GaIN HEMT Amplifier for C-band Space Applications

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1. Introduction
With the diversifying functions and increasing traffic of recent satellite communications, the amplifiers installed in satellites must provide higher power and improved efficiency. Commonly-used satellite-mounted amplifiers are, in general, either traveling wave tube amplifiers (TWTAs) or solid state power amplifiers (SSPAs) using gallium arsenide field-effect transistors (GaAs FETs). However, because of this high output power and high efficiency, TWTAs are used more often than SSPAs. Meanwhile, the gallium nitride high electron mobility transistor (GaN HEMT) is expected to improve the output power and efficiency of SSPAs. Owing to its material properties, the GaN HEMT is capable of high voltage operation and produces a high power density, and thus is expected to be a high-frequency device that realizes a high-power and high-efficiency SSPA, and in recent years, high-power GaN HEMT amplifiers are being developed at many research institutions(1)(2)(3)(4).

This time, based on Mitsubishi Electric's GaN HEMT device, we have developed a high-power and high-efficiency amplifier transistor, and verified that it provides sufficient reliability for satellite applications.

2. GaN HEMT High-Power Amplifier
2.1 Transistor characteristics
Mitsubishi Electric's GaN HEMT, which is used for the newly developed high-power amplifier, has the following structure-related advantages: (i) current collapse suppression and good pulse I-V characteristics by forming a passivation film using a catalytic chemical vapor deposition (Cat-CVD) process(5), and (ii) low on-resistance by reducing the resistance of ohmic contact using a silicon (Si) ion implantation process.

Figure 1 shows the output characteristics of the unit cell transistor. The evaluated element has gate dimensions of 0.6 μm in length and 1.2 mm in width, and the measurements were performed under the continuous wave (CW) condition at a C-band frequency (4 GHz) with a drain voltage Vd = 40 V, and a drain current Id (RFoff) = 50 mA/mm. The load and source impedances were determined so as to maximize the power added efficiency (PAE) at the fundamental and second harmonic frequencies. Under these conditions, the measurements of the unit cell element confirmed the superior performance of Mitsubishi Electric's GaN HEMT, that is, a PAE of 80% and output power density of 3.3 W/mm.

2.2 Design of internal matching circuit
To develop a high-power and high-efficiency amplifier using a high-performance transistor, it is important to optimize the matching circuit. The amplifier circuit was designed to minimize the matching circuit loss and optimally deal with the fundamental and harmonic (especially second harmonic) frequencies. Figure 2 shows the circuit configuration of the C-band 100-W output internally matched FET amplifier. Four GaN HEMT chips with a narrow gate width are combined in parallel to achieve a high output gain, and both the input and output matching circuits are configured with two-stage quarter-wave transmission line transformers.
to enhance the bandwidth. The source load at the second harmonic frequency significantly influences the efficiency, and thus it is optimized by using open-ended stubs located nearby the chip. The pattern layout of the output matching circuit is optimized so as to reduce the circuit loss.

Using the same technique, additional internal matching circuits were designed for the 20 W and 40 W output single-chip amplifiers.

2.3 Evaluation results of electrical characteristics

Figure 3 shows a photograph of the inside of the “MGFC50G3742S,” the 100-W output internally matched FET amplifier.

![Fig. 3 Internal view of MGFC50G3742S (100 W model)](image)

The cavity size of the package is 14.3 × 15.2 (mm), which are the same dimensions as Mitsubishi Electric’s GaAs 25-W amplifier. Four GaN HEMT chips and matching circuit boards are implemented inside the hermetically sealed package. The GaN HEMT chips are configured in parallel with a total gate width of 9.6 mm; and the input matching circuit board is configured in two stages on the aluminum and high permittivity substrates, while the output matching circuit board is in three stages on the aluminum and high permittivity substrates.

Figure 4 shows the output characteristics measured under the CW condition at a frequency of 4 GHz, Vd = 40 V, and Id (RFoff) = 2 A. This device has achieved industry-leading performance, namely, an output power at 2 dB gain compression point, P2dB, of 50 dBm, actual gain, Gp, of 11.4 dB, and power added efficiency, PAE, of 62%. Table 1 summarizes the product specifications of the commercialized C-band GaN internally matched FET amplifiers.

![Fig. 4 Output characteristics of MGFC50G3742S (100 W model)](image)

3. Reliability Tests for Space Applications

For space applications, it is vital to verify the reliability when the device is used in outer space. In general, reliability tests are performed on the long-term life, mechanical properties, etc. Mitsubishi Electric has conducted reliability tests under the conditions listed in Table 2.

![Table 2 Reliability test items](image)
the physical stresses in outer space were performed, and no failures were observed.

To determine the mean time to failure (MTTF: mean time to a component failure without maintenance), which numerically represents the product’s life time, a temperature accelerated test was performed on the 20-W output amplifiers operated at Vds = 47 V, and channel temperature (Tch) = 250/260°C. The calculation result indicates that the activation energy (Ea) is 1.62 eV, which ensures a high reliability with a life time of one million hours under the operating conditions of Tch = 175°C and Vds = 45 V. Figure 5 depicts the calculation result of MTTF.

We have also conducted direct current (DC) and radio frequency (RF) life tests as a part of the long-term life tests. The results of these life tests are shown in Figs. 6 and 7 (only P2dB data are shown). In these charts, the horizontal axis indicates the time, and the vertical axis indicates the variation in the device property. In these tests, the deterioration in P2dB is judged based on the criterion of ±1 dB. The DC life test was carried out under the conditions of Tch = 230°C and Vds = 45 V, and the variation in P2dB after 5,000 hours indicated a satisfactory level of equal to or less than 0.5 dB. The RF life test was carried out under the conditions of Tch = 230°C, Vds = 45 V, and an input power giving P2dB, and the variation in P2dB after 1,000 hours was sufficiently low at 0.2 dB or less.

The radiation tests were performed on the single event burnout and total dose effect, where high-energy heavy ions impinge on the semiconductor element, causing an instantaneous change in the electrode potential, resulting in an overvoltage or overcurrent flowing in the FET and the element may burn out (single event burnout), or accumulated radiation dose may cause deterioration of the semiconductor element (total dose effect). In the former test, Br ions were irradiated during the DC (pinch off) operation as well as during the RF operation where the output power was varied from the 2 dB gain compression point to the 13 dB gain compression point, and no element failures were observed in either case. In the latter test, cobalt 60 γ-rays were irradiated during the DC operation, causing no element failures.

The results of all the reliability tests are satisfactory, indicating sufficient reliability for the device to be used in outer space.

4. Conclusion

Using Mitsubishi Electric’s GaN HEMT, C-band high-power amplifiers for space applications have been developed. By minimizing the loss of the matching circuit itself and optimally treating the fundamental and harmonic (especially second harmonic) frequencies, industry-leading performance of 100 W power output and PAE of 62% under the CW condition has been achieved. In addition, various reliability tests were conducted assuming the conditions for satellite applications, and satisfactory results were obtained.

This time, we have commercialized a range of GaN HEMT C-band amplifiers with 20, 40, or 100-W internally matched FETs and 2-W output discrete FET device. The newly developed products provide high performance rivaling the TWTA, which has advantages of high power output and high efficiency, and will contribute to the development of a compact and lightweight SSPA.
References


