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SWITCH TO 42 VOLT AUTOMOTIVE SYSTEMS BRINGS CHALLENGES AND OPPORTUNITIES

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Switching to 42V automotive electrical systems almost seems like a no-brainer. But there's still a lot of engineering and testing to be done.

Historical Perspective

To meet ever increasing electrical power demands, automakers are moving to increase vehicle battery voltage from today's 14V to approximately 42V. It has been more than 40 years since US carmakers switched from the standard 6V system, a change triggered by similar power considerations. During that time, vehicle electrical power consumption has increased by more than 50 percent. Every year, new features and functions are added; the more recent ones include cell phones, personal computers, and satellite navigation systems. Currently, less than 30 percent of the energy in gasoline is used for locomotion; the remainder is wasted by inefficient components and burned off as waste heat during engine idling.

The next generation of automobiles will have even more electronics and require a power source with an output of more than three kilowatts, the limit of today's 14V system. A 42V system will deliver around eight kilowatts and allow better management of the higher power requirements. Numerous other advantages include:

- Reduced electrical current levels
- Downsized wiring and electrical components
- Lower electrical system cost
- Reduced mass and volume
- Improved fuel efficiency
- Lower vehicle noise, vibration, and harshness
- Improved system stability

A 42V system also sets the stage for advanced technologies that will allow a switch from mechanical belt-driven systems to those that are electrically powered. Possibilities include electric power steering, electromechanical brakes, electrical HVAC systems, electromagnetic valve trains, integrated starter-generators, and electronic ride control systems. The so-called "beltless engine" of the future will be another reason for lower weight packaging (because accessories can be located outside the engine compartment), leading to higher efficiency that improves gas mileage and reduces emissions.

42V Rollout

Initially, cars are expected to have a dual 14/42V system, which will help manage costs by avoiding a simultaneous switch of all vehicle systems to the new 42V standard. During the gradual changeover, some components will operate at 14V and some at 42V. This could persist for a few years, given that some 14V components, such as lamp filaments, are more rugged and last longer than their 42V counterparts. It could be that certain components, such as sensors, spark plugs, radios, and other electronic devices will always work better at 14V than at 42V.

Toyota Motor has already begun selling a 42V luxury sedan, but only in Japan. A few European cars have two lead-acid batteries on board, so higher voltage electrical system should follow soon. About two dozen vehicles with various types of 42V systems are in advanced design stages. US consumers will probably see the first dual 14/42V vehicles on showroom floors beginning with the 2004 model year, when General Motors rolls out its first-generation 42V system in a hybrid gas-electric pickup truck. Volume ramp-up is expected to start with the 2007 model year, particularly in large and midrange automobiles and light trucks (especially SUVs), where power-hungry features, fuel consumption, and emissions are becoming major issues. At least one forecast places production of 42V vehicles at around 13 million units by 2010.

Challenges

Before 42V systems can be adopted widely, many engineering problems must be addressed, including the engine/electrical system architecture and a migration strategy (dual 14/42V systems vs. straight 42V systems). Short-term challenges associated with dual voltage systems include more wiring, extra weight, and added complexity. Regardless of migration path, suppliers need time to develop new components and a part identification system that distinguishes between 14V and 42V parts.

Evaluation of Electrical and Electronic Components. While 42V is not far from 14V in physical terms, real-world issues are a cause for concern. Current 14V designs won't automatically work at 42V; even simple fuses will not migrate, let alone dimmers and active load controllers. Some fuse panel and harness makers have found that common 14V mini- and maxi-fuses do not behave properly at 42V. They can fail to interrupt excessive currents properly, causing serious overload conditions. Also, interconnection technologies have evolved for optimal cost and performance in a 14V environment. The present design of connectors, circuit breakers, and relay contacts may not be optimal at 42V. Therefore, manufacturers must re-evaluate component suitability for the higher voltage. Tests can range from simple continuity tests to full electrical characterization of a component's functional performance at 42V.

Reliability Issues. At 42V and higher power levels, many components, such as wires and relays, experience electrical stress that is three times higher than before. With higher stress, components tend to break down more often. Therefore, component and module manufacturers have to perform more reliability testing, such as burn-in and accelerated stress tests, to ensure adequate service life.

Safety Issues. Safe distribution of 42V power throughout a heavily optioned automobile also is a challenge. In the first place, the 42V standard was established because higher voltages create human safety issues. For example, 50V can stop a human heart, and anything higher than 60V requires more heavily insulated wires and connectors, which add weight. To prevent fires, electrical distribution designs must allow for jump-starting at the higher voltage, and provide protection if battery connections are reversed.

Component and Conductor Arcing. Relay, switch, and conductor arcing is another problem that must be addressed; its potential for serious damage is greatly increased in 42V systems. Recent research shows that 42V arc energy is 50 to 100 times higher than in a 14V system. Such arcing can generate temperatures up to 1800°F, ignite fuel vapors, start a fire in plastic insulation, and even melt metal. Simply redesigning relays, switches, and fuses for higher voltage and using flame-retardant materials is not a total solution; these component designs should suppress arcs. The same is true for other connections, particularly those that could be opened during replacement of fuses, batteries, and other components. Mechanical design features must ensure that electrical terminals are correctly seated and locked; therefore, increased use of clips, clamps, and shields may be required.

New Manufacturing and Test Requirements

Implementation of 42V systems will affect the design, manufacturing, assembly, and testing of most electrical and electronic components. Electromechanical components such as alternators, motors, and starters may require more time on field coil winding machines to get the same number of ampere-turns (given that the current and wire gauge will be one-third of what it was for 14V devices). Other components will be redesigned or replaced. In many cases, suppliers will be asked to make them lighter, more efficient, and less expensive. This probably means that semiconductors will replace electromechanical designs in some switch and relay applications. This will call for higher power devices, such as trench MOSFETs in higher voltage packages.

While basic designs of existing assembly and test equipment should be adequate for 42V components, the higher voltage will require some modifications. For instance, additional production testing may be required to verify arc suppression and EMI/EMC compliance. To design the new 42V components properly, car makers and their suppliers must understand critical engineering and performance issues. As a result, there will be increased R&D activity involving the electrical characterization of devices and their designs. Typically, this entails electrical measurements under various load conditions, insulation resistance and hi-pot testing, and very low resistance measurement of relay contacts and connector terminals.

<u>Simplifying and Speeding Up Measurements</u>. Many 42V tests will require only common instruments, such as load banks, high current power supplies, and DMMs. More specialized tests of conductors and insulators require instruments designed specifically for the measurement extremes involved in low resistance, high resistance, and low current testing. Complex devices, such as DC/DC converters, inverters, airbag igniter systems, and other electronic controllers require more extensive testing and multifaceted test systems.

Many of these devices contain a large numbers of conductor pathways, have many sensor inputs (temperature, vibration, humidity, etc.), and require multiple measurements, so signal switching systems are a valuable test tool. Matrix switches support fully automated testing, reduce the number of instruments required, simplify test procedures, and reduce test time. In such a test system, the measuring instruments, signal switching, and other critical components should be selected for ease of integration and optimum overall performance. Better still, use of a fully integrated datalogging and switch system (Figure 1) eliminates the need to integrate many of the test system components.

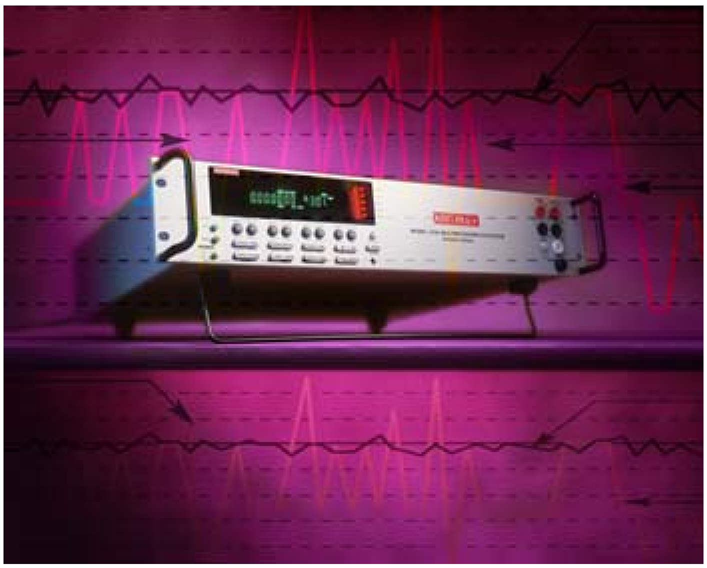

Figure 1. Keithley Model 2750 Multimeter/Switching System allows up to 2500 readings/second across 200 channels of differential switching for analog and digital I/O, plus 14 DMM measurement functions.

<u>Application Specific Measurements</u>. Many automotive electrical tests are essentially resistance measurements to verify continuity, or low leakage currents during hi-pot testing. Nevertheless, production testing may dictate multiple measurements in a specific sequence to check for proper assembly and wiring, which creates complexity in simple resistance measurements.

For instance, the electrical check on a vehicle's primary airbag inflator verifies proper characteristics in the pyrotechnic initiator, a fusible wire with a typical resistance of around 2–3 ohms. A second test checks the safety shorting clip ($<100m\Omega$) to verify that initiator pins are shorted together, a safety feature that prevents accidental activation during airbag handling and installation. (The shorting clip is removed after installation is complete.) A third test is a high voltage isolation resistance measurement to make sure there is no electrical leakage path (i.e., low resistance) between the initiator and the grounded metal housing of the system's electronic module, which otherwise could cause a "no-fire" condition. Some manufacturers perform additional electrical tests on their airbag modules and wiring harnesses using the same test stand.

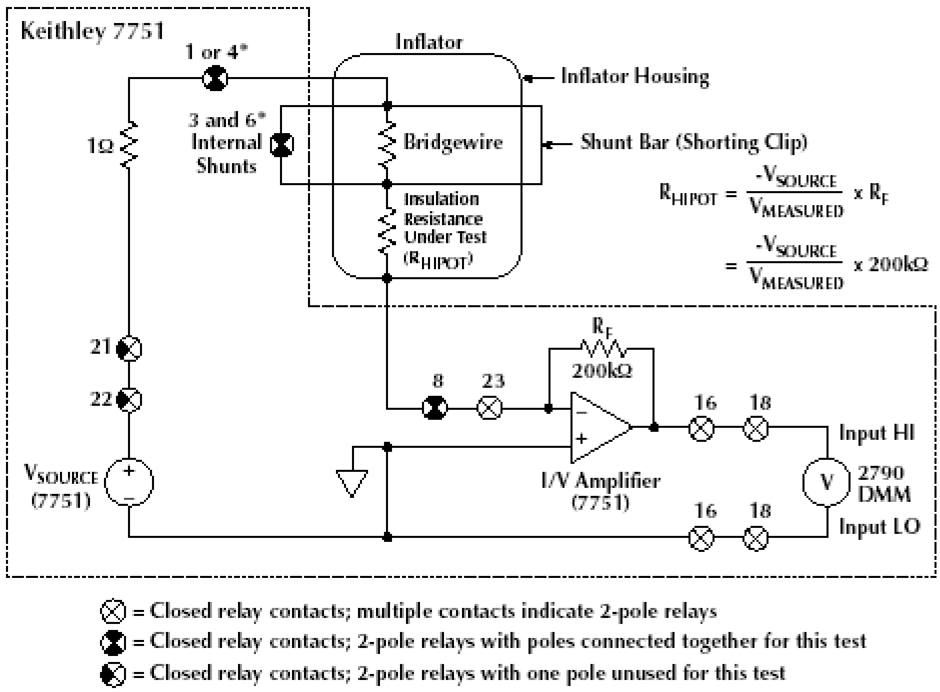

Figure 2. Hi-pot electrical test circuit using a Keithley Model 2790 Airbag Inflator Test System.

Often, developing such a system from individual instruments and switching components, and then implementing it on the production floor, can be quite costly. When available, an application-specific test system can save the user time and money by providing tightly integrated components in a single ready-to-run unit. Figure 2 illustrates an airbag inflator hi-pot electrical test circuit using such a system. The test system includes voltage and current sources integrated with measuring instruments and a switching matrix.

Ethernet-Based Test Solutions. The switch to 42V systems will be on a "fast track," so test data sharing across the enterprise will be important. Today, that often means feeding data to multiple departments across an Ethernet bus (Figure 3). Having Ethernet-ready instruments with tightly integrated measurement and switching functions greatly simplifies this task.

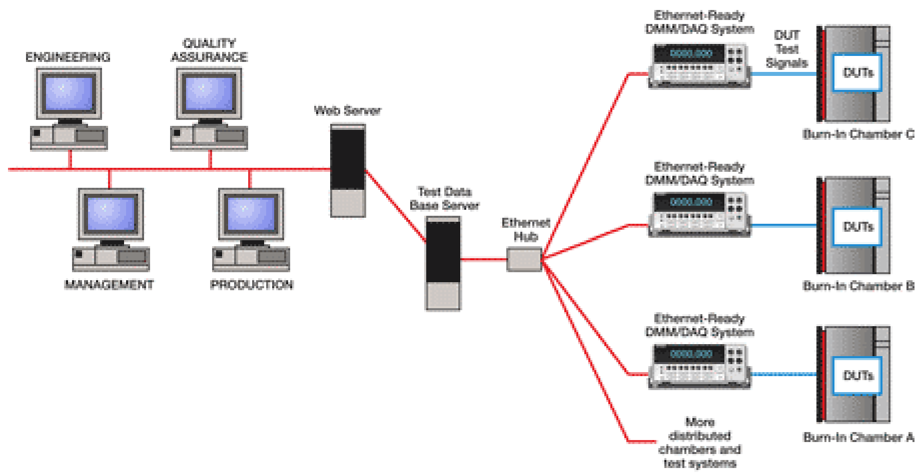

Figure 3. Typical distributed test and data sharing system. Burn-in chambers may be located in either R&D or production departments, and may include vibration as well as temperature cycling.

An additional benefit of Ethernet-based measurement solutions is that test engineers do not have to trade measurement accuracy for convenience and cost-effective data collection. While PC plug-in cards provide low cost, measurement quality usually is much lower than that available with benchtop instruments. When the benchtop instrument also has an Ethernet-ready interface, test engineers get the best of both worlds. This becomes increasingly important in a production environment with many test stations or multipoint sensors. In such cases, it's often more cost-effective to use an Ethernet-based instrument than to install multiple PC-based plug-in card systems.

The Look of the Future

Once the transition to a 42V power architecture is completed, wire gauges will be reduced, cable bundles will shrink, smaller connectors can be used, and wiring weight will drop. Along with lower cable costs, labor costs will be reduced because of simpler installation. Full benefits of the new architecture will include:

- Increased electrical power for cell phones, GPS units, audio systems, etc.
- Reduced size and mass of motors and other accessories
- More flexible, lighter weight packaging
- More efficient operation (improved fuel economy and lower emissions)

- The potential for redundant power sources
- Faster temperature change in the HVAC system
- Longer service life for many components and assemblies

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