Ultra-Wideband Digital Receiver – LNA Design

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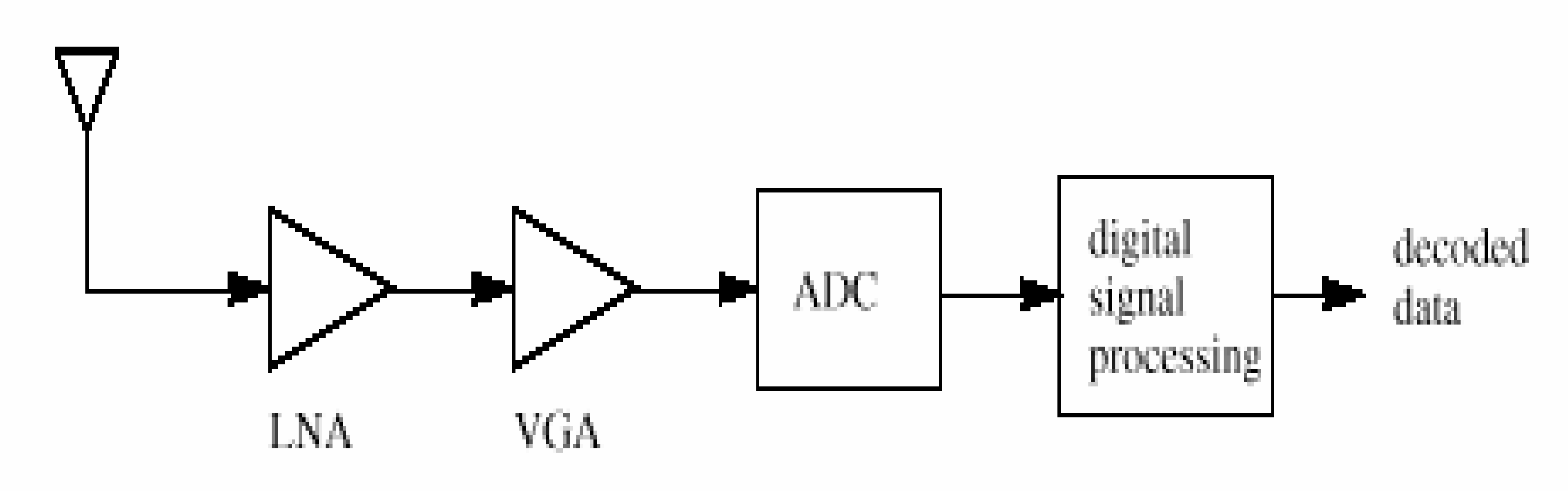
Why UWB Digital Receiver?

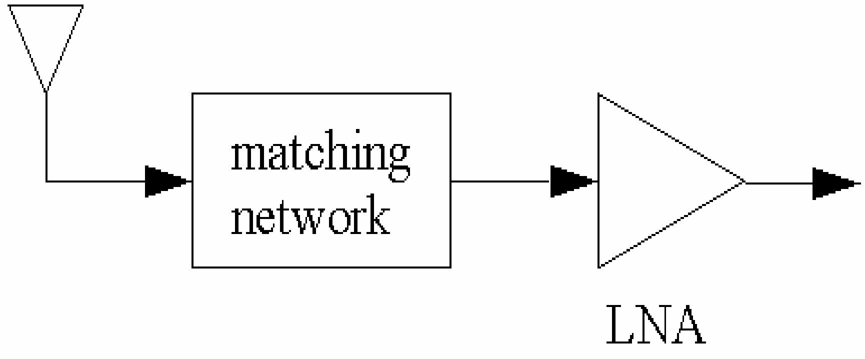
- Digital receivers perform receiver functions (e.g., correlation) digitally.
- Higher performance.
  - Employ large number of parallel correlators.
    - Need 100+ to exploit available diversity.
    - Not practical in analog receivers.
  - Employ sophisticated interference suppression algorithms.
- Higher levels of integration and lower power.

Basic UWB Digital Receiver Architecture



- Main challenges:
  - Low-noise amplification
  - Data conversion
  - Synchronization

UWB LNA Design Objectives



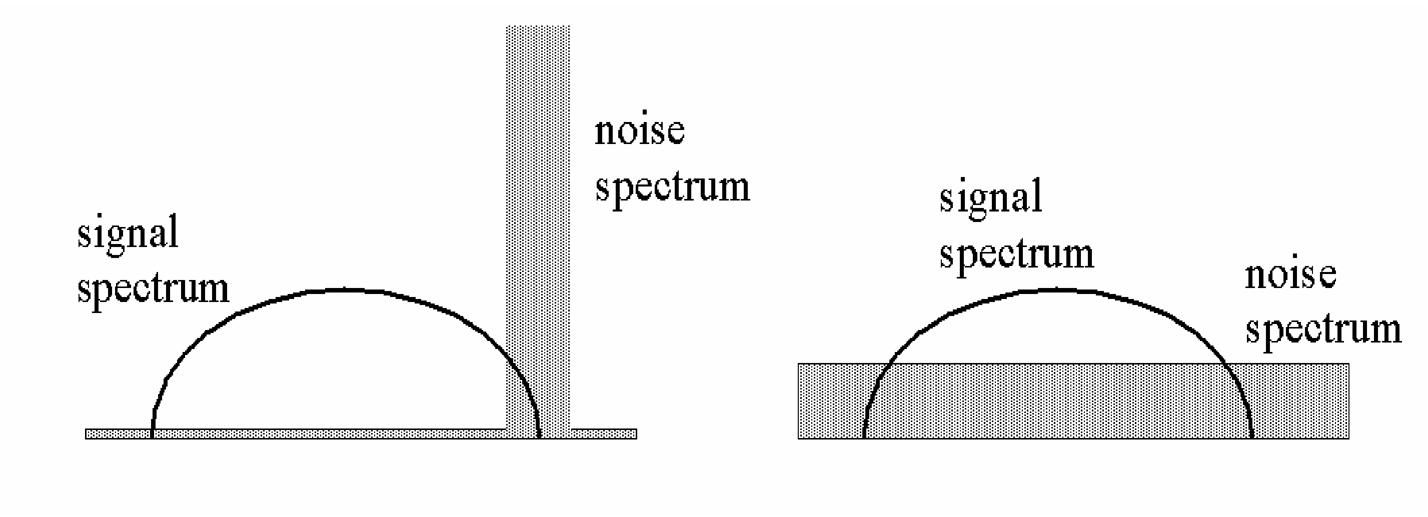
- Minimize noise figure.
  - NF = (Input SNR)/(Output SNR)
- Maximize signal voltage gain transfer.
- Minimize power dissipation.

Existing Work

- Narrowband matching.
  - Single-tone assumption.
    - NF = (output noise)/(input noise)
- Broadband matching (1970's).
  - Average single-tone noise figure.
    - No signal information.

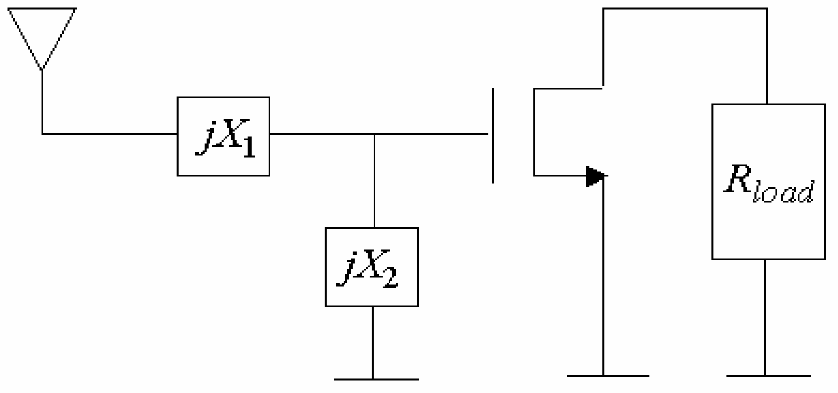
→ Develop matching technique that maximizes output SNR.

SNR Definition



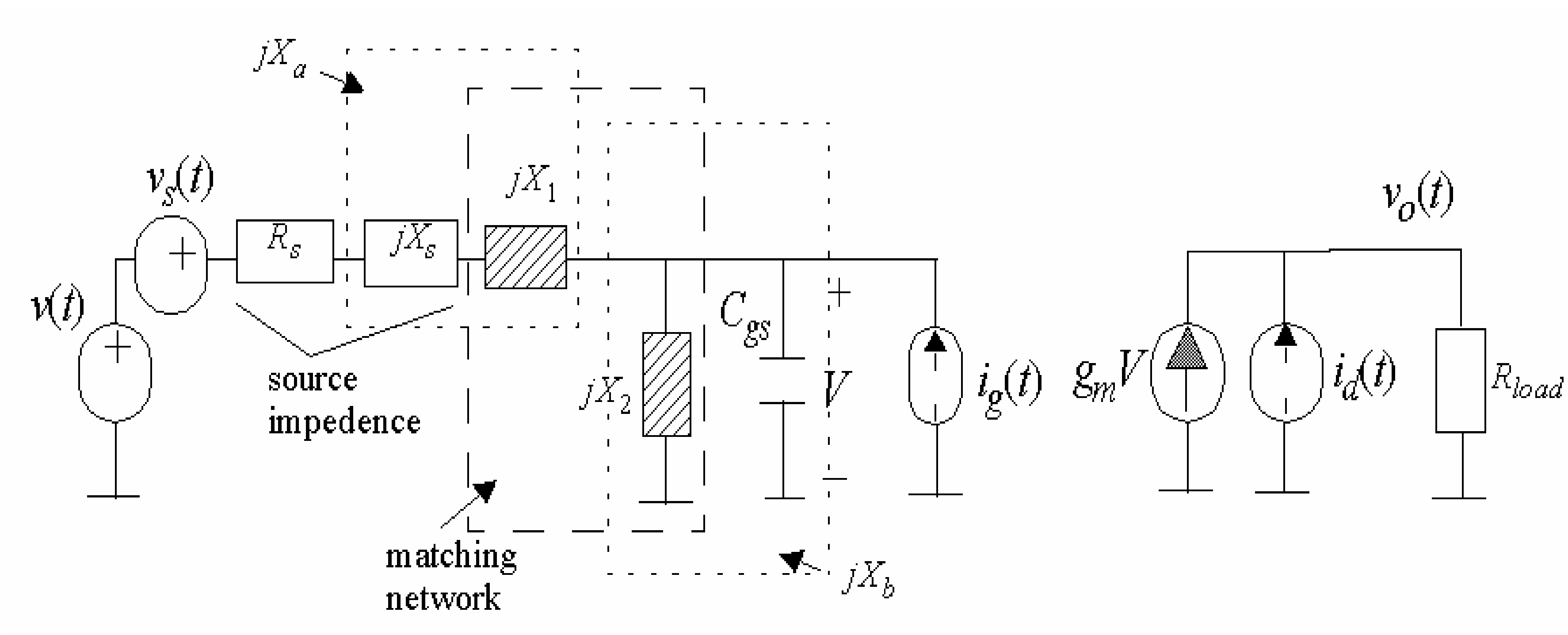
- SNR should depend on signal and noise spectrum.
- SNR defined as the matched filter bound.
  - Whitened matched filter for one-shot transmission.
  - Maximum achievable performance in a data transmission system.

Problem Formulation

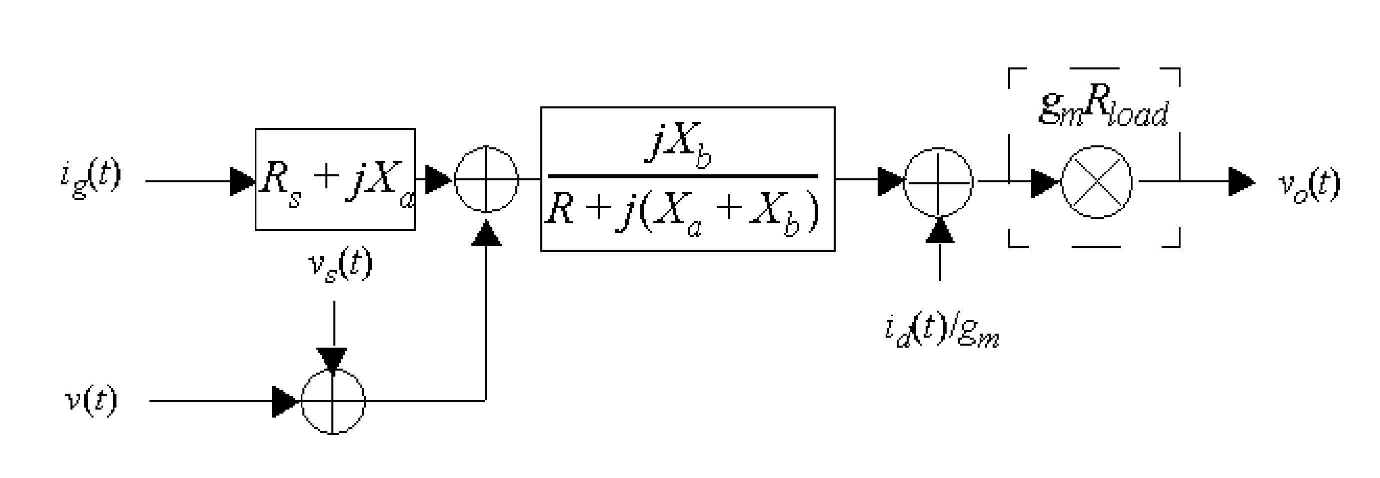


- Maximize output SNR for a given voltage gain while minimizing power dissipation.
- Matching circuits are lossless.
- Common source amplifier.

Equivalent Circuit Model



Equivalent System Model



- Design $X_a(\omega)$ and $X_b(\omega)$ to maximize output SNR.
  - Maximize signal voltage gain.
  - Minimize gate noise current gain.
  - Cancel gate and drain noise current.

Optimum LNA Matching

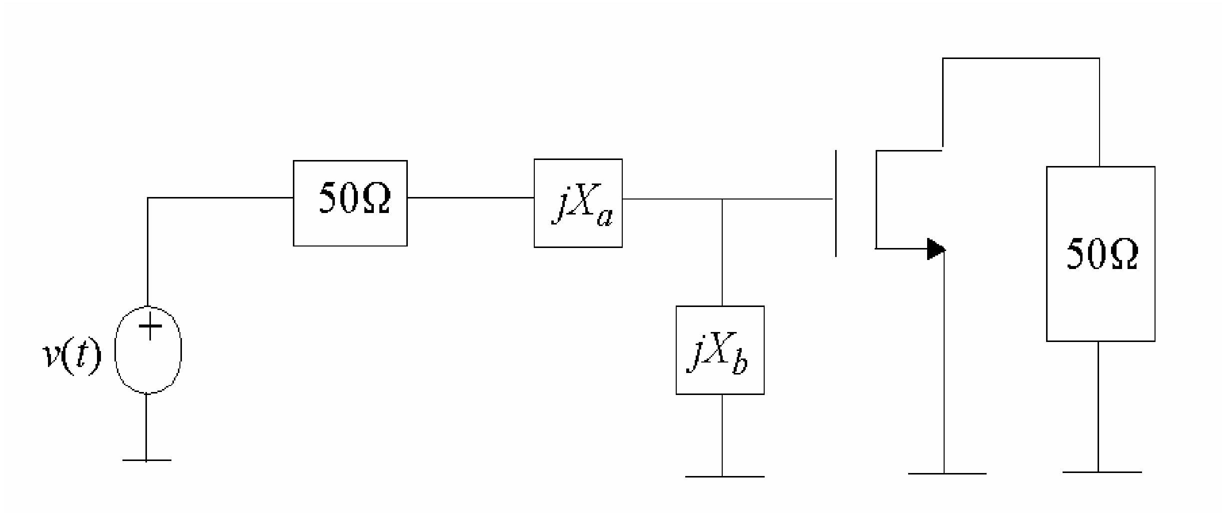
- Differentiate noise figure equation to solve for optimal $X_a(\omega)$ and $X_b(\omega)$.
- Resulting minimum noise figure given by

$$NF_{min} = \frac{\int |P(\omega)|^2 d\omega}{\int \frac{|P(\omega)|^2}{1 + \frac{\omega}{\omega_T}\sqrt{\frac{\delta\gamma}{5}(1 - |c|^2)}} d\omega}$$

Suboptimal LNA Matching

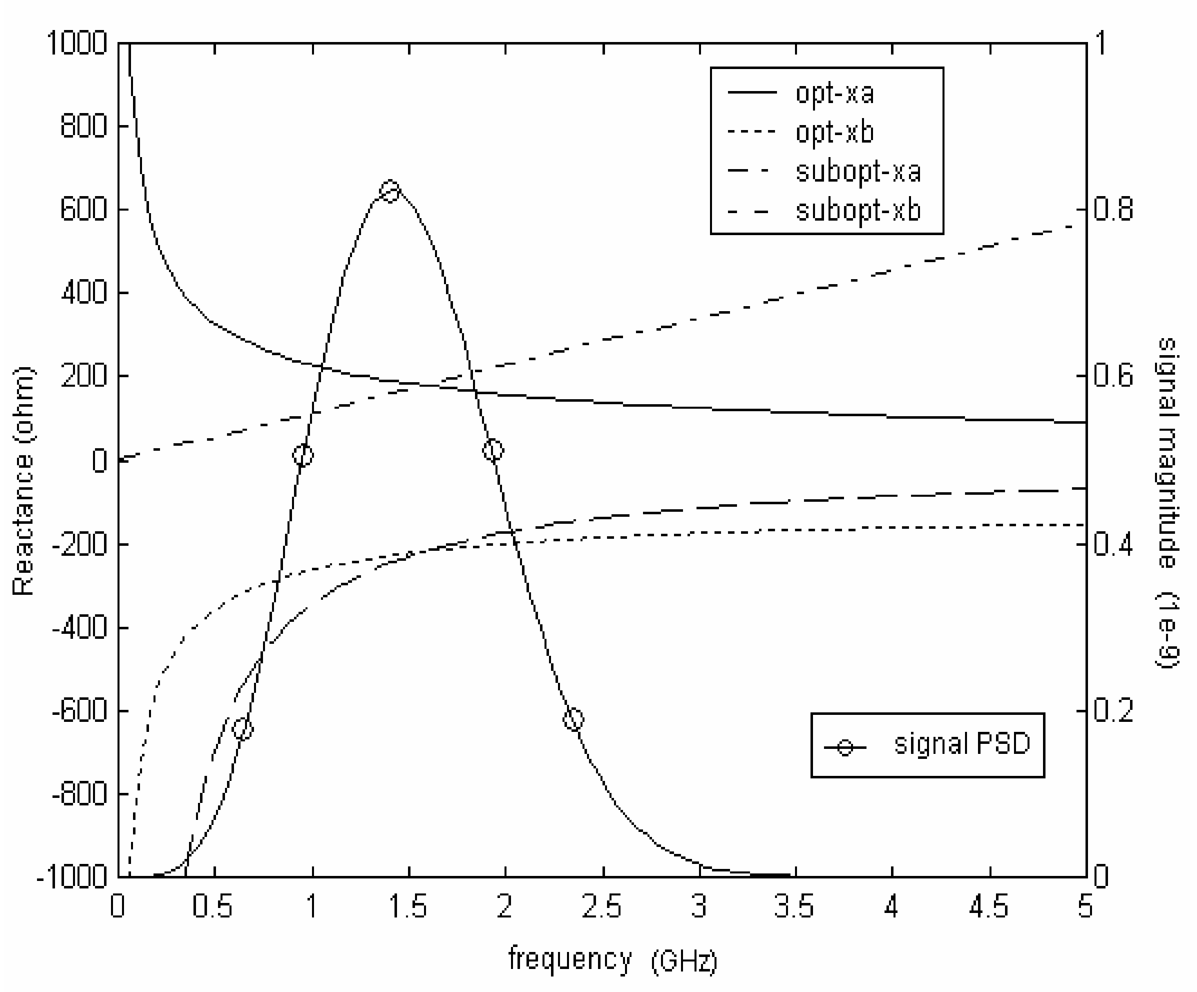
- Choose circuit structure that best approximates optimal $X_a(\omega)$ and $X_b(\omega)$.
- Perform numerical gradient search (e.g., Gauss-Newton method) to solve for L's and C's that minimize noise figure.
  - Initial point based on optimum $X_a(\omega)$ and $X_b(\omega)$.

Example

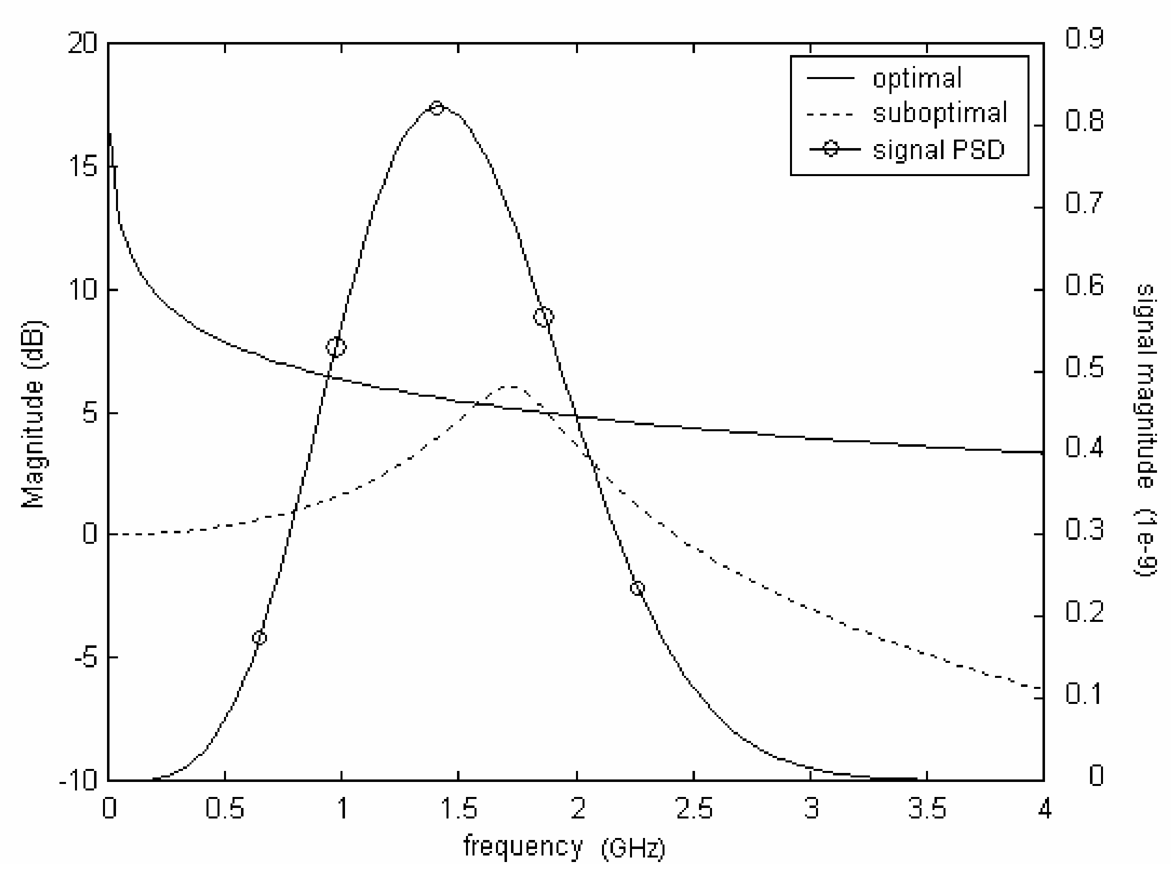


- Assume source and load impendence are 50 Ω.
- Received signal is 2nd derivative of Gaussian pulse.
- Standard 0.35um CMOS process.

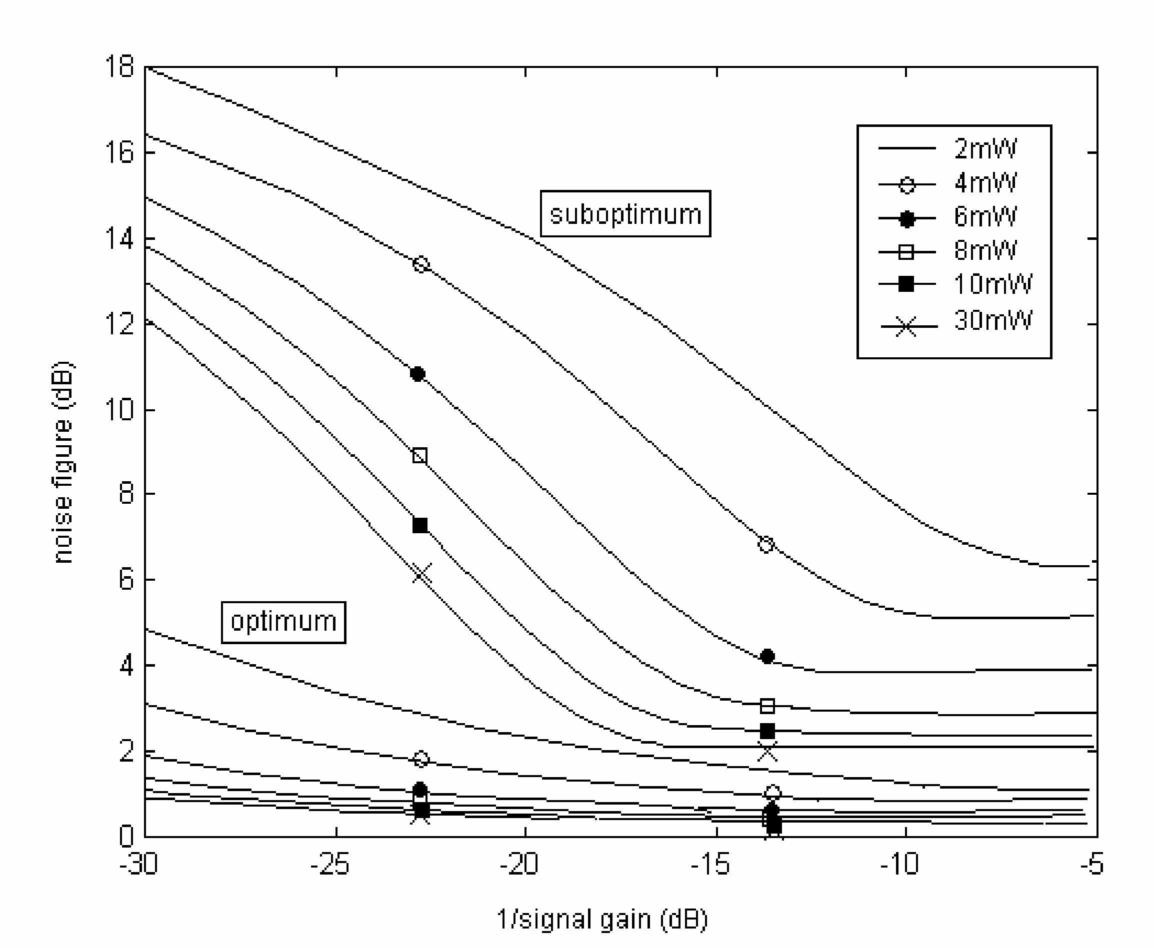
Design of $X_a(\omega)$ and $X_b(\omega)$



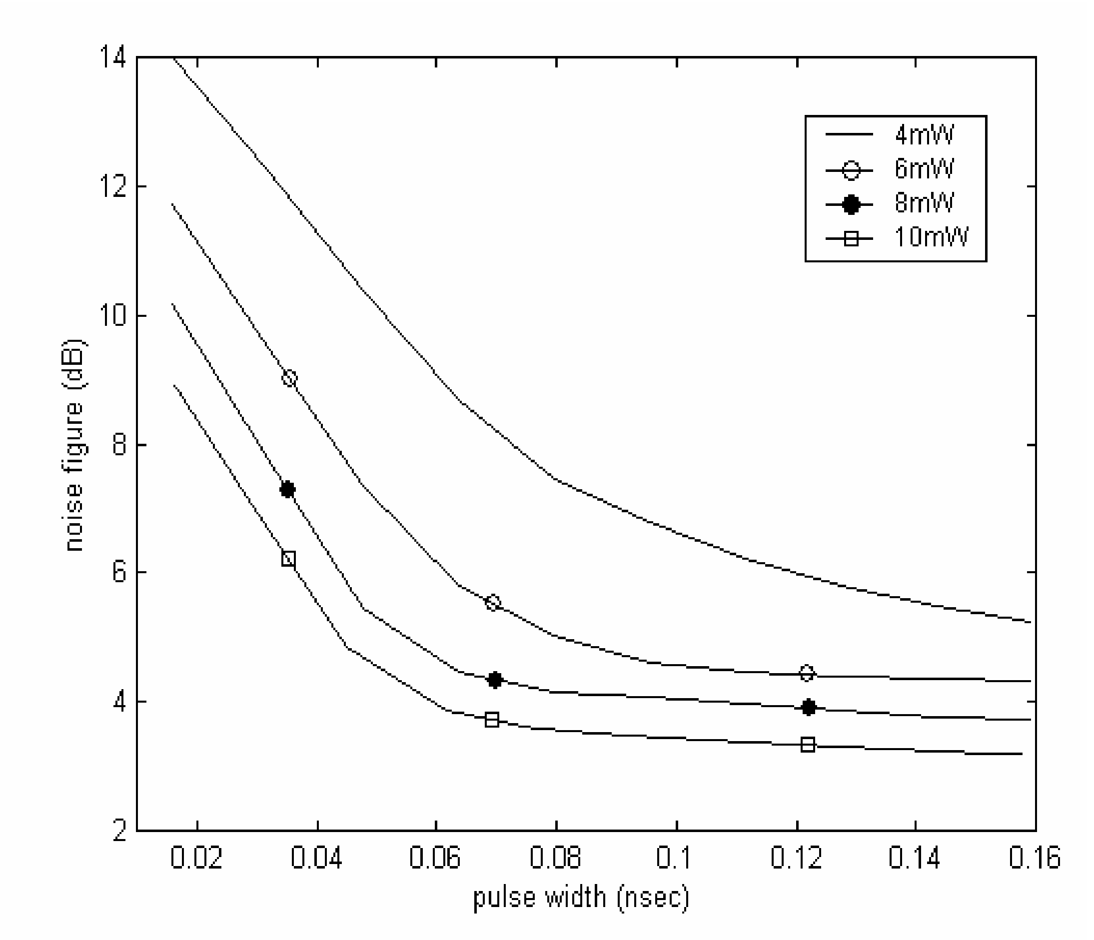
Voltage Gain in Matching Network



Noise Figure vs. Signal Gain



Effect of Gaussian Pulse Width



Conclusion

- Developed LNA design methodology suitable for wideband systems.
  - Maximizes output SNR, which is defined as the matched filter bound.
  - Applies equally to broadband and narrowband systems.
- Need multiple stages for efficient amplification.
- Large LNA power dissipation for very narrow transmit pulse (< 0.1nsec).
- Implement UWB receiver prototypes.