UHF RFID Antenna Impedance Matching Techniques

Kamron Sockolov
Maxim Integrated
Beaverton, OR, USA
kamron.sockolov@maximintegrated.com

Dean Arakaki
Dept. of Electrical Engineering
California Polytechnic State University
San Luis Obispo, CA, USA
darakaki@calpoly.edu

***Abstract*—The modified T-match network uses planar inductive strips for conjugate matching Radio Frequency Identification (RFID) Integrated Circuits (RFICs). Narrow and broadband matching techniques and electromagnetic simulations are applied in [1] for specific designs. This paper extends these efforts through antenna element parameterization and design trade-off analysis. Narrow and broadband designs are fabricated; antenna input impedance and tag range tests confirm predictions.**

Keywords—Antenna Matching; RFID

I. Introduction

RFID tags in the ISM 902MHz-928MHz band and global EPC 860MHz-960MHz band are powered passively (power extracted from carrier wave). Power exchange and transmit range is maximized when the tag antenna input impedance the conjugate of the RFIC input impedance. The RFIC load impedance to antenna voltage reflection coefficient s_r is [2]:

$$s_r = \frac{Z_{IC} - Z_A^*}{Z_{IC} + Z_A} \tag{1}$$

where Z_{IC} is the RFIC input impedance and Z_A is the matching network impedance, see Fig. 1. The Friis equation defines the transmit range [3]:

$$R = \frac{\lambda}{4\pi}\sqrt{\frac{P_T G_T G_R L(1 - |s_r^2|)}{P_R}} \tag{2}$$

where λ is the operating wavelength, P_T and P_R are transmit and receive power, G_T and G_R are transmit and receive antenna gain, and L is cable loss. Minimizing s_r maximizes read range.

II. Designs & Impedance Measurements

Narrowband and broadband (±1.5% and ±5.0% of center frequency) lumped element designs [1] use inductive matching strips (I_S and I_H in Fig. 2) to conjugate match the antenna to the RFIC.

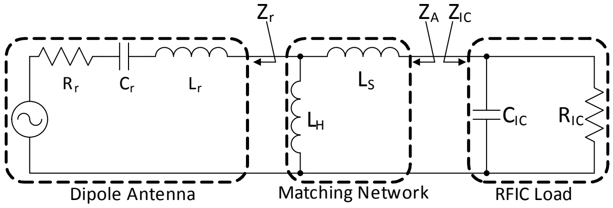

Fig. 1. RFID Tag Lumped Element Design

The narrowband antenna lumped element design is accomplished through Smith Chart matching. This design is converted to an equivalent network design and tuned to resonate in the 865MHz to 955MHz range; 910MHz center frequency. Alien Technology's Higgs-4 RFIC strap is the RFIC load. The Higgs-4 strap datasheet specifies shunt resistance and capacitance (1.8kΩ and 0.95pF) at minimum receive power -18.5dBm. The RFIC's 915MHz center frequency input impedance is 18.43-j181.2Ω.

Narrow and broadband antennas are designed (see Table I dimensions) to conjugate match Alien Technology's Higgs-4 strap RFIC. All antennas are simulated in Keysight's Advanced Design System's (ADS) Momentum electromagnetic simulator. Antenna input impedance is characterized relative to series inductor length variations. Simulated designs are silkscreened onto Dupont Melinex® ST504 *polyethylene terephthalate* (PET) film (sheet thickness t=150µm and dielectric constant ε_r=2.9) with Dupont 5025 silver ink (sheet resistivity is 12-15mΩ/sq/mil) at Cal Poly, San Luis Obispo's Graphic Communication Department.

Antenna impedance is measured at the feed (Fig. 2, gap g) with a two-port differential probe [5] in an anechoic chamber using a Vector Network Analyzer (VNA). Impedance measurement results are shown in Fig. 3 and Fig. 4. Narrowband antenna input resistance increases by 2Ωa/mm, while broadband antenna input resistance varies less 1Ω over the shunt inductor length range. Narrowband and broadband series reactance increases by 12Ω/mm and 9Ω/mm, respectively.

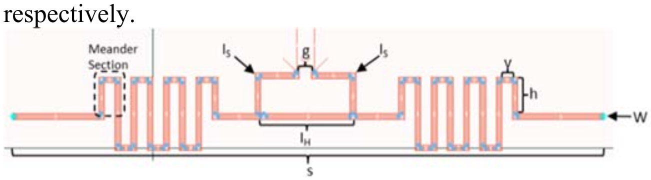

Fig. 2: Narrow and Broadband Antenna Dimensions, 915 MHz

TABLE I. Antenna Dimensions, 915MHz

Antenna Dimensions, 915 MHz		
Antenna Geometry	***Narrowband***	***Broadband***
Conductor Width (W)	1.1mm	1.1mm
Antenna Length (s)	113mm	90mm
Meander Sections (M)	14	14
Meander Spacing (v)	2.0mm	2.0mm
Meander Height (h)	6.0mm	6.0mm
Shunt Inductor (I_H)	18.0mm	4.0mm
Series Inductor (I_S)	18.0, 18.5, 19.5mm	22.0, 23.0, 24.0mm
Gap (g)	2.3mm	2.3mm

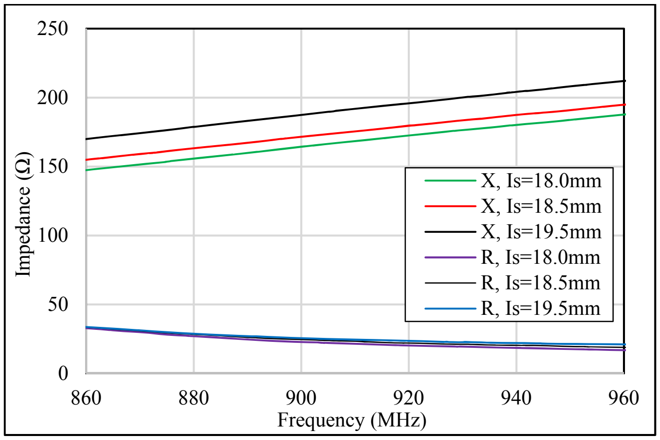

Fig. 3. Measured Narrowband Impedance

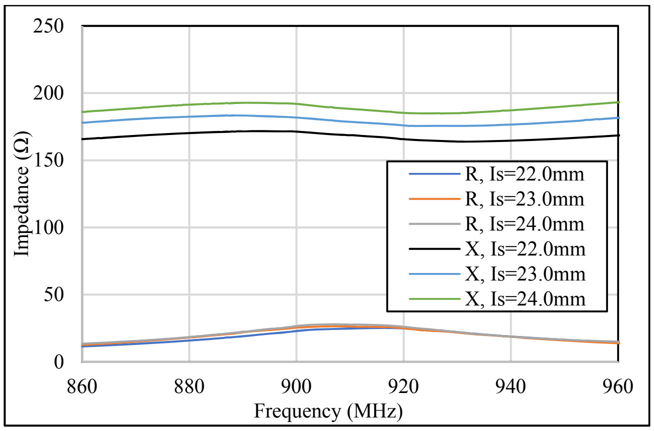

Fig. 4. Measured Broadband Impedance

III. Range Testing

Narrow and broadband antenna transmit distance is R_{meas}=4.0m; reader transmit power P_T is decreased until tag antenna to reader communications are disabled. Table II defines narrow and broadband range test conditions at 915MHz. Receive antenna gain G_R measurement requires a lossless matching network; hence, G_R is simulated in ADS. Transmit gain G_T is measured for a linearly polarized air dielectric patch antenna. Narrow and broadband results are shown in Table III. Calculated transmit distance R_{FRIIS} (2) is compared to measured results. Matching $|S_{11}|$ (1) results (Fig. 5) show narrowband antennas match over a 45MHz range; 90MHz for broadband antennas. Relative to broadband antennas, narrowband antennas require less transmit power due to greater gain.

TABLE II. Antenna Range Testing Conditions, 915MHz

Range Test Conditions at 915MHz, λ=0.328m		
Parameter	***Narrowband***	***Broadband***
R_{meas}	4.0m	4.0m
P_R	-18.5dBm	-18.5dBm
G_T	9.1dB	9.1dB
L	-1.1dB	-1.1dB
G_R	1.6dB	1.0dB
Γ_T	-30dB	-30dB

TABLE III. Narrow, Broadband Antenna/Higgs-4 RFIC Range

Narrowband Antenna/Higgs-4 RFIC Read Range				
I_S *(mm)*	P_T *(dBm)*	$\lvert S_{11}\rvert$ *(dB)*	R_{FRIIS} *(m)*	R_{FRIIS} - R_{meas} *(m)*
18.0	16.6	-11.3	4.3	0.3
18.5	16.7	-17.4	4.5	0.5
19.5	17.8	-10.0	5.0	0.8
Broadband Antenna/Higgs-4 RFIC Read Range				
I_S *(mm)*	P_T *(dBm)*	$\lvert S_{11}\rvert$ *(dB)*	R_{FRIIS} *(m)*	R_{FRIIS} - R_{meas} *(m)*
22.0	16.8	-9.5	4.0	0.0
23.0	17.0	-14.5	4.3	0.3
24.0	18.1	-12.0	5.0	0.8

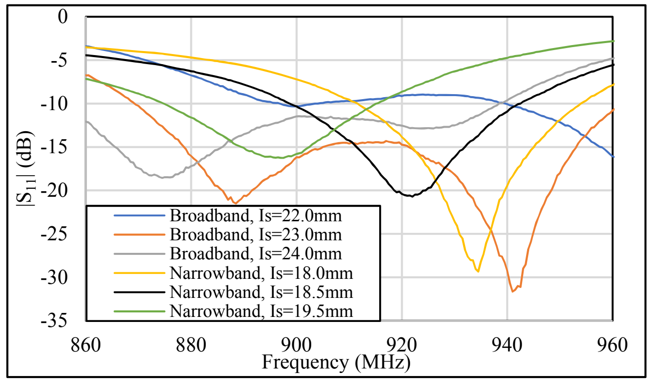

Fig. 5. Narrow, Broadband Antenna $|S_{11}|$ vs. Frequency

IV. Conclusion

Narrow and broadband modified T-match antennas are designed to conjugate match the Higgs-4 RFIC. Antenna elements are parameterized to demonstrate effects on input impedance; antennas are fabricated and range tested. Length *s*, shunt inductor length I_H and series inductor length I_L determine antenna input impedance and bandwidth. Broadband antennas have a shunt inductor length (I_H=4mm) and length *s*=90mm. Narrowband antennas use a longer shunt inductor length, I_H=18mm. To center the narrowband antenna impedance at 915MHz, antenna length *s* is increased to 113mm. Increasing length *s* increases the predicted antenna gain and transmit distance, confirmed by antenna range testing. Matching $|S_{11}|$ results show narrowband antenna matching over a 45MHz range (4.9%); 90MHz (9.8%) for broadband antennas, both within 1% of simulated values.

Acknowledgment

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