A High School Student's Research Experience in RF Engineering

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My name is Justine Kim and I am an energetic 17-year-old girl who attends an international school in the city of Daejeon, South Korea. My father, Joungho Kim, is a member of IEEE EMC Society. Above all, it is a great honor for me to have an opportunity to write this article for the IEEE EMC Newsletter as a young high school girl. I hope to encourage more high school girls to gain an exuberant interest in the field of RF engineering. Although young, I believe my experience in researching RFID systems has provided me with new eyes to view the world.

As a high school student, I found an interest in physics because I could be as creative as I wanted to be within the subject. Because there was no right answer to some problems, and because there were so many things left undiscovered, such facts elated me in a way that allowed me to be innovative. Since the winter of 2007, when I started going to a lab at the Korea Advanced Institution of Science and Technology (KAIST) every weekend, I could pursue my interest specifically in the field of electrical engineering. Such was possible because my father was a professor at KAIST; he had once suggested that I try a research project he had assigned to his undergraduate students. When I look back, I cannot believe that my dad had actually suggested such an idea… for a high school girl to work on a project that the undergrads were working on?

While electricity is involved in almost everything around us - both naturally and artificially - MP3, cellular phones, and laptop computers were, for example, some things that we as high school students cannot really live without, and I think that is why I was able to approach the field much more easily. However, attending a high school that did not really support students doing individual research, it was hard for me to manage both school and lab work as a junior level student. Nevertheless, with the help of a graduate student, Gawon Kim from the lab, by the second semester of my sophomore year, I was able to learn about Radio Frequency Identification systems and about its applications rather thoroughly.

The idea of the RFID system brought to me endless thoughts. When I went to school, seeing the security system, I thought of RFID. Whenever I rode subways, looking at my transportation card, I thought of RFID. Every day and every moment, I could see more and more RFID systems take place within our daily lives. The tags of RFID systems were getting smaller and smaller to the point where people were allowed to carry them as cellular phone accessories. Yes, scientists around the world are studying the RFID system, believing that it is something that can change the lifestyles of human beings in the near future and that it is one of the greatest human inventions of the modern era. But one day, I realized that people have put most of their effort in reducing the size of the RFID 'tag' rather than the reader. A thought passed my mind, "Wouldn't it be more beneficial to us to reduce the size of the reader? Why not apply the miniaturized readers in cellular phones; something that most of the younger generation carries around?"

Then, I learned that recently a cellular phone company in South Korea tried applying the RFID system in the mobile device, but failed to draw the public's attention. These products are produced in a Dongle mode, which means the 'Dongle' needs to be connected to the mobile phone's body only when being used to read the RFID tag, that is, not as part of the mobile phone itself. I thought, "That's it! That is exactly what I am going to work on! To overcome this inconvenience, I can design a UHF RFID reader antenna that is small enough to be placed into the body and can take the place of the Dongle when integrated into the mobile phone!" At this point then, everything started rolling.

RFID systems mainly operate through the RF signals of 13.56 MHz, 400 MHz, and 900 MHz for automatic identification of objects. Specifically, Ultra High Frequency (UHF) RFID that uses 900 MHz is considered as a field that needs further investigation for it uses the frequency that is not yet popularized and is in the early stage of being applied. An example that can be easily found is the Hipass system that is being used in Korea allowing cars traveling through the highways to pay the toll automatically. Knowing that the UHF RFID system is able to recognize signals swiftly, along with the capacity to hold a vast amount of information at the same time, I decided to target my antenna's frequency to 900 MHz.

The design of the UHF RFID reader antenna first started off as a form of a dipole antenna. Using the given equation, it was figured that in order for the antenna to have the target frequency of 900 MHz, the length of the antenna had to be 16.6 cm.

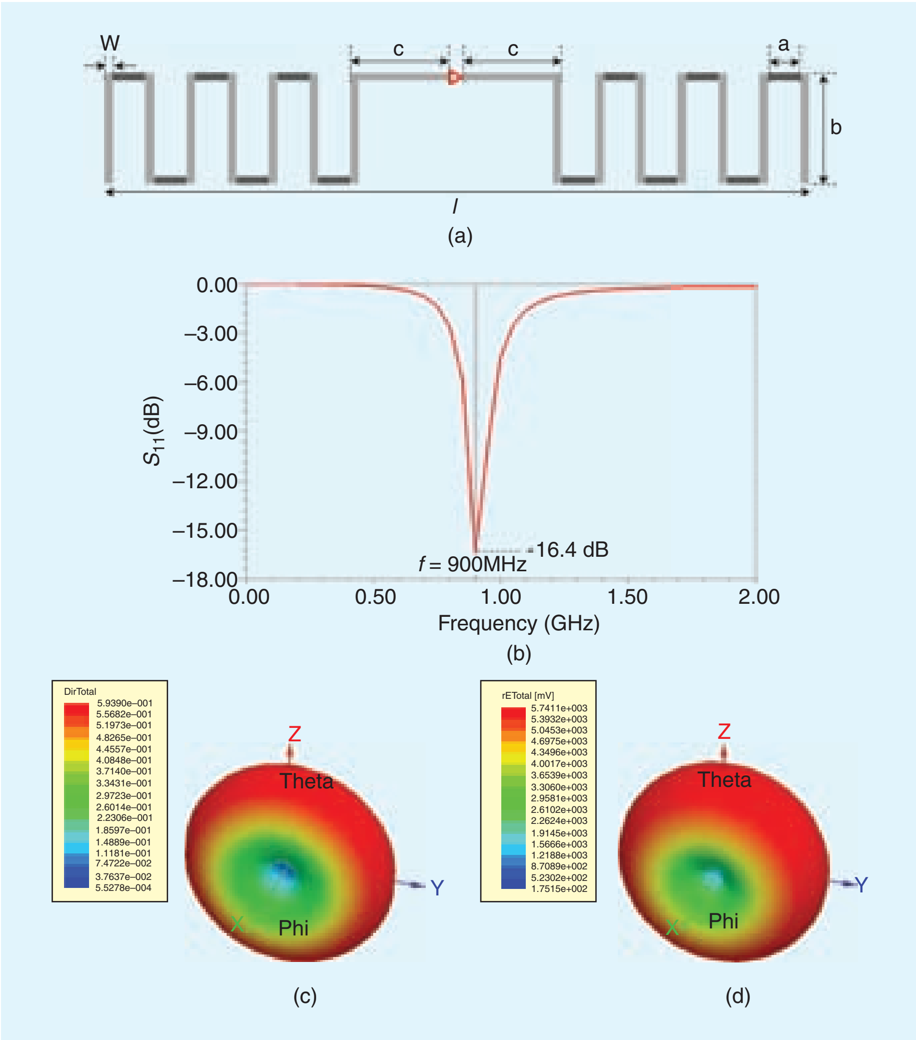
$$\lambda = \frac{v}{f} = \frac{c}{f} = \frac{3 \times 10^8 m/s}{900\,MHz} = 33.33 \text{ cm} \qquad \text{(Eq. 1)}$$

$$\frac{\lambda}{2} = 16.6 \text{ cm} \qquad \text{(Eq. 2)}$$

This 900 MHz dipole antenna is placed on the 0.2 mm-thick Printed Circuit Board (PCB) that faces both the air and the dielectric material of FR4. When the design based on the previous calculation is simulated using 3D Electromagnetic (EM) Full-wave Simulator, the frequency fell at 800 MHz. So that the frequency could be increased by 100 MHz, the length of the antenna was reduced according to the equation, yielding the resultant length of 14.4 cm and frequency of 900 MHz. However, it is obvious that a 14.4 cm-long antenna cannot fit into the mobile phone, so the designed antenna had to be varied in a way that would make use of smaller space. The easiest and the least complex way to do so was to transform the dipole antenna to the meander antenna, an antenna that is made serpentine to occupy the small space.

The resultant meander antenna resulted in having six sections that are meandered on each side of the antenna; they are symmetrical. In order to prevent the occurrence of coupling among these sections, the space between the lines was determined as ‘a (4 mm)’. The resulting size of the designed antenna is 7.5 cm by 1.1 cm. It is shown clearly that the length of the antenna is reduced; this can make much better use of the space than before.

In order to solidify the characteristics of the designed antenna, 3D simulation (HFSS) needed to be checked. I was really surprised to learn the value of the software. I really couldn’t believe that I was allowed to use such tools as my dad told me that it was something that only certain graduate students had the opportunity to work with. Using the program, in a way, was also greatly enjoyable, while in order to work with 3D simulator to test the antenna, the first step that needs to be taken is to draw the actual 3D structure of the antenna into the program. Since the design was not as keen and was rough at first, through the 3D EM full-wave simulation, it could be figured whether the structural dimension needed adjustment and what aspect of the antenna needed to be changed. When this was done, it also showed where the resonant frequency is the strongest, which represents whether or not the antenna has the capacity of reading the right frequency effectively. The frequency fell at 900 MHz and thus proved that the design was accurately made.



Simulation and Result of the Meander Antenna with Length 7.5 cm using a 3D Full-wave Simulator. (a) Suggested 900 MHz meander antenna structure and dimension from the top view. (b) Simulated s-parameter of the 7.5 cm length antenna. (c) 3D Directivity. (d) 3D E-field radiation pattern at far-range.

While the first design of the UHF RFID reader antenna was successfully made, I decided to try to make more efficient use of space; because mobile phone design may vary from one another, not one design can fit all mobile phones. This time, I designed the folded type antenna after countless simulations because the design could not be just bent from the flat antenna design. The resultant antenna follows with the frequency of 900 MHz.

But there was one problem I faced: it was the fact that the characteristics of the simulated antenna and the one in reality may differ. So, the UHF RFID reader system materialized with the implementation of the meander antenna. In order to fabricate the meander antenna on the PCB, it is necessary to put the layout of the designed antennas into drawings using Allegro of Cadence so that the manufacturer of the antenna knows exactly what to make out of the design. As was used for simulation and design, 0.2 mm thick dielectric material is used to support the copper-conductor.

The terminal layout was then given to the PCB manufacturer and was sent back with the implemented antenna, which was later used for measurements. It took two weeks for the manufacturer to go through the entire process of making the antenna.

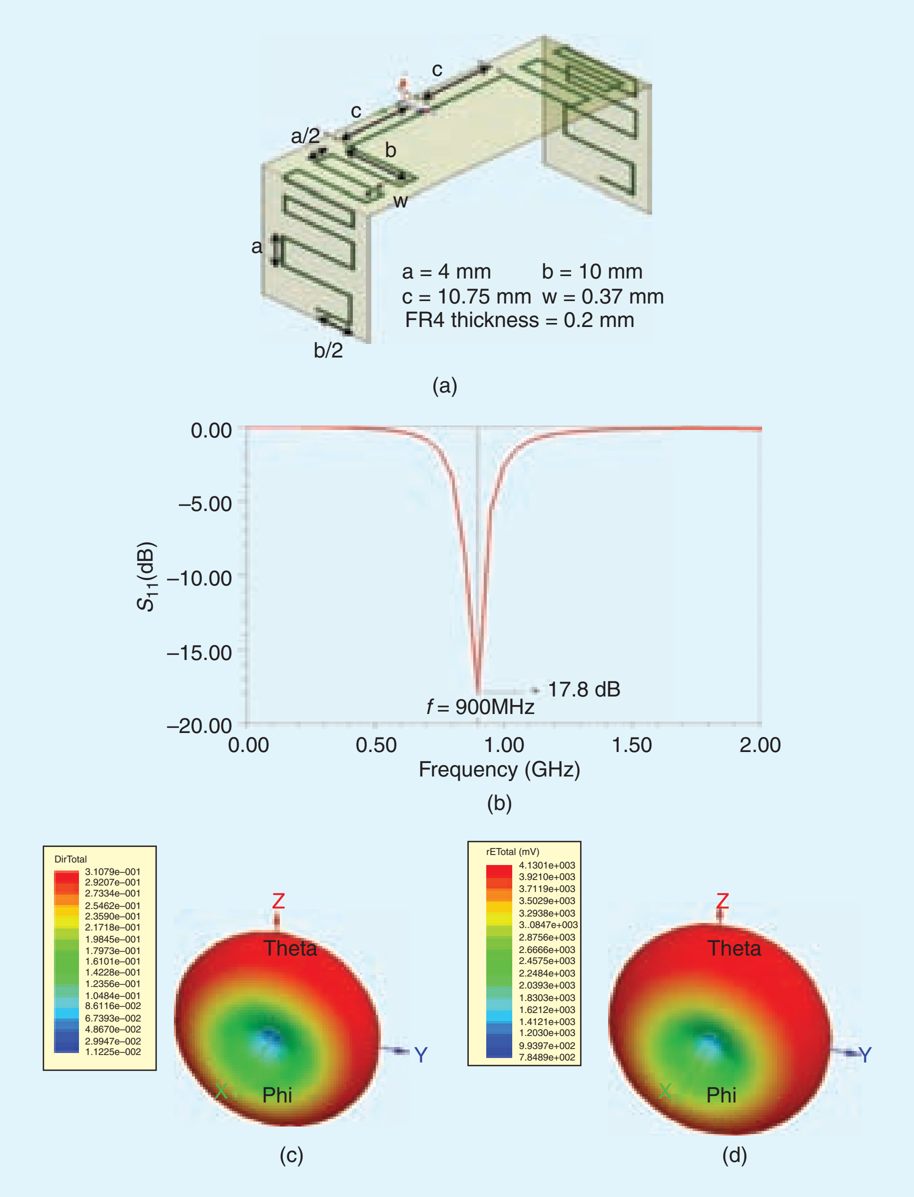
In order to test the characteristics and radiation efficiency of the manufactured antennas, they are connected to a Vector Network Analyzer (VNA) for measuring the S-parameter in the frequency domain. The SMA connector is then soldered onto the antenna to connect the cable that allows the measurements to take place. The frequency range of the measurement is from 30 kHz to 3 GHz. Only S11 is to be measured because the designed antenna is a single-port device and there is no according tag antenna designed.

As expected, both the flat-type and the folded-type antennas resulted in different frequencies so they had to go through the process of optimization. They were manually optimized, and in every process, the antenna resulted with different frequencies; this was repeated until both antennas ended up at 900 MHz. Additionally, in order to verify the characteristics of my designed antenna, I conducted various experiments in various conditions of weather, barriers, and direction of the tag/reader antenna. The UHF RFID reader antenna for the implementation of the mobile phone was successfully designed.

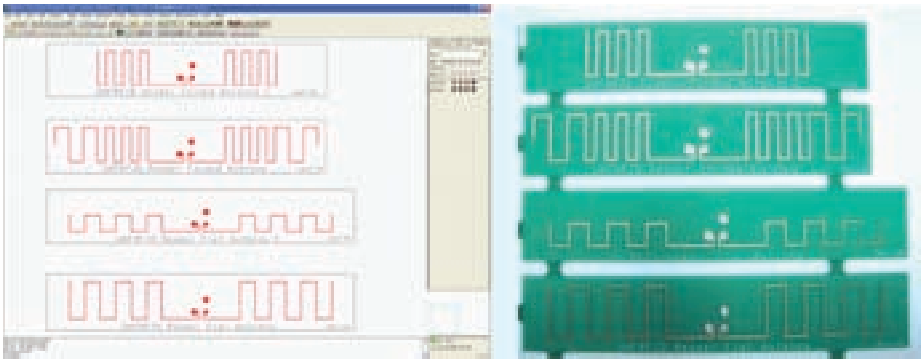
I was really proud of what I had created! All the effort and time that I had dedicated in the lab paid off greatly. At the same time, however, I doubted myself as to whether or not my designed reader antenna would be well received in the scientific society and the real world. Nevertheless, holding back my worries, I decided to attend the Korea Science and Engineering Fair (KSEF), where high school students from all over the country come and compete with the scientific research projects they have done over the years. It is a very competitive event as the top two students from the individual research category and the first place winner from the team category are given tickets to attend the Intel International Science and Engineering Fair (ISEF).

Knowing that students from these science high schools are some of the smartest in the country, and recognizing that I am the only one attending an international school, I could not adjust to the heavy mood that they carried during the second cut presentations. What made everything worse was that I had to make my presentation in front of all my competitors. Moreover, the judges tried to find flaws, rather than point out what I've done so well, in my research. This was a typical Korean way of judging, but it was still really stressful for me. Students stared at me as if thinking, "Who's that girl from an 'international' school? Why is she here? Why is she competing against us? Is she even good enough? Why isn't she wearing a school uniform? Why is she mixing Korean and English when making the presentation?" I expected no less from this typical competition. Who would pick an 'international' school student with an American passport to represent South Korea? I merely hoped to make the final cut, and when I did, I didn't expect anything more.

The day of the announcement for the winner of the KSEF, I could not believe my eyes. There it was, my name Justine, written down as a first

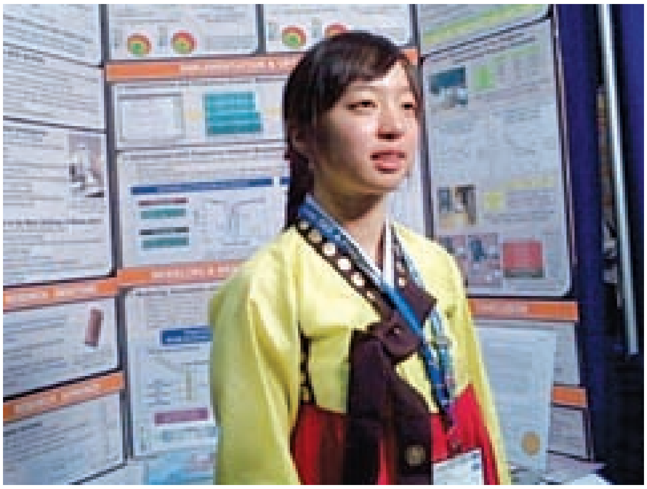


Simulation and Results of the Folded-type Meander Antenna using 3D Full-wave Simulator. (a) Simulation of folded-type 900 MHz meander antenna placed on the 2mm-thick PCB. (b) Simulated s-parameter of the folded-type antenna. (c) Directivity. (d) 3D E-field radiation pattern at far-range.



Layout of Designed Meander Antennas and Picture of Implemented Meander Antennas.

South Korea representatives (from top left, clockwise): Keun Hong Lee (17, CS), Seunghyun Oh (18, CH), Dongchan Kim (17, MI), GiSeok Choi (18, MI), Justine Kim (17, EE), and Huisu Yun (14, CS).



Justine Kim presents her research to a judge.

My finalist name tag and signature of Intel CEO, Craig Barrett.

place winner! I became one of the two individuals to represent South Korea at the Intel ISEF! It was such a great opportunity to even more thoroughly and deeply focus on my research and to meet high school students from all over the world who are interested in science and math as much as I am. Then, when all the Korea representatives got to meet together, I realized that I was the only girl.

Not only that, I was the first student from an international school, holding an American passport, to represent South Korea. During the course of preparation, as the boys and I were to travel to Reno, Nevada, to attend the Intel ISEF, we learned a lot from each other. But the fact that they would still be my competitors at the Intel ISEF did not change at all. I wanted to prove to everyone that I could be as good as anybody.

From May 11 to 16, I went through an experience that I will never forget. A total of 1563 participants from 56 countries were there. I realized that there were a lot of people from the United States because they chose the representatives of each state, not just the country. Moreover, unlike only six Korean students coming from one country, about 30 to 40 students came from each state! Six of the student representatives from Japan could not come at all after all that they had prepared for because the Japanese government did not allow them to travel abroad, afraid of the A (H1N1) influenza. I was absolutely terrified to meet so many 'smart' kids. Adding to that, there were an almost equal number of students competing in the category of Electrical and Mechanical Engineering. No one from Korea knew what to expect from me because there were no Korean representative who had competed in my category before. What was I to do? Still, I tried my best to prepare for the judging presentations and to make my poster display as alluring as possible.

There were many events that Intel had prepared for the finalists, which included pin exchanges among students around the world, a student mixer, talking with Nobel Prize winners, and so on. These were all great experiences that allowed

Finalists introduce their countries at the competition.

The third place winner after the grand award ceremony in front of her booth.

students to broaden their eyes towards the scientific community of the world.

The judges who came to judge us were professors from all over the world. People who were experts in the field in which students performed their research came to judge as well. Having read our papers and abstracts beforehand, they knew exactly what questions to ask and what to get out of us. The grand award judging lasted ten hours, which exhausted everyone. When it was all over, I was relieved that the judging was finally over, but at the same time, I wondered if I did well enough to place. Seeing students' work from my category, I was shocked how creative and innovative these students were. They invented things that I thought were impossible for a high school student to create! I had to repeatedly tell myself, "Hey, I placed first in Korea, why not here? Hey, I beat all those science school kids, why not the kids here?"

All those days of hard work, all those struggles that I had gone through, everything… "Justine Kim, South Korea" was announced and broke my spell. I smiled and I waved, but at the same time I cried. I just couldn't help myself. I was just proven world-wide. My work was proven worthy in front of the world's leading scientists! Placing third in the category of Electrical and Mechanical Engineering, I saw other Korean representatives screaming and clapping for me. Was this real? Was it really me who got the grand third award? When I got off-stage, I realized that the drama was not yet over; rather, it was just the beginning of everything. My dream of being one of the greatest scientists in history in the future was just taking its first step forward.

This award meant to me a lot, telling me that I could actually compete world-wide, and the research that I had done was something that was really worthy! Later, the judges told me that I did a fabulous job and that it would be great to see my designed antenna in the market in the near future.

Learning and researching the topic of RFID gave me an opportunity that not all high school girls can really experience. Such has bestowed on me the passion towards the field of electrical engineering.

I felt so thankful for those who helped me with my science project and made this all possible. I hope more high school students around the world could see, hear, and learn what I have by investigating RF engineering and be left with the lifetime memories. **EMC**