Tips for Optimizing Your Switch Matrix Performance

Application Note

In all but the simplest electronic test systems, switching is required. And as the number of contact points in your switching system increases, system complexity increases dramatically. Everything from choosing the physical interconnect methods, to managing the relay paths and routing becomes much more difficult as the number of connections increase.

So how do you design a switch architecture that makes the complexity manageable? Your goal should be a highly flexible, cost-effective, reusable system that saves time and money as you bring products to market. This application note offers eight tips to help you optimize your measurement matrix switching performance and give you the edge you need to be competitive.

Tip 1: Choose a switching topology that maximizes your flexibility

Tip 2: Design to meet your bandwidth, noise and crosstalk targets

Tip 3: Increase your manufacturing capacity by optimizing switching throughput

Tip 4: Increase the life span of your switch system – design for reliability

Tip 5: Design for both source and measure capability

Tip 6: Design for fast system development and deployment

Tip 7: Make sure your matrix is expandable

Tip 8: Reduce your risk – design for supportability

Well-engineered switching will improve your productivity, improve your test robustness, and result in efficient, supportable and reliable test systems.

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Tip 1: Choose a switching topology that maximizes your flexibility

If you design your switch systems for maximum flexibility, you will get the options you need during test plan development. Consider the classic multiplexer configuration (Figure 1a) vs. a matrix configuration (Figure 1b). Figure 1a shows a 1-wire configuration (top) and a 2-wire configuration (bottom). You can configure all of the switching topologies discussed here as either 1-wire or 2-wire configurations.

A multiplexer topology works well when you are using a single test instrument (such as a digital multimeter). Multiplexer switching topologies are commonly used for scanning applications. The biggest drawback is that they lack the flexibility to add additional instruments.

Matrix configurations work best for functional test system applications; they provide excellent signal routing flexibility (see Figure 1b). A matrix topology allows you to route various instruments to your device under test (DUT) as you execute your test plan. However, full matrix configurations can be very expensive for large matrix structures because of the higher relay contact count. Figure 1b shows a 1-wire matrix configuration (although you could construct a 2-wire version as well).

Figures 2a and 2b show variants of a full matrix that reduce the cost while still providing flexibility. you can think of this style of switching as multiple matrix blocks tied with a common bus, which is known as an analog bus (Abus). At a minimum, you will need to use a 4-wide analog bus for most functional test applications. If you increase the abus width to eight lines, the flexibility of the matrix increases significantly.

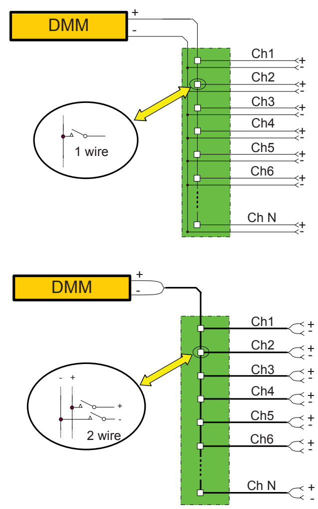

Figure 1A. 1- and 2-wire multiplexer configurations (N channel)

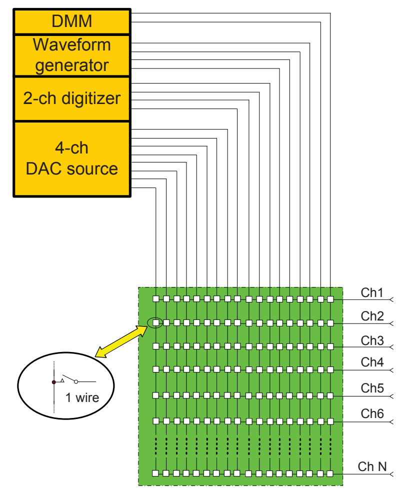

Figure 1B. 1-wire matrix configuration (18 x N channel)

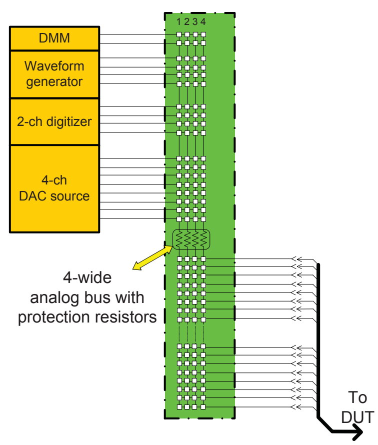

Figure 2A. 1-wire matrix configuration (4-wide bus)

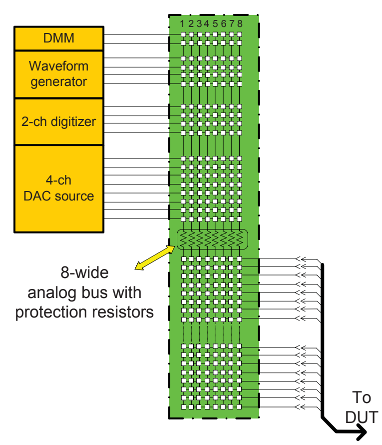

Figure 2B. 1-wire matrix configuration (8-wide bus)

For maximum switching flexibility, create a hybrid matrix configuration with a least four, and preferably eight analog bus lines. A hybrid matrix costs less than a full matrix structure and allows you to route signals from a variety of test instruments to your device under test.

Tip 2: Design to meet your bandwidth, noise and crosstalk targets

Measurement switching resides directly between your test instruments and your DUT. If the measurement switching doesn't meet your bandwidth, noise and crosstalk needs, all of your measurements will be compromised.

As discussed in Tip 1, switching topologies are commonly implemented in either 1-wire or 2-wire architectures. A 1-wire topology switches only a single relay to connect a single point on the DUT to the instrument (with the common line routed either directly or via a separate path). A 2-wire topology switches both a signal and common line together. The signal routing is designed so the loop area between the signal and common is small, which reduces the noise coupling and improves bandwidth.

To reduce the relay count and save money, you can use a single-wire switch system. But if you're application is sensitive and you need to achieve the lowest noise and the highest bandwidth, use a two-wire switching system.

Tip 3: Increase your manufacturing capacity by optimizing switching throughput

Achieving high throughput in a test system takes planning, especially in situations where test plans are switching intensive. In those cases, switch selection can make or break you're ability to meet capacity targets.

Armature relays, reed relays and FETs are the most commonly used switch types. Armature relays are robust and can carry significant current. However, the physical mass of the armature itself can cause switching times to be slow – as slow as 20 mS in some cases. Reed relays and FET switches, on the other hand, can be very fast – some can switch in 500 uS or less.

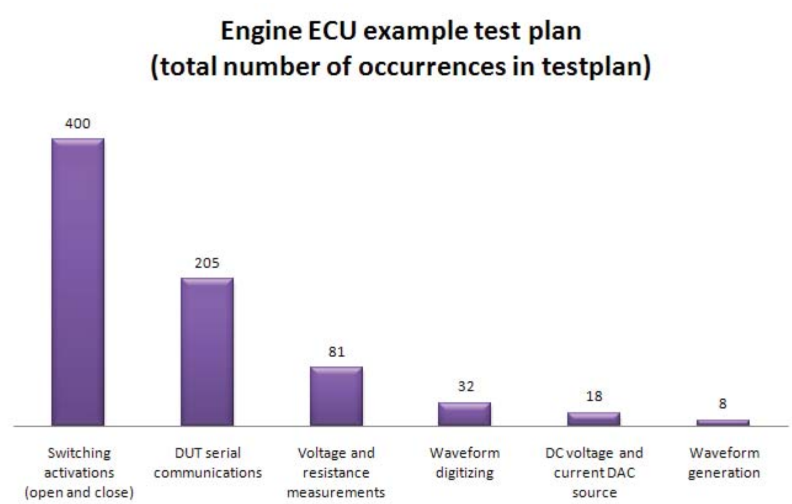

Figure 3. Histogram showing main test plan activities

FET switches are popular for multiplexer applications, where high scan rates are required for measurements. However, they have significant FET "on" resistance (usually in the neighborhood of 100 ohms), so they are not suitable for sourcing current, which is a requirement in many functional test applications. In addition, FET off state leakage may present problems in some applications.

Reed relays are a popular choice for high-switch-count, high-throughput tests. They switch very quickly because of the low mass of the reed contacts. Plus, they provide a true voltaic disconnect, which eliminates concerns about low-level leakage currents that sometime cause problems when you use FET switches.

To illustrate the impact of relay settling time on overall test time, Figure 3 shows a histogram of common measurement and switching activities during execution of a high-pin-count automotive ECU test plan.
In our example, the number of switch activations can reach up to 400 cycles. If you use armature relays that settle in 10 mS, the test time impact is significant, adding up to 4 seconds to a test plan. A reed relay that settles in 500 uS would improve test throughput dramatically.

For maximum tester throughput and best switching characteristics, use high-speed reed relays for measurement switching where possible.

Tip 4: Increase the life span of your switch system – design for reliability

As we discussed in Tip 3, the low mass of the reed relays allows them to provide excellent settling time. However, the low mass also makes the reed relay contact more susceptible to hot switching (switching with power on) and surge currents (switching capacitive loads).

With proper test planning, hot switching the relays can be avoided, and surge currents can be limited by adding a small amount of resistance to the discharge paths.

Consider the cases shown in Figures 4a, 4b and 4c. This test plan calls for measuring the voltage at node "A," followed by a measurement at node "B." When you measure node "A," the stray capacitance of the switch system will be charged to 24 volts (see Figure 4a).

When the system switches for test step 2, capacitor Cstray will discharge through relay 2 (see Figure 4b). This discharge does not produce much energy, and it does not immediately destroy the reed contact. Instead, it pits the contact surface and wears it down over time, which reduces its overall lifetime.

To limit the magnitude of the surge current, add a small amount of resistance, as shown in Figure 4c. Typically, 100 ohms is sufficient to dramatically extend the life of the relay.

If you limit surge currents and avoid hot switching, reed relays can have a long cycle lifetime of 10,000,000 cycles or more. Incorporate protection resistors into your switching structures to get maximum life from reed relays.

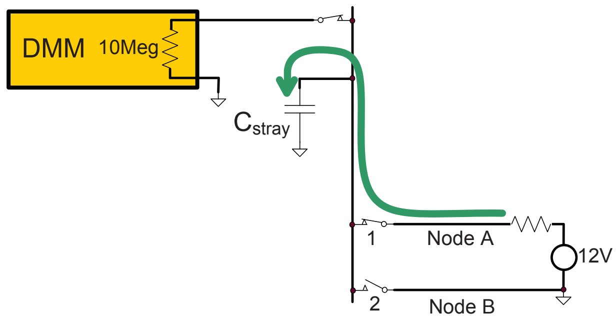

Figure 4A. Measuring node A charges C_{stray} to 24 Volts

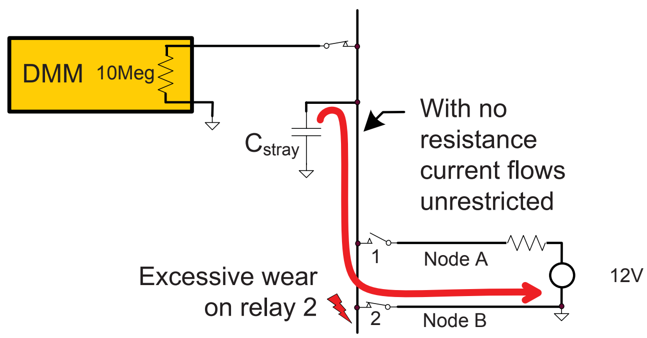

Figure 4B. When switching to node B, discharge of Cstray to ground causes momentary unrestricted surge current through relay 2

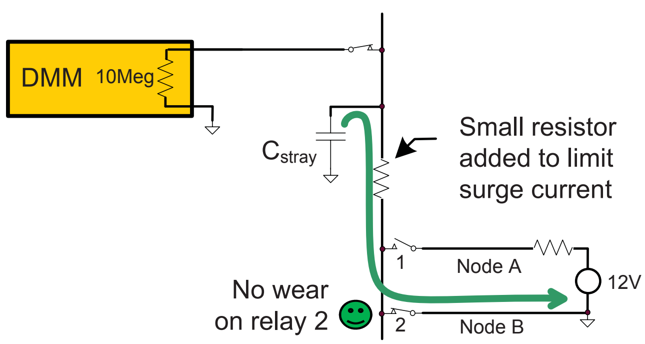

Figure 4C. Adding a small amount of resistance to the path limits surge current and extends the lifetime of the relay

Tip 5: Design for both source and measure capability

The 100-ohm protection resistor described in Tip 4 is small enough that it does not significantly impact measurement accuracy. However, in cases where the test requires you to route a low-level current source to the DUT, the protection resistor can cause problems. Even low currents across the 100-ohm protection resistor will cause large voltage drops. So the protection resistor that we added to extend reed relay life can also disrupt current flow through the matrix.

An innovative work-around for this problem is to use a protection resistor bypass relay. In situations where you must source current through the matrix, you can close the bypass relays to route currents around the protection resistor. With these bypass relays in place, you can source currents as high as 500 mA through the matrix and conveniently route them to the DUT pins as needed. Figure 5 shows how to implement this work-around.

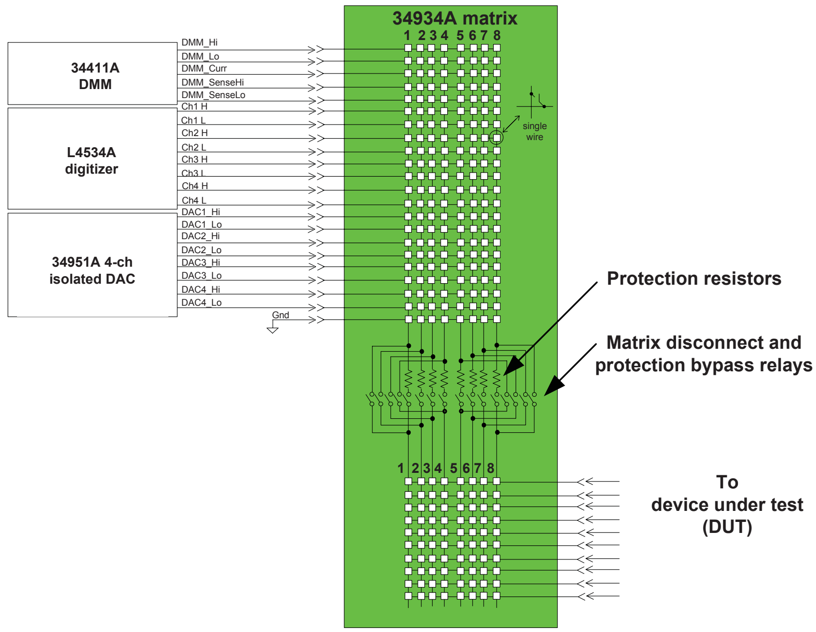

Figure 5. Protection resistor bypass relays and matrix disconnect relays in a switch system

Use a switching system with protection resistor bypass relays incorporated to give you the ability to source current through the matrix.

Tip 6: Design for fast system development and deployment

During the rush to get your test system designed, don't overlook the effort required to get your test plan up and running. Good software tools for system turn-on, development and debug can increase the efficiency of your test plan development.

It is helpful to have an independent tool to monitor the state of your relays during test plan development. You can use this tool to view and control the state of the relays while the test plan is running.

For example, the Agilent 34980A switch/measure unit provides an extremely useful LAN-based tool for this purpose, as shown in Figure 6. Using a simple Web browser, you can easily monitor and control the switches. Notice the graphical representation of the switch matrix – closed relay cross-points are shown with a solid black dot. You can simply click on the individual cross points to open or close the relay.

To use this capability for debugging a test plan, run the test using your application software, and pause it at the test you want to debug. Open up the 34980A Web browser to inspect the state of the relays. If you see an error in the relay setup, simply click on the relay that needs to be modified and continue with the test plan.

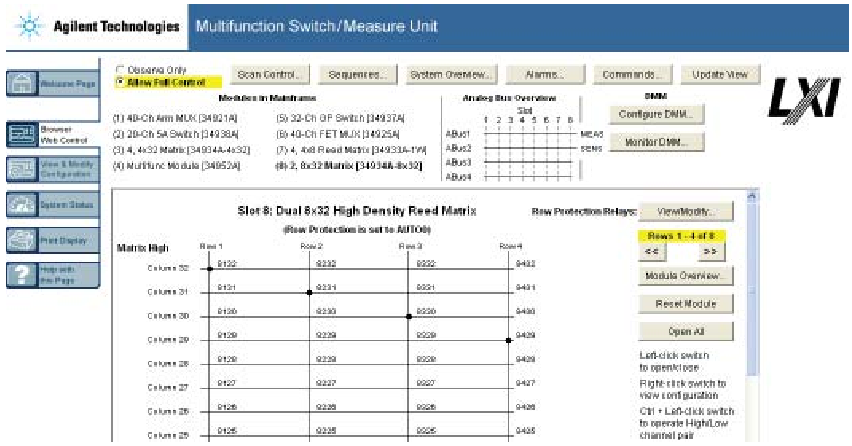

Figure 6. Graphical switching development tools can improve your time to deployment

> *For fast system turn-on, use switch monitoring and management tools such as soft front panels or LXI interface monitor and control features.*

Tip 7: Make sure your matrix is expandable

Consider this scenario: Your 100-pin DUT test plan is running just fine, but your manager suddenly asks you to re-tool your tester for a 200-pin DUT. If your switching system has an expandable architecture, this assignment is simple to implement. If it doesn't, you face a lengthy and possibly expensive retooling process.

In Tip 1, we discussed a variety of switching architectures and explained why a matrix with analog bus structure is the best solution. Using this topology, you can increase the number of DUT test points by simply adding another matrix section.

However, with each matrix section you add, the overall capacitance of the analog bus increases, so you must be careful. The increased analog bus capacitance can limit the bandwidth and rise time of the signals you are measuring. In a working test plan, when you add another matrix section, the increased capacitance may break existing working tests.

Some matrices include disconnect relays (see Figure 5) to keep the capacitance of the analog bus at a consistently low level. In large switching structures there may be several matrix blocks, but usually only one or two of them are active at a given instant. You can keep the bus capacitance low if you connect only the matrix blocks you are using during that particular portion of the test plan. To manage the connections, you will need a matrix relay product that includes analog bus disconnect relays.

Notice the matrix disconnect and protection bypass relays implemented in the Agilent 34934A high-density matrix card (shown in Figure 5). This matrix module automatically manages the state of your relays, closing and connecting only the matrix block used for a particular test.

To support large, expandable matrix structures, be sure the matrix relay product you use includes analog bus disconnect relays.

Tip 8: Reduce your risk - design for supportability

When you choose your switching products, consider in advance what it will take to make your switch system easy to support. For example, look at how physical interconnections are made. Are the switch connectors standard, low cost and available worldwide? What happens when you relocate your test system to another continent, and a cable is damaged? Most likely you'd prefer to avoid a phone call in the middle of the night requesting express shipment of an obscure tool that is needed to repair a defective cable.

When you are designing your switching system, make every effort to use switch modules with standard connectors. For example, sub-miniature D-style connectors are available around the world, and tooling for them is readily available from multiple distributors.

When you are deciding which switching product to use, consider doing a search of your favorite distributors for the mating connectors for that product. Check which connectors are in stock and what quantities are available and at what cost. In general, you will find the in-stock and lower-cost connectors in higher volumes, and they are more likely to be readily available around the world. Also, don't forget to consider any special tooling required for cable fabrication.

To improve the supportability of your test system, select switching products that use standardized connectors commonly available at distributors worldwide.

Putting it all together

Where can you find products that support the switching "best practices" we've outlined in this application note? Several relay card manufacturers provide reed relay matrix cards, although implementations vary substantially. Some matrix cards use proprietary, hard-to-find connectors and some don't have surge current protection resistors. Even in products that include relay protection resistors, there may not be a protection bypass capability, which limits your ability to route current through the matrix. The Agilent Technologies 34934A high-density matrix card has been carefully engineered to support all of these features.

High-performance switching using the 34934A high-density matrix

All of the bestpractices described above can be accomplished using the new 34934A high-density switch matrix module. The 34934A high-density (HD) module uses fast reed relays organized as four individual blocks in a 4x32 configuration. These blocks can be configured in multiple ways depending on your particular needs: You can create 1-wire or 2-wire, 4 x 128, 8 x 64 or 16 x 32 matrix topologies as needed by combining the quad 4x32 blocks as desired.

Each 4 x 32 block also contains disconnect relays, protection resistors and innovative protection resistor bypass relays. as shown in Figure 5. The addition of these unique features to each of the 4 x 32 blocks dramatically improves the versatility and performance of you final matrix configuration.

The addition of the disconnect relay allows you to build extremely large matrix solutions.

The 34934A modules even provide automatic management of the abus interconnect:

1. If no relays in the individual 4 x 32 relay block are used, then the modules leaves the block disconnected from the analog bus.
2. When the module is set in "automatic" mode, the 34934A module firmware will manage the state of the bypass relays.

These automatic management features allow you to focus on the important aspects of your test plan rather than worrying about managing disconnects.

Table 1. Summarizes the important features to remember when designing your switching solution.

	Tip		"Best practices"
✓	Tip 1	Choose a switching topology that maximizes your flexibility	Use a matrix structure with at least four analog bus lines and preferably eight analog bus lines.
✓	Tip 2	Design to meet your bandwidth, noise and crosstalk targets	1-wire switching topologies are lower cost, but 2-wire switching topologies are best if you require high bandwidth and low crosstalk.
✓	Tip 3	Increase your manufacturing capacity by optimizing switching throughput	High-speed reed relays provide fast, voltaic disconnect.
✓	Tip 4	Increase the life span of your switch system – design for reliability	Adding 100-ohm analog bus protection resistors will limit surge currents and extend relay lifetimes.
✓	Tip 5	Design for both source and measure capability	Use bypass relays to route around protection resistors when the matrix must carry currents.
✓	Tip 6	Design for fast system development and deployment	Use switching monitor and control software tools during application software development.
✓	Tip 7	Make sure your matrix is expandable	Select a matrix product that includes bus disconnect relays to reduce overall switching capacitance.
✓	Tip 8	Reduce your risk – design for supportability	Make sure your switching product uses standard, easy-to-find connectors and tooling.

Keep these tips in mind when you are designing your next test system. Well-engineered test system switching will improve your productivity, improve your test robustness, and produce an efficient, supportable and reliable test system.

Related Agilent Literature

Table 2.

Publication title	Pub number
Test System Signal Switching (app note) *http://cp.literature.agilent.com/litweb/pdf/5989-1634EN.pdf*	5989-1634EN
34980A switch/measure unit and 34934A data sheet	5989-1437EN

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