The Development and Qualification of a DC-DC Converter for 225°C (437°F) Operating Temperature

Abstract

This paper presents the development and qualification of high temperature electronic module packaging technology to service the requirements for extended and reliable operation at 225°C (437°F) for applications in the Oil & Gas, Automotive and Aerospace markets. It also covers the application of this technology to the first in a range of DC-DC converter modules and is based on Cissoid's 'ETNA' semiconductor components.

Introduction

A particular focus for the technology is for deep well drilling in the Oil and Gas industry. This industry has historically utilised conventional printed circuit board materials with 'through-hole' and 'surface mount' encapsulated components. This approach has been adequate, but is bulky and unreliable when subjected to the high temperatures, shock and vibration experienced at the drill head and this ultimately leads to reduced lifetime and increased cost.

An important consideration is the growth in complexity and functionality of electronics within the well, performing monitoring and control during drilling (MWD – Measurement While Drilling) and during oil and gas production (Intelligent Completions).

The fundamental technologies employed are based on C-MAC's 30 year experience in high reliability electronic solutions for safety critical, harsh environment applications. These core technologies are: hermetically sealed cavity housings, enclosing multilayer ceramic thick film substrates supporting 'bare' semiconductor devices which are attached to the substrate and wirebonded to the conductors. The technologies and resultant DC-DC module have been, wherever possible, developed in accordance with MIL-PRF-38534 standards and controls, albeit with extensions and increased test severities as appropriate.

The technologies have been extensively evaluated by C-MAC's on-site, independently accredited environmental Test House. They have been subjected to sequences of mechanical stressing at temperatures which simulate the conditions that the electronics will be subjected to in the application.

The approach taken was to develop fully representative test circuits incorporating the evaluated and selected range of materials and subject them to a sequence of electrical and mechanical testing to establish their integrity and suitability. This approach for evaluating technologies is based on the British Standards techniques for maintaining process controls by routinely manufacturing representative Capability Qualifying Circuits (CQC's) and subjecting them to a series of environmental tests over extended periods. The core technologies have routinely been tested by C-MAC for periods of up to 8,000 hours at elevated temperatures over the past two decades.

Technologies

The objective was to employ core material sets that are established in the electronics industry and have proven performance within certain boundaries and are cost effective and readily available.

(i) Enclosure

A metal cavity package was adopted. Based on kovar with nickel plating, this provides a rugged rigid housing with a temperature coefficient of expansion (TCE) of around 7ppm/°C closely matching the alumina substrate and suited to the expansion matched glass-to-metal seals for the electrical feed throughs.

(ii) Substrate

Thick film technology on ceramic (96%Al_2 O_3) is very well established and qualified. It is used in the automotive and aerospace industries in harsh environments such as engine monitoring and management.

Thick film conductors are generally noble metals, gold, palladium, platinum and silver compositions and alloys thereof that have a high resistance to corrosion or oxidation. These are sintered onto the substrate at elevated temperatures of typically 850°C to 950°C.

Thick film, printed resistors were evaluated on the base ceramic material and also on top of dielectric above multilayer interconnect.

(iii) Active Components

The components used were Cissoid's Silicon-On-Insulator (SOI) semiconductors that have been developed for 225°C operation.

(iv) Passive Components

Capacitors and Inductors for high temperature operation are available and have been selected for performance

Thick Film Characterisation

The evaluation and qualification programme covered the full range of material systems:-

Thick Film Conductors

Material A
Material B
Material C

Thick Film Dielectric

Material D

Thick Film Resistors

Material E

The conductor materials were analysed for printing characteristics, print definition, adhesion, resistivity and quality with consideration of cost.

Resistors were assessed for printing characteristics, value, stability, adhesion, temperature coefficient of resistance (TCE) and ability to be laser trimmed to precise values.

Assembly Technologies

(i) Wire Bonds

Both ultrasonic and thermosonic wire bonding were evaluated on all thick film conductors with wire sizes of 25μm and 38μm with both ball and wedge bonding techniques.

(ii) Solders & Adhesives

Different solders and adhesives were tested for ceramic substrate attachment into the package and attachment of active and passive components to the substrate.

Test Vehicle

The test vehicle was based on a conventional ‘plug-in’ (solid sidewall) Kovar package with 78 electrical pins (feed throughs). Size is approximately 2 inches x 2 inches x 0.25 inches high.

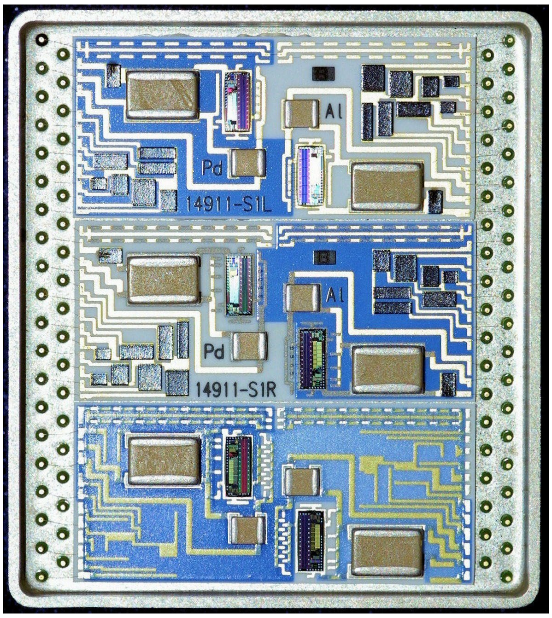
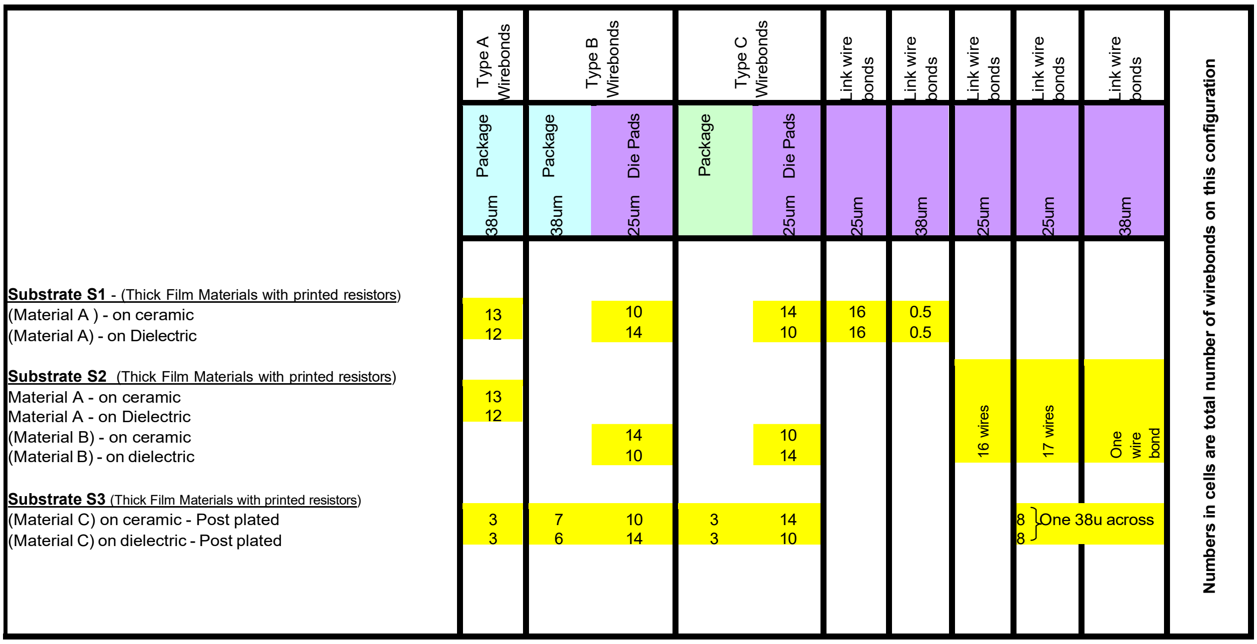


Figure 1 – High temp Test Vehicle

The module incorporates 3 near identical substrates with the full range of technologies under evaluation.

In addition, a separate test circuit was constructed to evaluate the electrical and mechanical performance and the mounting methods of very large bodied multilayer ceramic capacitors and toroidal inductors.

The test vehicle is shown in Figure 1, and the combination of materials in Figure 2. A batch of 35 pieces was assembled in accordance with MIL-PRF-38534 procedures and then subjected to a sequence of environmental testing.



	Type A Wirebonds	Type B Wirebonds		Type C Wirebonds		Link wire bonds	Link wire bonds	Link wire bonds	Link wire bonds	Link wire bonds	Numbers in cells are total number of wirebonds on this configuration
	Package 38um	Package 38um	Die Pads 25um	Package	Die Pads 25um	25um	38um	25um	25um	38um	
Substrate S1 - (Thick Film Materials with printed resistors)											
(Material A) - on ceramic	13		10		14	16	0.5				
(Material A) - on Dielectric	12		14		10	16	0.5				
Substrate S2 (Thick Film Materials with printed resistors)											
Material A - on ceramic	13							16 wires	17 wires	One wire bond	
Material A - on Dielectric	12										
(Material B) - on ceramic			14		10						
(Material B) - on dielectric			10		14						
Substrate S3 (Thick Film Materials with printed resistors)											
(Material C) on ceramic - Post plated	3	7	10	3	14				8 }One 38u across		
(Material C) on dielectric - Post plated	3	6	14	3	10				8		

Figure 2 – Materials Matrix

Environmental Testing

The environmental testing and qualification was performed under controlled conditions in C-MAC's environmental Test House.

Qualification Plan for the High Temperature Test Vehicle

Test Regime Rationale:

The test regime is designed to evaluate the performance of the materials and components both individually and in combination over the range of temperatures.

Four test temperatures were used during the different stages in the programme:

i. 125°C
ii. 200°C
iii. 225°C
iv. 250°C

The test plan included stress testing by three basic methods:

A. An endurance or life test where parts were subjected to constant extreme operating temperature whilst being subjected to electrical bias. This demonstrated the ability of the products to perform their function whilst exposed to the temperatures that will be encountered in the field.

B. The application of mechanical stress by the use of vibration and shock testing. These tests were performed on the modules at the maximum test temperatures. This demonstrated the ability of the modules to survive high levels of mechanical stress whilst being subjected to elevated temperature.

C. Temperature cycling and thermal shock testing in air was used to evaluate the reliability of the components and the adhesives used to attach the components when subjected to the disparate thermal expansions and contractions that could be experienced in use.

Acceptance Criteria:

The evaluation of the performance of the devices was based on the following criteria:

1) Electrical test of the devices designated performance as specified in the product test specification.

2) Hermeticity testing of the metal package to determine the ability of the welded metal joints and the glass to metal lead through to survive high temperature operation. This was in accordance with MIL-STD-883 method 1014

3) Residual Gas Analysis (RGA) of the internal atmosphere of the modules to understand the levels and constituents of the out gassing of the materials used in the construction of the device after exposure to high temperature operation. This was conducted in accordance with MIL-STD-883 method 1018

4) Performance of wire bond pull testing and die shear testing to measure the strengths remaining in the various welded and epoxy joints within the devices. Testing was conducted in conformance with MIL-STD-883 test methods 2011 and 2019 or 2027

Conditions of Test

Endurance (Life test): Devices were subjected to the declared temperatures, 225°C and 250°C. They were wired such that the module was subjected to the required electrical biases. Measurements were made at 168 hours, 500 hours and 1000 hours. Test conditions were in compliance with BS EN 60068-2-2 (2007) Dry Heat – see Figure 4.

Vibration and shock:
Vibration was random at a level of 15grms over a frequency range of 10 to 1000Hz. The vibration was applied for one hour in each of three axes at the specified temperature. Testing was in accordance with BS EN 60068-2-64 Random Vibration (Digital Control), Fh Mechanical Shock. The level was 500g-peak sine wave with duration of 1ms. 10 shocks and applied in each sense of three axes at the specified temperatures (60 shocks in total). Testing was in accordance with BS EN 60068-2-27 (Mechanical) Shock, Ea. – see Figures 3 & 5

Temperature Cycling:
Temperature cycling was carried out for the specified number of cycles and to the specified temperature extremes. The ramp rate was an average of 3°C per minute. The dwell time at each extreme was 15 minutes. For a total of 100 cycles. The device had bias applied during the temperature cycling test. Testing was in accordance with BS EN 60068-2-14 (1999) Change of Temp test Nb – see Figure 6

Thermal Shock:
Thermal shock consisted of 500 rapid changes of temperature between the specified extremes of temperature. Transition of the devices between the two chambers held at the specified temperatures occured within 1 minute. The module was non operational during thermal shock testing. Dwell time at extremes was 30 minutes. Testing was in accordance with BS9450 Clause 1.2.7.14 incorporating BS 9450 EN 60068-2-14 (1999) Change of Temp test Na – see Figure 6

Figure 3 Vibration Test Equipment

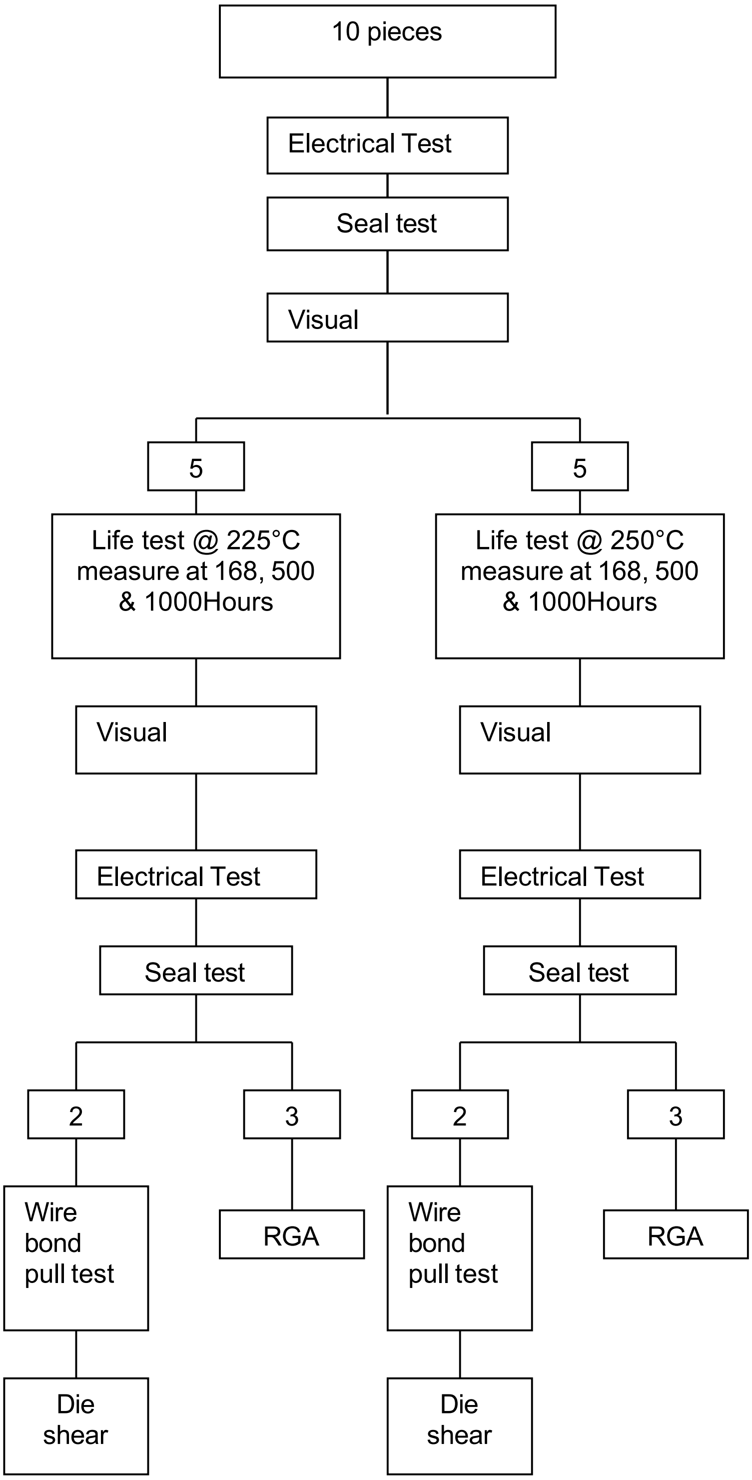


Figure 4 Endurance Test

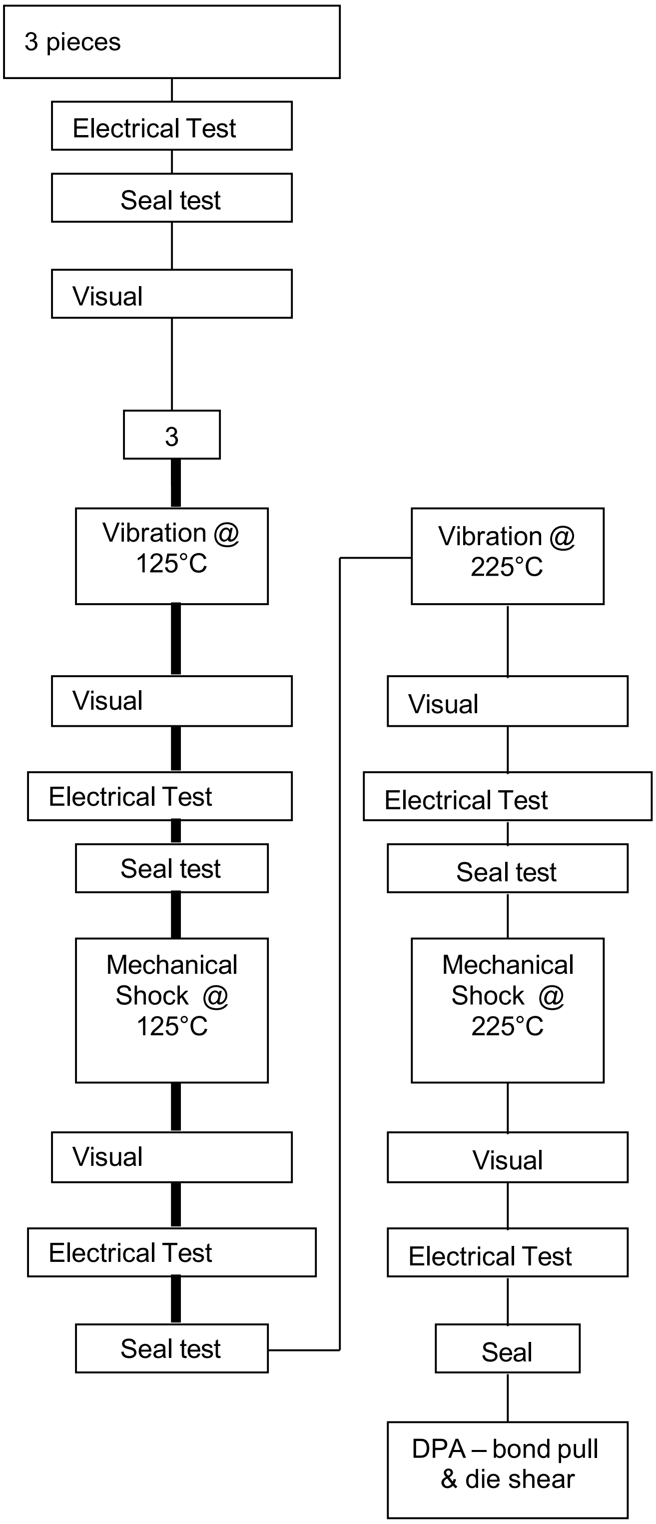


Figure 5 Vibration and Shock Test

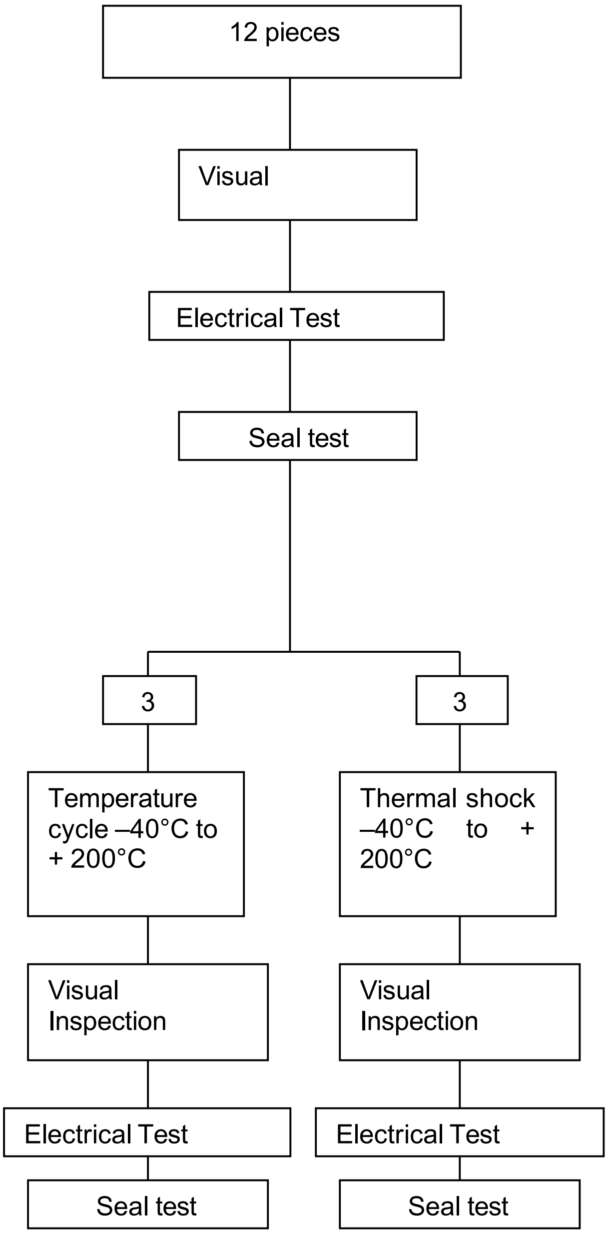


Figure 6 Temperature Cycle and Thermal Shock Test

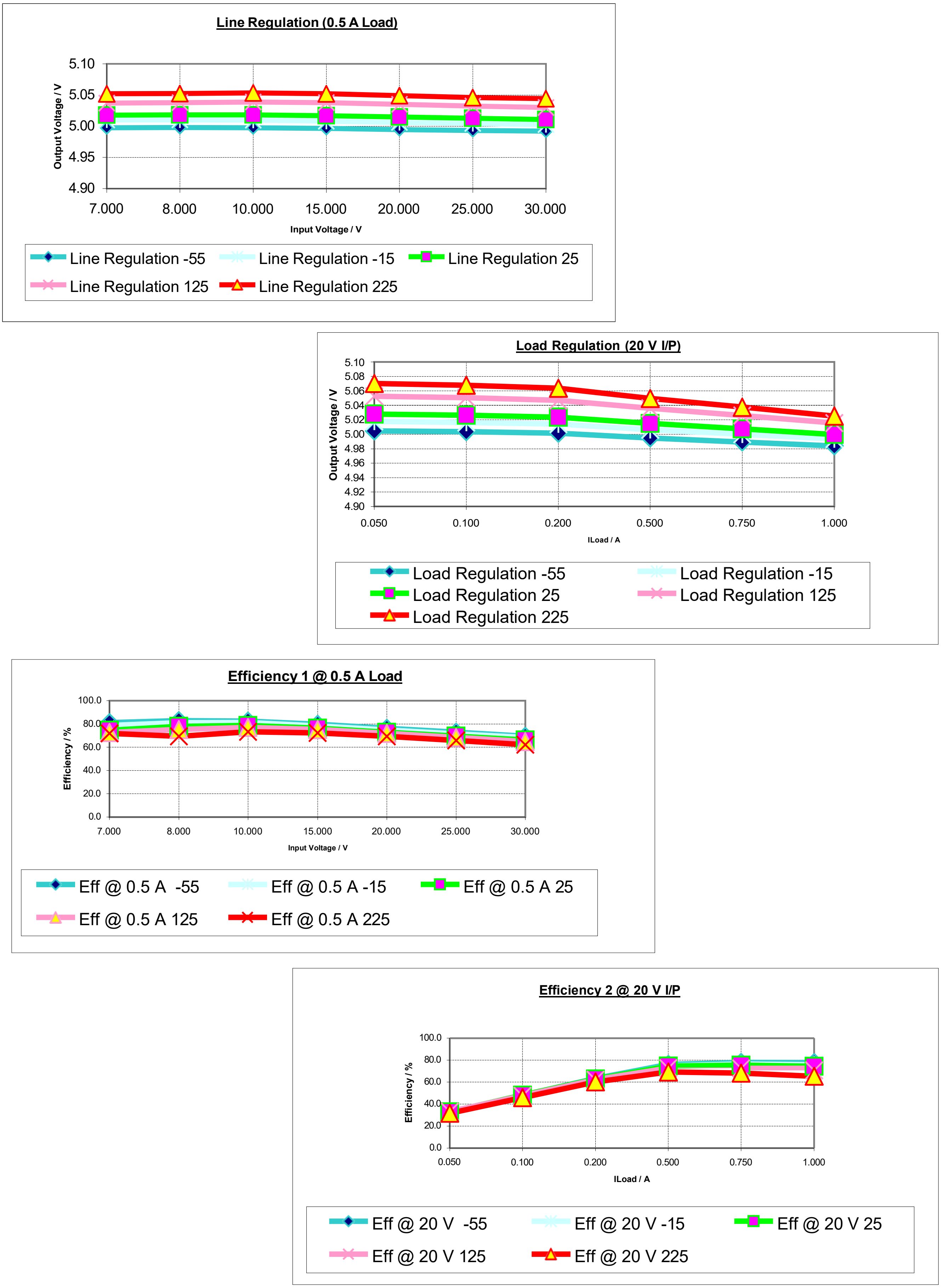


Figure 8 DC-DC Converter Test Results

Qualification Results for Test Vehicle

- Life test 1,000 hours @ 225°C case and 250°C case - Successfully completed and wire pull strengths good
- Temperature cycle 100 cycles, 200°C/-40°C - successfully completed with no failure
- Thermal shock 500 cycles, 200°C/-40°C - successfully completed, an extended 900 cycles and continuing.
- Mechanical shock, 500g-peak sine, 1ms. 10 shocks, 3 axes at 125°C and 225°C - successfully completed.
- Vibration 15grms, 10Hz to 1kHz, 3 axes at 125°C and 225°C - Successfully completed

DC-DC Converter

The DC-DC converter was constructed with the optimum material and technology set identified in the test module – See Figure 7.

The product was configured as a high aspect ratio (“long and Thin”) footprint with a constrained height such that it was suited for deep well drilling and would fit into a 1 inch diameter drill tube.

Figure 7 DC-DC External View

Electrical Performance

Supply Voltage: 7 to 30 Volts
Output Voltage: +2.5 to 25 Volts
Load Current: up to 1 A
See graphical data – Figure 8

Conclusions

The programme of material and process development and extensive environment testing and qualification was successful. The test vehicle was life tested at 250°C for 1,000 hours to provide a high level of confidence for operation at 225°C in the application.

The DC-DC converter product was subsequently realised using the selected material system and processes and demonstrated good electrical performance up to the specified operating temperature of 225°C (437°F). The product is now completing qualification against the environmental test plan stated.

It is concluded that the technologies are fit for purpose for 1,000 hours.

Acknowledgements

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