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First High-Temperature Electronics Products Survey 2005

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First High-Temperature Electronics Products Survey 2005

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Abstract

On April 4-5, 2005, a High-Temperature Electronics Products Workshop was held.[1] This workshop engaged a number of governmental and private industry organizations sharing a common interest in the development of commercially available, high-temperature electronics. One of the outcomes of this meeting was an agreement to conduct an industry survey of high-temperature applications. This report covers the basic results of this survey.

[1] [1] The April 4-5, 2005, a High-Temperature Electronics Products Workshop was sponsored by the DOE-Sandia Geothermal Research Department and the Air Force Research Laboratory, Wright-Patterson AFB, Dayton Ohio.

ACKNOWLEDGMENTS

This report was funded by the Sandia Geothermal Research Department under guidance from the Geothermal Program Office of the U.S. D.O.E. with aid from the U.S. Air Force Research Laboratory, Aircraft Power Systems at Wright-Patterson AFB, Dayton, OH.

This work survey was undertaken to aid in developing COTS (commercial-off-the-shelf) high-temperature, highly reliable electronic components and systems meeting the future needs of both organizations.

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EXECUTIVE SUMMARY

The survey targeted application designers in the aerospace, drilling and automotive industries via email and direct polling at the October 2005 meeting of the SAE-AE7 (Society of Automotive Engineers – Aerospace Electronics Chapter 7). Application engineers are concerned with design level issues. The majority of responses came from engineers within the aerospace industry.

Below is a list of general outcomes resulting from the survey.

1. The drilling industry market for high-temperature electronics is small - 100 to 1000(s) devices per year.
2. The aerospace industry has 10 to 100 times the market for high-temperature electronics as the drilling industry. The survey didn't distinguish between military and commercial aerospace applications, which might explain the wide range.
3. The drilling industry is thinking of near-term (1-2 yrs) solutions while the aerospace is looking at mid- to far-term (2-5 yrs and >5 yrs) solutions.
4. Most responses require operating temperatures of 150 to 300 °C. However, 5 out of 23 responded with +300°C temperature requirements.
5. The aerospace industry is more concerned with reliability than measurement accuracy. They clearly want design margins.
6. The high-temperature circuit application receiving the most support in this survey was the power converter. All three of the industries can use a high-temperature power converter: DC/DC and AC/DC.
    a. Market support for high-temperature power converters components is well within the range of 100K's parts per year.
    b. For 200-300°C power converters:
        1. Control circuits could use silicon SOI or SOS technology.
        2. Power devices could be SiC based.
        3. Capacitors are currently not available above 200°C.
    c. The high-temperature component most needing development for power converters are low loss, large valued capacitors.
7. Data acquisition was the second application receiving the most support. Non-volatile memory and 16-32 bit microprocessors are a major issue.

Contents

Introduction

On April 4-5, 2005, the first joint meeting between the aerospace and drilling industry was held in Dayton, OH, hosted by the Air Force Research Laboratory at Wright-Patterson. NASA-Glenn, JPL and the Army Research Laboratory also participated in the meeting. All of these organizations share a common interest in the development of commercially available high-temperature electronic components and sensors. One of the outcomes of the meeting was an agreement to conduct an industry survey of high-temperature applications. This report covers the basic results of this survey.

The survey targeted application designers in the aerospace, drilling and automotive industries via email and direct polling at the October 2005 meeting of the SAE-AE7 (Society of Automotive Engineers – Aerospace Electronics Chapter 7). Responses were given anonymously. The written responses to survey questions are given in Appendices B and C.

This was the first survey of its type. Many of the questions offered individuals the opportunity to write-in a response. A copy of the survey is attached as an appendix to this report. A follow on survey with more targeted questions is recommended.

For basic background on high-temperature applications, a list of commonly known high-temperature applications is also included in the Appendix A.

Who Responded

The first question of the survey asked: Please indicate what industry you work in. Please circle one or more. Below is a list of options and the numbers of circled responses.

- Aircraft Power – 15
- Aircraft Engines – 9
- Automotive – 2
- Electric Power Grid – 2
- Interstate Trucking – 0
- Radiation Hard Systems – 5
- Well Drilling & Exploration – 3
- Well Logging – 3
- Well Monitoring – 2

The survey attempted to reach application designers and not component producers. These responses came from ~20% of those poled. The majority of those poled are engineers having attended HiTEC (High-Temperature Electronics Conference) and the October 2005 meeting of the SAE-AE7 (Society of Automotive Engineers – Aerospace Electronics Chapter 7).

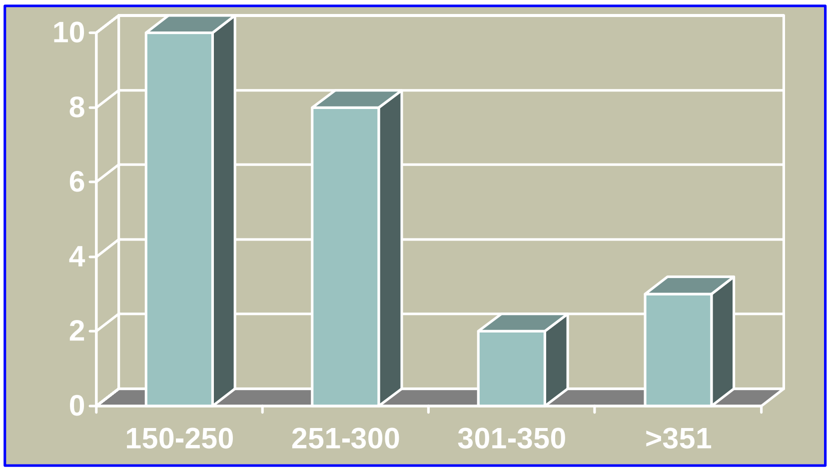
Individuals were also asked about temperature of interest:

> Please circle the temperature range needed by the application you listed as the most HT application benefiting your industry.

There were four temperature ranges:

A. 150-250°C	10 responses
B. 251-300°C	8 responses
C. 301-350°C	2 response
D. 351°C and higher	3 responses

Same results in graph form.



General Conclusions from Open Questions

There were a number of questions where the individual was given a chance to write-in a response. These comments are not easily tabulated in the form of a table. Each of the questions is listed below, along with the reasons for the question. General results of the question are suggested along with examples of actual given answers.

For a complete list of responses, see Appendix C: Other Responses to the Survey Questions.

Question #2: Please identify what one HT application would benefit your industry the most. If reasonable, please provide some of the necessary attributes needed for commercial success.

Reasoning: This question was asked to help identify common applications and basic requirements. Responses can be grouped in to two categories, power and data acquisition. There were 14 power applications given to 5 data acquisition. Most of the responses were power applications targeting power converters for both DC/DC and AC/DC. Among the power applications were two for high-temperature motor controls. Examples of responses are listed below.

Power Applications Response Examples:

- Power Converters (220Vac & 440Vac to 28Vdc) & Inverters (27Vdc to 115Vac)
- Power Converters 4-350kW
- Aircraft power electronics: voltages to 600V, -55 to 300ºC and capacitors with high efficiency and a 20 year life
- Aircraft Power Conversion: 10 to 100A / 1000V rectifiers & SCRs with 0.1-20uF / 600V capacitors
- High efficiency power converters (250-300ºC): Medium temp (150-200ºC) highly reliable power converters

Data Acquisition Response Examples:

- Sensor support electronics for HT well monitoring (250ºC), data acquisition, data reduction, memory, telemetry systems, batteries, DC/DC converters
- Sensors MTBF 20,000 hrs with high shock
- HT miniaturized combustion control system

In general, the drilling industry people favored data acquisition applications. The aerospace industry favored power applications with needs for engine data acquisition control systems.

Question # 3: Please identify what one HT application "outside" of your industry would benefit your industry the most.

<u>Reasoning:</u> This question was asked to encourage and gain insight for cross industry applications using the same high-temperature components. A few individuals responded by saying that they didn't know about high-temperature applications in other industries. Several answers indicated that some individuals didn't understand the question.

Examples:

- Aircraft engine distributed control most closely matches the component selection we need down hole. The promise of larger (future) volumes of this industry could encourage vendors to supply the smaller quantities we need for down hole right now. Similarly, the testing and qualification that we do now helps provide reliability validation for the more critical upcoming aircraft applications.
- Manufacture of HT analog and digital signal conditioning integrated circuits

- HT power devices (high-voltage caps and power transistors)

- Solid State Power Controller used to replace circuit breakers & relays

Clearly, there is room to improve the general cross industry understanding of high-temperature applications. There is a need to better identify industry requirements so that engineers within the aerospace, drilling and automotive industry can maximize the production volumes of high-temperature electronic components and sensors.

Question #4: From the list below, please circle 3 attributes that are the most important to the application you listed under question #2 above.

<u>Reasoning:</u> This question was asked to generate a feel for reliability requirements versus system performance. There were 7 possible choices, 'a' through 'g' as illustrated in the table below.

Choices	Description	# of Votes
A	Absolute sensor measurement accuracy	5
B	Relative sensor measurement accuracy	3
C	Expected operating life time before falling outside of specification	12
D	Expected operating life time before failing to function	19
E	Temperature design margins	14
F	Low supply current for battery operation	5
G	High signal voltages for reduced EMI	2
H	Accelerated life testing	7
	Total	67

The two measurement accuracy responses 'a' and 'b' only received 5 out of 67 votes. This indicates that most people didn't choose sensor performance at all. Most of the votes were used on reliability issues, option 'd', received the most votes, followed by option 'e'. These attributes are closely related.

In general, reliability issues are extremely important to the majority of our respondents. Most of the respondents come from the aircraft industry. So, reliability is going to be a major driving force in the creation of a high-temperature electronics industry.

Question Final Comments: Please feel free to make comments below. There is no need to include your name, and individual responses will be protected. Survey results will be publicly released by HTEP and belong to the SAE, Society of Automotive Engineers.

Reasoning: Allow respondents to make comments. Below are a few examples.

- I would much rather design with simple, basic building blocks that can be shared between applications across the HT community than to be forced into custom IC's where my volumes will never justify the initial investment. None of our individual applications are big enough to interest typical electronics vendors. The more willing we are as a high temperature community to share components and technologies, the more likely vendors will be to supply them to us.

- Component volumes are small, but system impacts are large. Long-term reliability at HT is key challenge.

- Aerospace objectives: High reliability converts
Minimize cooling volume & weight
Increase cooler efficiency

Component Wish List

Respondents were given a chance fill in a table. The table had three columns: Most Desired HT Components, Estimated. Development Time [near term- (1-2 yrs), mid term (3-5 yrs), far term (>5 yrs)], Estimated Volume for Your Application.

Some noteworthy results.

A. Number One Near-term Component needing development
    - Drilling industry - > 200°C high-density non-volatile Memory – 1000/yr.
    - Aerospace – 65-300°C SiC Diode - 3000/yr.

B. Mid-to Far-Term Development - 16 or 32 bit microprocessor
    - Automotive – 100-300K/yr.
    - Aerospace – 50 per aircraft (50 to 100K/yr)
    - Drilling – 1000s

C. Most Requested Components for Aerospace Industry
    - Power Semiconductor Devices 200-300ºC, Diodes, FETs, MOSFETS, IGBTs – in the 1000s/yr.
    - Capacitors – 100 to 800 volt, 10uF, low loss

D. Packaging (200-300ºC) – Drilling and Aerospace
    - Printed wiring boards, interconnects, insulation, potting materials, connectors, electrical feed-through, connectors

Differences in the three industries also became apparent within component selections.

A. Automotive industry generally high volume needed (100,000s/yr.)
    a. Automotive industry felt development of all products were far-term

B. Aerospace industry indicated a greater need for Power Semiconductor Devices & Power Management Devices
    a. Aerospace industry needs range from 1000s to 10,000s/yr. to 50-100/aircraft (50K-100K/yr) commercial
    b. Aerospace industry perceived more mid- to far-term development times

C. Drilling industry indicated greater need for Memory related devices & Sensors
    a. Well industries perceived more near- to mid- term development times of key components
    b. Well industries needs ranged from 100s to 1000s/yr.

The drilling industry has the closest (only) near-term applications, and is also the smallest in volume. The aerospace industry is next with near- to far-term applications with approximately 10 to 100 times the potential market. The automotive responses were far-term and relatively low volume by conventional automotive market standards. These results may be due to only two responses from this industry.

The overall conclusion of this survey identified the application with the most cross cutting industry support for high-temperature components was the need for power control electronics with a potential market >100K devices per year. Data acquisition was second with a need for non-volatile memory (Flash, EEPROM) listed as components needing development.

Conclusions

5a General Report Comments:

High-temperature components and sensors must also be reliable. The aerospace industry views reliability as vital.

The drilling industry views the development of high-temperature applications as short-term, 1 to 2 yrs, to mid-term, 3 to 5 yrs. The aircraft industry views high-temperature components at mid-term to far-term, >5 yrs. The two automotive responses were both long-term. Perhaps the cost conscious automotive industry is dependent on a 'mature' high-temperature electronics industry to help drive down costs.

The highest valued industry cross-cutting application is the need for power applications. The lack of a reliable high-temperature, low loss capacitor will limit growth in this area. The second most cross cutting application is data acquisition and control electronics. Electronics are needed to make wellbore measurements and control aircraft engine actuators. The lack of non-volatile memory and 16-32 bit microprocessors will limit growth in this area.

5a Recommendations:

A second survey, to be conducted during HiTEC, would make sense. To enhance that effort, the following survey improvements are recommended.

1. The first survey targeted application engineers working within the industry. A second more comprehensive survey should target both application engineers and high-temperature component designers.

2. An effort should be taken to include the interstate trucking industry in the survey.

3. An effort should be taken to include the electric utility industry for HTHV applications.

4. Among the list of potential industries make sure to separate military aircraft vs. commercial aircraft.

5. A second survey needs to ensure that questions refer to temperature as either ambient OR junction temperature.

6. There should be an increase in component specification questions.

APPENDICES

Appendix A.
Well Known Commercial High-Temperature Applications

By Randy Normann and Stan Atcitty
Sandia National Laboratories
January 2006

Introduction

This report was prepared to allow government organizations and private industry interested in developing sensors and electronics needed for high-temperature applications to better understand future applications. Discussions are general and should be used to help the reader gain an over view of future high-temperature commercial applications. This document is dated material and not intended to be a specification for any one application.

In general, future commercial applications for high-temperature electronics are also high-reliability applications. For example, a failed microprocessor in a drilling tool, 20 KFt deep in a well, can cost the drilling rig two days delay. Two days delay of an offshore drilling platform is approximately $500,000. Failures of shorting capacitor inside an automobile transmission can cost the auto manufacturer millions of dollars and a soiled reputation.

When considering developing a high-temperature component, always keep reliability in mind. There is a growing body of evidence that high-temperature electronics and sensors have greatly improved operating lifetimes at lower temperatures. Honeywell HT SOI electronics rated for 5 years at 225ºC have a potential for 10 years at 200ºC and 20 years at 150ºC. This level of reliability has commercial applications outside of the high-temperature applications listed here.

Oil and Natural Gas Wells

1. MWD (Measurement-While-Drilling) tools

   <u>General description:</u> MWD tools are instrumentation packages mounted behind the drilling bit. This location exposes the electronics and sensors to extreme heat and vibration. Typical measurements made by a MWD tool are: <u>azimuth, inclination, temperature, pressure, gamma and sometimes vibration and strain</u>. A typical MWD tool transmits data to the surface using pressure pulses of drilling mud. Pressure pulses are created by controlling a mud valve near the bit. The mud pulse transmission requires relatively high power (1Amp-100V) for valve actuation and significant data processing <u>(32 bit uP, DSPs</u>) to compensate for the slow data rate, <10 bits per second.

Typical operating temperature range from 30 to 175°C for ~90% of the market where 30 to 225°C covers 99% of the market. There are very deep natural gas wells planned for >30,000ft with potential temperatures of +250ºC.

Vibrations of 15 Gs are continuous while drilling. Shocks of 100 to 2000 Gs can occur on all three axis.

2. Logging tools

General description: Logging tools are used to survey a well. Logging tools are scientific in nature (16 bit A/D min) and in construction, providing a wide range of data. Logging tools are lowered into the well from the surface via a wire (slick line) or via electric conducting cable (wire line or eline). A slick line tool requires a HT battery and stores information inside its memory. A wire line tool reports information real-time as the tool moves up and down the well using a wire-line cable.

Typical operating temperature range 30°C to 225°C with some natural gas wells up to 250ºC.

Logging tools use electric magnetic, gamma, small motors, seismic, acoustic, vibration and other sensors. In general, most any HT sensor will find an application in the logging industry.

3. Production Well Monitoring

General description: In well monitoring, the electronic devices and sensors monitor and control reservoir production. These systems are considered permanently installed because of the difficulty in removal. In the future, systems maybe cemented in place. In general, these systems measure pressure, 3 phase flow (oil, gas & brine), density and can open or close a valve. The valve operation requires a small high torque motor. Because of the long-term exposure to the wellbore environment, these systems can be exposed to free hydrogen along with elevated temperatures.

Typical operating temperature range is between 30-175°C with approximately 95% of the wells <150°C.

Typical operating lifetime is 3 to 5 years for electronic controls placed on production tubing. Future installations where electronic sensors are placed with the cement annulus will need an operating life of 10 to 30 years.

Typical vibration is consistent with normal ground transportation to the site. Once installed within the well, vibration is virtually eliminated.

Geothermal Wells

1. MWD tools

General description: Measurement-While-Drilling (MWD) tools are the same as oil and natural gas MWD tools with the exception of higher temperatures. Reservoir ambient temperatures can reach 350°C. However, geothermal production wells are drilled using mud coolers to keep the bottom hole temperature below 225°C. Should the mud pump system fail, the tool will see reservoir recovery temperatures. As such, drilling tools should be designed to survive temperatures between 250 and 350°C.

Typical operating temperature range is between 150-225°C. Normal drilling conditions are controlled by using multiple mud coolers to cool the drilling mud and thus the well.

Survivable to 250-350°C. The normal drilling operation has failed and the drill bit and MWD tool are normalizing to formation temperature.

2. Logging tools

General description: Logging tools must operate at reservoir ambient temperature while logging the well. Normal geothermal production wells are isothermal, with hot reservoir fluid coming up the well from a deep production zones. A typical geothermal production well is producing +10 KHP inside a 6-8 inch pipe. This mass flow of fluid causes vibration. Shock occurs when the logging tool passes an elbow or hits an unknown well obstacle.

Upper temperature range of 325°C for ~95% of the market. An upper temperature range of 300°C for ~75% of the market.

A minimum operating life of 1000 hours at 300ºC will give the operator a minimum of 10 logs before replacing the electronics.

Automotive Conventional

General description: Automotive electronics are uniquely specified for each manufacturer and model. Automotive electronics must be cost competitive with existing low temperature devices. Automotive HT electronics are used in the engine, transmission and brake systems. The temperature requirements can vary based on location one the car and expected passive cooling. The automotive engineer needs to quickly validate the long-term reliability of their new designs with a minimum of accelerated life testing. Car models and automotive technology is constantly evolving.

Typical transmission and engine temperature specifications fall between 135 and 180°C for peak intermediate temperatures.

Life: The operating life is 10 to 20 years with only 10,000 hours of actual operation and only a few hundred hours near peak rated temperatures. Accelerated life testing is difficult because many automotive HT control electronics have failure modes close to the peak rated temperatures. Governmental environmental regulations require manufacturer warrantee for emission controls well beyond the auto manufacturer's general consumer warrantee.

Brake systems will require control sensors to operate +300ºC.

Automotive Hybrid/Electric Vehicles

General description: Automotive hybrid and all electric vehicles have additional considerations for applications for high-temperature electronics. Here automotive electronics share a common list of operational requirement with the aircraft industry. Hybrid and all electric cars require energy efficient electronics for motor controllers and power converters. Here low loss capacitors and power devices are critical. The ability to operate at high temperatures is needed to reduce size, weight and increase energy density. The automotive engineer needs to quickly validate the long-term reliability of their new designs with a minimum of accelerated life testing.

Typical motor controls temperature specifications fall between 125 and 150°C for peak intermediate temperatures. (However, as high-temperature electronic continues to evolve future systems will require much higher energy densities.)

Life: The operating life is 15 years with thousands of hours of actual operation time and only a few hundred hours near peak rated temperatures.

Power: General vehicle operating voltages of 12 and 42 volts. Power for motor drives and converters is 300, 600 perhaps higher voltages at ~30 kW continuous and 15 kW for 18 seconds.

Aircraft

1. Commercial Aircraft Distributed Engine Controls

General description: Currently, commercial aircraft use centralized engine controls, requiring up to 500 wires running from the cockpit to each engine. Each wiring harness requires a number of interconnects, leading to significant complexity and weight. A high-temperature distributed control system reduces the wiring harness complexity by a factor of 10 or more while saving weight. However, the distributed engine control system requires that electronic controls be placed within the harsh high-temperature environment.

The operating temperature can vary significantly between engine manufacturers and location of electronics on the engine. In general, temperature extremes are seen during takeoffs. Passive cooling can reduce peak operating temperature requirements.

Typical temperature operating range is –55 to 225°C.

The operating life is based on Time to Failure (TTF). Here TTF is well outside of the engine refurbish time. Failures are defined as a component falling outside of its performance specification by more than 5%. Failures occurring within the engine refurbish time should be in the low part per million to avoid unplanned maintenance. Only graceful failures can be tolerated.

Typical component operating life is 5 years with extensive thermal cycling.

2. Aircraft Power Electronics

General description: Aircraft power electronics are needed to replace existing hydraulic systems. To replace existing hydraulic systems, it will require an improvement in reliability, reduction in weight and reduction in overall aircraft maintenance. Power electronics for motor controls and electric brakes require HT capacitors, SiC drivers, circuit assemblies and control sensors. To fully benefit space considerations inside the aircraft, a minimum amount of passive air cooling can be used.

Typical temperature operating range is –55 to 350°C.

Typical component operating life is 5 years with extensive thermal cycling.

Electrical Utilities

General description: Electric utility system is made up of generation stations, transmissions, and distributed networks spread across the entire country. It supplies energy needs for various loads including residential and industrial customers. The transmission's robustness or its ability to withstand disturbances and maintain stability is dependent on proper control and protection. As the vertically integrated utility structure is phased out, centralized control of the bulk power system will no longer be possible. Transmission providers will be forced to seek means of local control to address a number of potential problems such as uneven power flow through the system (loop flows), transient and dynamic instability, subsychronous oscillations, and dynamic overvoltages and undervoltages. Power electronics can play a key role in increasing the reliability and security of the electric utility system by mitigating these potential problems.

Some examples of power electronics used in the electric utility system are fault current limiters, high voltage direct current (HVDC) converters for DC transmission, Flexible AC Transmission Systems (FACTS) for Volt Ampere (VAR) control, and solid-state transfer switches. All these systems today rely on silicon-based semiconductors to perform their functions. One of the major road blocks in silicon-based semiconductors is its voltage blocking capability and limited junction temperature. Higher voltage blocking (greater than 20kV) capability with higher junction temperature (greater than 150^0 C) is needed. Transmission applications rated at hundreds of kV and distribution applications rated at tens kV could directly benefit from this capability.

Appendix B. Written Wish List Results from the Survey

Below is the question as it appeared in the survey.

Please fill in the following table to your best guess to a level of detail that you feel comfortable with. (All results will be tallied for the purpose of sharing this with the high temperature electronic community. No responders name or affiliation will be identified.)

Most Desired HT Components (Rank in order of importance)	Estimated Development Time or Technical Challenge	Estimated volume for Your Application
(Ex: 10nF cap. w/X7R performance within operation range to 300°)	1–near term (1-2 yrs) or 1 – low 2-mid. Term (3-5 yrs.) or 2- med 3-far term (>5 yrs.) or 3 high	(ex. 10 per year, 10,000 per year…)

Below are responses given by category or industry.

Aircraft

Wireless Pressure sensor	3 – far	1000 per year
High power diodes	2 – mid	100 per year
SiC CCD array	3 – far	10 per year

None Given

Power control devices running at 300C	2	100,000/year
Capacitors at 300C	2	100,000/year
Control logic at 300C	2	100,000/year

Aircraft & Drilling

Capacitor with volume density similar to X7R (but reduced high-temp rolloff), capable for long-term (multi-year) operation to 250°C	2	10000/yr (within 3 years)
Microprocessor (8 or 16 bit) with embedded EPROM memory, for simple control loop applications.	2	2000/yr (within 3 years)
Small (1 to 2 Kbyte) serial EEPROM capable of 250°C operation	2	2000/yr (within 3 years)

PWM controller	1	1000/yr(within 3 years)
Batteries, capable for operation from 0°C to 250°C	2	1000/yr(within 3 years)
Low-noise programmable gain amplifier with long-term operation to 250°C	1	10000/yr (within 3 years)
Precision voltage reference (less than 2uVp-p noise to 100hz, less than 0.5% drift from 0C to 250°C, 0.1% initial accuracy)	1	10000/yr (within 3 years)
Precision Oscillator for 250°C operation	2	2000/yr (within 3 years)
DC-DC Converter for 250°C	2	1000/yr (within 3 years)

None Given

IGBT dual module 600V and 800A including a drive board and two current sensors	2 – mid	5000 per year
IGBT six pack module 600V and 200A including a drive board and two current sensors	2 – mid	1600 per year

Military and Space Applications

DC/DC converter, -55 to 250°C, 270V or 28V inputs, 3.3V, 5V, =/-10 output	2 and 2	500 - 1000
Power semiconductor devices, 300C, no depletion FET, enhancement type only, 600V/20A and 100V/50A rated	2 and 2	1000 - 2000
Magnetic core materials for power transformers and filters operable > 1 MHz and up to 300°C	2 and 2	2000
Power rectifiers, 300C, 100V/20A, 100V/50A and 50V/100A rated	2 and 2	1000 – 2000

High density low ESR, ESL ceramic stack-up capacitors for 300°C	2 and 2	3000 - 5000
A to D converters, 220°C, 12 bits resolution	2 and 2	1000
PWM control IC, 220°C, supporting both single ended and dual ended topologies	2 and 2	1000
Logic and memory devices, 220°C operable	1 and 1	2000
Sensors	1 and 1	2000

Drilling

1k Byte Serial EEPROM or OTPROM for coefficient storage	2	500/year
Low power, simple microcontroller (250ºC)	1	500/year
Printed wiring boards (250ºC)	2	500/year
OTP FPGA (250ºC)	1	500/year
Medium complexity DSP or microcontroller (250ºC)	2	500/year
Medium density PROM for code storage (250ºC)	2	500/year
10 to 100uF tantalum-like cap – 5V/250ºC	3	100/year

Aircraft

SiC diode @ 50A, 1.5kV, -65 to 300C	1	3000 per year
Wide Temp Potting and insulation systems – 65°C to 300°C	2	Xxx lbs per year
Wide temp magnetics including windings and B/H materials. (-65 to 300C)	2	
1uF cap. w/X7R performance within operation range -65C to 300°C, 400Vdc or 115Vac	2	1000 per year

>20uF cap (assuming film for better vibration and clearing performance) <=1000 VDC or <=480VAC applications performance and size of PP, PC or PPS operation range -65°C to 300°C cost of 2xPPS	2	20,000 per year
SiC switches (motor drive applications) 50kHz, 1.5kV, 1000A	2	10,000 per year
SiC switches (power supply applications) 500kHz, 1.5kV, 50A	2	2000 per year
Wide Temp Gate drives	3	1000
Wide temp interconnects	2	xxx

Aircraft Engines

Micro (16 or 32 bit) 200°C	2-med	50 per airplane
RAM 200°C	2-med	50 per airplane
ROM 200°C	2-med	50 per airplane
Flash EPROM 200°C	2-med	50 per airplane
OP AMP 200°C	2-med	100 per airplane
D/A 200°C	2-med	50 per airplane
A/D 200°C	2-med	50 per airplane
Communication BUS 200°C	2-med	100 per airplane
Static and Lightning Snubbers 200°C	2-med	500 per airplane
Electrolyic Caps 200°C	2-med	100 per airplane

Aircraft Engines

Packages with high temperature electrical feedthrough – to 600ºC	2 – mid term 2 to 3 years	5,000/year various applications

Packages with high temperature electrical feedthrough – to 1000ºC	3 – long term 3 to 5 years	1,000/year various applications
Electrical connector – multiple pins – to 600ºC	2 – mid term 2 to 3 years	5,000/year various applications
Surface mount resistors to 300ºC	Challenge is in reducing size from current leaded devices	10,000 per year
Surface mount chip capacitors to 300ºC	Challenge is in reducing six from current leaded devices	10,000 per year
Low noise op-amps to 300ºC	Reducing the thermal noise	1,000/year various applications
Low noise instrumentation amps to 300ºC	Reducing the thermal noise, resistor matching over temperature	1,000/year various applications

Drilling

High density flash memory	1	1000

Automotive

High-medium performances Embedded microcontrollers (16-32 bit). In the first stage they could be flash-less, then they should integrate the Flash memory (MPC5554)	3- far term	100,000-300,000 per year
Flash memory, EEPROM	3- far term	100,000-300,000 per year
Operational amplifier (eg. LM2940)	3- far term	100,000-300,000 per year
Smart power (driving 8-16 inductive load, 200 mA avg., 1 A peak, 50 breakdown voltage eg. TLE6230, TLE6240)	3- far term	100,000-300,000 per year
Smart power (driving 1-2 inductive load, 1 A avg., 3 A peak, 50 breakdown voltage eg. BTS6163, VND7NV04)	3- far term	100,000-300,000 per year
Power MOSFET (55 Volt, 35 A peak, eg BUK9212)	3- far term	100,000-300,000 per year
Power diode (55 Volt, 35 A peak, eg. STPS20H100)	3- far term	100,000-300,000 per year

Multiple Power supply (eg. TLE6361)	3- far term	100,000-300,000 per year
High speed CAN transceiver (e.g. TLE6250)	3- far term	100,000-300,000 per year
Electrolytic Capacitor (100-1000 uF, 100 VDC)	3- far term	100,000-300,000 per year
Shunt resistor (10-50mOhm, 1 W)	3- far term	100,000-300,000 per year

Aircraft

300ºC power MOSFET 1.5kV, 20A	3	1000/year
500ºC Integrated Amplifier Circuit	3	10,000/year
300ºC Power 1kV, 1uF Capacitor	3	1000/year
500ºC 1GHz RF Transistor	3	1000/year
500ºC Digital Logic ASIC	3	10,000/year
300ºC kW class DC-DC Converters	3	1000/year
500ºC Wireless telemetry chip	3	1000/year
500ºC MEMS power source	3	10,000/year

Aircraft Power

Capacitors 100pf to10uF, -55 to +250C	2-med	5K per year
Power MOSFETs to 600V	1-low	2K per year
Power MOSFET to 100V, 50A	1-low	5K per year
Rectifiers, 1000V (<5A)	1-low	5K per year
Rectifiers, 100V (50A)	1-low	5K per year

Aircraft Power

High temp rectifiers 300ºC; 20-100A/1000V	1	500 year
High temp. SCR 300ºC; 20-100A/1000V	2	100 year
High temp. capacitors 200ºC; 0.1-20uF/600V	1	300 year

Aircraft Power

FULL BRIDGE RECTIFIER 300V, 250A OPERATION TO 225ºC	2 -MED	50 – 300 per year
POWER CAPACITORS 50-100Uf OPERATION TO 225ºC	2 -MED	50 – 300 per year

Aircraft

MAGNETIC MATERIAL		
CAPACITORS, STORAGE		
POWER SEMICONDUCTORS		60,000/YEAR

Aircraft Power

600V, 150A – 600A IGBT and diode -40C up to 300C	2 – mid term	5000/year max.
1200V, 100A – 200A IGBT and diode -60C to 300C	3 – mid term	5000/year max.
20uf 800V cap. w/X7R performance	2 – mid term	10000/year max.
Components for drive of power bridge (npn transistors, pin signal diodes, resistors (1/4 – ½ W) decoupling capacitors (1uF, 100V) up to 200-300°C	2 – mid term	15000/yr max.
Opto-couplers (high speed (50nS), high CMRR(common mode rejection ratio) 10,000 to 50000 V/mS for up to 250-300°C	2 – mid term	10000/year max.

Aircraft Power

Batteries 200ºC+	3-5 yrs +	100/year?

Aircraft/Rad Hard

MAGNETIC CORE MATERIAL 1.2T 2 400ºC	2 YR FOR 1MHZ POWER DC-DC (1KW)	10,000 – 25,000/YR

Aircraft Power

Generator Control Unit	1 / 2	?
Bus Power Control Unit	1 / 2	?
Power Conversion Units	1 / 2	?

Other

Spring Material with high strength and low stress relaxation	Tech. Challenge: High	Small by commercial standards
High temp. noble metal plating system capable of 250ºC – 300ºC operation	Tech. Challenge: High	Small by commercial standards

Aircraft Power

100 – 1000 uF Caps		
Solid State Power Controllers up to 200°C		

Automotive

Switches	1 – 2	>10,000
Diodes	1	>10,000
Passives	2	>10,000
Packages	3	>10,000

Drilling

ASIC	1 – 2 yrs	3000/yr
A/D	1 – 2yrs	5000/yr

Aircraft Power/Engines

+ Cap (250-300°C)	Near/mid	2000 - 5000
+ Diode	Near/mid	2000 - 5000
+ FETMOS/Switch	Mid/far	2000 - 5000
+ IGBT Switch	Mid/far	5000
+ FPGA	Mid	1000
+ Sensors	Mid	2000

Aircraft Power (250 – 300°C)

Transistors	Low / mid	~200,000/year
Diodes	Low / mid	~200,000/year
Capacitors	Low / mid	~200,000/year
Connectors	Low / mid	~200,000/year
Cables	Low / mid	~200,000/year

Aircraft Power / Rad Hard

HT Caps 1 – 100pF, Tc ~300ºC	1 – 2yrs	25 – 100K
HT Magnetics 10 -100 nH, Tc ~300ºC	1 – 2yr	10 – 50K
HT Ceramics for circuits	1 – 2yr	10 – 50K
HT packaging for SiC power XTR	1 – 2yr	10 – 50K
SiC material WFR with low MPD	1 – 2yr	2 – 5K

Appendix C. Other Responses to the Survey Questions

Survey Questions

2. Please indicate with what industry you work in. Please circle one or more.

   a. Aircraft Power
   15

   b. Aircraft Engines
   9

   c. Automotive Conventional
   2

   d. Automotive Hybrid
   2

   e. Electric Power Grid (Electric Utilities including All Electric Ship)
   2

   f. Interstate Trucking
   0

   g. Radiation Harden Systems
   5

   h. Well Drilling and Exploration
   3

   i. Well Logging (both slick line and wire line)
   3

   j. Well Completion Monitoring and Control Electronics/Fiber Optics
   2

3. Please identify one HT application that would benefit your industry the most. If reasonable, please provide some of the necessary attributes needed for commercial success.

   Starter electronic Drive

   Wireless Sensors

   HT power components for aircraft power conversion and distribution, HT analog and digital components for jet engine and actuator control applications

Surface mount components (passives) to operate up to 330C

HT, integrated motor drives. This includes filters, power sections, and limited controls.

Having remote sensor interfaces (i.e., electronics located in close proximity to the sensors)

Sensor support electronics for HT well monitoring (250°C), data acquisition, data reduction, memory, telemetry systems, batteries, DC/DC converters

HT miniaturized combustion control system

Distributed control interface module: including serial communications link, sensor, signal conditioning, A/D, digital processor, small EEPROM, D/A or PWM output, reference, and regulator.

HT traction drive

Power Converters (220Vac & 440Vac to 28Vdc) & Inverters (27Vdc to 115Vac)

Power Converters 4-350kW

Sensors MTBF 20,000 hrs with high shock

High temperature power converter

Power conversion & distribution components – Integrated motor drives

HT DC/DC converter

Aircraft power electronics: voltages to 600V, -55 to 300ºC and capacitors with high efficiency and a 20 year life

Aircraft Power Conversion: 10 to 100A / 1000V rectifiers & SCRs with 0.1-20uF / 600V capacitors

High efficiency power converters (250-300ºC) : Medium temp (150-200ºC) highly reliable power converters

Power drive for flight controls – high reliability and moisture resistant packaging

High power, light weight and reduce volumes AC/DC and AC/AC converts

High Temperature Power Components – IGBTs, Rectifiers, Capacitors

4. Please identify what one HT application "outside" of your industry would benefit your industry the most.

    HT IGBTs

    HT sensors/devices for environmental and displacement measurement

    Uncertain

    Not sure

    Aircraft engine distributed control most closely matches the component selection we need down hole. The promise of larger (future) volumes of this industry could encourage vendors to supply the smaller quantities we need for down hole right now. Similarly, the testing and qualification that we do now helps provide reliability validation for the more critical upcoming aircraft applications.

    Manufacture of HT analog and digital signal conditioning integrated circuits

    HT power devices (high-voltage caps and power transistors)

    HT control logic devices

    High power electronics

    Solid State Power Controller used to replace circuit breakers & relays

    Sensors

    Signal conditioning (A/D) for HT sensors

    Transformers sensors, motors

    None

    HT Converts for High Voltages

    Automotive power and control electronics

    None

    All electric ship / EMALS
    None

    None

    None

5. From the list below, please circle 3 attributes that are the most important to the application you listed under question #2 above.

    a. Absolute sensor measurement accuracy
    5

    b. Relative sensor measurement accuracy
    3

    c. Expected operating life time before falling outside of specification
    12

    d. Expected operating life time before failing to function
    19

    e. Temperature design margins
    14

    f. Low supply current for battery operation
    5

    g. High signal voltages for reduced EMI
    2

    h. Accelerated life testing.
    7

6. Please circle the temperature range needed by the application you listed under #2 above.

    a. 150-250C
    10

    b. 251-300C
    8

    c. 301-350C
    2

    d. 351C- and higher
    3

Please feel free to make comments below. There is no need to include your name, and individual responses will be protected. Survey results will be publicly released by HTEP and belong to the SAE, Society of Automotive Engineers.

Additional Comments:

I would much rather design with simple, basic building blocks that can be shared between applications across the HT community than to be forced into custom IC's where my volumes will never justify the initial investment. None of our individual applications are big enough to interest typical electronics vendors. The more willing we are as a high temperature community to share components and technologies, the more likely vendors will be to supply them to us.

Component volumes are small, but system impacts are large. Long-term reliability at HT is key challenge.

Honeywell supplies high-temperature integrated circuit components, as well higher-level modules (accelerometers and multi-chip electronics modules) to the Oil & Gas industry and Avionics industry. Honeywell also has capability to provide high temperature pressure and magnetic sensors. This survey is constructed as though the respondents are selling systems into specific markets rather than components that span multiple markets. Our responses in this survey represent reasonable estimates of our potential component sales volume to these combined markets. Note that some of these sales may be to Honeywell business units with high temperature applications, such as turbine engines, auxiliary power units, industrial controls, and space/avionics controls.

Identification of multipurpose applications that cross various industries to justify development costs

Aerospace objectives: High reliability converts
Minimize cooling volume & weight
Increase cooler efficiency

More input on status & activity on HT passives

More detail related to power control devices would be great

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