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Industrial Research and Development

WHITEPAPER

RELIABLE, PRECISE & REPEATABLE MEASUREMENT DIGITALIZATION

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Energy efficiency stays an important topic. This is also true for lighting systems. Although efficiency has significantly increased with LEDs, it is still possible to improve efficiency and to make them more environmentally friendly. Digital controllers offer several advantages compared to analog control methods. Selecting Low-noise, low-power ADCs are the key for providing the best digital control performance. To guarantee the desired results, V-Research has therefore figured out a reference design for precise measurement with high robustness against noise, perfectly suitable for many high power applications - not just for LEDs.

Results in a Nutshell

The proposed reference design of a two-stage current to voltage conversion circuit with nano-watt ADC has been simulated, realized, and measured to confirm the expectations.

The tests were performed at 100KSPS (Kilo-Samples Per Second) and 300KSPS. Quantization Noise (QN), Quantization Error (QE) and Signal to Noise Ration (SNR) were reported.

Using a 12-Bit ADC, the results showed that up to a sampling rate of approx. 150kHz, the Effective Number of Bits (ENOB) is above 10 bits. At higher sampling rates, ENOB is still over 9 bits.

Measured SNRs of 61dB for 100KSPS and 54dB for 300KSPS respectively, also confirm that the cirquit is suitable for high power and high speed measurement applications.

The performance analysis in a worst-case scenario with 10 Amps at a high frequency of 1MHz showed a very high robustness that is required for high power applications.

Applications:

- Precision Power Measurement
- DC/DC and PFC Control
- Battery Charger
- Motor Control
- LED-Drivers

Features:

- Wide Input Voltage Range (3.3V-30V)
- Minimum Sensing Loss (0.02Ω, up to 25-W Support)
- High Bandwidth
- Tunable Gain (Two-Stage Amplification)
- Flexible ADC CM Voltage
- High CMRR Over Wide Frequency Range (Maximum Switching Noise Rejection)
- Noise-Immunity by Analog Unit Linear Regulation
- Up to 1MSPS Measurement
- Differential/Single Ended Input
- Adjustable ADC Input Common-Mode Voltage
- Ultra Low-Power ADC
- Simple Communication Interface
- 3.3V Logic Adaption

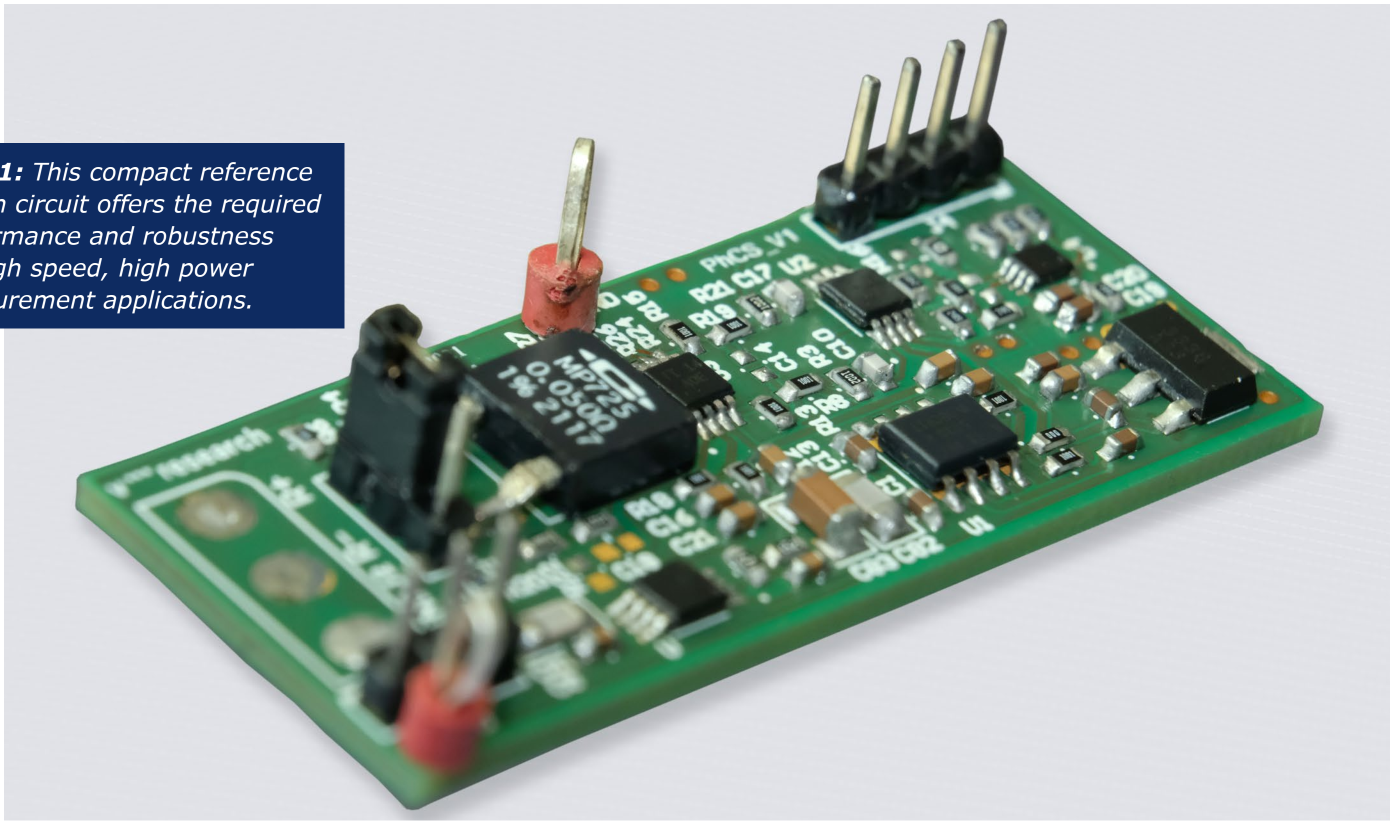


Abb. 1: *This compact reference design circuit offers the required performance and robustness for high speed, high power measurement applications.*

Problem Explanation on the Example of Lighting

Despite the introduction of energy efficient LEDs, lighting still contributes to 5% of total global carbon emissions each year. Therefore the industry still aims to increase system efficiency. Adaptive lighting is a promising solution. Therefore, state-of-the-art lighting systems must allow dimming over a very wide range.

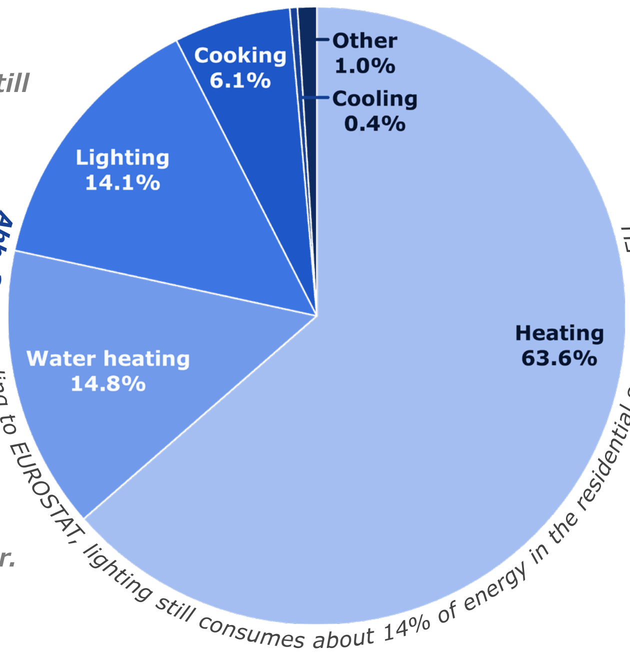


Abb. 2: According to EUROSTAT, lighting still consumes about 14% of energy in the residential sector of the EU.

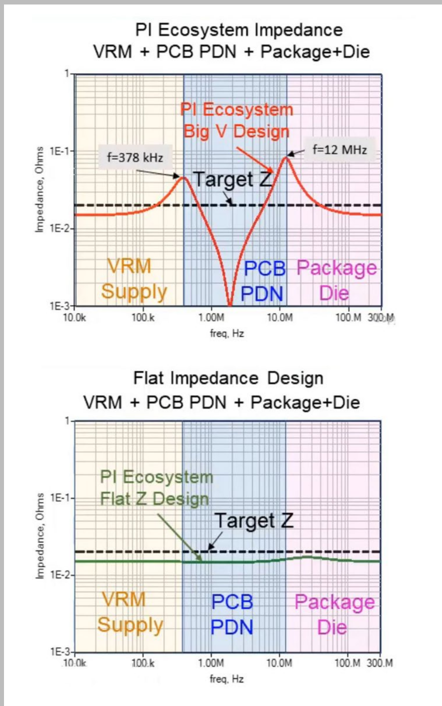
This requires accurate measurement of current and power. But many analog solutions just work reliable within a very limited range. They often show a non-linear behavior when this range is extended excessively.

Digital solutions may help in such a case. As modern LED-drivers are usually equipped with digital intelligence anyway, consequently it could also be used to control power. With this solution reliability and non-linearity issues for the extended working range can be solved if done right.

The use of low-noise, low-power ADCs is important to minimize power losses. They must measure very high and very low current correct and reliable, alike. This requires a thoroughly designed measurement network, printed circuit board layout and a high-quality realization.

The Importance Of The Power Distribution Network Impedance

The Power Distribution Network (PDN) impedance includes basically every element that is connected to the voltage and ground rail. While the system is too complicated for a calculation with closed-form equations, a low and flat PDN impedance in precise measurement is very important. This is especially true when using low voltage semiconductors, and with increasing switching frequency and high current this becomes even more critical.



Without considering flat impedance design you may run in heavy EMI issues and your system may suffer from inaccuracy, unstable power delivery and too high power losses. Therefore the PDN impedance must stay below the calculated target impedance, Z_T, in the whole range of operation.

The target impedance is calculated as

$Z_T = (V_{supply} \times ripple\%)/(50\% \times I_{max})$

In a standard Big V Design, this is not the case. Therefore the Flat Z Design must be considered (see graphs).

About the System

The proposed circuit provides ultra low power and precise current sensing for high-power applications with adjustable gain, high-bandwidth and fully-differential current-to-voltage conversion. This makes the circuit suitable for high-speed control applications.

The most important Details of the System

The high-side current sensing amplifier circuit supports a wide input range. With its two-stage amplification the circuit benefits from a high gain which directly increases the input voltage range and reduces sensing power losses.

A high Common Mode Rejection Ratio (CMRR) results in a maximum switching noise rejection and an accurate measurement. This offers ideal preconditions for high-speed applications up to the MHz-range.

For control purposes, an analog two-stage compensation is implemented thoroughly. Furthermore, the circuit covers a wide input voltage range from 3.3V to 30V for adopting a power converter auxiliary supply. The linear regulation provides immunity from switching noise propagation.

In this design, the first nano-Watt ADC from TI is applied to the circuit that allows ultra lower power applications such as “green mode operation”. Both, a single and differential input voltage option satisfy various configuration requirements. In addition to the tunable amplifier gain, the adjustable Common-Mode (CM) voltage supports the utilization of the full ADC input range while maintaining a maximum precision.

With up to 1MSPS and the simple SPI communication interface the circuit can support high frequency control applications.

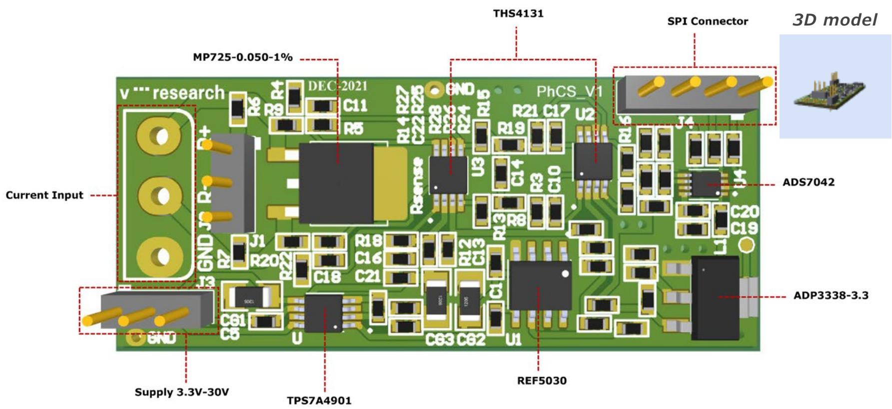


Abb. 3: *A brief description of the circuit (for interactive 3D model click on inset).*

PARAMETER	SPECIFICATIONS
Amplifier BW	> 15MHz
ADC BW	25 MHz
Input voltage	3.3V-30V
Current-to-voltage gain	100 to 400 mVPP/Amp
ADC Resolution	12 Bit
Differential ADC common-mode voltage	1.65V (adjustable)
ADC Maximum DR	1 MSPS
Measured SNR	61 dB (@100 KSPS) 54 dB (@300 KSPS)
SPI Clock	Up to 16 MHz
Logic Level	3.3 V

Table 1: *List of the most relevant design parameters*

The circuit is optimized for high-side current sensing, which has the advantage of undisturbed ground path. This in turn results in immunity from system transient and suppresses noise which normally is distributed from circuit ground connections.

Power Integrity - the Key for accurate Measurement

The chosen design of the measurement network guarantees a flat PDN impedance behavior in the relevant frequency range to avoid the problems described in the fact box on page 3. This accurate design enabled us to keep the PDN impedance flatness, while the two stage amplifier is still optimized to cover the full ADC input range. This way, the proposed solution allows an accurate measurement with high SNR and minimum offset errors at a high sampling rate.

Modelling the Circuit

As a first step, we strongly propose an analogue circuit Spice-model to evaluate the current to voltage sense signal after amplification. Through the evaluate in the analogue circuit Spice model, the designer can tune the analog unit before digital conversion. For the maximum performance and precision, the designer needs to adjust the two-stage amplifier gain to cover the full ADC input range. - We recommend to including a margin before saturation. – We modelled a simulation circuit for a 500kHz inductor switching current with output results as a reference model for further investigation.

While modelling the circuit, we also considered the PDN impedance behavior. Both, the simulation and measurement results prove a significant better impedance behavior than in a conventional design: impedance increase is approximately one magnitude lower at higher frequencies.

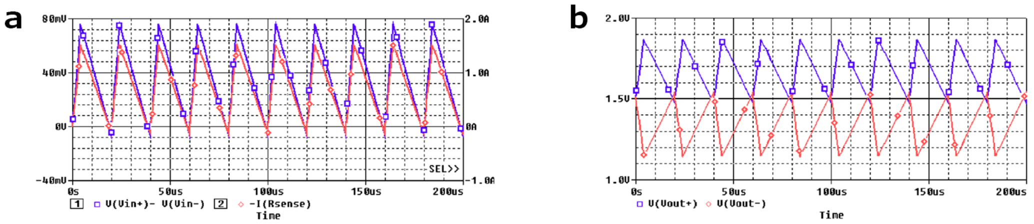


***Abb. 4:** Two stage analog current to voltage amplification circuit simulation: a) input b) output*

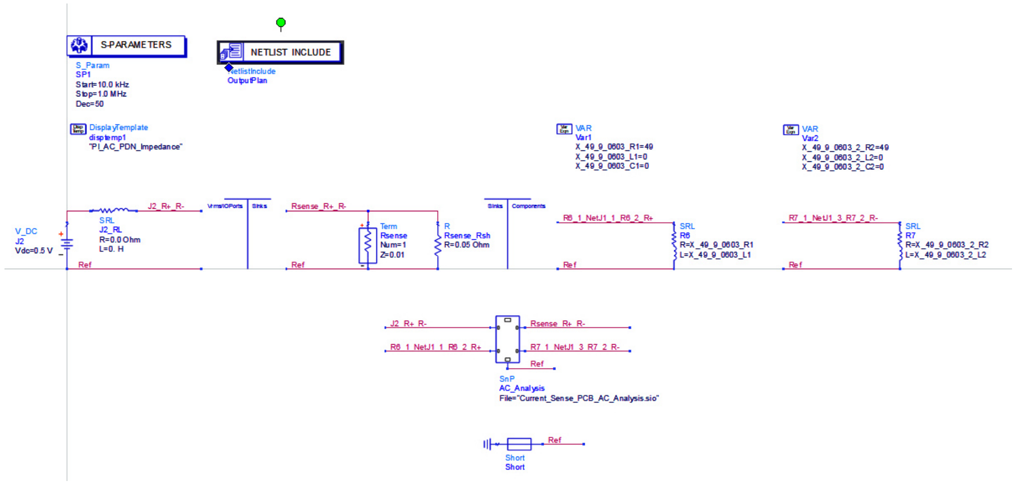


***Abb. 5:** PDN impedance test bench*

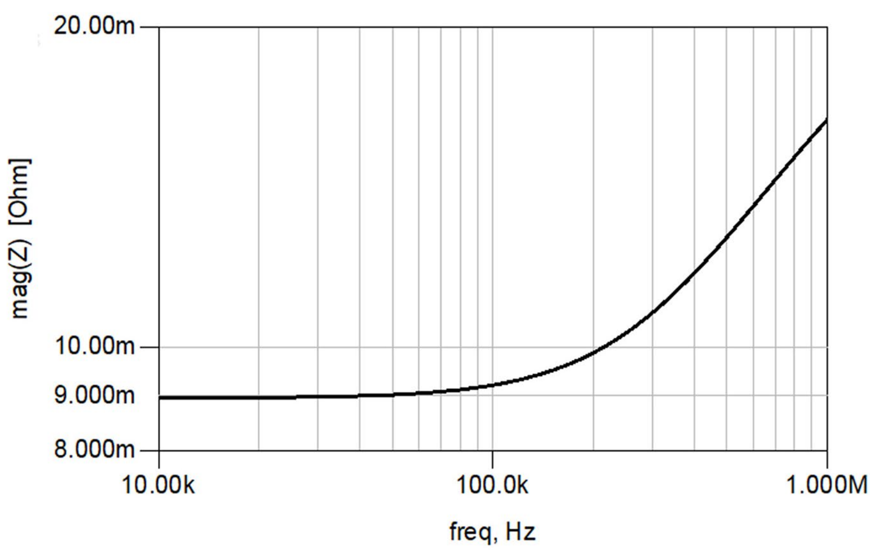


***Abb. 6:** PDN impedance test results*

The Concept Proves High Precision

The system precision is the capability to distinguish the signal from the noise. For this reason, we evaluated the sensing accuracy by Quantization Noise (QN) measurement with 50Ω input termination. The QN consists of distributed noise from a two-stage amplifier in addition to the ADC inherent sampling noise and a PCB effects. So, the normalized spectrum patterns (including the processing gain) were extracted from the Quantization Error (QE) amplitude to describe the system detection capability at mid and high sampling rates. At 100KSPS, the system QE range covered 3 digits (maximum 2LSB bits) while at 300KSPS it raised to 7 digits (maximum 3-LSB bits). Therefore, for sampling around 150KHz the ADC ENOB is 10 bits and for higher sampling rates it is still 9 bits. The normalized QN spectrum confirmed the spur and spike immunity and system reliability. Also, the SNR (without filtering and processing gain) measured by injecting full-scale sine signals from a clean source, results around 61dB for 100KSPS condition and about 54dB for 300KSPS respectively. The practical results are suitable for fast and accurate measurement in high power applications.

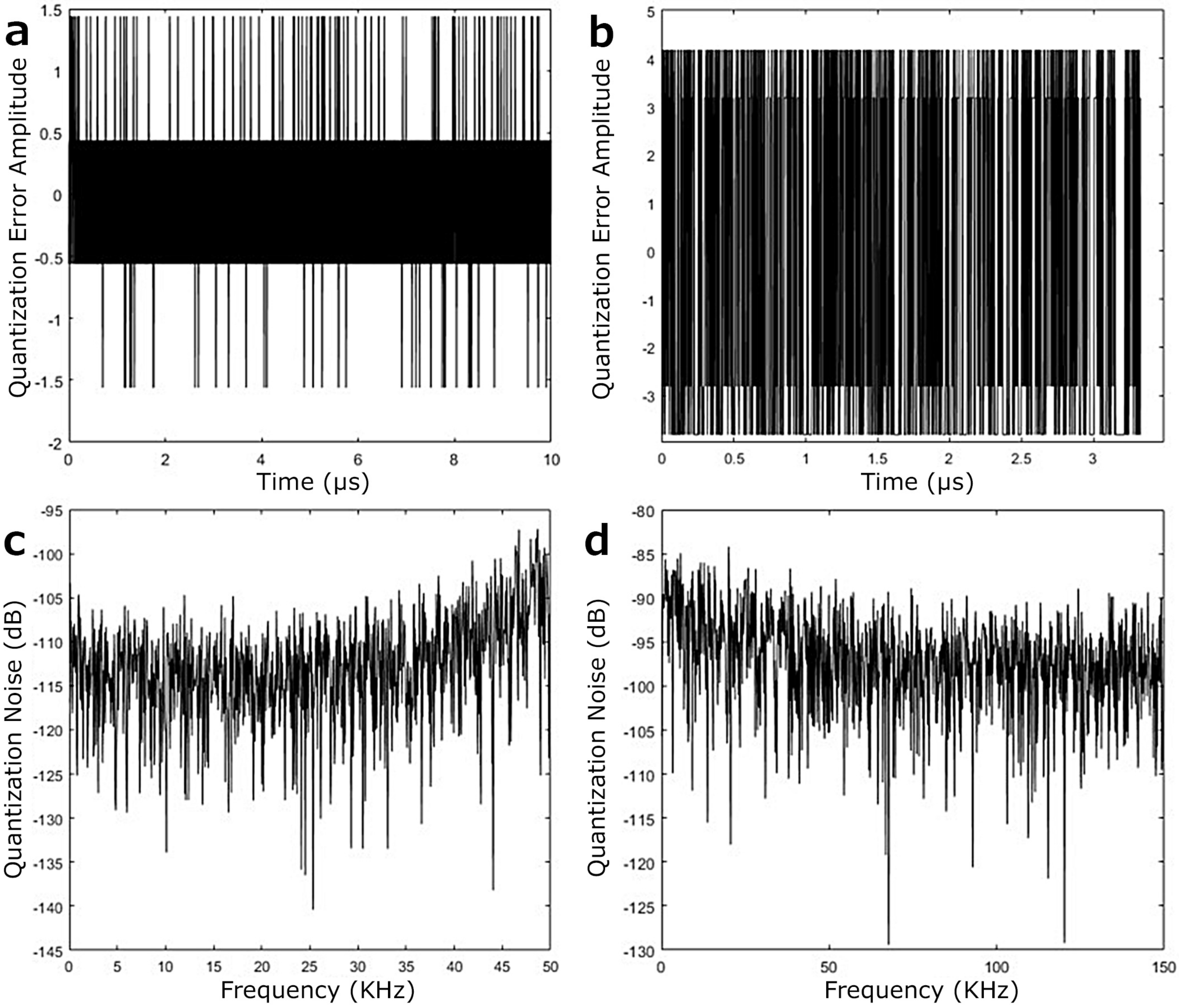


***Abb. 7:** QE and QN measured with 50Ω input termination: a) QE Amplitude @ 100KSPS; b) QE Amplitude @ 300KSPS; c) QN Spectrum @ 100KSPS; d) QN Spectrum @ 300KSPS.*

A Well Designed PCB Maintains A High Performance

To evaluate the PCB effect at high currents (DC analysis) and the influence of the signal path on other sections (AC analysis), we made the performance analysis under the worst case scenario. The results confirm a robust behavior and the expected high performance of the system.

An external 0.5V applied to the 0.05Ω sense resistance resulted in a 10A signal path though the PCB. We thoroughly reported the PCB behavior regarding voltage drop, power loss and current density, respectively.

With an AC analysis, we also determined the magnetic effect of a 1MHz, 10A AC signal caused by applying an external 1MHz, 0.5V AC voltage source to the sense resistor.

The simulation results confirm the PCB's robustness against conduction and radiation at very high current, which makes the designed prototype ideal for high power application.

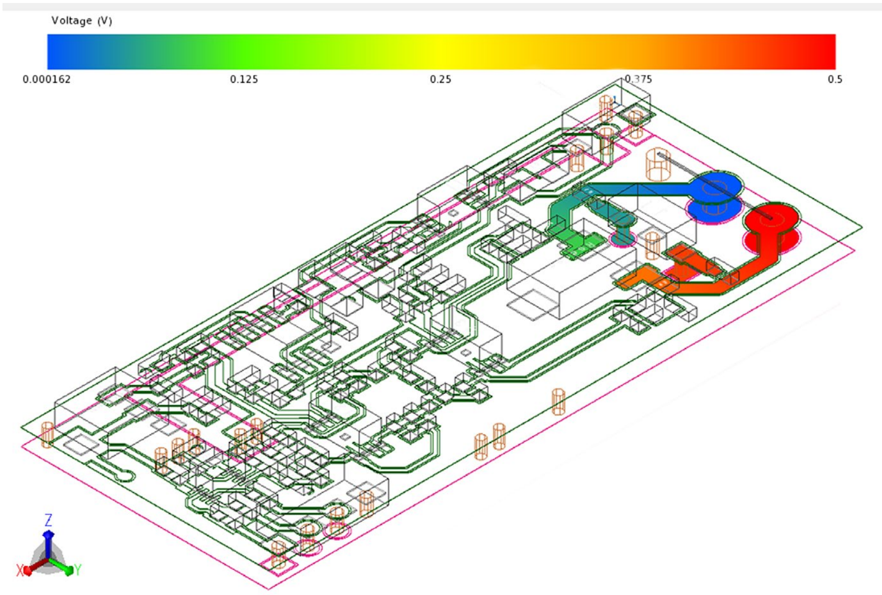


Abb. 8: *PCB behavior regarding voltage drop.*

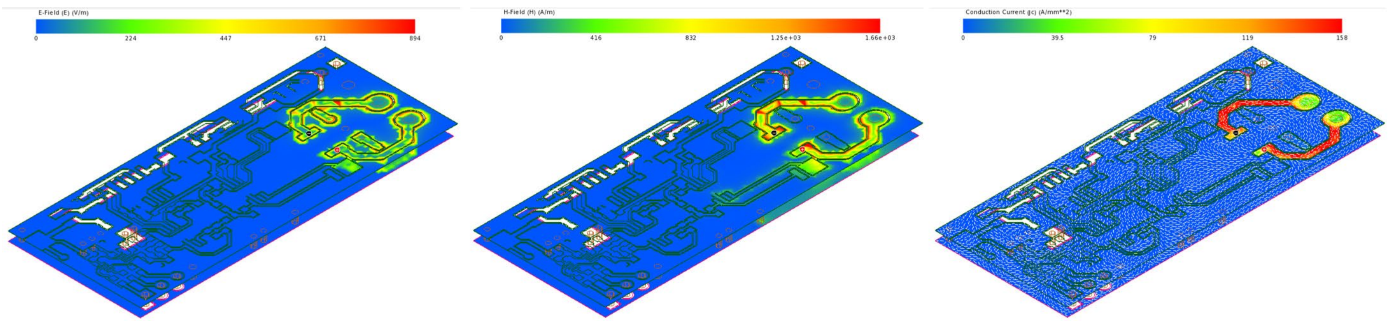


Abb. 9: *AC analysis of the magnetic effect*

Fazit

A thorough design of both the component values and the PCB layout are crucial to gain the maximal benefit from a technology. By considering this, the developed two-stage amplifier is the centerpiece of the Precision High Current Sense Circuit to take full advantage from the latest generation of low noise, low power ADCs ■

About V-Research

We are a non-university center of excellence for applied research, development and innovation in the technological-industrial field. Our activities have the ambition to meet complex tasks of the economy as well as to ensure our contribution to social development in a non-profit way. Together with our customers as partners, we achieve set goals in a solution-oriented and effective manner.

V-Research is characterized by the use of the latest methods from the fields of data science and computer-aided optimization, as well as sophisticated methodological approaches in the areas of digital engineering, photonics and tribo design.

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DIGITAL ENGINEERING	Structuring engineering sustainably - added value through digital technologies
PHOTONICS	The perfect lighting technology for every application
TRIBO DESIGN	Design and analysis of friction-loaded systems

Photonics

Photonics is the discipline of physics that deals with the various aspects of electromagnetic waves, from emission to propagation, modulation, and detection. A good portion of the applications are focused on the visible range of light, ultraviolet and infrared light.

Today, photonics has made its way into all aspects of our lives. Fiber optic lines are a cornerstone of our communication system. UVC disinfection has become an integral part of our lives. Laser treatments in medicine are commonplace, as are laser-based measurement systems or LED-based fitness trackers.

V-Research offers various services in the field of photonics. The spectrum of services ranges from research and development of drive electronics to complex optical systems for various applications.

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