Connector Reliability Testing: A Dualism of Testing Needs

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Modern electronic circuits are placing new and varied demands on connectors. Since connector reliability tests must ultimately match the needs of the electronics which will use these connectors, test specifications and methods can be meaningfully viewed from the electronics perspective, treating the connectors as "black boxes." Different types of electronic circuits have particular sensitivities to variations in the electrical characteristics of connectors. These sensitivities represent pathways for product malfunctions precipitated by connector deterioration. This article deals with the specifications of some general electronic families and how these characteristics relate to potential connector-induced malfunctions. A consideration of these issues is relevant to the evolution of new specifications and methods for connector reliability testing.

Typical connector reliability tests involve accelerated aging with some criterion for failure or wearout. Typical aging mechanisms include insertion, vibration, thermal cycling, thermal soaking, and corrosive environments, among others. Ideally, this abuse is administered while the specimen connectors are constantly monitored for deterioration. The most common indicator of electrical deterioration is contact resistance change at a constant, specified current. Connector failure is generally flagged by a resistance change exceeding a specified threshold. Further test specifications on this resistance change generally require a minimum duration for recognition, i.e., resistance changes exceeding the threshold for durations less than this minimum are ignored or not detected. Thus, the primary connector test parameters considered here are:

- Contact current
- Allowable contact resistance change
- Duration of resistance change

These test parameters are considered solely with regard to the operation of the electronics, ignoring other test parameters which relate to the physical mechanisms of contact resistance variations. Without addressing the validity of contact-physics test parameters, this analysis is single-mindedly conducted from the perspective of the operational requirements placed on connectors by the electronics considered in general groups.

> **"As circuits evolve and advance, so must connector tests and specifications."**

Two Types of Lines

Varying resistance in a connector gives rise to varying voltage drop in the conducting line according to Ohm's Law. These variations in signal strength constitute noise sources on the line, much the same as crosstalk or ground-loop noise, when viewed from the attached active circuitry. When this connector-induced noise exceeds the internal limits of attached circuits, malfunction results. Noise levels are conventionally expressed in voltage terms. The connector-noise (voltage level) is simply the product of the contact resistance and current and is greatest at the maximum current in the line for a given connector resistance change.

Connector-induced noise can be described by its frequency content (bandwidth) and noise-voltage amplitude. The sensitivity of an active circuit is likewise characterized by its signal bandwidth and acceptable noise amplitude. Comparison of the characteristics of the noise and the circuit sensitivity determines the potential impact of the noise on the electronics. For example, if the bandwidth range of the noise is greater (i.e., higher frequency content) than the highest response frequency of the active circuitry, the noise will essentially be invisible, i.e., masked by the relatively lower bandwidth of the circuitry. Similarly, if the ratio of the signal amplitude to noise amplitude is less than the maximum signal-to-noise ratio specification allowed by the active circuits, the noise will have little effect on the operation of the circuit. By categorizing circuits and their sensitivity characteristics, some general conclusions about connector testing requirements can be made.

If we consider the functional requirements of circuits utilizing connectors, conducting lines can be divided into two categories: digital lines and analog/DC lines. The class of digital signal lines is a well-defined category with readily available specifications on circuit requirements. By contrast, the analog/DC lines are very diverse in application and difficult to generalize according to functional or operational requirements. These two categories of lines are discussed in detail with summarized comparison below.

Digital Lines

Digital circuits have well-defined specifications for the three test-related parameters described above. The noise sensitivity or voltage noise margin for digital circuits is defined as the difference between the input logic level, high or low, V_{IHmin} or V_{ILmax} respectively, and the guaranteed worst case output (V_{OHmin} or V_{OLmax}) for those inputs. There are two distinct margins, one for high levels and one for low levels:

high noise margin = $V_{OHmin} - V_{IHmin}$

low noise margin = $V_{ILmax} - V_{OLmax}$

where V_{OHmin} is the minimum value for a high output and V_{IHmin} is the minimum value for a high input. Likewise V_{ILmax} and V_{OLmax} are the maximum values for low inputs and outputs, respectively. Clearly, the range of low to high inputs must be straddled by the comparable outputs in order for switching to be possible at all. Typically, the high and low noise margins are nearly equal.

The worst case noise margin is comprised of the remainder of the typical noise margin after subtracting the effects of chip max/min threshold variations and thermal differences under worst case supply conditions. This guaranteed minimum noise margin is substantially narrower than the typical noise margins. These worst case noise margins are presented for a number of digital circuit families in table 1.

For consideration of digital line performance, the current in the line is significant since this current acts through the connector resistance to generate noise voltage. The second column of table 1 lists the maximum output gate current allowable for each logic family listed. For this analysis, it is assumed that this maximum current is the current flowing through a "worst case" digital line connector. It should be noted that this is a worst case condition and that typical currents would be less than half this maximum.

Dividing the minimum, worst case noise margin by the maximum connector current yields the minimum connector resistance equivalent to the noise margin. This calculation has been performed for each logic family and the result presented in the third column in table 1. "Minimum Resistance" represents the connector resistance which creates connector-induced noise equal to the minimum noise margin at maximum gate current. Connector resistances less than these values of "Min R" cannot cause malfunctioning of connected active circuits. Thus, for connectors in digital applications, resistance change test-specifications should range in the ohms and tens-of-ohms level.

The noise bandwidth sensitivity of digital circuits is related to the maximum clock frequencies that can be utilized. Since edge triggering on clock cycles can occur twice each cycle, the half-period of the maximum clock speed provides a good indicator of the minimum duration noise event which could be recognized and impact the operation of the circuits. The fourth column of table 1 presents this information and is labeled "Min Cl HPer."

TABLE 1 — DIGITAL SIGNAL LINES

Logic Family		Min. Noise Margin	Max I	Min(ohms) Resistance	Min. Clock Half period
Bipolar	TTL	300 mV	16 mamp	19	20 ns
	LS	300 mV	8 mamp	38	45 ns
	S	300 mV	20 mamp	15	5 ns
	AS	300 mV	20 mamp	15	4 ns
CMOS	HS	1.25 V	20 mamp	63	28 ns
ECL	10k	125 mV	50 mamp	2.5	2.8 ns
	100kH	150 mV	50 mamp	2.5	2.0 ns
	III	115 mV	40 mamp	2.8	1.0 ns

Conclusion: Test for resistance changes >1 ohm with duration sensitivity <20 ns

This suggests that connector testing for digital lines should be conducted with duration sensitivities in the low nanosecond range. This analysis yields the conclusion that for the category of digital signal line connectors, test specifications should be limited to the range of "ohms" of resistance change with event duration detection in low nanosecond range. This conclusion is sharply distinct from the case of analog/DC lines, as will be shown in the following section.

DC-Analog Lines

DC-analog lines are not nearly as well-defined as the digital class. This category includes the complete range of analog signal electronics as well as low frequency and DC power supply lines. The range of currents in this category encompasses over twelve orders of magnitude from picoamps to amps. The range of noise amplitude sensitivities extends from microvolts to volts.

Unlike the digital case, there are great varieties of circuit design implementations that will enhance or reduce circuit sensitivity to connector resistance variations. Given the diversity of this circuit class and its extreme design-dependency, it is difficult to formulate a relationship between currents and sensitivities to noise amplitude and bandwidth, and thus the analysis will be far less comprehensive than the digital case. It should be noted that in general, higher currents are associated with lower sensitivity bandwidths and higher noise margins.

Considering high speed linear integrated circuits, some of the fastest currently have bandwidths in the 10 MHz range with gain falloff limiting most to a usable 1 MHz bandwidth. Maximum currents in this category range up to 100 milliamps with corresponding sensitivities in the millivolt range. A more typical maximum current of 10 milliamps is matched with typical sensitivities in the 10 microvolt range. In either case, sensitivities are limited to milliohm range connector-resistance variations.

Other types of analog circuits could be considered for case study. Microwave components such GaAs FETs with bandwidths in the gigahertz range are actually covered by the dig-

TABLE 2 — SUMMARY COMPARISON

Analog/DC Lines	Digital Lines
1) Narrow Noise Margins: 0.01% or Less	1) Wide Noise Margins: 2% or More
2) Maximum Currents: Greater Than 100 milliamps	2) Maximum Currents: Less Than 50 milliamps
3) Range of Design Options: a) Line Parallelism b) Reactive Loading	3) Relatively Limited Design Options to Reduce Effect of Connector R Variations
4) Limited Bandwidth Gains: Less Than 10 MHz	4) Constant Gain at Bandwidth: Greater Than 500 MHz
5) Implies Connector Testing: a) R Changes in 1 to 100 Milliohm Range b) Duration Sensitivities: Greater Than 0.1 μs c) Ignore "Shorter" Duration Changes	5) Implies Connector Testing: a) R Changes in 1 to 100 Ohm Range b) Duration Sensitivities: 1 to 20 ns c) Ignore Smaller R Changes

ital line category since lower currents render them insensitive to small resistance changes.

Another interesting example is DC supply lines to high speed digital circuits where currents can range greater than 10 amps. Here, capacitive loading is the design rule which dramatically reduces the bandwidth of connector resistance changes to a fraction of a megahertz. The case of high frequency analog communication equipment, UHF, microwave, etc., falls in the category of analog/DC lines since the actual signal (not carrier) bandwidths are quite low. Other examples can be cited which are matched by either the digital or analog/DC line class.

Other examples could be enumerated but would not alter the following conclusion; connector reliability testing for analog/DC circuit lines *could* be justified in the milliohm range with test sensitivities in microsecond range. "Could" is emphasized here since this is not a comprehensive argument for the necessity of testing in the milliohm range but rather a justification of a lower test limit. This is in sharp contrast to the digital case where significant resistance thresholds are 1000 times greater and sensitivity durations are at least 100 times less!

Connectors should be tested under conditions derived from the demands placed on the connectors by the electronics using them. Connector test specifications would then be a distillation of general electronic circuit specifications and usage. As circuits evolve and advance, so must connector tests and specifications.

Two distinct, complementary types of connector tests are suggested from this analysis. The most stringent requirements for these two categories are summarized in table 2. When performed as a complementary pair, these tests fulfill the electronic requirements of nearly all connector applications. It should be emphasized that these conclusions are based on a "user perspective" rather than on the physics of contact degradation. This latter approach provides insights into designing more reliable connectors but ultimately the demands of the connector user must be met through test specifications. This dualism of connector test needs is central to modern application.

fication program is a good system, it can still fall victim to counterfeiting. "Unqualified companies will actually use our name and stamp their part (as qualified to military specification)."

The counterfeiting of connectors qualified to military specifications recently came to light when the president of Inter-Conn Electronics, Inc., Anthony Walk, was indicted by a federal grand jury on two counts of conspiracy and one count of interstate transportation of money obtained by fraud. After McDonnell Douglas suspected that parts obtained from the firm for use in the Apache Helicopter were counterfeit, an investigation was begun by the Office of the Inspector General, Defense Criminal Investigative Services of the U.S. Army Criminal Investigation Command and the Federal Bureau of Investigation. Last month, Walk pled guilty and was sentenced to a three year term in federal prison; he also was ordered to pay approximately $140,000 in restitution and fines and was enjoined from entering into government contracts for five years, among other penalties.

There are many inducements to producing military connectors but also potential pitfalls. The military connector is a limited production item in contrast to the high-volume, repetitive nature of the typical commercial connector. Military production, for programs like the landing craft air cushion (LCAC), the V-22 and the F-18, are scheduled for as few as one system a month. In the short run, business is intermittent; one unit a month could be authorized. And, in the military environment, regardless of the quality of service provided, the government must request at least two sources to assure competitive bidding.

A benefit of the specification process to the manufacturer is that after the initial financial outlay for military qualification, the connector is much in demand in the commercial environment. According to Aiken, "If you have a $50,000 piece of equipment, you want a good connector. The '97 Series,' now very inexpensive, was developed as a MIL-C-5015 forty years ago. Now it is used on bowling pin equipment and for flash photography. The MIL-C-55305 card edge connector is used on gas pumps. It is a high reliability connector for the military. It has gas-tight joints for industrial gases, low insertion forces and it will mate and unmate 20,000 times."

Among the benefits to the OEM are asurance of quality and the cost-containment benefit of having multiple sources from which to obtain the connector. "The military connector is a multiple source connector," O'Hirok said. "You have good competition, so the price is down to where it becomes attractive not only for military procurement, but for the commercial and industrial side — the OEM doesn't have to invest a lot of money in evaluating, because it is known and qualified. Knowing he has multiple sources, the buyer feels very comfortable making that procurement."

"Although sometimes a military part may have too many 'bells and whistles,'" O'Hirok said, "there are good reasons commercial purchasers, like machinery and bio-medicine equipment manufacturers, buy military grade connectors."

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