

Broadband GaN HEMT Microwave Integrated Circuit for Space Applications

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We have developed a 40-W microwave integrated circuit (MIC) equipped with gallium nitride (GaN) high electron mobility transistors (HEMTs) that is functional in the L-band and S-band for satellite and rocket launch control applications. The MIC has a 10-W GaN HEMT in the front stage and a 40-W GaN HEMT in the post stage. It achieves an output of over 45 W, gain of over 30 dB, and power added efficiency (PAE) of 45% in the range of 1.0-1.7 GHz, while it shows an output of over 47 W, gain of over 30 dB, and PAE of 50% in the range of 2.0-2.7 GHz. The GaN HEMTs met all the reliability and lifetime requirements in a space qualification test. When used in a solid state power amplifier, the MIC will contribute to a reduction in the size and weight of satellites.

Keywords: GaN HEMT, microwave integrated circuit (MIC), broadband, space applications

1. Introduction

Space applications, such as navigation systems and satellite telecommunication systems, have come into widespread use, and accordingly the number of rockets to launch satellites is also rising. Against this backdrop, there is a growing demand for the power amplifiers to be mounted in satellites to be more compact, while at the same time producing higher output at higher efficiency. Conventionally, solid state power amplifiers (SSPAs) that use gallium arsenide field-effect transistors (GaAs FETs)*¹ have been commonly used for such purposes. Now gallium nitride high electron mobility transistors (GaN HEMTs)*² have become available, enabling much higher output in a smaller casing. Thus, SSPAs can now be downsized by using GaN microwave integrated circuits (MICs)*³. Currently, conversion to all-electric satellites, where the gas jet engine is replaced by an electrically driven engine, is being considered, and this should further expand demand for SSPAs that enable the host satellites to be downsized and reduced in weight.

Sumitomo Electric Industries, Ltd. is currently developing a GaN HEMT MIC with a high output (40 W), high gain (30 dB), and broadband operability (L-band*⁴: 1.0 to 1.7 GHz and S-band*⁵: 2.0 to 2.7 GHz) that can contribute to downsizing and weight reduction of SSPAs for space applications. This paper introduces the GaN HEMT MIC.

2. Development of Broadband GaN HEMT MIC

2-1 Development background and target performance

Sumitomo Electric has already developed a GaN HEMT operable in 200 W-class L-band⁽¹⁾ and 150 W-class S-band for space applications, and released its discrete driver with power outputs of 2 W, 10 W, and 40 W. However, these discrete products simply contain a GaN HEMT in their packages and require an external impedance matching circuit. The upper row of Fig. 1 indicates the Sumitomo Electric's currently recommended 150 W

S-band SSPA lineup. The power required in the driver stage is 40 W, and 2 W in the pre-driver stage, and a single external matching circuit is required for each stage. Thus the SSPA size is inevitably large. To eliminate this disadvantage of a large SSPA, we aimed to develop the lineup shown in the lower row of Fig. 1, by developing a MIC that contains two driver stages, a matching circuit, and a biasing circuit. The size of the conventional discrete product reaches 200 mm, including the 2 W and 40 W drivers as well as our own evaluation board, while the new 40 W MIC is only 44 mm. This means that we have reduced the product size to a quarter of that of the previous model.

We set performance targets for the new MIC as follows: 40 W output to drive the GaN HEMT, which outputs 200 W in the L-band and 150 W in the S-band at its final stage, 30 dB gain to drive the GaN HEMT while taking account of stability, and 45% or more power-added

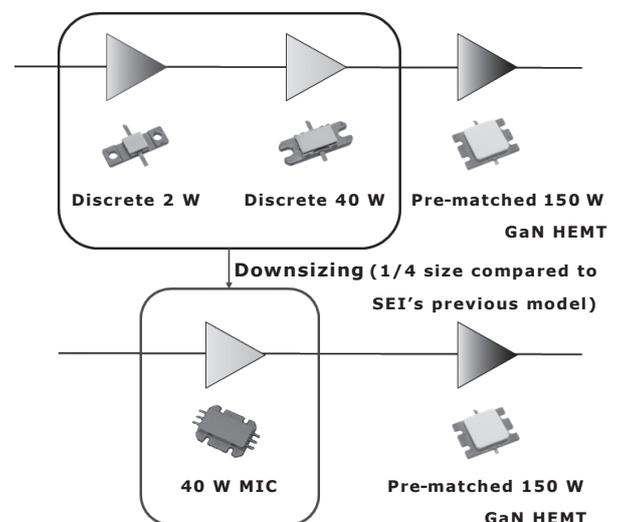


Fig. 1. Our recommended SSPA lineup with 150 W for S-band

efficiency (PAE) to ensure thermal reliability over an extended period of time.

To offer sufficient broadband characteristics, we designed the product to cover the L-band of 1.0 to 1.7 GHz in order to provide wide coverage of the 1.2 GHz band and the 1.5 GHz band that are mainly used by navigation systems, and the S-band of 2.0 to 2.7 GHz to be used for the satellite telecommunication systems and to control the rockets used to launch the satellites.

2-2 GaN HEMT configuration and MIC matching circuit design

To output 40 W power, we configured a 40 W GaN HEMT in the post stage and a 10 W GaN HEMT in the front stage with sufficient margin. The size of the 10 W GaN HEMT is 1.18 mm × 0.86 mm, and that of the 40 W GaN HEMT is 4.00 mm × 0.86 mm. The product package contains the two aforementioned GaN HEMTs and a matching circuit that includes a biasing circuit. As shown in Fig. 2, the package has radio frequency (RF) terminals, as well as terminals to apply voltage at the input and output gates and a drain bias. The package size excluding these terminals is 23.5 mm × 19.0 mm.

The internal matching circuit was designed based on the non-linear model to stably connect the driver and amplifier while confirming the band characteristics during RF operations. If the devices are simply connected, unnecessary gain is generated at frequencies lower than the main frequency band. In order to attenuate such gain, we placed high-pass filters*6 in which an inductor, resistor, and capacitor are combined, at the gates of the front stage and post stage.



Fig. 2. Exterior shape of GaN HEMT MIC

One of the parameters required for a product used in space is the reliability of the package and internal circuits against highly variable environmental temperatures. A DC blocking capacitor that uses high-permittivity substrates is particularly subject to reliability issues as it is made into a film to deliver the desired capacity and is therefore easily cracked during temperature cycle tests. To address this issue, we confirmed the level of stress applied to the internal circuit from temperature changes by using simulation models and then located the capacitor in a position where the stress is alleviated. We plan to confirm that the capacitor will not suffer from cracking in mechanical environmental tests and temperature cycle tests as a part of product qualification testing.

The circuit design of the 40 W L-band MIC is shown in Fig. 3, and its internal circuit is displayed in Photo 1. A series of resistors with a value that can withstand the input

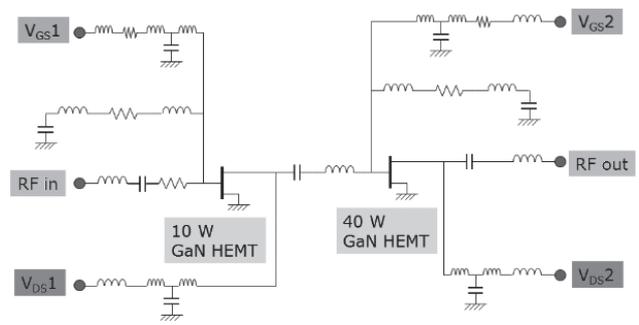


Fig. 3. Circuit design of 40 W L-band GaN HEMT MIC

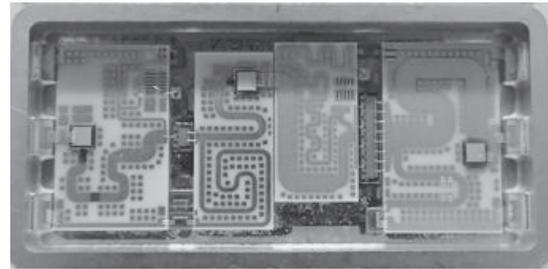


Photo 1. Internal circuit of 40 W L-band GaN HEMT MIC

power is inserted at the front stage of the 10 W GaN HEMT because the L-band tends to have high gain and easily becomes unstable.

The circuit design of the 40 W S-band MIC is shown in Fig. 4, and its internal circuit is displayed in Photo 2. For

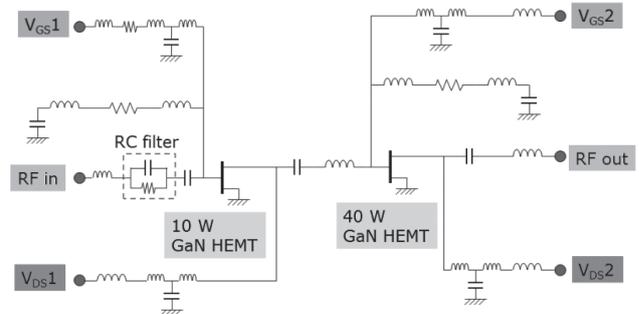


Fig. 4. Circuit design of 40 W S-band GaN HEMT MIC

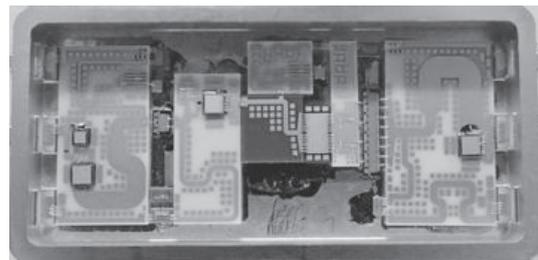


Photo 2. Internal circuit of 40 W S-band GaN HEMT MIC

the S-band, a filter in which a resistor and capacitor are placed in parallel, is located at the front stage of the 10 W GaN HEMT, as in the L-band MIC, to attenuate the gain only in the low frequencies.

3. Broadband GaN HEMT MIC Appraisal Results

3-1 Small-signal characteristics

Figure 5 represents S_{21} , the small-signal S parameter of the 40 W L-band GaN HEMT MIC and the calculated stability coefficient K . Within a range of the test frequencies from 0.05 to 6 GHz, K was greater than 1. This confirmed that the operation was absolutely stable in both the main band and lower frequencies of less than 1 GHz.

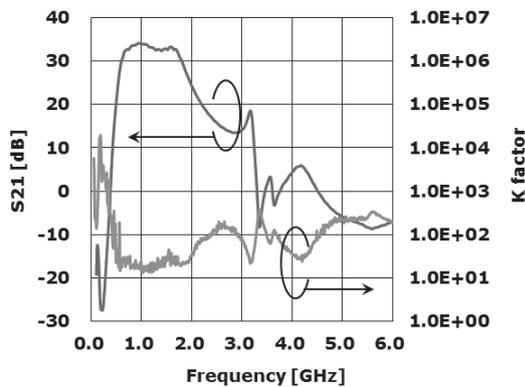


Fig. 5. Small-signal characteristics of 40 W L-band GaN HEMT MIC

Figure 6 shows the S_{21} of the 40 W S-band GaN HEMT MIC and the coefficient K . This also indicates that K was greater than 1 at the range of the test frequencies from 0.05 to 6 GHz, suggesting that the operation was stable.

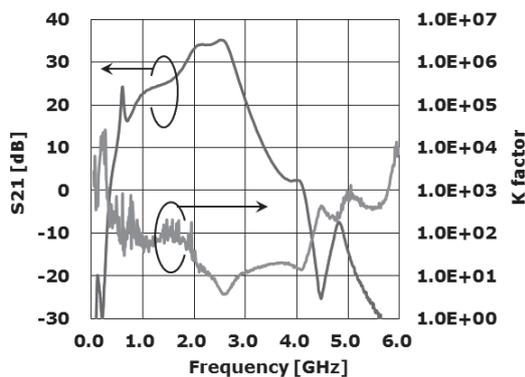


Fig. 6. Small-signal characteristics of 40 W S-band GaN HEMT MIC

3-2 RF characteristics

Figure 7 represents the RF characteristics of the 40 W

L-band GaN HEMT MIC. This figure shows the frequency response characteristics of the saturation power, power-added efficiency, and linear gain (GL). Within the band range from 1.0 to 1.7 GHz, a saturation power of 46.5 dBm, power-added efficiency of 45%, and linear gain of 30 dB were observed.

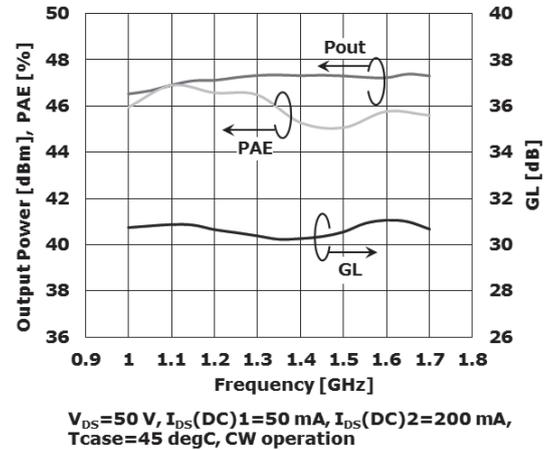


Fig. 7. RF characteristics of 40 W L-band GaN HEMT MIC

Figure 8 represents the RF characteristics of the 40 W S-band GaN HEMT MIC. Within the band range of 2.0 to 2.7 GHz, a saturation power of 46.7 dBm, power-added efficiency of 50%, and linear gain of 30 dB were observed.

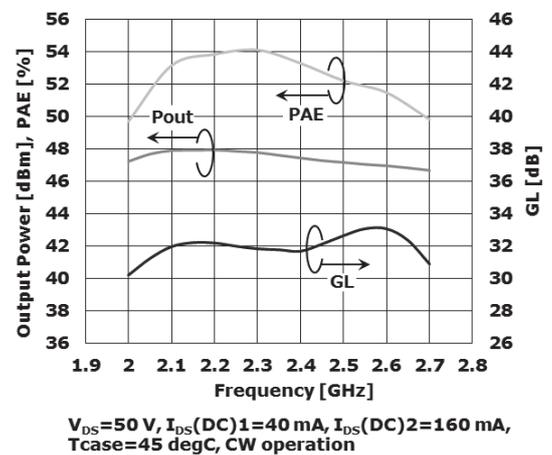


Fig. 8. RF characteristics of 40 W S-band GaN HEMT MIC

We also conducted a low temperature test (case temperature $T_c = -40^\circ\text{C}$) and a high temperature test ($T_c = 85^\circ\text{C}$) to observe operations of the MIC. At the low temperature in particular, the increased gain could destabilize operations. Thus, we made a careful observation of various RF input levels by changing the voltage and current. As a result, no oscillation or spurious signals*⁷

were observed and the MIC operated stably.

3-3 Evaluation board

Photo 3 shows the evaluation board for the L-band and S-band GaN HEMT MICs. The external circuit can be controlled just by connecting a 50 Ω transmission line and a lead from the biasing line, as the product package contains a biasing circuit as well as a DC blocking capacitor on its RF line.

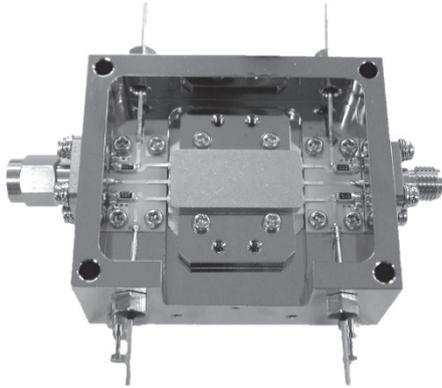


Photo 3. Evaluation board of GaN HEMT MIC

4. Conclusion

Table 1 lists the evaluation results of the characteristics for the newly developed 40 W L-band and S-band GaN HEMT MICs. Both the L-band and S-band GaN HEMT MICs achieved their performance targets, however, the power-added efficiency in the higher frequency S-band was higher than that in the lower frequency L-band, which is the reverse of what is required.

Table 1. Evaluation results of characteristic of 40 W L-band and S-band GaN HEMT MICs

Items	40 W L-band MIC	40 W S-band MIC
Drain voltage / V_{DS}	50 V	50 V
Drain current / I_{DS} (DC)	250 mA	200 mA
Operating frequency	1.0–1.7 GHz	2.0–2.7 GHz
Saturation power / P_{sat}	46.5 dBm	46.7 dBm
Linear gain / GL	30 dB	30 dB
Power-added efficiency / PAE	45%	50%

Two reasons can be considered as the cause of this phenomenon. One is that the conversion of the impedance to an optimum level may be difficult as the size of the internal matching circuit is larger in the L-band. The other possible reason is that the gain attenuation to prevent operational instability due to high gain may cause a high loss, leading to a low efficiency. The challenge for the future is to increase the power-added efficiency by resolving the above issues while minimizing the power consumption level in order to develop a high value-added product. Sumitomo Electric continues to refine the GaN HEMT

technologies to meet customers' needs for even higher output, broadband, and higher efficiency.

Technical Terms

- * 1 Gallium arsenide field effect transistor (GaAs FET): A field effect transistor based on gallium arsenide. GaAs FETs are suitable for microwave and high frequency amplifying purposes, as electrons can move about five-times faster than in transistors made of silicon.
- * 2 High electron mobility transistor (HEMT): A transistor that uses the two-dimensional electron induced on the heterojunction. This can form a channel with high electron density and low impurity scattering.
- * 3 Microwave integrated circuit (MIC): Refers to either a hybrid microwave integrated circuit or a monolithic microwave integrated circuit (MMIC). The MIC is made of insulator substrates, such as alumina, on which passive elements or a distributed constant circuit that operates in the microwave band are formed, with additional active elements, such as microwave transistors and diodes, mounted on top. The MMIC is an integrated circuit in which all the elements and circuits are formed as a unit on a substrate in a semiconductor manufacturing process.
- * 4 L-band: Refers to the microwave frequency range of 1 to 2 GHz. The band is used for a variety of purposes, including GPS navigation systems and mobile satellite telecommunication systems.
- * 5 S-band: Refers to the microwave frequency range of 2 to 4 GHz. The band is used for a variety of purposes including mobile telecommunication and wireless LANs.
- * 6 High-pass filter: A type of circuit called a frequency filter. The filter only allows frequencies higher than a specific frequency to pass. In filter circuits, the frequency that functions as the threshold to pass or block frequencies is called the cutoff frequency.
- * 7 Spurious signals: Unnecessary signal components other than input signals or predefined frequency components contained in the output signal of an amplifier, etc. Spurious signals include noise and signal distortion generated by the nonlinearity of a circuit.

Reference

- (1) K. Osawa, H. Yoshikoshi, T. Tanaka, A. Nitta, E. Mitani, and T. Satoh, "Over 74% Efficiency, L-Band 200W GaN HEMT for Space application," Proc. Eur. Microw. Conf., pp.397-400, London, UK (October 2016)

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