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 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.
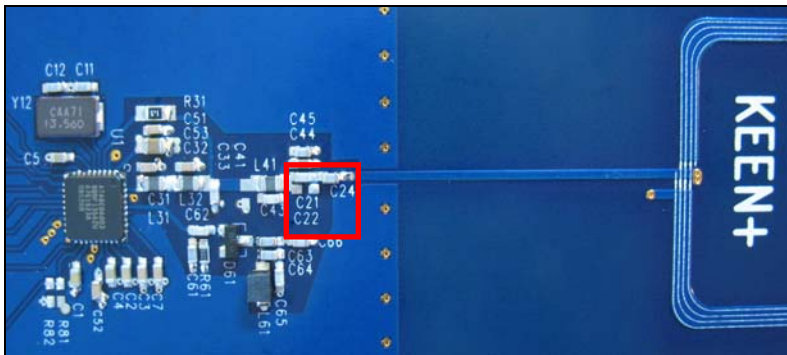

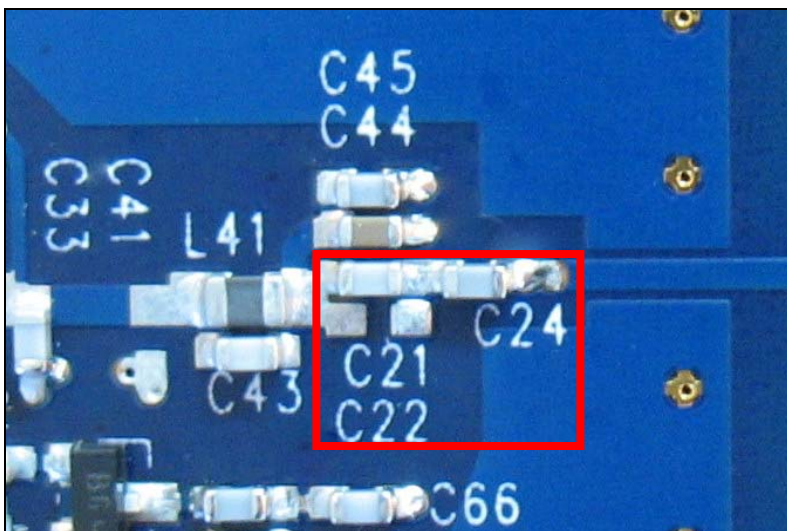Figure 1 – AT88RF1354 reader antenna matching network location

Figure 2 – AT88RF1354 reader antenna matching network components: C21, C22 and C24

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.
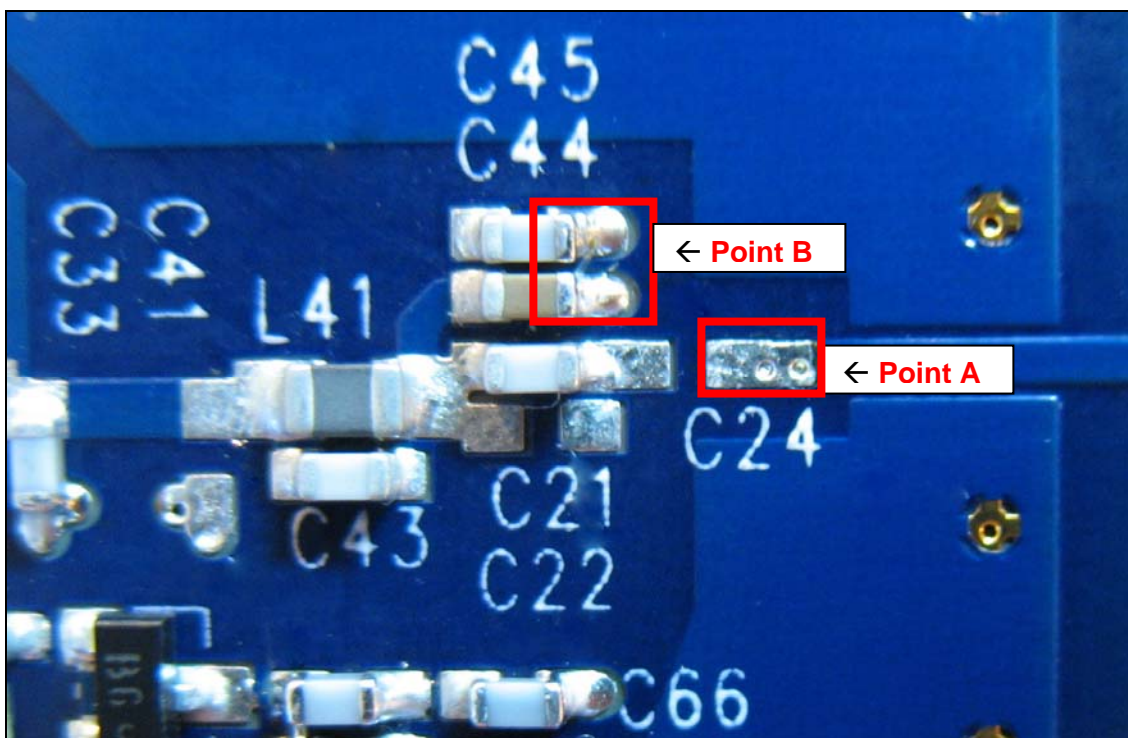

Figure 3 – AT88RF1354 reader antenna C24 and VSS_ANT test points

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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, $X_L = 2\pi * f * L$ where f = 13.56 MHz.
- If L = 1.0 µH

- $X_L = 2\pi * 13.56 \times 10^6 * 1.0 \times 10^{-6}$

- Therefore X_L = **85.2 Ω**

    b. Capacitive impedance, $X_C = 1 / (2\pi * f * C)$. At resonance, $X_L = X_C$. Substitute the value calculated for X_L into X_C and solve for C.
- $C_{INITIAL} = 1 / (2\pi * f * X_C)$

- $C_{INITIAL} = 1 / (2\pi * 13.56 \times 10^6 * 85.2)$

- Therefore $C_{INITIAL}$ **= 137.8 pF**

4.3. Step 3 – Calculate Initial Installed Matching Network

Now that $C_{INITIAL}$ 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 $C_{INITIAL}$ value. This methodology allows the matching capacitance to be swept on both sides of $C_{INITIAL}$.

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% C0G rated devices are required.
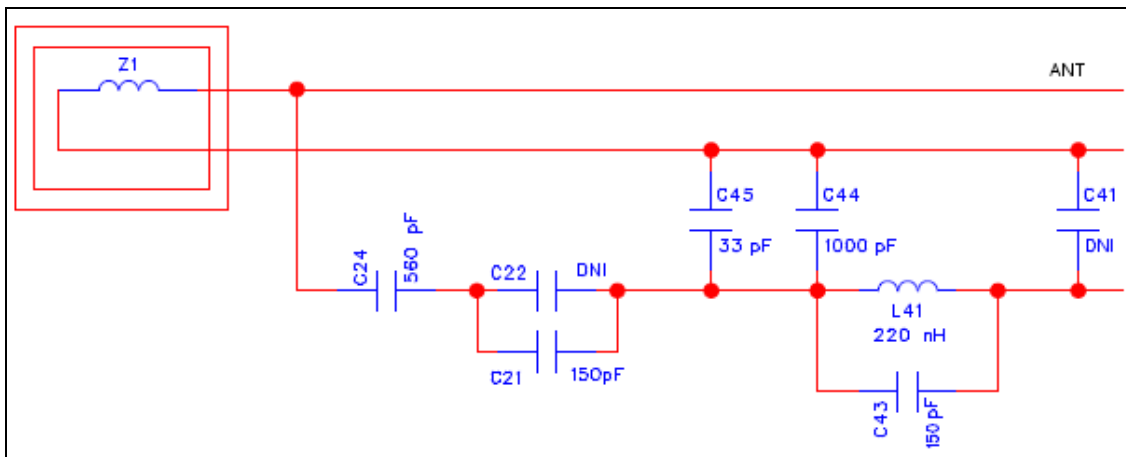

Figure 4 – Partial AT88RF1354 Keen+ transmit circuit schematic

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 $C_{INITIAL}$.

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: $C_{PARALLEL} = C_1 + C_2 + \dots C_N$

- Therefore $C_{PARALLEL}$ = 150 pF + 30 pF (the trimmer's midpoint). $C_{PARALLEL}$ = 180 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: $C_{SERIES} = 1 / (1 / C_1 + 1 / C_2 + \dots 1/C_N)$

- Therefore $C_{TOTAL} = 1 / (1 / 180 \text{ pF} + 1 / 560 \text{ pF}) = $ **136.2 pF**.

In this case the initial matching network happens to be very close to the calculated $C_{INITIAL}$ value. A reasonable starting point is creating an initial matching network within 5 – 8 pF of the calculated $C_{INITIAL}$ value.

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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.
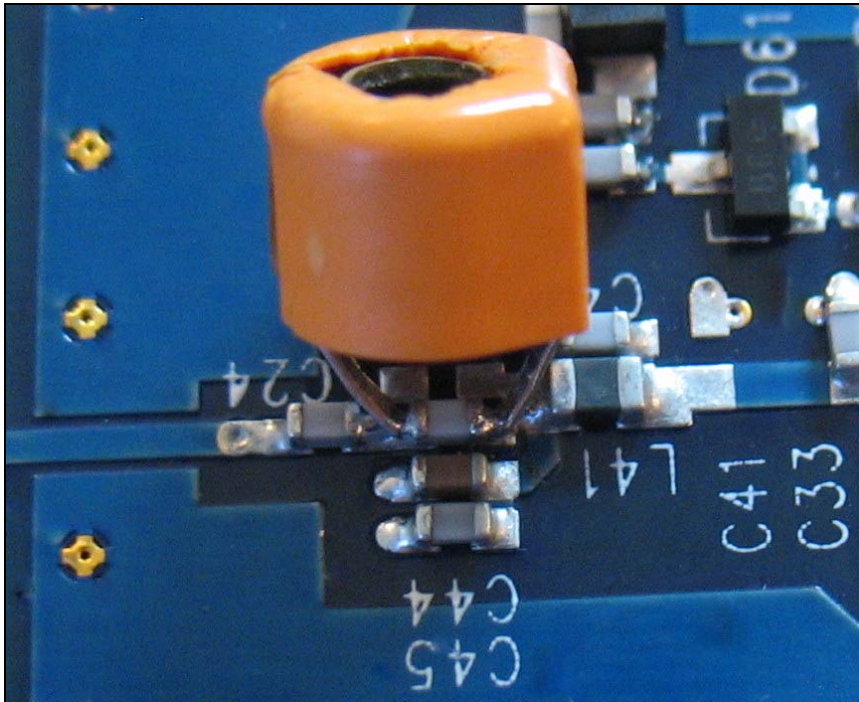

Figure 5 – AT88RF1354 initial matching network installed

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}. RF current, $I_{RF} = I_{ENABLED} - I_{DISABLED}$

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 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 pF and C21 = 180 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 pF.

b. Install a 50V, 2%, C0G capacitor at C21. For our example case, C21 = 180 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.

Value	Case Size 0603 (1608) Murata Part Number	Case Size 0402 (1005) Murata Part Number
5.6 pF	GRM1885C1H5R6BZ01	GRM1555C1H5R6FZ01
6.8 pF	GRM1885C1H6R8BZ01	GRM1555C1H6R8FZ01
8.2 pF	GRM1885C1H8R2BZ01	GRM1555C1H8R2FZ01
10 pF	GRM1885C1H100JA01	GRM1555C1H100KZ01
12 pF	GRM1885C1H120GA01	GRM1555C1H120GZ01
15 pF	GRM1885C1H150GA01	GRM1555C1H150GZ01
18 pF	GRM1885C1H180GA01	GRM1555C1H180GZ01
22 pF	GRM1885C1H220GA01	GRM1555C1H220GZ01
27 pF	GRM1885C1H270GA01	GRM1555C1H270GZ01
33 pF	GRM1885C1H330GA01	GRM1555C1H330GZ01
39 pF	GRM1885C1H390GA01	GRM1555C1H390GZ01
47 pF	GRM1885C1H470GA01	GRM1555C1H470GZ01
56 pF	GRM1885C1H560GA01	GRM1555C1H560GZ01
68 pF	GRM1885C1H680GA01	GRM1555C1H680GZ01
82 pF	GRM1885C1H820GA01	GRM1555C1H820GZ01
100 pF	GRM1885C1H101GA01	GRM1555C1H101GZ01
120 pF	GRM1885C1H121GA01	GRM1555C1H121GA01
150 pF	GRM1885C1H151GA01	GRM1555C1H151GA01
180 pF	GRM1885C1H181GA01	GRM1555C1H181GA01
220 pF	GRM1885C1H221GA01	GRM1555C1H221GA01
270 pF	GRM1885C1H271GA01	GRM1555C1H271GA01
330 pF	GRM1885C1H331GA01	GRM1555C1H331GA01
390 pF	GRM1885C1H391GA01	GRM1555C1H391GA01
470 pF	GRM1885C1H471GA01	GRM1555C1H471GA01
560 pF	GRM1885C1H561GA01	GRM1555C1H561GA01
680 pF	GRM1885C1H681GA01	GRM1555C1H681GA01
820 pF	GRM1885C1H821GA01	GRM1555C1H821GA01
1000 pF	GRM1885C1H102GA01	GRM1555C1H102GA01
1200 pF	GRM1885C1H122GA01	N/A
1500 pF	GRM1885C1H152GA01	N/A

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.

Antenna Matching

Appendix B. Revision History

Doc. Rev.	Date	Comments
A	Jan 2010	Preliminary draft

![Atmel logo]

Headquarters

Atmel Corporation
2325 Orchard Parkway
San Jose, CA 95131
USA
Tel: 1(408) 441-0311
Fax: 1(408) 487-2600

International

Atmel Asia
Unit 1-5 & 16, 19/F
BEA Tower, Millennium City 5
418 Kwun Tong Road
Kwun Tong, Kowloon
Hong Kong
Tel: (852) 2245-6100
Fax: (852) 2722-1369

Atmel Europe
Le Krebs
8, Rue Jean-Pierre Timbaud
BP 309
78054 Saint-Quentin-en-
Yvelines Cedex
France
Tel: (33) 1-30-60-70-00
Fax: (33) 1-30-60-71-11

Atmel Japan
9F, Tonetsu Shinkawa Bldg.
1-24-8 Shinkawa
Chuo-ku, Tokyo 104-0033
Japan
Tel: (81) 3-3523-3551
Fax: (81) 3-3523-7581

Product Contact

Web Site
www.atmel.com

Technical Support
securerf@atmel.com

Sales Contact
www.atmel.com/contacts

Literature Requests
www.atmel.com/literature