High Frequency RFID Reader Antenna Matching

1. Introduction

A high frequency reader system’s magnetic field is used for tag power and communication. One factor determining the magnetic field’s size and strength is antenna current. Increasing antenna current increases the magnetic field. Since every reader system design is unique, the reader’s antenna must be matched to achieve maximum antenna current flow. An antenna is matched when its inductance is a real impedance to the AT88RF1354 transmit circuit at 13.56 MHz.

This application note provides a recommended antenna matching procedure and examples. The process for matching antennas to AT88RF1354 reader systems does not require RF experience.

2. Assumptions

Although every reader system design is unique this procedure will enable users to accurately and successfully match their RFID reader system antenna. This application note assumes adherence to the following guidelines.

- This procedure assumes the user has duplicated the AT88RF1354 reference circuit reader block PCB layout and bill of material posted online at www.atmel.com.

- All references to component labels and positions in this document are relative to the AT88RF1354 reference circuit posted online.

- The inductance of the reader antenna windings and the path to the antenna is between 0.8 µH and 1.6 µH. Inductance values below 0.8 µH become increasingly difficult to match and the margin for error becomes very small.

- The reader antenna windings and the path to the antenna has a DC resistance less than one ohm. A high resistance path impedes current flow which may result in an inadequate magnetic field.

- This procedure assumes the reader antenna windings and the path to the antenna are manufactured using an identical and highly repeatable process.

- Antenna matching for systems with reader antennas in close proximity to metal surfaces is not covered in this procedure.
3. **Equipment Set**

The antenna matching process utilizes a tool set typically available in most engineering labs.

- Impedance analyzer or LCR meter.
- Personal computer or microcontroller system. Used to send reader system commands.
- A 3.3V – 5.0V linear DC power supply. Used for reader system power.
- Ammeter. A linear DC power supply ammeter with 1 mA resolution is an acceptable alternative.
- Solder station.
- Trim capacitor (i.e. Murata TZ03Z500F169B00, 6 – 50 pF. Available from Digikey, part number 490-1975-ND). Using trim capacitors with substantially more or less range may make the optimization process more difficult and time consuming.
- Trim tool or non-conductive screwdriver.
4. **Procedure**

The process for matching antennas to AT88RF1354 reader systems does not require RF experience. When the reader system and its antenna are produced by a highly repeatable process such as PCB manufacturing, the antenna matching procedure described within this application note is typically a one time process for each new system design. After the matching network component values have been accurately determined by this procedure, the same component values can be utilized with all other identical reader systems.

When a new system design is copied from Atmel’s online documentation, the matching process involves the updating of only three capacitor positions; C21, C22 and C24 (see Figures 1 and 2). This capacitor network allows virtually any matching network to be created using standard fixed value capacitors (see Appendix A). Since these capacitors are part of a resonant circuit and the final matching is entirely comprised of fixed value components, 50V, 2% C0G rated devices are required.

![Figure 1 – AT88RF1354 reader antenna matching network location](image)

![Figure 2 – AT88RF1354 reader antenna matching network components: C21, C22 and C24](image)
4.1. **Step 1 – Measuring Reader Antenna Inductance**

The reader antenna inductance includes the winding inductance and the inductance of the path to the antenna. An impedance analyzer or LCR is required. Since inductance is frequency dependent, it is best if the test frequency is at least 10 MHz and optimally 13.56 MHz.

**WARNING** – Hand held meters and instruments with long test leads may provide inaccurate results. A matched system can still be achieved but plan to spend additional time performing repetitive work.

a. Select either a bare reader board or a reader board with capacitor C24 removed.

b. While keeping the antenna away from metal surfaces, measure the path from the antenna side of C24 (Figure 3, point A), thru the antenna windings and back to VSS_ANT. A VSS_ANT connection point is available on the ground side of C44 and C45 (Figure 3, point B).

c. Record the inductance value. To provide a working example, a 1.0 µH reader antenna inductance will be the assumed reader antenna inductance.

![Figure 3 – AT88RF1354 reader antenna C24 and VSS_ANT test points](image-url)
4.2. **Step 2 – Calculate Initial Matching Capacitance**

Calculate the initial capacitance necessary to make the measured antenna inductance real at 13.56 MHz. As an example, assume a 1.0 µH inductance has been measured. All calculations must be done for each unique reader system. Due to a number of factors the calculated matching capacitance will not provide an exact answer. A precise answer will be determined empirically.

a. Inductive impedance, \( X_L = \frac{2\pi f L}{\text{where} f = 13.56 \text{ MHz}} \)
   - If \( L = 1.0 \mu\text{H} \)
   - \( X_L = \frac{2\pi \times 13.56 \times 10^6 \times 1.0 \times 10^{-6}}{\text{Therefore} X_L = 85.2 \Omega} \)

b. Capacitive impedance, \( X_C = \frac{1}{(2\pi f C)} \). At resonance, \( X_L = X_C \). Substitute the value calculated for \( X_L \) into \( X_C \) and solve for \( C \).
   - \( C_{\text{INITIAL}} = \frac{1}{(2\pi f X_C)} \)
   - \( C_{\text{INITIAL}} = \frac{1}{(2\pi \times 13.56 \times 10^6 \times 85.2)} \)
   - Therefore \( C_{\text{INITIAL}} = 137.8 \text{ pF} \)

4.3. **Step 3 – Calculate Initial Installed Matching Network**

Now that \( C_{\text{INITIAL}} \) has been determined, a trimmer and fixed value capacitors can be used to find the optimum matching network. The initial matching components should be selected so that when the trimmer is placed at its mid-point, the matching network’s capacitance is near the calculated \( C_{\text{INITIAL}} \) value. This methodology allows the matching capacitance to be swept on both sides of \( C_{\text{INITIAL}} \).

The matching process involves the updating of only three capacitor positions; C21, C22 and C24 (see Figure 4). This capacitor network allows virtually any matching network to be created using standard fixed value capacitors (see Appendix A). Since these capacitors are part of a resonant circuit and the final matching is entirely comprised of fixed value components, 50V, 2% COG rated devices are required.

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**Figure 4 – Partial AT88RF1354 Keen+ transmit circuit schematic**
Quite often an initial C24 value of 560, 680 or 820 pF is a good starting point for the matching network. Assuming a 5 – 50 pF trimmer is being used, the trimmer’s mid-point would be approximately 30 pF. Since C24 is in series with parallel capacitors C21 and C22, simply calculate a C21 value that when combined with the trimmer’s mid-point value, the total capacitance of C21, C22 and C24 is approximately equal to C\text{INITIAL}.

a. For this example select C24 = 560 pF and C21 = 150 pF.

b. Assume the 6 – 50 pF trimmer midpoint is 30 pF.

c. C21 and C22 are in parallel.
   - The total capacitance of parallel capacitors: \( C_{\text{PARALLEL}} = C_1 + C_2 + \ldots + C_N \)
   - Therefore \( C_{\text{PARALLEL}} = 150 \text{ pF} + 30 \text{ pF} \) (the trimmer’s mid-point). \( C_{\text{PARALLEL}} = 180 \text{ pF} \)

d. Calculate the matching network’s total capacitance. The total capacitance will be the parallel elements, C21 and C22, in series with C24.
   - The total capacitance of series capacitors: \( C_{\text{SERIES}} = \frac{1}{1/C_1 + 1/C_2 + \ldots + 1/C_N} \)
   - Therefore \( C_{\text{TOTAL}} = \frac{1}{1/180 \text{ pF} + 1/560 \text{ pF}} = 136.2 \text{ pF} \).

In this case the initial matching network happens to be very close to the calculated \( C_{\text{INITIAL}} \) value. A reasonable starting point is creating an initial matching network within 5 – 8 pF of the calculated \( C_{\text{INITIAL}} \) value.
4.4. **Step 4 – Install Initial Matching Network**

Using a solder station, install the initial matching network determined in step 3.

a. Assuming the example case, install a 560 pF, 50V, 2%, C0G capacitor at C24.

b. Continuing with the example case, install a 150 pF, 50V, 2%, C0G capacitor at C21.

c. Solder the trim capacitor across C21 or C22. Although the C21 and C22 pads are designed for fixed value surface mount capacitors, a trimmer can be temporarily soldered into the circuit (see Figure 5). After the trimmer has been soldered into position, inspect the board and confirm the modification has not created a short to C44.

![Figure 5 – AT88RF1354 initial matching network installed](image-url)
4.5. **Step 5 – Matching Network Optimization**

Now that the initial matching network is installed, the optimum matching can be determined empirically.

a. Connect the reader system to a linear DC power supply, ammeter and a controller.

b. Position the reader so that metal surfaces and cabling are at least one (1) antenna diameter away from the reader’s antenna.

c. Move all RFID tags at least one (1) antenna diameter away from the reader’s antenna.

d. Set the linear DC supply voltage in the 3.3V – 5.0V range. Enable the power supply.

e. Record the RF\_DISABLED system current, \(I_{DISABLED}\).

f. Using the controller write AT88RF1354 TXC register $0E$ to $04$.

g. Using the controller send the AT88RF1354’s RF Enable command, $0A$. The current value will increase if the reader system was assembled correctly.

h. While keeping your hands away from the reader circuit block and the reader antenna use a non-conductive screw driver and slowly adjust the trimmer.

   i. Monitor the current while making this adjustment.

   ii. Locate the trimmer position that causes the highest current reading.

i. Record the RF\_ENABLED system current, \(I_{ENABLED}\).

j. Calculate the RF current, \(I_{RF}\). \(I_{RF} = I_{ENABLED} - I_{DISABLED}\)

As a general guideline \(I_{RF}\) is 130 – 160 mA for a system powered at 3.3V and 140 – 170 mA for a system powered at 5.0V.

**Step 6 – Trim Capacitor Verification**

Although a maximum current reading was found during the prior step, the results must be confirmed. An impedance analyzer or LCR is required for this step. Since capacitance is frequency dependent, it is best if the test frequency is at least 10 MHz and optimally 13.56 MHz.

a. Remove the trim capacitor from the circuit.

b. Measure the trim capacitor and record the value.

WARNING – If the measured trim capacitor value is near either the upper or lower end of the trimmer’s range, the matching optimization results may be incorrect. Based upon the trim capacitor’s value, determine a new capacitance value for C21, C22 or C24 that will allow the trimmer to be nearer its mid-point when the maximum current point is found.

c. If the trimmer was found to be near either its minimum or maximum value, update the fixed capacitance as necessary at C21, C22 or C24. Repeat Step 5 – Matching Network Optimization.
4.6. **Step 7 – Determine Final Matching Components**

After optimization is complete, the matching components must be measured and the final fixed value matching components must be determined. An impedance analyzer or LCR is required for this step. Since capacitance is frequency dependent, it is best if the test frequency is at least 10 MHz and optimally 13.56 MHz.

a. Remove the trim capacitor from the circuit, measure and record its final value. Assume it measures 36.1 pF.
b. Remove C24 from the circuit, measure and record its value. Assume it measures 672 pF.
c. Remove C21 from the circuit, measure and record its value. Assume it measures 152.7 pF.
d. Calculate the final total capacitance from the measured values. For this example, \( C_{FINAL\_TOTAL} = 147.4 \text{ pF} \)
e. Virtually any precise matching capacitance value can be created with two or three standard value capacitors (see Appendix A). Determine a component combination that creates a total capacitance within +/- 2 pF of \( C_{FINAL\_TOTAL} \). Selecting \( C24 = 820 \text{ pF} \) and \( C21 = 180 \text{ pF} \) will result in a total capacitance of 147.6 pF. Therefore this component combination achieves the goal of being within +/- 2 pF of the empirically determined optimum matching.

4.7. **Step 8 – Install Final Matching Components**

Using a solder station, install the matching components determined in step 7.

a. Install a 50V, 2%, C0G capacitor at C24. For our example case, \( C24 = 820 \text{ pF} \).
b. Install a 50V, 2%, C0G capacitor at C21. For our example case, \( C21 = 180 \text{ pF} \).
c. Install a 50V, 2%, C0G capacitor at C22. For our example case, C22 remains unpopulated.

4.8. **Step 9 – Verify Final Matching Components**

The final matching network should be verified to identify math or assembly errors.

a. Connect the reader system to a linear DC power supply, ammeter and a controller.
b. Position the reader so that metal surfaces and cabling are at least one (1) antenna diameter away from the reader’s antenna.
c. Move all RFID tags at least one (1) antenna diameter away from the reader’s antenna.
d. Set the linear DC supply voltage in the 3.3V – 5.0V range. For consistency, use the same supply voltage as used in Step 5. Enable the power supply.
e. Record the RF\(_{DISABLED}\) system current, \( I_{DISABLED} \).
f. Using the controller write AT88RF1354 TXC register $0E to $04.
g. Using the controller send the AT88RF1354’s RF Enable command, $0A.
h. Record the RF\(_{ENABLED}\) system current, \( I_{ENABLED} \).
i. Calculate the RF current, \( I_{RF} \). RF current, \( I_{RF} = I_{ENABLED} - I_{DISABLED} \)

The RF current, \( I_{RF} \), calculated in Step 9 should be within about +/- 3 mA of the RF current determined in the final iteration of Step 5. For a given design, the six sigma RF current distribution for a large reader population will typically be within about +/-15 mA of the population mean.
## Appendix A. Capacitor Table

Component positions C21, C22 and C24 must use capacitors with a 50V, 2%, C0G rating. Standard capacitor values along with a recommended supplier’s part numbers are listed in the table below.

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<th>Value</th>
<th>Case Size 0603 (1608)</th>
<th>Case Size 0402 (1005)</th>
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**Notes**

1) Component positions C21, C22 and C24 must use devices with a 50V, 2%, C0G rating.
2) Capacitors 10 pF and smaller are typically not manufactured to a 2% tolerance.
Appendix B. Revision History

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<th>Doc. Rev.</th>
<th>Date</th>
<th>Comments</th>
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<td>Jan 2010</td>
<td>Preliminary draft</td>
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