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	Subsystem/Office Calorimeter Subsystem	
Document Title **CAL Dual PIN Photodiode Procurement Readiness Summary**		

Abstract

This technical note summarizes the procurement specification and controls of the LAT CAL Dual PIN Photodiode procurement and the supporting analyses, evaluations and tests which demonstrate that the specified item will meet the environmental and performance requirements of the Calorimeter Subsystem of LAT.

1 Introduction

The CAL team has about seven years of experience in developing the calorimeter design concept for LAT. This work has focused on Thallium doped Cesium Iodide detector elements read out by PIN photodiodes at each end. Table 1 summarizes the photodiode investigations. The concept of using a hodoscopic configuration of these detectors was first demonstrated in a beam test in 1997 at SLAC. These first demonstration calorimeters incorporated commercial PIN photodiodes manufactured by Hamamatsu. These diodes, S3590, consisted of a 100 mm^2 active area mounted in a ceramic carrier and encapsulated in a hard epoxy optical window. These diodes, attached to CsI crystals of 30 x 30 x 190 mm size were used in beam test demonstrations in 1996, 1997 and 1998.

1.1 Advanced Technology Program

As part of the GLAST Advanced Technology Program (ATD), the concept of the basic detector element – the Crystal Detector Element (CDE) – was advanced to address the dynamic range in energy to meet the GLAST objectives. To achieve the $\sim 10^6$ in dynamic range, the crystal readout was divided into two signal changes each supported by a PIN diode. Thus the concept of a Dual PIN PhotoDiode (DPD) for CAL was developed. The ATD design consisted of two PIN diodes with area ratios of 1:4 in a single ceramic carrier. We worked with Hamamatsu Photonics in the development and manufacture of ~350 of these diodes which were used in the manufacture of the ATD prototype calorimeter module – called the BTEM (Beam Test Engineering Model) or the BFEM (Balloon Flight EM) calorimeter. This module was used in beam tests at SLAC ('99) and at GSI ('00) and was subsequently flown on the LAT balloon flight in 2000. The BTEM/BFEM module identified several issues relative to the CDE that needed to be addressed in the flight units. In particular, the materials and process of bonding the DPD to the CsI crystal would not reliably survive the environmental temperature cycling expected for GLAST.

1.2 LAT CAL Engineering Model

The DPD concept which was developed for the LAT Engineering Model (EM) CAL module (and assumed flight modules) built on this BTEM experience. The area of the large diode was increased to improve the light yield and signal to noise at low energies. The area ratios became 1:6. To limit the capacitance effect of this larger area, the silicon die were modified to 300 um depletion depth (from ~200 um). These diodes, as all previous diodes, were assembled from the S3590 silicon die material. Again, the optical window encapsulant was a hard epoxy resin. However, based on testing and experience of the IBIS experiment on ESA's Integral, the EM DPD had a specification on the flatness of the optical window (+/- 2 um) which required polishing of the optical window by Hamamatsu. This diode was identified as the S8576 by HPK. Approximately 650 of these DPD were ultimately manufactured in about 5 different lots. These diodes were used in parts evaluations, bonding studies and for the assembly of CDE for the CAL Engineering Model.

Table 1. Summary of LAT CAL Photodiode Configurations

PIN Diode	Dates	Optical Window Material	Silicon Die thickness (um)	PIN A Area (mm^2)	PIN B Area (mm^2)
S3590	1/1996 – 12/1998	Hard epoxy resin		n/a	100
S3590-08 SPL	2/1999 – 10/2001	Hard epoxy resin	200	24	96
S8576	1/2001 -	Hard epoxy resin	300	25	152
S8576-01	2/2003 -	Silicone resin	300	25	147

Bonding experiments in the US and France resolved the bonding issues that were identified in the ATD program and the bonding material selected was Dow Corning 93-500 silicone elastomer with a primer. These bonds were shown to have margins of x5 or greater on required bond strengths. The bonds were, of course, compatible with the hard epoxy resin of the DPD. It became apparent, however, that the flatness of the optical was not necessary with the DC93-500 bonding material.

At the same time CEA/DAPNIA was performing evaluation and qualification testing on the S8576 diode in their laboratory and at Serma Technologies, Inc. These tests showed no particular problems with the diode except in one very critical area – the reliability of the optical window. Tests at Serma showed failures of the optical window epoxy – cracking and delamination from the ceramic carrier – in thermal cycling over the qualification temperature range and higher. The failures were generally correlated with the number of cycles and range in temperatures in the cycles but much variability was observed from lot to lot of test diodes. Diodes cycled over the qualification range frequently showed "microcracks", severe cracks, and/or delamination of the epoxy window from the ceramic carrier or silicon die. With the severe cracking or delamination, electrical failure of the diodes could occur, as the wire bonds to the die may be stressed or broken. These failures occurred because of the large CTE mismatch between the hard epoxy and the ceramic carrier of the DPD and only became apparent after ~20 thermal cycles. We note that the cracking of the epoxy was somewhat surprising to HPK since it generally has no effect on the electrical or optical properties of the diode. In the most severe cases after many cycles significant delamination caused shearing of the wire bonds of the die to the ceramic carrier resulting in electrical failure.

After much investigation and similar testing in France, USA and HPK, it became apparent that the hard epoxy optical window and epoxy polishing could not be controlled well enough to meet the LAT environmental requirements and the search for new optical window encapsulant began. Experiments with the bonding process proved that the DC93-500 bond material would flow into a non-flat cavity without any problems and the variation of bond thickness of the silicone bonding material was not an issue. With the removal of the flatness requirement on the bonding surface, softer materials such as silicone resins could be considered.

1.3 CAL Flight DPD – S8576-01

HPK offers an alternate optical window, Shin-Etsu Chemical Co KJR 9022E silicone resin (hereafter SE), with a significantly broader operational temperature range for surface-mount devices. This was an obvious choice to examine as a replacement of the hard epoxy window since HPK has considerable experience in using it with similar material. The concern in selecting the optical window material is long-term compatibility with the silicon die. These optical PIN diodes have very thin passivation and the contact with the optical window material could, over time, increase the leakage current to unacceptable levels.

Also, as part of the overall CAL module design review, we reduced risk associated with mechanical tolerance buildup by reducing the size of the ceramic carrier for the flight diodes by 1 mm in width and length. This reduction in carrier size required only a slight adjustment (~3%) in the active area of the low energy PIN diode.

To verify that the SE window material was compatible with the CAL requirements we studied both commercial versions of diodes with this window material as well as fabricating a few spare EM DPD with the new SE optical window material. The details and results of this testing are summarized in LAT-TD-01476-01.

2 Referenced Documents

Dual PIN Photodiode (DPD) Specification		
CAL Flight Dual PIN Photodiode Specification	LAT-DS-00209-11	30 Jan 2003
Dual PIN Photodiode Drawing (HPK S8576-01)	LAT-DS-01237-01	22 Nov 2002
CAL EM Dual PIN Photodiode Specification	LAT-DS-00072-03	20 Feb 2001
Flight DPD Verification Plan	LAT-SS-01451-01	22 Jan 2003
Evaluation and Test Reports		
Performance of HPK Photodiodes with ShinEtsu Silicone Window	LAT-TD-01476-01	07-Feb-2003
Flight DPD Encapsulant Outgassing Test	GSFC 28213	26 Nov 2002
Hamamatsu S3590 Radiation Test Data	HPK S3590-03	19 Nov 2001
EM DPD Irradiation Test (CEA)	LAT-TD-00787-01	10 Jun 2002
EM DPD Evaluation 1 (Serma)	Serma E01P1435	01 Jun 2002
EM DPD Evaluation 2 (Serma)	Serma E02P0638	01 Jul 2002
EM DPD Evaluation 3 (Serma)	Serma E02P1385	01 Nov 2002
EM DPD Evaluation 4 (Serma)	Serma E02P1443	01 Nov 2002
EM DPD Electrical Lead Corrosion Study 1	Serma E02P1638	12 Nov 2002
EM DPD Electrical Lead Corrosion Study 2	Serma E02P1865	13 Jan 2002

3 Responsibilities

The development of the CAL Dual PIN Photodiode requirements and specifications has been a joint responsibility of the Naval Research Lab and CEA/DAPNIA in Saclay. In this development we have worked closely with Hamamatsu in USA and Japan. The lead for design and testing issues at NRL is J. Eric Grove. The lead for design and testing at CEA is Philippe Bourgeois. Nick Virmani at NRL has lead responsibility for EEE parts, manufacturability and quality assurance issues.

The flight procurement is a joint responsibility of NRL and CEA. The contributions from CEA to the DPD are the qualification and acceptance screening of all DPD in addition to the procurement of ~200K $US in flight diodes. The contributions from NRL to the DPD are the overall management of the effort, coordination and negotiation of the specification, and procurement of the residual flight diodes (~$400K).

4 Specifications

The specification for the CAL Flight Dual PIN Photodiode is configured as LAT-DS-00209-11. These specifications have evolved from the specification, fabrication and testing of the Engineering Model Dual PIN Photodoide as configured in LAT-DS-00072-03. The DPD requirements, of course, flow down from the CAL Level III specification thru the CAL Level IV specification and the specification for the Crystal Detector Element. The key specifications are summarized here:

	Issue	Requirements / Comments
Mechanical	Dimensions and tolerance	Meet mechanical interface requirements w/ mechanical structure and minimize voids and passive material within CAL volume
	Materials	Flight approved materials Electrical leads that meet flight solderability requirements.
Optical Window	Material	Flight approved material

		Bond strength with DC93-500 bonding material Concavity and coverage of wire bonds between Si die and carrier.
Electrical Characteristics	Active area Capacitance Dark Current Sensitivity (540 nm)	
Environmental	Temperature Range Radiation Hardness	Qualification –30 to +50 degC (100 cycles) 10 kRad

Changes from the Engineering Model Dual Photodiode to the flight DPD, S8576-01:

- Ceramic carrier size – S8576-01 carrier is 1 mm smaller in width and length.
- PIN B silicon die active area – S8576-01 die is 0.5 mm smaller in one dimension (~3%).
- Electrical lead positions have been moved.
- Electrical leads shall be tinned by Hamamatsu prior to assembly of the silicon die to the carrier.
- Optical window encapsulant is changed to Shin Etsu silicone resin.
- Shipping container has been modified to provide ESD protection and to protect the electrical leads from bending.

5 Qualification Plan

Section 6.4 of the CAL Flight Dual PIN Photodiode Specification, LAT-DS-00209-11 addresses the product assurance requirements for the flight DPD including design, construction and process controls. In particular, section 6.4.11 identifies the qualification program for the flight DPD lots and the responsibilities of the vendor and the CAL team.

6 Verification and Testing

6.1 Engineering Model DPD

An extensive test program has been executed to verify that the dual PIN photodiode as specified (LAT-DS-00072-03) and procured for the CAL Engineering Model detector meets the performance and environmental requirements of LAT. The detailed evaluation of the EM DPD as a EEE part was performed in France under the direction of Philippe Bourgeois at CEA using facilities at CEA and the industrial test and evaluation company, Serma Technologies, Inc.

6.1.1 Performance

Much of the performance data is in the form of performance of the final Engineering Model crystal detector elements that were manufactured for the EM. For the EM, 124 CDEs were manufactured – 110 at NRL and 14 at CEA/DAPNIA. All these CDEs were manufactured with S8576 DPD except three which used the S8576 carrier and silicon die but were filled with the ShinEtsu silicone optical window material. Of these, 124 CDE, 113 were accepted as available for EM assembly. The rejected CDE, all from NRL, were generally rejected due to poor quality of the bond of one of the DPD to the crystal. These rejections are attributable to a failure in the bonding procedure and have nothing to do with the diode.

The EM CDE specification is found in LAT SS-00239-04. The light yield for the EM CDEs was found to be 8500 e/MeV. This is compared with the CAL Level IV spec of >5000 e/MeV. This significantly greater than spec'ed yield is caused by the larger area of the low energy PIN diode and the improved light yield associated with the VM2000 wrapping on the CDE.

6.1.2 Ceramic Carrier

The ceramic carrier of the S8576 DPD was studied by CEA and their supporting industrial test experts, Serma Techonologies. The results of that testing is summarized in the Serma Evaluation 1 Report, Serma E01P1435. No particular problems were identified with the carrier.

6.1.3 Die Attach

Serma also examined the silicon die attachment to the carrier in its Evaluation 1 Report. They noticed voids in the large die attachment in the test article that integrated to 15% of the area. However, there were no delaminations or changes in these after highly accelerated stress testing. Even though die attach is not an issue, the flight DPD specification addresses the ways to control the die attach and process monitors to b eused during die attach processes.

6.1.4 Optical and Electrical Performance

In Evaluation 1, Serma and CEA monitored the optical and electrical performance of the sample diodes. Except for those diodes that failed because of the cracking and delamination of the hard epoxy optical window, there are no significant changes in the DPD performance after highly accelerated stress testing.

6.1.5 Radiation Testing

The S8576 diode is manufactured using the silicone die of the S3590 series of commercial diodes. Hamamatsu provided historical radiation data for this material as seen in the referenced document, HPK S3590-03. CEA/DAPNIA performed radiation testing on the S8576 DPD. The report on that testing, LAT-TD-00787-01, is in general agreement with the Hamamatsu data. While CEA observed a larger than expected increase in dark current after irradiation, the S8576 diode is well within the dark current performance specification for CAL. Radiation testing will be performed again on samples from the flight lot.

6.1.6 Temperature Cycling

Temperature cycling of the S8576 DPD identified significant problems in the hard epoxy optical window material of this design. Diodes cycled over the qualification range frequently showed “microcracks”, severe cracks, and/or delamination of the epoxy window from the silicon die. With the severe cracking or delamination, electrical failure of the diodes could occur, as the wire bonds to the die were stretched or broken. These failures occurred because of a CTE mismatch between the hard epoxy and the ceramic carrier of the DPD. In the most severe cases after many cycles significant delamination caused shearing of the wire bonds of the die to the carrier resulting in electrical failure.

The investigation of this failure and its characterization is much of the topic of Serma Evaluations 1 – 3 and thermal cycling of diodes bonded to CsI at NRL. No satisfactory solution was found to these problems and an alternate optical window material had to be found.

6.1.7 Bonding to CsI

The tests of the EM DPD bonded to CsI crystals were performed at NRL and CEA/DAPNIA. Using the Dow Corning 93-500 silicone resin with DC92-023 primer, bonds to the CsI crystal were found to greatly exceed the required pull and shear strengths. At NRL over 90 sample bonds of BTEM and EM DPD to CsI crystals have been made. These samples were thermal cycled over the qualification range (-30, +50 degC). Some samples received over 100 thermal cycles. Light yield performance of the units was tested at 6 – 8 cycle intervals. After an initial drop of ~5% in yield thought to be caused by wetting of the Tetratek optical wrap to the crystal, no significant change in light yield were observed.

Bond strengths were tested on samples before and after thermal cycling. Typical shear strengths were 400 N (requirement is 35 N) and typical pull strength was 250 N (requirement is 10 N).

The EM DPD meets the bonding requirement to CsI using the planned DC93-500 silicone resin.

6.1.8 Electrical leads

The Serma evaluations of the EM DPD detected cracking and other problems with the electrical leads of the diode. The bending of the leads is thought to be caused by inappropriate handling of the diode during manufacturing and shipping. Hamamatsu apparently stored the diode with the electrical leads pushed into foam. The insertion and removal of the DPD from the foam caused the bending of the lead. (The flight diode specification corrects this handling problem.)

Additional problems discovered by Serma are related to the gold plating of the electrical leads. Scratches on the leads have been detected that, on occasion, appear to expose the Ni-Fe core. If the Ni-Fe is exposed, oxidation or corrosion of the lead occurs. This corrosion affects the solderability of the lead and is not acceptable.

Hamamatsu attributes these problems to the process by which the EM DPD were polished to achieve the required flat optical surface. The polishing fixture held the diode by the electrical leads. Hamamatsu proposed a revised polishing fixture for the flight units if polishing is required. This information has been transmitted to Hamamatsu for investigation with their ceramic carrier vendor. If this is the case, this problem is not an issue for the flight diodes since we have rejected polishing and the hard epoxy optical window for the flight units.

Additional investigation performed at Serma (Serma E02P1865) indicates that the corrosion on the part studied was present prior to the gold plating. If this is the case for the flight units, it will be easily revealed during inspections of the tinned electrical leads prior to assembly of the DPD. The change of the flight DPD to tinned electrical leads removes this risk to LAT.

6.2 Flight Model Configuration

The changes to the CAL DPD to the flight configuration have been tested in a limited number of prototypes that were manufactured using the few remaining EM DPD carrier and silicon die available at Hamamatsu. These units were encapsulated with the proposed ShinEtsu silicone resin. The testing of these units, along with commercial diodes from Hamamatsu that use this optical window material, form the basis of our confidence that the modifications from EM to Flight DPD will meet the requirements of the LAT CAL. The details of this testing is summarized in the document, Performance of HPK Photodiodes with ShinEtsu Silicone Window, LAT-TD-01476-01.

6.2.1 Performance

There is no significant performance change relative to the change from EM to Flight configuration. The active area of the large (low energy) diode has been reduced by about 3% which will contribute to an associated reduction in light yield in the low channel by 3%. As reported in LAT-TD-01476-01 the comparative measurements indicate a total reduction in light yield of about 10%. We are trying to resolve this reduction and believe it is associated with the bond quality issues in the tested CDE and have nothing to do with the ShinEtsu optical window. There is no difference in sensitivity measurements reported by Hamamatsu for the ShinEtsu-filled EM DPD relative to that measured for the hard epoxy EM DPD.

It should be noted that the measured light yield of the EM CDEs exceeds the requirement by over 40%.

6.2.2 Ceramic Carrier

The same processes and controls are incorporated into the manufacturing of the Flight DPD as used in the EM DPD. While the electrical lead positions and the size of the carrier have changed, there are no significant concerns relative to these changes in the carrier. CEA and Serma plan evaluation of the new carrier as part of the flight part qualification testing and the details are provided in LAT-DS-00209-11.

6.2.3 Die Attach

No changes from the EM DPD. Flight DPD specification has added greater detail of die attach process and controls that have been accepted by Hamamatsu.

6.2.4 Temperature Cycling

The temperature cycling specification for the flight DPD remains the same as for the EM DPD. Testing of commercial diodes as well as 4 EM DPD filled with the flight ShinEtsu silicone optical window show that this encapsulant does not have the thermal cycling problems exhibited by the hard epoxy optical window of the standard EM DPD. As presented in LAT-TD-01476-01, the commercial diodes received 180 cycles of the qualification temperature range and the special EM DPD received 100 cycles.

6.2.5 Bonding to CsI

Summarized in LAT-TD-01476-01.

6.2.6 Electrical leads

Changes in the specification for the flight DPD were designed to remove the problems observed with the EM DPD. The flight DPD spec prohibits the storage of DPD with the leads pushed into foam. Shipping and handling containers do not use foam. These changes prevent bending of the electrical leads and any potential cracking of the lead.

Additionally, the flight DPD specification calls for the tinning of the diode electrical leads prior to the assembly of the DPD. This provides greater protection of the lead relative to the cracking of the gold and corrosion that was detected in the EM DPD. Of course, the stress on the DPD leads has been greatly reduce for the flight DPD since there is no polishing of the window surface.

7 Procurement Issues

The problems with the EM DPD optical window material created serious problems for the delivery of flight DPD on the schedule required to meet CAL module deliveries. To mitigate these schedule problems, CAL management proposed and LAT IPO approved the initial procurement of ceramic carrier manufacturing tooling, silicon die masks and prototype flight DPD units. We have received the first empty ceramic carriers for evaluation by CEA and expect the delivery of 184 prototype flight DPD by the end of the month. These units permit evaluations and qualification testing by CEA and also provide units for bonding process development by CEA and its industrial partner.

Unfortunately, we need to initiate the initial flight procurement before the results of the evaluations of the prototype diodes have been completed. We will have completed the evaluations before Hamamatsu is ready to fill the carriers with optical window encapsulant, however. Hamamatsu needs about 3.5 months to provide the first shipment of flight DPD. The first delivery of DPD is scheduled for June 2003.

7.1 Quantity

Table 2 summarizes the estimated requirements for the number of flight DPD needed to execute the CAL manufacturing plan. The table works backwards from the number of CDE required for flight and associated spare CDE that are delivered to NRL. From that point, it summarizes the assembly steps and estimates the material losses at each step.

One of the largest losses is the fallout from bonding failures to the CsI. If a bond has bubbles, it is rejected. While the CsI crystal of a failed bond lay-up can be recovered by removing the diode and cleaning/polishing the CsI surface, the DPD involved in the bad bond will likely be lost. Our tests with commercial diodes with ShinEtsu silicone demonstrate that the DC93-500 can usually be cleaned off of the diode silicone but the stresses imparted into the ShinEtsu window and their impact on the adhesion of the window material to the ceramic carrier are uncertain. The safest plan is to assume the diode is lost in bonding failures.

It should be noted that the 10% bonding failure fallout in the table might be too optimistic. CEA reported a 40% bonding failure rate on the 14 CDE they manufactured. This higher rate was likely a learning curve relative to bubbles formed in the bonds. The bonding failures at NRL were about 15% but were not bubbles in the interface but believed to be a failure in a detail of the bonding procedure related to the curing of the primer prior to injection of the DC93-500.

7.2 Cost and Qualification Strategy

Single lot of carriers, minimizes qualification time and costs.

Order of additional diodes after first lot will have significant cost impact (~70% increase over initial cost for quantity of 1000 diodes, higher increase for smaller quantity). Response time for any additional diodes is on the order of four months.

Table 2. Estimate of Required DPD Quantities

Level	Operation or Loss Process	Loss %	Loss Count	TOTAL CNT
CDE	**Required CDE for Flight**			**1728**
	Flight Spares	6.4%	110	1838
	CEA Delivery to NRL			**1838**
	Acceptance Test Failures	1.0%	19	1857
DPD	**DPD for CDE Acceptance Test**			**3714**
	Bonding Process Fallout	10.0%	413	4127
	PhotoDiode Assy Fallout	2.0%	84	4211
	Solder/Stake Failures	1.0%	43	4254
	Spare DPD	2.0%	87	4341
	Electrical Screening Fallout	1.0%	44	4385
	Dimensional Fallout	1.0%	44	4429
	Lot Acceptance Test	1.0%	45	4474
	DPD Qualification		60	4534
	DPD Evaluation		48	4582
	Bonding Process Development		100	4682
	TOTAL DPD Requirement			**4682**

8 Risk Assessment

8.1 Risks

8.1.1 Bonding to CsI

Testing to date show no significant difference in bonding of the ShinEtsu-filled EM DPD to CsI. Bond strengths on the limited number of samples available indicate strengths that exceed requirements by large factors. The tests show that the ShinEtsu is well attached to the ceramic carrier – the ultimate failure of the bond is at the surface of the DC93-500 to the diode or the crystal, not interior to the diode window material.

NRL used its CDE bonding tooling to bond 6 of the ShinEtsu-filled EM DPDs to CsI and found no particular additional difficulty in executing the procedure relative to the standard EM DPD. This issue needs to be verified with the CEA tooling and with its industrial partner. The major issue relative to the bonding tooling is the concavity of the ShinEtsu-filled diode window relative to the flat, hard surface of the EM DPD. This concavity has to be considered in light of leakage of bonding material in the tooling. This was not a problem with NRL tooling; it must be verified by CEA.

8.1.2 Radiation Susceptibility

The only outstanding radiation susceptibility of the Flight DPD is related to the change to the ShinEtsu silicone optical window. All other elements of the diode have been investigated in the EM DPD testing. We need to verify the radiation hardness of the ShinEtsu and any impact on optical sensitivity of the DPD. This testing is planned with the prototype DPD that are available in late February. Additionally, a quick comparison with respect to the EM DPD will be performed next week by radiating a CsI cube with two DPD attached – an EM DPD and a ShinEtsu-filled EM DPD. This should identify any significant problem with radiation exposure.

8.1.3 DPD Qualification

As part of the first delivery of the Flight DPD lot, CEA will conduct qualification and lot acceptance tests. In the best of all worlds, manufacturing and delivery of additional DPD would be suspended until the qualification testing was completed. This is not possible with the current CDE production schedule. The early delivery schedule is a shipment of 600 DPD every 5 weeks. Consequently, the LAT team may be liable for all units in production until the completion of the qualification testing is complete.

We mitigate this liability by early evaluation of the prototype flight DPD that will be available in February. These tests are anticipated to provide the confidence that there will be no issues with the flight lot qualification.

8.2 Risk Removal

Most of the residual risk in proceeding with the DPD procurement could be removed by delaying the flight DPD procurement and, by result, the delivery of the flight CAL modules by about one month or until the evaluation of the prototype flight DPD is completed.

The residual risk relative to bonding of the DPD to CsI will not be removed until CEA and its industrial partner develop the tooling and execute test bonds with the prototype flight DPD. It appears that this testing is not possible until May 2003 at the earliest.

The completion of the testing of the EM CAL module is not believed to be a significant step in risk removal.

9 Summary

The risks are minor and are not likely to impact the reliability of the DPDs. Lets press on.