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Recent Advances in GaN Power Amplifier Design for Millimeter-Wave Applications

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Abstract

The millimeter-wave band has been widely used in satellite communications, base stations for mobile communication systems and other applications. GaN power amplifiers are promising candidate for the systems because of their high-power capabilities and high-efficiency characteristics in millimeter-wave band. This paper reports on a recent progress in Ka-band GaN amplifiers and design technology to achieve accurate amplifier design operated in higher frequency utilizing novel large-signal transistor model.

1. Introduction

Recently, high power amplifiers (HPA) are in increasing demand especially for millimeter-wave applications such as satellite communication, radar, very small aperture terminal (VSAT) and 5th generation mobile communication systems (5G). GaN monolithic microwave integrated circuit (MMIC) HPA with compact size and high performance have been reported [1]-[5]. The design of amplifier operated in millimeter-wave frequency is more challenging than lower frequency because the effect of parasitics cannot be neglected and the accuracy of large signal transistor is more important. In this paper, a novel large-signal model is introduced and design and measurement results of Ka-band HPA utilizing the model are shown.

2. Distributed Large-Signal Model

In conventional large-signal models, a multi-finger transistor is represented as a simplified equivalent circuit with single gate, drain and source components. This simplification degrades accuracy of the large-signal model especially at higher frequency because the phase difference of standing wave of the RF gate voltage between gate-fingers is neglected. To solve the problem, the scalable large-signal distributed model taking account of phase difference of RF gate voltage between fingers is presented as illustrated in Fig. 1[1]. To consider phase difference of RF gate voltage (V_g), characteristics of a N-finger transistor is modeled by combining N Angelov-GaN unit models, gate resistances, gate inductances, drain resistances, and drain inductances (R_{gi}, L_{gi}, R_{di}, and L_{di}, i=1~N). Each N unit model is connected via those parasitic parameters each other. In the distributed model, phase difference of the RF gate voltage is caused by the parasitic parameters (R_{gi} and L_{gi}), then the different gate voltage is applied to each finger. The model parameters were extracted from the measured I-V characteristics and S-parameters under multi-bias condition for GaN HEMT with 0.15-µm gate length.

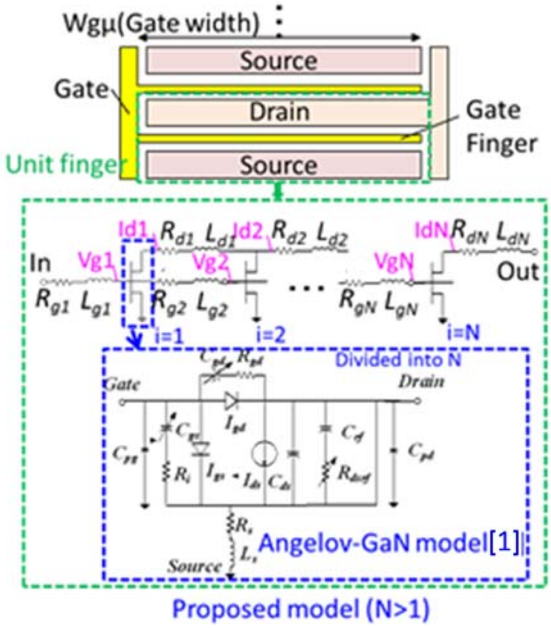

Fig. 1. Schematic of the proposed large-signal distributed model

2. GaN MMIC HPA for Millimeter-Wave Application

A Ka-band GaN MMIC HPA is designed and measured utilizing distributed large-signal model. Fig. 2 shows a photograph of the fabricated GaN power amplifier MMIC. The amplifier consists of 3-stage Class-AB amplifiers. The gate width of unit FET cells is 8 × 50µm. 16-FET cells are combined for the final stage. 8-FET cells and 4-FET cells are used for the 2nd and the 1st driver stage. The GaN MMIC HPA is fabricated utilizing Mitsubishi's 0.15-µm gate process with 50µm substrate thickness GaN-on-SiC technology. The chip size is 4.5 mm × 6.4 mm. Fig. 3 shows the measured small-signal characteristics of the GaN MMIC HPA under quiescent drain bias of V_d = 24V, drain current of I_{d1} = 80mA, I_{d2} = 160mA and I_{d3} = 320mA. The obtained small-signal gain is 18–26dB for 26.5–31GHz. Fig. 4 shows the measured large-signal characteristics of the MMIC PA under continuous wave operation, V_d = 28V, I_{dq} = 25mA/mm in test fixture at 28GHz. The measured saturated output power of 42.2dBm, power added efficiency (PAE) of 20.3% and G_p of 20 dB are obtained. Fig. 5 shows the measured saturated output power, G_p and PAE versus frequency under CW operation. The measured output power of 41.9 - 42.2dBm (15.5–16.6W) and peak PAE of 16.1–20.3% and Gp of 20–13dB over 15.6% fractional bandwidth in 26.5–31GHz are obtained. Table **1** summarize a performance of the HPA comparison to other reported GaN MMIC HPA. The measured performance demonstrates highest output power.

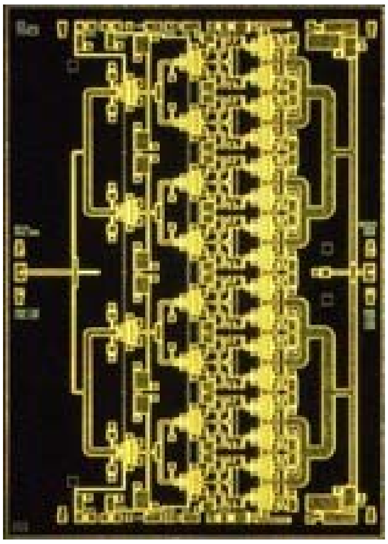

Fig. 2 Photograph of the Ka-band GaN MMIC HPA

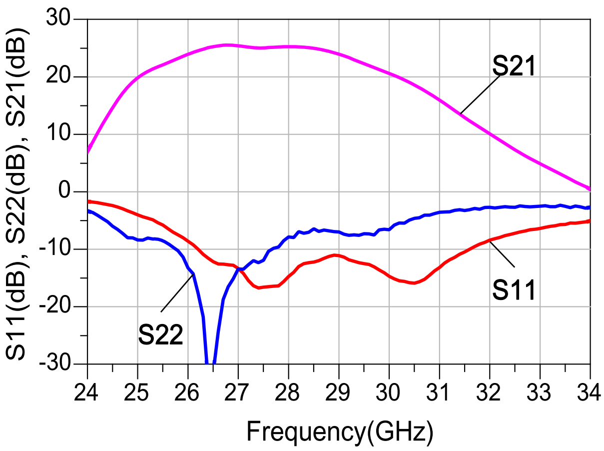

Fig. 3 Measured S-parameters of the Ka-band GaN MMIC HPA

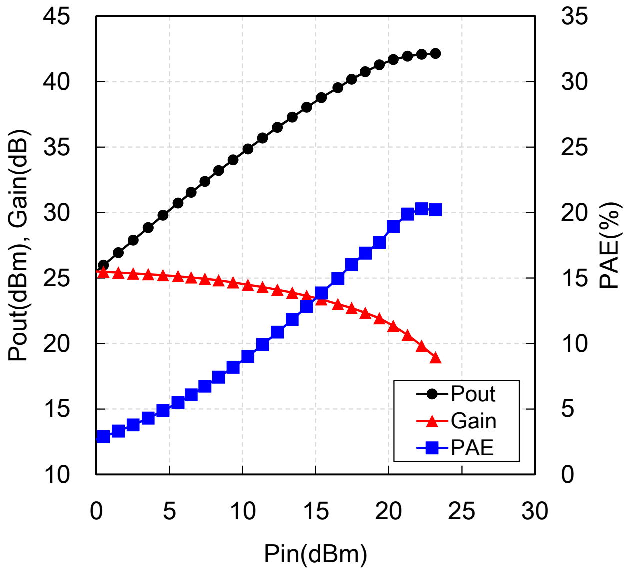

Fig. 4 Measured Large-signal characteristics of the MMIC PA under CW operation, V_d = 28V, I_{dq} = 25mA/mm in test fixture at 28GHz.

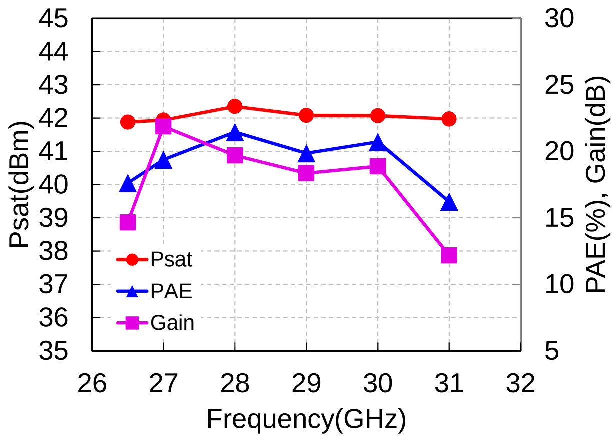

Fig. 5 Measured saturated output power, gain and PAE versus frequency under CW operation.

Table 1 Performance comparison to other reported HPAs

Frequency (GHz)	No. of stages	P_{out} (dBm)	PAE (%)	Refs.
26.5-31	3	41.9	16.1	This Work [2]
28-31	3	37.4	28	[3]
26-28	2	41.7	13.2	[4]
26.5-29	3	38.5	24.5	[5]
25.5-27	2	36.5	30	[6]

3. Conclusions

A distributed large-signal GaN HEMT model is proposed and a Ka-band GaN HPA MMIC is designed and measured utilizing proposed model. The designed HPA demonstrates significant performances thanks to the accuracy of the model. These results shows that these techniques are attractive solutions to achieve novel millimeter-wave systems.

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