Different LNA Topologies Designed with HEMT Technologies at Ka and Q Bands

Lakshmi Balla, Venkata Krishna Sharma Gollakota, Sandhya Teku

Abstract: The main drawback of designing LNA with CMOS technology is the high power dissipation. This problem can be overcome by designing LNA with HEMT technology. In this paper we went through several LNA's designed with different HEMT technologies from the past few decades. Assessment of different LNA topologies with HEMT technologies around ka and Q band is performed in this paper along with EM simulations of PP1010 unconditionally stable LNA.

Keywords: Complementary metal oxide semiconductor (CMOS); Low noise amplifier (LNA); Radio Frequency (RF); High electron mobility transistor (HEMT);

I. INTRODUCTION

LNA is key building block of RF receiver of wireless communication. LNA amplifies the received weak signal from an antenna at low noise level. As LNA is starting building block of the entire receiver system, LNA should be designed with low noise figure (NF) to maintain overall receiver NF low. LNA is used in numerous applications like radio astronomy applications, wireless local area networks, telecommunications, radar systems and satellite communications etc. Basic features of LNA are NF, gain, input and output return losses (IRL, ORL). All these features are represented by S parameters of the amplifier. Along with these features linearity, dynamic range, bandwidth, stability and power dissipation are also the important features to be considered while designing a LNA.

From the overall research, LNA design topologies with HEMT technologies are briefly classified into 6 sections. 1) The basic common source (CS) topology [1, 2] offers low NF but moderate gain compared to the other topologies. 2) CS topology with source degenerated with inductor [3, 4] offers good trade-off between NF and gain. 3) Self-bias topology [5, 6] avoids applying the bias at the gate of the HEMT. 4) Current reuse topology [7] where the same current flows through the two HEMT’s with both gates of the HEMTs grounded. 5) Distributed topology [8] where all the gates are connected to same point and all drains are connected to same point such that it leads to ultra wide bandwidth. 6) Resistive feedback topology [9] where the resistor is used in between the gate and drain such that it compensates the effect of cgd

II. CLASSIFICATION OF HEMT TOPOLOGIES

Various HEMT topologies of designing a LNA are briefly classified as

1) CS topology
2) CS with source degenerated with inductor topology
3) Self-bias CS/inductive degeneration topology
4) Current reuse common gate topology
5) Distributed LNA topology
6) Resistive feedback topology

III. COMPARISON OF DIFFERENT TOPOLOGIES OF LNA

1) CS HEMT topology

Basic CS topology of HEMT LNA is shown in Fig. 1, where dc bias is given to the gate and drain along with the matching networks at input and output side and zo indicates the terminating impedance both at input and output side.

Various CS LNA’s with different technologies designed around Ka, Q bands are reported in Table-I. Low NF of 1.8 dB achieved with 0.07 µm GaAs mHEMT [2] and 0.1 µm Inp HEMT [1] with CS topology. Finally within CS topology 0.07µm GaAs mHEMT and 0.1µm Inp HEMT offers best NF at Q band.
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Table-I: Comparison table of CS topologies

<table>
<thead>
<tr>
<th>Reference</th>
<th>Technology</th>
<th>Topology</th>
<th>No. of stages</th>
<th>Gain (dB)</th>
<th>NF (dB)</th>
<th>Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1]</td>
<td>0.1 µm Inp HEMT</td>
<td>CS</td>
<td>2</td>
<td>20</td>
<td>1.8</td>
<td>44</td>
</tr>
<tr>
<td>[2]</td>
<td>0.07 µm GaAs mHEMT</td>
<td>CS</td>
<td>4</td>
<td>28.2</td>
<td>1.8</td>
<td>33-50</td>
</tr>
<tr>
<td>[3]</td>
<td>0.1 µm GaAs mHEMT</td>
<td>CS</td>
<td>4</td>
<td>28</td>
<td>2.5</td>
<td>44</td>
</tr>
</tbody>
</table>

2) CS with source degenerated with inductor topology:

Fig. 2. CS with source degenerated with inductor topology

CS topology with source degenerated with inductor is shown in Fig. 2. It is the extension of CS topology where the source is degenerated with inductor. Generally, transmission line is used as an inductor. Remaining biasing networks, matching networks and terminating impedances are same as with CS topology.

Table- II: comparison table of CS with inductive degeneration topologies

<table>
<thead>
<tr>
<th>Reference</th>
<th>Technology</th>
<th>Topology</th>
<th>No. of stages</th>
<th>Gain (dB)</th>
<th>NF (dB)</th>
<th>Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[3]</td>
<td>0.15µm GaAs pHEMT</td>
<td>c.s with inductive degeneration</td>
<td>3</td>
<td>22.8</td>
<td>1.6</td>
<td>28</td>
</tr>
<tr>
<td>[4]</td>
<td>0.15 µm InGaAs mHEMT</td>
<td>c.s with inductive degeneration</td>
<td>3</td>
<td>31</td>
<td>2.8</td>
<td>44</td>
</tr>
<tr>
<td>[4]</td>
<td>0.15 µm InGaAs mHEMT</td>
<td>c.s with inductive degeneration</td>
<td>3</td>
<td>28</td>
<td>2.6</td>
<td>44</td>
</tr>
</tbody>
</table>

Various CS with inductive degenerated LNA’s designed at different HEMT technologies around Ka, Q band are reported in Table- II. Using inductive degeneration 0.15 µm GaAs pHEMT [3] results a low NF of 1.6 at Ka band. High gain of 31 dB achieved with 0.15 µm InGaAs mHEMT [4].

3) Self bias CS inductive degeneration topology:

Fig. 3. Self bias CS with source degenerated with inductor topology

Self bias CS topology with source degenerated with inductor is shown in Fig 3. In previous topology gate is biased with the dc supply, whereas self bias topology avoids the bias at the gate of the HEMT, and transmission line is used as inductive degeneration. Biasing networks, matching networks, terminating impedances are similar with other topologies.

Table- III: comparison table of self bias CS inductive degeneration topology

<table>
<thead>
<tr>
<th>Reference</th>
<th>Technology</th>
<th>Topology</th>
<th>No. of stages</th>
<th>Gain (dB)</th>
<th>NF (dB)</th>
<th>Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[5]</td>
<td>0.15µm GaAs pHEMT</td>
<td>Self bias c.s with inductive degeneration</td>
<td>2</td>
<td>18</td>
<td>1.5</td>
<td>42-44</td>
</tr>
<tr>
<td>[5]</td>
<td>0.15µm GaAs pHEMT</td>
<td>Self bias c.s with inductive degeneration</td>
<td>2</td>
<td>19</td>
<td>1.55</td>
<td>42-44</td>
</tr>
<tr>
<td>[6]</td>
<td>0.07µm AlGaAs/InGaAs mHEMT</td>
<td>Self bias c.s with inductive degeneration</td>
<td>3</td>
<td>20</td>
<td>2.5</td>
<td>40</td>
</tr>
</tbody>
</table>

Different LNA’s with CS self bias inductive degeneration around Q band are reported in Table III. Low NF of 1.5 dB obtained with 0.15µm GaAs pHEMT [5]. High gain of 20 dB obtained with 0.07µm AlGaAs/InGaAs mHEMT [6].

4) Current reuse common gate (CCG) topology

Fig. 4. current reuse common gate topology

CCG topology is shown in Fig. 4. In contrast to other topologies gates of both HEMT’s are grounded in this topology and same current is passed through the both the HEMT’s.

Table-IV: comparison table of current reuse common gate topology

<table>
<thead>
<tr>
<th>Reference</th>
<th>Technology</th>
<th>Topology</th>
<th>No. of stages</th>
<th>Gain (dB)</th>
<th>NF (dB)</th>
<th>Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[7]</td>
<td>0.12µm GaN pHEMT</td>
<td>CCG</td>
<td>2</td>
<td>15</td>
<td>3</td>
<td>33-41</td>
</tr>
</tbody>
</table>

Up to authors knowledge very few works found with current reuse common gate topology. The major drawback of the common gate topology is it offers relatively high NF compared to CS topology. Low input impedance offered by...
common gate topology is the important feature in designing LNA. This 0.12µm GaN pHEMT LNA [7] obtained a degraded performance in terms of NF and gain relative to GaAs HEMT LNA.

5) Distributed LNA topology:

![Fig. 5: Distributed LNA topology](image)

Distributed LNA topology using HEMT technology is as shown in Fig. 5. In contrast to the other topologies all the gates are connected to one point and all the drains are connected to one point and applied with bias, whereas all sources are grounded. This topology results an ultra wide bandwidth.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Technology</th>
<th>Topology</th>
<th>No. of stages</th>
<th>Gain (dB)</th>
<th>NF (dB)</th>
<th>Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[8]</td>
<td>0.15µm GaAs pHEMT</td>
<td>Distributed</td>
<td>2</td>
<td>15</td>
<td>3.3</td>
<td>50-60</td>
</tr>
</tbody>
</table>

0.15µm GaAs pHEMT LNA [8] using distributed method offers degraded performance of high NF and low gain compared with other methods of 0.15µm GaAs pHEMT LNA’s [3],[5].

6) Resistive feedback (RFB) topology:

![Fig. 6: Resistive feedback topology](image)

Fig. 6 shows the RFB topology. In this topology resistor is connected in between gate and drain of the HEMT to compensate the effect of $c_{gd}$. This topology is competitive with the other topologies in terms of NF and gain but its performance is degrades at lower frequencies.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Technology</th>
<th>Topology</th>
<th>No. of stages</th>
<th>Gain (dB)</th>
<th>NF (dB)</th>
<th>Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[9]</td>
<td>0.15µm E-mode GaAs</td>
<td>Resistive feedback</td>
<td>4</td>
<td>30</td>
<td>1.25</td>
<td>14-31</td>
</tr>
</tbody>
</table>

From Table- VI it can be observed that 0.15µm E-mode GaAs pHEMT [9] resistive feedback topology gives a very low NF of 1.25dB relative to the remaining all topologies. However resistive feedback causes high NF at low frequency band like L band.

IV. SIMULATION RESULTS OF PP1010 HEMT LNA

PP1010 HEMT is selected as active device for designing LNA. The characteristics of Ids vs Vds over fixed Vgs and Ids vs Vgs over fixed Vds of the PP1010 HEMT are shown in Fig. 7 and Fig. 8 respectively.

![Fig. 7: Ids vs Vgs curve of PP1010 for fixed Vds](image)

![Fig. 8: Ids vs Vds curve of PP1010 for fixed Vgs](image)

It can be observed from the Fig. 7 and Fig. 8 that the cutoff voltage for PP1010 HEMT is around -0.725V at Vds =1.5V. Hence Vgs of PP1010 HEMT is to be maintained above -0.725V.

![Fig. 9: MaxGain, NFmin vs Frequency](image)
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For low noise figure, PP1010 HEMT has to be biased at 10-15% of Idss. When PP1010 HEMT is biased for Vgs of -0.4V and Vds swept from 0-2 V, NFmin of 1.34 dB and maximum gain of 9.576 dB is obtained as shown in Fig. 9. Reducing the bias current gives a smaller NFmin, but the gain decreases as well. The bias current of 19 mA is a trade-off between NFmin and maximum gain.

V. CONCLUSION

Analysis of different LNA topologies with HEMT technologies from the past decades has been performed. Comparison is mainly concentrated on NF and gain parameters. Out of all topologies resistive feedback topology with 0.15μm E- mode GaAs pHEMT offers better performance at Ka band but performance is degraded at L band and 0.15μm GaAs pHEMT with CS and source degenerated with inductor topology results a better performance at Q band. EM simulations of PP1010 HEMT LNA are performed. Results exhibit the accuracy of developed EM model.

REFERENCES


AUTHORS PROFILE

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