

# **BLDC Integrated Controller and Smart 3 Phase Gate Driver**

# Datasheet

# **Product Feature Summary**

#### **General Features**

- Fully programmable drives optimized ARM<sup>®</sup> Cortex-M0 microcontroller (XMC1404 @ 48MHz main clock) with additional MATH Co-processor (96MHz)
- o 3 phase smart gate driver: 1.5A sink/ 1.5A source peak gate driver currents
- o 3 current sense amplifiers with integrated gain and offset generation
- o Integrated synchronous buck converter controller and LDO for complete BLDC system supply
- o 5.5V to 60V operating voltage
- o Supports trapezoidal commutation (6 or 12 steps) and FOC algorithms
- o 20 GPIOs plus up to 12 analog inputs

#### ARM<sup>®</sup> Cortex-M0, 32 bits microcontroller (XMC1404)

- CPU Subsystem
  - 32 bit ARM<sup>®</sup> Cortex-M0 (core clock 48MHz)
  - o MATH Co-Processor (96MHz) for optimized 32 bit division and 24 bit trigonometric calculations
  - o 0.84 DMIPS/MHz (Dhrystone 2.1) at 48 MHz
  - Nested Vectored Interrupt Controller (NVIC) with 64 interrupt nodes
  - o Internal slow and fast oscillators without the need of PLL
  - $\circ \quad \text{Real time clock module} \\$
  - Window watchdog
  - Up to 128kB of Flash (with ECC) and 16kB of RAM (with parity)
  - o Internal oscillator

### • Serial Communication Modules

- $\circ$  ~ Four USIC channels, each of them configurable as UART, SPI, IIC and more
- MultiCAN module (2 CAN nodes)
- Analog Frontend Peripherals
  - 12 bit A/D Converters (up to 12 analog inputs), 2 sample and hold stages up to 1.1MSamples/s with adjustable gain
  - 4 fast, general purpose analog comparators
- Industrial Control Peripherals
  - o 2x4 16-bit 96 MHz CCU4 timers for signal monitoring and PWM
  - 2x4 16-bit 96 MHz CCU8 timers for complex PWM, complementary high/low side switches and 3 phase inverter control
  - o 2x POSIF for Hall and quadrature encoders, motor positioning



#### • On-Chip Debug Support

- 4 hardware breakpoints
- ARM serial wire debug, single-pin debug interfaces

#### Programming Support

- Single-pin bootloader
- o Secure bootstrap loader SBSL (optional)

#### **Three Phase Programmable Gate Driver**

- 1.5A sink/ 1.5A source peak gate driver currents
- Programmable driving voltage (7V, 10V, 12V, 15V)
- Independently programmable high side/low side slew rate control
- 100% duty cycle

#### **Integrated Power Supply System**

- High efficiency synchronous buck converter with programmable switching frequency.
- Linear regulator (5V or 3.3V) with 300mA current capability supplying XMC1404 and other external components (DVDD)
- o Dual charge pump for supplying gate driver even at low supply voltage

#### **Three Current Sense Amplifiers**

- Integrated adjustable gain and offset
- Flexible protection and behavior programming
- Configurable for low side R<sub>DSON</sub> sensing

#### **Protection features:**

- o Easy brake mode with programmable braking response
- Over-Current Protection (OCP) on current sense amplifiers (programmable)
- o Over-Current Protection (OCP) for buck converter and DVDD linear regulator (programmable)
- Under-Voltage Lockouts (UVLO) for all internal/external supplies
- o Over-Voltage Fault (OVLO) reporting for buck converter and DVDD linear regulator
- Over-Temperature warning and shutdown (OTW, OTS) in gate driver and microcontroller

#### Thermally enhanced 64pin VQFN package

## **Potential Applications**

- Battery powered power tools and gardening tools
- Robotic lawn mowers
- E-bikes
- Robotics, RC toys, consumer drones and multi-copters
- Pumps and fans
- Other 3 Phase BLDC and PMSM motors



# **Product Description**

MOTIX<sup>™</sup> IMD70xA is a controller specifically designed for 3 phase BLDC or PMSM drives applications. IMD70xA integrates a fully programmable XMC1404 ARM<sup>®</sup> Cortex<sup>®</sup>-M0 microcontroller from Infineon XMC1400 family with 6EDL7141, a 60V three phase smart gate driver with integrated power supply. Both devices integrated allow an ultra-compact design for drives applications up to 60V including not only the microcontroller and a flexible 3 phase gate driver, but also the complete power supply required in the system (synchronous buck converter and LDO), 3 current sense amplifiers, protections and a remarkable set of configurations to adjust to specific needs.

XMC1404, ARM<sup>®</sup> Cortex<sup>®</sup>-M0 based microcontroller, incorporates dedicated features to improve motor drives control. Features like the MATH Co-Processor, a hardware unit clocked at 96MHz, enhances the calculation of divisions and trigonometric functions like 'Arctan', commonly used in Field Oriented Control of PMSM. Additionally, XMC1404 inherits most of the high end peripherals found in XMC4000 family (ARM<sup>®</sup> Cortex<sup>®</sup>-M4), like PWM timers-CCU8 and CCU4-, Position interface (POSIF) or serial communication modules including CAN, ensuring best in class control.

With up to 20 dedicated general purpose pins and up to 12 analog inputs, the user has full flexibility to implement specific functions externally like serial communications, security or safety related functions or auxiliary functions like LEDs, buttons or displays.

Internally, XMC1404 and 6EDL7141 are connected to ensure proper operation. These interconnects enable SPI communication between both devices for configurability and status reporting of 6EDL7141, 6 PWM signals for driving the motor, nFAULT reporting pin to inform the microcontroller of any possible fault on the power side, an enable driver pin, and a brake pin that can be also accessed externally for a double brake path.

6EDL7141 smart gate driver provides on the one side a flexible gate driving scheme and on the other side the necessary robustness and protection features to avoid failures in demanding drives systems. The gate driver outputs are placed strategically to allow best layout practices in power circuits.

In 6EDL7141, separate charge pumps for low and high side gate drivers support 100% duty cycle and low voltage supply operation. Supplies for the gate drivers are programmable to one of the following levels: 7V, 10V, 12V or 15V. Additionally, the slew rate of the driving signal can be programmed with fine granularity to reduce EMI emissions.

An integrated synchronous buck converter provides an efficient supply of current to the rest of the system. However, drives systems require high precision current measurements, involving a very precise ADC reference voltage. For that purpose, 6EDL7141 uses a linear voltage regulator (up to 300mA), powered by the buck converter to supply XMC1404 and other components in the system. With this advanced power supply architecture, not only the best possible signal quality is achieved, but also the power efficiency is optimized at any input voltage.

6EDL7141 also integrates three current sense amplifiers for accurate current measurements that support bidirectional low side current sensing with programmable gain. R<sub>DSON</sub> sensing is supported through internal connection of the phase nodes to the current sense amplifiers inputs. Low noise, low settling times and high accuracy are the main features of the integrated operational amplifiers. An internal buffer can be used to offset the sense amplifier outputs for optimizing the dynamic range. The outputs of the current sense amplifiers can be connected to ADC inputs in XMC1404 for accurate current sensing. Additional signal conditioning is therefore possible with external RC filter. The ADC can on top provide a gain factor that can be combined with the amplifiers one for best performance.

The device provides numerous protection features for improving application robustness during adverse conditions, like monitoring of power supply voltages as well as system parameters. The failure behavior, threshold voltages and filter times of the supervisions of the device are adjustable via SPI. Monitored aspects include motor currents, gate drive voltages and currents and device temperature. When a fault occurs, the

Datasheet



#### **Table of Contents**

device stops driving and pulls nFAULT pin low, in order to prevent MOSFET damage and motor overheating. Those signals are connected internally to XMC1404 to inform the processor that a fault has happened. The microcontroller can request more information on the fault via SPI commands.

In order to increase robustness in drives applications, inverter, motor and supply related pins in IMD70xA can withstand voltages of up to 90V. Motor related pins can even withstand negative voltage transients down to -8V without compromising functionality allowing faster switching of the inverter MOSFETs, therefore reducing switching losses.

# System Block Diagram

Figure 1 shows a simplified system block diagram where MOTIX<sup>™</sup> IMD70xA is used as 3-phase BLDC controller Hall-sensored BLDC motor control system.

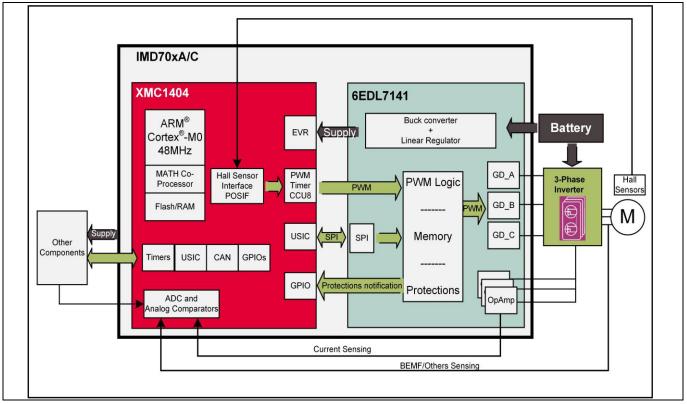


Figure 1 Simplified System Block Diagram

# **Package Description**

MOTIX<sup>™</sup> IMD70xA is integrated in a VQFN64 9mm x 9mm package with an exposed pad. The device and package information is shown in Table 1.

Part Number	Package	Body Size	Lead Pitch
IMD700A	PG-VQFN-64-8	9.0 mm × 9.0 mm	0.5 mm
IMD701A	PG-VQFN-64-8	9.0 mm × 9.0 mm	0.5 mm

#### Table 1Device and package information

*Note:* Refer to <u>XMC1400 Reference Manual</u> for full description of the device including registers and interconnects. Latest version can be found at Infineon website (<u>www.infineon.com</u>)

Datasheet

**Table of Contents** 



# **Table of contents**

Table	e of contents					
Prod	uct Feature Summary	1				
Potential Applications						
Prod	uct Description	3				
	em Block Diagram					
	age Description					
Table	of contents	5				
1	Pin Configuration	8				
1.1	Pin Assignment					
1.2	Pin Definition and Functions					
1.3	Interconnects Pin Description					
1.4	Interconnects Block Diagram	13				
2	General Product Characteristics	15				
2.1	Device Overview					
2.2	Absolute Maximum Ratings	15				
2.3	Recommended Operating Conditions					
2.3.1	XMC Pin Reliability in Overload	19				
2.4	ESD Robustness	20				
2.5	Thermal Resistance	20				
2.6	Electrical Characteristics					
2.6.1	MOTIX™ 6EDL7141 Electrical Characteristics	21				
2.6.2	XMC1404 Electrical Characteristics	30				
2.7	Electrical Characteristic Graphs	33				
2.8	XMC1404 Port I/O Alternate Functions Description					
2.8.1	XMC1404 Pin Definitions and Alternate Functions					
2.8.2	Port Pins for Boot Modes					
2.9	XMC1404 Chip Identification Number	45				
3	Drives Optimized Microcontroller Features: XMC1404 Overview	46				
4	MOTIX <sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver	47				
4.1	PWM Modes					
4.1.1	PWM with 6 Independent Inputs – 6PWM					
4.1.2	PWM with 3 Independent Inputs – 3PWM					
4.1.3	PWM with 1 Input and Commutation Pattern – 1PWM					
4.1.4	PWM with 1 Input and Commutation with Hall Sensor Inputs – 1PWM with Hall Sensors	53				
4.1.5	PWM with 1 Input and Commutation with Hall Sensor Inputs and Alternating Recirculation –					
	1PWM with Hall Sensors and Alternating Recirculation					
4.1.6	PWM Braking Modes					
4.1.7	Dead Time Insertion					
4.2	Gate Driver Architecture					
4.3	Slew Rate Control					
4.3.1	Slew Rate Control Parameters and Usage					
4.4 4.5	Gate Driver Voltage Programmability Charge Rump Configuration					
4.5 4.5.1	Charge Pump Configuration Charge Pump Clock Frequency Selection					
4.5.1	Charge Pump Clock Frequency Selection Charge Pump Clock Spread Spectrum Feature					
4.5.2	Charge Pump Clock Spread Spectrum Feature Charge Pump Pre-Charge for VCCLS					
4.5.4	Charge Pump Tuning					

Datasheet



## **Table of Contents**

4.6	Gate Driver and Charge Pumps Protections	69
4.6.1	VCCLS Under-Voltage Lock-Out (VCCLS UVLO)	
4.6.2	VCCHS Under-Voltage Lock-Out (VCCHS UVLO)	70
4.6.3	Floating Gate Strong Pull Down	70
5	MOTIX™ 6EDL7141 Power Supply Subsystem	72
5.1.1	Synchronous Buck Converter Description	
5.1.2	DVDD Linear Regulator	74
6	MOTIX™ 6EDL7141 Current Sense Amplifiers	76
6.1.1	R <sub>DSON</sub> Sensing Mode vs Leg Shunt Mode	
6.1.2	Current Shunt Amplifier Timing Mode	
6.1.3	Current Shunt Amplifier Blanking Time	
6.1.4	Current Sense Amplifier Internal Offset Generation	
6.1.5	Overcurrent Comparators and DAC for Current Sense Amplifiers	
6.1.6	Current Sense Amplifier Gain Selection	
6.1.7	Current Sense Amplifier DC Calibration	
6.1.8	Auto-Zero Compensation of Current Sense Amplifier	
7	MOTIX™ 6EDL7141 House-Keeping Functions	89
7.1	Hall Comparators	
7.2	Watchdog Timer	
7.2.1	Buck converter watchdog	90
7.2.2	General Purpose Watchdog	90
7.2.3	Locked-Rotor Protection Watchdog Timer	
7.3	Gate Driver ADC Module-Analog to Digital Converter	
7.3.1	6EDL7141 ADC Measurement Sequencing and On Demand Conversion	
7.3.2	Die Temperature Sensor	93
8	MOTIX™ 6EDL7141 Protections and Faults Handling	94
8 9	MOTIX <sup>™</sup> 6EDL7141 Programming-OTP and SPI interface	99
	MOTIX <sup>™</sup> 6EDL7141 Programming-OTP and SPI interface MOTIX <sup>™</sup> 6EDL7141 OTP User Programming Procedure: Loading Custom Default Values	<b>99</b>
9	MOTIX <sup>™</sup> 6EDL7141 Programming-OTP and SPI interface	<b>99</b>
<b>9</b> 9.1.1	MOTIX <sup>™</sup> 6EDL7141 Programming-OTP and SPI interface MOTIX <sup>™</sup> 6EDL7141 OTP User Programming Procedure: Loading Custom Default Values	<b>99</b> 100 101
<b>9</b> 9.1.1 9.1.2 <b>10</b> 10.1	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	
<b>9</b> 9.1.1 9.1.2 <b>10</b>	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107
<b>9</b> 9.1.1 9.1.2 <b>10</b> 10.1	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 107
<b>9</b> 9.1.1 9.1.2 <b>10</b> 10.1 10.1.1	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 107
<b>9</b> 9.1.1 9.1.2 <b>10</b> 10.1 10.1.1 10.1.2	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 110
<b>9</b> 9.1.1 9.1.2 <b>10</b> 10.1 10.1.1 10.1.2 10.2	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 110 113
<ul> <li>9</li> <li>9.1.1</li> <li>9.1.2</li> <li>10</li> <li>10.1</li> <li>10.1.2</li> <li>10.2</li> <li>11</li> </ul>	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 110 113 113
<pre>9 9.1.1 9.1.2 10 10.1 10.1.2 10.2 11 11.1</pre>	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 110 113 113 113
<pre>9 9.1.1 9.1.2 10 10.1 10.1.2 10.2 11 11.1 11.2 11.3 11.4</pre>	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface. MOTIX<sup>™</sup> 6EDL7141 OTP User Programming Procedure: Loading Custom Default Values MOTIX<sup>™</sup> 6EDL7141 SPI Communication.</li> <li>Device Start-up and Functional States MOTIX<sup>™</sup> 6EDL7141 Power Supply Start-up 1 Power Supply System Start-up 2 Gate Driver and CSAMP Start-up 2 Device Functional States.</li> <li>Register Map XMC1404 Registers MOTIX<sup>™</sup> 6EDL7141 Smart Gate Driver Register Map MOTIX<sup>™</sup> 6EDL7141 Registers Programmability MOTIX<sup>™</sup> 6EDL7141 Register Map</li> </ul>	99 100 101 107 107 107 110 113 113 113 114 117
<b>9</b> 9.1.1 9.1.2 <b>10</b> 10.1 10.1.2 10.2 <b>11</b> 11.1 11.2 11.3 11.4 Faults	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 110 113 113 113 113 114 117
<ul> <li>9</li> <li>9.1.1</li> <li>9.1.2</li> <li>10</li> <li>10.1</li> <li>10.1.2</li> <li>10.2</li> <li>11</li> <li>11.2</li> <li>11.3</li> <li>11.4</li> <li>Faults</li> <li>Temp</li> </ul>	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li> <li>MOTIX<sup>™</sup> 6EDL7141 OTP User Programming Procedure: Loading Custom Default Values MOTIX<sup>™</sup> 6EDL7141 SPI Communication</li> <li>Device Start-up and Functional States</li> <li>MOTIX<sup>™</sup> 6EDL7141 Power Supply Start-up.</li> <li>Power Supply System Start-up.</li> <li>Gate Driver and CSAMP Start-up</li> <li>Device Functional States.</li> <li>Register Map.</li> <li>XMC1404 Registers</li> <li>MOTIX<sup>™</sup> 6EDL7141 Smart Gate Driver Register Map</li> <li>MOTIX<sup>™</sup> 6EDL7141 Registers Programmability</li> <li>MOTIX<sup>™</sup> 6EDL7141 Register Map</li> </ul>	99 100 101 107 107 107 110 113 113 113 113 114 117 118
<ul> <li>9</li> <li>9.1.1</li> <li>9.1.2</li> <li>10</li> <li>10.1.1</li> <li>10.1.2</li> <li>10.2</li> <li>11</li> <li>11.2</li> <li>11.3</li> <li>11.4</li> <li>Fault:</li> <li>Temp</li> <li>Powe</li> </ul>	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 107 110 113 113 113 113 114 117 118 119
<ul> <li>9</li> <li>9.1.1</li> <li>9.1.2</li> <li>10</li> <li>10.1</li> <li>10.1.2</li> <li>10.2</li> <li>11</li> <li>11.2</li> <li>11.3</li> <li>11.4</li> <li>Faults</li> <li>Temp</li> <li>Powe</li> <li>Funct</li> </ul>	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 110 113 113 113 113 113 114 117 117 118 119 120
<ul> <li>9</li> <li>9.1.1</li> <li>9.1.2</li> <li>10</li> <li>10.1</li> <li>10.1.2</li> <li>10.2</li> <li>11</li> <li>11.2</li> <li>11.3</li> <li>11.4</li> <li>Faults</li> <li>Temp</li> <li>Powe</li> <li>Funct</li> <li>OTP S</li> </ul>	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 107 110 113 113 113 113 114 117 117 118 119 120 121
<ul> <li>9</li> <li>9.1.1</li> <li>9.1.2</li> <li>10</li> <li>10.1</li> <li>10.1.2</li> <li>10.2</li> <li>11</li> <li>11.2</li> <li>11.3</li> <li>11.4</li> <li>Faults</li> <li>Temp</li> <li>Powe</li> <li>Funct</li> <li>OTP S</li> <li>ADC S</li> </ul>	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 107 110 113 113 113 113 113 114 117 117 118 119 120 121
<ul> <li>9</li> <li>9.1.1</li> <li>9.1.2</li> <li>10</li> <li>10.1</li> <li>10.1.2</li> <li>10.2</li> <li>11</li> <li>11.1</li> <li>11.2</li> <li>11.3</li> <li>11.4</li> <li>Fault:</li> <li>Temp</li> <li>Powe</li> <li>Funct</li> <li>OTP S</li> <li>ADC S</li> <li>Charge</li> </ul>	MOTIX™ 6EDL7141 Programming-OTP and SPI interface	99 100 101 107 107 107 107 110 113 113 113 113 113 114 117 117 118 119 120 121 122 122
<ul> <li>9</li> <li>9.1.1</li> <li>9.1.2</li> <li>10</li> <li>10.1</li> <li>10.1.2</li> <li>10.2</li> <li>11</li> <li>11.2</li> <li>11.3</li> <li>11.4</li> <li>Fault:</li> <li>Temp</li> <li>Powe</li> <li>Funct</li> <li>OTP S</li> <li>ADC S</li> <li>Charg</li> <li>Device</li> </ul>	<ul> <li>MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface</li></ul>	99 100 101 107 107 107 107 107 110 113 113 113 113 113 113 113 113 113 113 113 113 113 112 121 120 121 122 122 123
<ul> <li>9</li> <li>9.1.1</li> <li>9.1.2</li> <li>10</li> <li>10.1</li> <li>10.1.2</li> <li>10.2</li> <li>11</li> <li>11.1</li> <li>11.2</li> <li>11.3</li> <li>11.4</li> <li>Fault:</li> <li>Temp</li> <li>Powe</li> <li>Funct</li> <li>OTP S</li> <li>ADC S</li> <li>Charg</li> <li>Device</li> <li>Fault:</li> </ul>	MOTIX™ 6EDL7141 Programming-OTP and SPI interface	99 100 101 107 107 107 107 110 113 113 113 113 113 114 117 117 118 119 120 121 122 122 123 123

Datasheet

# infineon

## **Table of Contents**

Configuration Register							
OC Configuration Register							
Sensor Configuration Register							
Natchdog Configuration Register1	.29						
Natchdog Configuration Register 21	.30						
Gate Driver Current Control Register1	.31						
Gate Driver Pre-Charge Current Control Register1	.33						
TDRIVE Source Control Register1	.34						
TDRIVE Sink Control Register	.34						
Dead Time Register1							
Charge Pump Configuration Register1							
Current Sense Amplifier Configuration Register1	.37						
Current Sense Amplifier Configuration Register 21							
OTP Program Register	.41						
12 Application Description14	.42						
12.1 Recommended External Components	.42						
12.2 PCB Layout Recommendations	.42						
Typical Applications							
13 ESD Protection	.49						
14 Package Information1	.52						
Revision history1							

Datasheet

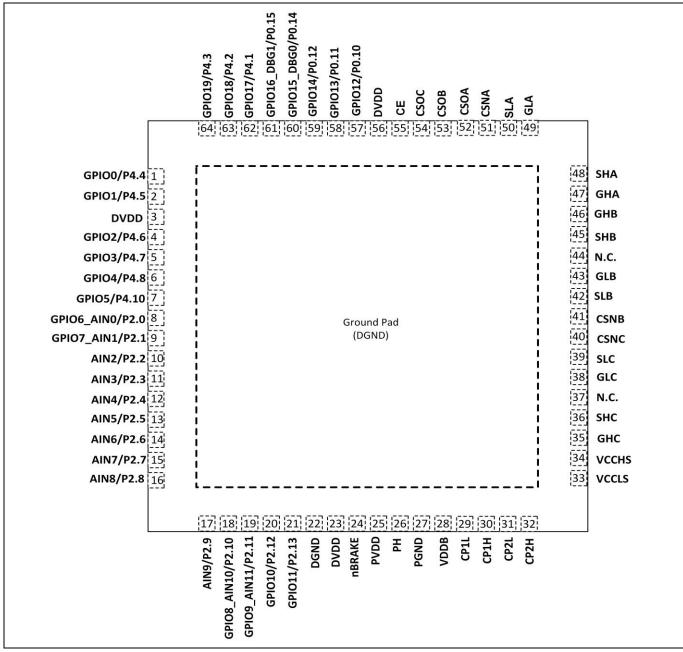
**Pin Configuration** 



# **1** Pin Configuration

# **1.1 Pin Assignment**

In Figure 2, the pinout of MOTIX<sup>™</sup> IMD70xA is presented.







**Pin Configuration** 

# **1.2** Pin Definition and Functions

Details regarding the pins of IMD70xA are shown in Table 1.

I: Input, O: output, IO: Input and/or Output, D: Digital, A: Analog, AD: Analog and/or Digital, P: Power, G: Ground.

able 1	Pin Def	ХМС		Type	Description
Pin #	Pin Name	Port	10	Туре	Description
1	GPIO0/ P4.4	P4.4	10	D -(STD_INOUT)	General purpose digital I/O. Standard bi-directional pads
2	GPIO1/ P4.5	P4.5	10	D -(STD_INOUT)	General purpose digital I/O. standard bi-directional pads
3	DVDD	VDD/ VDDP	Ю	Ρ	Microcontroller voltage supply. DVDD is generated from DVDD linear regulator in 6EDL7141 (pin 23 and 56) and must be connected to all DVDD pins. This voltage can be used to supply external components as well. Connect a capacitor to DGND in every DVDD pin.
4	GPIO2/ P4.6	P4.6	10	D -(STD_INOUT)	General purpose digital I/O
5	GPIO3/ P4.7	P4.7	10	D -(STD_INOUT)	General purpose digital I/O
6	GPIO4/ P4.8	P4.8	10	D -(STD_INOUT)	General purpose digital I/O
7	GPIO5/ P4.10	P4.10	10	D -(STD_INOUT)	General purpose digital I/O
8	GPIO6_AI N0/P2.0	P2.0	I	A/D - (STD_INOUT/A Analog input N)	
9	GPIO7_AI N1/P2.1	P2.1	I	A/D - (STD_INOUT/A N)	Analog input
10	AIN2/P2.2	P2.2	Ι	A - (STD_IN/AN)	Analog input
11	AIN3/P2.3	P2.3	I	A - (STD_IN/AN)	Analog input
12	AIN4/P2.4	P2.4	I	A - (STD_IN/AN)	Analog input
13	AIN5/P2.5	P2.5	I	A - (STD_IN/AN)	Analog input
14	AIN6/P2.6	P2.6	I	A - (STD_IN/AN)	Analog input
15	AIN7/P2.7	P2.7	I	A - (STD_IN/AN)	Analog input
16	AIN8/P2.8	P2.8	I	A - (STD_IN/AN)	Analog input
17	AIN9/P2.9	P2.9	I	A - (STD_IN/AN)	Analog input
18	GPIO8_AI N10/P2.10	P2.10	10	A/D - (STD_INOUT/A N)	Dual functionality pin. Analog input and general purpose digital I/O

#### Datasheet

# **Pin Configuration**



Pin #	Pin Name	XMC Port	10	Туре	Description	
19	GPIO9_AI N11/P2.11	P2.11	10	A/D - (STD_INOUT/A N)	JT/A Dual functionality pin. Analog input and general purpose digital I/O	
20	GPIO10/P 2.12	P2.12	10	A/D - (STD_INOUT/A N)	General purpose digital I/O	
21	GPIO11/P 2.13	P2.13	10	A/D - (STD_INOUT/A General purpose digital I/O N)		
22	DGND	VSS/ VSSP		Р	Ground connection for digital section. Supply GND, ADC reference GND	
23	DVDD	VDD/ VDDP	10	P Microcontroller voltage supply. DVDD is generated from DVDD linear regulator in 6EDL7141 (pin 23 and 56) and must be connected to all DVDD pins. This voltage can be used to supply external component as well. Connect a capacitor to DGND in every DVDI pin.		
24	nBRAKE	P1.3 <sup>1)</sup>	I	D (High Current)	After start-up, pin is used for motor braking. Active low	
25	PVDD	-		Р	Power supply of the device	
26	РН	-	0	Р	Buck phase node voltage. Connect to output inductor	
27	PGND	-	-	G Power ground used for buck converter, char pumps and gate drivers		
28	VDDB	-	-	Р	Buck output voltage. Connect capacitor between VDDB and PGND.	
29	CP1L	-	-	Р	Bottom connection of the charge pump flying capacitor 1	
30	CP1H	-	-	Ρ	Top connection of the charge pump flying capacitor 1	
31	CP2L	-	-	Ρ	Bottom connection of the charge pump flying capacitor 2	
32	CP2H	-	-	Ρ	Top connection of the charge pump flying capacitor 2	
33	VCCLS	-	-	P Output of low side charge pump. Connect a from VCCLS to PGND.		
34	VCCHS	-	-	P Output of high side charge pump. Connect a capacitor from VCCHS to PVDD or PGND.		
35	GHC	-	0	A	High side gate driving signal for phase C. Not connected or connected to PVDD if not used	
36	SHC	-	10	A	High side source connection (phase node) for phase C. Positive input of shunt amplifier C for R <sub>DSON</sub> sensing. Not connected if not used	
37	N.C.	-			Not connected	

## Datasheet

## **Pin Configuration**



Pin #	Pin Name	XMC Port	10	Туре	Description	
38	GLC	-	0	А	Low side gate driving signal for phase C. Not connected if not used	
39	SLC	-	10	A	A Low side source connection for phase C. Positive input of shunt amplifier C for shunt sensing Short to PGND if not used	
40	CSNC	-	I	A Current sense amplifier negative input for phase Short to PGND or DGND if not used		
41	CSNB	-	I	A	Current sense amplifier negative input for phase B. Short to PGND or DGND if not used	
42	SLB	-	10	A	Low side source connection for phase B. Positive input of shunt amplifier B for shunt sensing. Short to PGND if not used	
43	GLB	-	0	А	Low side gate driving signal for phase B. Not connected if not used	
44	N.C.	-			Not connected	
45	SHB	-	10	A	High side source connection (phase node) for phase B. Positive input of shunt amplifier B for R <sub>DSON</sub> sensing. Not connected if not used	
46	GHB	-	0	A	High side gate driving signal for phase B. Not connected or connected to PVDD if not used	
47	GHA	-	0	A	High side gate driving signal for phase A. Not connected or connected to PVDD if not used	
48	SHA	-	10	A High side source connection (phase node) for pl A. Positive input of shunt amplifier A for R <sub>DSON</sub> sens Not connected if not used		
49	GLA	-	0	A	Not connected	
50	SLA	-	10	А	Low side gate driving signal for phase A. Not connected if not used	
51	CSNA	-	I	A	Current sense amplifier negative input for phase A. Short to PGND or DGND if not used	
52	CSOA	-	0	A	Current sense amplifier output for phase A. Not connected if not used	
53	CSOB	-	0	A	Current sense amplifier output for phase B. Not connected if not used	
54	CSOC	-	0	A	Current sense amplifier output for phase C. Not connected if not used	
55	CE	-	I	D	Chip Enable. Starts up the device upon rising edge	
56	DVDD	VDD/ VDDP	-	Ρ	Microcontroller voltage supply. DVDD is generated from DVDD linear regulator in 6EDL7141 (pins 23 and 56) and must be connected to all DVDD pins. This voltage can be used to supply external components	

#### Datasheet

## **Pin Configuration**



Pin #	Pin Name	XMC Port	10	Туре	Description
					as well. Connect a capacitor to DGND in every DVDD pin. XCM1404 I/O port supply
57	GPIO12/P0 .10	P0.10	10	D - (STD_INOUT/cl ock_IN)	General purpose digital I/O. Can be used as high precision crystal/oscillator input
58	GPIO13/P0 .11	P0.11	10	D - (STD_INOUT/cl ock_O)	General purpose digital I/O. Can be used as high precision crystal/oscillator input
59	GPIO14/P0 .12	P0.12	10	D -(STD_INOUT)	General purpose digital I/O
60	GPIO15_D BG0/P0.14	P0.14	10	D -(STD_INOUT)	General purpose digital I/O. This is SWD pin for microcontroller debug I/F
61	GPIO16_D BG1/P0.15	P0.15	10	D -(STD_INOUT)	General purpose digital I/O. This is SWCLK pin for microcontroller debug I/F
62	GPIO17/P4 .1	P4.1	10	D -(STD_INOUT)	General purpose digital I/O. Can be used as Hall sensor input for POSIF module
63	GPIO18/P4 .2	P4.2	10	D -(STD_INOUT)	General purpose digital I/O. Can be used as Hall sensor input for POSIF module
64	GPIO19/P4 .3	P4.3	10	D -(STD_INOUT)	General purpose digital I/O. Can be used as Hall sensor input for POSIF module
ePad	DGND	VSS	-	G	Ground connection for digital section. Solder to PCB. Exposed Die Pad The exposed die pad is connected internally to VSSP. For proper operation, it is mandatory to connect the exposed pad to the board ground

1. Dual path for braking: internal connection of P1.3 through gate driver die

Datasheet

**Pin Configuration** 

# **1.3** Interconnects Pin Description

Table 2 shows a list of details of the interconnected pins between XMC1404 controller and 6EDL7141

able Z	Interconnects between devices								
XMC Port Pin	XMC Pad Type	6EDL7141 Pin	6EDL7141 Pin Description						
P0.7	STD_INOUT (standard bi-directional pads)	EN_DRV	Input digital. Enables the gate driver section and internal circuitry based on the configuration. Internal pull-down.						
P0.4	STD_INOUT (standard bi-directional pads)	nSCS	Input digital. Active low. Chip select for SPI communication						
P0.3	STD_INOUT (standard bi-directional pads)	SCLK	Input digital. Internal pull down. SPI Clock signal from XMC (master)						
P0.1	STD_INOUT (standard bi-directional pads)	SDO	Output digital. Internal pull down. SPI data input for XMC (master)						
P0.0	STD_INOUT (standard bi-directional pads)	SDI	Input digital. Internal pull down. SPI data output for XMC (master)						
P3.4	· · ·		Output digital. When low indicates a fault in 6EDL7141. Active low						
P3.3	STD_INOUT (standard bi-directional pads)	INHA	Input digital. PWM input high side phase A. Internal pull down						
P3.2	STD_INOUT (standard bi-directional pads)	INLA	Input digital. PWM input low side phase A. Internal pull down						
P3.1	STD_INOUT (standard bi-directional pads)	INHB	Input digital. PWM input high side phase B. Internal pull down						
P3.0	STD_INOUT (standard bi-directional pads)	INLB	Input digital. PWM input low side phase B. Internal pull down						
P1.0 High Current (high current bi-directional pads)		INHC	Input digital. PWM input high side phase C. Internal pull down						
P1.1 High Current (high current bi-directional pads)		INLC	Input digital. PWM input low side phase C. Internal pull down						
P1.2	P1.2 High Current (high current bi-directional pads)		Controller can use this pin to control Auto-Zero function.						
P1.3 <sup>1)</sup>	High Current (high current bi-directional pads)	nBRAKE	Input digital. Active low. Used for motor braking function in 6EDL7141. Pull up required via XMC P1.3						

Table 2	Interconnects between devices

1. Dual path for braking: external connection of IMD70xA via pin 24

# **1.4** Interconnects Block Diagram

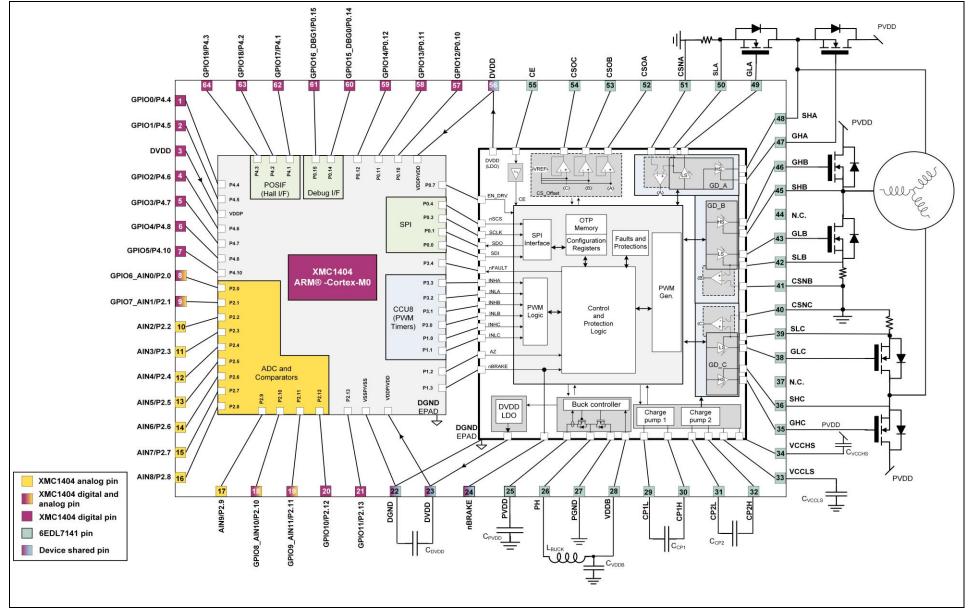
A block diagram showing the interconnection between XMC1404 and 6EDL7141 is given in Figure 3



Datasheet

#### **Pin Configuration**







Datasheet



# 2 General Product Characteristics

## 2.1 Device Overview

Table 3 shows the XMC1404 configuration regarding peripherals, core and memory.

#### Table 3XMC1404 Feature Overview

Features	IMD700A-Q064x0128	IMD701A-Q064x0128
Controller supply voltage	3.3V	5V
CPU Clock Frequency	48 MHz	48 MHz
Flash size (Kbytes)	128	128
SRAM size (Kbytes)	16	16
MATH co-processor	1	1
Auxiliary Timers (CCU4 units/timers/outputs)	2/8/8	2/8/8
PWM Timers (CCU8 units/timers/outputs)	2/8/321)	2/8/321)
Hall Sensor/Encoder Interface (POSIF units)	2	2
Serial Communication (channels)	4	4
MultiCAN+ (nodes/MOs)	2/32	2/32
ADC (kernels/inputs)	2/12	2/12
Analog Comparators	4	4
BCCU (units)	1	1
LEDTS (units)	3	3

1. Depending on pin availability. See Table 13 for possible pin functionality

# 2.2 Absolute Maximum Ratings

Table 4 shows the absolute maximum ratings for the device. Ratings are intended in the temperature range T<sub>j</sub>=-40°C to T<sub>j</sub>=115°C. All voltages are referred to ground (PGND for buck converter, charge pumps and gate driver related parameters and DGND for the rest), positive currents are flowing into the pin (unless otherwise specified).

Table 4	Absolute Maximum Ratings
---------	--------------------------

Downstaw	Gurahal		Valu	es	11	Condition
Parameter	Symbol	Min	Тур	Мах	Unit	
Supply voltage	PVDD	-0.3		70	V	
Supply voltage slew	SD			2	Muc	During start-up
rate	SR <sub>PVDD</sub>			0.25	V/µs	During active mode
CE pin voltage	V <sub>CE</sub>	-0.3		7	V	
Power ground to digital ground voltage	PGND – DGND	-0.3		0.3	V	

#### Datasheet

#### **General Product Characteristics**



<b>_</b>			Val	ues		Condition	
Parameter	Symbol	Min	Тур	Мах	Unit	Condition	
Low side gate driver supply voltage	VCCLS	-0.3		20	V	This is same as PVCC	
VCCHS voltage	VCCHS	PVDD- 0.3		90	V	VCCHS = PVDD + PVCC	
VCCHS-V <sub>SHx</sub> voltage	VCCHS-V <sub>SHx</sub>			90	V		
VCCHS-V <sub>GHx</sub> voltage	VCCHS-V <sub>GHx</sub>			90	V		
Source high side	V <sub>SHx</sub>	-8		70	V	DC voltage	
voltage		-10		70		500ns pulse max	
Source low side	V <sub>SLx</sub>	-8		8	V	DC voltage	
voltage/Shunt amplifier positive input voltage		-10		8		500ns pulse max	
Gate high side voltage	V <sub>GHx</sub>	-8		VCCHS+0.3	V	DC voltage,	
		-10		VCCHS+0.3		500ns pulse max,	
Gate low side voltage	V <sub>GLx</sub>	-8		VCCLS+0.3	V	DC voltage	
		-10		VCCLS+0.3		500ns pulse max	
Gate to Source high	V <sub>GHx</sub> - V <sub>SHx</sub>	-0.3		16	V	DC, T <sub>j</sub> = 25 °C	
side voltage		-2		16		500ns pulse max, T <sub>j</sub> = 25 °C	
Gate to Source low	V <sub>GLx</sub> - V <sub>SLx</sub>	-0.3		16	V	DC, T <sub>j</sub> = 25 °C	
side voltage		-2		16	-	500ns pulse max, T <sub>j</sub> = 25 °C	
Shunt amplifier negative input voltage	V <sub>CSN</sub>	-0.3		DVDD+0.3			
Flying capacitor 1 voltage	V <sub>CP1H</sub> - V <sub>CP1L</sub> ,	-0.3		9	V		
CP1L pin voltage	V <sub>CP1L</sub>	-0.3		9	V		
CP1H pin voltage	V <sub>CP1H</sub>	-0.3		20	V		
Flying capacitor 2 voltage	V <sub>CP2H</sub> - V <sub>CP2L</sub>	-0.3		70	V		
CP2L pin voltage	V <sub>CP2L</sub>	-0.3		20	V		
CP2H pin voltage	V <sub>CP2H</sub>	-0.3		90	V		
Buck converter output voltage	VDDB	-0.3		9	V		
Buck converter phase	N	-0.3		70	V	DC condition	
voltage continuous	V <sub>PH</sub>	-5		70	V	Less than 20 ns pulse	
DVDD regulator output voltage	DVDD	-0.3		6	v		
Current sense amplifier output voltage	V <sub>CSOx</sub>	-0.3		DVDD + 0.3	v		

#### Datasheet

# General Product Characteristics

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Parameter	Symbol		Val	ues	Unit	Condition
Parameter	Symbol	Min	Тур	Мах	Unit	Condition
Maximum current for 6EDL7141 digital pins	I <sub>DIG_IN_MAX</sub>	-1		1	mA	
Maximum current for 6EDL7141 analog inputs	I <sub>AN_IN_MAX</sub>	-1		10	mA	
Voltage on GPIOx digital pins with respect to DGND)	V <sub>GPIO_INx</sub>	-0.5	-	DVDD + 0.5 or max. 6	V	Whichever is lower
Voltage on AINx <sup>1)</sup> XMC1404 Port 2 pins with respect to DGND	V <sub>AINx</sub>	-0.3	_	DVDD + 0.3	V	-
Voltage on other AINx XMC1404 pins <sup>2)</sup> with respect to DGND	V <sub>AINx</sub>	-0.5	-	DVDD + 0.5 or max. 6	V	Whichever is lower
Input current on GPIOx/AINx pin during overload condition	I <sub>GPIO/AIN</sub>	-10	-	10	mA	
Absolute maximum sum of all input currents in GPIOx/ADC_INx pins during overload condition	I <sub>gpio/ain</sub>	-50	-	+50	mA	
Maximum current for GPIOx digital pins	I <sub>GPIO_DIG_IN_MAX</sub>	-1		1	mA	
Maximum current for XMC1404 analog inputs (AINx)	I <sub>AN_IN_MAX</sub>	-1		10	mA	
Junction temperature range	TJ	-40		115	°C	
Storage temperature range	Ts	-55		125	°C	
Case temperature	T <sub>CASE</sub>			145	°C	

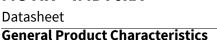
1. Excluding port pins P2.[1,2,6,7,8,9,11].

2. Applicable to port pins P2.[1,2,6,7,8,9,11].

Note: Stresses above the ones listed here may cause permanent damage to the device. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. These are stress ratings only which do not imply functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions.

Note: Absolute Maximum Ratings are not subject to production test, specified by design.







# 2.3 **Recommended Operating Conditions**

Operating at  $T_A = 25$  °C. All voltages are referred to ground (PGND for buck converter, charge pumps and gate driver related parameters and DGND for the rest), positive currents are flowing into the pin (unless otherwise specified).

Values are design targets to be confirmed after silicon characterization.

#### Values **Parameter** Symbol Unit Condition Min Тур Max V 5.5 60 Supply voltage **PVDD** 2 **During start-up** Supply voltage slew rate $SR_{PVDD}$ V/µs 0.25 During active mode V 0 CE pin voltage range $V_{CE}$ 6 External supply voltage DVDD 5.5 ٧ regulator output voltage -0.3 DC condition Buck phase voltage ٧ $V_{PH}$ 60 continuous -5 Less than 20 ns pulse $V_{\text{SHx}}$ Inverter phase voltage -8 60 High side gate driver VCCHS -0.3 75 V supply voltage VCCLS, Gate driver supply Programmable via SPI. This 7 15 V voltage (PVCC) value is equal to PVCC VCCHS-PVDD Gate driver maximum f<sub>PWM GD</sub> 200 kHz operating frequency Shunt amplifier input Sense amplifier configured for VSLx, VCSNx -0.3 0.3 ٧ shunt resistor sensing voltage range Current sense amplifier output pins voltage 0 DVDD V Vcsox range **Digital GPIOx or AIN pin** -0.3 DVDD ٧ V<sub>GPIOX/AINx</sub> voltage range Short circuit current of

-5

-40

Isc

∑l<sub>sc d</sub>

T,

5

25

115

mΑ

mΑ

°C

#### Table 5 Recommended operating conditions

range

all XMC digital outputs

Absolute sum of short circuit currents of the

Junction temperature

XMC device



# 2.3.1 XMC Pin Reliability in Overload

When receiving signals from higher voltage devices, low-voltage devices experience overload currents and voltages that go beyond their own IO power supplies specification.

Table 6 defines overload conditions that will not cause any negative reliability impact if all the following conditions are met:

- Full operation life-time is not exceeded
- Operating Conditions are met for
  - pad supply levels (DVDD)
  - o temperature

If an XMC pin current is outside of the Recommended Operating Conditions but within the overload conditions, then the parameters of this pin as stated in the Recommended Operating Conditions can no longer be guaranteed. Operation is still possible in most cases but with relaxed parameters.

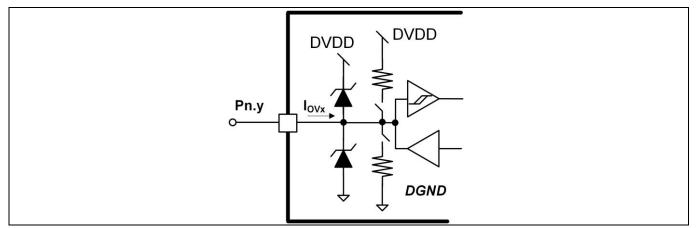
Note: An overload condition on one or more pins does not require a reset.

*Note:* A series resistor at the pin to limit the current to the maximum permitted overload current is sufficient to handle failure situations like short to battery.

#### Table 6Overload Parameters

Parameter	Symbol		Value	s	Unit	Note /
	Symbol	Min.	Тур.	Тур. Мах.		<b>Test Condition</b>
Input current on any XMC port pin during overload condition	Ιον	-5	-	5	mA	
Absolute sum of all XMC input circuit currents during overload condition	Iovs	_	-	25	mA	

Figure 4 shows the path of the input currents during overload via the ESD protection structures. The diodes against DVDD and ground are a simplified representation of these ESD protection structures.



#### Figure 4 XMC1404 Input Overload Current via ESD structures

Table 7 and Table 8 list input voltages that can be reached under overload conditions. Note that the absolute maximum input voltages as defined in the Absolute Maximum Ratings must not be exceeded during overload.

Datasheet

#### **General Product Characteristics**

#### Table 7 PN-Junction Characteristics for Positive Overload for XMC1404 pins

Pad Type	I <sub>ov</sub> =5mA
Standard, High-current, AINx/DIG_IN	$V_{IN} = V_{DVDD} + 0.5V$
	$V_{AINx} = V_{DVDD} + 0.5V$
	$V_{AREF} = V_{DVDD} + 0.5V - XMC1404$ analog reference
P2.[1,2,6:9,11]	$V_{AIN_{P2}} = V_{DVDD} + 0.3V$

#### Table 8 PN-Junction Characteristics for Negative Overload for XMC1404 pins

Pad Type	I <sub>ov</sub> =5mA
Standard, High-current, AINx/DIG_IN	$V_{\rm IN} = V_{\rm DGND} - 0.5V$
	$V_{AINx} = V_{DGND} - 0.5V$
	$V_{AREF} = V_{DGND} - 0.5V - XMC1404$ analog reference
P2.[1,2,6:9,11]	$V_{AINP2} = V_{DGND} + 0.3V$

#### **2.4 ESD Robustness**

ESD robustness related data is listed in Table 9.

#### Table 9ESD robustness data1)

Dewenneter	Gumbal	Values			11	Condition
Parameter	Symbol	Min	Тур	Мах	Unit	
ESD robustness all pins	V <sub>esd_hbm</sub>			2000	V	HBM <sup>2)</sup>
ESD robustness all pins	V <sub>esd_cdm</sub>			500	V	CDM <sup>3)</sup>
ESD robustness (corner pins)	V <sub>esd_cdm_corner</sub>			750	V	CDM <sup>3)</sup> for cornet pins only

1) Not subject to production test, specified by design

2) ESD robustness, Human Body Model (HBM) according to ANSI/ESDA/JEDEC JS001 (1.5k $\Omega$ , 100 pF)

3) ESD robustness, Charge Device Model (CDM) according to ANSI/ESDA/JEDEC JS-002

## 2.5 Thermal Resistance

*Note:* This thermal data was generated in accordance with JEDEC JESD51 standards. For more information, go to <u>www.jedec.org</u>.

#### Table 10Thermal resistance parameters

Devenedar	Gumbal		Values	5	Unit	Condition
Parameter	Symbol	Min	Тур	Мах		
Junction-to-ambient thermal resistance	$R_{\theta JA}$		29.5		°C/W	Ta = 25 °C, FR4 PCB, size: 76.2 × 114.3 × 1.57 mm³, stack 2S2P
Junction-to-case (top) thermal resistance	$R_{\theta JC(top)}$		18.9		°C/W	Ta = 25 °C







**General Product Characteristics** 



Devementer	Symphol		Values			Condition
Parameter	Symbol	Min	Тур	Мах	Unit	Condition
Junction-to-case (bottom) thermal resistance	$R_{\theta JC(bot)}$		6.45		°C/W	Ta = 25 °C

# 2.6 Electrical Characteristics

# 2.6.1 MOTIX<sup>™</sup> 6EDL7141 Electrical Characteristics

PVDD = 5.5 to 60 V,  $T_A = 25^{\circ}C$ , unless specified under test condition. All voltages are referred to ground (PGND for buck converter, charge pumps and gate driver related parameters and DGND for the rest), positive currents are flowing into the pin (unless otherwise specified).

Deveneter	Gunahal		Values		Unit	Condition				
Parameter	Symbol	Min	Тур	Мах	Unit	Condition				
Power Supply (PVDD)										
Supply voltage	PVDD	5.5		60	v					
PVDD current, ACTIVE mode including XMC1404 <sup>2)</sup>	IPVDD_ACTIVE	15		55	mA	V <sub>EN_DRV</sub> > V <sub>EN_DRV_TH</sub> , V <sub>CE</sub> > V <sub>CE_TH_R</sub> , PVDD = 40V, typical application.				
PVDD current , STANDBY mode including XMC1404 <sup>2)</sup>	IPVDD_STANDBY	10.5		15	mA	V <sub>EN_DRV</sub> < V <sub>EN_DRV_TH</sub> , V <sub>CE</sub> > V <sub>CE_TH_R</sub> , PVDD = 13V, typical application				
PVDD current, OFF mode (STOP state) including XMC1404 <sup>2)</sup>	IPVDD_OFF	5		20	μΑ	V <sub>EN_DRV</sub> < V <sub>EN_DRV_TH</sub> , V <sub>CE</sub> < V <sub>CE_TH_R</sub> . PVDD = 13V, typical application				

#### Table 11Electrical characteristics

#### **Gate Driver Output**

Low side gate driver supply voltage target	VCCLS	7		15	v	Generated from charge pump. Gate driver supply voltage programmable via SPI
High side gate driver supply voltage target	VCCHS	10.8		74.3	v	Generated from charge pump. Gate driver supply voltage programmable via SPI according to VCCLS
High side gate driver output	V <sub>GHx-SHx</sub>	0		VCCLS - 0.7	v	More details in section 2.7
Low side gate driver output	$V_{\text{GLx-SLx}}$	0		VCCLS	v	More details in section 2.7
Peak source current (high side and low side drivers)	I <sub>GD_SRC_PEAK</sub>		1.5		A	Current flowing from pin. Gate driver current programmable via SPI

#### Datasheet

#### **General Product Characteristics**



Daramatar	Symbol		Values	<u> </u>	Unit	Condition	
Parameter	Symbol	Min	Тур	Мах	Unit	Condition	
Peak sink current (high side and low side drivers)	Igd_snk_peak		1.5		A	Current into the pin. Gate driver current programmable via SPI	
Hold gate current <sup>1)</sup>	I <sub>HOLD</sub>		250		mA	Low side gate driver	
	THOLD		50			High side gate driver	
Source and sink current accuracy	I <sub>GD_ACCURACY</sub>	-20		20	%		
Charge pump clock frequency	f <sub>cp_clk</sub>	190		1600	kHz	Programmable via SPI	
Charge pump clock accuracy	f <sub>cp_clk_acc</sub>	-5		5	%	Charge pump clock accuracy	
Charge pump clock frequency spread spectrum <sup>1)</sup>	f <sub>cp_clk_ss</sub>	0		30	%		
High side gate driver				60	m 1	PVDD ≥ 9.5 V operation	
average current	I <sub>GD_VCCHS</sub>			30	- mA	PVDD < 9.5 V operation	
Low side gate driver				60		PVDD ≥ 9.5 V operation	
average current	GD_VCCLS			30	mA	PVDD < 9.5 V operation	
Charge pump ramp				250	μs	$C_{CP1/2} = 220 \text{ nF}, C_{VCCLS} = 1 \ \mu\text{F}, I_{LOAD} < 50 \ \mu\text{A}, PVCC = 12 \text{ V}. PVDD \ge 10 \text{ V}.$ Depends on capacitance values and features like charge pump pre- charge	
up time <sup>1)</sup>	t <sub>CP_START</sub>			1	ms	$C_{CPx}$ = 220 nF, $C_{VCCLS}$ =1 $\mu$ F, $I_{LOAD}$ <50 $\mu$ A, PVCC = 12 V. PVDD < 10 V. Depends on capacitance values and features like charge pump pre- charge	
Gate driver PWM frequency	$f_{PWM\_GD}$			200	kHz		
Input pin pulse width	t <sub>INx_PW</sub>	80			ns	Applies to INHx and INLx pins. Pre- charge current disabled, current setting to 1.5A	
Dead-time <sup>1)</sup>	t <sub>dt_rise</sub> , t <sub>dt_fall</sub>	120			ns	This is the minimum dead time value possible. If input signals have dead time lower than this, this value applies otherwise input PWM signal dead time is used. Value is programmable via SPI.	
Gate to Source passive weak pull- down resistor	R <sub>gs_pd_weak</sub>	70	100	130	kΩ	Always active	

Parameter

Gate to Source active

strong pull-down

**Propagation delay** 

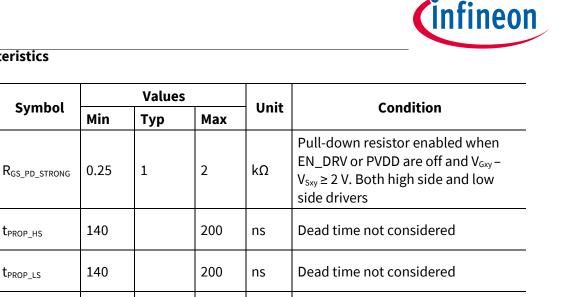
INHx to GHx

#### Datasheet

resistor

#### **General Product Characteristics**

 $t_{\text{PROP}\_\text{HS}}$ 



Propagation delay INLx to GLx	$t_{\text{PROP}\_\text{LS}}$	140		200	ns	Dead time not considered
Propagation delay matching high-low side <sup>1)</sup>	tprop_match_hl	0	25		ns	
Channel-to-channel propagation delay matching <sup>1)</sup>	tprop_match_ch	0		10	ns	
Channel-to-channel dead time matching <sup>1)</sup>	$t_{\text{DT}\_\text{MATCH}\_\text{CH}}$	0		10	ns	
Gate to source comparator threshold	$V_{\text{GS}\_\text{CPM}\_\text{TH}}$		250		mV	Threshold voltage referred to: For pull down GHx - SHx (resp. GLx- SLx for low side driver). For pull up VCCHS - GHx (resp. VCCLS - GLx for low side driver)
Gate to source comparator deglitch time <sup>1)</sup>	tvgs_смр_degli тсн		500		ns	

## Synchronous Buck Converter

Buck converter output target voltage	VDDB <sub>NOM</sub>		6.5			PVCC_SETPT=b'11, PVDD ≥ 8 V, $I_{VDDB} = 0 A$
			7.0		v	PVCC_SETPT=b'10, PVDD ≥ 8.5 V, $I_{VDDB} = 0 A$
			8.0			PVCC_SETPT=b'0x, PVDD $\ge$ 9.5 V, I <sub>VDDB</sub> = 0 A
Buck regulator output voltage at low VI	VDDB <sub>NOM_LV</sub>	4.6		6.5	V	PVCC_SETPT=b'11, 5.5 V ≤ PVDD < 8 V Buck with fixed 90% duty cycle. VDDB dependent on I <sub>VDDB</sub> . Min value defined at I <sub>VDDB</sub> = 200mA condition
input voltage (PVDD)	<b>.</b>	4.6		7.0		PVCC_SETPT=b'10, 5.5 V ≤ PVDD < 8.5 V Buck with fixed 90% duty cycle. VDDB depends on I <sub>VDDB</sub> . Min value defined at I <sub>VDDB</sub> = 200mA condition

Datasheet

#### **General Product Characteristics**



		4.6		8.0		PVCC_SETPT=b'0x, 5.5 V ≤ PVDD < 9.5 V Buck with fixed 90% duty cycle. VDDB depends on I <sub>VDDB</sub> . Min value defined at I <sub>VDDB</sub> = 200mA condition
Buck converter output voltage load ΔVD regulation <sup>1)</sup>		-10		9	%	PVDD > VDDB <sub>NOM</sub> + 2.5 V, $I_{VDDB}$ transient from 60 mA to 540 mA (10% to 90% load transient), $C_{VDDB}$ = 47 µF, L = 22 µH, $f_{BUCK_SW}$ = 500 kHz
		-9.5		5	%	$\begin{array}{l} PVDD > VDDB_{NOM} + 2.5 \ V, \ I_{VDDB} \\ \text{transient from 60 mA to 540 mA} \\ (10\% \ \text{to 90\% load transient}), \ C_{VDDB} \\ = 47 \ \mu\text{F}, \ L = 10 \ \mu\text{H}, \ f_{BUCK\_SW} = 1000 \\ \text{kHz} \end{array}$
Buck converter maximum average current	I <sub>VDDB_MAX</sub>			600	mA	PVDD ≥ 9.5 V. VDDB supplies charge pumps, DVDD linear regulator and VDDB pin
				200	mA	PVDD at low input voltage range (VDDB <sub>NOM_LV</sub> ). VDDB supplies charge pumps, DVDD linear regulator and VDDB pin
Buck converter maximum duty cycle	DC <sub>BUCK_MAX</sub>		95		%	
Buck converter high side switch R <sub>DSON</sub>	R <sub>dson_buck_hs</sub>	0.7	1.4	2.2	Ω	
Buck converter low side switch R <sub>DSON</sub>	Rdson_buck_ls	0.3	0.45	1.0	Ω	
Buck switching		440	500	590		Configurable via OTP write. May
frequency	f <sub>виск_sw</sub>	850	1000	1150	kHz	vary during load steps.
Buck converter soft start timing	tvddb_sft_start			1500	μs	Actual value depends on buck output filter

# Linear Regulator DVDD

Regulator target	ססעס		3.3		V	IMD700A part number
output voltage	DVDD		5.0			IMD701A part number
Output voltage accuracy	DVDD <sub>ACC</sub>	-2.5		2.5	%	
DVDD load current	I <sub>DVDD</sub>			300	mA	

#### Datasheet

# infineon

## **General Product Characteristics**

DVDD load current limit	I <sub>DVDD_LIM</sub>	50		450	mA	Programmable via SPI
Static line regulation	$\Delta DVDD_{\text{line}}$			10	mV	VDDB=6.5 V8 V, I <sub>DVDD</sub> =300 mA
Static load regulation				40	mV	VDDB=DVDD+1.5 V, I <sub>DVDD</sub> = 1 mA to 300 mA step
Analog programming pins period	t <sub>AN_T</sub>		25		μs	CS_GAIN
DVDD turn on delay	t <sub>dvdd_ton_dly</sub>	200		800	μs	Programmable via SPI. Delay between VDDB UVLO until DVDD ramp up start
DVDD soft start timing	tdvdd_sft_ start	100		1600	μs	Configurable via SPI- Current limited by $I_{DVDD_{-}I\_LIM}$ . If due to larger $C_{DVDD}$ values, programmed timing is not achievable, start-up time is defined by $t_{DVDD\_SFT\_START} = \frac{C_{DVDD} * DVDD}{I_{DVDD\_1\_LIM}}$

## **Current Sense Amplifier**

Closed loop gain	G <sub>cs</sub>	4		64	V/V	Configured either via external resistor or SPI
Gain error <sup>1)</sup>	G <sub>CS_ERROR</sub>	-1		1	%	Measured at SLx-CSNx=0.025 V
Offset input referred <sup>1)</sup>	V <sub>cs_os</sub>		200	600	μV	Gain=32, inputs shorted
Offset temperature drift <sup>1)</sup>	$\Delta V_{cs_{os}} / \Delta T$		5		μV/ °C	
Current sense blanking time	t <sub>cs_blank</sub>	0		8	μs	Programmable via SPI
Amplifier output	t <sub>cso_settling</sub>		600			Time from input signal step to 1% of final output voltage. Input voltage step of 0.2 V. Gain 4 to 24
settling time <sup>1)</sup>			1000		- ns	Settling time from input signal step to 1% of final output voltage. Input voltage step of 0.2 V. Gain 32 to 64
Unity gain bandwidth <sup>1)</sup>	GBW	5	8		MHz	
Common mode rejection ratio <sup>1)</sup>	CMRR	60	80		dB	Gain=8, f <sub>sw</sub> from 0 Hz to 80 kHz
Power supply		60				Gain=8, f<1 MHz
rejection ratio <sup>1)</sup>	PSRR	40			- dB	Gain=8, f<10 MHz
Input bias current	I <sub>CSN</sub>			50	μA	Current drawn into pin

#### Datasheet

#### **General Product Characteristics**



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Common mode input range <sup>1)</sup>	V <sub>cs_com</sub>	-0.3		0.3	v	
Differential mode input range	$V_{\text{CS}_{\text{DIFF}}}$	-0.3		0.3	V	
Current sense output voltage range	V <sub>cso</sub>	0.3		DVDD- 0.3	V	
Output voltage slew rate <sup>1)</sup>	SR <sub>cso</sub>	-10		10	V/µ s	Gain=8, $R_L$ =470 $\Omega$ , $C_L$ =330 pF. $V_{SLx}$ = +/- 250 mV
Propagation delay			130			CSAMP in shunt mode
from gate driver (Gxy) transition to CSOx activation <sup>1)</sup>	t <sub>csamp_prop</sub>		400		ns	CSAMP in R <sub>DSON</sub> mode
Output target voltage reference for current sense amplifier (offset)-VREF	V <sub>CS_REF</sub>	1/4* DVDD		1/2* DVDD	V	
Output voltage reference for current sense amplifier (offset) –VREF- accuracy	Vcs_ref_acc	-1.5		1.5	%	
Output short circuit limit	I <sub>cs_sc</sub>		20		mA	Pin CSOx shorted to ground
· · · · · ·			1.7			Normal mode
Auto-Zero active time	t <sub>auto_zero</sub>		2		μs	Rdson sensing mode
	t <sub>AUTO_ZERO</sub>			100		If GHx is switching
Auto-Zero cycle time	_CYCLE			200	μs	If GHx is not switching
AZ external Auto- Zero signal frequency <sup>1)</sup>	f <sub>az_cp_clk_off</sub>	5		100	kHz	
AZ external Auto- Zero signal pulse width <sup>1)</sup>	t <sub>az_ext_pw</sub>	0.1		3.5	μs	

# Current Sense Amplifier Over-Current Protection Comparator and DAC

Current sense over- current comparator hysteresis	V <sub>CS_OC_HYST</sub>		5	mV	
Over-current comparator input offset		-12	12	mV	
Over-current deglitch time	t <sub>cs_ocp_deglit</sub> сн	0	8	μs	Programmable via SPI



#### **General Product Characteristics**



Current Sense Input referred OCP threshold positive target level	V <sub>cs_ocp_thp</sub>	20	300	mV	Programmable via SPI
Current sense input referred OCP threshold negative target level	V <sub>cs_ocp_thn</sub>	-300	-20	mV	Programmable via SPI
Over-current blanking time	t <sub>ocp_blank</sub>	0	10	μs	Programmable via SPI:

# Gate Driver Analog to Digital Converter (ADC)

ADC resolution	ADC_N		7		bits	
ADC gain error	EGAIN	-0.5		0.5	%	
ADC offset error	$\epsilon_{\text{ADC_OFFS}_{\text{ERR}}}$	2		2	LSB	
ADC input clock	$f_{\text{ADC}\_\text{CLK}}$		12.5		MHz	
ADC conversion time	t <sub>conv</sub>		1.28		μs	

# Logic Level Digital Inputs (CE, EN\_DRV)

Internal pull-down resistor to GND CE	R <sub>PD_CE</sub>	350	625	850	kΩ	V <sub>CE</sub> > 2V
Internal pull-down resistor to GND EN_DRV	R <sub>pd_en_drv</sub>		500		kΩ	
CE threshold voltage rising	V <sub>ce_th_r</sub>	2.7			v	T <sub>A</sub> = -40 °C to 125 °C. This is the minimum CE pin voltage above which, any device (operated within recommended conditions) will activate the device operation.
CE threshold voltage falling	V <sub>ce_th_f</sub>			0.6	v	T <sub>A</sub> = -40 °C to 125 °C. This is the maximum CE pin voltage below which, any device (operated within recommended conditions) will stop the device operation.
CE pin sink current	I <sub>ce_snk</sub>			10	μΑ	Current flowing into CE pin
EN_DRV threshold voltage	$V_{\text{en_drv_th}}$		0.5* DVD D		V	
EN_DRV threshold voltage hysteresis	V <sub>EN_DRV_TH_HY</sub> s		4		%	Applies to $V_{EN_{DRV_{TH}}}$ thresholds

# 6EDL7141 OTP Programming

OTP programming supply	PVDD <sub>OTP_PR</sub>	13		v	Below this value an OTP blocking will occur
OTP programming temperature	T <sub>OTP_PROG</sub>		150	°C	Above this value an OTP blocking will occur

Datasheet

#### **General Product Characteristics**



## Watchdog

Watchdog buck converter input time	t <sub>wd_виск</sub>		1.5		ms	Applies to buck converter input selection only. Not configurable value
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## **Overload Protections Gate Driver**

		•	-			
PVDD UVLO threshold rising	$V_{\text{PVDD}\_\text{UVLO}\_R}$	4.95	5.1	5.25	v	
PVDD UVLO threshold falling	$V_{\text{PVDD}\_\text{UVLO}\_\text{F}}$	4.85	5.0	5.15	v	
VCCHS UVLO threshold rising	$V_{\text{HS}\_\text{UVLO}\_R}$	5.6	5.8	6.0	v	
VCCHS UVLO threshold falling	$V_{\text{HS}\_\text{UVLO}\_F}$	4.3	4.5	4.7	v	
VCCLS UVLO threshold rising	V <sub>LS_UVLO_R</sub>	6.1	6.4	6.7	v	
VCCLS UVLO threshold falling	V <sub>LS_UVLO_F</sub>	4.3	4.5	4.7	V	

# **Overload Protections Power Supply System**

VDDB UVLO rising threshold	Vvddb_uvlo_r	4.2	4.3	4.4	v	
VDDB UVLO falling threshold	$V_{VDDB\_UVLO_F}$	4.1	4.2	4.3	v	
VDDB OVLO rising threshold	Vvddb_ovlo_r	105	108	111	%	Percentage of target output value
VDDB OVLO falling threshold	Vvddb_ovlo_f	102	105	108	%	Percentage of target output value
Buck OCP (inductor			1.0		^	f <sub>BUCK_SW</sub> =500kHz
current) threshold	IBUCK_OCP_TH		1.3		A	f <sub>BUCK_SW</sub> =1MHz
Buck OCP hysteresis	IBUCK_OCP_HYS		50		mA	
DVDD UVLO rising threshold	V <sub>DVDD_UVLO_R</sub>		85		%	Percentage of target output value
DVDD UVLO falling threshold	V <sub>DVDD_UVLO_F</sub>		75		%	Percentage of target output value
DVDD OVLO rising threshold	V <sub>DVDD_OVLO_R</sub>		110		%	Percentage of target output value
DVDD OVLO falling threshold	V <sub>DVDD_OVLO_F</sub>		105		%	
DVDD target output current limit	I <sub>dvdd_i_lim</sub>	50		450	mA	Configurable via SPI

Datasheet

#### General Product Characteristics



DVDD target output		-30		10	%	T <sub>J</sub> =-40 °C to 125 °C, limit setting to 50mA
current limit accuracy	Idvdd_i_acc	-18		8	%	T <sub>J</sub> =-40 °C to 125 °C, for other limit settings
	Gate	Driver (	Over-Te	mperat	ure Prot	tection
Over-temperature shut-down threshold	OTS <sub>TH</sub>		150		°C	
OTS Hysteresis	OTS <sub>HYS</sub>		10		°C	
Over-temperature warning threshold	OTW <sub>TH</sub>		125		°C	Measured via internal ADC
Over-temperature warning hysteresis	OTW <sub>HYS</sub>		10		°C	
		SPI T	iming <b>F</b>	equirer	nents <sup>1)</sup>	
Clock period	t <sub>clk</sub>	77			ns	
Clock high time	t <sub>clkh</sub>	20			ns	
Clock low time	t <sub>clkl</sub>	20			ns	
SDI input data setup time	t <sub>set_sdi</sub>	10			ns	
SDI input data hold time	t <sub>HD_SDI</sub>	10			ns	
SDO output data delay time	t <sub>dly_sdo</sub>	0		20	ns	SCLK high to SDO valid
SDO rise and fall time	$t_{\text{RF}_{SDO}}$			10	ns	
nSCS enable time	t <sub>EN_nSCS</sub>			50	ns	nSCS low to SDO transition
nSCS disable time,	t <sub>DIS_nSCS</sub>			50	ns	nSCS high to SDO high impedance
nSCS hold time	t <sub>HD_nSCS</sub>	50			ns	Falling SCLK to rising nSCS
nSCS setup time	t <sub>SET_nSCS</sub>	50			ns	Falling nSCS to rising SCLK
nSCS sequential delay time	t <sub>SEQ_nSCS</sub>	450			ns	Rising nSCS to falling nSCS

1. Not subject to production test

2. For more details on XMC1404 power consumption, see XMC1400 datasheet. The consumption of XMC1404 is dependent on the specific usage of the device

**General Product Characteristics** 

# 2.6.2 XMC1404 Electrical Characteristics

Table 12 provides the characteristics of the input/output pins of the XMC1404.

The parameters listed in this section represents partly the characteristics of the XMC1400 and partly its system requirements. To aid interpreting the parameters easily when evaluating them for a design, they are indicated by the abbreviations in the "Symbol" column:

- CC: such parameters indicate Controller Characteristics, which are distinctive feature of the XMC1404 and must be regarded for a system design.
- SR: such parameters indicate System Requirements, which must be provided by the application system in which the XMC1404 is designed in.

*Note:* These parameters are not subject to production test, but verified by design and/or characterization.

*Note:* Unless otherwise stated, input DC and AC characteristics, including peripheral timings, assume that the input pads operate with the standard hysteresis.

Table 12 Input/Output Characteristics (Recommended Operating Conditions apply
---

Parameter	Symb	ol	Limit Values	-	Unit	Test Conditions
			Min	Мах.		
Output low voltage on port pins (with standard pads)	V <sub>olp</sub>	CC		1.0	V	I <sub>OL</sub> = 11 mA
				0.4	V	I <sub>oL</sub> = 5 mA
				0.32	v	I <sub>OL</sub> = 10 mA
Output high voltage on port pins (with	V <sub>OHP</sub>	СС	DVDD - 1.0	-	V	I <sub>OH</sub> = -10 mA
standard pads)			DVDD-0.4	-	V	I <sub>он</sub> = -4.5 mA
Input low voltage on port pins (Standard Hysteresis)	VILPS	SR		0.19 x DVDD	V	CMOS Mode
Input high voltage on port pins (standard hysteresis)	V <sub>IHPS</sub>	SR	0.7 x DVDD	-	V	CMOS Mode
Input low voltage on port pins (large hysteresis)	Vilpl	SR	-	0.08 xDVDD	V	CMOS Mode
Input high voltage on port pins (large hysteresis)	Vihpl	SR	0.85 xDVDD	-	V	CMOS Mode

#### Datasheet

#### **General Product Characteristics**



Rise/fall time on standard pad <sup>1)</sup>	t <sub>R</sub> , t <sub>F</sub>	СС	-	12	ns	50 pF, DVDD = 5V <sup>2)</sup>
Input hysteresis on port pin except P2.3 -	HYS	СС	0.08 xDVDD	-	V	CMOS mode standard hysteresis
P2.9 <sup>3)</sup>			0.5 xDVDD	0.75 xDVDD	V	CMOS mode, large hysteresis
Input hysteresis on	HYS_		0.08 xDVDD	-	V	CMOS mode standard hysteresis
port pin P2.3 - P2.9 <sup>3)</sup>		СС	0.35 xDVDD	0.75 xDVDD	V	CMOS mode, large hysteresis
Pin capacitance (digital inputs/outputs)	C <sub>IO</sub>	СС	-	10	pF	
Pull-up current on	I <sub>PUP</sub>	СС	-	-80	۵	V <sub>IH,min</sub>
port pins			-95	-	μA	V <sub>IL,max</sub>
Pull-down current on	I <sub>PDP</sub>	СС	-	40		V <sub>IL,max</sub>
port pins			95	-	μA	V <sub>IH,min</sub>
Input leakage current except P0.11 <sup>4)</sup>	I <sub>OZP</sub>	СС	-1	1	μA	0 < VIN < DVDD, T <sub>A</sub> 105 °C
Input leakage current for P0.11 <sup>4)</sup>	I <sub>ozp1</sub>	СС	-10	1	μΑ	0 < VIN < DVDD, T <sub>A</sub> 105 °C
Voltage on any pin during DVDD power off	V <sub>PO</sub>	SR	-	0.3	V	
Maximum current per pin (excluding P1, DVDD and VSS) <sup>5)</sup>	I <sub>MP</sub>	SR	-10	11	mA	-
Maximum current per high current pins	I <sub>mp1a</sub>	SR	-10	50	mA	-
Maximum current into V <sub>DDP</sub>	I <sub>mvdd</sub>	SR		TBD	mA	

Datasheet

#### **General Product Characteristics**



of V <sub>ss</sub>	Maximum current out	I <sub>MVSS</sub>	SR	TBD	mA
	of V <sub>ss</sub>				

1. Rise/Fall time parameters are taken with 10% - 90% of supply.

2. Additional rise/fall time valid for  $C_1 = 50 \text{ pF} - C_2 = 100 \text{ pF} @ 0.150 \text{ ns/pF} at 5 \text{ V supply voltage}.$ 

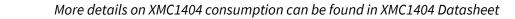
- 3. Hysteresis is implemented to avoid meta stable states and switching due to internal ground bounce. It cannot be guaranteed that it suppresses switching due to external system noise.
- 4. An additional error current (IINJ) will flow if an overload current flows through an adjacent pin.
- 5. However, for applications with strict low power-down current requirements, it is mandatory that no active voltage source is supplied at any GPIO pin when VDDP is powered off.

Note:



# 2.7 Electrical Characteristic Graphs

Following graphs provide information on the behavior of the device at different conditions. This data is not subject to production test. T<sub>A</sub> = 25°C, unless otherwise specified. All voltages are referred to ground (PGND for buck converter, charge pumps and gate driver related parameters and DGND for the rest).



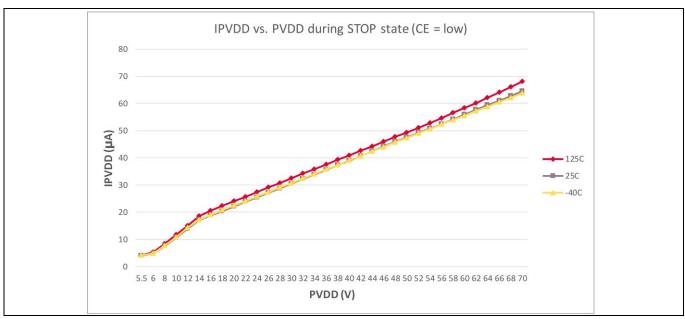
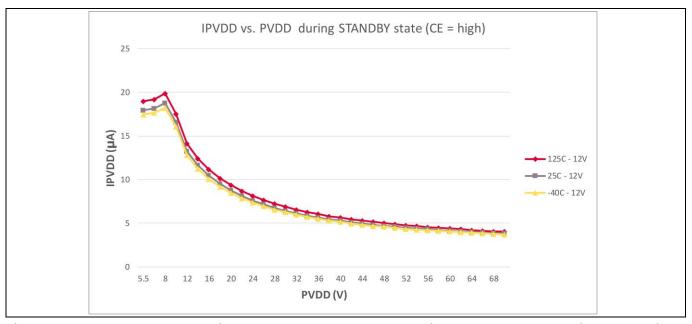


Figure 5 Current consumption on PVDD pin vs PVDD when both CE and EN\_DRV are below active thresholds.







#### **General Product Characteristics**

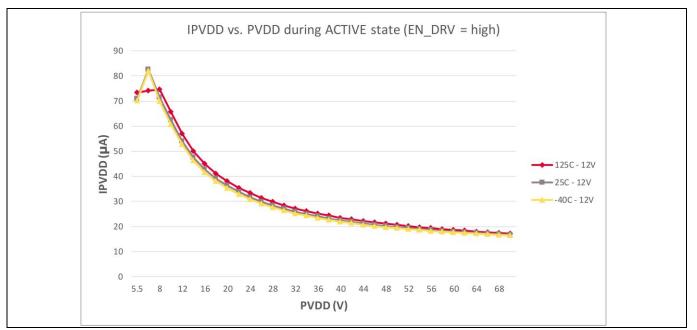


Figure 7 Current Consumption on PVDD vs PVDD voltage during ACTIVE state – CE and EN\_DRV are above active threshold

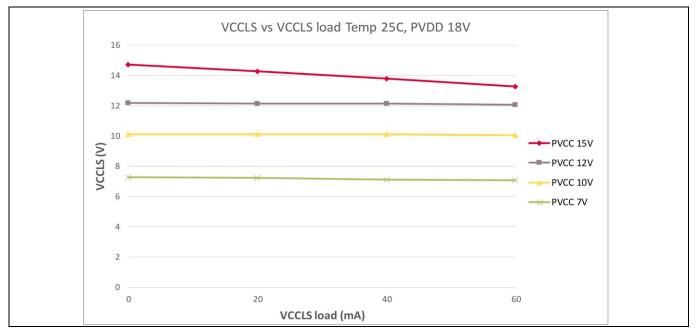


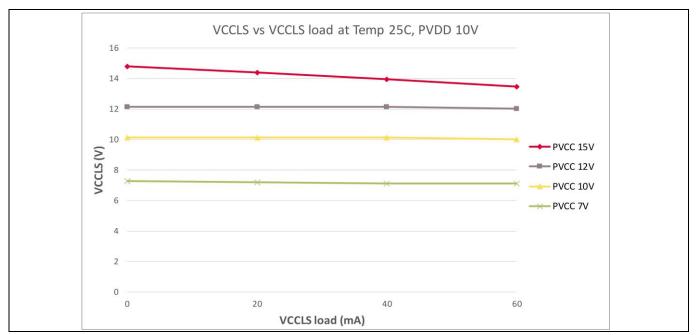
Figure 8VCCLS average voltage vs VCCLS load (DC) for different PVCC configurations at PVDD 18V. XMC<br/>active and executing code. Typical application with  $C_{CP1(2)} = 220nF$  and  $C_{VCCLS/HS} = 1uF.$  VCCHS<br/>load 20mA.

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#### Datasheet

#### **General Product Characteristics**



# Figure 9 VCCLS average voltage vs VCCLS load (DC) for different PVCC configurations at PVDD 10V. XMC active and executing code. Typical application with C<sub>CP1(2)</sub> = 220nF and C<sub>VCCLS/HS</sub> = 1uF. VCCHS load 20mA.

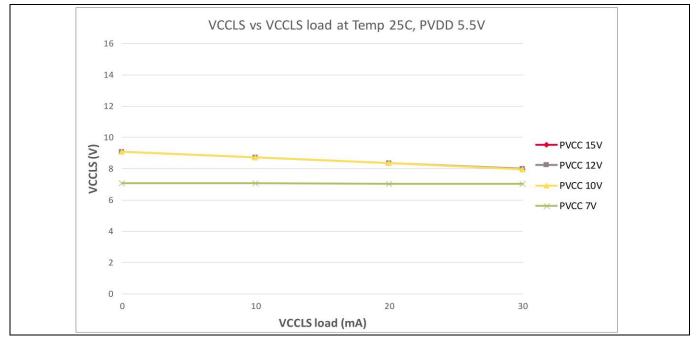
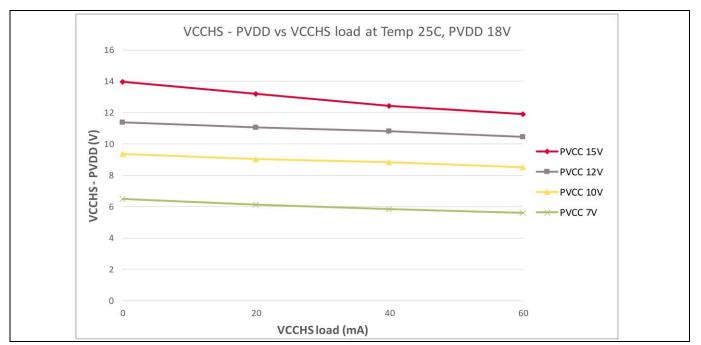


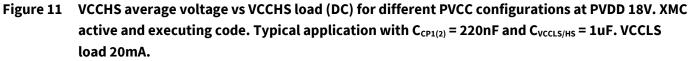
Figure 10 VCCLS average voltage vs VCCLS load (DC) for different PVCC configurations at PVDD 5.5V. XMC active and executing code. Typical application with C<sub>CP1(2)</sub> = 220nF and C<sub>VCCLS/HS</sub> = 1uF. VCCHS load 20mA.



Datasheet

#### **General Product Characteristics**





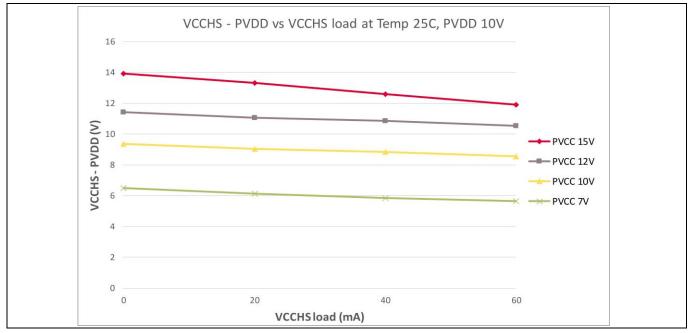
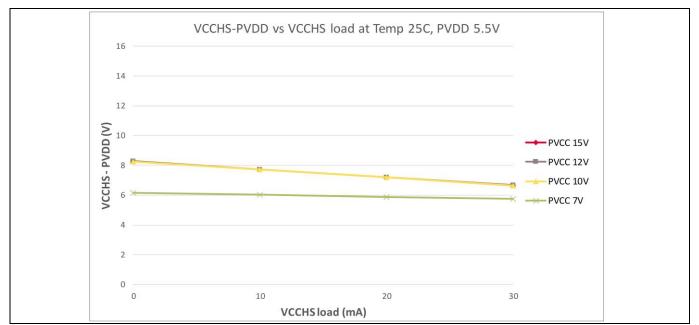


Figure 12VCCHS average voltage vs VCCHS load (DC) for different PVCC configurations at PVDD 10V. XMC<br/>active and executing code. Typical application with  $C_{CP1(2)} = 220nF$  and  $C_{VCCLS/HS} = 1uF$ . VCCLS<br/>load 20mA



Datasheet

#### **General Product Characteristics**



# Figure 13VCCHS average voltage vs VCCHS load (DC) for different PVCC configurations at PVDD 5.5V.XMC active and executing code. Typical application with C<sub>CP1(2)</sub> = 220nF and C<sub>VCCLS/HS</sub> = 1uF.VCCLS load 20mA

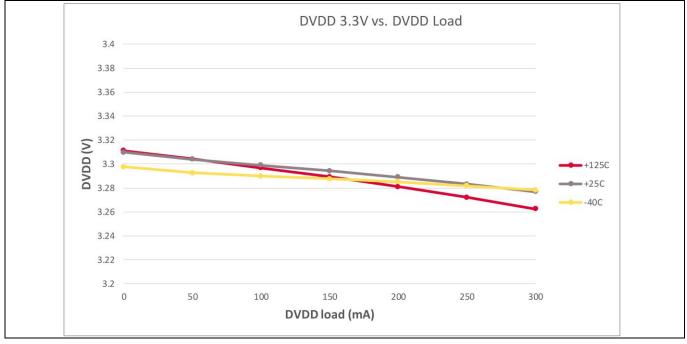


Figure 14 DVDD 3.3V output voltage vs DVDD load for IMD700A



#### **General Product Characteristics**

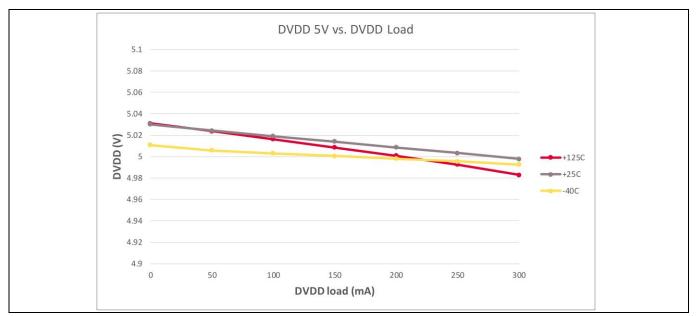


Figure 15 DVDD 5.0V output voltage vs DVDD load for IMD701A

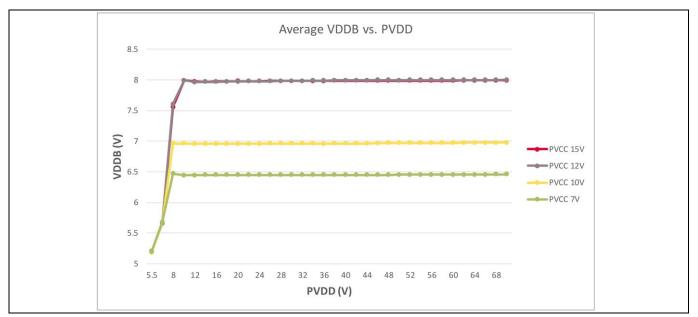


Figure 16 Buck converter average output voltage (VDDB) vs PVDD voltage. Typical configuration, with VDDB load 200mA and DVDD load of 50mA, buck converter switching frequency 500kHz, PVDD 18V.

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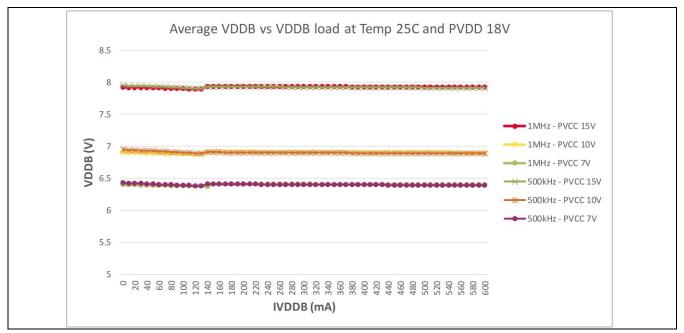


Figure 17Buck converter average output voltage (VDDB) vs VDDB load (IVDDB) for different PVCCand buck switching frequency operations. Typical configuration with PVDD 18V.

Datasheet

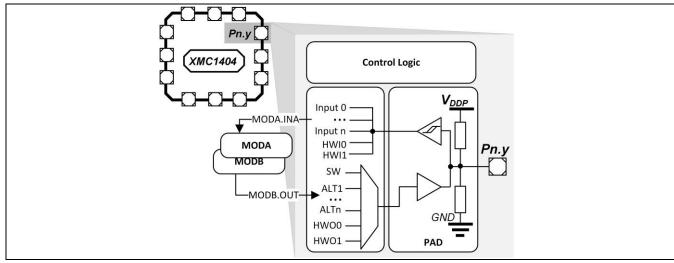


**General Product Characteristics** 

#### XMC1404 Port I/O Alternate Functions Description 2.8

The method presented in Table 13 is used to describe the I/O functions of each PORT pin:

Table 13	Port I/O Function Desc	ription		
Function	Outputs		Inputs	
	ALT1	ALTn	Input	Input
<u>P0.0</u>		MODA.OUT	MODC.INA	
Pn.y	MODA.OUT		MODA.INA	MODC.INB



#### Figure 18 Simplified Port Structure of XMC Pins

Pn.y is the port pin name, defining the control and data bits/registers associated with it. As GPIO, the port is under software control. Its input value is read via Pn\_IN.y, Pn\_OUT defines the output value.

Up to nine alternate output functions (ALT1 to ALT9) can be mapped to a single port pin, selected by Pn\_IOCR.PC. The output value is directly driven by the respective module, with the pin characteristics controlled by the port registers (within the limits of the connected pad).

The port pin input can be connected to multiple peripherals. Most peripherals have an input multiplexer to select between different possible input sources.

The input path is also active while the pin is configured as output. This allows to feedback an output to onchip resources without wasting an additional external pin.

Please refer to the Table 14 for the complete Port I/O function mapping.

Datasheet

**General Product Characteristics** 



## 2.8.1 XMC1404 Pin Definitions and Alternate Functions

In XMC1404 microcontroller, pins can be configured to perform different input and/or output functions. Each pin is connected internally to a de-multiplexer that allows that particular pin to be routed to different peripherals in the microcontroller. Input and/or output configurations are possible on most pins. Table 14 shows the different functions that are possible for XMC1404 pins in IMD70xA.

Table 14Pin definitions and alternate functions for XMC1404
---

Functi ons	Outputs									Inputs											
Pin	ALT1	ALT2	ALT3	ALT4	ALT5	ALT6	ALT7	ALT8	ALT9	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input
P0.0	ERU0.P DOUT0	LEDTSO.L INE7	ERU0.G OUT0	CCU40. OUT0	CCU80. OUT00	USIC0_CH 0.SELO0	USIC0_C H1.SEL O0	CCU81. OUT00	USIC1_C H1.DOU T0	BCCU0. TRAPIN B	CCU40. IN0AC					USIC1_ CH1.DX 0A	USIC0_ CH0.DX 2A		USIC0_ CH1.DX 2A		
P0.1	ERU0.P DOUT1	LEDTSO.L INE6	ERU0.G OUT1	CCU40. OUT1	CCU80. OUT01	BCCU0. OUT8	SCU.VD ROP	USIC1_C H1.SCLK OUT	USIC1_C		CCU40. IN1AC					USIC1_ CH1.DX 0B	USIC1_				
P0.3	ERU0.P DOUT3	LEDTSO.L INE4	ERU0.G OUT3	CCU40. OUT3	CCU80. OUT03	VADC0.EM UX01	CCU80. OUT11	USIC1_C H1.SCLK OUT			CCU40. IN3AC					USIC1_ CH0.DX 0B					
P0.4	BCCU0. OUT0	LEDTS0.L INE3	LEDTS0 .COL3	CCU40. OUT1	CCU80. OUT13	VADC0.EM UX00SERVI C	WWDT.E _OUT	USIC1_C H1.SEL O0	CAN.N0 _TXD			CCU41. IN0AB	CCU80 IN0AB							CAN.N0 _RXDA	
P0.7	BCCU0. OUT3	LEDTS0.L INE0	LEDTS0 .COL0	CCU40. OUT1	CCU80. OUT10	USIC0_CH 0.SCLKOU T	USIC0_C H1.DOU T0	VADC0.E MUX12O UT1	CCU41.		CCU40. I N1AB	CCU41. I N3AB					USIC0_ CH0.DX 1C	USIC0_ CH1.DX 0D	USIC0_ CH1.DX 1C		
P0.10/ XTAL1	BCCU0. OUT6	LEDTS1.L INE2	LEDTS0 .COL5	ACMP0. OUT	CCU80. OUT22	USIC0_CH 0.SELO1	USIC0_C H1.SEL O1	CCU81. OUT22					CCU80. IN2AB	CCU81.I N2AB			USIC0_ CH0.DX 2C		USIC0_ CH1.DX 2C		
P0.11/ XTAL2	BCCU0. OUT7	LEDTS1.L INE3	LEDTS0 .COL4	USIC0_ CH0.MC LKOUT	CCU80. OUT23	USIC0_CH 0.SELO2	USIC0_C H1.SEL O2	CCU81. OUT23									USIC0_ CH0.DX 2D		USIC0_ CH1.DX 2D		
P0.12	BCCU0. OUT6	LEDTS1.L INE4	LEDTS0 .COL3	LEDTS1 .COL3	CCU80. OUT33	USIC0_CH 0.SELO3	CCU80. OUT20		CAN.N1 _TXD	BCCU0. TRAPIN A	CCU40. IN0AA	CCU40. IN1AA	CCU40. IN2AA	CCU81.I NOAU	CCU40.I N3AA	CCU80.I N0AA	USIC0_ CH0.DX 2E	CCU80.I N1AA	CCU80.I N2AA	CAN.N1 _RXDA	CCU80.I N3AA
P0.14	BCCU0. OUT7	LEDTS1.L INE6	LEDTS0 .COL1	LEDTS1 .COL1	CCU80. OUT31	USIC0_CH 0.DOUT0	USIC0_C H0.SCLK OUT		CAN.N0 _TXD					CCU81.I N2AU	POSIF0. IN1B	USIC0_ CH0.DX 0A	USIC0_ CH0.DX 1A	USIC1_ CH1.DX 5B		CAN.N0 _RXDC	
P0.15	BCCU0. OUT8	LEDTS1.L INE7	LEDTS0 .COL0	LEDTS1 .COL0	CCU80. OUT30	USIC0_CH 0.DOUT0	USIC0_C H1.MCL KOUT		CAN.N0 _TXD					CCU81.I N3AU	POSIF0. IN2B	USIC0_ CH0.DX 0B		USIC1_ CH1.DX 3B	USIC1_ CH1.DX 4B	CAN.N0 _RXDD	

#### Datasheet



Functi ons	Outputs									Inputs											
Pin	ALT1	ALT2	ALT3	ALT4	ALT5	ALT6	ALT7	ALT8	ALT9	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input
P1.0	BCCU0. OUT0	CCU40.O UT0	LEDTS0 .COL0	LEDTS1 .COLA	CCU80. OUT00	ACMP1.OU T	USIC0_C H0.DOU T0	CCU81. OUT00	CAN.N0 _TXD						POSIF0. IN2A	USIC0_ CH0.DX 0C				CAN.N0 _RXDG	
P1.1	ERU1.P DOUT1	CCU40.0 UT1	LEDTS0 .COL1	LEDTS1 .COL0	CCU80. OUT01	USIC0_CH 0.DOUT0	USIC0_C H1.SEL O0	CCU81. OUT01	CAN.N0 _TXD						POSIF0. IN1A	USIC0_ CH0.DX 0D	USIC0_ CH0.DX 1D		USIC0_ CH1.DX 2E	CAN.N0 _RXDH	
P1.2	ERU1.P DOUT2	CCU40.0 UT2	LEDTS0 .COL2	LEDTS1 .COL1	CCU80. OUT10	ACMP2.OU T	USIC0_C H1.DOU T0		CAN.N1 _TXD						POSIF0. IN0A			USIC0_ CH1.DX 0B		CAN.N1 _RXDG	
P1.3	ERU1.P DOUT3	CCU40.0 UT3	LEDTS0 .COL3	LEDTS1 .COL2	CCU80. OUT11	USIC0_CH 1.SCLKOU T	USIC0_C H1.DOU T0	CCU81. OUT11	CAN.N1 _TXD									USIC0_ CH1.DX 0A	USIC0_ CH1.DX 1A	CAN.N1 _RXDH	
P2.0	ERU0.P DOUT3	CCU40. OUT0	ERU0.G OUT3	LEDTS1 .COL5	CCU80. OUT20	USIC0_CH 0.DOUT0	USIC0_C H0.SCLK OUT		CAN.N0 _TXD		VADC0. G0CH5					USIC0_ CH0.DX 0E	USIC0_ CH0.DX 1E		USIC0_ CH1.DX 2F	CAN.N0 _RXDE	ERU0.0B 0
P2.1	ERU0.P DOUT2	CCU40. OUT1	ERU0.G OUT2	LEDTS1 .COL6	CCU80. OUT21	USIC0_CH 0.DOUT0	USIC0_C H1.SCLK OUT		CAN.N0 _TXD	ACMP2. I NP	VADC0. G0CH6					USIC0_ CH0.DX 0F		USIC0_ CH1.DX 3A	USIC0_ CH1.DX 4A	CAN.N0 _RXDF	ERU0.1B 0
P2.2										ACMP2. I NN	VADC0. G0CH7		ORC0. Al N	USIC1_ CH0.DX 5E		USIC0_ CH0.DX 3A	USIC0_ CH0.DX 4A	USIC0_ CH1.DX 5A			ERU0.0B 1
P2.3												VADC0. G1CH5	ORC1. Al N	USIC1_ CH0.DX 3E	USIC1_ CH0.DX 4E	USIC1_ CH1.DX 5C	USIC0_ CH0.DX 5B	USIC0_ CH1.DX 3C	USIC0_ CH1.DX 4C		ERU0.1B 1
P2.4												VADC0. G1CH6	ORC2. Al N	USIC1_ CH1.DX 3C	USIC1_ CH1.DX 4C	USIC0_ CH0.DX 3B	USIC0_ CH0.DX 4B	USIC1_ CH0.DX 5F	USIC0_ CH1.DX 5B		ERU0.0 A1
P2.5												VADC0. G1CH7		USIC1_ CH1.DX 5D		USIC0_ CH0.DX 5D		USIC0_ CH1.DX 3E	USIC0_		ERU0.1 A1
P2.6										ACMP1. INN	VADC0. G0CH0		ORC4. Al N	USIC1_ CH1.DX 3E	USIC1_ CH1.DX 4E	USIC0_ CH0.DX 3E	USIC0_ CH0.DX 4E	USIC0_ CH1.DX 5D			ERU0.2 A1
P2.7										ACMP1. INP		VADC0. G1CH1	ORC5. AIN	USIC1_ CH1.DX 5E		USIC0_ CH0.DX 5C		USIC0_ CH1.DX 3D	USIC0_ CH1.DX 4D		ERU0.3A 1
P2.8										ACMP0. I NN	VADC0. G0CH1	VADC0. G1CH0	ORC6. Al N			USIC0_ CH0.DX 3D	USIC0_ CH0.DX 4D	USIC0_ CH1.DX 5C			ERU0.3B 1

#### Datasheet



Functi ons	Outputs									Inputs											
Pin	ALT1	ALT2	ALT3	ALT4	ALT5	ALT6	ALT7	ALT8	ALT9	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input
P2.9										ACMP0. INP	VADC0. G0CH2	VADC0. G1CH4	ORC7. Al N			USIC0_ CH0.DX 5A		USIC0_ CH1.DX 3B	USIC0_ CH1.DX B		ERU0.3B 0
P2.10	ERU0.P DOUT1	CCU40.0 UT2	ERU0.G OUT1	LEDTS1 .COL4	CCU80. OUT30	ACMP0.OU T	USIC0_C H1.DOU T0		CAN.N1 _TXD		VADC0. G0CH3	VADC0. G1CH2				USIC0_ CH0.DX 3C	USIC0_ CH0.DX 4C	USIC0_ CH1.DX 0F		CAN.N1 _RXDE	ERU0.2B 0
P2.11	ERU0.P DOUT0	CCU40.0 UT3	ERU0.G OUT0	LEDTS1 .COL3	CCU80. OUT31	USIC0_CH 1.SCLKOU T	USIC0_C H1.DOU T0		CAN.N1 _TXD	ACMP.R EF	VADC0. G0CH4	VADC0. G1CH3						USIC0_ CH1.DX 0E	USIC0_ CH1.DX 1E	CAN.N1 _RXDF	ERU0.2B 1
P2.12	BCCU0. OUT3	VADC0.E MUX00	USIC1_ CH0.SC LKOUT	USIC1_ CH1.SC LKOUT		ACMP2.OU T	USIC1_C H1.DOU T0	LEDTS2. COL6		ACMP3. INN						USIC1_ CH0.DX 3A	USIC1_ CH0.DX 4A	USIC1_ CH1.DX 0C	USIC1_ CH1.DX 1B		ERU1.3A 2
P2.13	BCCU0. OUT4	CCU40.0 UT3	USIC1_ CH0.MC LKOUT	CCU81. OUT31		VADC0.EM UX01	USIC1_C H1.DOU T0	CCU81. OUT33	CCU41. OUT3	ACMP3. INP						USIC1_ CH0.DX 5A		USIC1_ CH1.DX 0D			ERU1.3A 3
P3.0	BCCU0. OUT0	USIC1_C H1.DOUT 0	USIC1_ CH1.SC LKOUT	LEDTS2 .COLA	CCU80. OUT21	ACMP1.OU T	USIC1_C H0.SEL O1	CCU81. OUT21	CCU410 UT0	BCCU0. TRAPIN C	CCU41. IN0AA	CCU41. IN1AA	CCU41. IN2AA	CCU41.I N3AA	CCU81.I NOAA	CCU81.I N1AA	CCU81.I N2AA	USIC1_ CH1.DX 0E	USIC1_ CH1DX 1D	CCU81.I N3AA	ERU1.0A 1
P3.1	BCCU0. OUT1	USIC1_C H1.DOUT 0		LEDTS2 .COL0	CCU80. OUT20	ACMP3.OU T	USIC1_C H0.SEL O0	CCU81. OUT20	CCU41. OUT1								USIC1_ CH0.DX 2F	USIC1_ CH1.DX 0F			ERU1.1A 1
P3.2	BCCU0. OUT2	USIC1_C H1.SCLK OUT		LEDTS2 .COL1	CCU80. OUT11	ACMP2.OU T	USIC1_C H0.SCLK OUT	CCU81. OUT11	CCU41. OUT2							USIC1_ CH0.DX 3C	USIC1_ CH0.DX 4C	USIC1_ CH1.DX 3D	USIC1_ CH1.DX 4D		ERU1.2A 1
P3.3	BCCU0. OUT5	USIC1_C H0.DOUT 0		LEDTS2 .COL2	CCU80. OUT10	ACMP0.OU T	USIC1_C H1.SEL O0	CCU81. OUT10	CCU41. OUT3							USIC1_ CH0.DX 0E			USIC1_ CH1.DX 2A		ERU1.1A 3
P3.4	BCCU0. OUT6	USIC1_C H0.DOUT 0	USIC1_ CH0.SC LKOUT	LEDTS2 .COL3	CCU80. OUT01	USIC1_CH 1.MCLKOU T	USIC1_C H1.SEL O1	CCU81. OUT01								USIC1_ CH0.DX 0F	USIC1_ CH0.DX 1E		USIC1_ CH1.DX 2B		ERU1.2A 3
P4.1	BCCU0. OUT8	ERU1.P DOUT1	LEDTS2 .COL4	ERU1.G OUT1	CCU40. OUT1	ACMP3. OUT	USIC1_C H1.SEL O2	CCU81. OUT11	CCU41. OUT1		CCU40. IN1BA	CCU41. IN1AC	CCU80. I N1AU		POSIF1. IN0B	USIC1_ CH0.DX 5C					
P4.2	BCCU0. OUT4	ERU1.PD OUT2	CCU81. OUT20	ERU1.G OUT2	CCU40. OUT2	ACMP2.OU T	USIC1_C H1.SEL O3	CCU81. OUT12	CCU41. OUT2		CCU40. IN2BA	CCU41. IN2AC	CCU80. IN2AU	CCU81.I N1AB	POSIF1. IN1B	USIC1_ CH0.DX 5D					
P4.3	BCCU0. OUT5	ERU1.P DOUT3	CCU81. OUT21	ERU1.G OUT3	CCU40. OUT3	ACMP0.OU T	USIC1_C H0.SCLK OUT	CCU81. OUT13	CCU41. OUT3		CCU40. IN3BA	CCU41. IN3AC	CCU80. IN3AU		POSIF1. IN2B		USIC1_ CH0.DX 1B				

#### Datasheet



Functi ons	Outputs								Inputs												
Pin	ALT1	ALT2	ALT3	ALT4	ALT5	ALT6	ALT7	ALT8	ALT9	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input
P4.4	BCCU0. OUT0	LEDTS2.L INE0		LEDTS1 . COLA	CCU80. OUT00	USIC1_CH 0.DOUT0		CCU81. OUT00	CCU41. OUT0			CCU41. IN0AV				USIC1_ CH0.DX		USIC1_ CH1.DX			ERU1.0A 2
P4.5	BCCU0. OUT8	LEDTS2.L INE1		LEDTS1 .COL6	CCU80. OUT01	USIC1_CH 0.DOUT0	USIC1_C H0.SCLK OUT		CCU41. OUT1			CCU41. IN1AV				0C USIC1_ CH0.DX 0D	USIC1_ CH0.DX 1C	5F			ERU1.1A 2
P4.6	BCCU0. OUT2	LEDTS2 .LINE2	CCU81. OUT10	LEDTS1 .COL5	CCU80. OUT10		USIC1_C		CCU41. OUT2			CCU41. IN2AV		CCU81.I NOAB		00	USIC1_ CH0.DX 1D				ERU1.2A 2
P4.7	BCCU0. OUT5	LEDTS2 .LINE3	CCU81. OUT11	LEDTS1 .COL4	CCU80. OUT11		USIC1_C H0.SEL O0	CCU81. OUT03	CCU41. OUT3			CCU41. IN3AV					USIC1_ CH0.DX 2A				ERU1.0A 3
P4.8	BCCU0. OUT7	LEDTS2.L INE4	LEDTS2 .COL3	LEDTS1 .COL3	CCU80. OUT30	CCU40.OU T0	USIC1_C H0.SEL O1	CCU81. OUT30	CAN.N1 _TXD		CCU40. IN0AV	CCU41. IN0BA					USIC1_ CH0.DX 2B			CAN.N1 _RXDC	
P4.10		LEDTS2.L INE6	LEDTS2 .COL1	LEDTS1 .COL1	CCU80. OUT00	CCU40.OU T2	USIC1_C H0.SEL O3	CCU81. OUT32	CCU81. OUT00	BCCU0. TRAPIN D	CCU40. IN2AV	CCU41. IN2BA		CCU81.I N3AB			USIC1_ CH0.DX 2D	USIC1_ CH1.DX 5A			

#### **General Product Characteristics**

## 2.8.2 Port Pins for Boot Modes

Port functions can be overruled by the boot mode selected. The type of boot mode is selected via BMI (Refer to latest reference manual for the complete description at Infineon website: <u>www.infineon.com</u>. At the time of creation of this document, latest version can be found here: <u>XMC1400 Reference Manual</u>). Table 15 shows the port pins used for the various boot modes.

Table 15	XMC1404 Port Pin for Boot Modes in IMD70xA
----------	--

XMC1404 Pin	IMD70xA Pin	Boot	Boot Description
P0.14	GPIO15_DBG0/P0.14	SWDIO_0	Debug mode (SWD)
		SPD_0	Debug mode (SPD)
		RX/TX	ASC BSL half-duplex mode
		RX	ASC BSL full-duplex mode
		RX	CAN BSL mode
P0.15	GPIO16_DBG1/P0.15	SWDCLK_0	Debug mode (SWD)
		ТХ	ASC BSL full-duplex mode
		ТХ	CAN BSL mode
P4.6	GPIO2/P4.6	HWCON0	Boot Pins (Boot from pins mode must be
P4.7	GPIO3/P4.7	HWCON1	selected)

## 2.9 XMC1404 Chip Identification Number

The Chip Identification Number in XMC1404 allows embedded software to identify the device and its features. It is an 8 words value with the most significant 7 words stored in Flash configuration sector 0 (CS0) at address location: 1000 0F00<sub>H</sub> (MSB) - 1000 0F1B<sub>H</sub> (LSB). The least significant word and most significant word of the Chip Identification Number are the value of registers DBGROMID and IDCHIP, respectively.

Table 16Device Identification Number

Derivative Part Number	XMC1404 Flash Size	DVDD Supply Voltage (V)	Value	Marking
IMD700A - Q064x128	128kB	3.3	2700100A 07FF00FF 1E071FF7 30BFF00F 00000D00 00001000 00021000 10204083H	AA
IMD701A - Q064x128	128kB	5.0	2701100A 07FF00FF 1E071FF7 30BFF00F 00000D00 00001000 00021000 10204083H	AA



## Up to 128kB of Flash (with ECC) and 16kB of RAM (with parity) Internal oscillator

Window watchdog

## • Serial Communication Modules

 $\circ$  ~ Four USIC channels, each of them configurable as UART, SPI, IIC and more

Nested Vectored Interrupt Controller (NVIC) with 64 interrupt nodes

Internal slow and fast oscillators without the need of PLL

• MultiCAN module (2 CAN nodes)

## • Analog Frontend Peripherals

 12 bit A/D Converters (up to 12 analog inputs), 2 sample and hold stages up to 1.1MSamples/s with adjustable gain

MATH Co-Processor (96MHz) for optimized 32 bit division and 24 bit trigonometric calculations

• 4 fast, general purpose analog comparators

## • Industrial Control Peripherals

- $\circ~~$  2x4 16-bit 96 MHz CCU4 timers for signal monitoring and PWM
- 2x4 16-bit 96 MHz CCU8 timers for complex PWM, complementary high/low side switches and 3 phase inverter control
- 2x POSIF for Hall and quadrature encoders, motor positioning

## • On-Chip Debug Support

- o 4 hardware breakpoints
- ARM serial wire debug, single-pin debug interfaces

## • Programming Support

- Single-pin bootloader
- $\circ$  Secure bootstrap loader SBSL (optional)

 Note:
 Refer to XMC1400 Reference Manual for full description of the XMC1400 including register map and descriptions. For latest version, refer to Infineon website (www.infineon.com)



• CPU Subsystem

0

0

0

0

0

MOTIX<sup>™</sup> IMD70xA

## 3

## Drives Optimized Microcontroller Features: XMC1404 Overview

IMD70xA integrates a fully programmable XMC1404 device. Following are the main features of this device:

## ARM® Cortex-M0 32 bits microcontroller (XMC1404)

Real time clock module

**Drives Optimized Microcontroller Features: XMC1404 Overview** 

32 bit ARM<sup>®</sup> Cortex-M0 (core clock 48MHz)

0.84 DMIPS/MHz (Dhrystone 2.1) at 48 MHz

#### MOTIX<sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver

4

## MOTIX<sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver

6EDL7141 main core block is comprised of a complete three phase gate driver optimized for motor control applications. This gate driver is a floating driver capable of driving with configurable slew rate and driving voltage, a 3 phase 2 level inverter with up to 1.5A of both sourcing and sinking peak currents.

Programmable charge pumps supply the gate drivers ensuring 100% duty cycle and configurable driving voltage for maximum optimization of the gate driver.

Numerous protections are included to ensure safe operation of the gate driver system under stress conditions including a best in class phase node (V<sub>SHx</sub>) tolerance to negative voltage spikes (see Absolute Maximum Ratings table). This is of great importance for example during high side MOSFET turn off transition.

Configurations and settings are shared by all three half bridge drivers. This section describes the following features of the integrated three phase gate driver:

- PWM Modes
- Gate Driver Architecture
- Slew Rate Control
- Gate Driver Voltage Programmability
- Charge Pump Configurations
- Gate Driver and Charge Pump Protections

#### 4.1 PWM Modes

MOTIX<sup>™</sup> 6EDL7141 implements additional intelligence that allows the user to simplify the PWM generation on the XMC1404 side. That together with integrated protection features results in a highly robust and faster development for drives applications. An intelligent dead time unit will ensure no shoot through happens at any condition. A highly configurable braking mode provides safe reaction to motor or system events.

Following PWM modes can be selected via bitfield PWM\_MODE:

- 1. 6PWM
- 2. 3PWM
- 3. 1PWM and commutation pattern
- 4. 1PWM with Hall sensor commutation
- Note: Given the interconnection between 6EDL7141 and XMC1404, PWM Mode '1PWM with Hall sensors inputs' as provided in standalone 6EDL7141 is not possible. However, XMC1404 can create a copy of the Hall sensor inputs via firmware and benefit from some of the 6EDL7141 provided features like dead time insertion or rotor locked detection if necessary. Possible delays or mismatches are user (firmware) responsibility.
- Note: It is possible to use only one or two phases instead of the 3 phases, like for instance in a full bridge configuration. In such case, it is recommended to keep INHx and INLx signals of the unused phases shorted to DGND and the GHx, GLx, SHx and SLx signals open.

The PWM signals need to be generated in pins P1.0, P1.1, P3.0, P3.1, P3.2, P3.3 according to Figure 3, by XMC1404 timer CCU8 which is a dedicated PWM timer for motor control. Thanks to the alternate functions, both CCU80 and CCU81 are possible to be used providing further flexibility in terms of connectivity, as an example, input signals for both units are different, so start, stop, load or other timer commands can be triggered by



Datasheet



#### MOTIX<sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver

different sources depending on the unit selection. A CTRAP function (setting to passive all timer output) can be connected via GPIOP14/P0.12 to input section of CCU80 timer as well as to other CCU4 timers.

Following subsections provide further details on each of the PWM modes and sub-modes.

## 4.1.1 **PWM with 6 Independent Inputs – 6PWM**

When the PWM\_MODE register in 6EDL7141 is set to b'0 then the device is configured for 6 independent PWM inputs. In this mode XMC1404 must provide 3 pairs of complementary PWM signals with dead time between high side and low side PWM. A minimum dead time will be observed for safety reasons in the gate driver, in order to avoid strong shoot through condition.

nBRAKE pin can be used for braking the motor in a controlled manner. See 4.1.6 for more information on braking modes.

Table 17 shows the truth table for 6PWM mode while Figure 19 shows a system diagram for this mode.

INHx	INLx	nBRAKE	GHx	GLx	SHx
1	1	1	LOW	LOW	High-Z
1	0	1	HIGH	LOW	HIGH
0	1	1	LOW	HIGH	LOW
0	0	1	LOW	LOW	High-Z
Х	Х	0	Brake cfg.	Brake cfg.	Brake cfg.

#### Table 17Truth table for 6PWM mode.

Note: X means any level

Note: Brake function can be configured to switch on all low side MOSFETs, all high side MOSFETs, alternate between these two options or set all outputs to high Z

#### MOTIX™ 6EDL7141 Three Phase Integrated Smart Gate Driver

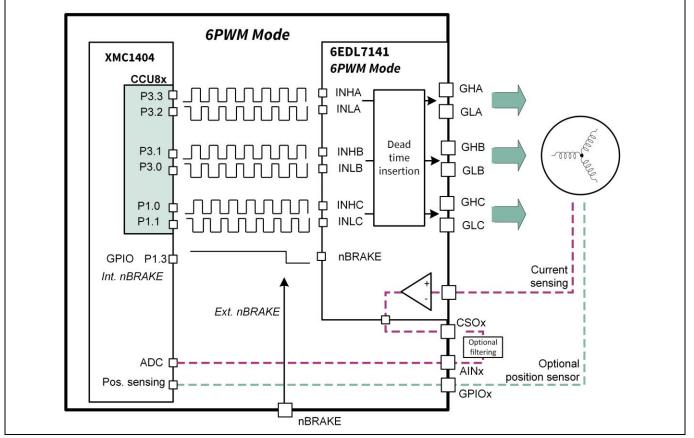


Figure 19 6PWM mode scheme

## 4.1.2 PWM with 3 Independent Inputs – 3PWM

MOTIX<sup>™</sup> 6EDL7141 can be configured to 3PWM mode by setting PWM\_MODE bitfield to value b'001. In such case, only 1 PWM signal (high side) per phase is necessary. The device will automatically generate the low side signals according to Table 18 and will insert a configurable dead time. Dead time is independently programmable for high to low (fall of phase node voltage) and low to high (rise of phase voltage) transitions through bitfields DT\_RISE and DT\_FALL.

INLx signals are ignored in this mode.

nBRAKE pin can be used for braking the motor. See 4.1.6 for more information on braking modes.

Figure 20 depicts a system diagram for this PWM mode.

INHx	INLx	nBRAKE	GHx	GLx	SHx
1	0	1	HIGH	LOW	HIGH
0	0	1	LOW	HIGH	LOW
Х	1	1	LOW	LOW	High-Z
Х	Х	0	Brake cfg.	Brake cfg.	Brake cfg.

#### Table 18Truth table for 3PWM mode.

Note: X means any level





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Note:

Brake function can be configured to switch on all low side MOSFETs, all high side MOSFETs, alternate between these two options or set all outputs to high Z

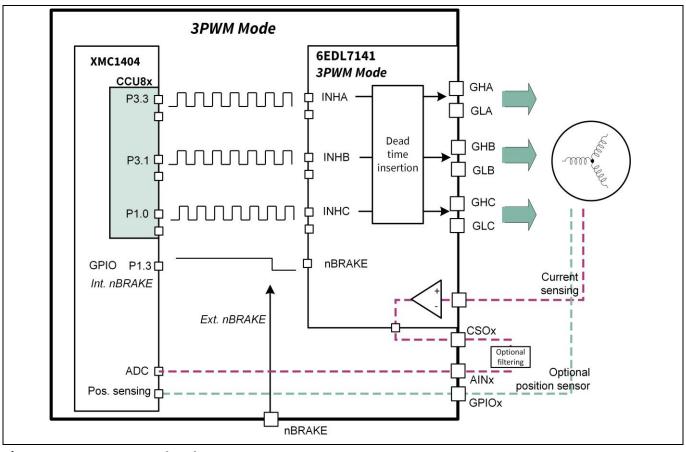


Figure 20 3PWM mode scheme

## 4.1.3 **PWM with 1 Input and Commutation Pattern – 1PWM**

When the PWM\_MODE register is set to b'010 then the PWM section in 6EDL7141 is configured to 1PWM mode. In this case, the duty cycle and frequency of signal INHA is used to determine the duty cycle (or amplitude) and the frequency of the PWM outputs generated. The rest of inputs are captured to decide the commutation pattern or state of the outputs. INHC signal can be used to implement 12 step trapezoidal commutation. Dead time is automatically inserted according to programmed values in bitfields DT\_RISE and DT\_FALL.

Figure 21 shows a schematic diagram of 1PWM mode.

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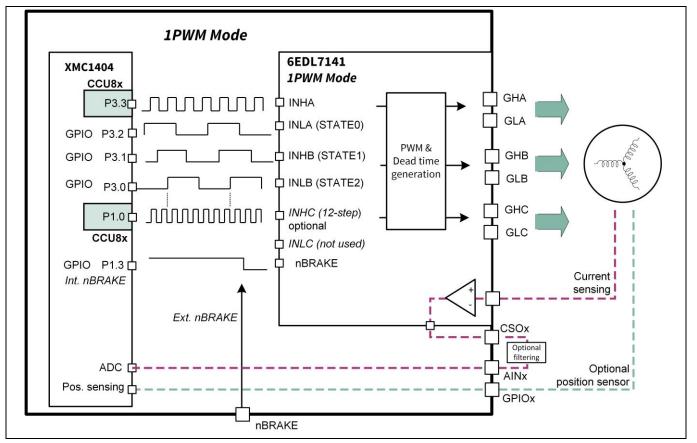


Figure 21 1PWM mode scheme

Additionally, the user has the option to select between two main commutation schemes programmable via register bitfield PWM\_FREEW\_CFG:

- **Diode freewheeling** bitfield PWM\_FREEW\_CFG =b'1: in this case, the freewheeling current will flow through the low side MOSFETs body diodes. The truth table for this mode is shown in Table 19.
- Active freewheeling bitfield PWM\_FREEW\_CFG =b'0: in this case the low side MOSFETs will be switched synchronously to reduce conduction losses on the body diode conduction. The truth table for this mode is shown in Table 20.Note:

#### **12 Step Trapezoidal Commutation**

Input INHC can be optionally used to create a 12 step trapezoidal or block commutation. This method energizes up to two phases at the same time in contrast to 6 step, where only one is active at any time. In 12 step trapezoidal commutation, torque ripple is improved and the angle created between stator and rotor flux vectors can be controlled within 30 degree accuracy instead of 60degree in 6 step trapezoidal commutation. This method improves motor efficiency and torque ripple, however requires additional position information. This information can be processed by a the integrated XMC1404 to produce signals INHA, INLA, INHB, INLB and INHC according to Table 19 or Table 20. As can be seen, from a system perspective, the INHC signal must toggle at every 30degree rotation (electrical).

In case the INHC signal is not toggled, the device will apply the commutation as shown in to Table 19 or Table 20. As an example, if INHC is left low, a classic 6 step trapezoidal commutation pattern will be produced. In case INHC is pulled high, the pattern will show a 30 degree advanced with respect to a standard 6 step trapezoidal commutation. The user can use this variants or toggle the INHC pin every 30 degree of rotation to create a 12 step commutation pattern.

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nBRAKE pin can be used for braking the motor. See 4.1.6 for more information on braking modes.

Here is a summary of inputs and output functionalities:

- INHA PWM input, defines PWM output duty cycle and frequency
- INLA, INHB, INLB Provide timing for modulation pattern changes
- INHC Signalizes 12 step states. Must toggle every electrical 30degree
- INLC This input is ignored in this mode. Recommended pull down.
- nBRAKE signal When active, will force the motor to brake.
- GHA, GLB, GHB, GLB, GHC, GLC Complementary PWM Output signals

Table 19 shows the possible states for this PWM mode using diode freewheeling while Table 20 shows the states in case of active freewheeling.

					INPTUS						ουτρυτ	S
State	INLA, INHB, INLB,	INHC	nBRAKE	GHA	GLA	GHB	GLB	GHC	GLC	SHA	SHB	SHC
AB	011	0	1	PWM	LOW	LOW	HIGH	LOW	LOW	HIGH	LOW	-
AB_CB	010	1	1	PWM	LOW	LOW	HIGH	PWM	LOW	HIGH	LOW	HIGH
СВ	010	0	1	LOW	LOW	LOW	HIGH	PWM	LOW	-	LOW	HIGH
CB_CA	110	1	1	LOW	HIGH	LOW	HIGH	PWM	LOW	LOW	LOW	HIGH
CA	110	0	1	LOW	HIGH	LOW	LOW	PWM	LOW	LOW	-	HIGH
CA_BA	100	1	1	LOW	HIGH	PWM	LOW	PWM	LOW	LOW	HIGH	HIGH
BA	100	0	1	LOW	HIGH	PWM	LOW	LOW	LOW	LOW	HIGH	-
BA_BC	101	1	1	LOW	HIGH	PWM	LOW	LOW	HIGH	LOW	HIGH	LOW
BC	101	0	1	LOW	LOW	PWM	LOW	LOW	HIGH	-	HIGH	LOW
BC_AC	001	1	1	PWM	LOW	PWM	LOW	LOW	HIGH	HIGH	HIGH	LOW
AC	001	0	1	PWM	LOW	LOW	LOW	LOW	HIGH	HIGH	-	LOW
AC_AB	011	1	1	PWM	LOW	LOW	HIGH	LOW	HIGH	HIGH	LOW	LOW
Align	111	Х	1	PWM	LOW	LOW	HIGH	LOW	HIGH	HIGH	LOW	LOW
Stop	000	Х	1	LOW	LOW	LOW	LOW	LOW	LOW	-	-	-
Brake	ххх	Х	0	Brake cfg.								

Table 19Truth table for 1PWM mode with diode freewheeling.

Note: X means any level

Note: SHx when HIGH means that SHx pin is switching between GND and the DC bus voltage or battery voltage according to PWM signals. '-' represents floating state, meaning both high side and low side MOSFETs are OFF

Note: Brake function can be configured to switch on all low side MOSFETs, all high side MOSFETs, alternate between these two options or set all outputs to high Z

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#### Table 20Truth table for 1PWM mode with active freewheeling.

	INPTU	S		OUTPUTS								
State	INLA, INHB, INLB,	INHC	nBRAKE	GHA	GLA	GHB	GLB	GHC	GLC	SHA	SHB	ѕнс
AB	011	0	1	PWM	!PWM	LOW	HIGH	LOW	LOW	HIGH	LOW	-
AB_CB	010	1	1	PWM	!PWM	LOW	HIGH	PWM	!PWM	HIGH	LOW	HIGH
СВ	010	0	1	LOW	LOW	LOW	HIGH	PWM	!PWM	-	LOW	HIGH
CB_CA	110	1	1	LOW	HIGH	LOW	HIGH	PWM	!PWM	LOW	LOW	HIGH
CA	110	0	1	LOW	HIGH	LOW	LOW	PWM	!PWM	LOW	-	HIGH
CA_BA	100	1	1	LOW	HIGH	PWM	!PWM	PWM	!PWM	LOW	HIGH	HIGH
BA	100	0	1	LOW	HIGH	PWM	!PWM	LOW	LOW	LOW	HIGH	-
BA_BC	101	1	1	LOW	HIGH	PWM	!PWM	LOW	HIGH	LOW	HIGH	LOW
BC	101	0	1	LOW	LOW	PWM	!PWM	LOW	HIGH	-	HIGH	LOW
BC_AC	001	1	1	PWM	!PWM	PWM	!PWM	LOW	HIGH	HIGH	HIGH	LOW
AC	001	0	1	PWM	!PWM	LOW	LOW	LOW	HIGH	HIGH	-	LOW
AC_AB	011	1	1	PWM	!PWM	LOW	HIGH	LOW	HIGH	HIGH	LOW	LOW
Align	111	Х	1	PWM	!PWM	LOW	HIGH	LOW	HIGH	HIGH	LOW	LOW
Stop	000	Х	1	LOW	LOW	LOW	LOW	LOW	LOW	-	-	-
Brake	ххх	х	0	Brake cfg.	Brake cfg	Brake cfg	Brake cfg.	Brake cfg.	Brake cfg.	Brake cfg.	Brake cfg.	Brake cfg.

Note: X means any level

Note:

SHx when HIGH means that SHx pin is switching between GND and the DC bus voltage or battery voltage. '-' is floating state, meaning both high side and low side MOSFETs are OFF.

Note: Brake function can be configured to switch on all low side MOSFETs, all high side MOSFETs, alternate between these two options or set all outputs to high Z.

## 4.1.4 PWM with 1 Input and Commutation with Hall Sensor Inputs – 1PWM with Hall Sensors

MOTIX<sup>™</sup> 6EDL7141 integrates three Hall sensor comparators to detect pattern of movement in the motor. This can be used for rotor locked detection but can also be utilized to drive the PWM commutation pattern automatically. In order to use this mode, user could use Hall sensor inputs connected to XMC1404 and replicate those signals, e.g. via GPIO handling in firmware, into 6EDL7141 inputs. This will enable usage of 6EDL7141 logic for PWM pattern generation as well as locked rotor detection.

To enable this PWM\_MODE bitfield needs to be configured to value b'011. The truth table presented in Table 21 dictates the commutation pattern. In this mode, Hall sensor inputs decide the switching pattern of the PWM output signals. The duty cycle and frequency of the output signals is determined by INHA duty cycle and frequency.

Dead time is inserted automatically according to programmed values in DT\_RISE and DT\_HALL.

In a similar way as in other PWM modes, the user has the option to select between two main commutation schemes programmable via bitfield PWM\_FREEW\_CFG in PWM\_CFG register: diode and active freewheeling. No





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truth table is shown for diode mode. This can be constructed by substituting "!PWM" cells in Table 21 by "LOW".

Similarly to other PWM modes, nBRAKE pin can be used for braking the motor. See 4.1.6 for more information on braking modes.

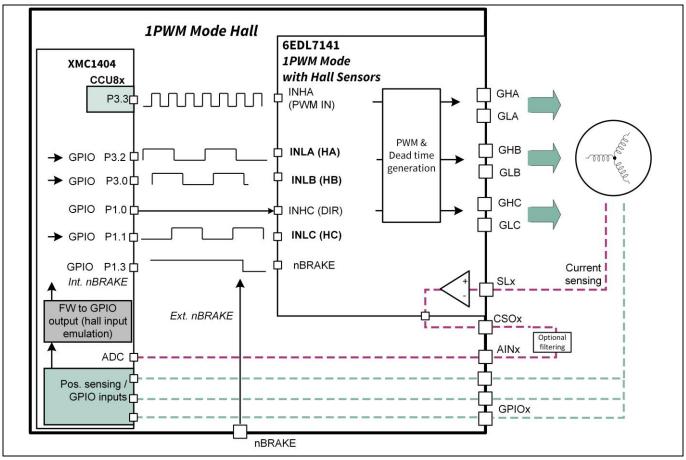


Figure 22 1PWM mode with hall sensors. Self-controlled pattern switching

Table 21	Truth table for 1 PWM mode with active freewheeling.

INPUTS			OUTPUTS									
INLx [A,B,C]	INHC- Dir	nBRAKE	GHA	GLA	GHB	GLB	бнс	GLC	SHA	SHB	ѕнс	
101	1	1	PWM	!PWM	LOW	LOW	LOW	HIGH	HIGH	-	LOW	
100	1	1	LOW	LOW	PWM	!PWM	LOW	HIGH	-	HIGH	LOW	
110	1	1	LOW	HIGH	PWM	!PWM	LOW	LOW	LOW	HIGH	-	
010	1	1	LOW	HIGH	LOW	LOW	PWM	!PWM	LOW	-	HIGH	
011	1	1	LOW	LOW	LOW	HIGH	PWM	!PWM	-	LOW	HIGH	
001	1	1	PWM	!PWM	LOW	HIGH	LOW	LOW	HIGH	LOW	-	
101	0	1	LOW	HIGH	LOW	LOW	PWM	!PWM	LOW	-	HIGH	
100	0	1	LOW	LOW	LOW	HIGH	PWM	!PWM	-	LOW	HIGH	
110	0	1	PWM	!PWM	LOW	HIGH	LOW	LOW	HIGH	LOW	-	
010	0	1	PWM	!PWM	LOW	LOW	LOW	HIGH	HIGH	-	LOW	

## Datasheet



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INPUTS			OUTPUTS										
INLx [A,B,C]	INHC- Dir	nBRAKE	GHA	GLA	GHB	GLB	бнс	GLC	SHA	SHB	ѕнс		
011	0	1	LOW	LOW	PWM	!PWM	LOW	HIGH	-	HIGH	LOW		
001	0	1	LOW	HIGH	PWM	!PWM	LOW	LOW	LOW	HIGH	-		
ХХХ	х	0	Brake cfg.										
111	Х	1	LOW	LOW	LOW	LOW	LOW	LOW	-	-	-		
000	Х	1	LOW	LOW	LOW	LOW	LOW	LOW	-	-	-		

Note: X means any level. XXX means any other combination on inputs not shown

Note: Grey cells represent forbidden states and should be avoided

Note: SHx when HIGH means that SHx pin is switching between GND and the DC bus voltage or battery voltage. '-' represents floating state, meaning both high side and low side MOSFETs are OFF

*Note:* For diode freewheeling mode, substitute "!PWM" cells by "LOW"

Note: Brake function can be configured to switch on all low side MOSFETs, all high side MOSFETs, alternate between these two options or set all outputs to high Z

These are the signals functionality for this mode:

- INHA PWM input, defines duty cycle and frequency of PWM output signals
- INLA, INLB, INLC Hall Sensor Inputs (HA, HB, HC) will define the PWM output pattern depending on motor position.
- nBRAKE signal when active, the device will force a brake event.
- INHC Direction control. Provided by a microcontroller, will define direction of motor rotation.
- GHA, GLA, GHB, GLB, GHC, GLC PWM output signals, high side and low sides.

A schematic representation of the commutation states is presented in Figure 23.

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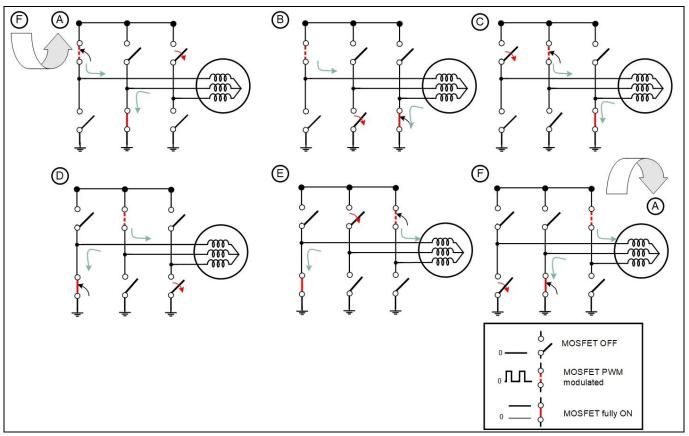


Figure 23 6 states switching overview. Diode freewheeling mode is represented here for simplification. Single direction considered.

## 4.1.5 PWM with 1 Input and Commutation with Hall Sensor Inputs and Alternating Recirculation – 1PWM with Hall Sensors and Alternating Recirculation

Thermal management in power tools systems is a key factor for achieving higher power densities. A more advance thermal management might allow smaller heat sink components or smaller PCB area. This PWM mode focuses on distributing the MOSFET stress more evenly between all MOSFETs in the inverter. This concept alternates the recirculation of the freewheeling current between high side and low side MOSFETs. This is achieved by extending the truth table shown in Table 21 into Table 22.

On the first rotation (electrical), the inverter will recirculate the current through the high side MOSFETS (PWM modulated MOSFET) and the low side MOSFET will be always ON. In the second electrical rotation, the low side MOSFETs will recirculate the freewheeling current (PWM modulated MOSFET), and therefore, the high side is the one fully ON. This cycle repeats in further rotations. A graphical representation for the switching states is presented in Figure 24. In this figure, states A to F represent high side modulation while states G to L represent the low side modulation. The state machine will return to state A after state L, starting over again the cycle.

PWM\_FREEW\_CFG configures this mode as well either as diode or active freewheeling. No truth table is shown for diode mode. This can be constructed by substituting "!PWM" cells with LOW in Table 22.

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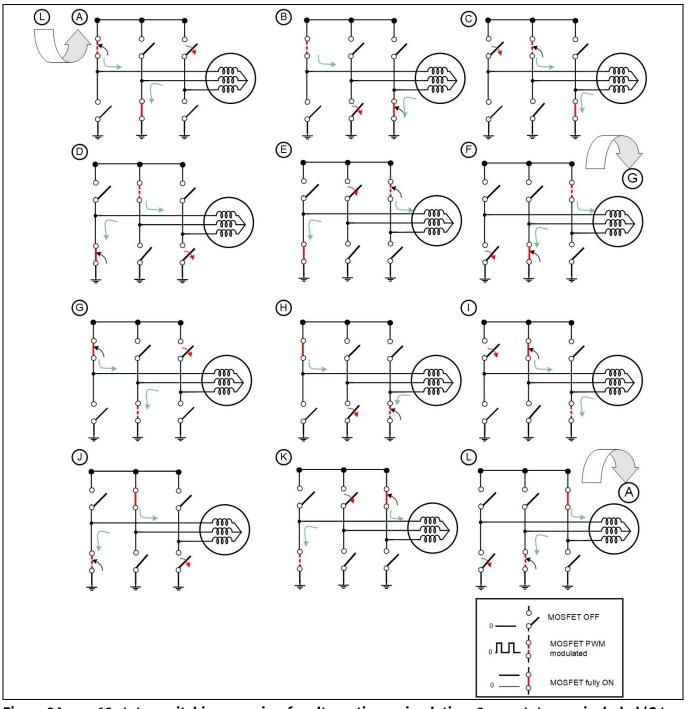
INPUTS			OUTPUTS										
INLx [A,B,C]	nBRAKE	Fully ON	GHA	GLA	GHB	GLB	GHC	GLC	SHA	SHB	SHC		
INHC (Di	r)=1												
101	1	Low side	PWM	!PWM	LOW	LOW	LOW	HIGH	HIGH	-	LOW		
100	1	Low side	LOW	LOW	PWM	!PWM	LOW	HIGH	-	HIGH	LOW		
110	1	Low side	LOW	HIGH	PWM	!PWM	LOW	LOW	LOW	HIGH	-		
010	1	Low side	LOW	HIGH	LOW	LOW	PWM	!PWM	LOW	-	HIGH		
011	1	Low side	LOW	LOW	LOW	HIGH	PWM	!PWM	-	LOW	HIGH		
001	1	Low side	PWM	!PWM	LOW	HIGH	LOW	LOW	HIGH	LOW	-		
101	1	High side	HIGH	LOW	LOW	LOW	!PWM	PWM	HIGH	-	LOW		
100	1	High side	LOW	LOW	HIGH	LOW	!PWM	PWM	-	HIGH	LOW		
110	1	High side	!PWM	PWM	HIGH	LOW	LOW	LOW	LOW	HIGH	-		
010	1	High side	!PWM	PWM	LOW	LOW	HIGH	LOW	LOW	-	HIGH		
011	1	High side	LOW	LOW	!PWM	PWM	HIGH	LOW	-	LOW	HIGH		
001	1	High side	HIGH	LOW	!PWM	PWM	LOW	LOW	HIGH	LOW	-		
INHC (Di	r)=0	•	-	•			·			•			
101	1	Low side	LOW	HIGH	LOW	LOW	PWM	!PWM	LOW	-	HIGH		
100	1	Low side	LOW	LOW	LOW	HIGH	PWM	!PWM	-	LOW	HIGH		
110	1	Low side	PWM	!PWM	LOW	HIGH	LOW	LOW	HIGH	LOW	-		
010	1	Low side	PWM	!PWM	LOW	LOW	LOW	HIGH	HIGH	-	LOW		
011	1	Low side	LOW	LOW	PWM	!PWM	LOW	HIGH	-	HIGH	LOW		
001	1	Low side	LOW	HIGH	PWM	!PWM	LOW	LOW	LOW	HIGH	-		
101	1	High side	!PWM	PWM	LOW	LOW	HIGH	LOW	LOW	-	HIGH		
100	1	High side	LOW	LOW	!PWM	PWM	HIGH	LOW	-	LOW	HIGH		
110	1	High side	HIGH	LOW	!PWM	PWM	LOW	LOW	HIGH	LOW	-		
010	1	High side	HIGH	LOW	LOW	LOW	!PWM	PWM	HIGH	-	LOW		
011	1	High side	LOW	LOW	HIGH	LOW	!PWM	PWM	-	HIGH	LOW		
001	1	High side	!PWM	PWM	HIGH	LOW	LOW	LOW	LOW	HIGH	-		
ХХХ	0	х	Brake cfg.	Brake cfg.	Brake cfg.	Brake cfg.	Brake cfg.	Brake cfg.	Brake cfg.	Brake cfg.	Brake cfg.		
111	1	1	LOW	LOW	LOW	LOW	LOW	LOW	-	-	-		
000	1	1	LOW	LOW	LOW	LOW	LOW	LOW	-	-	-		
ote: ote:	SHx и	ans any level vhen HIGH m	eans tha	t SHx pin	is switch	ing betwe	een GND d	and the D	C bus vol	•	-		
lote: lote:	voltag	vhen HIGH m ge. '-' represo iode freewhe	ents float	ting state	, meanin <sub>:</sub>	g both hi	gh side aı	nd low sic		•	-		

Note: For diode freewheeling mode, substitute "!PWM" cells by "LOW"

Note: Brake function can be configured to switch on all low side MOSFETs, all high side MOSFETs, alternate between these two options or set all outputs to high Z

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# Figure 2412 states switching overview for alternating recirculation. 6 new states are included (G to<br/>L) compared to other 1PWM modes. Diode clamping is represented here for simplification.<br/>Single direction considered

## 4.1.6 PWM Braking Modes

In all PWM modes presented in section 4.1, the device can go into a controlled braking mode. This braking mode will drive PWM signals in a way that the motor goes to a safe state in a controlled manner. This is of critical importance for some power tools applications where a sudden or uncontrolled braking can destroy elements of the tool or become a hazard to the user safety. Following events can trigger the braking action:

• Pull down of pin nBRAKE

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- Overcurrent protection (OCP) fault on current sense amplifiers -programmable
- Watchdog timer fault-programmable

From them, pin nBRAKE is the only that can be actively used by, for example an additional microcontroller to start a braking event. All other 3 are the reaction to a fault-detection.

Pin nBRAKE shall be high for normal operation of the motor. However, as soon as low level is detected in it, the gate driver logic will activate high side MOSFETs or low side MOSFETs therefore braking the motor actively.

Braking circuitry can be configured as illustrated in Figure 25 in the following modes by programming bitfield BRAKE\_CFG in register PWM\_CFG:

- Low side MOSFET braking: upon a braking event, all low side MOSFET will be activated and all high side MOSFET switched off.
- **High side MOSFET braking**: upon a braking event, all high side MOSFET will be activated and all low side MOSFET switched off
- Alternate braking mode: upon every new braking event, the system alternates between high side MOSFET braking and low side MOSFET braking. With alternate braking, stress on MOSFETs is distributed equally, therefore improving system robustness.
- **Non-power braking**-high impedance (high Z) outputs: upon a braking event all switches are forced to high Z mode. Currents present in motor windings will recirculate through MOSFET body diodes or other available structures in the inverter. This mode is recommended if a MOSFET short occurs in the inverter.

In IMD70xA, XMC1404 can modify brake related bitfields during run time of the system to adapt to given conditions.

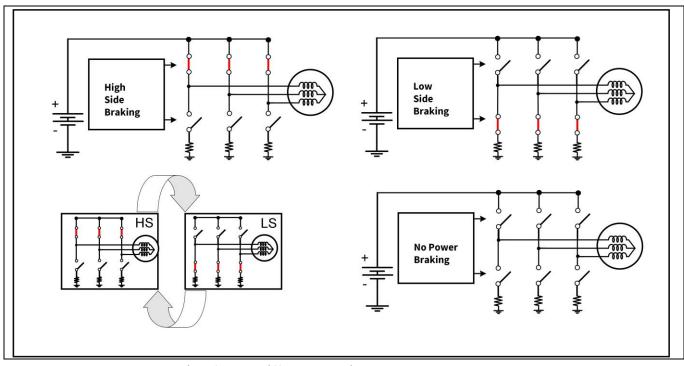


Figure 25 System overview for the different braking modes supported

Before the braking action starts, the gate driver prepares the inverter as fast as possible for a safe braking. Depending on the inverter state at the moment of the braking request, the device will need to switch off some MOSFETs and insert dead times. For example, if the braking signal arrives when phase A is, high side switchedoff and low side switched-on, and assuming a high side braking configuration, then will immediately switch off

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the low side MOSFET, insert the configured dead time and finally switch on the high side MOSFET of phase A with the rest of high side MOSFETs.

## 4.1.6.1 Double nBRAKE Path

During normal operation (after UVLO DVDD), the pin nBRAKE is an input (inverted logic) that can be pulled down to initiate a brake event, bringing the motor to a standstill in a controlled way. If the pin is set high, the PWM will resume and propagate normally the PWM inputs to the outputs. There are two sources for activating the brake events in IMD70xA:

- XMC1404 internal connection (P1.3--> nBRAKE): integrated XMC1404 can toggle the GPIO to activate or deactivate the braking action.
- IMD70xA pin 24 (nBRAKE): an external source like another controller or some logic, can trigger in parallel the braking event.

This is done to support increased flexibility in the braking scheme. Internally, both sources are electrically connected. A possible system diagram making use of the double braking path is shown Figure 26.

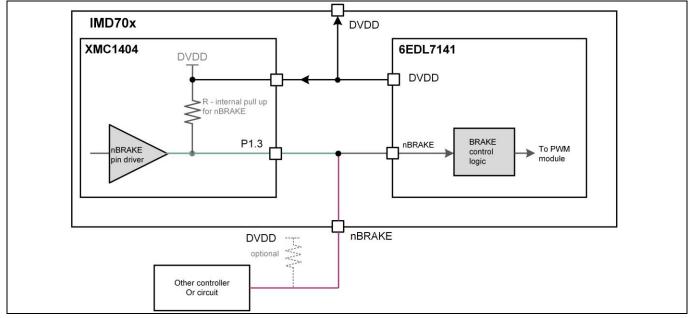


Figure 26 nBRAKE double path pin usage example: internal via XMC1404 controller P1.3 pin, and external via pin nBRAKE

## 4.1.7 Dead Time Insertion

The PWM unit in 6EDL7141 inserts automatically a dead time between complementary signals (GHx –GLx). DT\_RISE bitfield defines the dead time period for rising transition (of phase node voltage) while DT\_FALL defines independently the period for the falling transition. A minimum dead time (see Electrical Characteristics table for detailed values and conditions) will always be observed to avoid strong shoot through condition.

Figure 27 shows a detailed signal diagram of a 1PWM mode dead time insertion including the timing definitions. A propagation time ( $t_{PROP_{HS}}$  and  $t_{PROP_{LS}}$ ) elapses between the input signal and the actual gate driver output signals. These timing definitions are applicable to all other PWM modes.

Dead time and slew rate control features are designed in a safe way so that a change in slew rate will update in a synchronous manner to the PWM switching. This hinders any possible shoot through during the possible update of the slew rate during operation due to miss-alignment of timings.



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Note: The application software, must ensure that dead time is sufficient for the slew rate configuration and the MOSFETs selection. Current sense amplifier OCP can be used to detect excessive current in the system.

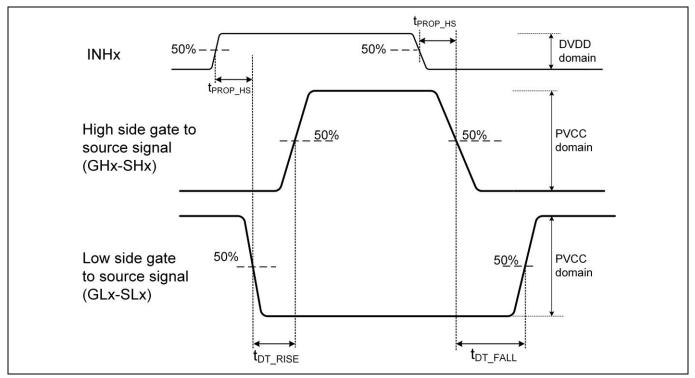


Figure 27 PWM insertion ideal timing diagram for 1PWM mode.

## 4.2 Gate Driver Architecture

Three identical pairs of high side and low side drivers are integrated. High and low side drivers are designed with the same architecture. However, supply domains for both sections are developed differently. Precise charge pumps are utilized to supply both drivers, VCCLS to the low side gate drivers, and VCCHS to the high side gate drivers. An overview of the general architecture is shown in Figure 28.



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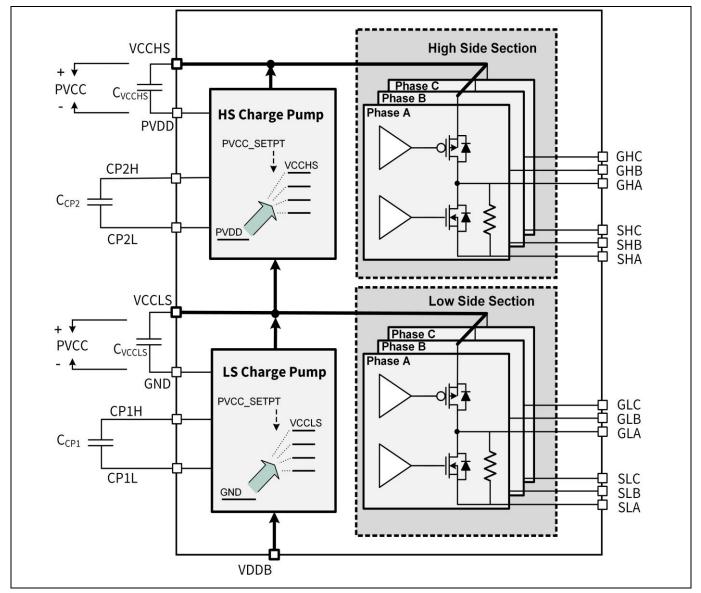


Figure 28 Gate driver architecture overview

The low side section of the gate driver is supplied by VCCLS. When the device is under normal operation, VCCLS is "PVCC" volts above ground. VCCLS voltage is generated by "LS Charge Pump" from VDDB voltage –integrated buck converter output voltage. An external "flying" capacitor C<sub>CP1</sub> is required for the charge pump to work properly.

The high side section of the gate driver is supplied by VCCHS. A separated charge pump generates "PVCC" volts above PVDD for properly bias of the high side MOSFET drivers. Similarly to low side section, a "flying" capacitor C<sub>CP2</sub> is necessary for proper operation of the charge pump. PVCC voltage is programmable via SPI registers and defines the gate driving voltage of the inverter power MOSFETs.

Additional decoupling capacitors C<sub>VCCLS</sub> and C<sub>VCCHS</sub> are required for VCCLS and VCCHS pins respectively. These and other required components recommended values are shown in Table 30.

The selection of those capacitors will have an impact i different parameters in the charge pump including the voltage ripple in VCCLS/HS, as well as the start-up time or the maximum load that the gate driver can sustain.



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## 4.3 Slew Rate Control

Control of MOSFET  $V_{DS}$  rise and fall times is one of the most important parameters for optimizing drive systems, affecting critical factors like:

- Switching losses,
- Dead time optimization,
- V<sub>DS</sub> ringing with possible avalanche event in MOSFETs. Avalanche is a critical factor in MOSFETs that can lead to device destruction or reliability issues,
- EMI design and optimizations,
- Control of negative spike in SHx pins,
- Possible snubber design (MOSFET snubber or bridge bypass capacitors)

MOTIX<sup>™</sup> 6EDL7141 is capable of adjusting the slew rate of the MOSFET switching (V<sub>DS</sub>). Slew rate control functionality controls independently the rise (low to high) and fall (high to low) slew rates of the drain-to-source voltage by adjusting the gate current applied to MOSFET gate.

Note:

*R<sub>g</sub>* resistors might be used, however, user must consider the voltage drop on the resistor when driving the MOSFET with the constant current provided by 6ELD7141

## 4.3.1 Slew Rate Control Parameters and Usage

User can configure the gate driver current and timings with following parameters via SPI accessible registers:

- I<sub>HS SRC</sub> bitfield IHS\_SRC: gate driver current value for switching **ON high side** MOSFETs
- I<sub>HS\_SINK</sub> bitfield IHS\_SINK: gate driver current value for switching **OFF high side** MOSFETs
- ILS\_SRC bitfield ILS\_SRC: gate driver current value for switching **ON low side** MOSFETs
- ILS\_SINK bitfield ILS\_SINK: gate driver current value for switching **OFF low side** MOSFETs
- I<sub>PRE\_SRC</sub> bitfield IPRE\_SRC: **pre-charge** gate driver current value for switching **ON both high and low side** MOSFETs. Needs to be enabled via bitfield IPRE\_EN, otherwise pre-charge will be set to max current.
- I<sub>PRE\_SNK</sub> bitfield IPRE\_SNK: **pre-discharge** gate driver current value for switching **OFF both high and low side** MOSFETs. Needs to be enabled via bitfield IPRE\_EN, otherwise pre-discharge will be set to max current.
- T<sub>DRIVE1</sub> bitfield TDRIVE1: amount of time that I<sub>PRE\_SRC</sub> is applied. Shared configuration between high and low side drivers
- T<sub>DRIVE2</sub> bitfield TDRIVE2: amount of time that I<sub>HS\_SRC</sub> and I<sub>LS\_SRC</sub> are applied. Shared configuration between high and low side drivers
- T<sub>DRIVE3</sub> bitfield TDRIVE3: amount of time that I<sub>PRE\_SNK</sub> is applied. Shared configuration between high and low side drivers
- T<sub>DRIVE4</sub> bitfield TDRIVE4: amount of time that I<sub>HS\_SINK</sub> and I<sub>LS\_SINK</sub> are applied. Shared configuration between high side and low side drivers

The driving implementation is presented in Figure 29. This represents a 6PWM mode in which the XMC1404 inserts a specific dead time between INHx and INLx signals. The driving scheme is applicable to other PWM modes. Propagation delays are not depicted for simplification of the diagram (see Figure 27 for details on propagation delay).

Once the gate is commanded to apply a change to the output, the gate driver will apply a constant current defined by the user programmable value  $I_{PRE\_SRC}$  for a time defined by  $T_{DRIVE1}$ . After  $T_{DRIVE1}$  period, the MOSFET gate voltage should ideally have reached the threshold voltage ( $V_{GS(th)}$ ). After  $T_{DRIVE1}$ , the gate driver applies next gate current configuration for a period defined by  $T_{DRIVE2}$ . The current applied in this period is decisive to determine both dI/dt and dV/dt of the MOSFETs as it will charge the  $Q_{sw}$  of the MOSFETs. User can alternatively decide to

#### Datasheet



reduce this period to cover only  $Q_{gd}$  portion, therefore controlling dI/dt region with the  $T_{DRIVE1}$  period for independent control. To ensure proper fine tuning, 6EDL7141 offers separate configuration registers for the high side and low side ( $I_{HS\_SRC}$  and  $I_{LS\_SRC}$  respectively).

Once  $T_{DRIVE2}$  period is elapsed, the gate driver applies full current (1.5A) to ensure fastest turn on of the MOSFET. This will fully charge the MOSFET gate ( $Q_{od} = Q_g - Q_{sw} - Q_{g(th)}$ )) till the programmed PVCC value.

A similar process takes place in the discharge of the MOSFET

## Attention: Consider that slew rate variation affects the actual dead time value. User must select dead time accordingly

#### VGS Comparators

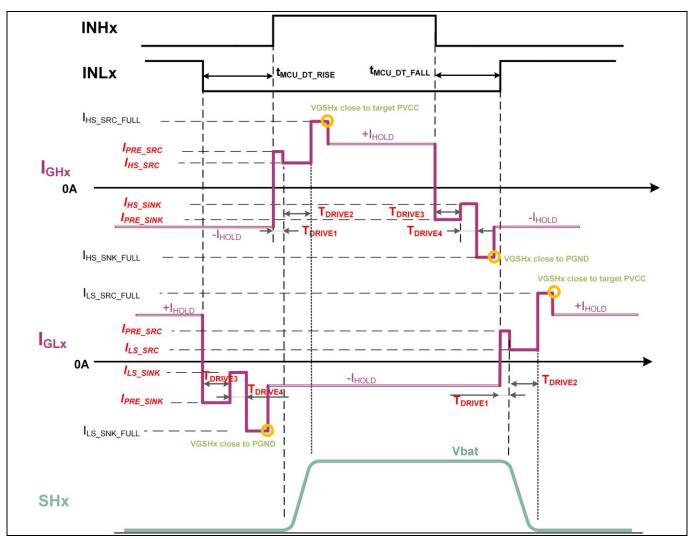
MOTIX<sup>™</sup> 6EDL7141 integrates gate to source comparators. These are used to detect when the Vgs signal is almost at the target value PVCC, i.e.  $V_{GSX} \ge PVCC - V_{GS\_CPM\_TH}$  during charging phase and  $V_{GSX} \le V_{GS\_CPM\_TH}$  during the discharge phase. When any of these happen, the comparator trips and sets the gate current to  $I_{HOLD}$  value. This is to reduce power consumption and help reducing the possible impact of the self-turn-on effect, for example when the high side MOSFET is turning on while the low side MOSFET is off. In this case, the hold current in the low side MOSFET will help tightening down the gate of that MOSFET to the source with  $I_{HOLD}$  strength. In Figure 29  $I_{HOLD}$  is shown as dashed and depending on VGS value will be applied sooner or later. In Figure 30 the thresholds for activating  $I_{HOLD}$  current are shown.

The comparator integrates a deglitching stage that avoids noise to activate the comparator erroneously during noisy events. The deglitching time is defined by  $t_{VGS\_CMP\_DEGLITCH}$ .



#### Datasheet

#### **MOTIX<sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver**



## Figure 29 Slew rate control timing for a complete switching cycle on a 6PWM mode-dead time assumed to be inserted by XMC1404. Propagation delays (INxy→Gxy) not considered for simplification. Parameters on red refer to programmable values

Figure 30 shows a detail of the charging and discharging transitions for a high side MOSFET. Similar applies to a low side MOSFET. The different gate charge areas of the MOSFET are shown. Thanks to the flexible timing structure and the high  $T_{DRIVEX}$  resolution, user has full control of the gate current applied during critical charge areas like  $Q_{sw}$  which is the key parameter controlling the MOSFET Vds slew rate. This at the same time can be done while maintaining fast charging of other areas like  $Q_{od}$  which typically is relatively large compared to  $Q_{sw}$  and therefore, as it does not affect neither dV/dt nor dI/dt, can be accelerated by increasing gate current.

Additionally, the pre-charge area ( $Q_{gs(th)}$ ), depending on the particular MOSFET, can benefit from a larger gate current than the one applied to the  $Q_{sw}$  region where maximum control is required. Thanks to the pre-charge current configuration, higher gate currents can be selected for  $Q_{gs(th)}$  reducing importantly the pre-charge timing, which otherwise could have needed several hundreds of ns to reach to  $V_{gs(th)}$ .

The pre-charge current can be selected from 17 different values. 16 defined by  $I_{PRE\_SRC/SNK}$  and additionally 1.5A, which is the maximum peak current capability of the gate driver. In case of large MOSFETs,  $Q_{gs(th)}$  during turn on or  $Q_{od}$  ( $Q_{od} = Q_g - Q_{sw}-Q_{gs(th)}$ ) during turn off, might benefit from using the whole gate driver capability. In order to enable the full strength during the pre-charge area, register I\_PRE\_EN has to be set in register IDRIVE\_PRE\_CFG.





#### Datasheet

#### MOTIX<sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver

- Note: When transitioning from one current setting to another, user can experience some transition period until new current value is up and stable. During this period, the current might become lower than programmed for a brief period before reaching the target value.
- Note: When the gate to source voltage is getting close to the target voltage, either PVCC when charging or PGND when discharging, the gate driver will not be able to fully maintain the target I<sub>G</sub> current. This effect deviates from the ideal behavior shown before and can follow similar behavior to the dashed lines in Figure 30. This is independent from the I<sub>HOLD</sub> values described before.

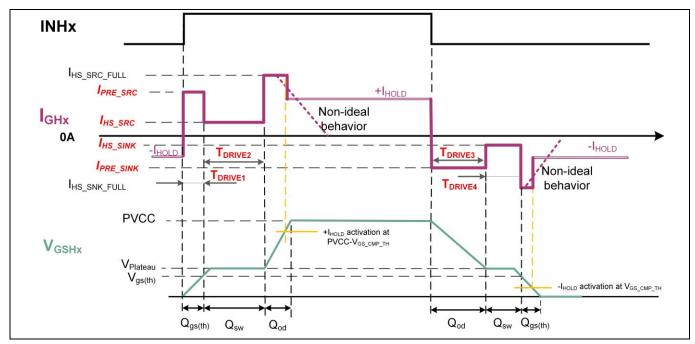


Figure 30 Detail of MOSFET gate charge during the charging and discharging transitions

In cases where  $Q_{g(th)}$  is too small to apply a larger current than the one used for slew rate control, user can set  $T_{DRIVE2}$  to value 0. This will results in the gate driver start driving the MOSFETs with  $T_{DRIVE1}$  and once the period is elapsed it will apply 1.5A ignoring  $T_{DRIVE2}$  configuration. This ensures optimal settings for both large and small MOSFETs and right fit for different technologies like OptiMOS<sup>TM</sup> or StrongIRFET<sup>TM</sup>. Similarly,  $T_{DRIVE2}$ ,  $T_{DRIVE3}$  and/or  $T_{DRIVE4}$  can be set to 0 resulting in those configurations being skipped. Figure 31 shows an example of this behavior where  $T_{DRIVE2} = 0$  while other  $T_{DRIVE3}$  settings are different than zero.

Note: When driving with a single timing setting the charge or the discharge phases, it is recommended to use either  $T_{DRIVE1}$  or  $T_{DRIVE3}$  as driving periods and make  $T_{DRIVE2}$  or  $T_{DRIVE4}$  equal to 0. The opposite is possible, however might result in selected timing ( $T_{DRIVE2}$  or  $T_{DRIVE4}$ ) becoming slightly shorter than the programmed value due to internal propagation delays. User must decide which solution fits better to the application

#### Datasheet

#### MOTIX<sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver

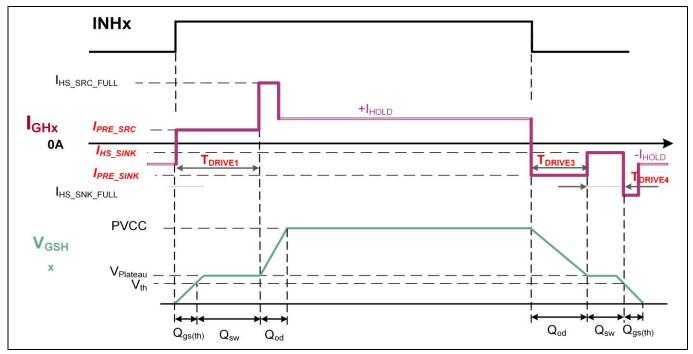


Figure 31 Detail of MOSFET gate charge during the charging and discharging transitions. T<sub>DRIVE2</sub>=0 example

## 4.4 Gate Driver Voltage Programmability

Different drives systems might benefit from different MOSFET technologies. An example is the common usage of logic level MOSFET vs standard or normal level MOSFETs, which show a higher threshold voltage ( $V_{gs(th)}$ ). For the same gate to source voltage, a logic level MOSFET presents lower  $R_{DSON}$  value than a normal level MOSFET.

Increasing the driving voltage helps reducing the R<sub>DSON</sub> of the MOSFET channel during conduction and as a result the conduction losses of the system. This is shown in Figure 32. However, increasing the driving voltage increases the rise switching times (rise and fall) leading eventually to higher switching losses. User must choose the right driving voltage depending on the system conditions.

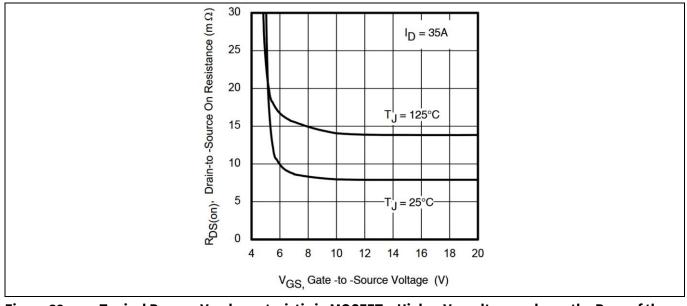


 Figure 32
 Typical R<sub>DSON</sub> vs V<sub>GS</sub> characteristic in MOSFETs. Higher V<sub>GS</sub> voltage reduces the R<sub>DSON</sub> of the MOSFET

ineon

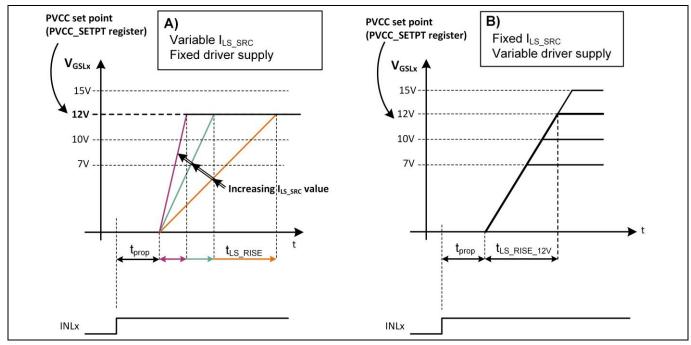


#### MOTIX<sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver

6EDL7141 allows designers to adjust the MOSFET driving voltage (PVCC voltage) via SPI registers. The same value PVCC applies to both high and low side charge pumps with four possible values: 7V, 10V, 12V, 15V. This is done via bitfield PVCC\_SETPT.

It is expected that the high side charge pump produces a lower voltage due to internal circuitry (diode).

Figure 33 shows an ideal example of how supply voltage of the driver and slew rate control can play a role together in an ideal turn on of a low side MOSFET. Section A of the figure shows how to set the slew rate of  $V_{GS}$  external MOSFET, by programming different current values (in this case  $I_{LS_{RISE}}$ ). Section B shows the case in which, provided a fixed gate driver current  $I_{LS_{SRC}}$ , PVCC is varied.



## Figure 33Gate driver slew rate configurability in an ideal low side MOSFET switching: A) given afixed supply voltage (PVCC=12V), variable ILS\_RISE B) Fixing the charging current, changes inPVCC produce different rise times

## 4.5 Charge Pump Configuration

User can adjust charge pumps operation in MOTIX<sup>™</sup> 6EDL7141 depending on the specific needs. Following sections describe this configurations.

## 4.5.1 Charge Pump Clock Frequency Selection

Charge pumps are based on switched capacitor circuits that work at a given switching frequency. 6EDL714 offers the possibility to choose four different clock frequencies via SPI programming of bitfield CP\_CLK\_CFG in register CP\_CFG. The selection of charge pump capacitors both flying and tank capacitors must be chosen according to this configuration and both affect start-up time of VCCLS and VCCHS rails as well as possible voltage ripple in those pins.

Note:



#### MOTIX<sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver

## 4.5.2 Charge Pump Clock Spread Spectrum Feature

When activated, this feature introduces artificially a frequency variation (see Electrical Characteristics table for values) into the charge pump clock signal. The frequency at which the charge pump operates will vary between those limits reducing the emission intensity on the target frequency value by distributing that energy over a wider range of frequencies.

## 4.5.3 Charge Pump Pre-Charge for VCCLS

Pre-charge of the charge pumps is a feature that, if enabled via SPI register, pre-charges the VCCLS rail right below the buck converter output voltage (VDDB) before the EN\_DRV pin is activated. This pre-charge takes place only the first time after a power up (CE cycle) sequence.

In this case, when EN\_DRV is activated to enable the driver stage, the charge pumps need to ramp up the voltage in  $C_{VCCLS}$  from the existing pre-charge voltage until the PVCC selected value, therefore reducing considerably the start-up time for the charge pump when compared to the default situation in which  $C_{VCCLS}$  needs to charge the whole PVCC voltage.

To enable the pre charge of VCCLS, bitfield CP\_PRECHARGE\_EN in register SUPPLY\_CFG must be set.

## 4.5.4 Charge Pump Tuning

The start-up time for the charge pumps, defined as the time that the VCCLS voltage requires to get to the target programmed voltage (PVCC Set point), depends on several factors:

- Target voltage programmed via PVCC\_SETPT register: the higher the longer the start-up time
- Charge pump clock frequency: higher clock frequency results in faster start-up time
- Charge pump tank capacitors (C<sub>VCCLS</sub>, C<sub>VCCHS</sub>): using VCCLS as example, a smaller value of C<sub>VCCLS</sub> will result in:
  - Higher VCCLS ripple
  - o Faster start-up time
- Charge pump flying capacitors (C<sub>CP1</sub>, C<sub>CP2</sub>): smaller capacitors lead to slower start-up time

The selection of those parameters have an impact as well in the VCCLS and VCCHS voltage ripple. If fast start-up time is not a design target, it is recommended to increase the  $C_{VCCLS}$  value to reduce ripple and to improve load transients. For a given  $C_{VCCLS}$  value, the selection of  $C_{CP1}$  will impact also the ripple in VCCLS and start-up time.

If start-up time needs to be optimized, charge pump pre-charge feature is recommended. This is explained in section 4.5.

The start-up behavior of the charge pumps and rest of power supply is shown in detail in section 10.1

## 4.6 Gate Driver and Charge Pumps Protections

The gate driver includes following protections:

- VCCLS UVLO
- VCCHS UVLO
- Floating Gate Driver Pull Down
- Dead Time insertion This is explained in section 4.1.7

## 4.6.1 VCCLS Under-Voltage Lock-Out (VCCLS UVLO)

The UVLO prevents the gate driver from propagating PWM signals if the drive voltage is not above the UVLO threshold as specified in the Electrical characteristics table.

#### MOTIX<sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver

During start-up, the charge pump voltage VCCLS will ramp up until the UVLO rising threshold is crossed releasing the UVLO status, allowing then the PWM to propagate.

In case of overload of VCCLS rail beyond the specified maximum load of the charge pump, the VCCLS will drop. Eventually, the VCCLS voltage can cross the VCCLS UVLO falling threshold leading to both the immediate stop of the PWM signal being transmitted to the MOSFETs by setting the gate driver in Hi-Z (high impedance) mode and also reporting a fault to the Fault handler. Consequently, the nFAULT pin will be pulled down so the XMC1404 can decide how to proceed.

## 4.6.2 VCCHS Under-Voltage Lock-Out (VCCHS UVLO)

Similarly to VCCLS, a UVLO mechanism is integrated for VCCHS voltage rail. The UVLO rising and falling thresholds can be found in the Electrical Characteristics table.

During start-up, the charge pump voltage VCCHS will ramp up until the UVLO rising threshold is crossed releasing the UVLO status, allowing then the PWM to propagate.

In case of overload of VCCHS rail beyond the specified maximum load of the charge pump, the VCCHS voltage will start dropping. VCCHS voltage can then cross the VCCHS UVLO falling threshold leading to both the immediate configuration of the gate driver to Hi-Z (high impedance mode) and also to the reporting to the Fault handler. As a result of the VCCHS UVLO, the nFAULT pin will be pulled down so XMC1404 can decide how to proceed.

## 4.6.3 Floating Gate Strong Pull Down

MOSFETs in an inverter can be exposed to non-zero gate voltage levels when the controllers or gate drivers are off. Sometimes those voltages are enough to activate or partially activate the MOSFETs leading to system failure or destruction if for example, a high side MOSFET and a low side MOSFET in an inverter leg activate at the same time. In order to prevent this behavior is common to assemble weak pull downs (in the order of  $100k\Omega$ resistors) between gate and source of the MOSFET to ensure that when the gate driver is off, the gate is pulled down to the source avoiding any turn on or partial turn on. As it is weak pull down, this does not have noticeable impact when the gate driver is active and driving MOSFETs normally.

These six R<sub>G-S</sub> resistors however require a good amount of PCB area and need to be placed in a location where the power layout needs to be optimized with no compromises.

In order to address this, 6EDL7141 gate driver integrates a floating gate strong pull down mechanism that includes both a passive and an active pull down:

- Weak Pull Down: a weak pull down (R<sub>GS\_PD\_WEAK</sub>) is always connected between gate and source of each gate driver output. This ensures a weak pull downs during states where the gate driver is off, either because EN\_RV is turned off or because the device is fully off (CE off). This mechanism is similar to the ones described above (R<sub>G-S</sub>).
- Strong Pull Down: additionally, during those gate driver off periods, if the external gate to source voltage increase for any reason as mentioned, an extra pull down, much stronger (R<sub>GD\_PD\_STRONG</sub>) is activated ensuring a tight pull down and hindering any possible partial turn on.



### MOTIX<sup>™</sup> 6EDL7141 Three Phase Integrated Smart Gate Driver

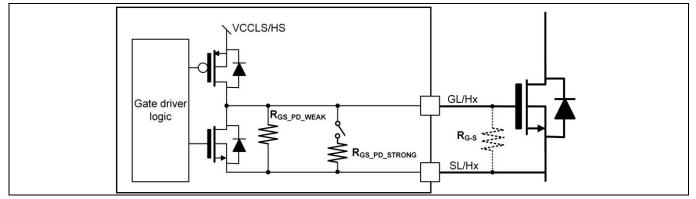


Figure 34 Floating gate driver pull down resistors. Strong pull down activates when gate driver is off and gate to source voltage increases

#### MOTIX<sup>™</sup> 6EDL7141 Power Supply Subsystem



#### 5

## MOTIX<sup>™</sup> 6EDL7141 Power Supply Subsystem

The device embeds an advanced power supply system comprised of:

- Synchronous buck converter including both power switches
- DVDD linear voltage regulator pre-programmed to 3.3V (IMD700A) or 5V (IMD701A)
- Charge pump for low side gate driver (described in 4)
- Charge pump for high side gate driver (described in 4)

MOTIX<sup>™</sup> IMD70xA has been designed for lowest Bill of Material (BOM). The synchronous buck converter does not require external components like diodes, voltage dividers or bootstrap capacitors yet at the same time reduces the low side conduction losses as it utilizes a NMOS instead of a diode.

The overall goal of the buck converter is to support the rest of the power supply system. With the help of an external filter (LC), it supplies both (high side and low side) charge pumps and the integrated DVDD voltage regulator. This architecture increases the efficiency of the device greatly compared to an only linear regulator system, yet maintains a very compact system solution. Furthermore, allows working at high supply voltage rating (PVDD).

DVDD linear voltage regulator is integrated to provide accurate and stable voltage to XMC1404 and other external components. In Figure 35, a schematic diagram of the complete power converter architecture and interconnections is showed.

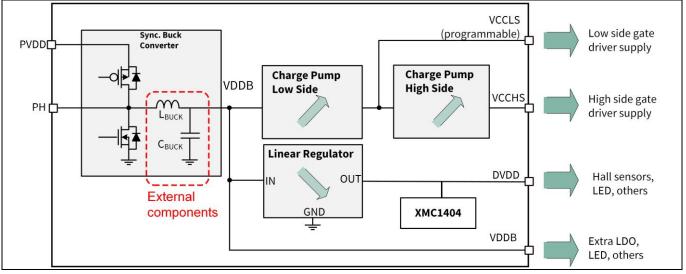


Figure 35 Block diagram of power converter architecture

Designers can use VDDB pin to supply external components as long as the current limits of the buck converterincluding charge pumps and linear regulator- are not exceeded. Nevertheless, over-current protections (OCP) are implemented for both buck converter and the linear regulator, preventing any damage to the device when overloading VDDB pin. Additional over-temperature protections (OTS, OTW) are integrated to ensure the device is under correct thermal conditions at any time.

## 5.1.1 Synchronous Buck Converter Description

Although integrated in the same package, the synchronous buck converter is designed completely independent of the rest of the gate driver circuitry. This makes the supply system robust against gate driver failures. As an example, the buck converter and linear regulator will still operate even if a failure occurs in the gate driver





section (e.g. VCCLS UVLO), ensuring right operation of circutis in the system supplied by the buck converter or LDO integrated.

The control method utilized is Adaptive Constant 'ON' Time (ACOT). In contrast to a pure constant ON time control method, ACOT allows for ON time variations during transitions to avoid large frequency jumps. Together with feedforward techniques, this buck converter can operate almost at fixed switching frequency.

Two different switching frequencies (500 kHz and 1 MHz) can be selected via SPI –BK\_FREQ bitfield-for the buck converter. The recommended inductor and capacitor for each configuration is provided in section 12.1. Recommended values for the inductor and capacitor are shown in Table 30.

Note: It is recommended to only modify the buck converter frequency via OTP

A detailed figure of both synchronous buck converter and linear voltage regulator circuits is depicted in Figure 36.

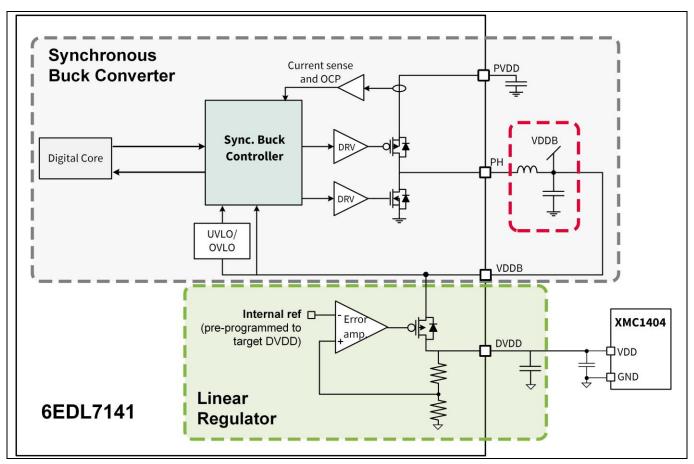


Figure 36 Detail of integrated synchronous buck converter controller and linear regulator

# 5.1.1.1 Buck Converter Output Voltage Dependency on PVCC\_SETPT

An important feature of the buck converter is the ability to automatically adjust VDDB target value depending on PVCC (target gate driver voltage) configured by user via SPI commands. This is done to optimize power losses in the device. For example, if the driving voltage PVCC is 7V, the target voltage of the buck converter is automatically set to 6.5V given and still the charge pumps will have enough room to reach PVCC = 7V on a 'doubler' configuration. The relationship between VDDB and PVCC is shown in Table 23.

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#### MOTIX<sup>™</sup> 6EDL7141 Power Supply Subsystem

Table 23	<b>Buck converter out</b>	put target voltag	ge vs PVCC	SETPT setting

PVCC_SETPT bitfield	PVCC target voltage (V)	VDDB (V)
b'11	7	6.5
b'10	10	7
b'00	12	8
b'01	15	8

Another important factor to consider in the synchronous buck converter output target voltage is PVDD or supply voltage. If PVDD is low enough so VDDB<sub>NOM\_LV</sub> rating applies (see Electrical Characteristics table), then the buck converter cannot ensure the target output voltage as provide in Table 23. In this situation, the buck converter enters a 'limiter' mode in which the duty cycle saturates to DC<sub>BUCK\_MAX</sub> (see Electrical characteristics table). If buck converter loading increases or PVDD voltage reduces further, VDDB voltage will drop. On the lower end, VDDB UVLO falling threshold protects from lower limits.

Therefore, depending on PVDD voltage, it is possible that VDDB cannot reach the target voltage, limiting as a consequence the actual PVCC voltage, which even in a doubler configuration might not be sufficient. The approximate possible PVCC voltage (= VCCLS) in the doubler configuration is given by the minimum between the target PVCC voltage or twice VDDB minus 1 V as shown in following equation:

$$PVCC_{max} \approx \min(PVCC Target Voltage, 2 * VDDB - 1V)$$
 (1)

As an example, if PVDD = 7.5V, VDDB  $\approx$  6.5V (limited by low PVDD), if PVCC\_SETPT targets 15V, the doubler on the charge pump will be able to reach maximum of approximately 2\* VDDB-1V  $\approx$  12V. If then PVDD rises to 12V, the VCCLS will be able to regulate to 15V as this value is below/equal to the value = 2\* VDDB (8V) -1V = 15V.

See 2.7 for more details on relationship between VCCLS, VCCHS and PVDD.

# 5.1.1.2 Synchronous Buck Converter Protections

Following protections are implemented to ensure correct operation of the buck converter:

- Output Under-Voltage Lock-Out (UVLO). See Electrical Characteristics table for specific values
- **Output Over-Voltage Lock-Out (OVLO)**. See Electrical Characteristics table for specific values. If the value is reached the buck converter will switch off both high side and low side MOSFETs interrupting any further energy transfer to the output.
- **Over-Current Protection (OCP)** cycle by cycle. Given a situation in which the current increases till the OCP level (see Electrical Characteristics table for details), the buck converter controller will truncate the high side FET PWM signal until next PWM period start. The low side FET will be driven accordingly after insertion of dead time. The OCP level reduces as well if PVDD is below 7.465V to ensure proper device operation.

Once the OCP event takes place, a counter will start counting for each consecutive period that the peak current is reached. After 16 periods, the Buck OCP fault is triggered and nFAULT pin (see Table 25) will be set low to inform the XMC1404 that can proceed with correcting actions. The Buck converter will continue operation in current limitation to ensure XMC controller is supplied. If the OCP does not trigger for 3 consecutive PWM periods, the counter will reset and will not trigger the Buck OCP fault. If the Buck OCP fault is activated, the bitfield BK\_OCP\_FLT in register FAULT\_ST will be set.

# 5.1.2 DVDD Linear Regulator

The integrated linear regulator generates the voltage rail DVDD that can supply XMC1404.

#### Attention: User must connect externally all DVDD pins as there is no internal connection for DVDD inside.

Datasheet

Datasheet

#### MOTIX<sup>™</sup> 6EDL7141 Power Supply Subsystem

DVDD linear regulator can be used as well to provide an offset to the current sense amplifiers integrated, allowing negative current measurements. See 6.1.4 for more details.

The linear regulator is soft started during ramp up of the device as depicted in Figure 56 after a delay time  $t_{DVDD_TON_DLY}$  once the buck converter has reached its UVLO level ( $V_{VDDB_THH_UV}$ ) and analog programming of CS\_GAIN is finished. The DVDD ramp up timing can be configured via SPI via bitfield DVDD\_SFTSTRT.

A schematic view of DVDD linear regulator and the interaction with the buck converter is presented in in Figure 36.

DVDD voltage is be used to supply the integrated XMC1404 controller and can be used to supply additional elements in the circuit like Hall sensors, LEDs, etc. A programmable OCP mechanism is provided to avoid damage to the LDO due to excesive current demand.

# 5.1.2.1 DVDD Linear Regulator OCP

DVDD OCP can be configured between 4 different levels by writing register DVDD\_OCP\_CFG. If the OCP for DVDD is reached, a fault will be reported on pin nFAULT. The DVDD OCP works in two different stages:

- 1. **Pre-warning mode at 66% of selected OCP level**: nFAULT pin will be pulled down to signal the controller that an OCP warning has occurred. If the current level reduces before reaching 100% level, the operation will continue normally releasing the nFAULT pin. The pre-warning allows some extra time for XMC1404 to make a decision on how to react to the possible OCP event.
- 2. **Current limiting mode at 100% of selected OCP level**: if current increases beyond the configured OCP level, the DVDD regulator will start limiting the current provided. This will cause a DVDD voltage drop, eventually resulting in a DVDD UVLO fault if DVDD UVLO threshold is crossed (see the Electrical Characteristics table for more details). Thanks to this limitation, possible shorts on DVDD rail will not affect rest of the system keeping these other components safe.

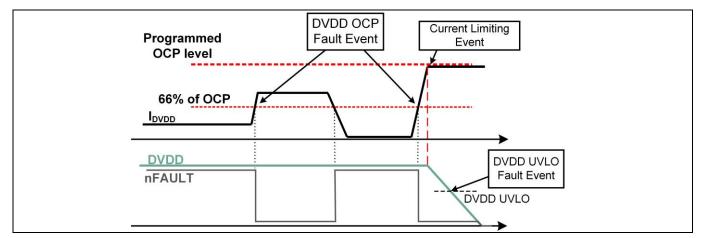


Figure 37 DVDD OCP behavior including pre-warning and current limiting modes

Note: The OCP in DVDD is suppressed during ramp up of the device to avoid that initial charge of DVDD decoupling capacitors (eventually large capacitors) triggers the OCP fault

Over-temperature faults (OTS, OTW) provide an additional level of protection. These will trip if too high temperature is developed in the device, for example when the DVDD linear regulator or the buck converter demand excessive load current.



#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

# 6 MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

The device integrates three current sense amplifiers that can be used to measure the current in the power inverter via shunt resistors. Single, double or triple shunt measurement are supported as shown in Figure 38.

CS\_EN bitfield enables each current sense amplifier individually. The output of the current sense amplifiers can be connected to the ADC inputs (AINx pin) of IMD70xA via optional RC filters to remove high frequency components. Gain and offset are generated internally and must be programmed via SPI commands.

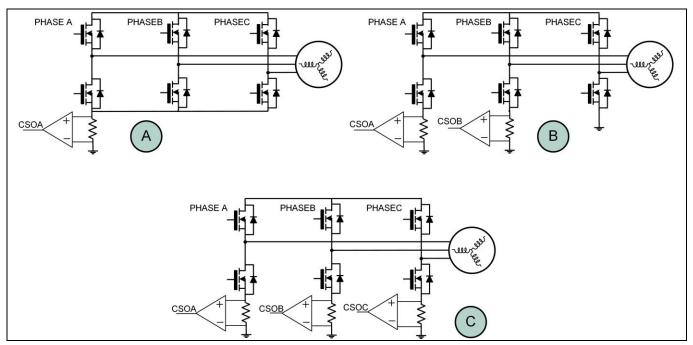


Figure 38 Single (A), dual (B) and triple (C) shunt current sensing configurations are supported

The current sense amplifier block contains the following sub-blocks explained in detail this section:

- **Current sense amplifier**: connected to external shunt resistor or internally to SHx and SLx pins for R<sub>DSON</sub> sensing configuration. This module amplifies the shunt voltage or V<sub>DS</sub> voltage to a more appropriate voltage level for a microcontroller ADC. It allows as well blanking the signal synchronized to PWM transitions, during periods where noise is disturbing the measurement. Gain must be set via SPI programming in IMD70xA, no resistor configuration is possible.
- **Output buffer**: allows adding a variable offset voltage to the sense amplifier output. The offset amount can be set to 4 different values by programming the internally generated level. With this implementation, negative current in current shunts can be measured. Additionally permits to optimize the controller ADC dynamic range according to system conditions.
- **Positive Over-Current comparator**: used for detecting the over-current condition on motor winding for positive shunt voltage This comparator can be used to apply PWM truncation in trapezoidal commutation schemes, limiting the motor current to the configured OCP threshold.
- **Negative Over-Current comparator**: used for detecting the over-current condition on motor winding for negative shunt currents
- **OCP Digital-to-Analog Converter (DAC)**: used for programming the threshold of the over-current comparators. One for positive level and a second one for negative level. Programming of DAC levels is shared among different OCP comparators.



#### Datasheet

#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

Current sense amplifiers are able to "Auto-Zero" during operation and ensures best accuracy of measurements during lifetime of the device. Additionally, the device includes a current sense amplifier user calibration mode that can be used to calculate residual offset before the driver is enabled (EN\_DRV low), therefore ensuring current in the inverter and in the shunts are zero. XMC1404 can remove this initial residual value from future measurements to improve accuracy.

Figure 39 shows these blocks and their interconnections.

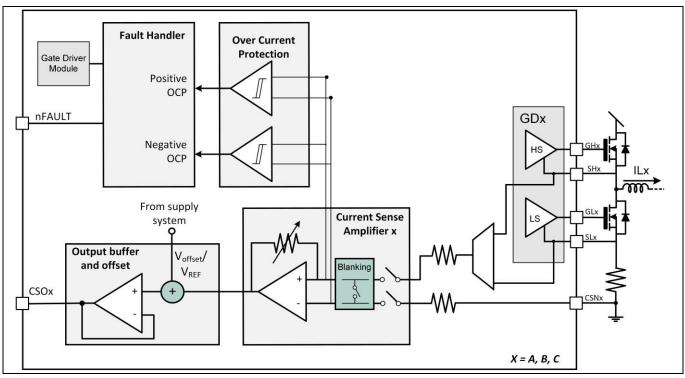


Figure 39 Current sense amplifier simplified block diagram

# 6.1.1 R<sub>DSON</sub> Sensing Mode vs Leg Shunt Mode

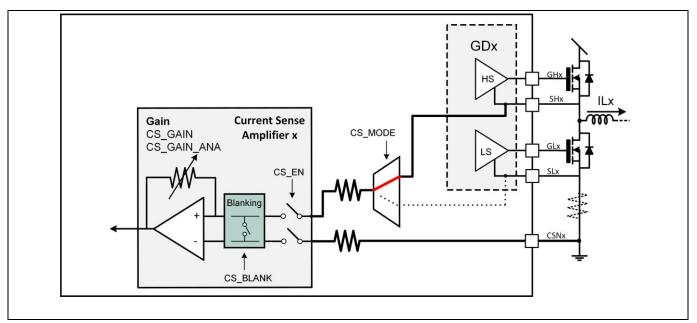
Current sense amplifiers in MOTIX<sup>™</sup> 6EDL7141 can be configured as leg shunt or R<sub>DSON</sub> sensing, where the 'ON' resistance of the MOSFETs is used as shunt in a 'lossless' measurement approach.

In R<sub>DSON</sub> mode, 6EDL7141 connects the drain of the low side MOSFET to the positive input of the current sense amplifier. The negative input is connected to the source as shown in Figure 40. This is in contrast to the external shunt configuration shown in Figure 41, where the positive input of the current sense amplifier is connected to the source of the low side MOSFET. Internal series resistors help filtering possible noise before the amplification takes place. Depending on the circuits and board design, a small filtering capacitor between SLx and CSNx pins can help cleaning up the current signal.

Note:	R <sub>DSON</sub> mode is only possible in 3 shunt mode (mode C in Figure 38)
Note:	In R <sub>DSON</sub> mode, the CSAMP is forced to be CS_TMODE = 0, meaning the current sense amplifiers are only active when low side is ON (GL ON mode).Writes different than b'0, will be ignored by the internal logic.
Note:	Temperature compensation for the R <sub>DSON</sub> measurement, if required, must happen via XMC1404 algorithms not provided here.



#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers



# **Figure 40** System diagram of a low side R<sub>DSON</sub> current sensing configuration utilizing integrated current sense amplifiers

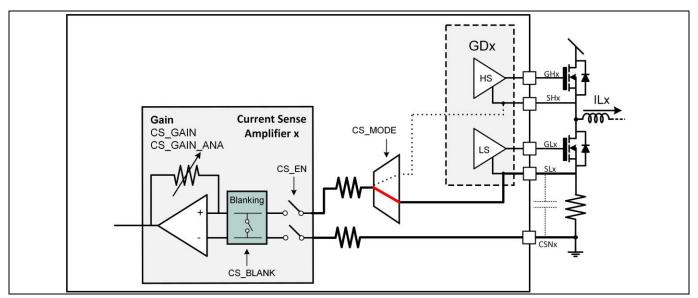


Figure 41 System diagram of an external shunt current sensing configuration utilizing integrated current sense amplifiers

# 6.1.2 Current Shunt Amplifier Timing Mode

Often in drives applications, the current is sampled via leg shunts. IN this case, the voltage in the shunt that needs to be amplified appears only when the low side MOSFET is turned on. In other cases, it might be useful to propagate the signal continuously. IMD70xA supports four different modes of operation of the current sense amplifiers regarding when the output pin CSOx is connected to the amplifierstage. These four modes are:

• Always OFF: current sense amplifier output disabled. This is achieved by disabling the amplifier in register CSAMP\_CFG via bitfield CS\_EN.



#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

- GL ON: in this mode, CSOx pin is connected to the amplifier only when the same leg or phase GLx signal is active. In single shunt mode, CSOx will be connected according to the OR'ing of all two or three GLx signals. If two or three amplifiers are enabled, then the signals for enabling CSox will be dedicated to that GLx signal. This mode is forced if R<sub>DSON</sub> sensing is selected to avoid possible overvoltage damage in the internal circuitry. In order to enable this mode, the amplifier must be enabled via CS\_EN bitfield in CSAMP\_CFG register and the timing mode selected via write to CS\_TMODE bitfield in SENSOR\_CFG.
- **GH OFF**: similarly to GL ON, this modes connects the CSOx outputs during GL ON period but extends that connection to the dead times both rising and falling. This is same than GH OFF. In some cases like during diode recirculation current, the diode might carry current that can be useful especially in cases where the PWM pulses are very narrow. Same as GL ON, single shunt will logic OR the GLx activations and three shunt modes will activate according to each GLx signal only. In order to enable this mode, the amplifier must be enabled via CS\_EN bitfield in CSAMP\_CFG register and the timing mode selected via write to CS\_TMODE bitfield in SENSOR\_CFG.
- Always ON: this mode connects continuously the activated amplifier CSOx signals to the amplifier independently of PWM signals. In order to enable this mode, the amplifier must be enabled via CS\_EN bitfield in CSAMP\_CFG register and the mode selected via write to CS\_TMODE bitfield in SENSOR\_CFG.

Figure 42 (cases 1 and 2) shows a comparison of the current sense amplifier working in both modes GL ON and GH OFF.

#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

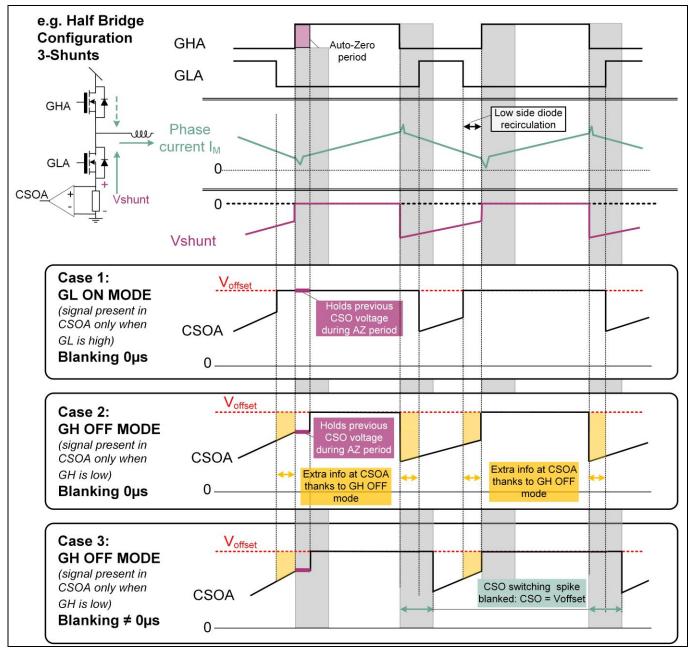


Figure 42 Current sense amplifier ideal timing mode examples. Mode GL ON and GH OFF operation in a half bridge example with leg shunt current sense configuration-3 active amplifiers. GH OFF can potentially propagate current information when the diode recirculates current. Auto Zero injected on GHx rising (internal sync.)

# 6.1.3 Current Shunt Amplifier Blanking Time

A programmable blanking period can be configured in the current sense amplifiers. The goal of adding some blanking time is to avoid propagating a distorted signal to the microcontroller ADCs during MOSFET switching transitions. Since both, phase node voltage SHx and SLx pins (CSNy) are subject to ringing due to the switching activity, the blanking module disconnects the inputs for a configurable time (CS\_BLANK). This action occurs in synchronicity with GHx signals (rising and falling edges) driving the external MOSFETs.

During the blanking time, pin CSO will show V<sub>offset</sub> voltage until the programmed blanking time period expires and inputs are connected again to the current sense amplifier. Two examples are shown in Figure 43. Example

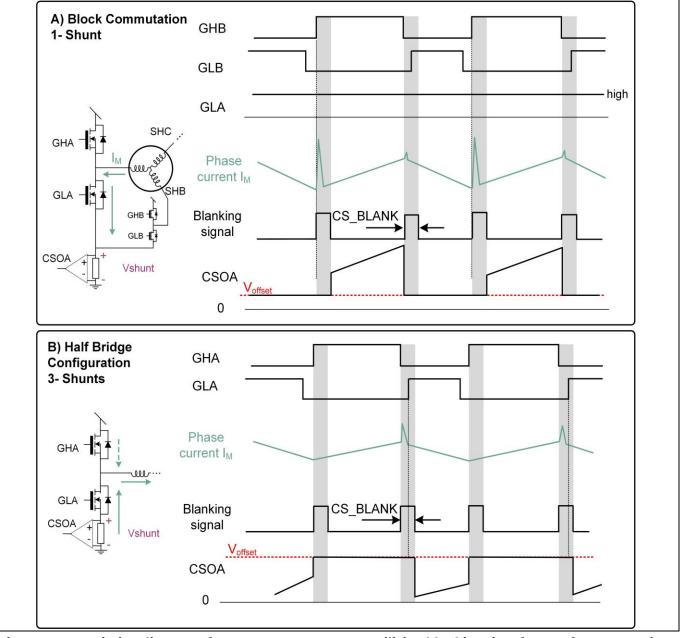




#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

A) represents a trapezoidal commutation scheme with 1 shunt similar to the one in Figure 61. In such case the high side of one phase (phase B) is switching, while the low side of another phase (phase A) is always ON, allowing the current to flow through the motor windings. As the low side MOSFET of phase A is ON for 120 degree of rotation, the current sense amplifier is amplifying the shunt voltage continuously except blanking and recirculation periods. These blanking periods corresponds to both high side and low side rising edges (ORing of all phases). In this case the voltage across the shunt is positive.

The example in B) corresponds to a generic half bridge configuration (e.g. synchronous buck converter). In this case, when high side is turned on, the current in the inductor increase, while in the complementary cycle when the high side switches off and the low side turns on after dead time, the current flows through the low side and starts decreasing. During the low side conduction, the current sense amplifier generates the shown output proportional to the voltage across the shunt, in this case negative.



# Figure 43Timing diagram of a current measurement utilizing blanking time feature for suppressing<br/>current spikes during MOSFET switching. A) Trapezoidal commutation with 1 shunt<br/>configuration. B) Generic half bridge configuration.



MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

# 6.1.4 Current Sense Amplifier Internal Offset Generation

6EDL7141 integrates an internal linear voltage regulator (DVDD) that can be used for offset generation in all integrated current sense amplifiers. The generated DVDD voltage can be scaled down to different programmable values to adjust the desired offset voltage level. Bitfield CS\_REF\_CFG controls this scaling factor.

XMC1404 generates internally the reference for the integrated ADC out of the supply voltage. In this way the microcontroller can accurately measure in a ratio-metric way the output of the current sense amplifiers increasing noise immunity. Figure 44 shows a block diagram representing this implementation. Only internal offset generation is possible in IMD70xA.

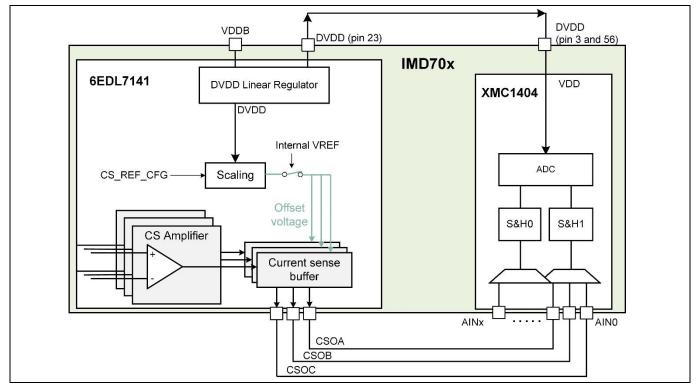


Figure 44 Current sense amplifier offset generation block diagram

# 6.1.5 Overcurrent Comparators and DAC for Current Sense Amplifiers

Two overcurrent comparators are implemented for monitoring the current in both positive and negative direction with an extensive level of programmability. Figure 45 shows a schematic diagram of this implementation. Both comparators monitor the current flowing through the shunts. The triggering level is independent from the gain setting of the shunt amplifiers and is defined as the voltage across the shunt. The comparator features a hysteresis (specified as V<sub>OC\_HYST</sub>) for consistent operation.

Positive and negative triggering levels for the comparator are set with two independent Digital to Analog Converters (DAC). These DACs are programmed via bitfields CS\_OCP\_PTHR for positive overcurrent protection and CS\_OCP\_NTHR for negative overcurrent protection. For possible threshold levels see the registers description in section 11.

The output of the comparators can be deglitched by programming register CS\_OCP\_DEGLTICH before reaching the Fault handler, where the fault will be processed (See section 6.1.8) and eventually will pull down nFAULT pin reporting a fault to XMC1404.



#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

Alternatively, the comparator output propagates to the PWM modules. PWM truncation can be enabled via bitfield CS\_TRUNK\_DIS. If PWM truncation is activated, the PWM module immediately interrupts the PWM signal without having to wait for the XMC1404 to make such decision if the OCP level is reached. This ensures fastest possible reaction time to the OCP event. Truncation is detailed in section 0.

CS\_OCPFLT\_CFG in register CSAMP\_CFG allows the user to set a target number of consecutive events (PWM cycles with current above OCP threshold) that will activate OCP fault. This means the user can configure the device to wait for several PWM periods before declaring a fault.

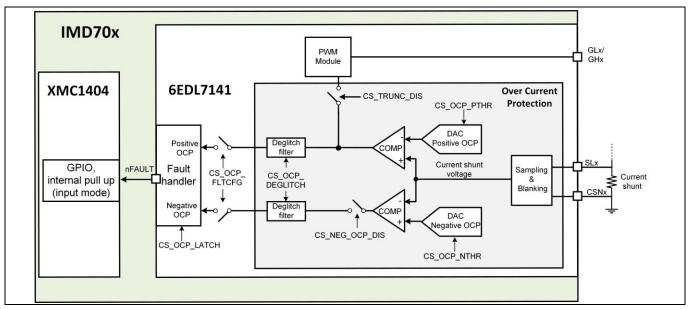


Figure 45 Current sense amplifier protections schematic block diagram

# 6.1.5.1 OCP Use Cases

The reaction to an OCP event is programmable via SPI. Following scenarios might be useful for different applications:

- **Apply PWM truncation** immediately after OCP event **and report on nFAULT** pin after OCP event- deglitching is disabled if truncation is enabled.
- **Disable reporting and keep truncation of PWM**. This can be useful during events where the reporting function to the microcontroller might not be necessary.
- **Trigger a configurable brake action** upon OCP event. If truncation is not desired, the brake event can be configured to e.g. brake the motor by shorting all low side MOSFETs. By using the deglitch function, the possible noise in the analog signal can be filter out to avoid false trip of the OCP. This configuration can be useful for FOC (Field Oriented Control) schemes given the flexibility. Braking is explained in more detail in sections 4.1.6 and 6.1.8.
- **Disable OCP protection,** both nFAULT reporting and truncation of PWM. In such case, OCP is ignored. This might be useful for transition states or stop procedures as well.

These configurations can be adjusted also during ACTIVE state of the device. It is also possible to select whether the OCP fault trips on a single event or more and whether is latched or not via bitfield CS\_OCP\_LATCH.

# 6.1.5.2 OCP Fault Reporting

In case of OCP fault, 6EDL7141 can report the fault by pulling down pin nFAULT. Internally, IMD70xA connects this pin to P3.4 pin in XMC1404. XMC code can poll this GPIO pin to be informed of the fault and make a decision.

Datasheet



Datasheet

#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

CS\_OCPFLT\_CFG in register CSAMP\_CFG allows the user to set a target number of consecutive events (PWM cycles with current above OCP threshold) that will activate OCP fault. This means the user can configure the device to wait for several PWM periods before declaring a fault and therefore be more conservative. Three options are possible: no fault, trigger immediately (i.e. trigger on all events) or trigger on a number of counts (8 or 16). The logic for the counting mode works as follows:

- 1. Every time that an OCP event occurs, a counter increments. All three phases have dedicated counters.
- 2. If any counter (ORing) reaches the target value configured in CS\_OCPFLT\_CFG, then the fault is asserted and nFAULT pin is pulled low.
- 3. If before reaching the target value, the OCP event does not occur for 3 consecutive PWM cycles, the counter is reset to value 0, starting over next time an OCP event takes place.

# 6.1.5.3 OCP Fault Latching

The OCP fault can be configured as latched or non-latched. This defines how the fault is cleared via register write. If configured as latched:

- and in counting mode (8 or 16): fault cannot be cleared until there is one whole PWM period without fault
- and in immediate or on all events mode: fault can be cleared only after the fault condition is released.

If not latched, the fault can be cleared any time. If conditions is still present after clear, the fault will be set again after the clear event.

Independently of the latch configuration, the status register will show that the fault happened.

# 6.1.5.4 PWM Truncation

PWM truncation is a method to intrinsically limit the current flowing into the motor by switching off the PWM signal immediately after OCP detection. In this way, the GHx signals (all three) are pulled down automatically when the configured peak current level is reached. Low side remains unaffected until the PWM resets, increasing current in the motor again. This happens in a PWM cycle by cycle base. An example of how PWM truncation works, is depicted in detail in Figure 46.

*Note:* Truncation occurs always on high side except for 1PWM mode with alternate recirculation, where the truncation occurs in low side during high side recirculation periods.

If PWM truncation is active, PWM truncation takes place upon OCP event in all phases. For example, if the protection is triggered in current sense amplifier A, then PWM signals in phases A, B and C will be truncated. This will enable single shunt systems to utilize any of the current sense amplifiers.

Blanking is applied to truncation logic on both rising and falling edge of high side as described in Figure 43, see register CS\_BLANK for blanking times. Blanking from all phases are OR'ed and prevent any miss-triggering of the PWM truncation during the blanking time selected by the user.

If truncation is enabled, the deglitching filter is automatically disabled. This means, if truncation is enabled, the nFAULT pin signalizes simply that a PWM truncation has occurred.

# Attention: Depending on the PWM modulation utilized, PWM truncation might not provide the desired results. In modulation schemes where it is possible more than one phase are energizing the motor at a given time like SVM FOC (Space Vector Modulated Field Oriented Control), it is recommended to disable truncation and use OCP fault instead.

#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

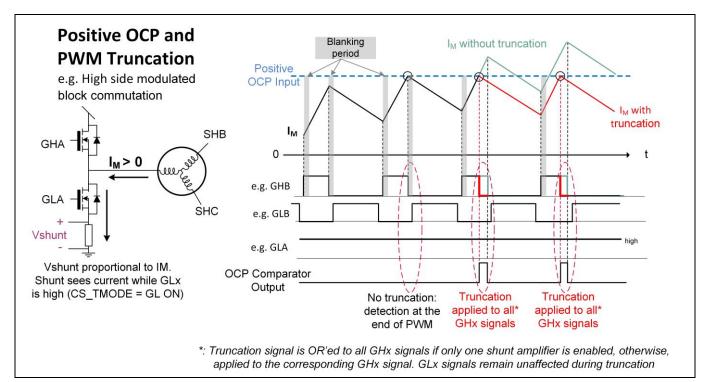


Figure 46 Positive OCP PWM truncation detail. I<sub>M</sub> refers to motor current.

# 6.1.6 Current Sense Amplifier Gain Selection

During start-up of the system, user must program the desired gain of the current sense amplifier. To do this, user must write bitfield CS\_GAIN\_ANA to ensure digital programming of the gain and write as well CS\_GAIN bitfield to set the actual gain. The actual value can be read in CS\_GAIN\_ST which reports the current gain value programmed. Gain of the shunt amplifiers can be programmed to one of the following values: 4, 8, 12, 16, 20, 24, 32 and 64.

Attention:Analog gain programming is not supported in IMD70xA devices. Default configuration is set to<br/>analog programming in 6EDL7141 and user must ensure to first change to digital<br/>programming and second to program desired gain before starting operation

# 6.1.7 Current Sense Amplifier DC Calibration

MOTIX<sup>™</sup> 6EDL7141 features a calibration method for the current sense amplifiers. This helps eliminate any unwanted offset in the output of the operational amplifiers before starting motor operation for example.

The activation of the DC calibration mode (only during ACTIVE state-EN\_DRV high) via register CS\_EN\_DCCAL programming, will short the inputs of the amplifiers. Once the DC calibration is enabled, the output on CSOx pins can then be measured by precise ADC channels in XMC1404 AINx pins to record any possible offset in the system. Any excess voltage in CSOx pin from internal VREF voltage can be subtracted by XMC1404 embedded code from any future measurements. It is recommended to perform DC calibration before the PWM is started, when the current in the shunts, is known to be zero. This algorithm must be implemented by user.

Once the offset value is captured, XMC1404 must set CS\_EN\_DCCAL bitfield again to '0' to finalize the calibration process and reconnect the operation amplifier to the input pins. Then the PWM signals can start-up.

*Note:* During calibration mode, if Auto-Zero is enable it will be executed every 100µs instead of 200µs.



#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

# 6.1.8 Auto-Zero Compensation of Current Sense Amplifier

Current sense amplifiers tend to accumulate offset during operation if they are not corrected. This can be due to temperature or the aging effects. The Auto-Zero feature of the current sense amplifiers provides an automatic way of compensating any possible drifts in the amplifiers. Internally the amplifier shorts the inputs to correct any possible offset excess for a t<sub>AUTO\_ZERO</sub> period of time. CSOx pin will hold the voltage before the Auto-Zero start during Auto-Zero period.

The Auto-Zero feature can be as well disabled via register bitfield AZ\_DIS in register CSAMP\_CFG.

# 6.1.8.1 Internal Auto-Zero

If configured as internally triggered or synchronized (by writing register bitfield CS\_AZ\_CFG), the Auto-Zero period starts with GHx signal rising edge after at least 100µsec from last Auto-Zero period (x depends on the activated current sense amplifier, A, B or C). The synchronized start of Auto-Zero period is chosen to interfere minimum possible with the shunt current sensing. When the high side MOSFET turns on, the low side MOSFET is off and therefore no signal should be present in the shunt in normal conditions, therefore not affecting the sampling of relevant information in the signal. Details of signals behavior example can be seen in Figure 42 or in Figure 47.

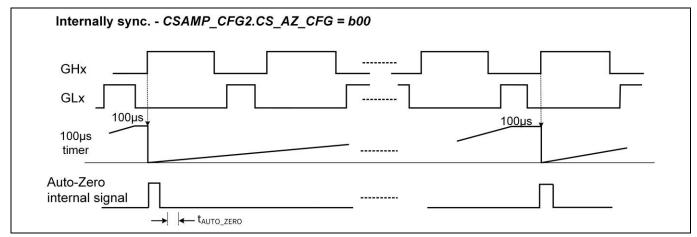


Figure 47 Auto-Zero operating modes. Auto-Zero occurs upon next GHx rising edge after timer has reached 100µs. Auto-Zero period will then rest the timer again

During start-up, the Auto-Zero function automatically activates to ensure that the amplifiers are optimized before the ACTIVE state is entered. This happens during charge pump start-up, this is from EN\_DRV turn on until charge pump UVLO is reached.

If no GHx rising edge happens for a given time ( $t_{AUTO_ZERO_CYCLE}$ ), for example if the low side is fully turned on for a long period in a 6-step commutation, then an internal watchdog will force an Auto-Zero compensation. Auto-Zero continuous during STANDBY state.

*Note:* When the Auto-Zero period finishes and the CSOx reconnects to the amplifier, it is expected to see a minor voltage glitch. This can be blanked or filtered out for example before the signal is provided to an ADC.

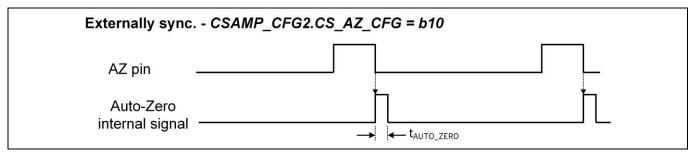


#### MOTIX<sup>™</sup> 6EDL7141 Current Sense Amplifiers

# 6.1.8.2 External Auto-Zero Synchronization via AZ Pin

User can enable external synchronization of the Auto-Zero function by writing register bitfield CS\_AZ\_CFG. In such case, the internal synchronization with GHx signals is disabled and the falling edge of pin AZ becomes the trigger for Auto-Zero correction period. This is depicted in Figure 48.

In IMD70xA, pin AZ is internally connected to pin P1.2. If externally triggered, XMC1404 can decide according to the particular current sense method when to execute the Auto-Zero correction by activating P1.2. Thanks to this feature the Auto-Zero effect can be moved, for example, far from the ADC sampling in XMC benefitting from the corrections but still being able to sample without the interference of the Auto-Zero process.



# Figure 48 Auto-Zero functionality with external synchronization. AZ pin falling edge will trigger the Auto-Zero correction period

# 6.1.8.3 External Auto-Zero Synchronization via AZ Pin with Enhanced Sensing

MOTIX<sup>™</sup> 6EDL7141 to stop the clock (clock gating) of the charge pump modules according to AZ pin state. If this feature is activated, the charge pumps clock will be gated from the rising edge of AZ pin until end of Auto-Zero period that starts after falling edge of same pin. The effect of the clock gating is the reduction of possible switching noise that can couple into PCB sensitive signals like CSOx or other ADC measured voltages by XMC1404.

Attention: During clock gating period, the charge pump stops operation. As a result, VCCLS and VCCHS rails stops regulation and can drop their regulated voltages. In most cases, VCCLS and VCCHS capacitors will maintain enough voltage to keep driving efficiently the MOSFETs. User must check that Recommended Operating Conditions and MOTIX™ 6EDL7141 Electrical Characteristics are respected. UVLO protections on both VCCLS and VCCHS are present in case a malfunction takes place, protecting the inverter

The operation of charge pump clock gating mode is shown in Figure 49.

#### Datasheet



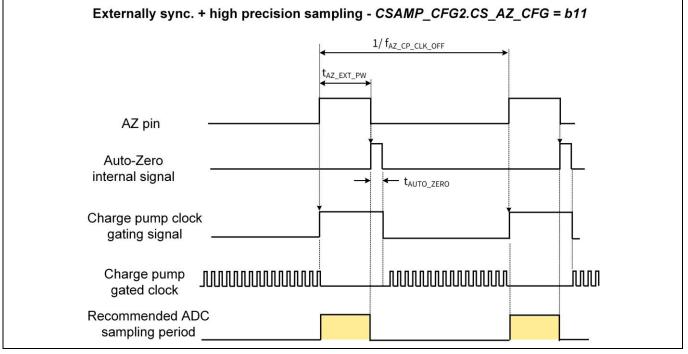


Figure 49 Signal diagram for the enhanced sensing mode using external synchronization of Auto-Zero function. The charge pump clock is gated to reduce switching noise coupling during periods where sensitive measurements are performed in the system like the ADC in XMC1404 or other external sampling circuits



7



MOTIX<sup>™</sup> 6EDL7141 House-Keeping Functions

# MOTIX<sup>™</sup> 6EDL7141 House-Keeping Functions

# 7.1 Hall Comparators

Hall comparators are designed to be used in 1PWM mode with Hall sensors or emulated signals from XMC1404, described in section 4.1.4 as well as for 'locked rotor' detection functionality described in 7.2.3.

The Hall inputs are digitally deglitched. That means those inputs ignore any extra Hall transitions for a configurable period of time. This is selected in bitfield HALL\_DEGLITCH that can be accessed via SPI commands. This prevents PWM noise from being coupled into the Hall inputs, which can result in erroneous commutation.

The polarity of the Hall sensor inputs can be read at any time in register FUNCT\_ST, bitfield HALLIN\_ST.

# 7.2 Watchdog Timer

MOTIX<sup>™</sup> 6EDL7141 integrates three independent watchdog timers that are SPI configurable. These are protection features used to ensure the correct functionality of different modules inside and outside the device, e.g. to ensure that XMC1404 is having correct behaviour by serving or 'kicking' the watchdog. To configure watchdog timers two registers are available: WD\_CFG and WD\_CFG2. The three independent watchdog timers are:

- Buck converter watchdog:
- General purpose watchdog
- Rotor locked watchdog

Each watchdog timer core unit includes a digital timer (watchdog timer). A source signal is connected to that timer which resets whenever a toggle occurs on the signal. Otherwise the timer keeps counting up. If the watchdog timer limit is reached without a reset input, then a fault takes place and action will be performed according to Table 25.

The reaction to a watchdog fault is programmable to following actions:

- Reporting to status register only.
- Reporting to status register and nFAULT pin connected internally to XMC1404 (pin P3.4).
- Trigger a configurable braking event.
- Select whether watchdog fault is latched or not.

An example of watchdog operation is presented in Figure 50. In this example, a generic signal 'WD\_Input' is resetting the counter periodically (for example when reading the status register). If the input signal stops toggling, the watchdog timer expires after the watchdog period resulting in a watchdog fault.

WD Input	
WD Counter Reset	
WD Counter Expiration	ĹĹĹ
WD Fault	





#### MOTIX<sup>™</sup> 6EDL7141 House-Keeping Functions

# 7.2.1 Buck converter watchdog

During start-up of the device, this watchdog monitors VDDB UVLO signal. When UVLO of VDDB is asserted, the watchdog is cleared. If UVLO of VDDB is not asserted within the watchdog period  $(t_{WD_BUCK_T})$ , the system will stop (STOP state in the state machine is described in section Device Start-up and Functional States) and stay disabled until a power cycle takes place. This watchdog can be used for safe start-up debugging. To enable this feature WD\_CFG2, bitfield WD\_BK\_DIS needs to be accessed.

# 7.2.2 General Purpose Watchdog

This watchdog timer can be configured to use different general purpose inputs (timer reset signal) via register WD\_INSEL. Possible inputs are:

- EN\_DRV: this is the default input. Due to connectivity between XMC1404 and 6EDL7141, it is not possible to generate a clock in EN\_DRV pin. Therefore, this input must not be used.
- **DVDD start-up**: during start-up, if this input is selected, the watchdog will be cleared upon DVDD UVLO signal assertion. If DVDD has not reached the correct value before the watchdog period, the DVDD regulator will retry to start. The number of attempts to restart DVDD regulator when start-up fails, can be configured in WD\_DVDD \_RSTRT\_ATT. Additionally, the time between restarts attempts is set in bitfield WD\_DVDD\_RSTRT\_DLY
- **Charge pumps start-up**: similarly, the start-up time of the charge pumps (both) can be monitored. The UVLO signal of both VCCHS and VCCLS will clear the watchdog, otherwise, a fault will be reported. To select this input, bitfield in WD\_INSEL has to be set accordingly.
- **Status register SPI read action**: in this configuration, the watchdog resets every time the FAULT\_ST status register is read via a SPI command. In this way, it checks that XMC1404 is active and that the SPI communication is working adequately.

The general purpose watchdog timer needs to be enabled via WD\_EN bitfield. Watchdog period programmed din WD\_TIMER\_T.

#### **Brake on General Purpose Watchdog Fault**

The general purpose watchdog timer can be configured to trigger a brake event when the comparator trips. This is activated in bitfield WD\_BRAKE and is only possible when 'Status register read' is chosen as input. The brake event can be configured to either brake the motor by shorting all high side MOSFETs, all low side MOSFETs, alternate between those options or set all MOSFETs to high Z. This is explained in more detail in sections 4.1.6. This is configured in bitfields BRAKE\_CFG in PWM\_CFG register.

# 7.2.3 Locked-Rotor Protection Watchdog Timer

MOTIX<sup>™</sup> 6EDL7141 provides a locked or stalled rotor protection function by integrating a dedicated watchdog timer. The rotor locked watchdog timer inputs are signals INLA, INLB and INLC. XMC1404 firmware needs to provide the Hall sensor signal copy into those pins. This protection is only possible when using Hall sensor based control schemes or 1PWM modes.

Locked or stalled rotor can occur in the event of a mechanical malfunction or excessive load torque that causes the motor to stop rotating while enabled. The locked rotor function can be enabled by setting the bitfield WD\_RLOCK\_EN to b'01.

A locked rotor condition is detected if the Hall pattern is maintained for  $t_{LOCKED}$  period. The  $t_{LOCKED}$  time is configured via SPI (bitfield WD\_RLOCK\_T).

In order to increase robustness, an especial case of rotor locked detection is implemented. In some cases, the motor stalls in a position in which the Hall sensors can still provide a cyclic or repeated toggling. In some cases
Datasheet 90 of 155 <a href="https://www.example.com">Revision v1.02</a>

Datasheet



#### **MOTIX<sup>™</sup> 6EDL7141 House-Keeping Functions**

vibration or bending of the motor can cause this effect, in other cases, the Hall sensors get stalled close to the magnets. The internal logic detects this condition as rotor locked. An example is of such Hall sensor inputs sequence that would report a fault is the following:

100, 101, 100, 101, 100, 101, .....

As soon as the locked rotor condition is detected, the device sets bitfields WD\_FLT and RLOCK\_FLT of the FAULT\_ST register to b'01. Upon detection of locked rotor condition the device enters high impedance state (high Z). Additionally, nFAULT pin will be pulled down. XMC1404 can read this signal (internally connected) and request a status update to the device or execute other corrective actions.

#### **Hall Sensor Malfunction**

In case of Hall sensor failure, the rotor locked protection can help to bring the motor to a safe state. The malfunction of 2 or 3 Hall sensors (erroneous operation of the GPIOs emulating the Hall sensors) will cause a rotor lock fault in 6EDL7141, however, a single Hall sensor failure cannot be detected as malfunction and does not trigger a fault.

The rotor locked condition can be reset by toggling EN\_DRV (switch off and on again).

#### Hall Comparators when PWM Signals are on Hold

If the PWM input signals generated by the controller stop switching while the rotor locked protection is enabled, 6EDL7141 will recognize this as a failure and it will trigger the rotor locked protection after  $t_{LOCKED}$  period. In case this behavior is not desired, the user code in the controller that stopped the PWM switching must be preceded by a command (SPI) to disable the rotor locked protection.

# 7.3 Gate Driver ADC Module-Analog to Digital Converter

MOTIX<sup>™</sup> 6EDL7141 integrates an ADC based on SAR architecture with 7 bits resolution. This ADC can be used to do redundant measurements to those executed in the XMC1404 controller or to measure gate driver related voltages. XMC1404 can request the results of these internal measurements via SPI reads of ADC\_ST register. The ADC can measure following inputs during ACTIVE mode:

- Automatically in ADC conversion sequence:
  - On die **temperature** sensor (see 7.3.2)
  - **PVDD:** supply voltage
  - VCCLS: low side gate driver supply
  - VCCHS: high side gate driver supply
- Other (on demand) conversion inputs selected via bitfield ADC\_OD\_INSEL :
  - IDIGITAL: device digital section current consumption
  - **DVDD:** linear regulator output voltage
  - **VDDB:** buck converter output voltage

Those ADC inputs are continuously converted in sequence. After each conversion is finished, the result of the conversion can be processed through integrated digital filters. These are moving average filters with configurable number of samples. PVDD uses a dedicated filter (ADC\_FILT\_CFG\_PVDD) while the rest share a second filter (ADC\_FILT\_CFG). The complete architecture of the ADC module is depicted in Figure 51.



#### **MOTIX<sup>™</sup> 6EDL7141 House-Keeping Functions**

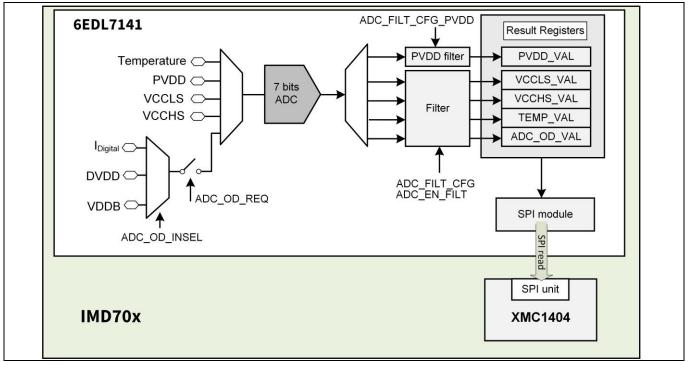


Figure 51 ADC module block diagram

Table 24 summarizes the ADC inputs characteristic including the scaling factors. These scaling factors can be used by XMC1404 firmware to calculate back the real analog values in volts, amperes or degree Celsius.

Measurement	On demand conversion			Scaling factor	
PVDD	Ν	PVDD_VAL	ADC_FILT_CF G_PVDD	$= (0.581 * PVDD_{VAL} + 5.52) V$	
Temperature	N	TEMP_VAL	ADC_FILT_CF G	$= (2 * TEMP_VAL - 94)^{\circ}C$	
VCCLS	Ν	VCCLS_VAL	ADC_FILT_CF G	$= VCCLS_VAL * \frac{16}{127}V$	
VCCHS	N	VCCHS_VAL	ADC_FILT_CF G	$= VCCHS_VAL * \frac{16}{127}V$	
Device current (I <sub>PVDD</sub> )	Υ	ADC_OD_VAL	ADC_FILT_CF G	$= (0.24 * ADC_OD_VAL)mA$	
DVDD	Y	ADC_OD_VAL	ADC_FILT_CF G	$= ADC_OD_VAL * \frac{DVDD_{TARGET}}{127} V$	
VDDB	Y	ADC_OD_VAL	ADC_FILT_CF G	$= ADC_OD_VAL * \frac{VDDB_{TARGET}}{127} V$	

Table 24ADC measurements overview

For example, if DVDD voltage is the desired parameter, XMC1404 will read via SPI register ADC\_OD\_VAL. With DVDD equal to 5V (IMD701A example) if the reading was 0x78=120 decimal value. XMC1404 controller can easily calculate the following:

$$DVDD = ADC_OD_VAL * \frac{5.0V}{2^7} = 120 * \frac{5.0V}{127} = 4.72V$$

(7)





#### **MOTIX<sup>™</sup> 6EDL7141 House-Keeping Functions**

# 7.3.1 6EDL7141 ADC Measurement Sequencing and On Demand Conversion

In ACTIVE state, the ADC converts repeatedly in loop the following sequence of 6 measurements:

- 1. PVDD
- 2. Temperature sensor
- 3. PVDD
- 4. VCCLS
- 5. PVDD
- 6. VCCHS

This is shown in Figure 52. Results of those conversions will be placed in the dedicated result registers that can be read via SPI by the XMC1404. PVDD result is reported in SUPPLY\_ST register, VCCLS and VCCHS are reported in register CP\_ST and the temperature measurement is reported in register TEMP\_ST.

Additional to the standard sequence, the user can select to have other signals converted on demand. Any of this "on demand" conversion inputs, can be injected once in the standard sequence. This is done by selecting the signal to be converted in bitfield ADC\_OD\_INSEL, and setting to '1' the request bitfield ADC\_OD\_REQ.

Note: The write of ADC\_CFG bitfields must happen in a single SPI write. A write to a single bitfield will overwrite the rest to the default value, so the full desired register value must be given in a single write or via read-modify-write sequence.

If an on demand conversion is requested, the ADC waits to finish (End Of Conversion) any running conversion. Then the requested on demand conversion is started. When the on demand conversion is finished, bitfield ADC\_OD\_RDY is set. XMC1404 code can poll this bitfield to make sure the result register contains newest value of the requested conversion. The result of the on demand conversion is located in bitfield ADC\_OD\_VAL and the sequence continuous right where it was interrupted after the EOC of the on demand conversion. This is illustrated in Figure 52.

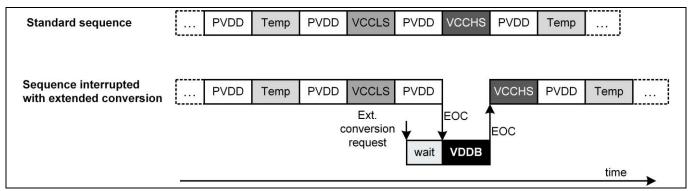


Figure 52 ADC sequencing and interruption by extended conversion request of VDDB signal

# 7.3.2 Die Temperature Sensor

An especially useful ADC measurement is the temperature of the die. The temperature of the device can be read via SPI by accessing bitfield TEMP\_VAL in TEMP\_ST register. The value is measured with a resolution of 2 degrees Celsius. Additionally, over-temperature warning and faults are implemented. In register SENSOR\_CFG (OTS\_DIS), the over-temperature shut down protection can be disabled. The threshold values are provided in Table 11. The occurrence of these faults can be detected by reading bitfields OTW\_FLT and OTS\_FLT.

According to Table 24, an example reading of 0x4A = 74 would convert into:

$$Temperature = TEMP_VAL * 2^{\circ}C - 94^{\circ}C = 74 * 2^{\circ}C - 94^{\circ}C = 54^{\circ}C$$



#### MOTIX<sup>™</sup> 6EDL7141 Protections and Faults Handling

8

# MOTIX<sup>™</sup> 6EDL7141 Protections and Faults Handling

MOTIX<sup>™</sup> 6EDL7141 contains an extensive number of protections. These are:

- Over-Current Protections (OCP) for:
  - DVDD linear regulator
  - o Buck converter
  - Motor leg shunt OCP
- Under-Voltage Lock Out (UVLO) protection for:
  - o Gate driver supply voltage both high side and low side drivers
  - Supply voltage PVDD
  - DVDD linear regulator output voltage
  - Buck converter output voltage
- DVDD linear regulator Over Voltage Lock Out (OVLO) protections
- Rotor locked detection based on Hall sensor inputs
- Configurable watchdog
- Over-Temperature Shutdown (OTS) and Warning (OTW)
- OTP memory fault.

An arbitration state machine, takes all the fault inputs from the specific fault blocks and decides which fault needs to be serviced first in case several faults occur at same time (same clock cycle). Once a fault is acknowledged, the system takes the specific action as shown in Table 25 and the arbitration round stops until the fault is cleared.

The state machine is split in two main independent arbitration sections:

- Supply faults (B0 to B4). B0 is highest priority.
- **Other faults** (F0 to F7). The fault that happens first will be dealt first and others will be ignored until this fault is removed. If more than one fault happens at the same time, then the one with the highest priority will be processed. (F0 is highest priority).

The resultant actions from both sections are OR'ed on nFAULT.

Additionally to any possible actions like switching off PWM signal, status bits will be updated to inform XMC1404 of any warning or/and fault occurrence. This is done regardless of priority and those status bits can be read via SPI commands by the microcontroller in the system.

Note: It is highly recommended to understand faults reason by reading the status registers and clear faults as soon as they occur so new events can be captured. This is done by writing register FAULTS\_CLR via SPI interface

Following registers provide information on the status of the device faults:

- FAULT\_ST: holds most of functional related faults. A fault might be triggered only after a number of events of a malfunction. Status will immediately record the event information.
- TEMP\_ST: provides status on temperature warning and the temperature reading itself
- SUPPLY\_ST: reports on status of all supplies UVLO/OVLO and OCPs
- FUNC\_ST: status of OCP faults for each of current sense amplifiers, Hall sensors, wrong hall pattern.
- OTP\_ST: programming and reading of OTP related faults

Datasheet



#### MOTIX<sup>™</sup> 6EDL7141 Protections and Faults Handling

In order to clear faults the user has to write via SPI the bitfield CLR\_FAULTS in FAULTS\_CLR register. However, to clear a latched fault, a write to CLR\_LATCH register is required.

If 'Motor leg shunt OCP' fault is programmed to be latched the fault cannot be cleared until:

- If in OCP counting mode (8, 16 periods) there is one whole PWM period without an OCP event or STANDBY state is entered.
- If in immediate trigger mode then it can be cleared after the fault is gone.

Datasheet



#### MOTIX<sup>™</sup> 6EDL7141 Protections and Faults Handling

Table 25	6EDL7141 faults and protections table
----------	---------------------------------------

Name	Description	Programma bility	Latched	nFAULT report	Active State	Prio	Action(s)
VCCLS UVLO	Charge pump low side UVLO fault	-	N	Y	DEV_ ACTIVE	F1 & F2 (shared)	• External MOSFET outputs set to Hi-Z independently of fault handling. Weak pulldown of all gate driver outputs
VCCHS UVLO	Charge pump high side UVLO fault	-	N	Y	DEV_ ACTIVE	F1 & F2 (shared)	• External MOSFET outputs set to Hi-Z independently of fault handling. Weak pulldown of all gate driver outputs
DVDD OVLO	DVDD OVLO fault	-	N	Y	All states after DVDD ok (after STANDBY)	В1	No action. XMC1404 to perform user action
DVDD OCP	DVDD OCP fault	Threshold level	N	Y	All states after DVDD ok (after STANDBY)	В3	No action. XMC1404 to perform user action
DVDD UVLO	DVDD UVLO fault	-	N(requires power cycle-CE toggle)	Y (howeve r is nFAULT supplied by DVDD)	All states after BUCK_ START	B0 and F0	<ul> <li>External MOSFET outputs set to Hi-Z. Weak pulldown of all gate driver outputs</li> <li>Waits for power cycle (CE pin low and high)</li> <li>Buck converter continues operation</li> <li>When DVDD UVLO happens the functional state machine changes from DEV_ACTIVE to DVDD_STOP. Please refer to section Device Start-up and Functional Statesfor details. From the application perspective, this faults is highest priority. Requires a power cycle (CE toggle)</li> </ul>
BUCK OCP	Buck Converter Over Current Protection	-	N	Y	All states after DVDD ok (after STANDBY)-	B2	<ul> <li>No action. XMC1404 to perform user action. Protection is blanked during start-up of charge pumps</li> </ul>

#### Datasheet



#### MOTIX<sup>™</sup> 6EDL7141 Protections and Faults Handling

Name	Description	Programma bility	Latched	nFAULT report	Active State	Prio	Action(s)
					Fault blanked during charge pump start		
Motor leg shunt OCP [2:0]	Current sense amplifier Over Current Protection for each phase	Threshold level, count on number of trips, reaction, PWM truncation	Programma ble- Latched if brake on OCP is active	Y	DEV_ ACTIVE	F4	<ul> <li>PWM truncation if configured.</li> <li>If fault is configured as "Latched" then: sets driver into Hi- Z. Weak pulldown of all gate driver outputs.</li> <li>Brake as defined in PWM_CFG register when CS_OCP_BRAKE register enabled. Fault latched if braking active</li> </ul>
Locked rotor	Locked rotor watchdog overflow	Timing	Υ	Y	DEV_ ACTIVE	F5	<ul> <li>External MOSFETs outputs set to High Z. Weak pulldown of all gate driver outputs</li> <li>Requires toggle of EN_DRV to re-start normal operation again</li> </ul>
Watch dog timers	Watchdog timer overflow. Several inputs programmable	Timing, reaction. Depending on input	Programma ble-Latched if brake on watchdog fault is enabled	Y (with input EN_DRV only, otherwis e not)	Depending on input, either START-UP or DEV_ACTIVE	F6	<ul> <li>If input: <ul> <li>EN_DRV - Hi-Z. Weak pulldown of all gate driver outputs</li> <li>Buck input- No action required from user or device.</li> <li>If charge pump input – nFAULT reported. Driver won't start-up.</li> <li>Others: brake as defined in PWM_CFG register when WD_BRAKE register enabled. Always latched if braked enabled</li> </ul> </li> </ul>
OTS	Over Temperature Shutdown	-	Υ	Y	DEV_ ACTIVE	F3	• External MOSFET outputs set to Hi-Z. Weak pulldown of all gate driver outputs

#### Datasheet



#### MOTIX<sup>™</sup> 6EDL7141 Protections and Faults Handling

Name	Description	Programma bility	Latched	nFAULT report	Active State	Prio	Action(s)
OTW	Over Temperature Warning	-	Ν	N (only status register report)	DEV_ ACTIVE	F8	No action. XMC1404 to perform user action
OTP Fault	OTP read fault or OTP user programming error	-	Y	γ	All states	F7	<ul> <li>External MOSFETs outputs set to Hi-Z</li> <li>Weak pulldown of all gate driver outputs</li> </ul>

#### MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface



# MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface

Programming of 6EDL7141 features in MOTIX<sup>™</sup> IMD70xA requires accessing internal registers via SPI interface shown in Figure 53.

The configuration of 6EDL7141 features, including gain of amplifiers, driving voltage for gate drivers or fault reactions, is stored in registers while the device is active. The configuration of those functions can be changed during run time operation via SPI commands. These registers are volatile memory cells and therefore, its information will be lost every time the power supply is removed from the device.

For this reason, 6EDL7141 integrates an OTP NVM (One Time Programmable Non-Volatile Memory) that stores a given default configuration even when power supply is not available. Initially the device is programmed with the default register settings provided in section 11. During startup phase of the device (see state machine flowchart in Figure 58), the configuration in the OTP will be copied or mirrored into registers. These registers are the ones that govern the actual behavior of the device. This is shown in Figure 53.

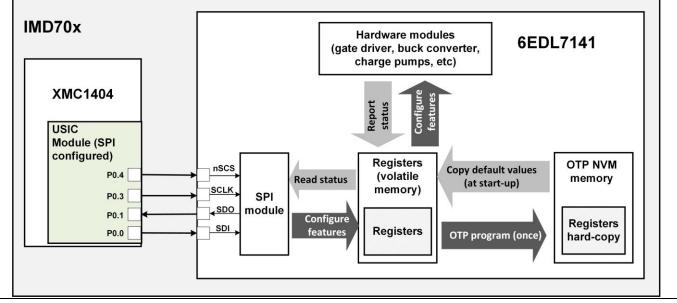


Figure 53 6EDL7141 programming overview

In case the default ("out of the fab") configuration of the device stored in OTP is not the desired one, the designer can select a different configuration for its application and store it indefinitely in the OTP memory (hard-copy). See section 9.1.1 for detailed procedure. This action can be done only once. A second write to the OTP is not possible. However, configurations can be overwritten on volatile registers after start-up via SPI commands as mentioned above.

The user configuration can be tracked thanks to a software ID bitfield -USER\_ID- located in OTP\_PROG register.

*Note:* It is therefore recommended that every writing action to the registers is followed by a confirmation read to ensure that written and read data in registers match and thus confirming correct programming.



# Datasheet MOTIX™ 6EDL7141 Programming-OTP and SPI interface

# 9.1.1 MOTIX<sup>™</sup> 6EDL7141 OTP User Programming Procedure: Loading Custom Default Values

The OTP is used for user configuration storage. The OTP module implements a double error correction, plus one additional error detection when programming it.

OTP programming must only occur in a controlled environment. This requires the user to ensure that programming happens at the correct supply voltage, this is PVDD> PVDD<sub>OTP\_PROG</sub>. Also the temperature must be below T<sub>OTP\_PROG</sub>. Internally both parameters are monitored. This means that if programming is attempted outside of these parameters it will not be started. If this blocking occurs, then bitfield OTP\_PROG\_BLOCK will be set to '1' to indicate that one of the parameter is outside of the required range. Default values (as given in bold in section 11.4) will be used after start-up in such situation. Further programming attempts are possible. OTP\_PROG\_BLOCK will be reset either when the programming finishes successfully or after a power down.

Following programming steps should be performed to write OTP with a specific configuration:

- 1. Start device into STANDBY mode (EN\_DRV<  $V_{EN_DRV_TH}$ )
- 2. Write registers to the desired default values via SPI write commands
- 3. Program these values into OTP using OTP\_PROG bitfield
  - a. If the temperature is higher than T<sub>OTP\_PROG</sub> or PVDD> PVDD<sub>OTP\_PROG</sub>, then programming does not start and OTP\_PROG\_BLOCK is set to '1'. Conditions might be modified and the programming can be attempted again. If the programming fails twice, the device will be blocked signaled by OTP\_USED=b'1, OTP\_PASS = b'0
  - b. If temperature and PVDD values are in range, programming starts, copying register parameters into the OTP memory. This can only be done once.
- 4. (Recommended) Check if OTP programming succeeded via bitfields OTP\_USED and OTP\_PASS or OTP\_PROG\_FAIL:
  - a. If the programming of the OTP failed, then the device will be locked until a power cycle (CE pin pulled down and up) takes place. Signaled by OTP\_USED=b'1 and OTP\_PASS = b'0 or simply OTP\_PROG\_FAIL =b'1. Further programming of OTP is not possible. Memory content is considered corrupted and therefore the part should be discarded.
  - b. If programming succeeded, then normal function will continue. This is signaled by OTP\_USED = b'01 and OTP\_PASS = b'01 or simply OTP\_PROG\_FAIL = b'0. It is recommended to perform a power cycle (CE pin pulled down and up) for new values to take effect after a successful programming

Trying to write an already programmed OTP will be ignored.

An OTP programming failure (wrong copy of registers into OTP memory) will force the device to enter STOP state during read out (see Figure 58). In such case, the fault is reported on nFAULT pin and XC1404 can perform a status read of 6EDL7141 to provide status of memory by reading bitfields OTP\_USED, OTP\_PASS, or OTP\_PROG\_FAIL, and OTP\_PROG\_BLOCK. The OTP possible statuses are described in Table 26.

If the user chooses to program OTP during start-up of the XMC1404 software, this should check each time that OTP\_USED = b'01 before programming again. Otherwise incorrect programming could occur.

#### Datasheet



Table 26	OTP programming status
----------	------------------------

Device status	OTP_ USED	OTP_ PASS	OTP_PRO G_BLOCK	OTP_PRO G_FAIL	Status Description
Non-programmed device	0	0	0	0	Default values used
Successful programming of OTP	1	1	х	х	User programming was successful. Upon start-up, the newly programmed default values will be loaded into registers for custom configuration
Programming blocked due to PVDD or temperature conditions	0	0	1	0	Part can be reprogrammed once condition are within limits
Programming started but failed due to PVDD or temperature conditions	1	0	1	1	Part must be discarded
Programming started but failed due to OTP issue	1	0	0	1	Part must be discarded

# 9.1.2 MOTIX<sup>™</sup> 6EDL7141 SPI Communication

All communication between XMC1404 and 6EDL7141 happens through the internal connection between both devices as shown in Interconnects Pin Description table. The SPI module in 6ELD7141is used to program the configuration registers and therefore to command the device for example to change settings or program OTP memory.

6EDL7141 SPI module is based on a 4-pin configuration. Data sampling happens during the falling edge of the SPI clock signal. This protocol can easily be implemented in XMC1404 USIC peripheral when configuring it as SSC channel. User must ensure that XMC1404 is properly configured according following write and read protocols.

All communication happens in a 24 bit length shift register.

- 7 bit address
- 16 bit data byte
- 1 bit command

Data is shifted in with MSB first. Two commands are defined:

- 1 Register write
- 0 Register read

Figure 54 and Figure 55 show respectively write and read operations with SPI interface.





#### Datasheet

#### MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface

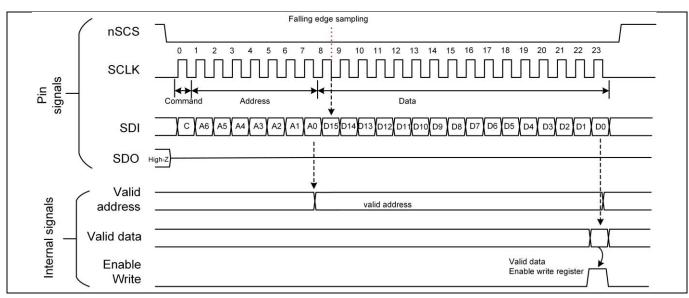


Figure 54 SPI write operation

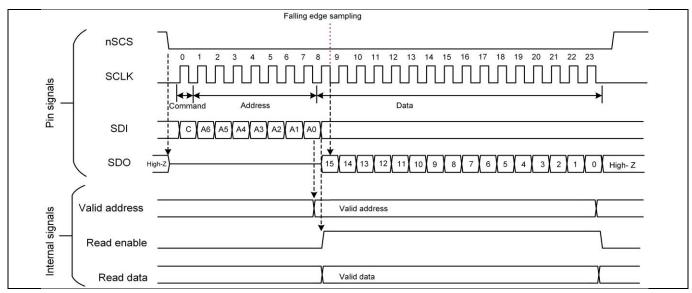


Figure 55 SPI read operation

# 9.1.2.1 SPI Communication Example

If for example, user wants to write new values TDRIVE1 = 50ns (0x01) and TDRIVE2 = 2540ns (0xFE), to register TDRIVE\_SRC\_CFG (address 0x19), then the content of the register needs to be 0xFE01 by collating TDRIVE2 and TDRIVE1 values. The microcontroller then needs to write following command in the SPI bus (SDI signal) once nSCS signal is pulled down:

#### Binary: b 1001 1001 1111 1110 0000 0001

#### Hexadecimal: 0x99 FE 01

If after write, a read is necessary, the following sequence must be applied by the microcontroller. This will read TDRIVE\_SRC\_CFG register by writing SDI signal:

#### Binary: b 0001 1001 ---- ----

Hexadecimal: 0x19 -- --

Datasheet



# 9.1.2.2 XMC1404 SPI Configuration Recommendation

In this section it is described the recommended configuration of XMC1404 USIC channel to communicate with 6EDL7141 interface. For this purpose, XMC Low Level Drivers have been used. APIs supported in by that library can be identified by the prefix "XMC\_", like XMC\_GPIO\_Init(). Three APIs are shown here:

- USIC SPI channel Initialization
- Read command
- Write command

#### **USIC SPI channel Initialization**

```
* DATA STRUCTURES
uint8 t error SPI;
/* SPI configuration structure */
XMC_SPI_CH_CONFIG_t spi_config =
{
 .baudrate = SPI BAUD RATE,
 .bus mode = XMC SPI CH BUS MODE MASTER,
 .selo inversion = XMC SPI CH SLAVE SEL INV TO MSLS,//Slave select active
low
  .parity mode = XMC USIC CH PARITY MODE NONE
};
/* GPIO SPI TX pin configuration */
XMC GPIO CONFIG t tx pin config =
{
  .mode = XMC GPIO MODE OUTPUT PUSH PULL ALT9 //Pin selection ALT9
};
/* GPIO SPI DX pin configuration */
XMC GPIO CONFIG t dx pin config =
{
  .mode = XMC GPIO MODE INPUT TRISTATE
};
/* GPIO SPI SELO pin configuration */
XMC GPIO CONFIG t selo pin config =
{
  .mode = XMC GPIO MODE OUTPUT PUSH PULL ALT8, //Pin selection ALT8
};
```

ineor



Datasheet

```
MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface
```

```
/* GPIO SPI SCLKOUT pin configuration */
XMC GPIO CONFIG t clk pin config =
{
  .mode = XMC GPIO MODE OUTPUT PUSH PULL ALT8, //Pin selection ALT8
};
/* API to initialize USIC SPI peripherals */
void spi master init(XMC USIC CH t * const channel)
{
/* Initialize GPIO */
  XMC GPIO Init (MOSI PIN, &tx pin config);
  XMC GPIO Init(MISO PIN, &dx pin config);
  XMC GPIO Init (SELO PIN, &selo pin config);
  XMC GPIO Init(SCLK PIN, &clk pin config);
 /* Initialize SPI master*/
  XMC SPI CH Init(channel, &spi config);
  XMC SPI CH SetWordLength (channel, SPI WORD LENGTH);
  XMC SPI CH SetFrameLength (channel, SPI FRAME LENGTH);
  XMC SPI CH SetBitOrderMsbFirst(channel);
  XMC SPI CH EnableSlaveSelect (channel, XMC SPI CH SLAVE SELECT 0); //Falling
sclk sampling and no polarity inversion
  XMC SPI CH ConfigureShiftClockOutput(channel,
XMC_SPI_CH_BRG_SHIFT_CLOCK_PASSIVE_LEVEL_0_DELAY_DISABLED,
XMC SPI CH BRG SHIFT CLOCK OUTPUT SCLK); //Slave select is active low to
communicate with 6EDL7141
  XMC SPI CH SetSlaveSelectPolarity(channel,
XMC SPI CH SLAVE SEL INV TO MSLS);
/* Initialize FIFO */
  XMC USIC CH_RXFIFO_Configure(channel, 40, XMC_USIC_CH_FIFO_SIZE_8WORDS, 2);
//receive from SPI slave: limit is 1, when FIFO is full with 2 word and a 3nd
is received, the event happens.
  //this is used in main to while until 3 words are received
  XMC USIC CH TXFIFO Configure(channel, 32, XMC USIC CH FIFO SIZE 8WORDS, 0);
/* Configure input multiplexer */
  XMC SPI CH SetInputSource(channel, XMC SPI CH INPUT DINO,
USIC1 C1 DXO PO 0); //PO.O DXOA, 6EDL SPI LINK SPI pin assignment
```

```
/* Start operation. */
```

Datasheet

}



#### MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface

```
XMC_SPI_CH_Start(channel);
error_SPI = 0;
```

#### **Read Command**

```
/*The RegAddr is the address of register to read. Data parameter is a pointer
to store the two bytes of data read from the register */
uint16 t Read Word 16b (uint8 t RegAddr)
{
  XMC_USIC_CH_RXFIFO_Flush(SPI_MAS_CH);
  SPI MAS CH->IN[0] = RegAddr & REG READ;
  SPI MAS CH \rightarrow IN[0] = 0 \times 00;
  SPI MAS CH \rightarrow IN[0] = 0 \times 00;
  uint32 t timeout counter = 0;
  while ((XMC USIC CH RXFIFO GetEvent(SPI MAS CH) &
XMC USIC CH RXFIFO EVENT STANDARD) == 0) /*wait for received data /2 words*/
  {
         if (++timeout counter > SPI TIMEOUT)
         {
          error SPI = 1;
          break;
         }
  };
 XMC USIC CH RXFIFO ClearEvent (SPI MAS CH, XMC USIC CH RXFIFO EVENT STANDARD);
  SPI MAS CH->OUTR; //data read of invalid data
  uint8 t data high = SPI MAS CH->OUTR; //data read of MSB
  uint8 t data low = SPI MAS CH->OUTR; //data read of LSB
  return ((data high << 8) + data low);</pre>
}
```

#### Write Command

```
/* To write data to register via SPI channel.
The RegAddr is the address of register to write to.
Data parameter is a pointer which stored the two bytes of data written to
the register */
void Write_Word_16b(uint8_t RegAddr, uint16_t data)
{
    XMC_USIC_CH_RXFIFO_Flush(SPI_MAS_CH);
    SPI_MAS_CH->IN[0] = RegAddr | REG_WRITE;
    SPI_MAS_CH->IN[0] = (uint8_t)(data >> 8);
    SPI_MAS_CH->IN[0] = (uint8_t)data;
    uint32_t timeout_counter = 0;
```



#### Datasheet

#### MOTIX<sup>™</sup> 6EDL7141 Programming-OTP and SPI interface

**Device Start-up and Functional States** 



# **10 Device Start-up and Functional States**

# 10.1 MOTIX<sup>™</sup> 6EDL7141 Power Supply Start-up

6EDL7141power supply section start-up can be divided in two main periods:

- **Power supply start-up**: initiated by CE rise, leads to ramp up of VDDB and DVDD rails.
- Gate Driver and CSAMP start-up: begins with EN\_DRV rise and results in charge pumps ramp up and current sense amplifiers activation

# 10.1.1 Power Supply System Start-up

Given a steady battery supply voltage (PVDD), the input pin CE will control the startup of the power supply system. Figure 56 shows graphically the ramp up of buck converter voltage once CE voltage goes above  $V_{CE_TH_R}$  value. If external filter capacitor is too large, the ramp up time might be exceeding the values provided in Table 11 ( $t_{VDDB\_SFT\_START}$ ). The integrated watchdog can be enabled to monitor and debug the start-up of VDDB, DVDD or charge pumps.

Soft-start for the buck converter is automatically implemented using an integrated DAC for generating the target reference. Once VDDB has reached its UVLO voltage, analog programming starts. This initiates a period of  $t_{AN_T}$  duration in which CS\_GAIN pin is read internally. The analog programming can be disabled via OTP programming, therefore reducing the start-up time.

After these analog programming period(s) have elapsed, another OTP programmable delay  $(DVDD_TON_DELAY)$  is inserted  $(t_{DVDD_TON_DLY})$  before the DVDD voltage starts ramping up. Longer delays allow the buck converter voltage to stabilize before the DVDD starts charging. If faster start-up time is required, the delay can be shortened taking into consideration the buck output voltage and the external components used  $(L_{BUCK}, C_{BUCK})$ . DVDD will ramp up in a configurable time (DVDD\_SFTSTART). Tuning of this value can help ensuring proper start-up.

# 10.1.2 Gate Driver and CSAMP Start-up

Once DVDD is up and stable, XMC1404 firmware starts execution until it decides to enable the gate driver. EN\_DRV pin needs to be set above  $V_{EN_DRV_TH}$  value to enable the driver section. Before this, no PWM signal will transfer to the gate of the MOSFETs. Once EN\_DRV is set above  $V_{EN_DRV_TH}$ , both low side and high side charge pumps ramp up to the target value PVCC. This time will depend on the different configurations (capacitors, charge pump frequency, PVCC voltage) as explained in 4.5.

The high side charge pump will start after enough voltage is built in the low side charge pump. After both high side and low side charge pumps UVLOs are reached, the PWM path is activated and the gate driver can output signals to the power MOSFET.

Note: Depending on timing of PWM send to inputs and charge pump capacitor values, the gate driver could start driving the MOSFETs while the charge pumps are not fully at target voltage if the PWM signal is activated early. User can delay the start of PWM signals until charge pumps are fully charged if this is required

#### Datasheet

#### **Device Start-up and Functional States**

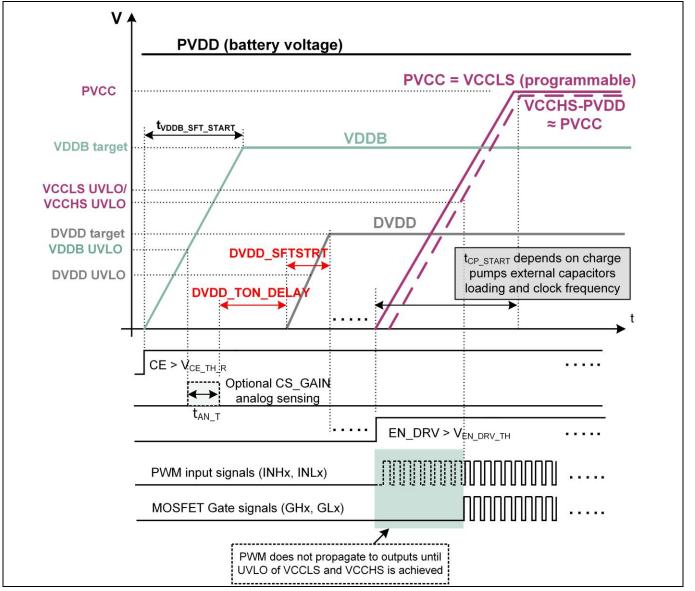


Figure 56 Start-up behavior of supply voltages at steady PVDD supply. EN\_DRV and CE\_EN functionality. DVDD\_SFTSTRT is an SPI programmable parameter

If CE is generated from PVDD, for example via a voltage divider as shown in Figure 61, the start-up behavior will follow the one in Figure 57 or similar. In such case, it is important to notice that the device will not start –i.e. the buck converter will not start switching - until both PVDD UVLO is released and the CE rising voltage thresholds (V<sub>CE\_TH\_R</sub>) are crossed, as can be seen in flowchart in Figure 58. The order of CE and PVDD can swap with similar results.

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#### Datasheet

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### **Device Start-up and Functional States**

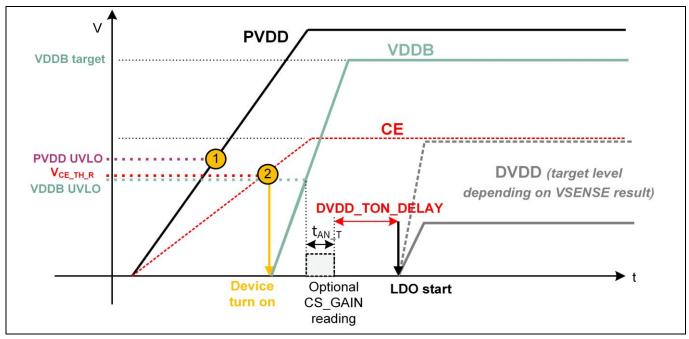


Figure 57 Start-up behavior detail when PVDD is ramping up and CE is created with a voltage divider from PVDD. Device will only turn on after events 1 and 2 occur, starting up the buck converter controller



### **Device Start-up and Functional States**

# **10.2 Device Functional States**

The functionality of the device is governed by a state machine. A flowchart of this state machine is shown in Figure 58.

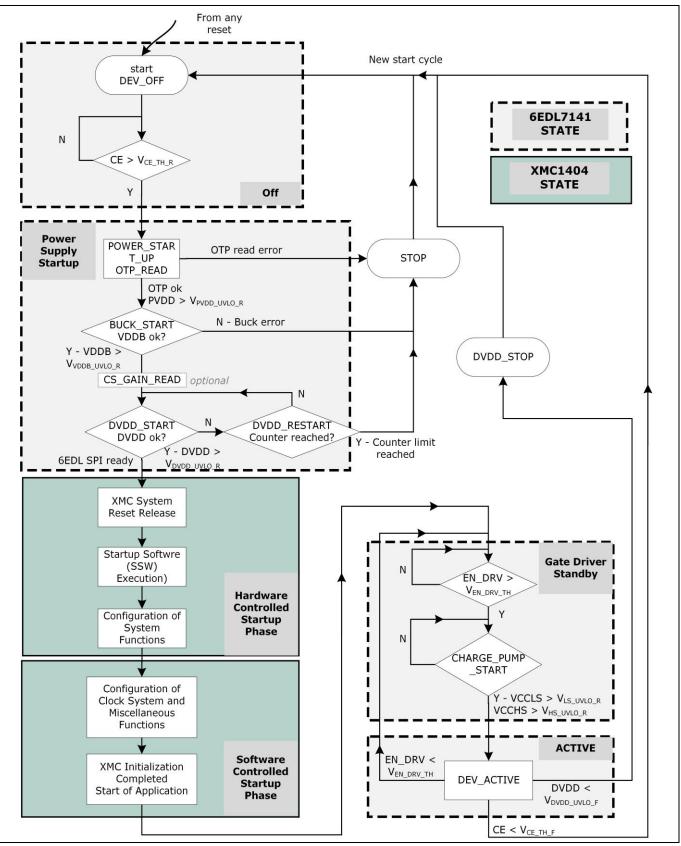


Figure 58

Flowchart diagram for power states of device

Datasheet

#### Device Start-up and Functional States



Following main states and substates can be considered for IMD70xA:

### **Off State**

• **DEV\_OFF** - This state is the default state when in reset.

### **Power Supply Start-up States**

- **POWER\_START\_UP, OTP\_READ** In this state voltage in PVDD is ramping up and checked by the 6EDL7141. Once ok, the OTP memory in 6EDL7141 is read. This is done before enabling any further blocks to ensure configuration is known. If a fault is signaled by the OTP block then the STOP state will be entered.
- **BUCK\_START** The buck converter is enabled in this state and the VDDB needs to be correct before leaving this state. If the VDDB has not reached the target voltage in a certain time, then the buck will be shut down and the device set in the STOP state.
- **CS\_GAIN\_READ** The device will sense pin CS\_GAIN (optionally programmable) to program the current sense amplifier gain if analog programming is selected. This is, if CS\_GAIN\_ANA is set to '0' then the CS gain will be set by the register CS\_GAIN. In case of digital programming the state is skipped. In IMD70x gain of current sense amplifiers must be set digitally via SPI commands, which will skip this state in the state machine.
- **DVDD\_START** at this point, once the buck converter output is stable, the linear voltage regulator for DVDD is ramped up according the start-up delay and soft start programming. At the end of this state, DVDD is at target voltage and stable. With this, the start-up procedure of the device finishes and enters a wait state until EN\_DRV signal arrives from a XMC1404. This will start the standby section.
- **STOP** If this state is entered it is because a serious fault with either the buck converter DVDD start-up. The device will not operate until a power cycle or EN\_DRV toggle takes place. SPI cannot be used during this state.

#### XMC1404 Hardware Controlled Start-up:

This state is entered automatically after power up of the microcontroller. This part is generic and it ensures basic configuration of the controller internal circuitry. The hardware setup needs to ensure fulfillment of requirements specified in the Absolute max table in order to enable reliable start-up of the microcontroller before control is handed over to the user software/application. The sequence where boot code gets executed is considered a part of the hardware controlled phase of the startup sequence. For details of the setup requirements, please refer to XMC1400 Reference Manual.

### XMC1404 Software Controlled Start-up:

The software controlled startup phase is the part where the application specific configuration gets applied with user software. It involves several steps that are critical for proper operation of the microcontroller in the application context and may also involve some optional configuration actions in order to improve system performance and stability in the application context.

Power-up of the microcontroller gets performed by applying DVDD supply (for details of the supply requirements, please refer to <u>XMC1400 Reference Manual</u>). The connection between pin 3 (DVDD input) and pins 23 and 56 (DVDD output/input) must be done at the PCB level to ensure XMC is properly powered, there is no internal connection internally in IMD70xA.

When XMC supply voltage reaches a stable threshold level, the power-on reset is released.

Next, after the on-chip oscillators in XMC generate a stable clock output, the system reset is released automatically and the Start-up Software (SSW) code starts to run in the controller. The system reset can be triggered from various sources like software controlled CPU reset register or a watchdog time-out-triggered reset.

After reset release, internal XMC clock signals MCLK and PCLK are running at 8MHz and most of the peripherals' clocks are disabled except for CPU, memories and PORT. It is recommended to disable the clock of the unused modules in order to reduce power consumption.

#### Datasheet





Start-up Software (SSW) execution: after the reset is de-asserted, CPU starts to execute the SSW code from the ROM memory. To indicate the start of the SSW execution, the pull up device in P0.14 is enabled. Pull up device is disabled during reset. SSW reads the Boot Mode Index (BMI) stored in Flash and decide the startup modes elected by the user. The Boot Mode Index is 2 Byte value stored in Flash and holding information about start-up mode and debug configuration of the device. For more details about the various startup modes and handling of BMI, please refer to <u>XMC1400 Reference Manual</u>.

To handle the initial hardfault error during the SSW execution, SSW installs "jump to itself" instruction at SRAM location 2000'000CH as temporary HardFault handler – until the user code installs its own. It is installed upon master reset only. During SSW execution, the SRAM area between 2000'00COH and 2000'0200H is reserved for usage by XMC1404 SSW, therefore the user software should not store in this area data which must be preserved throughout (non-power) resets.

### GATE\_DRIVE\_STANDBY

• **CHARGE\_PUMP\_START** - The charge pumps are enabled. If target voltages are reached, the device moves to DEV\_ACTIVE.

### ACTIVE

• DEV\_ACTIVE (or ACTIVE)

In this state the driver is ready to be used. The PWM path is enabled. If EN\_DRV signal goes low during active the device turns off both charge pumps and disables the PWM path by going into the STANDBY section.

• **DVDD\_STOP** - This state is entered from states after DVDD has been powered and DVDD rail fails. Device stops operation and requires a CE toggle or power cycle to restart. Buck converter and ADC remains active.

**Register Map** 



# 11 Register Map

# 11.1 XMC1404 Registers

For the configuration registers of XMC1404 microcontroller, refer the specific sections fully described in latest XMC1404 reference manual at Infineon website (<u>www.infineon.com</u>). At the time of creation of this document, latest version can be found here: <u>XMC1400 Reference Manual</u>.

# **11.2** MOTIX<sup>™</sup> 6EDL7141 Smart Gate Driver Register Map

Table 27 shows a complete list of 6EDL7141 registers accessible via SPI interface. Registers are explained in detail in this section.

Short Name	Long Name	Offset Address	Page Link
FAULT_ST	Fault and warning status	00н	117
TEMP_ST	Temperature status	01н	118
SUPPLY_ST	Power supply status	02н	119
FUNC_ST	Functional status	03н	120
OTP_ST	OTP status	04н	121
ADC_ST	ADC status	05н	122
CP_ST	Charge pumps status	06	122
DEVICE_ID	Device ID	07н	123
FAULT_CLR	Fault clear	10н	123
SUPPLY_CFG	Power supply configuration	11н	124
ADC_CFG	ADC configuration	12н	126
PWM_CFG	PWM configuration	13н	127
SENSOR_CFG	Sensor configuration	14н	128
WD_CFG	Watchdog configuration	15н	129
WD_CFG2	Watchdog configuration 2	16н	130
IDRIVE_CFG	Gate driver current configuration	17н	131
IDRIVE_PRE_CFG	Pre-charge gate driver current configuration	18н	133
TDRIVE_SRC_CFG	Gate driver sourcing timing configuration	19н	133
TDRIVE_SINK_CFG	Gate driver sinking timing configuration	1Ан	134
DT_CFG	Dead time configuration	1Вн	136
CP_CFG	Charge pump configuration	1Сн	136
CSAMP_CFG	Current sense amplifier configuration	1Dн	137
CSAMP_CFG2	Current sense amplifier configuration 2	1Ен	139
OTP_PROG	OTP program	1F	141

### Table 27Register map overview

#### **Register Map**



# **11.3** MOTIX<sup>™</sup> 6EDL7141 Registers Programmability

The programmable registers in 6EDL7141 can be programmed at any time after SPI interface is active, however, some of the bitfield changes will not have an effect until certain conditions occur. This is to protect from wrong behaviors or to avoid glitches in the operation. Three categories are defined:

- 1. **Always** programmable: programming these bitfields will have an effect immediately after programming in any state of the device. The effect can be synchronized with PWM or braking events for some cases.
- 2. **Standby** programmable: programming these bitfields will have an effect only when EN\_DRV level is low. If programmed when EN\_DRV is high, the register will show the new value, but effect will not be applied until EN\_DRV is pulled down. This is to avoid system malfunctions. Therefore these registers are recommended to be programmed before EN\_DRV is activated.
- 3. **OTP only**: programming these bitfields will have an effect only if programmed in OTP and after device new power up (PVDD). These are settings affecting the start-up of the device, namely bitfields whose effect takes place even before DVDD ramps up, therefore must be burned into OTP to be effective on next power up.

As an example, if during ACTIVE state a write happens to a 'Standby' value, the value will be written and reads to this register will return the written value, however, the value is not (shadow) transferred to actual effective register until the device state machine goes into STANDBY state.

Table 28 provides a categorization for every configuration of the device ('w' type bitfield)

<b>Register Name</b>	Bitfield Name	Programmability
SUPPLY_CFG	PVCC_SETPT	Standby
	CS_REF_CFG	Standby
	DVDD_OCP_CFG	Always
	DVDD_SFTSTRT	OTP only
	BK_FREQ	Standby
	DVDD_TON_DELAY	OTP only
	CP_PRE_CHARGE_EN	Standby
ADC_CFG	ADC_OD_REQ	Always – no OTP field, just register
	ADC_OD_INSEL	Always – no OTP field, just register
	ADC_EN_FILT	Always – no OTP field, just register
	ADC_FILT_CFG	Always
	ADC_FILT_CFG_PVDD	Always
PWM_CFG	PWM_MODE	Standby
	PWM_FREEW_CFG	Always
	BRAKE_CFG	Always
	PWM_RECIRC	Standby
SENSOR_CFG	HALL_DEGLITCH	Always
	OTS_DIS	Always
	CS_TMODE	Always
WD_CFG	WD_EN	Standby
	WD_INSEL	Standby
	WD_FLTCFG	Standby

### Table 28Register programmability

### Datasheet



# **Register Map**

Register Name	Bitfield Name	Programmability						
	WD_TIMER_T	Standby						
WD_CFG2	WD_BRAKE	Standby						
	WD_EN_LATCH	Standby						
	WD_DVDD_RSTRT_ATT	Standby						
	WD_DVDD_RSTRT_DLY	Standby						
	WD_RLOCK_EN	Always						
	WD_RLOCK_T	Always						
	WD_BK_DIS	OTP only						
IDRIVE_CFG	IHS_SRC	Always						
	IHS_SNK	Always						
	ILS_SRC	Always						
	ILS_SNK	Always						
IDRIVE_PRE_CFG	I_PRE_SRC	Always						
	I_PRE_SNK	Always						
	I_PRE_EN	Always						
TDRIVE_SRC_CFG	TDRIVE1	Always						
	TDRIVE2	Always						
TDRIVE_SINK_CFG	TDRIVE3	Always						
	TDRIVE4	Always						
DT_CFG	DT_RISE	Always						
	DT_FALL	Always						
CP_CFG	CP_CLK_CFG	Always						
	CP_CLK_SS_DIS	Standby						
CSAMP_CFG	CS_GAIN	Always – recommended to stop PWM first						
	CS_GAIN_ANA	Standby (change to digital mode)-change to analog mode only possible if written in OTP – do not change value, analog programming not possible in IMD70xA						
	CS_EN	Always						
	CS_BLANK	Always – recommended to stop PWM first						
	CS_EN_DCCAL	Standby						
	CS_OCP_DEGLITCH	Standby						
	CS_OCPFLT_CFG	Standby						
CSAMP_CFG2	CS_OCP_PTHR	Always						
	CS_OCP_NTHR	Always						
	CS_OCP_LATCH	Standby						
	CS_MODE	Standby						
	CS_OCP_BRAKE	Standby						
	CS_TRUNC_DIS	Always						
	VREF_INSEL	Standby						

### Datasheet



### **Register Map**

Register Name	Bitfield Name	Programmability					
	CS_AZ_CFG	Always					
	CS_NEG_OCP_DIS	Always					
OTP_PROG	OTP_PROG	Standby (programming of OTP only in Standby)					
	USER_ID	Always					

# Table 29 Register read/write coding description

Code	Access type	Description
res	No access	Reserved
r	Read	Read only. A write produces no action
rw	Read/Write	Read or write by user
W	Write	Write only. A read returns 0

### **Register Map**

# 11.4 MOTIX<sup>™</sup> 6EDL7141 Register Map

# **Faults Status Register**

If the status of one of the bits switches to value b'1, the corresponding fault/warning has occurred. To clear the fault use the clear faults bit in the FAULTS\_CLR register

# FAULT\_ST

										Reset Value 0000 <sub>H</sub>						
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
	0		OTP_ FLT	WD_ FLT	RLOC K_FLT	OTW_ FLT	OTS_ FLT	BK_OCP _FLT	DVDD_ OV_FL T	DVDD _UV_ FLT	DVDD _OCP _ FLT	CP_ FLT	cs	_0CP	_FLT	
	res		r	r	r	r	r	r	r	r	r	r		r		

Field	Bits	Туре	Description
CS_OCP_FL	2:0	r	Current sense amplifier OCP fault status
т			OCP (shunt amplifier OCP) fault status
			bXX0: No fault on phase A
			bXX1: Fault on phase A
			bX0X: No Fault on phase B
			bX1X: Fault on phase B
			b0XX: No Fault on phase C
			b1XX: Fault on phase C
CP_FLT	3	r	Charge pumps fault status
			Charge pump low side and high side combined fault status
			b0: No fault has occurred
			b1: A fault has occurred
DVDD_OCP_	4	r	DVDD OCP (Over-Current Protection) fault status
FLT			DVDD linear voltage regulator Over-Current-Protection fault status
			b0: No fault has occurred
			b1: A fault has occurred
DVDD_UV_F	5	r	DVDD UVLO (Under-Voltage Lock-Out) fault status
LT			DVDD UVLO fault status
			b0: No fault has occurred
			b1: A fault has occurred
DVDD_OV_F	6	r	DVDD OVLO (Over-Voltage Lock-Out)fault status
LT			DVDD OVLO fault status
			b0: No fault has occurred
			b1: A fault has occurred
BK_OCP_FL	7	r	Buck OCP fault status
т			Buck Over-Current-Protection fault status
			b0: No fault has occurred
			b1: A fault has occurred

 $00_{H}$ 

Address:

MOTIX™	IMD70xA
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# **Register Map**



OTS_FLT	8	r	Over-temperature shutdown fault status Over temperature shutdown event status b0: No fault has occurred b1: A fault has occurred
OTW_FLT	9	r	Over-temperature warning status Over temperature warning signal status b0: No warning signal has occurred b1: A warning signal has occurred
RLOCK_FLT	10	r	Locked rotor fault status Locked Rotor fault status using hall sensors b0: No fault has occurred b1: A fault has occurred
WD_FLT	11	r	Watchdog fault status Watchdog status b0: No fault has occurred b1: A fault has occurred
OTP_FLT	12	r	<b>OTP status</b> OTP (One Time Programmable) memory fault status b0: No fault has occurred b1: A fault has occurred
0	15:13	res	Reserved A read always returns 0

# **Temperature Status Register**

This register contains the 6EDL7141 die temperature value

٦	TEMP_ST											Address:				
												Reset	Value			0000 <sub>H</sub>
_	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0												TE	MP_V	AL.		
					res								r			

Field	Bits	Туре	Description
TEMP_VAL	6:0	r	<b>Temperature reading</b> Temperature value in step of 2 degrees b000000: -94 degrees Celsius every 2 degrees Celsius b1111111: 160 degrees Celsius
0	15:7	res	ReservedA read always returns 0

**Register Map** 



# **Power Supply Status Register**

This registers contains status of power supply related blocks

	SUPPLY_STAddress:Power Supply StatusReset Value										C	02 <sub>н</sub> 0000 <sub>н</sub>				
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	0 PVDD_VAL									VDDB_ OVST		DVDD _OVST		VCCHS_ UVST	VCCLS _UVST	
res							r				r	r	r	r	r	r

Field	Bits	Туре	Description
VCCLS_UVS	0	r	Charge Pump low side UVLO status
т			b0: Below threshold
			b1: Above threshold
VCCHS_UVS	1	r	Charge Pump high side UVLO status
т			b0: Below threshold
			b1: Above threshold
DVDD_UVST	2	r	DVDD UVLO status
			b0: Below threshold
			b1: Above threshold
DVDD_OVST	3	r	DVDD OVLO (Over-Voltage Lock-Out) status
			b0: Below threshold
			b1: Above threshold
VDDB_UVST	4	r	VDDB UVLO status
			b0: Below threshold
			b1: Above threshold
VDDB_OVST	5	r	VDDB OVLO status
			b0: Below threshold
			b1: Above threshold
PVDD_VAL	12:6	r	PVDD ADC result reading value
			This bitfields holds the analog to digital conversions value for PVDD
			input voltage
0	15:13	r	Reserved
			A read always returns 0

### **Register Map**



# **Functional Status Register**

Status of various functional signals.

15 14 13 12 11 10 9 8 7 6 5 4 3 2 1	03 <sub>н</sub> 0000 <sub>н</sub>
	0
O     CS_GAIN_ST     DVDD_ ST     HALLP OL_ST     HALLP	ST

Field	Bits	Туре	Description
HALLIN_ST	2:0	r	Hall sensor inputs status -
			HALL sensor input pins status for each phase.
			b0: signal is low
			b1: signal is high
			bit 0: Phase A
			bit 1: Phase B
			bit 2: Phase C
HALLPOL_S	3	r	Hall sensor polarity equal indicator
т			Status bit that indicate if all phases of the hall sensors have the same
			polarity at the same time.
			b0: Hall sensors have different polarity
			b1: Hall sensors have the same polarity
DVDD_ST	4	r	DVDD set point status
			DVDD set point read value.
			Note: For IMD700A the DVDD rail is forced to be 3.3V and for IMD701A
			is forced to 5.0V
			b0: 3.3 V – value for IMD700A
			b1: 5.0 V – value for IMD701A
CS_GAIN_ST	7:5	r	Status of the current sense amplifiers gain
			Shows the value of the current sense amplifier gain independently of
			whether programmed digitally or via external resistor
			b000: 4 V/V
			b001: 8 V/V
			b010: 12 V/V
			b011: 16 V/V
			b100: 20 V/V
			b101: 24 V/V
			b110: 32 V/V
			b111: 64 V/V
0	15:8	r	Reserved
			A read always returns 0

Datasheet

### **Register Map**

# **OTP Status Register**

OTP memory status information is found in this register.

ОТР	_ST												Address: set Value			04 <sub>н</sub> 0000 <sub>н</sub>
15		14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
						0							OTP_PR OG_FAIL	OTP_ PROG _BLOCK	OTP_ PASS	OTP_ USED
						res							r	r	r	r

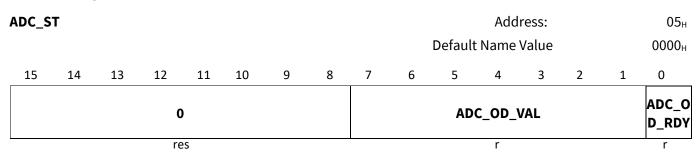
Field	Bits	Туре	Description
OTP_USED	0	r	OTP used This bitfield shows if OTP memory has been written by user or still holds factory defaults: b0: OTP memory is not used: factory defaults b1: OTP memory is used: new custom values loaded
OTP_PASS	1	r	<b>User OTP programming status</b> Is set if user OTP programming has passed without error. b0: Not programmed or not passed. b1: Programming passed without error.
OTP_PROG_ BLOCK	2	r	User OTP programming blocked Signals if OTP programming has been attempted when voltage or temperature outside range. b0: Programming was not blocked b1: Programming blocked
OTP_PROG_ FAIL	3	r	<b>OTP Programming fail</b> If set, indicates that the programming of the OTP has failed. b0: No failure. b1: Programming failed
0	15:4	res	Reserved       A read always returns 0



**Register Map** 

# **ADC Status Register**

ADC status registers.



Field	Bits	Туре	Description
ADC_OD_RD	0	r	ADC on demand conversion result ready
Y			This bitfields indicates if ADC result for one of the extended conversions is ready to be read
			b0: Not ready
			b1: Ready
ADC_OD_VA	7:1	r	ADC on demand result value
L			ADC result value for on demand conversions
0	15:8	res	Reserved
			A read always returns 0

# **Charge Pumps Status Register**

Charge pumps status registers.

CP\_ST Address: 06<sub>H</sub> **Default Name Value** 0000<sub>H</sub> 15 14 13 12 9 8 7 6 5 4 3 2 1 0 11 10 0 VCCLS\_VAL VCCHS\_VAL res r r

Field	Bits	Туре	Description
VCCHS_VAL	6:0	r	VCCHS ADC result reading value This bitfields holds the analog to digital conversions value for VCCHS voltage
VCCLS_VAL	13:7	r	VCCLS ADC result reading value This bitfields holds the analog to digital conversions value for VCCLS voltage
0	15:14	res	Reserved A read always returns 0



### **Register Map**



# **Device ID Register**

					r	es								r	
					(	)							DE	V_ID	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
<b>DEVICE</b> Device											Add Reset	ress: Value			07 <sub>н</sub> 0006 <sub>н</sub>
	- 15										امام ۵				07
Device	ID														

Field	Bits	Туре	Description
DEV_ID	3:0	r	Device ID
			Device identifier for user version control
0	15:4	r	Reserved
			A read always returns 0

# Faults Clear Register

Clear different faults in the device.

FAULT	S_CLR										Add Reset	ress: Value		(	10 <sub>н</sub> 0000 <sub>н</sub>
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
						0	)							CLR_ LATCH	
						r	es							w	W

Field	Bits	Туре	Description
CLR_FLTS	0	w	Clear all faults
			Setting this bitfield will clear all faults in the device excluding latched faults. A reading always returns 0.
			b0: No action.
			b1: Clear all fault status bits except latched ones
CLR_LATCH	1	w	Clear all latched faults
			Setting this bitfield will clear all (and only) latched faults in the device. A reading always returns 0.
			b0: No action.
			b1: Clear latched fault status bits
0	15:2	res	Reserved
			A read always returns 0



### **Register Map**



# **Power Supply Configuration Register**

This register contains bitfields to configure and control power supplies in the device.

SUPPLY_	CFG										Addı	ress:		11				
											Reset V	/alue		6000				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1 0				
CP_PRE CHARG E_EN		_TON LAY	BK_ FRE		0 DVDD_SFTSTRT DVDD_OCP_ CFG CS_REF_CFG													
rw	r	w	rw	re	es.	I		rw		rw rw rw								
Field																		
PVCC_S T CS_REF G		1:0		rw	Co b0: b1: b1: cu Sel am b0: b1: cu Sel am b0: b1: cu	<b>D: 12V</b> L: 15V D: 10V L: 7V <b>rrent s</b>	e VRE conse e VRE conse vDD DVDD	target F <b>referer</b> F voltag	ce co	nfigurat	ion (in	ternal V	ltage leve <b>REF volt</b> Ill 3 curre					
DVDD_C CFG	DCP_	5:4		rw	DV sel <b>b0</b> b02 b10		P thre value. <b>nA</b> nA	shold se	-	uration		occurs at	: 66% of t	he				
DVDD_S TRT	SFTS	9:6		rw	DV to 1 b00  100	DD line 1.6ms <b>D00: 1(</b> 001: 20  ) us ste	ear reg <b>)0 us</b> 0 us eps	r <b>t confi</b> gulator s	-		rammir	ng 100us	steppinį	g 100us up				
0		11:10	)	res	Re	served												

Datasheet

# **Register Map**



BK_FREQ	12	rw	Buck converter switching frequency selectionThis bitfield configures the switching frequency of the buck converterb0- Low frequency (500kHz)b1: High frequency (1MHz)
DVDD_TON_ DELAY	14:13	rw	<b>DVDD turn on delay configuration</b> The device will wait for the configured time before turning on theDVDD starting counting from VDDB UVLO during start-up of the deviceb00 - 200usb01 - 400usb10 - 600us <b>b11 - 800us</b>
CP_PRECHA RGE_EN	15	rw	Charge pump pre-charge configuration Enables during start-up the pre-charge of the charge pump <b>1'b0 : pre-charge disabled</b> 1'b1 : pre-charge enabled



Datasheet

### **Register Map**

# **ADC Configuration Register**

Note:

The complete content of the register must be written at once (read-modify-write). Writing a single bitfield at a time will set to default all other bitfields.

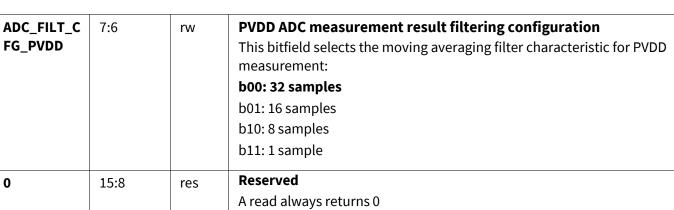
Configuration of ADC related functions.

A	)C_CI	FG											dress: t Value			12 <sub>н</sub> 0000 <sub>н</sub>
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
				0						_FILT_ _PVDD			ADC_E N_FILT		_OD_ SEL	ADC_ OD_RE Q
				r	es					rw		rw	rw	r	w	W

Field	Bits	Туре	Description
ADC_OD_RE Q	0	w	ADC on demand conversion requestSetting this bitfield will inject an additional measurement in the standard sequence. This additional measurement is selected in ADC_IN_SEL bitfield. A read always return 0. b0: No action.b1: Request the conversion of the signal selected in ADC_IN_SEL
ADC_OD_IN SEL	2:1	rw	ADC input selection for on demand conversionsThis bitfield configures the input to the ADC: <b>b00:</b> IDIGITAL: device digital area current consumptionb01: DVDDb10: VDDBb11: Reserved
ADC_EN_FIL T	3	w	<ul> <li>Enable filtering for on demand ADC measurement</li> <li>Enables moving averaging filter for on demand ADC measurements. A read always return 0</li> <li>b0: No action.</li> <li>b1: Enable filtering</li> </ul>
ADC_FILT_C FG	5:4	rw	<ul> <li>ADC generic filtering configuration</li> <li>Selects the moving averaging filter characteristic for the ADC measurements except PVDD measurements:</li> <li>b00: 8 samples averaging filter</li> <li>b01: 16 samples averaging filter</li> <li>b10: 32 samples averaging filter</li> <li>b11: 64 Samples averaging filter</li> </ul>

Datasheet

### **Register Map**



# **PWM Configuration Register**

Configuration of PWM related configurations.

Ρ	wм_c	CFG							Address:					13 <sub>H</sub>		
R												Rese	t Value			0000 <sub>H</sub>
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
					0					PWM_ RECIRC		AKE CFG	PWM_ FREEW_ CFG		PWM_M	ODE
				re	2S					rw	rw	/	rw		rw	

Field	Bits	Туре	Description
PWM_MODE	2:0	rw	PWM commutation mode selection
			PWM Mode selection:
			b000: 6PWM mode
			b001: 3PWM mode
			b010: 1PWM mode
			b011: 1PWM with Hall sensors – not possible due to interconnects –
			do not use
			b100: b111: Reserved
PWM_FREE	3	rw	PWM freewheeling configuration
W_CFG			This bitfield selects which rectification or freewheeling is desired (only
			for 1 PWM input modes)
			b0: Active freewheeling
			b1: Diode freewheeling
BRAKE_CFG	5:4	rw	Brake configuration
			Brake scheme configuration.
			b00: Low Side
			b01: High Side
			b10: High Z (no power)
			b11: Brake toggle-alternates between low and high side braking on
			every braking event



# **Register Map**



PWM_RECIR C	6	rw	PWM recirculation selection (only if PWM_MODE = b011:)Setting this bitfield will activate the alternating recirculation feature ofthe 1PWM with Hall Sensors and Alternating Recirculation PWM mode.Only functional if PWM_MODE=b011.b0: Disable alternating recirculation modeb1: Enable alternating recirculation mode
0	15:7	res	Reserved
			A read always returns 0

# **Sensor Configuration Register**

Sensors configuration.

SENSO	R_CFG							Addr Reset V			14 000				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
				0					CS_T	MODE	OTS_ DIS		HALL_	DEGLI	гсн
				res					rw		rw		r	w	

Field	Bits	Туре	Description
HALL_DEGLI	3:0	rw	Hall Sensor deglitch
тсн			Deglitch time configuration for Hall sensor inputs in steps of 640ns
			b0000: 0ns
			b0001: 640 ns
			in steps of 640 ns
			b1111- 9600 ns
OTS_DIS	4	rw	Over-temperature shutdown disable
			This bitfield allows to disable the shutdown feature due to over
			temperature in the device:
			b0: Enable shutdown protection
			b1: Disable shutdown protection
CS_TMODE	6:5	rw	Current sense amplifier timing mode
			This bitfield configures how the current sense amplifier operates
			regarding the timing related to the PWM signals:
			b00: CS amplifier outputs are active when GLx signal is high
			b01: CS amplifier outputs are active when GHx signal is low
			b1x: CS amplifier outputs are always active
0	15:7	res	Reserved
			A read always returns 0

**Register Map** 



# Watchdog Configuration Register

Watchdog controls.

WD_CFG										Addr Reset V				15 <sub>н</sub> 0000 <sub>н</sub>
15 14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			W	ID_TI	MER_1	Т				WD_FL TCFG	WD	D_INSEI	L	WD_EN
res				r	W					rw		rw		rw
Field	Bits		Туре	Des	scripti	ion								
WD_EN	0		rw	W b(	atchd 0: Wat	<b>log ena</b> og time t <b>chdog</b> chdog t	er enab <b>timer i</b>	s disał						
WD_INSEL	3:1		rw	Th op <i>bu</i> <i>to</i> <i>re</i> b0 b0 b0 b1 b1 b1 b1	his bitt ptions 000: El pintero progr 2011: Re 2010: D' 2011: V( 100: St 101: Re 110: Re	: <b>N_DRV</b> connec cammed eservec VDD (lir CCLS ar	lects th <b>pin (me</b> <b>ts betw</b> <b>d to oth</b> l near reg nd VCCH gister r	e input easure veen XI ger valu gulator HS, (cha	input MC140 Jue if w arge p	e watchdo signal fre 4 and 6EL vatchdog i umps) ate for de	equenc DL7141 is need	y)-Not   , must	poss	-
WD_FLTCFG	4		rw	Tł b(	his biti 00: Sta	atus re	ntrols t <b>gister (</b>	he read only	ction t	o a watch of nFAUL <sup>-</sup>	C	ult even	it:	
WD_ TIMER_T	14:5		rw	Th tii w (b b( 	his bith me is e atchdo ouck) v 00000 000000	elapsed	onfigur I with n I is trigg Og inpu <b>100 us</b> 200 us	es the <sub>l</sub> o re-sta ;ered. l t.	period art of t	l of the wa he timer l us steps. N	by the v	watchd	og ir	nput, a
0	15		res		<b>eserve</b> read a	<b>ed</b> always r	eturns	0						

### **Register Map**



# Watchdog Configuration Register 2

Watchdog configurations register extension.

WD_CFG2										Add	ress:			16 <sub>H</sub>
										Reset	Value			$0000_{\text{H}}$
15 14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0		WD_ BK_DIS	WD.	_RLOC	К_Т	WD_ RLOCK _EN	WD_	_DVDD	_RSTRT	_DLY	_RS	_DVDD TRT_A TT	WD_ EN_ LATCH	WD_ BRAKE
res		rw	1	rw		rw		r	W			rw	rw	rw
Field	Bits		Туре	Des	cript	ion								
WD_BRAKI	E 0		rw	Th th <b>b(</b> b1 m	nis bit e wat <b>): Noi</b> L: Bral	on watch fields pro cchdog ov r <b>mal reac</b> ke on wat s configur ingly	vides erflov tion t	the op v occur <b>:o fault</b> g fault (	tion to c s : (Automa	tically	latch	ed). Th	e brakin	g
WD_EN_LA CH	<b>T</b> 1		rw	Er b(	nable ): Fau	latching latching o Ilt not lat It latched	of wat c <b>hed</b>		•					
WD_DVDD RSTRT_AT			rw	Nu <b>bu</b> bu	umbe <b>)0: 0 a</b> )1: 1 a .0: 2 a	t delay fo r of restant attempts attempt attempts attempts	rt atte		or DVDD	WD				
WD_DVDD RSTRT_DL	7.4		rw	D\ Ti In b( b( b) b1	<b>/DD r</b> me af steps <b>0000:</b> 0001:	<b>estart de</b> ter WD tri s of 0.5ms <b>0.5 ms</b> 1 ms 7.5 ms	igger s	signal u	ıntil rest	art is a	attem	pted ag	ain for I	OVDD.
WD_RLOCI EN	<b>K</b> _ 8		rw	Er Er	n <b>able</b> nable	rotor loc rotor loc abled				g time	r inpu	t		

#### Datasheet

### **Register Map**



WD_RLOCK_ T	11:9	rw	Rotor locked watchdog timeout Watchdog timer period value (overflow value). In steps of 1s b000: 1 second b001: 2 s  b111: 8 s
WD_BK_DIS	12	rw	Buck watchdog disable Buck watchdog (start-up) disable b0: Buck watchdog enabled b1: Buck watchdog disabled
0	15:13	res	<b>Reserved</b> A read always returns 0

# Gate Driver Current Control Register

Gate driver current settings for slew rate control.

IDRIVE	_CFG										Address:					
						Reset Value							BBBBH			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
	ILS_SINK ILS_SRC									IHS_SINK IHS_SRC						
	re	S			r	W			r١	N		I	I	ſW		
Field		Bits		Туре	Des	cripti	on									

# **Register Map**

IHS_SRC	3:0	rw	High-side source current
			High side gate driver rise or pull-up gate current applied during period
			T <sub>DRIVE2</sub>
			b0000 - 10mA
			b0001 - 20mA
			b0010 - 30mA
			b0011 - 40mA
			b0100 - 50mA
			b0101 - 60mA
			b0110 - 80mA
			b0111 – 100mA
			b1000 - 125mA
			b1001 - 150mA
			b1010 - 175mA
			b1011 - 200mA
			b1100 - 250mA
			b1101 – 300mA
			b1110 – 400mA
			b1111 – 500mA
IHS_SINK	7:4	rw	High-side sink current
			High-side gate driver fall or pull-down gate current applied during
			period T <sub>DRIVE4</sub>
			Same coding as IHS_SRC
ILS_SRC	11:8	rw	Low-side source current
			Low side gate driver rise or pull-up gate current applied during period
			T <sub>DRIVE2</sub>
			Same coding as IHS_SRC
ILS_SINK	15:12	rw	Low-side sink current
			Low side gate driver fall or pull-down gate current applied during
			period T <sub>DRIVE4</sub>
			Same coding as IHS_SRC





### **Register Map**

# Gate Driver Pre-Charge Current Control Register

Low side gate driver control parameters

IDRIVE_PRE_	CFG										dress:			18 <sub>H</sub>
										Reset	Value			$00BB_{H}$
15 14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
		0				I_PRE _EN		I_PRE	_SINK			I_PR	E_SRC	
		r	es			rw		r١	N			I	Ŵ	
Field	Bits		Туре	Des	cript	ion								
I_PRE_SRC	3:0		rw	Pr	re-ch	arge sou	rce c	urrent	setting	g (T <sub>DRIV</sub>	'E1)			
				b0 b0 b0 b0 b0 b0 b1 b1 b1 b1 b1 b1 b1 b1 b1 b1 b1 b1	)0000 - )0011 - )0110 - )100 - )101 - )101 - )111 - )111 - 1000 - 1001 - 1001 - 1001 - 1001 - 1001 - 1101 - 1101 -	pull-up ga 10mA 20mA 30mA 40mA 50mA 60mA 80mA 100mA 125mA 150mA 175mA 250mA 250mA - 300mA - 400mA					pre-ch	arge pr	nase (1	DRIVE1)
I_PRE_SINK	7:4		rw	Fa	ill or p	<b>arge sinl</b> oull-dowr oding as	n curr	ent durii	- ·		e phase	e (T <sub>drives</sub>	.)	
I_PRE_EN	8		rw	En 1.! <b>b0</b>	nables 5A are <b>): Pre</b>	river pre- s extra pro- e applied charge o lied durin	e-cha durin <b>curre</b>	rge curro g T <sub>drive1</sub> a n <b>t enab</b>	ent cor and T <sub>driv</sub> <b>led</b> . Va	nfigura <sub>ve3</sub> perio lues I_	ods PRE_S			
0	15:9	)	res	es <b>Reserved</b> A read always returns 0										

**Register Map** 



# **TDRIVE Source Control Register**

 $T_{DRIVE1}$  and  $T_{DRIVE2}$  configuration registers for ate driver sourcing mode.

TDRIVI	E_SRC_	CFG									Ado Reset ۱	lress: Value			19 <sub>н</sub> FF00 <sub>н</sub>
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
			TDR	IVE2							TDR	IVE1			
<u> </u>			rv	V							n	N			

Field	Bits	Туре	Description
TDRIVE1	7:0	rw	TDRIVE1 timingTDRIVE1 value for high and low side. First turn on or pre-charge periodb00000000 - Onsb00000001 - 50ns (values between 0ns and 50ns not allowed)10ns stepsb11111111 - 2590ns
TDRIVE2	15:8	rw	TDRIVE2 timing         TDRIVE2 value for high and low side.         b00000000 - 0ns         b00000001 - 10ns         10ns steps         b11111111 - 2550ns

# **TDRIVE Sink Control Register**

Tdrive3 and Tdrive4 configuration registers for ate driver sourcing mode.

TDRIVE	E_SINK	_CFG									Ado	lress:			$1A_{H}$
											Reset	Value			FF00 <sub>H</sub>
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
			TDR	IVE4							TDR	IVE3			
			rv	v							r	N			

Field	Bits	Туре	Description
TDRIVE3	7:0	rw	TDRIVE3 timingTDRIVE3 value for high and low side. First turn off or pre-discharge periodb00000000 - Onsb00000001 - 50ns (values between 0ns and 50ns not allowed)10ns stepsb11111111 - 2590ns

### Datasheet

# **Register Map**



TDRIVE4	15:8	rw	T <sub>DRIVE4</sub> timing
			T <sub>DRIVE4</sub> value for high and low side.
			b0000000 - 0ns
			b0000001 - 10ns
			10ns steps
			b11111111 - 2550ns

# **Dead Time Register**

Dead time configurations.

DT_CF	G										Ado Reset ۱	dress: Value			1В <sub>н</sub> 3131 <sub>н</sub>
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
			DT_I	FALL							DT_	RISE			
			r	Ŵ							rw	/			

Field	Bits	Туре	Description
DT_RISE	7:0	rw	Dead time rise (of phase node voltage)           Dead time rise (low to high) value           b00000000: 120 ns           b00000001: 200 ns           In steps of 80ns              b00110001: 4040ns              b10010101: 12040 ns           b10010101: b1111111: Unused (defaults to 120ns)
DT_FALL	15:8	rw	Dead time fall (of phase node voltage)           Dead time fall (high to low) value           b00000000: 120 ns           b00000001: 200 ns           In steps of 80ns              b00110001: 4040ns              b10010101: 12040 ns           b10010110: b1111111: Unused (defaults to 120ns)

### **Register Map**

# **Charge Pump Configuration Register**

Charge pump related controls.

CP_CF	G										Ado Reset	dress: Value			1С <sub>Н</sub> 0000 <sub>Н</sub>
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
						0							CP_CLK _SS_DIS		_CLK_CF G
						res							rw		rw

Field	Bits	Туре	Description
CP_CLK_ CFG	1:0	rw	<ul> <li>Charge pump clock frequency configuration</li> <li>This bitfield configures the charge pump clock switching frequency.</li> <li>b00: 781.25 kHz</li> <li>b01: 390.6 kHz</li> </ul>
			b10: 195.3 kHz b11: 1.5625 MHz
CP_CLK_SS DIS	2	rw	Charge pump clock spread spectrum disable b0: Spread spectrum is enabled b1: Spread spectrum disabled
0	15:3	res	Reserved         A read always returns 0



# **Register Map**

# **Current Sense Amplifier Configuration Register**

Current sense amplifier configurations.

CSAMF	P_CFG										Ad	dress:			$1D_{H}$
											Reset	t Value			0028 <sub>н</sub>
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	CPFLT_ FG		OCP_ LITCH	CS_EN_ DCCAL		CS_E	BLANK			CS_EN		CS_ GAIN_ ANA	(	CS_G/	AIN
r۱	N	r۱	w	rw		rv	v			rw		rw		rw	

Field	Bits	Туре	Description
CS_GAIN	2:0	rw	Gain of current sense amplifiers
			Selects gain of current sense amplifier when digitally programmed
			b000: 4 V/V
			b001: 8 V/V
			b010: 12 V/V
			b011: 16 V/V
			b100: 20 V/V
			b101: 24 V/V
			b110: 32 V/V
			b111: 64 V/V
CS_GAIN_AN	3	rw	CS Gain analogue programming enable
Α			Change to b0 to program GAIN digitally - due to interconnects of
			XMC1404 and 6EDL7141, analog programming is not possible and
			CS_GAIN must be programmed digitally
			CS Gain analogue programming enable
			b0: Gain is selected via register configuration (CS_GAIN bitfield)
			b1: Gain is defined by CS_GAIN pin resistor
CS_EN	6:4	rw	Enable of each current shunt amplifier
			Enable of each current shunt amplifier
			bit 0: phase A
			bit 1: phase B
			bit 2: phase C
			b0: Amplifier disabled
			b1: Amplifier enabled

MOTIX™	IMD70xA
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# **Register Map**

CS_BLANK	10:7	rw	Current shunt amplifier blanking time
			Current shunt amplifier blanking time
			b0000: 0 ns
			b0001: 50 ns
			b0010: 100 ns
			b0011: 200 ns
			b0100: 300 ns
			b0101: 400 ns
			b0110: 500 ns
			b0111: 600 ns
			b1000: 700 ns
			b1001: 800 ns
			b1010: 900 ns
			b1011: 1 us
			b1100: 2 us
			b1101: 4 us
			b1110: 6 us
			b1111: 8 us
CS_EN_DCC	11	rw	Enable DC Calibration of CS amplifier
AL			DC calibration of CS amplifier
			b0: No calibration is executed
			b1: DC calibration mode executed: all power stages in high Z: powered
			but not driving
CS_OCP_DE	13:12	rw	Current sense amplifier OCP deglitch
GLITCH			OCP deglitch timing configuration of the OCP on current sense
			amplifiers-deglitch disabled (bypassed) if CS_TRUNC_DIS = b0
			(register CSAMP_CFG2)
			b00: 0 μs
			b01: 2 μs
			b10: 4 μs
			b11:8μs
CS_OCPFLT	15:14	rw	Current sense amplifier OCP fault trigger configuration
_CFG			OCP fault trigger configuration
			b00: Count 8 OCP events
			b01: Count 16 OCP events
			b10: Trigger on all OCP events
			b11: No fault trigger (PWM Truncation continues as defined in bitfield
			CS_TRUNC_DIS in register CSAMP_CFG2)



### **Register Map**



# Current Sense Amplifier Configuration Register 2

Current sense amplifier configurations extension register.

# CEAND CECO

CSAMP_	CFG2										Ado Reset	lress: Value			1Е <sub>н</sub> 0833 <sub>н</sub>
15 1	4	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CS_AZ_0 G															
rw	r	W	rw	rw	rw	rw	rw		rv	V		•		rw	
Field		Bit	s	Туре	Des	cription									
CS_OCI HR		3:		rw	Th 4't 4't 4't 4't 4't 4't 4't 4't 4't 4't		50mV 25mV 200mV 75mV 50mV 25mV 25mV 20mV 0mV 0mV 0mV 0mV 0mV	-		-				e OCP	

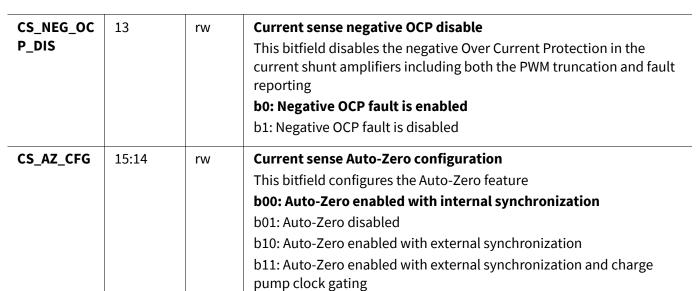
4'b1110: 30mV 4'b1111: 20mV

# **Register Map**

CS_OCP_NT HR	7:4	rw	Current sense amplifier OCP negative thresholds This bitfield configures the threshold level for the negative OCP 4'b0000: -300mV 4'b0001: -250mV 4'b0010: -225mV 4'b0011: -200mV 4'b0100: -175mV 4'b0101: -150mV 4'b0101: -125mV 4'b0111: -100mV 4'b1001: -80mV 4'b1001: -80mV 4'b1011: -60mV 4'b1011: -60mV 4'b1101: -30mV 4'b1110: -30mV 4'b1111: -20mV
CS_OCP_LA TCH	8	rw	OCP latch choice OCP fault can be selected with this bitfield to be a latched: b0: Unlatched b1: Latched
CS_MODE	9	rw	Current sense amplifier sensing mode Select between shunt resistor and R <sub>DSON</sub> sensing modes <b>b0: Shunt resistor</b> b1: R <sub>DSON</sub> sensing-CS_TMODE forced to be GL ON only
CS_OCP_BR AKE	10	rw	<ul> <li>Current sense amplifier brake on OCP configuration</li> <li>Brake on OCP</li> <li>b0: No braking upon OCP fault.</li> <li>b1: Brake on OCP fault (fault set to latched). The braking mode is configured in PWM_CFG register</li> </ul>
CS_TRUNC_ DIS	11	rw	<b>PWM truncation disable</b> Disables the truncation of PWM when an OCP occurs. This does not affect fault triggering. b00: PWM truncation enabled <b>b01: PWM truncation disabled</b>
VREF_INSEL	12	rw	<ul> <li>VREF source selection – DO NOT CHANGE – VREF external not possible</li> <li>This bitfield controls whether the current sense amplifier buffer offset (reference) is generated internally or is applied externally through the device pin VREF</li> <li>b0: Use internal – DO NOT CHANGE</li> <li>b1: Use external – This configuration is not possible</li> </ul>



### **Register Map**



# **OTP Program Register**

OTP program command and user ID.

OTP_F	ROG										Ado Reset ۱	dress: Value			1F <sub>н</sub> 0000 <sub>н</sub>
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
					0							USE	ER_ID		OTP_ PROG
					res						•	r	W		W

Field	Bits	Туре	Description
OTP_PROG	0	W	Program OTP
			Setting this bitfield will start programming of OTP
USER_ID	4:1	rw	User ID
			Space for user to enter an ID into OTP for version control
0	15:5	res	Reserved
			A read always returns 0

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Datasheet

**Application Description** 



# **12** Application Description

### 12.1 Recommended External Components

MOTIX<sup>™</sup> IMD70xA requires some external components for proper operation. Recommended components and values are listed in Table 30.

Element	Pin1	Pin2	<b>Recommended value</b>	Rating	Notes
C <sub>PVDD</sub>	PVDD	PGND	4.7µF	According to PVDD	
C <sub>DVDD</sub>	DVDD	DGND	10μF + 0.1μF	16V	
C <sub>VCCHS</sub>	VCCHS	PGND	1μF < C <sub>VCCHS</sub> < 2.2μF	25V if connected to PVDD or according to (PVDD+PVCC) if connected to PGND	Depending on VCCHS ripple and start-up requirements
C <sub>VCCLS</sub>	VCCLS	PGND	$1\mu F < C_{VCCLS} < 4.7\mu F$	25V	Depending on VCCLS ripple and start-up requirements
C <sub>CP1</sub>	CP1H	CP1L	220nF< С <sub>СР1</sub> <1µF	16V or 25V	0.47µF recommended
C <sub>CP2</sub>	CP2H	CP2L	220nF< C <sub>CP2</sub> <1μF	According to PVDD	0.47µF recommended
L <sub>виск</sub>	РН	VDDB	22μΗ	According to max	500kHz configuration
			10µH	– peak current	1MHz configuration
Свиск	VDDB	PGND	47 μF	16V	500kHz configuration
			47 μF		1MHz configuration

### Table 30 Recommended external components

### **12.2 PCB Layout Recommendations**

Layout is critical to ensure high quality signal and sensing. Different recommendations are provided in this section for best electrical, thermal and EMI results.

### Grounding and Supply

PGND is the ground used for the following sections in 6EDL7141:

- Buck converter
- Charge pumps
- Gate drivers for low and high side

DGND is used for:

- XMC1404,
- Digital logic in 6EDL7141,
- Current sense amplifiers
- DVDD

It is recommended to cover well components that refer to PGND with PGND solid planes and to cover DGND referred components with DGND solid plane. Also ensure that there is no overlap between PGND and DGND planes to avoid cross coupling.



### **Application Description**



However, PGND and DGND have be connected to the same electrical potential and must be connected to each other in one place in the PCB. The location depends on many factors. Sometimes close to the negative (return) of the supply or battery can lead to best results.

Decoupling capacitors for supply pin (PVDD) should be as close as possible to the pin 25 (PVDD) and pin 27 (PGND). It can as well be helpful to use a small 0.1uF capacitor for high frequency glitches suppression.

Generally speaking shielding of signals like gate signals but also sensing signals is important to avoid coupling and noise injection from other noisy areas.

If battery is expected suddenly drop close to the UVLO level of PVDD, it is recommended to have large capacitors that can maintain the supply voltage during those transients. Eventually, a diode (e.g. Schottky) can be used in series with PVDD and before the decoupling capacitor. This can avoid that the PVDD decoupling capacitors discharge to the battery or other circuits when the battery transient crosses below the PVDD UVLO level of 6EDL7141.

Similarly, CE pin if derived from the battery voltage with voltage dividers, might be affected by these transients. It can be a good idea to use a small capacitor in CE pin to ensure noise is not switching off the device. Current consumption of CE pin is extremely low. If the only way to discharge the CE capacitor is through 6EDL7141, the device might stay on for long periods. It could be useful to design a discharge path in case this is a problem.

### Thermal design

Depending on the configuration of the device and the usage of the different integrated power converters like synchronous buck, LDO or charge pump, the device will present different power losses that will translate into self-heating. User can choose for example the LDO output voltage: selecting 5V instead of 3.3V will reduce the losses in the LDO module. Another example: the buck converter output voltage (which is the input for the LDO), can be configured according to the gate driving voltage needs. If 12V/15V are not required, user can configure the buck converter to produce 7V output voltage, reducing the losses as well in the LDO when compared with the standard case 8V.

In order to dissipate the generated heat to the PCB is critical to have a solid connection of the device to the thermal pad (DGND pad). It is as well highly recommended to have a good amount of thermal vias that can transfer efficiently the heat from the pad to the PCB. An example is presented in Figure 59.

As a general rule, thicker PCB layers (2  $oz/ft^2$ -70 $\mu$ m- or above) can help dissipate faster any heat generated inside the device.

### **Buck Converter and DVDD**

The relatively high switching frequency and high voltage switching (PVDD to PGND) of the buck converter makes it a sensitive block in the device to pay extra attention during design phase.

Main goal is to reduce buck switching loop as much as possible (V<sub>PH</sub>-Inductor-Capacitor-VDDB). In 6EDL7141, most elements in the synchronous buck are integrated mitigating the EMI emissions, like external diode or low side MOSFET as well as the feedback or reference resistors.

Apart from the loop itself, it is very important to reduce in particular the V<sub>PH</sub> traces to the shortest possible and avoid any large copper amount in the inductor connection. This node is switching PVDD voltage at high frequency and therefore can be a source of noise in other elements especially this trace must be as far as possible from sensitive analog sensing like current sensing.

Figure 59 shows a possible buck converter layout with minimized  $V_{PH}$  trace and buck loop area.

#### **Application Description**



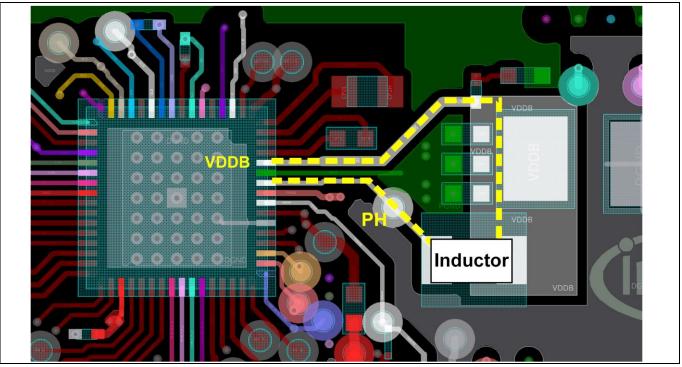


Figure 59 Buck converter layout recommendation. V<sub>PH</sub> trace and buck loop area (highlighted) must be minimized

DVDD linear regulator must be decoupled with capacitors placed as close as possible to the DVDD pins and connect as short as possible to DGND on the other terminal. Other components supplied by DVDD voltage are recommended to use additional decoupling local capacitors at those components. This is helpful to suppress possible noise captured by the routing of those traces.

### **Gate Driver and Charge Pumps**

Maintain as symmetric as possible gate signals including symmetry between phases (similar length for phase A, B and C) to avoid propagation delay mismatches. Keep as well gate current loops as short as possible and try to have as close as possible send and return signals.

The source signals of low side SLx, are shared between source of low side MOSFETs and top side sensing for shunt elements. It is recommended to optimize for the current sensing (symmetric tap of shunt terminal and parallel routing till current sense inputs), however, if current sense is not used, optimizing for gate driver performance is a good option.

Charge pump loops should be as small as possible, the charge pump flying capacitors must be placed close to the pins 29, 30, 31 and 32. Similar for the tank capacitors in VCCHS (pin 34) and VCCLS (pin 33). It is possible to place some of these capacitors in different layers as long as distance to the device is shortest possible.

Figure 60 shows and example of 6EDL7141 layout highlighting gate driver signals for high side and low side of phase A and the current sensing in a dual MOSFETs inverter.

Gate resistor can be used, however, user must know that the slew rate control of 6EDL7141 provides means to tune how fast MOSFETs switch in a programmable manner. Having Rg resistors will add additional voltage drop between 6EDL7141 and the gate of the MOSFET. Similarly, snubber elements (in parallel with MOSFETs) and bypass capacitors (high side drain to low side source) in the inverter can be used, nevertheless, the flexibility of the slew rate controller allows to remove those minimizing the BOM specially in a busy area of the layout, so more space can be used for the power section for example for better heat distribution in the PCB.

Datasheet

#### **Application Description**



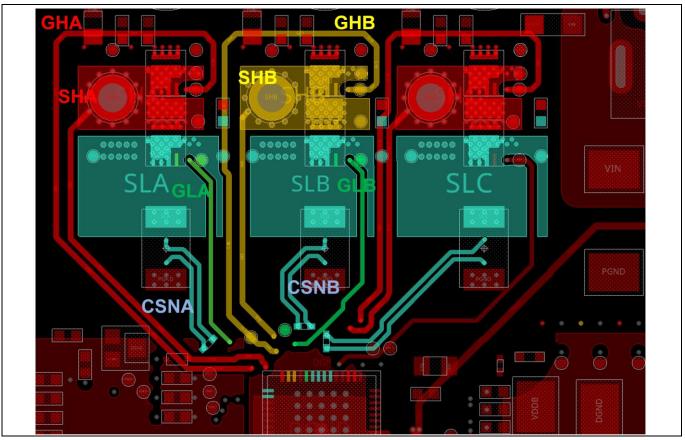


Figure 60 Gate driver and current sensing layout example. Signals are routed in a middle layer.

### **Current Sensing:**

RC filter at SLx and CSNx must be done with care and is not preferred. R1 and R2 as shown in 0, present voltage drop due to amplifier bias current and/or gate driver current, which affect the R<sub>shunt</sub> current sensing accuracy.

R1 limits the current of low-side (LS) gate driver and acts in fact as Rg. A parallel capacitor (C1 as shown below) between SLx and CSNx can be used. This can increase switching noise during MOSFET switching, at the same time improve steady state value. Larger C values will accentuate this effect. Depending on application this value can be adjusted. The parallel capacitor should be close to the SLx and CSNx inputs pins on PCB and values between 100pF to 1nF can be a good starting point.

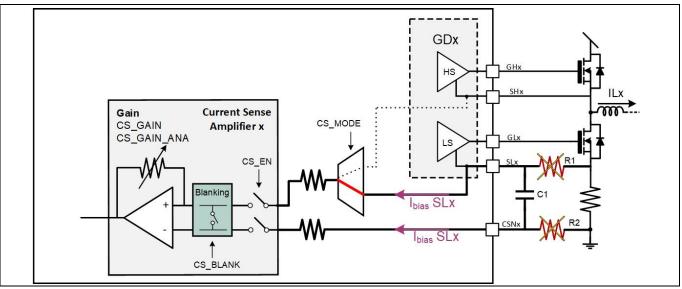
It is strongly recommended to use RC filter between current sense amplifier outputs (CSOx) and the ADC inputs in XMC1404 (AINx pins). Typical cut off frequency of 1MHz can be a good compromise between filtering capability and dynamic behavior, but user must decide depending on overall performance target.

Kelvin connection of shunt resistor is highly recommended as shown in Figure 60. Traces of SLx (red) and CSNx (blue) are routed in a middle layer in this case and covered with solid ground planes.



#### Datasheet

### **Application Description**



Current sense amplifier input filtering

# 12.3 Typical Applications

MOTIX<sup>™</sup> IMD70xA is a controller with integrated 3-phase gate driver IC to be used with external power MOSFETs for BLDC motor control applications. IMD70xA integrates as well a synchronous buck converter and a linear voltage regulator to provide power for charge pumps (gate drivers), XMC1404 and other external sensors. It integrates as well 3 current sense amplifiers with programmable gain. This can be used for single, double or triple shunt applications. This current information is used by XMC1404 to control the motor and to enhance the system protection.

Hall sensors can directly be connected to IMD70xA (through XMC1404 POSIF interface) inputs. An example configuration of this solution is presented in Figure 61. In this case, IMD70xA uses a single current sense amplifier.

Alternatively, Figure 62 shows a typical schematic for sensorless motor control method for BLDC motors. All 3 integrated current sense amplifiers are used to amplify the current flowing through current shunts. Current sense amplifier outputs are connected to the microcontroller ADC inputs so XMC1404 can control either torque, speed or position of the motor.

These 2 examples show only a basic set up. GPIOs and ADC inputs can be used for purpose like communication with other systems (e.g. SPI, UART, I2C), measurement of other magnitudes in the drive or for general purpose I/O like buttons or reading of a potentiometer.

Datasheet

### **Application Description**



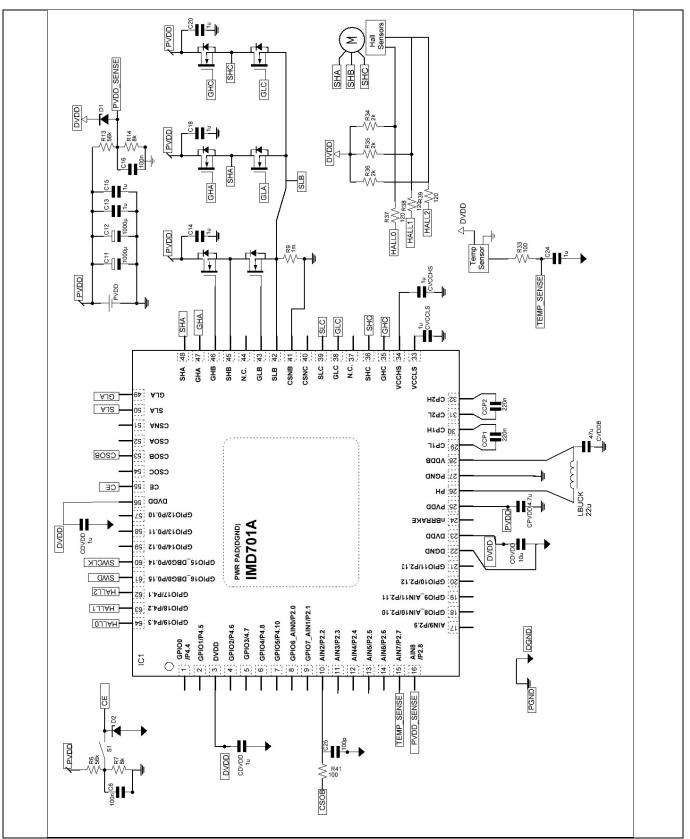


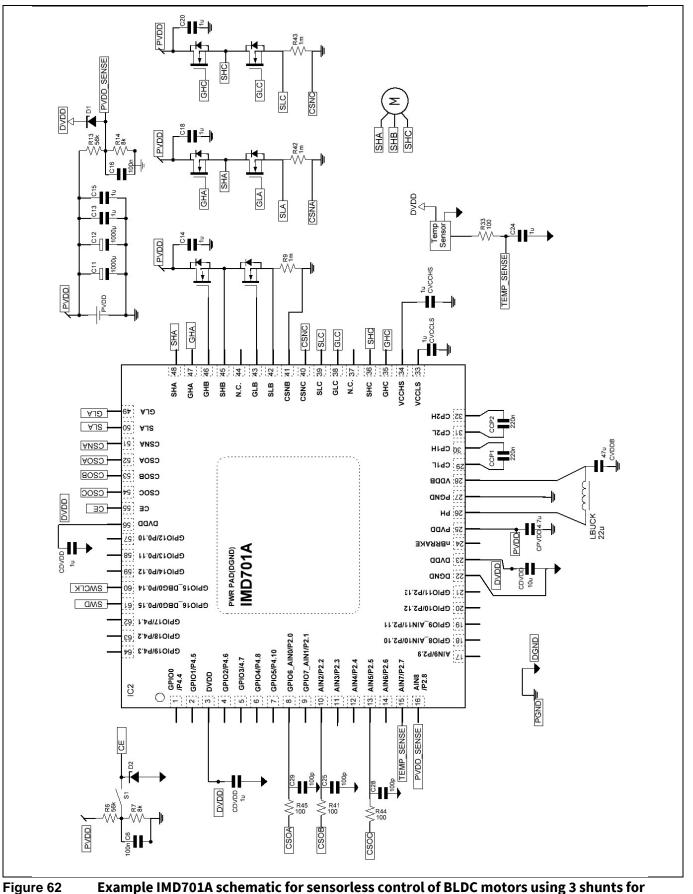
Figure 61

Example IMD701A schematic for trapezoidal or trapezoidal commutation control of BLDC motors using a single shunt configuration and 3 Hall sensors. Only minimum set up shown. GPIOs and ADC inputs can be used for auxiliary and general purpose (communication, LEDs, buttons, etc.). Voltage dividers and capacitors voltage rating must be calculated for the specific target PVDD voltage

#### Datasheet

### **Application Description**





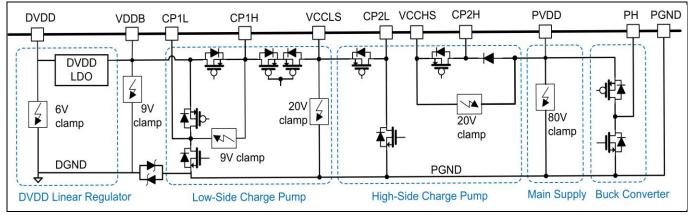
Example IMD701A schematic for sensorless control of BLDC motors using 3 shunts for current measurement. Voltage dividers and capacitors voltage rating must be calculated for the specific target PVDD voltage



**ESD** Protection

# 13 ESD Protection

Following diagrams show ESD protections and pin internal diagrams for different pins of the device.





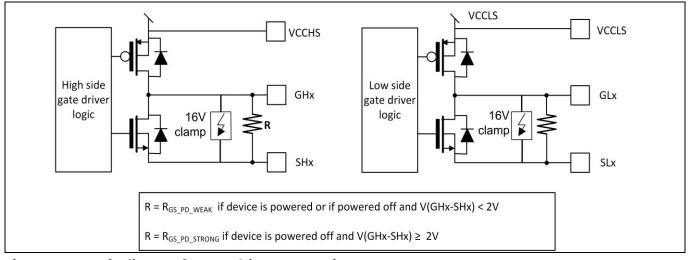


Figure 64 Pin diagram for gate driver output pins

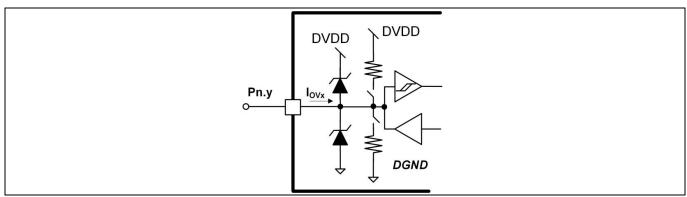


Figure 65 ESD protection and pin diagram for XMC pins

### Datasheet

### ESD Protection



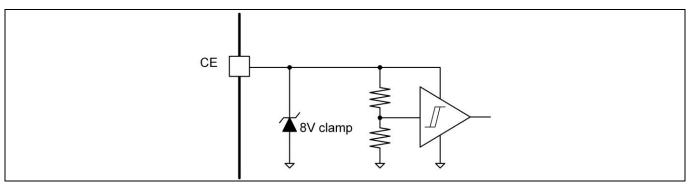


Figure 66 ESD protection and pin diagram for CE pin

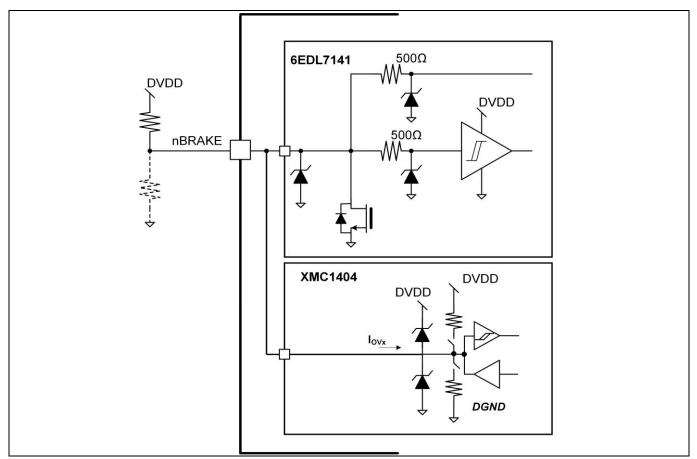


Figure 67 ESD protection and pin diagram for nBRAKE pin

### Datasheet

### **ESD** Protection



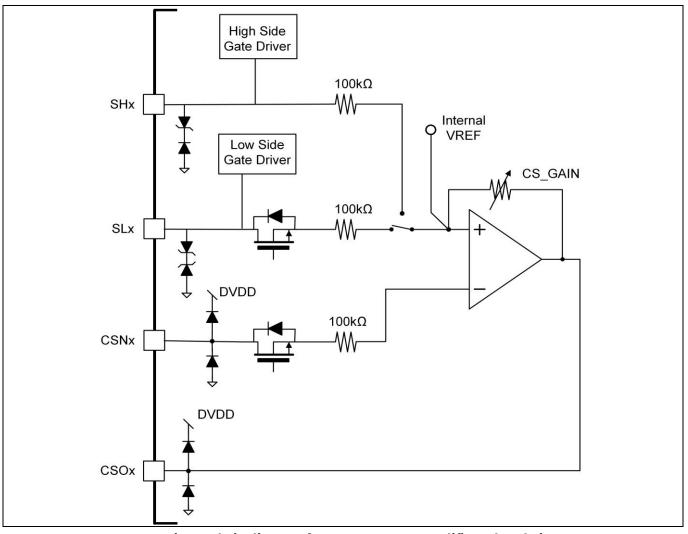


Figure 68 ESD protection and pin diagram for current sense amplifier related pins

**Package Information** 



# 14 Package Information

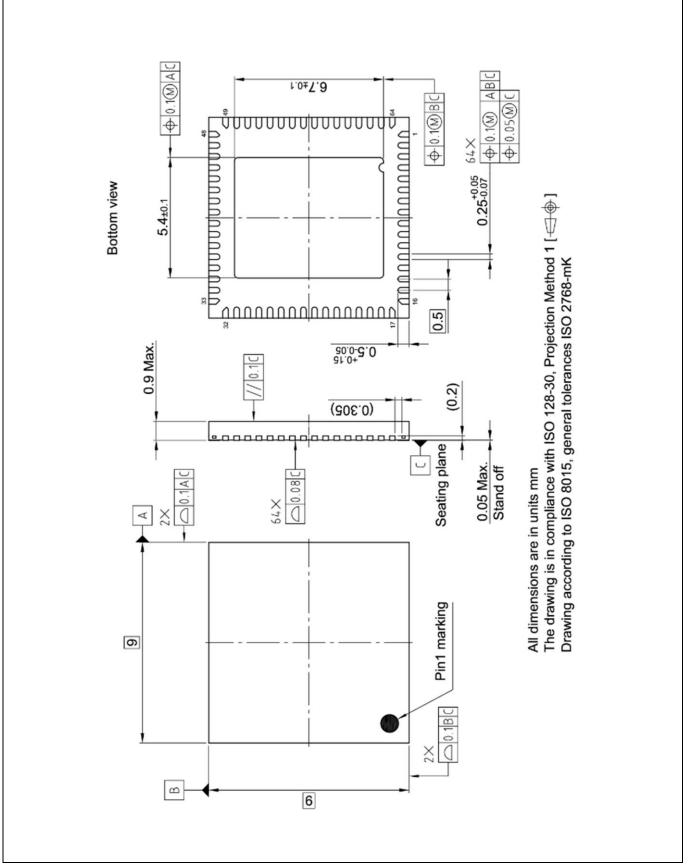
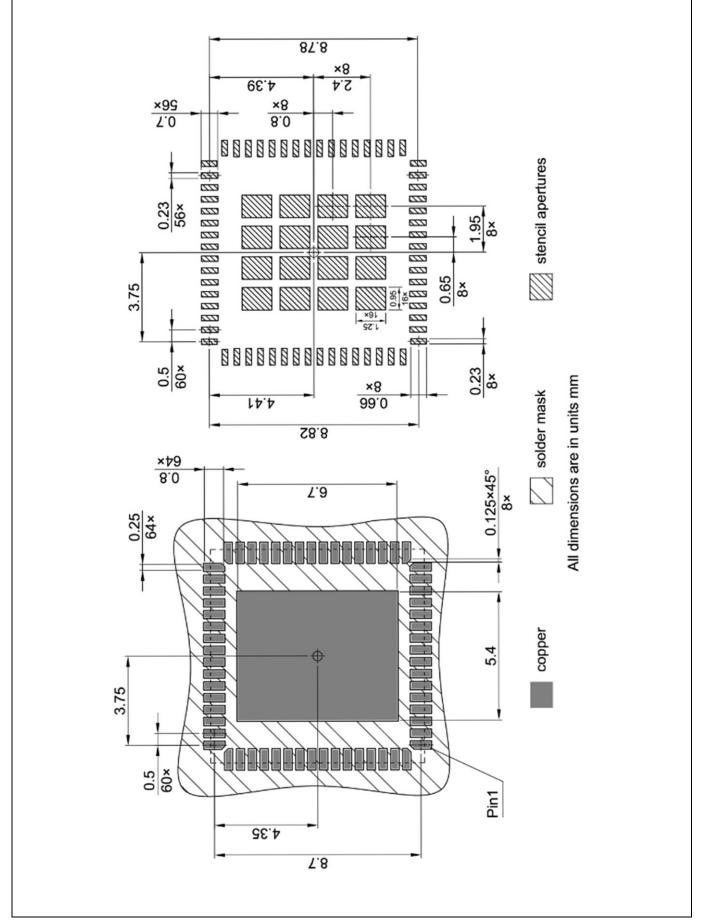
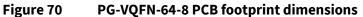


Figure 69 PG-VQFN-64-8 package outline

Datasheet

#### **Package Information**







Datasheet

# **Revision history**



# **Revision history**

Version	Description of change
V1.00	First public version
V1.02	Datasheet update
	Several editorial changes and typos
	Clarification on CE pin voltage thresholds in Electrical Characteristics table
	Added 'Thermal design' section in PCB layout recommendations
	Changed SPI min clock period to 77ns in Table 11
	• Changed DVDD OCP limit accuracy (I <sub>DVDD_LACC</sub> ) and added different specification for different OCP limit settings.
	• Removed pull down comment on nSCS pin in Table 2.
	• Typo in Table 2, SDI and SDO XMC reference to input/output functions were swapped

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