1 Overview

The Magnus® UHF RFID Tag IC (Integrated Circuit) is designed for use in EPCglobal™ Gen 2 (v. 2.0.0) and ISO/IEC 18000-6C compliant tags. It offers an unprecedented degree of user control and feedback, allowing precise management of tag response and correction of interference and detuning conditions.

Magnus® ICs features Chameleon™ technology that automatically adjusts the input impedance of the IC before the tag begins communicating back to the reader, to optimally tune the tag to varying frequencies, environmental conditions, and manufacturing variability. The tuning enables flat frequency response across the designed frequency band, enabling consistent performance over a much wider range of real world conditions.

To realize the full benefits of Chameleon™ technology, the antenna designer must account for the varying input impedance of the die over the frequency band of interest. Conventional design conjugate matches the antenna to the die at mid-band, then performance falls off as the frequency moves away from the tuned frequency. With an adaptive front-end, Magnus® adjusts the input capacitance to improve matching and maximize power transfer enabling peak performance across a broad range of frequencies. The antenna designer must account for the variable reactive portion of the antenna across the band of interest to match the tuning range of Magnus®.

2 Conjugate Match Across the Frequency Band

The input impedance model of Magnus® is a resistor in parallel with a variable capacitor. The antenna designer takes the specification for these and converts them to an equivalent series resistor and capacitor. The task of the designer is to design an antenna that provides a conjugate impedance match within the tuning range of the chip over the required bandwidth.

The match for the resistance is straightforward as the only design criteria is that they be as close as possible. To match the input capacitance of the die, the antenna must be inductive with a range of values that can be tuned by the variable input capacitance. If the calculated antenna reactance is X, then the capacitance needed to match that reactance is $1/(\omega X)$. This value for the needed tuned capacitance can be plotted vs. frequency to evaluate the match.

The design target for the reactive match can be visualized with a target design box. The left and right boundaries of the box set the desired bandwidth over which the Chameleon™ engine is to tune out the reactive mismatch. The top and bottom boundaries set the minimum and maximum capacitance available to the Chameleon™ engine. The goal of the design process is to have the tuned capacitance value sweep across the box between the upper and lower bounds.

For example, assume that the series input resistance is 3.5 Ω and that the series input capacitance can tune from 2.1 to 3.1 pF. The goal is to design a patch antenna that conjugate matches the chip in the North America RFID band spanning 902-928 MHz. The antenna is simulated with an electromagnetic simulator producing computed values for the input resistance and reactance. After optimization, Figure 1 shows the computed resistance, Figure 2 the computed inductance, and Figure 3 the required tuned capacitance computed from the inductance. The target design box is shown in blue. The Chameleon™ engine provides for reactive matching covering the desired band with 1-2 MHz of margin at the band edges. The remaining resistive mismatch at 910 MHz of 0.76 Ω creates an insertion loss of 2.3 dB.

Before a design is completely optimized, the tuned capacitance curve will emerge from the bottom or the top of the box. If it emerges from the bottom of the box, then the Chameleon™ engine cannot reduce capacitance enough and the sensor code will peg at 0. If the curve emerges from the top of the box, then the engine does not have enough capacitance to add and the sensor code will peg at 31. The goal of the designer is to adjust the antenna until the tuned capacitance curve enters and exits only from the sides of the design box.

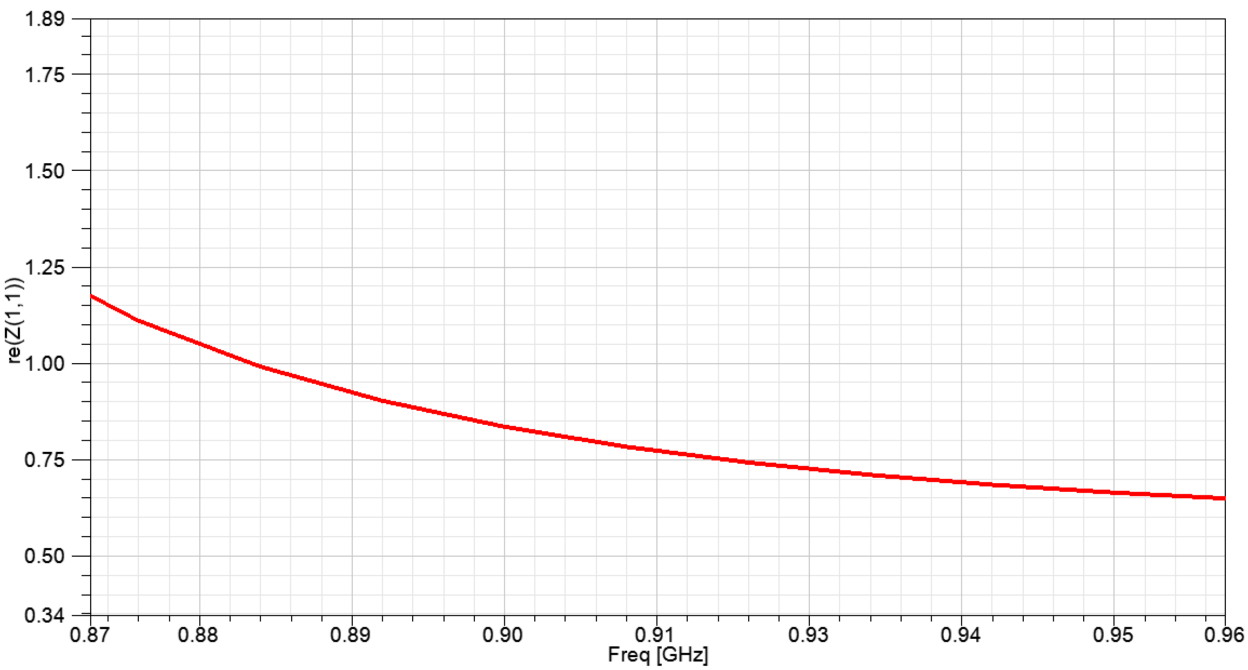

Figure 1. Resistance.

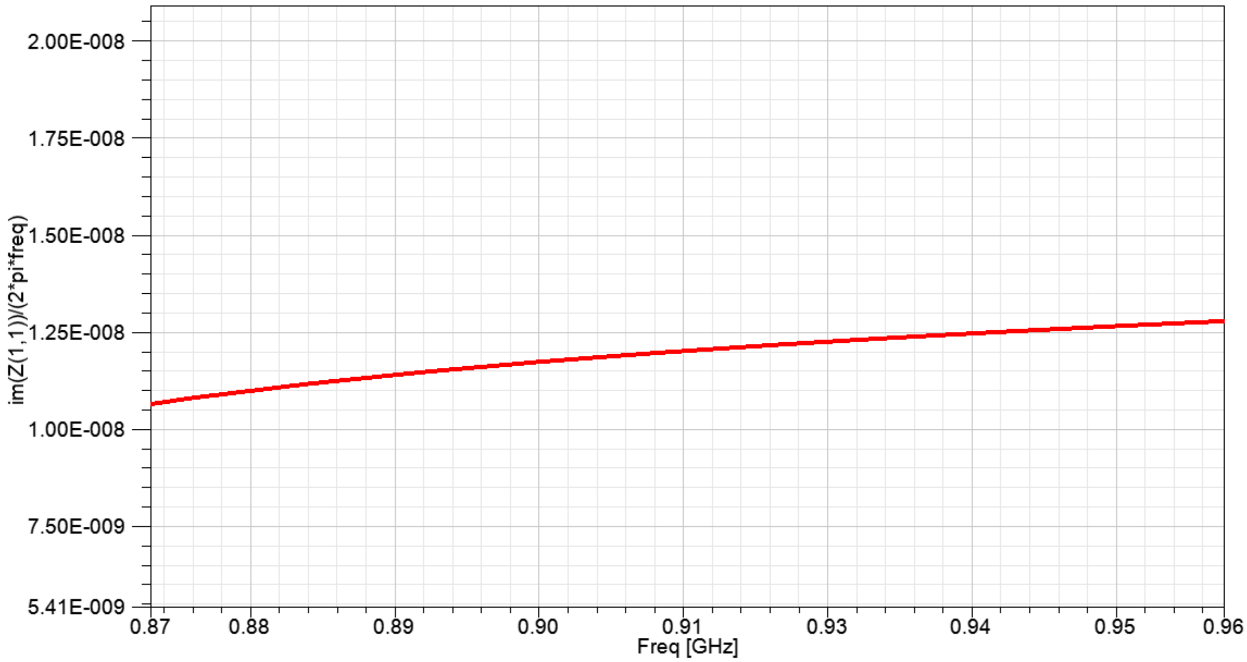

Figure 2. Inductance.

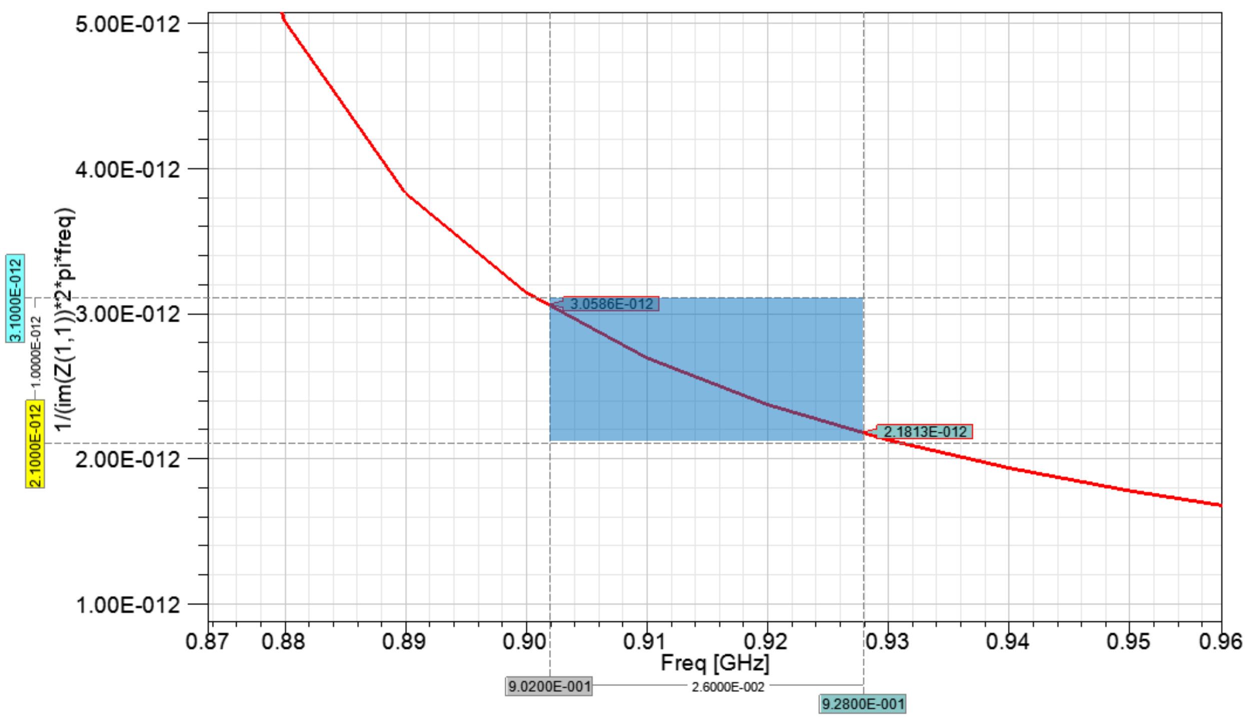

Figure 3. Tuned capacitance with target design box in blue.

3 Link Budget

After the antenna design is optimized, a spreadsheet calculation is generally used to estimate the performance of the tag. The spreadsheet takes into account antenna gain, insertion loss due to impedance mismatch [the conjugate match factor, or CMF], and chip sensitivity. For Magnus® chips, the impedance mismatch must be adjusted for each frequency, where the chip capacitance is adjusted to match the antenna inductance while the chip capacitance is within the tuning range, otherwise the chip capacitance is pegged either high or low depending on whether the tuned capacitance emerged above or below the design box.

For the example in Figure 3, for frequencies below 901 MHz, the link budget sets the series chip capacitance to 3.1 pF, while for frequencies above 931 MHz, the capacitance is 2.1 pF. For all frequencies in this example, the series chip resistance is set to 3.5 Ω. This means that for frequencies between 901 and 931 MHz, all of the impedance mismatch is due only to the resistive mismatch. Outside of these frequencies, the impedance mismatch is due both to resistive and reactive mismatch. The sensitivity of the tag within the design box is almost flat with respect to frequency for a reasonable match of the resistive components.

For a different antenna, a sensitivity spreadsheet calculation is shown in Table 1. This antenna is intended for the North America band shown by the blue highlighting. The required capacitance to match the inductive reactance of the antenna is satisfied by the Chameleon™ engine in the North America band. Outside the North America band, the engine provides the limit of higher or lower capacitance, as highlighted in red. Within the band, the only remaining component of the CMF is the resistive mismatch which is small, so the sensitivity of the tag is flat across the band. Note that for simplicity, the chip capacitance in the table uses continuous values while the Chameleon™ engine in practice uses 1 of 32 discrete capacitance values.

Table 1. Example sensitivity spreadsheet calculation.

Frequency	Tag Antenna Directivity	Tag Antenna Efficiency	Antenna Resistance	Antenna Inductance	C to Tune Antenna	Chip Resistance	Chip Capacitance	Chip Sensitivity	CMF	Sensitivity
MHz	dBi	%	Ω	nH	pF	Ω	pF	dBm	dB	dBm
860	4.23	8.70	15.09	-0.15	-232.70	3.50	2.10	-12	-15.92	10.29
870	4.23	9.06	8.46	4.71	7.11	3.50	3.10	-12	-10.24	4.43
880	4.23	9.33	5.56	7.57	4.32	3.50	3.10	-12	-6.57	0.64
890	4.23	9.52	4.04	9.47	3.38	3.50	3.10	-12	-1.46	-4.55
900	4.22	9.63	3.15	10.83	2.89	3.50	2.89	-12	-0.01	-6.05
910	4.25	9.69	2.59	11.86	2.58	3.50	2.58	-12	-0.10	-6.01
920	4.31	9.70	2.21	12.67	2.36	3.50	2.36	-12	-0.23	-5.95
930	4.38	9.67	1.95	13.33	2.20	3.50	2.20	-12	-0.37	-5.86
940	4.45	9.62	1.75	13.89	2.06	3.50	2.10	-12	-0.80	-5.48
950	4.53	9.54	1.61	14.36	1.95	3.50	2.10	-12	-4.35	-1.97
960	4.61	9.46	1.51	14.78	1.86	3.50	2.10	-12	-7.86	1.49

4 Antenna Detuning

The environment surrounding a tag affects its performance by changing the resistance and reactance of the antenna. RFID chips with fixed input impedance will still resonate with the antenna, but the resonant frequency may move out of the operating band. When this happens, tag sensitivity can be severely impacted.

The Chameleon™ engine tunes the tag at every power-up, so changing conditions can be accommodated to maintain performance within the operating band. Tag design can provide more margin for detuning effects by providing for additional tuning range outside of the band. Table 2 shows a tag where the tuning range of the Chameleon™ engine covers the full 860-960 MHz range.

Table 2. Example sensitivity spreadsheet for a tag with broadband tuning range for the Chameleon™ engine.

Frequency	Tag Antenna Directivity	Tag Antenna Efficiency	Antenna Resistance	Antenna Inductance	C to Tune Antenna	Chip Resistance	Chip Capacitance	Chip Sensitivity	CMF	Sensitivity
MHz	dBi	%	Ω	nH	pF	Ω	pF	dBm	dB	dBm
860	1.71	98.40	5.32	11.56	2.96	2.5	2.96	-12	-0.61	-13.0
870	1.72	98.66	5.72	11.48	2.91	2.5	2.91	-12	-0.72	-12.9
880	1.72	98.85	6.02	11.39	2.87	2.5	2.87	-12	-0.81	-12.9
890	1.72	98.98	6.20	11.29	2.83	2.5	2.83	-12	-0.87	-12.8
900	1.73	99.07	6.26	11.20	2.79	2.5	2.79	-12	-0.89	-12.8
910	1.73	99.11	6.22	11.11	2.75	2.5	2.75	-12	-0.87	-12.8
920	1.73	99.12	6.10	11.04	2.71	2.5	2.71	-12	-0.84	-12.9
930	1.74	99.09	5.92	10.98	2.67	2.5	2.67	-12	-0.78	-12.9
940	1.74	99.04	5.69	10.93	2.62	2.5	2.62	-12	-0.72	-13.0
950	1.74	98.97	5.45	10.89	2.58	2.5	2.58	-12	-0.64	-13.1
960	1.75	98.89	5.20	10.86	2.53	2.5	2.53	-12	-0.57	-13.1

The tag designer should leave some margin for the tuning range of the Chameleon™ engine to accommodate environmental effects that cause detuning of the antenna. The size of the margin is dependent on the application. Detuning caused by the presence of materials will generally push the resonance down in frequency, so more margin would be applied to the lower end of the frequency band.

5 Design Checklist

a) **Input Impedance** From the Magnus® data sheet, determine the input resistance and capacitive tuning range of the Chameleon™ engine.

b) **Bandwidth** Determine the frequency range over which the Chameleon™ engine must tune. This is application dependent. A starting point would be to target the RFID band plus margin on the high and low sides to enable Magnus® to achieve flat frequency response across the band. For the North America band of 902 – 928 MHz spanning 26 MHz, 10 MHz margins on each side would suggest a target bandwidth of 46 MHz. Note that wider bandwidth costs gain.

c) **Simulate** Sweep the frequency over a broad bandwidth, something like 800 – 1000 MHz, and calculate the resistance and inductance looking into the antenna terminals along with the gain.
d) **Calculate tuned C** Calculate the capacitance needed to tune out the antenna inductance, where the tuned capacitance is calculated as $1/(\omega X)$ and X is the antenna reactance.
e) **Optimize** Adjust the design until the tuned capacitance falls within the Chameleon™ tuning range and the antenna resistance is closely matched to the Magnus® resistance. Check tag system performance in a spreadsheet to verify optimum performance over the design frequency band.

6 Conclusion

The Chameleon™ engine of the Magnus® family of chips enables the tag designer to tune out the inductive reactance of the antenna across a specified bandwidth. The antenna designer should design the antenna inductance within the band such that the required tuning capacitance stays within the range of the Chameleon™ engine. The resulting tag will have flat performance response across the band limited only by the resistive mismatch and the frequency dependence of the antenna gain.

7 Notices

Customer is advised to provide appropriate design and operating safeguards to minimize the risks associated with its applications and products.

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