An X-band 250W Solid-State Power Amplifier using GaN Power HEMTs

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***Abstract* — More than 250W of peak output power (pulse width 64μs, duty cycle 7%) is achieved with newly developed X-band solid-state power amplifier. The final stage of the SSPA consists of four 80W class GaN power HEMTs and a low loss 4-way combiner. Compared with the conventional klystron tubes, our newly developed SSPAs are smaller, more reliable and require less amounts of occupied frequency bandwidth.**

***Index Terms* — Solid-State Power Amplifier, X-band, GaN HEMT**

I. INTRODUCTION

Klystron tubes, magnetron tubes and TWT amplifiers have been used widely for many kinds of radar systems, such as airport surveillance radar, weather radar, etc. Recently in S-band and C-band, there were some reports concerning solid-state power amplifiers (SSPAs) using silicon bipolar transistors and GaAs FETs. With many advantages of SSPA, it is believed that the tubes are replaced with SSPAs rapidly [1-3].

Above C-band, since the silicon transistors do not have enough gain and GaAs FETs do not have enough power, GaN HEMTs (High Electron Mobility Transistors) with higher gain and higher power have been studied and developed [4-6].

Although the output power of GaN HEMTs is not as high as that of tubes, GaN HEMTs can handle longer and higher duty pulses, which reduce interference and occupied frequency bandwidth. Using pulse compression techniques, radar systems using SSPAs show almost the same performances as tubes.

We have developed an X-band 250W SSPA, which consists of GaN HEMTs, a low loss combiner, and a driver amplifier.

This paper describes the key features and measured performance of the developed SSPA.

II. DESIGN AND FABRICATION OF SSPA

A. Block Diagram of SSPA

The block diagram of the X-band SSPA is shown in Fig.1. The X-band SSPA consists of a driver amplifier, a high power amplifier, and a drain drive circuit. The RF circuit block has 4-stage cascaded amplifier.

The driver amplifier includes a 7W GaAs MMIC, two 80W class GaN HEMTs and two isolators. The isolators improve the stability of amplifier chain and the return loss of RF input port.

The high power amplifier includes a 4-way power divider, four 80W class GaN HEMTs, four isolators and a low loss 4-way combiner. The isolators at each HEMTs output side improve isolation from each other and absorb the reflection power from the RF output port.

The GaN HEMTs operate as class AB amplifier, which is always active even if the input RF power is not applied. In order to reduce power consumption we built a drain drive circuit that switches the drain current off while the input RF power is not applied. The drain drive circuit consists of FET switches and a 4488μF (68μF×66) capacitor bank.

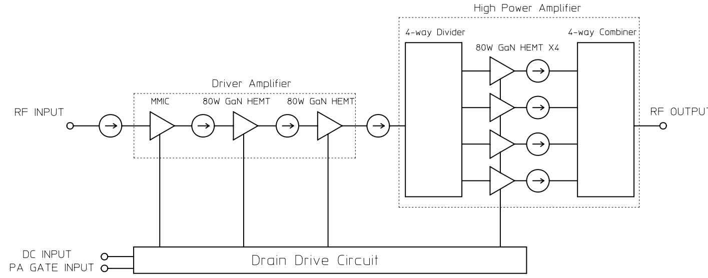

Fig. 1 Block diagram of the X-band 250W SSPA

Fig.2 shows the internal view of the driver amplifier, and the size is 30mm×155mm×15mm.

Fig.3 shows the internal view of the high power amplifier, and the size is 110mm×115mm×15mm.

Fig. 2 Internal view of the driver amplifier

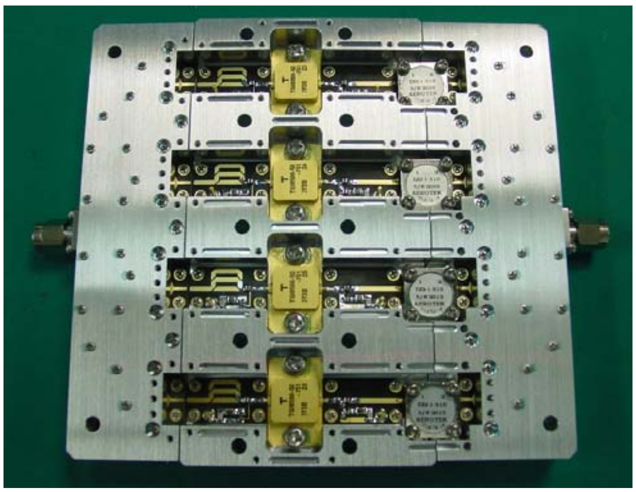

Fig. 3 Internal view of the high power amplifier

B. GaN power HEMT

Fig.4 shows the photographs of the developed X-band internally matched GaN power HEMT. There are two GaN HEMT chips in 21.0mm×12.9mm size package. Input port and output port are internally matched to 50Ω respectively.

The GaN HEMT chip size is 2.9mm×0.7mm, and the total gate-width is 11.52mm.

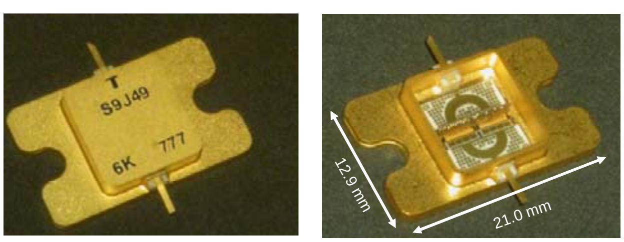

Fig. 4 External and internal view of the GaN power HEMT

Fig.5 shows a cross-sectional schematic of GaN HEMT chip. The GaN active layer is sandwiched between the AlGaN and the semi-insulating SiC substrate. Since the field plate gate has larger intrinsic capacitance and decreases the gain at high frequency, we chose the rectangular shaped gate.

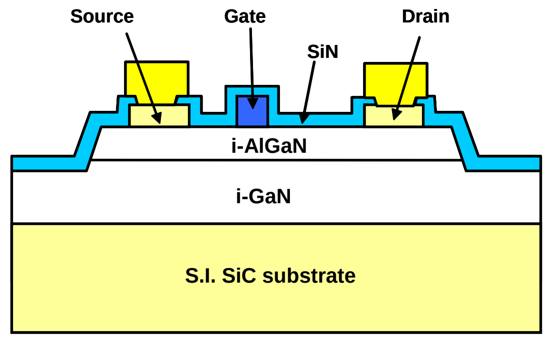

Fig. 5 Schematic diagram of GaN power HEMT

Fig.6 shows the measured output power, gain and power added efficiency of the developed GaN power HEMT at 9.5GHz. The bias condition was Vds=30V, flange temperature was 36°C and the operating mode was CW. The saturated power level was 49.1dBm (81.3W), the power added efficiency (PAE) was 34%, and the linear gain was 8.5dB.

The GaN power HEMT operates over 1000 hours within 0.5dB of power level variation at Tch=250°C. This means the MTTF of the GaN power HEMT operating at Tch=200°C is over 10 years.

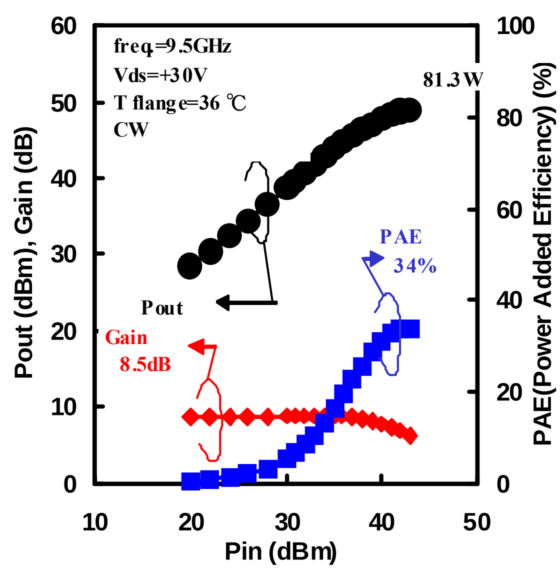

Fig. 6 Input-output characteristics of the GaN power HEMT

C. Power Combiner

In order to achieve high power and high efficiency of the SSPA, output powers from 80W GaN HEMTs have to be combined with minimum insertion loss. Therefore, we developed the low loss 4-way power combiner. The 4-way combiner has a suspended-line structure. It consists of copper conductor patterns on 0.25mm PTFE substrate and two aluminum plates. Between the substrate and aluminum plates, there are 1.2mm air layers respectively. Air layers are used because of decreasing dielectric loss.

Fig.7 shows the structure and pattern layout the of the 4-way combiner. Fig.8 shows the simulated insertion losses of four ways and return losses of every port of the 4-way combiner. From 9.5GHz to 10GHz, the simulated insertion losses are about 0.4dB, and the combined port return loss is 20dB at minimum. Each input port shows poor return loss, less than 5dB, because isolation resistors were removed to minimize the insertion loss of combiner.

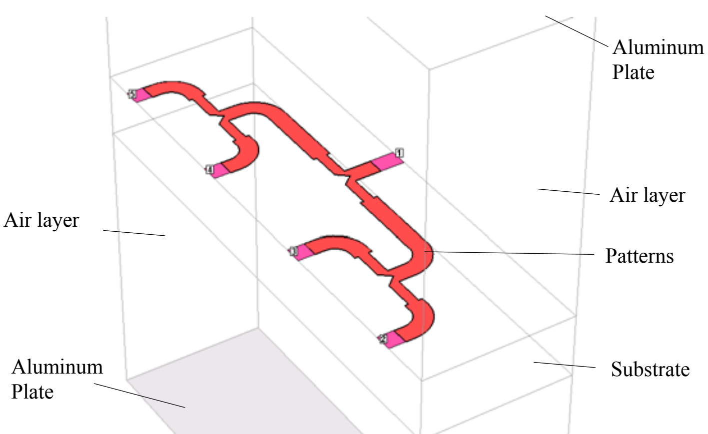

Fig. 7 The structure and pattern layout of the 4-way combiner

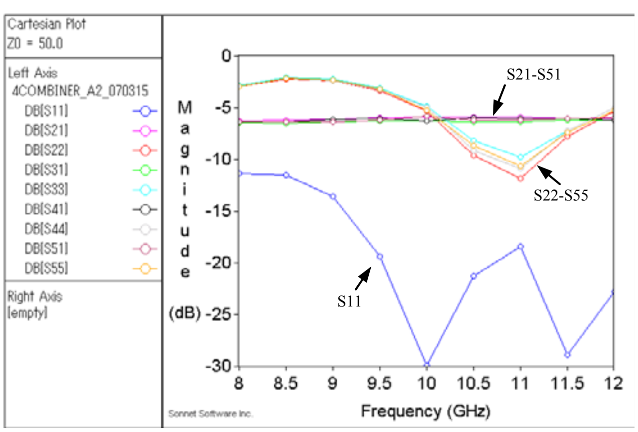

Fig. 8 Simulated result of the 4-way combiner

D. Isolators

Isolators are installed to protect the GaN HEMTs against the reflected power from the following stage and improve the isolation of each input port of 4-way combiner. Originally, conventional drop-in isolators were considered, however the increase of the insertion loss by 0.4dB at 100W was observed during individual component evaluation due to non-linearity. We worked with the manufacturer to develop new isolators for high power applications and the new isolators were not showing any degradation of loss up to 100W.

III. Experimental Result

We fabricated four SSPAs for transmitters of the weather radar system.

Fig.9 shows the measured peak output power and efficiency of the SSPA, operating at 9.45GHz, pulse width 64µs and 7% duty cycle. The peak output power is 54.2dBm (263W) at Vds=30V, 54.9dBm(309W) at Vds=35V, gain is 38.2dB and efficiency is 24.5% at Vds=30V.

Fig.10 shows the frequency dependency of the output power of the SSPA, the available bandwidth for over 250W(54.0dBm) is from 9.1GHz to 9.6GHz, and the variation of the power level is 0.3dB.

Fig.11 shows the output frequency spectrum at 9GHz band. This shows that there is no oscillation. The amount of occupied frequency bandwidth is narrower than the conventional klystron tubes.

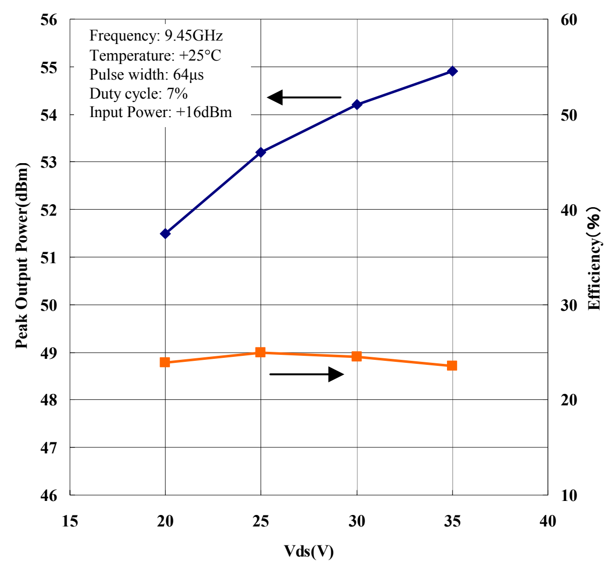

Fig. 9 Output power and efficiency versus drain voltage of the X-band 250W SSPA

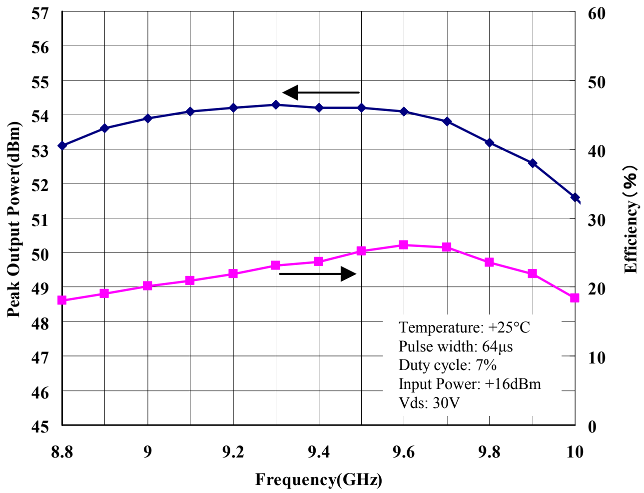

Fig. 10 Output power and efficiency versus frequency of the X-band 250W SSPA

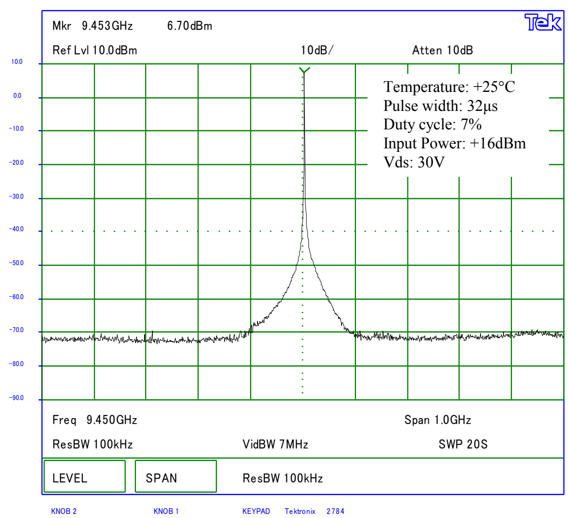

Fig. 11 Output spectrum of the X-band 250W SSPA

The measured performance of the SSPA is summarized in Table I.

Table I.
Performance of the X-band 250W SSPA

Item	Unit	Performance
Frequency	GHz	9.1～9.6
Peak Output Power	W	250
Pulse Width	µs	64
Duty Cycle	%	7
Total Gain	dB	38
Efficiency	%	21
Size	mm	HPA: 110×115×15 Driver: 30×155×15

IV. Conclusion

The X-band 250W solid-state power amplifier has been designed and fabricated. The SSPA consists of a driver amplifier, a high power amplifier and a drain drive circuit. The final stage of the amplifier includes four 80W class GaN Power HEMTs and a low loss suspended-line 4-way combiner. The SSPA provides more than 250W peak output power, more than 38dB gain and 21% of efficiency in the frequency range of 9.1GHz to 9.6GHz, under pulsed condition at a duty of 7% with a pulse width of 64µs. Our newly developed SSPAs are smaller, more reliable and require less amounts of occupied frequency bandwidth.

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