

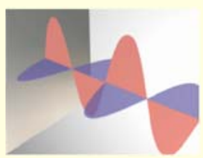

Radio Waves

Electromagnetic Radiation
Radio Transmission and Reception
Modulation Techniques

Electromagnetism

- Electricity and magnetism are different facets of *electromagnetism*
  - recall that a static distribution of charges produces an electric field
  - charges in *motion* (an electrical current) produce a magnetic field
  - a *changing* magnetic field produces an electric field, moving charges
- Electric and Magnetic fields produce forces on charges
- An *accelerating* charge produces electromagnetic waves (radiation)
- Both electric and magnetic fields can transport energy
  - Electric field energy used in electrical circuits & released in lightning
  - Magnetic field carries energy through transformer

Electromagnetic Radiation



- Interrelated electric and magnetic fields traveling through space
- All electromagnetic radiation travels at $c = 3\times10^8$ m/s in vacuum – *the* cosmic speed limit!
  - real number is 299792458.0 m/s *exactly*

Examples of Electromagnetic Radiation

- AM and FM radio waves (including TV signals)
- Cell phone communication links
- Microwaves
- Infrared radiation
- Light
- X-rays
- Gamma rays
- What distinguishes these from one another?

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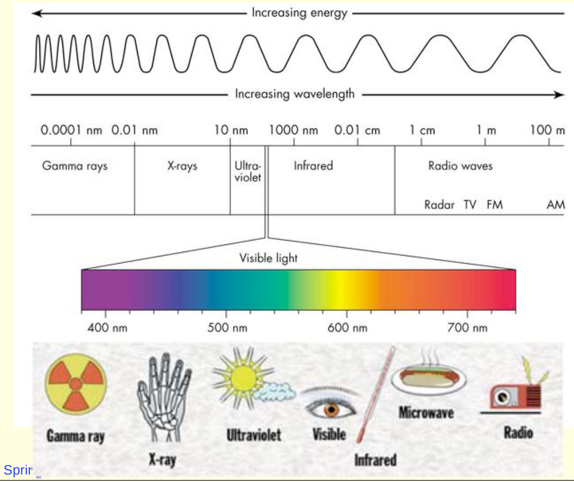
Wavelength (Frequency)



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The Electromagnetic Spectrum

- Relationship between frequency, speed and wavelength

$$f \cdot \lambda = c$$

f is frequency, λ is wavelength, c is speed of light

- Different frequencies of electromagnetic radiation are better suited to different purposes
- The frequency of a radio wave determines its propagation characteristics through various media

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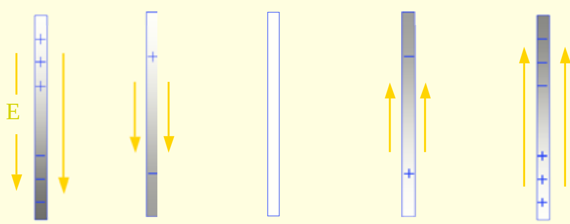
Generation of Radio Waves

- Accelerating charges radiate EM energy
- If charges oscillate back and forth, get time-varying fields



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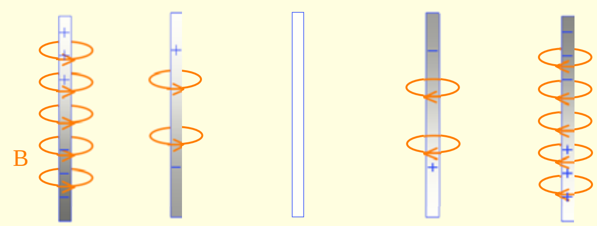
Generation of Radio Waves

If charges oscillate back and forth, get time-varying magnetic fields too. Note that the magnetic fields are perpendicular to the electric field vectors



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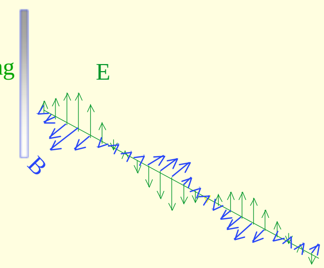
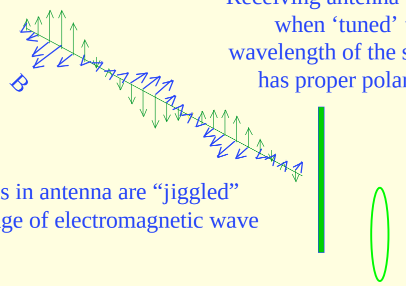
Polarization of Radio Waves

Transmitting antenna



Reception of Radio Waves



Receiving antenna works best when ‘tuned’ to the wavelength of the signal, and has proper polarization

Electrons in antenna are “jiggled” by passage of electromagnetic wave

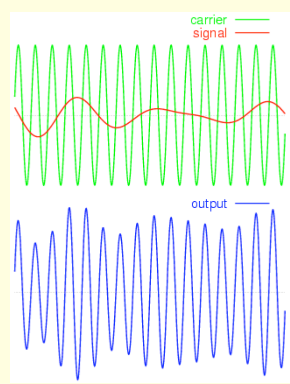
Optimum antenna length is $\lambda/4$: one-quarter wavelength

Encoding Information on Radio Waves

- What quantities characterize a radio wave?
- Two common ways to carry analog information with radio waves
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM): “static free”

AM Radio

- Amplitude Modulation (AM) uses changes in the signal *strength* to convey information



pressure modulation (sound)

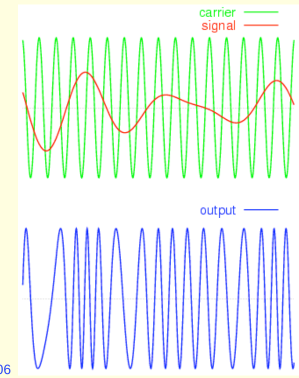
electromagnetic wave modulation

AM Radio in Practice

- Uses frequency range from 530 kHz to 1700 kHz
  - each station uses 9 kHz
  - spacing is 10 kHz (a little breathing room) → 117 channels
  - 9 kHz of bandwidth means 4.5 kHz is highest audio frequency that can be encoded
    - falls short of 20 kHz capability of human ear
- Previous diagram is exaggerated:
  - audio signal changes slowly with respect to radio carrier
    - typical speech sound of 500 Hz varies 1000 times slower than carrier
    - thus will see 1000 cycles of carrier to every one cycle of audio

FM Radio

- Frequency Modulation (FM) uses changes in the wave's *frequency* to convey information

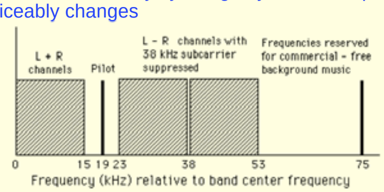


pressure modulation (sound)

electromagnetic wave modulation

FM Radio in Practice

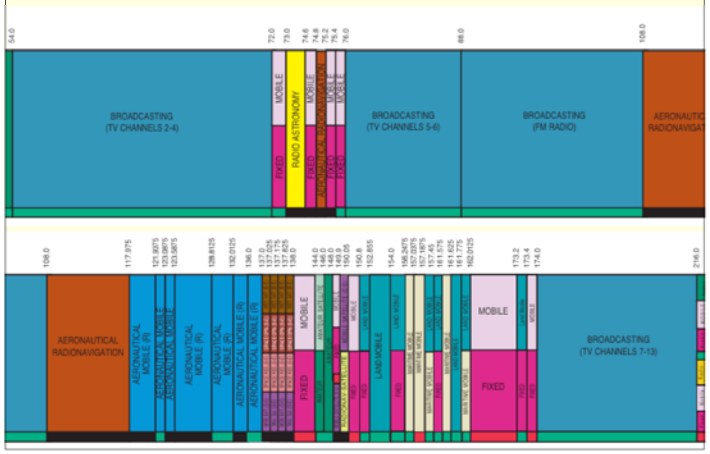
- Spans 87.8 MHz to 108.0 MHz in 200 kHz intervals
  - 101 possible stations
  - example: 91X runs from 91.0–91.2 MHz (centered at 91.1)
- Nominally uses 150 kHz around center
  - 75 kHz on each side
  - 30 kHz for L + R (mono) → 15 kHz audio capability
  - 30 kHz offset for stereo difference signal (L - R)
- Again: figure exaggerated
  - 75 kHz from band center, modulation is > 1000 times slower than carrier, so many cycles go by before frequency noticeably changes



AM vs. FM

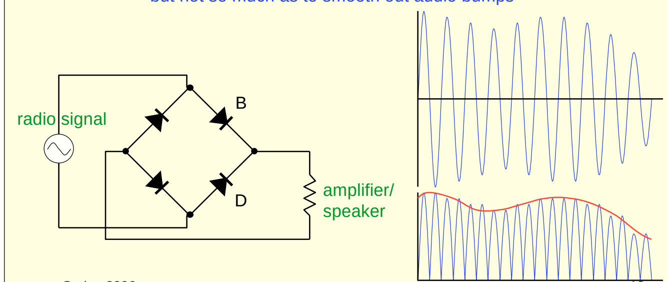
- FM is not inherently higher frequency than AM
  - these are just choices
  - aviation band is 108–136 MHz uses AM technique
- Besides the greater bandwidth (leading to stereo and higher audio frequencies), FM is superior in immunity to environmental influences
  - there are lots of ways to mess with an EM-wave's amplitude
    - pass under a bridge
    - re-orient the antenna
  - no natural processes mess with the frequency
    - FM still works in the face of amplitude foolery

Frequency Allocation



Converting back to sound: AM

- AM is easy: just pass the AC signal from the antenna into a diode
  - or better yet, a diode bridge
  - then use capacitor to smooth out bumps
    - but not so much as to smooth out audio bumps



Converting back to sound: FM

- More sophisticated
  - need to compare instantaneous frequency to that of a reference source
  - then produce a voltage proportional to the difference
  - Compute L = [(L+R) + (L-R)]/2; R = [(L+R) - (L-R)]/2
  - amplify the L and R voltages to send to speakers
- Amplification is common to both schemes
  - intrinsic signal is far too weak to drive speaker

Assignments

- HW5: 12.E.24, 13.E.13, 13.E.15, 13.E.16, 13.P.7, 13.P.9, 13.P.11, plus additional required problems available on website