Performance of RFID Tags with Multiple RF Ports

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Introduction

Passive radio frequency identification (RFID) is an automatic wireless data collection technology [1] where RFID reader transmits a modulated RF signal to the RFID tag consisting of an antenna and an integrated circuit chip. The chip receives power from the antenna and responds by varying its input impedance and thus modulating the backscattered signal with data. Important RFID tag characteristics are maximum range and orientation sensitivity. These characteristics can be improved in the RFID tags with multiple RF ports where each port can be connected to a different antenna. The signals from those ports can be combined to increase maximum tag range and to make it less sensitive to orientation.

Multiple transmit/receive antennas have been extensively used in wireless communications (see e.g. MIMO [2]). While in wireless applications the signal quality and hence the data rate are of primary concern, in passive RFID the extraction of maximum available power from RF signal is important in order to energize the chip. In this paper, we concentrate on analysis of read range and orientation sensitivity for RFID tags with multiple RF ports and present experimental data for one- and two-port tags.

Tag Range

In free space, the read range of a one-port RFID tag is given by [3]:

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau p}{P_{th}}} \quad , \qquad (1)$$

where λ is the wavelength, $P_t G_t$ is reader transmitted EIRP, G_r is the gain of the tag receiving antenna, τ is the power transmission coefficient, p is the polarization efficiency, and P_{th} is the threshold power of the RFID chip.

Combining signals from different antennas connected to different RF ports on the chip may provide more power to the tag and increase tag range. Fundamental limitation on increasing power collection by multi-port RFID tags is that antennas must either be spaced on the order of half a wavelength apart or be mutually orthogonally polarized. The range of RFID tag with N ports can be written as

$$r_N = K\, r , \qquad 1 \le K \le N \ , \qquad (2)$$

where K is the range increase factor.

Orientation Sensitivity

The orientation sensitivity is tag range variation with tag orientation. When the tag antennas are orthogonally polarized, they can be powered up from different polarization components of electromagnetic field. Orientation sensitivity (or, rather, insensitivity) can be defined as the ratio A of minimum and maximum values of tag range in free space for different tag orientations with respect to the reader antenna (which can be linearly or circularly polarized):

$$A = \frac{r_{\min}}{r_{\max}} \quad , \qquad 0 \le A \le 1 \; . \qquad (3)$$

For example, if the reader antenna is circularly polarized and the planar 2-port tag has two orthogonally polarized antennas, at least one tag antenna will be powered up regardless of the tag orientation. If tag orientation is limited to the polarization plane of the reader antenna (assume 0 dB axial ratio), both an ideal dual-polarized and a linearly polarized tag are orientation insensitive (A=1), but the range of the latter is $1/\sqrt{2}$ smaller (because of 3 dB polarization mismatch).

Signal Combining Methods

Range increase factor K and orientation insensitivity A both depend on the polarization of the reader transmitting antenna, the symmetry of tag antennas, and the particular signal combining method used in on-chip circuitry. One method is to select the best signal from one of the receiving antennas [4] which improves tag orientation insensitivity but not range. Another method is to combine signals from antenna ports after envelope detection [5, 6] which improves both tag orientation insensitivity and range. The range increase factor depends on how voltages [5] or currents [6] are combined together after the signal detection. The maximum possible range increase factor is K=N (if all voltages from N antennas add up perfectly to meet the voltage threshold and make on-chip circuitry operational).

Experimental Results

To evaluate orientation sensitivity and range, we used tags in Figure 1.

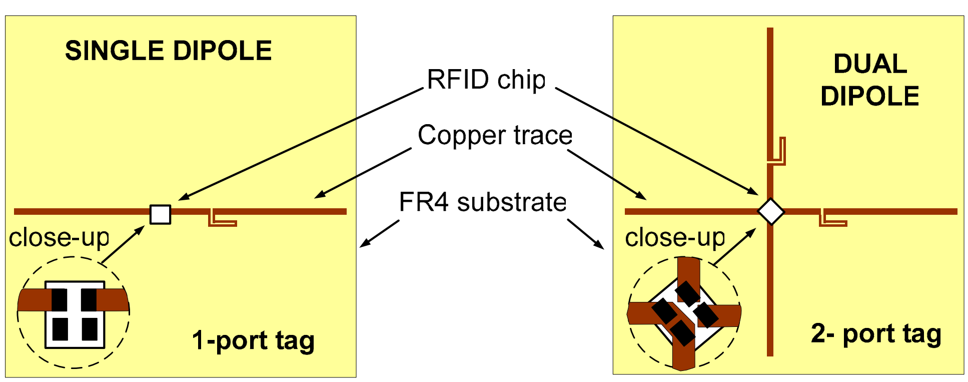

Figure 1. One- and two-port tags used in experiments.

The tag antennas were straight dipoles (chosen to eliminate coupling between antennas in a 2-port tag) with inductive stubs (for better impedance matching), arm lengths of 70 mm (short arm) and 80 mm (long arm), and trace width of 2 mm, etched on 14 mil FR4 substrate with 1 mil copper traces. The chip was 2-port UHF Gen2 Impinj RFID IC in TSSOP package. Tag range was measured in various orientations using test method referred in [2]. Tags lied in the plane perpendicular to the direction of propagation. The results are presented in Figures 2 and 3 for 1 W RFID reader connected to either linearly polarized (LP) antenna with 6 dBi gain or circularly polarized (CP) antenna with 8 dBic gain and approximately 3 dB axial ratio.

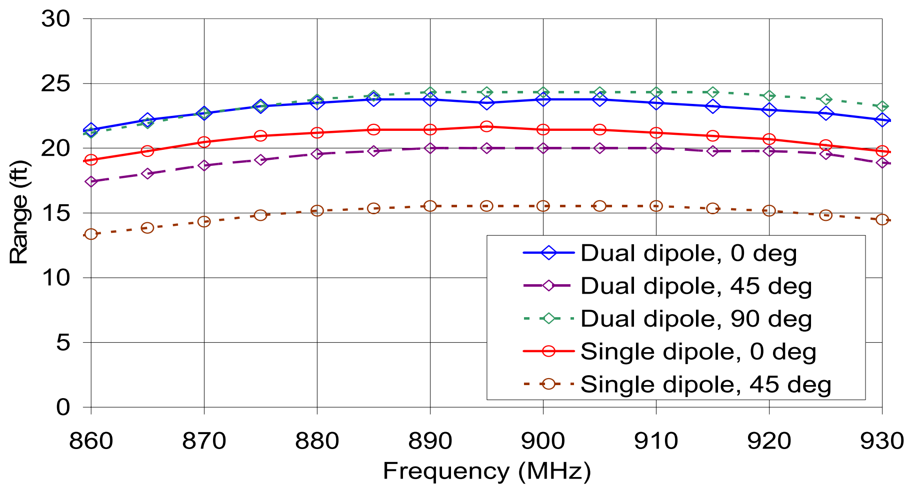

Figure 2 – Read range vs. frequency for one- and two-port RFID tags in various orientations tested with linearly polarized (LP) reader antenna.

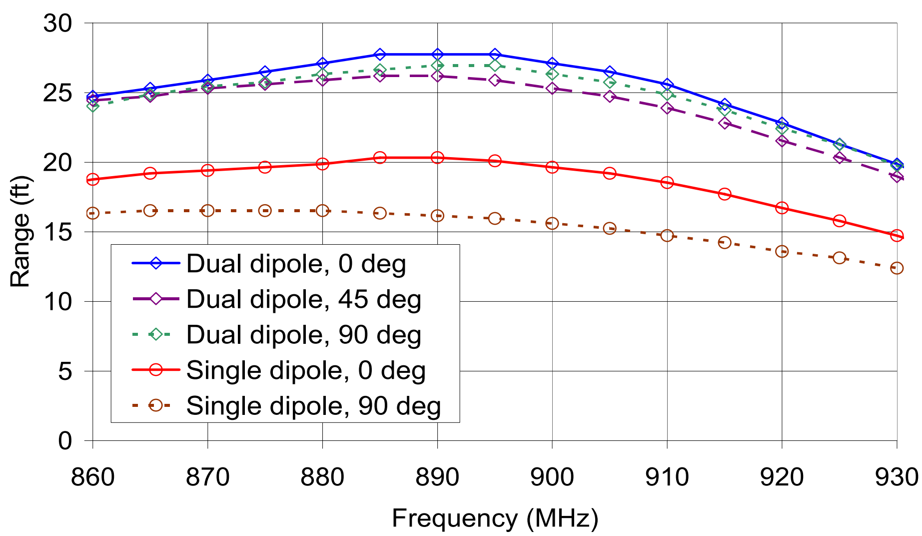

Figure 3 – Read range vs. frequency for one- and two-port RFID tags in various orientations tested with circularly polarized (CP) reader antenna.

Discussion

In Figure 2, dual dipole orientation insensitivity (calculated over 0, 45, and 90 deg. orientations) is *A*=0.82 (here and below, the values of *A* and *K* are averaged across the band of 860-930 MHz). Single dipole orientation insensitivity is A=0 (in 90 deg. orientation, it did not respond at all). The average ratio of single dipole ranges in 45 and 0 deg. orientations is 0.72 which is close to $1/\sqrt{2}$ expected from polarization mismatch. Dual dipole has slightly better maximum range than single dipole due to slightly better tag antenna matching.

In Figure 3, dual dipole orientation insensitivity increases to *A*=0.97. The range increase factor relative to single dipole is *K*=1.37. The ratio of single dipole tag ranges in 0 deg. and 90 deg. orientations is defined by the axial ratio of the reader antenna (approximately 3 dB).

The average ratio of single dipole ranges (for 0 deg. orientation) in LP and CP cases is 0.88 which corresponds to -1 dB difference between linear gains of CP and LP antennas (5 dBi and 6 dBi). The CP antenna increases the dual dipole range at best only by 18% which is due to its low gain and high axial ratio. If better CP antenna (with 9 dBic gain and 0 dB axial ratio) is used with 1 W reader to transmit 4 W EIRP, the dual dipole range can be expected to further increase.

Conclusions

Having several RF ports connected to separate antennas can significantly enhance tag range and orientation insensitivity. In an ultimate case, an RFID tag can draw power from all electromagnetic field components using co-located three-dimensional antenna structures such as the one described in [7].

References:

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