Whitepaper

RFID TAG ANTENNA DESIGN

DESIGN OVERVIEW AND GUIDELINES

Version 1.0

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OVERVIEW

This document will introduce key concepts for designing tag antennas with Monza tag ICs.

Monza ICs communicate using the RAIN RFID alliance protocol standard, which uses GS1 EPCglobal Gen2 Specification for UHF RFID at 860 MHz – 960 MHz. Hereafter, RAIN RFID refers to all RF communication related to Monza ICs.

BACKGROUND

The Impinj Platform brings item intelligence to everyday items, allowing the reach of the Internet to include objects as diverse as retail apparel, medical assets, freights and tracking containers, raw materials and even patients. Items that are tagged with a RAIN RFID tag chip have a digital identity – this tagged item is also called an Endpoint. Using RAIN RFID, Endpoints can be read passively from 10 meters away or more, depending on the use case.

The tag antenna or “inlay” is a key component in RAIN RFID solutions. It must be properly designed so the tag antenna performs well with the item it is attached to.

Designing the tag antenna to meet the use case performance requirement is very important. This whitepaper will go through typical design steps used at Impinj.

Readers should be familiar with basic RF parameters such as RF impedance, impedance matching, and dielectric loading to fully benefit from this document. An RFID tag testing system such as Voyantic Tagformance or CISC RFID Xplorer and an anechoic test chamber is required to assess the tag antenna. Computer simulation is also a great tool for designing tag antennas but field testing is always necessary to ensure the final design performs well in the intended use case.

TAG ANTENNA ANATOMY

Majority of the tag antennas on the market are dipole tag antennas. They consist of four main components outlined in Figure 1. The dipole antenna is the physical far-field component that enables long distance communication between reader and tag. The coupling section transfers power between the dipole and the inductor loop. The inductor loop resonates with the capacitance of the tag chip and delivers power to the chip. Finally, the tag chip is the central component of the RFID tag, which provides the core RAIN RFID capabilities.

Figure 1: Anatomy of a dipole tag antenna

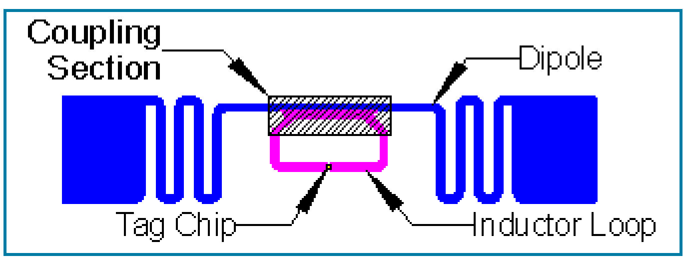


Diagram of Monza E62

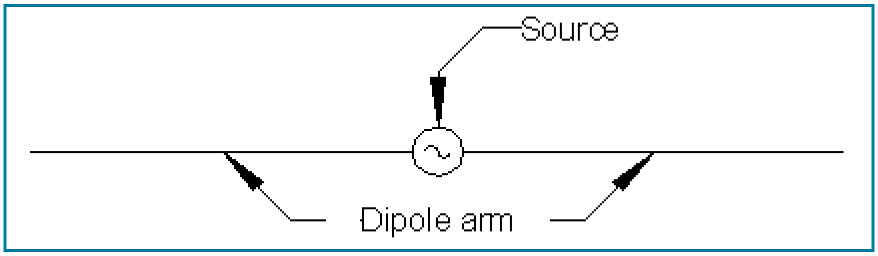
RFID Tag Chip

The tag chip, or Endpoint IC, communicates with the reader, by demodulating the signal it received on the antenna port and modulating out a signal back to the reader on that same port. The rest of the tag antenna serves as a communication link. RAIN RFID tag chips from Impinj are “passive” which means they do not have a built-in power source. Instead, the chip collects power from the reader’s RF signal. To efficiently collect power from the reader signal, the tag antenna impedance must be close to the conjugate match of the chip impedance. The chip impedance values for all Monza tag chips are in the tag chip datasheets, available at https://support.impinj.com.

Dipole Antenna

A dipole antenna (as shown in Figure 2) has two radiating arms that extend outward from a source (typically away on same axis). The length and the thickness of the dipole arm determines the major characteristics of the antenna. For example, a commonly used dipole is the half-wave dipole. The electrical length of a half-wave dipole approaches one half-wavelength at the desired frequency. The dipole radiates very efficiently at a half-wavelength. However, the dipole impedance value of 70 Ω (dipole impedance at resonance) is far from optimal for matching to a RFID chip. Also, the physical length (approximately 15 cm at 900 MHz for a half-wave dipole) is usually too long to be practical for most RFID applications.

Figure 2: A Typical Dipole Antenna



Inductor Loop

The inductor loop's two primary functions are to resonate with the chip's capacitance for matching, and to deliver the power coupled from the dipole to the chip. For RAIN RFID, the chip usually needs only one turn loop.

Coupling Section

The coupling section is where power is transferred between the dipole and the inductor loop. This section connects the dipole and the inductor loop inductively, similar to the coupling between the cores in a transformer – current in one portion (i.e. the dipole) induces current in the other region (i.e. the loop). This enables energy collected at long ranges using the dipole antenna to be delivered to the tag chip. Figure 1 features an example of a coupling section. The inductor loop and the dipole can be separated further to reduce the coupling or can be brought closer or share wider section to increase the coupling.

TYPICAL DESIGN CONSIDERATIONS

Common design considerations for tag antennas are defined below. Their specifications will affect how the final tag design is optimized.

Tag Size

The tag size should be specified early on. Typically, the tag antennas are inserted into labels with a predefined size fitted for the product. Therefore, the tag must be optimized within the label's size restrictions. For smaller labels, the dipole may need to use miniaturization techniques such as *meandering* to meet the performance requirement while staying within the size restrictions.

Performance

Performance usually means the minimum read range or operational distance. It can also be defined as tag sensitivity, the minimum radiated isotropic power required to successfully communicate with tag. The performance requirements describe how well the tag must perform *on the intended materials* for the given use case. The tag antenna dipole, inductor loop and the coupling all have to optimized in order to meet the performance requirements.

There are two possible causes if a tag fails a minimum read range requirement: a *forward-link* limitation, if the tag IC does not receive enough RF power to operate; or a *reverse-link* limitation, if the reader cannot detect the backscatter signal from the tag antenna. Identifying the correct link limitation is highly important, since the design optimization solution is different for those two problems. For more information about the RFID link budget, see the whitepaper entitled "RFID Link Budget Overview" on https://support.impinj.com.

Range of Materials to be Tagged

The tag antenna resonance determines performance and depends heavily on the type of material it's adhered to. Typically, the dipole resonance is more affected than the loop resonance by the material's dielectric properties. Common light dielectric materials include corrugated board and cardstock. Common heavy dielectric materials include denim jeans and glass. As you load the tag with heavier dielectric materials the dipole resonance will shift toward a lower frequency. The tag antenna length must be designed such that the dipole resonance is at the desired frequency for the materials selected. The dielectric constant for common materials can be found online.

DESIGN STEPS

A typical RFID tag chip has a complex impedance with real and nonreal values. For example, Impinj Monza R6 tag chip model is equivalent to a 1.2 kΩ resistor in parallel to a 1.44 pF capacitor. Directly connecting a dipole to the tag chip will result in a heavy mismatch from the complex impedance, leading to poor tag antenna performance. The design process outlined below will describe a methodology that will overcome this issue as well as meeting other requirements. The design process is outlined in three steps that analyze the individual components of the tag and how they interact with each other.

Inductor Loop Design

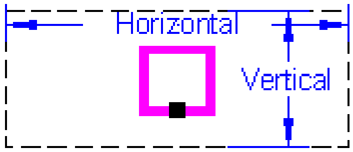
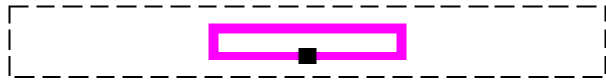
The first step in designing a tag antenna is to construct the inductor loop where the tag chip is mounted. One of the primary functions of the inductor loop is to set the resonance to match the capacitance of the chip. The shape of the inductor can take just about any form as long as it completes a loop. You may design the inductor loop using either an EM simulator or inductance calculators available on the Internet. Design the inductor loop so that the initial resonant frequency is around 890 MHz. The resonant frequency does not have to be highly accurate at this point since the resonance will change once the loop is connected to the dipole.

The inductor loop has three design parameters: the trace width, the loop area, and the trace length. As a rule-of-thumb, use a wide trace width to minimize Ohmic loss.

There are two main trade-offs for inductor loop design. The first is between the trace width and loop shape. Wider traces reduce Ohmic loss but the loop area must grow to compensate for reduced inductance. The second trade-off is between the loop area and the shape. If the shape is closer to circular or square the area needed to obtain the same inductance will be smaller than if the shape is long and narrow. Ultimately, the shape will most likely be determined by the size requirement. For a long skinny tag shape, a circular or square loop shape will not be suitable.

Two examples of loop shapes are shown in Figure 3 which would be ideal for the tag antenna sizes outlined. Notice that the loop is placed in the center of the inlay area, horizontally (though not always vertically) centered. Generally, that's the best location for the inductor loop. The tag chip is attached at the bottom center of the loop marked by the black square.

Figure 3: Inductor Loop Design Comparison

SQUARE TAG	LONG/THIN TAG
 Square Inductor Loop Design	 Long/Thin Inductor Loop Design

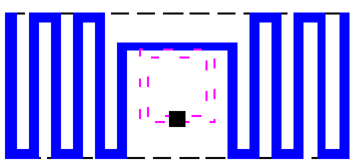
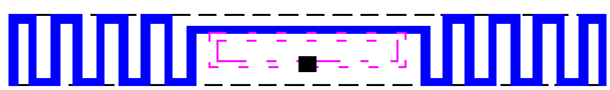
Dipole Design

The dipole antenna is the largest component on the tag antenna. Since the dipole has to stay within the label's size constraints, the dipole typically utilizes some size reducing techniques such as meandering, where the dipole bends back-and-forth. Reduction in size typically means less potential gain and bandwidth.

The dipole has one main trade-off: the trace width and the trace length. Similar to the inductor loop, wider trace width will minimize loss but require greater length to achieve the same resonant frequency. Also, wider traces may prevent the tag from obtaining the desired electrical length due to area limitation.

Examples of dipoles are shown in Figure 4. The two dipole designs shown here fill up the tag area almost completely. If the tagging material has heavy dielectric properties, the number of meander turns or bends may need to be reduced. Conversely, if the tagging material has light dielectric properties, you may need to reduce the trace width and increase the meandering. Using a simulation is highly recommended for this step. Just remember to add in the dielectric material the tag adheres to in the simulation. Performing this experiment in a lab using a vector network analyzer (VNA) will lead to a similar result.

Figure 4: Dipole Antenna Comparison

SQUARE TAG	LONG/THIN TAG
 Square Dipole Antenna	 Long/Thin Dipole Antenna

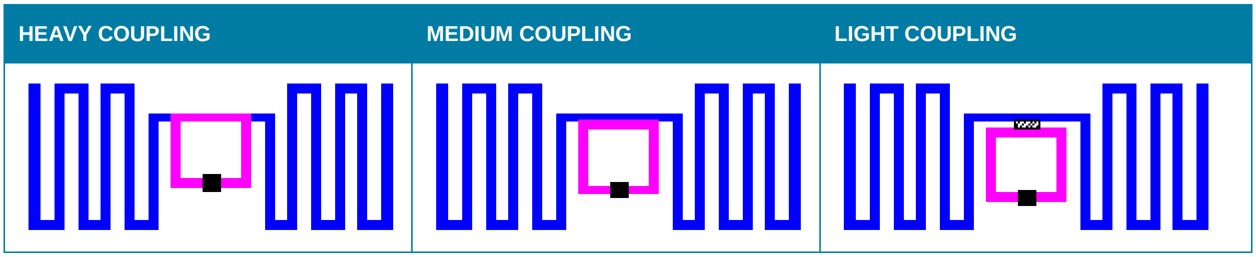
Attach Loop to Dipole Through Inductive Coupling

The inductor loop is a near-field structure due to its small size. Therefore, power must be transferred between the dipole and inductor loop in order for the tag chip to communicate with reader. Typically, the power transfer occurs through inductive coupling similar to that of a transformer. Therefore, the best location for the inductor loop is near the center of the dipole where the current magnitude is highest. Once the loop and dipole are coupled, the resonant frequency of both loop and dipole will shift and need readjustment. Also, the optimal coupling amount needs to be determined.

The amount of coupling used in joining the loop and the dipole has its own trade-off. Heavier coupled tags, where the loop and dipole are overlapping, will increase efficiency in power transfer but may lead to a narrower band tag. Also, the coupling determines the amount of impedance transformation. Hence the optimal amount of coupling will depend on the tag antenna size and the chip impedance.

The easiest way to control the amount of coupling is to vary the spacing between the inductor loop and the dipole as shown in Figure 5. Spacing is most commonly used at Impinj for tag antenna designs, although other methods are available to control coupling.

Figure 5: Controlling Coupling with Inductor Loop Spacing



Iterations

Once the inductor loop and the dipole are joined, resonant frequency of the inductor loop and the dipole will both change. Testing the prototype builds of the design on the intended material will show the actual dipole and loop resonances. It is difficult to precisely account for all the possible variation in simulation which is why prototypes should be tested. Often, the design will need to be re-optimized. The VNA will show where each of the resonances are. If the loop resonant frequency is too low, make the loop smaller. If it is too high, make the loop larger. Similarly, if the dipole resonant frequency is too low, reduce meandering or make the trace thicker. If it is too high, increase meandering or make the trace width thinner. Also experiment with the amount of coupling to achieve the optimal result.

CONCLUSION

The process of designing a tag antenna includes a series of optimizations and trade-offs between many parameters. The three design parameters are the inductive loop, dipole, and inductive coupling. Typically size is the first constraint to consider. Start the design within the size limit and determine if the design will meet other specifications. If not, determine how the tag can be optimized to meet the specification. It is also important to determine early if the performance specifications can be met in the physical space allowed. If the original specification makes tag design impossible, it may need to be revisited and adjusted before continuing. As with any other engineering work, the design process is very iterative and each iteration provides more information to further optimize the design. All three tag antenna components are dependent on each other, so the optimization steps can be counterintuitive at times.

As a high-level design introduction to tag antenna design, this white paper is not exhaustive. We recommend that you collect more detailed information for each step of your design process.

Monza tag ICs, with cutting edge performance and the proper tag antenna design, provide powerful solutions for your logistical and management challenges. For more detailed information, please contact support@impinj.com.

NOTICES