Ka-Band Solid-State Power Amplifier (KAPA) DS1 Technology Validation Report

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Ka-Band Solid-State Power Amplifier (KAPA) Fact Sheet

Lockheed Martin's Communications and Power Center (CPC) offers a complete line of communications products that includes a Ka-band Solid-State Power Amplifier (SSPA). Our standard Ka-band SSPA has greater than 2.5 W of output power and an overall efficiency of 14%.

The "plug-in" module approach allows the combination of multiple modules to obtain power output as high as 20 W. The SSPA is integrated with a high-efficiency electronic power conditioner (EPC) and consists of a three-stage radio frequency (RF) driver module and a three-stage RF output module. Input and output WR28 waveguide isolators are used for low voltage standing wave ratio (VSWR) and output module protection.

The RF output module combines three stages of amplification: stage one represents the basic building block of the entire output module. The RF output module (Figure 1) consists of a fully metalized diamond substrate that acts as a heat-dissipation path and carrier to the RF.

The block diagram of the SSPA is shown in Figure 2 with electrical performance at –14° C, +23° C and +40 C. Figure 3 shows the key performance parameters versus temperature and frequency. Temperature compensation and telemetry circuitry are incorporated in the SSPA design, allowing for complete system integration. The SSPA is fully space qualified, and the physical design and layout have successfully passed hundreds of non-operational thermal cycles ranging from –55 C to +125 C.

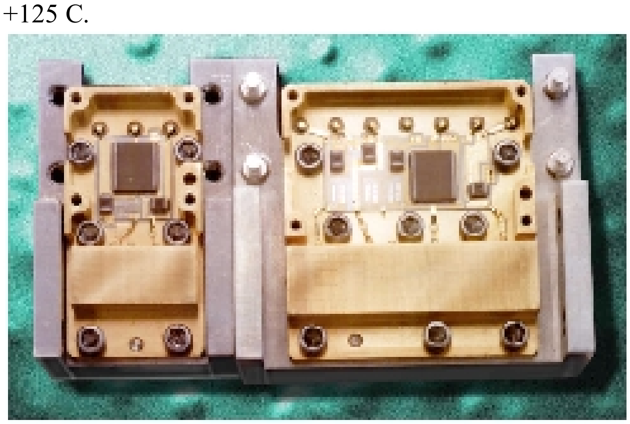

Figure 1. RF Module

For further information on the SSPAs and the full CPC product line call:
215-497-1559, or Fax: 215-497-1564
Contact our web site at http://www.payloads.com
Lockheed Martin
Communications and Power Center
100 Campus Drive
Newtown, PA 18940

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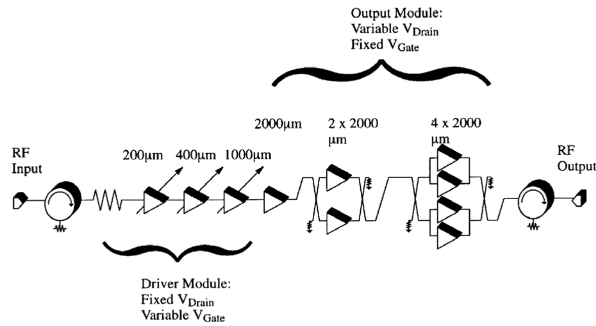

Temp (deg C)	Pwr Out (dBm)	DC Cons (W)	Comp Lvl (dB)	PAE (%)
–14	34.50	17.33	3.2	16.3
+23	34.30	18.74	3.8	14.4
+40	34.13	19.57	4.2	13.2

Freq = 32.0 GHz, RF Pwr Input = –3.0 dBm

Figure 2. SSPA Block Diagram

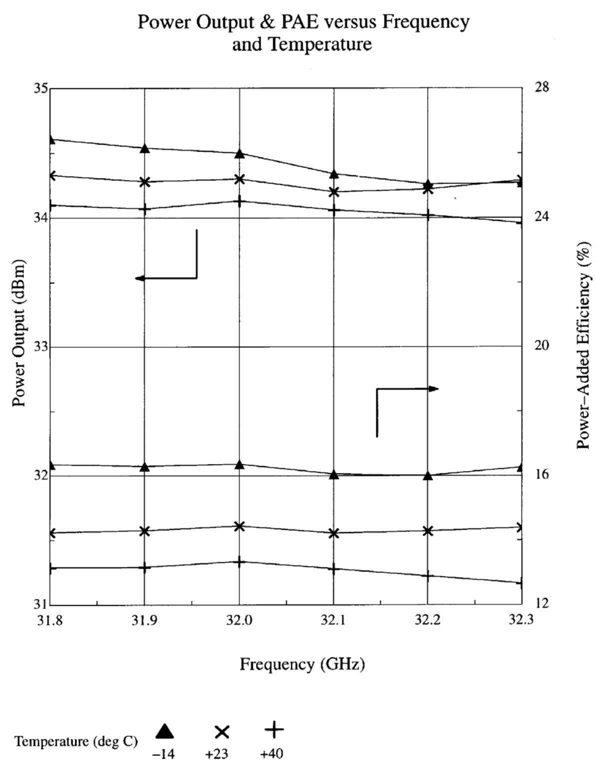

Figure 3. Key Performance Parameters Versus Temperature and Frequency

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Abstract

Communication subsystems for future missions must be low-mass and enable equivalent if not greater data return to the scientific community over the current X-band (8.4 GHz) links. One potential solution is to increase the downlink frequency to Ka-band (32 GHz). A major component required is the development of a power amplifier that can boost a transponder's exciter power from 0.5 mW_{rf} to more than $2W_{rf}$. This paper describes the basic characteristics of a Lockheed Martin Engineering Test Module Ka-band solid state power amplifier (SSPA) that was provided to the New Millennium Program for flight validation on the Deep Space 1 (DS1) mission. Initial in-flight data shows that the unit has been functioning nominally during the past year (1680 hours of operation accumulated). In addition, the unit has been power cycled 28 times and has gone through multiple-thermal cycles (due to the trajectory combined with autonomous spacecraft maneuvers for optical navigation measurements).

1.0 Introduction

The Ka-band Solid-State Power Amplifier (KAPA) is one of eight Level-1 technology validation objectives of the New Millennium Deep Space 1 (DS1) mission. The principal goal of the New Millennium Program (NMP) is to validate selected high-risk, high-benefit technologies to reduce the risks and costs future missions would experience in their use. With successful flight validation of the technology, the risk of using them is substantially reduced. Knowledge gained from incorporating the new capability into the spacecraft, ground system, and mission design sets a beneficial precedent for future missions.

KAPA was developed by Lockheed Martin Communications and Power Center under their own internal IR&D funding. An Engineering Test Module Unit was delivered to DS1 and integrated into the Telecommunication subsystem.

This unit has successfully demonstrated the highest-power solid-state Ka-band amplifier ever used for deep space communications. With future improvements in ground facilities and spacecraft hardware, Ka-band holds a potential four-fold increase in data rate in comparison with X-band. This is extremely important since a faster data rate reduces ground resources/mission operation support and project cost. Another benefit of going to Ka-band is the availability of greater bandwidth. Both NASA and commercial programs recognize this and are developing the technology to move beyond microwave bands, which are becoming crowded due to PCS and other emerging information technology ventures.

2.0 KAPA Description and Flight Qualification

KAPA's mass was 0.66 kg (this includes input/output isolators, power supply, telemetry circuitry, and RF electronics), with a RF output power of 2.2 W and a gain of 36 dB.

The unit was qualified to DS1 requirements that include:

- Random Vibration:

20 Hz	0.0322 G^2/Hz
50–500 Hz	0.2 G^2/Hz
2000 Hz	0.0126 G^2/Hz
Overall	13 G_{rms}

- Thermal Vacuum cycling from –14° C to +40° C
- Full EMC testing to MIL SPEC 461

Unique features include built-in input/output isolators and engineering telemetry monitors (two-gate currents, output drain voltage, and internal unit temperature). Due to the short development time for this unit, Lockheed Martin did not hermetically seal it. After delivery, some accelerated testing on other similar power devices has shown no major degradation after an initial burn-in. After 250 hours of ground operation (in both vacuum and atmosphere), the flight unit did not show any operational degradation. Caution was exercised to prevent the unit's operation for too long in open atmosphere or letting the unit's temperature drop below the dew point.

The key technology for KAPA is the use of 0.25 micron GaAs Pseudomorphic High Electron Mobility Transistors (PHEMT). The efficiency could have been optimized further with the use of 0.15 micron devices; however, time and resources defined what the final product would be in this fast-paced program.

3.0 KAPA Flight Validation

The telecommunication subsystem for DS1 was single string, as mandated by the project. Figure 1 is the DS1 telecom subsystem block diagram. The primary communication link is on Channel 19 at X-band for both uplink and downlink (7.168 GHz and 8.421 GHz, respectively).

As part of the technology demonstration, we have an auxiliary Ka-band downlink (32.155 GHz). The heart of the Ka-band downlink is the KAPA itself. Figure 2 is an interior view of the +X, +Y panel of the DS1 spacecraft, where a major portion of the active telecom subsystem electronics resides. Key components include the KAPA, a Detector Amplifier Module, and an SDST. KAPA dimensions are approximately 14.2 cm × 15.2 cm. The full Telecommunication subsystem was described in [1].

On December 9, 1998, the KAPA was first powered on in-flight (launch of DS1 was on October 24, 1998). Flight operation of the unit has been nominal. As of November 22, 1999, the unit has been power cycled more than 28 times and has logged more than 1680 hours of operating time (over a variety of temperature ranges). In the event that the Ka-band operation was not nominal, it was the responsibility of the flight team to ensure that enough data was available to determine what the anomaly could have been. This was accomplished both internally and externally to the KAPA itself. Internal to the unit-temperature sensor, gate-currents and gate-voltage telemetry are passed to the C&DH subsystem. External to the unit, RF power detectors monitor KAPA's input and output RF power. This ensures that the RF drive from the SDST—or any intervening component—is not responsible for any potential performance degradation.

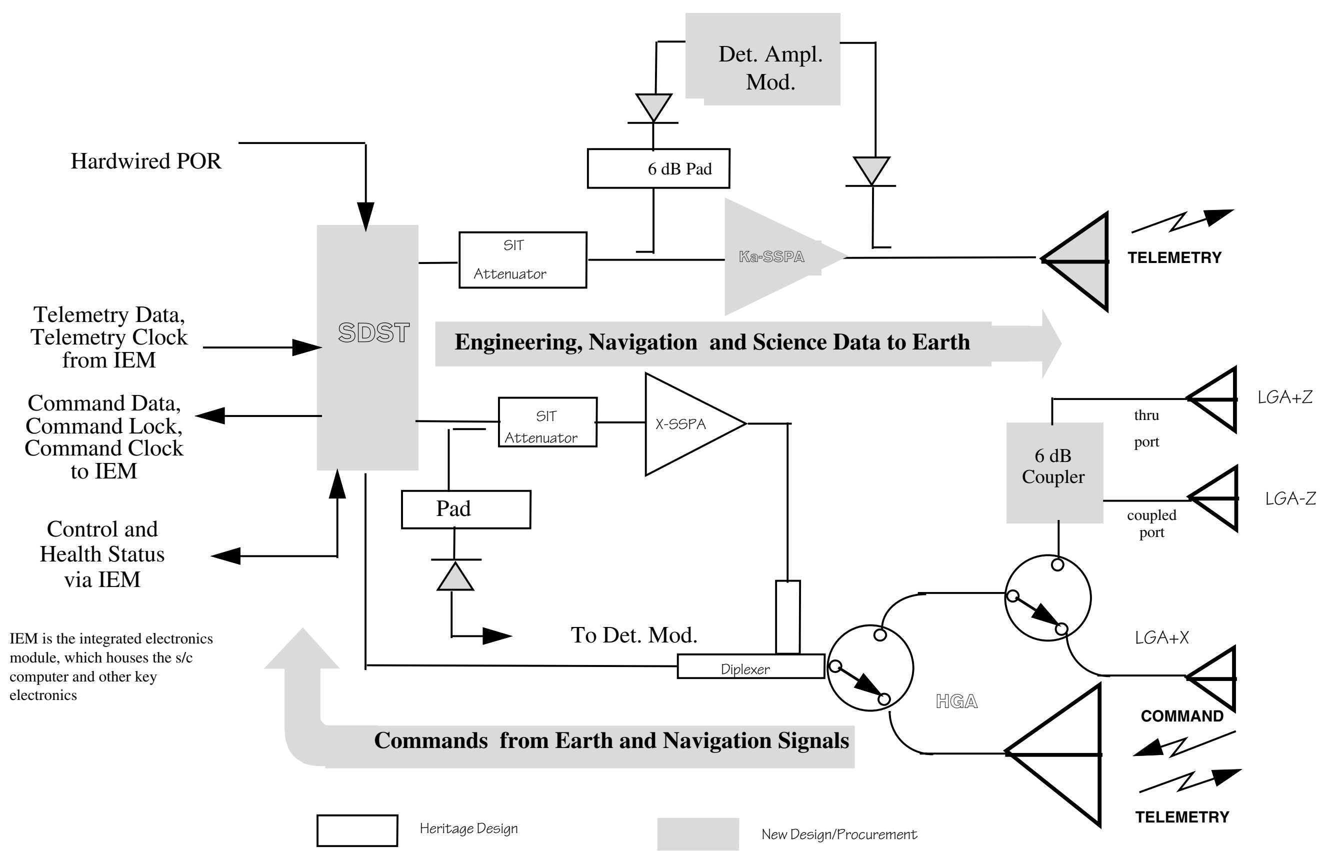

Figure 1. DS1 Telecom Subsystem Block Diagram

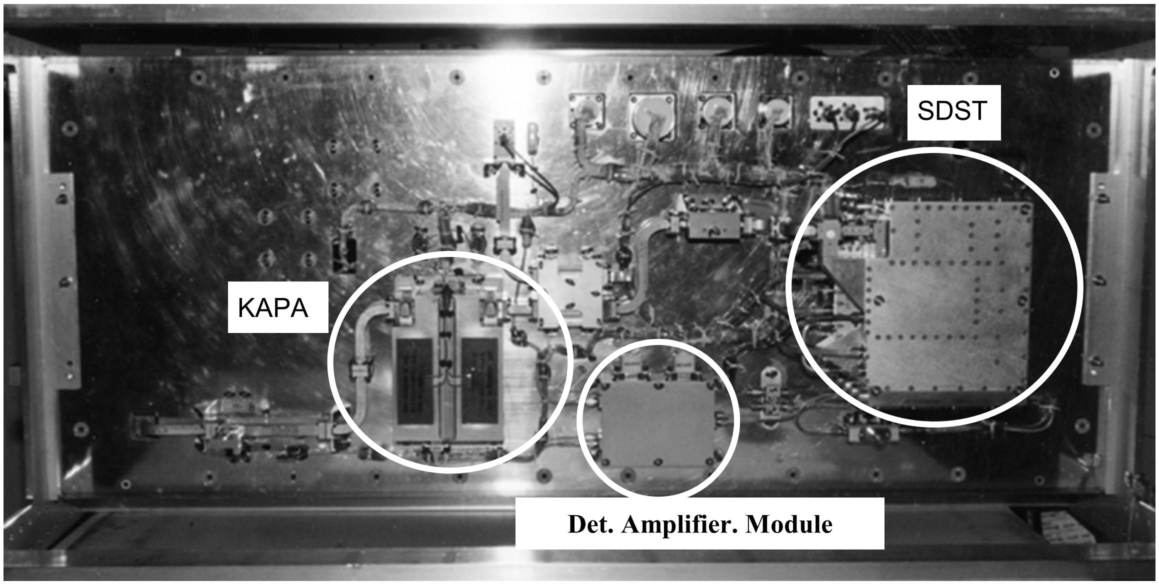

Figure 2. Interior View of the +X, +Y Panel

3.1 Validation Criteria

Pre-Flight:
Development of a 2.5 W_{RF} SSPA which has ~36 dB gain and provides critical engineering telemetry (gate current, drain voltage, and unit temperature) for unit-performance evaluation during flight.
Post Flight:
Launch to L+25 day Due to mission-pointing constraints for the Miniature Imaging Camera and Spectrometer (MICAS), a Ka-band communication link is not allowed during this period. > L+25 day The ability to have a Ka-band communication link is a major validation step.

3.2 Validation Evaluation/Summary

Pre-Launch		
Parameter	**Achieved**	**Benchmark (MGS Mission)**
Mass*	0.660 kg	>0.600 kg (and does not have input isolator)
RF Output Power	2.2 W	1 W
Efficiency*	13%	8.7%
Gain	36.4 dB	15 dB

Post-Launch (>L+25)	
Parameter	**Achieved**
RF Output Power	2.16 W
Efficiency*	12%
Gain	36 dB
*including DC-DC converter	

The unit's overall performance has been nominal. Analysis of data has been of the first order. Mainly, the Telecom Mission Operator plots data looking for any potential hazardous trends and ensures that it is within nominal operating range. A potential output-power step change was observed within the measurement-error range (0.5 dB); however, no visible trend is now apparent.

4.0 KA-BAND TECHNOLOGY

The desire to increase the data volume of future systems can be accomplished by going from X-band (8.4 GHz) to Ka-band (32 GHz). Theoretically, there is a 16-fold advantage. When one takes into account the realities of weather, spacecraft pointing, etc., the potential advantage is predicted to be a factor of 4. The KAPA is a major component required in achieving this important goal. The question now may arise, What does it take to have a Ka-band link? The downlink telemetry is modulated onto a subcarrier and then up-converted to Ka-band in the Small Deep Space Transponder (SDST). From the SDST, the signal may be coupled off to detectors or go directly to the power amplifier to increase signal strength. The KAPA provides this critical function (see Figure 1). From the amplifier, the signal can be routed through couplers and/or switches to the antenna, where it is radiated into free space.

Collecting all the facts presented thus far:

- Ka-band may enable greater science-data return.
- DS1 has validated operation of the highest-power solid-state Ka-band amplifier for Deep Space Communications.

This begs the question, Would we achieve a potential advantage for Ka-band communications? Initial results from [2] indicate that, based on scaled calculations from DS1 flight data, future systems could achieve the four-fold improvement.

5.0 SUMMARY AND CONCLUSION

DS1 has successfully demonstrated in-flight the operation of a Ka-band (32 GHz) Solid-State Power Amplifier (KAPA), which was an Engineering Test Module Unit provided by Lockheed Martin Communication and Power Center (using their own IR&D funding). This technology, in turn, has enabled further validation of Ka-band's potential advantage over X-band for deep space communications.

6.0 ACKNOWLEDGMENT

KAPA was developed by Lockheed Martin Communications and Power Center under their own internal IR&D funding. An Engineering Test Module Unit was delivered to DS1 and integrated into the Telecommunication subsystem.

Many people have contributed to the success of KAPA and its technology validation activities. The authors would like to acknowledge the following:

From Lockheed Martin CPC:

Mark Karnacewicz
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Ken Vaughn
Larry Newman

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Pam Chadbourne
Kathy Moyd
Marc Rayman
Rob Smith
Ben Toyoshima

Without their support the technology validation and characterization effort of the KAPA would not have been successful.

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7.0 REFERENCES

[1] Herman, M. I. et. al., "Deep Space One Telecommunication Development," AIAA/Utah State University Conference on Small Satellites, Logan, Utah, 1998.

[2] Chen, C.-C., et. al., "DS1 Technology Validation Report for Small Deep Space Transponder," Deep Space 1 Technology Validation Symposium, Pasadena, CA, February 8–9, 2000.

Appendix A. List of Telemetry Channels and Names

Table A1 is a list of all of the telemetry channels that the KAPA team collects and uses. Note the importance of "monitor" channels in this work. (Jim Taylor, 10/20/99.)

Table A1. Channels and Mnemonics

Channel	Mnemonic
T-3252	sdst_evnt_ct
T-3116	aux_osc_temp
T-3124	vco_tmp
T-4003	KAPA_ext_tmp
P-2061	ess_bus_v
A-1637	bbc_CtrlErr0
A-1621	bbc_CtrlErr1
A-1625	bbc_CtrlErr2
T-3502	kapa_dc_pwr
T-3503	kapa_rf_gain
T-3188	ka_tlm_mod
T-3136	katlm_coder
T-3180	ksubcar_freq
T-3101	ka_ranging
T-3105	ka_Exciter
P-3126	KAPA_on_off
M-0130	MCD1 SNR
M-0731	AA5 SS1 SNR
M-0723	AA5 PCN0
M-0727	AA5 PC
M-0725	AA5 SNT
M-0737	AA5 SPE
M-0304	ANT A EL ANG
M-0305	ANT A AZ ANG
M-0308	A CNSCN
M-0309	A CNSCN LOOP

Appendix B. Date of Turn-on/off and Frequency of Data Capture

The KAPA was first turned ON as part of a telecom technology validation activity on 98-343/08:15. It was left ON for over 30 hours, being commanded OFF at 98-344/14:41. Both times are per the ACE log.

The Ka-band downlink has been ON and OFF many times since then. Table B1 is a listing, as obtained from a telemetry query of the KAPA state itself, through 99-280. (Jim Taylor, 10/29/99.)

Table B1. Channels and Mnemonics

Time	KAPA State
1999-011T01:30:38.465	ON
1999-018T20:12:56.500	OFF
1999-018T23:40:06.500	ON
1999-020T19:14:12.305	OFF
1999-020T23:40:12.305	ON
1999-022T20:04:17.765	OFF
1999-022T23:40:07.765	ON
1999-026T21:44:04.176	OFF
1999-026T23:00:24.176	ON
1999-031T23:23:34.676	OFF
1999-032T23:00:22.289	ON
1999-041T21:11:11.398	OFF
1999-043T20:17:46.344	ON
1999-053T23:20:08.293	OFF
1999-054T04:30:44.219	ON
1999-054T19:01:56.387	OFF
1999-055T19:56:42.246	ON
1999-057T17:55:15.735	OFF
1999-058T00:30:15.981	ON
1999-060T10:20:16.226	OFF
1999-060T16:00:16.103	ON
1999-061T14:55:16.145	OFF
1999-061T23:00:17.038	ON
1999-064T09:55:17.242	OFF
1999-064T16:00:17.257	ON
1999-067T09:55:17.371	OFF
1999-067T15:05:17.295	ON
1999-068T14:50:17.326	OFF

Time	KAPA State
1999-068T22:00:17.339	ON
1999-075T06:40:38.551	OFF
1999-082T02:55:29.682	ON
1999-082T12:44:13.950	OFF
1999-088T20:30:12.579	ON
1999-089T04:40:32.570	OFF
1999-095T23:25:32.828	ON
1999-096T09:00:12.904	OFF
1999-102T22:40:33.763	ON
1999-103T05:50:12.513	OFF
1999-109T22:55:32.914	ON
1999-110T05:25:12.943	OFF
1999-116T20:55:13.383	ON
1999-117T04:15:33.301	OFF
1999-166T20:30:11.570	ON
1999-175T12:01:01.508	OFF
1999-209T14:50:39.103	ON
1999-209T19:28:59.126	OFF
1999-221T19:45:36.647	ON
1999-222T03:14:36.659	OFF
1999-242T20:45:24.536	ON
1999-243T06:29:37.526	OFF
1999-256T18:45:36.736	ON
1999-256T23:46:11.708	OFF
1999-277T21:08:37.596	ON
1999-278T05:34:24.616	OFF