RF shielding applied to RFID

Sree Ranjani Krishnan, Jia-Yang Gao

PC5214 - Essential techniques in experimental physics

Professor:
Prof. Dzmitry Matsukevich

Project
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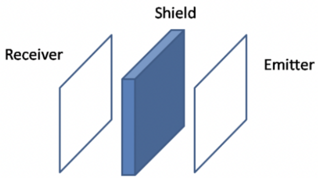
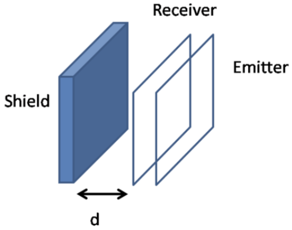
Introduction to RF shielding measurement

- Test the shielding effectiveness of a material.
- Emitter is a home built multi loop antenna (N=20) with 1.5GHz Function generator.
- Receiver is a home built multi loop receiver (N=20) with 2GHz oscilloscope.



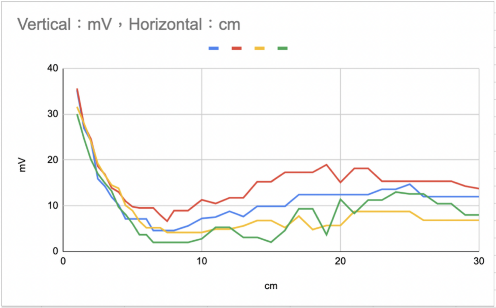
Shielding material between actual emitter and recei



Receiver between shielding material and emitter

Trouble shooting experience

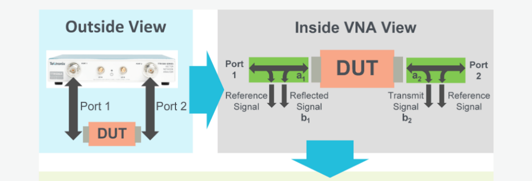
- Emitter is unstable if the impedance is not matched: beat signal
- Initially, we think is the characteristic of the antenna.
- Solve this issue by using a Vector Network Analyzer: measuring the impedance of the antenna.



Vector Network Analyzer (VNA)

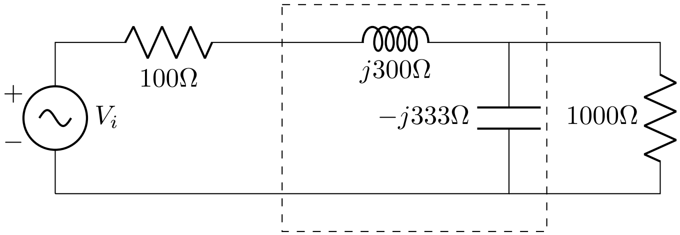
What is a Vector Network Analyzer and How Does it Work?

- 2 ports for testing device under test (DUT)
- VNA sends a signal from port 1, measuring the reflected/transmitted signal (amplitude and phase) on port 1(2) and vice versa.
- Calculate S-matrix: S_{xy}, where x is receiver port and y is emitter port
- $S_{xy} = \frac{b_x}{a_y}$, reflection/transmission ratio $\rightarrow$ impedance
- https://www.tek.com/en/documents/primer/what-vector-network-analyzer-and-how-does-it-work



Impedance matching

- Maximum power transfer from source to load
- $P = I_L^2 R_L = \frac{V^2 R_L}{(R_i + R_L)^2}$
- $\frac{dP}{dR_L} = \frac{V^2 (R_i + R_L)^2 - 2R_L (R_i + R_L) V^2}{(R_i + R_L)^4} = 0 \rightarrow R_i = R_L$
- Reduce unnecessary losses and unwanted reflections
- Ex. LC matching: $1000\Omega || (-j333\Omega) = 100\Omega - j300\Omega$

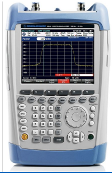


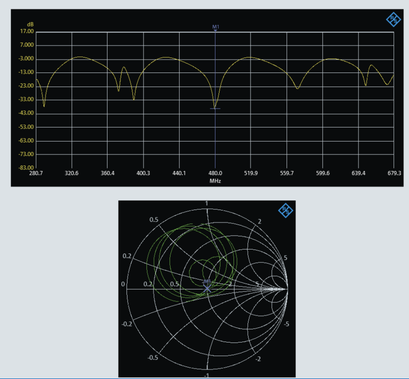
Impedance matching for the antenna

- Initially try to use home-built L-network, failed.
- Use 50Ω with a specific length cable, works for certain frequency: 11.3MHz, 98.9MHz, 193MHz, 287MHz, 385MHz, 480MHz, 567MHz, 664MHz
- Not perfectly matched, can use tunable L-network (broad band) or Pi-network or T-network (narrow band) to improve in future.

Impedance matching for the antenna

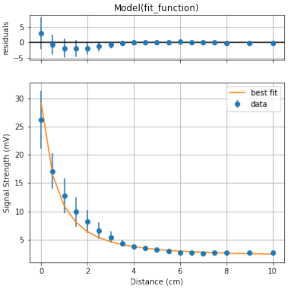
- One-port measurement
- Smith Chart: in the middle is 50Ω.
- Our Function generator is 50Ω.
- Measurement device: FSH8 spectrum analyzer (Rohde & Schwarz)





Results: Emitter 10.8MHz

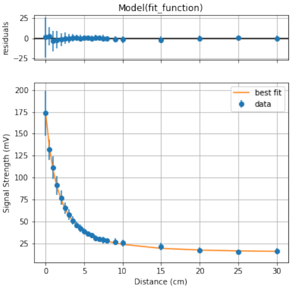
- 10 measurements for each data.
- Using lmfit: Non-Linear Least-Squares Minimization and Curve-Fitting for Python
- Fit function: $f(r, A, B, \epsilon) = \frac{A}{(r+\epsilon)^2} + B$




```
[[Model]]
    Model(fit_function)
[[Fit Statistics]]
    # fitting method   = leastsq
    # function evals   = 61
    # data points      = 19
    # variables        = 3
    chi-square         = 8.51668135
    reduced chi-square = 0.53229258
    Akaike info crit   = -9.24583231
    Bayesian info crit = -6.41251537
    R-squared          = 0.96886601
[[Variables]]
    A:    48.4546968 +/- 8.25345007 (17.03%) (init = 1)
    B:    2.06291088 +/- 0.11230873 (5.44%) (init = 1)
    eps:  1.33575663 +/- 0.16462978 (12.32%) (init = 1)
[[Correlations]] (unreported correlations are < 0.100)
    C(A, B)   = -0.9063
    C(A, eps) = +0.8993
    C(B, eps) = -0.7499
```

Results: Emitter 480MHz

- 10 measurements for each data.
- Using lmfit: Non-Linear Least-Squares Minimization and Curve-Fitting for Python
- Fit function: $f(r, A, B, \epsilon) = \frac{A}{(r+\epsilon)^2} + B$




```
[[Model]]
    Model(fit_function)
[[Fit Statistics]]
    # fitting method   = leastsq
    # function evals   = 29
    # data points      = 23
    # variables        = 3
    chi-square         = 0.91018963
    reduced chi-square = 0.04550948
    Akaike info crit   = -68.2807203
    Bayesian info crit = -64.8742377
    R-squared          = 0.99898080
[[Variables]]
    A:    1670.72131 +/- 62.4798113 (3.74%) (init = 1000)
    B:    14.3246736 +/- 0.36618190 (2.56%) (init = 100)
    eps:  3.22847030 +/- 0.08132679 (2.52%) (init = 1)
[[Correlations]] (unreported correlations are < 0.100)
    C(A, eps) = +0.9558
    C(A, B)   = -0.8140
    C(B, eps) = -0.6893
```

Why using $\frac{1}{r^2}$ fitting?

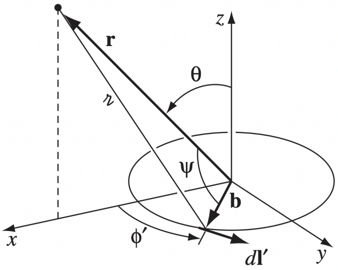
Theory from magnetic dipole radiation:

$$A(r,\theta,t) = -\frac{\mu_0 m_0 \omega}{4\pi c}\left(\frac{\sin\theta}{r}\right)\sin\left[\omega(t - r/c)\right]\hat{\phi} \tag{1}$$

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

approx 1: $b \ll r$, approx 2: $b \ll \frac{c}{\omega}$, approx 3: $r \gg \frac{c}{\omega}$.

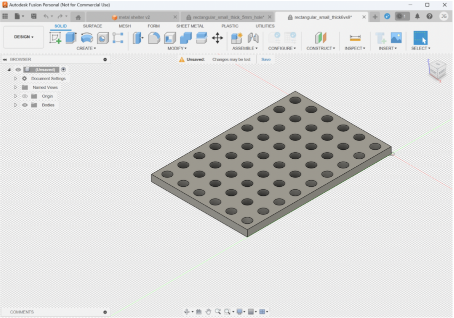
- For f=480MHz, $c/\omega = 9.95$cm
- For f=10.8MHz, $c/\omega = 442$cm
- b = 0.5cm, 0cm < r < 30cm
- $m_0 = \pi b^2 I_0$



RF Shielding material: 6061 aluminium alloy

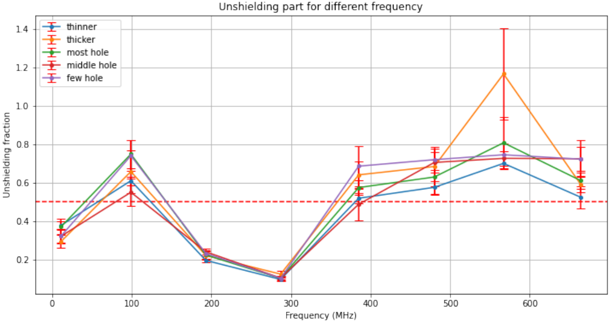
- Design: Autodesk Fusion
- Manufacturers: Teo Kok Seng, CQT
- `https://en.wikipedia.org/wiki/6061_aluminium_alloy`

Constituent element	**Minimum** (% by weight)	**Maximum** (% by weight)
Al	95.85%	98.56%
Mg	0.80%	1.20%
Si	0.40%	0.80%
Fe	0	0.70%
Cu	0.15%	0.40%
Cr	0.04%	0.35%
Zn	0	0.25%
Ti	0	0.15%
Mn	0	0.15%
(others)	0	0.15% total (0.05% each)



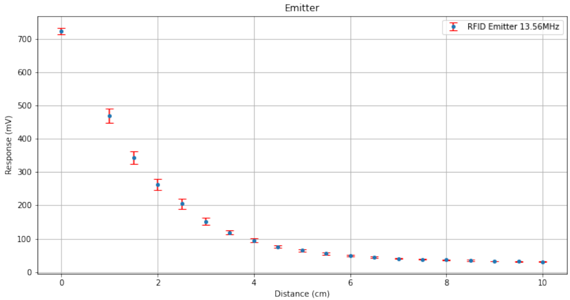
Shielding for different frequency at 1cm

- $x = \frac{u}{v} = \frac{V_{pp}(\text{shield})}{V_{pp}(\text{emitter})}$
- 10 measurements for both w/wo shielding.
- Error propagation: $\sigma_x = \sqrt{(\frac{\sigma_u}{v})^2 + (\frac{u\sigma_v}{v^2})^2 - 2\frac{u\sigma_{uv}}{v^3}}$



RFID emitter using Arduino: Test the shielding demo

- Emitter 13.56 MHz
- All shielding can shield the RFID card
- Demo in real device in presentation



Discussion

- All the code, data and slide latex file will be in GitHub: `https://github.com/GIAYANGGAO/RF_shielding`
- All the experiment results are produced in CQT level2 E workshop.
- Improve the home-built antenna by using tunable L-network if wanted.
- Improve the measurement error by using auto setup instead of using the hand if wanted.

Appendix: good learning material

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