Development of Onboard High Linearity Low Noise Amplifier and Solid State Power Amplifier for Satellite/Terrestrial Integrated Mobile Communication System

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Onboard Low Noise Amplifier (LNA) and Solid State Power Amplifier (SSPA) of STICS (Satellite /Terrestrial Integrated mobile Communication System) satellite is assumed to meet large signal interference from huge numbers of terrestrial communication terminals or to amplify hundreds of channels simultaneously. So, LNA required having high linearity and low noise figure simultaneously. We developed S-band onboard LNA which can efficiently operate high level interference wave that is 40 dB higher than that of desired wave. Also, for SSPA, we developed high linearity and high efficiency SSPA using GaN device.

1 Introduction

In Satellite/Terrestrial Integrated mobile Communication System (STICS), both the terrestrial and satellite communication systems use the same frequencies, and together with desired waves on the satellite, interference waves are also received from terrestrial systems. Therefore, the user link reception system on the satellite needs a Low Noise Amplifier (LNA) to be mounted thereon that has strong anti-interference characteristics and is highly resilient, and that operates appropriately even with this large amount of interference waves. Also, regarding the Solid State Power Amplifier (SSPA), to simultaneously amplify many communication channels, it must have high linearity, and it consumes almost all the power of the communication satellite, so high efficiency operation is desirable.

Previously, as an actual example of a satellite mounted LNA in the S-band, the literature [1] describes achievement of Noise Figure (NF) 1.4 dB, gain 44.8 dB, amplitude-frequency characteristics 0.5 dB/5 MHz, and phase shift 0.6°/5 MHz, but anti-saturation characteristics for LNA are not described.

This paper describes our development of a high linearity LNA to be mounted on a satellite, that operates effectively in a state with the interference waves level at least 40 dB higher than the desired waves, and our environmental tests and simple radiation analysis etc. done to verify its effectiveness. We also used GaN which is used in the latest device, to manufacture a high linearity SSPA for a satellite, and similarly performed environmental tests and simple radiation analysis, etc. to confirm its validity.

In this paper, the following Section **1** is the introduction, Section **2** describes development of a high linearity LNA, Section **3** describes development of a high linearity SSPA, and Section **4** states the conclusion.

2 Design and development of high linearity low noise amplifier[2]

For an LNA, as mission equipment in a satellite-mounted mobile communication system, to avoid interference from terrestrial systems, while it needs to have high linearity, it also needs NF suitable for satellite communications.

To achieve an LNA with excellent linearity and low noise characteristics, we divide the LNA into front and rear stages, for a basic configuration with the front stage amplifier focused on NF, and the rear stage amplifier having the desired saturated output.

In this case, the front stage amplifier needs to have excellent noise characteristics as a condition, and with regard to gain that it is desired to have, there are two ways of thinking. One way is: high gain is needed to reduce the rear stage amplifier's NF effects on the entire LNA's NF. The other way of thinking is: low gain is desired, to avoid having the entire LNA's linearity affected by the worse linearity due to the front stage amplifier's own intermodulation distortion (IM3). It is important to design with these two trade-offs in mind.

Also, characteristics desired in the rear stage amplifier are: while keeping in mind low noise characteristics and reduction of power consumption of the entire LNA, obtain desired saturation output, and maintain high linearity. Thus, it may be important to design an LNA while keeping in mind the trade-off between saturation output and power consumption. We designed and manufactured a high linearity LNA, based on the above viewpoints.

2.1 High Linearity LNA configuration

This high linearity low noise amplifier (LNA) in the feeding section has the function of receiving a 1980 to 2010 MHz frequency band input signal, and amplifying it to the desired output power, while maintaining low noise characteristics. The internal functions comprising the LNA are given below.

(i) Low noise amplifier part's function

While suppressing deterioration of the input signal's signal to noise (S/N), this part amplifies the signal to the desired output level and outputs it. In the amplifying component, we used the NE32500 GaAs HEMT chip made by NEC, which has excellent low noise characteristics.

(ii) Gain amplifier part's function

This part receives the input signal from the low noise amplifier part, and amplifies it to the desired output level. In the amplifier component, considering saturation output more than low noise characteristics, we used the NE67400 GaAs FET chip made by NEC. But if greater saturation output is needed, use of GaN FET could be considered.

Based on these needs, we set the LNA's target performance as follows.

A) Low noise amplifier part's performance

At 1980 to 2010 MHz, 32 dB typical gain and 0.75 dB max NF were set for the target performance of the low noise amplifier part.

B) Gain amplifier part's performance

At 1980 to 2010 MHz, 29.5 dB typical gain, 5 dB max NF, 0.5 dB, +17.5 dBm gain compression on output, and 24 dBc or greater IM3 (0.5 dB when gain compression) were set for the target performance of the gain amplifier part.

Overall target performance of the high linearity low noise amplifier prototype LNA combining the low noise amplifier part and gain amplifier part is given below.

Gain: 45 dB (typical)

NF: 0.9 dB or lower (normal temperature), 1.1 dB or lower (+55C°)

IM3: 24 dBc or greater (when at 0.5 dB gain compression point)

In STICS, the signal level of the LNA for satellite mounting is -123.6 dBm per 1 wave[3], and in the 30 MHz band, this is approximately -80 dBm if the capacity is 20,000 terminals. Accordingly, 10,000 times (200 million terminals for terrestrial terminals with the same output power as satellite terminals) was taken as a realistic needed value; that is, linear operation is done even if a 40-dB higher interference signal is input. By the configuration described above, for approximately a maximum -40 dBm input power and for saturation output (when 0.5 dB gain compression), we predicted an approximately 40-dB back-off state.

Figure 1 shows this LNA configuration. The reception signal input passes through the isolator, then passes through the low noise amplifier part and gain amplifier part, then is output to the terminal. As well as inserting the gain adjustment attenuator between the stages, power is supplied from the bias circuit. Figure 2 shows an exterior photo.

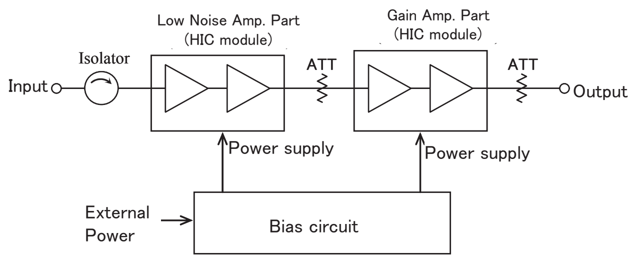


Fig. 1 Conceptual figure of LNA

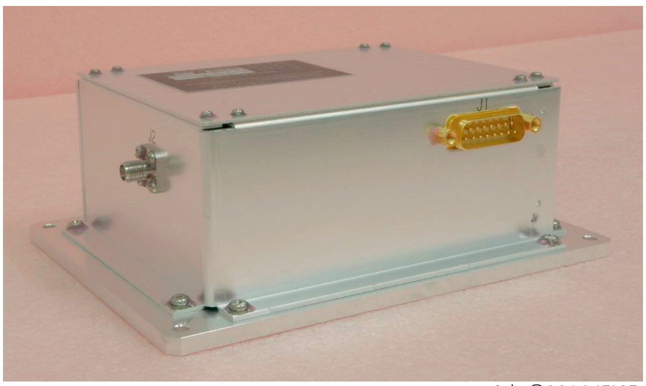


Fig. 2 Photograph of LNA

2.2 Experiment results of high linearity low noise amplifier

For the LNA, we measured electrical characteristics such as gain and NF, and did measurement tests of mechanical characteristics such as a vibration test and temperature cycle test. Table 1 summarizes the test results.

Also, Figure 3 shows results obtained for the frequency characteristics of the noise figure at each temperature. The noise figure is approximately 0.7 when ambient temperature is -10°C. Also, even at the maximum temperature of +55°C, the noise figure is 1.0 dB or less. Figure 4 shows frequency characteristics of gain. In-band, 45.7 to 46.0 dB linear gain can be obtained.

Figure 5 shows output characteristics of 1.995 GHz. 8.8 dBm output power was reached at the 0.5 dB compression point. Figure 6 shows the results of measuring anti-saturation characteristics when interference waves and desired waves existed simultaneously, by comparing input characteristics when there are only desired waves. Interference waves that are 40 dB higher than desired waves are input in the same frequency band. If input characteristics are measured with and without interference waves,

Table 1 Result of test

Item	Result of test
Frequency	1980-2010 MHz
Gain	46 dB(Typ.)
Noise Figure Third inter-modulation distortion	< 1.0 dB(+55℃) > 24.2 dBc
IIP3/OIP3 Input return loss	-25.0 dBm/ +20.5 dBm > 19.2 dB
Output return loss	> 23.1 dB
Amplitude variation	< 0.2 dBp-p
Phase shift	<1.37 deg
Interference condition	Linear operation is confirmed with input interference wave of 40 dB more than desired wave
Random vibration test	No variation before and after test
Cicric thermal test	No variation before and after test

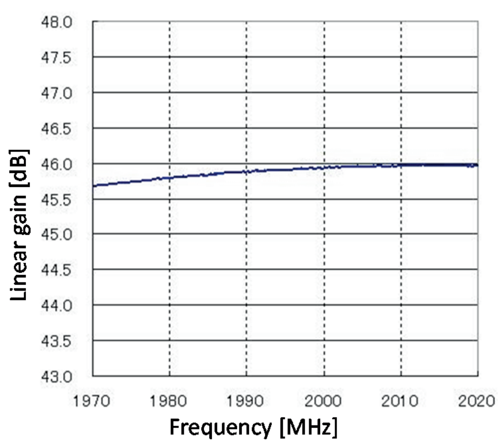


Fig. 4 Frequency characteristics of gain

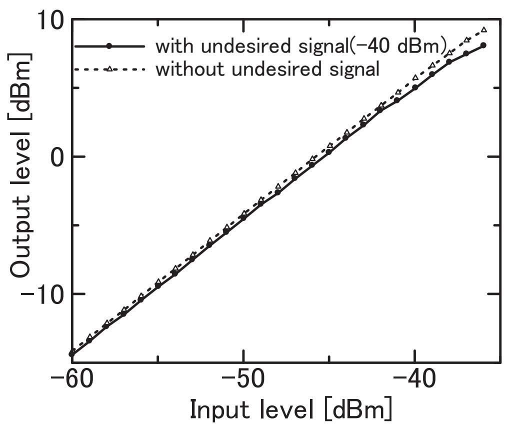


Fig. 5 Input/output power characteristics

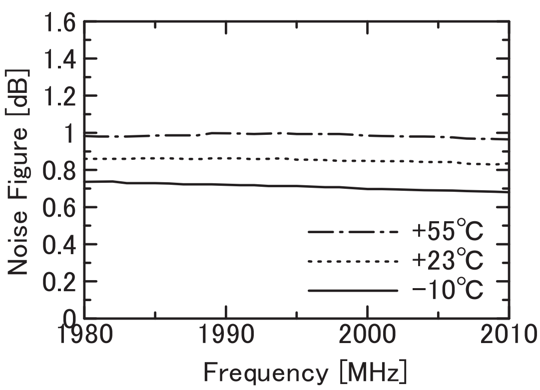


Fig. 3 Frequency characteristics of NF

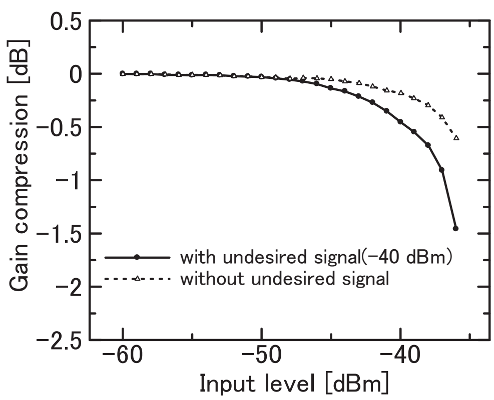


Fig. 6 Gain compressions vs. input power

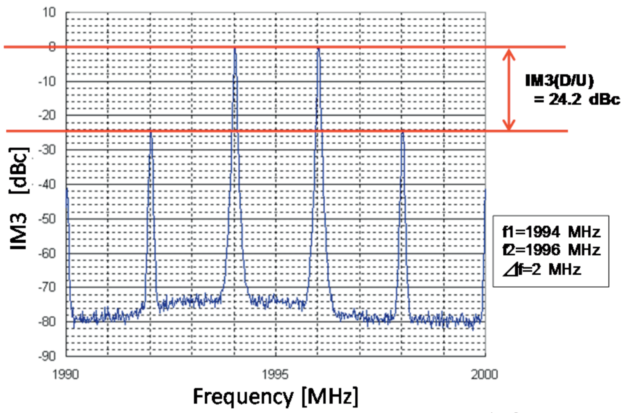


Fig. 7 3rd order intermodulation characteristics

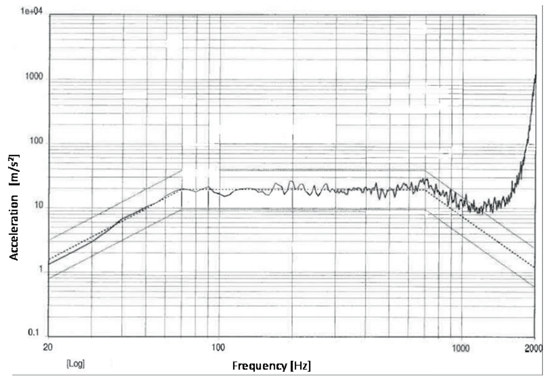


Fig. 9 Random vibration test result

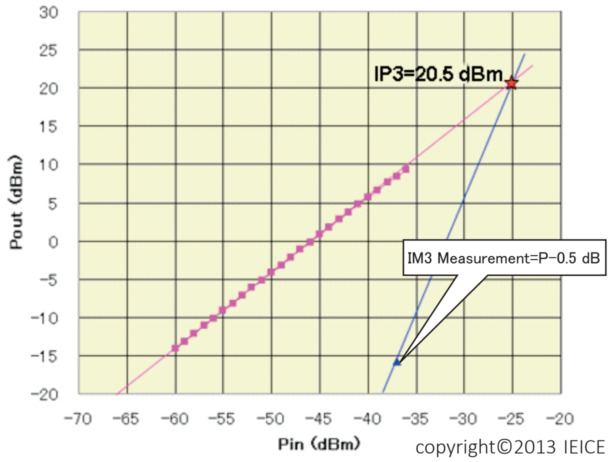


Fig. 8 IIP3 characteristics

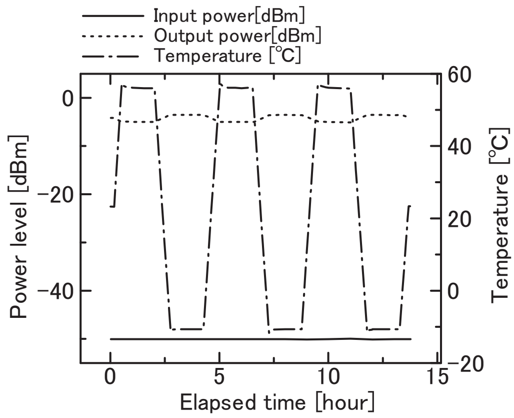


Fig. 10 Cyclic Thermal test result

then when there are interference waves, -40 dBm input power reaches the 0.5 dB gain compression point, which is 40 dB higher than the -80 dBm reference input level for desired waves. Therefore, we can conclude that it can do linear operations without saturation under conditions with interference waves 40 dB higher than desired waves.

Figure 7 shows the third-order Inter-Modulation distortion (IM3) characteristics of this LNA, and demonstrates that IM3 is 24.2 dBc. Figure 8 shows the third-order Input Intercept Point (IIP3) characteristics, and indicates that IIP3 is -25 dBm, which is equivalent to 20.5 dBm in the third-order Output Intercept Point (OIP3).

Looking at phase shift characteristics, phase shift was 1.37 deg. at the 0.5 dB gain compression point, but phase shift is 0.55 deg. at the maximum input level of interference waves (-40 dBm), so it seems this is not a problem for the system.

2.3 Environmental tests of high linearity low noise amplifier

To make this LNA mountable on satellites, we put it through a random vibration tests and thermal cycle tests. Figure 9 shows an example of the random vibration test results: from 20 Hz to 2,000 Hz, a maximum 20 m/s^2 acceleration was applied, and it was found that there were no changes from before to after it was vibrated. And Figure 10 shows the thermal cycle test results. In three thermal cycles from -15°C to +55°C, it was found that there are no problems in output power or gain.

2.4 Simple radiation analysis of high linearity low noise amplifier

Figure 11 shows a radiation protection conceptual diagram for the satellite-mounted device. For this simple radiation analysis, we did an analysis study for a 10-year total dosage, as described below.

This LNA's most critical part for radiation is the three-terminal regulator planned for use in the DC/BIAS circuit. This regulator's total radiation dose resistance is 300 Krad-Si.

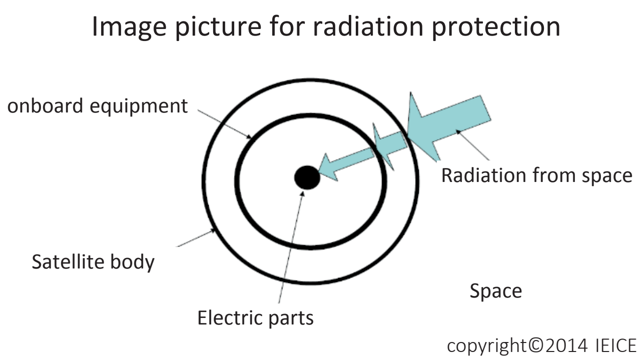


Fig. 11 Conceptual figure of radiological protection of onboard equipment

This regulator has at least 1.6-mm thick aluminum equivalent shielding on the LNA housing, and satellite structures can generally be expected to have 0.8-mm thick aluminum equivalent shielding, so a total 2.4-mm thick aluminum equivalent shielding would be provided.

As an example, considering the radiation environment of a GPM/DPR satellite, at 300 Krad-Si, 0.3-mm thick aluminum equivalent shielding is required. This LNA has 2.4-mm thick aluminum equivalent shielding, so approximately 800% of the required level is provided. Looking at the radiation environments of the surrounding GPM/DPR satellite or STICS satellite that is a geostationary satellite, they have similar levels or the geostationary environment has a somewhat harsher level, but this analysis result shows an ample shielding margin, so this design seems to have no problems for radiation tolerance in a geostationary satellite environment.

2.5 Summary of high linearity low noise amplifier

We developed an LNA with good high linearity characteristics and low noise characteristics (below NF 1 dB), as an LNA to be mounted on a satellite used in a Satellite/Terrestrial Integrated mobile Communication System. Even in conditions with interference waves at least 40 dB higher than desired waves, linear operation was confirmed, and environmental tests and a simple radiation analysis found it to be effective as a satellite-mounted LNA for STICS. It seems that this technology can contribute to enhancing the interference wave resistance characteristics and resilience of other satellite-mounted LNAs.

3 Study and components prototype of high linearity solid state power amplifier

3.1 High linearity SSPA outline

The high linearity SSPA is mounted in the final stage of the primary phased array feeder. This device supplies RF power to the primary feeding antennas. For the Solid State Power Amplifier (SSPA) required in STICS, in order to amplify multi-carrier signals, highly linear performance is required. To achieve high linearity in the SSPA, the first issue is to raise the saturation output of the SSPA, so an SSPA with large output power is required. In recent years, Gallium Nitride Field Effect Transistors (GaN FET) are attracting attention as a device for microwave communications. Development of GaN FET is advancing for devices suitable for increasing the saturation output and miniaturizing SSPA, and they have come to be applied in terrestrial microwave communication devices. By applying GaN FET in SSPA for satellite-mounted mobile communication system missions, one can provide an SSPA that achieves high linearity, better efficiency and greater miniaturization than an SSPA that used previous devices.

In this research, we prototyped a highly linear SSPA for satellite-mounted mobile communication system missions, that uses GaN FET. First, Subsections **3.2** to **3.3** describe the development of a final stage GaN amplifier as a component prototype. Then, Subsection **3.4** onward describe using a linearizer and front stage amplifier, etc. for a satellite-mounted SSPA, to form an amplifier with at least 25 dB gain, and we did thermal vacuum tests and simple radiation analysis, etc. to confirm its validity when mounted.

3.2 High linearity SSPA final stage unit

Figure 12 shows a function system diagram of the final stage unit of this linearity amplifier.

Figure 13 shows an external view of the final stage unit of the high linearity performance amplifier.

The overall size is (95 mm × 66 mm × 22 mm) or smaller. A GaN FET is mounted in the center, and for the input and output, matching circuits configured on a Teflon substrate are provided. The entire circuit uses connectors providing drain and gate voltage, and RF connectors providing input/output of RF, as external interfaces.

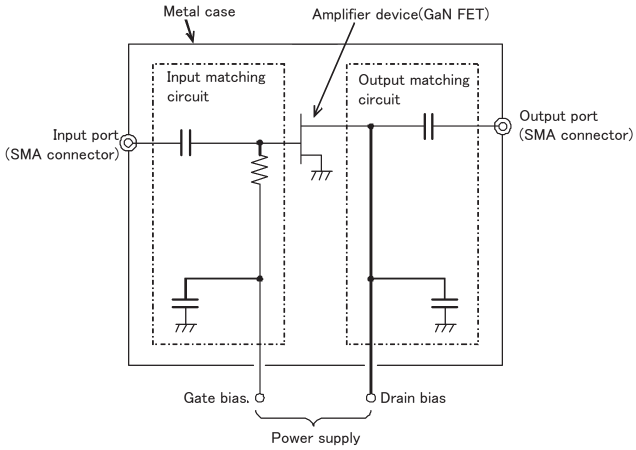


Fig. 12 Final amplifier unit of SSPA

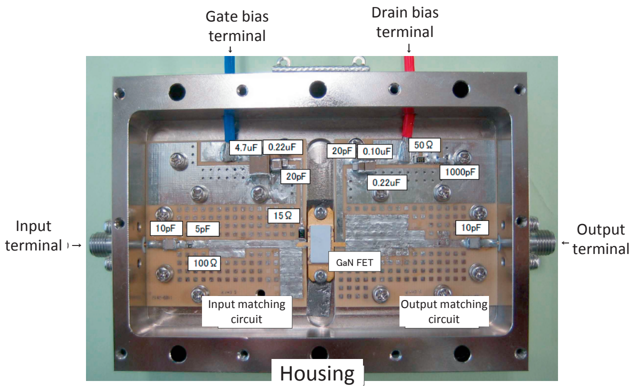


Fig. 13 Outer view of final amplifier unit

3.3 Measurement results of high linearity SSPA final stage unit

Table 2 shows the measurement results, using this high linearity amplifier.

Figure 14 shows the input/output characteristics of the final stage unit of this amplifier.

For the measurement frequency, we used 2.185 GHz as the center frequency. The black line shows the relationship between the RF input and RF output. At the 2 dB compression point, it reached 43.2 dBm (20.9 W), and satisfied the target value. The blue line shows power added efficiency; it has 59% power added efficiency at the same operation point. Measurements using this manufactured device almost satisfied the 60% target, but by adding to the output port a harmonic matching circuit using F-class amplifier theory, we confirmed that the 60% target can be reached.

Figure 15 shows the measurement results of intermodulation distortion characteristics. We used the frequencies f_1 = 2.184 GHz and f_2 = 2.186 GHz. At the 8 dB per wave back-off point, the intermodulation characteristic was -28 dBc. This result did not satisfy the -32 dBc target, but we judge that using an equalizer in this amplifier's front stage would improve linearity for the SSPA.

Table 2 Measurement result of final unit of high linearity SSPA

Item	Design result	Test Result
Matching with Antenna part and surround circuit	Same as on the left	Same as on the left
Frequency 2170~2200 MHz	Same as on the left	Same as on the left
Output power More than 20 W (2 dB compression point)	Same as on the left	43.2 dBm(20.9 W)
PAE 60%(2 dB compression point)	Same as on the left	59%
Type of amplifier GaN or GaAs	GaN	GaN
Third order inter-modulation distortion -32 dBc(8 dB backoff 2tone)	Same as on the left	-28 dBc

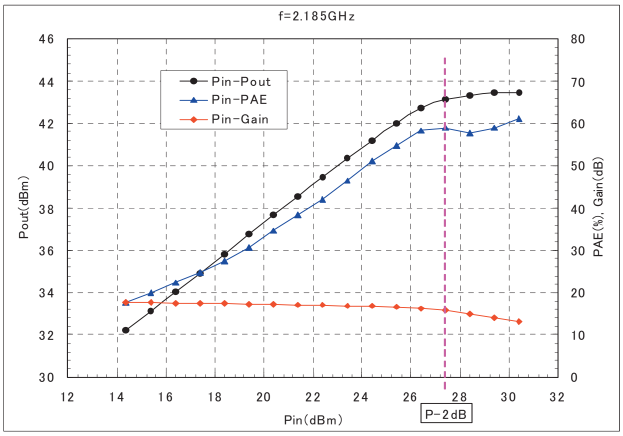


Fig. 14 Input vs. output characteristics of high linearity SSPA

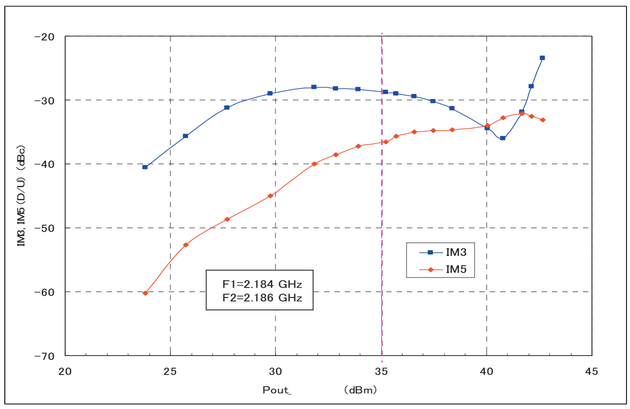


Fig. 15 3rd-order harmonics characteristics of high linearity SSPA

3.4 High linearity SSPA prototype

(1) Functions and performance of SSPA

After that, for the high linearity SSPA, we improved power efficiency of the high linearity SSPA final unit, then did further thermal vacuum tests, vibration tests and radiation analysis that are required for mounting the SSPA on a satellite. We thus confirmed it would operate in space environment conditions as mounted equipment. For the high linearity SSPA, we assumed a 20 W class output, used GaN that is an advanced device, and while maintaining linearity, we achieved 62% final stage power conversion efficiency. We further reconfigured the high linearity SSPA final stage unit we developed as described in the previous subsection, then installed a front stage amplifier, etc., and put together a high linearity SSPA. Its outline is given below.

In the primary feeding section, the high linearity SSPA has the function of inputting the +9 dBm standard input level signal, and outputting a signal at the 20 W or greater output level. The functions of the internal modules comprising the SSPA are given below.

(i) LNZR (Linearizer): This has characteristics that are the reverse of the passing phase of the linearity (especially the output signal for the input level) of the final stage GaN FET. This module improves (compensates) the passing phase characteristics of the SSPA. In areas with high input levels that deteriorate the linearity of the GaN FET, the passing phase's deterioration is also a cause of linearity deterioration typified by IM3, so it has an IM3 improvement function.

(ii) PIN ATT (Variable attenuator): This adjusts the total gain of the SSPA. Simultaneously with the gain adjustment function, it can also be given an SSPA gain temperature compensation function, but an SSPA gain temperature compensation function was not added to this SSPA.

(iii) LPA (Low Power Amp): Low signal level amplifier.

(iv) MPA (Medium Power Amp): It takes the LPA's output signal, and amplifies it to the input level of the HPA final stage amplifier.

(v) HPA (High Power Amp): As the final stage amplifier, it very efficiently amplifies the input signal to 20 W or greater power.

(vi) PSU (Power Supply Unit): It inputs the primary voltage, and supplies each power voltage used by each module in the SSPA. For this prototype, the primary voltage was set at +45 V.

Table 3 Taget paeformance of SSPA

Item	SSPA aimed performance
Frequency	2170～2200 MHz
Output power	>20 W (2 dB gain compression point)
PAE	>60%at last stage amp. (2 dB gain compression point)
3^{rd}-order harmonics distortion	>16 dB (2 dB comp point, 2-tone input)
Gain	>25 dB
Input return loss	>19 dB
Phase shift	<15 deg(2 dB comp point)
Amplitude variation	<0.5 dBp-p
Consumption power	<55 W
Other	Considering satellite mounting, vibration test, thermal vacuum test and radiation analysis are performed.

Table 3 shows the target performance of the SSPA.

(2) Configuration and external views of SSPA

Figure 16 shows the configuration of the SSPA. We installed a linearizer, PIN diode attenuator and front stage amplifier in the final stage unit used in the SSPA described in Subsection **3.1**. We also worked to further improve the power efficiency for the final stage unit.

Figure 17 shows external views of the SSPA.

(3) Performance test results for SSPA

Table 4 shows the test results for the target performance of the SSPA.

Figures 18 to 26 show typical test results. Figure 18 shows simple power input vs. power output characteristics (Pin vs. Pout) of the newly manufactured GaN FET final stage unit. Also, Figure 19 shows input power vs. gain characteristics (Pin vs. Gain). Moreover, Figure 20 shows input power vs. efficiency characteristics (Pin vs. efficiency). In these graphs, P-2 indicates the 2 dB compression point (33.1 W (45.2 dBm)). At this point, we were able to obtain 62% or greater power added efficiency.

Next, we obtained all SSPA characteristics. Figure 21 shows the characteristics of the input power vs. output power (Pin vs. Pout), power consumption, and gain of the SSPA at normal temperature. When the input power is at the rated value of 20 W, we achieved 37 dB gain, and 55 W or less power consumption. Figure 22 shows the input power vs. phase shift characteristics at normal temperature.

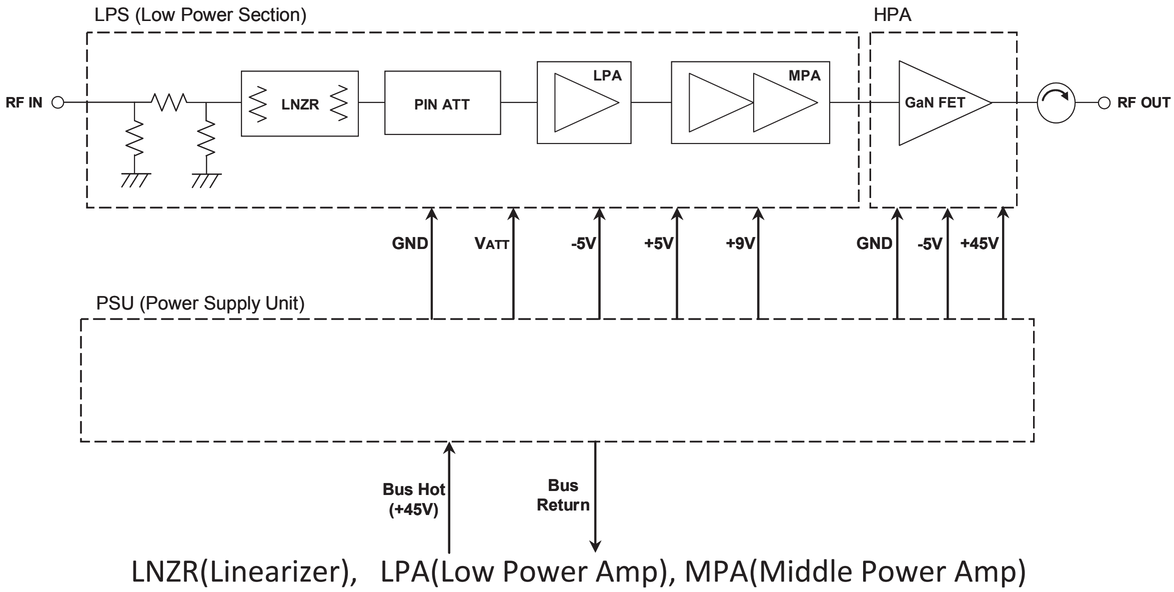
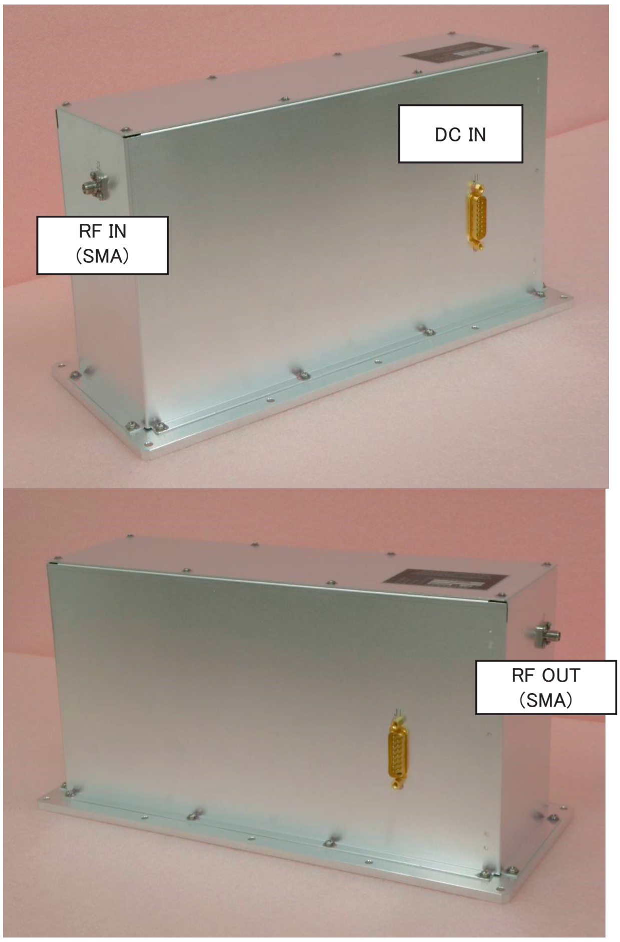


Fig. 16 Configurations of SSPA



324(L) × 132.8(W) × 153.5(H) (mm)

Fig. 17 Outer view of SSPA

Table 4 Test result

Item	Aimed Performance	Test result
Electrical specifications		
Frequency	2170～2200 MHz	Same as left
Output power	>20 W (2 dB gain compression point)	>33.1 W(45.2 dBm)
Linear gain	>25 dB	>37 dB
Input return loss	>19 dB	>19.9 dB
IM3	D/U >16 dB(2 dB comp point with 2-tone input)	>16.3 dB
Phase shift	>15 deg(2 dB comp point)	>2.2 deg
Amplitude variation	<0.5 dBp-p	<0.2 dBp-p
Consumption power	<55 W	<55 W
PAE of last stage	>60%	>62%
Environmental test		
Random vibration test	No variation	No variation
Thermal vacume test	No variation	No variation

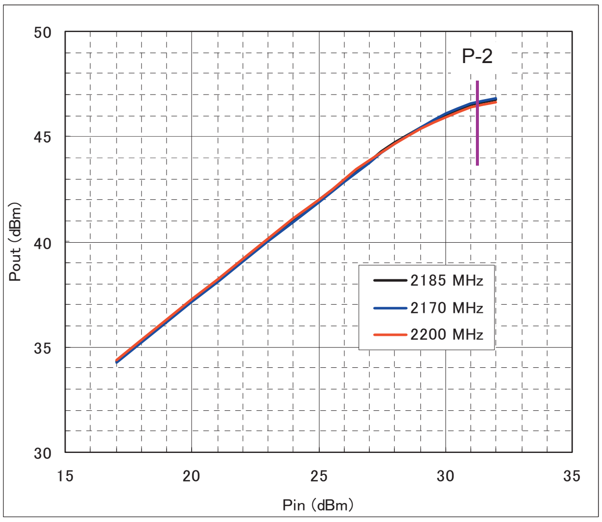


Fig. 18 Input vs. output of GaN FET

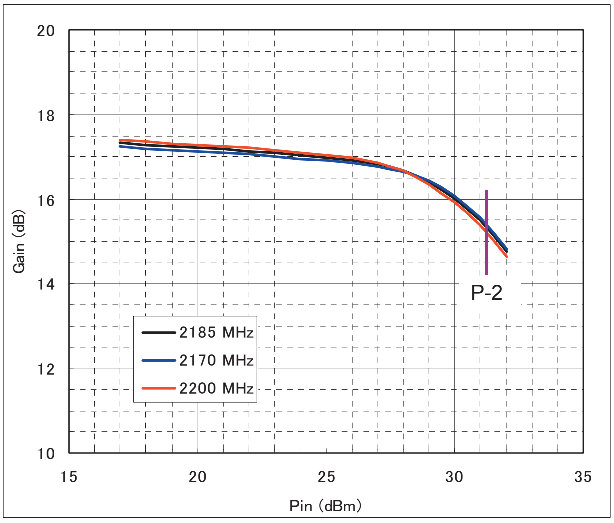


Fig. 19 Input vs. gain of GaN FET

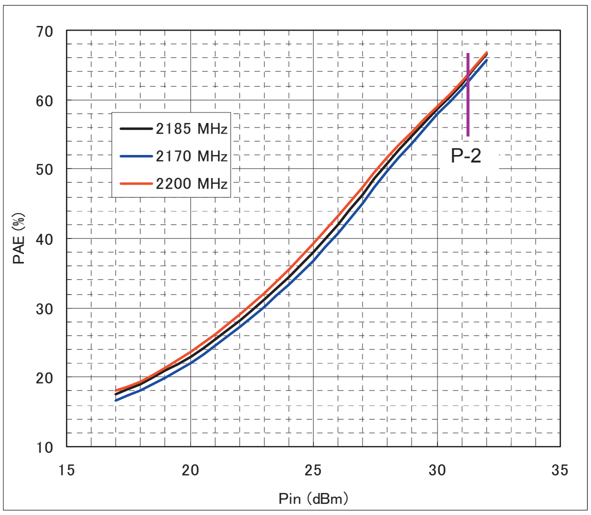


Fig. 20 Input vs. efficiency of GaN FET

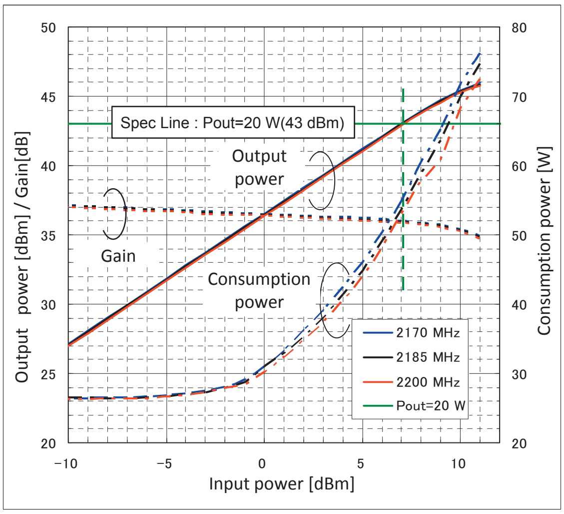


Fig. 21 Power characterestics of SSPA

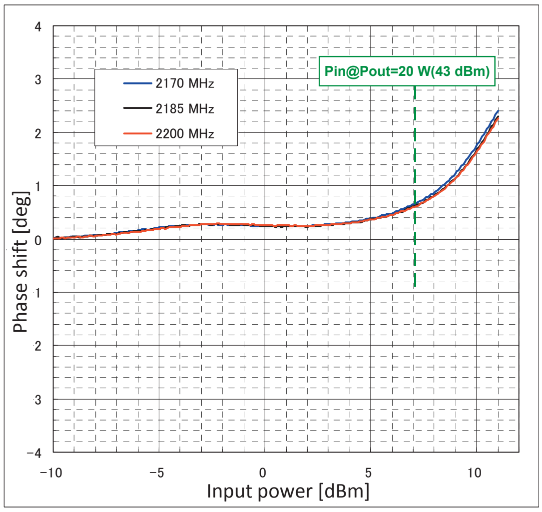


Fig. 22 Phase shift characteristics of SSPA

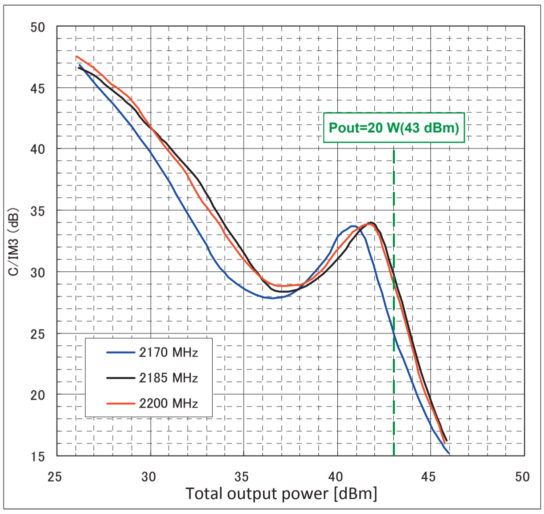


Fig. 23 IM3 characteristics of SSPA

Fig. 24 Thermal vacuum test setup (center: vacuum chamber)

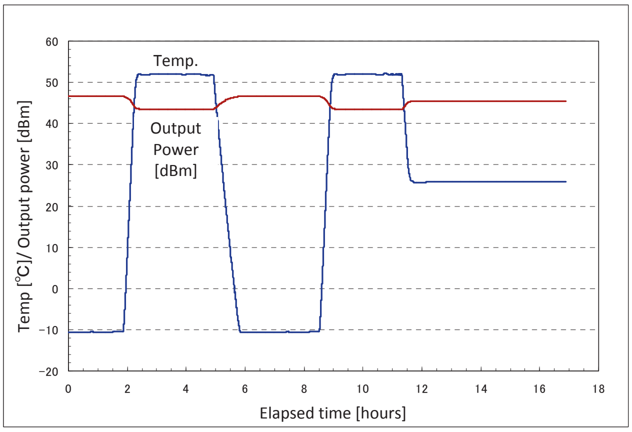


Fig. 25 Monitor data of thermal vacuum test

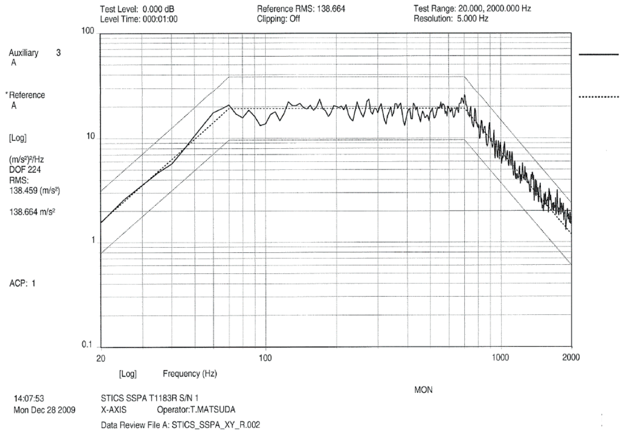


Fig. 26 Monitor data of random vibration test in X-axis

At the 2 dB compression point, it has the excellent characteristic of 2.2° or less. Figure 23 shows its IM3 characteristics. For 2 waves input at the 2 dB comp. point, we achieve D/U16.3 dB or higher.

(4) Environment test results of SSPA

For mounting this SSPA on a satellite, we performed a thermal vacuum test and random vibration test. Figure 24 shows the thermal vacuum test setup, and Fig. 25 shows the results. In two thermal cycles -10°C to +50°C, we confirmed there are no problems for output power or gain. Figure 26 shows an example of a random vibration test result. From 20 Hz to 2,000 Hz, we applied a maximum 20 m/s^2 acceleration, and confirmed there are no changes before and after vibration.

(5) Simple radiation analysis

Figure 11 shows a radiation protection conceptual diagram for satellite mounted equipment/parts.

In this simple radiation analysis, we did an analysis study for a 10-year total dosage, as follows.

For this SSPA, the most critical part for radiation is the PIN diode used in the PIN ATT part. Looking at other parts, the diodes and transistors (MOS FET), etc. used in the PSU have strong radiation resistant qualities (total dosage 500 to 1,000 Krad-Si), and the devices for RF use parts based on GaAs and GaN, so its radiation resistance is total dosage 1,000 Krad-Si, thus providing sufficient resistance.

The PIN diode's radiation resistance is a total dosage of 12 Krad-Si.

The PIN diode is used in the PIN ATT, which is enclosed in a metal case as an HIC, and the SSPA housing also has at least 1.8-mm aluminum equivalent shielding. In addition, one can generally expect a satellite structure to have 0.8-mm aluminum equivalent shielding, so a total 2.6-mm aluminum equivalent shielding is provided.

As an example, considering the radiation environment of a GPN/DPR satellite, at 12 Krad-Si, 1.8-mm aluminum equivalent shielding is required. This SSPA has 2.6-mm aluminum equivalent shielding, so it has shield thickness with an approximately 40% excess margin. Looking at the radiation environments in which the surrounding satellite is a GPM/DPR satellite or a geostationary STICS satellite, they have similar levels or the geostationary satellite environment is a little harsher, but this analysis result shows a sufficient shield margin, so it seems this design has no problems for radiation resistance in a geostationary satellite environment.

3.5 Summary of high linearity SSPA prototype results

For the high linearity SSPA in the feeding section, we designed, prototyped and evaluated the final stage unit, preamplifier, linearizer, etc. We manufactured an amplifier that satisfies the condition of 62% or higher power added efficiency at 20 W output class. Also, by environmental tests and simple radiation analysis, we confirmed there are no problems using this SSPA for a STICS satellite.

Examples of future issues for further improvement in characteristics:

1) Add a temperature compensation function to the PIN ATT part, aiming to enhance the temperature variation characteristics of the entire SSPA.
2) Select an optimal SSPA final stage GaN FET for 20 W output, aiming to improve overall SSPA efficiency.
3) Moreover, add a power supply voltage adjustment function to the GaN FET in the PSU, aiming to reduce power consumption.

4 Conclusions

We developed a low noise amplifier (LNA) that operates effectively, even in conditions with interference waves that are at least 40 dB higher than desired waves, for use in a Satellite/Terrestrial Integrated mobile Communication System (STICS). We also developed a high linearity solid state power amplifier (SSPA) using a GaN device with at least 60% power added efficiency, and at least 16 dB IM3. By doing environmental tests and simple radiation analysis, etc. for each, we confirmed its effectiveness when mounted on a satellite.

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References

1 Kenji Ueno,"3-6-1 Configuration of the Feed System", Special Issue on the Engineering Test Satellite VIII(ETS-VIII), Journal of NICT, Vol50, No3/4, pp.57–66, 2003.

2 Yoshiyuki Fujino, et.al.,, Development of onboard high linearity low noise amplifier for Satellite Terrestrial Integrated mobile Communication System," Trans IEICE on Communication (Japanese edition), J97-B(11) pp.1066–1070, Nov. 2014.

3 T. Minowa, et.al, Trans IEICE on Communication (Japanese edition), Vol.J91-B, No.12, pp.1629–1640, Dec. 2008.

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