# AN160197.1 - A technical overview of Relay Testing Products from Applied Relay Testing Ltd.

**Applied Relay Testing Ltd is a specialist Company that has created a range of advanced products dedicated to electromechanical and Photo-MOS relay testing. By employing measurement and control techniques that are usually only found within high-cost mixed-signal semiconductor test systems our equipment provides previously unattainable levels of relay-testing performance and throughput in such areas as low-level parametric measurement, high-voltage qualification and real-world contact life-testing. A number of Relay Manufacturers and Users now depend on these test systems for continuous use in production and in the Laboratory. This technical note outlines the application and measurement techniques of these systems and how they have been applied to the real-world testing of various relay types and parameters.**

## I. INTRODUCTION.

Until a few years ago, with few exceptions, most relay test equipment was created by in-house personnel employed by relay manufacturers or large users of relays. This approach was encouraged by the apparent simplicity of the circuitry required, the availability of qualified personnel, and the view that the end result was a greater control over the equipment created. Although there were some advantages in this approach, the resulting test systems were often constructed around slow GP-IB bus based measuring instruments and custom software that incurred unplanned development costs. A further 'weak-link' was often the follow-on work required to implement proper documentation for the equipment test and maintenance, leading to problems in properly supporting production. Only the larger more specialised groups were able to maintain this level of design activity and yet create well integrated controller-based high-speed equipment.

The need for in-house equipment resulted in the expansion of test equipment groups within the larger relay manufacturers, particularly during the late 1970's, but with the economic developments of recent years the skill of these personnel has become more highly valued when focused directly upon the relay product itself. The effect of this has been to reduce the size of these test equipment groups, even in some cases to entirely eliminate them, with the resulting management dilemma of how to share available resources between the creation of up-to-date test equipment and actual product engineering.

Applied Relay Testing Ltd realised that within the field of relay technology this had created a need for high-performance, well-engineered measuring equipment, specifically designed for the needs of relays, which, as well as solving in-house equipment design problems, could also provide industry-wide correlation of device test results, for example to aid the sometime difficult engineering discussions that occur between vendor and customer when measuring methods often differ.

Many engineers are prone to dismiss mechanical relay devices, regarding them as the 'weak-links' within a design and as only a simple switch to be used when a semiconductor device is not available. This view, enhanced by often glamorous semiconductor marketing, encourages engineers to assume that relay devices are becoming increasingly obsolete in favour of improved semiconductor techniques. Despite these predictions, - which ironically have been made now for several decades - the mechanical relay device is still an essential component within many designs and will continue to be developed and improved for many years to come.

Around the world there are many thousands of technologists currently working to design new relay devices and to refine the operation of existing parts. The result is a continued downward trend in both size and operating power for a given load capacity. At the same time, improved mass production and test techniques are ensuring that a low unit cost keeps mechanical devices competitive with other technologies.

Posed as a general question to the average electronic designer, the testing of a relay presents little theoretical difficulty, the apparent task being only to check for satisfactory contact resistance and to confirm the operate and release points to establish a good device. Although such simple testing might be adequate for an end-user, the relay manufacturer requires much more from the test equipment. For testing during relay production, the equipment has to confirm a good device, it has to be fast, accurate, traceable and produce reliable quality data to support process feedback.

To provide a turnkey solution to these needs, Applied Relay Testing Ltd has made available the following items of standard test equipment:

* The RT290, a high-speed parametric test system for low-level parameters.
* The RT901, a high-voltage ('Hi-pot') test system for dielectric withstanding voltage and insulation resistance.
* The RT96, a modular life-test system with real-world loads.

Each of these systems can operate stand-alone, or integrated together within larger fully-automatic test systems, and their key capabilities and measuring methods will now be examined in more detail.

## II. LOW-LEVEL PARAMETRIC TESTING WITH THE RT290

### *A. Introduction to the RT290.*

The RT290 is a dedicated parametric test system for monostable and bistable relay devices with up to 8 changeover contact sets. Over the last 5 years the RT90, a predecessor item of equipment, has built an enviable reputation for reliability and standardisation within a number of Laboratory and Production sites, and this new RT290 test system builds on this while adding a number of novel test features.

The design of the test system is to bias it towards the speed and reliability demands of production test, while ensuring that it can also be used just as easily within a laboratory environment to obtain measurement traceability between these applications. This together with various limitations of other relay test equipment has resulted in a system with the following main features:

* Fully parallel test architecture.
* DSP-based digital timing measurements.
* Full 4-wire Kelvin device connection.
* Uses only solid-state test switching.
* Test fixture 4-wire continuity measurement.
* Programmable contact loads.
* Can be used with temperature probe.
* Traceable calibration standards.
* Fast compiled software running on internal PC.
* Easy menu style programming.
* Automatic handler and solenoid-based test fixture support.

There is some small irony that to our knowledge, this is the first relay test system to have completely eliminated mechanical relay switching in favour of MOS devices in pursuit of the highest test speed and reliability.

Figure 1 shows the physical aspects of a complete RT290 test system.

Figure 1. RT290 overall view

A key design decision was taken to separate any high-voltage capability from the RT290 and to make this available as a separate product. Although systems with integrated high-voltage capability can appear attractive at first glance, there are extreme differences between the design of a device test-fixture suitable for parametric testing and a test-fixture designed for high voltage testing. This makes it impossible to combine these functions properly unless compromises are made.

### *B. General architecture of the RT290.*

The RT290 is built by combining an integrated industrial PC-compatible controller surrounded by our own high-speed circuitry dedicated to the specific needs of relay testing. The computer runs all test software and stores user data files using the standard WINDOWS or MSDOS operating systems.

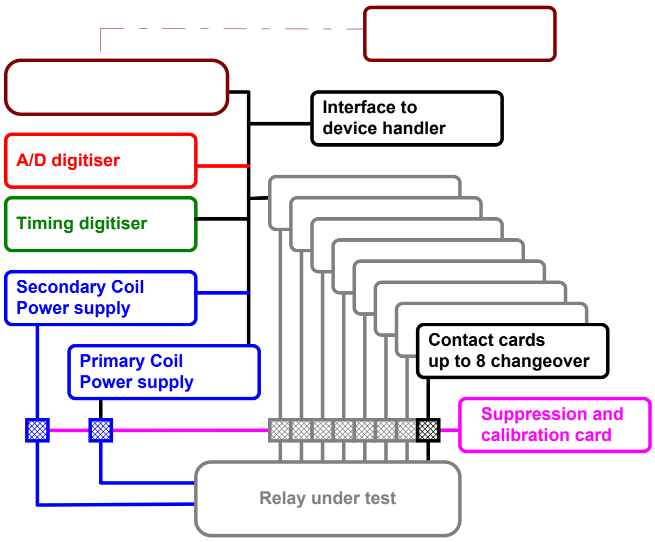



Figure 2. RT290 Internal Architecture

Figure 2 shows the functions within the RT290. It comprises a fully parallel 'changeover set' architecture, where each device contact set is assigned its own dedicated 'front-end' hardware circuitry. Up to eight contact cards can be installed to suit the complexity of the device being tested. All test hardware is directly 'visible' to the memory of the PC controller with the result that relay tests can be made with a speed that is often several hundreds of times faster than can be obtained with equivalent GP-IB or RS232 systems (see the examples in Table I). This method also eliminates firmware from within the system, making software upgrading or customising a straightforward task.

The RT290 can test monostable or bistable relays and has Photo-MOS relay test capability. Relay coils are routed from the power supplies to the device via positions for coil suppression networks located on a removable standards card directly accessible behind a hinged clear panel at the front of the RT290. This card allows the user to fit suppression components relevant to the test requirement, for example a simple diode, an R/C network, or a varistor and these networks can be switched in and out of the individual tests by simple software control. Software programmable power supplies control all device coil voltage and current conditions and also allow direct arbitrary synthesis of coil drive waveforms for AC coils or more advanced investigative techniques. This 'DSP architecture' is also used to digitise all measured parameters using a high-speed digitiser that operates synchronously with the coil waveform giving the system a high degree of flexibility in the manner of subsequent data processing.

Each 'contact card' provides dedicated hardware for one relay changeover contact and expansion is possible up to a maximum of eight cards. Circuitry is provided on each card to monitor the contact open / closed state, to buffer the contact voltage drop on both normally open and normally closed sides, and to implement a low-level active voltage clamp. During a typical device test, data is taken from all contact cards in parallel with important benefits on tester throughput and on the quality of the data measured, since all values will have resulted from a single device operation rather than repeated mechanical cycling.

Fig 3 shows how the physical layout is implemented to obtain the highest signal-noise ratios and to provide easy access for system servicing and calibration.

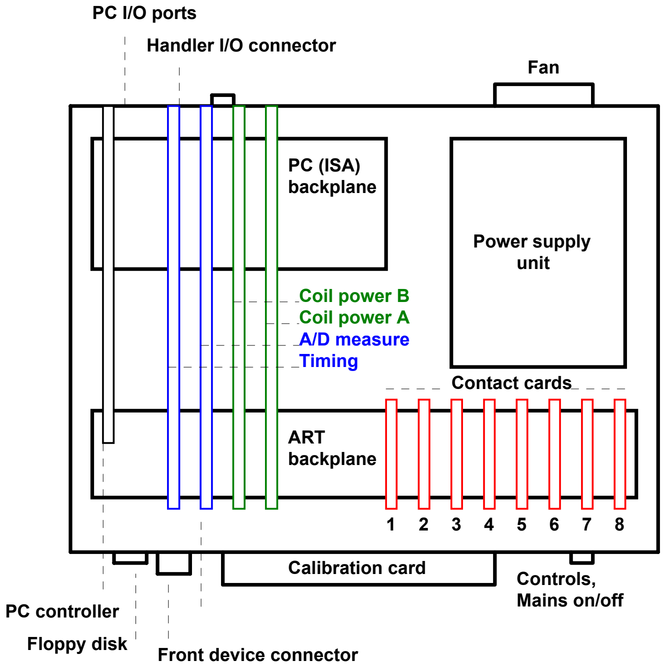



Figure 3. RT290 Internal Layout

The physical format of the RT290 is a standard 4U high, 19-inch rack chassis that can be housed to suit the application, for example either in a desktop case or as part of a larger test system within a free-standing equipment rack cabinet. This internal layout is designed to maximise ease-of-use and maintenance by attention to the following points:

* Access to coil suppression is at the front without removing the chassis.
* Internal cards are quickly removed or interchanged.
* Front panel test points are provided to avoid chassis removal.
* Front panel standard resistors are provided for system calibration.
* Key calibration data is stored on-card minimising the need for re-calibration.

Figure 4. RT290 OEM Rack case view

It was considered highly desirable to avoid the need to withdraw the RT290 chassis from its outer housing. As many engineers are well aware, such regular disturbance is often responsible for both introducing and clearing intermittent faults in equipment. The rule is that the less internal access required into a system, the more reliability can be expected from it. To promote this, on the RT290 it is possible to install coil suppression components and to perform all routine calibration by use of test-points and a removable card located as shown on the front of the system, often eliminating the need to gain any internal access.

### C. *Integrated calibration and self-test facilities.*

The RT290 has extensive internal calibration and self-test capability, with only simple external confirmation required to prove traceability between measured results and laboratory standards. Fig 5 shows how normal testing and self-test and calibration are selected by simple routing of the common measurement circuitry to either the device under test or to the front-panel standards card.

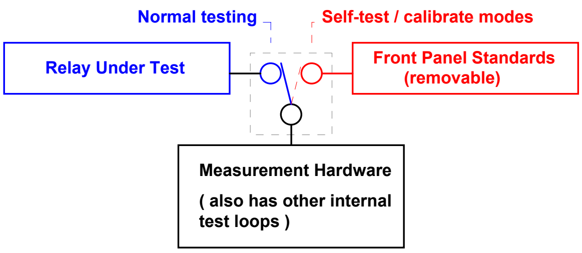



Figure 5. RT290 Self-test and calibration routes

The standards card is a set of decade 4-terminal precision resistors located on the front-panel of the system allowing it to be easily transferred between the RT290 and a standards laboratory. An integrated software self-test and calibration procedure allows all internal measurement circuitry to be confirmed or adjusted against these standards.

A pre-written self-test program can be loaded and executed from a  single menu selection and is designed to verify measured parameters against the standards card without changing any calibration settings, i.e. this closely approximates the actual measurement of device parameters. Normally only 'pass' information is required from this facility, but since the self-test program operates in the same way as a device test, all self-test results can be viewed, printed or logged in exactly the same way as relay device results. Another menu option executes a fully automatic calibration program which adjusts all internal circuitry against the values of the pre-calibrated standards. After this, calibration correction settings are stored on disk and automatically used for all subsequent system measurements.

Additional semi-automatic calibration procedures exist where some manual intervention is required, for example to obtain adaptor-relative 4-terminal continuity measurement values.

### D. *General device test capability.*

The RT290 provides pre-written 'test-types' that perform standard parametric measurements on a relay device. Test sequences may be built from one or more of these test types to provide the exact sequence of measurement and the electrical conditions required by the User. Common device parameters such as 'nominal voltage' can be 'broadcast' to all test steps to quickly create a working device test with no formal programming knowledge required.

Advanced techniques are used to obtain the best execution times for these test types with a summary of the major types and their speeds shown in table 1. Note that not all RT290 test types are shown in this list and that the times are actual device test times including and based on a 'slow' 4-pole changeover device that has been assigned a 15 ms mechanical settling time.

TABLE I
MAJOR TEST TYPES AND EXECUTION TIMES.

| Test type | Description of test. | Execution time* |
|---|---|---|
| Adaptor Continuity. | Measures all device pins confirming correct adaptor connection. | 38ms |
| Coil Resistanc e. | Measures the resistance of specified coil(s). | 50ms |
| Contact Resistanc e. | Measures the resistance of specified contacts. | 60 (<1mR) 150ms (<20uR) |
| Contact Resistanc e Stability. | Measures the delta, min, mean, max. and standard deviation of any number of contact cycles. | 105ms (<1mR) 250ms (<20uR) |
| Timing test | Measures the operate and release timing of specified contacts. | <100ms |
| Operate & Release V and I | Measures the operate and release parameters of a device. | 60ms + As theoretical down to 1ms settling |
| Contact set shorts | Detects shorts between contact sets. | 25ms |

* Note - execution time is actual device test times including and based on a 'slow' 4-pole changeover device requiring 15 ms mechanical settling times..

### E. *The benefits of relay parameter measurement*

*using the RT290 'DSP' architecture.*

The RT290 achieves a high test throughput by a combination of traditional analogue measurement techniques and more recent advances in digital control and software processing. This combination can be illustrated by a more detailed examination of the DSP architecture of the RT290 and the way in which measurements of contact resistance are made.

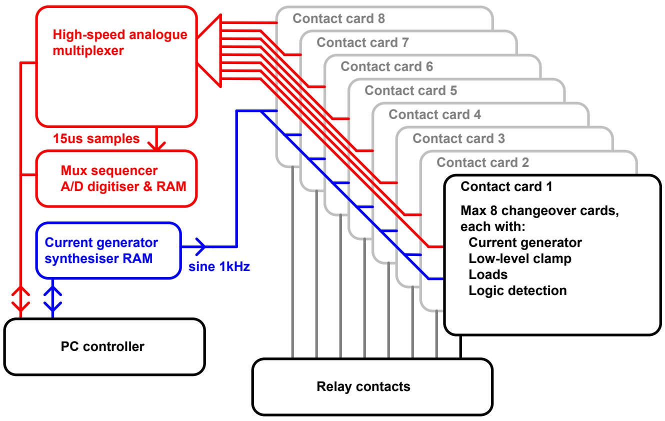



Figure 6. RT290 Contact resistance measure architecture using DSP techniques.

Fig 6 shows the internal signal flow that is employed when measuring contact resistance (CR). CR must be measured 'in parallel' on all contacts together, so the RT290 implements up to 8 'contact cards' each containing the necessary contact interface analogue circuitry and acting as a 'head unit' that connects using a 4-wire (Kelvin) connection directly to one changeover contact on the device-under-test. For low-level CR measurement this circuitry translates a common test current sine waveform into a constant applied contact current of typically 10mA, limiting the maximum open-circuit voltage of this waveform to a programmed level (for example 20mV) and buffers the resulting contact voltage-drop.

In normal test systems, this voltage drop would be processed using additional analogue circuitry to rectify and filter it before presenting it for measurement by an analogue to digital converter. In the RT290 each contact card output feeds a high-speed CMOS analogue multiplexer which is automatically sequenced around all contact cards and allows the A/D digitiser to 'capture' a single pattern that contains information about the contact resistance of the entire device in one 'snapshot'. This digitised version of all observed contact voltage drops is complete by the end of the contact resistance measurement period and subsequent software processing extracts individual contact resistance results for each contact. The test method is illustrated in Fig 7.

Digital signal processing techniques are becoming much more common in high-end measurement systems for the reason that much of the traditional analogue circuitry can be implemented using subsequent software processing, minimising drift and stray pick-up as well as centralising measurement resources.

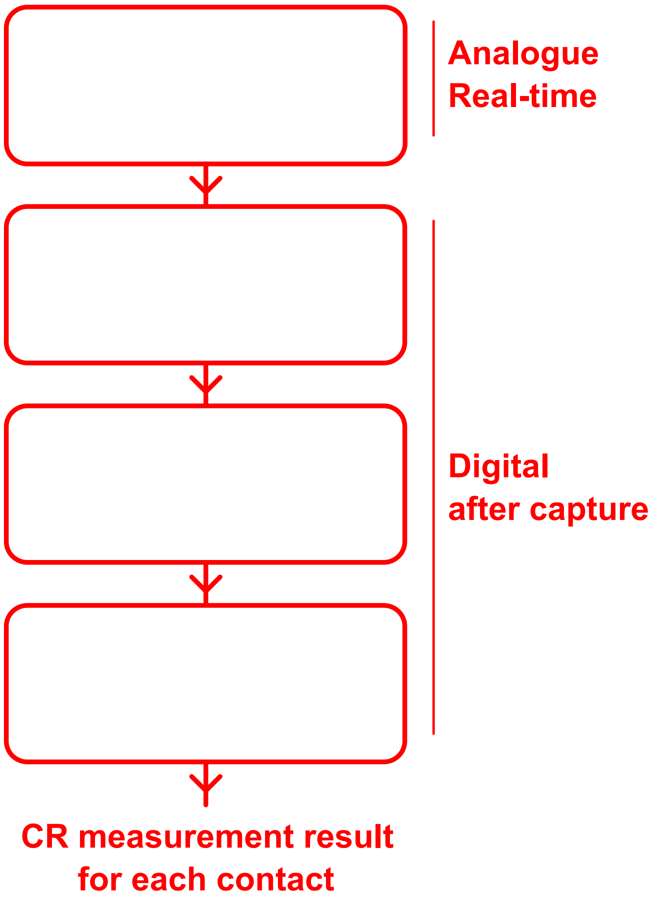



Figure 7. RT290 Contact resistance measure architecture using DSP techniques.

Correctly applied, this software processing achieves measured results that actually improve on stability over equivalent analogue techniques, and since the necessary algorithms do not need to run in 'real-time' we have easily implemented them to run in a few milliseconds on our internal PC controller using a fast, compiled, PASCAL language.

Another benefit of this DSP processing is that the quality of the measurement can be traded-off against measurement time by the User. In detailed laboratory investigations into contact resistance, the most precise, stable results are usually required and it is less important that such measurements may take 150ms to achieve a few tens of micro-ohms performance. In production however, a 50mR device contact can be tested against an 80mR test limit by using a short 60ms version of the same test, still with performance better than 1mR - a significant increase in throughput and of additional benefit where multiple CR measurements are required, for example in measuring CR stability. New relay devices are shrinking in geometry and it is reasonable to expect that this will lead to an increase in production line throughput requirements, making it essential that a parametric system can keep up with these increases. To this end the RT290 offers four settings for contact resistance measurement quality and we have seen actual device contacts measured in adaptors to better than 1mR in 20ms.

As well as these direct measurement benefits, a digital processing architecture can be reconfigured easily in software to apply it to the needs of different relay tests. For the measurement of contact timing for example, the RT290 configures its architecture such that the relay coil is switched at 'time zero' followed by the contact logic states being 'captured' into the digitiser RAM over the required test period. At the end of this time a pattern is available showing the actual contact activity whilst the device was switching. This contact pattern data is a standard RT290 display as shown in Fig 8.

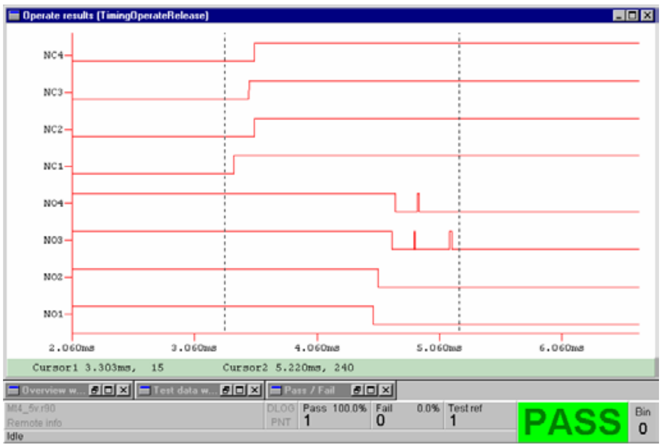



Figure 8. RT290 Timing test output graph showing actual contact effects at the switching point.

This display is analogous to viewing the 'captured' contact resistance voltage drop for CR measurement but where the actual contact open and closed states can be seen. During the timing test the RT290 further processes this displayed pattern to derive actual parameter values for operate and release time, bounce time and number of bounces for each relay contact. These values are then compared with pre-programmed test limits to obtain a pass or fail for that test step. An obvious benefit of this processing sequence is that data viewed graphically in a laboratory situation can be exactly correlated with parametric results obtained from a production line test and without any additional time penalty - the RT290 can do all of this timing test measuring and processing in less than 100ms.

When assessing a contact 'bounce', the RT290 uses its digital processing to apply exactly the required bounce criteria to the observed contact pattern, for example to apply the telecom specification that 'events of less than 10us shall be ignored'. With analogue filtering such simple definitions are actually quite difficult to implement and create inaccuracies in bounce counts when the actual bounce is close to the definition limit. These relay contact 'bounces' are often a subject of much discussion between Customers and Vendors and the RT290's various levels of 'brick-wall' filtering using digital techniques ensures that contact display and measurement is as close as possible to the specification.

*F. An example of a magnetic circuit investigation.*

For the relay designer, the ability to make magnetic circuit investigations is very important, and much time can often be spent in setting up the hardware to investigate relationships between various motor and contact parameters. Using the synchronous digital capability of the RT290 it is possible to synthesise coil drive waveforms whilst synchronously capturing contact electrical conditions to aid in such investigations.

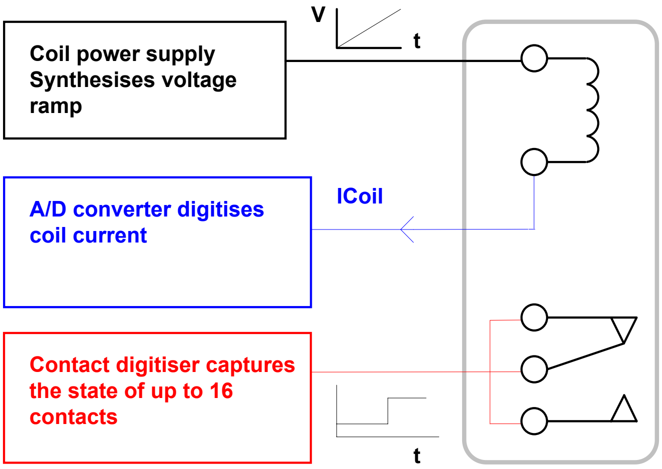



Figure 9. Configuration for monitoring magnetic circuit effects between motor and contact sets.

In the example configuration shown in Fig 9, a linear voltage ramp is synthesised and applied to the device coil. At the same time the coil current and all contact states are captured and digitised. The 'test' runs for some 25ms during an operate or release action of the device and at the end of this time, information is available of the form shown in Fig 10 that clearly shows the motor action in relation to the contact activity. Software processing development is currently being undertaken to use this method to implement a routine 100% production test for contact force.

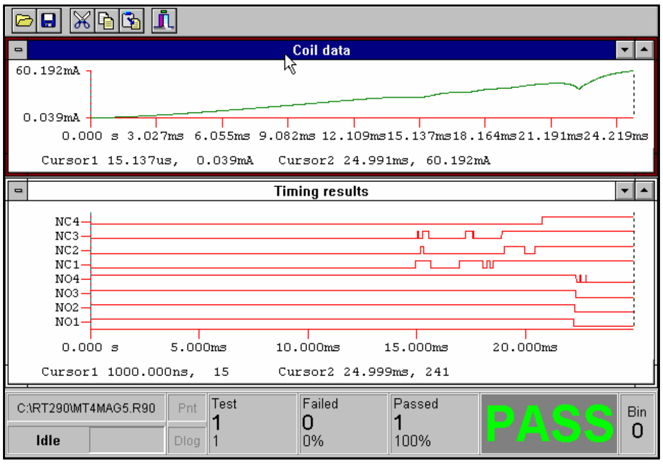



Figure 10. Typical output of the magnetic circuit investigation.

*G. Software programming facilities and the ZEUS test shell.*

Deciding on a suitable environment for programming relay tests can be difficult. There is no doubt that the flexibility and speed of 'raw' compiled 'C' code is an attractive solution for a well-defined production application, but the price can be long development times and the requirement for a high level of programming expertise. At the other extreme the traditional 'menu style' programming (where the user simply enters numeric values and chooses items from lists) can create test sequences quickly but can appear clumsy and inflexible when used for production requirements. To reconcile these demands, Applied Relay Testing has created their ZEUS test shell, a menu-programmed environment that has a number of custom programming extensions that make it possible for users to create tests quickly whilst retaining a high level of conditional control over test actions if and when required.

The RT290 implementation of this test shell is available with versions for MSDOS or Windows environments to suit any special production or laboratory preferences. Relay test 'types' are selected by the user and built into an ordered test sequence where each test step makes the required actions and measurements on the relay device under test. The actions of each test step can be modified by the user by editing its conditions. Running the test sequence gives an overall PASS or FAIL and individual pass, fail and numeric results for each test step.

Fig 11 illustrates an overall test sequence shown in its 'test data' display form in which the test program would be designed. It can be seen to clearly display each test step and the order of actual test execution.

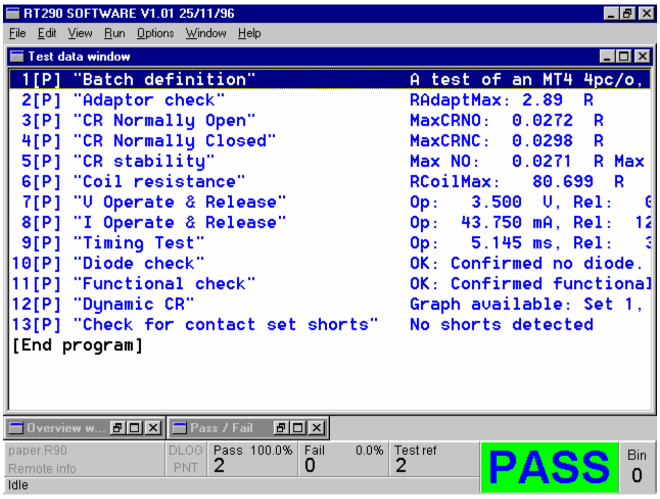



Figure 11. An RT290 display of an overall relay test sequence.

Selecting the Coil Resistance test step '6' and opening it for viewing we see the following typical displayed layout for a test step as in fig 12:

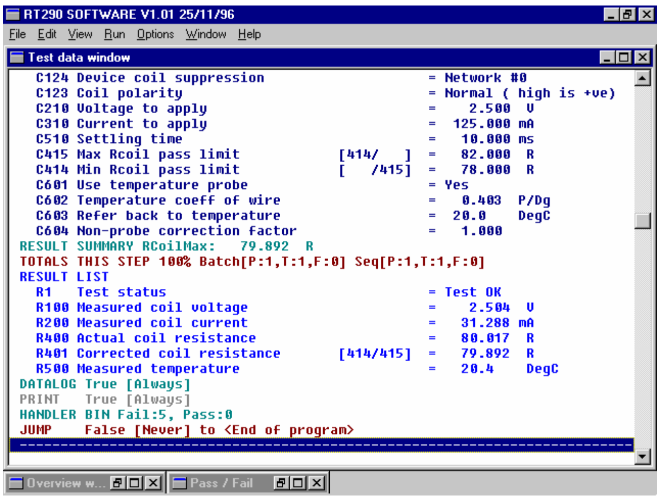



Figure 12. The RT290 Coil Resistance test step opened to display all of its data.

The test conditions appear in the upper part of the display (e.g. C210) and the test results in the lower part (e.g. R100). The conditions section comprises supplied constants (e.g. C602, 'Temperature coefficient of wire'), device settings (e.g. C210, 'Voltage to apply'), and actual program test limits (eg C414 and C415). Results comprise measured and derived values including the 'bottom line' result R410 ('Corrected coil resistance'). Other lines are additional controls and summary items for this test step. Test programming involves simply changing the required conditions by entering new values or selecting from a list of pre-defined choices. To quickly create complete test sequences, several methods are available to enter 'common' conditions, while for the greatest flexibility each test step may be programmed with its own specific test conditions.

Most users have a well defined idea of the amount and type of information that they wish to see on the screen during normal use of the equipment, for example a production application may call for only a few results and totals. To provide this, the test shell includes a flexible 'overview' mode of display as shown in Fig 13.

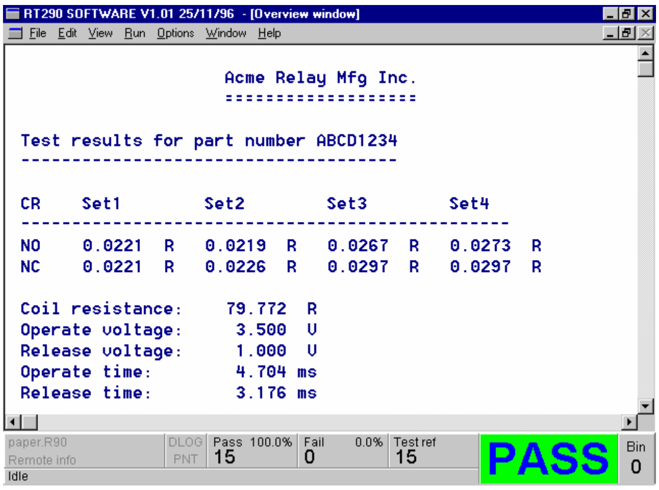



Figure 13. An example of the custom 'overview' window that simplifies displayed information during routine testing.

This overview display is a free-form text template that can be designed and laid out by the User to suit the actual display requirements of the application, including as much or as little of the actual test data information as is required. For example after only one test sequence run on a 4-pole changeover relay, the test data display of Fig 12 contains a scrollable display of over 100 actual results, and although there are ways of reducing the displayed test data information, the overview window provides a fully customisable display that can be made to show only those items chosen and to require no scrolling. This display style may be mixed with other display summaries such as those shown in Figs 14 and 15 to obtain the most brief yet informative combination that the application dictates.

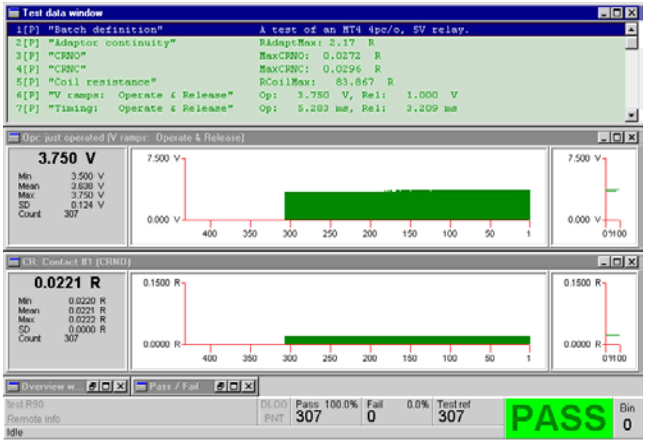



Figure 14. An example of a 'production' display that includes historical statistics for two parameters.

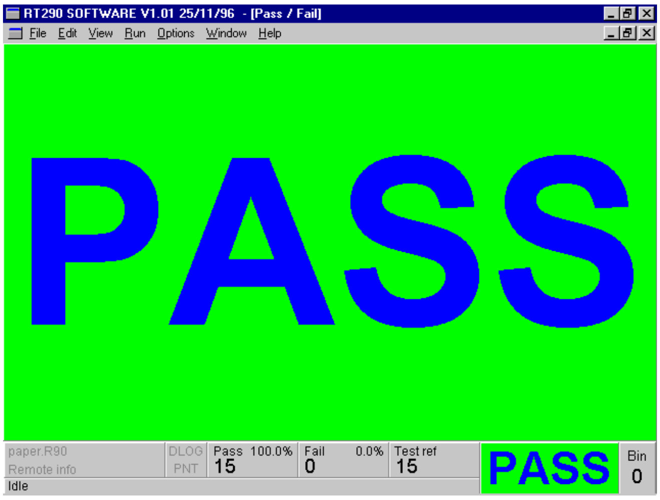



Figure 15. Some applications may benefit from the least amount of displayed data.

The ZEUS test shell goes a long way beyond conventional menu programming environments with its comprehensive facilities for device sorting and grading. The test sequence shown in Fig 11 can be viewed in another mode that shows only the test steps, their 'bin' values and 'jumps' as shown below in Fig 16.

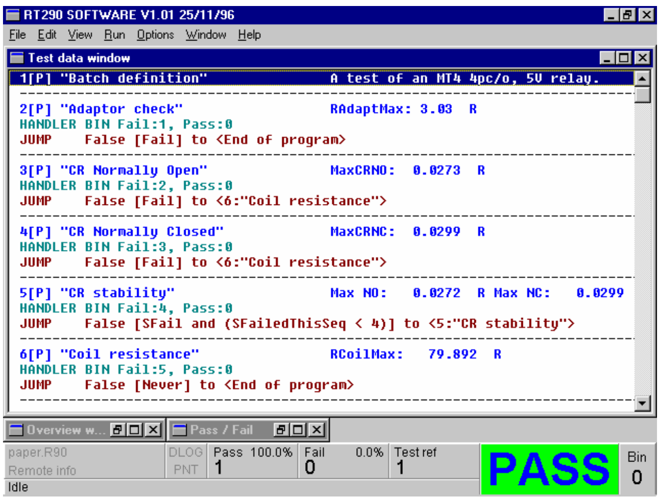


Figure 16. A view of a test data sequence showing only the test steps, their 'bin' values and 'jump' statements for sorting and grading.

This shows the first few test steps of the sequence each with a pair of 'control statements'. After executing a test step, the JUMP statement allows control to be transferred to another test step based on some expression - for example the 'Adaptor check' test step is seen to transfer control directly to the end of the program, skipping all other tests if it fails ([FAIL]), i.e. there was no valid device connection to permit the other test to execute. Another example shows the 'CR Normally Closed' test skipping the 'CR stability' test if it should fail. More complex expressions are also possible as shown in the jump statement for 'CR stability', here programmed to re-test the test step automatically up to 4 times in any one sequence if it fails. The HANDLER BIN statement specifies the external output from the tester based on the pass/ fail result of each test step. Both PASS and FAIL values are programmable to unique values that signal externally to a device handler allowing it to sort devices into various fail and pass grades. By using combinations of these BIN and JUMP statements, 'intelligent' production test sequences can be constructed that routinely make short simple and fast device tests but where more investigative tests are made should a device fail, so maintaining the highest possible production throughput combined with the maximum failure data.

An advanced feature of the software is that any numeric condition in any test step can also take a 'BASIC-like' expression that can reference other conditions or results anywhere in the test sequence - much like the action of a dedicated relay test 'spreadsheet' where every condition and result has been assigned a 'cell reference'. Using this capability it is possible to link test steps together to implement some custom test situation that would otherwise require a new test type to be created, for example where it might be required to measure contact resistance at (say) 120% of the measured relay operate voltage. This capability can also be used to create a generic test sequence where most conditions are simply expressions based on 'one-time' definitions of device values. As well as referencing other conditions and results these expressions can also include many pre-declared global functions such as step and sequence totals, or 'true' or 'false' results from step or sequence pass / fail results.

## III. TESTING RELAYS AT HIGH-VOLTAGE

### *A. Introduction to the RT901 High-voltage Relay Test System.*

High-voltage testing of any device is not a simple process, due in part to the necessary safety precautions which slow the otherwise straightforward test methods and to the rate with which high voltages can be switched at the device under test. This difficulty increases when testing multi-contact relays due to the large number of test paths that must be verified, each requiring repeated reconnection of device and test system.

Applied Relay Testing has produced the RT901 which dramatically simplifies and speeds the high-voltage testing of relay and other multi-terminal devices by allowing fixed test leads to be connected to each terminal of the relay device and then to use internal switching to route high-voltages, grounding or current flow detection to the required device pins under control of a simple User-defined software test sequence.

Figure 17. A typical RT901 High Voltage Relay Test System.

The RT901 can be visualised as a 'hi-pot' tester with an integral high-voltage, low leakage multiplexer, but its design and architecture goes further to allow turnkey testing on monostable or bistable relay devices with up to six changeover contacts and one or two coils. For the demands of production test and a high test confidence, a modular hardware architecture is used with a comprehensive integrated self-test (see Fig 18).

Testing is controlled by an integrated PC-compatible processor that controls the hardware modules using a high-speed 2-wire serial link. Using simple menu programming techniques, pre-written test 'types' such as 'breakdown' or 'insulation resistance' are selected and their conditions edited to obtain the required parameters and device routing. These test steps form a device test sequence that can easily be created for a production test application (where the device is required to be quickly confirmed as functional against specified voltages) or for a laboratory investigation (where voltage ramps are required to determine actual device breakdown or insulation resistance parameters).

Figure 18. Close-up of an interchangeable high-voltage generator on the RT901.

## B. *RT901 Design and architecture.*

Each test step in the software device test sequence specifies a required device route for the application of high-voltage and the connection of grounding or current-detection resources. The architecture that is used to create this capability is shown in Fig 19.

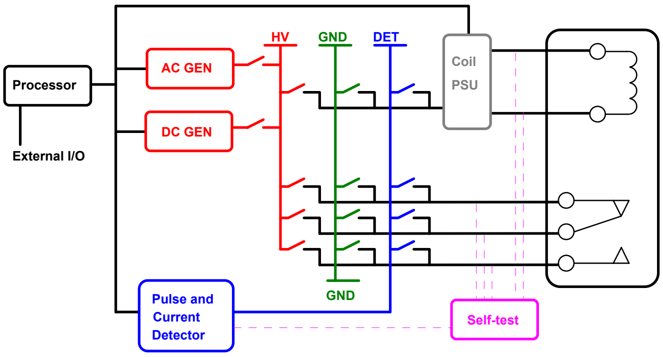



Figure 19. The architecture of the RT901 High-voltage Test System.

For simplicity, this architecture is illustrated with the example of a single changeover contact monostable device. Two high voltage generator modules are available, one for AC and the other for a DC supply. Under control of the integrated processor, any terminal of the relay under test can be connected to any one of the 3 'buses' shown, i.e. the high-voltage bus, the ground bus, or the detector bus. A device test is then performed by configuring the selected generator to supply its output to one group of device pins via the high voltage bus, and connecting the current detector to another group via the detector bus. Other pins are either specified to remain either ‘open’ or ‘grounded’. The current detector has a programmed monitoring ‘time window' during which it records any current events that exceed a programmed amplitude and pulse width - this permits the User to employ their own in-house definition of what actually constitutes a ‘breakdown event’. In addition to the milliampere levels of detection necessary for breakdown testing, the internal guarded construction of the test system and its multiplexer is able to support measurements of device current down as far as picoampere levels for insulation resistance testing.

This architecture and its software control greatly simplifies the testing of relays, since no user interaction is required. As well as an obvious improvement in safety, the RT901 has features that ensure a very short production test time for functional tests, with up to 7 device routes tested per second. This high speed is obtained by a combination of techniques including the use of vacuum tungsten multiplexer reed switches and careful attention to the high-voltage generators to ensure that they can be turned on and off quickly but in a controlled manner - this allows the multiplexer to switch ‘cold’ and gives a fast set-up and clear down of charge at the device. To achieve this has required some special high voltage power supply generation techniques to be developed.

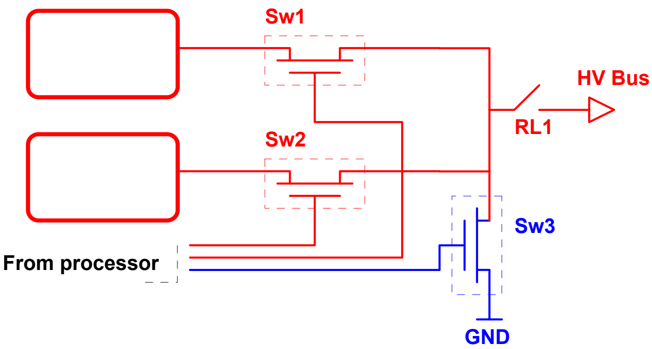



Figure 20. The high-speed HV output switching that selects the DC generators in the RT901.

Fig 20 shows the method used in the high-voltage DC generator for fast settling to the required test voltages. This switching solves a major problem with high DC voltages in that they cannot be programmed to a specific target value very quickly. Typically, it is possible to quickly move upwards to a target voltage, but moving back downwards to a lower voltage requires some type of charge sinking mechanism which is difficult to manage with a single high voltage DC power supply. A bipolar output supply with feedback can seem attractive but can exhibit stability problems during the transition. The solution used here is to capitalise on the usual relay requirement for two major test voltages by creating a generator that contains two fixed DC power supplies, one for the 'across contacts' voltage, and the other for the 'coil to contacts' voltage. These two 5kV power supplies 'DC1' and 'DC2' are routed through specially developed 7kV MOSFET semiconductor switches SW1 and SW2 to the common high-voltage bus, with a third grounding switch SW3. Prior to a fast production test where fixed voltages are to be applied to the relay device and breakdown events monitored, the test system programs DC1 and DC2 to each of the two discrete relay test voltages required and they now remain fixed (unless required by more complex test programming). During the actual test step, switch SW1 or SW2 connects the required generator to the high voltage bus, with SW3 closing to provide a controlled discharge of the bus between test steps. Whilst the bus is discharged, the mechanical multiplexer relays are permitted to take a new state ready for the next test and so do not switch any 'hot' load. Using this technique, it is possible to generate voltage 'pulses' at the device with widths of only a few tens of milliseconds, making it possible to perform a high-voltage test sequence on even a complex relay device in only a few hundred milliseconds.

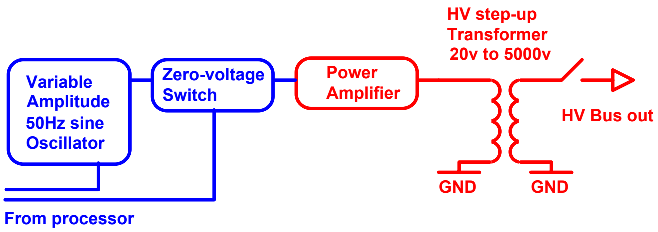



Figure 21. The signal path in the AC generator.

The RT901 has high-voltage AC capability which is implemented using the AC generator architecture shown in Fig 21 and which is capable of any combination of amplitude groups of sine-wave cycles at the device. Just prior to a group of cycles, the processor configures the variable amplitude oscillator to the required voltage and to start the cycle group, a zero-voltage switch gates this oscillator through to the power amplifier such that the resulting transformer drive starts and stops cleanly at a zero crossing. With the forced drive voltage from the low-impedance power amplifier, the HV bus settles to the new demanded sine amplitude within a few milliseconds and thus needs no actual discharge. Since these cycle groups have no DC component, the settling time to a new amplitude is almost zero. AC waveform ramps are also controlled to only change amplitude at the zero-crossing.

*C. Safety with high voltages on the RT901.*

The vital issue of safety with high-voltages is addressed at several levels within the RT901. All device connections are made using easily accessible front-mounted high-voltage connectors and coaxial cable but with access to these connections restricted by a fixed acrylic panel. This prevents unauthorised tampering while still allowing system operation to be observed on the indicator Led's associated with each device pin.

The high voltage switching and generation is under software control and cannot be relied upon for the ultimate safety of personnel, so it is necessary to create an interface to an external interlock 'break' switch that must open to permit access to the device under test or for adaptor maintenance. To connect to this interlock circuit the RT901 physically separates its internal high-voltage circuitry into a 'generator bus' and a 'connection bus', each brought out to an external high-voltage connection and making this connection is necessary before any device terminals are able to take up the programmed high voltage. In a typical complete installation a suitable device test-fixture would be provided having an opening access cover which breaks this interlock link and shorts all device pin connections to ground thus providing a high degree of safety to the Operator.

*D. The importance of equipment self-test for relay high-voltage testing.*

In any relay test situation it is always very important to have a high level of confidence in the reported results. With a parametric system this is relatively easy since an adaptor continuity test is available to confirm that a device actually exists and in any case most measured parameters 'fail-safe' outside of their associated limit pairs to give a high degree of certainty that faulty hardware is detected. However when testing for breakdown or leakage current the nature of the equipment and the connection to the device creates a situation where missing devices or faulty connections might be assessed incorrectly as a 'pass', a situation to be particularly avoided in automated production test.

As a production tester, the RT901 attempts to prevent this in two main ways. First, the breakdown test can be used 'inverted' i.e. to 'expect' a 'breakdown' to occur at a specified low voltage, allowing the User to create a simple 'device exists' check by testing across known closed contacts instead of always testing only paths that are open. Second, every connection to the device has an integral hardware feedback path inside the RT901 that routes from the actual device pin connector back into the measuring circuitry via a very high value resistor (see 'self-test' in Fig 19). The fully automatic self-test program makes a number of internal checks on the generators and other resources followed by more system-wide checks including this feedback route, verifying every device connection to be capable of sourcing a high voltage and detecting small currents. Although by itself this does not confirm that the device is actually connected, the technique does rule out all open-circuit faults in the internal test hardware and high-voltage multiplexer that may otherwise lead to faulty devices being 'passed'.

*E. Automating high voltage testing chores with software.*

The RT901 software is designed to allow the user to quickly set-up and run high-voltage relay device tests for either production or laboratory test. Production testing would typically use the 'breakdown pulse' test type (dielectric withstand voltage) to quickly perform a go/no-go check on the device by applying a fixed, programmed voltage to the required device terminals and confirming that no breakdown events occur during an allowed monitoring time window. Laboratory testing would typically use the 'breakdown ramp' test to establish the actual point at which breakdown events occur by creating a test voltage ramp with programmed start, stop, step size and application rate parameters. By default, the first breakdown event causes the ramp to return to zero with the event voltage recorded. Other test types such as leakage current (insulation resistance) are also available for inclusion and can be mixed with breakdown tests or used to create completely stand-alone insulation resistance device tests.

A typical device test sequence is built up from one or more of these test types, and they can be mixed or repeated freely using our ZEUS test software described more fully in section II.G. Each test type is configured with a number of input parameters ('conditions') which are easily edited, defining voltages, times, device terminal groups and other test step characteristics. An example of some of these conditions and the ease of editing the required device pin routes is shown in Fig 22 where the User can create a 'footprint' for any test device and simply click on the pin to specify its settings for each test step.

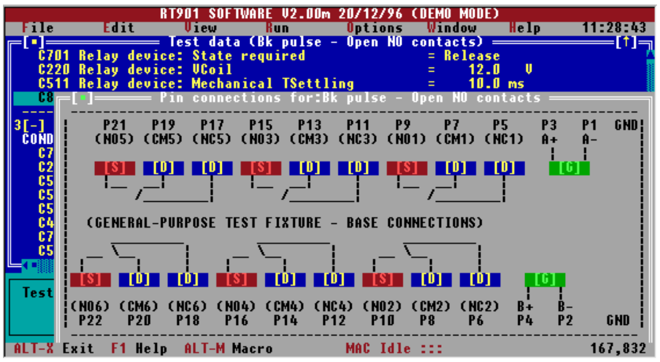



Figure 22. An example of assigning pin resources using a device 'footprint' in the RT901 test software.

All test conditions can be edited by simple key-presses, prompting the User for either numerical values or with a menu list of the available choices. For advanced Users, arithmetic expressions can be used in place of simple numeric values, too, allowing a 'spreadsheet' style of test programming. An important point is that this high-voltage testing environment is identical to that of our RT290 parametric test system, resulting in a useful saving in learning time and making it very convenient for Users and Operators who need to move between the systems.

## IV. COMBINING EQUIPMENT FOR HIGH-VOLTAGE AND LOW-LEVEL PARAMETRIC RELAY TESTS.

For maximum throughput in a production application, parametric and high-voltage tests can be made together using a configuration similar to that shown in Fig 23.

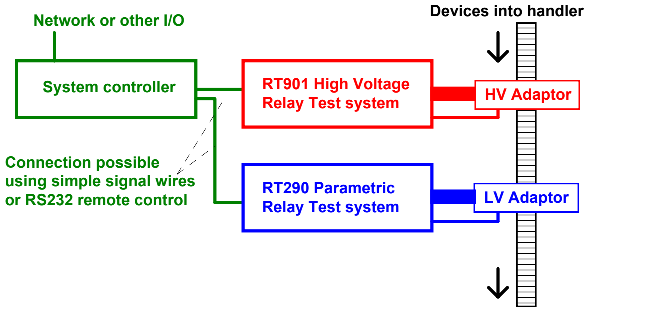



Figure 23. An example of the interconnection of equipment for a combined high and low-voltage production test.

Here a system controller - either a PLC, logic hardware or other host, can trigger measurements to be made by both systems using one of two interconnection methods:

* Simple wired connection using 'START', 'BUSY' and 'BIN NUMBER' signals.
* Flexible RS232 serial remote control commands for measurement, test data file transfer and self-test.

In particular the RS232 connection allows a controller-based system to be built very quickly and has been used in real-world applications to feed-back real time measured results to control previous processes 'on-line'.

## V. FLEXIBLE DEVICE TEST FIXTURING FOR HIGH VOLTAGES AND LOW LEAKAGE CURRENTS.

### *A. Introduction to the ART General Purpose Test Fixture.*

In many situations high voltage test systems such as our RT901 is connected directly to the Customers own mechanical handling equipment which already contains fixturing for the device. In situations such as Laboratory test where stand-alone, more flexible fixturing is required, Applied Relay Testing have developed a general-purpose test fixture that achieves a high level of performance at high voltage and low leakage currents.

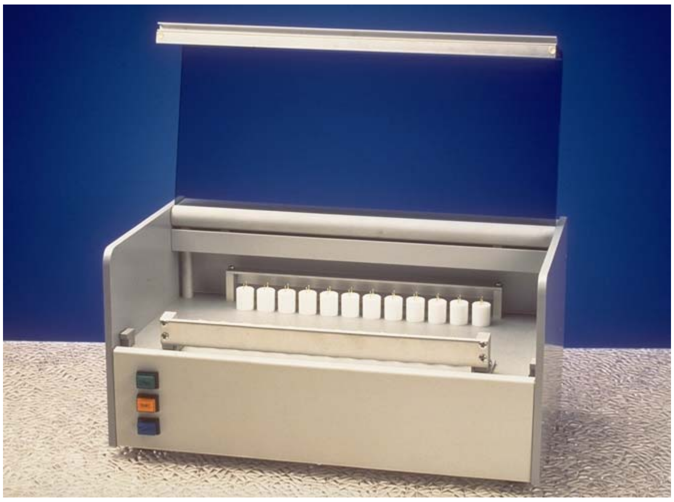
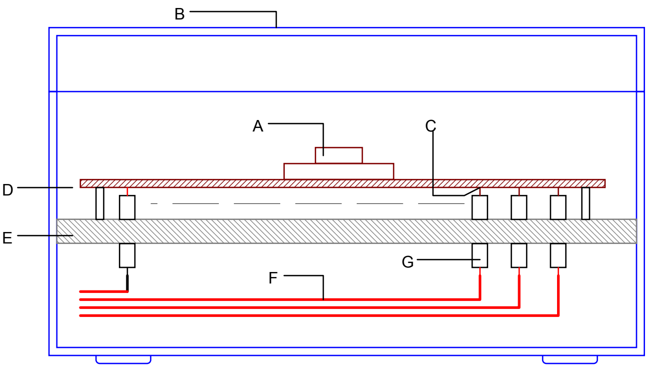


Figure 24 The general-purpose test fixture with device insert removed, showing the guarded device connections and sprung probes.

## B. Test fixture design.

The fixture is based on a fully-guarded, interlocked concept that uses individual PTFE device connection pillars each loaded with two spring probes and useful to around 10kV. A cross-section as viewed from the front is shown in Fig 25.




Key to drawing:

| | |
|---|---|
| A | Device under test in socket, or empty if adaptor card is uncommitted style. |
| B | Transparent hinged cover, preventing access whilst voltages are present. |
| C | Pad on adaptor card underside. For High Voltage use, this pad is tracked directly to device with maximum spacing. For Insulation Resistance (leakage) measurements, an alternative adaptor card provides full guarding of each pad / track. |
| D | Adaptor card to suit specific device footprint, or uncommitted style for full flexibility. |
| E | Fixed support plate to carry nail assemblies and adaptor supports. |
| F | Cables to test system. |
| G | Nail assembly connecting cables to adaptor card. 2 paralleled nails mate with a single pad on the adaptor card for good connection. |

Figure 25 Major features - GP Test Fixture.

This shows how each device connection is fully guarded by the action of the aluminium base plate (E) providing a ground path for any stray leakage currents. Various device footprints and fixture options are implemented by the use of insert (D) which carries the actual device socket. This insert has gold-plated track pads that mate with the spring-loaded probes and can be exchanged in a few seconds. All electrical connections are made using coaxial cable and internal SHV connectors giving excellent shielding and protection for both high-voltages and low currents.

A range of inserts are available ranging from the simplest 4mm terminal version to a surface mount relay style as shown in Figs 26 and 27.

Figure 26. Test fixture with a general-purpose 4mm terminal adaptor installed.

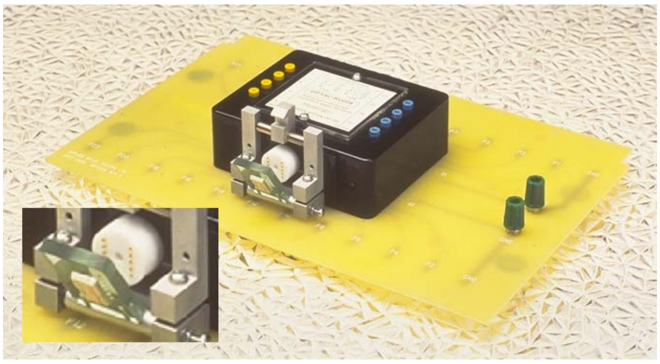


Figure 27. A close-up of a surface-mount relay adaptor insert for the text fixture showing detail (inset) of the retaining mechanics..

## C. Test fixture safety.

Safety issues are addressed at several levels with the General-purpose Test fixture. Firstly, an integral high-voltage interlock switch works together with a lid locking mechanism and is designed to close only when the test fixture lid is closed. Normally this switch is interfaced to the test equipment and connected between the high-voltage generation and its distribution, ensuring the removal of high voltages when device access is permitted. Secondly, shorting links are mechanically linked internally to ground every test fixture connection unless the lid is locked, ensuring that any remaining stored charge is removed before access.

## VI. LIFE-TESTING

### *A. Introduction to the RT96 Life-test system.*

To assess relay contacts under the conditions to which a Customer puts them, Applied Relay Testing offers the RT96, a modular Relay Life-Test System, which uses high-speed digital techniques to provide flexibility, turnkey operation, and measurement traceability.

The RT96 runs a life-test on up to 20 changeover contacts, making measurements of contact resistance, stick and bridge on every contact and on every operate and release operation throughout the test. Measurements are made in the presence of an optional load bank which can be fitted with a range of standard and custom load capability including Imax, Vmax and cable load types.

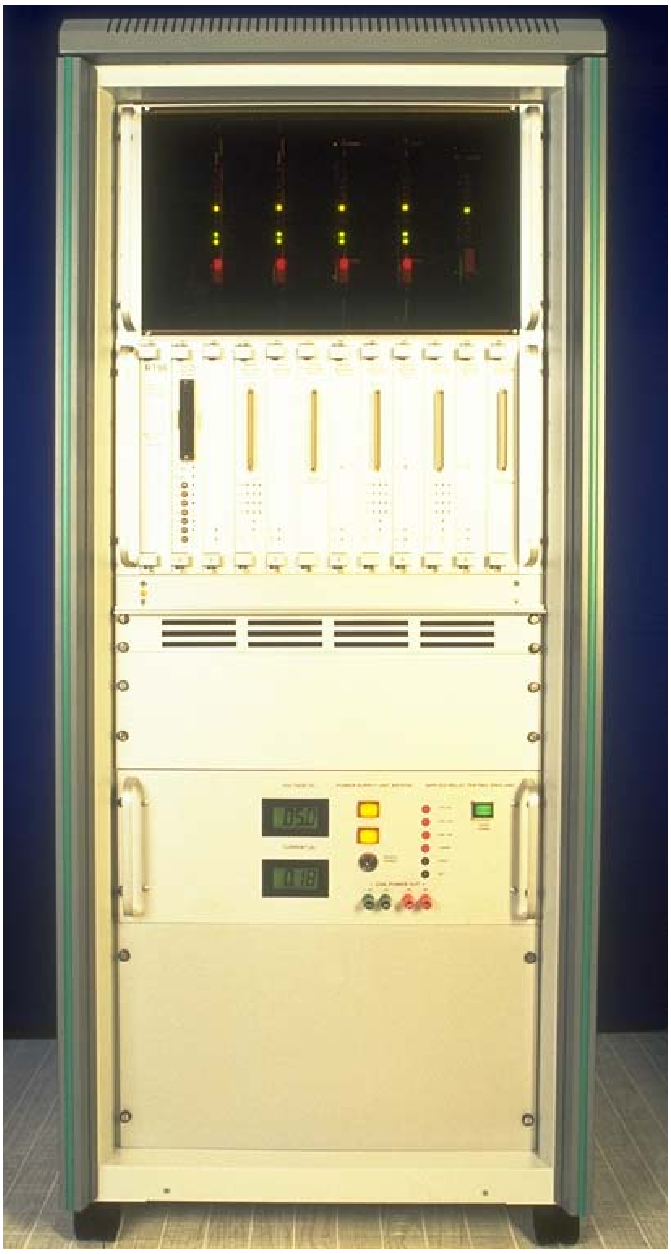


Figure 28 Overall view - RT96 life-test system.

During the life-test, the device contacts switch with the load networks applied, thus their environment is defined only by the load type, applied voltage and software-programmable parameters. After each contact switching action, the load network is then electrically removed and wide-range resistance measurement circuitry applied to all contacts, making defined measurements that do not depend on load parameters for their accuracy. The benefit of this technique is to provide standard, traceable contact measurement results across a range of life-test load types.

Devices can be mounted locally on small adaptor cards or housed within an adjacent environmental chamber and can be connected by simple low-cost flat-cable adaptor leads.

In addition to its routine parallel life-test capability, the RT96 has extensive internal device and test signal routing allowing it to offer as standard:

* Fully automatic self-test and calibration routines.
* Connection of a selected device to an external monitor connector for measurement by other equipment.
* Connection of any measurement channel to removable internal precision standards for traceable performance.
* Automatic device continuity confidence test before starting life test.

For example using these additional signal routes, the RT96 is designed to support the connection of the RT290 parametric relay test system allowing more extensive device investigation if required.

### *B. RT96 physical layout.*

A typical RT96 system as shown in Fig 28 is installed into a free-standing 19-inch equipment rack and is configured to the required test capability by using inter-linked modules together with a range of real-world load types. This example system comprises the options of (in order):

* Load rack with integral cable load
* Measurement rack for 20 contacts
* Multi-fan cooling with filter
* Coil and system power supply
* PC controller computer.

Additional rack space can be occupied if larger cable load types are employed, or the system can easily be re-configured in a lower-profile desktop format.

### *C. RT96 Electrical design and architecture.*

The overall architecture of the RT96 is shown in Fig 29.

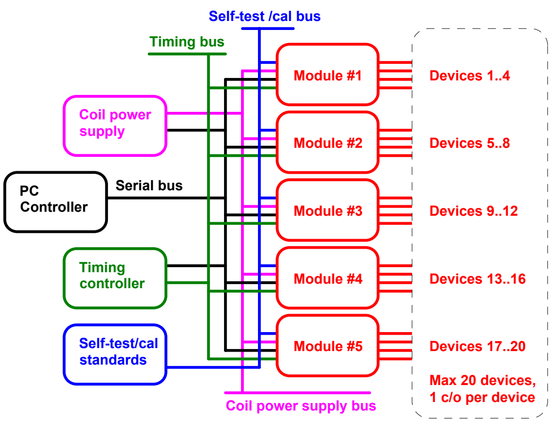



Figure 29. The electrical architecture of the RT96 life-test system.

This shows how a PC controller communicates with up to 5 life-test modules via a simple high-speed serial bus. Each module is in control of up to 4 relay devices and with one changeover contact per relay. Any number of modules between 1 and 5 can be used in the system, giving a maximum of 20 contacts in total.

The module architecture is shown in Fig 30.

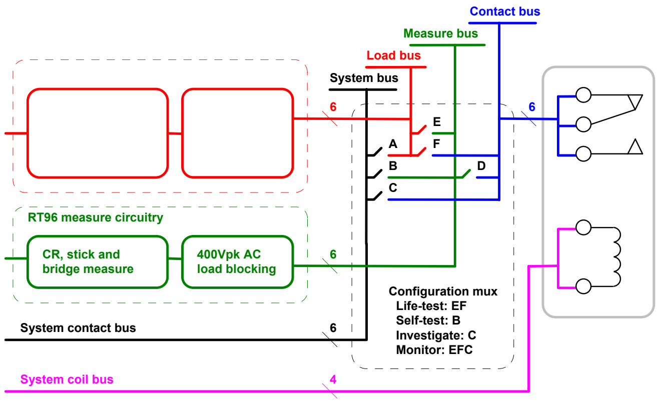



Figure 30. The electrical architecture of the RT96 showing the connection of each device contact.

Each module comprises CR, stick and bridge measurement together with an interface to optional active load circuitry. A flexible mechanical multiplexer combines these measurement, load and system buses together with the device connections and permits the system to be configured into life-test, self-test, 'investigation' or 'monitoring' modes. During a life-test, all 20 relays cycle together under overall control of a timing controller that implements a cyclic pattern pre-programmed by the test program designer and usually loaded as a pre-written test data file. This timing information controls the exact time points of the contact measurement and application or removal of the active load circuitry, causing each relay contact to experience switching under actual load conditions followed by low-level parametric measurement that is independent of the load circuitry. Although there are mechanical relay devices within the test system for configuring it into its basic testing modes (eg life-test, self-test etc.), all switching during life-testing is performed using only semiconductor devices. This load switching and measurement technique is shown in Fig 31 using a simple resistive load 'Rload', and showing only one device contact for simplicity.

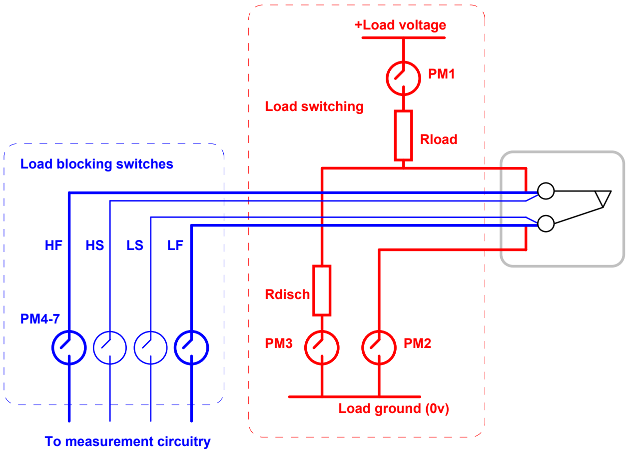



Figure 31. The use of semiconductor switches in the RT96 to switch between the contact loads and the measurement circuitry.

All switches PM1..7 in this diagram are MOSFET devices, either discrete power devices (for DC operation) or Photo-MOS relays (for AC operation). The cyclic nature of a life-test switching operation starting with an open contact is as follows:

* Connect the load to the open contact using switches PM1 and PM2 (measurement switches PM4..7 are open).
* Operate device - the contact then switches under resistive load ‘Rload’ and ‘Load voltage’.
* Close switch PM3 and open switch PM1 to ‘soft’ discharge the load circuit to ground via ‘Rdisch’.
* Open all load switches PM1..3 - device contact ‘floats’.
* Close measurement switches PM4..7 to commence low-level contact measurement procedure.
* Open measurement switches PM4..7
* Repeat this sequence again for the contact opening.

For other load types ‘Rload’ is replaced with the required components. The exact implementation of the ‘discharge’ circuit will also depend on these components.

*D. Standard life-test load types.*

A range of plug-in load types has been created to allow turn-key life-tests to the common device specifications, for example VMax, IMax and Telecom cable load types. The more demanding ‘ringing’ and ‘capacitor discharge’ telecom specification loads are also available. These load types and their origins are summarised in table II.

TABLE II
RT96 LOAD TYPES.

| **Load type** | **Description.** |
|---|---|
| VMax. | High voltage resistive switching to 250Vac, 50VA per contact [1]. |
| IMax | As Vmax but high current resistive switching to 1.25A, 50VA per contact. |
| Telecom Cable loads. | Open ended, resistive or inductive cable loads [1]. |
| ANV cable load (cyclic) | Loads, cable and switching as in specification [2]. |
| Ringing load | Subset loads, cable and switching as in specification [3]. |
| NTI Capacitor discharge load. | As specification [4]. |
| NTI Inductive load | As specification [5]. |
| NTI ‘Worst-case ringing’ load | As specification [6]. |
| NTI ‘Dial pulse condition ‘B’ | As specification [7]. |
| NTI ‘Dial pulse condition ‘C’ | As specification [7]. |

Most load types are based on specific plug-in cards allowing fast setup for a new test and where power resistors feature in the load specification these can usually be interchanged within the card allowing additional variation to V/I conditions.

*E. Software capability.*

Using the supplied control software, life-test parameters can be edited and saved to disk for later loading as standard test method files. This software provides all of the facilities of the RT96 including other support functions such as self-test, auto calibration and device investigation options. During the life-test, device data is available for inspection on the display in the form of numeric and histogram data. At intervals, this data is written to disk files designed to be compatible with a wide-range of spreadsheets and database tools. ART have developed a standard database application tool that works with these files to produce various graphical and tabular reports using a commercial windows-based relational database package.

Using the statistical software, reports and graphs of failed device performance by CR and functional failures can be quickly extracted and integrated into any windows-based word-processor.

Fig 32 and Fig 33 are example extracts from final reports showing graphical and tabular output of life-test results.

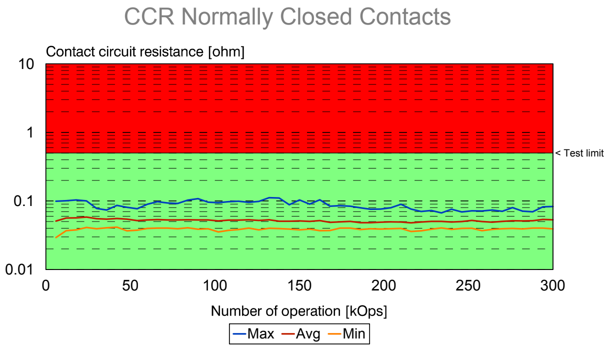



Figure 32. Example graphical output - device contact resistance, normally open contact.

| Relays: All | CR Normally Open Contact | | | Batch Details: No sample plan; No lot; 3 NOCR Fails | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Interval | Statistics (mR) | | | Switching operations by class in 1000's | | | | | | Failure rate (1000's) |
| cycles (1000's) | Mean | SD | Max | <10 mR | 10-200 | 200-500 | 500-800 | 800-1000 | >1000 mR | |
| 1 | 22.625 | 10.242 | 60.623 | 0.000 | 1000.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2 | 24.887 | 62.528 | 2194.898 | 0.000 | 999.950 | 0.000 | 0.000 | 0.000 | 0.050 | 0.050 |
| 3 | 27.095 | 101.130 | 2194.898 | 0.000 | 999.900 | 0.000 | 0.000 | 0.000 | 0.100 | 0.100 |
| 4 | 21.287 | 6.293 | 36.996 | 0.000 | 1000.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**Summary:**

| Interval | Statistics (mR) | | | Switching operations by class in 1000's | | | | | | Failure rate (1000's) |
|---|---|---|---|---|---|---|---|---|---|---|
| cycles (1000's) | Mean | SD | Max | <10 mR | 10-200 | 200-500 | 500-800 | 800-1000 | >1000 mR | |
| 4 | 23.973 | 45.048 | 2194.898 | 0.000 | 999.962 | 0.000 | 0.000 | 0.000 | 0.038 | 0.038 |

Figure 33. Example tabular output of life-test data showing statistical results for all devices on the normally open contact.

### *F. Making additional measurements during a life-test.*

The architecture of the RT96 allows for other equipment to be connected to make additional measurements during a life-test, perhaps when a failure occurs or at specified contact cycling intervals. For example the RT290 parametric test system can be connected to the RT96 and programmed to make additional timing, CR or operate and release measurements on one or more devices as shown in Fig 34.

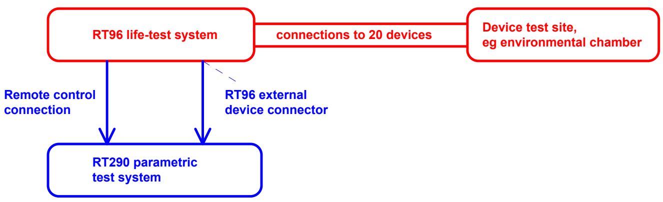



Figure 34. Example of the connection of additional parametric measurement to RT96 life-test system.

Here, the RT290 has its device connections connected to the RT96 external device connector - a system-wide bus that allows any nominated relay device connected to the RT96 to be accessed. In this mode, RT290 parametric measurements are made automatically by the RT96 routing the required device(s), removing its internal circuitry and then instructing the RT290 to make a measurement via the standard remote control serial port.

In addition to this simple external routing of a device, the RT96 system bus can also be used to monitor or measure device contact waveforms during a life-test with RT96 circuitry connected and operational.

## VII. REFERENCES.


[1] Specification IEC 255-14 Sections 4 and 4.5.

[2] 1-in-4 cycling ANV load as detailed in Alcatel Bell specification 1AB 0001 4000 DS ZZA.

[3] AC ringing load as detailed in Alcatel Bell specification 1AB 00014 0001 DS ZZA.

[4] Northern Telecom Capacitor charge / discharge load specification NPS25174-24 Fig 3.

[5] Northern Telecom Inductive load specification NPS25174-20.

[6] Northern Telecom 'Worst-case ringing' load specification NPS25174-25 page 37.

[7] Northern Telecom 'Dial pulse condition 'B' and 'C' specification NPS25174-25 pages 39 and 40.