

Tag Tuning

Introduction

RFID tags extract all of their power to both operate and communicate from the reader's magnetic field. Coupling between the tag and reader is via the mutual inductance of the two loop antennas, see Figure 1. The efficient transfer of energy from the reader to the tag directly affects operational reliability and read/write range. Generally, both 13.56 MHz and 125 kHz RFID tags use parallel resonant LC loop antennas, tuned to the carrier frequency. This application note gives an overview of basic tag antenna tuning.

Antenna Equivalent Circuit

The RFID circuit is similar to a transformer in which loop inductors magnetically couple when one of the loops, in the case of the reader antenna, is energized with an alternating current, thus, creating an alternating magnetic field. The tag loop antenna acts like the secondary of a transformer where an alternating current is induced in the antenna, extracting energy from the magnetic field. Generally, the larger the diameter of the tag antenna loop, the more magnetic flux lines pass through the coil. This increases the transfer of energy from the reader to the tag.

Figure 1. RFID Tag Coupling to a Reader's Magnetic Field

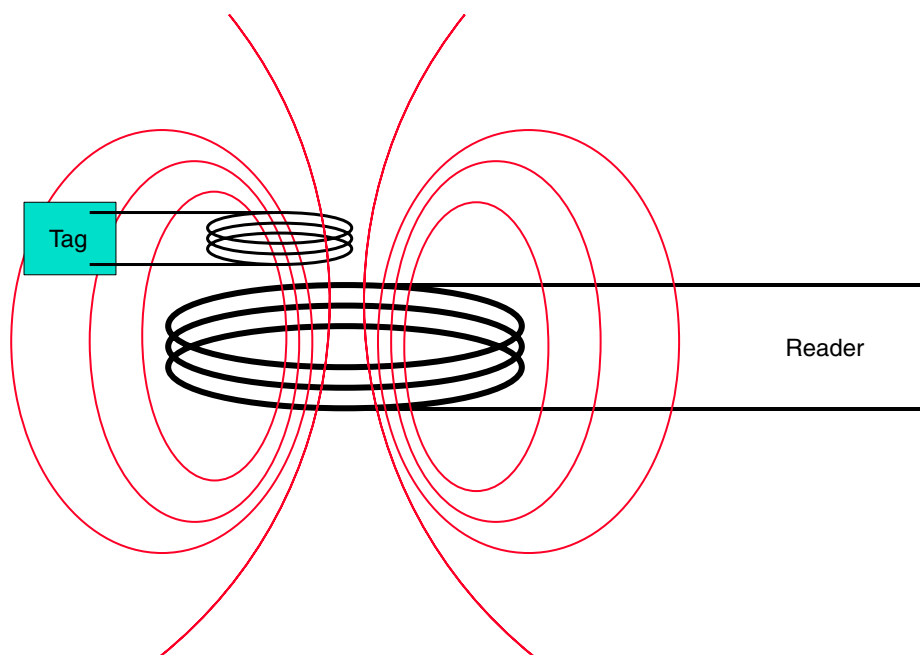


Figure 2 shows the equivalent circuit where the reader and tag antennas are magnetically coupled via mutual inductance M . The parallel resonant circuit of the tag antenna includes the L_2 inductance of the loop, the resistance of R_{antenna} of the loop, and the capacitance. The capacitance includes the sum of the tuning capacitance, which is sometimes integrated onto the tag chip, and the parasitic capacitances of the coil and tag materials. The chip load is often modeled as a resistance at its highest current usage, usually either at power-up reset or during an EEPROM write. Keeping



Tag Tuning/RFID

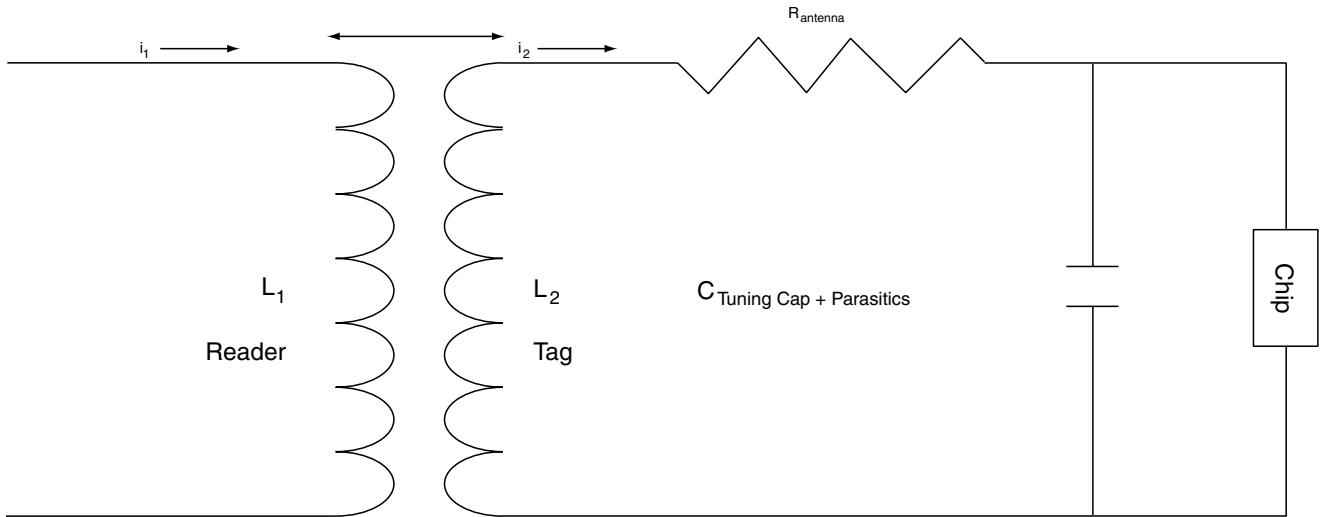
Application Note

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the resistance of the coil to a minimum increases the Q of the antenna and increases the energy available to the tag.

Figure 2. Equivalent Circuit Diagram



Antenna Tuning to Resonance

The resonant frequency of a parallel resonant LC circuit can be calculated by:

$$f_{res} = \frac{1}{2\pi\sqrt{L_2 \cdot C}}$$

Using the on-chip tuning capacitor value gives a good first approximation for calculating the antenna coil inductance. Solving for the value of coil inductance at the carrier frequency resonance:

$$L = \frac{1}{(2\pi f)^2 \cdot C}$$

Examples

The coil inductance for an AT88RF256-13 with a 30 pf tuning capacitor:

$$L = \frac{1}{(2 \cdot 3.1415 \cdot 13.56 \times 10^6 \text{ Hz})^2 \cdot 30 \times 10^{-12} \text{ farads}} = 4.5 \times 10^{-6} \text{ Henrys or } 4.5 \mu\text{H}$$

The coil inductance for the AT88RF020 and the AT88RF080 with an 82 pf tuning capacitor:

$$L = \frac{1}{(2 \cdot 3.1415 \cdot 13.56 \times 10^6 \text{ Hz})^2 \cdot 82 \times 10^{-12} \text{ farads}} = 1.6 \cdot 10^{-6} \text{ Henrys or } 1.6 \mu\text{H}$$

The coil inductance for the AT88RF256-12 with a 150 pf tuning capacitor:

$$L = \frac{1}{(2 \cdot 3.1415 \cdot 125 \times 10^3 \text{ Hz})^2 \cdot 150 \times 10^{-12} \text{ farads}} = 10.8 \times 10^{-3} \text{ Henrys or } 10.8 \text{ mH}$$

The coil inductance for the AT24RF08CN with a 5 pf on-chip capacitor plus a 470 pf external tuning capacitor, similar to the AT24RF08-EK tags:

$$L = \frac{1}{(2 \cdot 3.1415 \cdot 125 \times 10^3 \text{ Hz})^2 \cdot 475 \times 10^{-12} \text{ farads}} = 3.4 \times 10^{-3} \text{ Henrys or } 3.4 \text{ mH}$$

The coil inductance for an e5530 with a 5 pf static plus a 4 pf dynamic on-chip capacitor plus a 390 pf external tuning capacitor, from the example in the data sheet:

$$L = \frac{1}{(2 \cdot 3.1415 \cdot 125 \times 10^3 \text{ Hz})^2 \cdot 399 \times 10^{-12} \text{ farads}} = 4.05 \times 10^{-3} \text{ Henrys or } 4.05 \text{ mH}$$

The coil inductance for an e5551 with a 5 pf static plus a 25 pf dynamic on-chip capacitor plus a 360pf external tuning capacitor, from the example in the data sheet:

$$L = \frac{1}{(2 \cdot 3.1415 \cdot 125 \times 10^3 \text{ Hz})^2 \cdot 390 \times 10^{-12} \text{ farads}} = 4.2 \times 10^{-3} \text{ Henrys or } 4.2 \text{ mH}$$

The coil inductance for an e2261 with a 30 pf on-chip capacitor plus a 390 pf external tuning capacitor:

$$L = \frac{1}{(2 \cdot 3.1415 \cdot 125 \times 10^3 \text{ Hz})^2 \cdot 420 \times 10^{-12} \text{ farads}} = 3.9 \times 10^{-3} \text{ Henrys or } 3.9 \text{ mH}$$

Note: All of these example calculations give a nominal inductance for resonance and neglect stray capacitances from the tag material. These approximations do not compensate for antenna detuning due to mutual inductance of multiple tags in a reader magnetic field. Tuning the devices sold with a 10 pf is described below.

Antenna Selection with 10 pf Integrated Tuning Cap

Synopsis

It is recommended that an external tuning capacitor be used with the 10 pf versions of Atmel's 13.56 MHz RFID tag chips. The 10 pf versions of the AT88RF001, AT88RF256-13, AT88RF080 and AT88RF020 chips were designed with a nominal 10 pf internal tuning capacitance on the coil pins to allow the customer to select the external antenna configuration appropriate for the application. In most cases both a capacitor and an inductive antenna coil will be connected across the coil pins to form a resonant antenna circuit. For external tuning capacitors over 15 pf, adding 10 pf to the external capacitance will give the correct total capacitance for calculating resonance. One should use caution when tuning an antenna using only the 10 pf on-chip capacitor following the guidance below. Versions of Atmel's 13.56 MHz chip with larger than 10 pf on-chip tuning capacitors can be tuned with only the on-chip capacitor referring to the equations above.

Integrated Tuning Capacitor

The standard production and sample versions of the 10 pf devices are designed with a nominal 10 pf internal tuning capacitance on the coil pins. This capacitance may vary over a range of 7 to 13 pf over temperature, voltage, frequency, and manufacturing process variations. This integrated capacitance is composed primarily of parasitic elements of the coil pin circuit, including junction and gate edge capacitances. These parasitic capacitances do not behave in a linear manner over temperature, voltage, and frequency. For most applications the best communication range and performance is achieved when an external tuning capacitor is connected in parallel with the antenna coil, forming a resonant circuit. Nonlinearity of the internal tuning capacitor does not significantly affect RFID performance when an external capacitor is used to tune the antenna to resonate at 13.56 MHz.

Matching Antennas Using External Tuning Capacitor

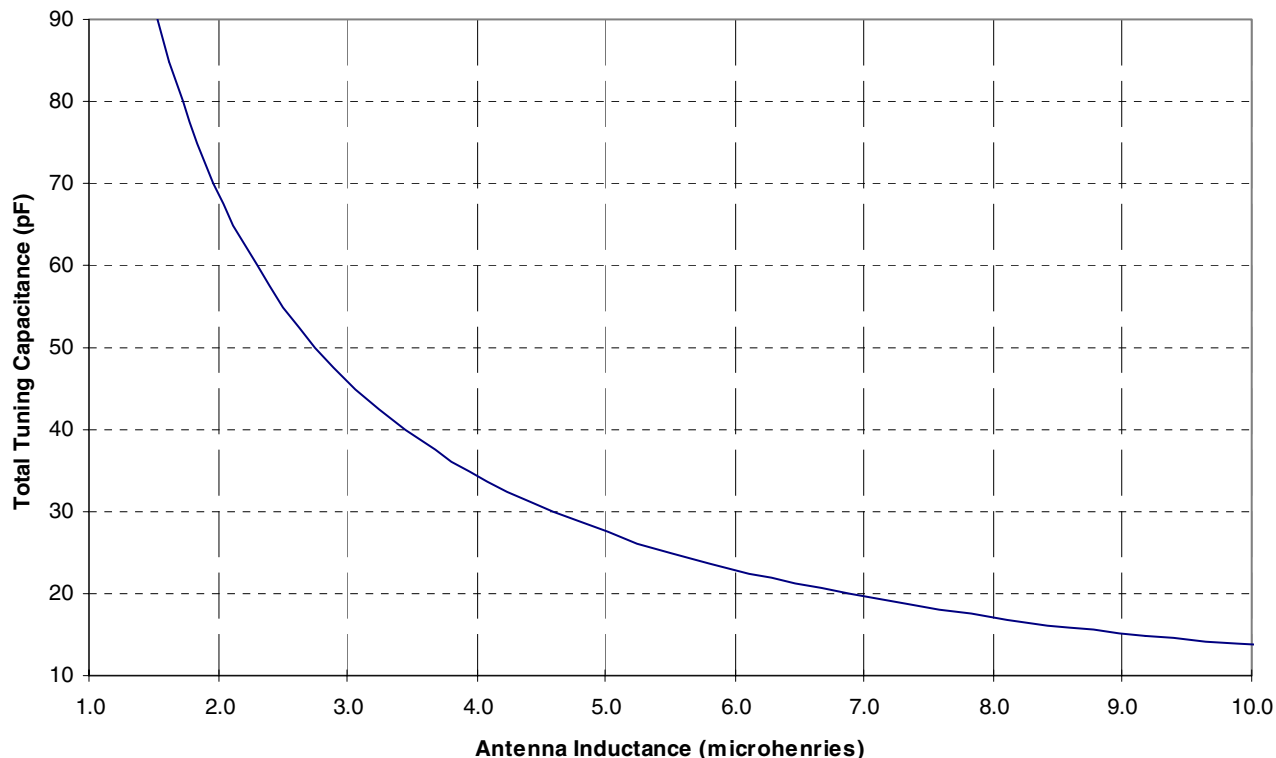
Tuning the RFID tag to resonate at the carrier frequency produces the maximum communication range. This tuning is accomplished by matching the antenna inductance with a tuning capacitor to produce resonance at 13.56 MHz.

The equation for resonance is:

$$f_{\text{res.}} = \frac{1}{2\pi\sqrt{L_2 \cdot C}}$$

For these RFID ICs, the resonant frequency f_0 is 13.56 MHz, L is the antenna inductance, and C is the total internal and external capacitance across the coil pins. Since the internal tuning capacitance is 10 pf nominal, the additional capacitance required is easily calculated using the equation above. Alternately, the values can be read off of the graph in Figure 3.

Figure 3. Component Values for Tuning an RFID Tag Antenna to 13.56 MHz



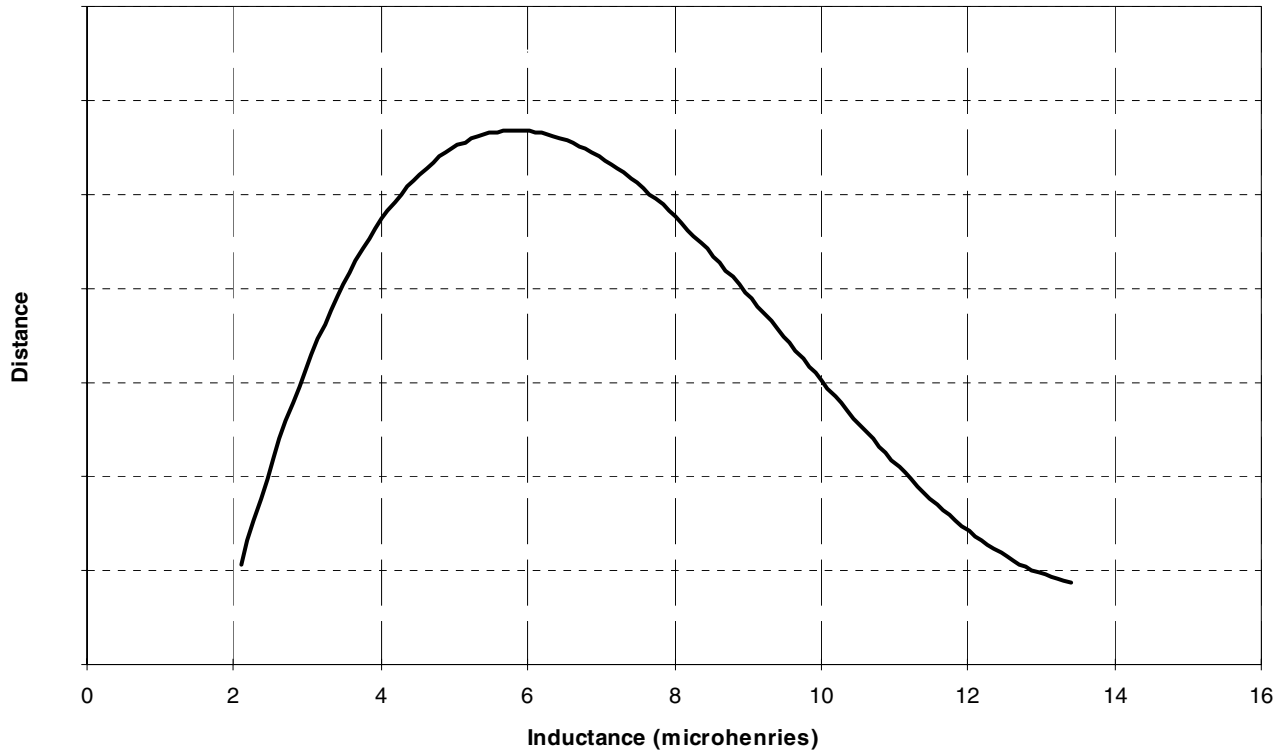
For example, if there is a 3.0 microhenry (μH) antenna, then Figure 3 shows that the total coil pin tuning capacitance should be 46 pf. Since the internal tuning capacitance is 10 pf nominal, add a 36 pf ceramic chip capacitor across the coil pins to achieve resonance at 13.56 MHz.

Matching Antennas Without External Tuning Capacitor

The calculated antenna inductance to achieve resonance at 13.56 MHz is 13.8 μH for the standard 10 pf devices. Laboratory measurements using various antennas without additional external tuning capacitance revealed a “phantom” capacitance on the coil pins that dramatically impacts performance.

Antennas of various inductances were fabricated with solid copper wire, and the distance at which the IC received sufficient power from the RF field to begin transmitting the ID was measured. The results are plotted in Figure 4.

Figure 4. AT88RF001 Active Distance from Antenna vs. Tag Antenna Inductance



Examination of Figure 4 reveals that the optimum antenna inductance for the 10 pf devices without external tuning capacitance is approximately 6 μH . The operating distance with a 6 μH antenna is equal to that of a lower inductance tag antenna tuned to resonate at 13.56 MHz.

Using the equation for resonant circuits, it is evident that a 6 μH antenna in parallel with a 23 pf capacitor produces resonance at 13.56 MHz. The integrated tuning capacitance between the coil pins of the 10 pf devices was measured as 10 pf. The parasitic capacitance of the antenna coil and the fixturing used in this experiment was measured to be 3.4 pf. So of the 23 pf of capacitance expected, 13.4 pf was identified by small signal measurements on the antenna circuit. The remaining 9.6 pf of “phantom” capacitance is the result of large signal interaction of the coil pin circuits with the antenna.

When the 10 pf ICs are operating, the RF field produces a sinusoidal voltage across the coil pins of 12 to 16 volts peak-to-peak. The active circuits on the coil pins interact with the coil current and voltage in a nonlinear and complex manner. These large signal interactions are not well understood, but have been found experimentally to be equivalent to 9.6 pf of “phantom” capacitance between the coil pins.

These tests demonstrate that an RFID tag can be constructed with no additional tuning capacitance. The antennas used in these tests were constructed of copper wire coils, which have significant parasitic capacitance. Production antennas fabricated of thick film conductors may have more or less parasitic capacitance than the test antennas, so it may be desirable to increase or decrease the antenna inductance slightly to achieve maximum read/write range.



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