A noise-cancelling technique in a wideband LNA achieves low noise figure (NF) and source impedance matching without global feedback. The 0.25μm LNA provides <2.4dB NF from 0.01-2GHz, total voltage gain is 13.7dB, -3dB bandwidth is 0.01-1.6GHz, S11 is <-36dB, and S12 is <-10dB. IIP2 is 12dBm, and IIP3 is 0dBm drawing 14mA at 2.5V.

**Outline**

- Introduction
- Existing Wideband Techniques
- Noise Canceling Technique
- CMOS Circuit Implementation
- Measurement Results
- Conclusions

**Introduction:** (1)

- Why Wideband LNAs?
  - Wideband Receiver
    - E.g.: CATV
  - Multiband Receiver
    - E.g.: Base Station
- Implementation: ✓ CMOS ✓ No Inductors

**Introduction:** (2)

- Key LNA Requirements:
  - Multi-decade Bandwidth: MHz -> GHz
  - Source Impedance Matching: \( Z_{IN}=R_S \)
  - Low Noise Figure (NF): <3dB
- Other:
  - Gain, Linearity, Isolation, ... etc.

**Existing Wideband Techniques:** (1)

- Input device determines \( F=\frac{SNR_{OUT}}{SNR_N} \)
- \( F \) to \( Z_{IN}=R_S \) Trade-off:
  - Low \( F \) Laaaaaarge \( g_m \) and \( R_i \)
  - \( Z_N=R_S \) \( \frac{1}{g_m}=\frac{1}{R_S} \) and \( R_S=R_g \) \( F>2 \) (NF>3dB)!!

**Existing Wideband Techniques:** (2)

- \( F \) to \( Z_{IN}=R_S \) decoupling via feedback
  - \( F=1+\frac{\frac{1}{g_m}}{\frac{1}{g_m}+R_S/R} = 1+\frac{R_S}{R} \)
  - \( R_{IN}=\frac{1}{1+Av} \)
  - \( Av=\)Multiple stages \( \bigstar \) Instability!
  - \( \bigstar \) Matching and Gain coupled \( \bigstar \) AGC@\( Av=R_g \)!
  - \( \bigstar \) Loop-gain <1 for \( Av \) \( \bigstar \) Modest Linearity!

**Noise Canceling Technique:** Principle (1)

- \( R_{IN}=\frac{1}{g_m} \)
- \( \bigstar \) Signals @ nodes X and Y: OPPOSITE SIGN
- \( \bigstar \) Noise @ nodes X and Y: EQUAL SIGN!
Noise Canceling Technique: Principle (2)

\[ \text{Noise Cancels if } V_{in} A + V_n = 0 \quad \Rightarrow \quad A = \frac{1}{1 + R/R_n} \]

But Signals Add!!

Matching, ...but no output noise \[ R_n \text{ and } F \text{ decoupled} \]

Depends on \( R_s \)

Noise Canceling Technique: Properties (1)

\[ F = 1 - \frac{2}{A_{VF}} \cdot \frac{8 - 6 A_{VF} + A_{VF}^2}{A_{VF}^2} > 1 - \frac{2}{A_{VF}} \]

Feed-forward \[ \Rightarrow \text{ Instability risks relaxed} \]

Matching and Gain decoupled \[ \text{AGC} \quad \Rightarrow \quad R_n = R_s \]

Noise Canceling Technique: Properties (2)

\[ I_{Bias} \]

- Bias noise \( I_{bias1} \), cancels too
- Robust to device parameter variations:
  - \( \text{Canceling independent of: } Z_y, Z_o, Z_n = 1/g_{m1} \)
  - \( \text{For } \varepsilon = g_{m2}/g_{m3} \cdot 1 - R/R_s \quad \Rightarrow \quad F = 1 + \text{NEF} \cdot (\varepsilon A_{VF}) \)
    (Monte Carlo: \( 4 \sigma(NF) < 0.2 \text{dB} @ 2 \text{GHz} \))

Noise Canceling Technique: HF Limitations

\[ C_{\text{IN}} \]

\( C_{\text{IN}} \) Noise canceling degrades @ HF

\( \Delta N(f) = 0.1 \text{dB@1GHz and 0.4dB @2GHz (Simulation)} \)

- Compensation helps e.g. shunt peaking

CMOS Circuit Implementation: Schematic

AC coupling: HPF

Bias decoupling

Inverter: Larger \( g_{m}/I_o \)

- Better Isolation
- Lower \( C_{\text{IN}} \)

CMOS Circuit Implementation: Simulation

Cancellation check:

\[ S_W: \text{CLOSED, } C_2 = 0 \]

\[ S_W: \text{OPEN} \]

Yes! It works

CMOS Circuit Implementation: Chip

\[ 0.25 \text{mm} \]

\[ 0.3 \text{mm} \]

Measurement Results: (On-Wafer)

\[ f \text{ [MHz]} \]

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**Measurement Results: NF (PCB)**

- **NOISE FIGURE NF$_{200}$**
  - [Graph showing NF vs. frequency](image)
  - Due to $C_{in}=1.2pF$

**Measurement Results: IIP2 (PCB)**

- **OUTPUT POWER $P_{out}$**
  - [Graph showing $P_{out}$ vs. $P_{in}$](image)
  - $f_1=200MHz$ and $f_2=300MHz$

**Measurement Results: IIP3 (PCB)**

- **OUTPUT POWER $P_{out}$**
  - [Graph showing $P_{out}$ vs. $P_{in}$](image)
  - $f_1=900MHz$ and $f_2=905MHz$

**Measurement Results: Summary**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
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<tbody>
<tr>
<td>$</td>
<td>A_{FE}</td>
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<tr>
<td>-3dB BW</td>
<td>2-1600 MHz ($C_{GAS}=C_{PD}=0.2pF$)</td>
</tr>
<tr>
<td>$</td>
<td>S_{21}$</td>
</tr>
<tr>
<td>$</td>
<td>S_{11}$</td>
</tr>
<tr>
<td>$</td>
<td>S_{22}$</td>
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<tr>
<td>IIP3 (input ref.)</td>
<td>0 dBm ($f_1=900MHz$ &amp; $f_2=905MHz$)</td>
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<tr>
<td>IIP2 (input ref.)</td>
<td>12 dBm ($f_1=200MHz$ &amp; $f_2=300MHz$)</td>
</tr>
<tr>
<td>ICP1 (input ref.)</td>
<td>-9 dBm ($f_1=900 MHz$)</td>
</tr>
<tr>
<td>$NF_{S11}$</td>
<td>$&lt;=2dB [0.25-1.1 GHz]$ &amp; $&lt;=2.4dB [0.15-2 GHz]$</td>
</tr>
<tr>
<td>$f_{NC}$</td>
<td>$14mA @ 2.5Volt$</td>
</tr>
<tr>
<td>Area and Technology</td>
<td>$0.3x0.25mm^2$ in a 0.25um CMOS</td>
</tr>
</tbody>
</table>

**Conclusions:**

**New Wideband Low-Noise Technique:**
- Matching-device noise cancels: NF & match decoupled!
- Wideband sub 3dB NF
- Good stability (feed-forward)
- Variable gain @ constant match

**Demo:** 0.25um CMOS LNA
- 14dB gain over > 2 decades (2-1600MHz)
- NF< 2.4dB over > 1 decade (150-2000 MHz)

**Generalization:**
- Other implementations, devices and WB building-blocks.