Space 35-Watt Q-band Linearized Traveling-Wave Tube Amplifier Flight Set

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Abstract: *Stellant Systems has completed shipment of a flight set of spaceflight-qualified 35-W Q-band linearized channelized traveling-wave tube amplifiers (LCTWTAs) operating over 40 - 42 GHz in a conduction-cooled package. This paper will detail the flight set performance and flight qualification test results.*

Keywords: Traveling wave tube; RF amplifier; satellite communications; Q-band.

Introduction

The model 2000HDA-A16 linearized, channel-amplifier traveling-wave tube amplifier (LCTWTA), designed and manufactured by Stellant Systems, Inc., consists of a linearized channel amplifier (LCAMP), traveling-wave tube (TWT), and electronic power conditioner (EPC). The TWT and LCAMP completed flight qualification testing in 2018. This particular model LCTWTA produces a minimum of 35 W RF power at end-of-life (EOL) across the frequency band of 40 – 42 GHz. A flight set of 31 units were delivered in support of a commercial HTS spacecraft, shown in Figure 1. The TWT itself is qualified for operation up to 200 W over the full 37.5 to 42.5 GHz Q-band allocation representing the highest CW power helix TWT qualified for space applications at Q-band[1]. These LCTWTAs enable gigabits-per-second (Gbps) data rates by providing unprecedented power, efficiency, and linearity for a Q-band downlink. This model LCTWTA was awarded an R&D 100 award in 2019.

Background

This paper discusses the Stellant Systems Q-band LCTWTA producing 35 W of CW, linearized saturated RF power over 40 - 42 GHz. Figure 2 shows the model 2000HDA-A16 EPC with the model 9922HA conduction-cooled TWT next to the linearizer and channel amplifier (LCAMP).

Traveling-Wave Tube (TWT)

The TWT model 9922HA employs a helical RF circuit with periodic, permanent magnet (PPM) focusing packaged for conduction cooling. The electron gun is a dual-anode, isolated-focus-electrode design, and is designed for greater than 15 years of mission life. The helix circuit is designed to provide CW saturated RF output at 35 W RF over the 40 to 42 GHz Q-band frequency range. The 9922HA was designed primarily using the Naval Research Laboratory codes CHRISTINE 3D[2] and MICHELLE[3].

Figure 1. A commercial HTS spacecraft employing multiple Stellant Systems Q-band LCTWTAs.

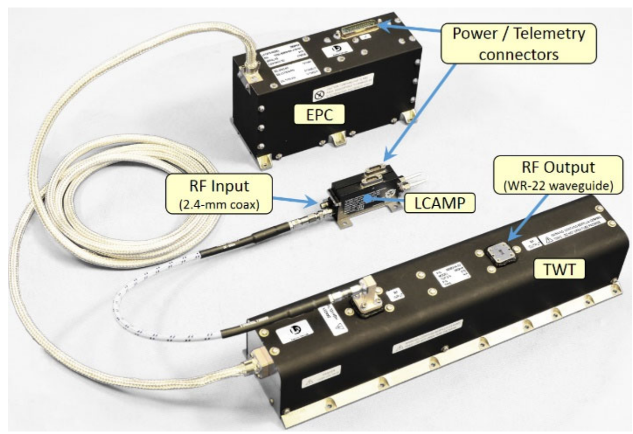

Figure 2. The Stellant Systems Model 2000HDA-A16 Space Q-band LCTWTA for high-data-rate Space-to-Earth communications.

TWT Qualification

The model 9922HA TWT is part of the 9922H TWT family which completed flight qualification in 2018. Average measured TWT RF performance at ambient temperature is shown in Table I.

Table I. 9922HA TWT performance.

Freq (GHz)	40.0	42.0	(No drive)
Drive Level	SAT		
Iw (mA)	0.44	0.43	0.22
Pin (dBm)	-8.9	-8.3	
Sat Pout (W)	40.3	37.8	
Sat Gain (dB)	54.9	54.0	
Total DC (W)	81	79	31
Thermal Diss (W)	41	41	31
Overall Eff (%)	49.7	47.8	

The TWT body current at saturated drive level is below 0.5 mA (flight set average) while the output power exceeds 37 W (beginning of life) across 40.0 to 42.0 GHz with an average efficiency of ~49%. TWT qualification details are covered in [1].

Electronic Power Conditioner (EPC)

The electronic power conditioner (EPC) shown in Fig. 2 is the 7-kV model 2000HDA, first launched in 2003, now with over 2400 units in orbit and a cumulative 170 million operating hours. It is capable of processing over 300 W of DC power. The EPC can be configured to accept either regulated or unregulated spacecraft bus voltages of up to 100 volts. The EPC efficiency ranges between 91% and 95% depending on the spacecraft bus voltage interface and the extremes of the environmental requirements.

LCTWTA Performance

The Stellant LCAMP is shown in the middle of Fig. 2. An LCAMP consists of a channel amplifier (CAMP) and linearizer. The LCTWTA has an input dynamic range from -49 dBm to -13 dBm with 36 gain steps in 1.0 ± 0.3 dB increments in Fixed Gain Mode (FGM). In ALC mode, this LCTWTA has a minimum control range of +2 to -13 dB relative to saturation with 36 gain steps in 0.5 dB ± 0.25 dB increments, and linearizer provides ~5 dB gain expansion and 40° phase expansion over swept power with 20° intentional phase expansion variation across frequency to match TWTA characteristics.

Thirty one (31) integrated LCTWTAs were delivered for this program. They were tested over a temperature range from approximately 0°C to +60°C. The efficiency of the entire LCTWTA, along with the noise power ratio (NPR), plotted vs. output power, is shown in Fig. 3. The range across units, frequency, and temperature is shown by the dotted curves, with the heavy curves showing the average. The 0 dB point on the horizontal axis corresponds to ~39 W output power.

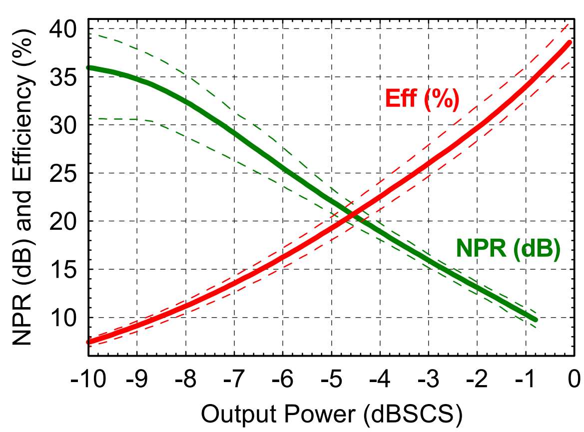

Figure 3. 2000HDA 35-W Q-band LCTWTA measured NPR and efficiency versus output power for flight set.

The output power and phase versus drive for the flight set are shown in Fig. 4. Again, the heavy curves show the flight set average across units, frequency, and temperature, and the dotted curves show the range. The LCAMP was able to compensate to keep the phase shift at an average of ~10 deg at saturation.

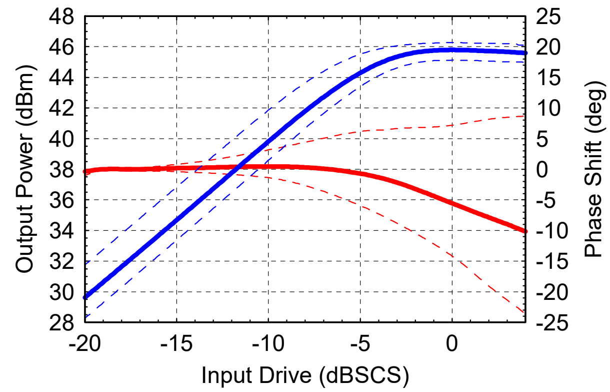

Figure 4. 2000HDA 35-W Q-band LCTWTA measured output power and phase vs. drive for the flight set.

Conclusion

Stellant Systems has delivered a large flight set of 35-W Q-band LCTWTAs for a high-throughput satellite (HTS) application. The performance will enable Gbps-level total data transfers via downlink.

Acknowledgements

Initial funding for the 9922H Q-band TWT design was provided under NASA Glenn contract no. NNC12CA45C.

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