AN2009-06

MIPAQ™ sense

Making use of Modules with integrated Current Measurement

Industrial Power

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1 The MIPAQ™ Family – A brief Introduction

MIPAQ™ is a new functional product family and dedicated to useful integration of electronics into power modules. The MIPAQ™ family was developed in order to offer Modules Integrating Power, Application and Quality. It is a functional product family within Infineon's IGBT modules portfolio. The combination of an IGBT module and the integration of sensing and driving electronics leads to an optimized solution in mastering the challenge of designing powerful and compact inverters for low and medium power at low costs, contributing to energy savings to improve profitability and protect our environment at the same time.

The MIPAQ™ family today has a hierarchical structure of three product types:

- MIPAQ™ base – a Module with integrated current sensing shunts
- MIPAQ™ sense – a Module with integrated, fully digital current measurement
- MIPAQ™ serve – a Module with adapted driver electronics and temperature measurement

This document focuses on the application and the special features of the MIPAQ™ sense.

Prior to operating and handling the module, please carefully read and completely understand this application note!

1.1 Product Range

MIPAQ™ sense provides an IGBT sixpack plus fully digital, galvanically isolated current measurement inside using Sigma-Delta Converters. The modules come in sixpack configuration with NTC and are available in the well-proven EconoPACK™ 3 housing with 75A and 100A nominal current at 1200V blocking voltage.

1.2 Scope of Applications

The current sensing shunts inside the MIPAQ™ sense are located in the output lines to measure the true application current under all conditions. The MIPAQ™ sense therefore is an excellent choice for general purpose as well as servo-drives. It will work in applications like uninterruptable power supplies (UPS) as well as solar inverters and low power machinery like pumps, fans or air conditioning systems. The accurate measurement and the excellent stability of the sensors make the MIPAQ™ sense a good candidate for high performance drives like tooling machines and supports the implementation of highly sophisticated regulation algorithms like field oriented control (FOC) or direct torque control (DTC).

1.3 MIPAQ™ notation

The notation of MIPAQ family modules follows the Infineon rules for standard industrial modules. The capital "I" as a first digit denotes that the module is part of the MIPAQ family. The designation for a module is explained in Table 1:

Designation Example	Information on		Explanation
IFS 100 S 12 N3 T4	Configuration	FZ	Single Switch
		FF	Half Bridge
		FS	Sixpack
	Rated Chip Current in A	**100**	
	Level of Integration	B	MIPAQ™ base with integrated shunts
		S	MIPAQ™ sense with integrated digital current measurement
		V	MIPAQ™ serve wit adapted driver electronic and digital temperature measurement
	Voltage Class	**12**	Maximum blocking voltage in 100V
	Package used	**N**1…**3**	Econo1 to Econo3
		P	EconoPACK4
		U1…3	Smart1 to Smart3
	Chip Technology	**T4**	Low-Power IGBT 4
		E4	Medium-Power IGBT 4
		P4	High-Power IGBT 4

Table 1   Example on MIPAQ™ Module notation

2 Electrical Characteristics

From optical point of view, the MIAPQ™ sense as displayed in Figure 1 appears to be a plain sixpack built into a standardized EconoPACK™ 3 housing:

Figure 1   **MIPAQ™ sense in the established EconoPACK™ 3 housing**

Besides the type designation, the slightly different pinning compared to the standard module is the only visible difference. The additional pins belong to the power supply of the Sigma-Delta Converter included and the 5V-CMOS-compatible output signals. The MIPAQ™ sense benefits from having PressFIT connectors to achieve solder-free mounting. Further information on this technology can be found in the according Application Note AN 2007-09 *PressFIT mounting technology*. The document can be downloaded at Infineon's Document Database

2.1 Current Sense Shunts

Though many different systems can be used to measure electric current, shunts have proven to resemble the best possible sensor when it comes to integrating current measurement into power electronic devices. Among the reasons that lead to this setup are:

- Shunts provide the mandatory operating temperature range and easily withstand the high temperatures inside of power electronic modules
- Shunts have a proper geometric size for the integration
- The shunt that was especially designed for this kind of modules comes with outstanding thermal capabilities, excellent thermal transfer to the module's baseplate and high cycling capabilities towards power- and thermal cycling.
- Bearing in mind that a precise reading is necessary across a wide temperature range, the material utilized provides excellent linearity in the temperature range common to power electronic modules.
- Shunts do not show effects like offset, hysteresis or distortion after exceeding the rated current limits e.g. during short circuit
- Shunts as sensors do not inherently limit the bandwidth of the measurement.

2.2 Sigma-Delta Converter

The analog-to-digital converter inside the MIPAQ™ sense is based on the so called Sigma-Delta (Σ/Δ) principle. This is an integrating method that allows flexible handling of the information acquired. It is characteristic for this method that a trade-off between conversion time and measurement accuracy can be chosen to suit the application's needs.

Basics on the conversion method are described in section 3 *Basics on Σ/Δ Data Conversion*.

2.3 Internal Schematic

To provide a current measurement that captures the application's current in all points of operation, it is essential to choose a position for the sensor in line with the application as shown in Figure 2:
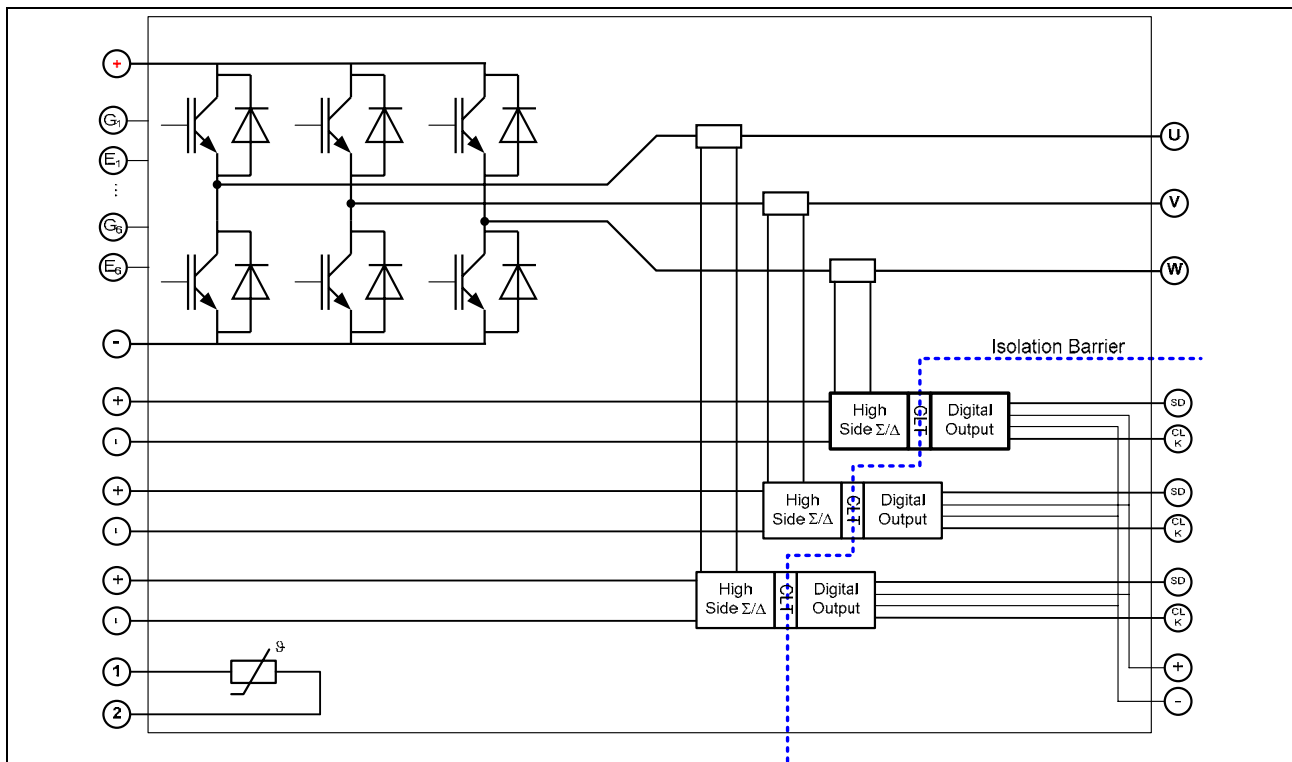

Figure 2   Schematic of the IFS100S12N3T4

Compared to a solution with open emitter connections and shunts in series to the emitter paths, this configuration comes with several advantages:

- There is no influence to the Gate-Emitter voltage of the low-side IGBT
- Even the minute stray inductance of the shunt itself would influence the switching behavior if mounted in series to the emitter; however, it is of no influence if connected in series to the application.
- A freewheeling current can be measured in both upper and lower half of the sixpack.

2.4 The Shunt's properties

In theory, the current to be measured is proportional to the voltage drop across the shunt. Practically, the temperature inside the module influences the shunt's resistance as both the shunt and the silicon inside the power electronic contribute to increase the temperature level. To get an accurate and precise reading the shunt's resistance has to remain constant with regard to temperature including the whole possible range of operating conditions. Within the MIPAQ™ sense this is achieved using materials with very low temperature dependencies. As depicted in Figure 3, the linearity of the shunt included is excellent over a wide range of temperatures:
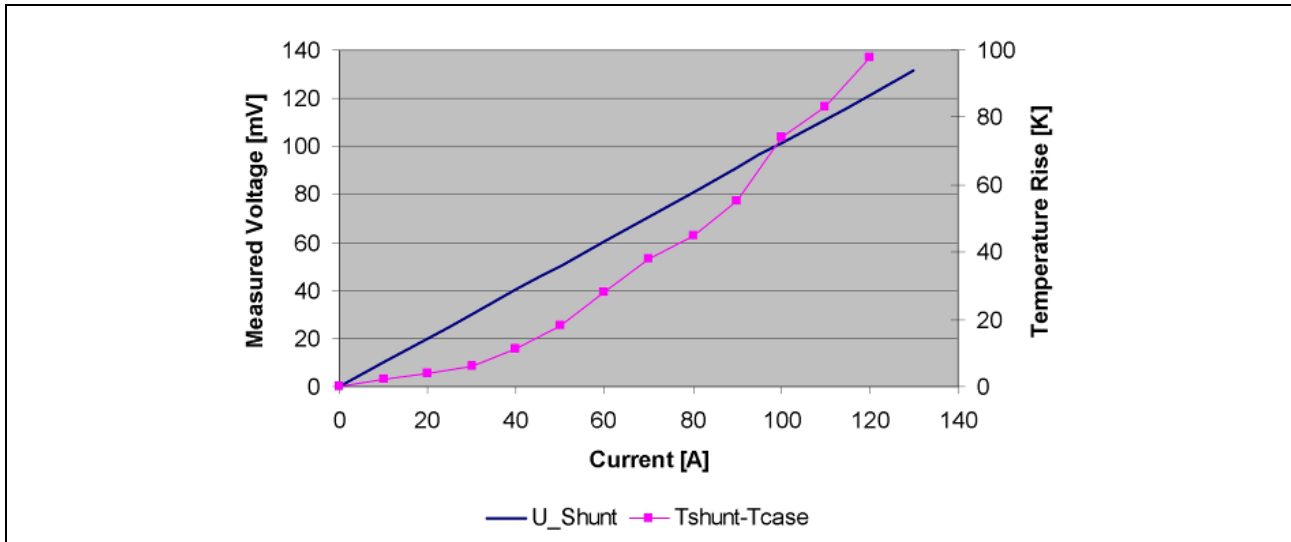
Figure 3   Shunt temperature development as a function of forward current. DUT: Shunt 1mΩ

An additional temperature rise may appear as a consequence of the baseplate heating up during operation. This too will add to the shunt's temperature. However the influence is marginal as hinted out in Figure 4:
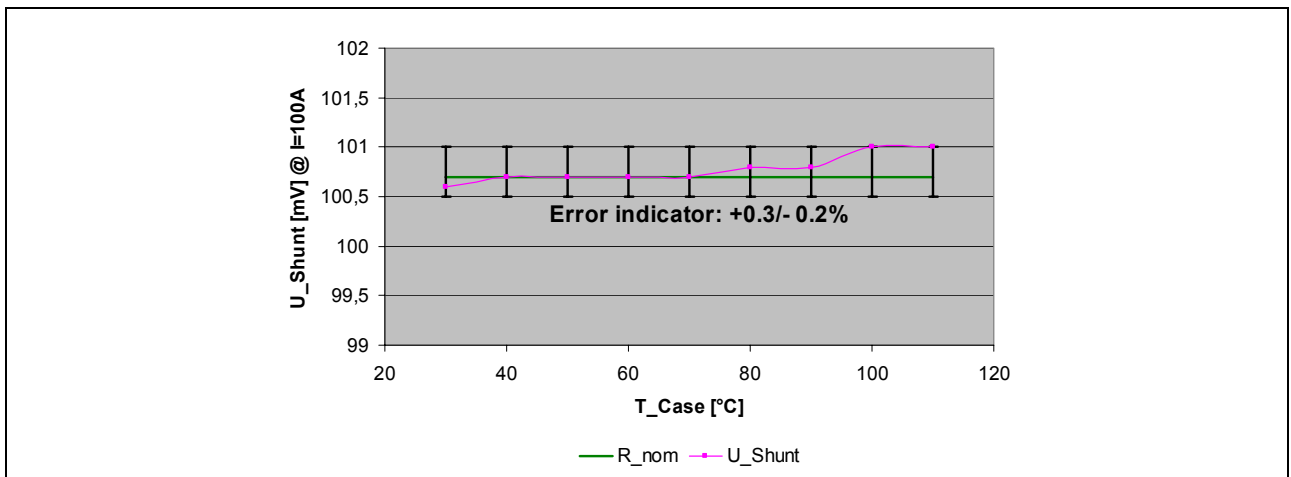
Figure 4   Shunt voltage as a function of baseplate temperature. DUT: Shunt 1mΩ, I=100A

2.5　　　　Capturing the shunt's voltage

The shunt is connected in series to the application. This inherently means that it is connected to high voltages referred to either side of the DC-link. To properly capture the shunt's voltage, a device with differential input is necessary that has its reference set to the upper IGBT's emitter potential. An overview is given in Figure 5:
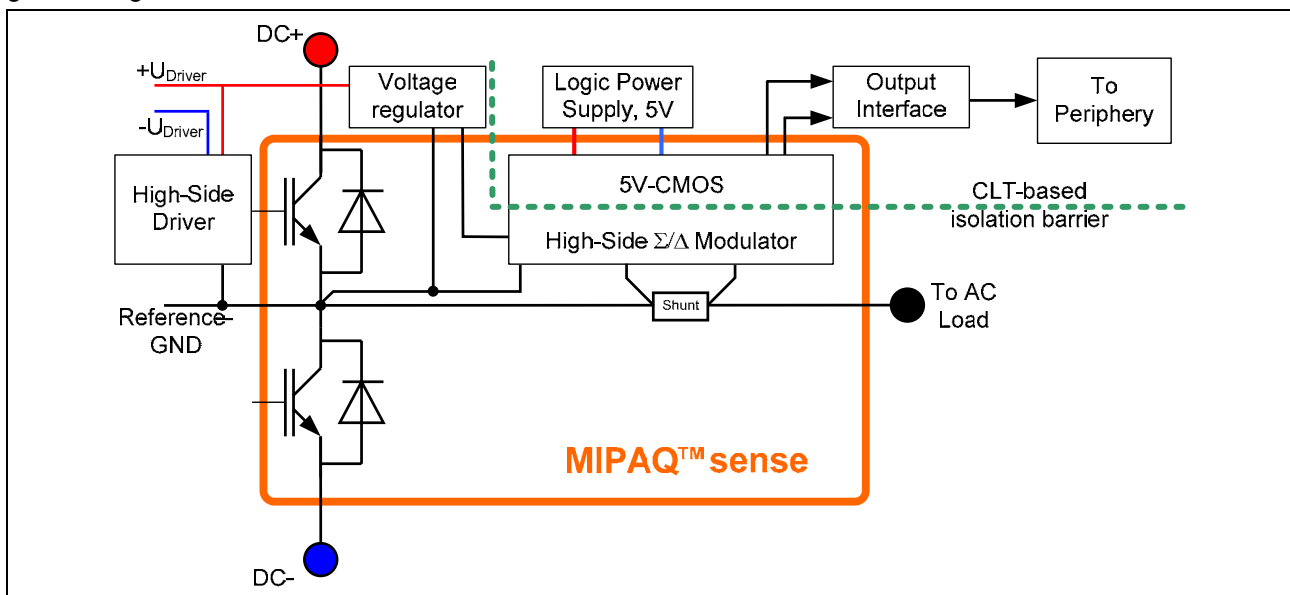

Figure 5　　　Capturing the Shunt's voltage

Voltage Regulator

As the driver supply is also referenced to the IGBT's emitter potential, the supply for the Σ/Δ-Converter can be derived from this source as well. As it is recommended to have the IGBT-driver supplied with a bidirectional voltage, a conventional line regulator is required to provide the voltage to the converter's high voltage side. The supply voltage has to be kept within 4,75V…5,25V.

Logic Power Supply

To interact with the digital control electronic, the internal Σ/Δ-converter's low voltage side needs to be supplied with a voltage of 4,5V…5,5V referenced to the control's ground.

Σ/Δ-Converter

Based on the EiceDRIVER Coreless Transformer technology, the internal converter provides basic galvanic isolation. It allows access to a single bit datastream and a clock signal for synchronizing.

Output Interface

Depending on the application's needs, an additional output interface may be necessary. The converter provides raw-data in form of a single bit datastream and an according clock signal. An interface can be utilized to convert the datastream into any format or protocol advantageous for an individual solution.

3 Basics on Sigma-Delta Data Conversion

The following sections give a brief introduction on topics related to Sigma-Delta data conversion. However the present document as an application note for a power electronic module can not hold the answers to all questions regarding this method. A list of literature is added at the end of the document for further information.

3.1 Introduction to A/D-Conversion

Analog to digital conversion is a necessary step to connect the analog world to digital equipment. The converters to transfer an analog signal into digital information can be separated into two groups depending on the approach to generate the digital information:

Nyquist-Rate A/D-Converters

The Nyquist sampling theorem defines the minimum number of samples that a band-limited signal should contain in the time domain if no loss of information or aliasing distortion by recovering the sampled signal is mandatory. Accordingly, the analog signal must be sampled at a frequency higher than twice the baseband cutoff frequency. Converters with sample frequencies in a range slightly higher than twice the baseband cutoff frequency are referred to as Nyquist-rate converters. An additional low-pass filter is necessary at the converter's input to fulfill the Nyquist-criteria.

Oversampling A/D-Converters

A/D-converters with a sampling rate exceeding the Nyquist-rate are referred to as oversampling converters. Oversampling by itself only achieves modest improvements in the converter's resolution. If however the quantizer is also embedded in a feedback loop, it is possible to significantly increase the resolution of a converter beyond what can be achieved simply by oversampling. It is important to note that the quantization process in an oversampled converter employing feedback differs fundamentally from that in a Nyquist-rate converter. It is not necessary to quantize the signal in an oversampled converter to the full resolution of the converter, since each sample of the output signal is related to more than one input sample. The digital filter that follows the oversampled converter, groups many coarsely quantized samples to yield a more precise estimate of the analog input signal. At the same time, a lower sampling rate suitable for a microcontroller or DSP is generated. Each output sample is generated from a long sequence of input samples. In many cases, single-bit quantization is sufficient in an oversampled feedback modulator. In recent years, this kind of conversion technique represented by the so-called Sigma-Delta Converter has become the choice for digital audio equipment like CD-players or DAT-recorders. Several advantages make oversampling converters an excellent alternative in power electronics as well. One particular advantage of oversampling methods is the nois-shaping, shifting the quantization noise to higher frequencies. This also reduces the efforts if low-pass filter design.

3.2 The Sigma-Delta A/D-Conversion Principle

The complete A/D-Converter is separated into two functional blocks. First the analog signal is connected to the Σ/Δ-Modulator that transforms the analog information into a single bit datastream. To achieve a proper resolution with a single bit output, massive oversampling is required. Typically Σ/Δ-systems have a sampling frequency in the range of several MHz, the converter integrated into the MIPAQ™ sense features 10MHz. The second block consists of a digital filter also called decimator.

As the modulator provides an integrated signal, a decimator is necessary to fulfill several tasks:

1.) Apply a low pass filtering to eliminate high frequency noise
2.) Decimation of the integrated value to reconstruct the initial value
3.) Transform the single bit datastream into an according N-bit information

The overall structure of a $\Sigma/\Delta-$based analog to digital conversion is depicted in Figure 6:
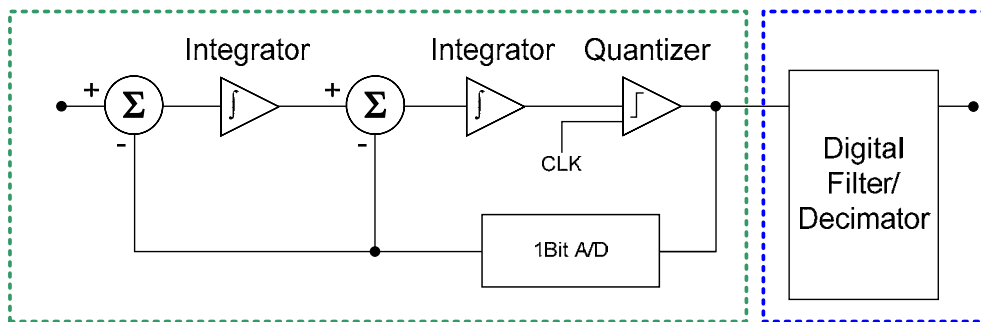
Figure 6 Σ/Δ**-based A/D-Converter with second order modulator**

The MIPAQ™ sense only includes the second order Σ/Δ-Modulator marked with the green dashed box in Figure 6 above. From the modulator, a single bit datastream is generated and available as an output. The ratio of ones and zeros within this datastream represents the average value of the analog voltage while a ratio of 1:1 represents the input 0V. Though the modulator introduces noise to the datastream it can be shown that this noise is shifted to frequencies in the range of the sampling frequency. The effect is called "noise shaping" and a basic feature that allows achieving resolutions beyond 12bit if proper digital filtering is applied.

3.3   Recommended Decimator

The Σ/Δ-Modulator shifts noise to high frequencies, therefore a low-pass filter is needed before the digital signal is passed on to the decimator. This filter is often considered to be an inherent part of the decimator. For the decimator, the cascaded integrator comb structure (CIC) has become state of the art. Figure 7 gives an overview on this structure:
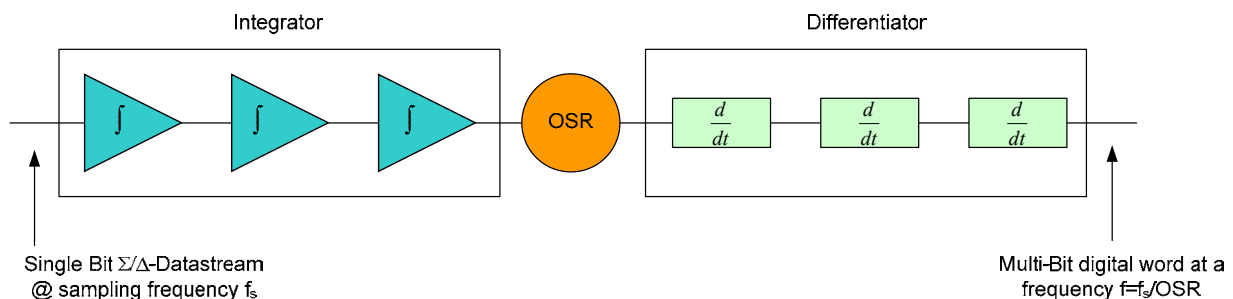

Figure 7   Cascaded Integrator Comb (CIC)

Due to its transfer function in the frequency domain representing a sinus cardinalis, this structure is also known as sinc^k-filter with k representing the order of the filter which is related to the number of integrators and differentiators used. The OSR in Figure 7 is the oversampling rate. The output rate for the multi-bit digital word is determined by the ratio of sampling frequency and oversampling rate.

With the transfer function of the structure being

$$|H(f)| = \left(\frac{1}{OSR} \cdot \frac{\sin\left(\pi \cdot f \cdot \frac{OSR}{2} \right)}{\sin\left(\pi \cdot \frac{f}{2} \right)} \right)^{k}$$

the filter's response |H(f)|dB can be plotted. For an OSR of 16 the filter's response is the one displayed in Figure 8:

Response of a sinc³-filter
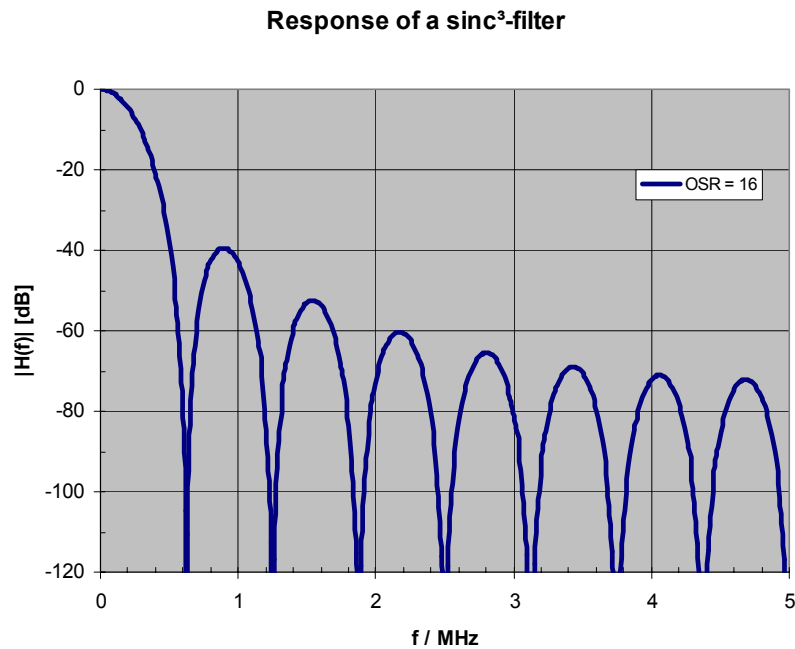
Figure 8   Response of a sinc³-filter in the frequency domain

As the -3dB-value is in the kHz-range, the CIC-structure inherently provides the necessary low-pass-filter. This is beneficial as the output current's frequencies to be measured within the MIPAQ™ sense in motor drive application usually stay well below 1kHz.

Increasing the OSR improves the resolution and increases the signal-to-noise ratio (SNR) but also has an effect on the duration for the data-conversion. It is an inherent feature of the Σ/Δ-Conversion that a trade-off between conversion speed and conversion accuracy can be chosen to best suit the application. The correlation between these parameters is given in Table 2 and valid for the 10MHz-modulator incorporated within the MIPAQ™ sense:

OSR	t_{conv} [µs]	Resolution [Bit]	$f|_{-3dB}$ [kHz]	SNR [dB]
8	2,4	10	320	63
16	4,8	13	164	84
32	9,6	16	80	105
64	19,2	19	40	126

Table 2   Correlation between OSR, conversion time, resolution, cut-off frequency and Signal-to-Noise ratio

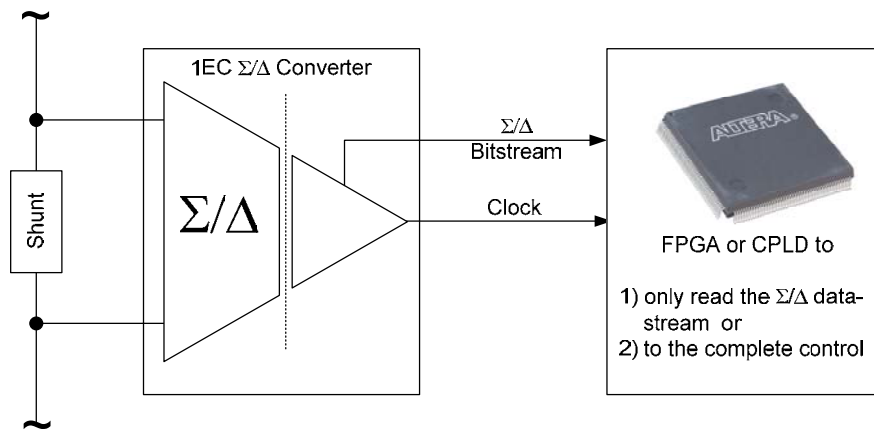## 3.4   Decimator Implementations

In general there are two ways to implement the decimator. The hardware-approach consists of commercially available digital filters that accept the Sigma-Delta datastream as an input and provide the according output in either a protocol form like SPI or as parallel multi-bit information. One possible option for an integrated digital filter is the HCPL-0872. This configurable filter provides the possibility to adjust the OSR according to the desired accuracy and has several output options to choose from. Figure 9 gives an overview on a setup using this particular IC:
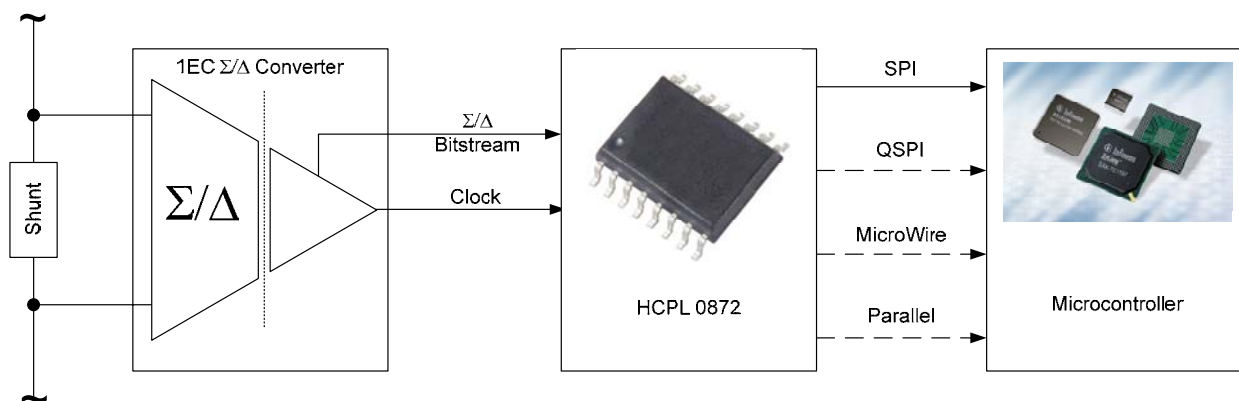
Figure 9   Decimator implementation utilizing digital filter IC

A more flexible solution is given by implementing the digital filter into programmable logic devices. As only about 100 logic blocks are needed to program a sinc³-decimator, a small CPLD or FPGA is sufficient. If however a larger FPGA is used in the design to carry out the control and regulation, the decimators can also be integrated into the FPGA and internally interlinked to provide the data for the current control. An according setup is given in Figure 10:

Figure 10   Implementation of the decimator using programmable logic

A VHDL-Code to start implementing the decimator is available on request; please contact us via E-mail for more detailed information.

Though a direct connection of the single-bit stream to a microcontroller seems possible, the pure amount of data will lead to an enormous amount of processing resources to be bound to this process. Therefore, this kind of processing the modulator's output is not recommended.

4   Handling and Mounting

"MIPAQ" does not refer to a certain package but to functionality. Mounting and handling different modules however is related to the package utilized. The following sections interlink the Application Notes on how to mount and handle different packages.

For any given Module it is recommended to apply thermal grease to form a proper thermal interface to the heatsink. As described in the Application Note AN 2006-002 *Application of screen print templates to paste thermal grease within IGBT modules* it is recommended to utilize a process that achieves sufficently reproducible results. The document can be downloaded at Infineon's Document Database

4.1   MIPAQ sense in Econo3-Packages

For mounting and handling instructions regarding Econo-Type modules please refer to the Application note AN2002-04 *Econo Modules: Mechanical Attributes for new FS und FP Econo-series*, please use the link above to go to Infineon's Document Database.

5 Literature for further studies

In addition to the well known sources for topics on electrical engineering and the datasheet of the MIPAQ™ sense, the following publications were considered helpful:

Delta-sigma ADCs in a nutshell
Bonnie Baker, December 2007
Internet Resource: Electronics Design, Strategy, News (EDN)

System and Circuit Approaches for the Design of Multi-mode Sigma-Delta Modulators with Application for Multi-standard Wireless Receivers
Dissertation by Juan Jesus Ocampo Hidalgo
TU Darmstadt, December 2004
Download at TU Darmstadt

IGBT-Module integrated Current and Temperature Sense Features based on Sigma-Delta Converter
Daniel Domes, Ulrich Schwarzer
PCIM 2009, Proceedings pp 741ff

Decimation Lowpass Filter for Sigma-Delta Modulators
Rüdiger Kusch, Hamburg, Diplomica GmbH, 2002

Principles of Sigma-Delta-Modulation for Analog-to-Digital Converters
Park, S. MOTOROLA Application Notes.

An Economial Class of Digital Filters for Decimation and Interpolation
Hogenauer, E. B.
IEEE Transactions on Acoustics, Speech and Signal Processing, Volume 29,
Issue 2, Apr 1981 pp. 155 – 162

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