High Power Ku-band GaN MMIC and Internally Matched HEMTs for Satellite Communication

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1. Introduction

In the satellite communication market, both the increase in communication traffic and the growth in demand for mobile stations are advancing, and there is a strong demand for higher output power, more compact transmitters for satellite communication earth stations. By using GaN (gallium nitride) with high dielectric breakdown voltage instead of the conventional GaAs, we realized high-voltage operation and high power density, and developed a miniature, high output power device for a transmitter. With the newly developed device, a lineup of Ku-band devices consisting of two types of internally matched GaN high electron mobility transistors (HEMTs) and GaN monolithic microwave integrated circuits (MMIC) for driver-stage has been commercialized (Fig. 1).

![Fig. 1 Ku-band GaN MMIC and GaN HEMTs](image1)

2. 50 W Internally Matched HEMT

In order to realize high gain in the high-frequency Ku band (between 13.75 and 14.5 GHz in the case of an earth station), we developed a GaN transistor with a gate length ($L_g = 0.25 \mu m$) that is shorter than the gate length ($L_g = 0.75 \mu m$) of the C-band transistor already being mass-produced. The frequency ($f_k$), which indicates the point of conversion between the maximum stable gain (MSG) and the maximum available power gain (MAG) of the developed transistor ($W_g = 50 \mu m \times 10$), was increased from the previous 13.8 GHz to 19.5 GHz, which is an improvement of approximately 1.5-fold. As a result, it was found that this product has adequate high-frequency performance as a Ku-band transistor.

Figure 2 shows the evaluation results for the input power versus output power characteristics of the Ku-band 50 W internally matched HEMT (MGFK47G3745A), which uses this transistor. A saturated output power of 47 dBm (50 W), linear gain of 8.0 dB, and power-added efficiency (PAE) of 30% are obtained at 14.125 GHz. The package size of this product is 21.0×12.9×4.5 (mm), and an output of 50 W has been realized simultaneously with downsizing to an even smaller package than that of the conventional 25 W GaAs FET.

![Fig. 2 RF Characteristics of Ku-band 50W HEMT (MGFK47G3745A)](image2)

Figure 3 shows the third-order intermodulation distortion (IM3) characteristics of this device. The output power at IM3 = -25 dBc (linear output power) that is required to secure the necessary communication quality for a satellite communication earth station is 45 dBm at the power supply voltage of 24 V. The device has the world’s top level of saturated output power and linear output power as a product that uses a miniature package.

![Fig. 3 IM3 Characteristics of Ku-band 50W HEMT](image3)
3. 80 W Internally Matched HEMT

In the field of satellite communication, both communication speed and communication traffic are increasing, and there is a strong demand for earth station transmitters that are compact and produce a high output power. To satisfy this demand, we developed an 80 W internally matched HEMT aimed at realizing a device for the final stage that produces higher output.\(^{(2)}\) Figure 4 shows the input power versus output power characteristics of the Ku-band 80 W internally matched HEMT (MGFK49G3745). A saturated output power of 49.5 dBm (89 W), a linear gain of 9.3 dB, and a power-added efficiency of 30% were obtained at Vd of 24 V. Figure 5 shows the IM3 characteristics of this device. The linear output that satisfies IM3 = \(-25\) dBc is 46 dBm. The package size of this product is 24.0 × 17.4 × 4.3 (mm), and the device realizes high output power that is three times greater than that of the conventional 25 W GaAs FET with the same package size. The device produces the world’s top level of saturated output.

4. Two-Stage Amplifier Characteristics

GaN HEMTs are very promising in that they enable transmitters to be made compact yet with a high output power. On the other hand, they have a characteristic called soft compression, whereby the gain starts to fall with lower output power than the saturated output power. In the case where GaN HEMT devices are coupled together to make a multi-stage amplifier, the soft compression characteristics of each device are superimposed on each other, which reduces the gain linearity for the entire amplifier from a low output level, causing the deterioration of distortion characteristics.

To resolve this issue, we developed a GaN MMIC device that contains a linearizer for improving the distortion characteristics of the device for use at the driver stage.\(^{(3)}\) Generally, an FET amplifier has the characteristics which cause the gain to fall and the phase to become positive as the input power is increased. These characteristics in the AM-AM and AM-PM (AM: amplitude modulation; PM: phase modulation) cause IM3 to deteriorate. In order to suppress this deterioration, we developed the MMIC containing a linearizer that has characteristics opposite to the change in AM-AM and AM-PM of the amplifier. A significant suppression of the deterioration of IM3 can be achieved with this MMIC, because the linearizer works to cancel out the change in AM-AM and AM-PM and to smoothen the AM-AM and AM-PM characteristics of the entire MMIC. This MMIC has AM-AM characteristics in the gain expansion direction, and also utilizes a parallel-type diode linearizer consisting of resistors and diodes, which are effective for reducing the size of the chip.\(^{(3)}\)

To empirically verify the suppression of IM3 deterioration by this MMIC, we fabricated and evaluated a trial 2-stage amplifier consisting of the MMIC as the driver stage, and a GaN internally matched HEMT as the final stage. Figure 6 shows the evaluation results. The distortion characteristics of a GaN MMIC with a built-in linearizer were lower over almost the entire output zone.
than that of a GaN MMIC without a linearizer. A linear output power of a GaN MMIC with a built-in linearizer was 5 dB higher than that of a GaN MMIC without a linearizer with the power supply voltage 24 V. It was confirmed that a GaN MMIC with a built-in linearizer was effective for improving the GaN multi-stage amplifier performance in regard to distortion characteristics and linear output power.

Next, we developed a 2-stage amplifier consisting of the MGFG5H1503, which had been commercialized as a GaN MMIC with a built-in linearizer, coupled to the MGFK47G3745A, which is a 50 W internally matched HEMT (Fig. 7). We connected the input and output terminals to each device, and also connected the devices to each other, using the 50 Ω line provided on an alumina substrate. Resinous substrates with a bias circuit were installed on both sides of the alumina substrate as well as an aluminum heat sink on the underside of the substrate. Also, in order to improve the spatial isolation characteristics between each device, we covered the entire substrate with an aluminum block with apertures so as to surround the devices on the substrate. As a result, at a frequency of 18 GHz or below, isolation between the input and output terminals was 60 dB or more.

Figure 8 shows the evaluation results for the input and output characteristics of this 2-stage amplifier. The characteristics obtained at a frequency of 14.125 GHz were saturated output of 47 dBm (50 W), linear gain of 29 dB, and power-added efficiency of 24%. Also, as shown in Fig. 9, the linear output power satisfying IM3 = -25 dBc was 45 dBm, equivalent to that obtained when using a 50 W HEMT alone. It is confirmed that using a GaN MMIC with a built-in linearizer as the driver stage is a solution to suppress the soft compression characteristics, which had been an issue with GaN multi-stage amplifiers, thus successfully realizing a GaN multi-stage amplifier with high linear output power.

5. Summary
As the devices for Ku-band amplifiers of satellite communication earth stations, we commercialized a 50 W internally matched HEMT (MGFK47G3745A) with a world top level output power in a package that is smaller than that of the conventional 25 W GaAs FET, an 80 W internally matched HEMT (MGFK49G3745) that has marked a world-leading output power, and a GaN 20 W MMIC with a built-in linearizer (MGFG5H1503) with a world-class distortion compensation performance. Also, we made a prototype 2-stage amplifier consisting of an MMIC coupled with a 50 W HEMT, suppressed the soft compression phenomenon peculiar to GaN, and realized high linear output power. We hope that our lineup of Ku-band GaN devices produces high output power for satellite communication transmitters, and contributes greatly to the miniaturization of these transmitters.

References
(1) H. Koyama et al.: A 0.25 μm Gate AlGaN/GaN HEMT for X-band Using RELACS Process, 2012
