charges. In the same geographical area, the phenomenon of magnetism was noticed with magnetic ore.
22 centuries later…

- William Gilbert (1540-1603) repeated the experiments and coined the word “electron”
- Benjamin Franklin (1706-1790) introduced terms “positive” and “negative” for electric charges
Electric force and current

Charles Augustin de Coulomb (1736 – 1806)

- Luigi Galvani (1737-1798)
- Animal electricity
- Experiments with current stimulation of frog leg nerves
Generating electrical power

Alessandro Volta (1745-1827)

First battery: (1800) zinc and copper disks separated by leather soaked in vinegar.

Tela’s Niagara Falls power plant (about 100 years later)
Magnetism and electromagnetism

Hans Christian Oersted  
(1777-1851)

Michael Faraday  
(1791-1867)  
The makers of radio

The scientists

James Clark Maxwell (1831 – 1879)
Oliver Heaviside (1850 – 1925)
Heinrich Hertz (1857 - 1894)
Edwin Armstrong (1890-1954)

The businessmen

Lee DeForest (1873-1961)
Guglielmo Marconi (1874-1937)
Nikola Tesla (1856-1943)
The first radio engineer

First Radio Wave Propagation Demonstrations

Tesla’s first UAV
Radio changed ship traffic

1909, SS Republic
1700 lives saved
Radio changed ship traffic

Titanic, Radio call sign: MGY
Mobile phones shrunk quickly

Marconi, 1930s

Bell Labs, 1970s

Erickson, 1980s
Everywhere, smaller and more powerful
Current challenges

• More information and connectivity
  ➢ Bandwidth

• Energy / power
  ➢ Reduce power consumption
    • More efficient circuits
    • Miniaturize
    • Manage heat
    • Better manufacturing and recycling
  ➢ “Mobile” energy

• New applications for radio
  – Medical
  – Industrial
  – Who knows?

Power amplifier of transmitter consumes most of the power

• Each sector: 100W
• 50% efficient
• 4x less heat
• Less $ and CO₂
Better energy efficiency

- Better amplifier design (efficiency > 80%)
- Miniaturization – higher level of integration
- New semiconductors (GaN)
- New amplifier architectures

Power loss = voltage x current

DC (Battery)

signal in

to

signal out

40W PA
4-18GHz
(with Prof. Filipovic)
New semiconductors (GaN): “Star” power amplifiers

2GHz, ~10W, 83% efficiency

3.8mm x 2.3mm chip

10GHz, ~10W, 68% efficiency

New challenges:
- Bandwidth
- Power
More information: complex signals

High efficiency

Low efficiency

DC (Battery)

signal in

signal out

Change battery voltage very fast
First integrated PA and dynamic power supply

Integrated very efficient radio PA with very fast dynamic power supply
Collaboration with CoPEC (Prof. Dragan Maksimovic)

~ 3mm x 5mm

For a broadband 4G signal
- on average >22 points efficiency improvement!
- 3 x less heat
Current challenges

• More information and connectivity
  – Bandwidth
• Energy / power
  – Reduce power consumption
  – “Mobile” energy
• Solving new problems
  – Safety
  – Medical
  – Industrial

Wireless powering and the “Internet of things”
Wireless powering

- High power
- Near field
- Challenge: efficiency

- Low power far-field
- Sensors (IoT)
- Challenge: small, cheap

With CoPEC, Prof. Afridi
Harvesting ambient RF power

Powering wallpaper

Autonomous monitoring
Some low-power applications

Low duty cycle patient health monitoring sensors

Aircraft wing corrosion monitoring

Sensors for “green” buildings

Monitoring mold, HVAC flow, occupancy, light level, etc.
Safety

Is it SAFE?

Typical Exposures provided by the World Health Organization (WHO)

- Microwave Oven: 50 mW/cm²
- Cell Phone: 50 mW/cm²
- Radars: 20 mW/cm²
- TV/Radio Transmitters: 10 mW/cm²
- RF Power Transmitter: 20 µW/cm²

Anesthetized mouse with inhibited thermal regulation

1-degree increase!
Safety: active vs. passive

Our bodies absorb radio waves
- EM simulation for antenna design (IT’IS, ETH Zurich)

But, they also EMIT radio waves
- This can be detected passively

With Dr. Grossman, NIST
Medical applications

High magnetic field MRI
• Large bore, patient comfort
• Higher resolution
• Increased signal

Internal body temperature measurements
• Heavy training
• Cancer cells and Inflamed tissues
• Sleeping disorders
• Tissue ablation monitoring
Radiometer thermometers

- Everything emits EM waves at all frequencies
- Function of temperature
- Low radio frequencies pass through the body ~5cm
- Measure RF power externally, determine temperature by signal processing

Proof of concept: 0.5K accuracy
The final frontier

Entry Phase

- h = ~3522 km
- t = 0
- Deploy Supersonic Parachute
- Heat-shield Separation
- Entry Balance Mass Jettison
- Radar Activation and Mobility Deploy
- Back-shell Separation
  - t = 309 s
  - h = ~800 m AGL

Supersonic Parachute Descent

- h = ~8 km
- t = 247 s

Powered Descent

- h = ~19 m
- t = 341 s
- Rover Touchdown

Sky Crane

- h = ~8 m

Flyaway

Landing of Curiosity on Mars

Zoya Popovic, University of Colorado, Boulder, 2016
Mars landing radar

Radar operating ~30GHz
~ 1m x 0.5m x 5cm
200-GHz antenna for new miniaturized landing radar

32 x 32 element array

6cm x 6cm

Beam scanning detects obstacles on surface
The future

Low-power efficient autonomous radio nodes

Diagnosing

Communicating

Exploring

Controlling, healing, entertaining, ....

Wearing

keeping us busy!