On-Orbit Performance of the CloudSat EIK and Future Space Missions

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1. INTRODUCTION

The Extended Interaction Klystron (EIK) is a multi-cavity electronic amplifier, providing enhanced power, bandwidth and efficiency at millimeter frequencies in a compact device. Since 1990's CPI Canada has developed space flight EIK's for various space missions. First W-band space qualified EIK was developed for NASA's CloudSat mission [1]. The satellite was activated in June 2006. Additional Ka-band and W-band EIKs are currently under development for the EarthCARE mission and for a variety of space-borne Topo-mapping radars. This paper presents on-orbit performance of the CloudSat EIK and reviews requirements, design and performance of EIK's for future space missions.

2. CLOUDSAT OPERATION

The CloudSat mission provides cross-sectional view of clouds with information on their thickness, altitude, optical properties, water and ice content. The payload includes the first space-borne 94 GHz cloud profiling radar (CPR) that is 1000 times more sensitive at profiling clouds than existing weather radars. The satellite was launched in April 2006, and the radar has been in continuous service from June 2, 2006. Over 5,000 hours of CPR operation is accumulated at the time of this abstract submission. The EIK generates pulsed power of 1.9 kW with peak cathode loading of 10 A/cm^2. Life-test data predicts that cathode current will drop by 10% after approximately 20,000 hours of operation with consequent reduction in gain by ~3 dB and output power by ~2 dB. To optimize lifetime performance, the EIK was overdriven at the beginning of operation by 1.8 dB. Initial on-orbit performance is in a good agreement with the design predictions. Figure 1 presents the variation in RF transmit power as detected by the CloudSat calibrator during the first 6 months of operation. More performance data will be available at the time of the conference.

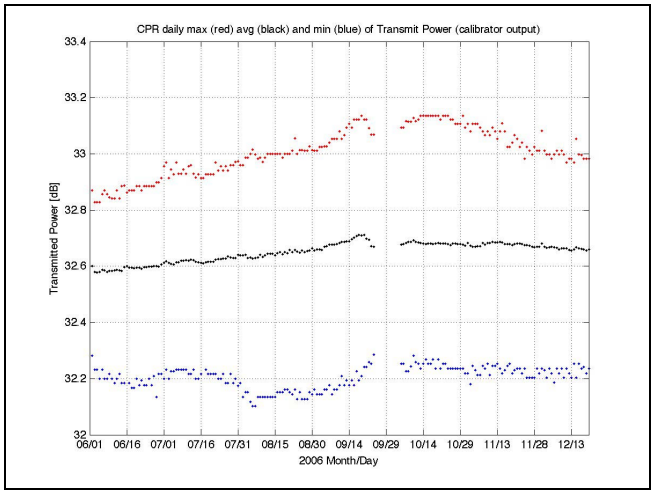

Fig.1. Transmit Power at Calibrator Output
Provided courtesy of JPL

CloudSat has two EIK's on board - one operational and one redundant. The flawless operation of CloudSat and the significance of the collected data it is proposed to extend the CloudSat mission up to 5 years.

3. CATHODE LIFETESTING

In order to predict cathode life and determine EIK optimum operating conditions, cathode life testing was performed at CPI [2]. The cathodes used in tests were identical to those used in the CloudSat EIK. The cathodes were integrated in the Life Test Vehicles (LTV), which were designed to reproduce the environment experienced in the CloudSat EIK. The LTV's were operated continuously with applied accelerating voltages. Figure 2 shows an increase in work function measured for a cathodes operating at optimum temperature. These results indicate that cathode life could exceed 30,000 hours at a current density of 10 A/cm^2.

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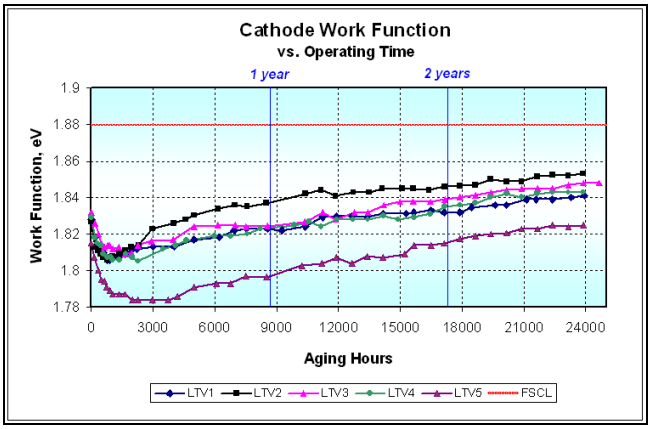

Fig.2: Cathode work function measured during 24,000 hours of operation

4. EARTHCARE EIK DEVELOPMENT

EarthCARE (Earth Clouds, Aerosols and Radiation Explorer) is the 6th Earth Explorer Core Mission of the European Space Agency and a joint undertaking with the Japan Aerospace Exploration Agency (JAXA). Similar to the NASA "A-train" it will study and analyze the interaction and impact of clouds and aerosols on the Earth's radiative budget. The EIK specification is similar to CloudSat with the challenge of longer operational life and higher duty cycle. To ensure over 30,000 hours of reliable on-orbit operation, the EIK design has been updated to reduce cathode loading and electrical stress [3]. Following successful testing of Engineering Models, design qualification is currently underway. Flight Models will be delivered by 2010, and satellite launch is scheduled for 2012.

5. Ka-BAND EIK's FOR WEATHER AND TOPO-MAPPING RADARS

Various space missions require 35 GHz High Power pulsed amplifiers. Specification requirements range from 800 W at 0.5% duty cycle for the rain radar to 3 kW, 30% duty cycle for a deep space mission Topo-mapping radar. For these applications CPI developed a highly efficient and compact Ka-band EIK on the platform of the W-band space-qualified model [4]. These EIK's share the same beam-optics and packaging, and operate with the same Power Supply. Demonstrated performance is summarized in Table 1. Recently CPI completed development of a high power compact collector, which was tested at duty cycles up to 30%. This collector will be mated with the space-borne EIK, resulting in new performance targets listed in the table.

Parameter	Demonstrated Performance	Follow-up Development
Peak Power	1300 W	3000 W
Bandwidth	200 MHz	>80 MHz
Duty Cycle	10%	25%
Gain	47 dB	50 dB
Efficiency	40%	45%
Weight	6.4 kg	<8 kg
Lifetime	50,000 hours	>35,000 hours

Table 1: Ka-band EIK's for space-borne applications

6. CONCLUSIONS AND ACKNOWLEDGEMENTS

CPI Canada continues to demonstrate leadership in design and manufacture of millimeter-wave Extended Interaction Klystrons. Following successful development and on-orbit operation of the CloudSat EIK, more flight models of W-band and Ka-band EIK's are currently under development.

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7. REFERENCES

[1] Dave Berry, Albert Roitman and Brian Steer, "State-of-the-Art W-band Extended Interaction Klystron for the CloudSat Program" 5th IEEE International Vacuum Electronics Conference 2004, Monterey, California, 27-29 April 2004

[2] Pierre Waller *et al.,* "Cathode Life testing for the EarthCARE Extended Interaction Klystron", 4th IEEE International Vacuum Electronics Conference 2003, Seoul, Korea, 28-30 May 2003

[3] Albert Roitman *et al.,* "Extended Interaction Klystrons for Space-borne Applications", 6th IEEE International Vacuum Electronics Conference 2005, Noordwijk, The Netherlands, 20-22 April 2005

[4] Albert Roitman *et al.,* "Compact High Power Ka-band Extended Interaction Klystrons for Terrestrial and Space Applications", 7th IEEE International Vacuum Electronics Conference 2006, Monterey, California, 25-27 April 2006