Report 1

Evaluation validity in systems with continuous, automatic measurement

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Rapid strides are being made in miniaturizing electronic equipment while simultaneously offering improved functions and performance. Companies are under pressure to reduce product development time, while equal pressures demand that product safety and reliability be maintained. To handle these opposing demands, both the effectiveness and the accuracy of environmental testing require further improvement. To meet such requirements, we at Tabai Espec are incorporating measurement of electrical characteristics in our environmental test equipment. This arrangement enables us to continually measure specimen characteristics under environmental conditions, and thus grasp real time characteristics when determining malfunction modes. We are currently developing a full line of automatic measuring systems. This report will introduce some aspects of evaluation systems and discuss the effectiveness of automatic measurement systems.

1. Introduction

To produce ever-more-compact electronic equipment, companies are striving to miniaturize chip sizes, especially for chips used in semiconductor IC packages and electronic parts. Complicating the problem has been rapid pace of the development of build-up circuit boards*1, which make high-density mounting possible. Studies of new methods and materials for connecting IC packages are also proceeding at a fever pitch. To further complicate matters, developers are not only working under the constraints of market competitiveness with regard to cost and functions, but they are also working under the constraints of global environmental protection and societal regulations, such as using Pb-free solder*2, meeting VOCs regulations*3 for flux, and developing environmentally friendly printed circuit boards. While handling such a wide variety of requirements, developers must also shorten the development time while maintaining product reliability. To meet these conditions, developers must have a means of accurately and more effectively assessing safety and reliability.

At Tabai Espec, in addition to checking functions and evaluating reliability, we are combining our widely used environmental equipment, and while running environmental tests we are continuously measuring electrical characteristics of specimens. By extracting real time data, we are developing automatic measuring systems that are able to detect malfunctions and failures. In this report, I would like to present some real world examples of evaluations involving continuous measurement of electrical characteristics of specimens in the environments used for these tests. I would also like to discuss the effectiveness of these measurement systems.

2. How evaluation needs to be done

To guarantee reliability of products with complicated advanced functions while covering a wide variety of development requirements in less time than ever before, developers must be able to improve the effectiveness and accuracy of product evaluation. Fig. 1 presents some suggestions for methods to improve the effectiveness and the accuracy of evaluation.

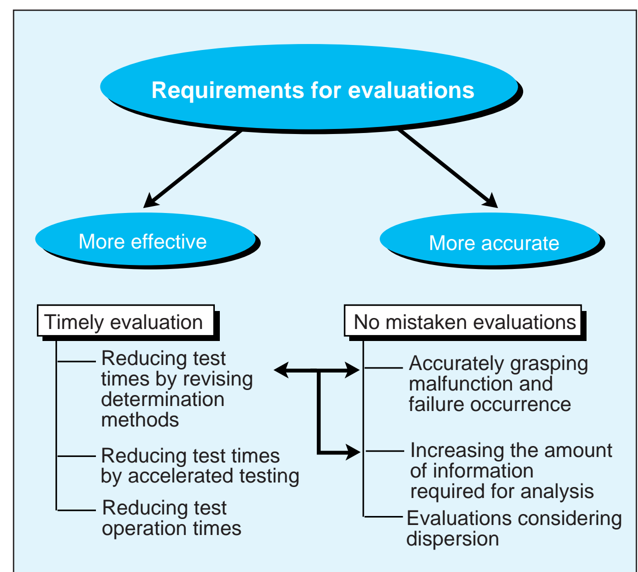


Fig. 1 Requirements for evaluation

*Measurement system integrated group

2-1 Evaluating more effectively

To evaluate more effectively, first of all, the time required to make evaluations must be shortened. Next, test times must be reduced by cutting down the time taken for the test operation itself as well as by revising the determination methods for evaluation. For example, when running a product life test, in the most general evaluation method, failure and relative advantages of different specimens is extrapolated from data measured at specific intervals. In this case, if evaluation could be made with data from shorter measurement intervals, it would be possible to assess product life and malfunctions more quickly and shorten test times. Also, applying accelerated life testing would be very effective in reducing test times. At this point, I would like to discuss reducing test times, and making more efficient evaluations based on data from continuous measurements and more efficient test operations.

2-2 Evaluating more accurately

Current products boasting advanced functions with high-density mounting are experiencing failure modes that did not occur in previous products. These advances mean that even slight changes in characteristics can lead to failure, and so current evaluation practices must be much more strict. To improve evaluation accuracy, there is greater need to be more precise in capturing failure phenomena, and a concurrent need to increase the amount of data used for analysis.

In other words, it is difficult to determine whether failures only occur in specific environments and whether failure will occur unless the product is in such a specific environment. Reproducibility (the ability to predict test results) is also difficult to obtain. For example, continuously measuring specimen characteristics as well as selecting measurement methods that are appropriate to the characteristics of failure modes occurring in the test environment used both are indispensable for detecting insulation deterioration due to ion migration, defective contact due to differences in coefficients of thermal expansion, and fluctuations in resistance values due to cracking.

To clarify failure modes and to more accurately predict product life, we must be able to accurately detect not only the fact of failure occurrence but also the time of occurrence. We must also be able to make our analyses based on data that can contrast fluctuation in specimen characteristics with such environmental conditions as temperature and humidity. We must further maintain a large enough quantity of data to enable us to make statistical determinations that consider dispersion. Since the time of running the test does not change, if we can even slightly increase the amount of data used for analysis, we will be able to obtain more accurate evaluation results.

3. Automatic measurement systems

Fig. 2 shows the basic approach to developing automatic measurement systems that we use at Tabai Espec. Automatic measurement systems combine environmental tests with electrical measuring equipment, making it possible to measure the electrical characteristics of electronic parts and devices in real time under environmental test conditions, and process the resulting data. System hardware and software are designed so that while operating under environmental test conditions, they are able to accurately grasp the data required for evaluation and to capture changes in characteristics that are peculiar to specific modes of failure. Computers are used to fully automate test management, data processing, and control of the environmental test equipment.

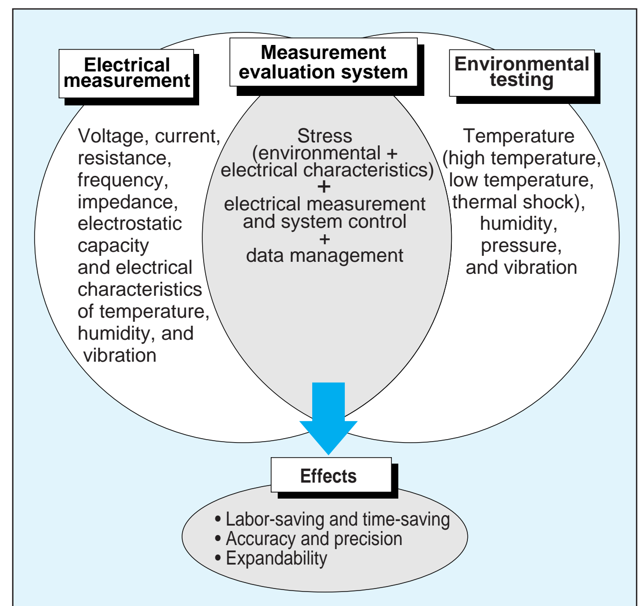


Fig. 2 Basic approach of automatic measuring systems

Our line-up of automatic measurement systems includes such equipment as ion migration evaluation systems, insulation resistance evaluation systems, leakage current measurement systems, and short interruption measurement evaluation systems. (Fig. 3)

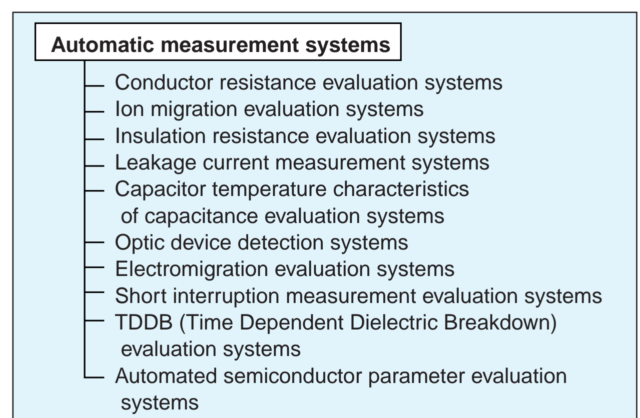


Fig. 3 Main automatic measurement system products

4. Validity of continuous, automatic measurement

Now, let's look at the validity of continuous measurements in test environments using examples from evaluating ion migration, solder connection reliability, and short interruptions, and let's consider the possibility of using automatic measurement systems.

4-1 Evaluating ion migration

4-1-1 Necessity of evaluating ion migration

Ion migration is the phenomenon of precipitate growth in the gap between facing or adjacent electrodes on a printed circuit board. This growth results from metal ions from one electrode being reduced as metal at the base of the other electrode.

Ion migration can only occur when there is moisture in the presence of an electrical field between the electrodes. In reality, occurrence is usually linked to the effect of impurities on the circuit board that precipitate out on the positive side. Photo 1 shows a picture of a ion migration occurrence in a test using the water drop method. Because it is extremely fragile, the ion migration substance fuses and disappears in a very short instant due to current occurring in the instant of a short circuit.

The ion migration phenomenon has been well known for years. Recently, though, ion migration has been occurring more frequently due to such factors as finer pitches being incorporated in the printed patterns in wiring in IC packages such as BGA*5 in build-up circuit boards. Other factors include stronger electrical fields between the patterns, smaller insulation gaps, impurities in flux residue and new materials, and the impact of humidity absorption due to the portability of the electronic equipment. The fact that ion migration leads quickly to failure places a high priority on evaluation of the phenomenon.

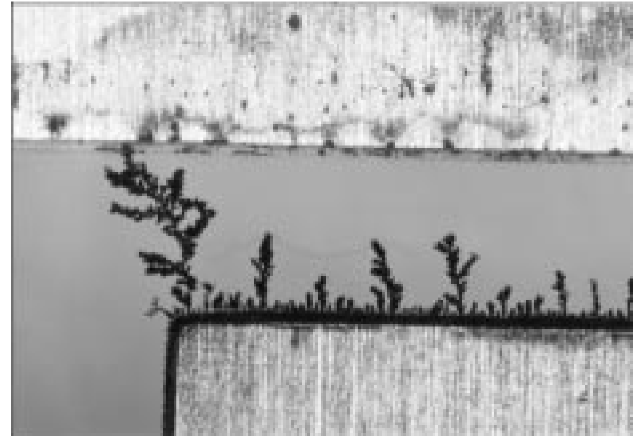
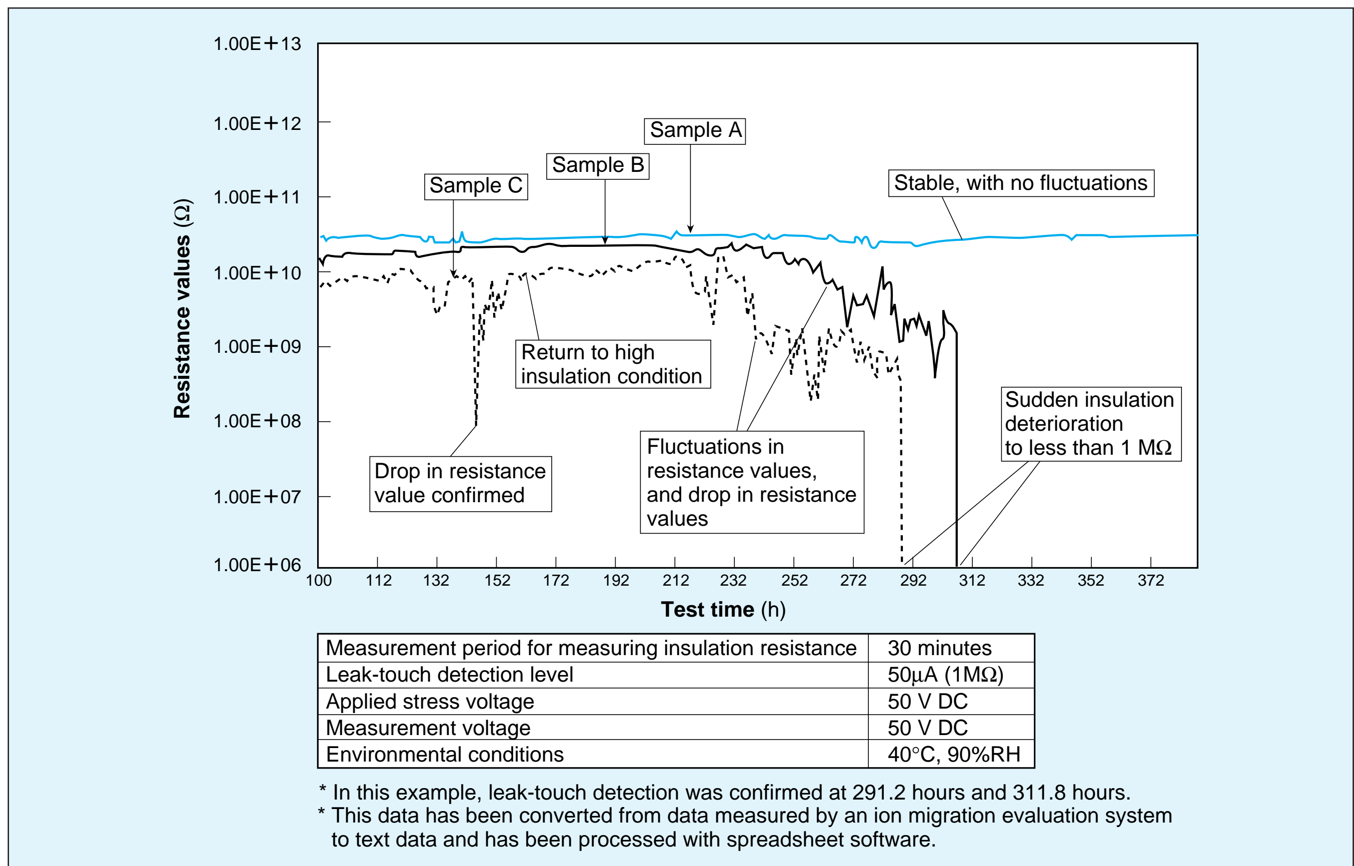


Photo 1 Ion migration

4-1-2 Validity of continuous, automatic measurement in evaluating ion migration

Ion migration is generally evaluated using comb-patterned printed circuit boards as specimens, and applying voltage between the comb-patterned electrodes in a high-temperature, high-humidity environment. The insulation resistance between the electrodes is measured by removing the specimens from the temperature and humidity chamber at specified intervals and measuring them at room temperature. However, using this evaluation method that I have just described, it is possible for the specimen to recover high insulation characteristics at the time of measurement. Therefore, there is a danger that



Measurement period for measuring insulation resistance	30 minutes
Leak-touch detection level	50μA (1MΩ)
Applied stress voltage	50 V DC
Measurement voltage	50 V DC
Environmental conditions	40°C, 90%RH

* In this example, leak-touch detection was confirmed at 291.2 hours and 311.8 hours.
* This data has been converted from data measured by an ion migration evaluation system to text data and has been processed with spreadsheet software.

Fig. 4 Insulation deterioration characteristics under high-temperature, high-humidity conditions

the specimen will be mistakenly determined to have no malfunction, even though a malfunction has occurred. In addition, manually measuring the insulation resistance of each specimen and processing that data is time-consuming and inefficient. To resolve these issues, it would be possible to continuously and automatically measure insulation deterioration and changes in insulation resistance occurring in an extremely short time due to ion migration while applying stress voltage between the electrodes under conditions of high temperature and high humidity. Fig. 4 shows an example of deterioration characteristics obtained by continuously measuring flux insulation resistance in a high-temperature, high-humidity environment.

As you can see from these measurement examples, by measuring insulation resistance under conditions of high temperature and high humidity, we can accurately capture the insulation deterioration characteristics caused by ion migration, as well as the time at which the failure level was attained. From fluctuations in the resistance values, we were able to confirm that a gap exists between specimens at the initial stage when the test started. We were also able to obtain information confirming the major fluctuation in resistance values leading up to failure.

4-1-3 Ion migration evaluation systems

Ion migration evaluation systems require the ability to detect insulation deterioration at high speed under environmental test conditions, as well as the ability to accurately measure changes in insulation resistance. A truly convenient system should have linked control with the environmental test equipment, and be able to perform simultaneous graphing of insulation resistance values and the test environment (such as temperature and humidity). It should also process data on a LAN and be able to confirm operating conditions.

Let's look at a real world example of an ion migration evaluation system. (Photo 2)

This system can accurately measure insulation resistance on the order of 10^{13} Ω, and by detecting leak-touch can detect changes in insulation resistance in an extremely short time when ion migration occurs.

Photo 2 Ion Migration Evaluation System AMI-025-P (left), and Temperature and Humidity Chamber (right)

Table 1 Main specifications

Item	Specifications
Model	AMI-025-P
Measurement range	1×10^6 Ω to 3×10^{13} Ω (measurement cable tip)
Measurement interval	Min.0.1 hour (in 0.1 hour steps)
Leak-touch detection range	1 to 100 μA
Leak-touch detection speed	μ seconds order
Measurement voltage	3V to 100V DC
Applied stress voltage	3V to 100V DC (Can be set independent of measurement voltage)
Number of measurement channels	Standard: 25 channels Maximum: 1 rack, 150 channels
Power requirement	100V AC, single phase 15A

* Measurement voltage and applied stress voltage can be up to 500 V.

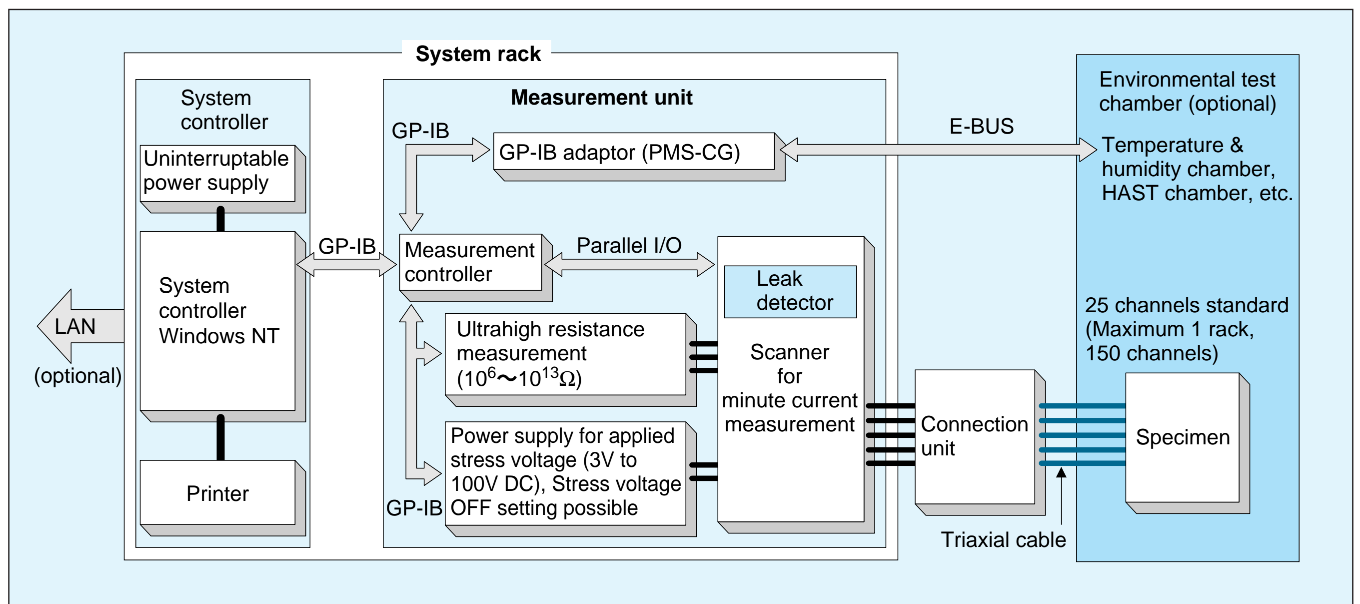


Fig. 5 System Block Diagram

The standard unit also uses a scanner to switch among measuring up to 25 specimens. The scanner uses specially developed high resistance measurement to achieve stable measurement in the high resistance range. Other features include a converter for linking environmental test equipment to the power source for applying stress voltage, a special cable for measuring high insulation resistance, a relay unit, and a control computer. All units required for tests can be placed on a single rack. Fig. 5 shows the system layout, while Table 1 shows the main specifications.

4-2 Evaluating reliability of solder connections

4-2-1 The need for evaluating reliability of connections

The appearance of build-up circuit boards and array type IC packages such as BGA and CSP*6 has dramatically increased mounting density, bringing about a great leap forward in product miniaturization.

However, since BGA and CSP are directly connected to the printed circuit board pattern using balls of solder covering the bottom surface of the package, the difference between the coefficient of thermal expansion of the package and that of the circuit board results in stress that cannot be dispersed or alleviated, with the result that this stress becomes focused on the solder. As a result, the stress is known to appear as cracking in the solder connection, and this factor causes the loss of connection reliability. The miniaturization of electronic parts has also had the effect of making the equipment tend to be more strongly affected by internal heat, and to increase stress due to the greater differences in coefficient of thermal expansion resulting from the greater temperature gap between the operating temperature and idle temperature. On the other hand, because of package miniaturization, the connections are also miniaturized and thus have less connection strength, increasing the necessity of evaluating connection reliability.

4-2-2 Validity of continuous, automatic measurement in evaluating connection reliability

When evaluating connection reliability, temperature cycle testing is used for environmental conditions to evaluate the impact of stress generated by the differences in coefficients of thermal expansion among each component material. To evaluate the connection condition, at each specified cycle (e.g., when running a 1,000-cycle test, at cycles 100, 250, 500, and 750) the specimens are removed from the test chamber, and the resistance of the connections is measured at room temperature, and the values are compared to the initial values and the specimens are inspected visually. However, in this method, even when cracking occurs in connections under environmental conditions (especially when exposed to high temperatures) of temperature cycle tests, the cracked surfaces become electrically connected at room temperatures, and no changes show up in resistance values. Therefore, it is difficult to accurately capture the occurrence of cracking in resistance measurements at room temperatures. With BGA and CSP, the connections are on the package bottom surfaces and so are difficult to evaluate through observation. Visual inspection is also difficult in other cases such as when the connections are covered with resin.

These problems could be resolved in an extremely effective manner if we could continuously capture changes in connection resistance values under temperature cycle test conditions and evaluate the increase in those resistance values as substitute characteristics for the occurrence of cracking. Compared to the conventional method, this approach would make it possible to evaluate more accurately (detecting failure) and more efficiently (determining malfunctions within the optimum test time).

Fig. 6 shows an example of characteristics when continuously measuring changes in resistance values of solder connections (BGA) under temperature cycle test conditions. After 320 cycles, the resistance of sample A and sample B were measured at room temperature, and showed no major changes compared with initial values. However, the continuous measurement data revealed that sample B had major changes in resistance on the order of kΩ changes in the high-temperature region of around 307 cycles. Evaluating with this method, we are able to determine that failure has indeed occurred and we are able to accurately capture the time of failure (the cycle number). By observing the progress during the test, we are able to instantly determine malfunction occurrence and the relative merits of the various samples from changes in characteristics leading to the failure level, and this is connected to reducing the test time.

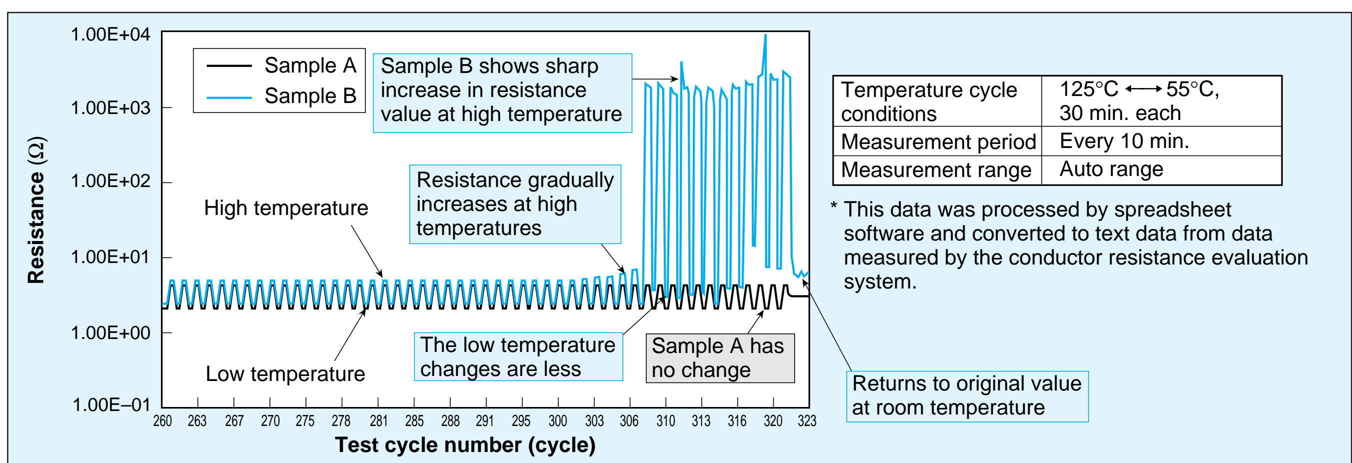


Fig. 6 Conductor resistance change characteristics under temperature cycle test conditions

4-2-3 Evaluation system for printed circuit board and solder conductor resistance

Next, let's consider real world examples of evaluation systems for printed circuit board and solder conductor resistance. (Photo 3) This system is used with environmental test equipment such as thermal shock chambers, and so the equipment provides such functions as automatically measuring specimen resistance under test environment conditions, processing data of resistance value changes that can cause cracking, and determining malfunctions. Fig.7 presents a layout diagram, and Table 2 gives the main specifications.

Photo 3 AMR-040-P Evaluation system for printed circuit board and solder conductor resistance (left), and TSA-70L Thermal shock chamber (right)

Table 2 Main specifications

Item	Specifications
Model	AMR-040-P
Measurement ranges	1×10^{-3} Ω to 3×10^{4} Ω (measurement cable tip)
Measurement interval	Min. 6 seconds (10 channels), (in 0.1 hour steps)
Measurement ranges	10mΩ, 100mΩ, 1Ω, 100Ω, 1kΩ, 10kΩ and automatic range
Measurement frequency	1kHz
Maximum voltage applied	20mV
Measurement method	4-terminal measurement method (end of measurement cable)
Number of measurement channels	40channels standard, Max. 280 channels
Power requirement	100V AC, single phase 15A

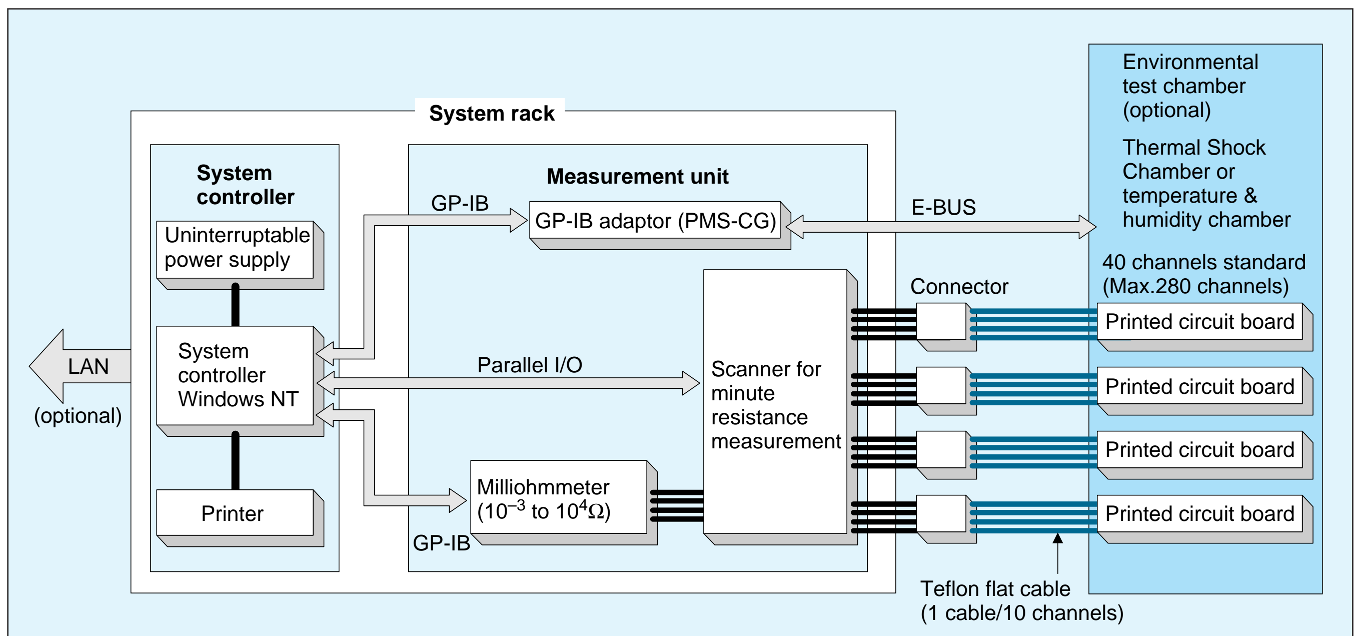


Fig. 7 System Block Diagram

4-3 Evaluating short interruption

4-3-1 The need for evaluating short interruption

Electronic equipment with advanced functions suffers problems from conditions that did not cause trouble for previous equipment, and so we must be aware that even slight changes in characteristics can lead to failure. One such factor that can cause failure is short interruption (circuit connection is cut off for an instant).

Conventionally, short interruption has been evaluated using connection equipment such as connectors and relays used in electronic equipment mounted in automobiles under test environment conditions with severe vibration. However, more recently, the portability of general electronic equipment has led to a higher probability of its being subjected to vibration. As a result, there is now an even greater need to evaluate this phenomenon to prevent the resultant instantaneous signal cut-off from causing mistaken operation with serious repercussions to product life.

4-3-2 Problems in evaluating short interruption

The general approach to evaluating short interruption is to apply vibration to the specimen and take measurements to determine whether short interruption occurs at points of contact and connections.

The guideline for determining failure in the test is usually, "short interruption did not occur for a minimum of 1μsec." The method of measuring short interruption, as shown in Fig.8 using a connector as an example, is to apply steady current to the point of connection with the connector engaged, and use the trigger function of an oscilloscope or memory recorder to detect a voltage surge for an extremely short instant at the point of contact.

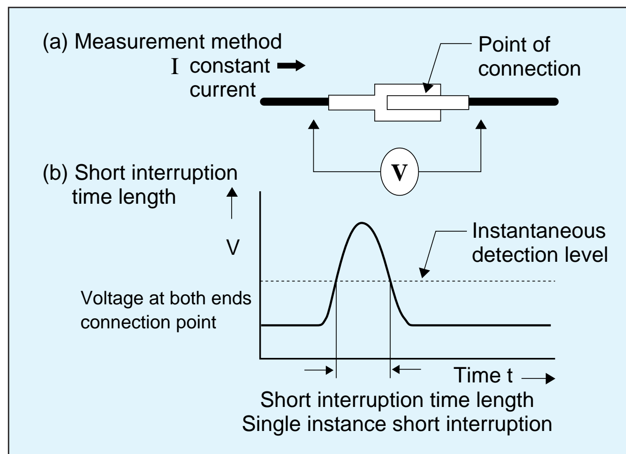


Fig. 8 Method of measuring short interruption

However, testing multiple specimens with this method would require as many measuring instruments as specimens. From the standpoint of cost, the limited number of specimens that can be tested simultaneously becomes a problem. Furthermore, this method cannot be used to continuously measure occurrences of short interruption, nor can it connect the occurrence of the phenomenon to the vibration at that point in time. These limitation mean that this approach cannot provide the amount of useful information we would like to have.

4-3-3 Short interruption evaluation systems

Short interruption evaluation systems are able to collect and record data under conditions of vibration test and thermal shock environments. These systems can measure the number of multiple occurrences of continuous short interruption of multiple specimens, the time length of each occurrence, the vibration frequency and acceleration, and the temperature. (Photo 4) Fig.9 shows the system layout, and Table 3 presents the main specifications.

Photo 4 Weather-Proof Vibration Shaker (left), Connector short interruption evaluation system (center), and temperature and humidity chamber (right)

Table 3 Main specifications

Item	Specifications
Model	AES-005
Applied current	1 mA to 100 mA DC, in 1 mA steps
Short interruption detection level	0.5 V to 2.0 V DC
Short interruption time length	Min. 500 nsec. (Min. resolution, 100 nsec.)
Short interruption occurrence count	Max. 500 times
Measurement items	Number of occurrences of short interruption, shot interruption time length, vibration condition at time of detection of short interruption (optional)
Number of measurement channels	Standard, 5 channels Max. 75 channels
Power requirement	100V AC, single phase 15A

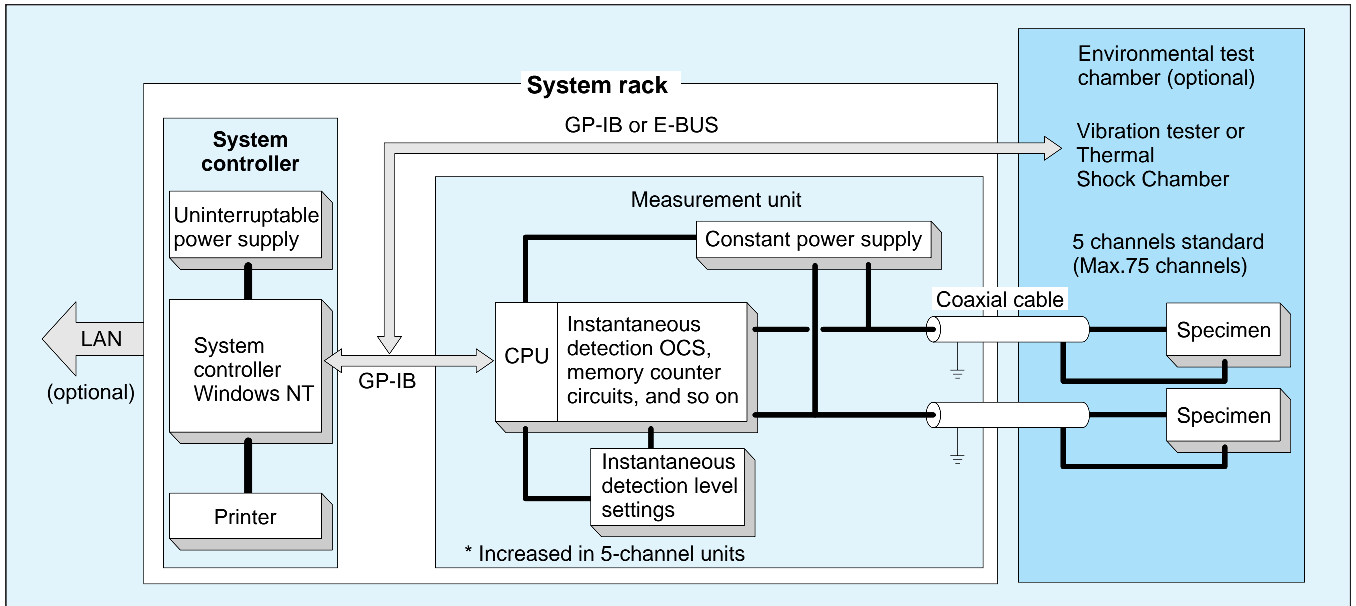


Fig. 9 System Block Diagram

4-3-4 Examples of continuous, automatic evaluation in short interruption evaluation systems

Next, I would like to present an example of using a short interruption evaluation system to continuously measure short interruption occurrence at a relay contact point.

To confirm the occurrence of short interruption due to vibration at a relay contact point, a measurement cable from the short interruption evaluation system is connected to the relay contact point and a vibration test is run. The results, as seen in Fig. 10, reveal 57 occurrences of short interruption in one sweep from 10 Hz to 100 Hz. The maximum length of time for short interruption is found to be 3.4μsec.

(Measurement conditions are:

(1) applied current, 1 mA,

(2) detection level for short interruption, 0.5 V,

(3) length of time for short interruption, detected over 500 nsec.,

(4) vibration conditions: Refer to Fig.11 for vibration test conditions.

Note: since the vibration conditions were used to generate short interruption, the conditions were much more severe than usual.)

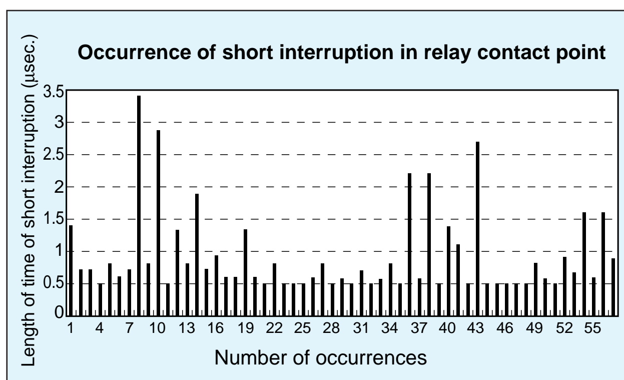
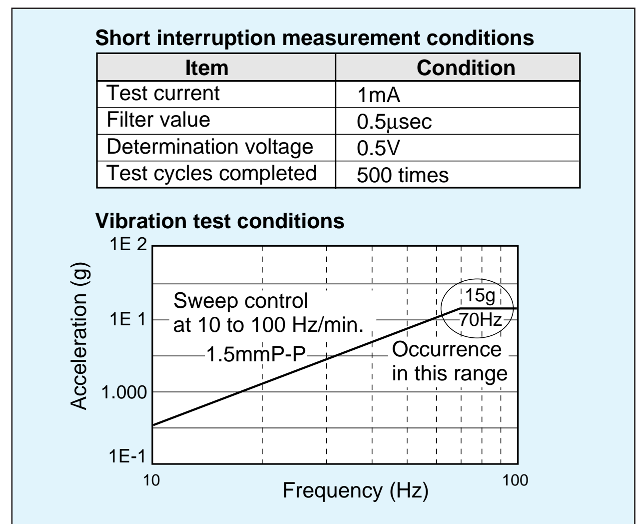


Fig. 10 Test results



Short interruption measurement conditions

Item	Condition
Test current	1mA
Filter value	0.5μsec
Determination voltage	0.5V
Test cycles completed	500 times

Fig. 11 Vibration test conditions

When the number of occurrences of short interruption and the length of each occurrence can be continuously measured in this way, we can much more easily grasp the characteristics in relation to elapsed time and test conditions. Furthermore, by simultaneously collecting and recording the data under conditions generating the short interruption (e.g., vibration frequency, sweep time, and temperature), we are able to obtain valid data for evaluation. Because we are also able to test multiple specimens simultaneously, we can compare specimen differences and see product dispersion. Testing not only becomes easier, evaluation becomes more accurate and more efficient.

This system can also be used with temperature cycle test conditions to evaluate whether defective contact is generated for extremely short times due to differences in thermal expansion coefficients of various connection materials and connection parts.

5. *Conclusion*

Combing automated systems with environmental tests and measurement and data processing enables us to attain exceptional improvement in evaluation efficiency. Using data from continuous measurements under test environment conditions, we can capture previously unknown phenomena and achieve more accurate evaluation results. We are very confident that this advanced testing method will prove to be an extremely effective tool for evaluation.

Terminology

* 1 Build-up circuit board
A high-density printed circuit board using a copper-clad laminate as a core, and having alternate conductive and insulating layers (optic-sensitive resin) build-up on top of the core.

* 2 Pb-free solder
The toxicity of lead in solder has come to be regarded as an environmental problem. When solder is exposed to rain, the lead leaches out of the solder and is thought to pollute the soil and the subterranean water supply, and so efforts are under way to regulate the use of lead. Because of this, developers are working to create Pb-free solder compounds.

* 3 VOCs (Volatile Organic Compounds) regulations
VOCs refer to chemical compounds such as PAN (Peroxyacetylnitrate) and optical oxidants formed in reaction to ultraviolet rays when both NOx and organic compounds with low boiling points are present. These substances may be harmful to humans and animals, and so legislation has been proposed to eliminate the use of VOCs in Europe and America.

* 4 Environmentally-friendly printed circuit boards
Fireproof electrical equipment is in high demand from the standpoint of safety. Halogen compounds are used on printed circuit boards for their fireproof quality, but these present dangers of creating organic toxins such as dioxin and benzofuran when incinerated. Environmentally-friendly printed circuit boards are those being developed that do not rely on the use of halogen-based fireproofing.

* 5 BGA (Ball Grid Array)
BGAs are IC packages capable of high-density mounting. The bottom surface of the package serves as the connecting end to the circuit board, and balls of solder are arranged in a grid pattern on the bottom surface for mounting.

* 6 CSP (Chip Size Package)
CSPs are also IC packages capable of high-density mounting. They are surface-mounted packages that are constructed the same size as semiconductor chips, or equivalent to BGA size.