

QUALIFICATION OF DC DC CONVERTER HYBRID FOR SPACE PROGRAMMES

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Abstract

DC to DC Converters are used in various ISRO programs to provide regulated voltage and current sources to subsystems. Power and regulation requirements vary widely across various subsystem and Spacecraft applications. DC to DC Converters are primary building blocks of Power System of a Spacecraft. The increasing limitations on space and weight have increased demands to achieve a higher degree of integration while maintaining overall reliability and performance. Hybrid Microcircuit DC-DC Converters have become the preferred choice over surface mount technology (SMT). HMC DC-DC Converters based on Thick film technologies offer size, weight, performance, and reliability and cost benefits for Space applications. 30W DC DC Converter using Thick Film technology has been developed for use in various space programs of ISRO. New processes and unique special subassemblies designed and developed were adopted to realise this DC DC Converter. The challenge was to qualify this DC DC Converter Hybrid to ISRO standards. This paper provides the details of ongoing qualification activities

which include Process Qualification and Product Qualification of DC DC Converter Hybrids for Space application. Approach adopted for qualification to realise reliable DC DC Converter Hybrids is also provided.

Key Words : Hybrid Microcircuit (HMC), DC DC Converter, Process Qualification, Product Qualification

1 INTRODUCTION

DC to DC Converters are used in space application to provide regulated voltage to subsystems. Thick film hybrid DC DC Converter offer reduced size & weight and improved performance. Fig. 1 gives the basic elements of the Thickfilm HMC DC DC Converter.

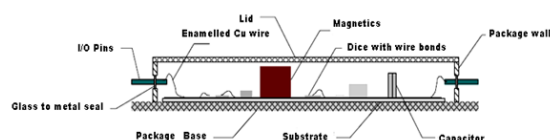


Figure 1: Elements of Thickfilm HMC DC DC Converter

The High Reliability requirements of the DC DC Converter Hybrid for Space application are a challenge. Hybridisation of DC DC converter requires development of processes to handle large power dissipation, high input /output currents with minimal internal losses and new packaging techniques to increase circuit density. Power Hybrids used for Space application must be constructed to be mechanically rugged and meeting hermeticity.

ISAC has developed and qualified 4.5W DC DC Converter Hybrid which are being widely used for all ISRO Space crafts. Since Power and regulation requirements vary widely across various subsystems and Spacecraft applications, there was requirement to hybridise 30W DC DC Converter which required use of new materials and processes. Detailed feasibility study was conducted in terms of material & component selection, process finalisation and 30W DC DC converter HMC was developed in package of size 3.5 x 3.5 x 0.65, 30W HMC internal view is given in Fig. 2. Due to high reliability requirements for space application it is necessary to verify the

properties and compatibility of all the new processes and materials in order to use them effectively and reliably for space application. This paper provides the details of the approach adopted for qualification of 30W DC DC Converter for space application. This paper also brings out the challenges faced during screening/qualification and how these challenges were addressed to meet the MIL standard requirements.



Figure 2: Internal view of 30W HMC DC DC Converter HMC

2 QUALIFICATION APPROACH

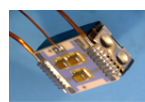
Due to the requirement of large power dissipation and current handling capability, fifteen new thick film processes were developed to minimise electrical resistance and improve thermal conductivity. Some of those new processes were solder die attachment, substrate to molybdenum package attachment using conductive film adhesive to enable large power dissipation, Aluminium wire bonding/gold ribbon bonding and soldering of enamelled copper wire to solder able gold metallisation to enhance current handling capacity. To realise the converter with minimum size and weight, seven subassemblies were designed. The subassemblies designed are as follows:



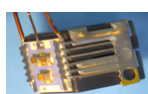
Input Inductor and Capacitors subassembly



Input Inductor and capacitor subassembly



CTC21E-C Capacitor subassembly



CTC21E-D Capacitor subassembly



CTC21E-C Capacitor Subassembly



CTC21E-D Capacitor subassembly



CTC21E-C Capacitor Subassembly

The above new processes and assembly techniques were unique and developed to meet the requirements of 30W DC DC converter HMC. Qualification activities were initiated for the developed 30W DC DC Converter HMC. The qualification cycle of 30W DC DC Converter HMC is categorised into Process Qualification for the fifteen new processes / subassemblies and Product Qualification which involves generation of qualification plan and evaluation.

2.1 Process Qualification

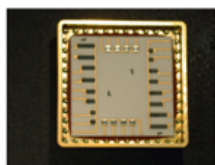
During process qualification manufacturing process parameters are optimised and process window is established to obtain desired results. Process Identification Document (PID) which includes process details, raw material control and in process checks is generated/approved. The manufacturing process is held within the established limits and material control within specification and test patterns representative of individual process or combination of process are realised. These test patterns are evaluated over environmental/mechanical stresses so that uniform quality of hybrids is produced using the process. The basic process qualification plan

was derived from ISRO-PAS-206, the following additional requirements for DC DC converter were addressed and plan was generated accordingly.

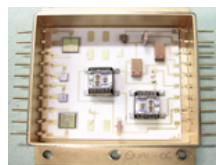
- Since number of processes required to be qualified were more, the processes required to be qualified were combined and the qualification samples were divided into 7 sets so that the samples submitted for process qualification were optimized.
- Layouts for process qualification test patterns were generated such that all the assembled components / subassemblies were terminated to the package pins to facilitate electrical measurements during evaluation. Layouts were designed as per the guidelines provided in ISRO-PAS-206
- Electrical test is conducted after every mechanical / environmental test to verify the performance of the process under evaluation. Electrical test for the components were carried out as per the test conditions provided in respective MIL Standards whereas procedures for electrical testing for each of the subassemblies were derived and adopted during process qualification.
- General visual inspection guidelines as per MIL-STD-883, Method 2017 were followed for the regular hybrid construction. Due to the use of unique processes/ subassemblies in realization, visual inspection guidelines were generated and adopted during qualification.

Table - 1

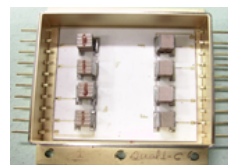
SET	PROCESSES
1	Printing of solderble gold paste and 10 ohm resistor paste
2	Attachment of RM0505 chip resistor Solder die attachment Attachment of CWR-29-H Capacitor & CTC21(D) Capacitor subassembly Vertical mounting of Ceramic Capacitor using epoxy
3	Stacking and attachment of Ceramic Capacitor Stacks
4	Attachment of POT core (Main transformer) Attachment of stacked CTC21(E) subassembly Substrate attachment to molybdenum package
5	Attachment of output inductor subassembly (Torroidal core) Attachment and interconnection of input filter
6	Ball on wedge for 1 mil gold wire, Reverse bonding for 5 mil aluminum wire for diodes. Ribbon bonding for post to substrate
7	Sealing of large size package



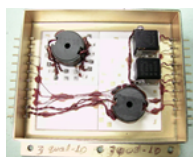
SET 01



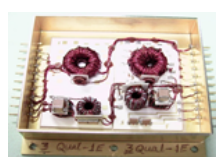
SET 02



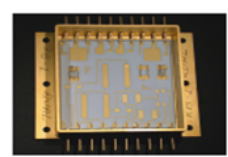
SET 03



SET 04



SET 05



SET 06

TABLE -2 SOLDERABLE GOLD PASTE / RESISTOR PASTE PRINTING EVALUATION

Test and	Test conditions
Visual inspection	Mil –Std -883, Method 2017
Bake	125°C for 72 hrs
Temperature cycling	-55°C and 125°C , 10min dwell, 15 cycles
Visual inspection	As per Mil –Std -883, Method 2017
Temperature cycling	-55°C and 125°C , 10 min dwell, 100 cycles
Conductivity measurement	
Visual inspection	As per Mil –Std -883, Method 2017
Adhesion test for solder joint pad (22AWG copper wire solder to the pads)	>20N/ MIL-STD- 883 Method 2004, Test condition D (Pull test)
Die shear test for Capacitors	As per Mil –Std -883, Method 2019

Table 3 ELEMENTS AND SUBSTRATE ATTACHMENT EVALUATION

Test	Condition
Pre cap visual inspection	MIL-STD-883, Method 2017
Rework of die attach	50 %
Electrical measurements	As per device spec
Bake (sealed Packages)	125°C for 72 hours
Temperature cycling	-55°C to +125°C, 15 cycles, 10 minutes dwell time at each temp
Mechanical shock	1000g, SRS
Seal leak	Fine & Gross , Method 1014
Electrical measurements	As per device spec
Subgroup – 1	
Temperature cycling	-55°C to +125°C, 100 cycles, 10 minutes dwell time at each temp.
Electrical measurements	As per device spec
Mechanical shock	1500g, SRS
Electrical measurements	As per device spec
Delid /Visual inspection & Die shear	
Subgroup 2	
High temp storage	125°C for 1000 hours.
Electrical measurements	As per device spec
Mechanical shock	1500g, SRS
Electrical measurements	As per device spec
Delid /Visual inspection & Die shear	
Subgroup 3	
Vibration	20g Sine 21.4 <u>grms</u> Random
Electrical measurements	As per device spec

TABLE 4 WIRE / RIBBON BOND EVALUATION

Test	Condition
Internal Visual inspection	
Bake	125°C for 72 hrs
Temperature cycling	- 55°C to 125°C , 10 cycles
Mechanical Shock	1000 g 5RS, 5 pulses
Seal leak	Fine & Gross Method 1014, MIL-STD-883
Temperature cycling	- 55°C to 125°C , 100 cycles
Bake	1 Hour at 300°C
Delid / Internal Visual Inspection/ Destructive Bond pull test	

TABLE 5 SEALING EVALUATION

Test	Condition
External Visual	
Temperature cycling	-55°C and 125°C , 50 cycles
Vibration	Sine 20g, All 3 axes, 20Hz to 100Hz Random – 21.4 <u>grms</u> 3 axis 20-2000 Hz
Seal Leak	Fine and Gross Fine leak: 30 <u>psia</u> for 50 hours (Acceptable Limit = 5 X 10 ⁻⁶ <u>atm</u> cc/sec) <u>Grpss</u> leak: 30 <u>psia</u> for 24 hours
External Visual	

The test patterns as shown above were subjected to environmental/mechanical stresses as per the generated test plan. All the processes/subassemblies have successfully met the electrical and visual requirements.

2.2 PRODUCT QUALIFICATION

On successful completion of Process qualification it required to conduct to Product qualification tests for the HMC prior to use in Spacecrafts. Product qualification includes Layout Approval, Reliability Analysis (Derating analysis and Thermal analysis), Proto evaluation and Circuit Type Qualification

2.2.1 LAYOUT APPROVAL

Layout is designed as per the guidelines provided in ISRO-PAS-206. Wire bonds and track widths of the conductor were designed to carry high currents with derating. The layout is divided into three sections Input section, control section and Output section for ease of

fabrication and testing at substrate level. The layout is verified for fabrication/assembly process compatibility, producibility, thermal and electrical requirements. The layout is approved after successful verification of the requirements.

2.2.2 REALIABILITY ANALYSIS

Reliability analyses like derating and Thermal analysis were completed and approved prior to manufacturing of qualification and flight models. Due to long term reliability requirement for space application Parts Stress Derating analysis is carried out to verify that all components are derated as per the guidelines provided in EEE PARTS STRESS DERATING GUIDELINES FOR ISRO SATELLITE PROGRAM.

Thermal Analysis was carried out to estimate the steady state temperature of the components in the package under full load condition. After predicting the temperatures for various cases further analysis was carried out to reduce the temperatures of the components by thermal control measures. Mounting guidelines for the HMC DC DC converter on spacecrafts was also addressed and finalised based on thermal analysis.

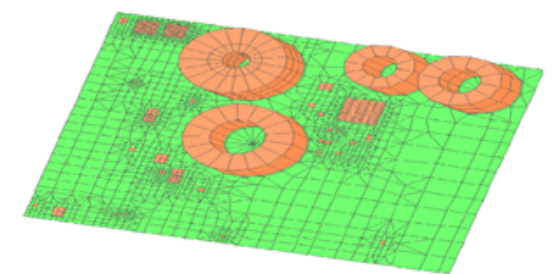


Figure 5: Thermal image showing substrate and components

2.2.3 PROTO EVALUATION

Based on the identified processes and approved layout, prototype HMCs were fabricated. Prototype HMCs were evaluated to meet the visual and electrical performance over operating temperature limits.

DC DC converter HMC has large power dissipation and hence thermal management to ensure that all elements are operating within their design temperature rating during testing and further during operation are to be addressed. Infrared thermal imaging was carried out at HMC fabrication facility on prototype HMC to generate a quantified thermal map of all the elements in the DC DC converter HMC during operation under full load condition. It helps in detecting the temperatures of all elements in the package. Fig. 6 provides the thermograph plot and temperatures of critical dissipating elements in DC DC converter.

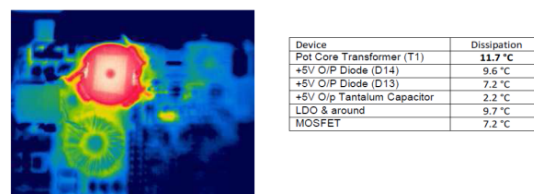


Figure 6: Thermograph of 30W DC DC converter

2.2.4 CIRCUIT TYPE QUALIFICATION

On successful completion of Process qualification and Prototype evaluation, fabricated HMCs are subjected to Circuit Type qualification (CTQ) tests prior to flight usage. CTQ is a qualification programme for the hybridised electronic circuit design for each HMC that is developed for space application.

CTQ includes Mechanical tests, Environmental Tests, Life Tests, High Temperature Storage tests. All HMCs are subjected to Screening prior to CTQ tests. In addition to above tests DC DC converter HMC for space application has to be subjected to additional requirements like ESD test, EMI/EMC test, Radiation test and Thermal Vacuum test. Qualification plan was derived from ISRO-PAS-206 with additional requirements for DC DC Converter HMCs. Table 7 and 8 gives the screening and CTQ plan for 30W HMC DC DC converter.

TABLE 7 SCREENING

Sub Group	Test	Test conditions	MIL-STD-883 Method
1	Initial Electrical	As per Specification	
2	Stabilization bake	72hrs at 125°C	1008
3	Temperature cycling	-55°C to 125°C, 10 cycles	1010
4	Mechanical shock	1000g, SRS	2002
5	PIND	Condition B	2020
6	Pre burn in Electrical measurements	As per Specification	1015
7	Pre burn in Electrical	As per Specification	
8	Burn in – duration	110°C for 520hrs	1015
9	Post burn in electrical	As per Specification	
10	Active thermal cycles	-30°C to 65°C, 05 cycles	
11	Seal (Fine & Gross)	Fine : 30psia for 50hrs Gross: 30 psia for 24 hrs	1014
12	External visual inspection		2030

TABLE 8 CIRCUIT TYPE QUALIFICATION

TEST GROUP/ SAMPLES	TEST	TEST CONDITIONS
MECHANICAL GROUP	Mechanical shock	1500g, SRS
	Vibration	20g Sine: 20Hz to 100Hz, All 3 axis Random: 21.4 grms, 20 to 2000Hz
	Seal leak test	Seal leak Fine:- 30 psia for 50 hrs Limit : 5 X 10 ⁻⁸ atm cc/sec Gross :- 30 psia for 24 hrs No stream of bubbles
	Electrical Test	As per specification
	Delid, Internal Visual	@40 X
ENVIRONMENTAL GROUP	Solderability	MIL-Std-202, Method 208H
	Thermal shock	-55°C to +125°C, 2 Sec transfer time, dwell time 5mins, 15 Cycles
	Temperature cycles	-55°C to +125°C dwell time 10mins, 100 Cycles
	Electrical Test	As per specification
LIFE TEST GROUP	Life Test	@ 110°C for 4000hrs
THERMOVAC AND HIGH TEMPERATURE STORAGE GROUP	Thermovac	-30°C to + 65°C, (profile as per ISRO-PAS-206)
	High temperature storage	2000 hrs at 125°C
EMI / EMC TEST		ISRO Standard
RADIATION TEST		AS per requirement
ESD TEST		MIL –STD -883, Method 3015.8

3 CHALLENGES IN SCREENING AND QUALIFICATION

Due to the use of large size package/cavity size and large power dissipation several challenges were encountered in Screening / Quali-

fication and these challenges were addressed to meet the MIL standard requirements.

3.1 SEAL LEAK CONDITIONS

This test is performed to verify the hermeticity of the sealed HMC. Seal leak test for regular HMCs (Cavity size lesser than 20cc) is performed as per fixed conditions of Method 1014 of MIL-STD-883 whereas the cavity size of 30W DC DC converter is much higher (~ 51 cc). Flexible method as per Method 1014 of MIL-STD-883 was adopted to work out the bombing conditions for this HMC instead of fixed method. The following formula was used and the bombing conditions (30 psia, 50 hours) were arrived to meet the MIL requirements.

$$R_1 = \frac{LP_E}{P_o} \left(\frac{M_A}{M} \right)^{\frac{1}{2}} \left\{ 1 - e^{-\left[\frac{Lt_1}{VP_o} \left(\frac{M_A}{M} \right)^{\frac{1}{2}} \right]} \right\} e^{-\left[\frac{Lt_2}{VP_o} \left(\frac{M_A}{M} \right)^{\frac{1}{2}} \right]}$$

Where:

- R_1 = The measured leak rate of tracer gas (He) through the leak in atm cc/s He.
- L = The equivalent standard leak rate in atm cc/s air.
- P_E = The pressure of exposure in atmospheres absolute.
- P_o = The atmospheric pressure in atmospheres absolute. (1)
- M_A = The molecular weight of air in grams (28.96).
- M = The molecular weight of the tracer gas (Helium) in grams. (4)
- t_1 = The time of exposure to P_E in seconds.
- t_2 = The dwell time between release of pressure and leak detection, in seconds.
- V = The internal volume of the device package cavity in cubic centimeters.

3.2 PARTICLE IMPACT NOISE DETECTION (PIND)

This test is a non destructive test to detect loose particles inside the device cavity and is conducted as per MIL-STD-883, Method 2020; Condition A. The shaker drive test frequency is required to be determined by the package internal cavity height using the following formula as given in MIL standard and is worked out to be 60 Hz.

$$F = \sqrt{20 / [(D)X(0.0511)]}$$

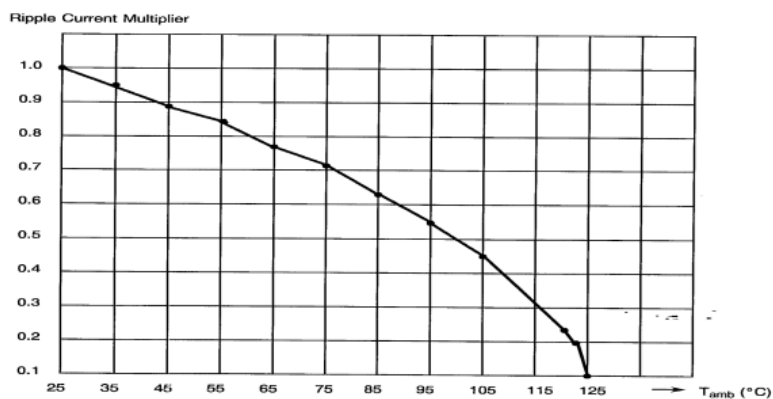
where: D = Average internal package height (in inches).

20 is a constant in this application and is equal to sinusoidal acceleration of 20g.

F is the shaker drive test frequency (in Hz)

3.3 BURN-IN TEMPERATURE

This test is performed at rated operating conditions to eliminate the device with inherent / manufacturing defects which cause time and stress dependent failures. This test is performed at 125 o C , 320 hours minimum as per Method 1015 of MIL-STD-883 for regular HMCs as per space application. As per the requirements specified in MIL, maximum rated junction temperature of any of the device and cure temperature of polymeric materials shall not be exceeded during conduct of burn-in. In 30 W DC DC converter HMC, Ripple current rating of the capacitors specified that the burn-in temperature for this converter shall be less than 115 o C. Based on the IR thermal imaging report and the ripple current rating of capacitor, it was decided to conduct burn-in at 110 o C. for duration of 520 hours as per Method 1015 of MIL-STD-883.



3.4 MECHANICAL TEST LEVELS

DC DC converter has to be subjected to Mechanical shock and vibration test as part of Screening and Qualification. In view of the use of large size special package, the levels experienced by the product in various launchers were encompassed and the mechanical test levels specifications were derived by mechanical experts at ISAC. The finalised test levels were Mechanical Shock: 1000g SRS for acceptance & 1500g SRS for Qualification, Vibration: 20g Sine, 20-100Hz & 21.4 grms Random, 20-2000 Hz

3.5 THERMAL VACUUM TEST

HMCs with large power dissipation is subjected to Thermal vacuum tests. This test is performed to verify the performance of the HMC under thermal and vacuum conditions & also to verify that the operating temperature of the HMC is within design requirements. Thermo vacuum test was conducted and performance was satisfactory. Temperature of the HMC was found to be within the specification.



Figure 7 : Thermovacuum test

3.6 ELECTROMAGNETIC INTERFERENCE / COMPATIBILITY TEST

All DC DC converters are required to meet Electromagnetic Conducted Emission (CE) and Electromagnetic conducted susceptibility (CS) as per ISRO standards. 30W DC DC converter developed

has in built filter to meet EMI / EMC standards. As part of CTQ, EMI/EMC test was conducted and HMC performance was satisfactory during/post EMI/EMC test.

3.7 RADIATION TEST

DC DC converter HMCs requires operating continuously in the radiation environment without performance degradation with accumulative total ionising dose (TID) in the range of 100 Krad. All the components used to realise the converter are procured to meet the radiation requirements of 100 Krad. In addition to that radiation test was conducted on the realised DC DC converter as part of CTQ and performance was verified under radiation environment satisfactorily.

3.8 ELECTROSTATIC DISCHARGE

Electro Static Discharge Test (ESD) was included in the qualification plan to classify the 30W DC DC converter according to its susceptibility to damage or degradation due to ESD. This classification is used to specify appropriate handling requirement for the HMC. This test was conducted in accordance with Method 3015 of MIL-STD-883 and has met the Class 2 requirements.

3.9 TEST JIGS

Electrical Performance of the HMC is verified at various stages during screening and qualification. Since every HMC has a unique set of electrical parameters associated with it and is unique in measurements, custom built jigs are realised to test the HMCs. Test Jig consists of Signal generation (if any), monitoring and load circuitry and socket to mount the HMC, heat sink (depending on the power dissipation). Fig 8 shows the custom built jig realised to test and conduct burn in of the DC DC Converter HMC. Special custom built sockets are used for I/O pin connections and heat sink is provided for proper heat dissipation.

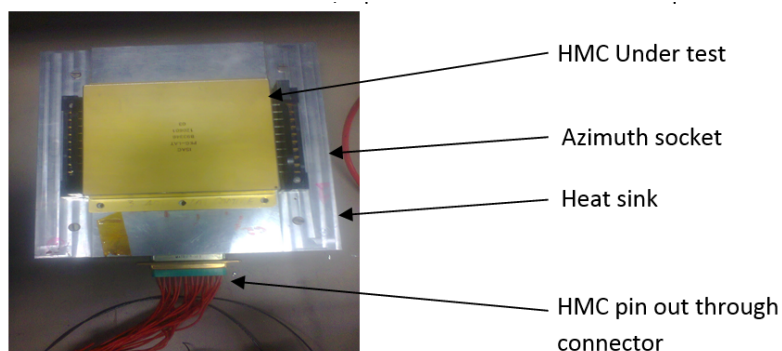


Figure 8 : Test jig

4 CONCLUSION

This paper presents the approach adopted for qualification of the DC DC Converters which include requirements of ISRO standard and additional unique requirements for DC DC Converter for Space application. This paper also brings out the challenges faced in generating in Screening and Qualification plan and how these challenges were addressed in carrying out the tests to meet the MIL Standard requirements. On successful qualification, 30W DC DC Converter HMC would be used in Space programmes.

ACKNOWLEDGMENT

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References

- [1] ISRO-PAS-206 *Qualificaiton Requirements for Thickfilm Hybrid Microcircuits for space applicaiton*
- [2] MIL-STD-883 *Military Standards for testing Microelectronics devices* TSGD30W_HMC_DCDC01 Thermal Analysis of 30W HMC DC-DC converter
- [3] ISRO-ISAC-AR *Parts Stress Derating Analysis* of 30W DC DC converter Thermography inspection report

