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REPRINT

SMD resistors (original size)

High-quality yet low-priced current sense resistors

New resistor designs (shunts) for the automotive industry

Today's requirements of the automotive industry exceed the industry's usual 100 A for SMD resistors so that novel, extremely low-ohmic high-load precision resistors are required. These are produced by Isabellenhütte, using a patented process during which the resistors are punched from electron-beam welded Cu-Manganin-Cu-strips. The product is a reasonably priced, extremely low-ohmic SMD resistor (up to 0.1 mΩ) for high-currents ranging up to 300 A.

By Dr. Ullrich Hetzler

In the next few years and decades, the automotive industry will experience its „electronic revolution". The vehicle of the future will contain hundreds of microcomputers that communicate among each other, with the driver and with the environment (traffic control, satellite navigation, telephone, etc.). However, the process of changing from or replacing conventional control systems to, or in combination with electronic systems, has already begun, specifically in the field of power electronics for controlling and activating motors, valves and other actuators.

The Electronic Stability Program (ESP) introduced in the Mercedes A series due to stability problems that had been experienced („Elk-Test") should be mentioned in this regard. This control system has proven to be successful, not only in Daimler's entire model range, but is now used by most of the other car manufacturers. It can be anticipated that it will be a part of the standard equipment in all vehicle types within the next few years. The same is applicable to applications, such as the electrical power steering (EPAS and EPS), an electronically controlled drive system for the radiator, water pump, compressor for the air-conditioning system and fan drive, and direct fuel or diesel injection (common rail, pump nozzle).

Not too far in the future, even more spectacular developments, such as drive-by-wire (fully electronic steering), brake-by-wire and the electromechanical valve drive to replace the camshaft are to be expected. All these sub-units together will require so much electric energy that the present 12 V vehicle electrical system will have to be replaced by the 42 V electrical system, which has already been designed. The electric energy will be supplied to the individual current-consuming units via a so-called power bus. The intelligent control of these current-consuming units will be coordinated via an information bus (CAN, LIN).

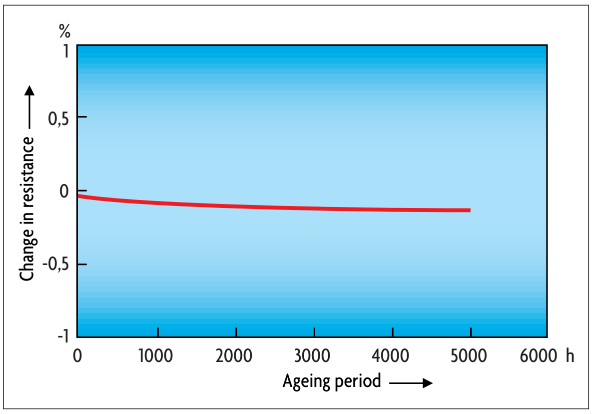

Figure 1. Current sensing resistors on the basis of a Manganin alloy offer long-term stability rated < 0.5 % under full load.

On the other hand, this architecture will require a new version of a three-phase electric generator that works directly at the crankshaft and that must generate power of 10 to 20 kW, at least for short periods of time. Operated as a motor, this generator also functions as a highly dynamic starter (integrated starter generator ISG), which can be used, if necessary, as an acceleration booster with an additional torque up to 100 Nm. Due to its high dynamics, the ISG can also actively „offset“ engine vibrations.

In-depth functional analyses indispensable

For all these systems, it is necessary that the micro-processor receives an accurate feedback on their function and condition. Apart from voltage, torque and temperature, information on the current flow is of decisive significance in many cases. As different physical measuring principles and design forms exist for current sensors, the environmental conditions typical of the car, electric limiting values and costs must carefully be considered and compared to ensure that the optimal sensor is chosen.

The most important requirement for the electronic system in the vehicle is the 100 percent functional reliability over the entire life period of the vehicle. This naturally requires components that operate safely even under extreme temperature, humidity and load conditions (–40 to 150 °C and humidity values up to 100 %). In many cases – for instance for electronic power steering – the current sensor must record 60 to 80 A with an accuracy of better than 1 %. Simultaneously, it must tolerate pulsed currents of more than 100 A – for instance for power steering operation when the vehicle is standing – without any damage.

In addition to these stability requirements, the sensor signal should largely be independent of the temperature (small temperature coefficient), have a high long-term stability and its inductance should be as low as possible. The last point is of utmost significance as almost all applications operate in the switch mode. With increasing switching frequencies, higher currents and lower resistance values (e.g. 0.1 mΩ for 200 A), the significance of the inductance of the component and the design becomes increasingly more important. A typical inductance limiting value in this range is a value < 1 nH.

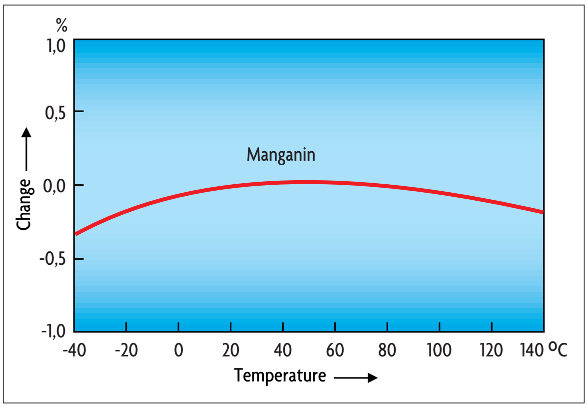

Figure 2. Close tolerances down to 0.5 % are additional features of this resistor type.

Selection of the sensor

Component suppliers are aware of the strict requirements of the automotive industry for maximum reliability and simultaneously minimum costs. Only those sensor types that are manufactured using highly reliable processes and materials, will thus be successful. Moreover, all stages of the manufacturing process must clearly be traceable. Component size is one of the most important requirements. The sensor must be small, suitable for all SMD soldering processes and must be packed on continuous tapes for automatic assembly.

All these requirements considered, the shunt resistor (current sensing resistor, CSR) would definitively be chosen from all the sensor types available. Hall-effect sensors and magneto resistive systems have disadvantages with regard to the temperature coefficient (TC), long-term stability and their operating temperature range. Current transformers, on the other hand, are large, expensive and not optimally compatible with SMD technology.

Several manufacturers are now offering various technologies and designs of current sensing resistors (CSR). However, only a few of these fully comply with the strict requirements of the automotive industry. Thick and thin film resistors, for instance, are available in a variety of SMD sizes and at very reasonable prices. However, the currents that need to be measured in the automotive field require resistance values in the lower milliohm range, a high power dissipation and high accuracy. To achieve these requirements, thick and thin film technology would lose their principal advantage of low cost. For resistance values of less than 1 Ω, the temperature coefficient of thick and thin film resistors considerably increases, easily reaching values between 300 and 500 ppm/K at 10 mΩ and as a result, the required accuracy in the operating temperature range can no longer be achieved. Their low pulse current rating, particularly required for clocked applications, is an additional disadvantage.

Low-ohmic wire wound resistors are also available in the milliohm range

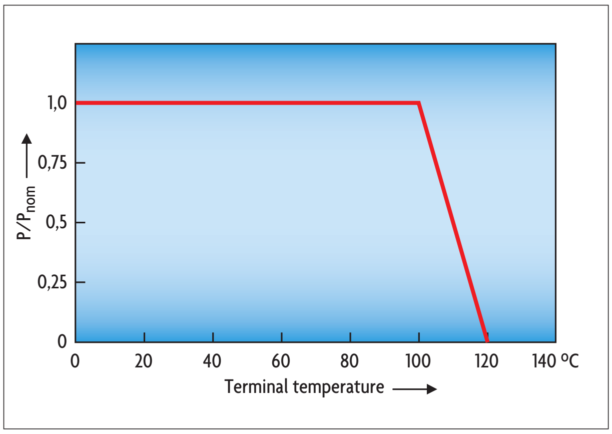

Figure 3. No power derating at temperatures below 95 °C.

with TC values of less than 100 ppm/K. Nevertheless, large structural shapes and a comparably high inductance are disadvantages of these conventional designs. Few SMD designs are offered and achieving tight tolerances is difficult and increases costs.

Etch process foil resistors, on the other hand, are the most promising solution for low-ohm SMD resistors. Various manufacturers have developed two technological variants in the last few decades: NiCr foil on ceramics and Manganin on metal substrate (Cu or Al).

The *NiCr/ceramics technology* provides highly accurate resistors with TC values of less than 3 ppm/K. Because extremely thin foils with a high specific resistance are used, the resistors can only be realised in the range of 1 Ω or more. The *Manganin/metal technology*, in contrast, provides the benefit of a low-cost, fully automated manufacturing process. As a large number of resistors are arranged on a so-called production plate, the majority of the process steps can – as is the case for semiconductor production – be realised as „parallel manufacture“ so that the costs per piece can be kept relatively low. Due to the rectangular outer shape, it is easily possible to fully automate subsequent work on the individual part.

Over the last few years, this technology has been developed and perfected by Isabellenhütte under the name ISA-PLAN®. The Manganin alloy was developed by the company 100 years ago, and is ideally suited for the manufacture of resistors in the mΩ range due to its low TC value (typically 10 ppm/K), its significantly low thermal electromotive force against copper and the extremely high long-term stability. It provides additional features, such as a high time stability (better than 0.5 % under full load, *Figure 1*), close tolerances up to 0.5 % (*Figure 2*), no power derating under 95 °C (*Figure 3*); low internal thermal resistance up to 1 K/W, high power density up to 20 W/cm^2 and the ability to produce finished package dimensions down to the standard „1206“ size.

Manufacturing technology in key words

The ISA-PLAN® process starts with lamination of the Manganin foil to a metal substrate of copper or anodised aluminium. This high temperature resistant adhesion has been optimised in terms of its adhesive strength, insulation and, above all, a low thermal resistance between the resistor foil and the substrate. The lamination is achieved by a special pre-treatment of the resistor foil and the substrate while in a vacuum and under high pressure and high temperature to ensure stable adhesion conditions without inclusion of air.

After cleaning, marking and punching indexing holes, the panels go through a photolithographic process during which the individual resistor patterns (sometimes more than 10 000 per production plate) are defined. Only by this planar structure, combined with the etch technology, is it possible to manufacture ideal four-terminal SMD resistors in the range of a few milliohms. The four-terminal (Kelvin) design completely eliminates the influences of the Cu connection on the resistance value and the TC, guaranteeing high reproducibility. Any influences of the quality of the solder joints on the resistance value are thus eliminated.

After the etching process, further chemical treatments as well as highly automated processes such as laser processing and trimming, follow. The resistors are separated from the substrate by laser, punching or sawing. Systems that also operate fully automatically perform the final treatments, such as cleaning, resistance measurement, marking and packing in tape and reel for automatic SMD assembly at the customer. To detect any defects in the etch structure each resistor is tested in these systems under electrical pulse load with subsequent eva-

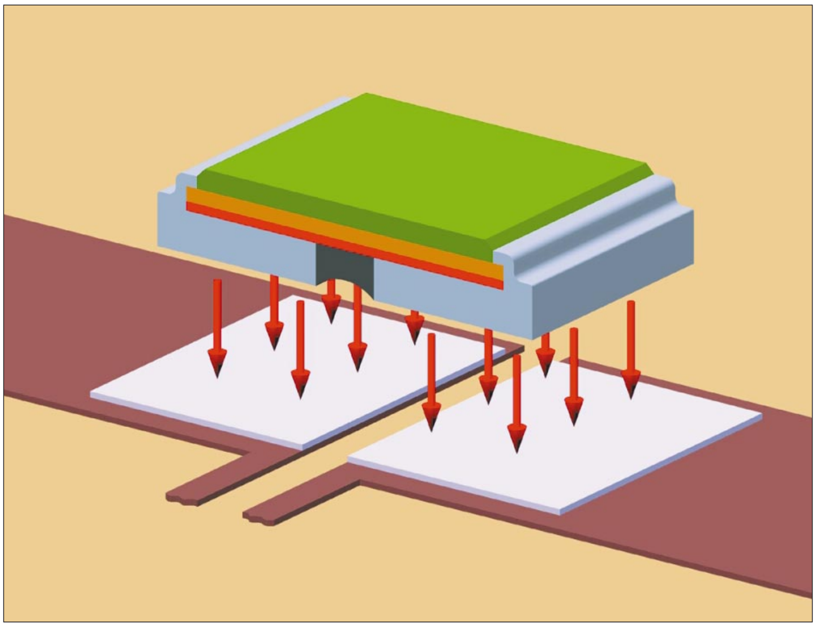

Figure 4. Example of a SMD resistor based on the ISA-PLAN® technology

luation of the IR image. The finished reels are sealed in foil and are treated with nitrogen gas to maintain their solderability. Each reel is identified with a one or two-dimensional barcode that contains all the relevant data, such as resistor type, value, tolerance, date code, quantity and reel number to ensure traceability. It is also possible to identify the resistor with a customer-specific part number.

Due to the diverse requirements of the end users, a wide range of SMD resistors (*Figure 4*), based on the ISA-PLAN technology, e.g. hybrid assembly, has been created in the last few decades.

Present automotive applications require maximum load capacity

The latest requirements of the automotive industry now exceed the 100 A for SMD resistors, so novel, extremely low-ohm high-current capacity sense resistors (HCSR) had to be developed. For their manufacture, Isabellenhütte uses a patented process during which the resistors are punched from electron-beam welded Cu-Manganin-Cu-strips. The product is a low-priced, extremely low-ohm SMD resistor (down to 0.1 mΩ) for high-currents ranging up to 300 A. This new technology has already proven to be successful in many applications in electric power steering, high-current-DC/DC converters and battery control systems. Thanks to the high flexibility of this technology, relatively small investments are necessary to design customer or application specific solutions in order to overcome any space and assembly restrictions.

The 42-V vehicle electrical system is inevitable. However, it is likely that two parallel vehicle electrical systems will be required during an interim period. Electric, hybrid and fuel cell drives with advanced generator types will prevail, providing interesting solutions with regard to low fuel consumption and a reduced environmental impact. The power bus will require novel wiring structures. New, intelligent power semiconductors will be required to control the large number of actuators, and the control of the power and the battery (power and battery management) will play a central role. One may anxiously await these as well as other changes in the vehicle that are imminent in the near future. What is certain is that automotive electronics will require and initiate further innovations in the field of power electronics, particularly in the field of active and passive components and their assembly and integration technology. *go*

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studied semiconductor physics at the University of Karlsruhe and graduated in the field of ferroelectric field effects in 1976. After working in the IBM research department in California for one year, he became the head of the research and development department at Isabellenhütte, where he has been employed for the last 23 years. During this time, a number of novel low-ohm resistor designs have been developed and are in use worldwide.
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