Space Qualified 200-Watt Q-band Linearized Traveling-Wave Tube Amplifier

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Abstract: *L3 Technologies Electron Devices Division, (L3 EDD) and L3 Technologies Narda Microwave West (L3 NMW), are completing space-flight qualification for a 200-watt Q-band linearized channelized traveling-wave tube amplifier (LCTWTA) capable of over 5 GHz instantaneous bandwidth in a conduction-cooled package. This paper will discuss the LCTWTA performance, manufacturing and flight qualification test results.*

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

Introduction

The model 2600H linearized, channel-amplifier traveling-wave tube amplifier (LCTWTA), designed and fabricated by L3 Technologies Electron Devices Division (L3 EDD) and Narda Microwave West (L3 NMW), consists of a linearized channel amplifier (LCAMP), traveling-wave tube (TWT), and electronic power conditioner (EPC), which have all completed flight qualification testing. Producing up to 200 W of CW saturated RF power over bandwidths over up to 5.0 GHz in the 37.5-to-42.5 GHz Q frequency band; this LCTWTA represents the highest CW power helix TWT qualified for space applications at Q-band. It maintains typical efficiency, linearity and noise performance. In addition, a linearized, channel amplifier for the same band is completing qualification at L3 Technologies Narda Microwave West (L3 NMW). Together, the 9922H TWT and the linearized channel amplifier, combined with an L3 EDD electronic power conditioner such as the 2600H, will provide unprecedented amplifier performance for commercial space downlink applications.

Background

This paper discusses the L3 EDD Q-band LCTWTA. It produces up to 200 W of CW, linearized saturated RF power over up to 5 GHz in the Q frequency band. Figure 1 shows the model 2600H EPC with the model 9922H conduction-cooled TWT next to the L3 NMW linearizer and channel amplifier (LCAMP).

Traveling-Wave Tube (TWT)

The TWT model 9922H 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 power up to 200 W RF over the 37.5 to 42.5 GHz Q-band frequency range. The 9922H was designed primarily using the Naval Research Laboratory codes CHRISTINE 3D[1] and MICHELLE[2].

Figure 1. 2600H EPC (upper left) with 9922H TWT (middle) and L3 NMW LCAMP (lower right).

TWT Qualification

The model 9922H TWT is completing flight qualification. Measured RF performance at ambient temperature is shown in Table I.

Table I. 9922H TWT performance.

Freq (GHz)	37.5	40.0	42.5	(No drive)
Drive Level		SAT		
Iw (mA)	0.42	0.44	0.55	0.13
Pin (dBm)	0.3	-1.2	-0.3	
Sat Pout (W)	204	208	201	
Sat Gain (dB)	52.8	54.4	53.4	
Total DC (W)	335	347	346	112
Thermal Diss (W)	131	139	145	112
Overall Eff (%)	61.0	59.9	58.2	

The TWT body current at saturated drive level is below 0.6 mA while the output power exceeds 200 W across 37.5 to 42.5 GHz with an average efficiency of 60%.

The overall space-flight qualification effort includes a range of operating and non-operating environmental tests. TWT qualification testing began after exhaustive acceptance test processing and performance quantification. Qualification testing includes random vibration testing, pyrotechnic shock testing, and thermal-vacuum cycling. The random vibration is at levels of up to 18.9 Grms for a minimum of three minutes per axis. For shock testing a high-performance vibration table was used to simulate a shock pulse over the frequency range from 100 Hz to 10 KHz. Each test was performed three times per axis for a total of 9 pyrotechnic shock qualification pulses at levels of up to 2590 g's. Thermal vacuum testing is now being performed over all operating conditions from non-operating to full RF power. Sixteen (16) thermal vacuum cycles will be performed over the temperature range of -20^{0}C to 86^{0}C. Four "cold starts" will soak the non-operating TWT to thermal stability at -35^{0}C and then initiating a full RF power start and CW operation. The unit will also demonstrate non-operating survival from -35^{0}C to 95^{0}C.

At each intermediate step and again once all environmental testing completed, the TWT will be exercised through a full functional and operational test regime.

Electronic Power Conditioner (EPC)

The electronic power conditioner (EPC) shown in Fig. 1 is model 2600H, qualified in 2016[3]. This EPC is capable of processing up to 600 W of DC power at voltages of up to 12 kV. 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 environmental extremes requirements. At power levels below approximately 40 W, the Q-band TWT can mate to the lighter L3 EDD model 2000H or 2410H EPCs which provide cathode voltages up to 7 kV.

Linearized Channel Amplifier (LCAMP)

The L3 NMW LCAMP is shown at the lower right in Fig. 1. An LCAMP consists of a channel amplifier (CAMP) and linearizer. The CAMP operates in fixed gain mode (FGM) or automatic-level-control (ALC) mode. In ALC mode, a fixed drive level is provided to the linearizer over a wide input dynamic range. In the fixed gain mode (FGM), the CAMP provides a variable gain that may be used for various system purposes such as ground mode testing. The CAMP provides 53 dB linear gain across the 37.5 to 42.5 GHz band. The linearizer is a unity-gain pre-distorter that follows the CAMP. Its purpose is to compensate TWT non-linearity and provide reduced back-off levels of operation to enhance system linearity, power, and efficiency. Figure 2 shows typical improvement in noise power ratio (NPR) achieved by the linearizer. The LCAMP thermally compensates for the TWTA performance with thermistor-based control circuitry. Both CAMP and linearizer are mounted to a common baseplate and take an 8 V supply with 7 W power consumption. RF input and output connectors are coaxial 2.4 mm.

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 FGM. In ALC mode, this LCTWTA has a minimum control range of +2 to -13 dB relative to saturation with 30 gain steps in 0.5 dB ± 0.25 dB increments, and typically 18 dB range with 36 control increments. The 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.

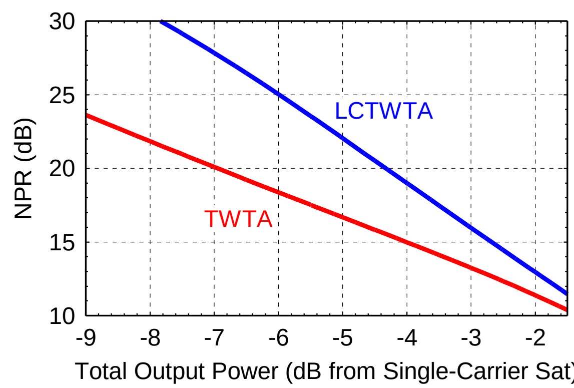

Figure 2. Simulated LCTWTA NPR performance based on measured EM TWT and LCAMP data.

Conclusion

As a result of the thorough qualification testing, L3 EDD, with support from L3 NMW, is prepared to offer unprecedented Q-band RF amplifier performance from a flight-qualification-tested LCTWTA delivering power levels up to 200 W with LCTWTA efficiencies over 50% and NPR approaching 20 dB at 4.5 dB OBO from saturation.

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