AN12633

Switching from MC33771B to MC33771C

Rev. 1 — 10 February 2020 Application note

1 Introduction

The MC33771C is a successor of the MC33771B. The MC33771C offers an averaging functionality and improved communication. Other functions are not changed. The MC33771C is pin and package compatible to the MC33771B.

MC33771C improvements:

- Averaging of up to 256 samples possible
- Potential reduction in the diagnostic filtering time from 25 to 6 ms
- Inductive and capacitive coupling support (current transformers & current external components)
- Improved communication protocol
- Up to 63 nodes are supported in one daisy chain
- Supports 20 m cable length between two nodes with transformer isolation
- Loopback support for one daisy chain

1.1 Feature comparison

The following table shows a comparison of the MC33771B and MC33771C.

Table 1. Feature comparison

Parameter	MC33771B	MC33771C
Voltage channels	14	14
Supply Vpwr Range (max transient)	9.6 V to 61.6 V (75 V)	9.6 V to 61.6 V (75 V)
Supply current adder when TPL communication active ($I_{VPWR(TPL\_TX)}$)	typ. 50 mA	max. 16 mA
Cell terminal input voltage range	–0.3 V to 5 V	–0.3 V to 5 V
Typical measurement error (data sheet parameter) $V_{ERR33RT}$	±0.8 mV	±0.8 mV
Functional safety	Single-chip ASIL-C ASIL-D compliance	Single-chip ASIL-C ASIL-D compliance
Isolated communication speed	2 Mbps	2 Mbps
Communication isolation	Inductive	Inductive, capacitive
Max nodes per daisy chain	15	63
CRC bit	8	8
Comms bit	40	48
Communication forwarding	Switch	Repeater
Integrated balancing	< 300 mA	< 300 mA

Parameter	MC33771B	MC33771C
Balancing sleep mode	Yes	Yes
Averaging	No	Yes
LPF capacitance (for OL diagnostic)	470 nF	100 nF
Diagnostic filter timing [1]	25 ms	6 ms
Deep sleep mode	No	No
GPIO / analog measurement inputs	7	7
Current channels	1	1
Coulomb counter	1	1
Package	64-pin LQFP-EP	64-pin LQFP-EP

[1] For information on calculation of the timing, refer to the corresponding safety manual.

1.2 Reasons to switch from MC33771B to MC33771C

The changes in the silicon from MC33771B to MC33771C as listed in Table 1 results in an improved communication and an additional averaging functionality.

The improved communication is beneficial during each of the following situations:

- Long daisy chains with high number of nodes are used
- Capacitive coupling is of interest

Section 2 "Changes in the communication" explains the differences in the communication in detail.

The averaging functionality:

- Provides faster sampling of the cell voltages, which reduces input filter BOM costs
- Offloads the MCU because the average calculation is done inside the device
- Offloads the communication because less data must be transmitted

Section 3 "Averaging functionality" explains the benefits of the averaging functionality in detail.

2 Changes in the communication

For the communication there are three main categories of changes:

- Physical layer for the communication changes to include the repeat functionality
- The TagId and RC are removed and a MsgCnt is added instead
- Communication frame length changes from MC33771B of 40-bit to MC33771C of 48-bit
- Some changes in the digital domain and the registers to include the averaging functionality

Figure 1 highlights the changed blocks in the block diagrams of the MC33771B (left side) and MC33771C (right side)

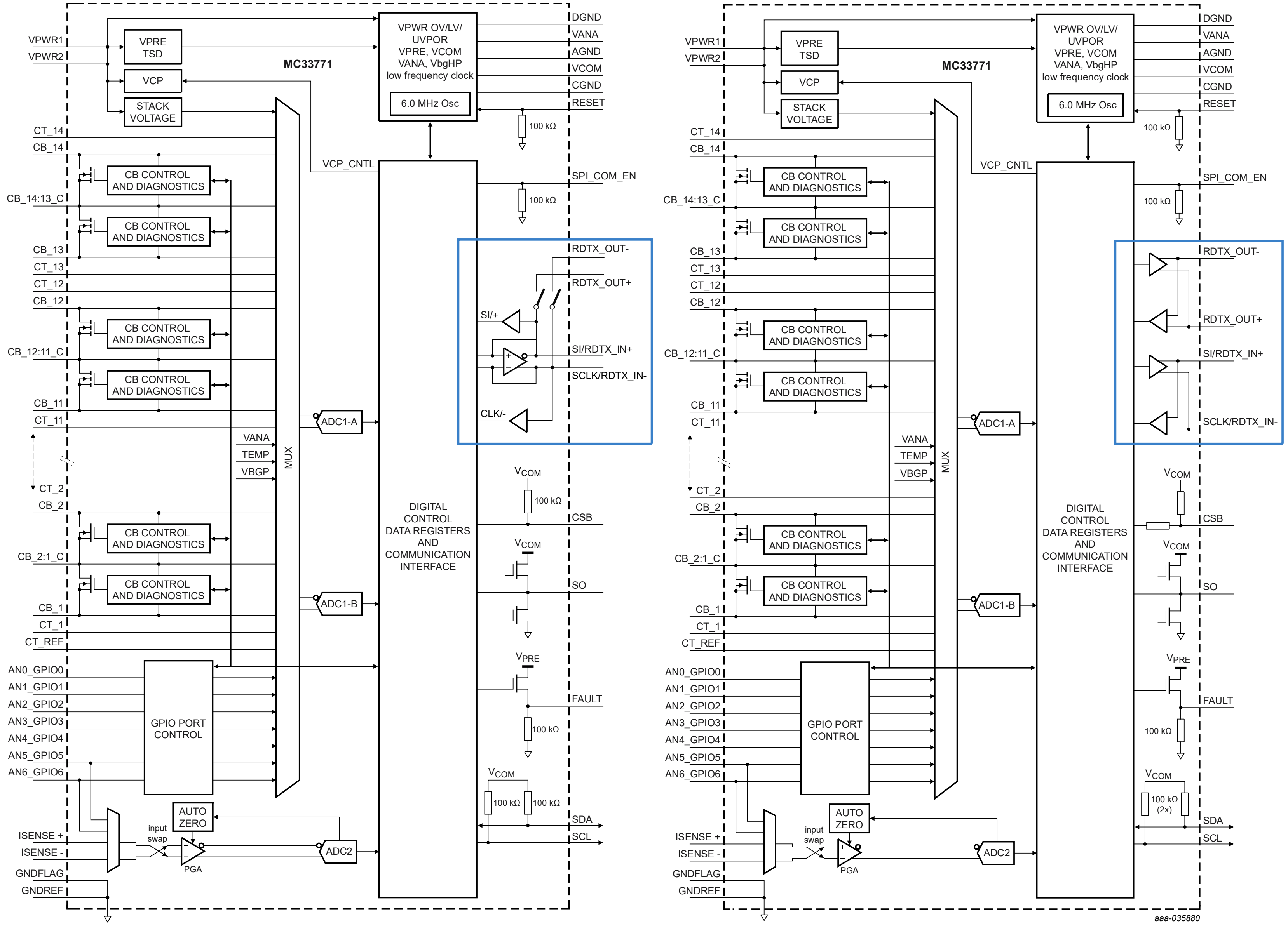
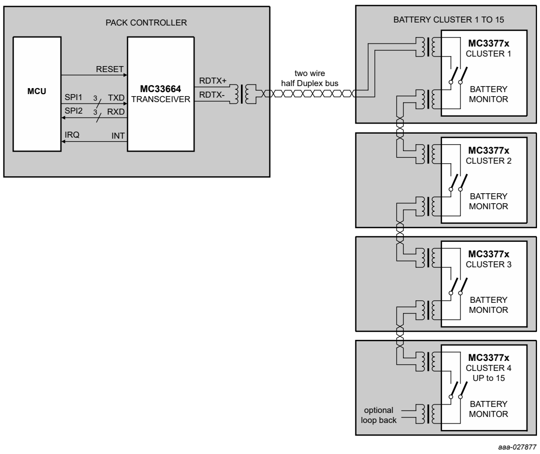
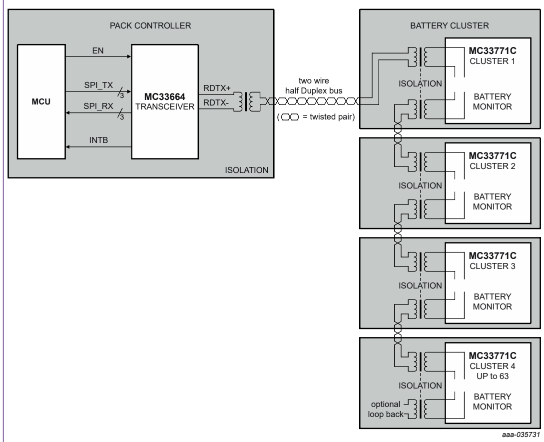


Figure 1. Comparison of block diagrams

2.1 Changes in electrical layer

The changes in the electrical layer of the communication are summarized in Table 2.

Table 2. Comparison of the electrical layer for communication

Device	MC33771B	MC33771C
Topology drawing	 **Figure 2. MC33771B**	 **Figure 3. MC33771C**
Communication forwarding	Communication is forwarded via switches	Communication is retransmitted by each node
Bus segmentation	None. Each node communicates to entire daisy chain	Segmented. Each node communicates with next node only
Hop delay	Each message arrives at all nodes at same moment in time	Repeated introduction of a delay (~0.95 µs) between nodes
Signal attenuation	Each wire segment (bus switch, and transformers) contributes to signal attenuation	Each node retransmits the message. No accumulation of attenuation.
Max. number of nodes	Limited by signal attenuation (max. 15)	Max. 63 (limited by address space of protocol)
Compatible with MC33664	Yes	Yes

While in the MC33771B, the communication is forwarded by a switch. The MC33771C repeats received symbols (SOM, EOM, Logic 1 and Logic 0). A check for message integrity during forwarding is not performed. Message integrity is checked on a complete frame basis by each node. The repeating avoids degradation of the signal between nodes and therefore allows longer daisy chains. For a system with an MC33771C, it is implied that each node retransmits every message. To avoid a massive increase in the overall power dissipation, the drive strength of the transmitter is adapted. Depending on the number of nodes, the current consumption is comparable to a system using the MC33771B.

2.2 Changes in the external components

The changes in the electrical layer require some changes in the recommended external components. Impacted is the communication from node to node. Also, the recommended circuit between the MC33664 and the first node changes. See the data sheet of MC33771B and MC33771C for the recommendations on the external components.

2.3 Protocol layer

The 40-bit message protocol of MC33771B has been extended to 48 bits for MC33771C to support additional features. An overview of the protocols and the changes is in the tables below.

Table 3. MC33771B protocol

Register data 16 bits	Master/slave 1 bit	Register address 7 bits	CID 4 bits	RC 2 bits	CMD 2 bits	CRC 8 bits
[39:24]	[23]	[22:16]	[15:12]	[11:10]	[9:8]	[7:0]

Table 4. MC33771C protocol

Register data 16 bits	Master/slave 1 bit	Register address 7 bits	Reserved 2 bits	CID 6 bits	MsgCntr 4 bits	Reserved 2 bits	CMD 2 bits	CRC 8 bits
[47:32]	[31]	[30:24]	[23:22]	[21:16]	[15:12]	[11:10]	[9:8]	[7:0]

Table 5. Protocol comparison

Bit field	40-bit protocol (MC33771B)	48-bit protocol (MC33771C)	Changes	Description
Register data/ number of registers	16 bits	16 bits	Unchanged	Memory data content This field holds the register data in write mode and specifies the number of consecutive registers to be read in a burst read.
Master/slave identifier	1 bit	1 bit	Unchanged	Indicates if the message is for master or slave
Register address	7 bits	7 bits	Unchanged	Memory address 0 to 127 registers
Reserved	—	2 bits	Changed	Added reserved bits for future use
Cluster ID (CID)	4 bits	6 bits	Changed	
Message counter (MsgCntr)	2 bits	4 bits	Changed	The TagId and RC is removed and a MsgCnt is added instead
Reserved	—	2 bits	Changed	Reserved
Command (CMD)	2 bits	2 bits	Unchanged	Indicates the operation to be performed (for example, read, write), Master sends request, Slave sends responses 0: NOP 1: Read request 2: Write request 3: Global write
CRC	8 bits	8 bits	Unchanged	CRC for message integrity

2.4 Digital and register changes

To include the new functions, some digital changes and register changes are done.

2.4.1 Repeater function

The MC33771C is utilizing a repeater function for the communication. The repeat function is achieved by having bidirectional transceivers. The second transmitter retransmits the signal received at the first receiver. The retransmission avoids signal attenuation and jitter accumulation.

2.4.2 Echo response

For the MC33771B write commands to a single slave prompt a single echo response. To optimize (reduce) bus traffic, the MC33771C does not send echo response messages.

2.4.3 EOM timeout

The MC33771C utilizes an EOM timeout feature of t_{EOM}. The device discards a communication frame once the time between SOM and EOM is longer than t_{EOM}. To signal the fault event, the COM_ERR_FLT fault bit is set and the COM_ERR_COUNT is incremented. This procedure avoids communication freeze due to a corrupt message.

2.4.4 INIT register: termination resistance and bus switches

The content of the INIT register was changed to enable storage of longer CID. Instead of controlling the bus switch and a single termination resistor, the termination resistors for both communication directions can now be controlled.

Table 6. INIT register of MC33771B

Bit	15:6	5	4	3:0
Content	not used	RTERM	BUS_SW	CID [3:0]

Table 7. INIT register of MC33771C

Bit	15:8	7	6	5:0
Content	not used	TPL_ TX_ Term. (RDTX_ IN)	TPL_ TX_ Term. (RDTX_ OUT)	CID [5:0]

The RTERM bit is used to terminate the bus. In the MC33771C, there are two bits, TPL_TX_ Term[RDTX_ IN] and TPL_TX_ Term[RDTX_ OUT], that allow a termination of each side of the device.

In the MC33771B, the BUS_SW allows a manual control of the bus switch. The MC33771C forwards the messages automatically whenever the device is enumerated (CID not equal to 0).

2.4.5 ADC_CFG register: control of averaging functionality and TAG ID

To allow the control of the averaging function, the bit field AVG in the ADC_CFG register replaces the bit field TAG_IG. The functionality of TAG_ID is replaced by MSGCNTR in message protocol.

Table 8. ADC_CFG in MC33771B

ADC_CFG																
$06	bit 15	bit 14	bit 13	bit 12	bit 11	bit 10	bit 9	bit 8	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
Write	TAG_ID				SOC	PGA_GAIN			CC_ RST	Not used	ADC1_A_DEF		ADC1_B_DEF		ADC2_DEF	
Read					EOC_ N	PGA_GAIN_S			0							
Reset	0	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1

Table 9. ADC_CFG in MC33771C

ADC_CFG																
$06	bit 15	bit 14	bit 13	bit 12	bit 11	bit 10	bit 9	bit 8	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
Write	AVG				SOC	PGA_GAIN			CC_ RST	Not used	ADC1_A_DEF		ADC1_B_DEF		ADC2_DEF	
Read					EOC_ N	PGA_GAIN_S			0							
Reset	0	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1

The AVG bit field allows now to select how many consecutive samples are averaged. Options are 1 (no averaging), 2, 4, 8, 16, 32, 64, 128, and 256. The no averaging option allows backward compatibility to MC33771B.

2.4.6 System configuration register 1 – SYS_CFG1

The reset value of the SYS_CFG1 register has been changed from 9001h in MC33771B to 1001h in MC33771C. With this change the cyclic timer is configured from 1.0 seconds (MC33771B) to disabled (MC33771C).

2.4.7 Wake-up mask registers – WAKEUP_MASK1 to WAKEUP_MASK3

The reset value of the WAKEUP_MASK1, WAKEUP_MASK2, and WAKEUP_MASK3 registers has been changed from 0000h in MC33771B to FFFFh in MC33771C. With this change all the wakeup events related to these registers are per default disabled.

3 Averaging functionality

Due to the averaging functionality, the measurement schemes for MC33771B and MC33771C are different.

3.1 Measurement scheme: MC33771B

The MC33771B performs an on-demand ADC conversion and provides the results via the communication interface. An on-demand conversion is started by setting the SOC bit in the ADC_CFG register. The MC33771B performs the ADC conversion within t_{ECO}. Once the ADC conversion is complete, the MCU has to request the conversion result. The MC33771B communicates then the data to the MCU.

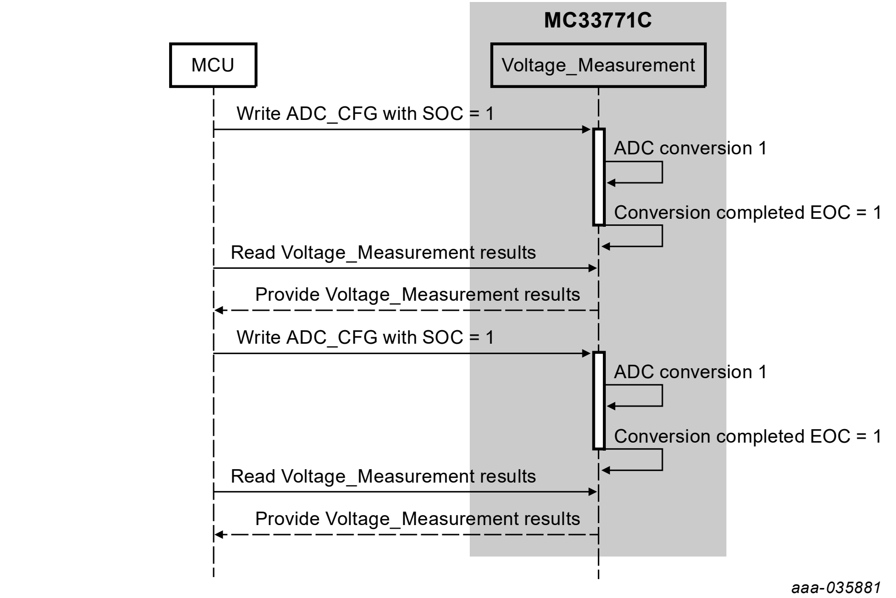


Figure 4. Example sequence diagram of measurement routine with MC33771B

The timing diagram shows the sequence with additional information.

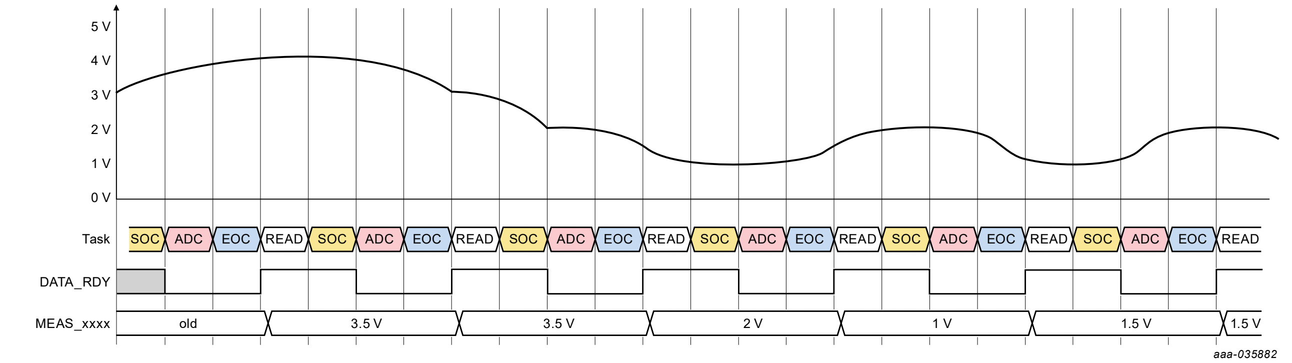


Figure 5. Example timing diagram of measurement routine with MC33771B

The time needed for a measurement cycle is calculated as shown in Table 10.

Table 10. Measurement example timing MC33771B

Action	14-cell system	96-cell system (7 ICs)
Send start of conversion command	1 frame = 23.9 µs	1 frame = 23.9 µs
Perform ADC conversion	520 µs	520 µs
Request result IC1	1 frame = 23.9 µs	1 frame = 23.9 µs
Wait for response IC1	1 µs	1 µs
Receive results IC1	23 frames = 548.6 µs	23 frames = 548.6 µs
Request result x other ICs	n.a.	6 x 1 frame = 143.1 µs
Wait for response x other ICs	n.a.	6 × 1 µs = 6 µs
Receive results x other ICs	n.a.	6 × 21 frames = 3005 µs
Total:	1.12 ms	4.27 ms

Table 10 shows that the communication of the data is limiting the frequency at which the measurements can be performed.

To avoid aliasing, frequency content above half the sampling frequency has to be filtered before the sampling (Nyquist theorem). For the MC33771B this is done by an external low-pass filter. With the typical recommended value of R_{LP} of 3 kΩ, the required capacity C_{LP} can be calculated. The calculation below shows the impact of the different sampling frequencies on a simple low-pass filter.

***Note:** NXP recommends using a 2-stage low-pass filter for applications.*

Table 11. Filter calculation for a single stage low-pass filter

Item	14-cell system	96-cell system
Sampling time	1.12 ms	4.27 ms
Filter cut off frequency $f\_cut\_off = \left(\frac{1}{2*t\_sample}\right)$	448 Hz	117 Hz
R_{LP}	3 kΩ	3 kΩ
$C_{LP} = \frac{1}{2p(f\_cut\_off)*R_{LP}}$	119 nF	453 nF

Notes:

- *NXP recommends using the resistors and capacitors as stated in the product data sheet.*
- *The external filter has an impact on the timing of the CTx Open Detect and Open Detect Functional Verification. See safety manual SM02 for details.*

3.2 Measurement scheme MC33771C

The MC33771C performs an on-demand ADC conversion in the same way as the MC33771B. However, the MC33771C can perform multiple conversions directly after each other. An automatic averaging of the results is performed once the measurements are completed. Once the measurements are completed, the MCU has to request the averaged results. The MC33771C communicates then the data to the MCU.

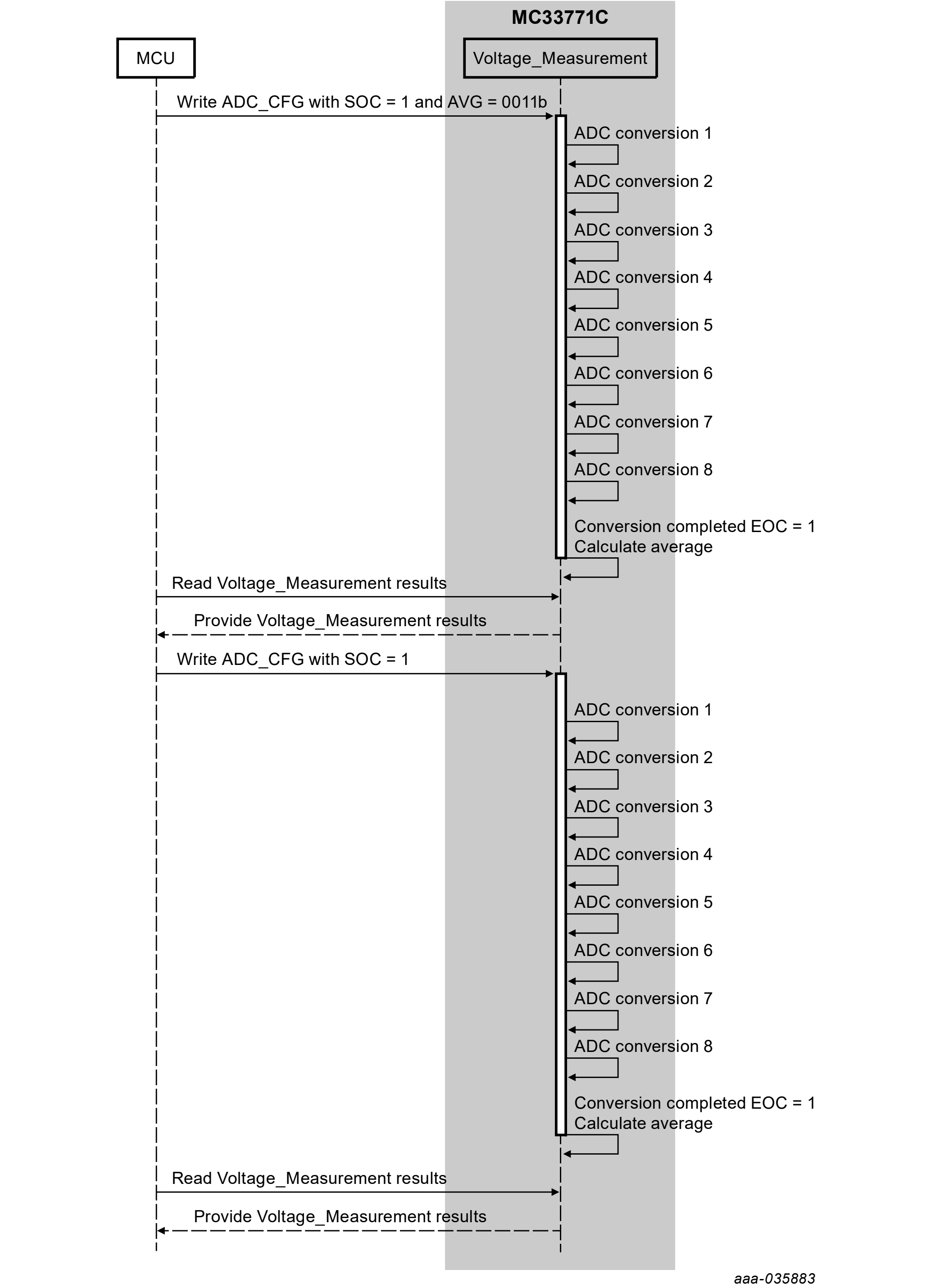


Figure 6. Example sequence diagram of measurement routine with MC33771C using averaging

The timing diagram shows the sequence with additional information.

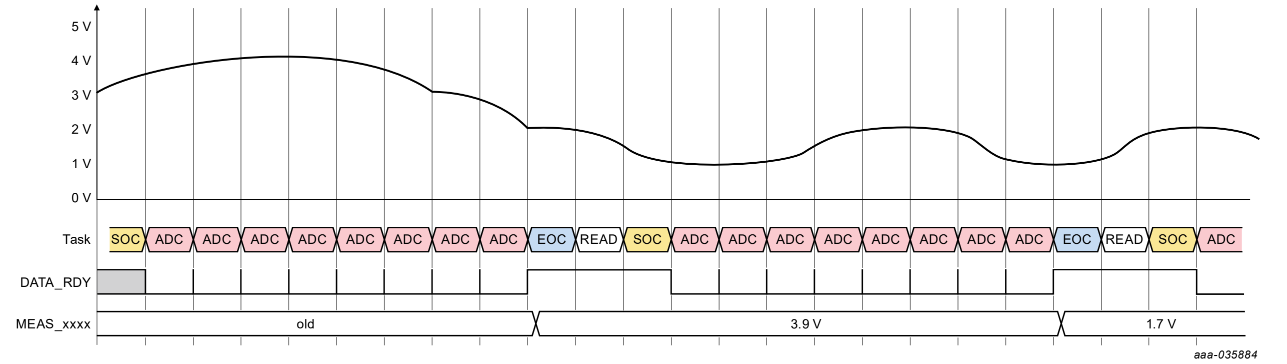


Figure 7. Timing diagram of measurement routine with MC33771C using averaging

The time needed for a measurement cycle is calculated as shown in Table 12.

Table 12. Measurement example timing MC33771C (32 averaging)

Action	14-cell system	96-cell system (7 ICs)
Send start of conversion command	1 Frame = 28.7 µs	1 Frame = 28.7 µs
Perform ADC conversions (32 * t_{EOC})	16.6 ms	16.6 ms
Request result IC1	1 Frame = 28.7 µs	1 Frame = 28.7 µs
Wait for response of IC1 and interframe spaces	88 µs	88 µs
Receive results IC1	23 Frames = 660.1 µs	23 Frames = 660.1 µs
Wait for response x other ICs	n.a.	6 × 1 Frame = 172 µs
Receive results x other ICs and interframe spaces	n.a.	6 × 88 µs = 528 µs
Request result x other ICs	n.a.	6 × 21 Frames = 3616 µs
Total:	17.4 ms	21.7 ms

The averaging functionality of the MC33771C allows, compared to MC33771B (see Table 10), to spend more time on the measurements (ADC conversions). The time needed for communication is not changing significantly. More ADC conversions can be done in same amount of time. Due to no interruption of the measurements, the ADC conversion is now performed with a fixed frequency of around 1.92 kHz.

The calculation below shows the results of MC33771B and a filter needed for MC33771C using averaging.

Note: *NXP recommends using a 2-stage low-pass filter for applications.*

Table 13. Filter calculation

Item	MC33771B 14-cell system	MC33771B 96-cell system	MC33771C using averaging, independent of cells
Sampling time	1.12 ms	4.27 ms	520 µs
Filter cut off frequency $f\_cut\_off = \left(\frac{1}{2{*}t\_sample}\right)$	448 Hz	117 Hz	1.92 kHz (assuming 16 bit resolution)
R_{LP}	3 kΩ	3 kΩ	3 kΩ
$C_{LP} = \frac{1}{2p(f\_cut\_off){*}R_{LP}}$	119 nF	453 nF	55 nF

Notes:

- *NXP recommends using the resistors and capacitors as per the data sheet.*
- *The external filter has an impact on the timing of the CTx Open Detect and Open Detect Functional Verification test. See safety manual SM02 for details.*

3.2.1 Synchronous measurement scheme

In the synchronous measurement scheme, the ADC conversion of all the devices in a system is triggered at the same moment in time. The simultaneous start off all measurements results in a simultaneous end. The measurement data must be transmitted at the same moment in time. During the transmission, no ADC conversion is performed and the system is 'blind'. The 'blind' time depends on the amount of data to be transferred.

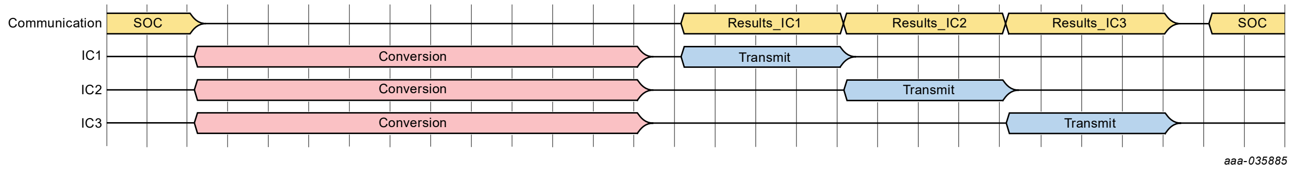


Figure 8. Synchronous measurement scheme

3.2.2 Interleaved sampling scheme

A way to limit the the blind time of the system to a minimum is to interleave the measurements. The start of conversion command is not given to all devices in a chain simultaneously, but with a delay. The conversion results are also available with a delay. While one device transmits data, the other devices keep on sampling.

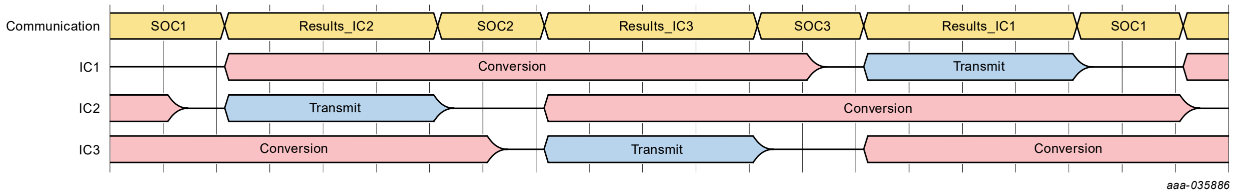


Figure 9. Interleaved sampling scheme

3.3 Changes in UV / OV comparisons

The UV / OV detection bits are used in various procedures. The procedures include the UV / OV monitoring of the cells, but also the CTx Open Detect and Open Detect Functional Verification (SM02) and others.

3.3.1 UV / OV comparison in MC33771B

The UV/OV comparators in MC33771B are evaluated after a conversion is done. The evaluation is independent if the conversion is initiated by an on-demand conversion or by a cyclic conversion.

3.3.2 UV / OV comparison in MC33771C

The UV/OV comparators in MC33771C are evaluated after the conversion process is completed. For cyclic conversions, the device is not performing averaging, so the UV/

OV bits are updated after each cyclic conversion. When the conversion is initiated by an on-demand conversion, the MC33771C performs the requested averaging cycles. Afterwards the averaged result is used for UV/OV comparison.

4 Averaging of the current measurement

MC33771C provides an averaging functionality for the cell voltages' measurements. For the current measurement no dedicated averaging functionality is implemented, however the coulomb counting feature can be used for measuring the average current.

Note: *The implementation of the coulomb counter is identical for MC33771B and MC33771C. The method described here therefore applies to both chip versions.*

In case a conversion with multiple averaging cycles for the voltage is initiated, the current measurement will be updated after each conversion.

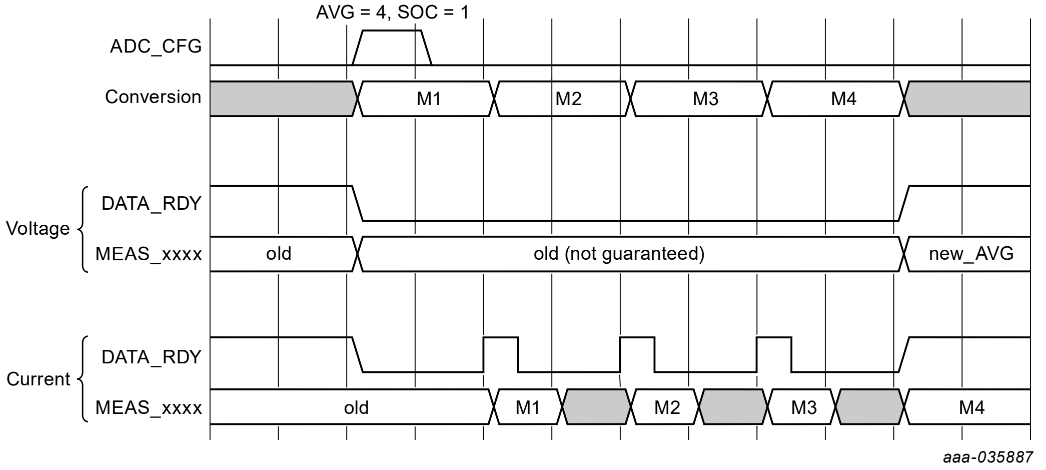


Figure 10. Conversion with averaging of four consecutive samples

Once the current measurement is enabled in normal mode, the MC33771C measures the current continuously.

The discrete integral of the measurement is stored in the coulomb counter. The MC33771C provides the number of accumulated samples. Knowing the integral, the number of samples, and the time needed for each sample, it is possible to calculate the average current during the sampling period. The data sheet shows a generic procedure to calculate the average current. Some simple example is shown below.

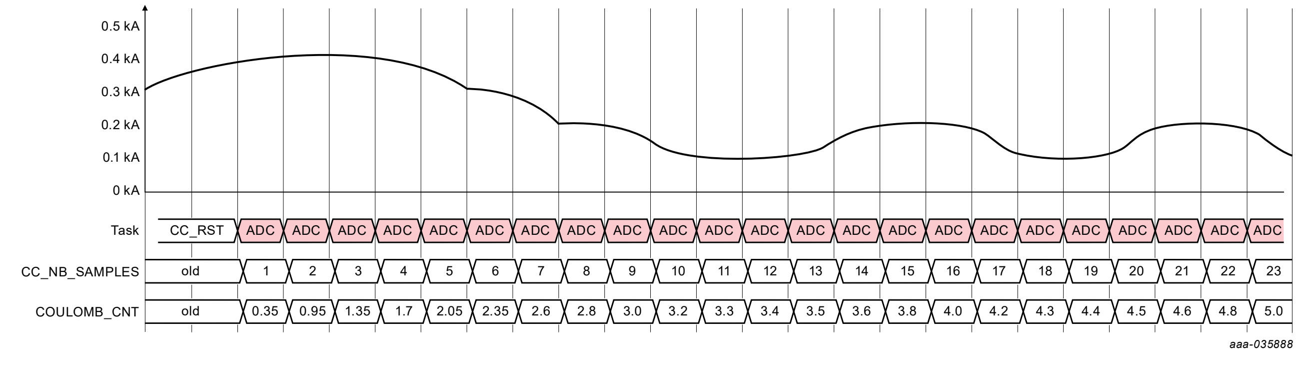


Figure 11. Coulomb counter

Figure 11 shows an example of a measurement. To ease the understanding the figure shows the y-axis in ampere, the coulomb counter does not show a unit. At the start of the measurement, the counter is reset. At the end of the figure, the device has done 23 accumulations and the coulomb counter shows 5.0 kA samples. The average current can be calculated to 5.0 kA samples / 23 samples = 0.217 kA = 217 A.

4.1 Synchronized current and voltage measurement

For impedance calculations, it is important to have the current and voltage measurements synchronized. The MC33771C offers two ways to derive the average current together with an averaged voltage measurement.

4.1.1 Reset the counter when starting an ADC conversion

New conversions are started by setting the SOC bit in the ADC_CFG register. The CC_RST bit, which resets the coulomb counter, is also in the ADC_CFG register. By setting both bits in one command, a conversion of the voltages and a reset of the counter is initiated. When the averaging feature is used, the device executes several voltage measurements. For each individual measurement, the current measurement is updated. The coulomb counter accumulates all measurements.

Note: *The coulomb counter accumulates all samples of the current measurement. The current measurement register provides the value of the current at the middle point of the last completed conversion. See data sheet for more details.*

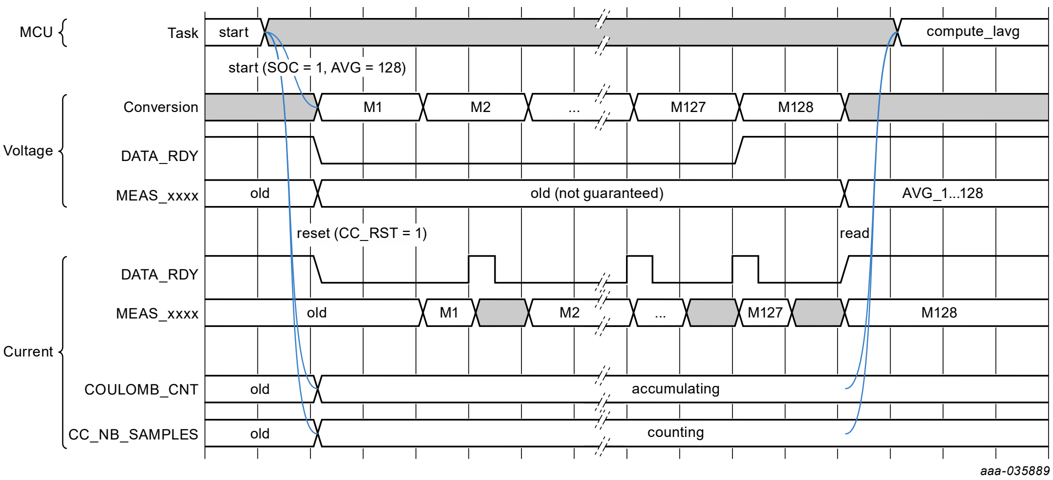


Figure 12. Example with averaging over 128 voltage measurements

A simultaneous start of the current measurement and the voltage measurement is ensured. The voltage averaging will end after t_{EOC} times the specified number of samples to be converted (Register ADC_CFG, bit field AVG). Reading the coulomb counter exactly after the conversion time, provides a simultaneous end of the measurement.

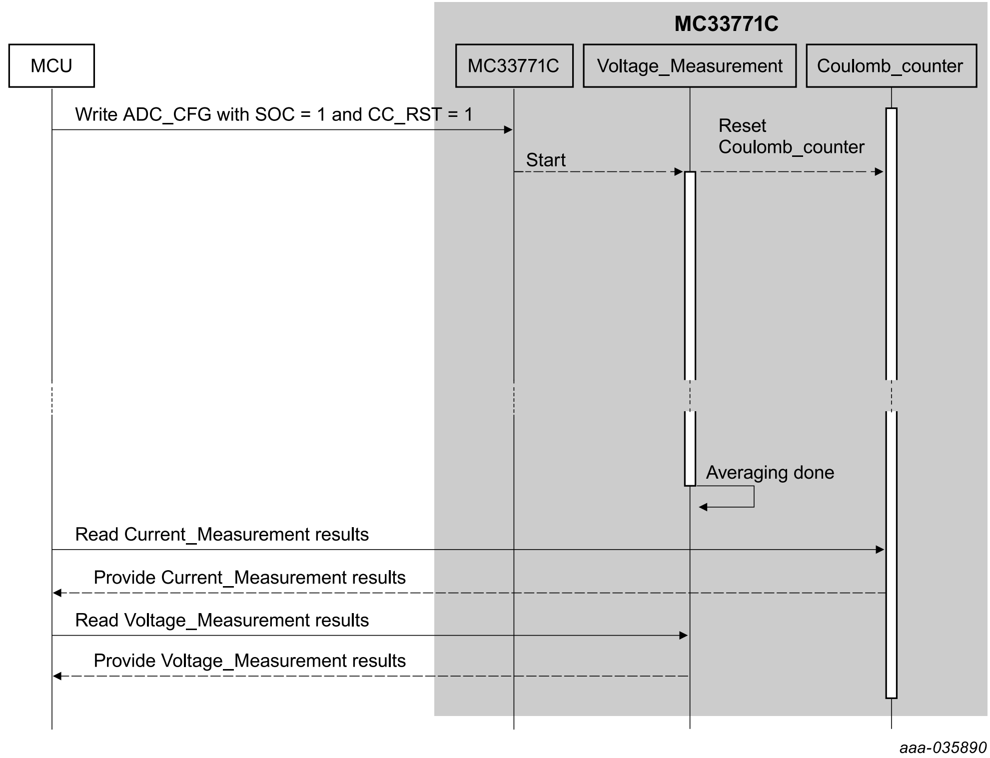


Figure 13. Sequence with coulomb counter reset

The coulomb counter in the MC33771C has a width of 32 bits, while the current measurement has a width of 19 bits. The spare 13 bits allow the device to perform at least 2^{13}= 8192 conversions before the coulomb counter will overflow. With t_{ICONV}, the time before an overflow can happen can be calculated. The time to overflow is longer than the maximum averaging time the device offers. As the coulomb counter is reset every time a voltage conversion is started, an overflow of the coulomb counter cannot happen.

4.1.2 Read the counter before starting a new conversion

If a reset of the coulomb counter is not desired, the coulomb counter must be read in close time correlation to the SOC command. The values that this reading provides are then the start value for the coulomb counting. After the expected end of the conversions, the coulomb counter is read again to provide a simultaneous end of the measurement.

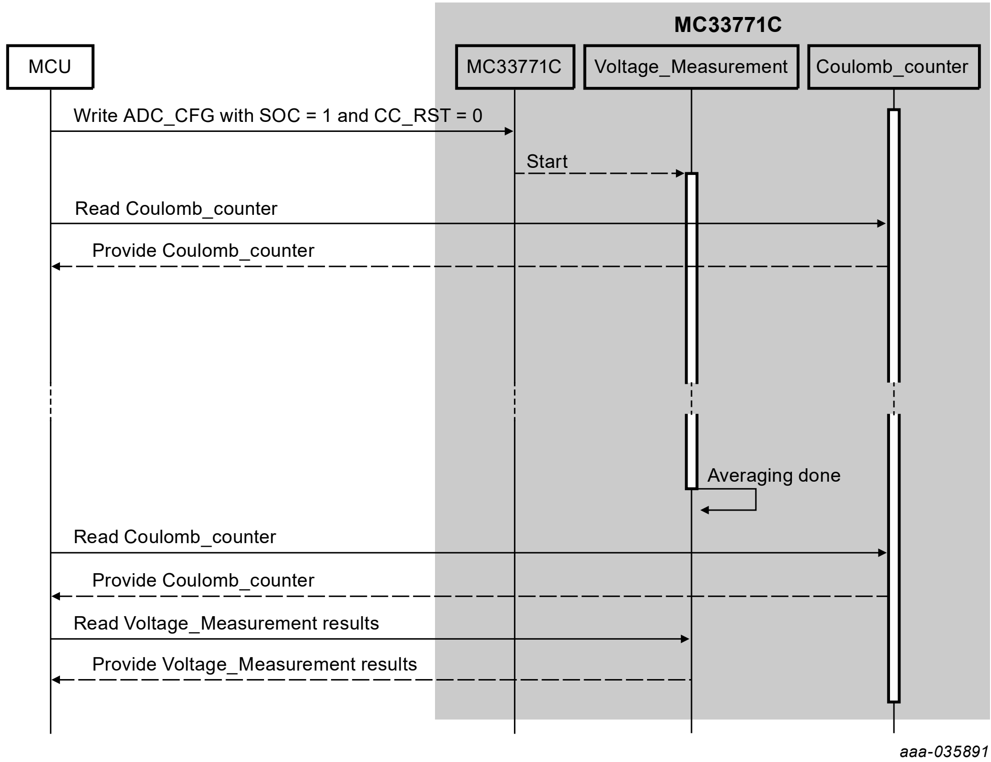


Figure 14. Sequence without coulomb counter reset

If the coulomb counter value is close to the minimum or maximum value, some overflow or underflow of the counter is possible. An overflow or underflow event is signaled by the MC33771C with the CC_OVR_FLT bit. The ADC2_OFFSET_COMP[CC_P_OVF] and ADC2_OFFSET_COMP[CC_N_OVF] bits signal the overflow and underflow conditions. Overflows of the CC_NB_SAMPLES registers is signaled by the ADC2_OFFSET_COMP[SAMP_OVF]. The MCU has to handle the overflows before performing the average calculations.

4.1.3 Derivations

Variation of the two main principles stated above are possible. For example, the ADC2_OFFSET_COMP[CC_RST_CFG] bit can be used. Setting this bit 1 configures the device to reset the coulomb counter when the coulomb counter is read. Some separate reset is not necessary. Using the ADC2_OFFSET_COMP[CC_RST_CFG] set to 1 in the procedure shown in Section 4.1.2 "Read the counter before starting a new conversion" resets the counter with the read of the coulomb counter. The reset would allow an easier calculation of the average current and prevent overflows during the averaging. Because the coulomb counter is read exactly before reset, the total coulomb count information is available for the application.

4.1.4 Items to consider

When using the coulomb counter to average the current, consider the following items.

1. **Do not execute safety mechanisms while averaging the current**
   Some safety mechanisms (for example, SM37 and SM38) perform diagnostics of IC internal resources for current measurement. While executing one of these safety mechanisms, the coulomb counter accumulates the diagnostic signal instead of

the actual current. Other safety mechanisms similar to SM39 use AN5 and AN6 as current measurement input. For details on the here mentioned and the other safety mechanisms, see the safety manual of the MC33771C.

2. **Inaccuracy due to PGA gain change**
The MC33771C allows an automatic gain control of the PGA used for the current measurement. In case the gain is changed between two chopped measurements, the flag MEAS_ISENSE2[PGA_GCHANGE] indicates reduced accuracy for the resulting measurement value. The coulomb counter continues with the accumulation, even when there is a measurement with reduced accuracy reported. For a single current measurement value, a reduced accuracy is very relevant. The average current measurement described here however, uses many samples. Reduced accuracy on a single sample has little influence on the averaged result.

5 Checklist for switching from MC33771B to MC33771C

The following table shows a checklist when changing from MC33771B to MC33771C.

Table 14. Checklist for switching from MC33771B to MC33771C

Item	Remark
Adapt communication protocol	Ensure no message violates the EOM timeout (Section 2.4.3)
Adapt external circuit for MC33664	Only needed when TPL communication is used
Adapt external circuit for MC33771C	Only needed when TPL communication is used
Adapt SW not to make use of TAG_ID	TAG_ID is no more supported in MC33771C
Adapt SW for MsgCounter	
Adapt SW to use averaging functionality	Only when averaging function is desired
Adapt input filters for cell voltages	Only when averaging function is desired
Check safety manual for modified safety mechanisms	Only when averaging function is desired

6 Legal information

6.1 Definitions

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Date of release: 10 February 2020
Document identifier: AN12633