A GaN MMIC FEM(Front End Module) with 5GNR Performance Verification in mmWave

line 1: 1st Ji Hye Hwang
line 2: *ICT Device & Packaging Center*
line 3: *Korea Electronics Technology Institute*
line 4: Gyeonggi-do, Korea
line 5: jh93322@keti.re.kr

line 1: 2nd Kwang Ho Ahn
line 2: *ICT Device & Packaging Center*
line 3: *Korea Electronics Technology Institute*
line 4: Gyeonggi-do, Korea
line 5: khajoh@keti.re.kr

line 1: 3rd Ki Jin Kim
line 2: *ICT Device & Packaging Center*
line 3: *Korea Electronics Technology Institute*
line 4: Gyeonggi-do, Korea
line 5: sergeant@keti.re.kr

line 1: 4th Soo-Chang Chae
line 2: *ICT Device & Packaging Center*
line 3: *Korea Electronics Technology Institute*
line 4: Gyeonggi-do, Korea
line 5: sc.chae@keti.re.kr

***Abstract*— This study presents the design of FEM (Front-End Module) with 100 nm GaN HEMT technology and HTCC process. A customized transistor model enables the designing circuits operating at Ka-band. The designed results at center frequency achieved the Tx small signal gain is 21.8 dB, the saturated output power (Psat) is 33 dBm, the power added efficiency (PAE) is 20.1% and the EVM with average power of 23dBm is 3.49%. Also, The Rx small signal gain is 23.8dB, the Noise figure is 3.53dB and TRx isolation is 32.2dB.**

Keywords—FEM, Front End Module, Tx, Rx, GaN, Low noise, 3W Power amplifier, Ka-Band, 28GHz, n257

I. Introduction

In this paper, suggest FEM that is essential for commercializing 5G in the FR2 band around in the world in 2023. The expected 5G momentum is possible only when mmWave in the n257 band are used. Currently, there are many beamforming research results mainly in CMOS, but basically, CMOS is limited in terms of average output power and noise level. If EIRP needs to be raised with high resolution mmWave-Radar and repeater requiring high-performance, a small number of beamformers or antenna elements, the FEM must be placed on a beamforming antenna composed an existing CMOS.

II. Design

A. Power amplifier(PA)

The TR size of the unit cell was selected as 480μm in consideration of thermal gradation, and the three-stage cascade structure is shown in Fig.1. in consideration of the gain and power characteristic. To ensure that the power amplifier operates under the best conditions and achieves its full potential, need to analyze the load impedance of the output characteristics. Load Pull simulations obtain the impedance of the Smith Chart, select the output power of the power amplifier and the Power Added Efficiency (PAE) to be designed based on it. Load Impedance is 9.3+j*12.5 and Input Impedance is 2.2+j*5.5. At this time, PAE (Power-Added-Efficiency) is 49.5%, Output Power is 31.8dBm. For Output Power analysis, Gain Compression Point is set to 1 dB. as frequency increases, the performance of circuits designed with multiple unexpected phenomena, such as mutual-inductance or coupling between parasitic components and path may differ in practice. Therefore, to obtain a more accurate value, the circuit of the Power Amplifier was transformed by layout, which was designed in schematic, and proceeded EM simulations. After full stage matching, 28 GHz PA has 36% PAE within bandwidth (26.5 to 29.5 GHz) at 36.5dBm and has a gain of more than 23dB. It can be seen that it is designed almost similarly except for a slight decrease in efficiency due to insertion loss compared to load-pull simulation.

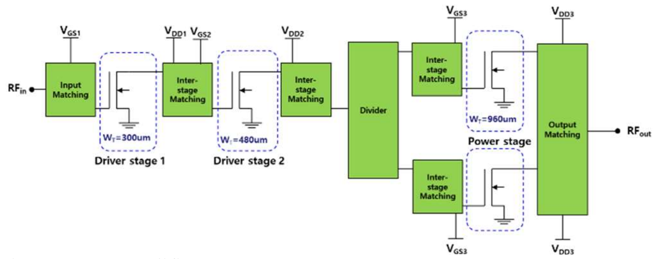


Fig.1. Power amplifier structure

B. Low noise amplifier(LNA)

The TR size of the unit cell was selected as 100μm in consideration of optimal noise point, and the three-stage cascade structure. For the same reason power amplifier, low noise amplifier was proceeded EM simulations. After full stage matching, 28 GHz LNA has 1.56dB NF value within bandwidth (26.5–29.5 GHz) and has a gain of more than 24.9dB.

C. Switch(SPDT)

As the operation frequency reaches to mmWave band, the parasitic reactance and resistive loss of the HEMT device increase drastically, resulting in poor on-and-off performance. Thus, to ensure wideband operation and high isolation between the on and off states, artificial transmission line based SPDT switch is designed. The simulated insertion loss is always less than 1.13dB while the simulated isolation is always better than 31.8dB within the selected operation bandwidth from 26.5GHz to 29.5GHz. Further, the simulated output P1dB of the SPDT within the operation band is found to be 41dBm.

D. HTCC module

Thermal effect while operated device is a very important issue in the GaN device. Is causes performance degradation and consequently fails to show the best performance. Thus, in this paper used HTCC process, because it has characteristics that combine easily and compactly carrier heat sink that can have a heat dissipation effect and printed circuit board(PCB). Also, it has a high thermal conductivity. So, it fits the concept of heat dissipation in this module. Although it is important to have good heat dissipation characteristics, the loss of the module itself is also considered, so here is summarized in compared to the simulation data of TLY5 as shown in Table 1. In the simulation, a Taconic TLY-5 substrate with a relative permittivity of 2.2, loss tangent of 0.0009 and thickness of 0.254 mm and HTCC substrate with a relative permittivity of 8.4, loss tangent of 0.001 and thickness of 0.15 mm is used.

Table I The comparison between HTCC and TLY5

Specification	HTCC	TLY5
Freq.(GHz)	26.5 to 29.5	
Loss (dB/mm)	0.10	0.02

III. Measurement and Analisys

The PA, LNA and SPDT were fabricated with OMMIC 100nm GaN/Si process as shown in Fig.2.

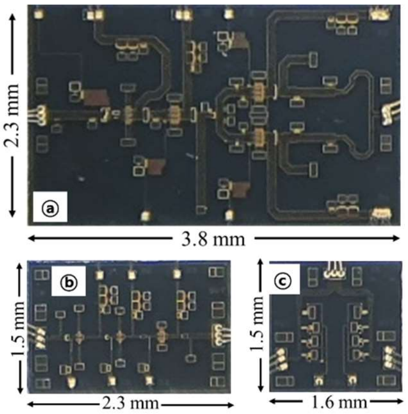


Fig. 2 Fabricated of (a) GaN/Si PA, (b) GaN/Si LNA and (c) GaN/Si SPDT switch MMICs

A. HTCC Line loss

Before integrating the fabricated GaN MMICs as a single FEM, the conventional transmission lines was fabricated. Fig. 3., the difference value of the simulated and the measured loss variation is less than 0.24 dB within the target operation band.

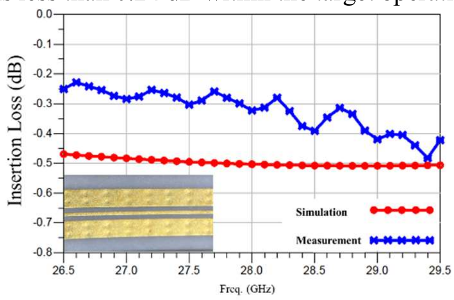


Fig. 3. The comparison between simulation and measurement result of line

B. Implementation and measurement of the FEM

The complete FEM was implemented by the fabricated MMICs and interstage matching lines on a HTCC PCB and a 1.0 mm CPC (Cu-MoCu-Cu) carrier as shown in Fig. 4. To verify the performance of the complete FEM, both Rx-mode and Tx-mode S-parameters were also measured as shown in Fig. 5 (a) and (b), respectively. Also, to verify the linearity of Tx-mode and noise characteristic of Rx-mode were measured as shown in Fig.6. (a),(b) and Fig.7.(a),(b). In Tx-mode EVM is less than 3.74% with average Pout of 23dBm and Rx-mode noise figure is less than 3.9dB within the target operation band.

Identify applicable funding agency here. If none, delete this text box.

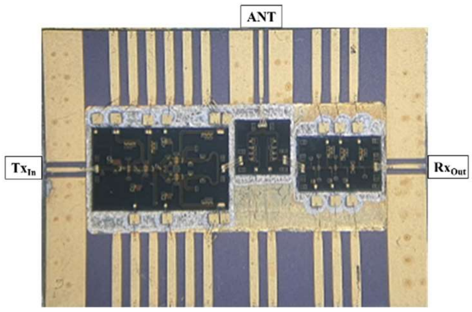
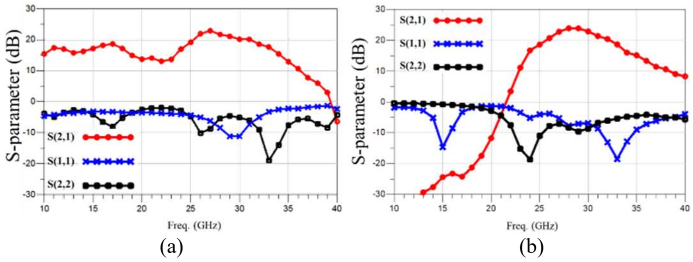
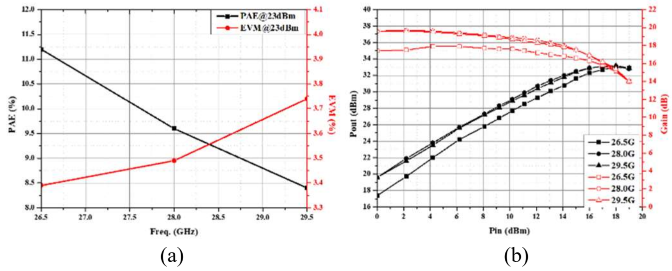


Fig. 4 Fabricated FEM with a photograph



(a) (b)

Fig. 5 The measured S-parameters in (a) Tx-mode and (b) Rx-mode



(a) (b)

Fig. 6 The measured (a)EVM at average power of 23dBm and saturated Pout in Tx-mode

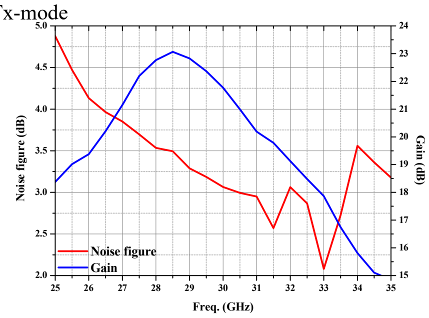


Fig. 7 The measured noise figure in Rx-mode

IV. Conclusion

In this paper, mmWave-5G FEM configured by GaN/Si MMICs has been presented. Then, all MMICs have been integrated within a single carrier as a FEM and successfully verified by a 5G NG signal with 64-QAM,100MHz bandwidth and 120kHz source carrier spacing.

Acknowledgment

This work was supported by the Korea Evaluation Institute of Industrial Technology grant funded by the Ministry of Trade, Industry and Energy. [20011456]

References

[1] Sherif Shakib, “A Highly Efficient and Linear Power Amplifier for 28-GHz 5G Phased Array Radios in 28-nm CMOS”, IEEE, 2016,51, 3020 - 3036.

[2] Jill C. Mayeda*, Jerry Lopez*, Donald Y.C. Lie*, “Broadband High-Efficiency Linear Power Amplifier Design for Millimeter-Wave 5G”, IEEE, 2020, 2158-1525