ELEN 3401 Electromagnetics
Project Topic List

Please choose a project topic from the list below or create your own. If you decide to choose a topic not on the list, email your suggestion to the TAs Brett (bcg2133@columbia.edu), Brian (zw2542@columbia.edu), and Professor Bergman for approval by noon of Thursday March 27.

Topic selections and teams are due **Friday March 28**.

1. Fiber Optics
Without fiber optics, the internet as we know it today most likely would not exist. Optical fiber supports incredibly high bandwidth data transmission over tens of thousands of kilometers with the addition of optical amplification, enabling global communication on a massive scale. This project should address the fundamentals of guided waves, fiber modes, dispersion, amplification (EDFAs), and current telecommunication fiber standards.

2. Medical Imaging
Imaging is ubiquitous in medicine—since the advent of X-ray radiology, imaging techniques and technologies have become increasingly sophisticated to cover a wide range of diagnostics. This project should address the interaction of electromagnetic waves with human tissue/bones as well as different imaging technologies (MRI, radiography, etc.) focusing on their physical principles but also including their broader medical applications.

3. OLEDs
Modern displays recently underwent a major shift from LCD (liquid crystal display) technology to now primarily LED (light emitting diode). OLEDs are a subset of LEDs that use organic compounds for the emissive electroluminescent layer of the diodes and are found in many high-end televisions and mobile devices. This project should address the physical mechanism behind how OLEDs emit light, the differences between standard LED and OLED displays, and how they are fabricated.

4. RF Antennas
Shortly after James Clerk Maxwell predicted electromagnetic waves in 1864, the first antenna was built by Heinrich Hertz in 1888. Since then, radio has been a mainstay in communication systems around the world. Despite its age, RF remains a rich field with the introduction of Wi-Fi networks and 4G LTE along with many other contemporary advances. This project should address the physical fundamentals of how antennas transmit and receive electromagnetic radiation, different types of antennas, and how data is encoded into the radiation (modulation).

5. LIDAR
LIDAR (light detection and ranging) uses pulsed laser light to gather spatial information (location and speed) by measuring how the light is reflected back to the sensor. LIDAR has many important applications including high resolution imaging of the Earth's surface to create precise maps and the control of self-driving cars. This project should address the physics of LIDAR, the differences between incoherent and coherent regimes, the design of LIDAR systems, and its wide variety of applications.

6. Optical Metrology
Optical metrology is the study of measurements using light. In 2005, John L. Hall and Theodor W. Hänsch shared the Nobel Prize in Physics for the development of an ultra-precise spectroscopy technique using optical frequency combs. More recently, gravitational waves were detected by LIGO by precisely measuring the phase of light in an interferometer. Optical metrology is a rich and far-reaching field that is incredibly important in much of contemporary research. This project should give an overview of the field along with the detailed physics of some techniques and devices (e.g. optical clocks, interferometers, etc.) of the team's choice.

7. Integrated Photonics
Advances in nanoscale fabrication have enabled low-loss optics at the chip scale for applications in communication, computing, and sensing systems. In the coming years, silicon photonic interconnects will become ubiquitous in high performance computing and data center systems due to their small footprint, high bandwidth, and low energy dissipation. This project should address the fundamental physics of light propagation in dielectric waveguides, basic photonic devices (directional couplers, phase shifters, ring resonators), and applications of the team's choosing (potential directions are optical interconnects, integrated photonic sensors, etc.).

8. Solar Cells
Renewable energy has become an increasingly important area of research, and a large amount of solar energy hits the Earth's surface every day that can be captured and used. Solar cells absorb incident light and convert it to electrical energy with an efficiency that depends on the design and materials used. This project should address the physical mechanism behind solar cells including p-n junctions and semiconductor physics along with common materials used and efficiencies of current state-of-the-art systems.

9. Image Sensors
With the rise of smartphones, nearly everyone has a high-quality digital camera with them at all times. The image sensors in these handheld devices and other digital cameras are created with the same CMOS technology used to fabricate computer chips, and active-pixel sensor (APS) technology is rapidly advancing. This project should address the physical mechanisms of both APS and CCD sensors and their design/fabrication.

10. Free Space Optics

Like in fiber optics, in free space optics information is encoded on light and transmitted/received, but through air or space rather than confined in glass fiber. The field of free space optics offers promising solutions to problems such as overcrowding of RF signals, providing service to those that RF cannot reach, and interconnecting satellites in orbit. This project should address the physical mechanisms behind how light is modulated, transmitted, and received in free space optical devices along with potential applications of free space optical systems. Also discuss prevailing difficulties such as diffractive spreading and atmospheric conditions.

11. Photonic Computing

Photonic computing uses photons instead of electrons for data processing, offering advantages in speed, energy efficiency, and bandwidth. This project should explore the principles and applications of photonic computing, focusing on its key components, including waveguides, modulators, and resonators and other optical devices. Through simulations and theoretical analysis, this project should examine the potential and tradeoffs of photonic computing for high-performance applications, such as artificial intelligence and data-intensive computing