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LNA based on a low cost (~USD1.30) commercial GaAs pHEMT MMIC offers wideband (0.4~1.4 GHz) and room-temperature low noise (~0.3 dB) performances that satisfy the SKA low cost and no-cooling requirement

Chin-Leong Lim

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LNA based on a low cost (~USD1.30) commercial GaAs pHEMT MMIC offers wideband (0.4~1.4 GHz) and room-temperature low noise (~0.3 dB) performances that can satisfy the SKA low cost and no-cooling requirements.

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Commercial MMIC advantages

• Fabricated LNA shows $F = 0.3 \text{ dB (Tn=21K)}$, $G = 18 \text{ dB}$, $P_{1\text{dB}} = 22 \text{ dBm}$ and $OIP_3 = 37 \text{ dBm}$. $BW = 0.35 \text{ to } >2 \text{ GHz at 10 dB point}$. (outperforms previously published custom designs).

• Lower price than custom designs because of economy of scale & intense supplier competition.

• No masks and foundry fees.

• Short LNA development time through manufacturer-supplied models, reference boards & other design tools.

• Industry standard packages can be handled by SMD pick & place mc. NO wire-bonding to bare die, hermetic package, or Peltier cooling, etc.

• Devices have undergone extensive electrical, mechanical and environmental reliability tests.

• Field defects can be returned to manufacturer for failure analysis & corrective action.
Commercial MMICs weaknesses

Historical reluctance to adopt commercial devices for RT based on presumption of inferior performances compared to custom designs.

“(Bandwidth, noise and linearity) requirements make it not very likely that components of the telecommunication industry can be used directly. Dedicated development of integrated circuits for SKA will therefore, be required.”


“…with the SKA achieving its sensitivity predominantly through area increase, the application of commercially available discrete components should not be ruled out.”

Custom design #1: 0.18μm CMOS, 1000x800 um, unpackaged

Custom design 3: package scale Peltier cooling


Noise temperature vs. Peltier power

F ≈ 1 dB

F ≈ 1.3 dB

Tn [K] @ 2.6GHz
Tj [°C]

80um InP

Ppelt [W]
0.4-1.5 GHz LNA based on a commercial GaAs pHEMT MMIC

Outline:

• Device details.
• Reducing noise.
• Fabrication.
• Modeling.
• Testing.

Avago Technologies
MGA-633P8 LNA MMIC
0.25 um GaAs ePHEMT – cost vs. performance,

\( f_T > 30 \text{ GHz} \), reach target G in 1 amp stage.

Common-source amp and bias regulator.

I\( \text{dd} \) adjustable (25~75 mA) via ext resistor to bias regulator.

Amp and bias on same material = temperature compensation & de-sensitive against \( V_T \) variation (manufacturability).
Improve noise figure by minimizing matching loss

\[ A(dB) = 20 \log \left( \frac{Q_u - \sqrt{\frac{R_H}{R_L}} - 1}{Q_u} \right) \]

\[ \downarrow A, \ \frac{R_{IN}}{R_S} \to 1. \]
\[ W_G \sim 50\Omega. \]
\[ \Gamma_{IN} < 0.3 \ (0.4 - 10 \text{ GHz}). \]
\[ \text{Wider BW.} \]
Improve noise figure by increasing metal thickness

Thickness Au interconnect: 2 um → 4 um, 2x over previous process.
Reduce resistive losses = ↓ Johnson noise.
When $Z_i \approx 50R$, $A_{IN}$ insensitive to the Q of L1.

The input components more like bias network than $Z$ match.

$\Delta F < 0.05$ dB for 5x change in Q.

Low cost (lossy) components can be used without impacting NF.
Complete LNA circuit

No. of off-chip components: 9.
Bias components not feasible to integrate.
Evaluation PCB

10mil Rogers RO4350 PCB.

0402 size RLC.

A = 8x10 mm.
The MMIC was modeled using scattering (s2p) and noise parameters obtained from measurement on a Thru-Reflect-Line (TRL) fixture.

For off-chip RLC, only 1st order parasitics are considered.
Gain & Return Loss vs. frequency

G > 15 dB.

IRL, ORL < –10 dB over 0.4~1.4 GHz.

Wide matched BW (RL≤-10 dB) = 0.35 – 6 GHz – prevents filter detuning.

Good agreement between model & measurement.
Noise figure vs frequency

F \approx 0.3 \text{ dB at mid-band.}

F < 0.4 \text{ dB over } 0.4\text{~}1.4 \text{ GHz.}

F_{\text{SIM}} > F_{\text{MES}} \text{ because of automated source pull tuner loss.}
Out-of-band stability

Feeds & post LNA filters can be highly reflective outside pass-band.

\( k > 1 \) from HF to 20 GHz.

Unconditionally stable.

Wideband gain & \( S_{21} \) & \( k \)

Start: 50 MHz

Stop: 20 GHz

#2, 5V53mA

Unconditionally stable!

\( K = 1 \)
Desensitization & gain compression

Large geographic spread = stations in urban areas desensitized by TV/radio/cellular Tx.

P1dB = immunity to sensitivity reduction in the presence of stronger adjacent channel interference.

$G \approx 18 \text{dB}, \downarrow 1 \text{dB at } \Pi = 5.3 \text{ dBm}, \text{OP1dB}=22.3 \text{ dBm}.$

Hi P1dB by $I_{dd} \propto \Pi$, class AB.
3\textsuperscript{rd} order intercept point (900 & 901 MHz tones)

\[ OIP_3 = P_{\text{fund}} + \frac{\Delta IM}{2} \]

\( \uparrow \text{OIP3} = \text{less spurious in noisy (e.g. urban) RF environment.} \)

\( \text{OIP3}>37 \text{ dBm}. \)
Gain, P1dB & OIP3 vs. bias

OIP3 can be varied over 10 dB while G & P1dB minimally affected.

When less linearity is required, Idd can reduced to conserve P, & vice versa.

ΔP1dB < 0.5 dB
ΔG < 0.5 dB
ΔOIP3 ≈10 dB

OIP3 vs. Idd
Start: 25 mA
Stop: 75 mA
Vd=5v, 900&901MHz

Oip3 vs. Ids
G  P1dB  Oip3
Performance comparison with custom designs

<table>
<thead>
<tr>
<th>Ref.</th>
<th>F (dB)</th>
<th>G (dB)</th>
<th>BW @ RL ≤-10dB (MHz)</th>
<th>P1dB (dBm)</th>
<th>OIP3 (dB)</th>
<th>OIP3 – P1dB (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belostotski, 2007</td>
<td>0.6</td>
<td>16</td>
<td>500-1500</td>
<td>6</td>
<td>14.5</td>
<td>8.5</td>
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<tr>
<td>Enguehard, 2009</td>
<td>1.4</td>
<td>16</td>
<td>1000-2500</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
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<tr>
<td>This work, MGA-633P8</td>
<td>0.3</td>
<td>18</td>
<td>350-2500</td>
<td>22.3</td>
<td>37</td>
<td>14.7</td>
</tr>
</tbody>
</table>

G & F specified at fc.

Conclusion: Commercial device has better noise & linearity performances.
Summary

Commercial GaAs pHEMT devices advantages:

1. Zero device development time.
2. No setup cost (e.g. masks, foundry fees).
3. Economy of scale – lower unit cost than custom designs.
4. Faster LNA development / prototyping with manufacturer supplied design tools - s2p, circuit model, application note and evaluation PCB, etc.
5. Extensively reliability tested.
6. Manufacturability - industry standard package suits pick and place automation & internal bias compensates against parametric / operating temperature variations.
7. Noise performance better than reported custom designs & close to cryo-cooled level.
8. High P1dB, OIP3 & Linearity Figure of Merit – interference resistant.