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Development of 20 GHz-Band On-Board Power Amplifiers

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ABSTRACT

A high-efficiency and light-weight SSPA and TWTA for use in a 20 GHz-band satellite transponder is developed. The SSPA features a compact, highly efficient output power combiner. The output power of the SSPA is 3.3 W with an efficiency of 21% at 18.365 GHz and it weighs only 750 g. The TWTA features a high-efficiency, compact size 3-stage collector and high-switching frequency power supply. The TWTA delivers an output power of 12 W with 31% efficiency at 20.645 GHz and weighs only 1430 g.

1. INTRODUCTION

Reduction in weight and power consumption of on-board power amplifiers is very important, because a power amplifier accounts for a large percentage of a transponder's weight and power consumption.

Traveling-wave tube amplifiers (TWTAs) have been widely used up to the 20 GHz band because of their high output power capability and relatively high efficiency. Solid-state power amplifiers (SSPAs), on the other hand, have advantages of high reliability, small size, and light weight, therefore SSPAs have been used in the 4 GHz band and have been installed on many satellites[1]. In higher frequency bands such as 12 GHz, 20 GHz and 38 GHz[2], SSPAs are being developed.

This paper describes the development of a 3 W SSPA and a 12 W TWTA which feature high efficiency and light weight. The weight and efficiency of various output power amplifiers were first estimated on the bases of the technologies developed in achieving the SSPA and TWTA. Then the SSPAs and TWTAs were compared considering weight and power consumption.

2. SSPA DESCRIPTION

Amplifier circuit design

The amplifier is composed of six amplifier modules, in which two or three hybrid IC amplifier stages are packaged. The block diagram of this amplifier are shown in Fig. 1. The output power is obtained by combining four module outputs in the H-plane tee. The outputs of the two modules are combined in parallel at the same waveguide arm. This output combining circuit can be made compactly, which reduces the weight of this SSPA. The GaAs FETs used in this amplifier have an impulse-doped GaAs active layer with an AlGaAs buffer layer grown by MBE and a gate length defined by electron-beam lithography of 0.4 µm. The FETs exhibit excellent performance at a power added efficiency of 35% with 27.6 dBm output power at 18.365 GHz. The output stage FET gates are biased to a level which corresponds to AB class operation considering 3rd-order intermodulation (IM3) and AM-PM conversion coefficient specifications.

Power supply design

An efficiency of 87% has been achieved using MOS FETs for the main switching device, simplification of the circuit, and optimum switching frequency.

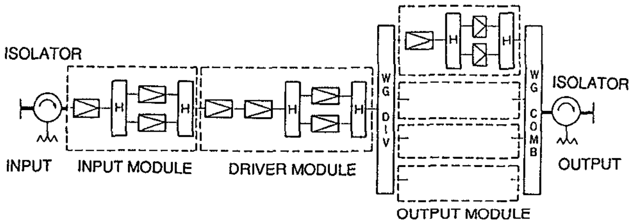

Fig. 1 Block diagram of SSPA

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SSPA characteristics

Figure 2 shows the output power, IM3 and efficiency versus input power at 18.365 GHz and 23°C. The SSPA achieves an output power of 35.2 dBm (3.3 W) with saturation gain of 35 dB and an efficiency of 21%. The IM3 at input power of -10 dBm (sum of two carrier level) is -20 dBc. An AM-PM conversion coefficient at 18.365 GHz is shown in Fig. 3. The AM-PM conversion coefficient at an output power of 35.2 dBm is 4°/dB. Figure 4 shows the frequency response of the output power. An output power flatness of less than 0.2 dBp-p is obtained over a frequency bandwidth of 200 MHz. An external view of the SSPA is shown in Fig. 5.

The characteristics of the SSPA are summarized in Table 1.

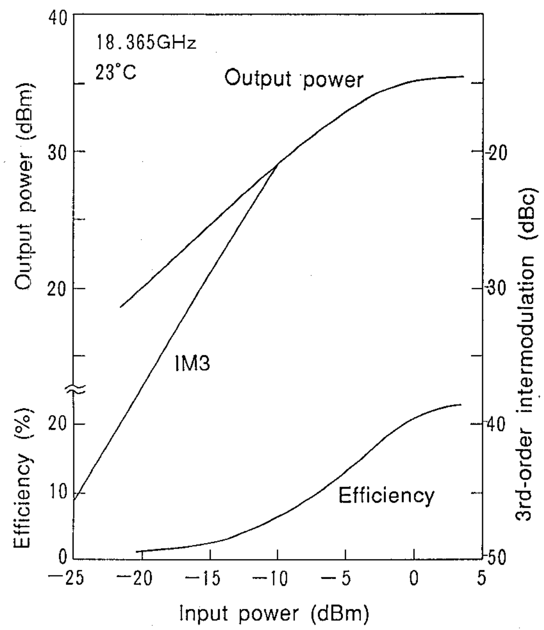

Fig. 2 Output power, IM3 and efficiency of SSPA at 18.365 GHz

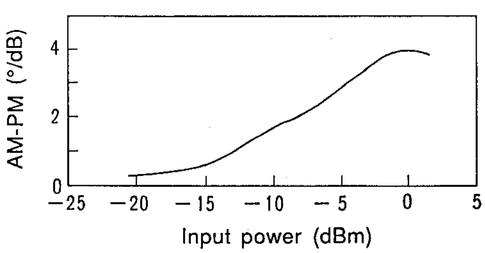

Fig. 3 AM-PM conversion coefficient of SSPA at 18.365 GHz

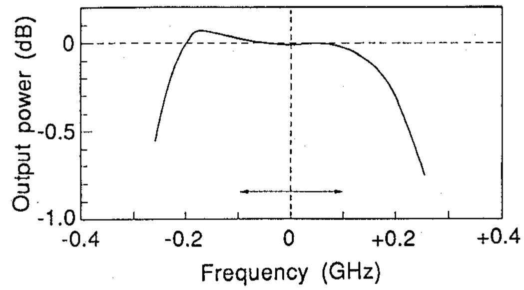

Fig. 4 Frequency response of SSPA
Center frequency: 18.365 GHz
Reference power level: 30.5 dBm

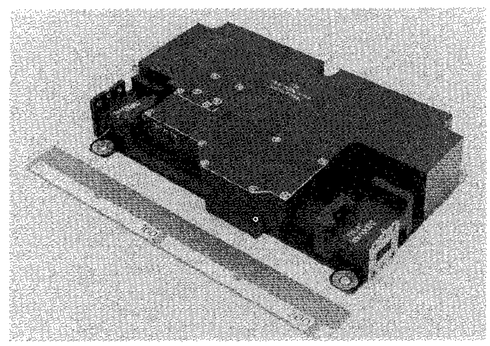

Fig. 5 Photograph of SSPA

Table 1 Characteristics of 20 GHz-band SSPA (23°C)

Frequency	18.365 GHz
Output Power	3.3 W
Saturation Gain	35 dB
Efficiency (SSPA)	21%
(Power Supply)	86%
3rd-Order Intermodulation	-20 dBc
AM-PM Conv. Coeff.	4°/dB
Weight	750 g
Size	114X118X36 mm

3. TWTA description

TWTA design

The following technologies, which have simplified the power supply function, have led to a reduction in the weight of the TWTA.

① cathode temperature optimizing and TWT screening methods which provide a lifetime of ten years without changing anode or heater voltages.

② discharge-free electrode construction which makes a protection circuit unnecessary against surges in helix current.

③ electrode voltage ripple conditions that allow optimum filter and output circuit design of

the power supply.
④thermal design technologies for TWT helix structure that allow simultaneous build-up of high-voltages.

TWT design

Methods have been developed for estimating the lifetime of an impregnated cathode and for optimizing cathode operating temperature. The lifetime of the M-type impregnated cathode is estimated to be more than ten years[3]. A low-temperature coefficient (-0.02%/°C) magnet has been developed that improves helix current temperature stability. High tube efficiency is achieved by a new type of 3-stage collector. A novel collector structure was utilized in reducing the TWT's weight. A ceramic cylinder forms the outer structure of the collector portion of the tube in which three different collector electrodes are installed.

Power supply design

Weight reduction has been achieved by increasing switching frequency to 200 kHz in order to reduce the size of the transformers and capacitors, and by developing surface mount technology on a ceramic board for low-power dissipation circuits such as the control circuit. Power loss caused by charging and discharging current of stray capacitance in a high-voltage transformer, increases at higher switching frequency. This power loss was reduced by setting the magnetizing inductance to the optimum value via the core gap length in the transformer.

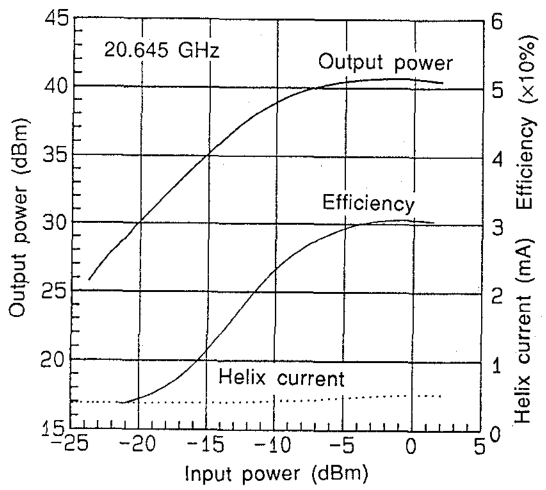

Fig. 6 Output power, helix current and efficiency of TWTA at 20.645 GHz

A weight of less than 700 g for the power supply has been achieved while maintaining relatively high efficiency of 82% by using the technologies described above.

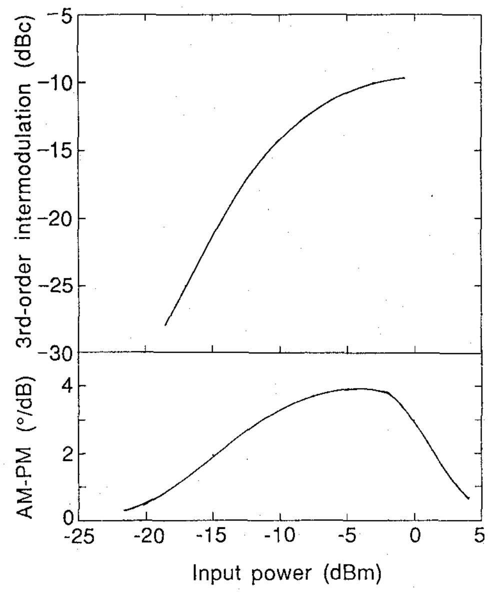

Fig. 7 IM3 and AM-PM conversion coefficient of TWTA at 20.645 GHz

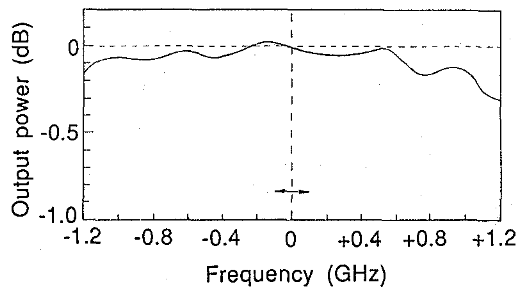

Fig. 8 Frequency response of TWTA
Center frequency: 20.645 GHz
Reference power level: 40.8 dBm

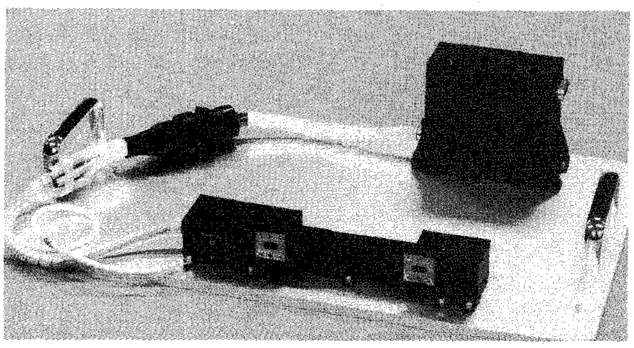

Fig. 9 Photograph of TWTA (engineering model)

TWTA characteristics

Figure 6 shows the output power, helix current and efficiency versus input power at 20.645 GHz and 23°C. The TWTA achieves an output power of 40.8 dBm (12 W) with saturation gain of 43 dB and efficiency of 31%. The IM3 and AM-PM conversion coefficient at 20.645 GHz are shown in Fig. 7. The AM-PM conversion coefficient at an output power of 40.8 dBm is less than 4°/dB. The IM3 at input power of -11 dBm (sum of two carrier level) is -16 dBc, which is sufficient for use in digital communication systems. Figure 8 shows the frequency response of the output power. A frequency bandwidth of more than 1 GHz is obtained for an output power deviation of 0.5 dBp-p. An external view of the TWTA is shown in Fig. 9.

Table 2 shows the characteristics of the TWTA at 23°C.

Table 2 Characteristics of 20 GHz-band TWTA (23°C)

Frequency	20.645 GHz
Output Power	12 W
Saturation Gain	43 dB
Efficiency (TWTA)	31%
(TWT)	38%
(Power Supply)	82%
3rd-Order Intermodulation	-16 dBc
AM-PM Conv. Coeff.	4°/dB
Weight (TWTA)	1430 g
(TWT)	590 g
(Power Supply)	700 g
(Isolator, Cable)	140 g
Size (TWT)	67X275X 47 mm
(Power Supply)	53X142X112 mm

4. COMPARISON OF SSPA AND TWTA

The weight and efficiency of various output power amplifiers have been estimated on the bases of the technologies developed in achieving the SSPA and TWTA introduced above. A new figure of merit, "equivalent weight", is the sum of the real weight of a power amplifier, and that of the solar cells and secondary battery necessary to generate power for the amplifier. Figure 10 shows the equivalent weight of the SSPAs and TWTAs as a function of output power. From this figure, it can be seen that the SSPA has an advantage over the TWTA for output power of less than 5 W, at this point in time.

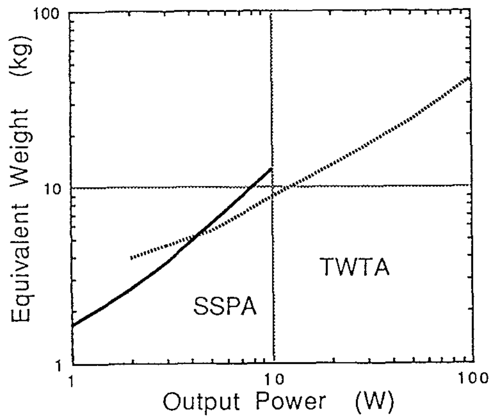

Fig. 10 Equivalent weight of 20 GHz-band SSPA and TWTA

5. CONCLUSION

A high-efficiency and light-weight solid-state power amplifier and traveling-wave tube amplifier have been developed for 20 GHz-band on-board transponders. The SSPA provides 3.3 W output power at 21% DC to RF efficiency and weighs only 750 g. The TWTA provides 12 W output power at 31% DC to RF efficiency and weighs only 1430 g. On the bases of the technologies developed in achieving these amplifiers, the SSPAs are compared to the TWTAs as 20 GHz-band on-board amplifiers. We concluded that for the output power of less than 5 W, the SSPA is superior to the TWTA considering both weight and power consumption.

The developed SSPA will be installed in the sixth Japanese Engineering Test Satellite (ETS-VI), which is scheduled for launch in 1993, to verify the performance in the actual space. The TWTA will be installed in some future satellites.

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