

# RFID Radio Circuit Design in CMOS

Minhong Mi, Ansoft Corp.



*LeadingInsight*

Application Workshops for High-Performance Design

# 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**



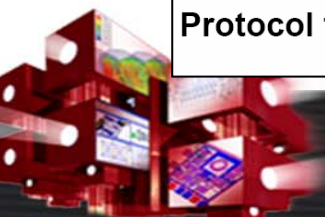
# Overview of RFID Radio Circuits at System Level

Specification for RFID Air Interface



Powered by GS1

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

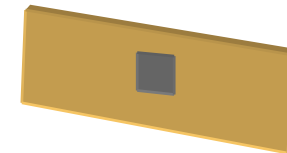


# Overview for RFID Radio

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

Antenna gain  $G_t=3\text{dB}$

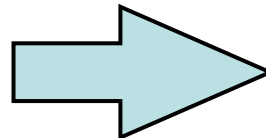
Antenna gain  $G_r=1.64\text{ dB}$



Tag

Loss ~ 47 dB

EIRP = 4W



Receiving power  
~ -1dBm

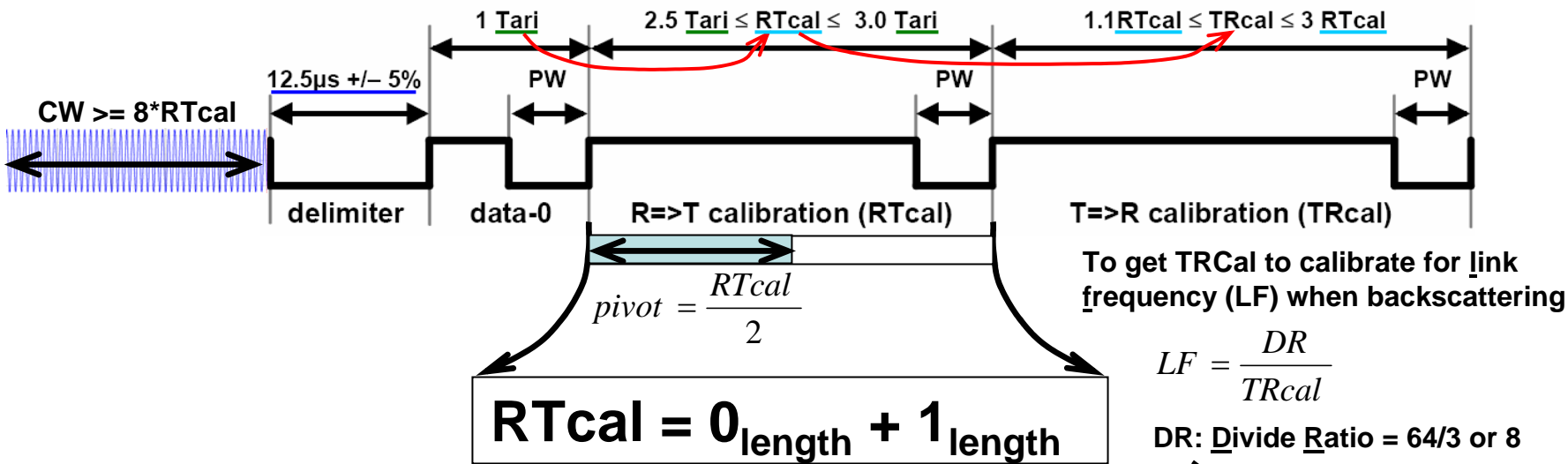
Tx Antenna Gain	3	dB
Rx Antenna Gain	1.64	dB
Frequency	950	MHz
Distance	10	meter
Speed of Light	3.00E+08	m/s
Loss	47.36	dB
Tx Power	46.43	dBm
Rx Power	-0.92	dBm



# Overview for RFID Radio (2)

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

## R=>T Preamble

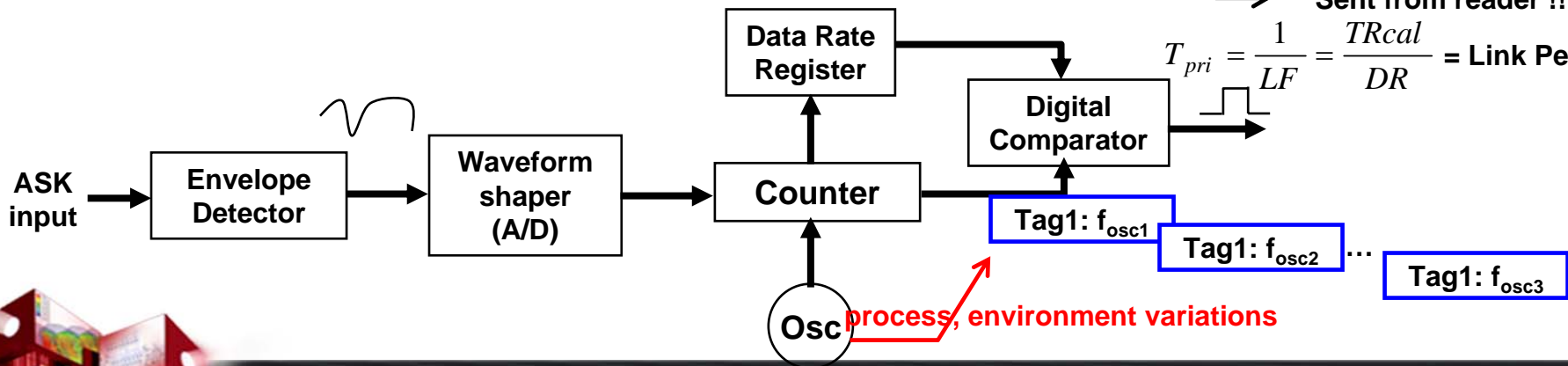


$$LF = \frac{DR}{TRcal}$$

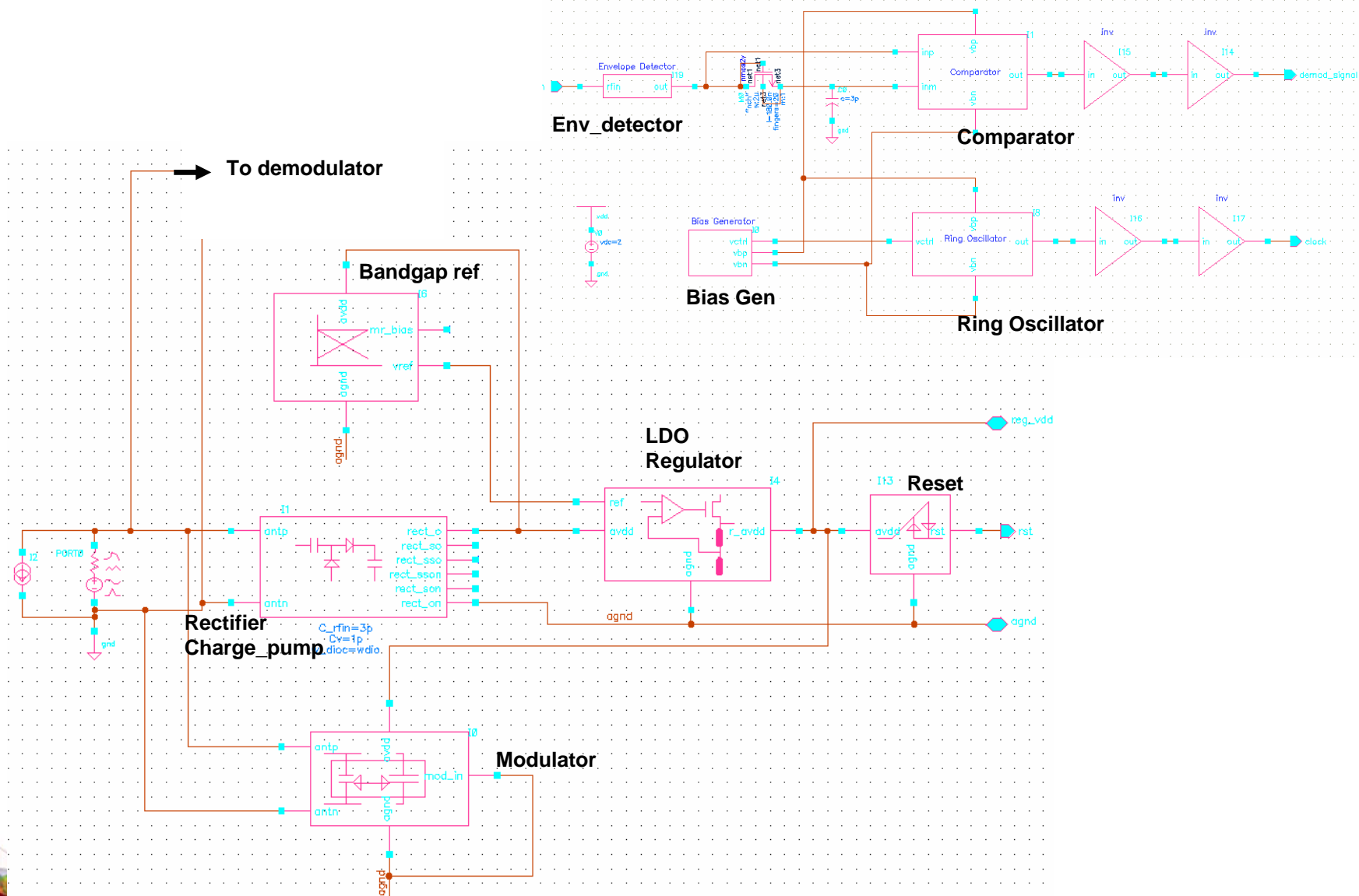
DR: Divide Ratio = 64/3 or 8

Sent from reader !!

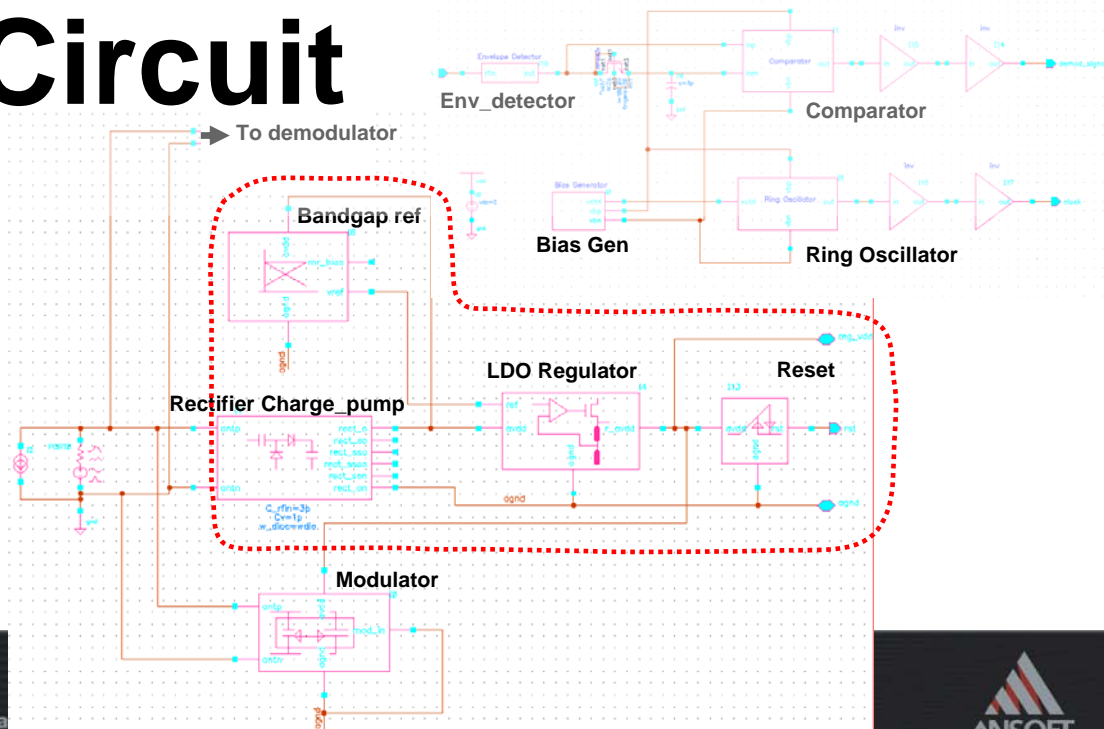
$$T_{pri} = \frac{1}{LF} = \frac{TRcal}{DR} = \text{Link Period}$$



# Overall Block Diagram for RFID Radio



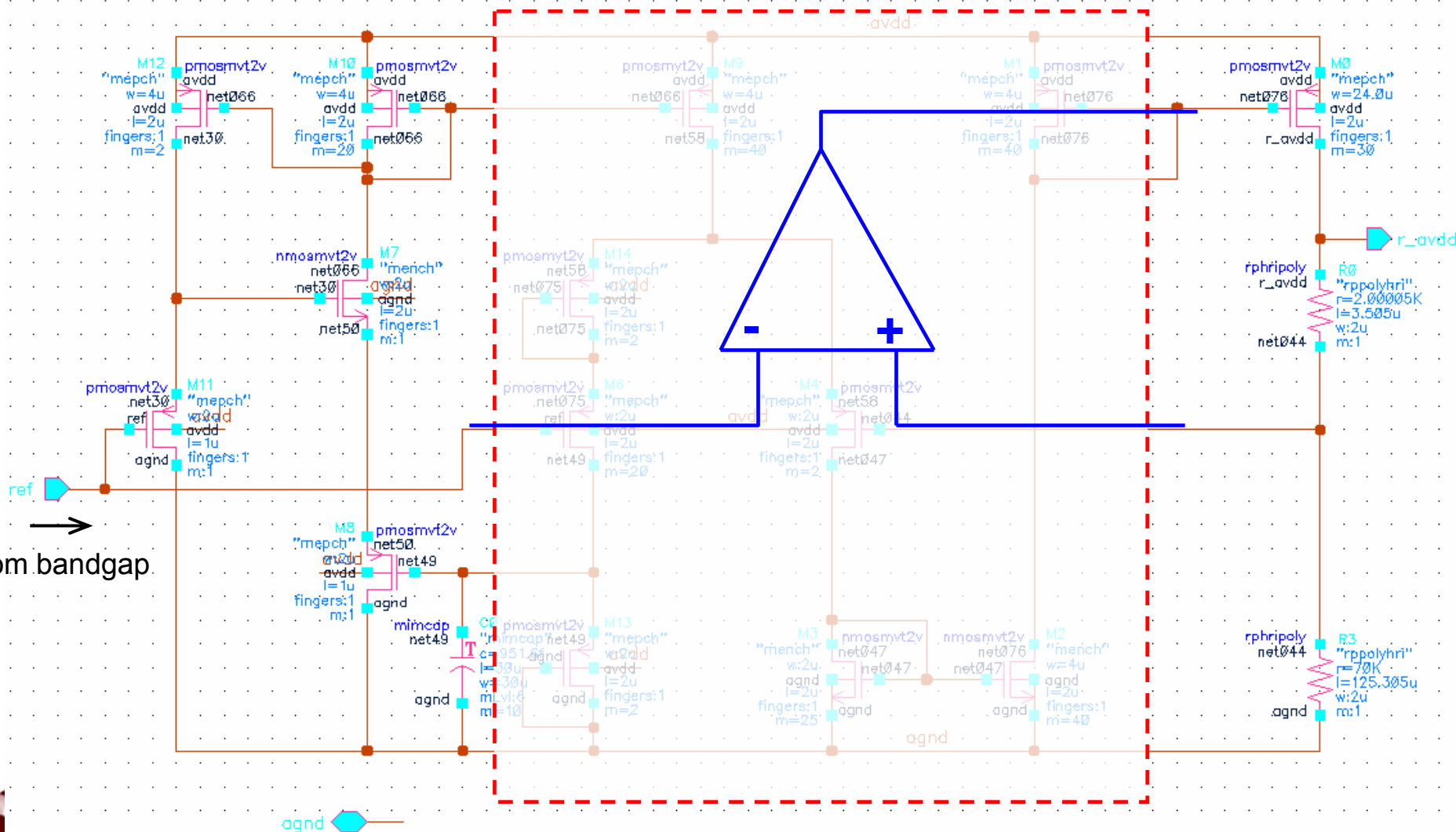
# Power Generation & Management Circuit





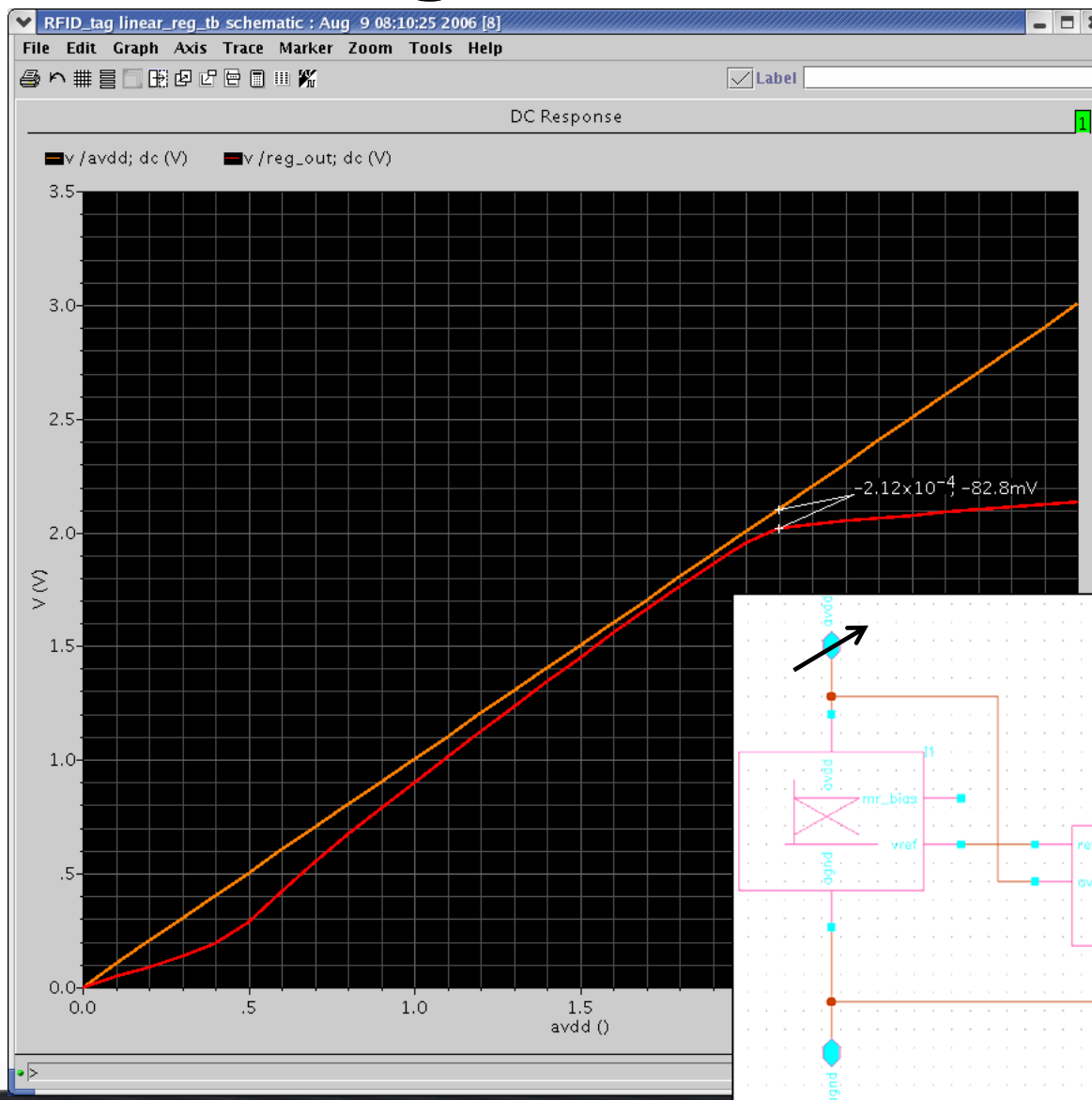
# Power Management Circuit (LDO voltage regulator)

avdd

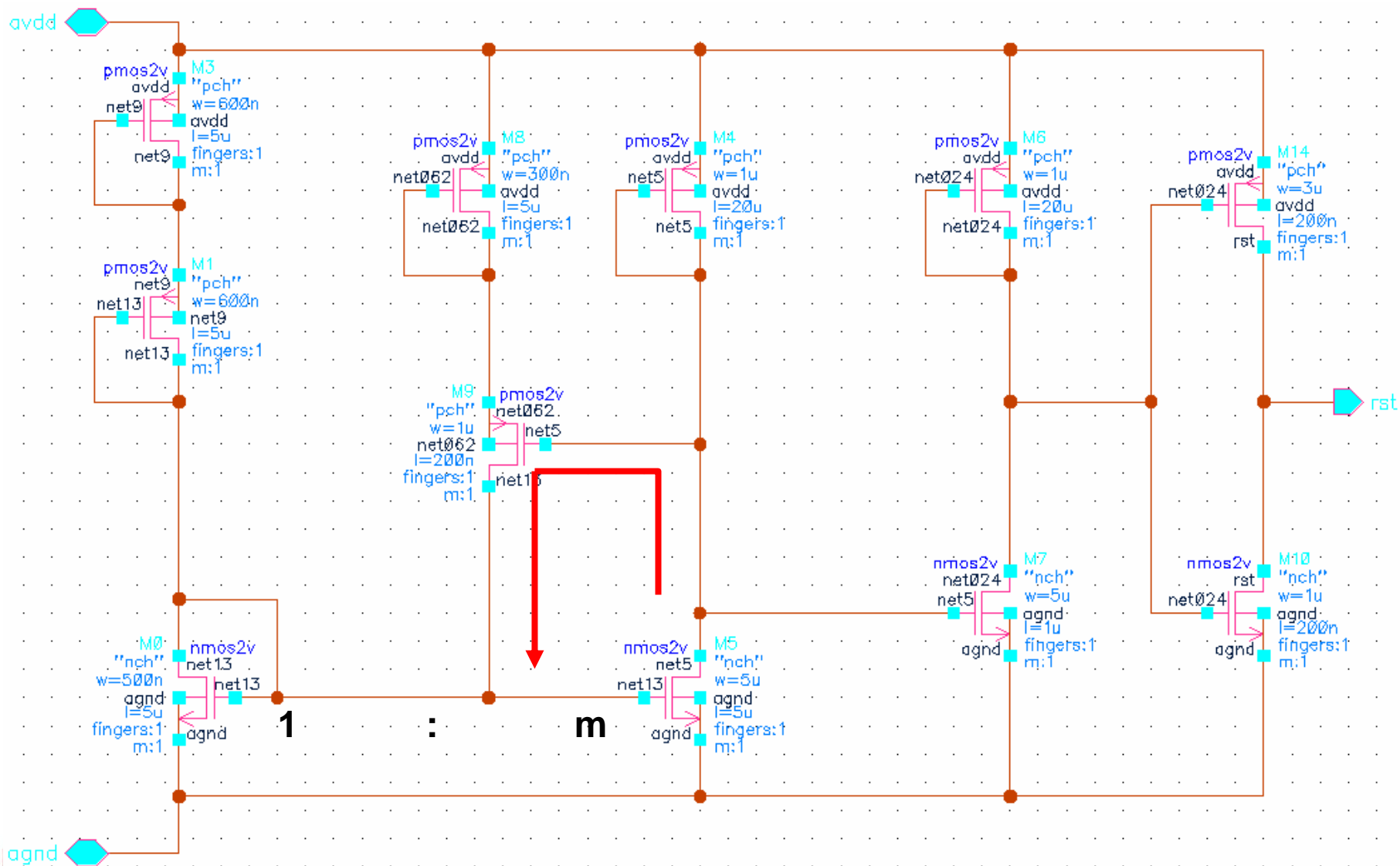


agnd

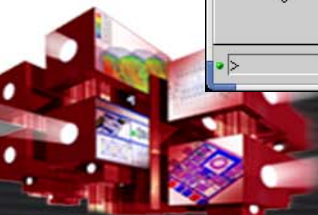
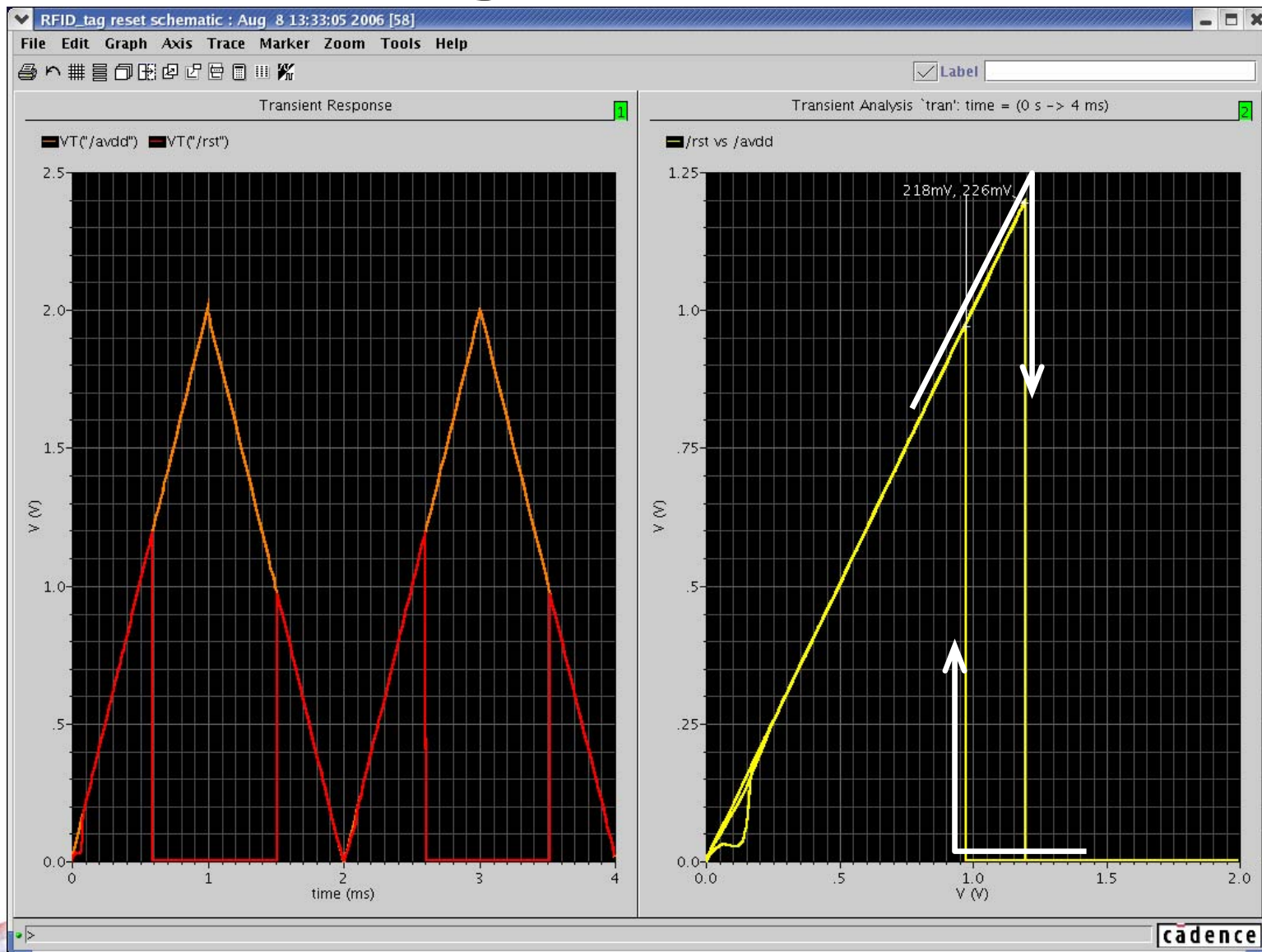
# Power Management Circuit (LDO Test)



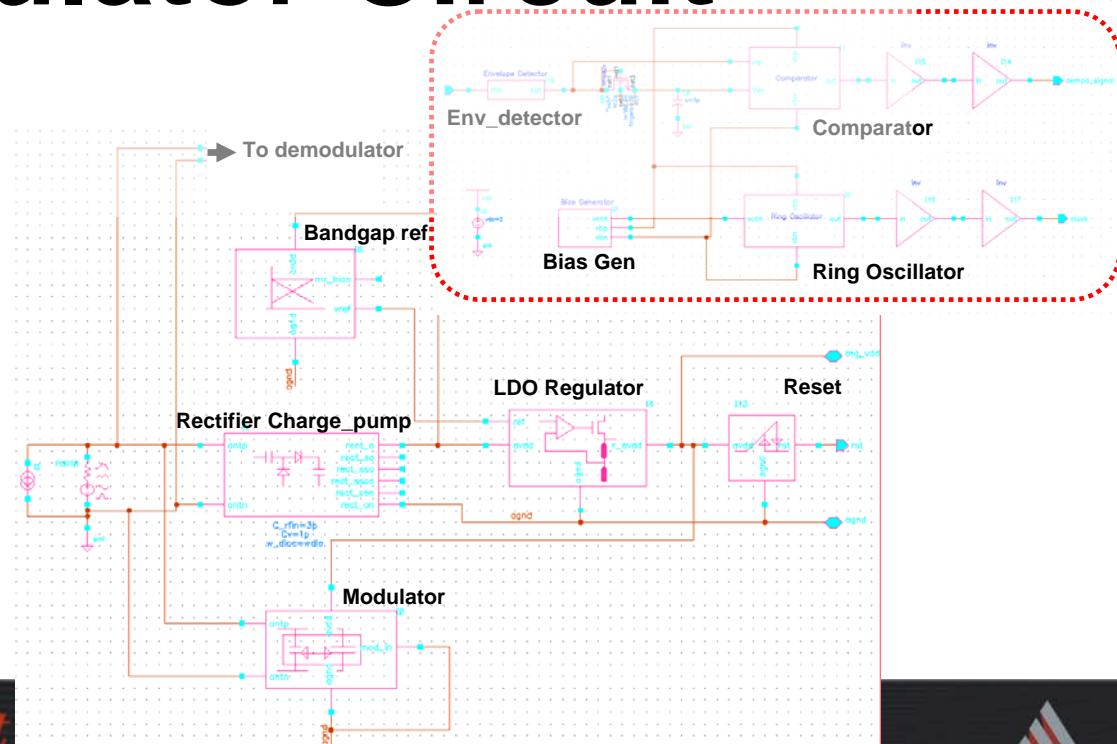
# Power Management Circuit (Reset)



# Power Management Circuit (Reset test)



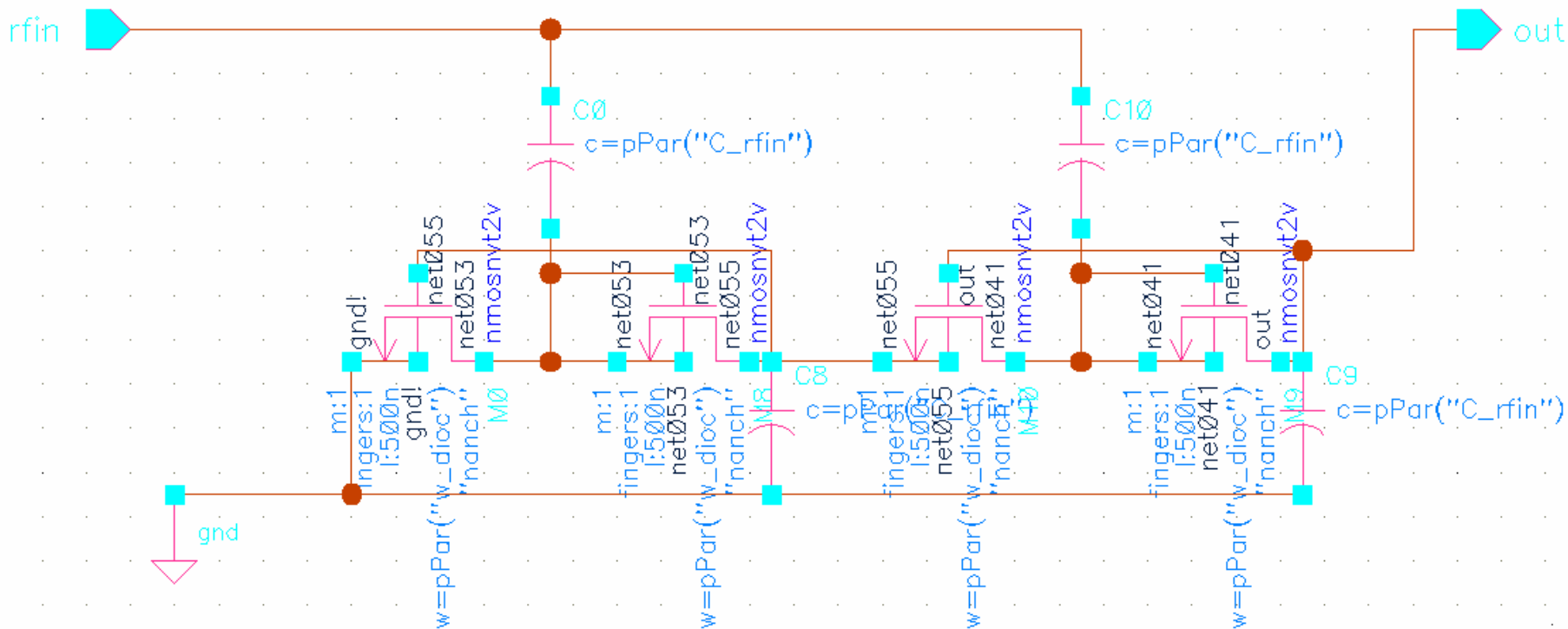
# Demodulator Circuit



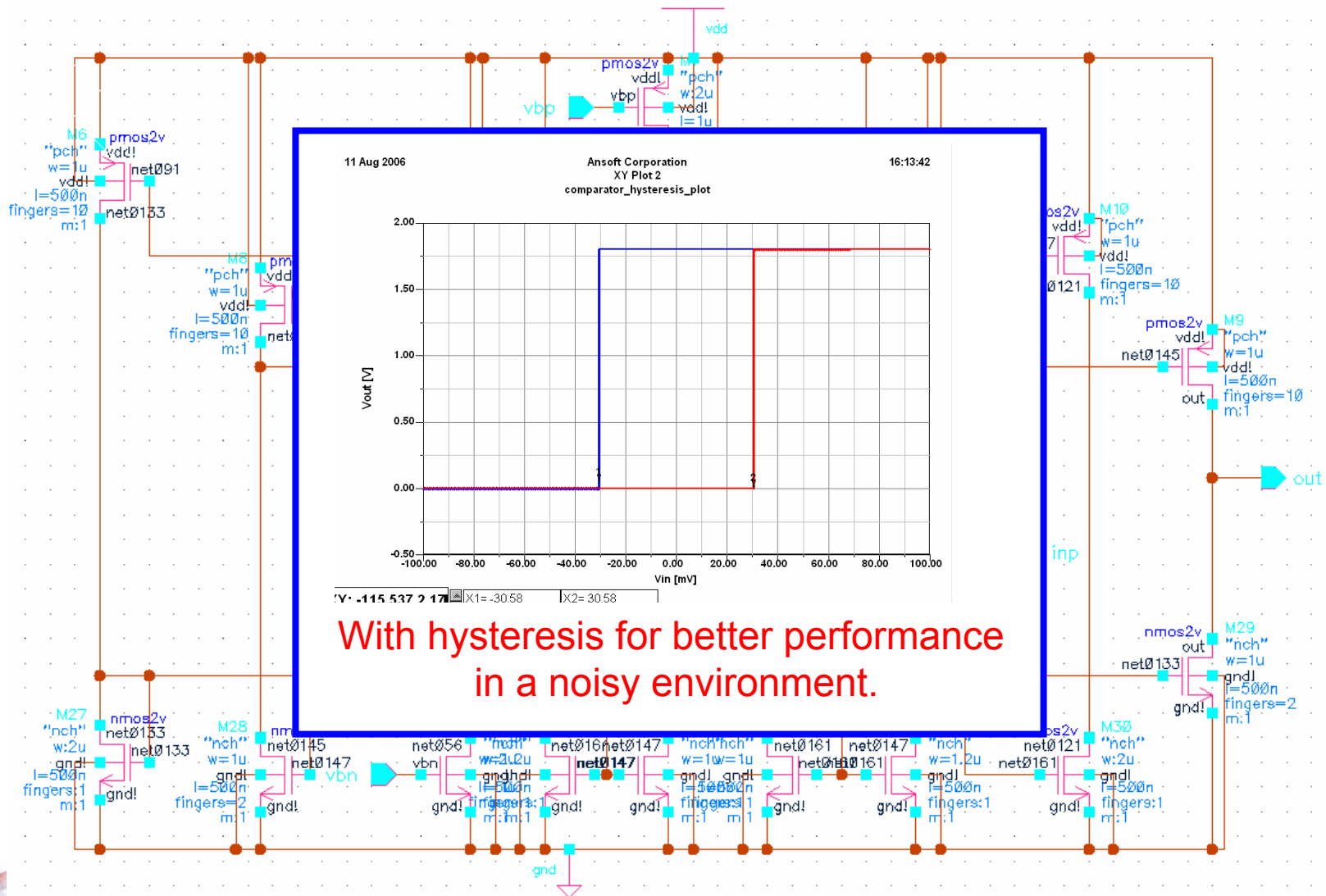


# Demodulator Circuit (Envelope detector)

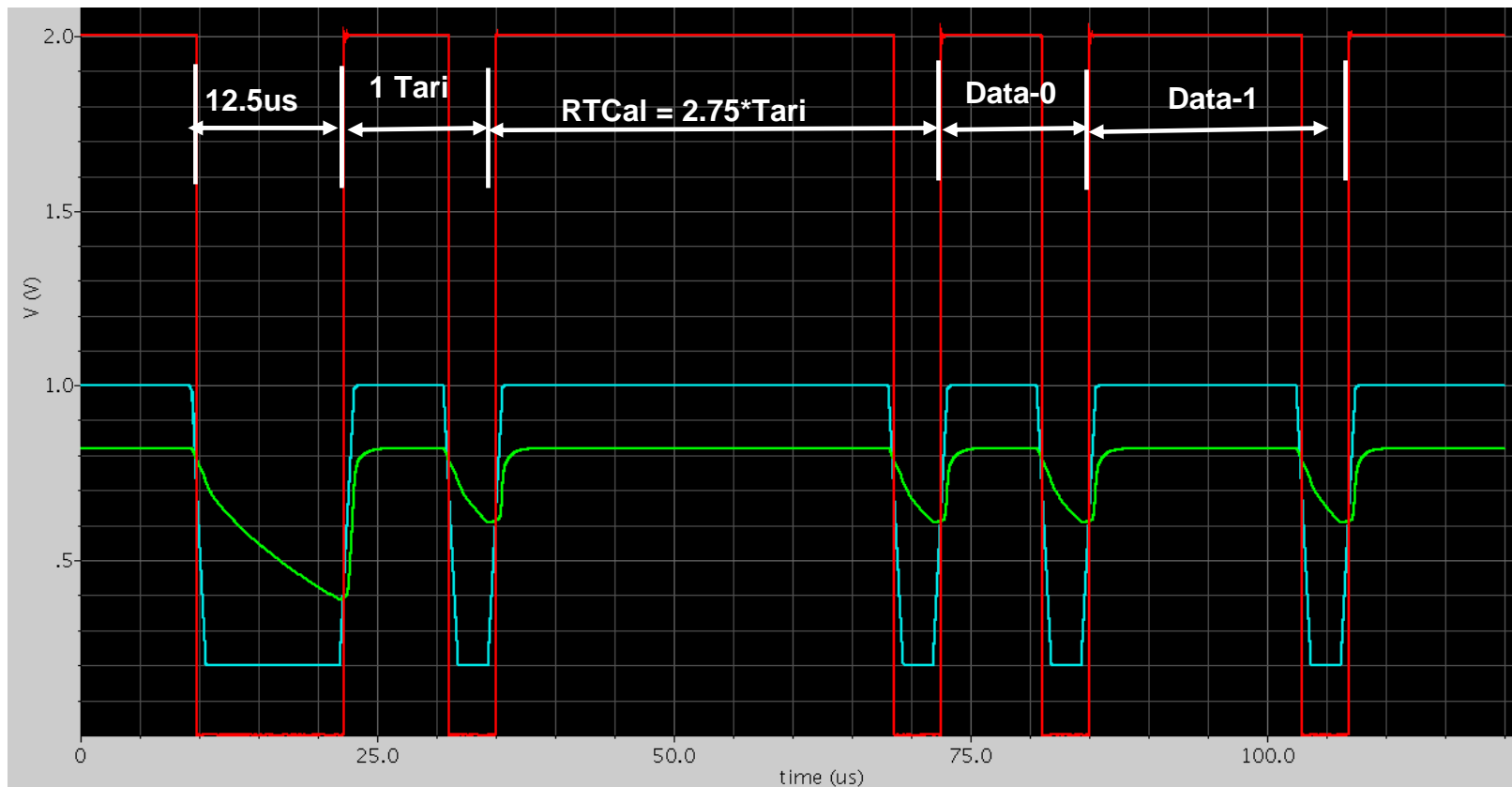
Implemented with a two stage charge pump circuit



# Demodulator Circuit (Comparator)

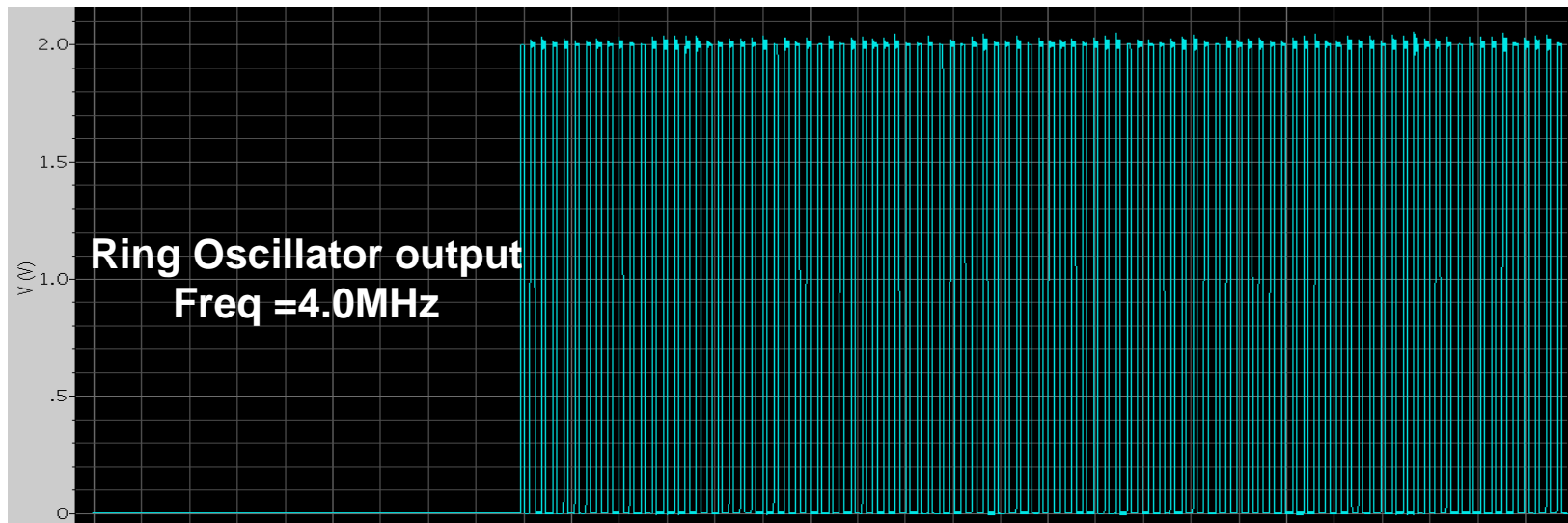


# Demodulated Signals

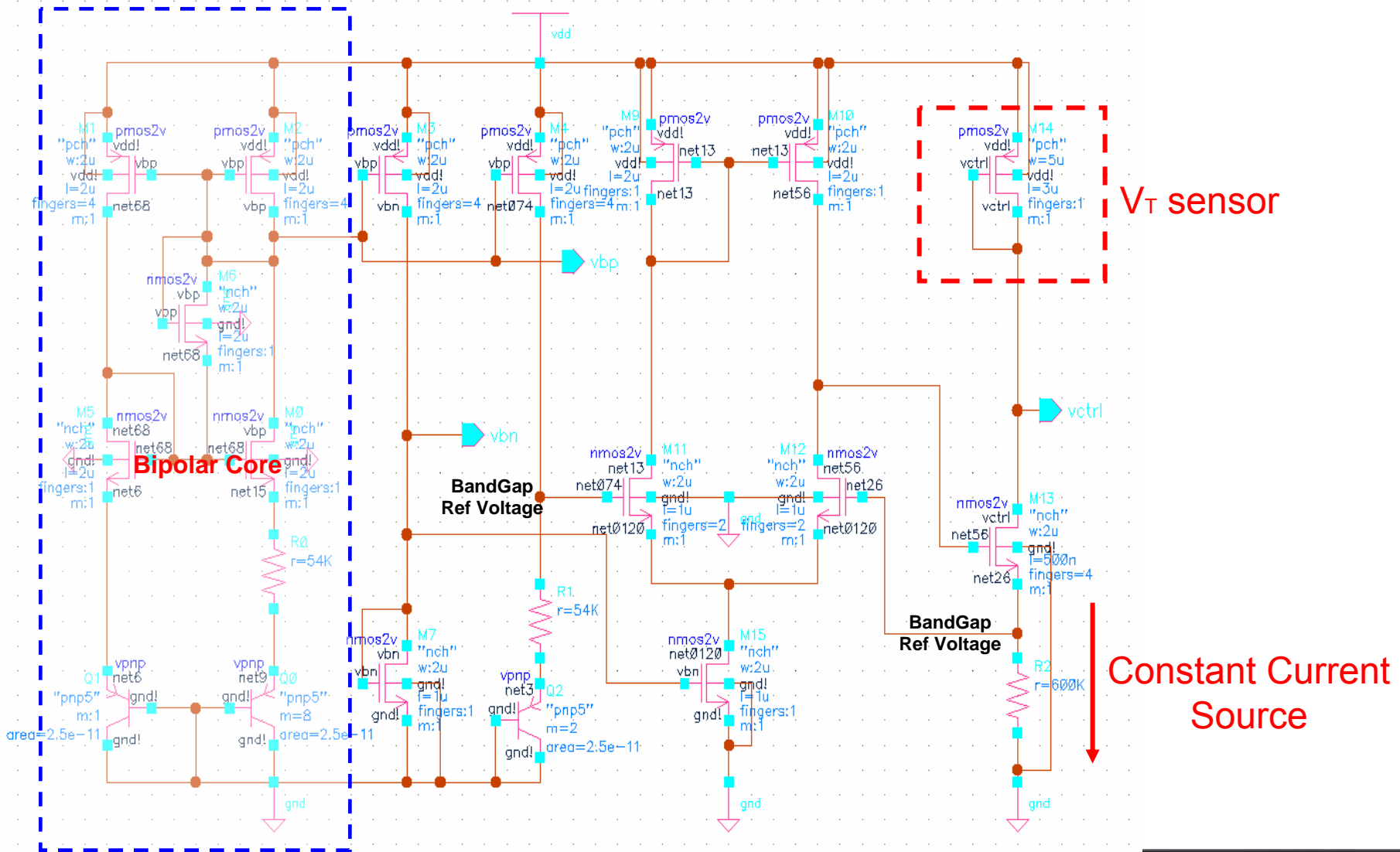




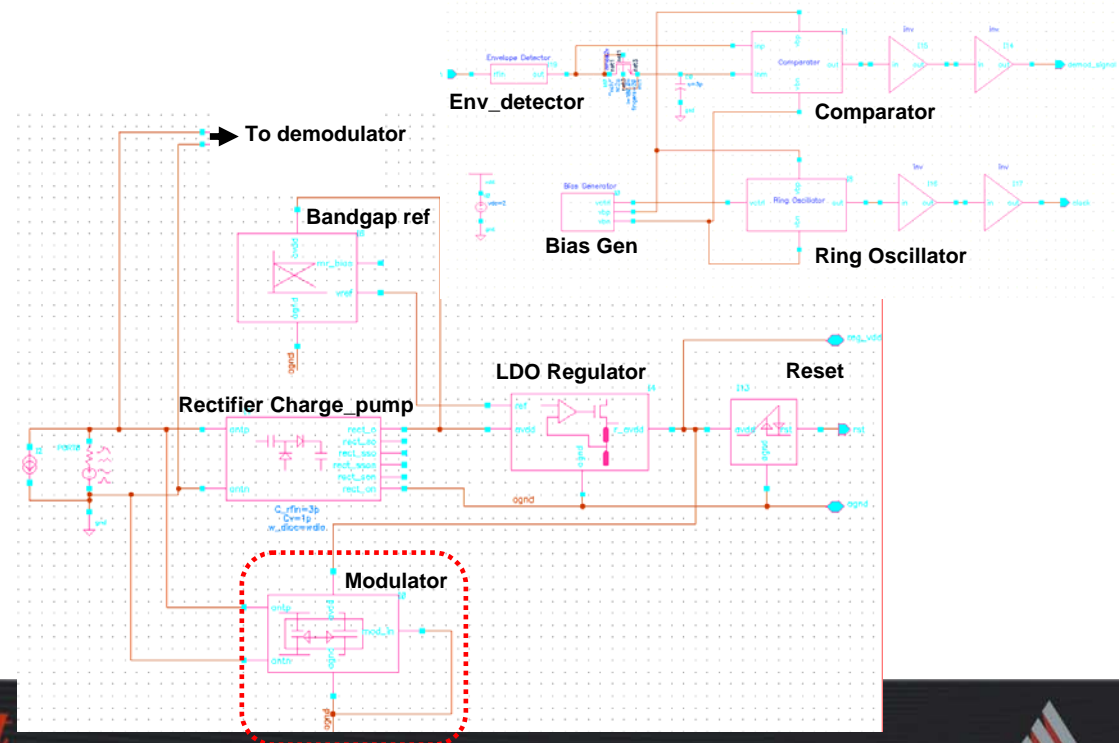
# Ring Oscillator Output



# Demodulator Circuit (Bias and Control)



# Modulator Circuit



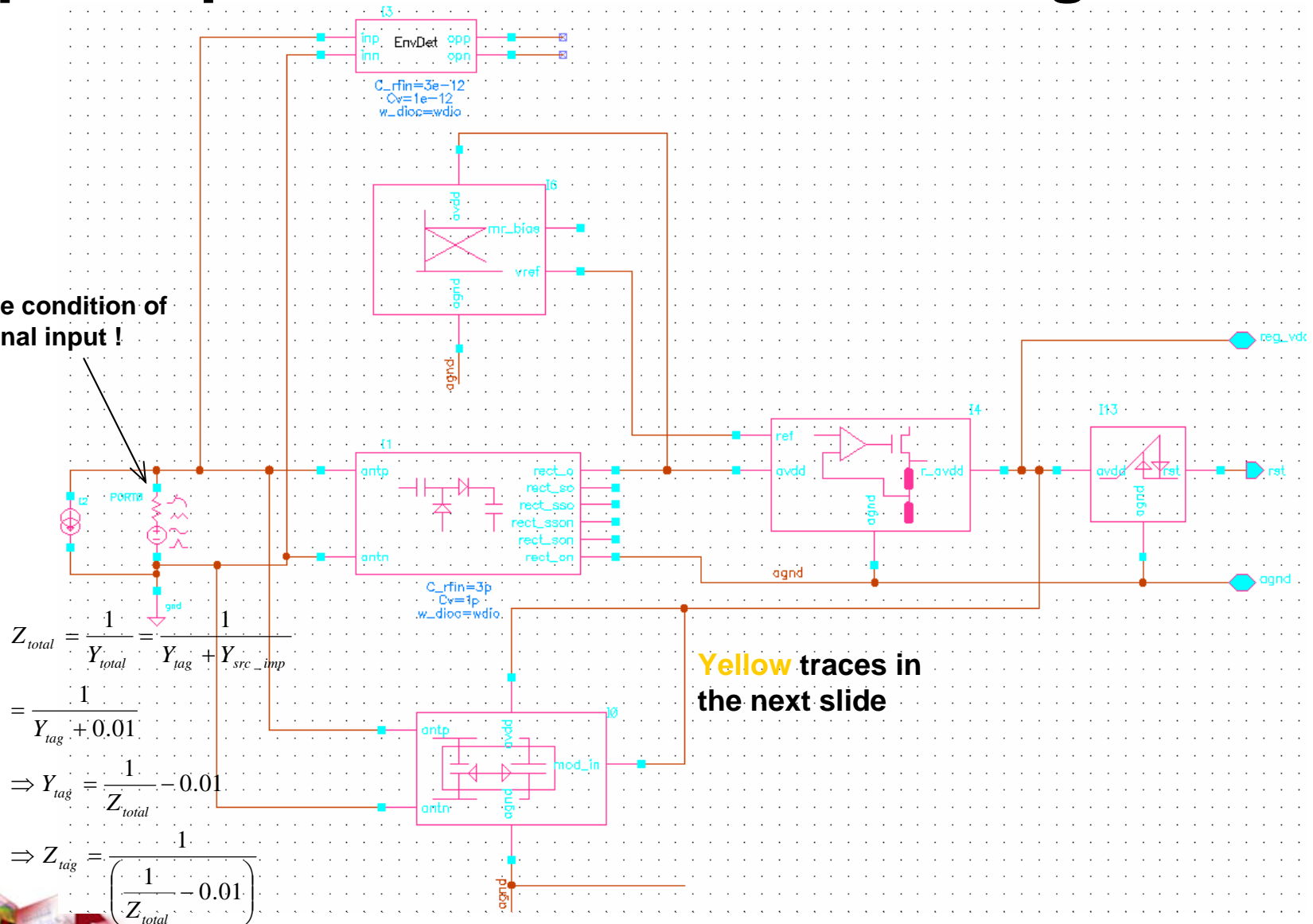


# Tag's Overall Radio Simulation and Verification

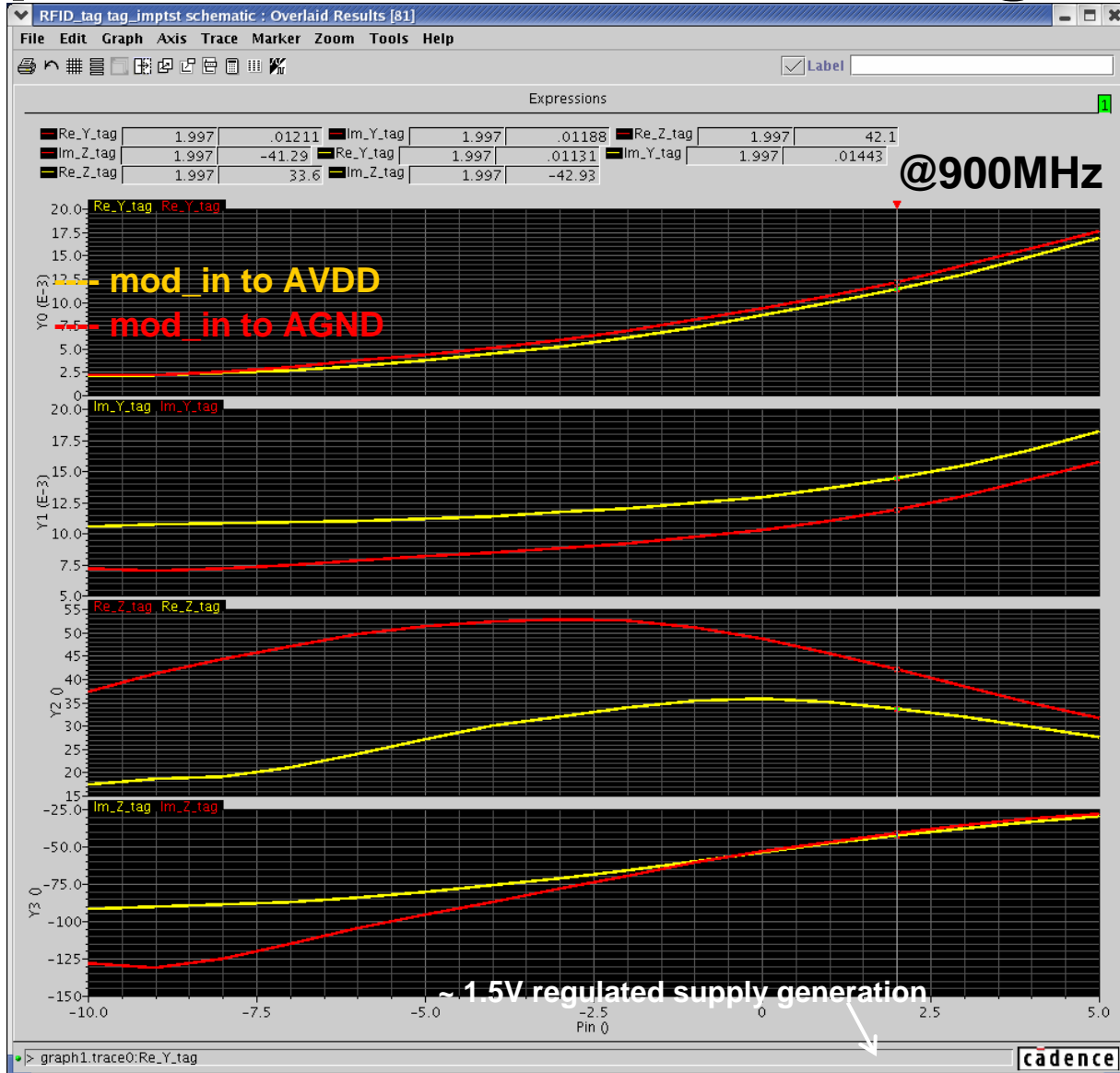


# Input Impedance Simulation for Tag's Radio

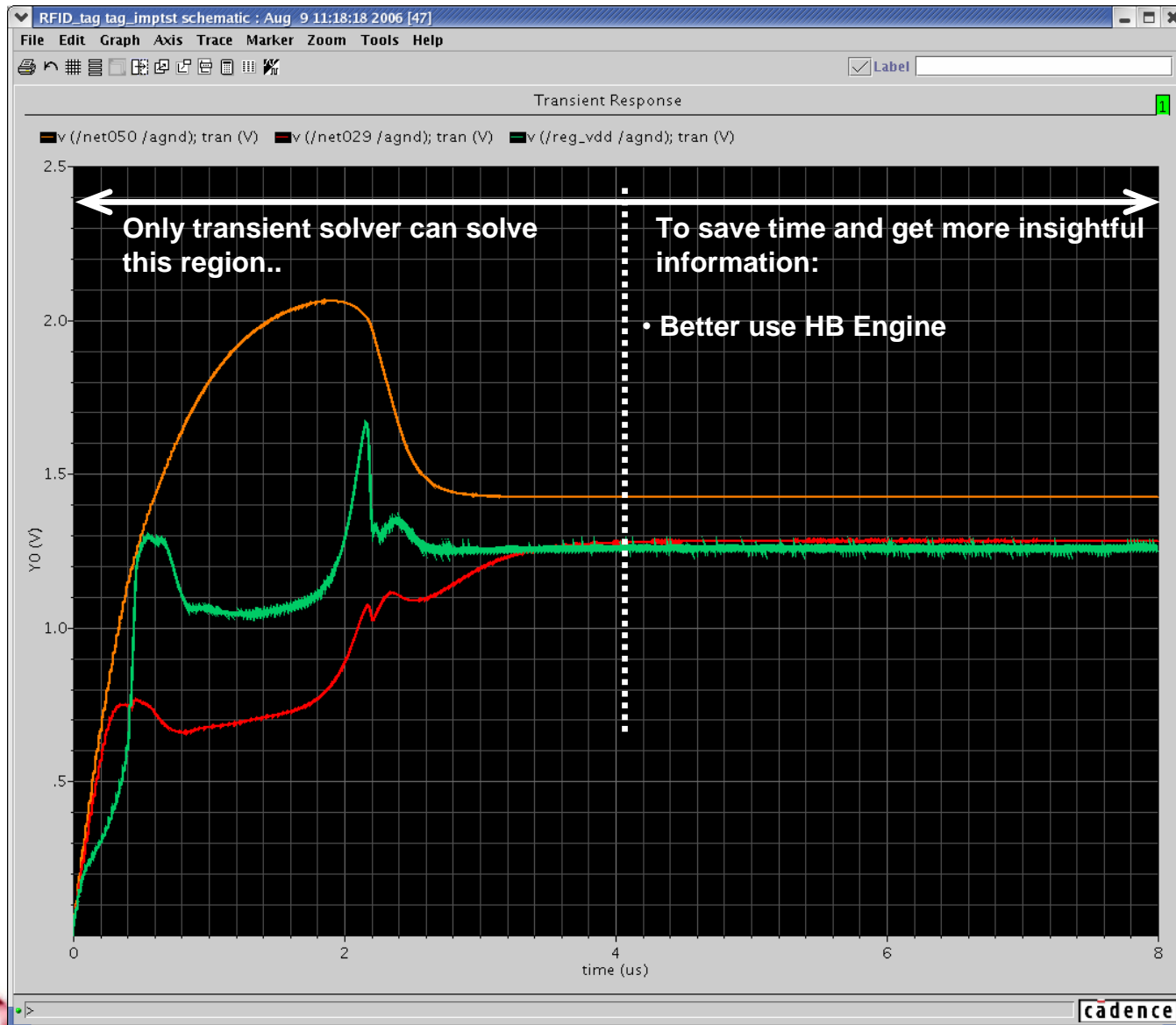
Under the condition of large signal input !



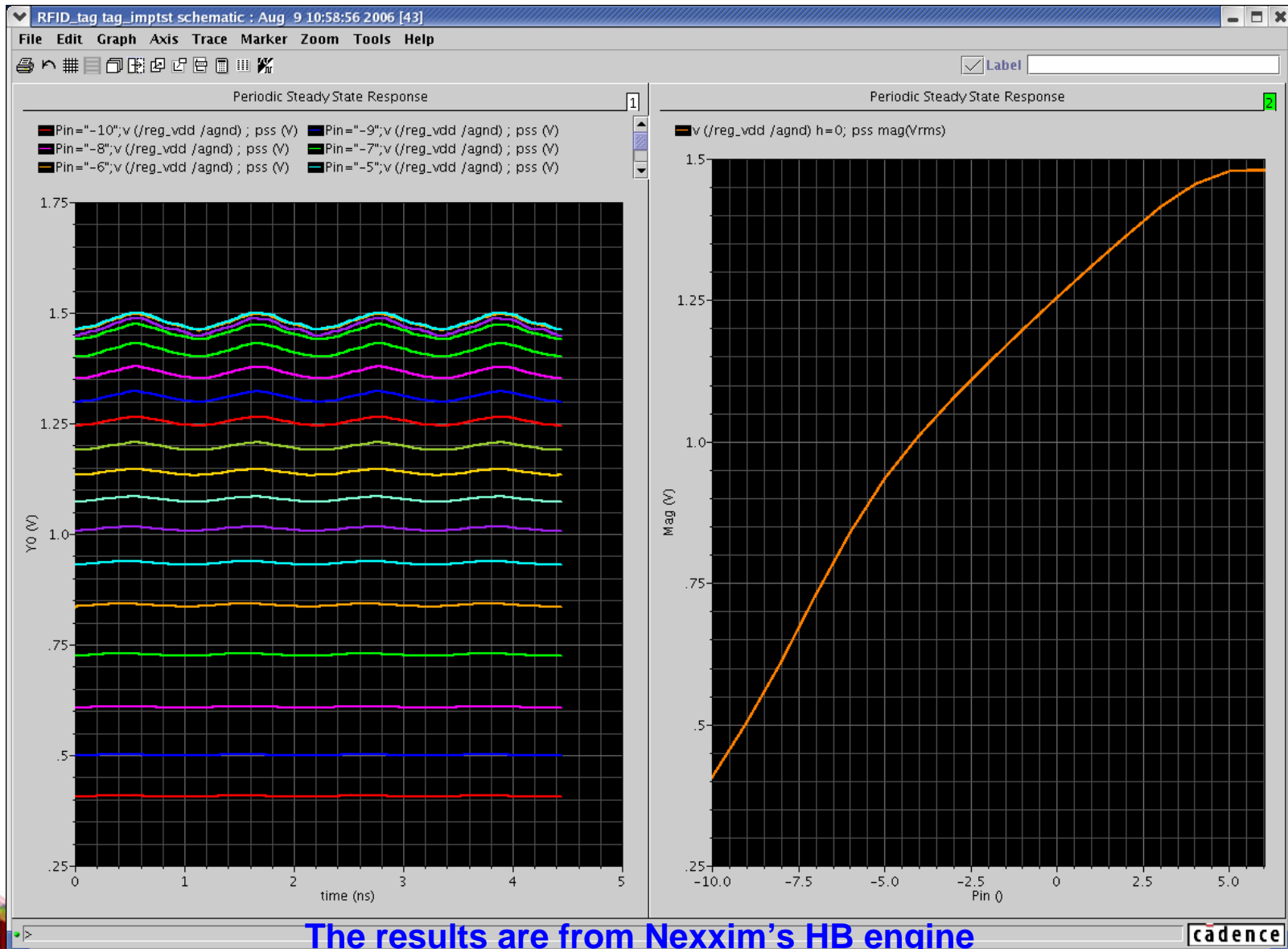
# Input Impedance Simulation for Tag's Radio



# Continuous Wave (CW) Input (Transient)



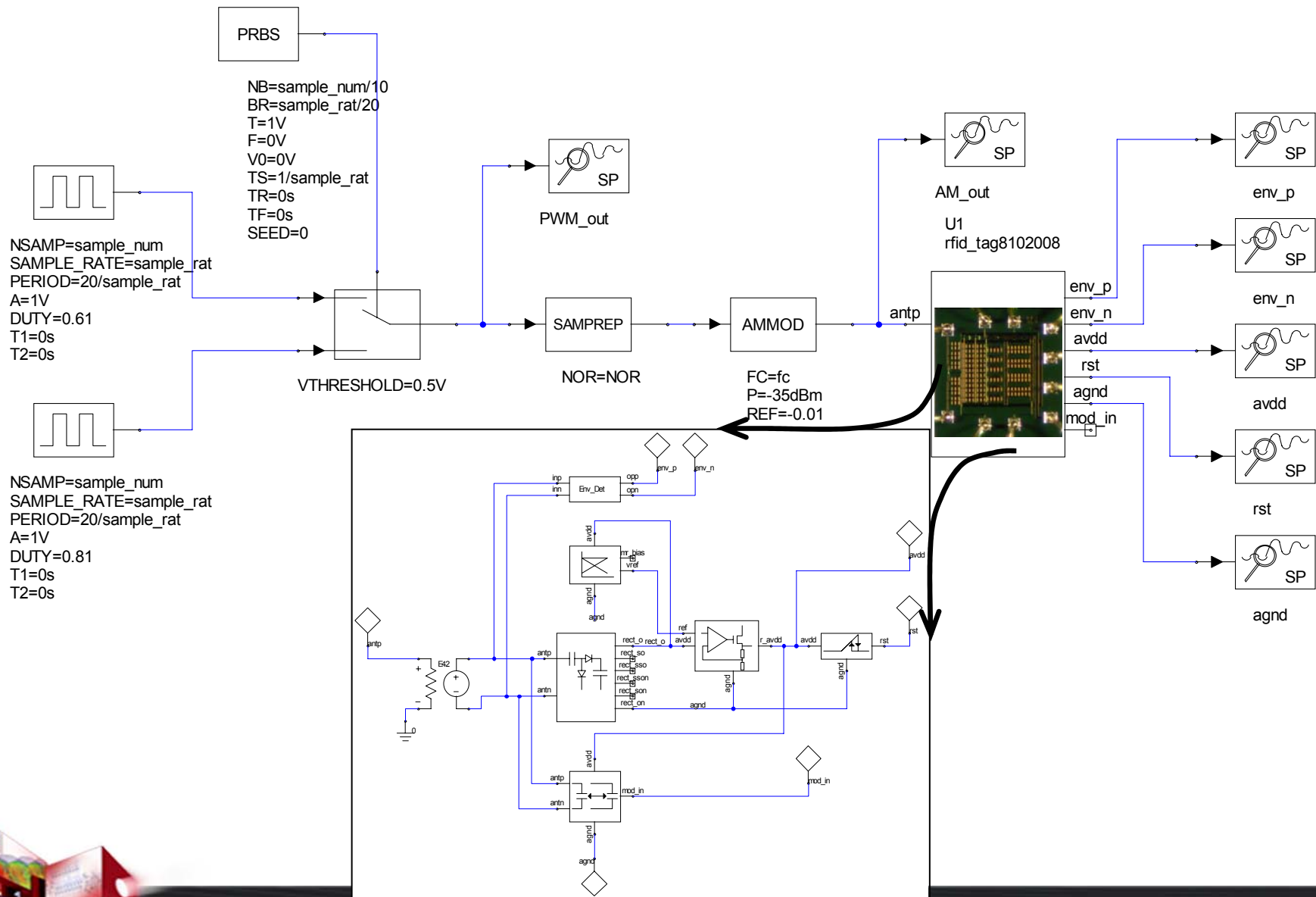
# Continuous Wave (CW) Input (Harmonic Balanced: HB)



The results are from Nexxim's HB engine

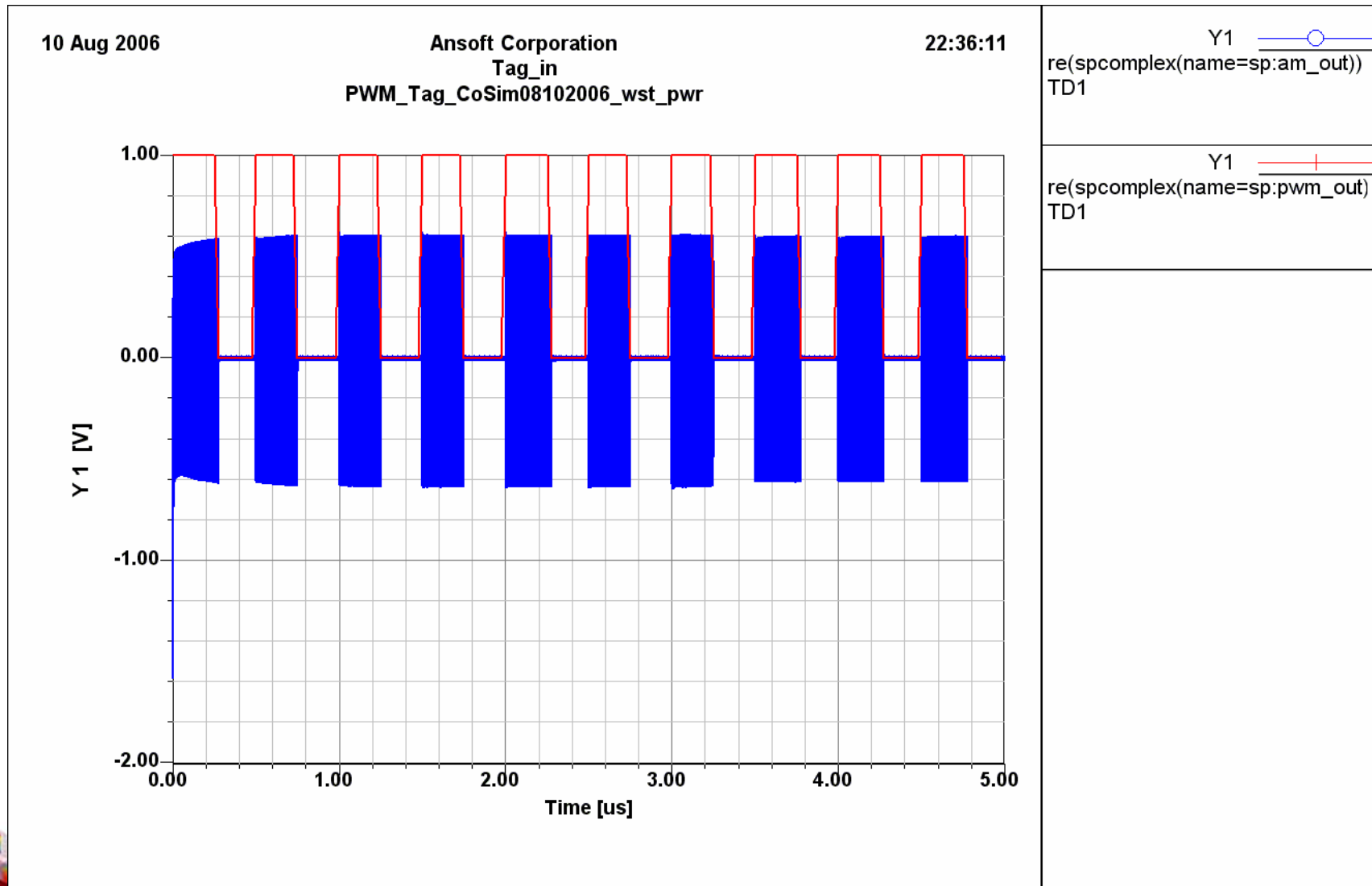
cadence

# System/Nexxim Co-simulation



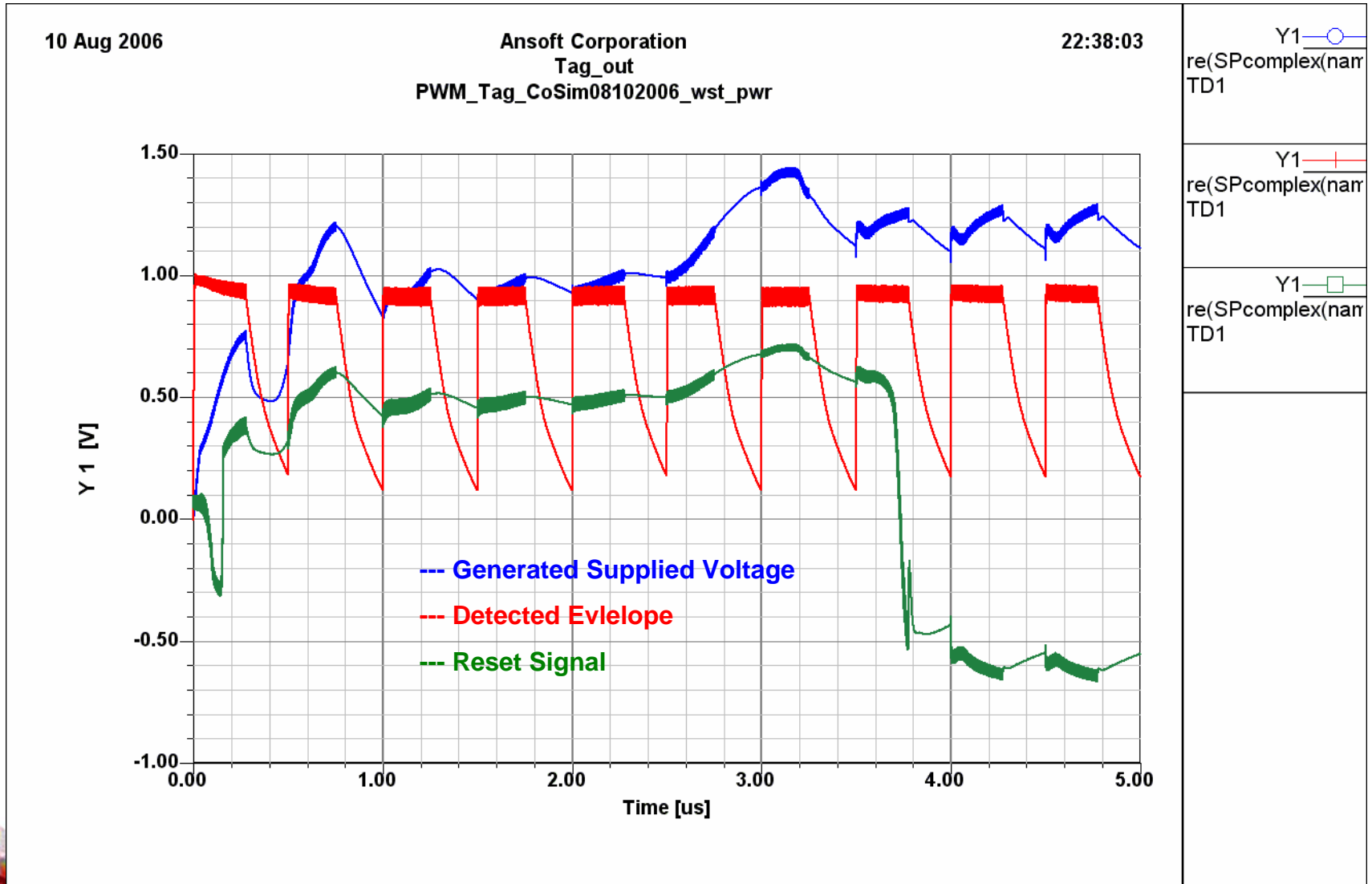
# System/Nexxim Co-simulation

Worst case for supplied voltage generation duty cycle = 47.5%



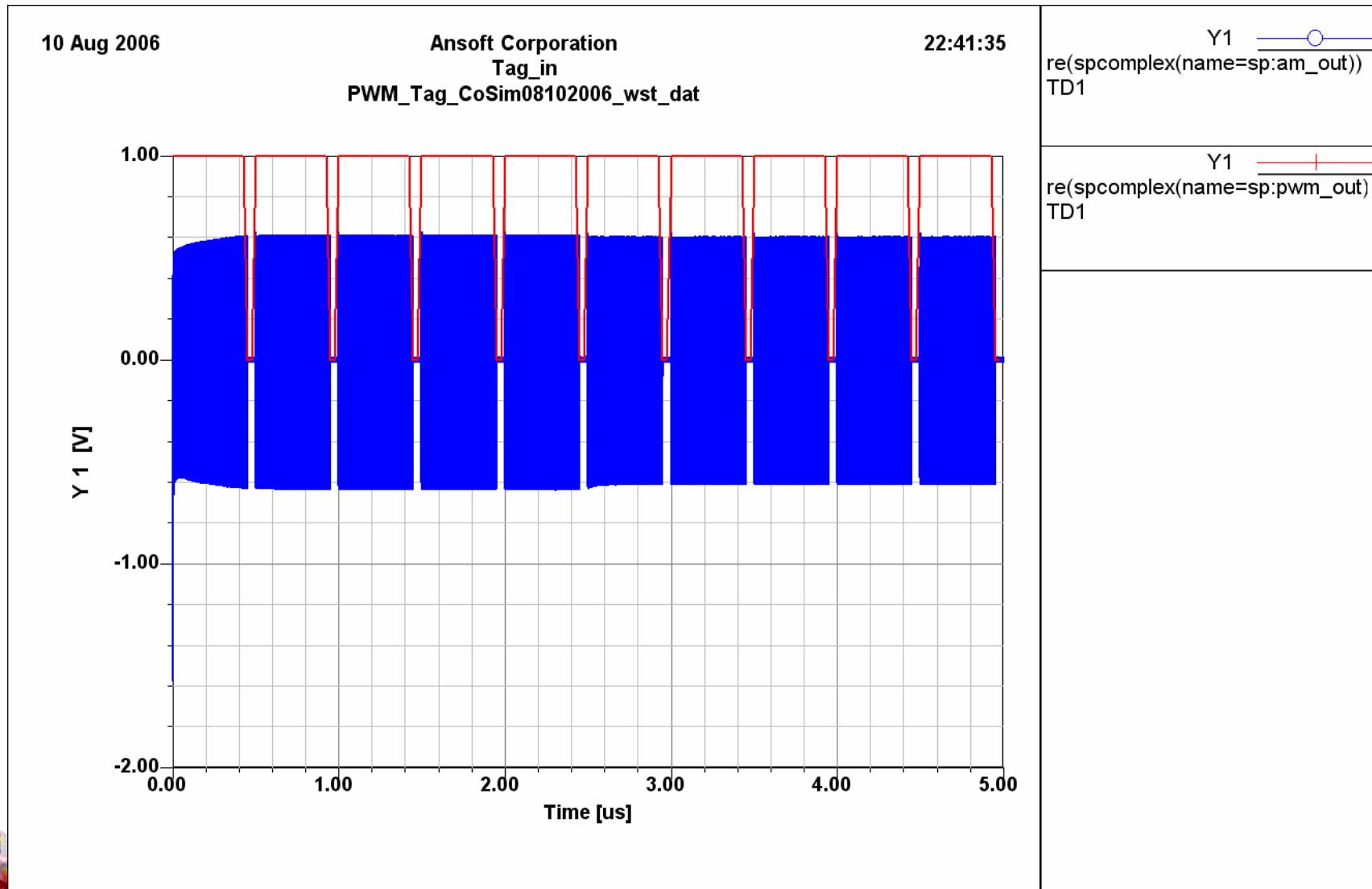
# System/Nexxim Co-simulation

Worst case for supplied voltage generation duty cycle = 47.5%



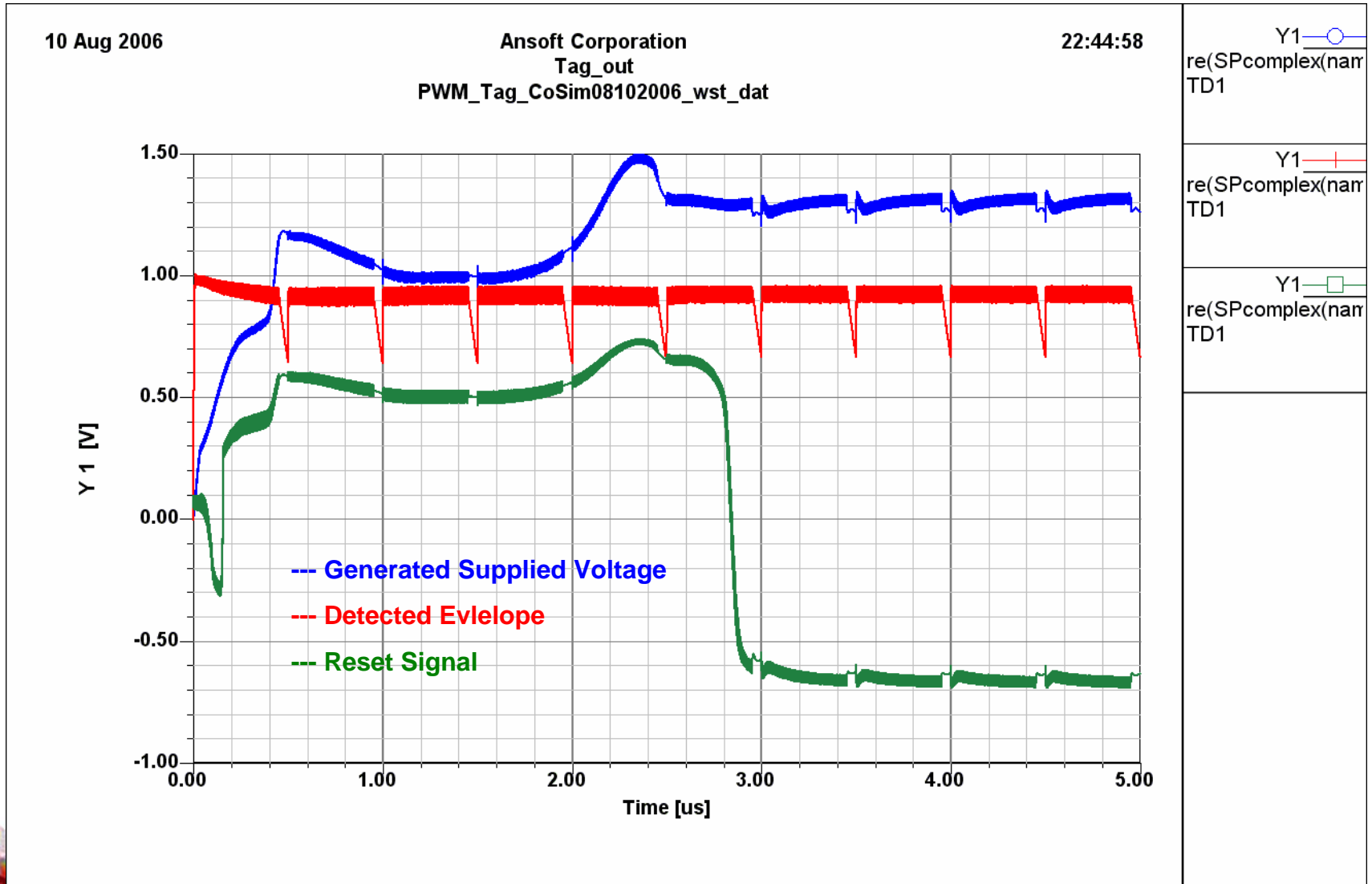
# System/Nexxim Co-simulation

Worst case for envelope detection: duty cycle = 13.25%



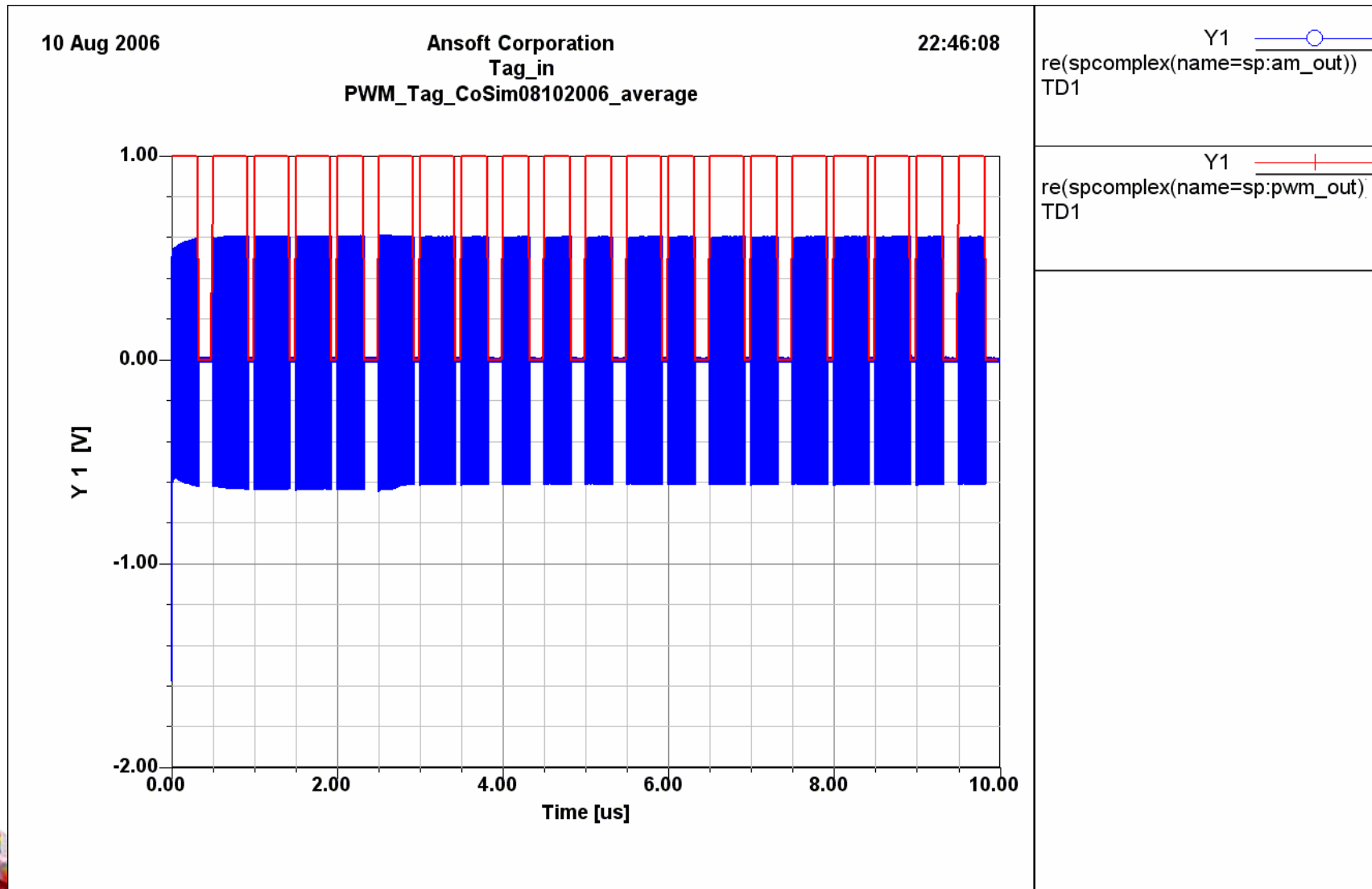
# System/Nexxim Co-simulation

Worst case for envelope detection: duty cycle = 13.25%



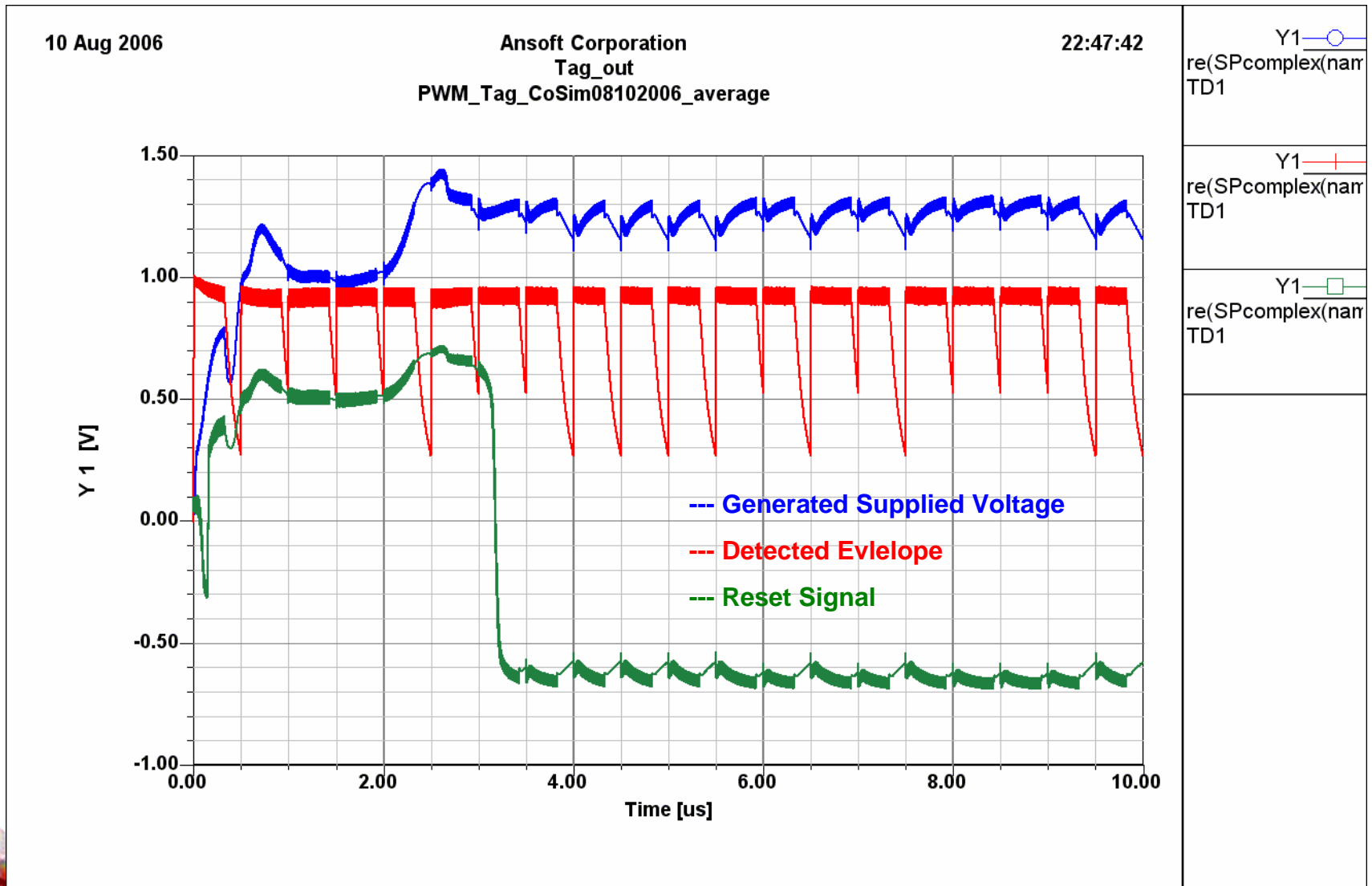
# System/Nexxim Co-simulation

Typical case:  $RT_{cal} = 2.75 \cdot T_{ari}$ ,  $PW = 0.4 \cdot T_{ari} \rightarrow$  Average duty cycle = 71%



# System/Nexxim Co-simulation

Typical case:  $RT_{cal} = 2.75 \cdot T_{ari}$ ,  $PW = 0.4 \cdot T_{ari} \rightarrow$  Average duty cycle = 71%



# UHF RFID Antenna Design and Simulation





# 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 ( $0 \leq \tau < 1$ )

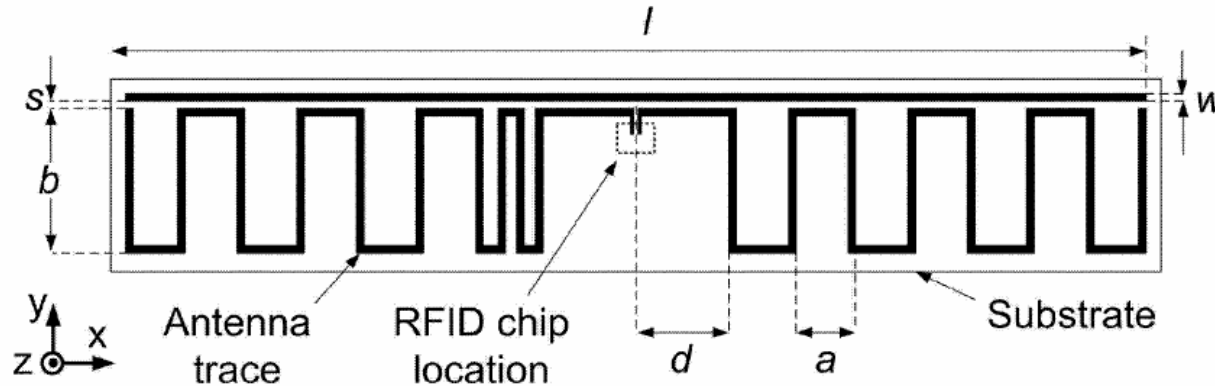
$$\tau = \frac{4R_c R_a}{|Z_c + Z_a|^2} \quad \text{Mismatch Factor}$$

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

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

**Goal: maximize power absorption by designing tag antenna impedance that resonates with chip impedance**

# Simulation and Optimization



Note: This antenna was designed for  $Z_a = 16 + j 350 \Omega$

## Dimensions Taken From Reference Paper

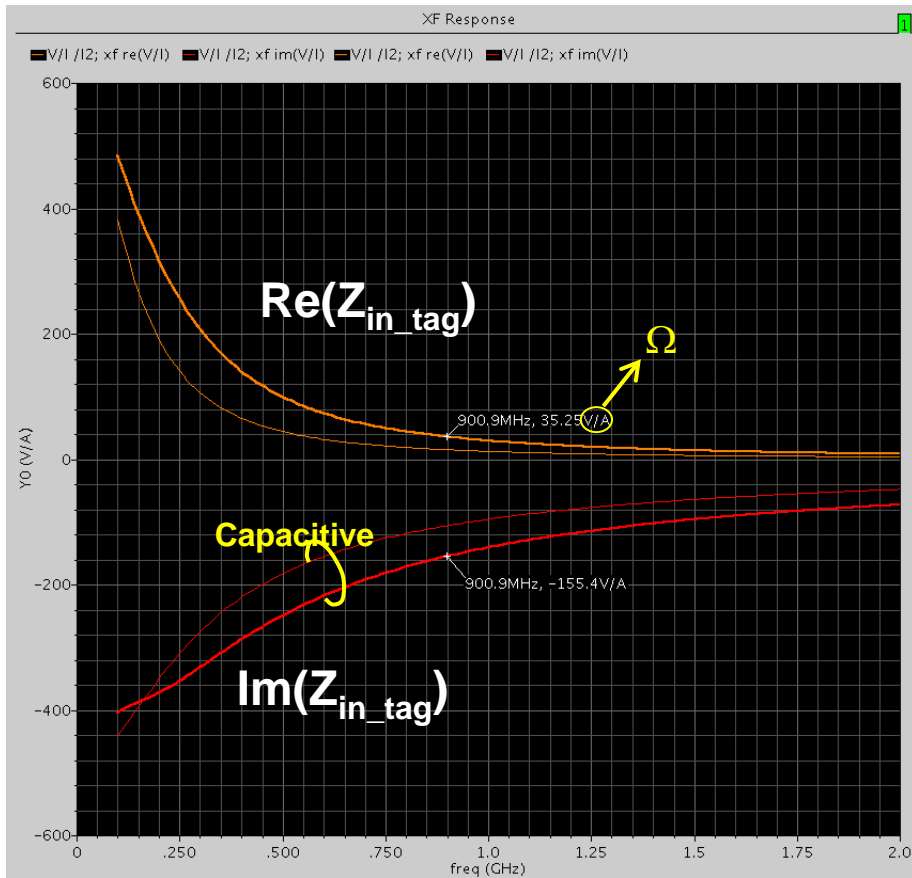
PARAMETERS OF THE LOADED MEANDER TAG ANTENNA (mm)

Parameters	$l$	$w$	$s$	$d$	$a$	$b$	$t_s$	$t_a$
Values	96	0.7	0.7	9	6	14	0.051	0.018

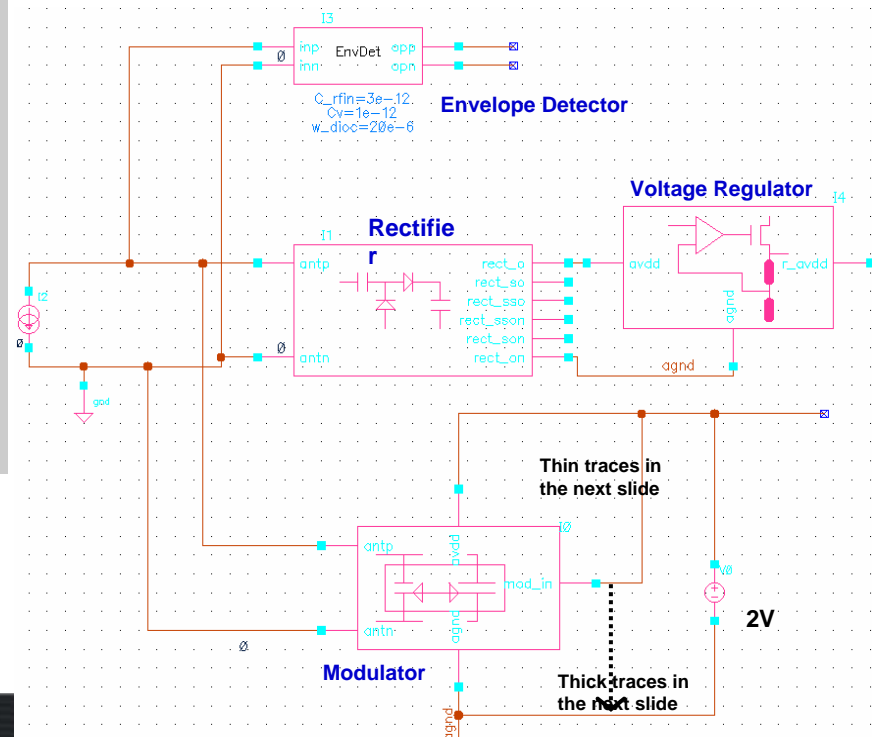
Adjust parameters  $l$ ,  $w$ ,  $s$ ,  $d$ ,  $a$ ,  $b$  to achieve desired antenna input impedance



# Target Impedance From Circuit Simulation



Small signal chip impedance is  $Z_c = 35 - j 155 \Omega$



# Simulation in Ansoft Designer

**Loading Bar Reduces Resistance**

**Provides inductive reactance**

Name	Value	Unit	Evaluated Value
L	100	mm	100mm
w	0.7	mm	0.7mm
s	1.2	mm	1.2mm
b	14	mm	14mm
a	L/20		5mm

**Optimize to Match Target Impedance**

RFID1 (C:\Ansoft\_Projects\)  
 PlanarEM2  
 PlanarEM3  
 PlanarEM4

Edges do not define a valid port (8:27 PM Aug 20, 2006)  
 Edges do not define a valid port (8:27 PM Aug 20, 2006)  
 Optimization Analysis on OptimizationSetup1 has been started (8:34 PM Aug 20, 2006)  
 A variation (a=3mm b=14mm L=50mm s=0.7mm w=0.7mm) has been requested (8:34 PM Aug 20, 2006)  
 Number of triangles: 702 Number of rectangles: 523 (8:34 PM Aug 20, 2006)  
 Average minimum triangle angle: 26.3 Minimum triangle angle: 3.09 (8:34 PM Aug 20, 2006)  
 Number of edges: 2419 Number of internal edges: 1779 (8:34 PM Aug 20, 2006)  
 Average edge length: 0.000985 Maximum edge length: 0.0048 Maximum/Average: 4.9 (8:34 PM Aug 20, 2006)  
 Number of non-planar (3D) elements: 0 (8:34 PM Aug 20, 2006)

PlanarEM3 Optimization Analysis on Local Machine - RUNNING  
 Solving a=5mm b=14.014216689849mm L=100mm s=0.7mm w=0.7mm  
 PlanarEM3: Fast Frequency Sweep on Local Machine - RUNNING  
 Freq. #3: 910.000000 MHz Matrix Solution

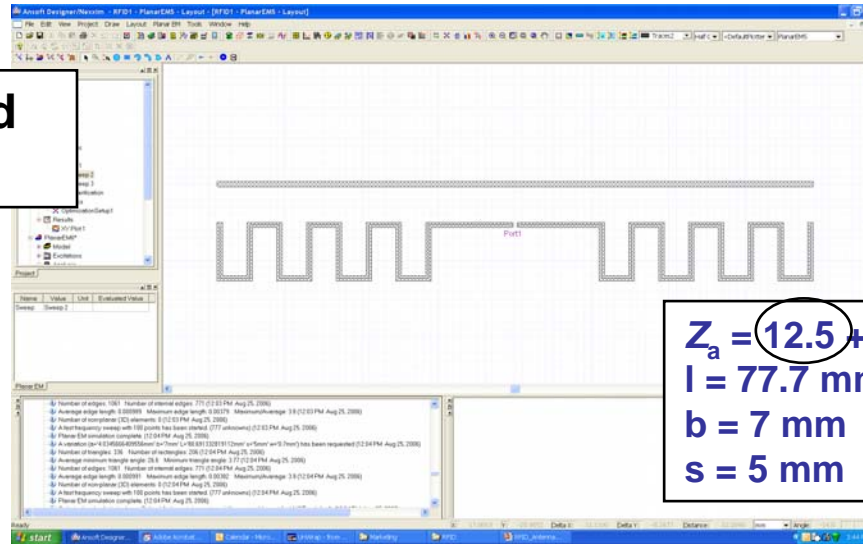


# Results

## Goal

Small signal chip impedance is  $Z_c = 35 - j 155 \Omega$

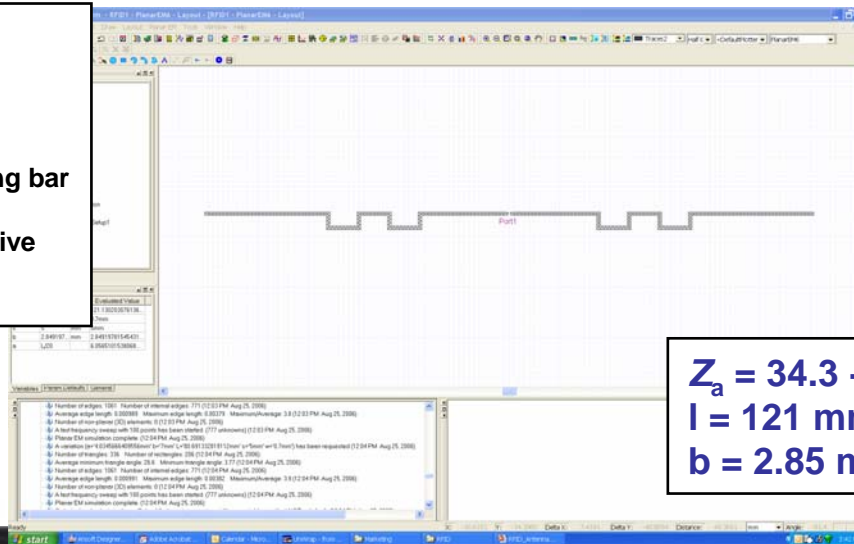
Optimized Result



New Design

Removed loading bar

Reduced inductive meanders



Meets goal but larger in size

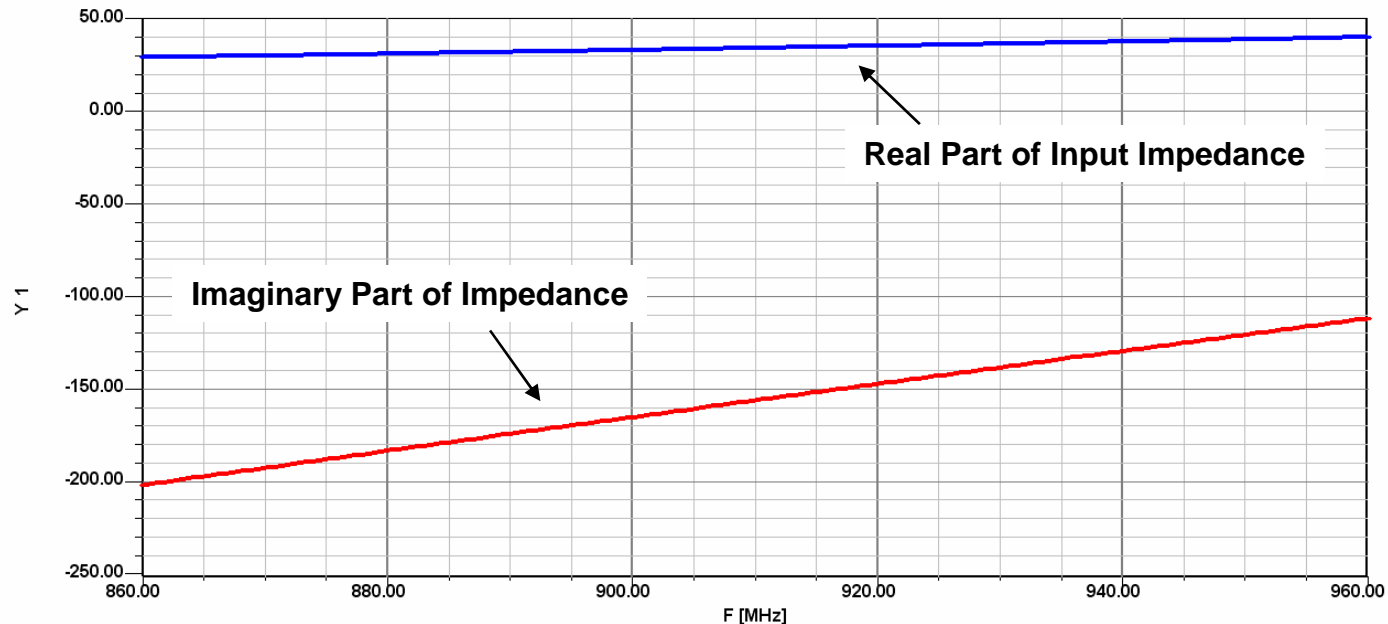


# Swept Frequency Performance

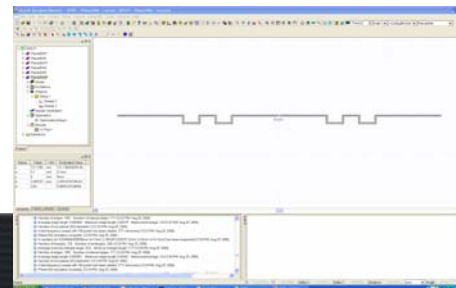
25 Aug 2006

Ansoft Corporation  
XY Plot 1  
PlanarEM6

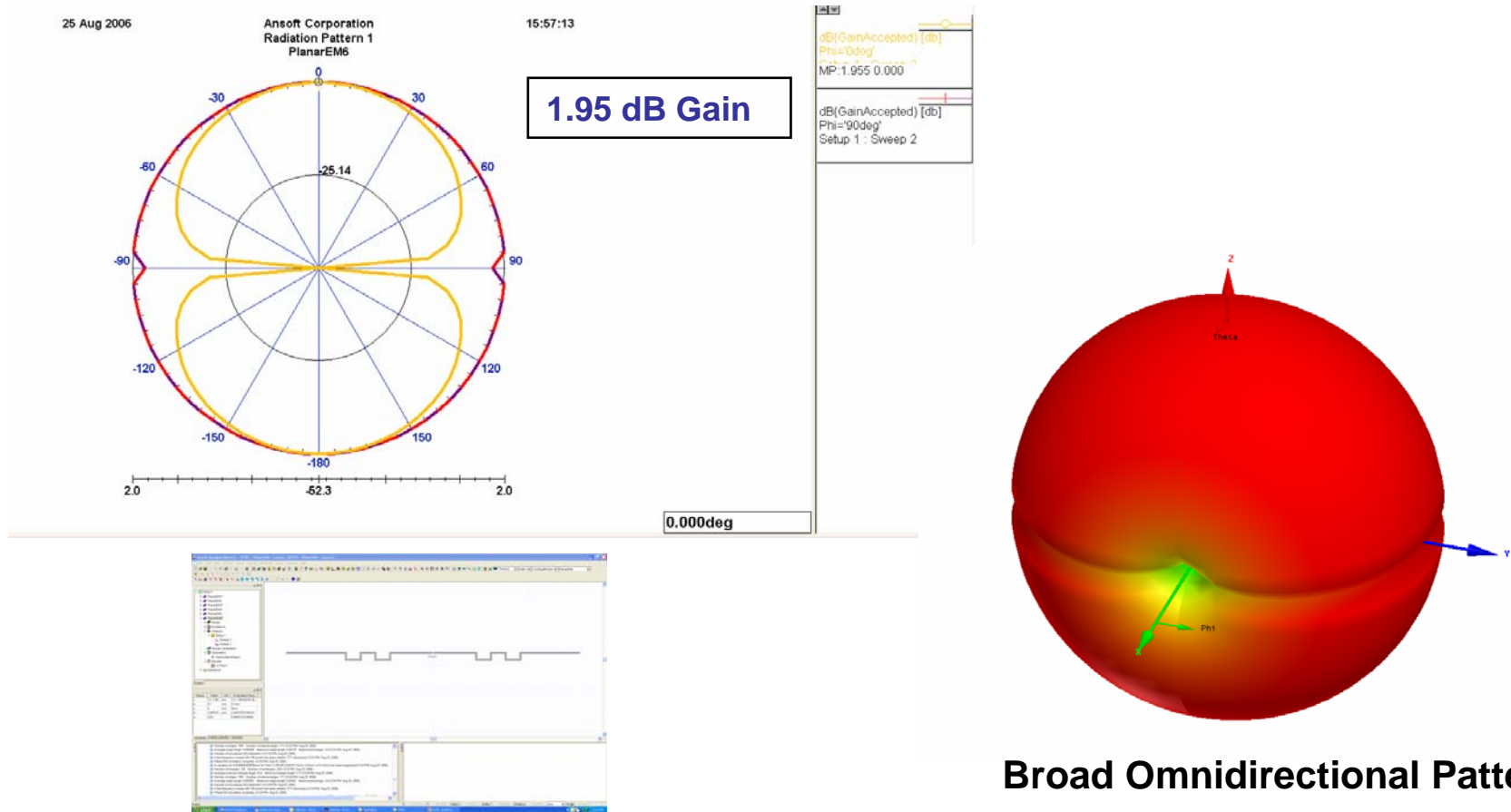
16:13:26



Antenna design provides relatively flat response across UHF RFID band



# Far-field Radiation Performance



# 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!



*LeadingInsight*

Application Workshops for High-Performance Design

# Appendix: Entry for Nexxim/Cadence Integration

The image shows two overlapping windows from the Virtuoso Analog Design Environment. The background window is titled "Virtuoso® Analog Design Environment (1)" and shows a simulation setup for "UWB\_ckt" using the "spectre" simulator. The foreground window is titled "Nexxim Simulator Control" and contains the following sections:

- Select Simulator:** Radio buttons for "Nexxim" (selected) and "Spectre".
- Nexxim Logging Control:** Radio buttons for "Off" (selected) and "On".
- Pre-Process Netlist:** An "Edit Netlist" checkbox.
- Harmonic Balance:** Radio buttons for "Single" and "Multi".
- Fundamental Tones:** A text field containing "3.5G".
- No. of Harmonics:** A text field containing "10".

On the right side of the foreground window, there is a vertical toolbar with several icons. A red box highlights the "Netlist & Run" icon (a traffic light with the green light lit). A red arrow points from the "NEXXIM" label in the top right corner of the foreground window to this icon. A black arrow points from the "Tools" menu in the background window to the "Nexxim ..." option.

The background window's "Tools" menu is open, showing options such as "Parametric Analysis ...", "Comers ...", "Monte Carlo ...", "Optimization ...", "RF", "Calculator ...", "Results Browser ...", "Waveform ...", "Results Display ...", "Job Monitor ...", and "Nexxim ...".

The text "Netlist & Run" is written in black next to the highlighted icon in the toolbar.