The Test, Usage and Maintenance of Power Switching Subsystems

Kevin Paton

Teradyne, Inc.
North Reading MA
Kevin.Paton@teradyne.com

Abstract — **Unlike signal switching, power switches have significant minimum operational requirements for both voltage and current. These minimum requirements affect usage in test programs and self test approaches. This paper will discuss the considerations necessary when testing power switches or when using power switching in test programs. In addition, techniques will be described which can reduce or remove build up of deposits, improving switch operation.**

I. INTRODUCTION

Unlike signal switching, power switches have significant minimum operational requirements for both voltage and current minimum requirements affect usage in test programs (TPSs) and self test approaches. In addition to TPS usage and testing considerations, power switches must also be maintained since they have a tendency to build up deposits on their contacts which can degrade the characteristics of the switch. However, there are techniques which can reduce or remove build up of deposits, improving switch operation.

II. POWER SWITCHING SPECIFICATIONS

When creating a system self test or laying out the paths to be used in a test program, the test engineer needs to consider the types of signals or power that will pass through the various switches to determine if the switch specifications line up with the actual requirements of the self test or the test program. When reviewing switch specifications the usual ratings that one would investigate include capabilities such as maximum power, maximum voltage, maximum current and path resistance. However, one specification that often goes unnoticed is the minimum contact rating. From Wikipidea "The minimum contact rating is based on what is known as the "wetting current" (or *sealing current*) is the minimum current needing to flow through a newly-closed mechanical switch or relay in order to break through any film (contact oxidation) that may have been deposited on the switch contacts while open. The film (contact oxidation) occurs often in areas with high humidity" [1]

The reason this rating is important is that any time a signal, either complex or DC, is transmitted through a switch and that signal has current and / or voltage levels less than the switch's minimum contact ratings it can lead to unreliable operation (the reasons for this will be described below). Yet many engineers do not even consider this rating. Some switch vendors even leave this rating off of their published switch specifications

however, it is critical that the test or TPS designer obtain this specification because it is an important factor in the design of the test. If it is not in the standard published datasheet then the switch vendor should be approached to supply this specification.

One key characteristic that affects these ratings is the relay contact material. Switches that handle up to 3 Amps will typically have some form of gold plating on their contacts. If is the switch supports between 3 Amps and 5 Amps, the gold plating tends to be an option but above 5 Amps the switch contacts will be constructed of some other more robust metal, such as silver or tungsten, which is not quite as good a conductor as gold but can tolerate the higher currents being switched.

The following three tables contain specifications for different switch types, which illustrate how the minimum contact rating can vary based on the current carrying capabilities of the relays involved. These tables contain specifications for signal switching with very low minimum contact ratings to high power switching with much higher current and voltage minimums.

Table 1 shows the specifications for a signal switch module. Note that the maximum current value is only 2 amps and the minimum contact rating of the signal switch is very small at 10mV and 10uA.

GENERAL SPECIFICATIONS	
MODEL TYPE	Multiplexer
CHANNELS	64 x 1
VXI DEVICE TYPE	Register Based
VXI *PLUG&PLAY* WIN95/NT	Yes
SWITCHING TIME	< 3 ms
RATED SWITCH OPERATIONS	
Mechanical	1×10^7
Electrical	1×10^6 (Full Load)
POWER SPECIFICATIONS	
MAXIMUM SWITCHING VOLTAGE	300 V ac rms, 300 V dc
MAXIMUM SWITCHING CURRENT	2 A
MAXIMUM SWITCHING POWER	60 W dc, 125 VA
DC PERFORMANCE	
PATH RESISTANCE	< 0.5 Ω
INSULATION RESISTANCE	$> 1 \times 10^9$ Ω
MINIMUM CONTACT RATING	10 mV dc, 10 µA

Table 1 - Vendor signal switch specification sheet

The next "level" of switches are low power switches, which operate from 3 amps to 5 amps. It is important to note that although switches with these specifications are sometimes used for signal transmission, doing so uses the switch outside of its specified operating area. This type of switch will have a minimum contact rating that is higher than the signal switch, a

rating of 5V and 10 mAmps is common. These switches with maximum current values between 3 amps and 5 amps may or may not have gold plated contacts. Relays that operate in this range may offer gold plating as an option but this option is transparent to the end user and is dictated by the switch module vendor which adds some difficulty for the test engineer when determining if a cleaning approach should be employed.

One characteristic of this type of switch is that if the contacts are not gold plated, their ability to deal with signals below the minimum contact rating is not very good. But when the switch contacts are gold plated the switch transmission of these "below minimum contact ratings" signals can be quite successful. The reason for this is that the gold plated contacts, if not abused with hot switching, will be more resilient to oxidation build ups and the quality of the transmission of low power signals will be more consistent over time. If the contacts are not gold plated then the transmission capabilities can deteriorate over time although this situation can be remedied if a cleaning technique is employed.

Table 2 contains the specifications for a high current power switch. Note that the maximum current is 16 amps and the minimum contact ratings are much higher at 12V and 100 mAmps. It is not uncommon for power switches to have a minimum contact current rating as high as 1Amp.

GENERAL SPECIFICATIONS	
MODEL TYPE	Power
CHANNELS	20 SPST
VXI DEVICE TYPE	Register Based
VXI*PLUG&PLAY* WIN95/NT	Yes
SWITCHING TIME	< 10 ms
RATED SWITCH OPERATIONS	
Mechanical	1 x 10⁷
Electrical	1 x 10⁵ (Full Load)
POWER SPECIFICATIONS	
MAXIMUM SWITCHING VOLTAGE	400 V ac, 125 V dc
MAXIMUM SWITCHING CURRENT	16 A
MAXIMUM SWITCHING POWER	300 W dc, 4000 VA
DC PERFORMANCE	
PATH RESISTANCE	< 0.1 Ω
INSULATION RESISTANCE	> 1 x 10⁹ Ω
MAXIMUM THERMAL OFFSET / CHANNEL (HI-LO)	< 50 µV
ISOLATION	> 1 x 10⁷ Ω
MINIMUM CONTACT RATING	12 V dc, 0.1 A

Table 2 - Vendor signal switch specification for a high current power switch

A. Minimum Contact Rating

The materials used to construct power relay contacts are typically metals such as tungsten or palladium and alloys such as silver/nickel. These metals tend to oxidize in a very short period of time even in a sealed relay. This oxidation increases the resistance across the contacts so it is important that it is removed for optimal operation of the switch. To do this a minimum voltage and current combination must be applied which causes electrical and thermal destruction, thus eliminating the layer of contaminants.

This electrical destruction is in the form of an arc or a spark at lower voltage and is known as "A-fritting". The electrical destruction forms a thin hole in the oxidation layer which allows current to flow. The resulting current flow is known as "B-fritting" and this flow generates the thermal destruction that removes the rest of the contaminants.

Figure 1 shows a graphical depiction of the electrical and thermal destructive effect. In this graph the two types of fritting are clearly demonstrated along with the affect on the

impedance across the switch contacts. On this particular switch A-fritting occurs when the signal across the contacts hits approximately 330 mV and completes when the current hits approximately 0.4 amps at which point the voltage level drops to a steady 0.18 V regardless of the level of current that is supplied.

This graph also depicts the affect that the fritting has on the path resistance. Initially there are 1.5 ohms across the switch but after A-fritting this immediately drops to around 0.5 ohms. As more current flows, B-fritting causes the contact resistance to drop even further.

Note the initial resistance of 1.5 ohms drops to 19 mOhms after fritting (From Tyco Automotive app note)
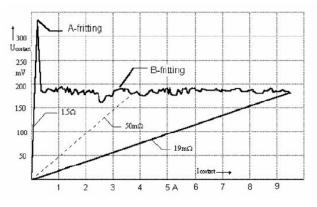

Figure 1 - Affect of fritting

B. Self Test

Typically, when a designer starts looking at switch module self tests within a system they produce a layout in which they bring a DMM to the receiver interface and use a jumper pattern across the switches to measure the switch module relays for both opened and closed resistances. This approach works well for signal switching but when testing power switches, using a standard DMM approach can lead to problems.

As shown in Table 2 the minimum current needed to ensure relay closure on that particular power switch was 100 mAmps and 12V. However, when making resistance measurements the typical DMM uses voltages and currents that are much smaller than the switch's minimum contact rating. Table 3 shows the current and voltage values used by several popular COTs instruments when measuring resistance at the lowest meter range, the range used to make the closed relay measurements. Note that none of these modules come close to the 12 volts, 100 mAmps necessary to meet the minimum contact resistance specification for this switch.

Meter	Current	Voltage
Teradyne Ai760	1mA	100 mV
Agilent 1412	1mA	100 mV
Agilent 3458	10mA	100 mV
Teradyne Ai710	100mA	500 mV

Table 3 – Current and Voltage Levels Used by Various DMMs When Making Low Range Resistance Measurements

Given this information the only practical way to reliably test power switches is to use a DC power supply to source the

required voltage and current levels. Most testers offer some form of off the shelf DC power supply that provides internal voltage and current read-back capabilities, required by this self test approach.

In the test configuration illustrated in Figure 2 a DC power supply with internal measurement capabilities is connected in a configuration which allows testing of 5 individual switch modules. A load resistor is placed across the DC power supply allowing the power supply to be tested before any relay verification is done. In the design, a precision (0.5%) 100 ohm, 25 watt load is chosen to allow the best combination of voltage and current verification of the supply. The supply used is a 35V, 8.5 amp supply so the full voltage of the supply (35V) can be verified and the current can be tested to approximately 350 mAmps. If the power supply test fails then no switch tests are run.

An important aspect of having the 100 ohm load across the DC power supply is that it provides the means to factor out the error in the power supply measurement circuitry. This test approach uses the DC power supply to measure the current passing through the relay test paths but on many power supplies the amount of specified error can be significant enough so that using a DC power supply is impractical, in some cases reaching 80% error. To overcome this problem an initial measurement is made by setting the DC power supply to the test voltage that will be used in the relay test which in this case is 12 volts. In an ideal set up this would result in 120 mAmps across the 100 ohm load. By using the same test voltage and highly accurate load resistors, the resulting current measurement across the 100 ohm load will provide an offset to be used for all relay path measurements. For example, if the calculated expected value is 120 mAmps but the initial test result is 100 mAmps, adding 20 mAmps to all relay test result calculations will factor out the power supply and load error.
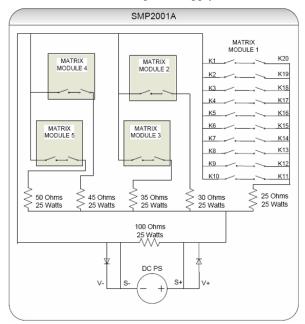

Figure 2 - Self Test Layout using Single DC PS to Test 5 Modules

The test configuration in Figure 2 allows the 20 switches per module to be tested by one power supply. This configuration is robust however, if a path is stuck closed, an alternate means must be used to determine which switch module is faulty. To help isolate this type of failure down to the module level different load resistors are used for each module under test. If there is a stuck closed path the module will be indicted based on the calculated path resistance. This would be caught during the initial test when the power supply is tested standalone across the 100 ohm load. If a switch path is shorted the load associated with that module would then be in parallel with the power supply's 100 ohm test load and the resulting current allows the test program to mathematically determine the faulty module. Because of the possibility of a shorted path it is important that a reasonable current limit value is chosen during this initial test to eliminate the possibility of damage to the test circuitry or the module under test.

C. Test Limits

When calculating the test limits, the first step is to determine the expected current through a perfect path. Table 4 contains values particular to the first module in Figure 2, which has a 25 ohm load attached resulting in an expected current of 0.60 amps ($12V/(100\Omega\|25\Omega)$). If the maximum relay path resistance to be allowed is 3 ohms the low limit would be:

- Test Limit = Vin / (((R_PS_load || R_module_load) * (1+R _load_error)) + R_test_limit)

- Test Limit = 12v / ((20 Ω *1.01) + 2 Ω)

- Test Limit = 541 mAmps

Calculations for Relay Testing								
Vin	PS Load	R2	R1//R2	Curr R1	Curr R2	Curr Total	Power R1	Power R2
12V	100Ω	25 Ω	20 Ω	120 mA	480 mA	600 mA	1.44W	5.76W

Table 4 - Key Voltages and Currents in the Test Circuit

On the high limit side the only factor which should allow the measured current to go above the 0.60 amp expected current would be an error in the 25 ohm module test load and since all other sources of error would have been factored out in the initial current test. This would occur if the 25 ohms load was less than 25 ohms. Using a 1 Ω limit would produce an upper value of 619 mAmps.

- Test Limit = 12v / (100 ||(25 Ω - 1 Ω)) = 619 mAmps

D. Relay Cleaning

In the power relay specifications section, the effect that "fritting" has on clearing the relays of contamination was discussed. In some situations the buildup of contaminants on power relays can become significant enough that a method is required to rectify the problem. To deal with this issue relay vendors recommend periodic cleaning through the use of arcing. From a Tyco application note: "Controlled arcing of short duration can be beneficial in achieving the rated life of the contacts".

Unlike fritting, in which minimum levels of voltage and current are applied to a closed relay, arcing is achieved through hot switching of the relays with higher levels of voltage and

current applied. The appropriate voltage and current levels are based on the type of material used in the relay contacts.

The first step in designing an approach to generate a cleaning arc is to determine the metals that make up the relay contacts so that the specific levels of voltage and current necessary to develop an arc can be defined. It may require contacting the switch vendor for a relay datasheet if the information is not available in the switch module user's manual. It may also be possible to track down the appropriate relay data sheet by getting the relay part number off of the relay as shown in Figure 3, an actual switch module relay photo.
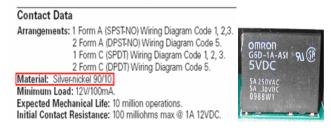

Figure 3 – Spec sheet showing relay contact material

Once the contact material is known, Table 5 can be referenced to determine the arcing voltage and current necessary for the relay to be cleaned. For example, the contact material of the relay in Figure 3 consists of a combination of silver and nickel. Based on the material with the higher values, in this case nickel, by selecting a voltage of 14V and a current of 0.5 amps, an arc will be generated.

Material	Electrical Conductivity	Melt Voltage	Arc Voltage	Arc Current
Gold	77	0.43	15	0.38
Nickel	25	0.65	14	0.5
Palladium	16	0.57	15	0.5
Silver	105	0.37	12	0.4
Tungsten	31	0.75	15	1.0

Table 5 - Relay arcing voltage and current values (From Tyco app "Relay Contact Life" [3])

Knowing the arc voltage and current, a load must be chosen which will produce the required arc current when the power supply is programmed to output the arc voltage. In this case using a 28 ohm load would produce the exact current of 0.5 amps desired when the power supply is set to 14V. Since these values do not have to be exact, opting for a more common 25 ohm, 25 watt load resistor is a good option. This will provide a current of 560 mAmps from the power supply and is sufficient for this cleaning approach.

The cleaning approach itself can be an automated program with a formal fixture or, if the need for cleaning is infrequent, a manual set up can be built using the switch module's soft front panel to manually control the switches. The photo in Figure 4 is an actual set up used to manually clean switch modules. In this case power is brought from an onboard DC power supply to the switch interface via jumpers that contain the required load. A daisy chain of jumpers is placed across the switches with the high lead on one side of the relay string and the low lead on the other. Since there is no requirement to test the relays it is not necessary to isolate the individual relays, which makes a daisy chain approach the preferred method.
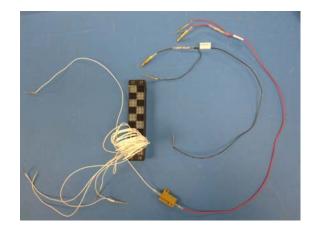

Figure 4 - Relay cleaning setup

E. Automated Example

Figure 2 shows the schematic used for the self test but now the setup will be used to clean the five individual switch modules. Table 6 shows the load resistors used and the power and current calculations. Note that the voltage is kept at a minimum of 14V and the current at 0.5 amps or greater to meet the arcing level requirements derived from Table 6.

This design example would be overly complicated if it was not a dual purpose approach. If this was to be used only for relay cleaning the design could be simplified. All load resistors with the exception of the 25 ohm load could be eliminated and the switches ganged together to accomplish a cleaning circuit.

Note that in the previous Self Test section all the self tests are run at lower voltages while, for the relay cleaning, the voltages are increased. This keeps the arcing limited to the cleaning procedure only.

Calculations for Cleaning Currents and Voltages								
Vin	PS Load	Rsw	Rld// Rsw	I Rld	I Rsw	I Total	Power Rsw	Power T
14V	100 Ω	25 Ω	20 Ω	140 mA	560 mA	700 mA	7.8 W	9.8 W
15V	100 Ω	30 Ω	23 Ω	150 mA	500 mA	650 mA	7.5 W	9.75 W
18V	100 Ω	35 Ω	26 Ω	180 mA	514 mA	694 mA	9.3 W	12.5 W
23V	100 Ω	45 Ω	31 Ω	230 mA	511 mA	741 mA	11.75 W	17 W
25V	100 Ω	50 Ω	33 Ω	250 mA	500 mA	750 mA	12.5 W	18.75 W

Table 6 - Calculations for the first two modules being tested using layout in Figure 2

F. Gold Plated Relays

When considering cleaning power switches, it is important to know that if the switch handles 5A or less there is a chance that the relay contacts are gold plated. A gold plated contact resists oxidation and is a superior conductor. Because of this, switches using gold plated relays tend to work well below the minimum contact rating allowing even TTL signals to pass. If the contacts are gold, using the arcing process could cause the gold plating to burn off of the contacts resulting in degraded operation at levels below the relay's minimum contact rating. If the switching will be used at levels over the minimum contact

rating, this is not an issue but if the switches will be used to pass lower level signals, hot switching should be avoided.

Note: The possibility of using 5A power switches as signal paths is not recommended but is raised here because it is not uncommon to see this in real world applications. This approach has potential issues which, are discussed in the section entitled "Real Life Examples, Problems, and Considerations".

G. Examples of the Affects of Relay Cleaning

The results in Table 7 and Table 8 show measurements made on a 5A power switch before and after a cleaning cycle. Most of the pre-cleaning measurements are well over 500 mOhms with one at almost 3 ohms. After cleaning, all of the readings are around 500 mOhms or better. Through experimentation it was found that after a couple hundred cycles the measurements were back to the pre-cleaning state. What is interesting about this demonstration is that by cleaning, the user could make measurements well under the minimum contact rating value … for a while.

The measurements in Table 7 and Table 8 were made with a standard DMM so no fritting takes place during these measurements. Although the DMM does not meet the minimum contact rating, for this demonstration it provides a more tangible affect of the cleaning. If a measurement approach was used that did meet the minimum contact rating, it could be assumed that the results in Table 7 would be significantly better but would mask the cleaning affect.

Resistance	0.000e+000	1.192e+000	3.000e+000
Resistance	0.000e+000	5.317e-001	3.000e+000
Resistance	0.000e+000	1.068e+000	3.000e+000
Resistance	0.000e+000	6.357e-001	3.000e+000
Resistance	0.000e+000	1.872e+000	3.000e+000
Resistance	0.000e+000	1.649e+000	3.000e+000
Resistance	0.000e+000	5.745e-001	3.000e+000
Resistance	0.000e+000	2.774e+000	3.000e+000
Resistance	0.000e+000	1.009e+000	3.000e+000
Resistance	0.000e+000	1.640e+000	3.000e+000
Resistance	0.000e+000	5.207e-001	3.000e+000
Resistance	0.000e+000	1.107e+000	3.000e+000
Resistance	0.000e+000	7.926e-001	3.000e+000
Resistance	0.000e+000	1.916e+000	3.000e+000
Resistance	0.000e+000	1.405e+000	3.000e+000
Resistance	0.000e+000	6.233e-001	3.000e+000
Resistance	0.000e+000	7.803e-001	3.000e+000
Resistance	0.000e+000	7.505e-001	3.000e+000
Resistance	0.000e+000	7.726e-001	3.000e+000
Resistance	0.000e+000	1.235e+000	3.000e+000

Table 7 - Relay measurement results before cleaning routine

Resistance	0.000e+000	4.420e-001	3.000e+000
Resistance	0.000e+000	4.581e-001	3.000e+000
Resistance	0.000e+000	4.760e-001	3.000e+000
Resistance	0.000e+000	4.815e-001	3.000e+000
Resistance	0.000e+000	4.876e-001	3.000e+000
Resistance	0.000e+000	5.168e-001	3.000e+000
Resistance	0.000e+000	5.062e-001	3.000e+000
Resistance	0.000e+000	4.922e-001	3.000e+000
Resistance	0.000e+000	4.976e-001	3.000e+000
Resistance	0.000e+000	4.551e-001	3.000e+000
Resistance	0.000e+000	4.856e-001	3.000e+000
Resistance	0.000e+000	4.864e-001	3.000e+000
Resistance	0.000e+000	5.018e-001	3.000e+000
Resistance	0.000e+000	5.324e-001	3.000e+000
Resistance	0.000e+000	4.921e-001	3.000e+000
Resistance	0.000e+000	4.781e-001	3.000e+000
Resistance	0.000e+000	4.542e-001	3.000e+000
Resistance	0.000e+000	4.590e-001	3.000e+000
Resistance	0.000e+000	4.861e-001	3.000e+000
Resistance	0.000e+000	4.874e-001	3.000e+000

Table 8 - Relay measurement results after cleaning routine

H. Symptoms Indicating Relay Cleaning is Necessary

When oxidation builds up on switch contacts, various symptoms can indicate that a cleaning cycle is warranted.

1) Failures in TPSs start appearing on previously working TPSs or there are self test errors reporting path continuity problems. These may be hard errors or they may be intermittent failures since each closure of the affected switches can make varying level of contact.

2) If you connect a meter across the various switches then you may observe:

a) Resistances over the rated path resistance – usually more than an ohm.

b) If the relay is cycled opened and closed different resistance values are seen and can be very inconsistent with variations of 100s of mOhms to ohms. On a clean relay you will usually see reading within 10 or 20 mOhms on a switch cycle.

c) If you leave the meter attached you may see the readout drift lower over time although the drift can reverse and go back up. Regardless, the drift can be over the range of many ohms.

I. Effects of Hot Switching

Although the cleaning process involves hot switching the effects on the switch life should not be adverse and, in fact, should help to extend the switch life. The cleaning approach described above involves currents which are relatively low, around ½ amps. The graph in Figure 10 demonstrates the effect of hot switching on a common relay family that is used on 5 Amp switch modules readily available for test systems. It is clear that hot switching at certain currents can significantly reduce the life of the particular switches while, at the levels being used to accomplish the cleaning process (0.5 amps typical), degradation is not a factor.
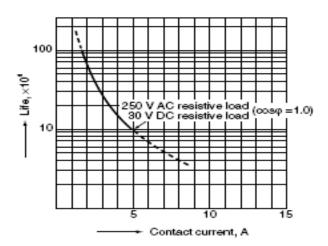

Figure 5 - Effect of hot switching on relay life

A.   TPS Failure Leads to More DMM Induced Failure Symptoms

A customer reported that his TPS would not run consistently. He stated that he could connect up his handheld meter across the switching being used by the TPS and see elevated readings that were inconsistent and tended to float around, therefore he suspected the connections to his power relays were the cause. He re-terminated several of the receiver pins involved and this did not changed the results.

A field service engineer was dispatched to investigate and used the system self test to diagnose the problem. It was found that there were two faulty pins at the switch module interface and that the pins the TPS designer had flagged with his manual measurements were actually in good working order. The handheld meter the designer had used delivered 1 mAmp at 100 mV to measure a power switch that had a minimum contact rating of 500 mAmps at 12 V. To effectively trouble shoot these switch paths the customer would have needed a power source with a load in series that would create ½ amp of current required by the switch he was measuring. With this set up the hand held meter could be used in the DC voltage mode to take a voltage measurement that could be used to calculate the resistance.

B.   Intermittent TPS Results

It is not uncommon to find power switches, particularly lower level 5A power switches, used as paths for various signals and for connections to make resistance measurements in addition to their intended purpose of passing power. This practice is highly discouraged.

Related to this situation, a customer reported that their test program, which had operated effectively for months, was now displaying intermittent results. It was determined that the test used power switches to transmit TTL signals. Table 9 shows the voltage and current levels for TTL signals and one can see that many of the logic levels do not have the voltage and current levels needed for fritting to take place.

Some factors could cause this type of failure.

- Deposits caused by oxidation increase the path impedances over time potentially causing a program that worked reliably initially to become intermittent.

- The power switch possibly has gold plating on the contacts which, if used in other TPSs to pass higher currents and/or were being hot switched, could eventually burn off, causing the path transmission characteristics to significantly degrade over time to the point that the paths can no longer support TTL signal transmission

Logic State	Output	Input
Voltage High	2.4 V	2.0 V
Voltage Low	0.4V	0.8 V
Current High	400 uA	40 uA
Current Low	16 mA	1.6 mA

Table 9 - Power and current levels for TTL signals

In this situation, the engineer can either rewire the fixture and rewrite the TPS to use signal switching or use a regular relay "cleaning" regimen. The cleaning techniques were described in the previous section with the end result being that the contaminants that can build up on relay's contacts can be removed allowing the switch to work at levels below the minimum contact rating. This customer opted to rewire their fixture which was the recommended approach.

IV.   CONCLUSION

When laying out test programs or self tests the test engineer needs to take into account all switch module specifications including the often ignored minimum contact rating specification to ensure that the best available paths are used for the signal and power routing. Using power paths for signal transmissions should absolutely be avoided. A TPS using this approach may appear to work during the initial development cycle it could very well fail weeks or months down the road displaying intermittent failures which are difficult to diagnose.

When testing or troubleshooting power switch paths the engineer has to consider the limitations of using standard DMMs to make path resistance measurements. Using a DMM will provide some basic information but only readings that indicate a total closed path (shorted) or an open can be trusted. Readings that vary from 1 ohm to 100 ohms could be caused by oxidation on the relays not overcome by the current and voltage from the meter. The best approach for testing power switch paths is to use DC power supplies which provide the minimum levels of voltage and current required to ensure a solid relay closure.

To get the longest possible life from power switches and to obtain consistent test results over a long period of time, a relay cleaning program along with the necessary fixturing and software are needed. Cleaning should be done at intervals which are dictated by the test system's usage and the cleaning approach should be adjusted based on feedback from system users regarding any TPS or self test intermittencies.

V.   REFERENCES

[1] Wikipedia, Definition of Relay Wetting Current, http://en.wikipedia.org/wiki/Wetting_current

[2] VTI Corporation, SMP3001, SMP5005 and SMP2001 Specification Sheet, SMP2 Series User's Manual, July 2004,

[3] Tyco Electronics Corporation, Relay Contact Life, http://relays.tycoelectronics.com/appnotes/app_pdfs/13c3236.pdf

[4] Tyco Electronics Corporation, Power Switching Applications for High Voltage Relays, Graph showing hot switching effects , http://relays.tycoelectronics.com/kilovac/power/

[5] Porter Brumfield Spec sheet link - RT Series Potter Brumfield Relay Specification http://relays.tycoelectronics.com/pnb.asp (click on RT DC Coil – 8-16A, One or Two Poles)

[6] Omron Corp, 5A Slim socket mountable PCB Relay– http://www.components.omron.com/components/web/webfiles.nsf$FILES/family.html?ID=TABE-72ZR5S

[7] Tyco T90 relay spec sheet - http://relays.tycoelectronics.com/pnb.asp (click on T90 - 30A, 1 Pole, DC Coil PCB Relay)

[8] Agilent 3458A DMM data sheet - http://cp.literature.agilent.com/litweb/pdf/5965-4971E.pdf

[9] Agilent 1412 DMM data sheet - http://cp.literature.agilent.com/litweb/pdf/5965-5563E.pdf