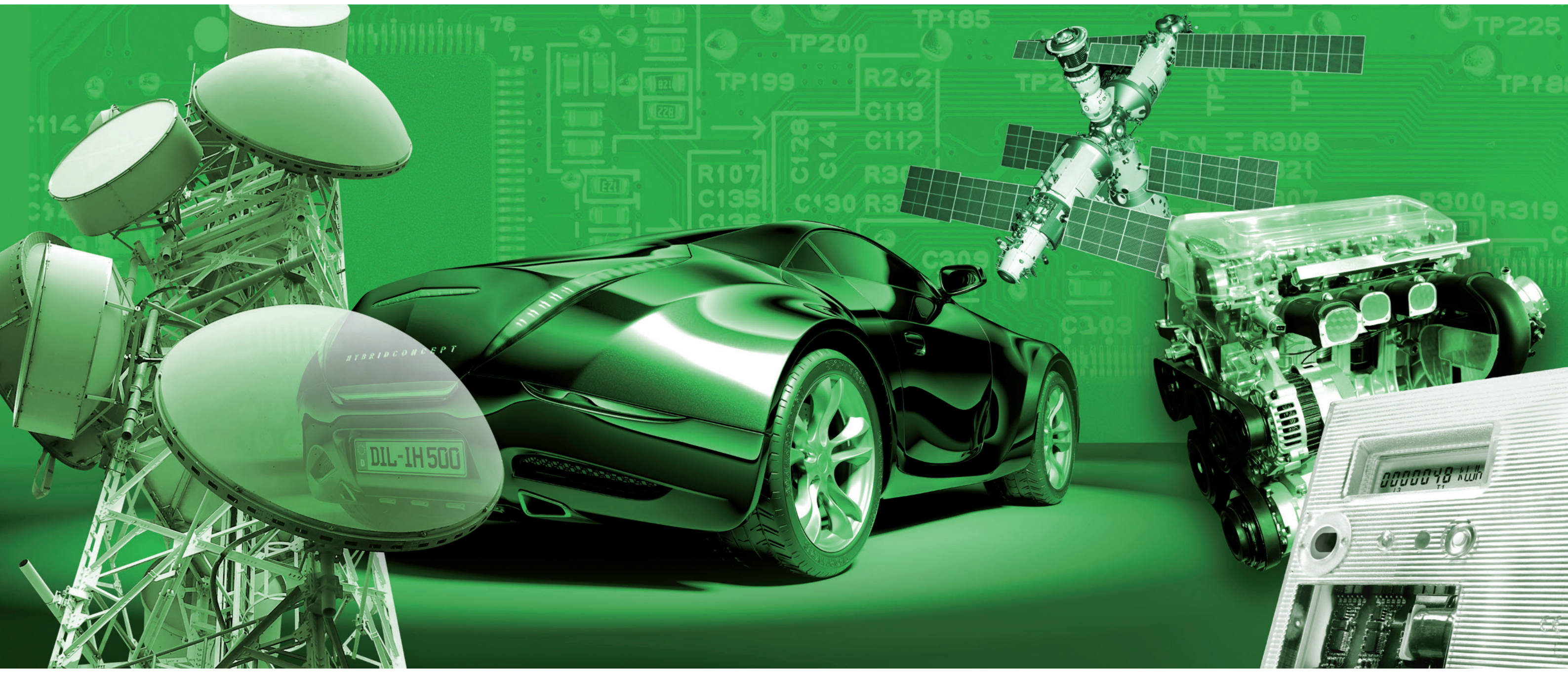
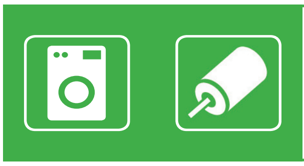


LOW-OHMIC PRECISION AND POWER RESISTORS

APPLICATION NOTE WHITE GOODS



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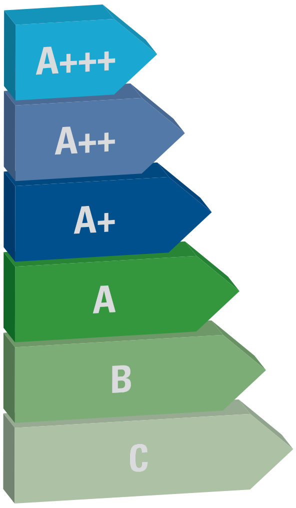
Today, it is inconceivable to have electronic appliances without an indication of their energy efficiency. Particularly in the EU, where transnational and politically motivated demands for a reduction in CO_2 emissions, and consequently the saving of energy, is leading to an overall energy-saving awareness not only in Industry. Large household electrical appliances such as washing machines, refrigerators and freezers, in particular, have become pioneers in achieving even higher energy efficiency classes in recent years; the growing consumer demand and statutory obligations have had the desired effect.



In most cases, manufacturers achieve an improvement in the energy efficiency of their products through the integration of „smart components". The greatest savings potential is to be seen in drives or motors where, for example, the changeover from AC motors to DC or EC motors offers energy savings of up to 30%. Fully integrated EC motors offer the most efficient solution, but are very expensive by comparison with modern BLDC motors. Consequently the manufacturers rely on the use of these low-consumption drives in combination with (the manufacturer's own) external control electronics and software.

ISABELLENHÜTTE
Innovation by Tradition

How are the BLDC motors applied?

BLDC motors are representatives of commercially available 3-phase AC rotary field motors with permanent magnets and are characterised in particular by their compact design and practically wear-free operation. In conjunction with selective control, they can be operated at high efficiency even at low speeds.

The (pulse width-modulated) control of a BLDC motor is generally accomplished by means of three MosFET half-bridges with two motor phases always being actively „energised" and driven in succession to generate a rotary field.

Brushless DC Motor Control

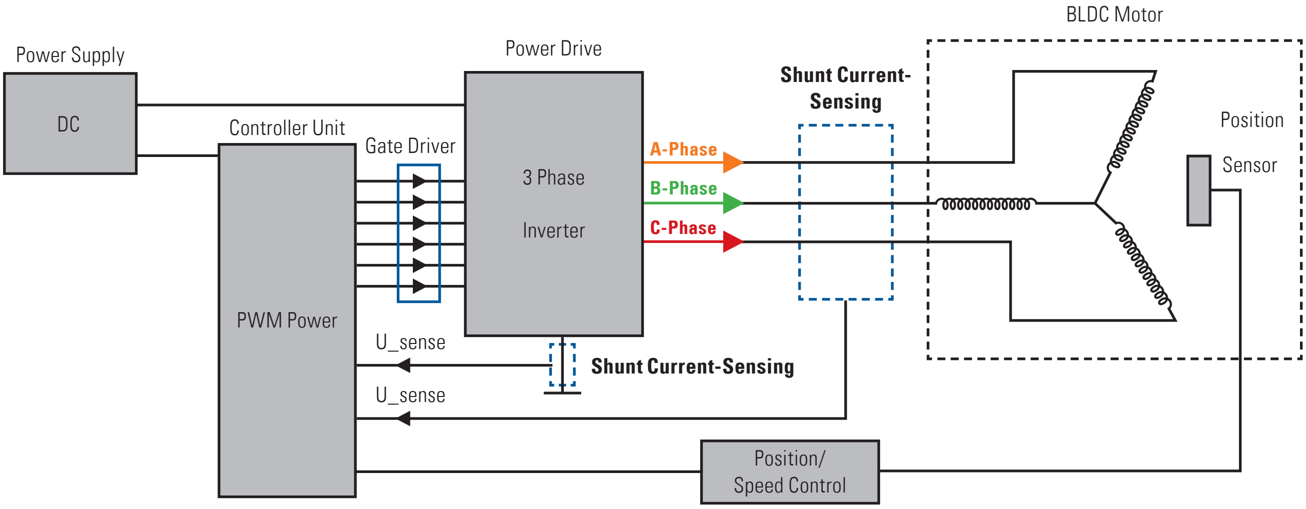


Figure 1: Schematic block diagram of a control unit for a BLDC motor.

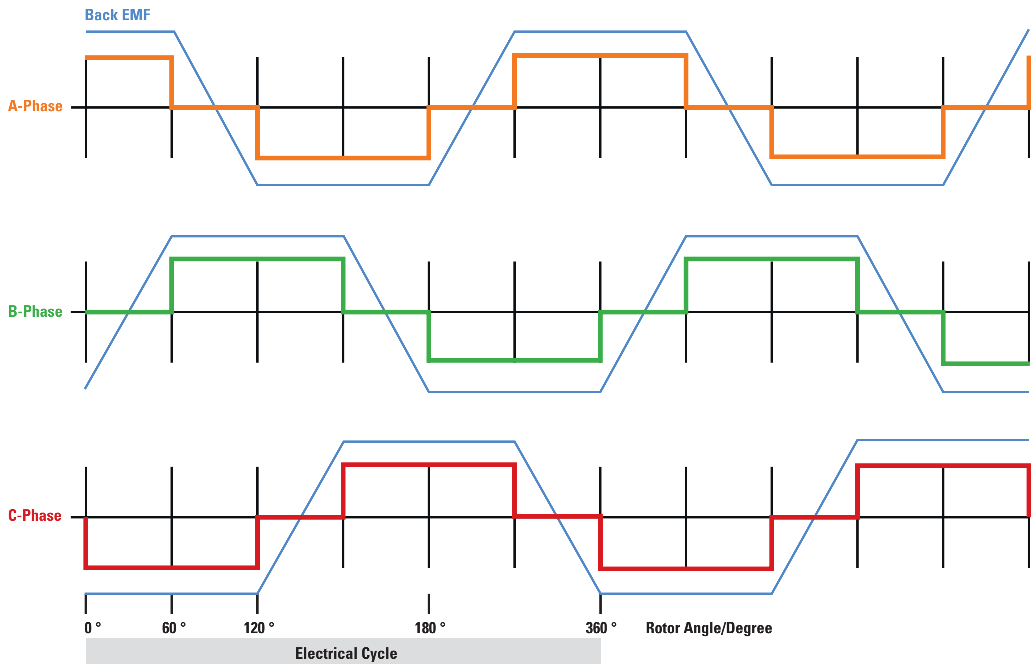


Figure 2: 3-Phase Duty Cycle of the PWM signal.

The carefully developed control electronics and software thereby preferably follow the approach of a field-oriented control (FOC) that has a low power consumption of the whole assembly and thereby allows the BLDC motor to operate at maximum torque practically the whole time. This is reflected in use by "smooth running", whether under load or at low speeds.

The principle of field-oriented control is based on sequential driving of the pole pairs in the stator of the BLDC motor using a correspondingly pulsed direct current. In order to be able to take full advantage of the above benefits for the field-oriented control, it is essential to know as much about the current flowing through the windings of the stator as possible; the quality, precision and reliability of the complete motor control thus depends on the quality, precision and reliability of the current measured. A low-ohm current measuring resistor (shunt) is ideally suited for this application.

How is the current measured via a shunt?

According to Ohm's Law (R = U/I), the voltage drop U_R across the measuring resistor is proportional to the current flowing through the resistor. From the measured and evaluated voltage it is possible to determine very precisely the current intensity according to the circuit requirements. The voltage signal U_R can, for example, be forwarded via a delta-sigma converter with electrical isolation or a suitable OP-Amp circuit to an evaluation electronics unit (controller).

There are thereby several fundamental possibilities for measuring the current using a shunt:

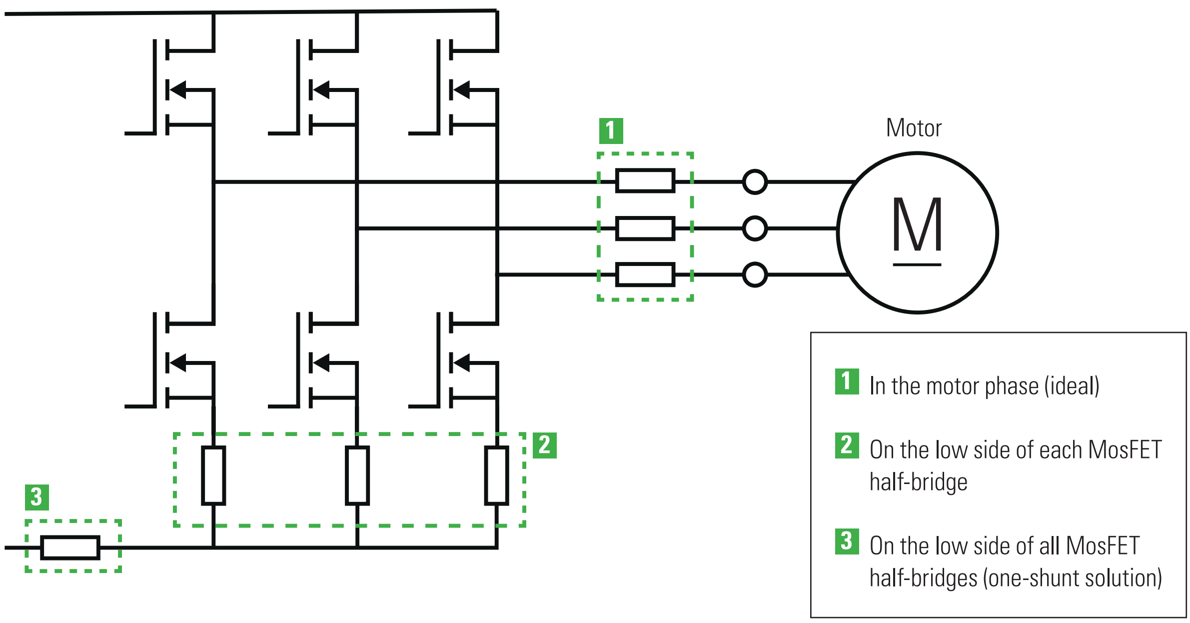


Figure 3: Possible positions for current measuring via shunts in a BLDC motor controller.

Whether only one shunt is used for budget cost reasons, or a shunt is used on each phase is ultimately dependent on the application, accuracy requirements and installation space. In both cases the function of the shunt is to measure the current and to forward the declining voltage to the downstream circuit.

The choice of the right shunt

Two key points should be considered in order to choose the right resistance value.

The resistance has to be sufficiently high so that the declining voltage signal is also high enough that it can still be amplified sufficiently by the downstream amplifier circuit and can be reliably detected by the converter. If the selected resistance value is too low, there is the risk that the amplifier design becomes too sensitive and every interfering noise signal which is also amplified directly affects the useful (measuring) signal, thereby the result is not suitable for the control.

Alternatively, the resistance of the shunt must not be too high; as shown by the formula

$$\mathbf{P_L = I_L^2 \times R_L}$$

there is power dissipation in every current-carrying conductor that can be detected as a heat loss or rise in component temperature. This applies in particular to shunts where this effect is many times stronger and more concentrated than in conductors of other passive components. Consequently the choice of the maximum allowable resistance value is limited in order to keep the resulting power dissipation/heat loss as low as possible.

The following factors should be taken into account when choosing a suitable resistance value for a shunt.

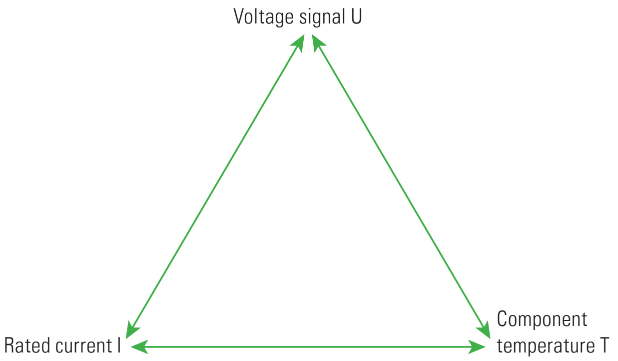


Figure 4: "Magic triangle" of the right choice of shunt

Power electronics for drives (e.g. for the drum of washing machines or dryers) use typical resistance values between 10 mOhm and 50 mOhm for their shunts. For less "power-hungry" drives, shunts can also be used with resistance values up to 500 mOhm (e.g. for fans of extractor hoods).

Challenges of implementation in practice

From the point of view of the electrical demands on the choice of a suitable resistance value, this can be very quickly determined from the desired voltage signal and the underlying rated current using Ohm's Law. With the result thus calculated, you can then choose from the wide range of shunts of different sizes and designs in the market.

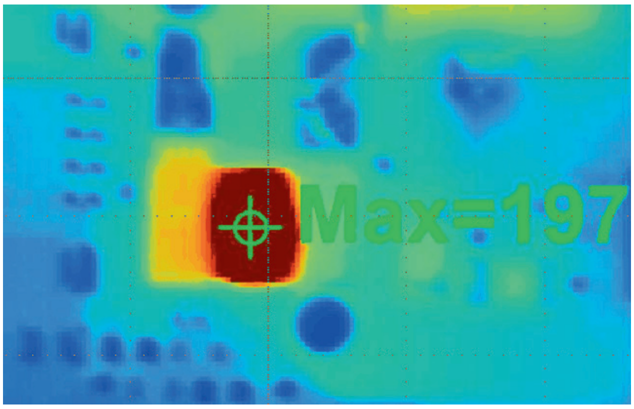


Figure 5: IR image of a metal foil current measuring resistor, size 2512, under nominal electrical conditions at the time of the original circuit design.

In the initial choice of the component, this method almost completely ignores thermal demands, e.g. from VDE or UL specifications; this can then have a very negative effect during the later course of the finished product qualification by infringing the above mentioned VDE or UL regulations. It is not unusual for the electrical demands to be satisfied, while the thermal demands for control elements and modules are far exceeded, leading to the need for costly redesign measures. The first challenge can be seen here in the thermal behaviour of the shunt to be used, expressed as the coefficient of the internal heat resistance Rthi [K/W].

The second notable challenge for the shunt to be used results inevitably from the component temperature in that the resistance changes with the change in temperature. This behaviour is referred to as temperature-dependent resistance drift and is essentially a material property of the resistor material used in the shunt. This effect, expressed by the "temperature coefficient" TCR [ppm/K], provides sufficient information on the measuring inaccuracy to be expected with rising component temperature.

The fact that both challenges exist not only on the data sheet, but do indeed also present hardware developers with unexpected problems, can be seen from the attempted solutions to date:

- Use of larger-sized shunts than (electrically) necessary
  More space required, higher component costs with no added value
- Use of several shunts in series or parallel configuration for power and/or temperature compensation
  Susceptible to faults and tolerance, as well as far greater space requirement thanks to the multiplicity of components, higher component and process costs with no added value

Although these conventional approaches are pragmatic, they do show the need for a simpler solution, in the best case scenario, of a one-component solution at a reasonable cost.

ISA-PLAN® solution

ISA-PLAN® current measuring resistors from Isabellenhütte Heusler GmbH & Co. KG are characterised by outstanding component and material properties which do indeed allow the above-mentioned technical challenges to be met in the sense of a one-component solution.

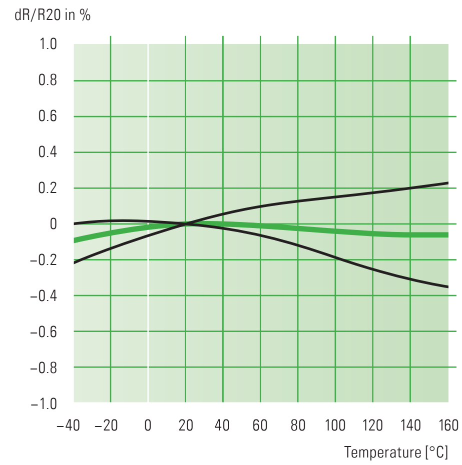
The multi-layer structure of the ISA-PLAN® resistors allows a uniform and almost complete absorption of the heat into the carrier substrate of the resistor, from where the heat energy can be very well dissipated via the soldered joint to the conductor, and from there to the printed circuit board (and possible heat sink). This is clearly reflected in very low R_{thi} values that are lower by a factor of between 2 and 5 to comparable metal foil or thick/thin film resistors. As a result, ISA-PLAN® resistors also have a correspondingly higher continuous power rating as follows:

Size	Rated power [W]
0805	0.5
1206	1.0
2010	2.0
2512	3.0
2817	5.0

The use of resistance alloys from our own production make the ISA-PLAN® resistors the solution of choice. Additionally, from the point of view of the TCR, MANGANIN® and ZERANIN® alloys proved to be most suitable for use in ISA-PLAN® resistors. These resistors have been in use for a very long time, and today can be found in practically all fields of application from white goods to motor vehicles.

If we consider the component level and not the resistor material as such, then ISA-PLAN® resistors are characterised by an overall TCR that is generally already lower than the TCR or the resistor material generally used in metal foil or thick/thin film resistors.

Temperature dependence of the electrical resistance



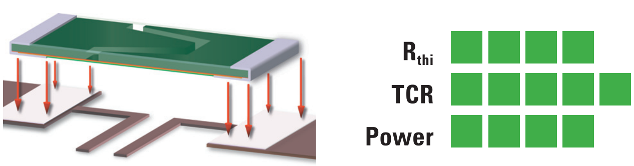
—— (black)	Upper/lower limit
—— (green)	Typical temperature dependence of a resistor

Figure 6: TCR curve of an ISA-PLAN® current measuring resistor, taking the example of Type VMP

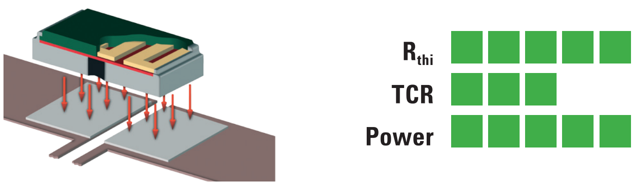
Part recommendations for applications in white goods – Take us at our word!

Depending on the electrical and thermal demands for the controller, the following component series from the Isabellenhütte Heusler GmbH & Co. KG product portfolio offer potential solutions to the challenges described above:

The „Classic" – VMx: One for all!



The "Indestructible" – SMx: When you want to go a little further!



The "Latest" – CMx: For medium and small powers!

Glossary

BLDC Motor	Brushless DC Motor, typically synchronous motors powered by a DC Source and triggered by 3-phase PWM signal.
PWM signal	Pulse-width modulation is a methode to encode a massage into a pulsing signal to drive motors very precise.
Half bridge	Electronic circuit in a H-arrangement that enable the voltage to be applied across a load in either direction.
FOC	Field oriented control is a method where the stator currents of a electric motor are identified as two orthogonal components that can be visualised with a vector, one for the magnetic flux and the other for the torque.
Shunt	Low Ohmic power resistor to measure current very precise and stable over life time.
Op-Amps	Operational amplifier is an activ component with a differential input and single-output for amplifying low voltage to a higher level.
R_{thi}	Internal heat resistance indicates the rating of heat conductivity of a shunt from the inner hot-spot into the terminals and is expressed in K/W.
TCR	The temperatur coefficient indicates the change of resistance by heating up for a certain temperature range. The temperatur coefficient is expressed in ppm/K.
Thermal EMF	The thermal EMF describes a process of voltage generation on a contact point between different materials.

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