RFID Radio Circuit Design in CMOS

Minhong Mi, Ansoft Corp.
Outline

• Overview of RFID Radios at System Level

• Power Generation/Management Circuit
  • Rectifier, Charge-pump, **Low-Drop Out (LDO) Voltage Regulator, Reset Circuit**

• Demodulator Circuit
  • Envelope Detector, Ring Oscillator, Comparator

• Modulator Circuit
  • Bias Generator, Phase Modulator

• Overall Radio Simulation and Verification
  • Input Impedance Simulation (under large signal condition)
  • System/Nexxim Co-sim (with deep-modulated ASK input)

• Antenna Design
Overview of RFID Radio Circuits at System Level

EPC™ Radio-Frequency Identity Protocols
Class-1 Generation-2 UHF RFID
Protocol for Communications at 860 MHz – 960 MHz
Overview for RFID Radio

\[ Loss \ [dB] = 20 \log \left( \frac{4 \pi fd}{c} \right) - 10 \log Gt - 10 \log Gr \]

Antenna gain \( Gt = 3 \text{dB} \)

Antenna gain \( Gr = 1.64 \text{ dB} \)

EIRP = 4W

Distance \( d = 10 \text{m} \)

Loss \( \approx 47 \text{ dB} \)

Receiving power \( \approx -1 \text{dBm} \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx Antenna Gain</td>
<td>3 dB</td>
</tr>
<tr>
<td>Rx Antenna Gain</td>
<td>1.64 dB</td>
</tr>
<tr>
<td>Frequency</td>
<td>950 MHz</td>
</tr>
<tr>
<td>Distance</td>
<td>10 meter</td>
</tr>
<tr>
<td>Speed of Light</td>
<td>3.00E+08 m/s</td>
</tr>
<tr>
<td>Loss</td>
<td>47.36 dB</td>
</tr>
<tr>
<td>Tx Power</td>
<td>46.43 dBm</td>
</tr>
<tr>
<td>Rx Power</td>
<td>-0.92 dBm</td>
</tr>
</tbody>
</table>
Overview for RFID Radio (2)

\[ 1 \cdot T_{ari} = \begin{cases} 
6.25 \mu s \\
12.5 \mu s \\
25 \mu s 
\end{cases} \]

RTcal = 0\text{length} + 1\text{length}

\[ \text{pivot} = \frac{RTcal}{2} \]

R\rightarrow T \text{ Preamble}

\[ \text{CW} \geq 8 \cdot RTcal \]

To get TRCal to calibrate for link frequency (LF) when backscattering

\[ LF = \frac{DR}{TRcal} \]

DR: Divide Ratio = 64/3 or 8

\[ T_{pri} = \frac{1}{LF} = \frac{TRcal}{DR} \]

= Link Period

Sent from reader !!

Tag1: f_{osc1}  Tag1: f_{osc2}  ...  Tag1: f_{osc3}

process, environment variations

Leading Insight
Application Workshops for High-Performance Design

ANSOFT
Overall Block Diagram for RFID Radio

- Rectifier
- Charge Pump
- Bandgap ref
- LDO Regulator
- Modulator
- Comparator
- Env_detector
- Bias Gen
- Ring Oscillator
- Reset

To demodulator
Power Generation & Management Circuit
Power Generation Circuit (Rectifier & Charge_Pump)

Large capacitor implemented with MosVar to make slow charge-pump
Power Management Circuit (LDO voltage regulator)
Power Management Circuit (LDO Test)
Power Management Circuit (Reset)
Power Management Circuit (Reset test)
Demodulator Circuit
Demodulator Circuit (top level)
Demodulator Circuit (Envelope detector)

Implemented with a two stage charge pump circuit
Demodulator Circuit (Comparator)

With hysteresis for better performance in a noisy environment.
Demodulated Signals

- 12.5us
- 1 Tari
- RTCal = 2.75*Tari
- Data-0
- Data-1
Demodulator Circuit (Ring Oscillator)

Replica Feedback

Comparator

Differential Delay Block
Ring Oscillator Output

Freq = 4.0 MHz
Demodulator Circuit (Bias and Control)

VT sensor

Constant Current Source
Modulator Circuit
Modulator Circuit for PSK
Tag’s Overall Radio Simulation and Verification
Input Impedance Simulation for Tag’s Radio

Under the condition of large signal input!

\[
Z_{\text{total}} = \frac{1}{Y_{\text{total}}} = \frac{1}{Y_{\text{tag}} + Y_{\text{imp}}} \\
= \frac{1}{Y_{\text{tag}}} + 0.01 \\
\Rightarrow Y_{\text{tag}} = \frac{1}{Z_{\text{total}}} - 0.01 \\
\Rightarrow Z_{\text{tag}} = \frac{1}{Y_{\text{tag}}} = \frac{1}{\left(\frac{1}{Z_{\text{total}}} - 0.01\right)}
\]

Yellow traces in the next slide
Input Impedance Simulation for Tag’s Radio

- mod_in to AVDD
- mod_in to AGND

@900MHz

~ 1.5V regulated supply generation
Continuous Wave (CW) Input (Transient)

- Only transient solver can solve this region.
- To save time and get more insightful information:
  - Better use HB Engine
Continuous Wave (CW) Input (Harmonic Balanced: HB)

The results are from Nexxim’s HB engine
**System/Nexxim Co-simulation**

```
NSAMP=sample_num
SAMPLE_RATE=sample_rate
PERIOD=20/sample_rate
A=1V
DUTY=0.61
T1=0s
T2=0s

VTHRESHOLD=0.5V
```

```
NSAMP=sample_num
SAMPLE_RATE=sample_rate
PERIOD=20/sample_rate
A=1V
DUTY=0.81
T1=0s
T2=0s
```

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PRBS
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PWM_out
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SAMPREP
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AMMOD
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AM_out
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U1
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rfid_tag8102008
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SP
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env_p
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env_n
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System/Nexxim Co-simulation

Worst case for supplied voltage generation duty cycle = 47.5%
System/Nexxim Co-simulation
Worst case for supplied voltage generation duty cycle = 47.5%
System/Nexxim Co-simulation

Worst case for envelope detection: duty cycle = 13.25%
System/Nexxim Co-simulation

Worst case for envelope detection: duty cycle = 13.25%
System/Nexxim Co-simulation

Typical case: RTcal = 2.75*Tari, PW = 0.4*Tari ➞ Average duty cycle = 71%
System/Nexxim Co-simulation

Typical case: RTcal = 2.75*Tari, PW = 0.4*Tari ➔ Average duty cycle = 71%
UHF RFID Antenna Design and Simulation
Design Method

- The method follows recently published work on RFID tag design.

Design Goals

• Primary goal is to design an antenna that maximizes RFID read range
  – Range is limited by tag response threshold (tag power absorption):

\[
range = \frac{\lambda}{4\pi} \sqrt{\frac{P_t G_t G_r \tau}{P_{th}}}
\]

  – where

- \( \lambda \) = wavelength
- \( P_t \) = Power of transmitter
- \( G_t \) = Gain of transmit (reader) antenna
- \( G_r \) = Gain of receive (tag) antenna
- \( P_{th} \) = Tag response threshold power
- \( \tau \) = mismatch factor (0 ≤ \( \tau \) < 1)

\[
\tau = \frac{4R_c R_a}{|Z_c + Z_a|^2}
\]

Mismatch Factor

\[
Z_a = R_a + jX_a \quad \text{Chip impedance}
\]

\[
Z_c = R_c + jX_c \quad \text{Antenna impedance}
\]

Goal: maximize power absorption by designing tag antenna impedance that resonates with chip impedance
Simulation and Optimization

Note: This antenna was designed for $Z_a = 16 + j350 \, \Omega$

Dimensions Taken From Reference Paper

PARAMETERS OF THE LOADED MEANDER TAG ANTENNA (mm)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$l$</th>
<th>$w$</th>
<th>$s$</th>
<th>$d$</th>
<th>$a$</th>
<th>$b$</th>
<th>$t_s$</th>
<th>$t_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values</td>
<td>96</td>
<td>0.7</td>
<td>0.7</td>
<td>9</td>
<td>6</td>
<td>14</td>
<td>0.051</td>
<td>0.018</td>
</tr>
</tbody>
</table>

Adjust parameters $l, w, s, d, a, b$ to achieve desired antenna input impedance
Target Impedance From Circuit Simulation

Small signal chip impedance is $Z_c = 35 - j 155 \, \Omega$
Simulation in Ansoft Designer

- Provides inductive reactance
- Loading Bar Reduces Resistance
- Optimize to Match Target Impedance
Results

**Goal**

Small signal chip impedance is \( Z_c = 35 - j 155 \, \Omega \)

\[ Z_a = 12.5 + j 148 \, \Omega \]
\[ l = 77.7 \, \text{mm} \]
\[ b = 7 \, \text{mm} \]
\[ s = 5 \, \text{mm} \]

Too low

---

**Optimized Result**

\[ Z_a = 34.3 + j 155 \, \Omega \]
\[ l = 121 \, \text{mm} \]
\[ b = 2.85 \, \text{mm} \]

Meets goal but larger in size

---

**New Design**

- Removed loading bar
- Reduced inductive meanders
Swept Frequency Performance

Antenna design provides relatively flat response across UHF RFID band
Far-field Radiation Performance

1.95 dB Gain

Broad Omnidirectional Pattern
Conclusions

• UHF RFID tag RF/analog circuits have been designed and tested at circuit and system levels using Ansoft tools within the Cadence environment.

• Meandered (inductive) dipole antenna was designed for this specific tag.

• Ansoft team has comprehensive understanding of EPC Global Standard
Thank you!
Appendix: Entry for Nexxim/Cadence Integration