How to Achieve High Performance in Low-Cost Key-Fob Applications

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An RF transmission system for automotive applications must meet specific requirements to be successful. The most important technical criteria are the power consumption and the maximum radiated power. The RF system needs to react to environmental changes and adjust itself for maximum efficiency without any additional effort from the user. The automatic antenna tuning function in the ATA583x transceiver family from Atmel® is an easy way to achieve this. It ensures that the magnetic loop antenna matches the target frequency independent of environmental influences. The antenna tuning occurs completely autonomously with no extra effort by the auto manufacturer or the end user.

Automotive Application Requirements

In the automotive industry the on-going trend is towards smaller, more powerful, and cheaper electronics modules. This forces automotive suppliers to continuously develop new technologies and procedures to keep pace. Small size and lower costs often correlate closely. One example is the antenna in automotive key fob applications. External antennas are expensive and have a large footprint. Therefore, the industry uses cost-effective solutions such as printed magnetic loop antennas. However, with these antennas it is impossible to achieve the required high performance. So how can designers create small designs that are both cost-effective and realize high-performance? The solution is a chip that uses an autonomous algorithm capable of tuning the RF system. That way the application achieves the best possible performance independent of environmental influences.

Environmental Influences

A key fob application needs to operate properly and reliably even under the most difficult conditions. Temperatures may range from -30°C in winter and up to +70°C during summer. Direct solar exposure creates even higher temperatures. Humidity can vary from 100% to zero. During development of the device, the engineers match a printed magnetic loop antenna to the maximum RF output power. They specify the matching under laboratory conditions and then insure conformance during manufacturing. In real life, however, temperature and humidity change constantly. In addition, the capacitance will change when the user's hand touches the key fob. This strongly influences the magnetic loop antenna's electrical characteristics (see figure 1). Key fob designs using metal or chrome plating intensify this effect.

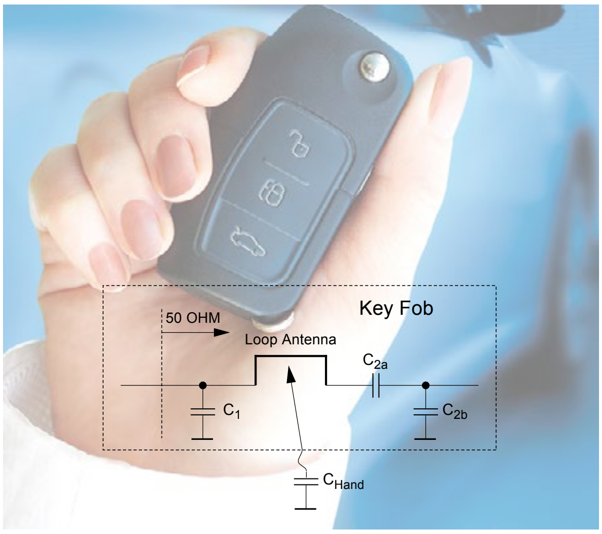

Figure 1. Influence of Human Hand's Capacitance on the Magnetic Loop Antenna

The increased capacitance affects the radiated output power, and the resulting weak radiation signal reduces the operating distance, which is a key criteria for every key fob application. Automatic antenna tuning helps to prevent the negative effects of environmental influences. A dedicated design adapted to the individual application ensures optimum results.

Application Set-up and Matching Network

The Atmel ATA583x RF transceiver family has an embedded RF switch for optimum matching during transmit and receive mode. For transmission mode, you only need the matching network consisting of L_3 and C_9. You add L_1 (L_2) and C_4 (C_3) for reception mode. Both networks result in a 50Ω matching at the output of the internal switch (SPDT_ANT). The firmware controls the switch to select the path for the

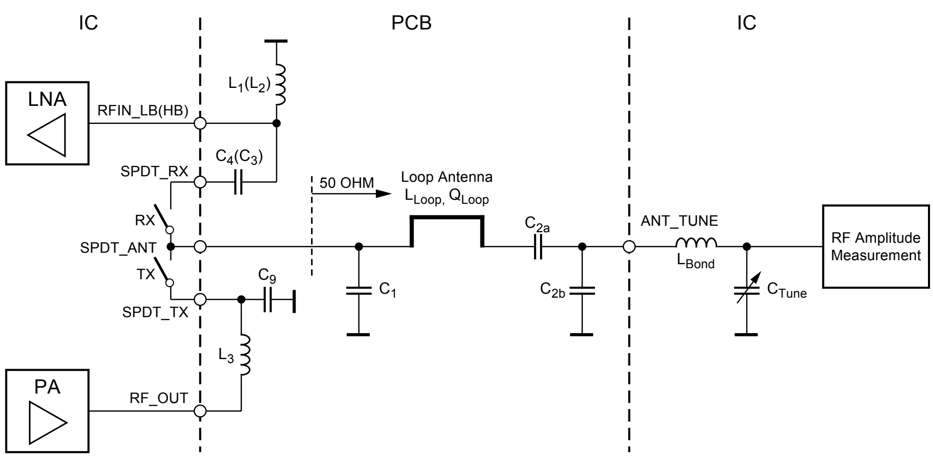

Figure 2. Typical Key Fob Application with a Magnetic Loop Antenna

reception or the path for the transmission. You set up the 50Ω matching by selecting the external capacitors C_1, C_{2a}, and C_{2b}, the parameters of the magnetic loop antenna, and the internal tuning capacitor C_{Tune} that is connected via the IC's bond wire inductance L_{Bond} (see figure 2). The C_{Tune} capacitor directly influences the matching at the end of the loop antenna and serves to adjust the system.

Automatic Antenna Tuning Function

The firmware located in system ROM controls the automatic antenna tuning function. This enables autonomic matching and tuning of the printed magnetic loop antenna to the required resonance frequency, no matter the prevailing ambient conditions.

As shown in figure 3, an amplitude detector, a comparator, and a DAC (digital-to-analog converter) perform the tuning.

The amplitude detector converts the maximum antenna voltage to a DC voltage. The DAC converts an internal reference value to a DC voltage. The comparator compares this to the measured value. The amplitude detector has four operating ranges that are automatically set by the firmware to cover the amplitude voltage range at the ANT_TUNE pin.

An approximation algorithm handles the tuning process. This algorithm uses the internal variable C_{Tune} tuning capacitor over a nominal range of 4pF to 9pF with a tolerance of ±15%. This is achieved with 16 steps at a maximum 0.33pF per step. During auto-tuning the value of C_{Tune} adjusts the matching at the end of the magnetic loop antenna. This occurs while the internal circuit measures the RF amplitude. The resulting capacitor value guarantees a maximum amplitude at the ANT_TUNE pin. This maximum amplitude provides the

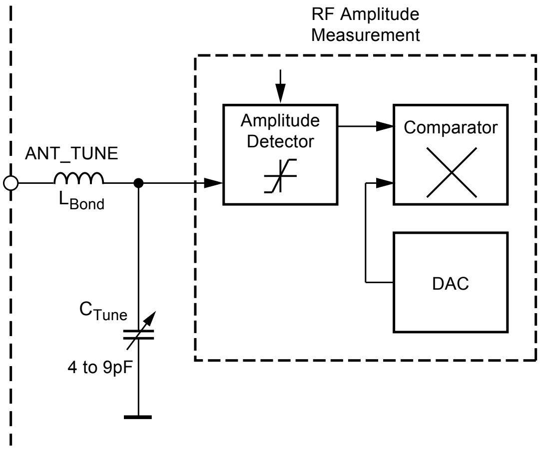

Figure 3. Tuning Circuit with Amplitude Detector, DAC and Comparator

maximum radiation of the magnetic loop antenna. The chip stores the tuning capacitor setting internally. It is used for further RF operation in RX mode, TX mode, and RX polling mode. The next tuning process or a system reset will adjust the capacitor accordingly.

To optimize the set-up you need to select the external components to provide the best effect of the tuning capacitor. One of the most important parameters is the maximum RF amplitude at the input of the level detector. If the input exceeds 3Vpp it may happen that tuning is impossible due to overload of the internal circuit. This overload may also cause a permanent change of the internal circuit. Figure 4 shows how to adjust the amplitude according to the transformation network between pin SPDT_AND and pin ANT_TUNE.

It is good practice to verify the required network values and the calculation results prior to actually starting the design.

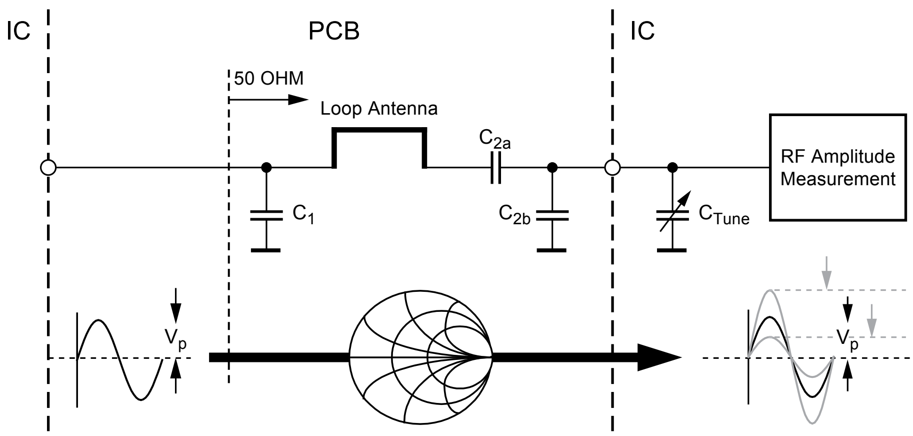

Figure 4. Amplitude Adjustment

Application Design and Calculation

You can calculate the matching values for the magnetic loop antenna by using the equations below. Based on that results, you can then define the maximum amplitude at the input of the level detector. This enables you to gain in-depth knowledge of the application and to set-up matching that guarantees a properly-operating application with the best possible performance. First convert the known output power from dBm to mW (equation 1).

$$P_{In}[mW] = 10^{\frac{P_{In}[dBm]}{10}} \qquad \text{(equation 1)}$$

You then calculate the amplitude voltage of the signal that is included in the radiation circuit (equation 2), where Z_{In} is the input impedance and PIn the load power. The amplitude voltage at the output of the SPDT switch is used to calculate the amplitude level at the end of the loop antenna (as given in equation 12) and at the input of the ANT_TUNE pin (see equation 13).

$$V_{In} = \sqrt{2 \times Z_{In} \times P_{In}} \qquad \text{(equation 2)}$$

The quality factor of the loop is needed to analyze the application. First calculate the loop resistance (equation 3):

$$R_{Loop} = \frac{l}{2w} \times 2.59e^{-7} \times \sqrt{f} \qquad \text{(equation 3)}$$

where w = geometrical width of the loop trace and l = loop length

Next, calculate the quality factor of the loop (equation 4). The angular frequency includes the overall target resonance frequency. You need to know this value, including all potential tolerances.

$$Q_{Loop} = \frac{\omega L_{Loop}}{R_{Loop}} \qquad \text{(equation 4)}$$

In case Q is known, you can simply adapt equation 4 so that R_{Loop} will be the result of the calculation. Several other equations are also available to obtain the three parameters used in equation 5.

Using the known parameters from the magnetic loop antenna allows you to calculate the required matching elements to achieve the maximum radiated power for the target frequency. Equations 5 to 7 help to obtain the target values for the matching elements. The first step is to calculate the parallel resonance impedance using equation 5.

$$Z_{ll} = Q_{Loop} \times \omega L_{Loop} \qquad \text{(equation 5)}$$

Knowing the impedance allows you to evaluate the transformation ratio Z_{In} to Z_{ll} by means of equation 6. This formula also helps to find out the voltage amplitude transformation.

$$r = \sqrt{\frac{Z_{ll}}{Z_{In}}} \qquad \text{(equation 6)}$$

Equation 7 enables you to calculate a loop capacitance that depends on the target frequency.

$$C_{ll} = \frac{1}{\omega^2 L_{Loop}} \qquad \text{(equation 7)}$$

With equations 8 and 9 it is possible to calculate the theoretical matching network (see figure 5).

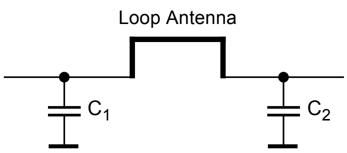

Figure 5. Loop Antenna Matching Circuit

$$C_1 = C_{ll} \times r \qquad \text{(equation 8)}$$

$$C_2 = \frac{C_{ll}}{1 - \frac{1}{r}} \qquad \text{(equation 9)}$$

C_2 is equivalent to a series-parallel matching circuit that includes C_{Tune} (figure 6).

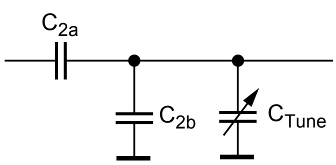

Figure 6. C2 Equivalent Circuit

You derive the values of C_{2a} and C_{2b} as a capacitive voltage divider where C_{2b} is in parallel with the internal capacitance C_{Tune} (equations 10 and 11).

$$C_2 = \frac{C_{2a} \times \left(C_{2b} + C_{Tune}\right)}{C_{2a} + C_{2b} + C_{Tune}} \qquad \text{(equation 10)}$$

$$C_{Tune} = \frac{C_2 \times \left(C_{2a} + C_{2b}\right) - \left(C_{2a} \times C_{2b}\right)}{C_{2a} + C_2} \qquad \text{(equation 11)}$$

You should dimension C_{2a} and C_{2b} so that equation 11 results in a C_{Tune} value that the IC can reach with its tuning capacity array. This is also the case for the threshold values of the target frequency.

Independent of the matching, the transformation ratio helps to obtain the amplitude voltage at the end of the magnetic loop antenna using equation 12.

$$V_{C2a} = V_{In} \times r \qquad \text{(equation 12)}$$

With this result and the capacitive voltage divider consisting of C_{2a}, C_{2b} and C_{Tune}, you can evaluate the amplitude level at the level detector (equation 13).

$$V_{ANT\_TUNE} = \frac{V_{C2a} \times C_{2a}}{C_{2a} + C_{2b} + C_{Tune}} \qquad \text{(equation 13)}$$

Your application design is set up properly if the voltage at the level shifter input does not exceed the specified value.

A designer not only needs to do the entire calculation for the typical standard case but also for the tolerance values of the target frequency. It may occur that a frequency extreme has a higher amplitude at the level detector than with the nominal frequency. If all values have been thoroughly calculated, the resulting application is capable to handle any environmental influences without additional user involvement. For more details see the ATA5831 datasheet (a summary version is available at http://www.atmel.com/Images/Atmel-9285s-Car-Access-ATA5831-ATA5832-ATA5833_Datasheet.pdf, full version available under NDA).