# A Practical and Reliable Method for Detection of Nanosecond Intermittency[a]

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## ABSTRACT

**Problems associated with testing of connectors for nanosecond intermittency are summarized. Methods are described that provide a practical and reliable approach to nanosecond intermittency testing of connectors.**

## INTRODUCTION

Electrical connector reliability is vital to the performance of nearly all electronic systems. Contact intermittency can result in loss of information or even in total system failure. In an effort to address such reliability concerns, intermittency/discontinuity tests were conducted. At present, industry standards utilize test procedures capable of detecting elevated contact resistance events lasting more than 1 microsecond. Considering speed and performance of most of today's electronics devices current test specifications are inadequate and concerns have arisen that microsecond intermittency testing will not assure reliable connector functionality. Considerable pressure is building to require intermittency testing with minimum-duration detection limits in the nanosecond range. However, issues related to electromagnetic shielding and to signal transmission quality present serious challenges to valid nanosecond intermittency testing. The potential problems are:

a) Electromagnetic interference (EMI) can generate events that are interpreted by commonly used instruments as intermittency and cause a connector to incorrectly fail the test.

b) Parasitic reactances in a test specimen and the test fixture can mask short duration intermittency and cause a faulty connector to incorrectly pass.

These problems can be avoided with test and equipment specifications that are adequately detailed and technically sound. Specifications and test methods described in this paper satisfy these requirements and have been demonstrated to provide a practical and reliable approach to nanosecond intermittency testing of connectors.

## PROBLEM DEFINITION

Unlike most other electronic components, connectors cannot be permanently sealed, are susceptible to corrosion, and experience wear. Typically the loss of connector integrity results in partial or total failure of the associated electronic systems. Connector manufacturers routinely subject their products to a wide variety of environmental stress tests for quality assurance and control. Since excessive resistance or intermittency is the failure mode of electrical connectors, performance testing criteria are generally based upon contact resistance.

Contact resistance has been shown to be influenced by mechanical stress, which results in transient variations, or intermittency, in degraded contacts.[1] Short duration intermittents are often the initial manifestations of progressive contact deterioration. Steady state contact resistance monitoring offers an unlikely means of detecting the onset of contact malfunction. For this reason, test procedures have been developed and are specified explicitly to detect transient or intermittent contact events.

Environmental stress tests such as vibration or shock are designed to produce some motion at the contact interface. These

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[a] A paper on the subject matter was presented by the same authors at the 20th Annual Connector and Interconnection Symposium and Trade Show, San Jose, CA, 1995. Said paper is published in the proceedings of that conference and contains as appendix a full copy of reference 7.

mimic the forces of deterioration which cause intermittency in real-world electronic systems. During testing, a current is passed through the contacts while the voltage across the contact is monitored. Often, in order to increase the sample population size, many contacts are wired in a series string with voltage monitoring across the ends of the string. The intermittency duration sensitivity required for a majority of test specifications is designated as 1 microsecond.[2,3] On the basis of what had been promoted as the prime mechanism for the development of intermittencies, contact bounce, the 1 µs detection level seemed entirely appropriate. Calculations based upon various contact mechanical properties indicated that sub-microsecond intermittencies would be extremely unlikely, if not impossible.[4] Additionally, early published work had indicated that failures attributed to intermittencies of less than 1 µs duration had never been observed.[5]

However, as data transmission speeds increased electronic device manufacturers became more concerned about errors in data transmission — especially in the 1 to 10-nanosecond range. It became apparent that intermittency tests conducted with a 1-µs detection specification would not be acceptable — regardless of assurances that such intermittencies would not be possible. The insistence on shorter duration intermittency detection capabilities became stronger with the revelation that short duration ‘‘opens’’ in the 5- to 10-nanosecond range had been detected. W. H. Abbott reported the detection of extremely short duration intermittencies on degraded tin plated contacts.[6] The mechanism proposed by Abbott does not depend upon *contact bounce* but is instead a consequence of relative motion at the interface of partially film covered contacts. Replication of this work and confirmation of postulated failure mechanisms for this range of intermittency duration would be very useful. But in the meantime designers of high speed circuits need to have contacts and connectors tested to an adequately short intermittency duration to protect their application. AMP Test Specification 109-188 offers a corresponding procedure.[7] It describes a method for detecting contact resistance transients of resistances greater than a specified upper limit and lasting for at least a specified minimum duration selected from the set of $\{1, 10, 50 \text{ ns}\}$. The specification is intended to provide a technically sound method for connector testing with duration sensitivities as short as 1 nanosecond. A typical connector will filter intermittencies of shorter duration, so that testing for them is both unnecessary and impossible. The specification is equally valid for longer duration sensitivities such as 10 or 50 nanoseconds. Testing is essentially continuous, which is more thorough than a sampling approach.

## DESIGN CHALLENGES

Connector manufacturers have been asked to perform intermittency tests based upon established 1 µs procedures in which the term 10 ns has been substituted.[8] Using this approach problems are inevitable.[b] One of them is that test specimen conductor length causes parasitic series inductance, which filters the desired test signal with a L/R time constant.[c] This prevents the signal from ever getting to the detector. A crude design rule of thumb to avoid this effect is that test specimen wiring must be less than 10% of the signal's electrical length. According to this rule, the maximum test specimen length would be 30 m for a 1-microsecond, but only 30 mm for a 1-nanosecond signal. For instance, if the test specimen wiring is longer than 30 mm, an intermittency of 1 ns might be filtered so that it escapes detection. Thus, some provision must be made to assure that this filtering effect is not significant.[7, sect. 4.1 B] Another problem is scaled up similarly. False failure indications induced by EMI is approximately 3 orders of magnitude more severe for 1-nanosecond than for 1-microsecond testing.

Of serious concern is the fact that by necessity the test specimen conductors act as an antenna. Experience has shown that even at 1 µs EMI associated with this effect influences the measurements. Nanosecond intermittency detection is also sensitive to the problematic frequency range between 1 and 1000 MHz.

An early solution to the filtering effect, also known as masking, was to locate the detection circuitry on or near the test specimen. If this is done, special care must be taken that the detection circuitry does not experience the same stress as the test specimen. Also, testing a large number of contacts in a small area is impossible, because there is no room for all the detectors. EMI can make it impossible to pass a good connector. Finally, shielding the detector is difficult.

These disadvantages can be overcome by a remotely located detector connected to the test specimens with properly used coaxial transmission lines. Flexible coaxial cable permits the use of a heavily shielded detector, which greatly simplifies solution of the EMI problem. The shielded detector is isolated from the test specimen environment and the space it occupies is no longer an issue. The detector suitable for this technique is available in commerce[d]. Because of these advantages, the work reported in this paper concentrated on this technque. Its main procedural steps are

(1) to wire the test specimen to a coax,
(2) to connect the coax to the detector,
(3) to check detector for failure indications.

## DETECTOR REQUIREMENTS FOR SHORT DURATION SENSITIVITY

If a current is passing through the test specimen, a voltage will appear across it according to Ohm's law. A detector must be capable of supplying this current and of determining the test specimen resistance from the voltage which appears on the coaxial cable at the input. With a circuit shown in Figure 1 this is possible. Ignoring the transmission line for the moment, simple circuit analysis will provide the necessary formula for determining the test specimen resistance. Actually the correct

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[b] Conceptually, this approach could be compared with a recommendation to use a contact rated at 1 A at a current of 100 A.

[c] See the section DETECTOR REQUIREMENTS FOR SHORT DURATION SENSITIVITY.

[d] Model 32 EHD, Analysis Tech (Anatech) Corp., Wakefield MA.

use of the transmission line is critical. In this design its only effect is to add a delay as the signal travels from end to end. The logic for this follows.

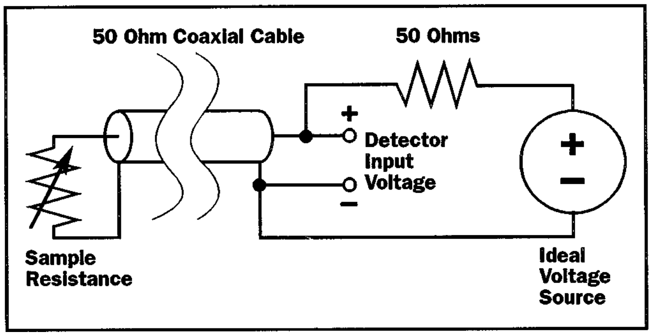

**Figure 1.** Detector input equivalent circuit.

A transmission line can transport a signal from one end to the other without significant distortion if used properly. Generally, this is taken to mean that the source and load impedances must match the transmission line characteristic impedance across the frequency range of interest. In the application discussed here, all signals originate at the test specimen. No signals will be travelling in the other direction, so the 50-ohm termination resistance for a 50-ohm coaxial cable is not required at the test specimen end. When the specimen quickly changes resistance, a quick change of the voltage results. That voltage enters the transmission line, which provides an equivalent circuit of a Thevenin-voltage source in series with 50 Ω. When the generated signal arrives at the detector, the detector provides the exact same equivalent circuit. Thus, no reflections occur, and the exact voltage of the test specimen appears at the detector, delayed by the cable transit time. Thus, the coaxial cable can be ignored in calculating the test specimen resistance as a function of time. The detector source match must be maintained from a very high frequency down to, and including, direct current.[7, sect. 2.1 C] Energy storage components, i.e., capacitors or inductors can not be a part of this input equivalent circuit without causing source match problems at either direct current (dc) or high frequencies.

## TEST SPECIMEN REQUIREMENTS FOR SHORT DURATION SENSITIVITY

The use of a nanosecond intermittency detector does not guarantee that nanosecond duration intermittencies can be detected in testing. It is also necessary to severely limit test specimen series wiring and conductor length. A good, 1-nanosecond electrical model for a series wired test specimen could be hopelessly complex. A nanosecond intermittency will be filtered differently depending upon where it originates in such a model. Both, sensitivity and duration will be affected. Some simplifying assumptions are necessary to design a test to ascertain that the test specimen will not do excessive filtering of the desired signals. If the test specimen high frequency electrical model were to be simplified to just one component, the component would be a series inductor. The transmission line can be modelled as a 50-ohm resistor. The resultant equivalent circuit is shown in Figure 2. Resistance of the specimen is assumed to be small compared to 50 Ω, which is the transmission line impedance, and is replaced by a signal voltage source.

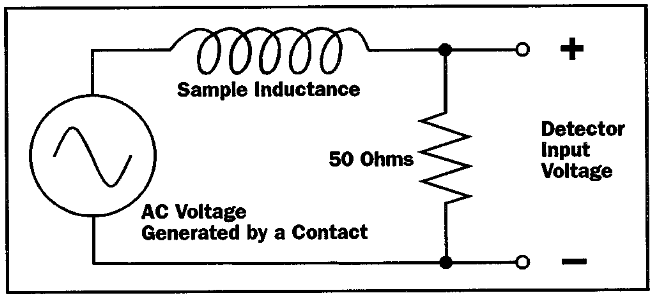

**Figure 2.** Proposed test specimen equivalent circuit.

A step change in voltage generated at the test specimen will appear across the 50-ohm resistor with a finite L/R time constant. If this time constant could be measured easily, the filtering effects of the test specimen could be restricted by the specification. One possibility would be to use a step generator and an oscilloscope. But, this would add another 50-ohm resistance to the equivalent circuit. A better and simpler technique is to replace the detector with a time domain reflectometer (TDR). It sends a voltage step down the test specimen coaxial cable and measures the reflection from the specimen. The L/R time constant will appear on the reflected step. The test specification[7, sect. 4.1 B] restricts sample filtering effects by linking this reflected waveform, with its L/R time constant, to the minimum intermittency duration desired in testing. If the time constant is too long, i.e., if there is excessive filtering, the minimum intermittency duration of the test must be increased or the test specimen must be improved.

With 1 µs intermittency detection, the only concern in test specimen series wiring is that the total resistance of the specimen not exceed the failure threshold resistance setting of the detector. Test specimens are often wired with many contacts in series, which makes testing less expensive. The test specimen inductance that results is not a problem at 1 µs. In testing for contact bounce, i.e., vibration and shock testing, lengths of wire are used to relieve stress. This wire adds about 10 nH per cm of inductance. However, in nanosecond testing, these inductances must be minimized to pass the TDR test in the test specimen preparation.[7, sect. 4.1 B] Fewer contacts in series is better. Just 2 contacts in series can, at times, introduce too much filtering for a good test. Instead of wire for stress relief the test specification recommends miniature coaxial cable right up to the test specimen.[7, Fig. 5] Test specifications for vibration and shock may have to be modified to allow the use of miniature coax. But, it still might not be possible to pass the TDR test for 1-nanosecond minimum intermittency testing, even when only one or two contacts are in series and little or no wire is used. In this case, a longer *minimum intermittency duration* must be selected from Figure 1, of the test specification.

## ELECTROMAGNETIC INTERFERENCE CONSIDERATIONS

False failure indications may be just irritating at 1 µs but at 1 ns they can be fatal to the technique. Theoretically, EMI cannot be totally eliminated but must be reduced to a level sufficient to generate confidence that false failure reports will be very unlikely. The preferred solution is to locate all equipment involved in a test in a shielded room. This could be an expensive requirement when a large vibration facility is involved. Shielding the test specimen appears to be another ideal solution but is usually not practical. If the test specimen is inaccessible to EMI, it is also inaccessible for application of test stresses. The shield is being stressed with the test specimen, and may be protecting the specimen. Shield design selection and grounding to reduce EMI requires special skills which often call for outside consultants. Everything seems to be a far field problem at 1 GHz, which many will find unfamiliar. Electrostatic discharge (ESD) involving hand held metal is a particularly difficult EMI problem, even at low voltages and great distance.

## DETECTOR

The test specification[7, sect. 2.1 A] contains a modest EMI immunity requirement for the detector. It is the same as that for ordinary personal computers sold in Europe and was chosen because electrostatic discharge (ESD) testing is inexpensive, easily done, and includes some very high frequency stresses. TEMPEST level shielding performance is recommended, but requiring it in the specification would mean expensive testing. The specified test is a reasonable, once only expense and eliminates a major category of EMI problems.

## INTERCONNECTS

Coaxial cable is by definition shielded. Miniature coaxial cable is specified for connection to the test specimen because it is flexible, light, and allows many connections, e.g., detector channels to a small connector. However, it does not have sufficient shielding to avoid frequent problems by itself. Thus, the specification has only a short length of it used between the test specimen and a patch panel.[7, Fig. 5] Braid-over-foil shielded RG-58 is also not shielded well enough for this test. An ESD discharge in the same room where the test specimen is located can induce 0.5 V through the cable, even when the specimen is perfectly shielded. Only RG-223 double braid cable shields sufficiently and has low enough attenuation at high frequencies. It is used between the detector and the patch panel. The EMI problem is now eliminated everywhere except between the patch panel and any metal used in fixturing.

## TEST SPECIMEN WIRING

Up to this point shielding has been used to completely eliminate coupling at the detector, and between it and the patch panel. Attempts to perfectly shield the test specimen are confronted with difficulties. Usually a ground loop exists that places a large EMI voltage between the test specimen and any fixturing metal, for instance that used on a vibration machine. Also between these is a parasitic capacitance through which EMI current is introduced directly into the test specimen. This can be reduced by connecting the miniature coaxial cable shield to the fixturing metal. However, when this is done, large EMI currents will flow down the miniature coaxial cable shield, which is not a good shield. The solution offered in the AMP test specification for low frequencies is to introduce a low inductance ground strap[7, Fig. 5, label E] to carry EMI currents around the test specimen to the patch panel previously mentioned.

At high frequencies, this one solution is insufficient or ineffective. At low frequencies, a ground loop must enclose a large area to pick up large amounts of energy. At 1 GHz, however, because of the parasitic capacitance between test and fixturing metal, the smaller loop formed by the fixturing metal, the ground strap just mentioned, and the miniature coaxial cable, is big enough to develop a large EMI voltage across this capacitance. To eliminate this problem, a high frequency ground[7, Fig. 3, label D] is introduced. It functions similarly to the low frequency ground connection described above. The effectiveness of this ground is highly dependent upon fixturing and test specimen geometry as well as the skills of the test engineer.

The test specification contains also two other precautionary notes[7, sect. 4.2]. At a frequency of 1 GHz a quarter wave antenna is only 7.5 cm (3 inch) long. Thus, any contact with a few cm wire attached to it will be carrying high frequency EMI. Crosstalk or mutual capacitance will couple a small percentage of this energy into monitored circuits, causing false failure indications.

Finally, it must be pointed out that the actual test specimen circuit loop area has to be kept small. It can pick up EMI directly from ambient high frequency magnetic fields. Test specimen filtering effects, discussed earlier also become worse with a large loop area.

## CONTROL CHANNELS

The precautions of the last section greatly reduce but do not eliminate EMI. Another strategy is necessary to identify possible EMI. Control channels are dedicated to monitoring loops of wire which have no contacts to fail, but are designed to be more sensitive to EMI than the test specimen. They must be *far* more sensitive to EMI than a typical test specimen because the high-frequency ground previously described can vary greatly in effectiveness from test to test or from specimen to specimen. The strategy applied for designing the control channels consists essentially of doing just the opposite of some of the precautions listed in the previous section. This means that the high frequency ground be eliminated. The high frequency ground loop is completed by a connection from the control loop to an unused test specimen, providing the parasitic capacitance to the fixturing metal.[7, Fig. 5 B, Fig. 6] For the control channels the test specimen loop area is deliberately kept large. If a control channel registers an intermittency, one presumes that all events registered during that polling period may have been EMI induced.

## TRIP THRESHOLD RESISTANCE AND CURRENT

As in other specifications, in AMP 109-188[7] an intermittency is defined as a test specimen resistance which exceeds a given trip threshold resistance for a given duration. The duration sensitivity of the detector must be better, i.e., be smaller than the specified duration. For the given trip resistance, AMP 109-188 recommends 10 Ω using a current of 100 mA.[7, sects. 1.3, 2.1 B] These values were deliberately selected high because of potential EMI effects. EMI generates a voltage at the detector input that is not influenced by the detector current setting. Experience by the authors suggests that a trip voltage setting of 0.1 V would result in serious EMI problems, 0.5 V would work much of the time, and 1.0 V would make the test relatively immune. After selecting 1.0 V, the lowest trip resistance will occur with the highest test dc current. Previous 1 µs duration testing was done with 100 mA current. A potential of 1 V and a current of 100 mA yield the recommended 10 Ω trip resistance. This magnitude of resistance increase appears consistent from the standpoint of noise margins associated with digital devices.[9] Contact resistance fluctuations of this order would be expected to introduce signal errors.

## POLLING PERIODS IN TESTING

When the detector is checked by an operator, or *polled* by a computer, it indicates that either no intermittencies, or that one or more intermittencies have occurred. If a control (EMI) channel registers an event during this time, all other events on other channels must be presumed to be EMI induced and not contact failures. Thus, if a test is polled only once, a single EMI event would invalidate all, i.e., 100% of the data. If the test comprises 1000 polls at equal time intervals, one EMI event invalidates only 0.1% of the data. The Anatech 32 EHD detector can be polled by a personal computer in 2-second intervals when EMI is suspected to be a problem. The resulting data record is called an *event history*. It can provide other clues to separate EMI effects from real contact failures. For instance, intermittencies can often be expected to increase in frequency with test duration. Or intermittencies may occur at certain vibration frequencies during mechanical testing. Likely, EMI is going to follow some other pattern.

## DETECTOR REQUIREMENTS AND EVALUATION

If tests are to be conducted outside a shielded room, considerable effort must be expended in test specimen wiring and providing control channels. Fortunately, detector performance is primarily determined by design. In general the critical high bandwidth and electromagnetic tests needed to certify detector performance need only be performed by the manufacturer of the detector. These should be repeated after any servicing. Regular calibration should only be necessary to confirm the dc trip resistance, which is performed at relatively low cost. In AMP 109-188 three tests are recommended for the equipment manufacturer.[7, sect. 2.1] They are for shielding (ESD), for duration sensitivity and for source match, the latter at dc and with a TDR.

As mentioned before in the section DETECTOR, the shielding test corresponds to the European Community ESD requirement for computers. Only an ESD *gun* is required to do the test. Anything that the gun can deliver to any part of the detector shall not cause a failure indication. If the detector trip voltage can be adjusted, it is recommended to reduce it to 0.1, 0.05 V or less, and to advise the user that the detector passes this test down to the trip voltage tested.

The duration sensitivity test[7, sect. 2.1 D] is very similar to a TDR test. The minimum voltage of a 1-nanosecond duration pulse that will register an event is compared to the same test done using dc. The pulse amplitude is not measured at the detector input because imperfect source match changes shape and amplitude of the arriving pulse.

Finally, a detector source match test will confirm that the transmission line problem was correctly solved and that good microwave design technique was used. Since time domain signals are measured by the detector, the most meaningful source match data would come from a TDR-like test conducted at the detector trip point which is 10 Ω at 100 mA. However, an alert test engineer will spot a hazard in this test. The recommended test specimen current during testing is 100 mA, which few TDR's can sink without damage. In the Anatech 32 EHD reducing the test specimen current does not change the source match in its linear region. Therefore, the TDR test may be done at a lower current. Another possible problem with some detector designs is that the TDR puts 50 Ω, not 10 Ω, on the detector. For example, the Anatech 32 EHD input is operating in its linear region with 10 Ω, but is in a nonlinear region at 50 Ω and 100 ma. Using a network analyzer for TDR solves these problems. A 10-ohm resistor is placed on the bias port of the test set, and the bandwidth is selected to give the desired effective rise time.

A dc source match test is also required, because the above does not check source match down to dc. To illustrate what can happen, these authors once had a detector that would not trip if the test specimen resistance was increased slowly to an open circuit. Clearly, the voltage at that detector's input did not correspond to a unique value of test specimen resistance, as would be the case for the equivalent detector input circuit of Figure 1. To test source match at dc, measure the voltage across a known resistor value between 1 Ω and 10 Ω while the resistor is connected to a detector input. Do the same for a second known resistor value. The source resistance can be found by solving the two equations with two unknowns describing this experiment. The calculated resistance should equal 50 Ω. If one of the resistors is higher than 10 Ω including an open circuit, the detector input may be operating in a non-linear region, giving erroneous test results.

## IMPLICATIONS FOR PRACTICAL TESTING

AMP 109-188[7] gives a high level of performance and confidence for both the vendor and the customer of a tested product. The laws of physics exact a cost for this, though. The most obvious difference from previous 1-microsecond testing is that series wiring of the test specimen is greatly restricted because of the need to reduce filtering effects. Typically, for 1 ns, only two contacts in series are possible. Thus, with the same effort only a small percentage of the number of contacts can be tested at 1 µs as done in the past. Wire has previously been used for stress relief. To pass the test specimen TDR test, miniature coaxial cable may have to substitute. The EMI loops for the control channels and the use of polling periods to identify EMI add complexity, but little additional work. Not every problem can be anticipated by a test specification. Necessarily, there will be some variation in testing quality depending on the skill of the individual test engineer. This must be expected particularly when making the high frequency ground. Sites with much EMI will be at a disadvantage. Wintertime and in general periods of exceptionally low relative humidity usually cause additional EMI from ESD.

Most of the complexity of the specification[7] discussed here is applies when testing is done outside a shielded room. If it is done inside a properly shielded chamber, there is no EMI and the only technical challenge is the test specimen TDR test for filtering effects.[7, sect. 4.1 B] Another situation that would minimize the EMI threat is to set up a test fixture where no metal exists within 10 cm of the test specimen wiring. In this case, the high frequency ground becomes unnecessary.

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Dr. Sofia worked for the Draper Laboratories on inertial guidance platforms for the Trident Missile Program under the Department of the Navy. In 1980 he began consulting independently for military subcontractors and computer companies in the New England area. In 1983, he founded Analysis Tech (Anatech), a company concentrating on the development and manufacture of electronic test equipment for reliability testing of electronic equipment. Anatech currently offers specialized systems and accessories in the areas of interconnect reliability testing and semiconductor thermal testing.