RF Circuits & Antennas for <1GHz UWB

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Introduction

What's special about UWB RF circuits?

- No tuned circuit
  - Couldn't just look at one frequency point anymore
- Phase response is important
  - Requires constant group delay to avoid distortion of the waveform

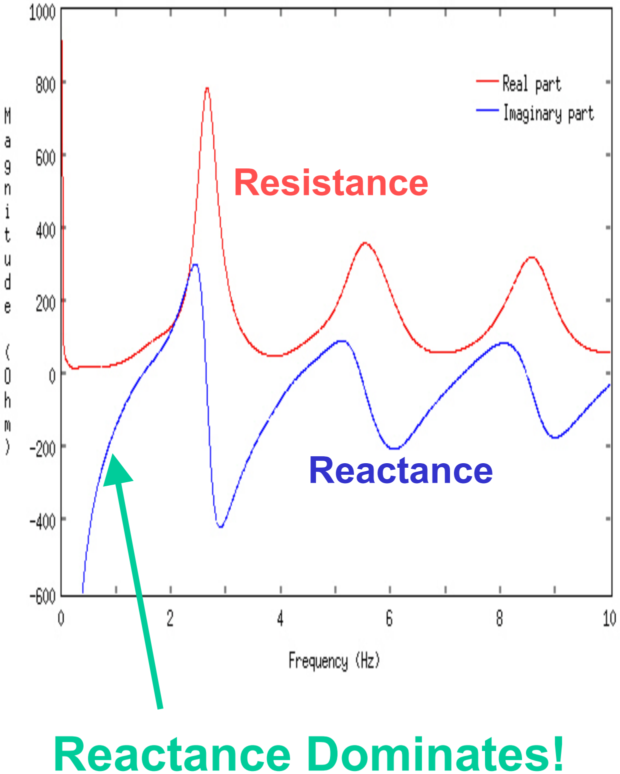
Why talk about antennas?

- Everything varies with frequency
  - Radiation pattern, directivity, impedance, etc..
  - Couldn't draw antenna as a 50ohm resistor. Have to learn more…

UWB Antennas

- UWB antennas for indoor wireless applications
  - Small size
  - Broadband
  - Omni-directional
- Small size → Narrowband
  - Antenna Q ~ (λ^3)/(antenna size)
  - Build a circuit network to reflect the impedance variation
- Small size → Omni-directional
  - Spatial phase difference is small
  - Variation of radiation pattern in low freq regime is small

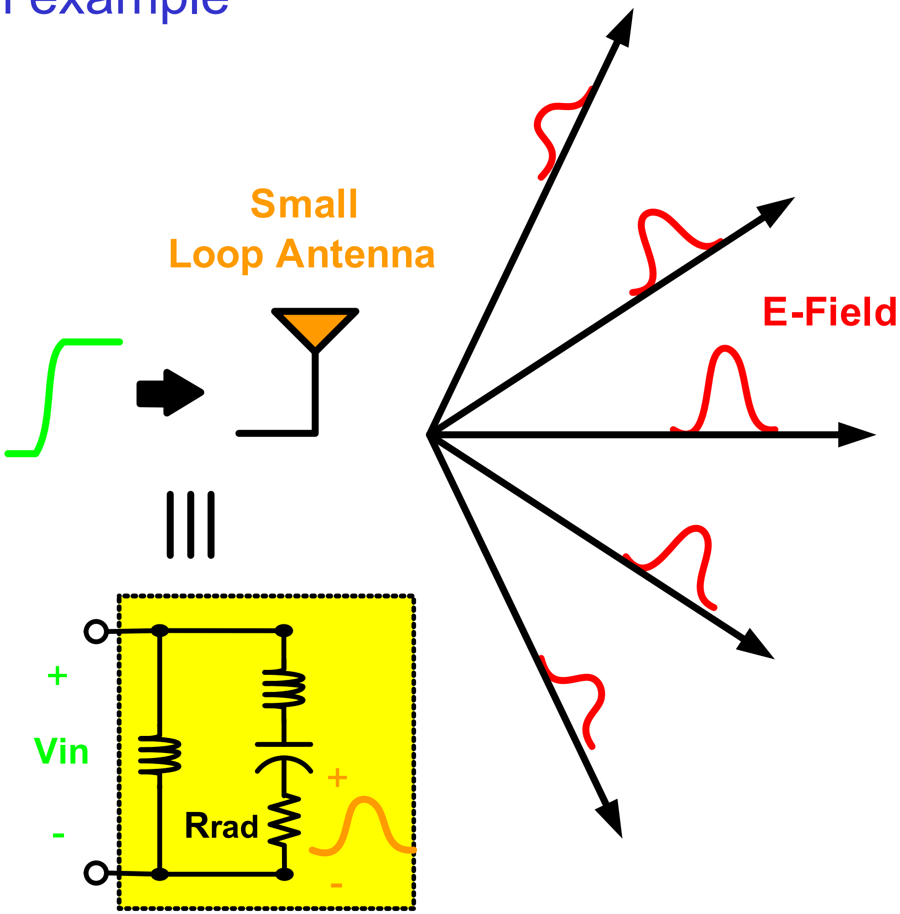
6cm Dipole Antenna Input Impedance



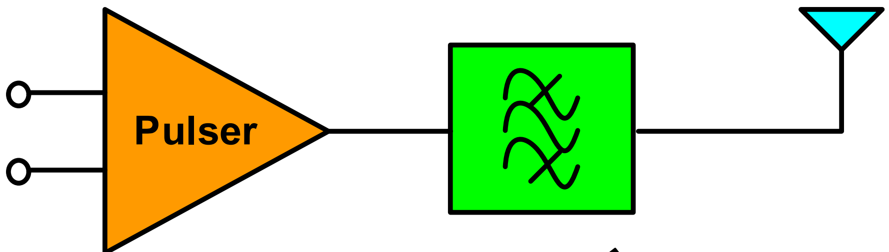
Small Antenna Modeling

Take small loop antenna as an example

- Curve-fitting the input impedance
  - Only one resistor
- E-fields in all directions are with almost the same waveform
- By superposition, voltage waveform across Rrad is equal to the far-zone E-field waveform
- Estimate radiated E-field in SPICE

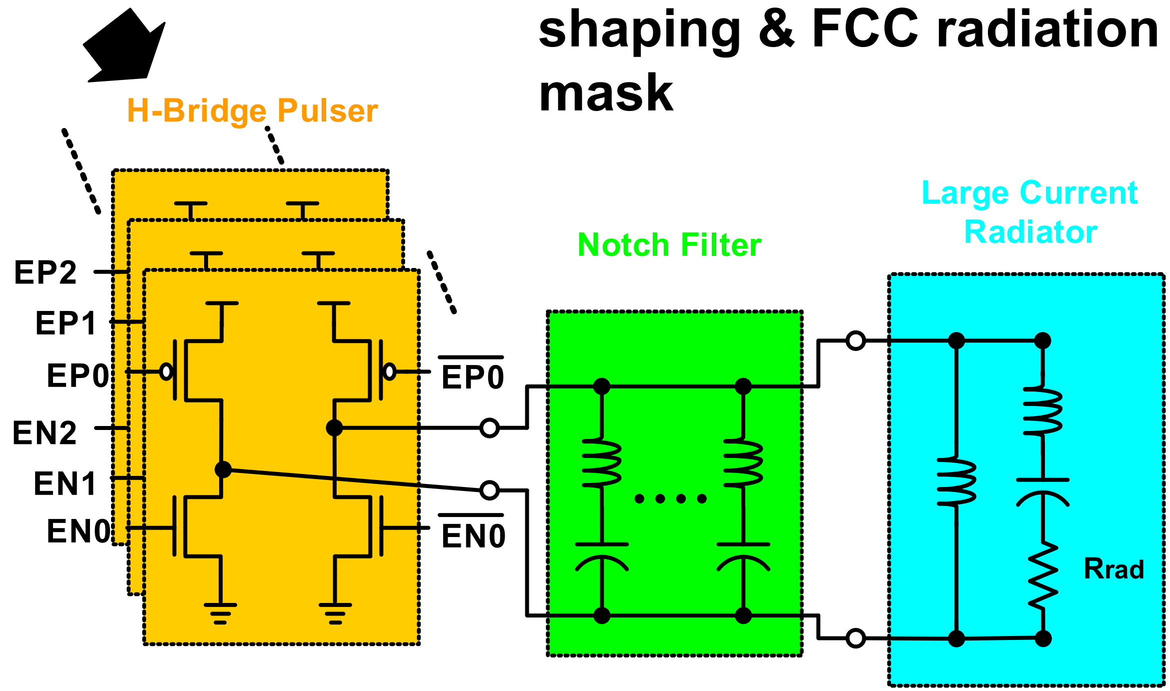


UWB Pulser/Antenna Co-design



- Large Current Radiator (LCR) as the TX antenna
- Notch filter for pulse-shaping & FCC radiation mask

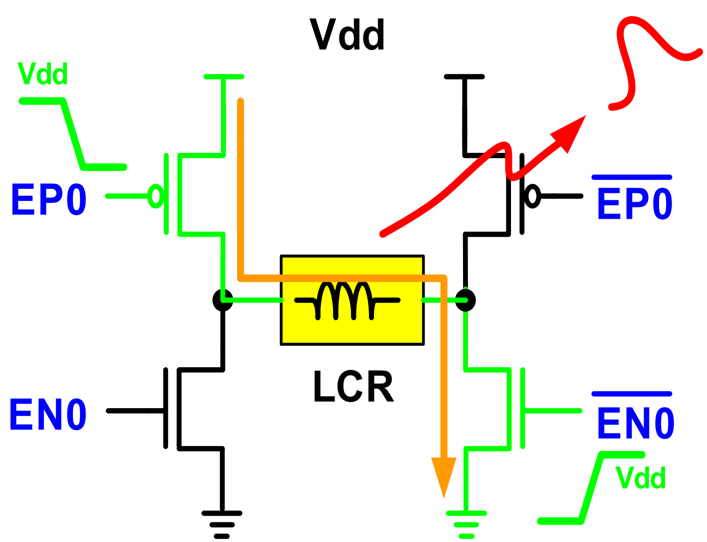
- H-bridge pulser to drive inductive load
- Flexible driving force by parallel structure

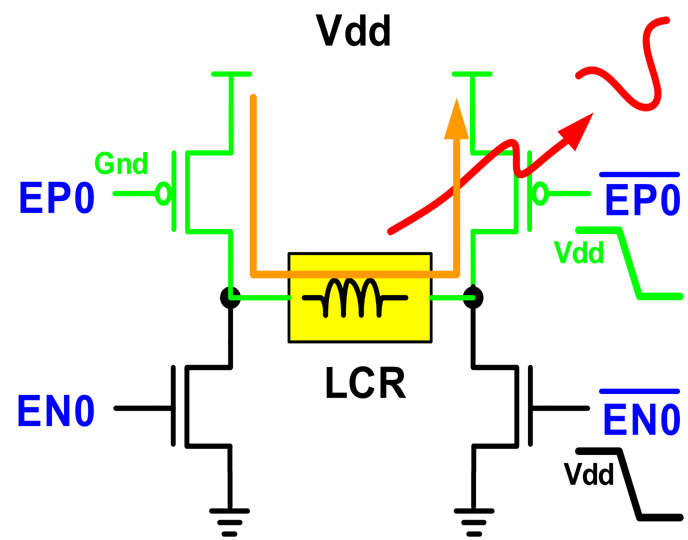


H-bridge Operations (Transmit ‘0’)

- EP0 & $\overline{\text{EN0}}$ turned on
- Current flows from Vdd to Gnd thru LCR
- Fast-rising voltage at LCR terminals generates a positive Gaussian pulse

- $\overline{\text{EN0}}$ off and $\overline{\text{EP0}}$ on
- Current flows back to Vdd
- Fast-falling voltage at LCR terminals generates a negative Gaussian pulse

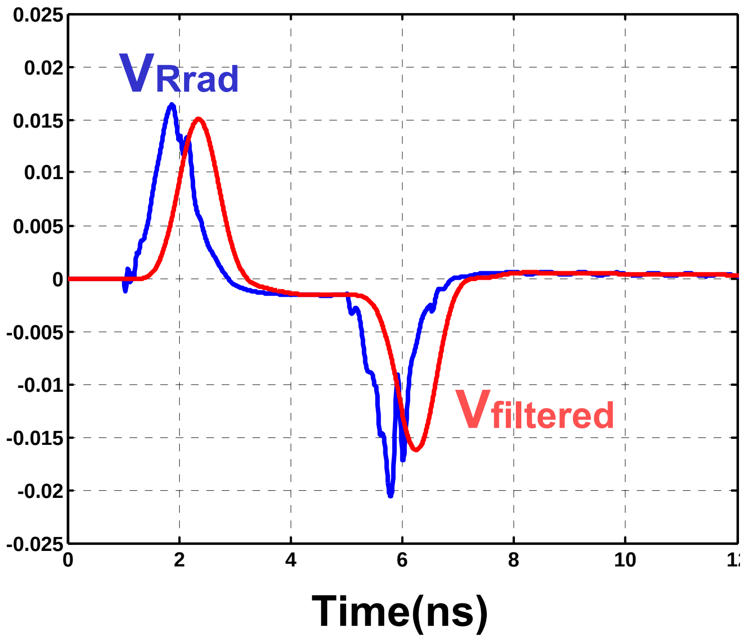


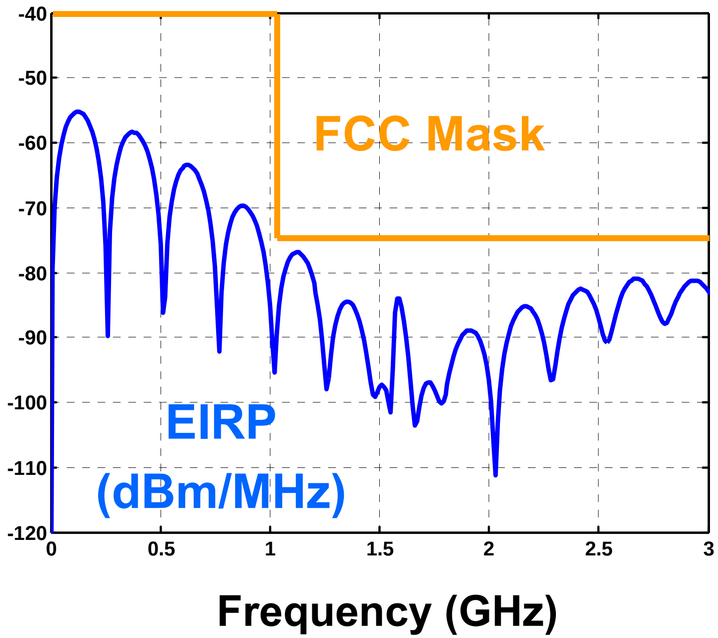


H-bridge Simulation Results

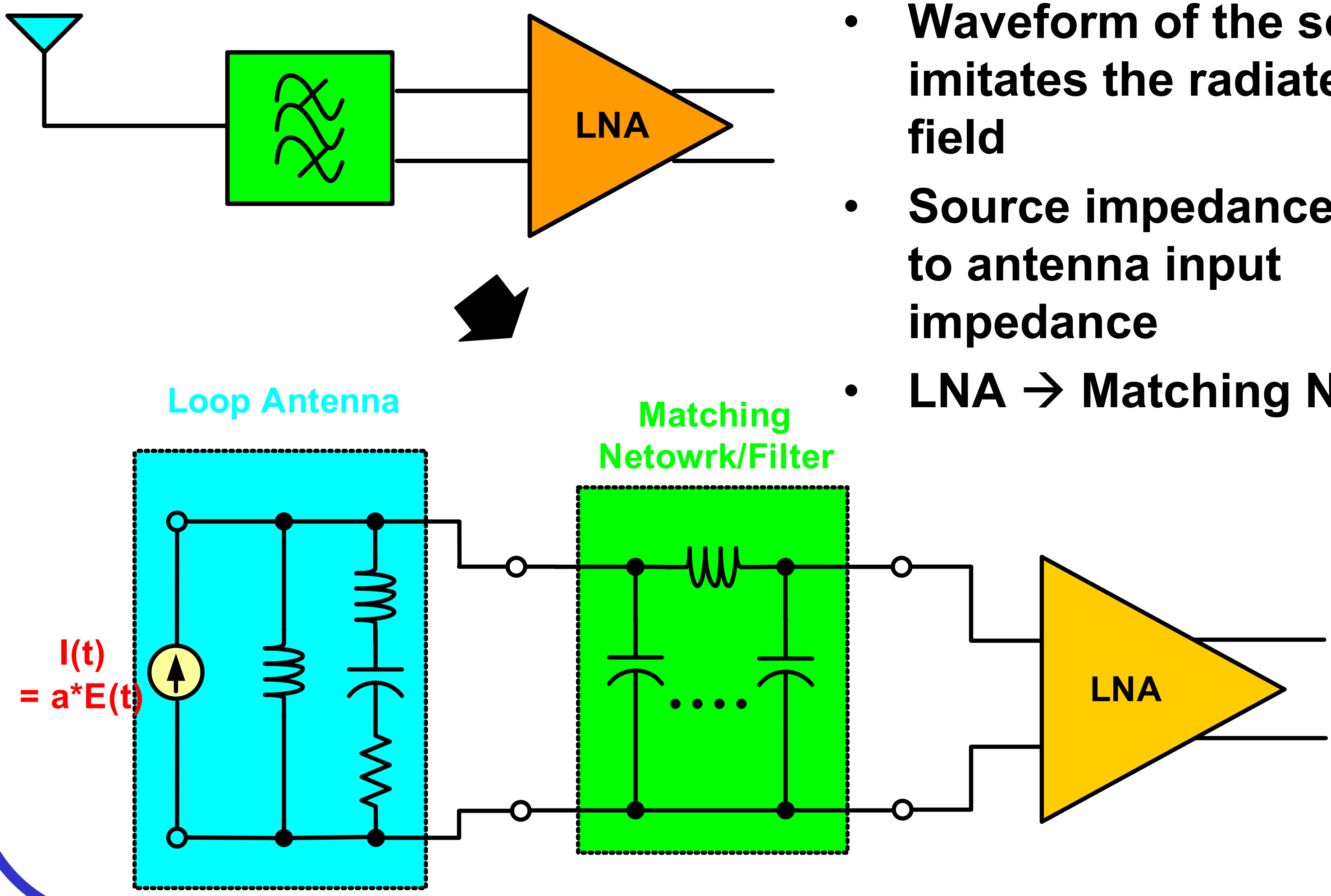
- Doublet is generated
- Pulse-width ~ 1ns
- Smoothed after low-pass filtering at the receiver

- Meet FCC's rule
- EIRP will increase when PRF(Pulse Repetition Freq) increases





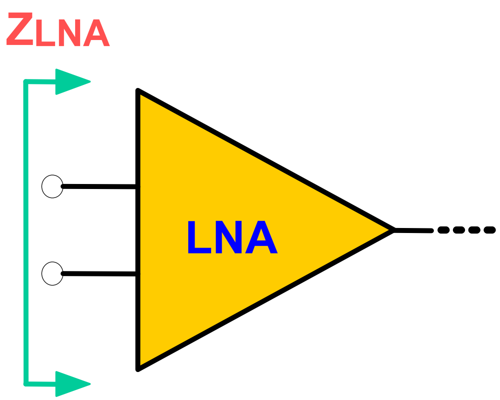
UWB Receiver Front-end



- Waveform of the source imitates the radiated E-field
- Source impedance equal to antenna input impedance
- LNA → Matching Network

Sub-mW UWB LNA Design

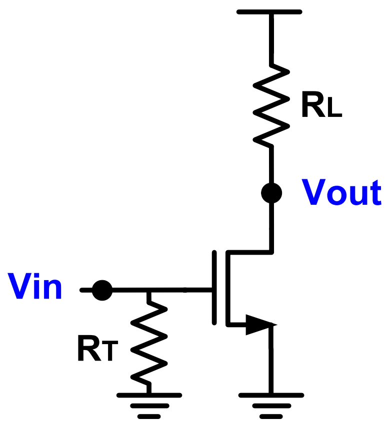
- Specifications
  - Fully-differential for on-chip interference immunity
  - Voltage Gain > 15dB
  - 3dB BW : 0.1~1GHz
  - NF < 6dB
  - Linearity : doesn't matter
  - Constant group delay
  - Input impedance : 50ohm
  - *Goal : Minimize power consumption (< 1mW)*



- Low input impedance sets the power consumption
- What LNA topology should be used?

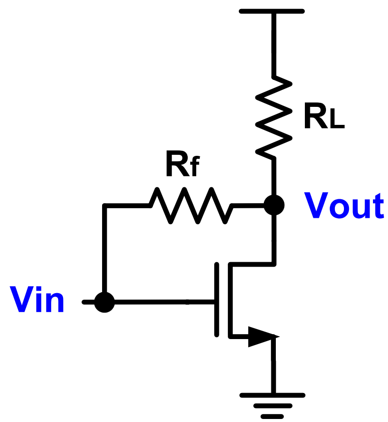
Existing Wideband LNA's

R-terminated



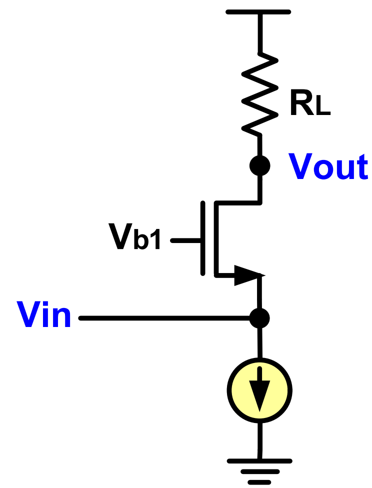
$R_{in} = R_T$

Shunt-Feedback



$R_{in} = R_f/(1+g_m R_L)$

Common-Gate

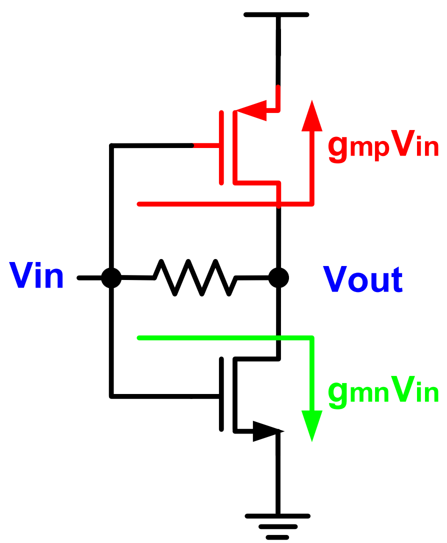


$R_{in} = 1/g_m$

- **Resistive-terminated LNA has very bad NF**
- **Shunt-FB and CG LNA's need g_m = 40mA/V which makes sub-mW power consumption unfeasible**

Current-Reuse Technique

Shunt-Feedback

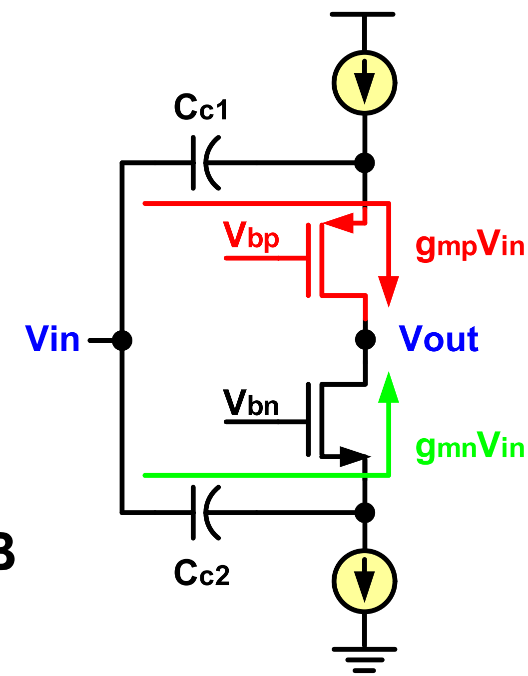


$R_{in} = 1/(g_{mn}+g_{mp})$

$R_{in,diff} = 2/(g_{mn}+g_{mp})$

- **PMOS are added in as amplifying devices**
- **No extra DC current**
- **$G_m = g_{mn} + g_{mp}$**
- **R_{in} is halved**
- **Voltage gain is doubled**
- **NF decreased by 3dB**
- **BW decreased but OK**
- ***Still burn > 1mW***

Common-Gate



$R_{in} = 1/(g_{mn}+g_{mp})$

$R_{in,diff} = 2/(g_{mn}+g_{mp})$

FB/CG Hybrid LNA

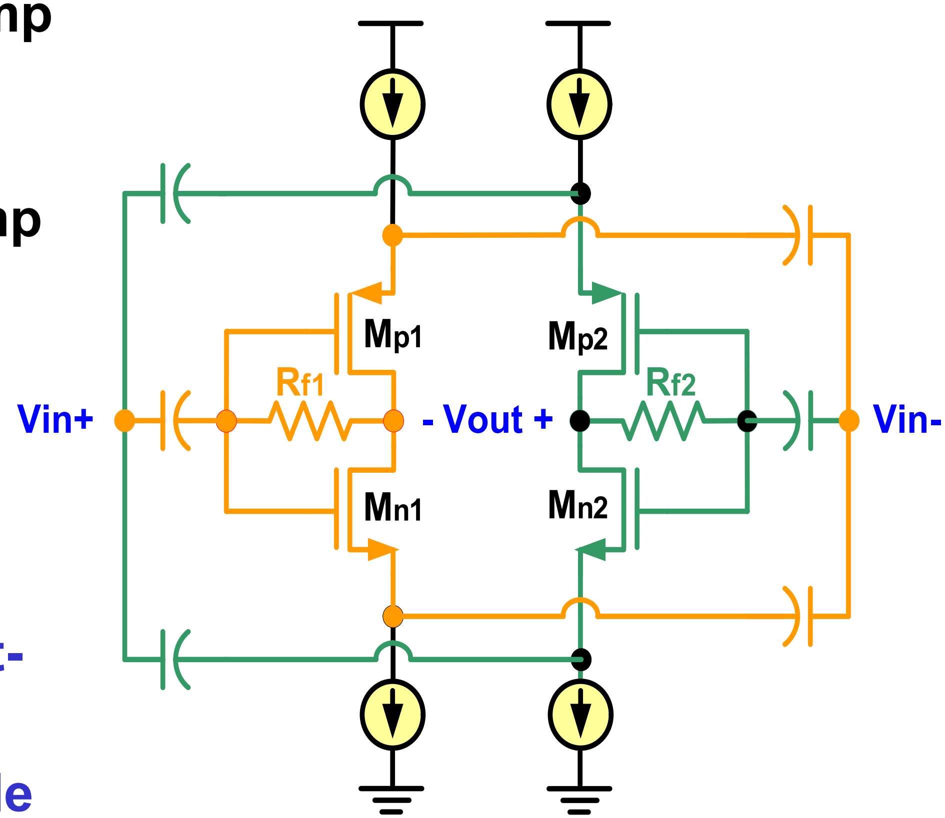
- $M_{p1}/M_{n1}/R_{f1}$ act as FB Amp to V_{in+} and CG Amp to V_{in-}
- $M_{p2}/M_{n2}/R_{f2}$ act as FB Amp to V_{in-} and CG Amp to V_{in+}
- $R_{in} = 1/\ [\ 2*(g_{mn}+g_{mp})]$

  For R_{in} = 50ohm,

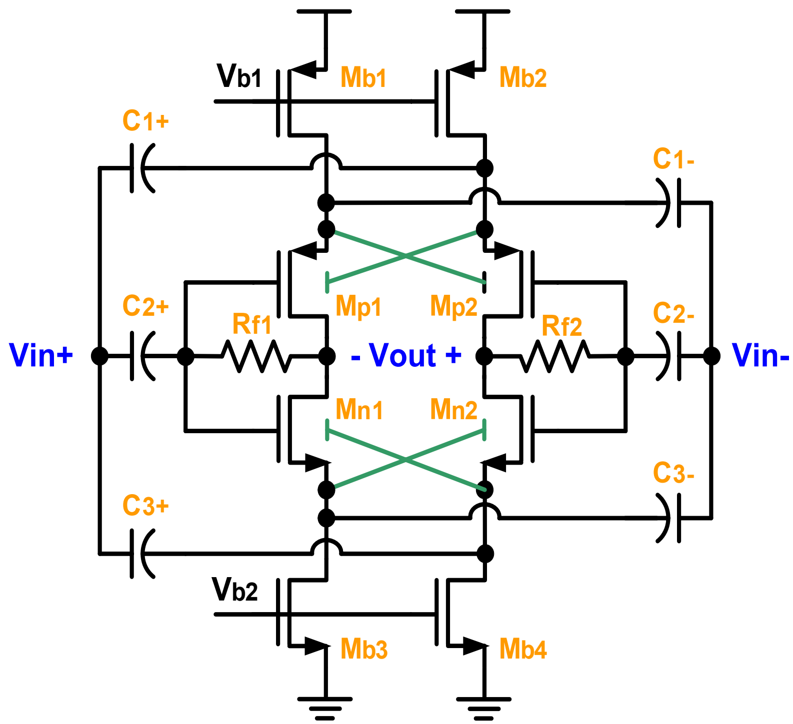
  $g_{mn} = g_{mp} = 5mA/V$

  → 8 times smaller than 40mA/V in CG or Shunt-FB amplifier!

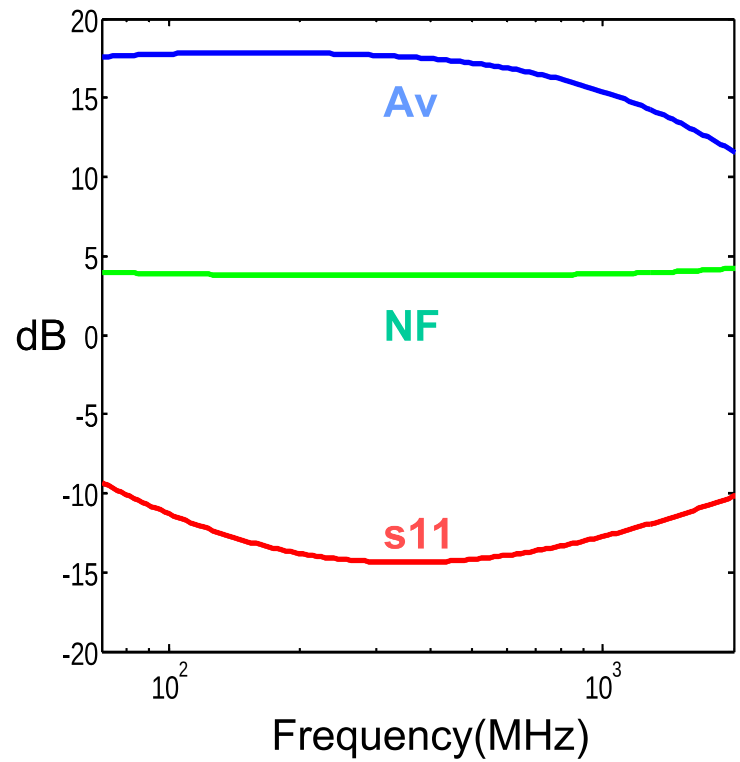
  → sub-mW LNA feasible
- $A_v = 2*(g_{mn}+g_{mp})*R_f$



LNA Schematic & Simulation



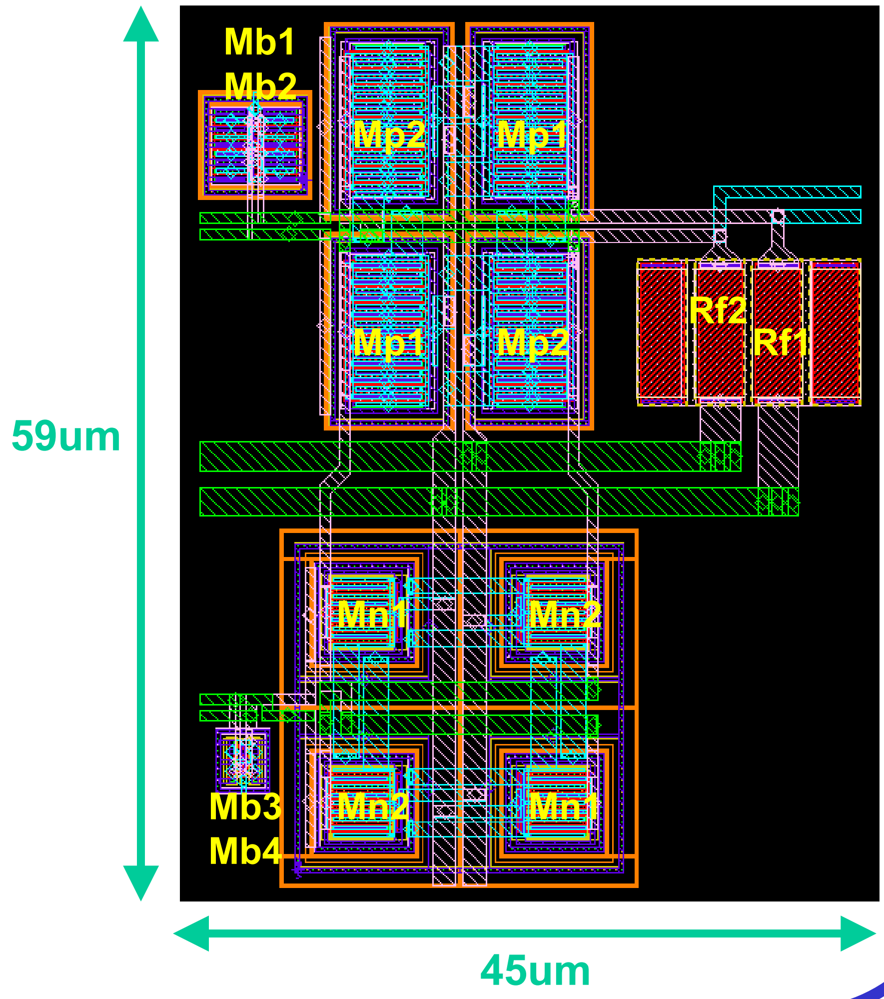
- Back-gate Cross-coupling enhances Gm by 10%



- *Power = 0.61mW*
- All the specs are met

UWB LNA Layout

- ST Microelectronics 0.13um CMOS triple-well process
- Layout area:
  59um x 45um
- Common-centroid layout for good transistor matching
- Dummy for good resistor matching
- Capacitors not shown



Future Work

- Wideband matching networks will be investigated to complete the receiver front-end
  - How much can we gain from them?
- Compare performance of different antenna/LNA combinations at the receiver
  - Loop antenna? Monopole antenna?
- Research on 3-10GHz UWB front-end
  - Antenna Q is small, but directivity goes up
  - Different methodology is needed