ECE 604, Lecture 28

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Contents

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1 Types of Antennas

There are different types of antennas for different applications. We will discuss their functions heuristically in the following discussions.

1.1 Resonance Tunneling in Antenna

A simple antenna like a short dipole behaves like a Hertzian dipole with an effective length. A short dipole has an input impedance resembling that of a capacitor. Hence, it is difficult to drive current into the antenna unless other elements are added. Hertz used two metallic spheres to increase the current flow. When a large current flows on the stem of the Hertzian dipole, the stem starts to act like inductor. Thus, the end cap capacitances and the stem inductance together can act like a resonator enhancing the current flow on the antenna.

Some antennas are deliberately built to resonate with its structure to enhance its radiation. A half-wave dipole is such an antenna as shown in Figure 1. One can think these antennas are using resonance tunneling to enhance their radiation efficiencies. A half-wave dipole can also be thought of as a flared open transmission line in order to make it radiate. It can be gradually morphed from a quarter-wavelength transmission line as shown in Figure 1. A transmission is a poor radiator, because the electromagnetic energy is trapped between two pieces of metal. But a flared transmission line can radiate its field to free space.

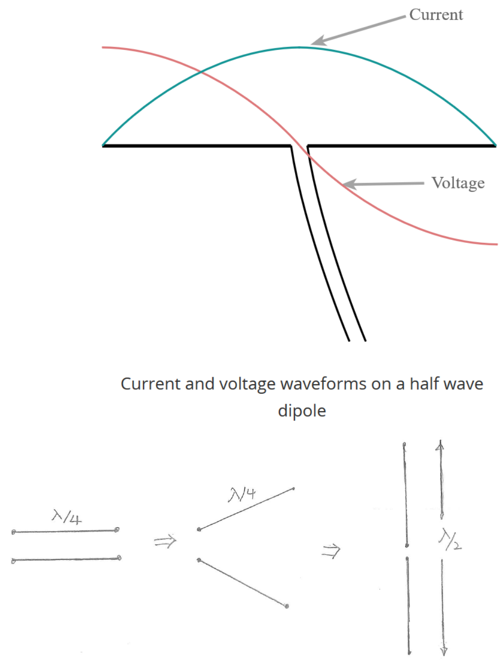


Figure 1: Courtesy of electronics-notes.com.

The disadvantage of a half-wave dipole is that it has to be at least about half a wavelength before it radiates well. Engineers are creative, and they invent the folded dipole. For antennas of the same size, a folded dipole can resonate at a lower frequency because the current does not stop abruptly at its two ends. Figure 2 shows a Yagi-Uda antenna driven by a folded dipole.

Figure 2: Courtesy of Wikipedia.

A Yagi-Uda antenna is also another interesting invention. It was invented in 1926 by Yagi and Uda in Japan by plainly using physical intuition. Physical intuition was a tool of engineers of yesteryears while modern engineers tend to use sophisticated computer design software. Surprisingly, the elements of dipoles in front of the driver element are acting like a waveguide in space, while the element at the back acts like a reflector. Therefore, the field radiated by the driver element will be directed toward the front of the antenna. Thus, this antenna has higher directivity than just a stand alone dipole.

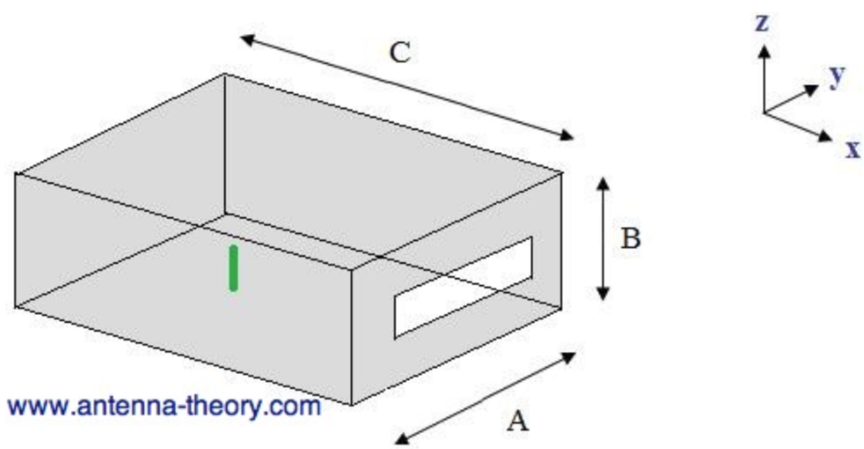


Figure 3: Courtesy of antenna-theory.com.

Another way to improve the radiation efficiency of antenna is to make it radiate via a cavity. A cavity-backed slot antenna uses such a concept and this is shown in Figure 3. A small dipole with poor radiation efficiency is places inside the cavity. When the operating frequency is close to the resonant frequency of the cavity, the field strength inside the cavity becomes strong, and much of the energy can leak from the cavity via the slot on its side. This makes the antenna radiate more efficiently into free space compared to the small dipole.

Another antenna that resembles a cavity backed slot antenna is the patch antenna, or microstrip patch antenna. This is shown in in Figure 4. This antenna also radiates efficiently by resonant tunneling. The resonant frequency of the patch antenna (top of Figure 4) is roughly when L is half a wavelength. This is similar to the resonant frequency of a transmission line with open circuit at both ends. The current sloshes back and forth across the length of the patch antenna along the L direction. The second design (bottom of Figure 4) has an inset feed. This allows the antenna to resonate at a lower frequency because the current has a longer path to slosh through when it is at resonance.

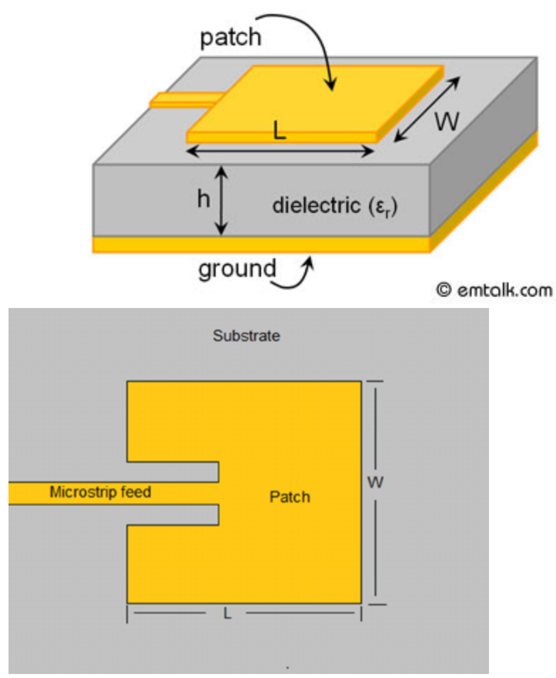


Figure 4: Courtesy of emtalk.com.

1.2 Horn Antennas

The impedance of space is 377 ohms while that of most transmission line is 50 ohms. This mismatch can be mitigated by using a flared horn (see Figure 5).

One can think that the characteristic impedance of a transmission line made of two pieces of metal as $Z_0 = \sqrt{L/C}$. As the horn flares, C becomes smaller, increasing its characteristic impedance to get close to that of free space. This allows for better impedance matching from the source to free space.

A corrugated horn, as we have discussed previously in a circular waveguide, discourages current flows in the non-axial symmetric mode. It encourages the propagation of the TE_{01} mode in the circular waveguide and hence, the circular horn antenna. This mode is axially symmetric. Hence, this antenna can radiate fields that are axially symmetric.

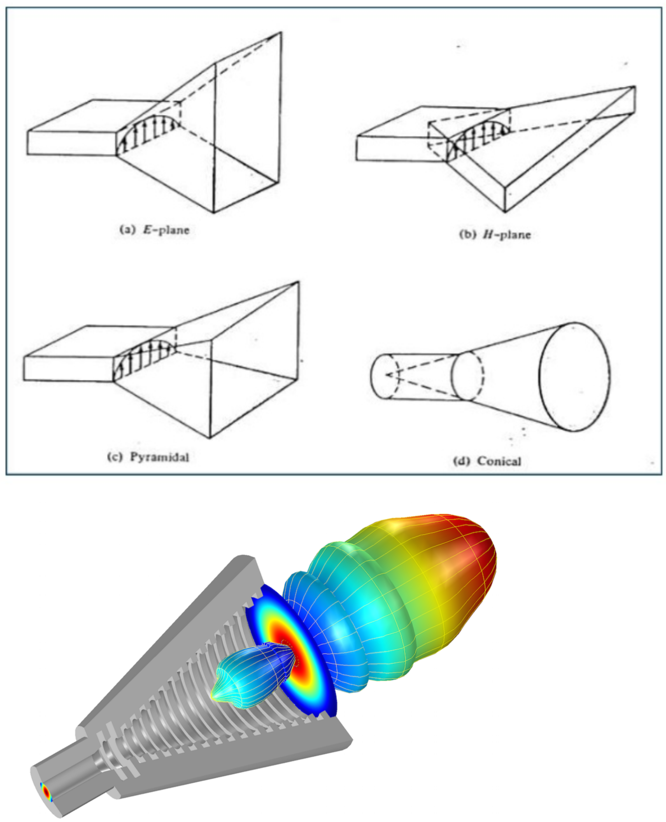


Figure 5: Courtesy of tutorialpoints.com and comsol.com.

A Vivaldi antenna (invented by P. Gibson in 1978), is shown in Figure 6. It is also called a notch antenna. It works by the same principle to gradually match the impedance of the source to that of free space. But such a gradually flared horn has the element of a frequency independent antenna. The low frequency component of the signal will radiate from the wide end of the flared notch, while the high frequency component will radiate from the narrow end of the notch.

Thus, this antenna can radiate well over a broad range of frequencies, and this gives the antenna a broad bandwidth performance. It is good for transmitting a pulsed signal which has a broad frequency spectrum.

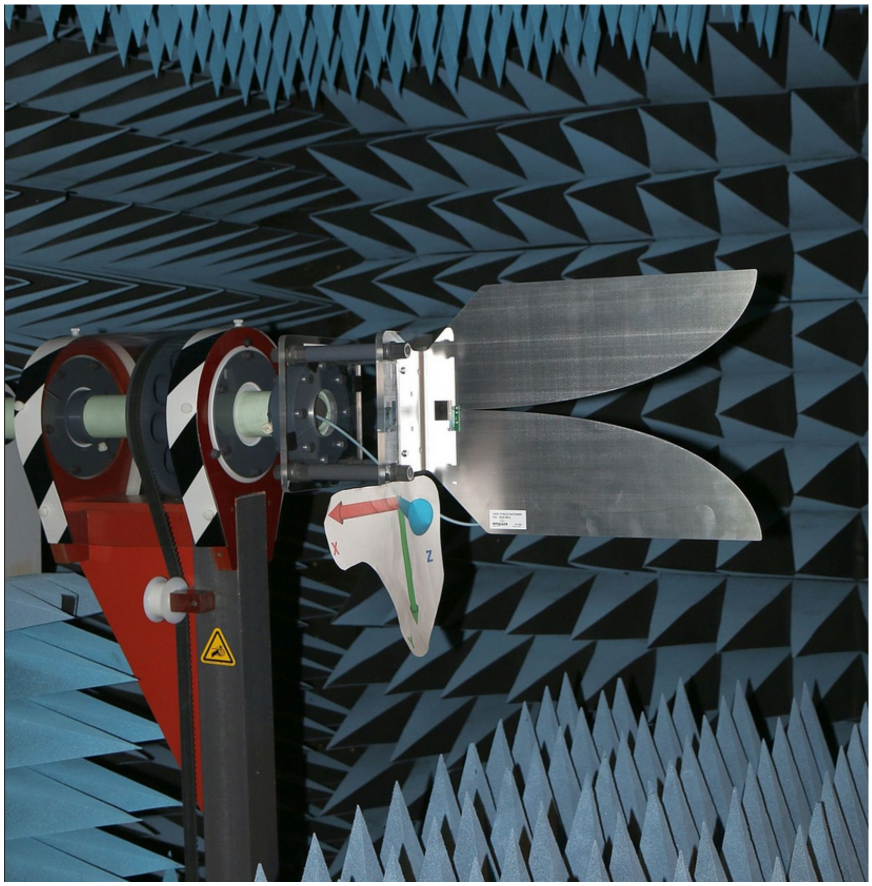


Figure 6:

1.3 Quasi-Optical Antennas

High-frequency or short wavelength electromagnetic field behaves like light ray as in optics. Therefore, many high-frequency antennas are designed based on the principle of ray optics. A reflector antenna is such an antenna as shown in Figure 7. The reflector antenna in this case is a Cassegrain design where a sub-reflector is present. This allows the antenna to be fed from behind the parabolic dish where the electronics can be stored as well.

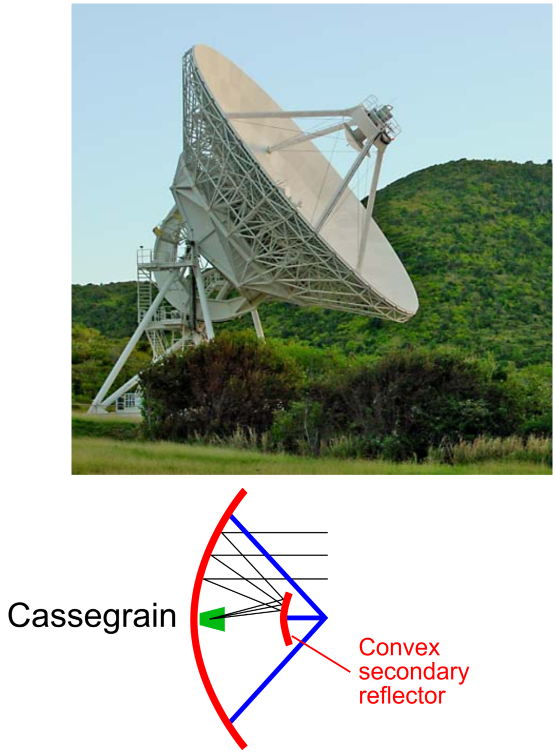


Figure 7: Courtesy of NRAO and rev.com.

Another recent invention is the reflectarray antenna as shown in Figure 8. Due to recent advent in simulation technology, complicated structures can be simulated on a computer, including one with a complicated surface design. Patch elements can be etched on a flat surface as shown, giving it effective impedance that is spatially varying, making it reflect like a curved surface. Such a surface is known as a meta-surface. It can greatly economize on the space of a reflector antenna.

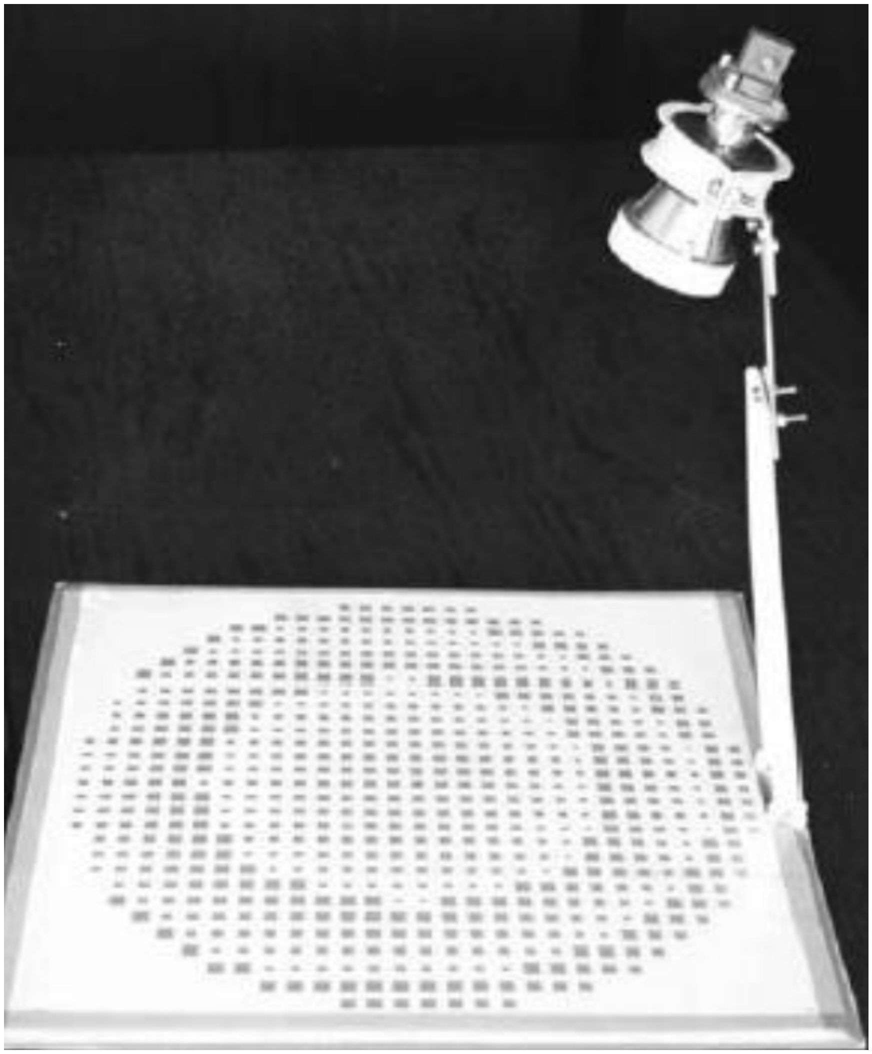
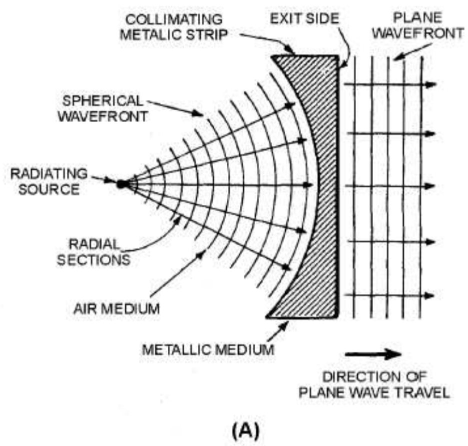


Figure 8: Courtesy of antenna-theory.com.

Another quasi-optical antenna is the lens antenna as shown in Figure 9. The design of this antenna follows lens optics, and is only valid when the wavelength is very short compared to the curvature of the surfaces. In this case, reflection and transmission at a curve surface is similar to that of a flat surface. This is called the tangent-plane approximation of a curve surface, and is valid at high frequencies.



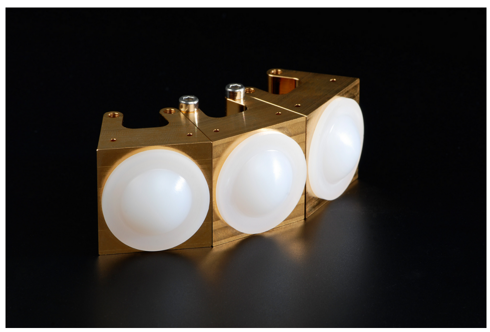


Figure 9: electriciantutoring.tpub.com and micro-radar.de.

1.4 Small Antennas

Small antennas are in vogue these days due to the advent of the cell phone, and the importance of economizing on the antenna size. Also, the antennas should have enough bandwidth to accommodate the signals from different cell phone companies, which use different carrier frequencies. An interesting small antenna is the PIFA (planar inverted F antenna) shown in Figure 10. Because it is shorted at one end and open circuit at the other end, it acts like a quarter wavelength resonator, making it substantially smaller. But the resonator is low Q because of the "slots" around it from whom energy can leak.

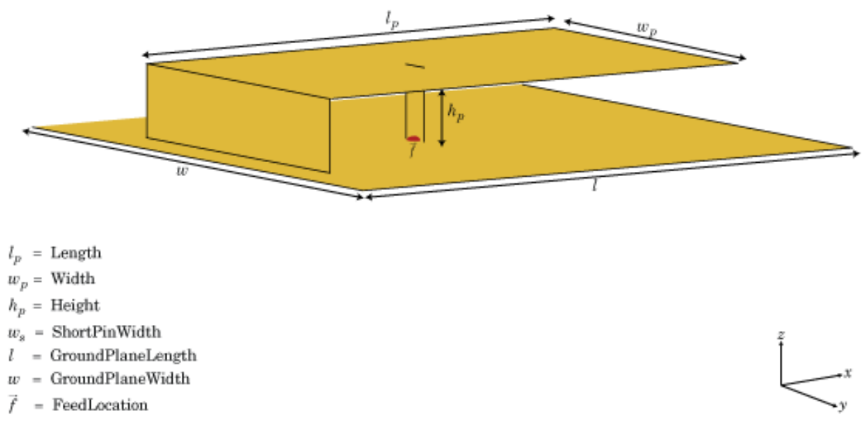


Figure 10: Courtesy of Mathworks.

An interesting small antenna is the U-slot antenna shown in Figure 11. Because the current is forced to follow a longer path by the U-slot, it has a lower resonant frequency and hence, can be made smaller. In order to give the antenna a larger bandwidth, its Q is made smaller by etching it on a thick dielectric substrate (shown as the dielectric material region in the figure). But feeding it with a longer probe will make the bandwidth of the antenna smaller, due to the larger inductance of the probe. An ingenious invention is to use an L probe. The L probe has an inductive part as well as a capacitive part. Their reactance cancel each other, allowing the electromagnetic energy to tunnel through the antenna, making it a better radiator.

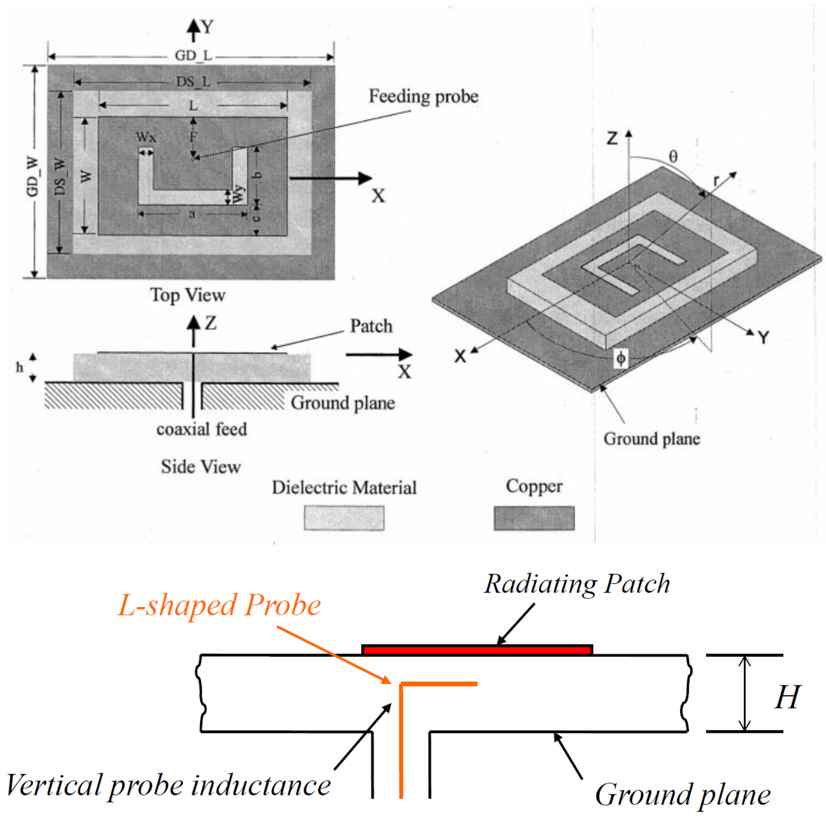


Figure 11: Courtesy of K.M. Luk.

Another area where small antennas are needed is in RFID (radio frequency identification) tag. Since tags are placed outside the packages of products, an RFID tag has a transmit-receive antenna which can talk to a small computer chip where data about the package can be stored. An RFID reader can quickly communicate with the RFID tag to retrieve information about the package. Such a small antenna design for RFID tag is shown in Figure 12. It uses image theorem so that the antenna can be made half as small. Then slots are cut into the radiating patch, so that the current follows a longer path. This lowers the resonant frequency of the antenna, allowing it to be made smaller.

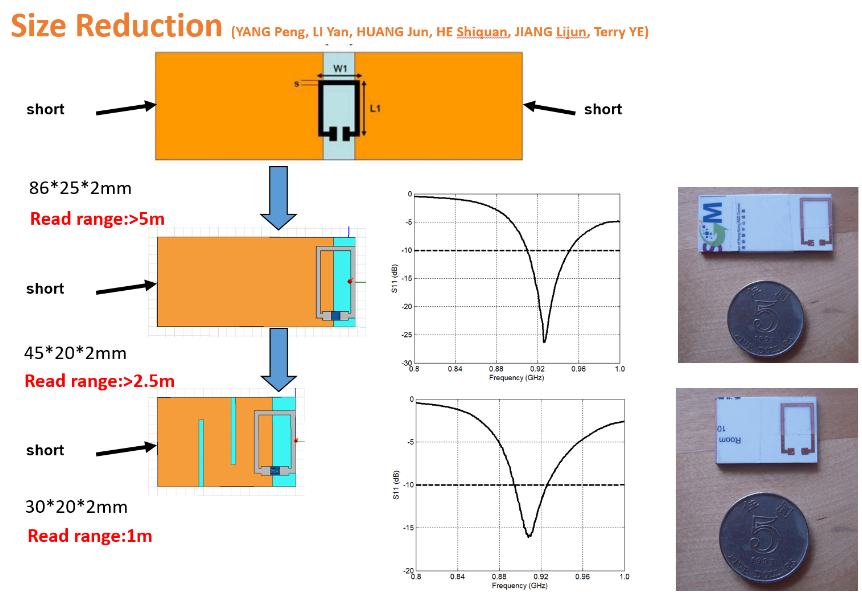


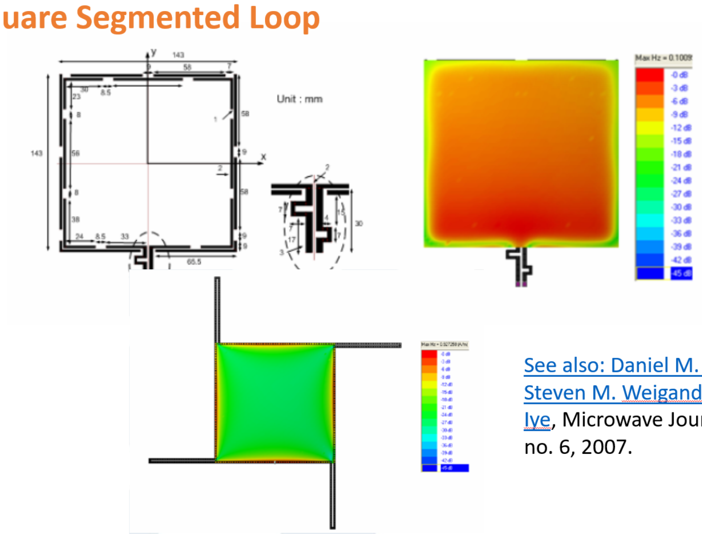
Figure 12:

An RFID reader can be designed to read the information from a batch of vials or tubes containing different chemicals. Hence, a large loop antenna is needed at a sufficiently high frequency (for large bandwidth). However, driving a loop antenna at a sufficiently high frequency will result in a non-constant current around the loop. (Fundamentally, this comes from the retardation effect of electromagnetic field.) This will result in a non-uniform field inside the loop defeating the design of the RFID reader.

One way to view how the non-uniform current come about is that a piece of wire becomes a tiny inductor. Across an inductor, $V = j\omega LI$, implying a 90° phase shift between the voltage and the current. In other words, the voltage drop is always nonzero, and hence, the voltage cannot be constant around the loop. Since the voltage and current are locally related by the local inductance, the current cannot be constant also.

To solve the problem of the current and voltage being non-constant around the loop, the local inductor is connected in series with a capacitor. This causes them to resonate. At resonance, the current-voltage relationship across the tank circuit is such that there is no voltage drop across the tank circuit. In this case, the voltage becomes uniform across the loop so is the current. Therefore, one way to enable a uniform current in a large loop is to capacitively load the loop. This will ensure a constant phase, or a more efficient reader. Such a design is shown in Figure 13.

Square Segmented Loop



See also: Daniel M. Dobkin, Steven M. Weigand and Nathan Iye, Microwave Journal, vol.50 , no. 6, 2007.

By CHEN Zhi Ning, from ASTAR, Singapore, 2009

Current Distribution and Measured S11

(YANG Peng, LI Yan, HUANG Jun, HE Shiquan, JIANG Lijun, Terry YE)

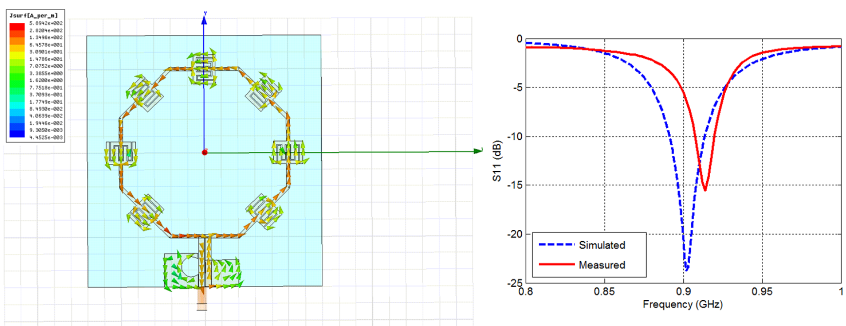


Figure 13: