Lab 1: RF Spectrum
Today

• Frequency, wavelength
• Antennas
• RF exposure
Frequency and Wavelength
Wavelength and Frequency

- wavelength = (speed of light) × (period)
- wavelength = (speed of light) / (frequency)

If we measure speed in $10^6$ m/s, and frequency in MHz, then

$$\text{wavelength (in m)} = \frac{300}{\text{frequency (in MHz)}}$$
Finding Wavelengths

• What are the wavelengths for
  • Citizens band ~30 MHz
  • FM radio ~100 MHz
  • Cell phone ~900 MHz
  • WiFi ~ 2.4 GHz and 5.5 GHz
Finding Frequencies

• What are the frequencies for
  • 33 cm ISM band
  • 2 m Amateur band
  • 60 m shortwave band
  • 200 m AM band
UNITED STATES FREQUENCY ALLOCATIONS
THE RADIO SPECTRUM

3 kHz — 3 MHz

3 MHz — 30 MHz

30 MHz — 300 MHz

300 MHz — 3 GHz

3 GHz — 30 GHz

30 GHz — 300 GHz
Non-Federal Travelers Information Stations (TIS), a mobile service, are authorized in the 535-575 kHz band. Federal TIS operates at 150 kHz.
Amateur Bands
Antennas
Resonance

Tuning Fork

Pendulum
Pendulum

- Think of it as a swing
- How often should you push?
- When should you push?
- How hard/long should you push?
Pendulum, Input

- Push once per cycle works well
- How about twice per cycle?
- Once every two cycles?
- Only certain frequencies couple energy into the system
Resonant Antennas

- Current flows along conductor
- Electric and magnetic fields propagate at the speed of light
- We’d like the antenna round trip to match the transmit frequency

\[ E(t) \quad i(t) \quad H(t) \]
Dipole Antenna

- Drive the antenna at center, offset
- Sets the input impedance
Dipole Antenna

- Sinusoidal input sets up half cycle of current along antenna

- Length should be 1/2 wavelength for the frequency

\[ i(t,x) \]

![Diagram of Dipole Antenna](image)
Dipole Antenna

- Oscillating electric field propagates away from antenna
Dipole Antenna

- Length is 1/2 wavelength of the transmit carrier frequency
- For 150 MHz one wavelength is 2 m, and the antenna should be 1 m long
- For 450 MHz, one wavelength is 67 cm, and the antenna should be 33 cm long
Dipole Radiation Pattern

Horizontal

Horizontal

Vertical
Polarization

- Polarization is the direction of the electric field (horizontal, vertical, circular)

- A horizontal dipole has a horizontal polarization

- A vertical dipole has a vertical polarization

- If the transmitting and receiving antennas have different polarizations, there can be a very large signal loss
1/4 Wave Vertical Antennas

- Conducting surfaces (the earth, your car roof) act as current mirrors
- You get the second half of the antenna for free!
Key Points

- **Half-Wave Dipole**
  - Usually horizontal
  - Driven at middle
  - Half wavelength

- **Quarter Wave**
  - Usually vertical
  - Driven at end
  - Quarter wavelength
How Long are These?

- 1/4 wave FM antenna (100 MHz)
- 1/2 wave TV antenna (300 MHz)
- 1/4 wave WiFi antenna (6 GHz)
- 1/4 wave cell phone antenna (600 MHz)
- 1/4 wave shortwave antenna (3 MHz)
RF Exposure
RF Exposure

- Exposure to high levels of RF can cause problems.
- If precautions are taken, RF exposure is minimal and not dangerous.
- Problem is RF energy can heat body tissues.
- Heating depends on the RF intensity and frequency.
RF Power Density

- Actual transmitter power.
- Antenna gain and proximity.
- Transmission duty cycle.
Antenna Proximity

- Controlled Environment:
  - People know what they are doing, and that the RF is there
  - Higher power allowed

- Uncontrolled Environment:
  - You have no idea, or have no control of people near your antenna.
  - Less power is allowed because you have to assume the worse case scenario.
RF Exposure and Frequency

- When body parts act like antennas, those parts absorb RF energy at certain frequencies (wavelengths) more efficiently and increase risk.

- RF exposure risk varies with frequency.

- More caution is dictated at some frequencies more than other frequencies.

- At what frequencies are you a 1/2 or 1/4 wave dipole? Assume you are 2 m tall, for simplicity.
RF Exposure and Frequency

- Controlled
- Uncontrolled

Power Density (mW/cm²)

Frequency (MHz)

0.3 1.34 3.0 30 300 1500 100,000

0.1 1 10 100

5.0

ARRL0047
RF Exposure and Frequency

• You will see this plot in almost every FCC filing.

• Does the specific device in question produce heating above the standard spec?

• This doesn’t address other ways that RF might interact with tissue. These are still research topics, and under very active research.

• However, we’ve done a very large population study, and any negative effects are exceedingly difficult to find.