MMIC Applications to Space Equipment

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ABSTRACT

We demonstrated high power and low noise GaAs MMIC amplifiers for K- to Ka-band space equipment. For high power application, two different approaches were adopted. A SIV(Source Island Via-hole) FET high power amplifier achieved a saturation output power of 33 dBm with a power added efficiency of 26% at 21 GHz, which also provided an output power as high as 32 W when 16 chips of them were power-combined in an SSPA for an on-board transponder. On the other hand, a p-HEMT high power amplifier using lumped element matching circuits provided a P1dB of 31 dBm with a linear gain of 11.5 dB at 19 GHz.

For low noise application, p-HEMT low noise amplifier delivered a super low noise figure of 1.0 dB with an associated gain of 18 dB at 32 GHz. Gamma ray irradiation hardness of mm-wave MMIC LNAs was also investigated, up to 1E7 rad, which indicated that the p-HEMT MMIC LNA has sufficient gamma ray hardness in the space environment.

INTRODUCTION

Monolithic microwave integrated circuit(MMIC) technology has been widely used for space-born applications, since the technology is suitable for the transponder which needs small size, light weight, and high reliability. Moreover, to obtain wide frequency band characteristics with high reproducibility and performance uniformity, MMIC technology must be the best candidate. Recently, many satellite communication systems with higher capacity have been proposed(1) for new generation satellite communication services in K- to Ka-band. In such systems, MMICs are expected as key components of highly complex TX and RX modules in active phased array antenna(APAA)s.

P-HEMT devices for MMICs are very promising to improve efficiency of the high power amplifier(HPA) and noise figure of low noise amplifier(LNA). The efficiency of HPA is most important in terms of power consumption and thermal design. While for space use, reliability of p-HEMTs is indispensable. Especially, radiation hardness is one of the key items which should be verified for the space application. This paper addresses our recent High power and low noise MMIC applications using the state-of-the-art p-HEMT technology and also introduces an example of irradiation effects on a millimeter-wave MMIC(2).

High Power MMIC Amplifiers for Transmitter

For the high power application to space equipment, we applied two different approaches to accomplish high-performance MMIC power amplifiers. One approach is a development of SIV(Source Island Via-hole) FET structure(3) to be endowed with extremely low thermal resistance and low parasitic source inductance, and the other is to develop high-performance power p-HEMTs(4).
The former technology was applied to a 20 GHz band high power amplifier(3). The cross-sectional drawing of the SIV FET structure developed for this high power amplifiers is shown in Fig. 1. This MESFET has a 30 μ m substrate thickness and source via-holes, each of which connects each source electrode and the backside gold plated heat sink (PHS). This unique FET structure features an extremely low thermal resistance of 18℃/W and a low source parasitic inductance of 1.6 pH for an 75×24 μ m device. It demonstrated more than a 33 dBm output power with a 26 % power added efficiency. Furthermore, an output power of as high as 32 W was attained when sixteen chips of the MMICs were combined in an SSPA for an on-board transponder (3). This is the largest output power level at this frequency band.

The latter technology has been applied to our 20 GHz band medium power and high power amplifiers. They exploited AlGaAs/InGaAs/GaAs p-HEMTs as an active device. A double-hetero-junction structure was applied by using an MBE. The gate length of the T-shaped gate is set at 0.2 μ m, which was defined by EB lithography technology. The substrate thickness of the MMIC was set at 100 μ m. At the drain voltage of 5.0 V and the drain current of 50 mA, a 1 dB gain compression output power of 24.4 dBm with a power gain of 9.4 dB and power added efficiency of 57% was obtained at 18 GHz. This is good performance enough to realize high efficiency monolithic amplifiers at K-band.

The developed K-band MPA MMIC is shown in Fig. 2. The chip size is 1.94 mm X 1.0 mm. Since the miniaturization of the chip size is very important to reduce the module size, the MMIC employed lumped element matching circuits at input and inter-stages, which is very useful for reducing the chip size. A flat and high linear gain of 15.0 dB were achieved with input and output return losses of more than 10 dB at 17 to 20 GHz. And the uniformity of RF performances were also studied. At 19 GHz standard deviation of gain was less than 0.64 dB in the same wafer. A 1 dB-compressed output power of 24.7 dBm were obtained at 19 GHz with bias conditions of Vd= 5.0 V and Id= 270 mA, and saturated output power was 25.8 dBm.
The K-band HPA MMIC is shown in Fig. 3. The chip size is 1.94 mm X 2.0 mm. This MMIC also employed full lumped element matching circuit configuration. The frequency characteristics of the amplifier is shown in Fig 4. A flat linear gain of 11.5 dB was achieved over 17 to 20 GHz. At 19 GHz, standard deviation of gain was less than 0.42 dB in the same wafer. A 1 dB-compressed output power of 31.0 dBm was obtained at 19 GHz with a bias condition of Vd= 5.0 V and Id= 1200 mA, and a saturated output power was 31.5 dBm.
Similar p-HEMTs and lumped element matching technologies were applied to Ka-band MMIC power amplifiers and modules. Figure 5 shows a Ka-band PA module as an example utilizing ceramic-wall package, in which Ka-band HPA and MPA chips were mounted in cascade. This compact module delivered a maximum output power of 30 dBm with a more than 20 dB gain at Ka-band.

Low Noise MMIC Amplifiers for Receiver

AlGaAs/InGaAs/GaAs single doped p-HEMTs with a gate length of 0.15 μ m were employed in our low noise amplifier. The epitaxial layers of the p-HEMT were formed by MBE. A Si planar doping layer was grown in the n-AlGaAs electron supply layer for better RF gain and noise performance. The T-shaped gate was formed by using electron beam lithography and reactive etching processes(5). The p-HEMT device provided an excellent low noise figure of 0.9 dB with an associated gain of 8 dB at 35 GHz and a 0.8 dB NF with a 12 dB Ga at 26 GHz.

In order to make the best use of these superior RF performances of the p-HEMTs, it is foremost important in designing amplifiers to suppress unnecessary gains at lower frequencies yet maintaining the superior RF performances in the designed frequency region. To meet this purpose, we intended to design MMIC DC power supply circuits to make them act as proper high-pass filters as well in conjunction with source inductive feedback circuits. Figure 6 illustrates a circuit diagram of the developed MMIC LNA(5). The C1 and C2 values in the DC supply circuits were carefully optimized to deliver the proper filter characteristics. The filter characteristics are plotted in Fig. 7. This figure suggests that the designed filter certainly possesses large gain suppression in the lower frequency region while a small loss less than 1 dB in the frequency range of our interest about 30 GHz. A micro-photograph of the developed low noise MMIC amplifier is shown in Fig. 8, where the chip size is 2.3 $\times$ 1.3 mm2. It provided a noise figures of less than 1.4 dB in the entire designed frequency range between 26 and 35 GHz.

Figure 9 is a microphotograph of another type of three stage low noise VGA MMIC(6). The chip size is 3.4 mm X 1.4 mm. A single gate p-HEMT was utilized in the first stage, since the noise performance of a dual gate p-HEMT is usually inferior to that of the single gate one. A dual gate p-HEMT was utilized in the second and the third stage of the amplifier in order to realize wide gain control range. A lightly series feedback was adopted to obtain better noise figure and VSWR simultaneously for the first stage p-HEMT. Figure 10 shows the measured gain control performance of the VGA MMIC with the drain voltage of 2.0 V. The gain control range of more than 50 dB was achieved. The minimum noise figure of 1.4 dB was obtained with an associated gain of 29.2 dB at 33 GHz. The noise figure was less than 2.0 dB with the associated gain of more than 28.9 dB from 28 to 35 GHz.

Gamma ray irradiation hardness of millimeter-wave low noise p-HEMTs were investigated for space-born applications(2). Gamma ray was irradiated to 50 GHz band monolithic p-HEMT low noise amplifiers with DC bias and the change of DC and RF performances were measured. Figure 11 shows gamma-ray irradiated results of RF performances. No degradation of RF performance was observed up to 1E7 rad. The gain decreased more than 0.5 dB at 1E8 rad dose.

It suggests that the p-HEMT has over a hundred year of life time under gamma-ray irradiation in the space environment.

CONCLUSION

We have demonstrated high power and low noise GaAs MMIC amplifiers for K- to Ka-band space equipment. For the high power application, two different approaches were adopted. A SIV(Source Island Via-hole) FET high power amplifier has achieved a saturation output power of 33 dBm with a power added efficiency of 26% at 21 GHz, which also has provided an output power as high as 32 W when 16 chips of them are power-combined in an SSPA for an on-board transponder. On the other hand, a p-HEMT high power amplifier using lumped element matching circuit has provided a P1dB of 31 dBm with a linear gain of 11.5 dB at 19 GHz.

For the low noise application, p-HEMT low noise amplifier has delivered a super low noise figure of 1.0 dB with an associated gain of 18 dB at 32 GHz. Gamma ray irradiation hardness of mm-wave MMIC LNA has been also investigated, up to 1E7 rad, which indicated that the p-HEMT MMIC LNAs have sufficient gamma ray hardness in the space environment.

These MMIC technologies will be useful for front-end receivers and SSPAs in the future space equipment,

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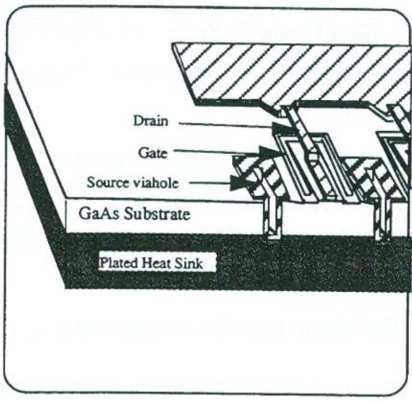

Fig.1 Cross-sectional view of the SIV(Source Island Via-hole) structure FET.

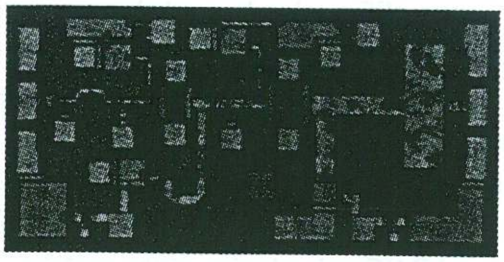

Fig.2 Microphotograph of the MPA MMIC.

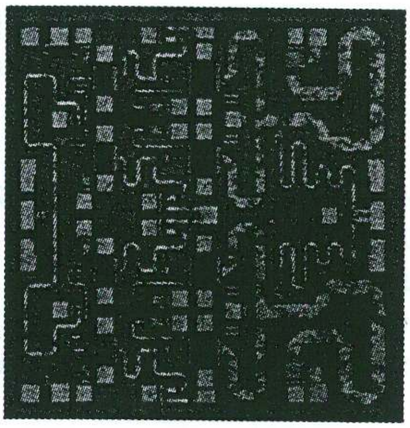

Fig. 3 Microphotograph of the HPA MMIC.

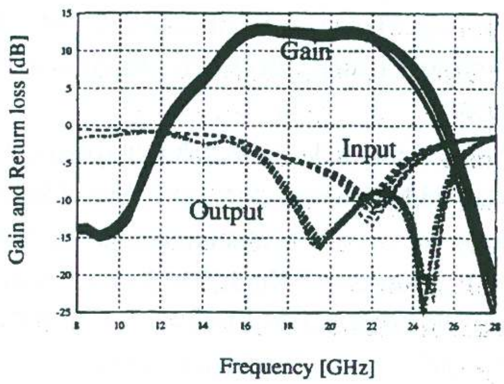

Fig.4 Frequency characteristics of the HPA MMIC.

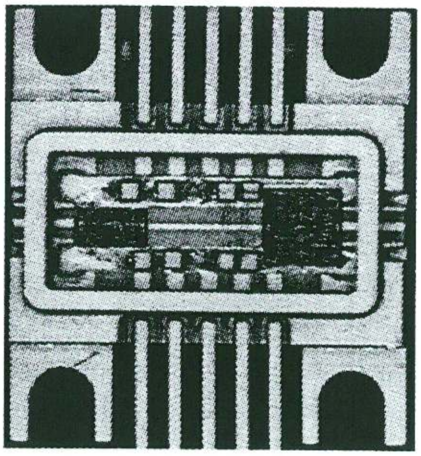

Fig.5 Ka-band power amplifier module

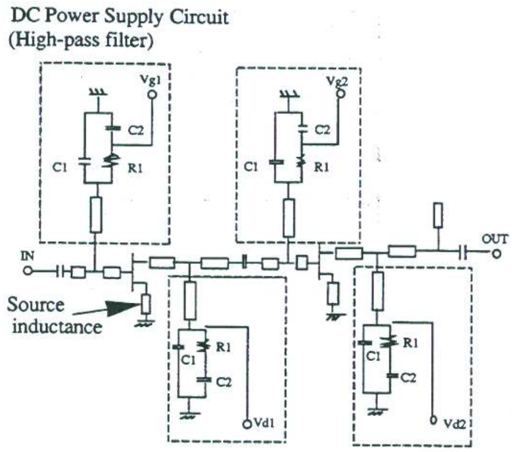

Fig.6 Circuit diagram of the LNA MMIC.

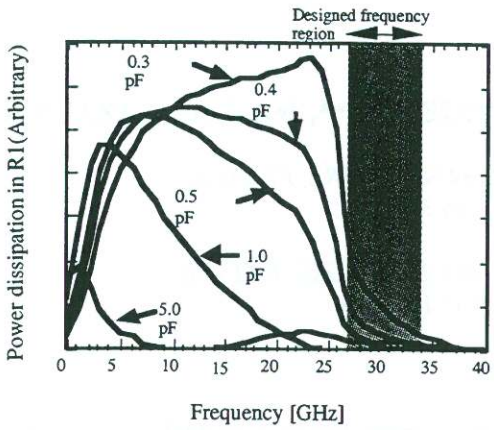

Fig.7 Filter characteristics of DC supply circuit.

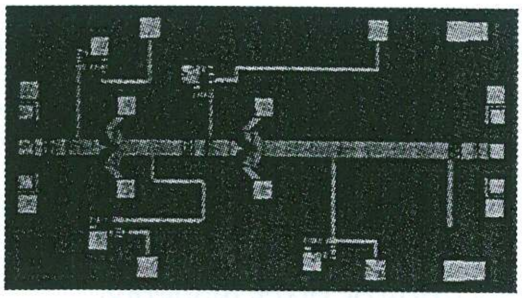

Fig.8 Chip Photograph of theLNA MMIC.

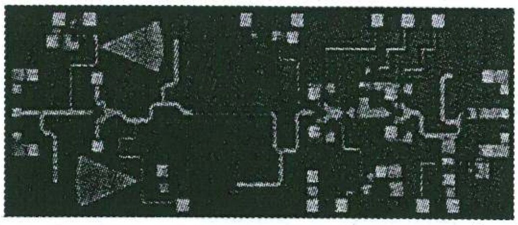

Fig.9 Microphotograph of the VGA MMIC.

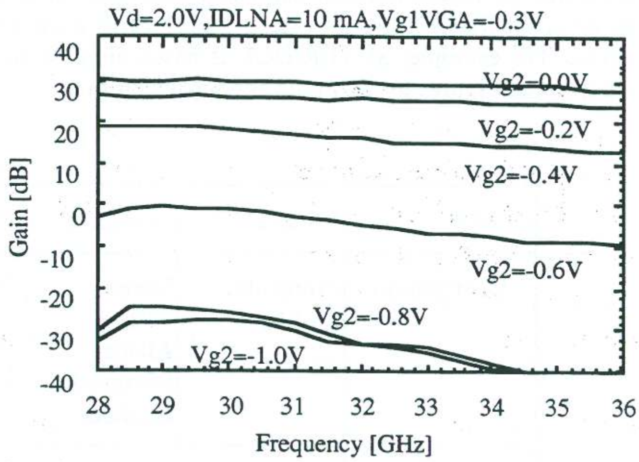

Fig.10 Measured gain control performance of the VGA MMIC.

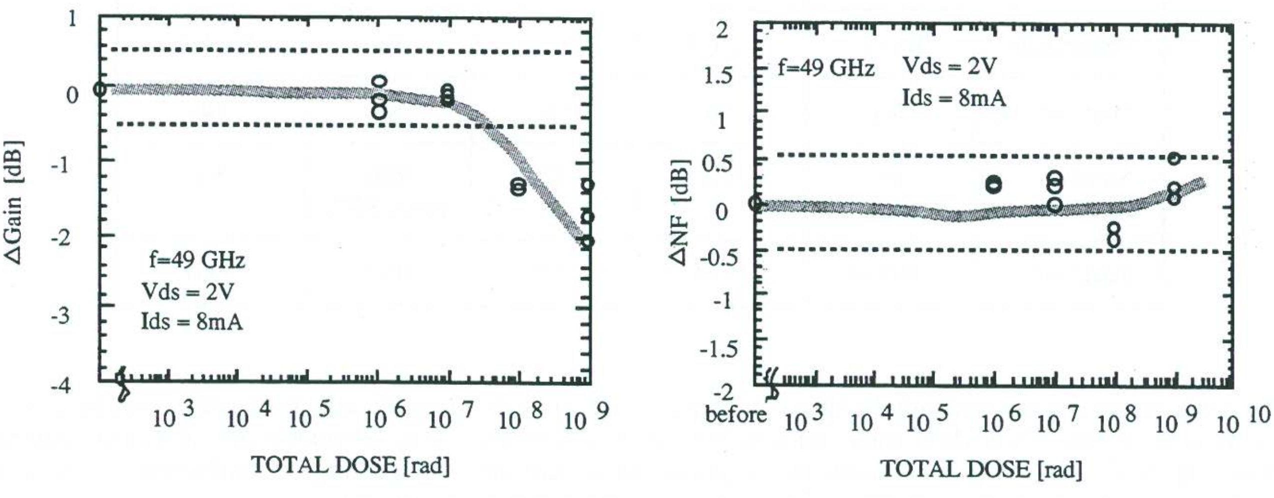

Fig.11 Gamma-ray irradiated results of gain and noise figure.