A BiCMOS Ultra-Wideband 3.1-10.6GHz Front-End

Fred S. Lee and Anantha P. Chandrakasan

Massachusetts Institute of Technology

Cambridge, MA

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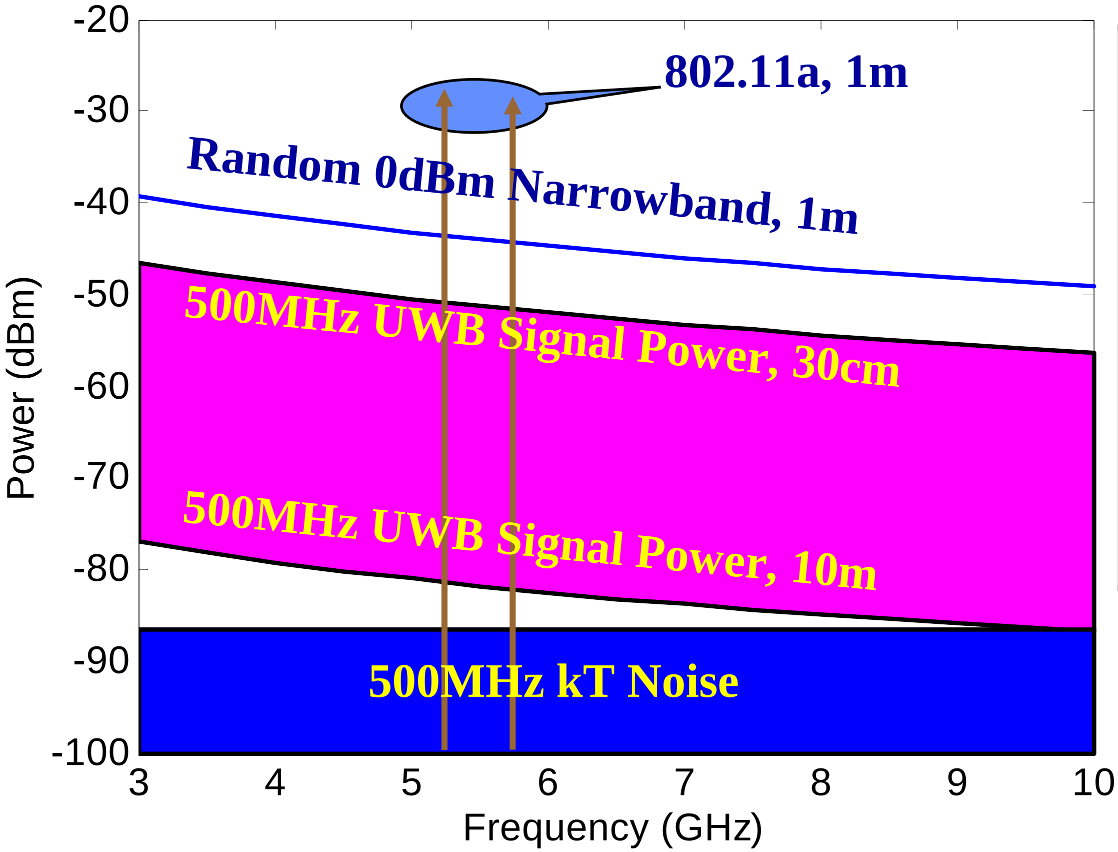
Outline

- UWB Wireless Channel Characteristics
- Receiver Architecture
  - Matching
  - Single-to-Differential Converter w/Notch
- Circuit Design
- Measurement Results
- Conclusions

UWB Wireless Channel Characteristics



Signals	Power @ TX	TX-RX Distance	Power @ RX	V_{ampl} @ RX
500MHz UWB @ 3.35GHz	-14dBm	30cm	-47dBm	2.6mV
500MHz UWB @ 10.35GHz	-14dBm	10m	-87dBm	26µV
802.11a @ 5.25GHz	15 dBm	1m	-29dBm	10mV
Random @ 3.1GHz	0 dBm	1m	-39dBm	3.2mV

S. Ghassemzadeh, et al., "UWB indoor path loss model for residential and commercial buildings," VTC 2003

Design Specifications

Noise Figure

NF < 4.5 dB

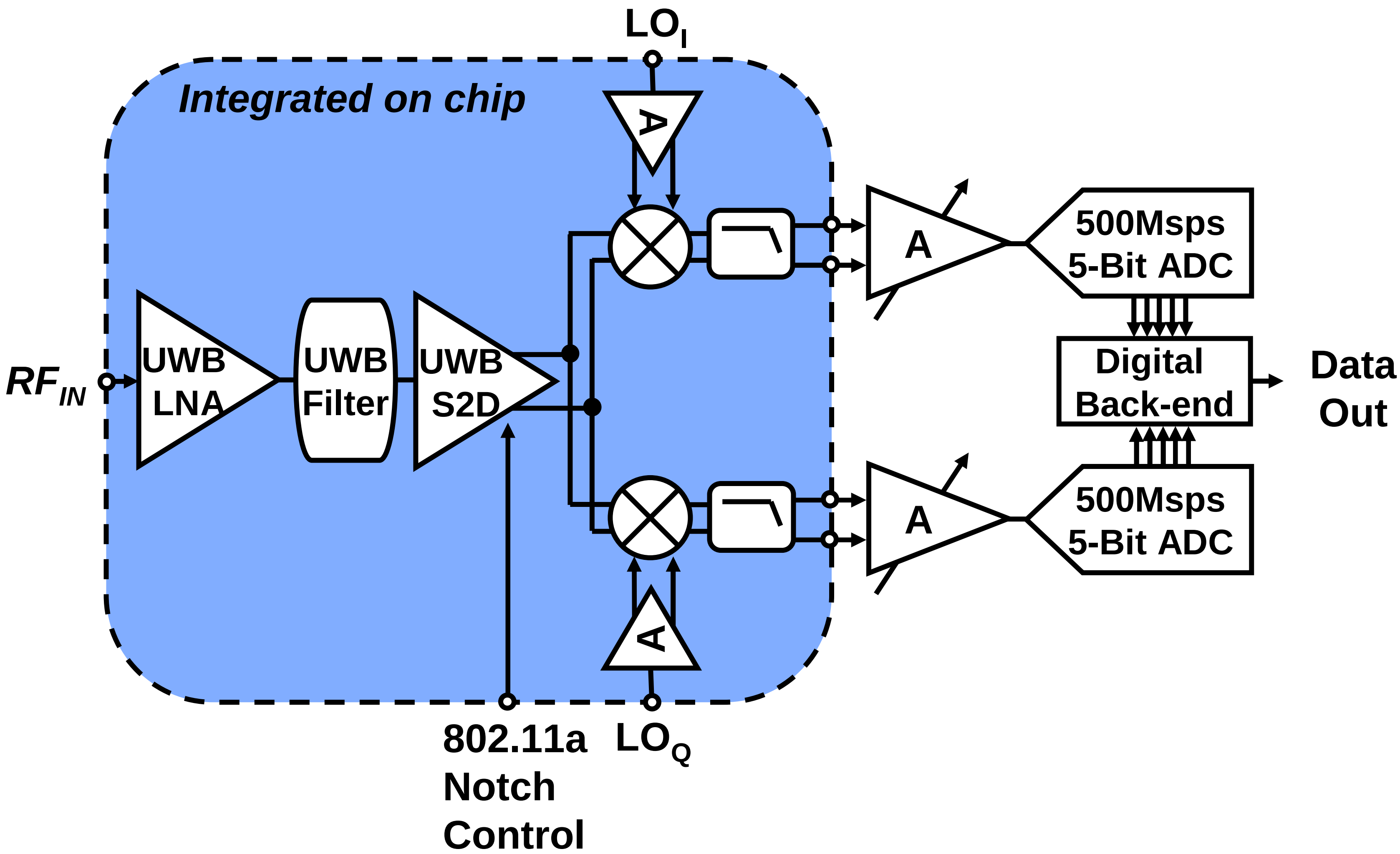
Dynamic Range

For +/-200mV ADC input range, minimum gain = 32dB

Linearity

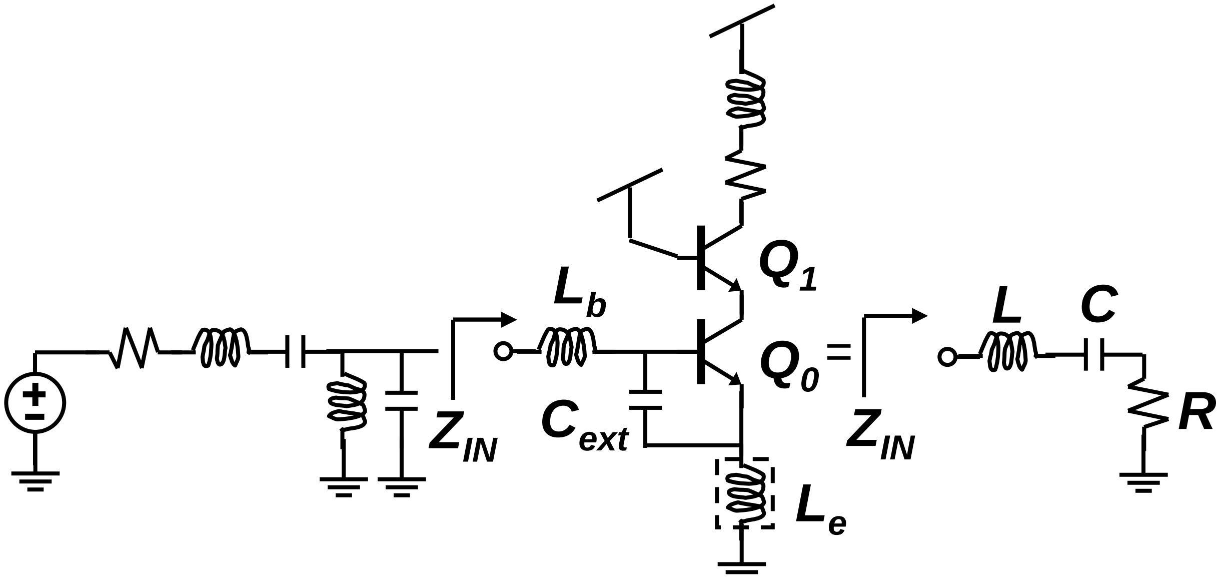
P1dB > -30dBm

Receiver Architecture



Wideband LNA – Ladder Matching

Wideband LNA – ladder match (Ismail, et al., "A 3-10GHz low-noise amplifier with wideband LC-ladder matching network," JSSC 2004)



$$L = L_b + L_e$$

$$R = \frac{g_m L_e}{C} = 2\pi f_t L_e$$

$$C = C_\pi + C_\mu + C_{ext}$$

$$g_m = 0.067 \qquad C_\pi = 170\ fF$$

Achieves close to NF_{min} for NF and power match

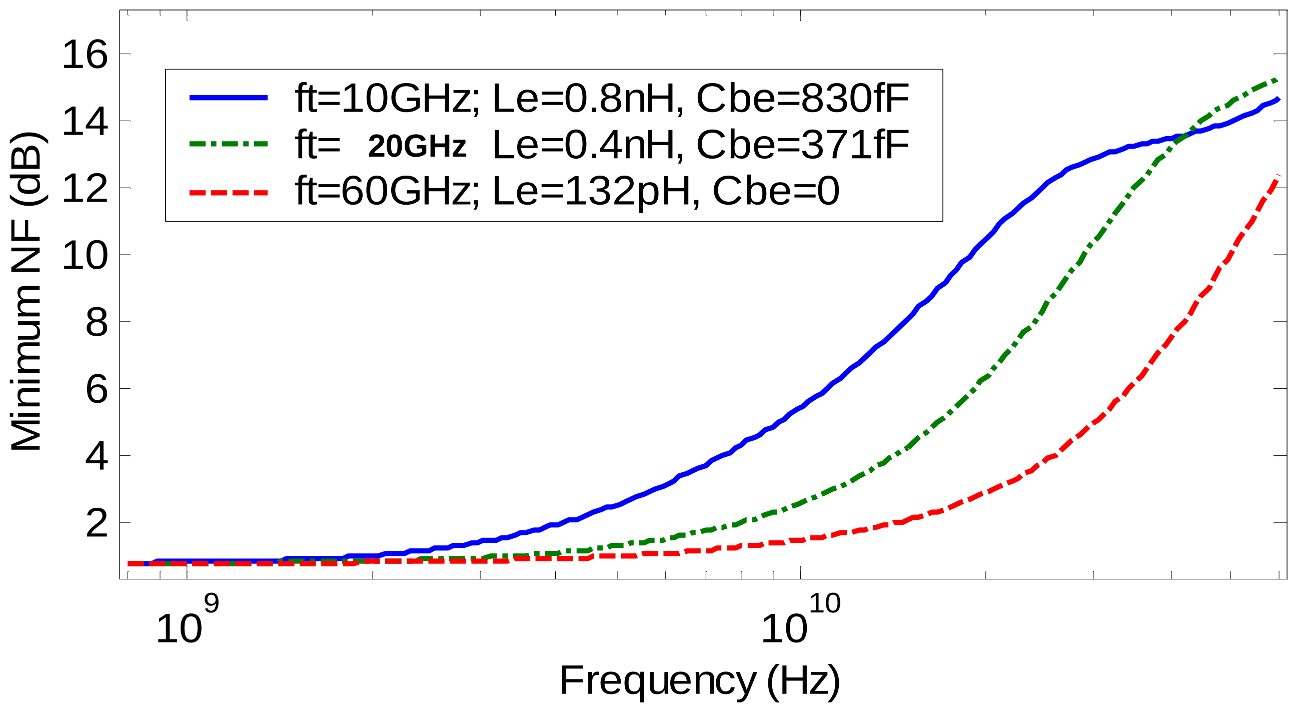
R formed by $g_m L_e / C$, and other LC components keep S_{11} within -10dB across the bandwidth of interest

Wideband LNA – NF_{min} and f_t Tradeoff

NF_{min} equation: $$NF_{\min} = 1 + \frac{1}{\beta} + \sqrt{2 g_m r_B}\sqrt{\frac{1}{\beta} + \left(\frac{f}{f_t}\right)^2}$$

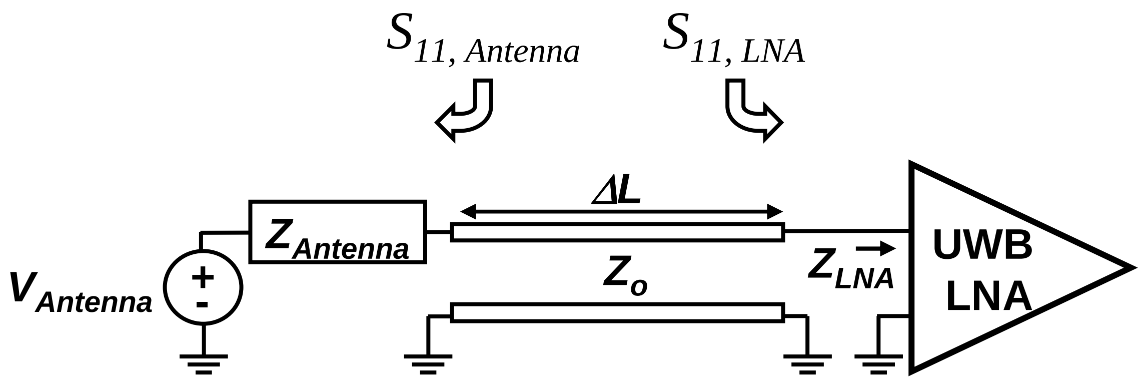
To keep $R = \frac{g_m L_e}{C} = 2\pi f_t L_e$ **constant with L_e ⇧, C_{ext} of C must ⇧ to ⇩ f_t.**

With f_t ⇩, R is constant, but NF_{min} ⇧ !



Operate LNA at high f_t to minimize NF_{min} and noise match at 10GHz

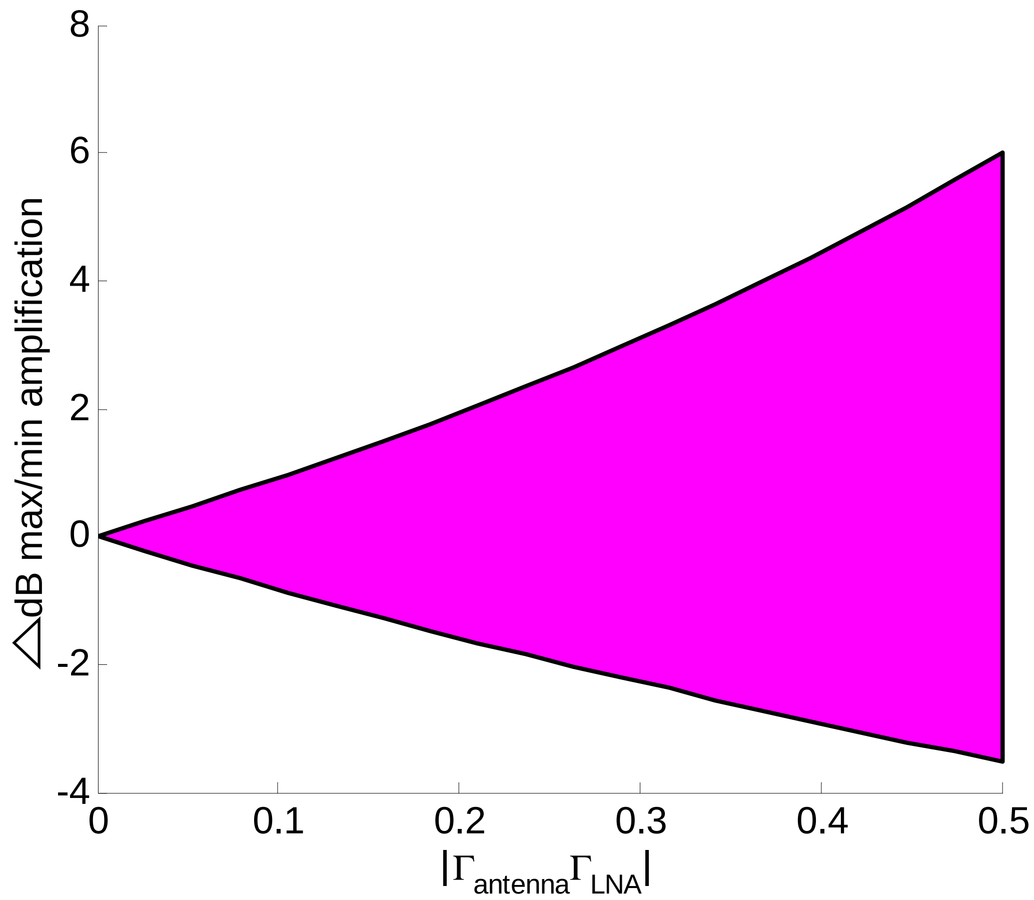
Reflections in Un-Matched Environment



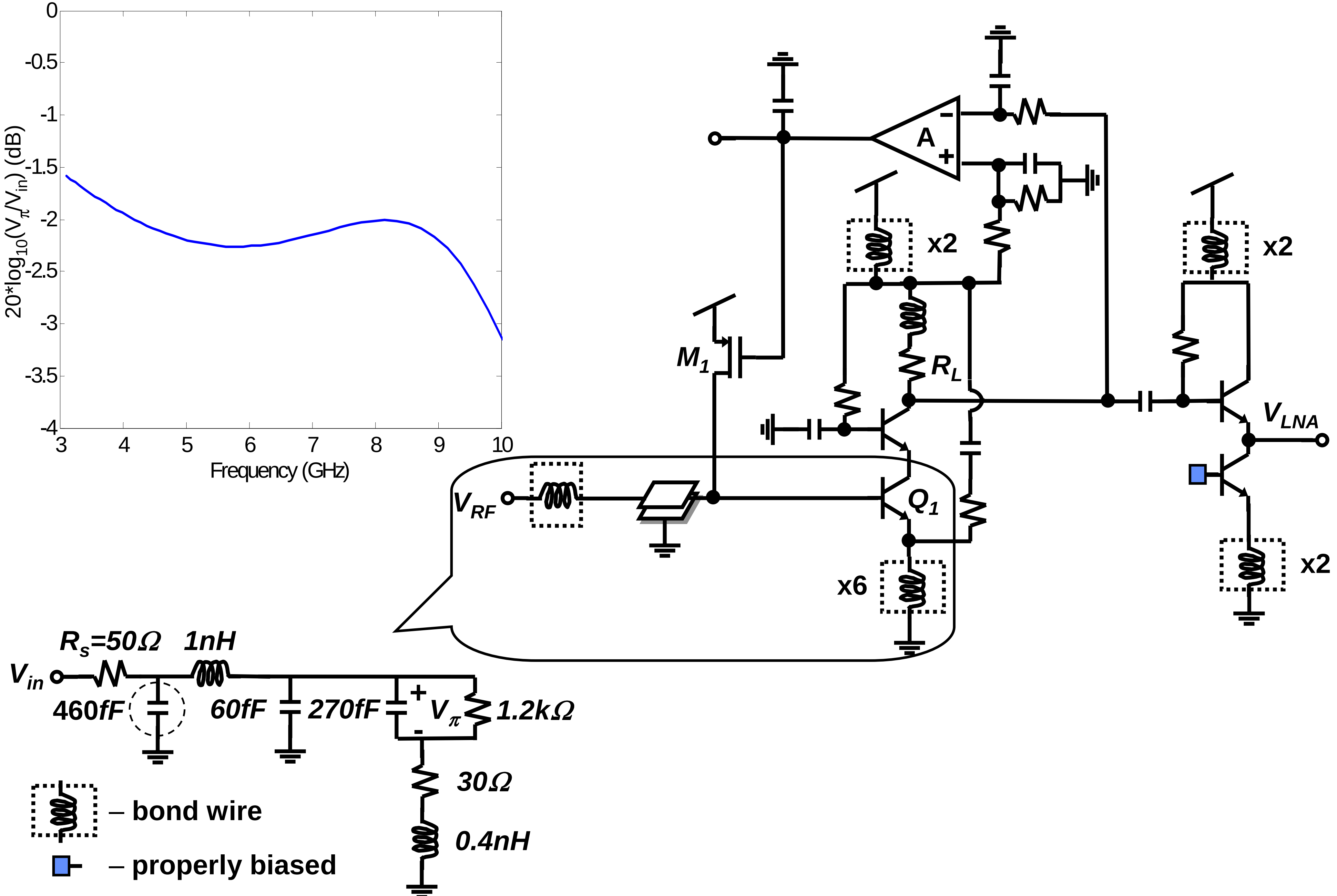
$$A_{max} = \left(1 - L^2 \left|S_{11,Antenna}\right|\left|S_{11,LNA}\right|\right)^{-1}$$

$$A_{min} = \left(1 + L^2 \left|S_{11,Antenna}\right|\left|S_{11,LNA}\right|\right)^{-1}$$

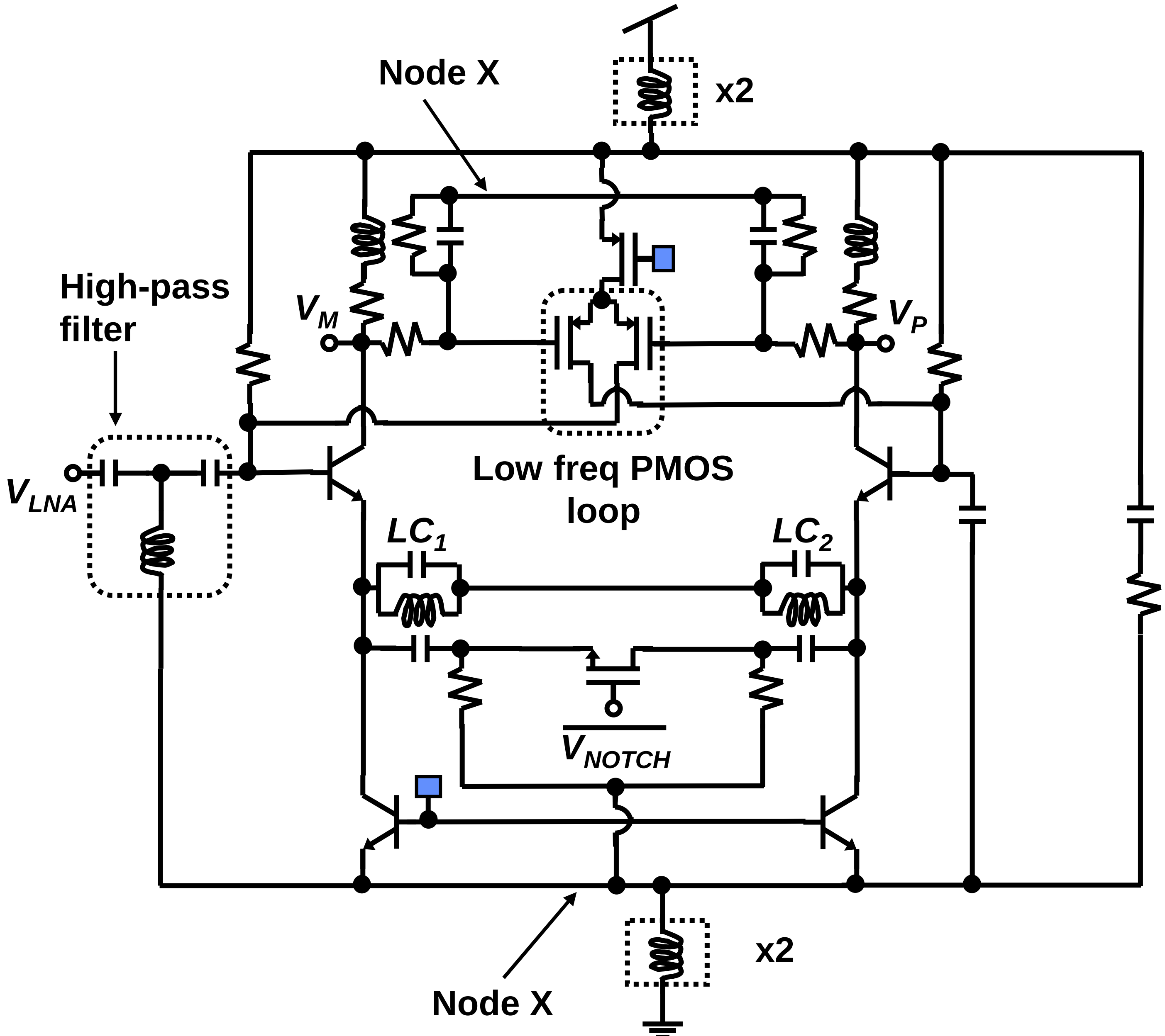
L is loss; if L = 1, TX line is lossless



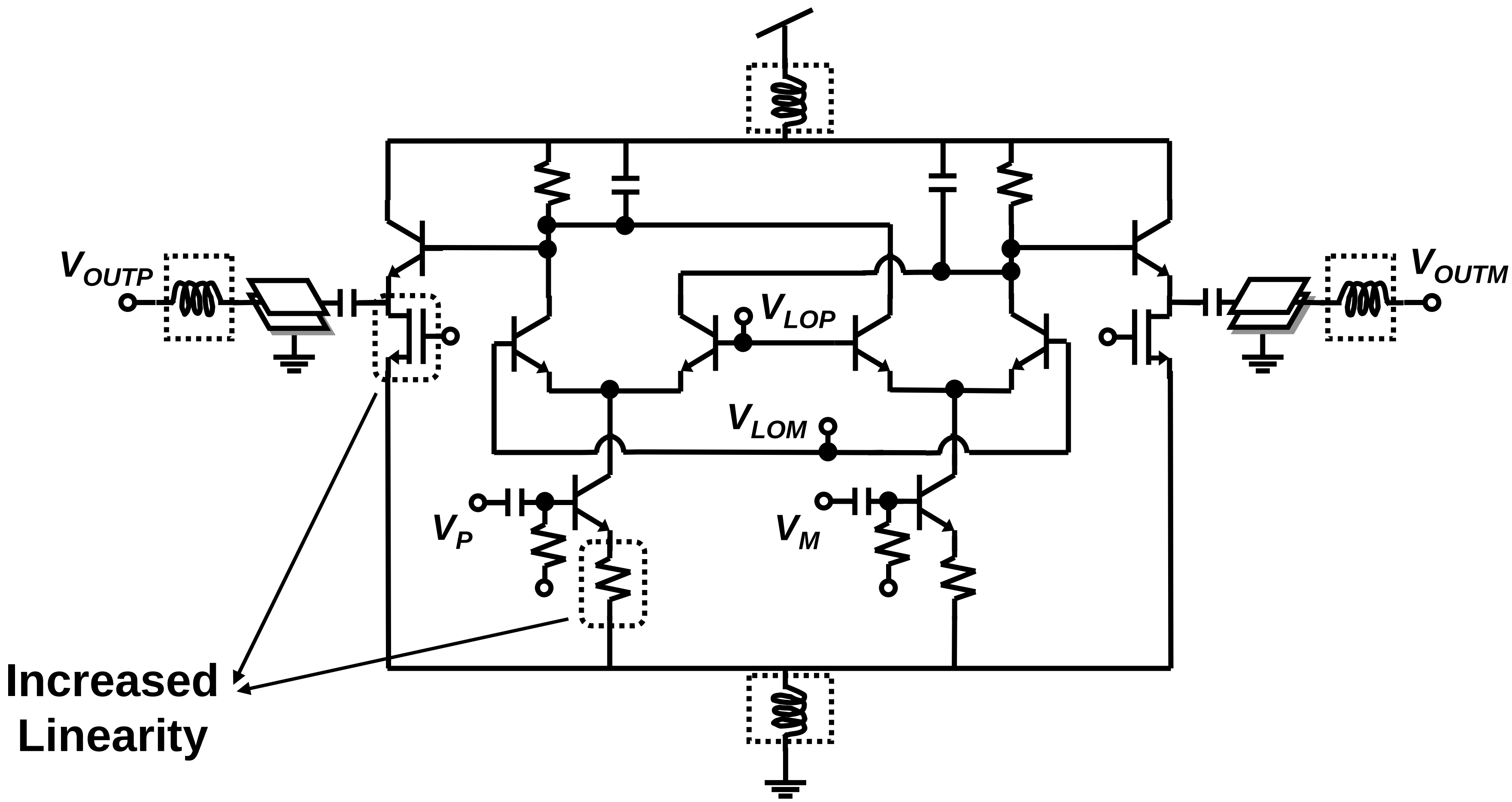
Circuits – LNA Schematic



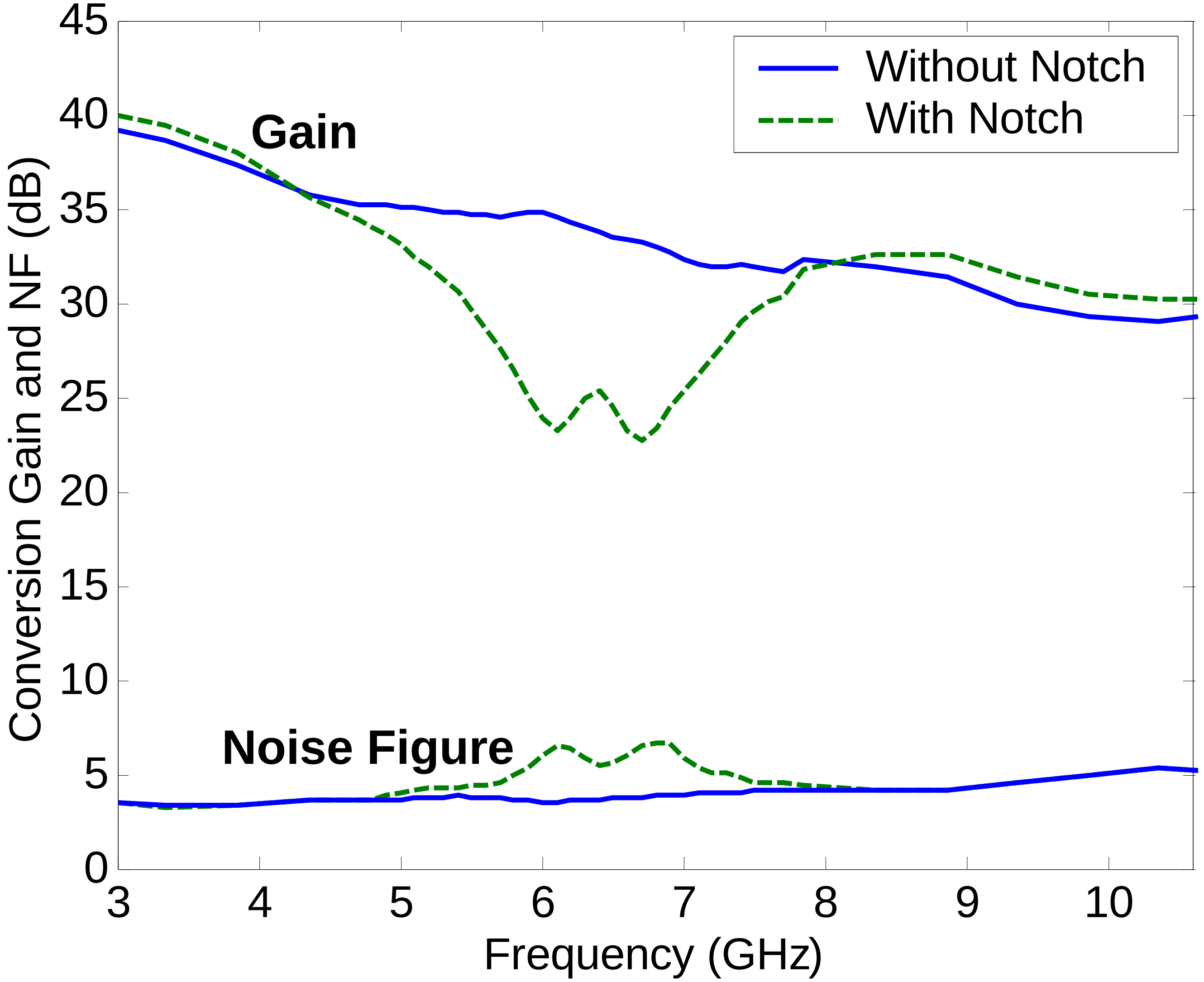
Circuits – UWB Filter and S2D



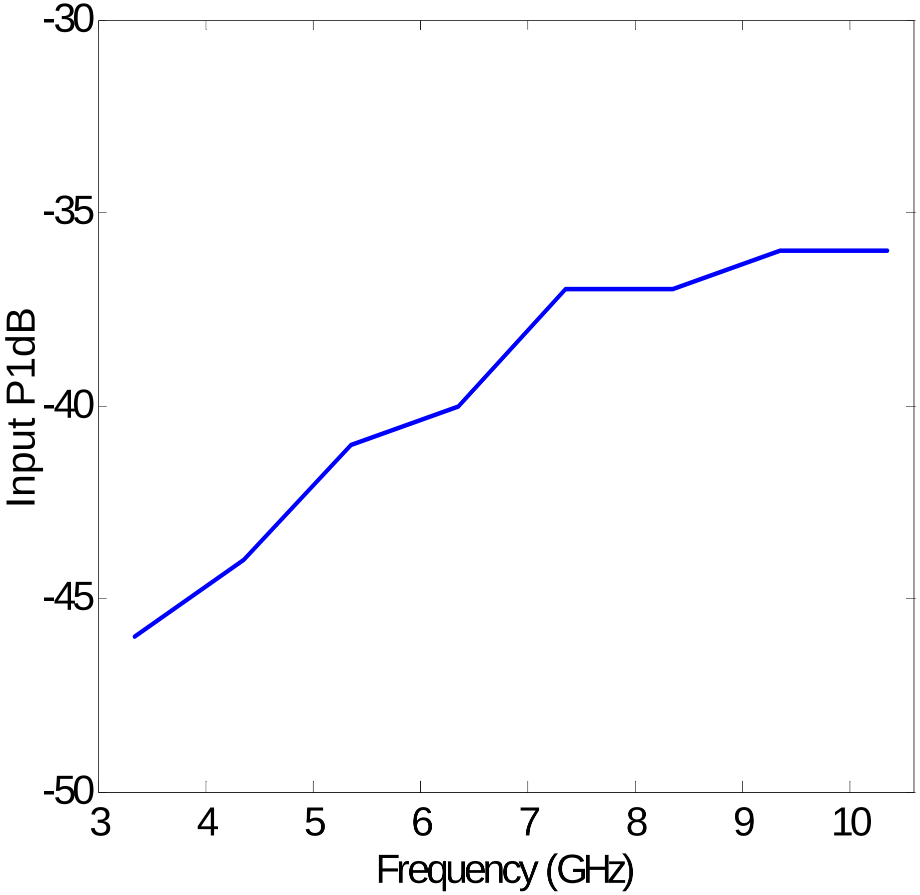
Circuits – Double-Balanced Gilbert Mixers

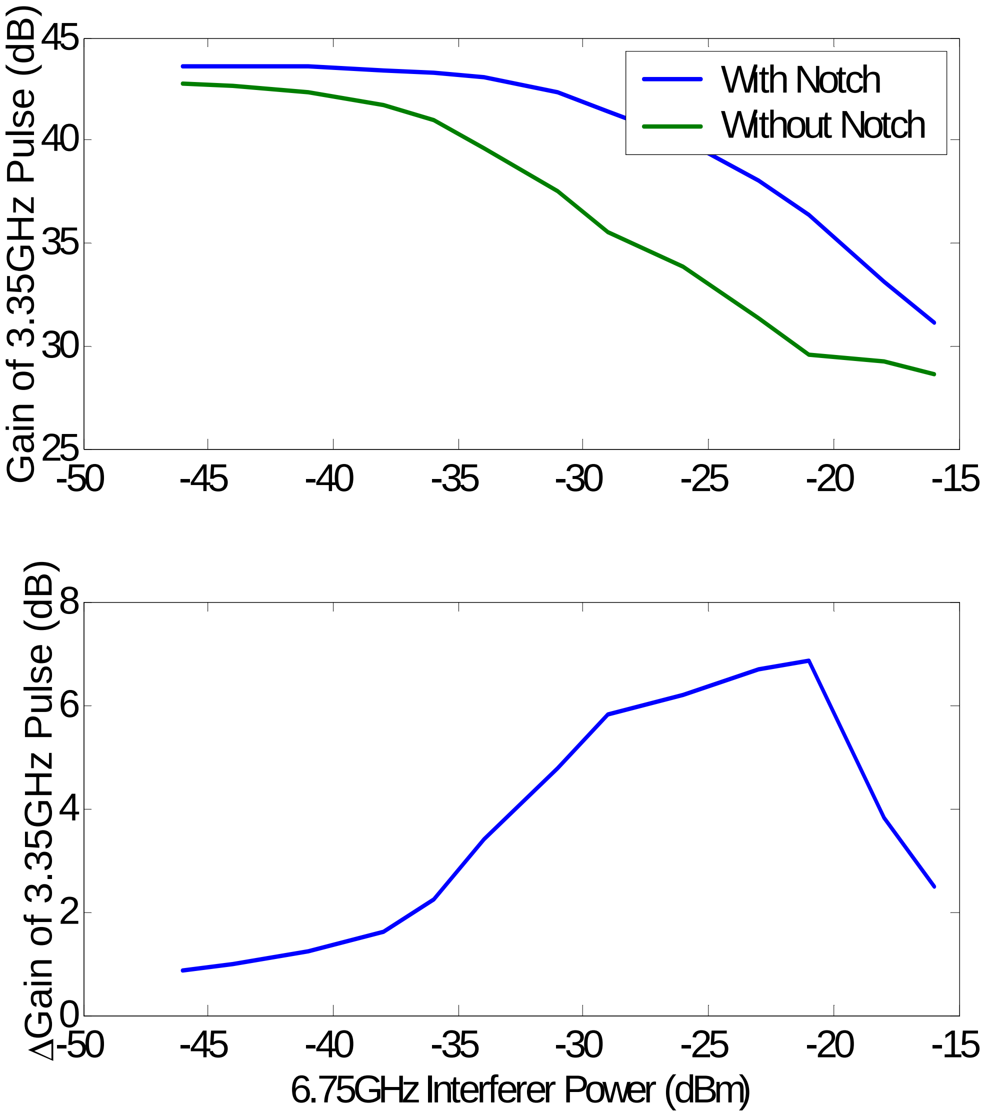


Wired Measurements – Conversion Gain and NF

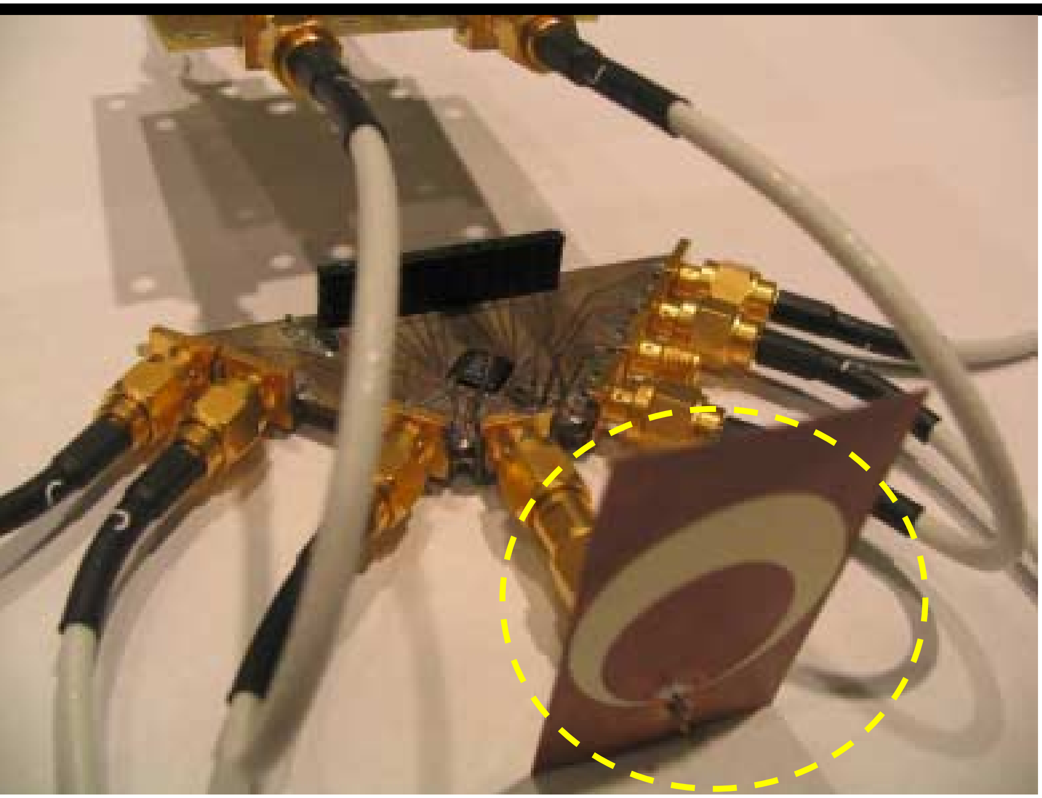


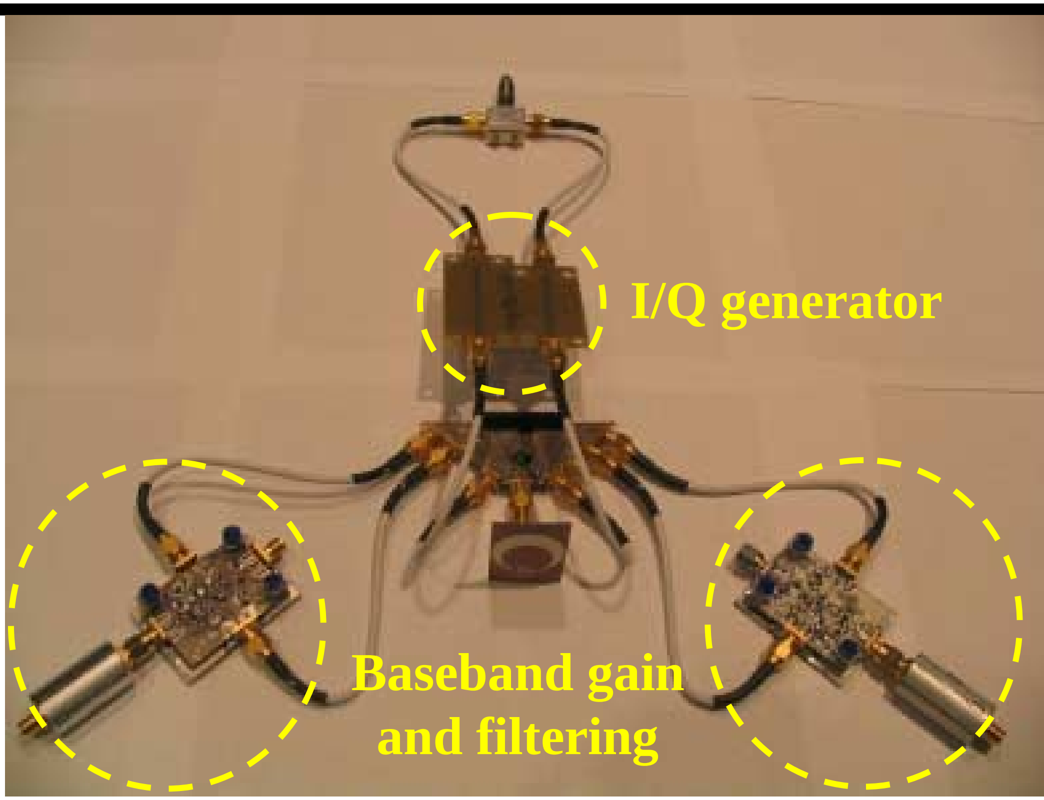
Wired Measurements – Notch Effectiveness



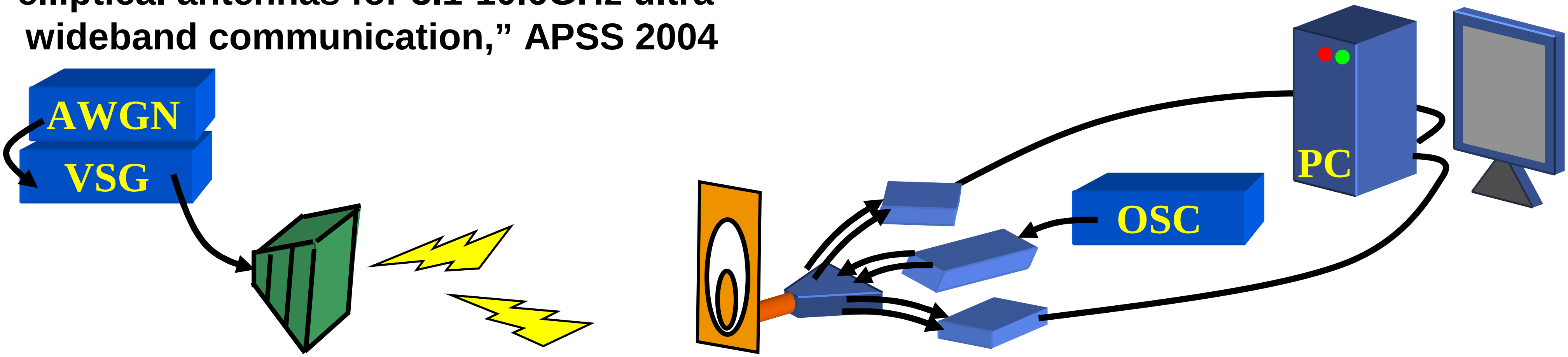


Wireless Measurements Setup

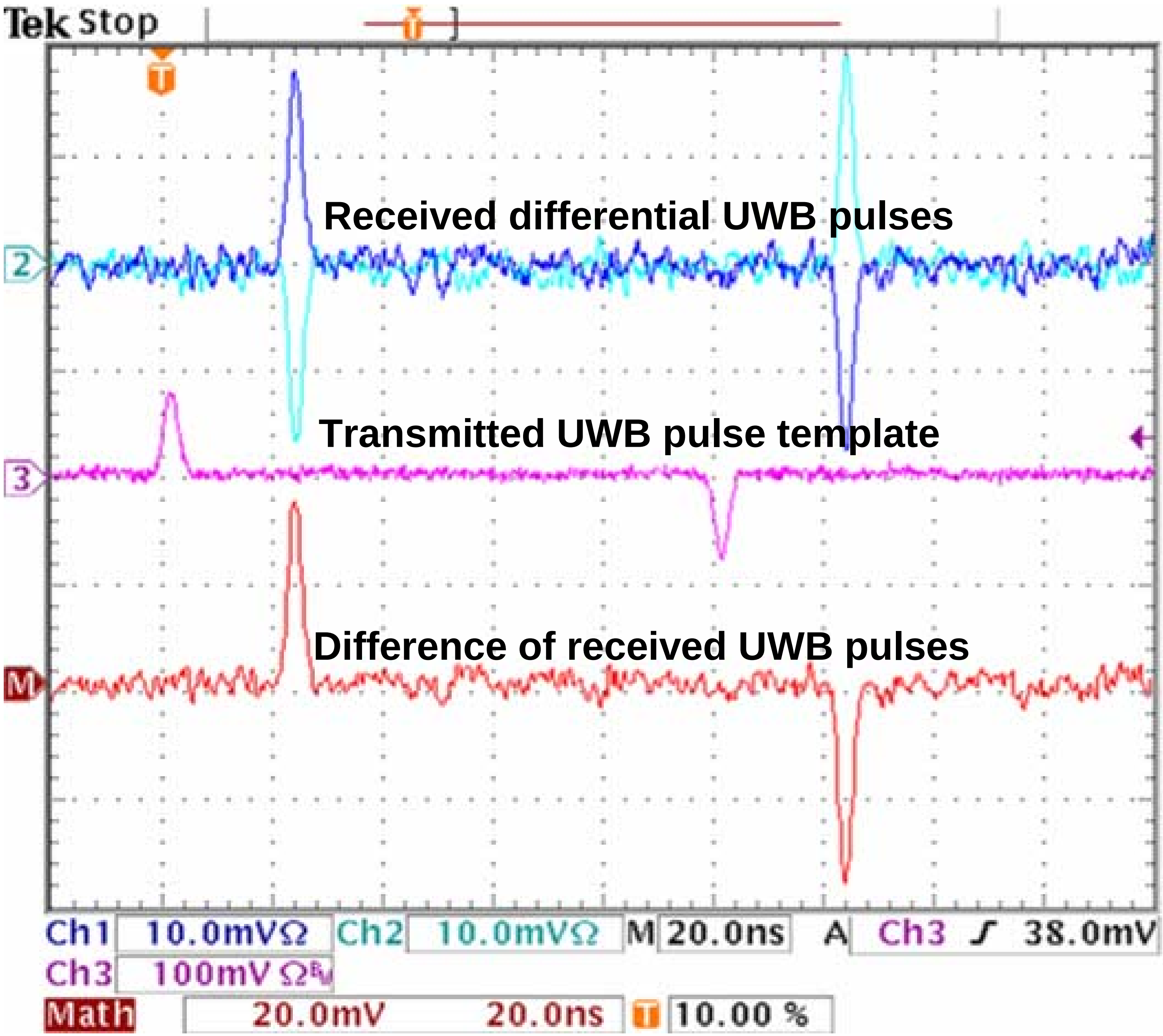




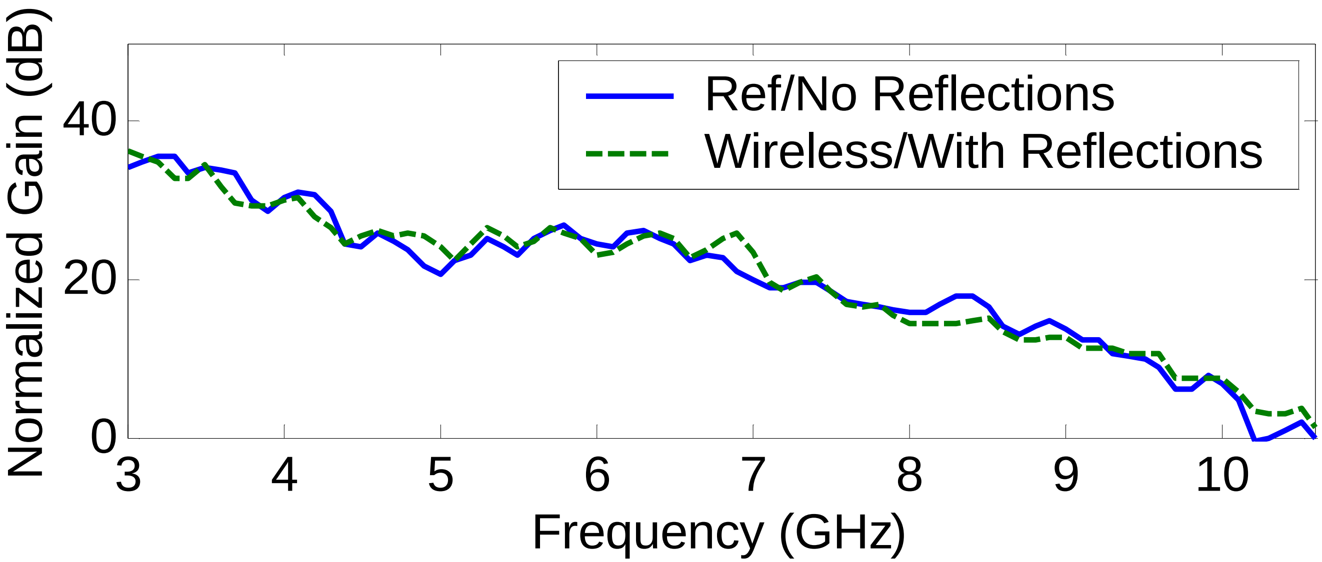
Powell, et al., "Differential and single ended elliptical antennas for 3.1-10.6GHz ultra-wideband communication," APSS 2004

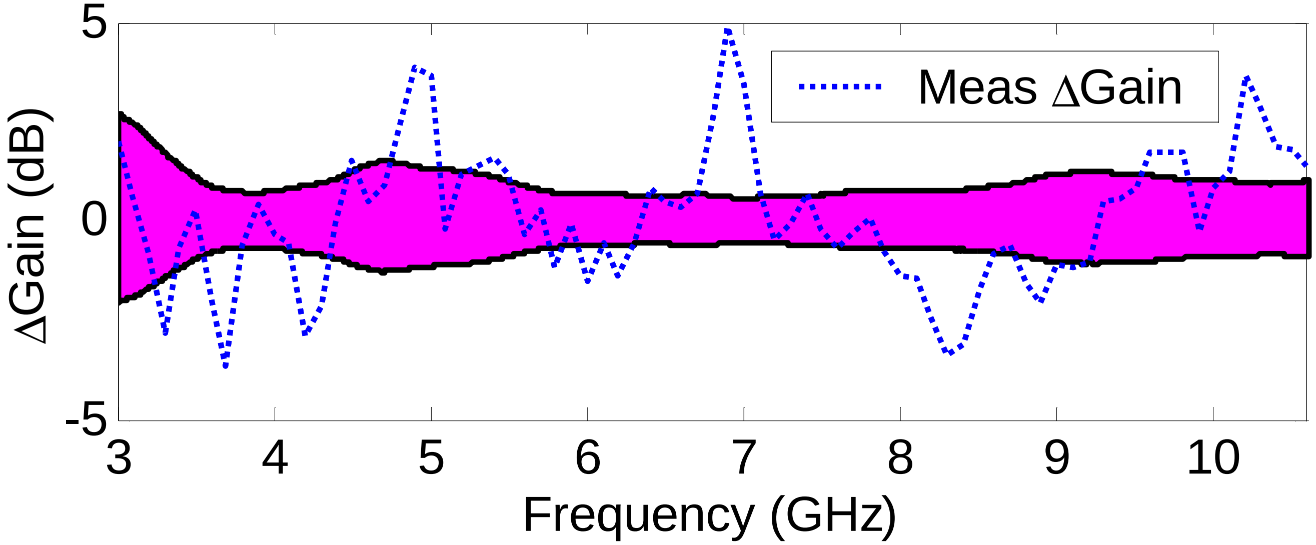


Wireless Received UWB Pulse Signals



Wireless Verification of Un-Matched Front-End





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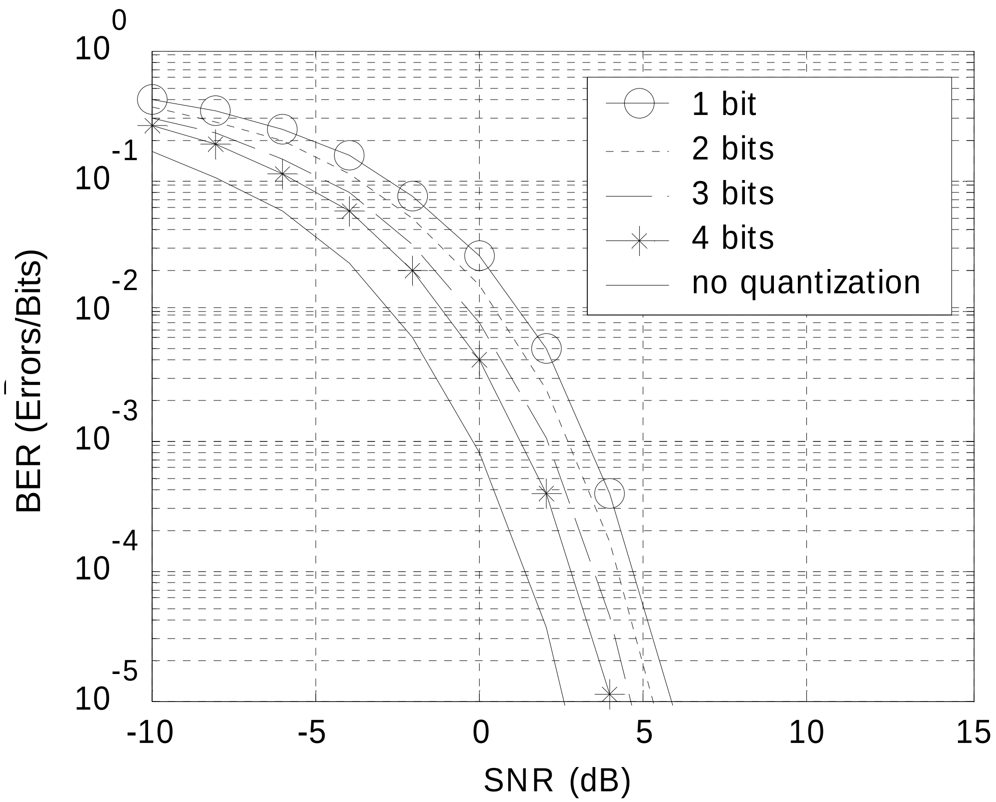
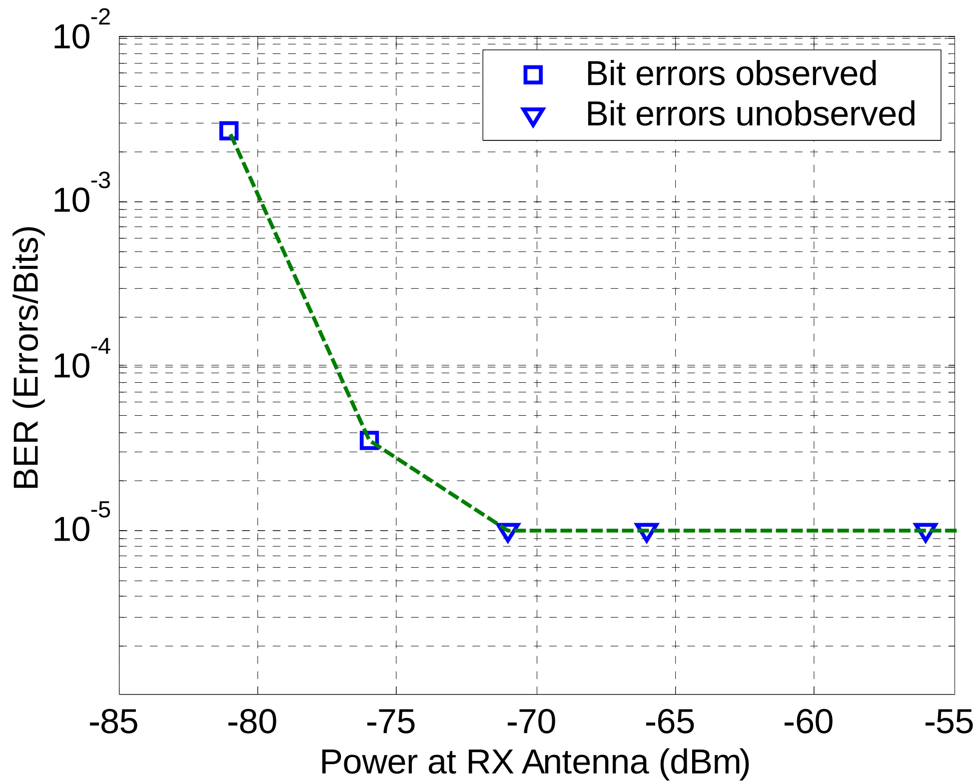
$$A_{\min} = \left(1 + L^2 \left|S_{11,Antenna}\right| \left|S_{11,LNA}\right|\right)^{-1}$$

Ref obtained by piecing together the gains of:

- **TX/RX antennas path loss, when antennas are driven and loaded with properly matched impedance**
- **RFIC conversion gain when driven by a matched source**

Wireless Bit-Error-Rate Results @ 6.85GHz

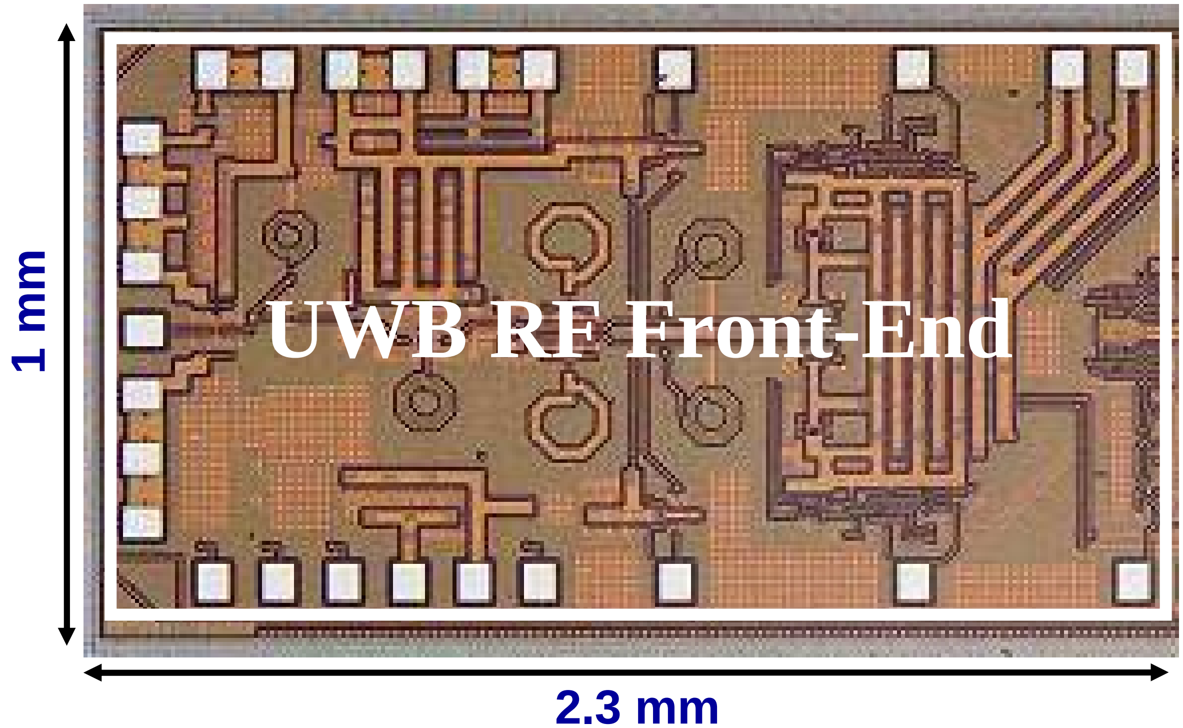




Blazquez, et al., "Digital architecture for an ultra-wideband radio receiver," VTC 2003

- **To compare plots, change "Power at RX Antenna" to "SNR" by:**
  - **Assuming kTB in 500MHz band is -87dBm**
  - **$SNR=dBm_{RX}-87+NF$**
- **We find that these plots match within 2-3 dB**

Chip Photo and Performance Summary



Front-End RFIC Summary

Specification	Value from 3.1-10.6GHz
Conversion Gain	39 to 29dB
NF	3.3 to 5dB
Input P1dB	-46 to -36dBm
Notch Filter Attenuation	10dB
BER @ sensitivity	2.7×10^{-3} @ -81dBm
Process technology	0.18μm SiGe BiCMOS

Power Consumption at 1.8V

Block	Power (mW)
LNA	4.23
Buffer, S2D & notch	13.5
2 mixers and buffers	21.6
2 LO amplifiers	14.4
Total	***53.73***

Conclusions

- **Un-matched LNA can achieve better noise performance**
- **RF notch filter can improve robustness to interference**
- **UWB packaged chip verified in wireless system environment**