Radio Frequency shielding applied to RFID

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In this final report, we demonstrate that by using a 6061 aluminum alloy shielding plate, we can protect an RFID card from a 13.56MHz Arduino MFRC522 RFID emitter. Additionally, we characterize the shielding effectiveness for different RF frequencies ranging from 11.3MHz to 664MHz using our home-built multi-loop circular antenna. We found that for frequencies of 11.3MHz, 287MHz, and 385MHz, the shielding effectiveness can reach at least 50% with five different types of home-built shields. This report can serve as a starter guide for designing RF shields using 6061 aluminum alloy.

I. INTRODUCTION

Radio Frequency (RF) shielding is widely used in various fields. For example, in Thorlabs' photodetectors, shielding is employed to minimize the pickup of electromagnetic interference from the environment when measuring laser power. In this final report, we will demonstrate how using a 6061 aluminum alloy shielding plate can protect an RFID card from a 13.56MHz Arduino MFRC522 RFID emitter. The report is organized as follows: Section II describes the setup used to measure RF shielding effectiveness and the challenges encountered during the measurement. Section III explains what a Vector Network Analyzer is and its relevance to impedance matching. Section IV details the measurements conducted for characterizing the home-built antenna and the physics behind the fitting. Section V presents our results and discusses future improvements.

II. SETUP FOR MEASURING THE RF SHIELDING

In the setup, we use a 1.5GHz function generator to generate the RF signal and a 2GHz oscilloscope to measure the response from the receiver. We quantify the response from the emitter based on the peak-to-peak voltage response in the receiver. In Figure 1, we place the shielding material between the emitter and the receiver to quantify the shielding effectiveness. In Figure 2, we place the shielding material behind the RFID card. This setup demonstrates that even when the shielding is positioned behind the RFID card, allowing the card to directly contact the emitter, the RFID can still be effectively shielded.

We repeated the measurements ten times to reduce measurement error. When measuring the antenna's emission profile, impedance matching is a crucial criterion to ensure the measurements are repeatable and stable. If

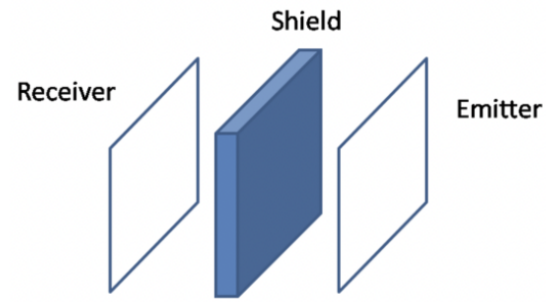

FIG. 1. Setup for measuring the RF shielding effectiveness

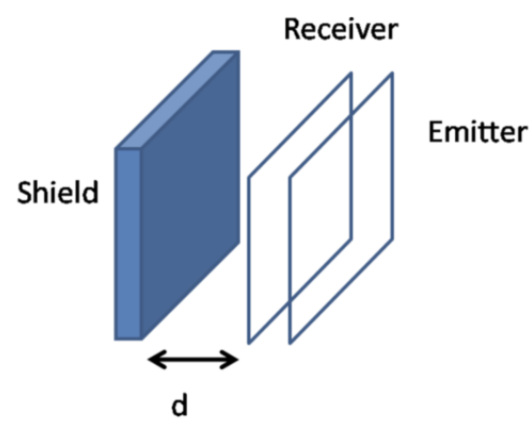

FIG. 2. Setup for testing the RF shielding in RFID case

the impedance is not matched, the variance of the measurements will be too high, rendering them unusable for quantifying both the home-built antenna and the shielding effectiveness. The variance could result from a drop in the emitter's signal rather than the shielding itself, as shown in Figure 3, where each of the four different colors corresponds to four repeated measurements.

III. VECTOR NETWORK ANALYZER (VNA) AND IMPEDANCE MATCHING

To solve the impedance mismatch between the function generator and the home-built antenna, we used a Rohde

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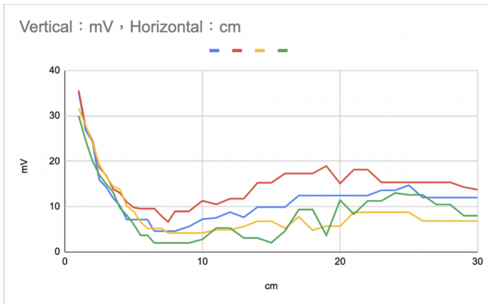


FIG. 3. Raw data to demonstrate the problem of impedance matching

FIG. 4. R&S FSH8 specturm analyzer

& Schwarz FSH8 spectrum analyzer, which includes a Vector Network Analyzer (VNA) function, as shown in Figure 4. Based on the Smith chart (Figure 5), we selected certain frequencies to ensure that the impedance is close to the optimal 50 Ω. The corresponding frequencies are 11.3MHz, 98.9MHz, 193MHz, 287MHz, 385MHz, 480MHz, 567MHz, and 664MHz. In the future, we can improve the setup by using a tunable L-network, which will add flexibility in selecting frequencies for testing RF shielding. Currently, the setup can only be used at the frequencies mentioned above.

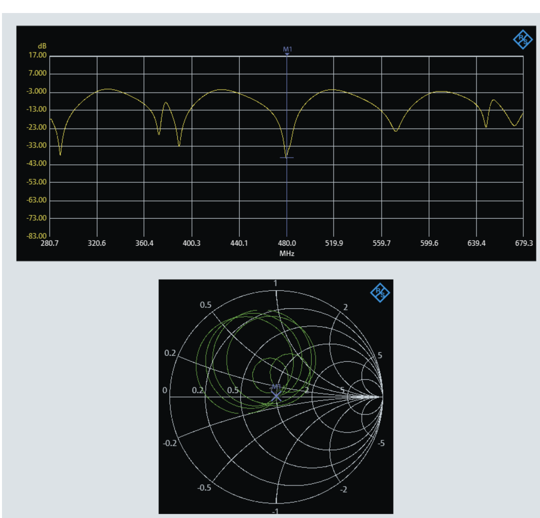
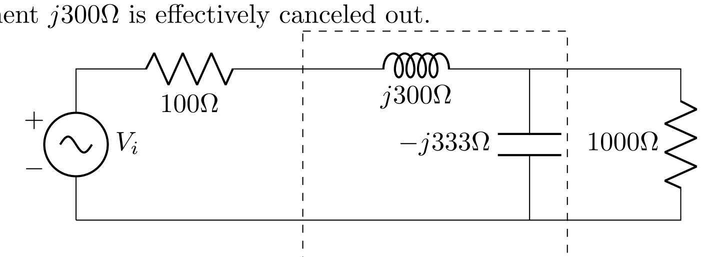


FIG. 5. Smith chart from FSH8

$$P = I_L^2 R_L = \frac{V^2 R_L}{(R_i + R_L)^2} \tag{1}$$

$$\frac{dP}{dR_L} = \frac{V^2(R_i+R_L)^2 - 2R_L(R_i+R_L)V^2}{(R_i+R_L)^4} = 0 \rightarrow R_i = R_L \tag{2}$$

The physics behind impedance matching is that it maximizes power transfer from the source to the load (see Equation 2). We use an LC matching network as an example (Figure III) to illustrate impedance matching. In this LC matching example, the source impedance is 100 Ω and the load impedance is 1000 Ω. By using an inductor and a capacitor, the effective impedance becomes $1000\Omega||(-j333\Omega) = 100\Omega - j300\Omega$, which matches the source impedance. Additionally, the reactive component $j300\Omega$ is effectively canceled out.



IV. MEASUREMENT RESULTS

A. Characterizing the home built antenna

We measure the response from the receiver at different positions ranging from 0 cm to 30 cm for frequencies of 10.8 MHz and 480 MHz used in the emitter. Before discussing the rationale behind using a $1/r^2$ fit, we need to describe magnetic dipole radiation. According to electromagnetic theory, the vector potential of magnetic dipole radiation, when using three approximations, is as follows:

$$A(r,\theta,t) = -\frac{\mu_0 m_0 \omega}{4\pi c}\left(\frac{\sin\theta}{r}\right)\sin\left[\omega(t - r/c)\right]\hat{\phi} \tag{3}$$

The three approximation are:

$$b \ll r \tag{4}$$

$$b \ll \frac{c}{\omega} \tag{5}$$

$$r \gg \frac{c}{\omega} \tag{6}$$

The average poynting vector is:

$$S_{avg} = \left(\frac{\mu_0 m_0^2 \omega^4}{32\pi^2 c^3}\right)\frac{\sin^2\theta}{r^2}\hat{r} \tag{7}$$

From Equation 7, we can see that a $1/r^2$ fit can be used if the approximation holds. However, in the 10.8 MHz

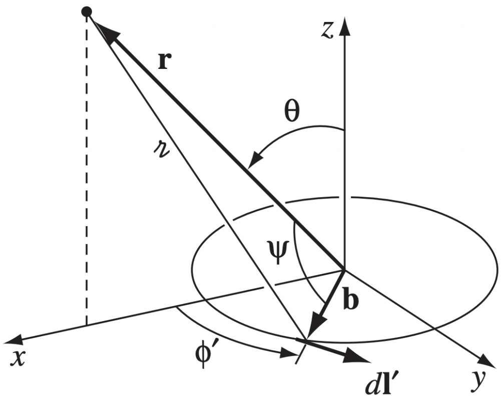


FIG. 6. Magnetic dipole radiation, picture taken from textbook: INTRODUCTION TO ELECTRODYNAMICS 4th FIG 11.8

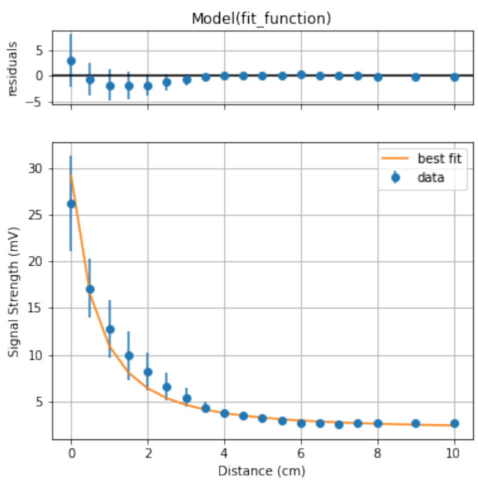


FIG. 7. $1/r^2$ fit with 10.8MHz case

case, the data do not fit well with the $1/r^2$ model. In contrast, the 480 MHz case fits quite well, achieving a χ^2 value of 0.91. The physics behind this difference is that for the 10.8 MHz case, the c/ω is approximately 442 cm, while for the 480 MHz case, it is around 9.95 cm, with our measurement range between the emitter and receiver spanning from 0 cm to 30 cm. This discrepancy shows that the approximation is not valid for 10.8 MHz, whereas it is nearly appropriate for 480 MHz.

B. Testing shielding effectiveness for different home built shielding plate

For the measurements taken with 1 cm distances between the emitter and receiver, and with the shielding positioned between them, we have obtained the following results (see Figure 10). The vertical axis is defined

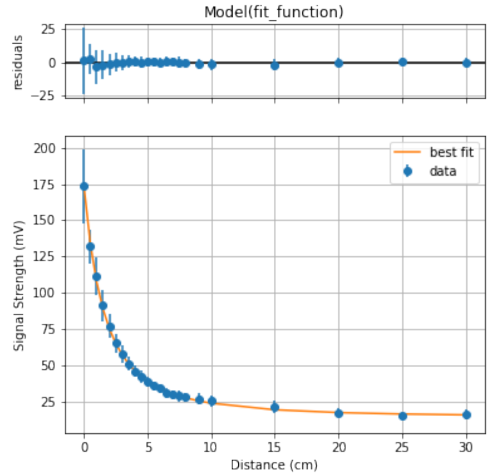


FIG. 8. $1/r^2$ fit with 480MHz case

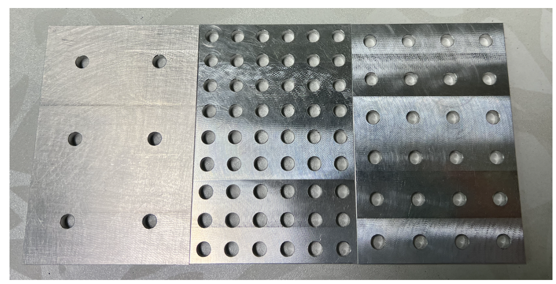


FIG. 9. Picture of shielding

as $x = u/v = V_{pp}(\text{shield})/V_{pp}(\text{emitter})$ and the error bars are generated through error propagation:

$$\sigma_x = \sqrt{(\frac{\sigma_u}{v})^2 + (\frac{u\sigma_v}{v^2})^2 - 2\frac{u\sigma_{uv}}{v^3}} \tag{8}$$

We summarize the data in Table I for different dimensions of the shielding plates we used. For all types of shielding with holes, we used the same hole size ($d = 5cm$) as shown in Figure 9.

Type	Width	Length	Thickness	Hole density
thinner	6cm	9cm	0.4cm	no hole
thicker	6cm	9cm	0.8cm	no hole
most hole	6cm	9cm	0.4cm	54 holes
middle hole	6cm	9cm	0.4cm	24 holes
few hole	6cm	9cm	0.4cm	6 holes

TABLE I. Different shielding plate

The measurement at 567 MHz has an issue with measurement error, resulting in an unphysical ratio exceeding 1. Despite this, we have included it to present the actual data collected without discarding any results. To reduce measurement errors, we might need to adopt a

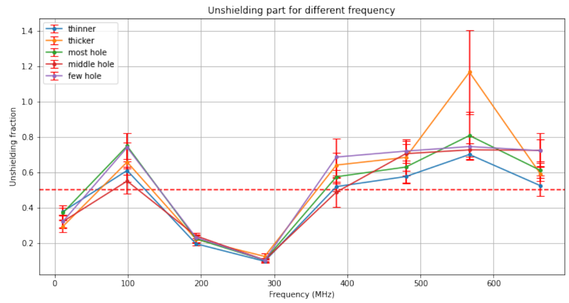


FIG. 10. Shielding effectiveness for different frequency

more systematic and automatic method of measurement, rather than using manual techniques. We currently use manual methods because the standard devices for holding the position of the receiver often contain metal, which could interfere with the measurements when testing the RF shielding effectiveness.

Based on these results, we can estimate that when using a 13.56MHz Arduino MFRC522 RFID emitter, our home-built shielding will demonstrate a certain level of effectiveness. We will double-check the effectiveness of all home-built shielding using the Arduino MFRC522 RFID emitter during the live presentation. All types of shielding are effective, even if the shield is placed behind the RFID card. Furthermore, we find that even if we drill many holes into the shielding, its effectiveness remains on the same order as those without holes.

V. CONCLUSIONS AND OUTLOOK

In this report, we demonstrate that by using 6061 aluminum alloy, we can shield the RF signal from the RFID emitter. We also measure the shielding effectiveness across a range of frequencies from 11.3 MHz to 664 MHz. For future improvements, we might need to use a home-built tunable L-network to maximize impedance matching. Additionally, we might need to construct an automatic measurement setup that avoids RF shielding effects to gather more reliable data for achieving statistical significance. All codes and data are uploaded to GitHub: `https://github.com/GIAYANGGAO/RF_shielding`.

VI. APPENDIX

A. Good learning material

Here, we present some useful materials for those interested in further details. We do not include many references in this report, as the ideas and results presented are simple and straightforward.

- `https://www.youtube.com/@RohdeundSchwarz`

FIG. 11. Arduino MFRC522 RFID emitter

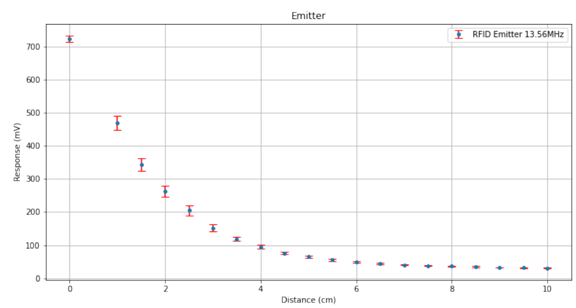


FIG. 12. Measurement for RFID emitter

- `https://www.nxp.com/docs/en/data-sheet/MFRC522.pdf`
- `https://www.rohde-schwarz.com/us/products/test-and-measurement/handheld/rs-fsh-handheld-spectrum-analyzer_63493-8180.html`
- `https://www.modusadvanced.com/rf-shielding`

B. Data for Arduino RFID emitter

We use the Arduino MFRC522 RFID emitter, as shown in Figure 11. We measure the peak-to-peak voltage response from the receiver when using this Arduino RFID emitter, as illustrated in Figure 12.