Review on High Gain and High Performance N-Polar GaN MIS-HEMT at 30 GHz

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ABSTRACT

The GaN HEMTs are well suited for receiver applications. But non-linearities, such as third-order intermodulation products can lead to signal distortion. Such non linearities are dominated by transconductance and its derivatives. A modified device structure of N-polar GaN MIS-HEMTs designed for high gain, have excellent linearity performance for low-power receiver applications at 30 GHz. An OIP3/PDC of up to 15dB is demonstrated at 30 GHz using a vector receiver load pull system.

KEYWORD: GaN, N-polar, linearity, inter modulation distortion, Transconductance

INTRODUCTION

As a semiconductor material, Gallium Nitride (GaN) has higher electron mobility and higher electron saturation velocity compared to Si. This makes GaN excellent choice for high frequency operation. This material has bandgap of 3.4eV which is several times greater than that of Si[5]. GaN high electron mobility transistor (HEMT) have low on-state resistance and superior high-speed switching performance as well as high breakdown voltage. Technologies and research in GaN in scaling the gate length into deep submicron region have extended usable frequency range to millimeter waves. GaN HEMTs are mainly used for power amplification and for low power receiver applications.

The linearization technique in device level is discussed for receiver application. The parameters such as transconductance $g_m$ and its derivatives (such as $g_{m2}$ and $g_{m3}$) are the main factors that govern linearity of the device and intermodulation distortion [10]. The intermodulation distortion are spurious frequency components[11] that can lead to signal distortion in front end receivers.

Under two-tone stimulus, the linearity metrics are IM3, C/IM3, OIP3 and $OIP3/P_{DC}$. The power in third-order intermodulation products is indicated by IM3. Ratio of carrier power to IM3 is shortly termed as C/IM3. Output-referred third order intercept point (OIP3) mentioned in [1], [10] is the deduced output power at which the carrier power equals IM3. OIP3 normalized over dissipated DC power ($OIP3/P_{DC}$), is a figure of merit for comparing the linearity among different devices and bias conditions, giving importance to power dissipation. This is the best metric for comparison of linearity among devices.

The device is designed for high transconductance. In order to decrease $g_{m3}$ the biasing condition is selected for two-tone load-pull measurement. High transconductance indicates high gain. Low $g_{m3}$ indicates high OIP3. For achieving linearity in device, some modifications in design structure in Ga polar GaN MIS HEMT in [6], [7], [8] as well as in N polar GaN MIS HEMT in [2], [3], [11] were reported. The device structure in [2] showed $OIP3/P_{DC}$ of up to 11.4 dB at 30 GHz.

DEVICE STRUCTURE

The device structure from the N-polar GaN MIS-HEMT mentioned in [2] are modified using thin AlGaN/GaN cap which is used to improve gain and scaled gate-length for higher transconductance and low drain bias voltage [1].


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Using metal organic chemical vapour decomposition (MOCVD), the sample is grown on a miscut SiC substrate. The techniques of epitaxial growth [12] is mostly same for planar N-polar devices [13] and GaN cap was added for better millimeter-wave performance [3]. The 2-dimensional electron gas (2DEG) within the GaN channel is formed at its bottom interface with the AlGaN barrier. Then the 2DEG is bordered by AlGaN. The source and ohmic drain contacts are realized by molecular beam epitaxy regrown n⁺GaN, and electron beam deposited Ti/Au metal stack. The gate trench was accomplished by removing the AlGaN cap layer with non-selective etch and then utilizing BCl₃/SF₆ selective dry etch for removing the GaN cap and stop on the AlGaN interlayer. 7 nm of SiNx gate dielectric is deposited by MOCVD in the gate trench, followed by a Cr/Au T-gate metal stack. Information on device fabrication can be referred in [3].

The transconductance and its derivatives such as \( g_{m2} \) and \( g_{m3} \) is shown in Fig 3. Beyond peak of \( g_m \), there will be sharp decrease in \( g_m \) when gate voltage is increased. This usually happens in GaN HEMT devices. One of the bias conditions for high OIP3 is using \( g_{m3} \) zero crossing point where device turns on and at a limited range of gate bias, OIP3/P_{dc} will be at peak value. In this graph, \( g_{m3} \) crosses zero at \( V_{GS} = -5.18 \text{V} \), a good linear response and a peak in the OIP3 and OIP3/P_{dc} is expected.

**RESULTS AND DISCUSSIONS**

The output and transfer characteristics was observed with 800 ns of drain pulse width and 1μs of gate pulse width. The measurements in Fig. 2 and Fig. 3 are taken at quiescent gate and drain bias (\( V_{GSQ}, V_{DSQ} \)) of (−6V;+7V) to observe the relevant I-V characteristics for RF measurements. Within the transfer curve (Fig. 2), the pulsed gate voltage (\( V_{GS,P} \)) has been swept from −6V to 0V, whereas pulsed drain voltage (\( V_{DS,P} \)) is maintained at +7V. Threshold voltage of −5.24V and maximum transconductance (\( g_m \)) of 0.53 S/mm peaking at \( V_{GS} = -4.3 \text{V} \) was observed.
The linearity performance in Fig 5 was observed using two tone load pull input bias sweep. The red curve indicates coarse sweep and blue curve finer $V_{GS}$ capture peak $OIP3/P_{DC}$. At $V_{GS} = -5.1$ V there is sharp peak $OIP3/P_{DC}$ that is adhering with Fig 3 at zero crossing point. Over limited range of gate bias there is peak $OIP3/P_{DC}$. This means that linearity is sensitive to gate bias.

![Fig 6 Total output power in the fundamental tones and corresponding OIP3](image1)

**Fig 6** Total output power in the fundamental tones and corresponding OIP3

In Fig 6 and Fig 7, two-tone load-pull input-power sweep at 30 GHz with tone spacing of 1 MHz are represented. The biasing is done at $V_{GS}$ of $-5.125$ V, $I_{DQ}$ of 135 mA/mm and $V_{DSQ}$ of 7V. In Fig 6, there is generation of low IM3, with IM3 better than 50 dBc for input powers less than $-5$ dBm (Fig 7). The device exhibits a maximum $OIP3$ of 32 dBm and a transducer gain ($G_T$) of 12.7 dB at $P_{IN AVAILABLE}$ of $-12.1$ dBm (Fig 6). This shows maximum $OIP3/P_{DC}$ of 15 dB in Fig 7 which is great linearity performance at 30 GHz.

**CONCLUSION**

With new design structure of N-polar GaN MIS-HEMT there is excellent gain and linearity performance of device for receiver application at 30 GHz. The biasing is done at $V_{GS}$ of $-5.125$ V, $I_{DQ}$ of 135 mA/mm and $V_{DSQ}$ of 7V. It is found that at the $OIP3/P_{DC}$ is 15dB and over a limited range of gate-bias and linearity is sensitive to bias with a two-tone load-pull input-bias sweep. With further device engineering we can study and predict distortion for higher performance device with low power consumption.

**REFERENCES**


