Keysight Technologies

Right Load Switching and Simulation Design Choices for High Current and Mechatronic Functional Tests

White Paper

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Abstract

In a typical mechatronic manufacturing functional test setup, actual load simulations are usually done by connecting the DUT outputs to power or ground in order to establish either a high or low side driver. Each output is connected with different load and the test will either be sequential or concurrent. At lower power levels, these can usually be managed with general purpose switches. However, when it comes to higher power levels of currents over 5 amps, such switching and loading might pose a greater challenge. Furthermore, critically in the manufacturing line, the tradeoff between cost and test time would have a great influence on the test strategy.

This paper will present some key points to design a cost effective high power switching and load management solution. Firstly, we will discuss the selection process for the types of relays to be used in the switch methodology. Next, for automotive testing where high current measurements are typically done at the output channels, we will look into how this measurement is done; with or without loads and by instantaneous or continuous measurements. Then, we will discuss single load or multi load connections and explore different approaches. These connections provide simulation at different loading conditions. A typical example would be to emulate the steering wheel audio control button with different resistive loads. Subsequently, we will also discuss voltage protection and temperature cooling which are essential in such high power applications. Finally, we will give a bird eye's view on the complete high level architecture of the combination of switch and load box, where usually the right solution is more than the sum of the parts.

By providing the reader with guidance and tips on which design and methodology to adopt for the high power switch and load solutions, a cost effective yet robust solution that promotes reusability of the test system in high mix test environment would be at your fingertips.

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Introduction

In a typical end of line production, functional final test is usually the last gate to ensure the highest level of quality in a product. Functional testing verifies that all input and output pins of the product are working within specification and it is usually done by simulating the input with the actual signals and loading the output with the real loads for every single pin. The tests will run pin by pin sequentially to check the pins individually.

For a typical mechatronic device under test (DUT) such as engine control unit (ECU), it usually has 200 to 450 pins. To make the situation tougher, this kind of DUT usually involves high power testing with many pins that carry current of more than 5 Amps. By taking the ECU example, to check pin by pin, this will involve a lot of switching, including high power switching. The low power switching can be easily managed by general purpose relays. However, the high power switching will need special attention in terms of the switching equipment used. In addition, high power loading at the output pins may need to handle the power level or a sudden spike.

To achieve the minimum cost of test, both high and low mix production environments require each a different test strategies. For high mix production, the tester is being shared between a few homogenous or similar products. Low mix production would have systems dedicated to a few high volume DUT. Regardless of the mix, the tester should be designed to scale for different products without significant changes on the test system core.

This paper will be a step by step process to guide the test engineers that deal with high power DUT from choosing the simplest high power switches up to the details of designing the complete loading concept. The focus takes into account not only technical specification, it also discusses the practicality of the concepts on the actual production floor. The aim of this paper is to strive for a better design decision making process for high power switching and loading in a functional final test system.

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1. Choosing the right relays

Relays are defined as electrical devices that are able to connect 2 or more adjacent nodes together. A relay can be activated either by a current or signal in one circuit or in the same circuitry. There are different types of relays, electromechanical relay, reed relay, solid state relay and FET switches. Among these switches, electromechanical relays and solid state relays are the most common relays being deployed in the high power environment. Although the reed relay is able to switch very fast and have long lifetime, it has very small contacts and is very susceptible to damages from arcing which restrain its application for high power. The FET switch on the other hand, uses a series of CMOS transistors for switching by driving the gates of the transistor directly. Although both have the fast switching speed and smallest form factor, they are more suitable for very low voltage signals.

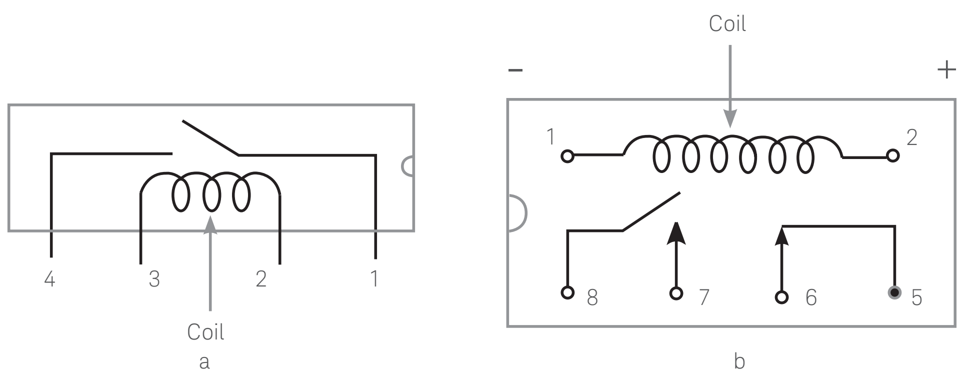

Figure 1. Electromechanical Relay (a) single pole single throw, (b) single pole double throw

Electromechanical relays architecture has a coil and the armature to close the switch. When the coil is being energized by having current flowing through it, a magnetic field will be induced at the coil and this will moves the armature to close or open the contact. From Figure 1, it is obviously galvanically isolated from its relay contact. When the relay is at the close position, it is in direct contact which results in very minimal contact losses. Obviously, when it is in the open state, there is no physical contact at all between two nodes. Not only it has no polarity, it does perform better in areas with environmental noise. However, electromechanical switches are generally larger physically and take up more space on the PCB board. With a very low speed of relay operation, typically 5ms to 15ms and lower lifespan, it is comes at a higher cost. Not to mention, the relay creates a loud sound when bouncing the armature.

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The construction of the solid state relay will have the load to be connected through one or more semiconductor such as MOSFET and it has a relay driver which is also galvanically isolated from the loading section. One of the examples is shown in Figure 2 which uses the power LED to actuate the device. The example is a photo-coupled solid state relay. Some other solid state relays are transformer-coupled and hybrid solid state relay. The operating time of solid state relays are faster compared to electromechanical relays as it depends on the actuators (which is the LED turn on and off for this example). Some manufacturers claim that these relays has unlimited life cycle if it is operated in normal operating condition. Its operation is completely silent and it is smaller in size. The disadvantage of the relay is that its voltage and current characteristic is not linear. In a closed state, there exists a small resistance of typically 50 to 100 mΩ. Meanwhile, the open state does not completely open the load paths and this allows leakage current to flow. It is more prone to surge and electrical noise as well.

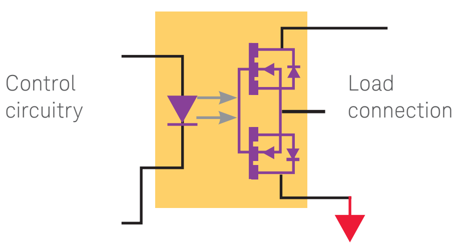

Figure 2. Solid state relay

Typically, in high power environment, the currents are higher and loads have small resistance value. The current measurement test for the path to load is often taken to characterize the output of the unit under test. An experiment was conducted to check on the performance of both electromechanical relay and solid state relay. The connections are shown in Figure 3. The actual experiment is done by replacing the motor and lamp with resistive loads and similar specification. From the results, the current drop in electromechanical switches is insignificant. While for solid state relay, a significant current drop is observed.

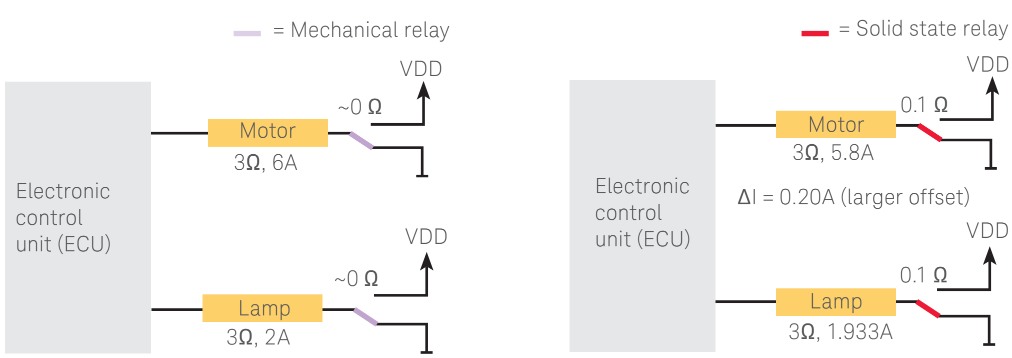

Figure 3. Experiment setup for mechanical relay vs solid state relay

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2. Handling current measurement

The basic of current measurement is to connect an ammeter in series in the circuit. When there are a lot of loads, connecting ammeter in series at every single output pins would need an impractical units of ammeter. This would be too costly for simple current measurements in the test system. Furthermore, most of the ammeters suitable for production test has a maximum input of 3A and is not a suitable choice for high current applications. Since measuring current is very required in high power testing, the common practice is to implement either the shunt resistor or the current transducer method.

The shunt resistor method would be the easiest to implement. Based on Ohm's Law, it uses a voltmeter to measure the voltage across the shunt resistor on each load and convert it back to the appropriate current with the formula I =V/R. When there are many different loads that need to be measured, and when there is only one voltmeter, we can switch to different paths to measure the voltages accordingly, see Figure 4. Shunt resistor should be chosen carefully as it affects the circuitry - since it is in series on the circuit, this affects the measurement results. Normally, high precision (~0.1%) and with low resistance value (≤50 mΩ) shunt resistor is the right choice. It is a very cheap solution and small in size. Since the choices of precision resistors with low resistance value and high current handling are limited in the market, this shunt resistance methodology of measuring current is suitable for paths lower than 15 Amps.

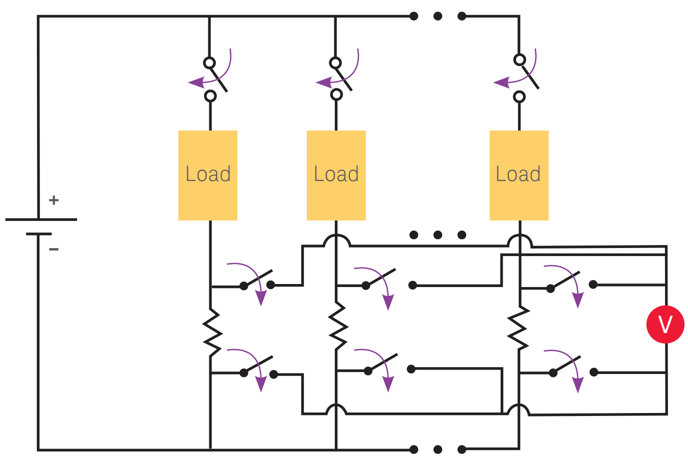

Figure 4. Shunt resistor method of current measurement

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The current transducer methodology is shown in Figure 5. For discussion purposes in this paper, a closed loop current transducer is used. The primary current (I_p) is the current that is of interest to measure. The primary current creates magnetic flux and this drives the secondary windings to drive a current. The complete architecture has a hall sensor which is connected to some electronic circuitry and are used to generate secondary current (I_s) and this is a representation of the primary current according to ratio of the windings. A voltage measurement across the R is then converted back to its equivalent current value to determine the Ip. The current measurement is galvanically isolated and it does not affect the measured path. It can to be placed anywhere in the path. The added advantage of current transducer is that it is usually capable of handling very high current. However, the current transducer is very bulky, and high in cost. It is also susceptible to external magnetic interference.

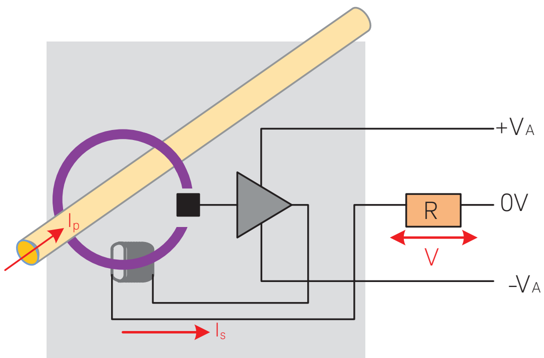

Figure 5. Close loop current transducer (extracted from LEM website)

3. The high side driver, low side driver, multi load and bridge load

Most of the DUT outputs are either high side drivers or low side drivers. The high side driver has the load connected in between the switch and ground while the low side driver has the load connected in between the power and switch. When designing the switching card, a good design would create flexibility for the users to switch to connect the loads either to ground or power for all channels.

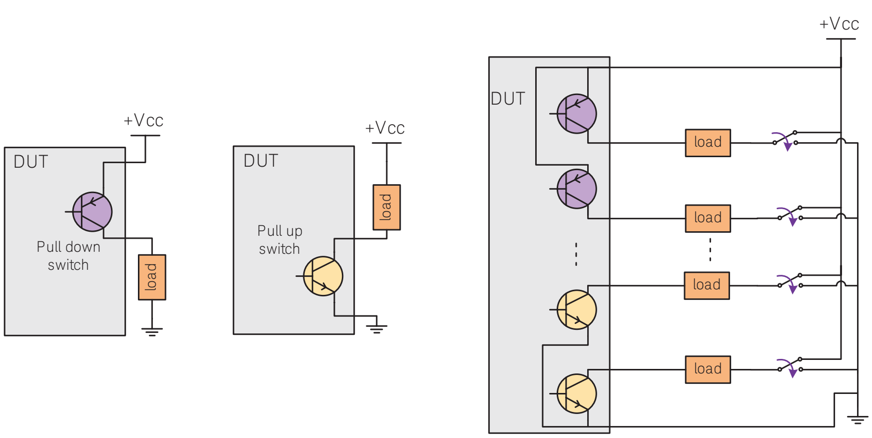

Figure 6. High side driver and low side driver and its equivalent switching for power or ground in a complete circuitry

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Some DUT load outputs need to be connected to variable loads to simulate different scenarios. Examples for this application are the windshield wiper test and the steering wheel audio controls. Different resistive values are needed to simulate the speed of wiper or the audio volume. In production, using variable loads incur higher cost while fixed loads are a cheaper alternative. With this consideration, some load channels should be designed to support multiple loads for each channel to cater for different loads.

With this approach, the number of cables needed between the DUT and test system will reduce significantly and this will be much more cost effective. Output leakage test is commonly performed on the output pins of engine control unit before actual loads are connected. During this test, the output pins are simulated at a no-load condition to check if the output driver has any leakage.

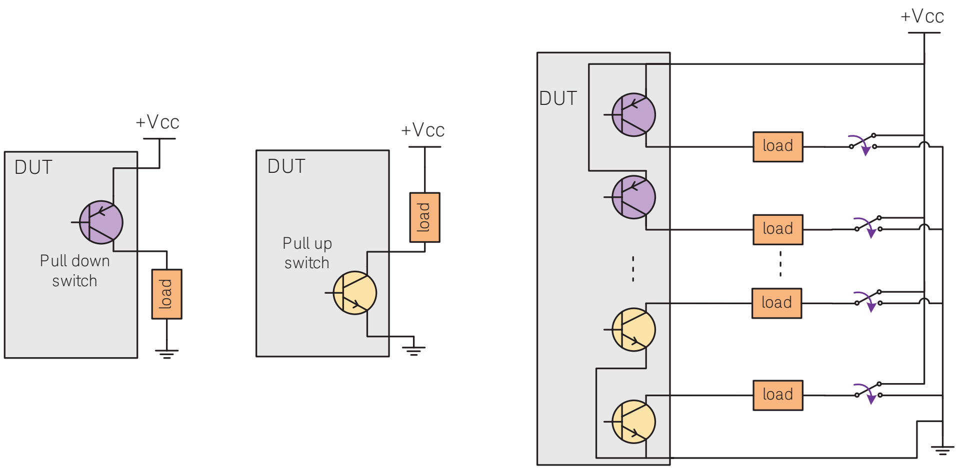

Figure 7. Multiple load configuration for load channels which is suitable for output leakage test

Bridge loads are a common loading technique whereby the loads need to be connected to another channel to create a loop. These loads are not connected to power or ground. A typical example of the bridge load is the stepper motor driver. A good design of load channels is when the same load channels are able to support bridge loads and also the normal high side driver/low side driver loading.

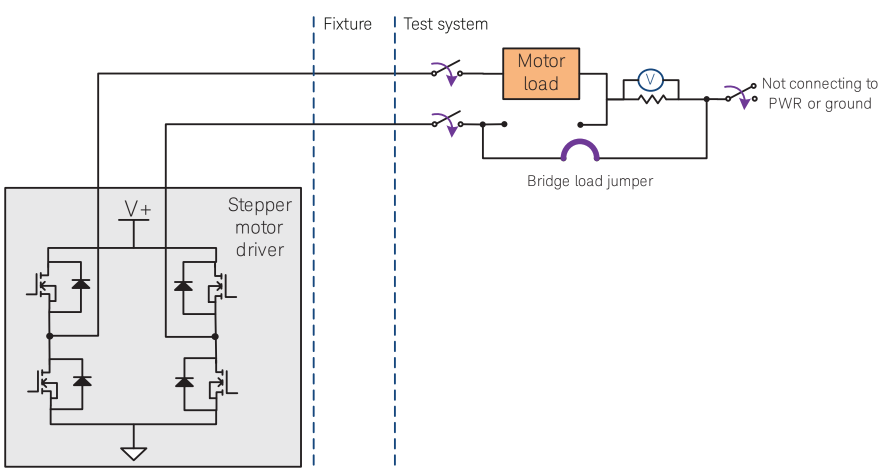

Figure 8. Bridge load for stepper motor application

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4. Inductive loads and flyback effect

Inductive loads such as solenoids are common loads for high power DUT. Inductive loads will attempt to resist the sudden drop of current by using its stored magnetic field energy to create its own voltage. This phenomenon is called flyback. Flyback is a sudden voltage spike for inductive loads when its supply voltage is abruptly removed. This will potentially create undesirable damage to other test board components as the large potential difference created can cause electrons to arc across the air-gap of the open switch. Refer to Figure 9a, the flyback voltages is more than -200 V.

There is a need to implement flyback protection for inductive loads. The simplest way is to connect a diode in parallel to the inductive load. The diode will continuously loop the inductive load flyback effect until the energy is dissipated through losses in the wire or resistor. Having a small resistance value in series with the inductive load makes the inductive load energy dissipate faster. From Figure 9b, it is obvious that the flyback voltage is minimized.

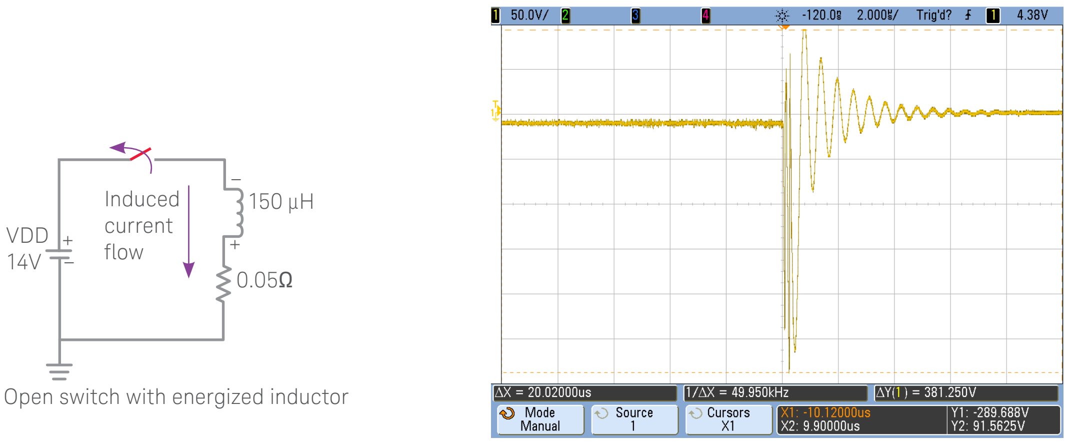

Figure 9a. Flyback is observed on digitizer when switch is opened.

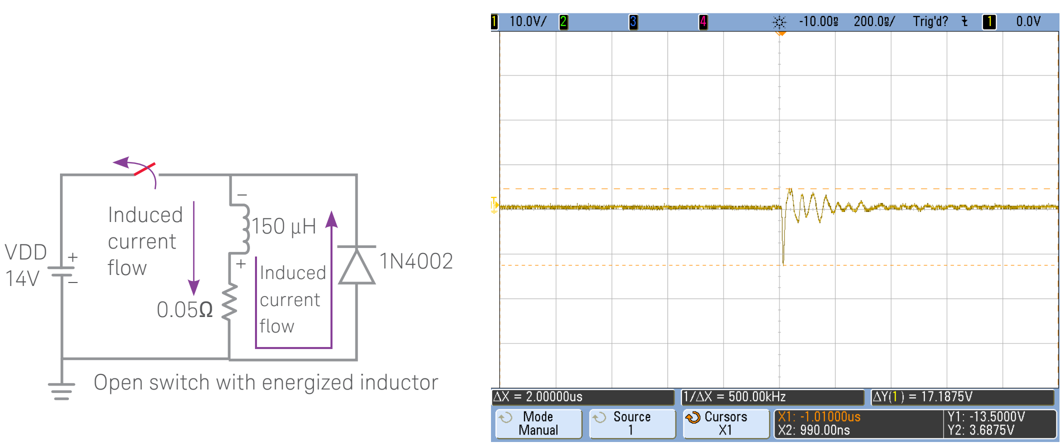

Figure 9b. With flyback protection circuitry, the voltage spike is reduced.

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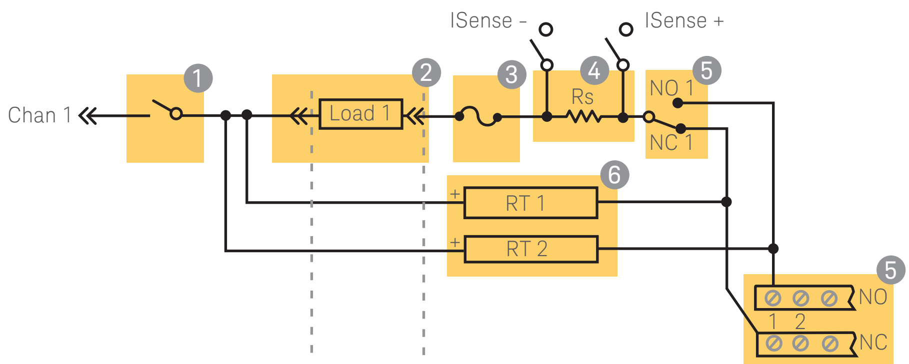
5. The combination

Eventually, all the consideration above needs to be taken into account when designing the complete circuitry of loading and switching. This is an example of load channels from Keysight's E6176A load card that is able to handle up to 7.5 A current with peak currents of 15 A per channel. Figure 10 illustrates the key considerations presented thus far in the example of the E6176A load card.



1. This is the relay that turns the load channel on or off. For E6176A, the relay being used in electromechanical relay instead of solid state relay with the reason of lower resistance and complete disconnect when relay is at open state.
2. This is a terminal or mating for user to mount loads connectivity. For smaller loads, the loads will be mounted on the connector itself, while for heavier loads, it will be mounted externally.
3. A fuse is added to add extra protection to the circuitry when overcurrent. The fuse deployed should be easy to fix and remove.
4. Current sensing circuitry with shunt resistor is shown. This shunt resistor will then switch and connect to a DMM to measure voltage across it.
5. To accommodate high side driver and low side driver, SPDT switches are used to switch to power or ground.
6. Flyback protection is deployed in parallel to the inductive load and shunt resistance. This will create loop to dissipate the energy of coil when the circuit is cut off.

Figure 10. An example of a complete load channel

6. What else to consider?

As we have learnt, load switching for a single DUT might involve 200 pins and above. To have all these high power load switching channels to fit into a box, the heat dissipation for the channels is crucial. A good selection of materials, the combination of heat sinks and identification of the hot spots are part and parcel of designing a high power switch box. The mechanical design of the chassis must be designed to facilitate air circulation. This would mean more empty space is needed, at the right places to enable the exhaust fans to push heated air out of the chassis. Good air ventilation helps to prevent overheating, improving system measurement accuracy and prolonging the system reliability in manufacturing environment.

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Since these load switching boxes will be implemented in production for testing purposes, the design of the switch paradigm should match the production environment. Load switching can be placed either on the fixture or inside the test system. With the switches on the fixture, intensive design needs to be on the fixture and size of the fixture may increase. The cost of the fixtures are typically higher as well. On the other hand, it promotes shorter wire length between the loads and DUT. In contrary, when switches are placed inside the system, such as the off the shelf Keysight E6198B Switch Load Unit, it helps to create a standard design of the system that is scalable. In addition, the fixtures would tend to be on the lower cost side.

Ultimately both paradigms are useful for different production environments. When the production is a low-mix high volume environment, it would be much more cost effective to have the switch-in-fixture design as there are less fixtures used per system. However, when the production is in a high-mix low volume environment, having switch-in-system design would be a better option because it promotes the reuse of switches on the system which makes it highly scalable. In addition, since the fixture design is simpler without the switching components and cheaper, the overall cost of test would be lower when there is a significant high mix of products running on the same system with the switch-in-system.

High mix - low volume

		DUT A	DUT B	DUT C	DUT D	DUT E	DUT F	Total
Switch in:	Fixture	$	$	$	$	$	$	$$$$$$
	System			$$$				$$$

Each DUT fixture requires its own set of switches. Less cost effective for high mix.

Low mix - high volume

		DUT A	DUT B	Total
Switch in:	Fixture	$	$	$$
	System	$$$		$$$

Due to low mix and lower cost of customer switches in the fixture compared to a centralized switch box in the rack, it is more cost effective to have it in the fixture.

Figure 11. An illustration of the switch in fixture or system in two production environments.

Summary

In summary, the complete design of a switch load unit involves a thorough study of many design aspects such as the ones presented here. The right relays and the suitable current measurement techniques are only a portion of the complexity of the design. High side and low side drivers, multi-load requirements and bridge loads are also key considerations in switch load unit design. From a safety point of view, Flyback protection should always be included into the design if there are inductive loads. On the mechanical side, the ventilation of the complete design must be evaluated and tested. Finally, understanding the production test scenario and choosing the right switch paradigm is most vital in achieving the lowest cost of test.

About the Authors

Lok Teng Kee and Chuah Rhun Chia are Technical Marketing Engineers while Derek Ong was the Marketing Manager at Keysight Technologies.

Lok Teng Kee holds a Bachelor degree in Electronics and Electrical Engineering from University Science Malaysia. Prior to Agilent Technologies, he was a Test Development Engineer in Avago Technologies where he was a pioneer in setting up test systems for NPI products.

Chuah Rhun Chia holds a Bachelor degree in Electronics Engineering from Malaysia's Multimedia University. She has worked at Agilent Technologies for 9 years, where she has been working in functional testing, for both wireless and automotive industries.

Derek Ong holds a Bachelor's degree in Electronics and Electrical Engineering from University of New Brunswick, Canada. He has 12 years of experience in the automotive electronics and semiconductor test industry with Agilent Technologies and Carsem.

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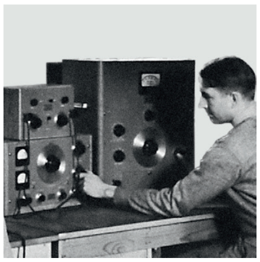
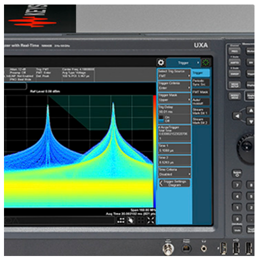


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