20. 마이크로파 및 전파(Ⅰ)

Design and Simulation Study of A C-band PHEMT MMIC Power Amplifier for Wireless Local Area Network Application

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Abstract The paper describes the design of a C-band MMIC power amplifier utilizing GaAs pseudomorphic high electron mobility transistor and includes the simulation results of the performance of the power amplifier topology by use of Advanced Design System software. The passive circuit networks such as DC bias. negative feedback loop, power coupler and impedance matching circuit are implemented with microstrip stub and lumped component. The schematic simulation results show: the power amplifier can provide 24.28 dBm output power, 25.28 dB transducer power gain and 39.7% power-added efficiency at 1dB compressing operating point in frequency range from 5.0 GHz to 5.5 GHz, the input and output return losses are all less than -10 dB. The layout of amplifier shows chip area will be about 3.2X2.0 mm^2.

1 . Introduction

The spectacular growth of video, voice and data communication over the internet and mobile telephone justify great expectations for mobile multimedia system and service. Research and development for next generation of wireless broadband multimedia communication system (WBMCS), are taking place all over the world. WBMCS will integrate various functions and applications of contemporary mobile telephone communication, wireless Local area network and computer communications and provide its users with customer premises service. High-speed wireless WAN and LAN systems and technologies are the cores to develop WBMCS. Its research has been drawing much attention of famous companies, institute and universities in the world. In japan, Communication Research Laboratory is working on the broadband mobile communication system in SHF band with a channel bit rate of up to 10 Mbps and indoor high speed SHF band wireless LAN

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with a target bit rate of up to 155 Mbps.

In the United States, Bell Laboratories and Computer & Communication Research Laboratories of Nippon Electric Company are developing seamless WAN , broadband adaptive homing ATM architecture and wireless ATM network.[1] In South korea, Electronics and Communication s Research Institute is exploring and developing the key device and system technologies of 25Mbps wireless ATM LAN system using 5GHz unlicensed NII frequency band based on IEEE802.11-a standard.[2]

With the evolution of existing and new standards for mobile communication systems and wireless multimedia service, the quantity and complexity of the signals to be transmitted from a single location is increasing. The requirements placed on RF power amplifiers, which are used in such systems, are subsequently increasing in terms of bandwidth, output power, efficiency, and allowable level of output distortion. The growing requirement and need for amplifiers provide new challenges to semiconductor industry and RF circuit designer. Metal-Semiconductor Field Effect Transistor (MESFET) amplifiers are good candidates to satisfy the above requirements, and has been used in transmitter /receiver module in civil communication and military ECM applications widely.

High electron mobility transistors (HEMTs), which rely on the use of AlGaAs /GaAs hetero-junctions for their operation, provide significant performance improvements over conventional MESFET utilizing junctions between like materials, ana offer many advantages in microwave, millimeter wave, and high-speed analogy and digital integrated circuit, monolithic microwave /millimeter wave integrated circuit (MMIC/M^{3}IC). Pseudomorphic high electron mobility transistor (PHEMT) uses a thin InGaAs layer as the two-dimensional electron gas channel material and has a larger conduction band discontinuity at the AlGaAs/InGaAs hetero-interface which allows even higher current density and transconductance than possible with a conventional HEMT. PHEMT can maintain the low noise figure and high gain over a broad range of operating current as compared to MESFET and conventional HEMT, and has stimulated great interest for high speed and extremely-high-frequency, low-noise, high-gain, and power amplifier applications.

Supported by “25 Mbps Wireless LAN System” project in ETRI of Korea, we designed a C-band PHEMT MMIC power amplifier, which will be used in 5GHz RF Front End chip, based on ETRI's PHEMT library and MMIC foundry fabrication process. The performance specification of amplifier are given in Table 1. ADS software is used to simulate the performance of the device and other optimization issues. The simulation result such as pldB. power-added efficiency (PAE), input / output port return loss of the device are given in the paper.

2. Characteristics of the PHEMTs

We began power amplifier design by researching the stability, power handling capacity of PHEMTs provided by ETRI's MMIC foundry.

2.1 Stability

The stability of the amplifier is determined from PHEMT stability, passive matching network, and source / load terminations. In an amplifier two-port network, when the magnitude of complex reflection coefficient at input or output is larger than unity, oscillation will possible occur resulting from either the input or output port presents a negative resistance. At a given operating frequency, if the real part of input and output impedance of an amplifier are greater than zero for any passive load and source impedance, the device is unconditional stable. There is no combination of passive source and load impedance that will cause the device to oscillate. Whether a PHEMT is unconditional stable or not on the condition of a given frequency band and input power range can be confirmed by experimentally or analytically and numerically measuring it S-parameters at input and output ports. There are two sets of useful criterions for two-port network stability, they are Rollets stability factor K and Edwards stability factor Mu. Having $Mu > 1$ is the single necessary and sufficient condition for unconditional stability of the two-port network. when K and $|\triangle|$(the determinant of the S-parameter matrix) are all greater than 1, the two-port network is unconditional stable, in other cases, the two-port network is potential unstable, it can be induced into oscillation by certain source and load impedances.

ETRI's MMIC foundry can provide two-, four- and eight-finger interdigital T-gate PHEMT. The gate length of PHEMT is 0.2 um, single-finger gate-width is 50 um, maximum operating frequency is greater than 180 GHz, maximum transconductance is larger than 450mS/mm. To ascertain whether these categories of PHEMTs are unconditional stable or not, We numerically measured the small signal and large signal S-parameters of common-source PHEMT operating at the frequency range from 4.0 GHz to 6.0 GHz by use of ROOT model of FET in ADS S-parameter and Large-Signal S parameter, simulation environment, and calculated the corresponding Edwards stability factor Mu. The results showed these PHEMTs are all potential unstable in C-band frequency range. Fig.1 showed the stability graph of common-source eight-finger PHEMT (dot line).

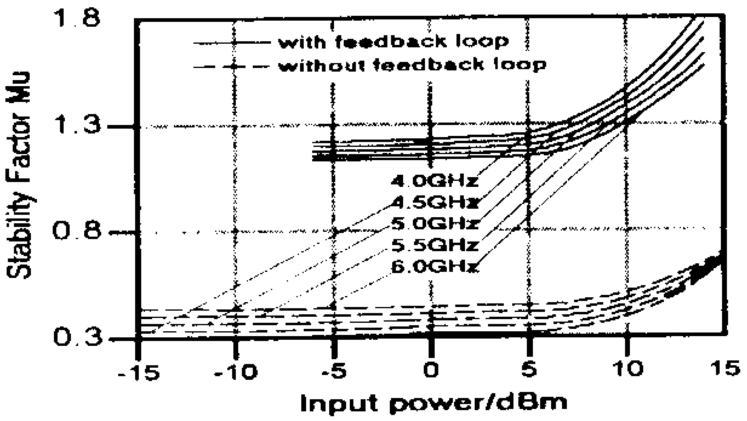


fig.1 Stability of eight-finger PHEMT without and with shunt negative feedback loop (V_{ds}=4.0V, V_{gs} = -0.3V)

One of approaches to design an amplifier using potential unstable PHEMT is proper design and careful consideration of passive matching network, source and load impedances so that the passive terminations produce a stable amplifier. Alternative measure is to make potential stable transistor into unconditional stable device by either resistive loading technique or negative feedback technique. Simple resistive loading techniques can improve PHEMT stability, but it will degrade power gain and noise figure. A proper negative feedback can not only stabilize a PHEMT by neutralizing S_{12}, but also provide a flat gain response over a broadband, reduce the input and output VSWR and improve the linearity of power amplifier. On the minus side, negative feedback will degrade the noise figure and reduce the maximum power gain available from a PHEMT.

In this design, we adopt a shunt negative feedback loop, which is a RLC series branch connected between the gate and the drain, to stabilize potential unstable PHEMT. Each component in negative feedback loop has a particular role to play in achieving maximum performance. Feedback resistor $R_{fb}(\in(300,350)\Omega)$ is the key element and determine the power gain and bandwidth of the designed amplifier. Feed inductor $L_{fb}(\in(0.2,0.5)nH)$ introduces a degree of frequency dependence into the feedback loop, at the lowest frequencies it has no effect and R_{fb} controls the power gain level, but at high frequencies the reactance of L_{fb} increase, which reduces the amount of negative feedback, its effect is to maintain flat gain and give operation up to a higher frequency. Feedback capacitor $C_{fb}(8pF)$ is used to isolate the positive drain bias from the negative gate bias.

The feedback component parameters are finally optimized to obtain a wanted maximum power gain and bandwidth in the design. Stability graph of common-source eight-finger PHEMT with shunt negative feedback loop is also showed in Fig.1(solid line). From Fig.1, it is seen that PHEMT with feedback loop be unconditional stable over the frequency range from 4.0 GHz to 6.0 GHz and the 30dBm dynamic range of input power.

2.2 Gain

The maximum stable gain G_{MSG} and maximum power gain available $G_{A.max}$ of a PHEMT are very important performance parameters, its value represents the inherent amplification potentiality of a PHEMT at given frequency, dc bias point and input power level. The amplification stage number of the designed amplifier can be estimated and determined according to the $G_{A,max}$ and G_{MSG} of used PHEMT.

We simulated the G_{MSG} of single common-source PHEMT without and with shunt negative feedback loop. The results are showed in Fig.2. It is seen that the maximum stable gain of eight-finger PHEMT without /with feedback loop are correspondingly about 18.98 dB and 18.78dB at 5.10GHz. Negative feedback loop reduces G_{MSG} available from a PHEMT by about 0.2dB in small-signal region and elevates large-signal power gain, hence improve performances of a power amplifier.

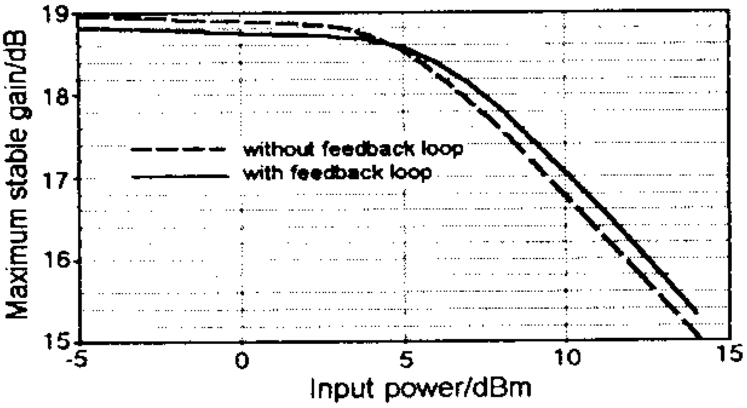


Fig.2 The G_{MSG} of PHEMT without and with negative feedback loop (V_{ds}=4.0V, V_{gs}=-0.3V, f=5.1GHz)

2.3 Output Power capacity

Power amplifier essentially operates at large-signal state and involve in nonlinear behavior. Adequate linearity for a power amplifier used in single-carrier and multi-carrier complex modulation RF signal transmitter is necessary so that the output distortion is controlled in an acceptable level. The linearity of PHEMT power amplifier is determined by the power handling capacity of transistor. The maximum linear output power $P_{out.ML}$ of a PHEMT is usually expressed as output power per millimeter gate-width at the 1 dB gain compression point.

$P_{\text{out.ML}}$ is determined by the maximum drain current $I_{\text{ds.max}}$ and the highest voltage $V_{\text{ds.highess}}$ that can exist between the drain and source. Whether $P_{\text{out.ML}}$ of a PHEMT can be extracted out or not depends on loading impedance and the dc biasing operating point. The optimal load impedance for maximum linear power output is obtained experimentally and numerically by use of load-pull technology[3].

We simulated the dependence of the maximum output power of eight-finger PHEMT with feedback loop on input power using two-tone load-pull technique by tuning load impedances in the whole smith impedance chart (f=5.25GHz, the PHEMT is biased at V_{ds}=4.0 V and V_{gs}=-0.3 V for class A dc operating point), and obtained an unique load impedance which allows maximum output power is 44.7+j8.8 Ω. Adopting power match method, we designed a single-stage eight-PHEMT power amplifier and simulated its performance using Harmonic Balance Analysis simulator of ADS software. Fig.3 gives the dependences of device output power, power gain and PAE on input power. The results show: the $P_{\text{out.ML}}$ is 20.84dBm(121.4mW), PAE 40.2% and power gain 13.84dB at the 1 dB power gain compressing operating point. Based on $P_{\text{out.ML}}$ obtained, we estimated that the output power per millimeter gate-width of the eight-finger PHEMT is about 300 mW in C-band frequency range.

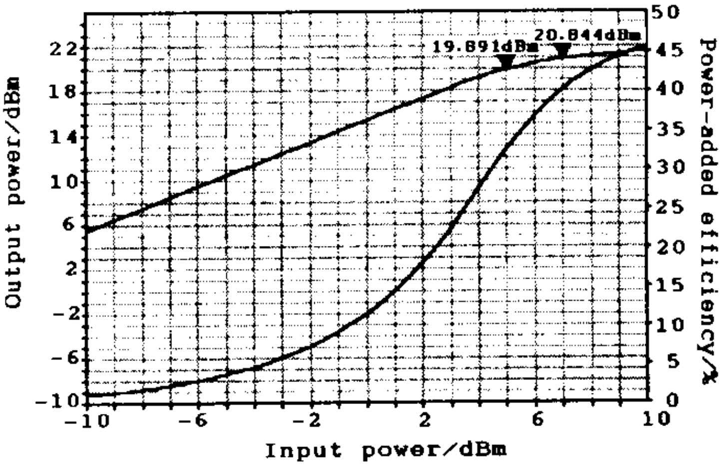


Fig.3 Output power, gain and PAE of single-stage amplifier versus input power ($V_{ds,}$=4.0V, V_{gs}=-0.3V, f=5.25GHz)

3. Amplifier Design and Circuit Topology

The cascade amplification and power combining technologies are used in the power amplifier design in order to realize the requirement of 23dBm output power and 20 dB power gain at the 1 dB gain compressing operating point. We adopted a Class A, two-stage cascade amplification, one-stage power combining power amplifier circuit topology for the better output power linearity, adequate PAE and smaller chip size in the premise of satisfying P1dB output power specification. The layout of the amplifier is showed in fg.4. Short circuit microstrip stubs biasing techniques is used to apply using two independent dc supplies. The microstrip stubs, a quarter-wavelength long at 5.25 GHz, are shored by means of the 8-pF decoupling microstrip thin film capacitor so that different polarity bias voltages can be applied to the gate and drain electrode of PHEMT. These stubs provide a near open circuit at the fundamental frequency, while producing a near short circuit at even harmonics for improving DC-to-RF conversion efficiency[4]. The width for the microstrip stub on 100um-thick GaAs substrate is decided on the requirement of maximum current density of metal and total dc-current passing through dc biasing stubs. The L-C impedance matching networks at output ports of each PHEMT transform 50 Ω load to a wanted load which the maximum output power of the PHEMT is extracted by. At input port of each PHEMT, a conjugate impedance matching is realized by L-C passive network. The three-port microstrip power splitter can couples input power into two-output branch at equal-power and equal-phase manner. In the frequency range from 4.75 GHz to 5.75 GHz, the insertion loss is less than 0.60 dB, the returm loss is less than -10.dB at the input port, the return loss is less than -16 dB. 72Ω NiCr thin film resistor effectively isolates the two output ports and provides a better impedance matching conditions for the output ports. The chip size is about 3.2x2mm^2.

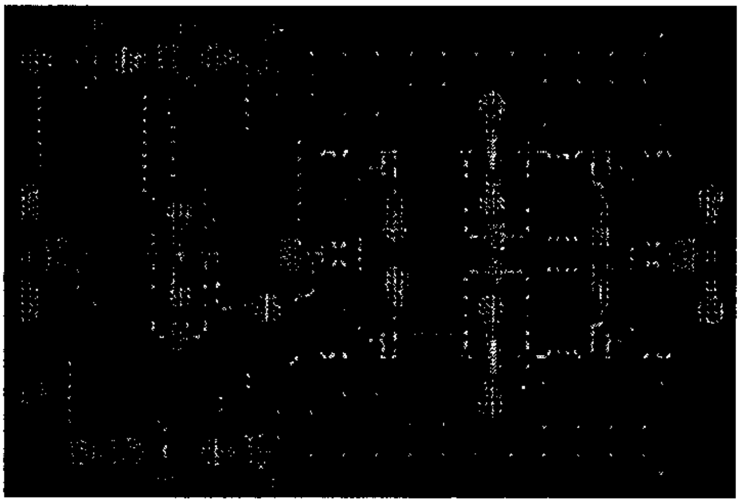
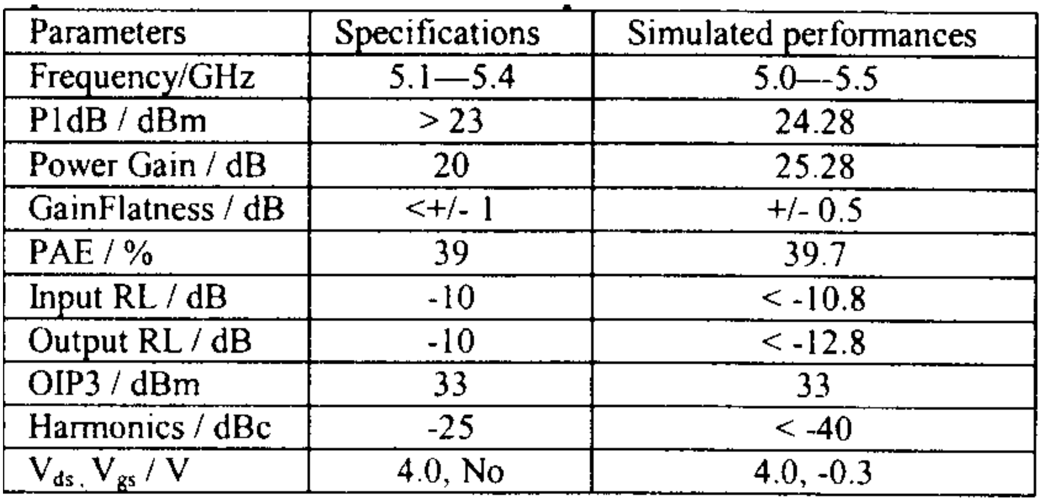


Fig.4 The layout of the amplifier

4. Simulation and Results

The performance of the designed power amplifier is simulated and optimized using ADS software based on the systematical and overall considerations and compromise of performance and chip size. The simulation results about the dependence of return losses at input and output port, transducer power gain, output power and PAE on input power and frequency are showed in Fig. 5(a)-(c). Comparison of simulated performances and required specifications is given in Table 1 . Overall, the designed PHEMT MMIC power amplifier will satisfy all required specifications.

Table 1. Comparison of specifications and simulated performances of the Power Amplifier



Parameters	Specifications	Simulated performances
Frequency/GHz	5.1—5.4	5.0—5.5
P1dB / dBm	> 23	24.28
Power Gain / dB	20	25.28
GainFlatness / dB	<+/- 1	+/- 0.5
PAE / %	39	39.7
Input RL / dB	-10	< -10.8
Output RL / dB	-10	< -12.8
OIP3 / dBm	33	33
Harmonics / dBc	-25	< -40
V_{ds}, V_{gs} / V	4.0, No	4.0, -0.3

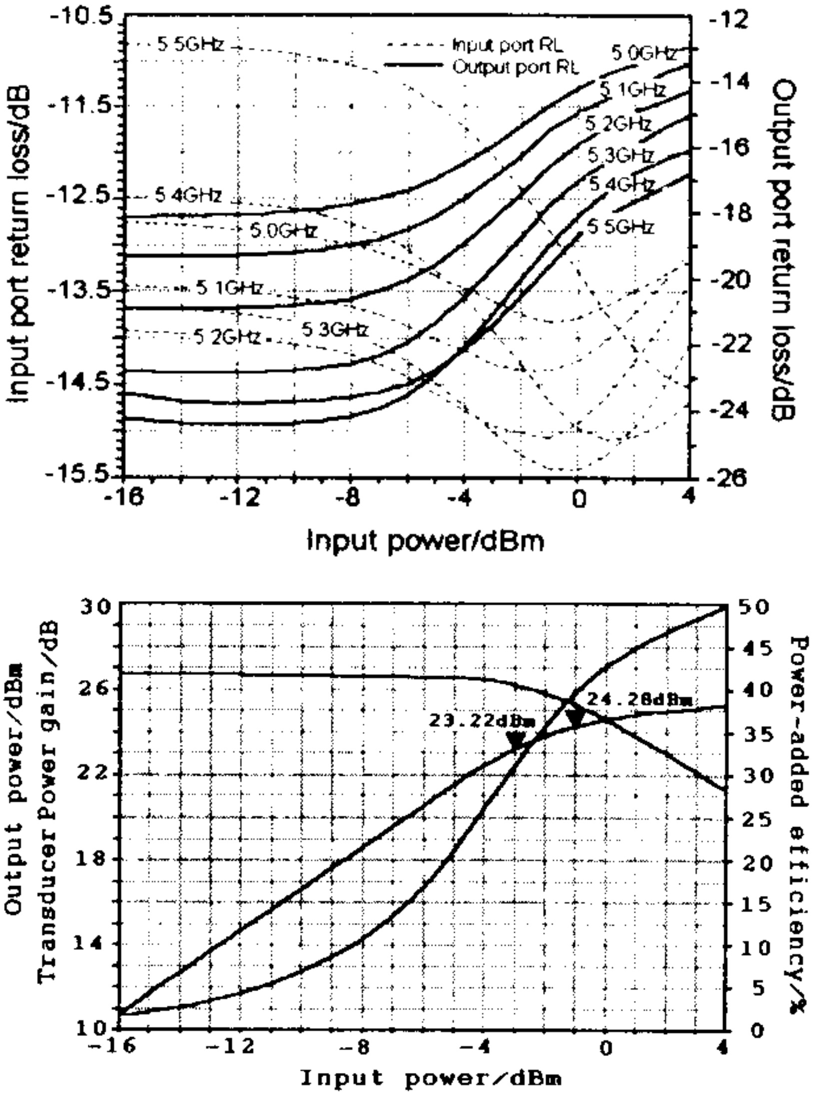


Fig.5 Simulated (a) Return losses, (b) output power, PAE and power gain versus input power(f=5.25GHz)

Acknowledgement

The authors gratefully thank Mr. Seokyong Han for valuable help. We would like to acknowledge the assistance of colleagues at ETRI.

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