

**Survey of Sensor
Requirements for
Environmental Exposure
of Electronic Assemblies**

C P Hunt

June 1998

© Crown copyright 1998
Reproduced by permission of the Controller, HMSO

ISSN 1361-4061

National Physical Laboratory
Teddington, Middlesex TW11 0LW, UK

Extracts from this report may be reproduced provided the source is acknowledged.

Approved on behalf of Managing Director, NPL, by Dr C Lea,
Head, Centre for Materials Measurement and Technology

Survey of Sensor Requirements for Environmental Exposure of Electronic Assemblies

Christopher Hunt
Centre for Materials Measurement and Technology
National Physical Laboratory
Teddington
Middlesex, UK, TW11 0LW

ABSTRACT

The electronics industry subjects circuit assemblies to a wide range of environmental conditions throughout its lifetime. Throughout the various stages of assembly, test, transit and use, the circuit assemblies experience different stresses with varying magnitude. This limited survey establishes the requirement of manufacturers to interrogate assemblies, the premise being, that an ability to identify the historical environment record of exposure, is a useful aid in the diagnostic processes for the optimisation and repair of assemblies.

This survey's intent was to develop a broad understanding of industries' requirements in terms of what parameters required monitoring. This report covers the results of that survey and draws conclusions as to the way forward to meet these requirements.

CONTENTS

1	INTRODUCTION	1
2	SURVEY REPORTS FROM COMPANIES	1
2.1	COMPANY A	1
2.1.1	Resume of Company A	1
2.1.2	Company A Discussion.....	1
2.2	COMPANY B.....	2
2.2.1	Resume of Company B.....	2
2.2.2	Company B Discussion	2
2.3	COMPANY C	3
2.3.1	Resume of Company C	3
2.3.2	Discussion of Company C	3
2.4	COMPANY D	3
2.4.1	Resume of Company D	3
2.4.2	Company D Discussion.....	4
2.5	COMPANY E.....	4
2.5.1	Resume of Company E.....	4
2.5.2	Discussion of Company E.....	4
2.6	COMPANY F.....	5
2.6.1	Resume of Company F	5
2.6.2	Discussion of Company F	5
2.7	COMPANY G	5
2.7.1	Resume of Company G	5
2.7.2	Discussion of Company G	6
2.8	COMPANY H.....	6
2.8.1	Resume of Company H.....	6
2.8.2	Discussion of Company H.....	6
3	DETECTION OF STRAIN IN ASSEMBLIES	6
4	DISCUSSION.....	7
4.1	SENSOR PARAMETERS	7
4.2	APPLICATION OPTIONS.....	8
4.3	SENSOR PACKAGING AND COST.....	8
4.4	DESIGN ISSUES AND REQUIREMENTS	8
5	CONCLUSIONS	9

1 INTRODUCTION

As part of the NPL programme on developing measurement methods for the electronics industry we have carried out a project to define the need and specification of sensors to monitor environmental exposure. For high value electronic assemblies it is very desirable to know the cause of any failure, so as to avoid similar future failures and the associated expense and loss of customer confidence. Any assembly experiences a range of stresses during its lifetime, from production, through test, transit and use. It is not only useful from a design point of view to know why an assembly has failed, but also from a liability stand point as well. If assemblies have seen stresses outside their design specification then this will have implications in the resolution of customer and supplier disputes over responsibility.

Prior to the consultation process the objectives of the survey were discussed with the NPL industry advisory group (IAG). This group comprises mainly industrialists, and complemented by academic and trade federation representation. An initial driving force for the project was the experience of a major OEM with a production problem. It had experienced a major problem with defective product after it had left the manufacturing site. After some fairly exhaustive investigation the defects were traced to a bed of nails tester. Visual inspection and the tester itself did not reveal any defects. The IAG however expressed reservations about the concept of using a sensor to monitor individual assemblies for defects that may then be repaired. Production processes are now optimised and controlled so that there is the minimum of test and inspection. To develop a sensor that may facilitate repair by additional inspection of the product, hence, did not find favour. However, the IAG did see merit in the concept when used to monitor field returns and faults that may have occurred during transit.

The consultation with industry therefore set out to establish what environment excursions were important in terms of functionality and reliability, when they were likely to be important, what size and cost of sensor was acceptable, and frequency or accessibility of stored data. A mixture of industry sectors was approached. These were chosen where it was considered utilisation of sensors might be taken up. The chosen companies varied in size from SMEs to large international companies. The most obvious industry sectors are avionics and military, where numerous applications can be envisaged. Other sectors considered included telecommunications, SME equipment manufacturers, and a contract manufacturer. The companies interviewed were: Baydel, D2D, GEC-Marconi, Lucas, Nokia, Nortel, Page Aerospace, and Racal Avionics.

2 SURVEY REPORTS FROM COMPANIES

2.1 COMPANY A

2.1.1 Resume of Company A

Company A have a large range of products from domestic to military. The site visited mainly supports the military and high tech products, and is the research and development site for the company. Consequently there is a large range of scientists and skills located at the site and the meeting there was attended by various group leaders.

2.1.2 Company A Discussion

There was a wide ranging discussion about the application of sensors. This proved problematic since it was difficult to focus down on specific applications and hence start to form a specification for what a sensor package might look like. A number of the parameters to be

measured were considered with temperature being discussed a great deal. The size of the device was discussed and possible fabrication routes suggested. Interest in the MCM route was expressed as a possible route for manufacture. Using such high density packaging techniques a sensor device with memory and battery power could be realistically produced with a cost under £100, if in sufficient numbers. To rank the various physical parameters in importance, and in terms of the application, it was decided to construct a table, and this is shown below. The numbers in the table are a score from 1 to 10, with 10 being the highest, and were the consensus figures from the people in the room. The table was constructed for the various use environments: process, storage, transit, use and maintenance; and for the various physical parameters: temperature, humidity, shock, vibration, flexing, magnetic, electrical over stress with the equipment off, and electrical over stress with the equipment on.

Ranking of Physical Parameters in Use Environments

	Process	Storage	Transit	Use	Maint/cce	Average
Temp	10	8	8	10	5	8.2
Humidity	3	8	8	8	5	6.4
Shock	5	3	9	9	9	7.0
Vibration	2	3	9	9	3	5.2
Flexing	7	3	7	7	9	6.6
Magnetic	0	3	4	4	4	3.0
EoS (Off)	0	1	1	6	8	3.2
EoS (On)	0	1	1	6	8	3.2
Average	3.4	3.8	5.9	7.4	6.4	

The table shows that temperature was the most desired parameter to record and that the use environment was the most important. However, transit and maintenance were also occasions where it was desired to have some knowledge of the product history via sensor data. Transit is particularly interesting, since it would be the intention that this is a relatively benign environment.

The electromagnetic influences were not thought to be as useful as the others, with temperature, humidity and deformation being the most important.

The data recording protocols were discussed and it was considered relatively easy to set up a controller that could measure cycle numbers, cycle ranges (maximum and minimum).

Overall the concept of making a sensor to be incorporated in equipment was very well received.

2.2 COMPANY B

2.2.1 Resume of Company B

Company B are a small company of 50 people making very high reliability hard disk arrays. The product is used where the user cannot tolerate the loss of information online from the hard disk store, and require zero down time. Consequently the product has a high level of redundancy. The customers site the units in offices or air conditioned rooms and are not moved about.

2.2.2 Company B Discussion

The environment that these devices are situated in is not particularly arduous and hence the

use of environmental sensors is not necessarily required. The units do include a modem and information from the unit can be monitored remotely. The product does include a temperature sensor inside the box, which can be monitored remotely down the modem. This is included since disk drive read/write errors increase with temperature and become unacceptable at a certain temperature. Consequently there was some interest in locating a small temperature sensor on the board, probably located close to the CPU.

Such a device would have to reasonably small, no more than 20x20mm and be around the £20 mark to be acceptable.

There was no interest in shock or humidity, and no other requirements were considered to be necessary.

2.3 COMPANY C

2.3.1 Resume of Company C

Company C is a UK defense contractor, although the company has a wide range of products, this particular site makes units that go into helicopters. They have two products: (i) one type with a production of 230 units a year, with each unit comprising 18 PCBs, (ii) the second type, with a production of 52 units a year. Each PCB costs about £600. Following production the PCBs are given an exhaustive burn in. During the 80 hour burn in, with the PCBs in the powered up state, the PCBs are thermally cycled between -55 and 75°C in an 8 hour cycle, which also includes 15 minutes of 2G vibration every hour. Hence the PCBs have rugged testing to get rid of *infant mortalities*. The boards have an event log, so if there is a failure the status around the board is recorded. The event log has battery back up.

2.3.2 Discussion of Company C

Since the design and testing is so rugged it was initially envisaged that there would not be any application for sensors. However, on further consideration it transpired that a temperature sensor had been incorporated but was not actually being monitored. In the future it was felt that the temperature sensor will be used. Vibration may be something they may need to monitor, and it would be useful if it could record amplitude and frequency. Altitude may also be something they will need to monitor.

There was no interest in humidity, and no other requirements were considered to be necessary.

In conclusion there was only mediocre requirement for such a sensor. The ruggedness of their assemblies means that there is not the requirement to determine field failures for an environmental exposure. Problems with their assemblies were more likely to be associated with deficiencies or errors occurring in production.

2.4 COMPANY D

2.4.1 Resume of Company D

Company D are the leading contract electronics manufacturer (CEM) in the UK. Contract manufacture is a very popular option for a number of OEMs, for both big and small companies, and represents a significant volume of the electronics business. The big CEMs are

heavily relied on for their expertise and skill in circuit design and fabrication. Company D have a large facility and participate in collaborative research projects.

2.4.2 Company D Discussion

Any CEM is always led to a large degree by what the customer requires, and these requirements are almost invariably cost driven. This leaves little opportunity to widen the specification to include additional items. Having discussed this, they were interested in the potential for such a concept under specific conditions. They did not feel there was potential requirement or need for any sensor in their production, but felt that it would be worthwhile in incorporating such devices onto the more expensive boards. For these boards it was difficult to know the environmental requirements but temperature and humidity were probably the most likely candidates.

In conclusion since a CEM is not in the driving seat regarding design it would not always be easy for them to incorporate sensors onto boards. The use of sensors within their own production process was considered to be an unnecessary luxury. Too few production problems arise, that the cost of the sensor would not outweigh the benefits. Using sensors on their customer boards was felt to be a good idea and would be promoted if available at an economic price.

2.5 COMPANY E

2.5.1 Resume of Company E

Company E design and manufacture *full authority fuel systems* which are mounted directly onto jet engines. They are tied in with a number jet engine manufacturers. The electronics is the unit controlling the jet engine and is the interface with the pilots' controls in the cockpit. The units are mounted in this harsh environment only to make the engine a complete unit, requiring no added or remote control units. These units cost £50,000 and consist of 30 boards with one level of redundancy. They manufacture around 20 units a month. Variants of the product are made for both the commercial and military markets.

Company E have a lot of design know how and everything is generated internally. On the manufacturing side they have a medium size surface mount assembly area. These units are not situated in a production line. Company E have spent a lot of effort in producing substrates that match thermal expansion to the ceramic devices being mounted on the substrate. The substrates are polyimide based with two separate layers of copper/invar/copper. The boards have 10 multilayers. Because of limitations in the polyimide and copper/invar/copper, they are now developing a poly-aramid substrate with carbon/copper/carbon interlayers. They also have a thin film area. Units are screened by a burn in schedule similar to that used by Company C, although the testing set up is not as extensive and the level of vibration testing not as searching.

2.5.2 Discussion of Company E

The units are mounted in a severe environment and are consequently of a rugged design. Furthermore as an engine gets older, vibration in the engine increases with wear and bird strikes. The units principal environmental constraints are that the operating temperature should not exceed 90°C, the vibration level should not exceed 100g and there should be no lightning strikes earthing out through the box.

The box itself does have a simple thermistor device but nothing on the boards. However, maximum temperatures on boards would be of interest. The temperature after landing in the middle east in the middle of the day can be very high, especially if there is no breeze.

There was far more discussion about vibration. After discussing this for some while they decided that either vibration or strain should be measured. They would wish for an event log which told them every time the unit saw more than 100g.

Lightning strikes can be a problem and a record of these would be useful. At present if struck by lightning they rely on only one half of the controller being destroyed, and hence using the redundancy in the unit.

The unit's service life is 8000 hours, so they do not usually see them again unless there is a suspected fault. (Often units are returned with no fault found, and connector problems are suspected). Hence the sensors would be useful in logging exposure information.

There was no interest in humidity, altitude and pressure, and no other requirements were considered to be necessary.

2.6 COMPANY F

2.6.1 Resume of Company F

Company F are a major player in the telecommunications industry. They manufacture products from hand sets through to full exchanges and are suppliers to BT and AT&T. The site has a fair degree of autonomy and supports its own research and that in universities. They are at the leading edge of environmentally friendly processing for the industry. They have some of the latest production equipment and have explored tomorrow's assembly technology. They have evaluated the options of lead free solders, and have successfully trialed a lead free products for internal company use.

2.6.2 Discussion of Company F

Company F were one of the companies who raised this project area as an issue. However, the individual responsible for this has now left the company. The original idea was to find a method for logging the various assembly processes and hence determine subsequently whether their product was fit for use. The apparatus was envisaged as either inspecting the product or riding with it and logging the environment. Company F were interested in monitoring temperature and stress on the board during production. Discussing the issue at the meeting, the concept was now considered to be less useful, especially compared with that of field returns. Transportation was considered to be an issue, with goods occasionally being damaged before delivery. When installed the operating temperature environment was felt to be important.

If the sensor unit were to be mounted on the PCB itself, a size of no more than 20 x 20 mm could be accepted. A tolerable cost would depend on use, for example if reusable then up to £100 would be acceptable. In both assembly and transportation, a detachable sensor that rides with the equipment, that can be interrogated by an engineer was considered to be very useful.

2.7 COMPANY G

2.7.1 Resume of Company G

Company G is one of the worlds major electronic OEMs, with this particular site a primary manufacturer of telecommunication base stations. Company G has of the world wide market of \$4bn. An individual electronic base station unit costs £40K. This facility has four lines running. Virtually all the production guidelines come from their headquarters, with some design facilities.

2.7.2 Discussion of Company G

The product is very demanding in terms of the technology used in building the PCBs. There is no free space for any additional components. Once installed the unit is robust in its environment, which is stationary in some enclosure. However, problems are frequently encountered with shipping of the units around the world. Problems encountered can be attributed to physical shock, getting too hot and condensation. There is some concern as well in use with too low humidity, which can exacerbate electrostatic discharge.

A detachable sensor that rides with the base station to the delivery point and could then be interrogated by the installation engineer was considered to be a very useful idea. The idea of a reusable device was attractive. Since the device would not be located on the board, size would not be an issue and reuse of the device would mean the design could be flexible. A £100 cost would be acceptable.

2.8 COMPANY H

2.8.1 Resume of Company H

Company H is a small company with 150 employees and a turn over of £12m. It manufacturers small electrical units, typically power supply and lighting units, for commercial airlines. Company H does have a few military contracts. The products Company H produce are generally used as sub-systems, and are not particularly safety critical. The units are usually sited inside the airframe and hence are not subjected to particularly harsh conditions. The value of products varies considerably, some simple units typically cost \$255, while at the top end their power converters cost \$25,000.

2.8.2 Discussion of Company H

Company H's range of products revealed a range of interest in sensors. Their product range is almost entirely for the aviation industry. Since their products are located within the airframe, humidity and vibration are not of concern. At the bottom end of their product range there is little interest and little scope for sensors within the products budget, but at the high end there are possible applications. For these high value units high temperatures and voltage over supply can be a problem. Company H felt that temperature sensors would be useful as a diagnostic and as a real time interrupt or warning for the aircraft. Demand would be led by their customers, although Company H would promote them as an option for their product if they were available at an economic rate.

The size of the component would be important, when mounted on the PCB it could be no more than 20 x 20 mm. A tolerable cost would be no more than £20.

Company H did not feel that the use of sensors in production was an issue.

3 DETECTION OF STRAIN IN ASSEMBLIES

One of the original concerns expressed by one the companies was the detection of high strain in assemblies. This strain may originate from thermal or mechanical processing. At NPL a

novel method developed for an alternative purpose by Nick McCormick was adapted to investigate its applicability. The method is a correlation technique between images for a before and after condition. The method applies interpolation techniques between pixels of the captured image to achieve resolutions of 0.1% of a pixel. This typically equates to $0.1\mu\text{m}$, and a sensitivity to very small strains. The computationally arduous part is to register the two images and then compute the shift from one image to another. The number of reference points that are selected depends on the user, and how fine the mesh is set. This ability to measure the shift at all the mesh coordinates makes it possible to determine the inter-strain between components, and the intra-strain within components.

Hence, the method proposes, in principle, a technique to monitor whether strain has been put into an assembly. For example if there were concern about a thermal process, the technique could be used to evaluate the induced strain between the varying thermal capacities of components on the PCB. Such a process may result in a PCB achieving a range of temperatures across the board, which may leave residual strain.

It is envisaged that images are captured at various points in a process for comparison at some future time. At present the correlation routine takes a few hours on a workstation to perform. So for any implementation the program will need further development, and a powerful computer would need to be available.

4 DISCUSSION

Overall the response from the companies, was very positive towards the sensor concept. The discussion of the companies' responses divides neatly between the parameters to be recorded and the application options where the measurements should be taken. We will consider the parameters to be measured first.

4.1 SENSOR PARAMETERS

It is very clear from the survey that temperature recording is the parameter most desired by everyone to monitor. This is easily understood, in as far as it is the most frequent cause of problems and failure, and has a severe effect on circuit performance. This is particularly so with temperature sensitive devices, such as disk drives. Problems with temperature can easily arise in all stages of a circuits lifetime; in processing, storage/transit and use. Transit may be unexpected, but for exporters it can be a problem if equipment is left sitting exposed in the hot places of the world. We will not consider the process side, since as we discuss later this did not prove to be a big issue. Temperature history in use and maintenance was an issue, especially if the unit were exposed to high temperatures from external sources, and would considerably aid diagnostics.

Humidity was a concern to the companies, and was mentioned to some degree by all of them. However, it was really only of concern to the companies putting equipment into rugged environments, and those who had concern about transit conditions. Since, humidity measurements complement temperature during natural exposure conditions, it is not unexpected that companies should find it a desirable parameter to measure. A humidity sensor has the added benefit of capturing the occasional accident of PCBs being dropped into water.

The next area in priority was exposure to mechanical stress. Although this was only of concern with a couple of companies in use environments, it was of concern to everyone in terms of transit. Most equipment is not packaged to withstand excessively rough handling.

Hence, if equipment becomes damaged during transit, the manufacturer would have some knowledge about the physical conditions causing the problem. Of interest would be shock, e.g. if equipment is dropped, with vibration also being of concern, but to a lesser degree. This information would be particularly useful if the time of the damage was known. Considering the use environments, for the companies where this might be a problem, the designers had ensured a sufficiently rugged design that monitoring mechanical stress was superfluous. Indeed one company was testing its PCBs at up to 100G in vibration. Therefore the mechanical stresses that required monitoring were shock and vibration, and in the range that is typical for monitoring transit conditions.

The other suggested parameters to measure were more specific to individual companies. Examples of these were: lightning strikes, magnetic fields, and electrostatic conditions. Since these proved to be of interest only to single companies we will not consider these further.

4.2 APPLICATION OPTIONS

Five distinct application scenarios were identified. These were: processing, storage, transit, use, and maintenance. These were often reduced to three scenarios for the majority of companies, storage and maintenance were not considered worthy of attention.

This project was conceived around an issue occurring during processing. Although considered during the discussions it was clear that there was a majority view, this was of less importance than transit and use. This view is quantified to some extent by the table made at Company A. Between transit and 'use', it was 'use' that was of more interest, and in particular temperature. The transit application was a surprise, and the wide interest expressed by the companies. It has become apparent that a sensor for use in monitoring transit conditions would not only be of use to the electronics industry but could have potentially a very wide suite of applications. Anything that is fragile or sensitive could be a possible application area, e.g. the food industry.

4.3 SENSOR PACKAGING AND COST

Everyone agreed that ideally any package should not occupy any space and be zero cost. It is to what degree these constraints are relaxed that controls any final design. For some companies putting anything extra on their boards was a non-starter and so any sensor would have to be incorporated into the box of the unit. For others the cost was a big issue, and it would have to be under £20. If used in a transit mode, then there would be a degree of recyclability and a higher cost could be tolerated. The power from the unit was discussed and there was a mixed response, with power being taken from the main equipment being acceptable, to the sensor being battery powered. Clearly if being used in a transit application, then a self contained battery would be the preferred option.

As a broad design specification it was clear that any sensor unit should be approximately no bigger than 20 x 20 mm in size, a cost of approximately £100 for a reusable unit would be acceptable and a definite requirement for a battery powered unit.

4.4 DESIGN ISSUES AND REQUIREMENTS

From the above it is clear that no unusual parameters are required to be measured, but rather the well known parameters detailed above. Sensors for these are readily available in compact form, and hence sensor development is not an issue. What any user does not have at this moment, is access to a composite sensor measuring the defined parameters, with a recording system.

The issue therefore is to discover whether all these sensors can be packaged together with some memory, a processor and a battery, into the small package defined above at an acceptable cost. Clearly the package should have some form of communication so the data can be extracted.

5 CONCLUSIONS

Eight widely differing companies have been visited and their potential requirements for sensors noted. The companies expressed a strong preference for the collection of data of their product during exposure in 'use' and 'transit' scenarios that their products experience. The data they would require are: temperature, humidity, mechanical shock and vibration. They would like the exposure history to be stored inside the sensor device, with the data down loaded at some convenient time decided by themselves. The unit should have the option to be battery powered.

The requirements of a future project are therefore to carry out a design scoping exercise for a sensor package that utilises the microsensors available today in a small package with associated devices, including a controller, memory and communications capability at a size and cost that meets the requirements of the industry.

This project has been written around the requirements of the electronics industry. However, a stand alone sensor would have many other applications across a wide range of industries.

ACKNOWLEDGEMENTS

This work was carried out as part of a project in the Materials Measurements Which Affect Processability (MMP9) Programme of the UK Department of Trade and Industry.