A solution for the testing of complex multi-pole connectors and relays

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***Abstract* – The passive component marketplace is changing, a change which is becoming more and more apparent within the relay marketplace. End-users require more modularity and devices with simple basic functionality such as a 2-pole changeover relay are frequently being enhanced to a higher level of complexity either by placing more devices within the one package (e.g. two relays within the one box) or with the addition of internal protection components such as varistors or diodes. In the case of these 'complex passives' the question of production testing both the basic part and its additional components arises, a challenge particularly where these devices may be both low in volume and demanding electrically in their test requirements.**

This paper describes an approach to the testing of these complex multi-pole devices by reviewing the techniques used within the Reflex950, a new high pin-count test system for low-level and high-voltage tests on mixed multi-pole parts such as connectors, relays and switches. Featuring a maximum of 160 Kelvin pins, the Reflex950 handles this new generation of 'complex passives' with test methods that owe much to conventional relay testing. A key feature of the paper will be to highlight the new techniques that we have developed and how these relate to the increasing complexity of passive devices in general and relay devices in particular.

I. INTRODUCTION.

A. Welcome to 'complex passives'.

The passive and active category headings under which electronic components are grouped are becoming increasingly blurred together. Technically, relays are classified as 'passive components' yet their number of pins and complexity often suits them to be termed a functional electronic module in their own right. Add some internal protection devices - themselves passive or active components - or double or treble the number of devices within the package and the whole becomes a passive sub-assembly – we might term this device a 'complex passive'. This increased functionality is becoming much more popular for the following reasons:

- It improves the modularity of the system within which it is a part.
- It improves overall system reliability.
- Adds value for its manufacturer
- Adds convenience for the system integrator.

Some examples of these devices are:

- Multiple relays within one housing such as those for ATE matrix applications, automotive window control and redundant safety circuits.
- IC packages containing multiple micro-relay devices [3]
- Relays with in-built over-voltage protection for contacts and / or coils provided by varistors or diodes.
- Connectors with filtering components built in to limit EMC transmission.

This paper will outline the challenges of testing these devices and illustrate a solution – the Reflex950.

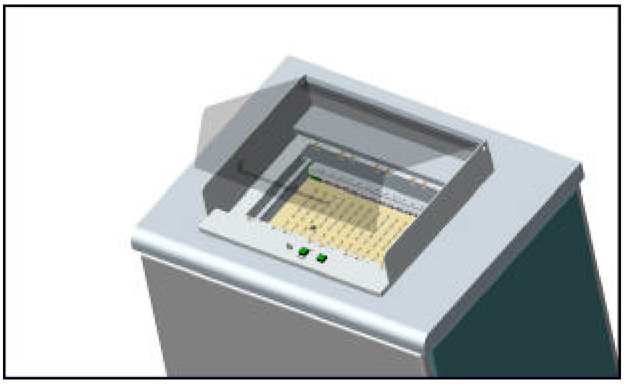

Figure 1 The Reflex950

B. Complex devices add huge value – lives can be at stake.

A common motivation to add internal passive components to relays and connectors is for the control of system EMC performance. Product radio frequency (RF) emissions and susceptibility are now serious issues and there is a whole raft of FCC and EU legislation in place to ensure compliance with strict standards. In turn, system builders place demands on the interconnection and switching devices not only for their own EMC performance but since these parts often form natural input or output 'bridges' between equipment, they are often called upon to host additional filtering or suppression components to further improve overall system performance.

Electronic equipment often contains many interconnection routes joining modules and circuit cards with relays, connectors, cable assemblies. These paths frequently act as antennae for the unwanted emission and susceptibility of the product to RF energy - a car electric window might move sporadically as the driver operates his mobile telephone for example. To counter this, relay and connector manufacturers have developed variants which incorporate filter components actually inside the device body. The benefit of these is that the system manufacturer can fit either a filtered or non-filtered version of the same device depending on results from measurements made upon the product, perhaps instead of incorporating space-hungry suppression components on a circuit card. In the case of a filtered connector for example, its filtering action is especially efficient due to the location and compact size of the filter components. With the massive rise in the use of RF equipment there is now a large added-value market in these filtered devices.

There are a number of horror stories involving the impact of unwanted voltages or currents on electrical apparatus but one of the more recent was the TWA flight 800 disaster in 1996 where probable cause is believed to be that of a fuel tank explosion which resulted in the total loss of the aircraft and all 230 lives [1]. The cause of the explosion cannot be accurately determined, but safety programs implemented following on from analysis of the crash have focussed on inserting voltage and current protection devices actually within existing cable harnesses running to the fuel tanks of all Boeing 747's in service. This protection includes series fuses and parallel over-voltage suppressors actually within connectors and compatible modules so that retrofitting can be easily performed. Several manufacturers such as Goodrich [2] now provide such components.

All complex passives should be tested for as many electrical parameters as possible to ensure that they are performing to their published specification. As the complexity of the device rises a little – for example by adding just a single suppression component to a switch - the effort of electrical testing rises significantly, since the device is now non-standard and there are probably more test routes and failure modes to cover. In the case of a filter application it is not easy to routinely measure the filter characteristics at R.F frequencies so production testing must concentrate on measuring the low-frequency parameters of each device pin such as contact resistance, breakdown voltage, leakage current (insulation resistance) and capacitance. Although the measurements are mostly those same fundamental parameters already measured by general relay or connector test equipment the challenge is to create an economical item of test equipment for working with these highly customised devices and yet which is universal enough to be applied quickly and conveniently to any similar test application.

II. MEETING THE TEST CHALLENGE.

A. *Our test requirements.*

To test a device with unknown internal functionality and a large number of pins requires significant flexibility. We need a test system that provides:

- Configurable electrical test resources for the measurement of the fundamental device parameters, e.g. resistance, capacitance, HIPOT (breakdown) and insulation resistance.
- A flexible mechanical and electrical route between the test resources and the pins of the device.

Traditionally these goals are met either with a high-cost formal semiconductor test system or with an in-house GPIB 'rack-and-stack' solution. Unfortunately the former is usually expensive and the latter often lacks reliability and throughput for production use. ART's Reflex950 was designed to bridge the gap between these two extremes, and recognizes that the capability required within a semiconductor test system is often not needed in testing these complex passives.

B. *Connecting device to tester – fixturing is vital.*

Fixturing is of vital importance when testing small batches of complex devices since the costs of ad hoc solutions for connecting between a test system and device can often exceed the test system itself many times over. The Reflex950 is based on the popular 'bed-of-nails' solution, a technique already proven for relay testing by ART in our RT900 high-voltage test system. The principle is shown topographically in Fig 2.

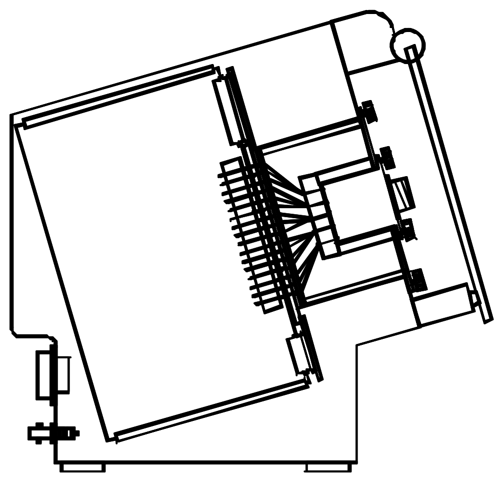

Figure 2 Test system fixturing to device - topographical example.

This shows how the test electronics is mapped mechanically on to the device under test using an interchangeable test adaptor which plugs into the test system, mating with fixed test system probes to provide the physical interconnection for a specific device. An electrical matrix further permits devices with the same physical footprint but varying electrical connections to employ the same adaptor module. A typical plug-in module is shown in Fig 3.

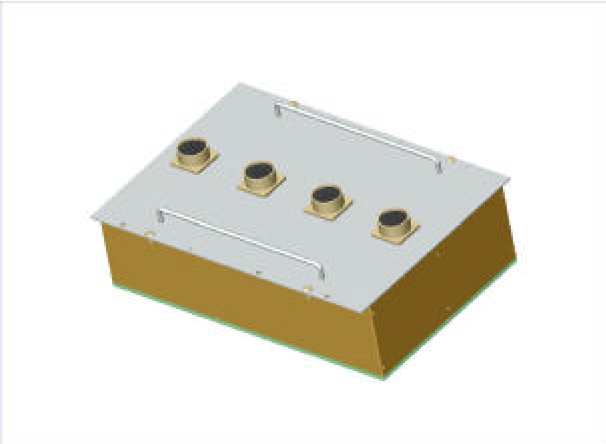

Figure 3 – A device fixture insert for connectors.

This solution not only provides an excellent mapping solution for custom wiring various devices through to the tester, but its construction ensures a very low leakage environment coupled with an inherently high breakdown voltage, avoiding the need to employ expensive H.V. connectors. Fig 4 shows the detail of the matrix card pins that mate with pads that in turn are let in to the base of the adaptor module. In use, the adaptor module is installed by an operator and pulled down by a few millimetres into its operating position by pneumatic action just prior to testing a batch of devices.

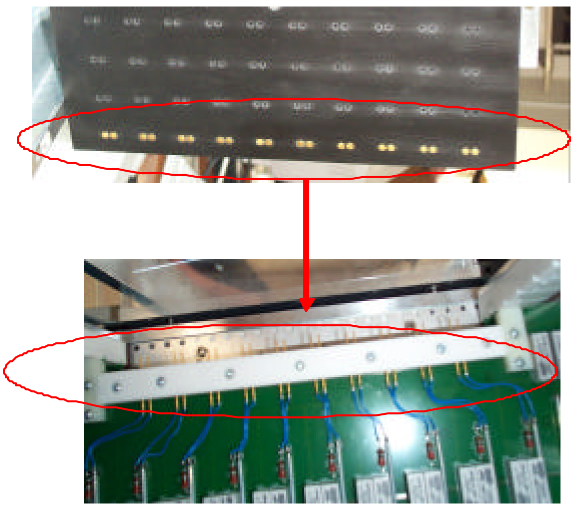

Figure 4 – The matrix card pins mating with the base of the adaptor module.

The typical electrical performance of this mechanical solution is in the region of 10^{13} ohms for a path from device through to the tester – several orders of magnitude greater than the typical 10^{9}-10^{10} ohm specification usually specified for the device under test.

C. *Configurable resources are dictated by the device.*

When designing a general-purpose tester for 'complex passives' its impossible to know in advance which parameters will need to be tested. If it's a relay, we can guess that contact resistance, coil resistance and timing will feature prominently, but add some suppression components and we must now test for standoff voltage and confirm a breakdown characteristic. Leakage current may also need to be tested. To achieve this, we need some standard resources – a configurable V-I power supply and some custom capability that can be provided by an internal GPIB bus. Note that it is important to be careful with use of the GPIB bus, it's popular and well-supported but it's not very fast and can be unreliable in production environments.

A block diagram of the Reflex950 is shown in Fig 5. The matrix architecture is based on our existing RT901 5kV, 22-pin high-voltage relay test system [4] but with extensive additions to fixturing support and parametric measurement.

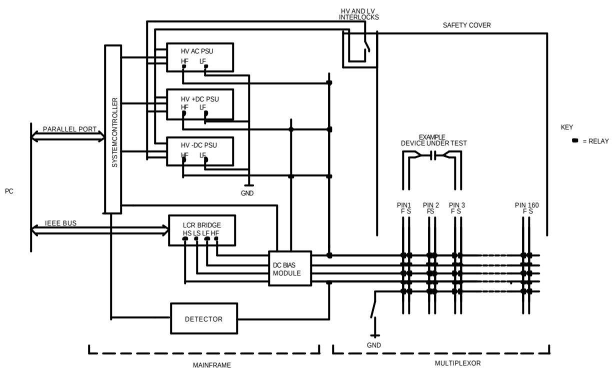

Figure 5 – Reflex950 block diagram.

Configurable 4-quadrant AC and DC power supplies are combined with low-level LCR measurements using a fully Kelvin 160-pin matrix to map to the device pins. Direct control of the matrix and power supply hardware is provided together with a GPIB bus for the LCR meter and any additional instruments. An abbreviated specification of the filter connector test system variant is shown in Table 1

Parameter	Value
Test voltage	+/- 2100V
Capacitance	1pF – 6uF
DF	0-0.1
Resistance	0.1mR – 1MR

Kelvin connections	160

Table 1 – Reflex950 specification – connector test version.

III. AN EXAMPLE REFLEX950 TEST CHALLENGE – TESTING FILTERED CONNECTORS.

A. Test requirements of a filtered connector.

To put these test challenges in perspective, we will look at an actual test implementation, that of testing filtered connectors. A filtered connector is a standard connector but with the addition of internal passive components to form a traditional 'T' or 'Pi' filter on one or more pins between one side of the connector and the other. (Fig 6).

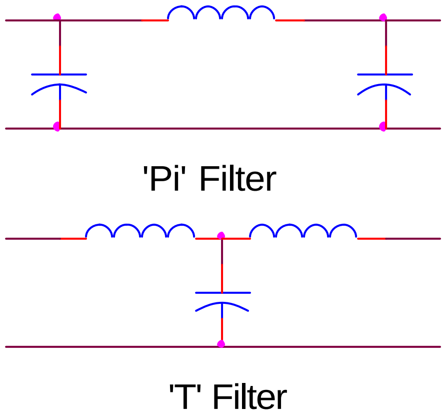

Figure 6 'Pi' and 'T' filters

The result is that low-frequency signals or simple power supply voltages pass through the connector as intended, but higher frequencies such as unwanted EMC radiation are attenuated. Since cable harnesses often perform as extremely efficient antennas, the use of filtered connectors has dramatically increased with the rise in product EMC performance legislation.

An example of the physical construction of a filtered connector is shown diagrammatically in Fig 7.

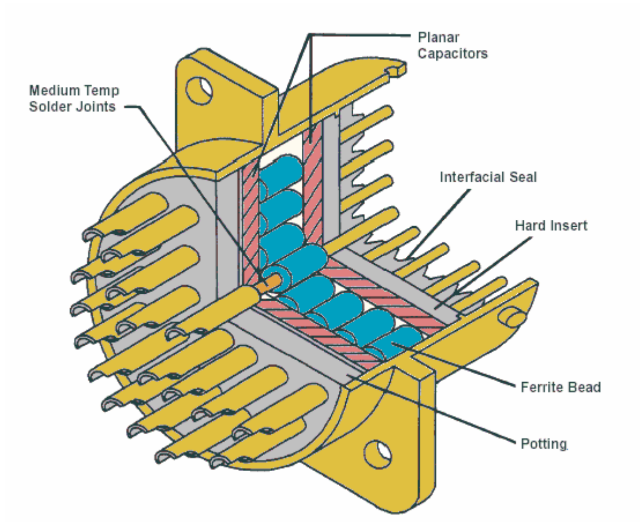

Figure 7 – Filtered connector construction.

Connector pins pass through the connector body but have a ferrite bead passed over them in the centre of the body. On either side of the ferrite bead is a planar capacitor array which can either a PCB with surface mount capacitors or a monolithic multilayer array 'biscuit'. Examples of these are shown in Fig 8

Figure 8 – Planar capacitor arrays.

In addition to these L-C filter components there are often additional varistor or diode components which provide transient over-voltage limiting and practical connectors often have 'straight through' pins that omit filtering if electrical reasons require it.

Standard (un-filtered) connectors require the following basic electrical tests:

- HIPOT (high-voltage breakdown testing).
- Insulation resistance (leakage current).
- Contact resistance.

Filtered connectors add to these basic tests with the following additional electrical tests:

- Pin capacitance (to monitor the capacitance array).
- Standoff voltage of transient protection components.
- Breakdown voltage of transient protection components.

It is interesting to note that other than the absence of a coil motor, the requirements for connector testing are similar in many ways to those of relays and switches but with a significantly larger number of device pin connections.

B. *Applying the Reflex950 to filtered connector testing.*

The features of the Reflex950 can be harnessed to test filtered connectors as follows:

- The flexible fixturing modules permit a wide range of connector types to be interchanged quickly, whilst the mounting of the modules actually on the tester electronics keeps stray capacitance to a very low level.
- A wide range of software test types permits the user to design test programs either for fast operator-based production applications or for detailed engineering device analysis.

The Reflex950 provides extensive support for programmable fixturing. Not only are the resources programmable to any desired tester pin, but the device under test can have its pins numbered or named to suit the test application with these names available to be utilised within the test application programming. This 'mapping' is stored with the test program and recalled transparently to the user yet can be editing easily by engineering staff. Each map file contains not only a list of the tester pins and their connection to the device, but an actual layout of the device pins, permitting on-screen pictures of the device footprint and any failing pins as shown in Fig 9.

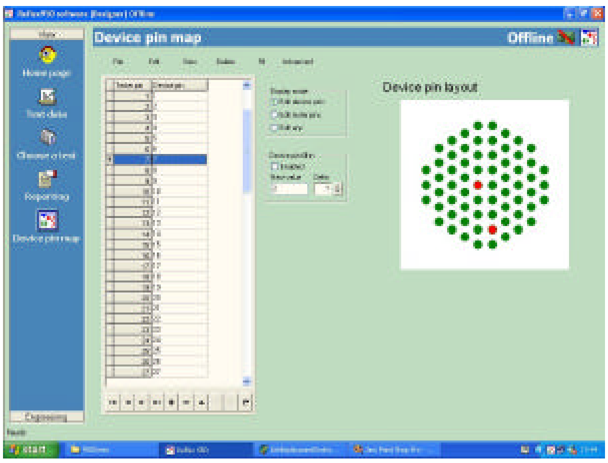

Figure 9 – Flexible device pin mapping on to tester pins.

Within the detail of the test program, device pin groups are frequently repeated. At the lowest level within the test program these pin groups are simple text strings or ranges such as D0..7, A1 etc, but with its knowledge of the physical positions of each device pin, the Reflex950 provides graphical user entry of selected pins on a device footprint wherever pin group entry is required. (Fig 10).

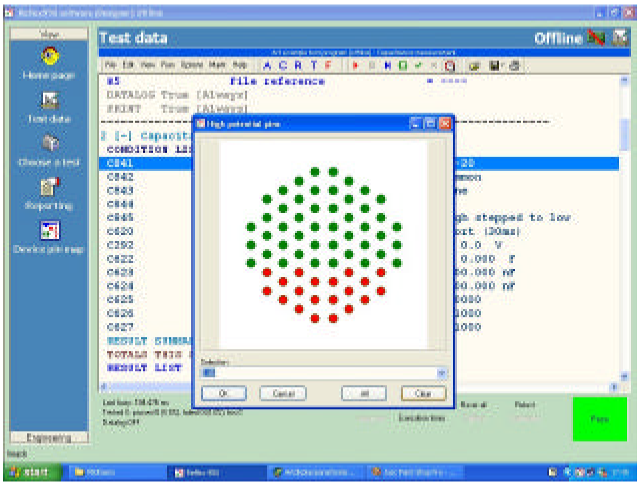

Figure 10 – Graphical device pin selection using a device footprint.

C. *Measuring pin capacitance at working voltage.*

For filtered connectors, capacitance measurement is a key parameter because it is directly related to the filtering ability of the connector. It should be measured precisely, both to ensure the filter quality and to compare actual performance with expected performance, further ensuring that there are no manufacturing defects. In addition to this requirement for accurate capacitance measurement there is a further complication whilst measuring capacitance. Under actual operating conditions a filtered device pin will (probably) have an operating voltage upon it (it may be a supply rail delivering power from a power supply for example) and will be simultaneously performing a filtering task by means of its exhibited capacitance. As a result, the 'Holy Grail' for filtered connector manufacturers is to be able to measure the capacitance of the connector pin actually <u>at</u> a nominated DC or AC voltage. This measurement is more important than one would first imagine because of the voltage versus capacitance characteristic of ceramic capacitors which can cause capacitance to drop to around 20% of its original value when a working voltage is applied (Yes – down to a FIFTH of the original, stated value!). To measure capacitance at this working voltage is very difficult if one is simply applying a commercial LCR meter to the capacitor measurement since such meters are limited to a few tens of volts of 'bias voltage'. To circumvent this limitation the Reflex950 includes a novel bias unit which conditions the device connections of a commercial LCR meter such that the device measurement is combined with up to +/-2kV of AC or DC voltage, permitting full capacitance and dissipation factor measurements to be made at any desired bias or polarising voltage. Fig 11 shows the block diagram of this technique.

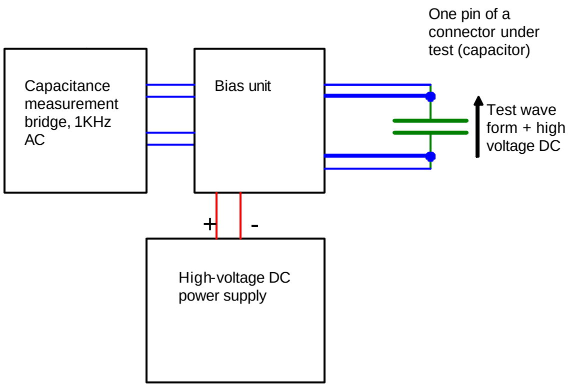

Figure 11 – Measuring capacitance at working voltage.

With this facility, the filtering ability of a connector can be 100% tested in production instead of relying on sample testing for this characteristic.

D. *Coping with data from a large number of potential measurement paths.*

Complex passives are also quite unpredictable for the exact measurement paths that will be required to be tested, let alone the measurement parameters themselves. For example, HIPOT measurements are usually performed simply between nominated single pins and a common (a connector shell for example). During engineering investigations however, many more measurement paths may be specified either to improve test coverage or to further analyse a known failure into an exact failure path. (The worst-case scenario for data generation is a full pin-to-every-other-pin test). The Reflex950 copes with this path variation by decoupling the path measurement results from the test program using results logged to disk in the background but with this data presented visually in the foreground (Fig 12).

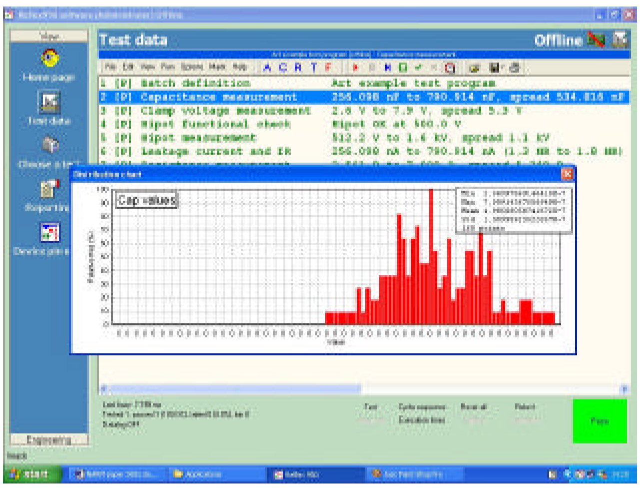

Figure 12 – Visual histograms for presenting data.

E. *Providing a general-purpose 'Complex passives' test system.*

The Reflex950 aims to be at home testing a range of passive devices such as relays, connectors and switches. To this end, the test types reflect the tests required on these parts. The test programmer uses ART's standard programming environment, often employing existing relay test programs, for example those that may already exist by working with one our relay test systems such as the RT290 or Reflex20. In this sense, the Reflex950 can also be considered as a more flexible, lower-voltage alternative to our 5kV, 22-pin test system RT901. Alternatively if a test program is required to be written from scratch, simple wizard entry is provided. Figure 13 shows an example of an operate & release voltage test construction when the system is used in relay test mode.

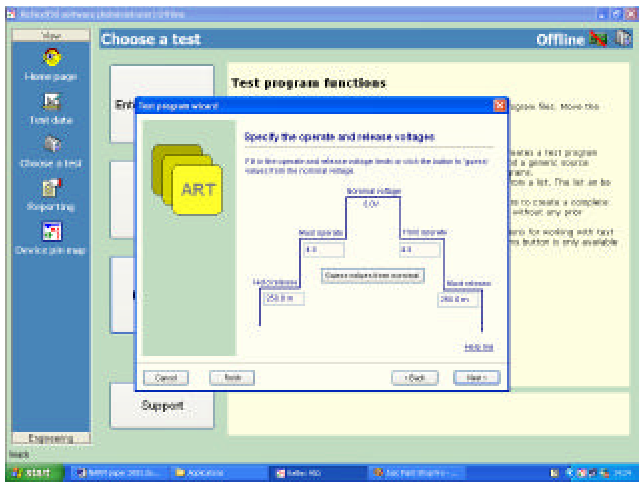

Figure 13 – Operate & release voltage 'wizard' entry when constructing a relay test program.

IV. CONCLUSION

This paper has introduced a general-purpose test system for the testing of 'complex passives' – devices such as relays, switches or connectors with in-built additional components. It has been shown that whilst the test requirements of such devices are quite stringent, a commercial system such as our Reflex950 can be applied as a turnkey solution without resorting to the high cost of a full semiconductor test system or having to create an in-house solution.

V. ACKNOWLEDGEMENT.

Applied Relay Testing Ltd would like to thank the staff of a number of passive device manufacturing companies and users for their valuable help and constructive comments, in particular Syfer Technology (Norwich UK) and Deutsch Connectors Ltd (UK).

VI. REFERENCES.

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[2] Suppression device data, for example the manufacturers web site www.goodrich.com

[3] William P.Taylor, Mark G.Allen and Charles R.Dauwalter "Batch Fabricated Electromagnetic Microrelays" *Proc. of the 45th relay conference, NARM, April 1997*

[4] B.J.Frost "A New Generation Of Test Equipment" *Proc. of the 45th relay conference, NARM, April 1997*