

A Novel Planar Microstrip Antenna Design for UHF RFID

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ABSTRACT

Passive UHF RFID tags generally do not work well near metal or water. Microstrip antennas offer a potential solution, but suffer from manufacturing complexity because a need for via or some other reference to ground. We present a new antenna and matching circuit design using a balanced feed that eliminates any reference to ground and thus simplifies the antenna's construction.

1. INTRODUCTION

Radio frequency identification tag (RFID) has emerged as a promising technology for increasing visibility and efficiencies in the supply chain. In particular Passive UHF (~860-960) MHz tags represent a near optimal combination of cost and performance. Passive RFID tags are available at \$0.20 US and can be detected 4 - 7 meters away. Asset tracking is a particularly useful application, since RFID can help in automated tracking of high-value assets. UHF RFID tags show performance degradation when placed near high dielectrics and lossy materials (e.g. water) and conductors. Unfortunately most assets are metal made or encased in metal containers. Active RFID systems offer an alternative to this, but are considerably more expensive.

Microstrip antennas offer a potential solution to this problem, since a Microstrip antenna has a ground plane. Theoretically, the antenna would work equally well when attached to any material. Microstrip antenna designs however suffer from manufacturing complexity. Most Microstrip designs use feed techniques that require connection between the antenna layer and the ground plane. Furthermore, the microstrip patch impedance has to be matched to the conjugate IC impedance in order to enable efficient power transfer. The traditional techniques used for constructing matching networks is by a cross-layered structure, such as a via or a shorting wall. Cross-layer structures require more complex and costly construction. Recently passive tags that use the inverted F antenna were proposed [1]. These are three layer structures with via connecting across the layers. A more recent advancement was the use of shorting metal plates [2] that eliminates the need for a via. The shorting wall can be viewed as a continuous conductive layer that crosses three layers. While this is an improvement in some ways, it still requires 3-D structure in which the conductors pass between the substrate.

We present here a completely planar microstrip RFID tag design. This implementation does not require any cross layered structures and hence greatly simplifies tag construction. The new antenna and the matching circuit design using the balanced feed approach eliminates any reference to ground.

2. APPROACH

Traditionally microstrip antennas are viewed as unbalanced devices. A microstrip feed is single feed that can be designed as probe, edge feed, or aperture feed. The reference is always with respect to the ground plane. Thus, one end of the RFID IC is connected to the antenna plane while the other end is grounded. The exception is when a single line feed is split into two feeds 90° out of phase with respect to each other in order to achieve circular or elliptical polarization. We believe it is this perspective that has lead to various complex Microstrip designs.

In contrast, we view the microstrip as a capable balanced feed structure. The premise of our approach is that we use two feeds and two unbalanced transmission lines to effectively create a single (virtual) balanced transmission line. The two lines have odd mode symmetry, so traditional odd-mode analysis is sufficient for describing the antenna and matching circuit. Here, we conceptually divide the antenna and IC into two halves as shown in Figure 1. The dashed line represents the line of symmetry, and is a line of a virtual short circuit. If one views only the top half with the source impedance, characteristic impedance of the transmission line, line lengths, and the dashed line as a ground, it is apparent that this is a simple, single shorting stub matching circuit. We call this design the dual feed mechanism with a shorting stub matching network.

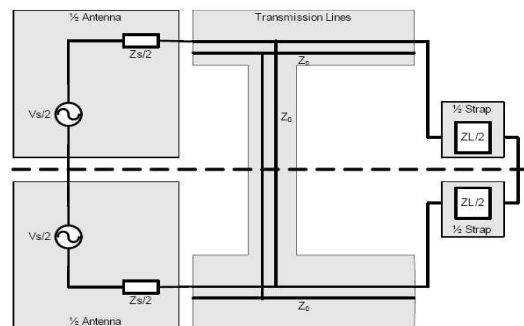


Fig: 1 Odd mode analysis view.

The RFID ICs were measured to have resistive impedance in the range 10-30Ω, and reactive (capacitive) impedance of 130-160Ω. The RFID IC that we match to is hence assumed to have an impedance of approximately 15-j150Ω. The matched line lengths are calculated to match the real part of IC impedance and the shorting stubs are used to adjust the reactive component. Thus if we assume the IC impedance to be R-jX the Load impedance to the patch is matched to R+jX (complex conjugate of the IC impedance). The tag design details are discussed in the following section.

3. DESIGN

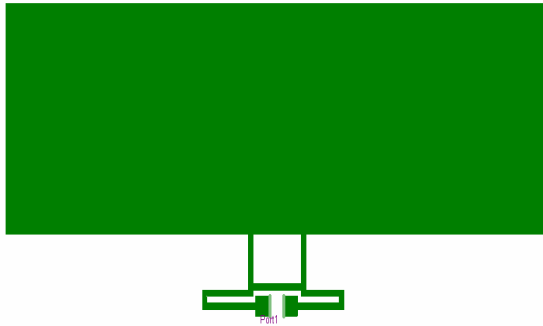


Fig: 2 Planar Microstrip RFID tag – top view

Our initial design was based on the dual feed approach with a shorting stub matching network as described in Section 2. The above construction uses high impedance dual feed lines each of 1mm thickness and a shorting stub of the same width for the matching network. The entire matching network has a vertical length of 12.4mm and a horizontal length of 30mm. The patch length is chosen such that it resonates on the desired substrate between 865 – 875 MHz which includes the UHF range of RFID in Europe (865-868 MHz). A thin (60 mils) material with low loss like, polyethylene ($\epsilon_r = 2.31$, $\tan\delta = 0.0023$) is used as the substrate. The feed lines are attached to the non radiating edge such that they are symmetric about the middle of the patch which acts as a virtual ground. The lines lengths are adjusted to provide the conjugate match to the strap impedance for maximum power transfer. Hence the target port impedance is $15+j150\Omega$. For simplicity, we consider rectangular shaped tags. (Other geometries are planned for future work). The rectangular patch has area 114mmx 35mm. The ground plane is kept 10mm in excess to the antenna dimensions in order to create an infinite plane effect. Thus the total size of the antenna is 135mm X 67mm.

Prototypes of the novel planar microstrip tag for UHF RFID were fabricated and tested in our lab. The details of the simulated and measured performances are described briefly in the next section.

4. ANALYSIS AND RESULTS

The microstrip antenna design was simulated using Ansoft Designer based on the method of moments. The simulation assumes that the antenna is traced on a substrate 60 mils thick with an infinite ground plane. We assume that an infinite ground plane is well approximated by a 10mm excess on all sides of the trace for practical applications. The simulation results shown below are plots of the impedance curves, return loss, and gain (in dBi) measured over all frequency values from 860 – 875 MHz.

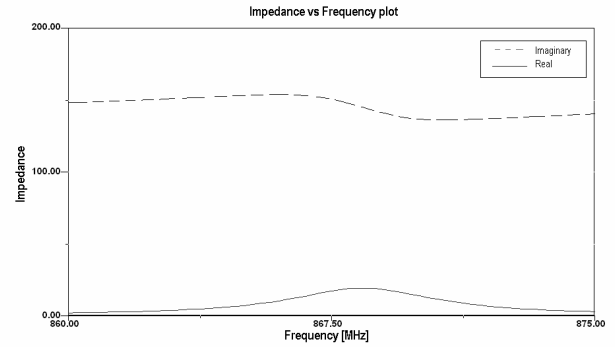


Fig: 3 Impedance vs. Frequency.

The impedance plot shows that the tag resonates at 867.5 MHz and the resistive impedance varies between 2 to 19 Ω and the reactive impedance is between 136 to 154. Ω in the given frequency range. The S_{11} and Gain plots are shown in Figure 4 and Figure 5 respectively

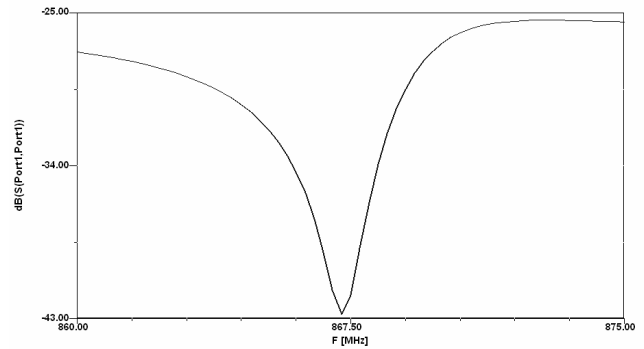


Fig: 4 S_{11} .

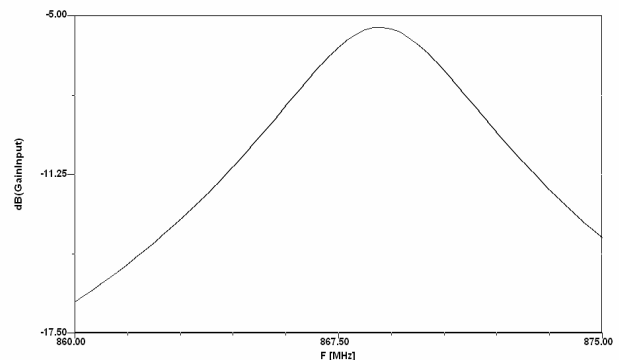


Fig: 5 Gain.

The above plots show that the maximum power transfer occurs at 867MHz when the return loss is minimum (-43 dB). The matching network provides a good match at all frequencies as the return loss remains under -25db. The Gain curve shows peak gain input at the point of resonance. The simulated peak value corresponds to -5.5dBi. The 3dB bandwidth is measured to be 5.1 MHz between 866.2 to 871.3 MHz.

Validation of the above simulations was done by fabricating a prototype of the tag and measuring its performance using readers that are configured to operate in the European frequency band. The performance characteristics of the tag were measured by comparing it against a commercially available tag.

In our experiment we read the tag at a fixed distance of 9feet from the reader antenna while decreasing the reader transmit power in steps of 0.5 dBm, and varying the frequency. The ‘turn-on’ power is defined as the minimum reader transmit power with which the tag can be detected at a fixed distance. Our tag and the commercial tag were both tested in identical experimental environments to measure the tag performance. We performed a frequency sweep over our tag in the ETSI frequency band from 865 to 870MHz. The tag shows a minimum turn-on power of 19dBm between 865.5-866.5 MHz. The measured results showed that the tag performance was offset in frequency by 2 MHz compared to the simulation results. Refer Figure 6. This variation could be attributed to the design imperfection in the prototype and also to the impedance mismatch due to manual RFID IC attachment. It is also noted that the experiment was conducted in a non-anechoic environment and is hence susceptible to fading and multi-path.

In testing the commercial tag we assume that it is designed to operate in the FCC frequency band, with a peak gain of -1.25dBi. We performed a frequency sweep from 905 to 926MHz; with increasing attenuation applied to the reader transmit power. The minimum turn-on power for the commercial tag is 21dBm.

The difference in the peak gains of our tag and the commercially available tag is 4.2dBi. Hence we expect that our tag will have a turn-on power ~4dBm more than that of the commercial tag. However we observe that our tag turns on 0.5dBm below that of the commercial tag. This could be due to the assumptions on which the commercial tag simulation is based, conductive losses in the etched silver inlay and differences in RFID IC technology, which is different between our tag and the commercial tag.

5. CONCLUSIONS

We present a microstrip RFID tag that is thin and constructed completely of planar elements. The simple, planar nature makes constructing the microstrip RFID tags significantly simpler than those requiring vias or shorting walls. We achieved this by using a balanced feed and matching circuit. Odd-mode analysis and traditional matching circuit techniques can then be used to design the matching circuit. Finally, we presented results that showed good overall performance, but expected narrowband operation. The low gain could be due to high density surface currents present in the matching circuit and conductive loss.

In the future, we plan to explore matching network designs that are compact and also will increase the peak gain. We believe that the tag read distance is gain limited and hence there is ongoing work to make these antennas that have optimal gain characteristics. We are also investigating antenna designs that are resonant at multiple frequencies as a means to obtain acceptable minimum gain over the entire ISM frequency range in both US and Europe. We are also investigating the interaction of the balanced feed and alternative antenna geometries, as well as other matching circuit techniques.

6. REFERENCES

- [1] H. Kwon and B. Lee, *Compact slotted inverted-F RFID tag mountable on metallic objects*, IEE Electronic Letters, **41** (2005) no. 24, pp. 1308—1310.
- [2] Ukkonen, L., Engles, D., Sydanheimo, L., and Kivikoski, M.: ‘*Planar Wire-type Inverted-F RFID tag Antenna mountable on metallic objects*’. 2004 IEEE AP-S International Symposium (Monterey, California), June 20-26, 2004, vol. 1, pp. 101—104

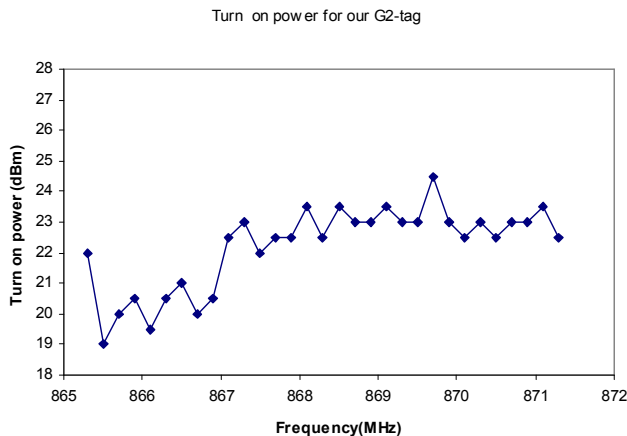


Fig: 6a Turn-power for our tag.