EGR 215 Topics in EE E&M

Electromagnetism, or E&M for short, started off being **about making electromagnetic radiation (transmitters to antennas**), and **receiving electromagnetic radiation (antennas to receivers**), the combination being wireless telegraphy, or radio, first developed by Marconi around 1896.

Then in 1930 someone noticed a problem with radio reception when an airplane flew between transmitter and receiver, and radar (radio detection and ranging) was discovered.

But really, **E&M is the fundamental (physically correct) way electrical things REALLY work**, i.e. when our lumped approximation breaks down, E&M still works. **E&M is the application of Maxwell's equations** to reality. They are:

Gauss's law of electricity $\varepsilon_o \oint \mathbf{E} \cdot d\mathbf{A} = q$ (You can find Ohm's law hidden here.)

Gauss's law of magnetism $\oint \mathbf{B} \cdot d\mathbf{A} = 0$

Ampere-Maxwell Law $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_o \left(\varepsilon_o \frac{d\Phi_E}{dt} + i \right)$

Faraday's Law $\oint \mathbf{E} \cdot d\mathbf{l} = -\frac{d\Phi_B}{dt}$

If you feel a certain visceral thrill at the prospect of solving these equations, E&M may be the right field for you.

Antennas convert from circuit parameters (voltage and current) to electromagnetic radiation and vice versa. The simplest antenna is just a length of wire. In the 1930s more powerful antenna were created by grouping lengths of wire in arrays. One type of antenna is the Yagi. Yagi was a professor in Japan in the 1930's. The antenna was actually invented by his graduate student, Uda, but Yagi got all the credit. (To his credit, he did not try to claim it - just everyone knew who Yagi was, but nobody new Uda.)

In 1963, Arno Penzias was a staff member of the radio research department of Bell Labs. He had a PhD in Physics from Columbia, but he basically worked as a high-powered radio engineer. His boss told him and his buddy Robert Wilson that Bell had a problem with electromagnetic noise interfering with satellite communication. So Penzias and Wilson went out to this huge horn antenna and started tightening up the noise situation. First they pointed it at an empty part of the sky to minimize external noise. Then they cleaned the bird poop off the antenna (several stories high), fixed all the holes, replaced the coaxial cable, etc, etc, etc. But there was always too much noise.

Finally they decided that they had run out of internal and local sources of noise, and still had too much noise, and went to talk to a colleague of Penzias' at Princeton (where he was an adjunct professor of Physics). The colleague, Robert Dicke, suggested that the noise was actually the background noise from the Big Bang. Sure enough it was, and

Penzias and Wilson got the Nobel Prize. Dicke, who had made a theoretical prediction that the noise would be found, and was constructing a radio telescope to observe it when Penzias brought in his result, got zilch. (In fairness to Penzias, he had realized what he was probably looking at before he went to Dicke and showed that the spectrum matched the expected shape from the Big Bang.)

Things are antennas whether you want them to be or not. This is the basis for the interest in E&M on microprocessors. The conductive strips of metal on integrated circuits are fine antenna at 1 GHz, and they both send and receive radiation - meaning that when you send a 1 down one conductor, a 1 might also arrive along the conductor next to it! This **crosstalk** is becoming a major concern in chip design, and E&M analysis of chip layouts is a difficult computational problem.

Radar works by bouncing electromagnetic waves off of other objects, and listening to the direction and time delay of the echo. The Döppler effect can also tell you the velocity of the target from the frequency shift of the echo. Radar was a good example of a solution looking for a problem for a long time. The first radar-related patent was issued to a German engineer in 1904(!). In 1922 the US Naval Research Lab demonstrated that a ship passing between a transmitter and a receiver caused a change in reception, and suggested this could be used for detection or navigation. The admirals yawned and told the scientists to think of something else.

In 1930 the NRL "rediscovered" radar when a scientist noticed that an airplane flying around caused radio interference. The admirals still yawned, but the scientists would not give up. They figured out how to put the transmitter and receiver on the same antenna (needs a fast switch) and had radar installed on a battleship by 1938. It was a supersecret project to make a secret weapon that would win the war.

Unfortunately, Great Britain, Germany and Japan also had supersecret war winning radar projects underway in the 1930's. Technically German radar was the best, with radar on a battleship in 1936, and consistently better (higher frequency, better resolution, higher range, more reliable) radars. Britain's radar was not as advanced, operating at a frequency that was really too low and requiring trailers of electronics (vacuum tubes at the time) and huge antennas 300 feet high, and just barely getting into operation in time for the war. But British integration of radar into their air defense system was the most advanced, and it helped them win the vital Battle of Britain in the summer of 1940.

At which point Germany decided the war was won and there was no further need to develop radar, while Great Britain and especially the US forged ahead. By 1943 radar fit into airplanes, and by 1945 into 40mm anti-aircraft shells.

E&M is more than electromagnetic radiation. Coaxial cable is coax due to E&M. Insulation design depends on E&M. **Superconductivity, where resistance of certain substances goes to zero at low temperatures**, is fundamentally an electromagnetic phenomena. Optics, and **photonics, the interaction of visible light and electronics**, are both basically electromagnetic phenomenon.

Communication Theory

Communication theory, or information theory, deals with the transfer of information from one place to another by various means. Theoretical interest in communications theory started with the telegraph in 1841. For some reason it worked better if the wires were on poles instead of laying on the ground--which stimulated thought on the topic. Interest heightened with the telephone, and later radio's AM and FM were different methods of encoding signals. However, all of this work was narrowly focused on making the electrical systems work.

Communications theory finally got a start in 1924 when Harry Nyquist at Bell labs discovered that there was a theoretical maximum transmission rate over communications channels that was a function of **bandwidth, the range of frequency that can be sent over the channel**. Nyquist is with us today reminding us to sample analog signals at twice the rate of the highest frequency of interest (the Nyquist criterion).

In 1928 R.V.L. Hartley, also at Bell labs, published a paper on "Transmission of Information" that was the foundation of information theory. In 1948 Claude V. Shannon, also of Bell labs, built a towering and complete edifice on this foundation when he published the monumental article "The mathematical theory of communications" in the Bell labs technical journal. It basically stated every major theorem of interest in the field of communications theory, AND proved them all. Among other things, Shannon realized that ***meaning*** **and** ***information*** **are separate. Information (in bits) can be engineered while meaning is in the eye of the reader**. For example, 31 is an ASCII A. It is also three times 10 plus one. The information is still 00110001, but the meaning depends on context and the reader. Shannon also showed that **you could guarantee perfectly accurate transmission even in the presence of noise by correctly encoding the signal**.

Since then communications engineers have been sweeping up the debris from the construction project and generating applications like:

Cell phones
Packet switched computer networks
Other kinds of computer networks (X.10, token ring, etc.)
Optical fiber communications
etc.

Hedy Lamarr from www.msencarta.co

Finally, we can't leave communication theory without mentioning Hedy Lamarr. Born in Austria, Hedy was an actress who became scandalously world-famous for her nude scene in the 1933 Czech movie *Extasy*. The film was excommunicated by the Pope, banned by Hitler in Germany and also banned in the USA. Hedy subsequently married a rich Nazi who tried to buy up and destroy every copy of the film in existence (Mussolini would not sell). Banking on her fame, Hedy got a fat Hollywood contract and came to the US to make movies starting in the late 1930's. Her biggest hit was *Samson and Delilah* in 1949. She turned down the lead in *Casablanca*.

In 1940 Hedy teamed up with composer George Antheil to suggest a method of unjammable communications to remotely control torpedoes. The application is silly on the face of it. Torpedos run underwater and can't receive radio signals. But the concept was highly valuable. The idea was to have a transmitter-receiver pair that would shift the frequency they operated on rapidly and in synchronization. Thus anyone attempting to jam the signal would have to shift the frequency of the jammer. The system had enough redundancy to get the information it needed through between the time of frequency shift and the time the jammer shifted. The shifting was coordinated with player piano rolls!

Although never built, the patent was the basic technology for secure spread-spectrum communication technology in use today.

Hedy died in Florida in 2000.

Sources

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