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Measurements of Dark Area in Sensing RFID Transponders

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Abstract

Radiofrequency(RF) signal is a key medium to the most of the present wireless communication devices including RF identification devices(RFID) and smart sensors. However, the most critical barrier to overcome in RFID application is in the failure rate in detection. The most notable improvement in the detection was from the introduction of EPC Class1 Gen2 protocol, but the fundamental problems in the physical properties of the RF signal drew less attention. In this work, we focused on the physical properties of the RF signal in order to understand the failure rate by noting the existence of the ground planes and noise sources in the real environment. By using the mathematical computation software, Maple, we simulated the distribution of the electromagnetic field from a dipole antenna when ground planes exist. Calculations showed that the dark area can be formed by interference. We also constructed a test system to measure the failure rate in the detection of a RFID transponder. The test system was composed of a fixed RFID reader and an EPC Class1 Gen2 transponder which was attached to a scanner to sweep in the x-y plane. Labview software was used to control the x-y scanner and to acquire data. Tests in the laboratory environment showed that the dark area can be as much as 43 %. One who wants to use RFID and smart sensors should carefully consider the extent of the dark area.

Keywords : RFID, Sensors, Interference, Dark Area, Ground

1. INTRODUCTION

With the advancement in the electronics technology utilizing RF signal, the realization of the ubiquitous era approaches rather quickly. Among the various RF devices, smart sensors and RF identification(RFID) devices have been applied to the very broad application area which includes laboratories, environmental hazards, transportation, manufacturing, logistics, and pharmaceutical drug pedigree. The RFID systems using high frequency(HF) band around 13.56 MHz have been widely commercialized in bus, subway, access control, etc. However, the RFID systems using ultra-high frequency(UHF) band around 900 MHz and above have been limited in commercialization because of the notable failure rates in detection[1].

The most notable improvement in detection was from the introduction of EPC Class1 Gen2 protocol. This improved the data communication speed by almost four times, raising the reading speed from 230 readings/sec to 880 readings/sec. Also, the data security level was enhanced by giving the users the authority to access a specific memory area with a chosen password. However, we still need to improve the failure rate that limits the application area of these devices[2-3].

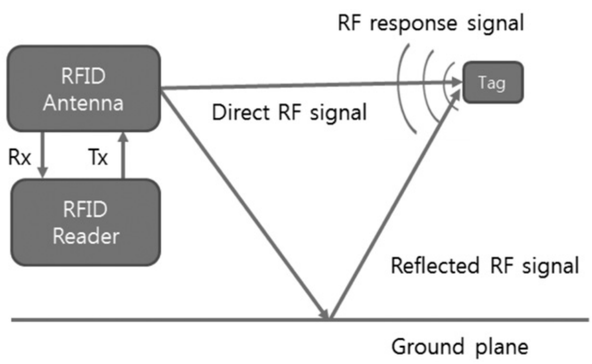

Fig. 1. Schematic diagram of an RFID system.

Fig. 1 shows the schematic drawing of an RFID system. An RF electromagnetic field that is generated from an RFID reader may excite a transponder, and the reader may recognize the existence of the transponder by detecting an electromagnetic field generated from it. However, the field from the reader can be modified by the existence of a ground plane and external noises. Thus, it producesa dark area where the intensity of the field is too small to excite the transponders[4-5].

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In this work, we have used Maple, a mathematical computation program, to understand the distribution of the electromagnetic field in space when the field was generated from an antenna. By introducing the ground planes, we observed the change in the field distribution and in the existence of the dark area. After noting the possible generation of the dark area, we have constructed an x-y scanner system to measure the dark area in the laboratory environment where the ground planes and external noise sources were present[6-7].

2. EXPERIMENTS

We constructed an x-y scanner to measure the dark area of RF electromagnetic field. The maximum range of scan area was 3 m x 1.5 m. We used belt/pulley combinations that operated with step motors to cover this wide area and to achieve a resolution of 1 cm. We used the Labview software from National Instruments to control the x-y scanner, to acquire the detection results from the RFID reader, and to provide a graphical presentation. Our graphical software could control the motors to move the transponder to specific positions and automatically scan the specified area.

We used step motors from Autonics to control the x-y scanner and the motor controllers from National Instruments to control them. Even though there is a -3dB loss in circularly polarized antennas, we used a circularly polarized antenna in this experiment as the circularly polarized electromagnetic wave is the least dependent on the direction of the antenna in the transponder. It is preferred to use a linearly polarized antenna only when the direction of the tag is fixed. The circularly polarized antenna is the most widely used antenna in practical applications.

In this experiment, we used KIS900WT-4CH 900 MHz RFID reader from Kiscom Co., LTD and ALN-9540 EPC GEN2 Squiggle™ transponder from Alien Technology Corporation[8]. We chose KIS900WT-4CH 900 MHz RFID reader as it used bi-static type antennas and separate transmitting and receiving channels. It supported EPC class 1 Gen2 and both RS-232 and TCP/IP interfaces. Size of the transponder was 95 mm x 8.15 mm, and it had 96 bit memory.

Even though we used commercially available RFID reader and transponder, we fabricated the reader antenna by ourselves as the antenna performance was one of the most critical parts in this work. We fabricated a circularly polarized antenna to work along with KIS900WT-4CH 900 MHz RFID reader. By using bi-static type antennas, we could obtain good isolation in the receiving channel and in the transmitting channel. Thereby, we could achieve better performance in acknowledging transponders. Careful 50 ohm impedance match was considered in the design of the antenna as the impedance mismatch can reduce the transmittance power in RF field.

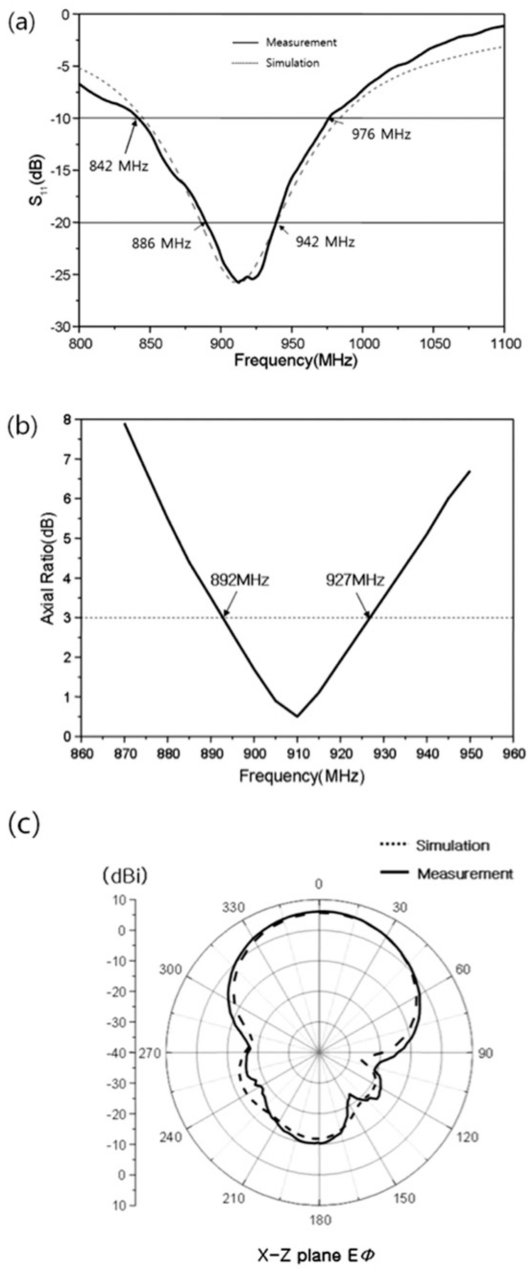

Fig. 2. (a) Simulated and measured reflection coefficients vs. frequency, (b) Measured axial ratio, and (c) Measured and Simulated antenna gain.

Fig. 2 shows (a) the simulated and the measured reflection coefficients, (b) the measured axial ratio, and (c) the measured antenna gain of the fabricated antenna. The size of the antenna was 25 cm x 21 cm. The designed frequency band of the antenna was 147 MHz. When measured, the -10 dB bandwidth was 134 dB ranging from 842 MHz to 976 MHz, and the -20 dB bandwidth was 56 MHz ranging from 886 MHz to 942 MHz. This agrees well with the simulation result which is shown as a dotted line in Fig. 2(a). The simulation was done using the CST Microwave Studio[9]. The reflection coefficient at the center frequency of 912 MHz was -25.7 dB. In order to minimize the detection dependence on the orientation of the transponder antenna, we needed a small axial ratio of the circular polarized antenna. Axial ratio of this antenna exhibited circular polarization characteristics for the bandwidth of 35 MHz ranging from 892 MHz to 927 MHz based on 3 dB criteria, as shown in Fig. 2(b). The measured gain of the antenna was 5.25 dBic, and this agrees fairly well with the simulation result which was performed using the CST Microwave Studio, as shown in Fig. 2(c).

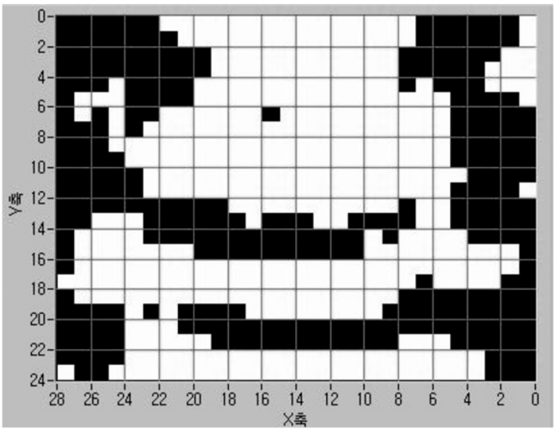

Fig. 3. Results of the detection area measurement performed using a transponder. The direction of the transponder antenna was in the same direction as the minor axis of the reader antenna.

Fig. 3 shows the results of the detection area measurement that was obtained from the x-y scanner. As there was quite a bit of disturbance from the outside noise during daytime, the measurements were done in the night time, mostly from midnight to dawn. In this measurement, the direction of the reader antenna and the direction of the transponder antenna were aligned in such a way that the direction of the transponder antenna was in the same direction with the minor axis of the reader antenna. The scan area was 280 cm x 144 cm and it was divided into 28 x 24 squares. The distance between the scan plane and the reader antenna was set to 2 m. While scanning, we measured if the reader can excite and recognize the transponder. If it did we made a white square, and if it didn't we made a black square. In other words, the black region in Fig. 3 represents the dark area where the electromagnetic field was too weak to excite the transponder. The total dark area was 43 % of the total scanned area. For each measurement we turned on the RFID reader to read for 3 sec and off for 2 sec to move the transponder to the next position. The measurement grid interval was 10 cm in the x-axis and 5 cm in the y-axis. Repeated measurements that were performed at other days showed fairly consistent maps.

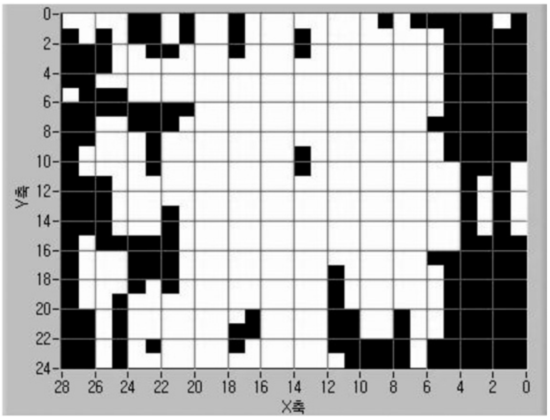

Fig. 4. Results of the detection area measurement with the direction of the transponder antenna set in the same direction as the major axis of the reader antenna.

Fig. 4 shows the results of the measurement when the direction of the transponder antenna was in the same direction with the major axis of the reader antenna, that is, 90˚ with the minor axis of the reader antenna. For this arrangement the total dark area was 34 % of the total scanned area. This was less than the value from Fig. 3. This was due to a slight distortion from the perfect circular polarization of the RF field.

We also measured the depth of the dark area by directly measuring the received power from the reader. In order to perform this measurement we attached a separate antenna to the transponder holder, and it was connected to a spectrum analyzer(HP8564E). In this set up, we were able to directly measure the electromagnetic field strength to find out the threshold power that is required to recognize the transponder. Fig. 5 shows the results. Regions of the dark area may be formed for the received power lower than -12 dB.

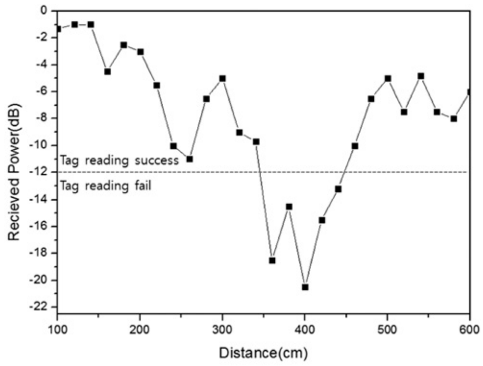

Fig. 5. Power measured for the various distances between the antenna and the transponder. The dark area may be formed when the received power was lower than -12 dB.

3. DISCUSSIONS

The complicated dark area distribution in Fig. 3 and 4 may be explained by the RF field that is reflected from the environmental walls and objects. The codes are exchanged between RF receivers and sensing transmitters through the RF fields. And the RF fields are mostly generated from various kind of antenna[10-12]. Even though there are many different kinds of antenna, these antennas are mostly based on a dipole antenna. Dipole antenna is a simple linear current carrying wire, but its theoretical analysis can serve as the basis to explain the radiation field from more sophisticated antennas. Average power density radiated from a dipole antenna is given by[13]

$$\mathbf{W}_{av} = \frac{1}{2}\mathrm{Re}(\mathbf{E} \times \mathbf{H}^{*}) = \hat{\mathbf{r}}\frac{Z_0}{2}\left(\frac{kI_0 l}{4\pi}\right)^2 \frac{\sin^2\theta}{r^2} \qquad (1)$$

where Z_0 is the impedance of the free space, k is a wave number, I_0 is the magnitude of the dipole current, and l is the length of the dipole. Equation (1) shows that the contour of the constant average power density from a dipole antenna in the open space has the shape of a circle. Average power densities from more complicated antennas may have similar functional forms. One can generalize this equation to any arbitrary shape of an antenna and can express it as Friis Transmission equation[14]

$$P_r = P_t\left(\frac{\lambda}{4\pi r}\right)^2 G_t G_r \qquad (2)$$

where P_r is the received power, P_t the transmitted power, $(\lambda/4\pi r)^2$ the free space loss factor, G_t the gain of the transmitting antenna, and G_r the gain of the receiving antenna.

Most of the RFID applications are not in a totally open space, but rather they involve some noise sources and reflections from ground planes, in addition to many other possible distractions. Now, we calculate the effect of a ground plane to the average power density that was radiated from a dipole antenna. When a dipole is perpendicularly away from a ground plane by a distance h the average power density from this dipole is given by

$$W_{av} = \frac{Z_0}{2}\left(\frac{kI_0 l}{4\pi}\right)^2\left[\left(\frac{r\sin\theta}{\xi^2}\right)^2 + \left(\frac{r\sin\theta}{\eta^2}\right)^2 + 2\frac{(r\sin\theta)^2}{\xi^2\eta^2}\cos k|\xi-\eta|\right] \qquad (3)$$

where, $\xi^2 = r^2 + h^2 - 2rh\cos\theta$ and, $\eta^2 = r^2 + h^2 + 2rh\cos\theta$.

Equation 3 shows that the presence of the ground plane introduces a complexity in the power pattern of the electromagnetic field from an RF antenna.

Most spaces may have a floor and walls. So we calculated the average power density from a dipole antenna when there is a grounded floor under the dipole antenna at a distance h and a grounded wall facing the dipole at a distance d. It is given by

$$W_{av} = \frac{Z_0}{2}\left(\frac{kI_0 l}{4\pi}\right)^2\left[\left(\frac{r\sin\theta}{\xi^2}\right)^2 + \left(\frac{r\sin\theta}{\eta^2}\right)^2 + \left(\frac{2d-r\sin\theta}{\zeta^2}\right)^2 \left(\frac{2d-r\sin\theta}{\chi^2}\right)^2 + F + G + H\right] \qquad (4)$$

where

$$F = 2\frac{(r\sin\theta)^2}{\xi^2\eta^2}\cos k|\xi-\eta| - 2\frac{(r\sin\theta)(2d-r\sin\theta)}{\xi^2\zeta^2}\cos k|\xi-\zeta|,$$

$$G = \frac{(r\sin\theta)(2d-r\sin\theta)}{\xi^2\chi^2}\cos k|\xi-\chi| - 2\frac{(r\sin\theta)(2d-r\sin\theta)}{\eta^2\zeta^2}\cos k|\eta-\zeta|,$$

$$H = -2\frac{(r\sin\theta)(2d-r\sin\theta)}{\eta^2\chi^2}\cos k|\eta-\chi| + 2\frac{(2d-r\sin\theta)^2}{\zeta^2\chi^2}\cos k|\zeta-\chi|,$$

$\xi^2 = r^2 + h^2 - 2rh\cos\theta$, $\eta^2 = r^2 + h^2 + 2rh\cos\theta$,

$\zeta^2 = \xi^2 + (2d)^2 - 4rd\sin\theta$,

and $\chi^2 = \eta^2 + (2d)^2 - 4rd\sin\theta$.

Contour plot of the spatial distribution of the electromagnetic power density was calculated by using Maple and it is shown in Fig. 6. In calculations, we used Z_0 = 376.6 ohm, k = 19.04 rad/m, l = 1.65 cm, I_0 = 0.532 A. With two ground planes in perpendicular, quite complicated pattern in the power of the electromagnetic field was formed. Thus, the dark area becomes more distributed over the space. Moreover, the interference due the ground planes, absorption, diffraction, and fading effect from the temporal change of media can distort the field distribution.

Even though Fig. 6 is not from the exact calculation of the real test environment, it supports the existence of the discontinued contour line and the discontinuous regions of the dark area. If there is an important application to be carried out in a specific environment, then the exact calculation can be performed by using our approach. But, the environment always changes, and so the exact calculation may be meaningless.

Our measurement implies that the failure rate improvement in detection from the raised data communication speed is limited by the physically produced dark area. Therefore, we suggest that the best solution to improve the failure rate may be the scanning of the reader antenna angle. This in turn will vary the temporal mapping of the dark area, and therefore no dark area may exist at a fixed region.

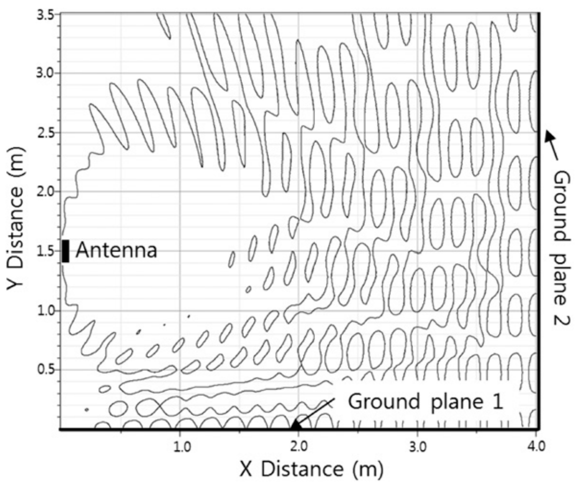

Fig. 6. Contour plot of the radiated power from a dipole when two ground planes, one on the floor(x-axis) and the other on the wall opposite to the y-axis, exist.

4. CONCLUSION

In this work, we have constructed a test system which is composed of an x-y plane scanner, to map the dark area in detecting the RFID transponders. Tests in the laboratory environment showed that the dark area can be as much as 43 %. By using a dipole antenna we calculated the interference effect on the electromagnetic field when the ground planes existed. The calculations by using Maple showed that the distributed dark area can exist when the ground planes are introduced. One who wants to use RFID in his applications should carefully consider the extent of the dark area that will cause a high failure rate in detection.

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