

Closed-loop current sensing systems with magnetic field probe incorporating a new sensor signal conditioning IC.

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Abstract. This paper touches the applications for closed-loop magnetic current sensors, the principle of the compensation-type sensor and the function of the magnetic field probe. It compares the different types of closed- and open-loop sensing principles in terms of accuracy, drift and noise. The functional blocks of a new signal conditioning IC, as well as its additional functions, are described. The last part describes the processing and evaluation of the output signal of the sensing system.

Closed-loop magnetic current sensing

Closed-loop magnetic current sensors measure currents from DC up to high frequencies and contain a galvanic separation between the primary circuit and the output signal.

Typical currents range from a few amperes up to several hundred amperes full range. Some sensor types can measure more than 1000 ampere peak current.

Closed-loop magnetic current sensors are suitable for various applications, such as motor current monitoring in variable speed drives, battery- and output current sensing in uninterruptible power supplies, output current capturing in welding inverters, input-, output-, as well as fault-current detection in photovoltaic systems and numerous other tasks in the field of switched-mode power conversion.

Functional principle

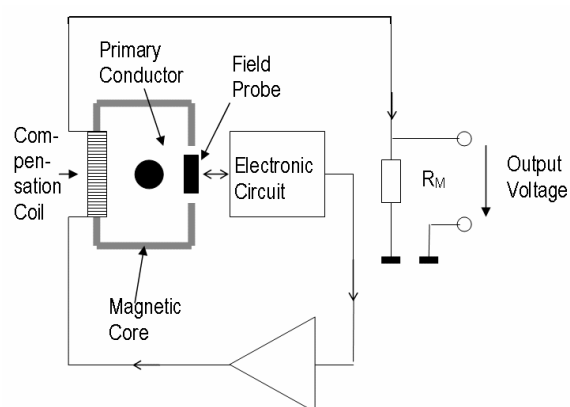


Fig. 1 Block diagram of closed-loop current sensor

The DC- or low frequency currents to be measured are magnetically coupled to a

secondary coil through a gapped soft magnetic field-concentrator core. The magnetic flux of this core is measured inside the gap and controlled to zero by a compensation current proportional to the primary current, divided by the turns-ratio.

At higher frequencies (>10 kHz), the system works as a current transformer and the output of the compensation current driver serves as a ground reference point. The transition between the two operational modes is smooth.

The compensation current, or a derived voltage over a series-connected measuring resistor, is the output variable of the sensor.

Magnetic field probe sensors

An advanced principle for zero-field detection in the gap of the field-concentrator core uses a magnetic probe. Here, the field is not detected by the usual Hall – Effect device. The field-probe sensor instead consists of a coil, wound on its own soft magnetic core, which is formed of a strip of amorphous metal.

A high-frequency square-wave voltage, generated by a transistor bridge, drives a current into the probe coil, magnetizing the probe core from positive into negative saturation and vice versa. A comparator detects the duty cycle of the drive current. In case of no magnetic field present, it is 0,5. A field present disturbs the symmetry of the probe core and changes the duty cycle of the PWM signal at the comparator output, from which the compensation current is derived.

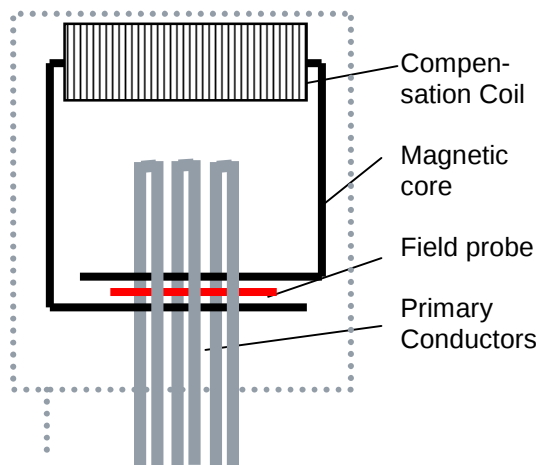


Fig. 2 Schematic construction of a magnetic probe current sensor

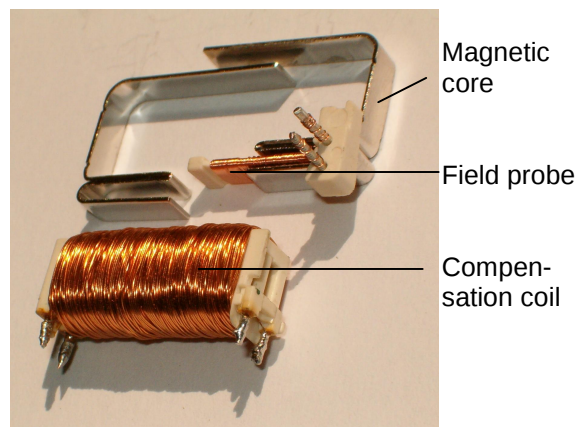


Fig. 3 Key components of magnetic probe current sensor

The frequency of the probe PWM signal of the newest technology sensors is in the range 250 ... 550 kHz, which is far above the usable frequency range of such a sensor, typically reaching up to 100 kHz, and the crossover frequency of the control loop (typically 10kHz).

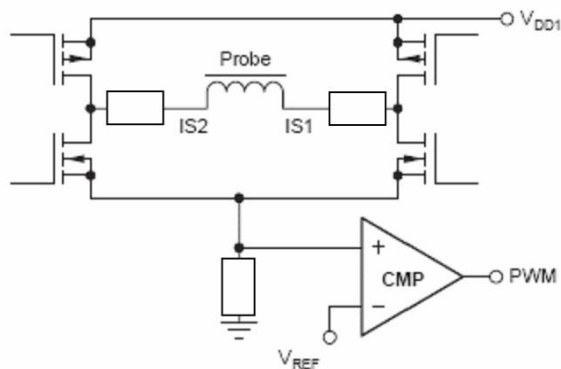


Fig 4 Magnetic probe drive circuit

Advantages of the magnetic field probe

The magnetic field probe sensor offers several advantages over the Hall-effect probe sensor, mainly coming from the avoidance of typical semiconductor disadvantages, like wide distribution of critical parameters (e.g. offset), noise and thermal drift.

The probe-gain can be defined as the ratio between the output voltage of the probe and the input current, when the control loop is opened. The duty cycle of the PWM- signal of the magnetic probe circuit now varies with the primary current, the PWM signal is integrated and yields an (internal) output voltage. The variation of this output voltage with the primary current is the probe gain. The Hall-effect device instead produces a voltage directly. The high gain of the magnetic probe of 0,5 V/A exceeds the Hall – effect devices gain of 1 mV/A by far. This high gain causes a high measuring precision and requires less gain of the subsequent amplifier stages, which leads to a low noise output and reduces any amplifier-related influences (e.g. amplifier offset).

The low offset of the magnetic probe circuit (10 mA primary current equivalents vs. 100 to 200 mA of a Hall – effect device) comes from the virtually perfect symmetry of the magnetic hysteresis of the field probe core and causes a low offset also at the output. Hall – effect devices not only produce much larger offsets, they also are subject to wide distribution and thermal drift of the offset.

All accuracy influencing properties of field-probe sensors are virtually not temperature dependent. This makes such sensors superior, when offset, linearity and overall accuracy are considered over the full operating temperature range and not only at room temperature. Typical total errors of magnetic field probe sensors in the -40 ... +85°C temperature interval are 1 ... 1,5%, Hall Effect sensors offer in the same interval 2 3% accuracy.

Humidity can influence the output voltage of high ohm voltage output Hall-effect devices by creating leakage current paths. The low – ohm magnetic probe circuit is not harmed by humidity. Therefore, the probe and its circuitry do not need a special coating or moulding. Such sensors are well suited for operation in tropical climate.

A new signal conditioning IC

The new signal conditioning IC DRV401 for closed-loop magnetic field probe current sensors contains almost the complete sensor electronics on a chip. This covers the field probe interface, filters, an H-bridge compensation-current driver, a differential output voltage driver and a precise reference-voltage source. Only a few passive components and the magnetic circuit have to be added, to create a complete high precision current sensing device.

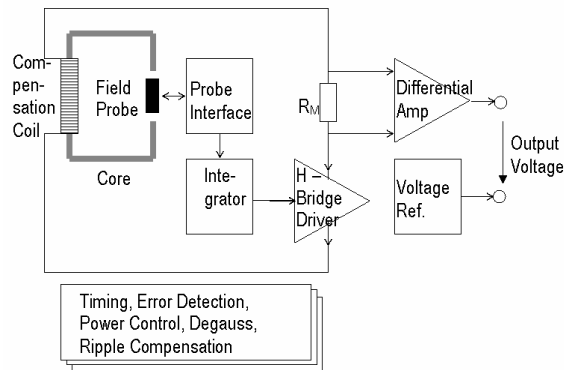


Fig. 5 Block diagram of magnetic probe current sensor with voltage output

Functional description of the IC DRV 401

The IC operates at +5V unipolar supply.

The PWM signal of the field probe interface described in the previous chapter, is low-pass filtered by an integrator, followed by an integrator-differentiator stage. Thus it forms the signal for the compensation current driver and limits the bandwidth for achieving the stability of this high-gain control loop.

The compensation driver has to be able to drive a maximum current of $I_{prim,max} / n$ through the resistance of the compensation coil and the measuring resistor. The higher currents it can drive, the wider the current-ranges of the resulting sensor can be. Thus the driver is designed as a full bridge, which makes it possible, to drive the required currents from a single supply of only 5 Volts.

For even higher currents, an external output stage can be added, e.g. operating from a $\pm 15V$ dual supply. To maintain the loop stability in this case (an additional stage adds gain), the internal voltage gain is reduced by 8 dB.

The compensation current flows through a measuring- or shunt – resistor. The voltage over the resistor is picked up and amplified by a fixed-gain differential amplifier. This high CMRR differential amplifier is necessary due to the differential (H – bridge) drive of the compensation current.

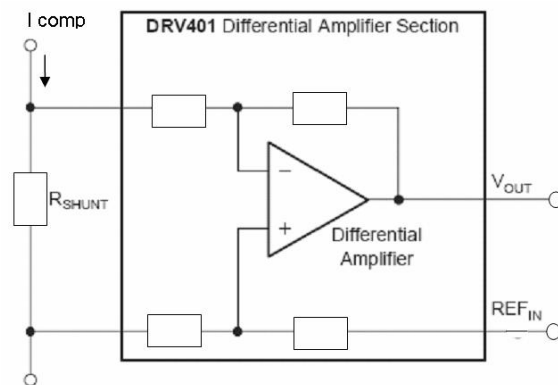


Fig 6 Differential amplifier output stage

Additional Functions the IC DRV 401

The new IC also offers important additional functions.

A demagnetization of the sensor (DEMAG – pin) core reduces the hysteresis-offset of the core and thus improves the accuracy of the sensor. This function either be activated at power-on or on request, e.g. after a system re-start following a short circuit- or overload situation.

The over range output (OVER-RANGE – pin) is activated by detecting a current through the measuring resistor, which is high enough, to cause a clipping of the output differential amplifier. So the overrange signal can be used for a reliable over current- or short-circuit detection in the power electronics system. It replaces additional circuitry, which otherwise would have to be put in place by the system designer. During an over current situation, the polarity of the current is stored. As soon as the primary current comes back into the measuring range, its magnitude and polarity are indicated reliably again.

An extensive self – control circuitry monitors several functions of the current sensor and indicates various malfunctions, which can occur (ERROR – pin):

- A brown-out of the supply voltage ($<4V$, $>100\mu s$)
- An open circuit of the field probe

- A short circuit of the field probe
- An open circuit at the compensation coil
- An overcurrent situation at power-on

A so-called ripple reduction minimized the remainder of the probe switching signal, which couples through to the output signal. This signal normally does not disturb the sensing accuracy, because it is a low amplitude, high frequency (250 ... 550 kHz), zero – symmetric signal, which can be further reduced by low – pass filtering the output signal. Additionally, low – capacity compensation coils and an active ripple reduction by subtraction of the signal from the compensation current help forming an output signal with extraordinary low-noise.

A precision band gap reference voltage source is also integrated. It delivers 2,5 V with a low drift of typically 10ppm/K and is intended to be used as the reference point for the output voltage.

The IC DRV 401 is available in a QFN-20 (RGW), 5x5 mm housing with 1/40" pitch as well as in a SO-20 (DWP) dual in line housing with 1/20" pitch, the latter being intended for the use in higher power electronic boards with thicker copper plating.

Internal and external use of the IC DRV 401

The IC DRV401 is the heart of a new range of integrated current sensors. Those products serve as easy to design in, off the shelf, stand alone solutions, offering galvanically separated current sensing from 2 A to 200 A, operating from a single +5V supply or from a dual +/-15V supply.

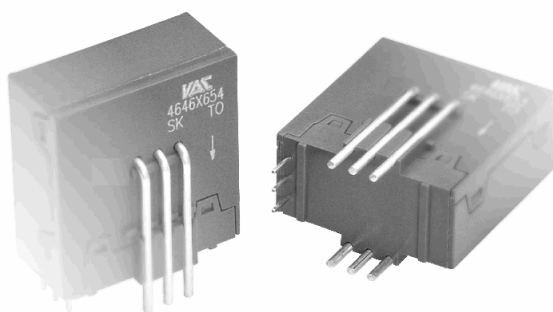


Fig 7 Example of an integrated current sensor for maximum currents of 50 A_{rms} and ± 150 A_{peak} in a small housing (approx. 22 x 10 x 24 mm)

Passive current sensing modules, containing the galvanic separation and the magnetic circuit, but not the signal processing electronics, are also available. Deciding for this solution, the designer

can tailor his sensing system to the maximum current of his applications. He also can use all of the above described additional functions of the IC by integrating it into his control electronics.



Fig 8 Example of a passive current sensing module (100 A_{rms}, ± 160 A_{peak}), offering a large window (26 x 11 mm) in a compact housing (approx. 40 x 30 x 14 mm)

Between sensing module and the electronics circuit, a four wire connection is necessary, two each for connecting the probe and the compensation coil. The distance between electronics and module can reach up to 1m.

Ways of further signal processing

The output variable of the IC can be further processed and converted into a digital value in various ways by widely available standard-components.

The signal output of the IC should be coupled to the input of the ADC via a low pass filter. This filter limits the signal bandwidth (i.e. creates a defined bandwidth) and it decouples possible input sampling noise from the IC output. As an alternative, a delta-sigma modulator with a digital filter can be used.

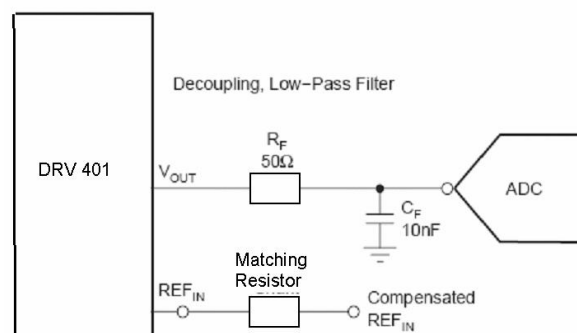


Fig 9 Differential amplifier output stage with ADC

ADS1204 is a four channel differential input delta-sigma ($\Delta\Sigma$) modulator with 100dB dynamic range. With the appropriate digital filter and modulator rates, the device can be used to achieve up to 16-bit resolution. Effective resolution of 12 bits can be obtained with a digital filter data rate of 160 kHz at a modulator rate of 10MHz. AMC1210 is the appropriate four-channel digital filter, used for processing the bit streams of the modulator.

ADS7861/2 are four channel 12-bit SAR (successive-approximation register) ADCs. They convert the input voltages into a serial or parallel digital output signal with a 500 kHz sampling rate. ADS8361 is the equivalent 16 bit serial output version.

If three channels of such four channel systems are used for current sensing, the fourth channel can be used for resolver position decoding in motor drives, for temperature sensing, voltage measuring, or similar.

For more complex systems, requiring a higher number of analog input channels, an ADC like the ADS7869 should be preferred, which offers 12 independent differential input channels and a variety of additional functions.

All described delta-sigma modulators and ADCs work from a single +5V supply and accept a $\pm 2,5V$ input voltage range around a 2,5V reference voltage, which can be delivered from an internal source, or received from an external source. So they comply perfectly with the signal conditioning IC DRV401.

References:

VAC product brochures:

„New Active Current Sensors for Maximum Accuracy”

“Passive Current Sensors for the Operation with the IC DRV 410”

“Applicational Hints to the IC DRV401”

All available as PDFs under:

www.vacuumschmelze.de / Products / Cores and Inductive Components / Applications / Current Sensors

Texas Instruments datasheet for the DRV401, available as a PDF under:

<http://focus.ti.com/docs/prod/folders/print/drv401.html>

Texas Instruments datasheets for the further signal processing ICs, available as PDFs under:

<http://focus.ti.com/docs/prod/folders/print/ads1204.html>

<http://focus.ti.com/docs/prod/folders/print/amc1210.html>

<http://focus.ti.com/docs/prod/folders/print/ads7861.html>

<http://focus.ti.com/docs/prod/folders/print/ads7862.html>

<http://focus.ti.com/docs/prod/folders/print/ads7869.html>