Development of 30 kW-Class X-Band Solid State Power Amplifier for the Misasa Deep Space Station

NAKAHARA Toshihaya, YAMADA Youhei, OTAKE Toshiya, ASAO Hiroyuki, IZUKURA Kenji, KOHIGASHI Kousuke

Abstract

Under contract with the Japan Aerospace Exploration Agency (JAXA), NEC Corporation has delivered a 30 kW-class X-band solid state power amplifier to the Misasa Deep Space Station (Ground station for deep space exploration and telecommunication: GREAT) located in Saku City, Nagano Prefecture. To date, klystrons have been used for the high power X-band transmitters required for deep-space probe operations, but NEC has succeeded in implementing the world's first X-band solid state power amplifier in the 30 kW-class by multiple-stage combining of power amplification units using domestically produced gallium nitride (GaN) devices.

Keywords
deep space station, X-band, solid state power amplifier, GaN, radial combiner, multiple-stage combining of power amplification units, heat exchanger

1. Introduction

NEC has been engaged in the space industry as a manufacturer and integrator of systems comprising satellites, rockets, and ground stations, with major operations including the development of onboard equipment for satellites and rockets, tracking and control systems, rocket launch pads and systems, and other related systems and equipment. In particular, we have been developing and operating many ground stations for deep space exploration for over 35 years, starting with the development of the transmitting/receiving system for the Japan Aerospace Exploration Agency's (JAXA) Usuda Deep Space Center (UDSC).

In February 2021, the Misasa Deep Space Station was established in Saku City, Nagano Prefecture as the successor to the UDSC. In the same way as for the UDSC project, NEC was once again responsible for the development of the transmitting/receiving system for the new space station.

The high power X-band transmitters required for deep space exploration in the past used klystrons. However, klystrons for such a power class were available only from a U.S. manufacturer, so the production of such devices in Japan has been a longstanding desire.

NEC has developed the world's first solid state, high power amplifier in the 30 kW-class by multiple-stage combining of 125-W power amplifiers using domestically produced gallium nitride (GaN).

The rest of this paper introduces this 30 kW-class X-band solid state power amplifier.

2. Configuration of X-band Solid State Power Amplifiers

The X-band solid state power amplifier (X-SSPA) system is shown in **Fig.** below.

First, the X-band (7 GHz band) signal injected into the X-SSPA is fed into the drive amplifier to drive amplification. The amplified signal is then split into two paths and output to power amplifier #1 and power amplifier #2 using a waveguide. The signals in power amplifier #1 and #2 are further split into 192 paths (4 x 48) and input into 384 units of 125 W power amplifiers (125W_PA). The power amplifier component amplifies power to 125 W per each 125W_PA unit, with groups of 48 units combining to generate a transmission signal of approx-

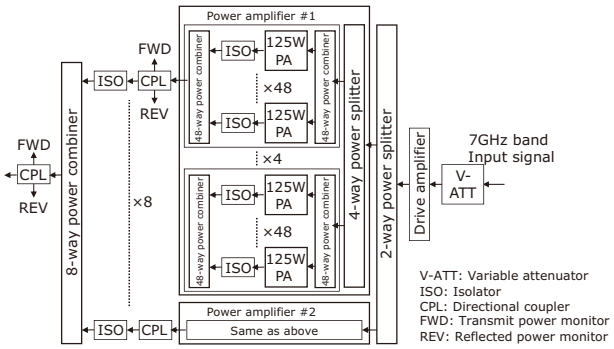

Fig. X-band solid state power amplifier system.

imately 4.8 kW. Each power amplifier is equipped with four sets of 48-way power combiners, which output four 4.8 kW transmission signals to 8-way power combiners.

Then, in the 8-way power combiner, eight 4.8 kW signals from each of the power amplifier components combine to generate a 30 kW-class transmission signal.

The X-SSPA is equipped with directional couplers for monitoring the transmission power and reflected power generated from the eight 4.8 kW transmission signals as well as directional couplers to monitor the transmission power and reflected power of the transmission signal output from the 8-way power combiners. The X-SSPA is also equipped with a protection function that instantly shuts down the output of the high power amplifiers if any anomalies occur on the load side after the signals are combined in the 8-way power combiners that cause the reflected power of the 4.8 kW transmission signal or the transmission signal output from the 8-way power combiners to exceed the threshold value.

3. Key Technologies of X-band Solid State Power Amplifiers

3.1 125W_PA using GaN HEMT

The X-band signal input to each 125W_PA is amplified by the first-stage amplifier, and then further amplified by the second-stage amplifier to achieve an output power of 125 W.

The first-stage amplifier uses a GaN high-electron-mobility transistor (HEMT) manufactured by Sumitomo Electric Device Innovations, Inc., and the second-stage amplifier also uses a GaN HEMT manufactured by the same company.

Photo 1 shows the external view of the 125W_PA.

The 125W_PA consists of a GaN-mounted power amplifier part, and power supply part that supplies DC power to the power amplifier part. The 125W_PA was developed jointly by NEC Network and Sensor Systems, Ltd. and Tamagawa Electronics Co., Ltd. for use with the 30 kW-class X-SSPA. To reduce heat generation in the back-end amplifier, which is usually a challenge in SSPA systems, the power and efficiency of the 125W_PA is matched to maximize device performance, achieving an average of 43% Power Addition Efficiency (PAE).

3.2 Power combining technology

The output of the 125W_PA is first input to a 48-way power combiner and the 48 input signals are combined. **Photo 2** shows the external view of the 48-way power combiner.

The 48 input signals are carried via coaxial cables, and the output signals via waveguides. The 48 input ports are aligned evenly spaced around the radial type combiner.

As can be seen in **Photo 3**, the 8-way power combiner, which combines the outputs of the eight 48-way power combiner, is also a radial-type combiner.

These radial type combiners use existing technologies developed jointly by NEC Network and Sensor Systems, Ltd. and Nihon Koshuha Co., Ltd. to correct amplitude and phase deviations in multiple-stage combining in order to calibrate each of the 384 units of 125W_PAs to

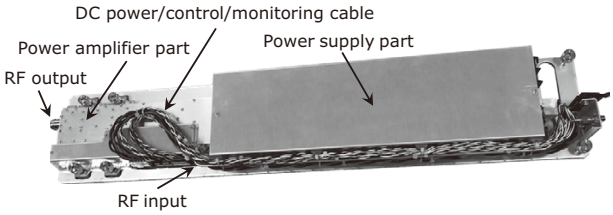

Photo 1 125W_PA.

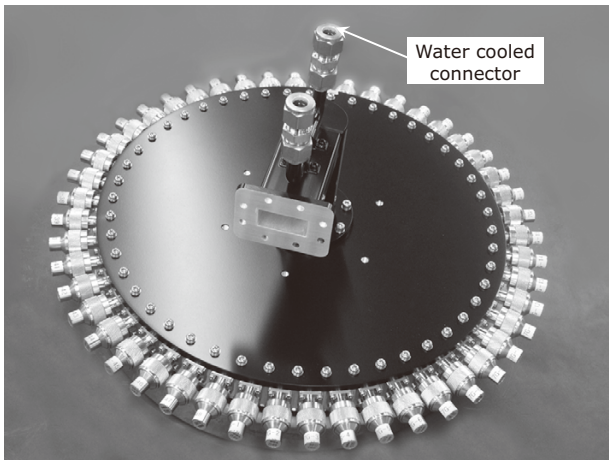

Photo 2 48-way power combiner.

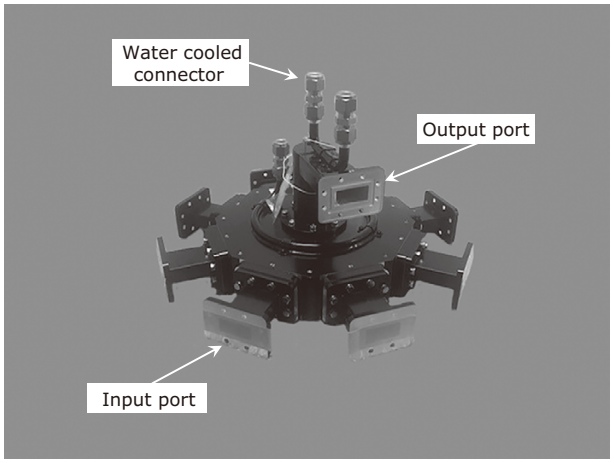

Photo 3 8-way power combiner.

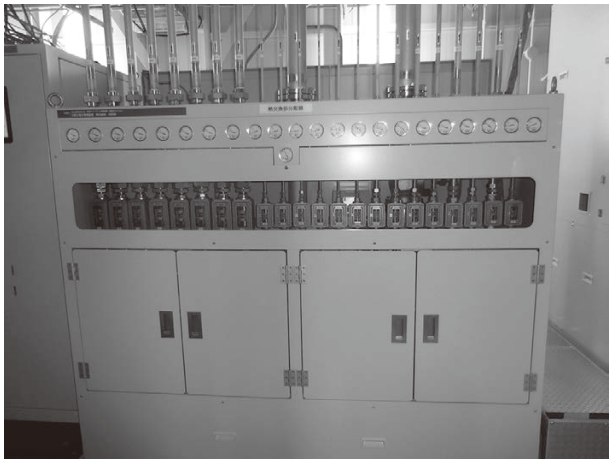

Photo 4 Heat exchanger (Partial view).

the optimum values. This approach has enabled us to achieve a low signal loss of 0.4dB in the multiple-stage combining (Total combining loss exhibited from the 48-way power combiner and 8-way power combiner, excluding the signal loss in the interim waveguide process).

3.3 Water-based cooling technology

What is especially important for stable operation of the 125W_PA is to stabilize the temperature by dissipating the heat generated by the GaN HEMT in the final stage.

In the X-SSPA, a cooling plate is provided for each of the 48 units of 125W_PA, and each 125W_PA is placed in contact with the cooling plate, and the temperature is controlled by water cooling the cooling plate.

Photo 4 shows the external view of the heat exchanger for water cooling. The heat exchanger is manufactured by Toyoko Kagaku Co., Ltd.

Because of the large power output of the 30 kW class, which means high heat generated by signal loss in the waveguide circuit, the waveguide circuit is also cooled by water.

3.4 Auto Level Control (ALC) Function

The X-SSPA has the Auto Level Control (ALC) function to keep the output power constant within a range of 0.3 dB.

The directional coupler (Fig.) at the output of the 8-way combiner detects the transmitted power, and based on the detected transmitted power, the variable attenuator (Fig.) installed in the first stage of the drive amplifier automatically controls the signal input level to keep the output level within a range of 0.3 dB.

4. Features of X-band Solid State Power Amplifier

Table shows the main specifications of the X-SSPA and **Photo 5** shows its external view.

The newly developed X-SSPA has three output power

Table Main specifications of X-SSPA.

Item	Specification
Frequency band	7GHz band
Output power modes	200 W/2 kW/20 kW*
Output power variation range	-3 to 0 dB for each output power mode
Power consumption	220 kW including controller and heat exchanger

* Power at the interface with the antenna. The power drops by the amount of loss in the waveguide circuit from the 8-way combiner output end to the interface point.

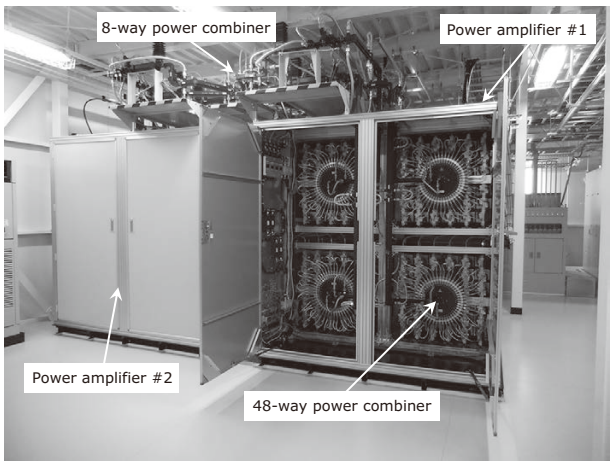

Photo 5 X-SSPA.

modes of 200 W, 2 kW, and 20 kW, which can be selected according to the operation of the probe.

In the 200 W and 2 kW output mode, the number of 125W_PAs to be operated is reduced to 48 units (1/8) and 128 units (1/3) respectively.

In the 20 kW output mode, all 384 units of 125W_PA are operated. Even if one or two 125W_PAs fail, the overall power drop is minimal, so operation can be continued, providing stable spacecraft operation.

To achieve future scalability, the SSPA combining method, which is power-upgradable, is adopted.

5. Conclusion

In this paper, we introduced the 30 kW-class X-band solid state power amplifier. The solid state high-power amplifier enables more stable operation than the klystron type amplifier, but the klystron type amplifier is still superior in terms of size and power consumption. NEC will continue with proactive research and development into the 30 kW-class X-band solid state power amplifier to achieve further reductions in size and power consumption.

The details about this paper can be seen at the following.

Related URL:

Misasa Deep Space Station GREAT2 PROJECT
https://www.isas.jaxa.jp/home/great/english/indexen.html

Sumitomo Electric Device Innovations, Inc.
– Product Information related to GaN HEMT
https://www.sedi.co.jp/products/index.html?version=en

Authors' Profiles

NAKAHARA Toshihaya
Senior Expert
Space Systems Division

YAMADA Youhei
Manager
Space Systems Division

OTAKE Toshiya
Assistant Manager
Space Systems Division

ASAO Hiroyuki
Senior Manager
Radio & Sensor Engineering Department
Technology Development Division
NEC Network and Sensor Systems, Ltd

IZUKURA Kenji
Manager
Radio & Sensor Engineering Department
Technology Development Division
NEC Network and Sensor Systems,Ltd

KOHIGASHI Kousuke
Assistant Manager
Structural Design Engineering Department
Technology Development Division
NEC Network and Sensor Systems,Ltd

Information about the NEC Technical Journal

Thank you for reading the paper.
If you are interested in the NEC Technical Journal, you can also read other papers on our website.

Link to NEC Technical Journal website

Japanese English

Vol.16 No.1 Social Infrastructure that Guarantees Safety, Security, Fairness, and Efficiency

Vol.16 No.1
October 2021

Special Issue TOP

Papers for Special Issue

NEC Information