Infineon Mobile Robot (IMR) main control

User guide for DEMO_IMR_MAINCTRL_V1

About this document

Scope and purpose

The purpose of this document is to provide a comprehensive functional description and user guide for the DEMO_IMR_MAINCTRL_V1 demonstration board. Both hardware and software are shown and explained in detail with additional flowcharts where necessary. Furthermore, a basic quick-start guide is provided for the intended use as the Infineon Mobile Robot (IMR) main processor.

Intended audience

The intended audience for this document is design engineers, technicians, and developers of electronic systems.

Infineon components featured

- TLS205B0EJ V33 low-noise 3.3 V fixed linear voltage regulator
- TLE9351BVSJ High-speed automotive CAN transceiver (CAN and CAN FD)
- XMC4700-F100K2048 AA 32-bit microcontroller with Arm® Cortex®-M4 (XMC™)

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Safety precautions

Note: *Please note the following warnings regarding the hazards associated with development systems.*

Table 1 **Safety precautions**

	Warning: *The DC link potential of this board is up to 1000 VDC. When measuring voltage waveforms by oscilloscope, high-voltage differential probes must be used. Failure to do so may result in personal injury or death.*
	Warning: *The evaluation or reference board contains DC bus capacitors, which take time to discharge after removal of the main supply. Before working on the drive system, wait 5 minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	Warning: *The evaluation or reference board is connected to the grid input during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by an oscilloscope. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	Warning: *Remove or disconnect power from the drive before you disconnect or reconnect wires, or perform maintenance work. Wait five minutes after removing power to discharge the bus capacitors. Do not attempt to service the drive until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.*
	Caution: *The heat sink and device surfaces of the evaluation or reference board may become hot during testing. Hence, necessary precautions are required while handling the board. Failure to comply may cause injury.*
	Caution: *Only personnel familiar with the drive, power electronics and associated machinery should plan, install, commission and subsequently service the system. Failure to comply may result in personal injury and/or equipment damage.*
	Caution: *The evaluation or reference board contains parts and assemblies sensitive to electrostatic discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable ESD protection handbooks and guidelines.*
	Caution: *A drive that is incorrectly applied or installed can lead to component damage or reduction in product lifetime. Wiring or application errors such as undersizing the motor, supplying an incorrect or inadequate AC supply, or excessive ambient temperatures may result in system malfunction.*
	Caution: *The evaluation or reference board is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.*

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1 Introduction

1.1 Mobile robot general description

Mobile robots are now common in applications from logistics, warehouse centers, production sites, hospitals, restaurants, schools, and as last-mile package-delivery vehicles. On a high level, mobile robots are of two main types:

- **Automated guided vehicles (AGV):** “Fixed” vehicles that follow predefined paths using lasers, barcodes, radio waves, vision sensors, or magnetic tapes for navigation
- **Autonomous mobile robots (AMR):** “Not fixed”, and do not need external paths as these use autonomous mapping, localization, navigating, and obstacle avoidance by using sensors

Usually, the robots are battery-powered, where the voltage level depends on the size and weight characteristics.

1.2 IMR description

The board described in this document is primarily targeted to be used in combination with the Infineon Mobile Robot (IMR). The IMR is a comprehensive robotic platform intended to be used with a wide variety of different boards, such as sensors, motor control, wireless communication, and battery management.

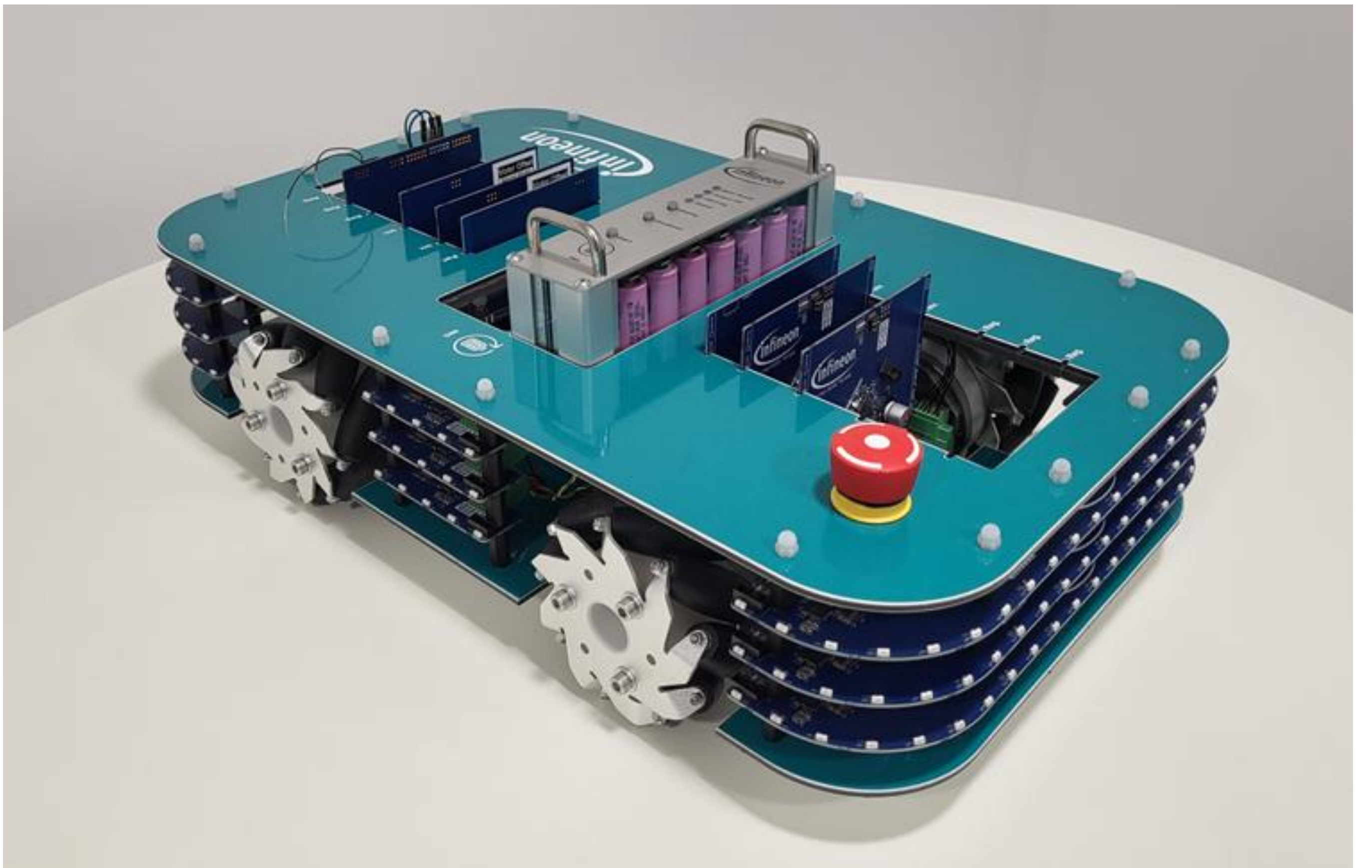

Figure 1 Isometric view of the IMR

The overall target of the IMR is to provide a demonstration platform for autonomous service robot functionalities using Infineon components. In the initial version of the system, the target is to use a commercially available remote control in combination with the DEMO_IMR_MAINCTRL_V1 board to control the IMR's initial features.

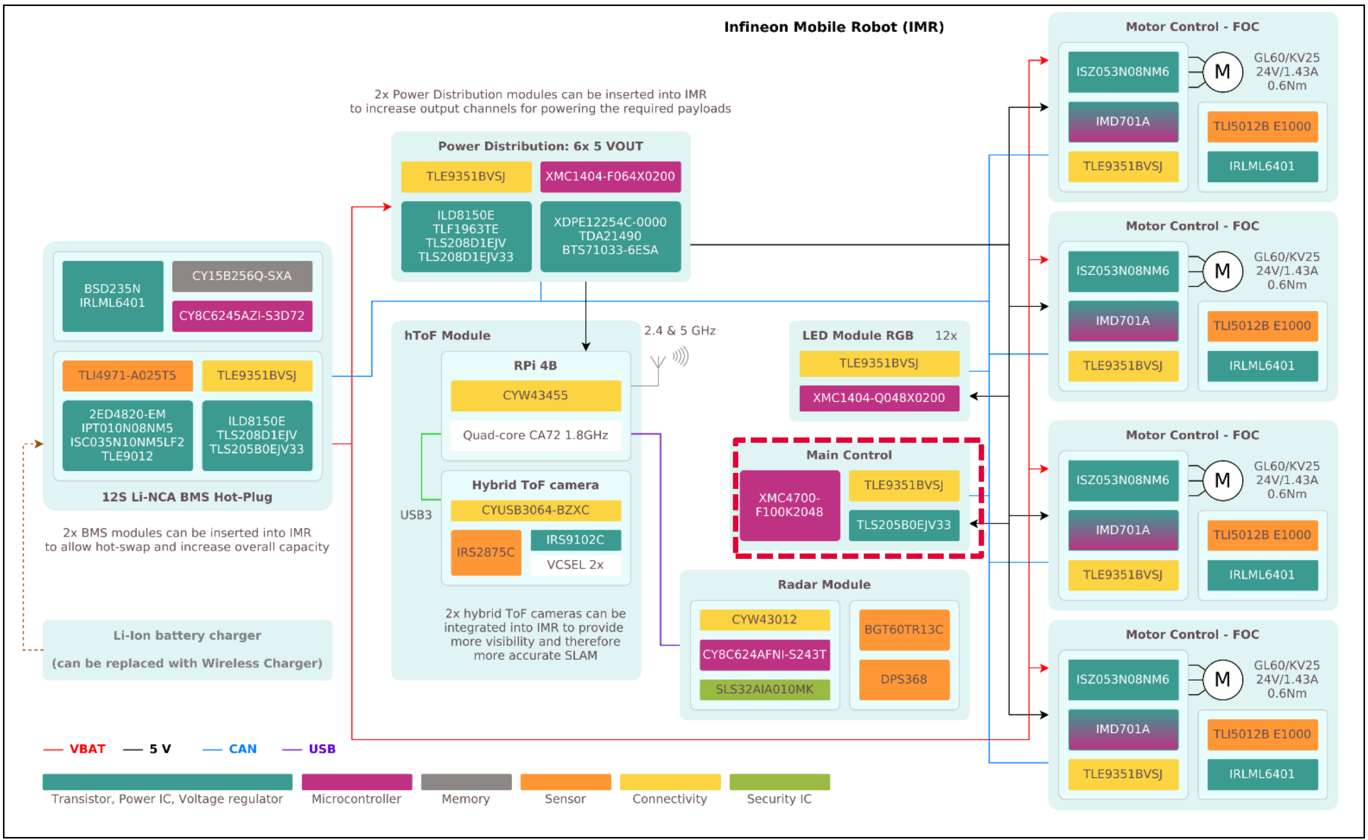

Figure 2 Overview of the IMR, with the board described in this document highlighted in red

1.3 Demo board description

The DEMO_IMR_MAINCTRL_V1 board is a modular robot control solution, specifically designed to work with the IMR card edge connector interface. The board features an XMC4700 series Arm® Cortex® M4 microcontroller performing all necessary calculations regarding robot movements. The board can be supplied either via the external 5 V power connector or via the 5 V line provided by the edge card connector. Furthermore, this voltage is used by the TLS205B0EJV33 linear regulator to generate the necessary 3.3 V supply for the XMC4700.

After installing the board vertically into one of IMR's regular slots, all the necessary communication is handled via the provided serial communication CAN interface. The board utilizes the TLE9351BVSJ high-speed automotive CAN transceiver, which is capable of supporting up to 5 Mbit/sec data rate. Specific to IMR, the standard data rate of up to 1 Mbit/sec is adopted.

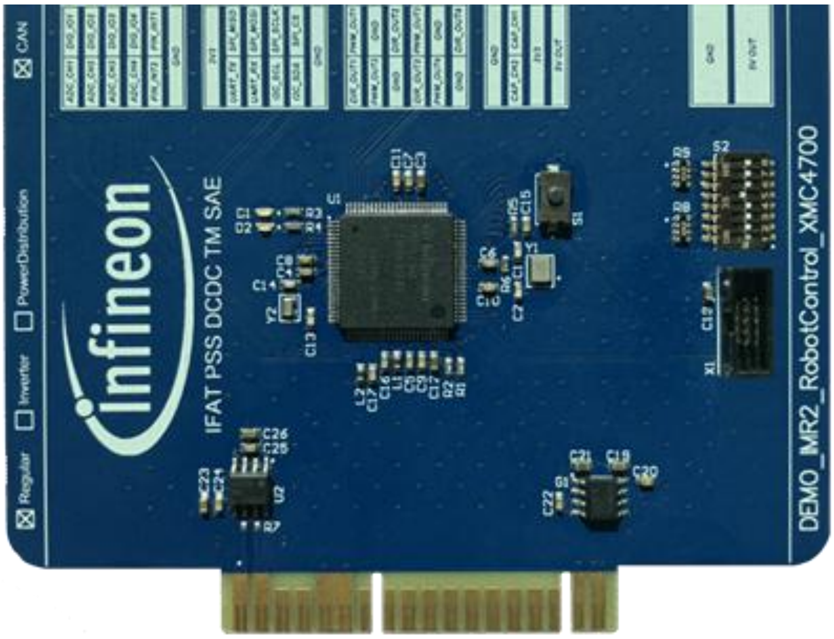

Figure 3 DEMO_IMR_MAINCTRL_V1 board top view (width × height: 100 mm × 88 mm)

1.4 Overview of the connectors

To support a wide variety of different peripherals in combination with the DEMO_IMR_MAINCTRL_V1 board, several connectors are placed on the board. To utilize most of the available pins on the XMC4700, the board provides:

- Four digital inputs/outputs
- Four analog inputs
- Two ERU digital inputs
- Four digital PWM outputs
- Four digital outputs
- Two PWM capture inputs

For serial communication, the connectors feature UART, I2C, and SPI.

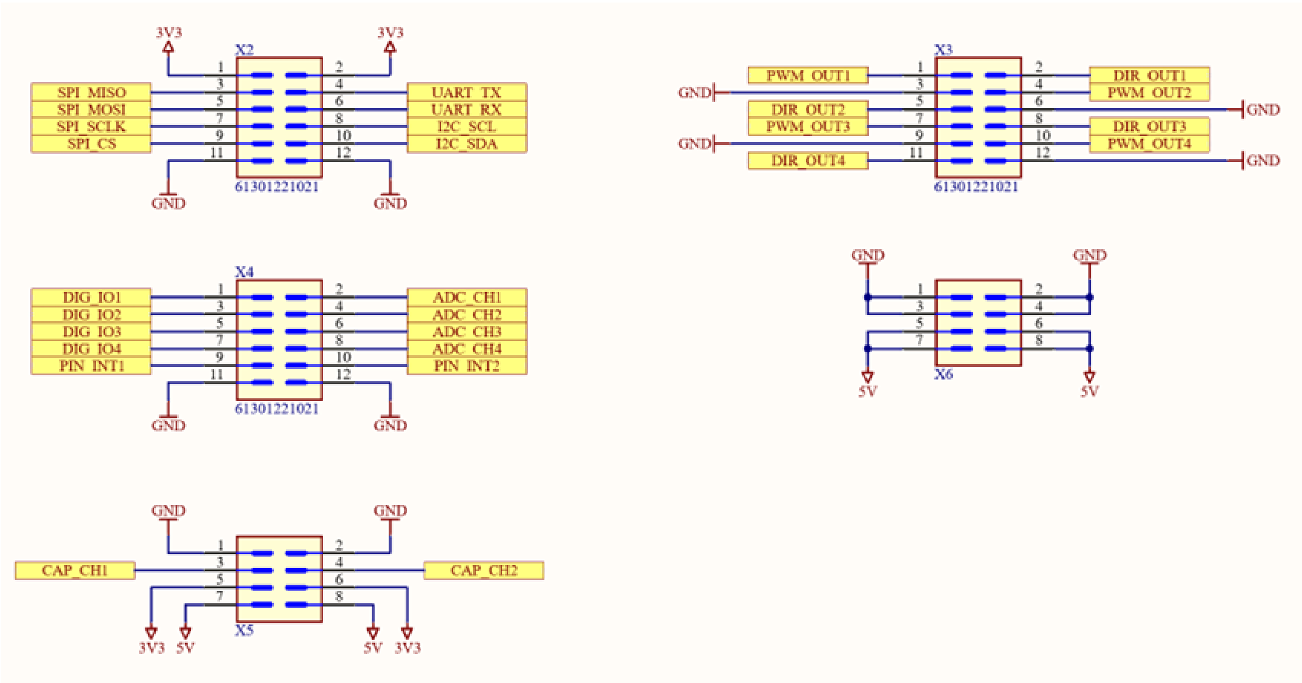

Figure 4 **Schematic overview of peripheral connectors: COM_CommunicationPort.SchDoc**

The following table shows the connection between connector X4 and XMC4700 featuring most of the dedicated analog and digital inputs/outputs.

Table 2 Connector X4 and connection to XMC4700 – Analog/digital inputs/outputs

Function	XMC™ pin	Function	Description
ADC_CH1	P14.0	Analog input	ADC input channel 1
ADC_CH2	P14.1	Analog input	ADC input channel 2
ADC_CH3	P14.2	Analog input	ADC input channel 3
ADC_CH4	P14.3	Analog input	ADC input channel 4
DIG_IO1	P3.0	Digital input/output	Universal digital I/O
DIG_IO2	P3.1	Digital input/output	Universal digital I/O
DIG_IO3	P3.2	Digital input/output	Universal digital I/O
DIG_IO4	P0.9	Digital input/output	Universal digital I/O
PIN_INT1	P2.0	Digital input/ERU	ERU capable digital I/O
PIN_INT2	P2.7	Digital input/ERU	ERU capable digital I/O
GND	–	Signal ground	0 V

The following table shows the connection between connector X2 and XMC4700 for all necessary serial communication protocols featuring full-duplex UART, I2C, and four-wire SPI.

Table 3 Connector X2 and connection to XMC4700 – USIC serial inputs/outputs

Function	XMC™ pin	Function	Description
3V3	–	Signal power	3.3 V DC regulated
UART_TX	P5.1	Serial output	UART transmit line
UART_RX	P5.0	Serial input	UART receive line
I2C_SCL	P2.4	Serial I2C clock	I2C clock line
I2C_SDA	P2.5	Serial I2C data	I2C clock data
SPI_MISO	P3.4	Serial SPI MISO	SPI master in; slave out
SPI_MOSI	P3.5	Serial SPI MOSI	SPI master out; slave in
SPI_SCLK	P3.6	Serial SPI SCLK	SPI serial clock
SPI_CS	P4.1	Serial SPI CS	SPI chip select
GND	–	Signal ground	0 V

The connector dedicated to motor drive is described in the following table. Should the connected hardware not be able to receive motor drive commands via the CAN interface, up to four individual PWM signals can be used to interface the motor drives. Each of these PWM signals is also accompanied by an additional direction pin (digital output).

Table 4 Connector X3 and connection to XMC4700 – Motor drive inputs/outputs

Function	XMC™ pin	Function	Description
PWM_OUT1	P1.0	Digital output/PWM	Motor drive 1 PWM output
DIR_OUT1	P0.3	Digital output	Motor drive 1 direction output
GND	–	Signal ground	0 V
PWM_OUT2	P1.1	Digital output/PWM	Motor drive 2 PWM output
DIR_OUT2	P0.4	Digital output	Motor drive 2 direction output
GND	–	Signal ground	0 V
PWM_OUT3	P1.2	Digital output/PWM	Motor drive 3 PWM output
DIR_OUT3	P0.5	Digital output	Motor drive 3 direction output
GND	–	Signal ground	0 V
PWM_OUT4	P1.3	Digital output/PWM	Motor drive 4 PWM output
DIR_OUT4	P0.6	Digital output	Motor drive 4 direction output
GND	–	Signal ground	0 V

The following table shows the connection between connector X5 and XMC4700 featuring two PWM capture inputs. These inputs can be used to interface most PPM remote controls if necessary. Additionally, both 3.3 V and 5 V are provided to be used by an external remote control.

Table 5 Connector X5 and connection to XMC4700 – Remote connector

Function	XMC™ pin	Function	Description
GND	–	Signal ground	0 V
CAP_CH1	P2.2	Digital input/output	PWM capture input channel 1
CAP_CH2	P2.3	Digital input/output	PWM capture input channel 2
3V3	–	Signal power	3.3 V DC regulated output
5V	–	Signal power	5 V DC regulated output

Table 6 Connector X6 – 5 V power connector

Function	XMC™ pin	Function	Description
GND	–	Signal ground	0 V
5V	–	Signal power	5 V DC regulated output

1.4.1 Edge card header

In addition to the connectors mentioned before, the main interface to the IMR is realized as an edge card header on the bottom of the board, as shown in Figure 5. The double-sided header has 18 pins on each side for a total of 36 pins.

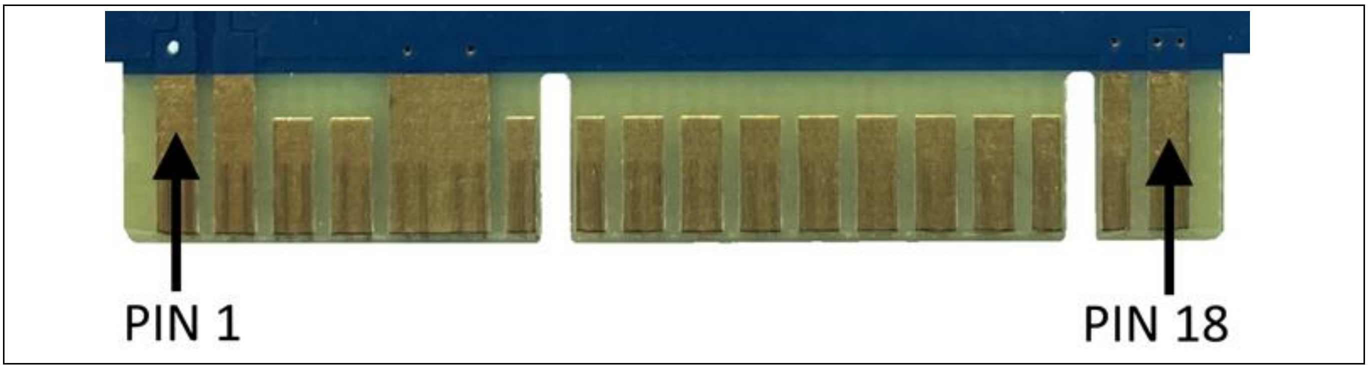

Figure 5 **Edge card header with 36 pins (18 pins symmetrical, top and bottom); designed to work with EBC18DCWN-S371 board-to-board receptacle connector**

The selected counterpart for the edge card header is the EBC18DCWN-S371 board-to-board receptacle connector from Sullins Connectors. Since all communication is done via the CAN interface (CAN_H and CAN_L), these are the only interface pins needed in addition to power connections, as can be seen in the following table.

Table 7 **Pin out of main control board slot on IMR motherboard with thick row lines marking polarizing key positions**

PIN	Function	PIN	Function
A1	CAN_L	B1	5 V
A2	CAN_H	B2	GND
A3	–	B3	–
A4	–	B4	–
A5	GND	B5	GND
A6	GND	B6	GND
A7	–	B7	–
A8	–	B8	–
A9	–	B9	–
A10	–	B10	–
A11	–	B11	–
A12	–	B12	–
A13	–	B13	–
A14	–	B14	–
A15	–	B15	–
A16	–	B16	–
A17	GND	B17	GND
A18	5 V	B18	5 V

2 Hardware

This chapter focuses on describing the most important functional parts of the board hardware in more detail. Additionally, the full schematics can be found in the appendix including microcontroller schematics and an overall overview.

2.1 3.3 V DC regulator circuitry

To provide the necessary 3.3 V power supply for the XMC4700 microcontroller, the TLS205B0EJ V33 LDO is chosen. The TLS205B0 is a micropower, low noise, low dropout voltage regulator. The device is capable of supplying an output current of 500 mA with a dropout voltage of 320 mV. Designed for use in battery-powered systems, the low quiescent current of 30 µA makes it an ideal choice [1]. Furthermore, it supports a wide input voltage range of up to 20 V, while keeping the number of necessary auxiliary components low.

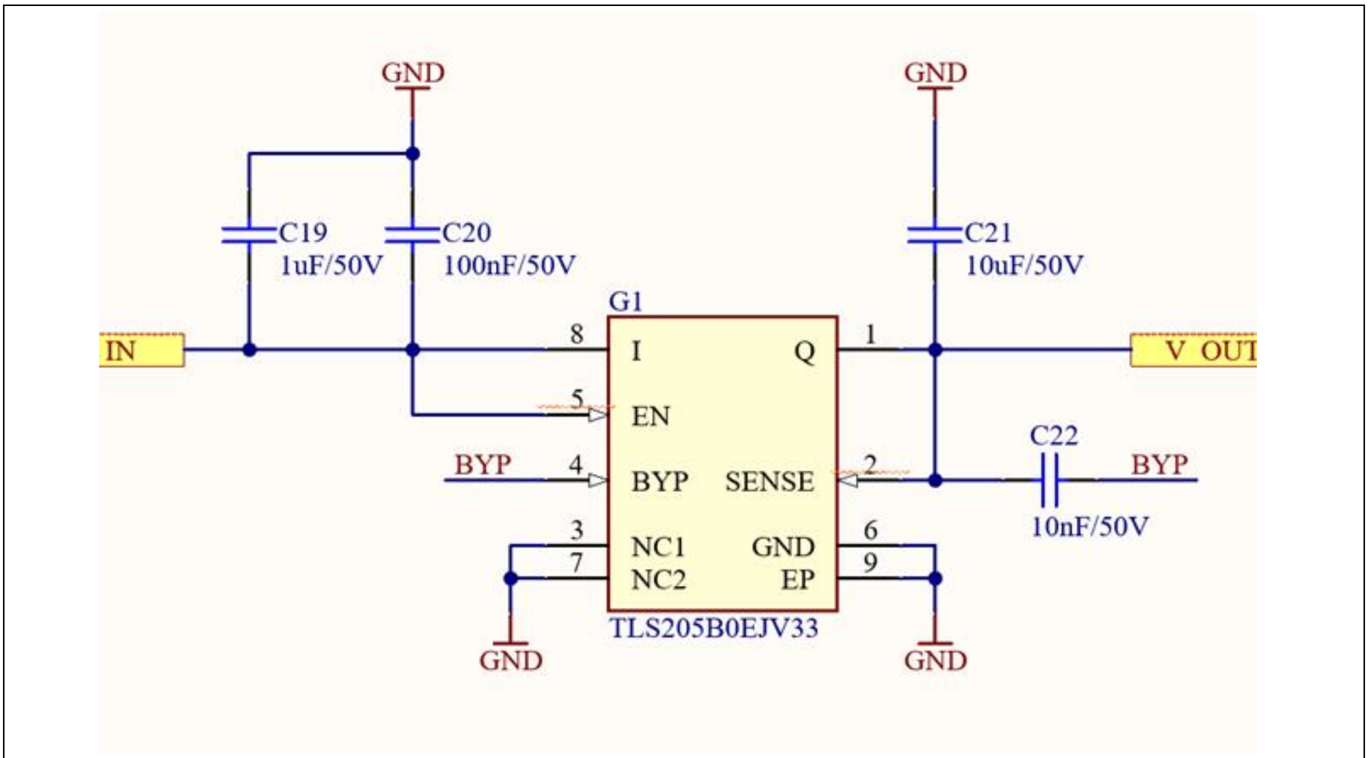

Figure 6 TLS205B0EJV33 LDO circuit for a fixed 3.3 V output

2.2 CAN serial communication interface

All necessary communication from and to the board is realized via CAN bus communication. For this purpose, the TLE9351BVSJ high-speed CAN FD transceiver was chosen as it is a high-speed CAN transceiver, used in HS CAN systems for automotive applications and industrial applications [2].

The VIO feature of the TLE9351BVSJ allows you to set individual voltage levels for the CAN bus and the interface to the microcontroller. In this case, the VCC is supplied by 5 V via the edge card connector while the VIO is supplied with 3.3 V to be able to interface the transceiver directly with the microcontroller. Additionally, the STB pin is routed to the microcontroller for the possibility to send the transceiver into standby mode.

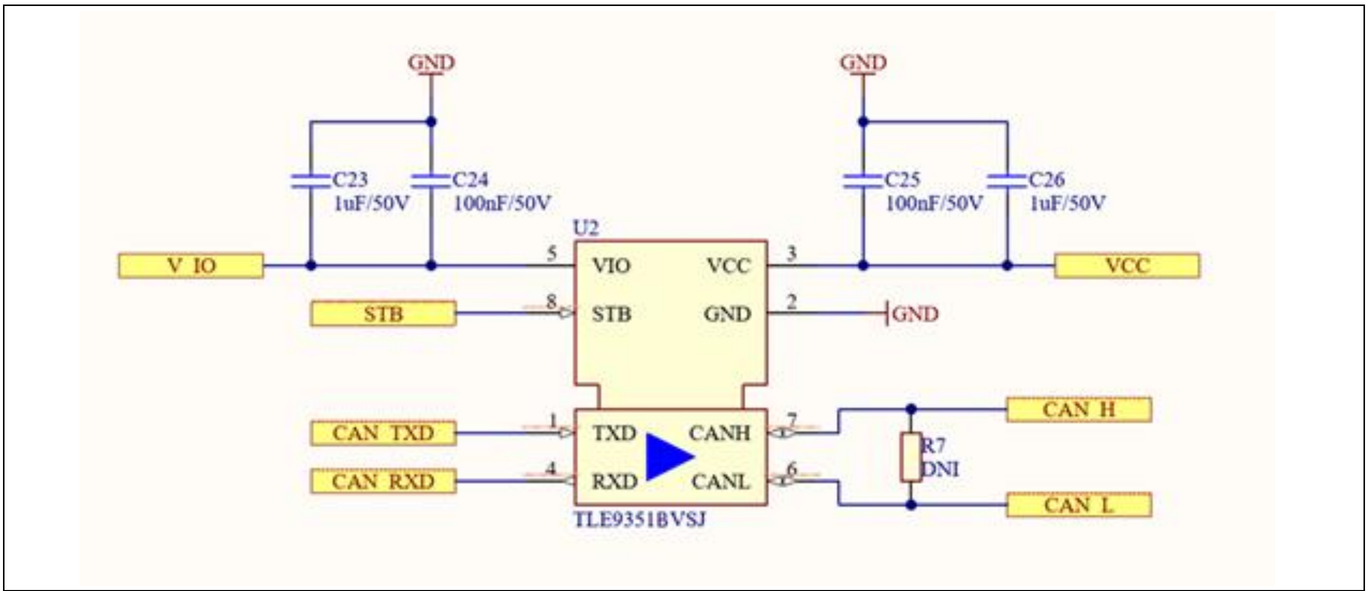

Figure 7 **TLE9351BVSJ CAN transceiver including the VIO feature for a separate I/O supply level**

For the unique identification of each board, the following DIP switch is implemented. Each pin is pulled-up via a 20 kΩ resistor and therefore provides an inverted logic, that must be considered when reading the pin via the XMC4700 microcontroller. As the current setup only includes one main control board, the boards CAN IDs are fixed in the software and not influenced by the dip switch setting.

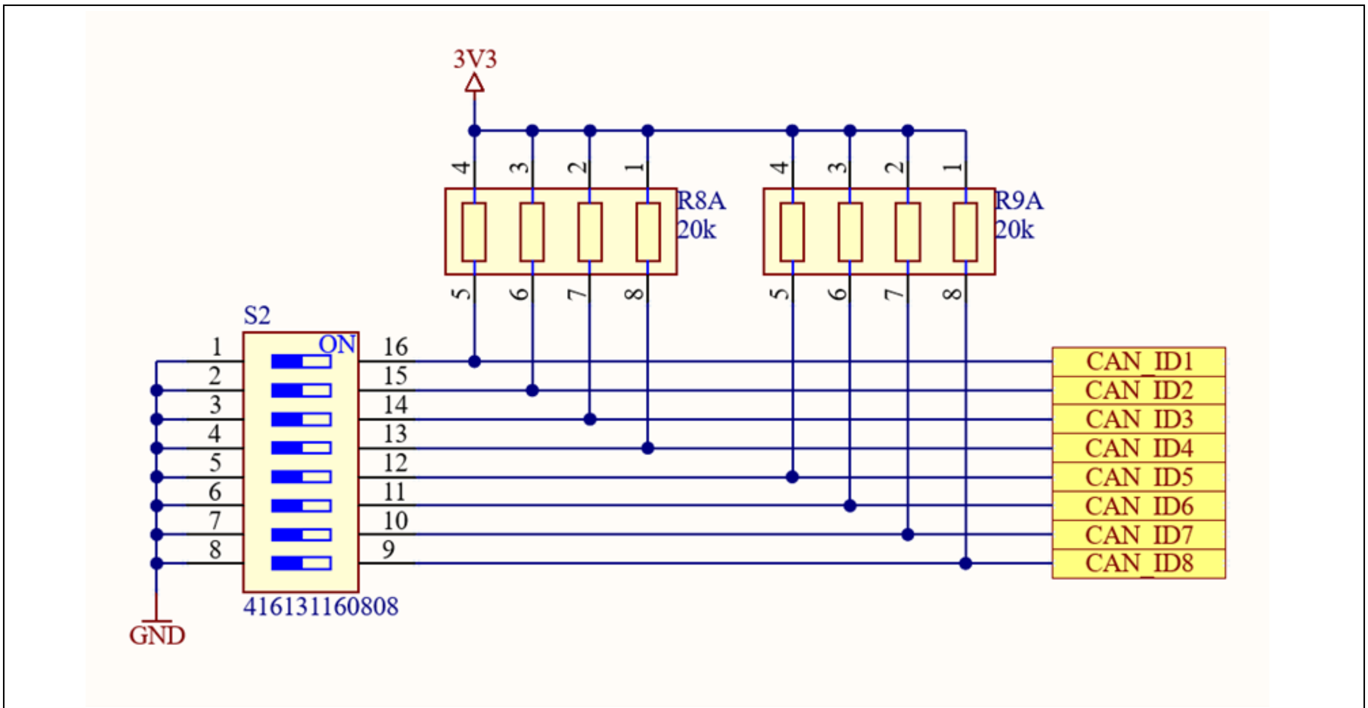

Figure 8 **Identification circuit including the 8-pin DIP switch**

Each individual switch is connected to an individual pin of the XMC4700 to individually set up to 255 devices. Furthermore, the following table shows each DIP switch pin and the corresponding XMC™ pin for reference and the decimal value assigned to the pin. With the pull-up resistor to 3.3 V, the pins follow an inverted logic: the OFF state on the DIP switch represents a logic high on the XMC™ pin and vice versa.

Table 8 DIP Switch S2 – CAN node identifier logic and pin assignment

CAN ID bit	ID10	ID9	ID8	ID7	ID6	ID5	ID4	ID3	ID2	ID1	ID0
DIP switch	N/A	N/A	N/A	Pin 8 (MSB)	7	6	5	4	3	2	Pin 1 (LSB)
XMC™ pin				P1.4	P1.5	P1.10	P1.11	P1.12	P1.13	P1.14	P1.15

3 Software

After giving a short introduction to XMC™ microcontrollers, this chapter focuses on describing the functional software routines in more detail. Additionally, the full software can be found in the Infineon GitHub repository.

3.1 XMC™ microcontroller

The XMC™ microcontroller family, based on the Arm® Cortex® M cores, is suitable for real-time critical applications where an industry-standard core is needed. It is dedicated to applications in the segments of power conversion, factory and building automation, transportation, and home appliances. The XMC4000 series features the Arm® Cortex® M4 core in combination with exceedingly versatile peripherals for most applications [3].

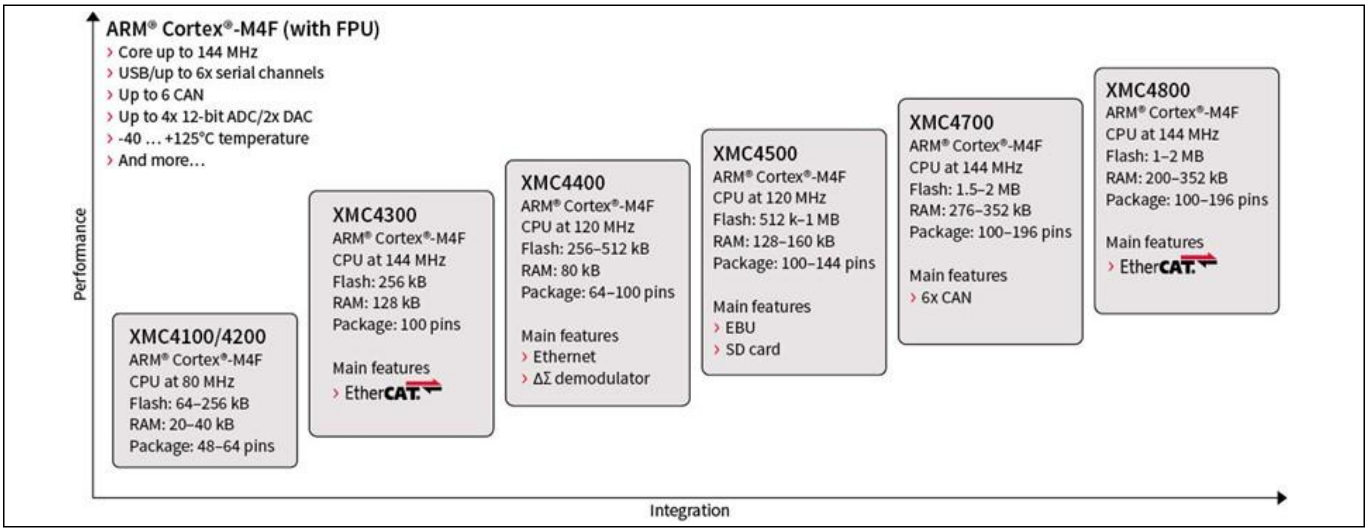

Figure 9 XMC4000 series sub-groups [3]

The microcontroller for this specific application must perform at a reasonable clock frequency, provide multiple analog and digital channels, and have the capability to support multiple communication interfaces (I2C, SPI, UART, CAN etc.). The 100-pin LQFP100 packaged XMC4700-F100K2048 supports a 144 MHz clock frequency, 2048 kB of flash memory, 352 kB of SRAM and enough I/O pins to support the required functions [4].

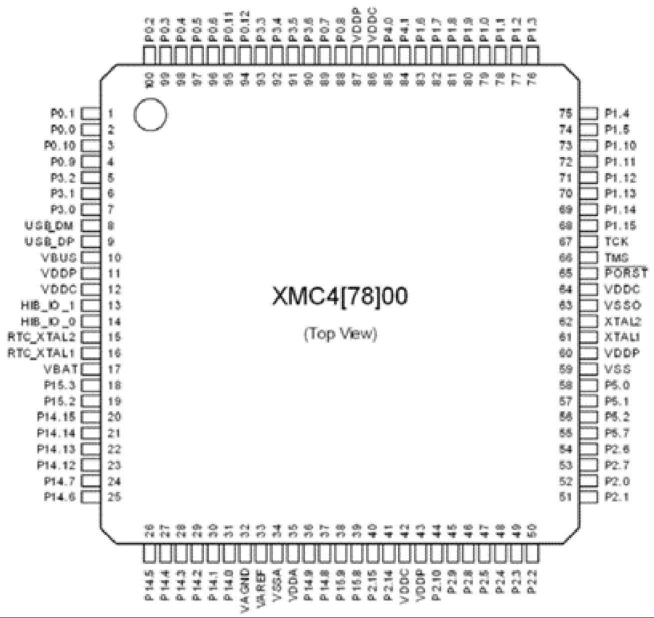

Figure 10 XMC4700/4800 LQFP100 pin configuration (top view) [4]

3.2 Software description and flowcharts

The software main function starts by initializing the peripherals with the settings from the device configurator, which can be found inside the project repository. Afterwards, the software enters the program's while-loop to continuously check for new SBUS messages from the remote control that can be parsed into any commands for the IMR. At the same time, CAN trajectory commands are read and processed. Commands from the BMS to reduce the power output to prepare for hot-swapping take the highest priority, followed by remote control input from SBUS, and finally trajectory commands from CAN.

Whenever a complete SBUS message has been received, the remote-control channel data can be processed using the "`Process_RC_Inputs`" routine, followed by resetting the timeout variable that is cyclically set in the 100 ms routine. More information regarding the SBUS protocol can be found, e.g., on the Bolderflight GitHub [9]. With the processed data, the "Switch_SA" position is checked to decide if a new lighting effect needs to be sent to the LED boards. Next, the "Switch_SD" position is checked to decide if the robot is "Armed" or not. If the switch is in its lowest position, the remote-control inputs are processed using inverse kinematics, otherwise all motor outputs are set to zero, see Figure 11. Further details on switch positions can be found in the section Quick start guide about the remote-control implementation.

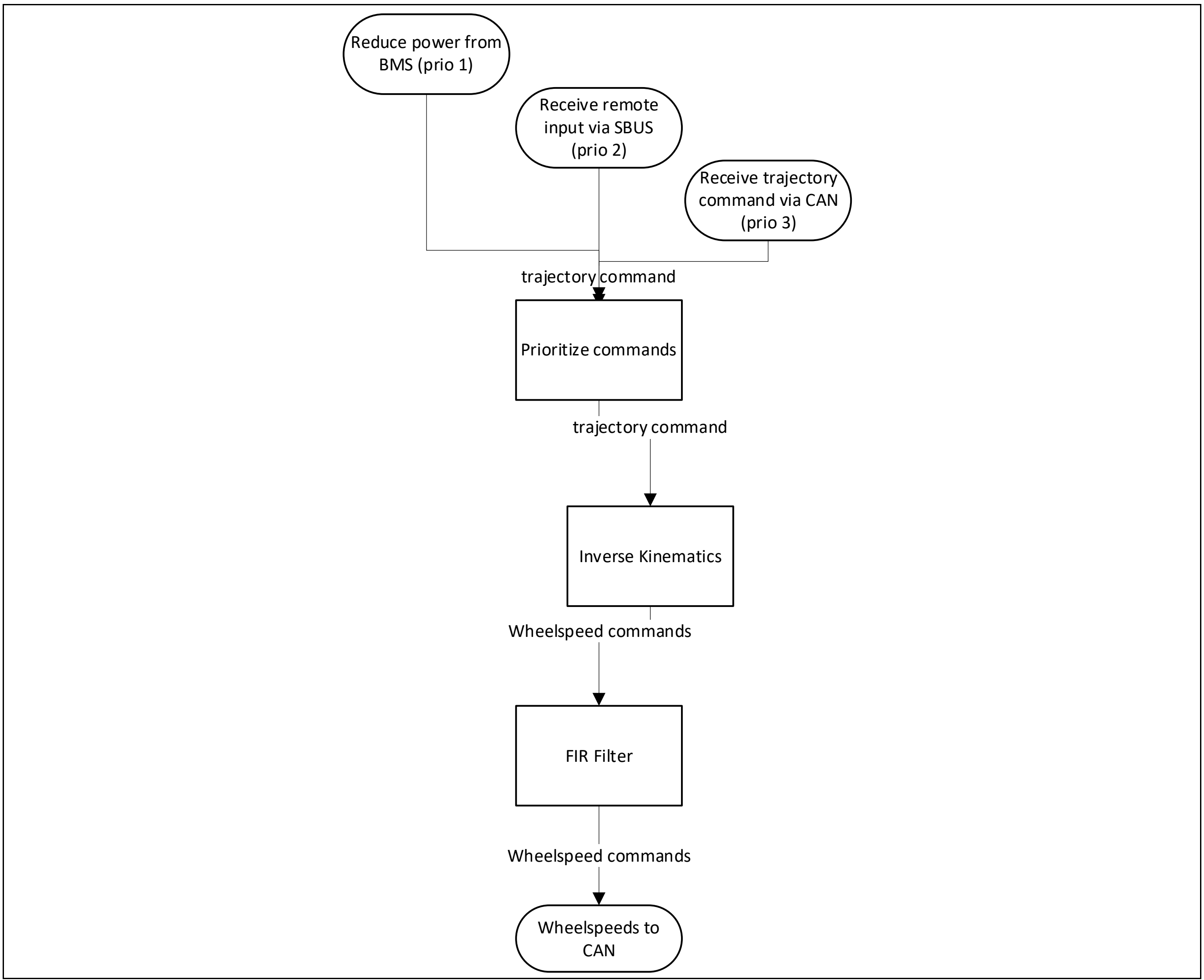

Figure 11 Trajectory and inverse kinematics

After processing the input and deriving individual wheels speeds, they are then sent to each individual motor (Front Left – **FL**, Front Right – **FR**, …) using the "`CAN_TX_Request`" routine. If needed, the lighting CAN command is also sent to the respective LED boards.

To prepare for the event of a remote-control failure or disconnect, a periodic 100 ms watchdog is implemented. It checks if the timeout variable is still active since the last time it has been set inside the same routine. This means, if the routine is called two consecutive times without the timeout variable being reset in the main routine, a timeout has been detected and a zero command is sent to each of the motor drives.

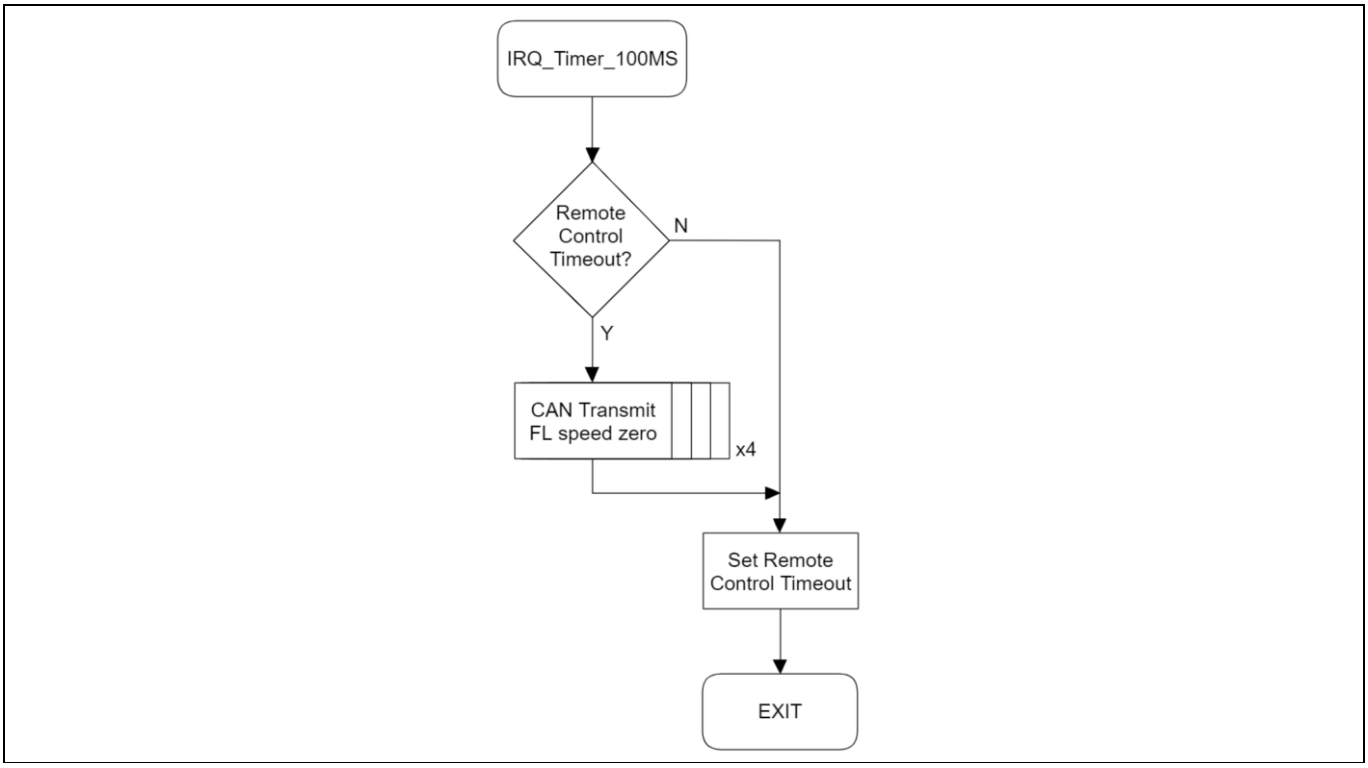

Figure 12 Interrupt service routine for detecting timeouts periodically (100 ms)

Figure 13 shows the "`Process_RC_Inputs`" routine used to process the remote-control channel data and normalize it for further calculations. The stick inputs are normalized using the values for their center value, the maximum deviation from the center and the normalized target maximum value for further processing. Additionally, an adjustable square dead-zone is implemented to reduce unnecessary and unwanted twitching of the motors. The dead-zone assists the user by allowing a certain threshold when moving the control sticks back to the center position. This routine is performed for each individual stick input:

- **Left Stick**: Up, Down, Left, and Right
- **Right Stick**: Up, Down, Left, and Right

Subsequently, a similar process is used on each of the switch channels. Depending on the remote-control setup, each channel must be checked if it fits between the selected channel range. Depending on the selected switch, either two or three switch positions can then be identified. In the current version, lateral movements (left, right, forward, backward, and diagonal) are performed using the right control stick while rotational movements can be performed by moving the left stick left and right.

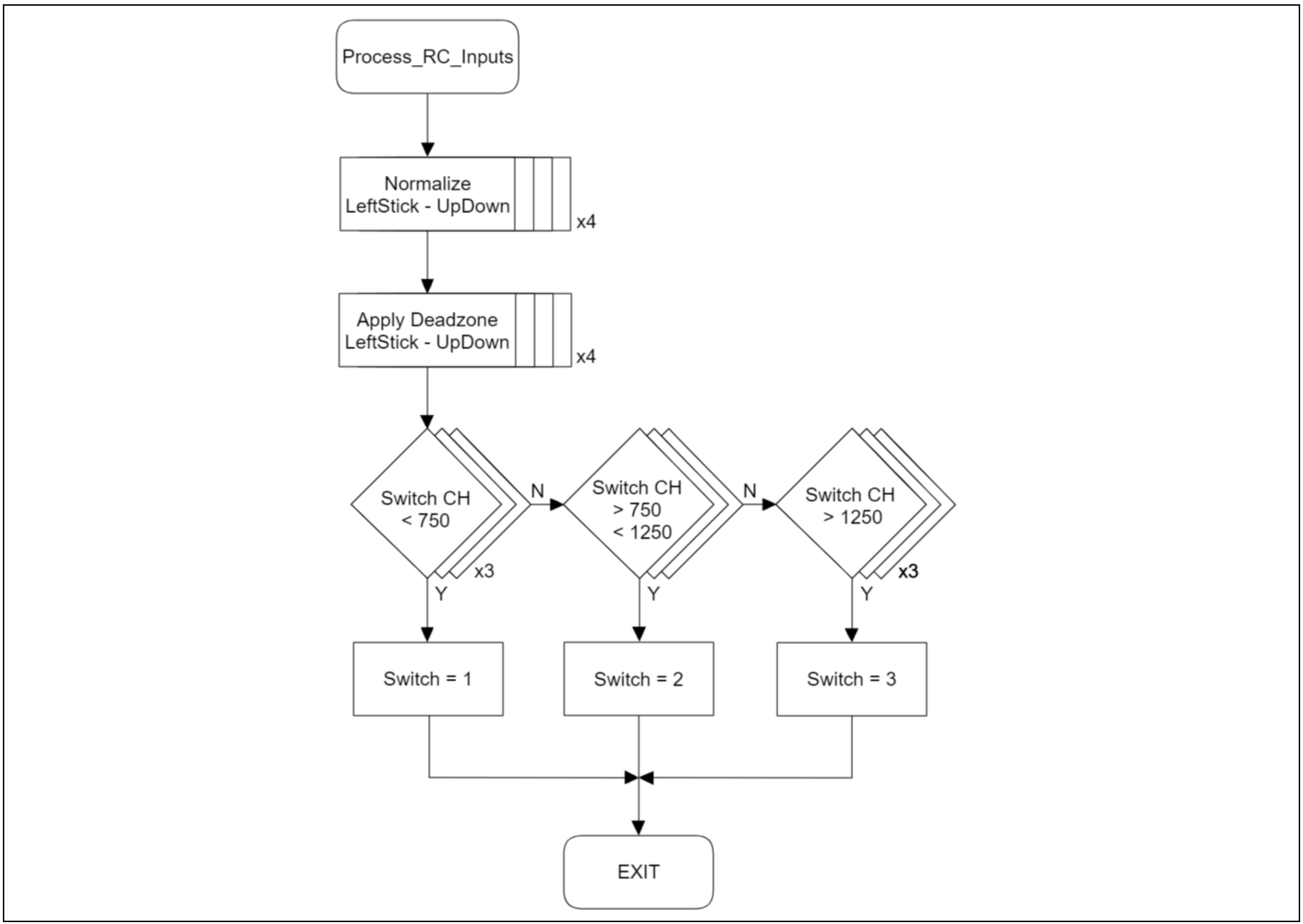

Figure 13 Routine for processing received channel information from remote control

After scaling and normalizing all required remote-control inputs, further processing needs to be done to define the motor control signals. Each vehicle direction needs specific signals to each of the motor drives to perform either lateral (**a**, **b,** or **c**) or rotational (**d**, **e,** and **f**) movements, also simultaneously. Figure 14 shows the possible movements and each respective motor direction to perform the said movement [10]. This calculation is achieved by multiplying the intended robot velocity with a 4x3 matrix, the Jacobian [11], [12], to obtain the intended wheel speeds, see Appendix B. A FIR filter with up to 5 elements may be used to limit the acceleration of each wheel. Furthermore, the resulting wheelspeeds are checked against the maximum possible wheel speed and scaled down, if necessary. This ensures that the relation between the wheels speeds is preserved and intended motion is performed, even if at a lower speed.

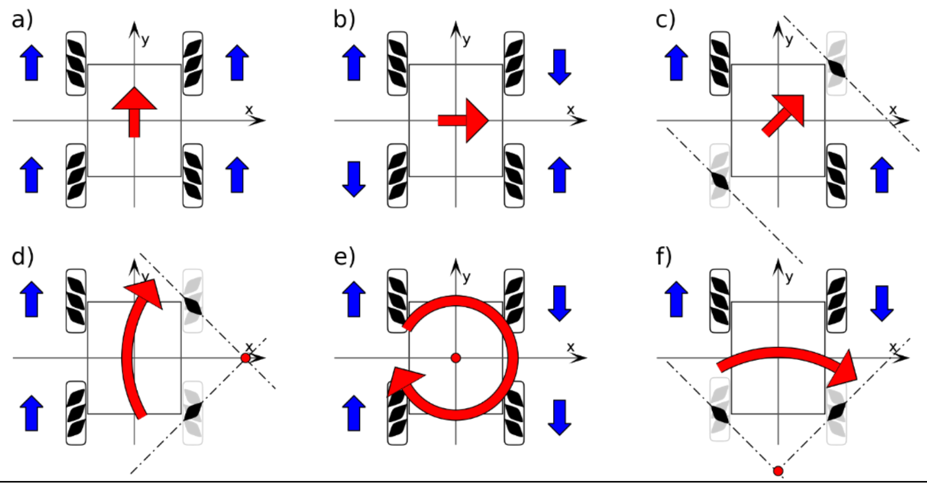

Figure 14 Specific motor actuation for movement in any direction (blue: wheel drive direction; red: vehicle moving direction) [10]

The feedback from the position sensors on each wheel is collected and used to estimate the current movement of the robot, see Figure 15. This is done by applying direct kinematics or the inverse Jacobian.

$$\begin{pmatrix} v_x \\ v_y \\ \omega_z \end{pmatrix} = \frac{1}{4} \begin{pmatrix} -r_w & r_w & -r_w & r_w \\ r_w & r_w & -r_w & -r_w \\ 4.78 & 4.78 & 4.78 & 4.78 \end{pmatrix} \begin{pmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{pmatrix}$$

Equation 1 Inverse Jacobian

Where,

- v_x, v_y is the robot velocity in x and y
- ω_z is the yaw rate of the robot
- r_w is the radius of the robot's wheels
- ω_i are the measured wheels speeds

The factor 4.78 is derived from a more complex calculation considering the exact position of the wheels, see [12] and Appendix B.

Note that for the current navigation stack, this estimate from the main control is not used. To achieve higher precision, the raw data from the encoders is directly processed by the navigation SW, without relay.

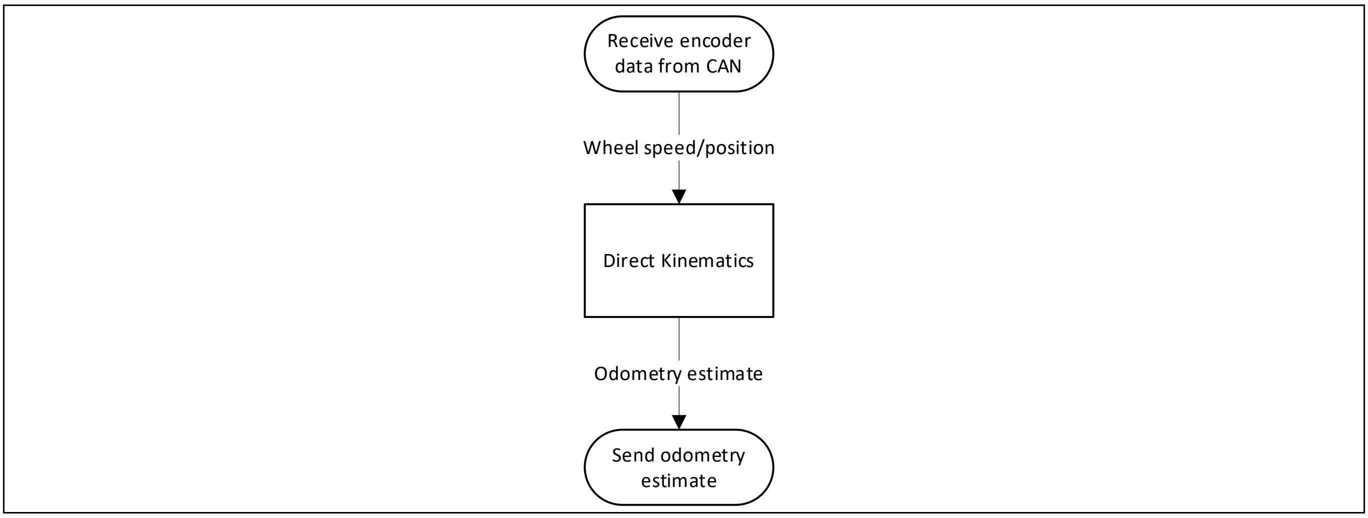

Figure 15 Encoder data and odometry

3.3 CAN communication

The main control serves as the central hub for CAN communication. The majority of messages on the CAN bus are either sent or read by the main control. The specifics of messages concerning motor control, battery management system (BMS), power distribution, and LED boards can be found in the respective documents [5], [6], [7], and [8]. The messages specified in Table 2 are used to communicate with the higher-level control unit, such as a navigation unit (e.g. NVIDIA Jetson), that sets the movement required for the entire robot. Both VELOCITY_COMMAND and ODOMETRY_ESTIMATE contain the linear velocities in the horizontal plane and the angular velocity (yaw rate), once as a command, and once as an encoder-based estimate. The factors used to convert numeric values given in physical units to the signed 16-bit integers used on the CAN bus are derived from an arbitrary choice of a maximum representable linear velocity (3 m/s) and turn rate (2π rad/s). For every physical signal contained in the data portion, the decoding description is given in italics:

- **U/S**: Unsigned/Signed
- **Factor**: Factor with which the value in the CAN data has to be multiplied to arrive at the physical value
- **Unit**: The unit of the signal

All signals use big-endianness ("Motorola" convention) for their byte order.

Table 9 Main control CAN messages

		Byte #									
Command	**ID**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Description**	**Rate**
VELOCITY_COMMAND	0x41C	Linear velocity x *S, 9.15527e-05, m/s*		Linear velocity y *S, 9.15527e-05, m/s*		Angular velocity *S, 0.000191742, rad/s*				Velocity command to main control. Linear velocity factor: $\frac{V_{max,Robot}}{2^{15}} = \frac{3}{2^{15}}$ Angular velocity Factor: $\frac{\omega_{max,Robot}}{2^{15}} = \frac{2\pi}{2^{15}}$	10 Hz
ODOMETRY_ESTIMATE	0x440	Linear velocity x *S, 9.15527e-05, m/s*		Linear velocity y *S, 9.15527e-05, m/s*		Angular velocity *S, 0.000191742, rad/s*				Odometry estimate sent by main control factors: see above	10 Hz

4 Quick start guide

This section is intended to be a reference to get started with using the described board as a robot control module for IMR. Further chapters include the necessary steps to program and debug the hardware, set up the hardware for CAN communication, and to interface a commercial remote control for use with the IMR.

As the board is powered on, the onboard LEDs have been programmed to be as follows:

- The blue LED blinks when the CAN messages transmission is successful. If CAN communication is problematic, the blue LED will be off
- The green LED lights up if the SBUS-based remote control is actively in use

4.1 In-circuit debugging with Micriμm μC/Probe for XMC™

For further debugging, use the μC/Probe XMC™ developed by Micriμm on the Infineon website. The μC/Probe can be used to track selected variable values without the need to pause the debugging session. For this specific project, a pre-configured μC/Probe GUI has been realized and can be found inside the project files with the *.wspx* extension. The panel may be configured by the developer to display any variables of interest, which can be represented numerically or in a graphical form such as a linear meter, dial, or cylindrical bar indicator. Numeric values can be scaled to display a percentage or shown in their original form.

The panel shows each individual motor outputs and all remote-control switch readings. Each motor output can be monitored while actively debugging. Furthermore, the switches indicate the current status for lighting effects and arming of the motor outputs.

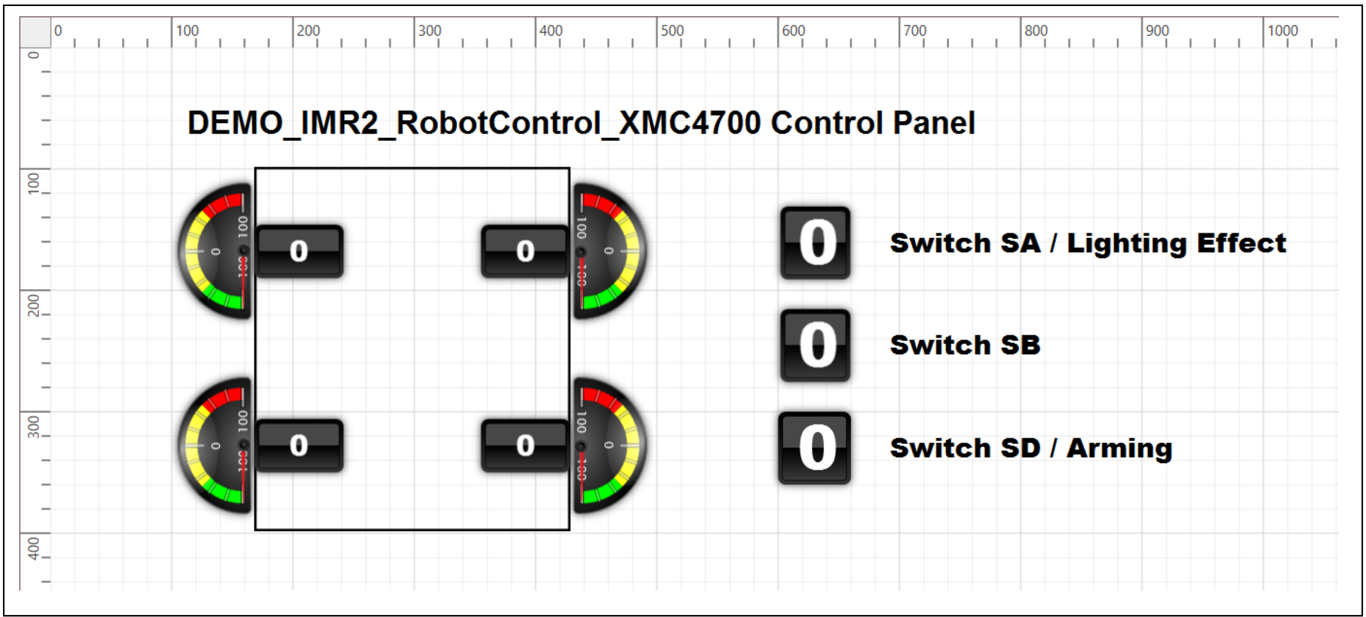

Figure 16 Micriμm μC probe monitoring panel

4.2 Remote control implementation

The DEMO_IMR_MAINCTRL_V1 board features multiple interfaces to implement an external remote control with either SBUS, IBUS, or PPM. Depending on the selected protocol and the chosen remote-control manufacturer, a different interface might be needed. In this specific case, the FrSky XM+ 16-channel receiver is used in combination with the FrSky Taranis X9D Plus remote control. Due to FrSky being the chosen remote-control manufacturer, the protocol being implemented is the SBUS interface.

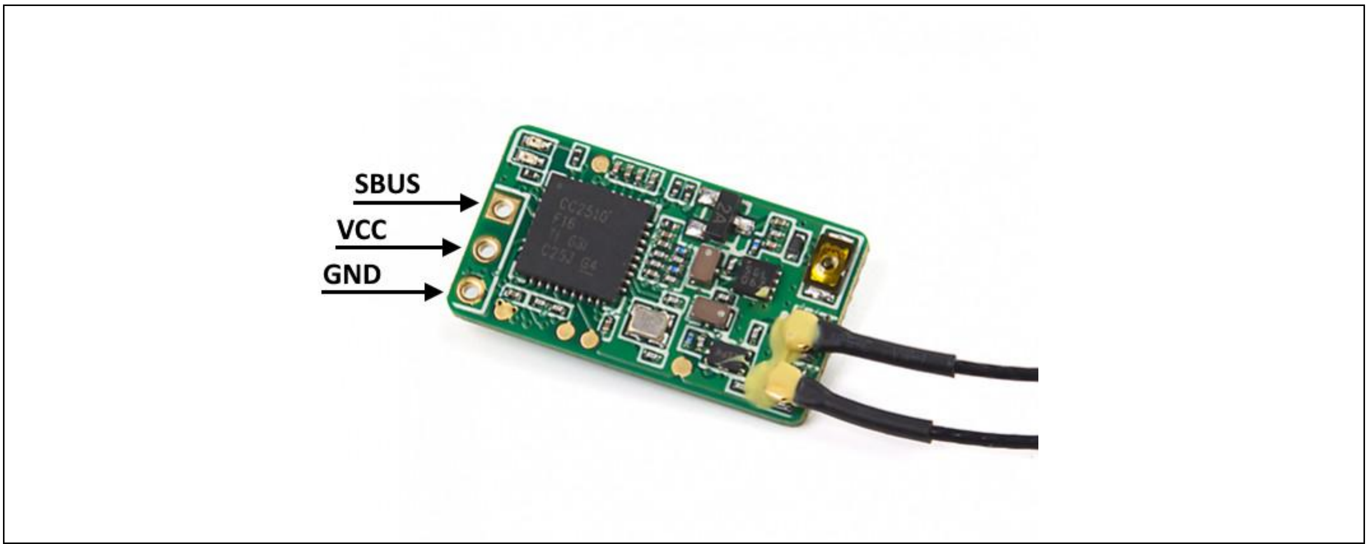

Figure 17 FrSky XM+ overview with available connectors: SBUS, VCC, and GND

The SBUS interface is typically only available as an inverted signal that needs to be inverted manually outside of the FrSky receiver hardware. To interface the FrSky XM+ receiver with the XMC4700 MCU, a non-inverted signal is required, which can be accessed on the receiver hardware as shown in Figure 18. The originally inverted SBUS signal is cut-off from the external connector (Pin 1) while the non-inverted signal is extracted and connected to the connector in its place.

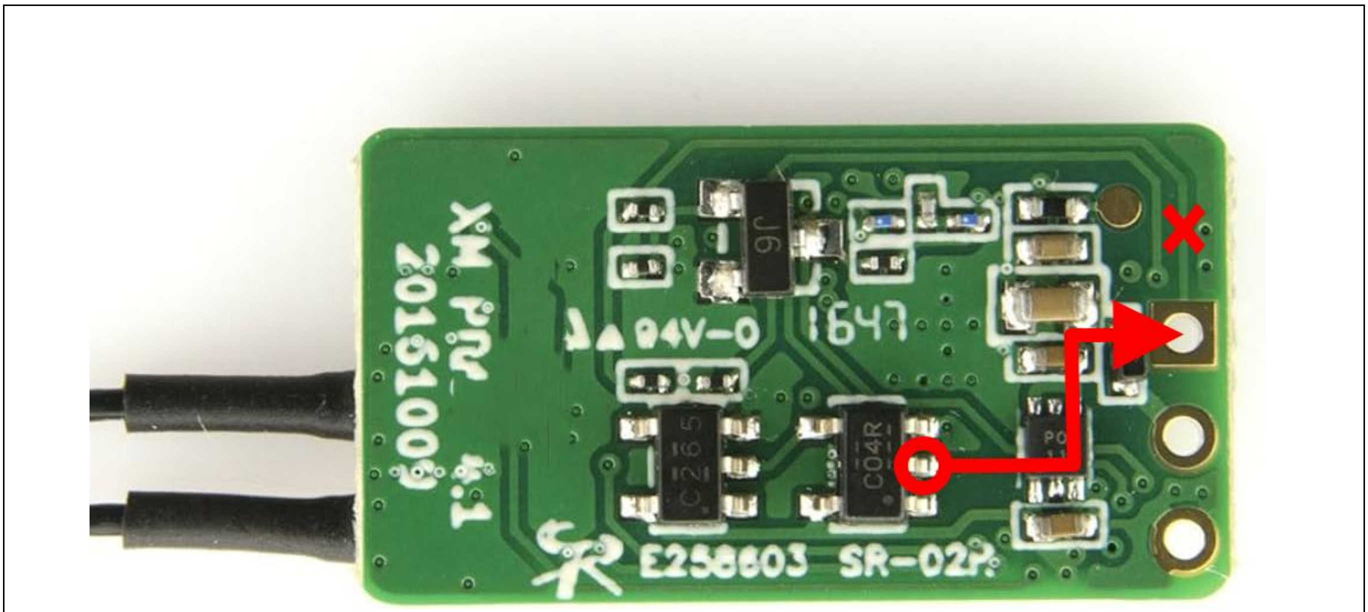

Figure 18 FrSky XM+ modifications to access the non-inverted SBUS signal

After applying the necessary modifications to the FrSky XM+ receiver, it can be connected to the DEMO_IMR_MAINCTRL_V1 board. To remove the need of a level shifter, the receiver is powered using the 3.3 V regulated DC output. Furthermore, the SBUS line is connected to the boards receiving UART line (UART_TX) to be able to properly parse the incoming serial communication.

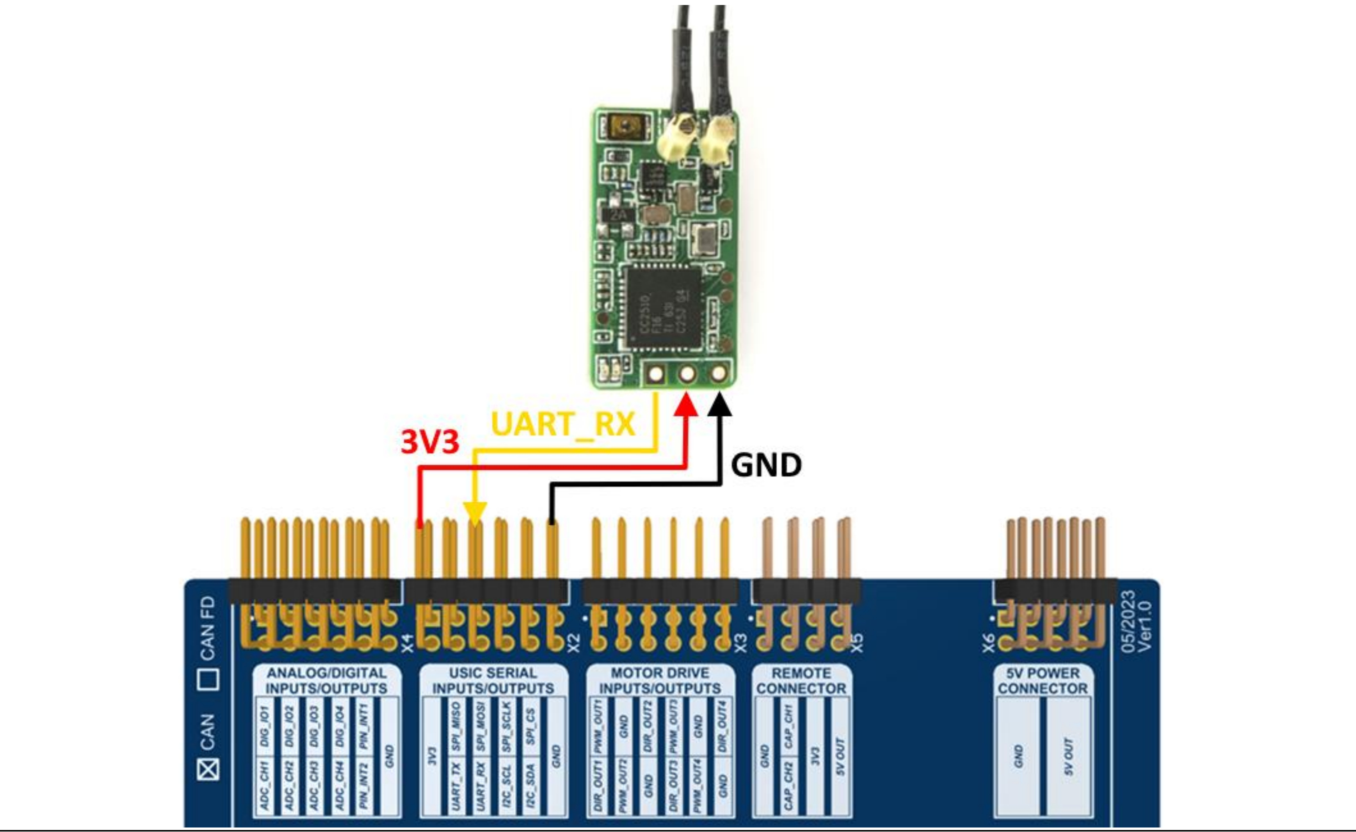

Figure 19 Wiring diagram to connect the FrSky XM+ with the DEMO_IMR_MAINCTRL_V1 board

With the wiring completed, the receiver can then be connected to the remote control following the standard RC binding procedure (see Instruction Manual for FrSky XM+). Note that the remote-control mode must be set to D16 with the channel range from CH1 to 16. The selected hardware used to work with the provided software is the X9D+ digital telemetry radio system from Taranis, as shown in Figure 20.

Figure 20 Taranis X9D+ digital telemetry radio system – remote control

5 Bill of materials (BOM)

Designator	Manufacturer	Part number	Quantity	Value/rating
C1, C2	Würth Elektronik	885012006093	2	8.2 pF/100 V/0603/10%
C3, C12, C21	Würth Elektronik	885012106031	3	10 µF/25 V/0603/20%
C4, C5, C6, C7, C8, C9, C10, C11, C15, C16, C17, C20, C24, C25	Würth Elektronik	885012206071	14	100 nF/25 V/0603/10%
C13, C14	Würth Elektronik	885012006050	2	6.8 pF/50 V/0603/10%
C18, C19, C23, C26	Würth Elektronik	885012206076	4	1 uF/25 V/0603/10%
C22	Würth Elektronik	885012206065	1	10 nF/25 V/0603/10%
D1	Würth Elektronik	150060BS75000	1	Blue/470 nm
D2	Würth Elektronik	150060GS75000	1	Green/525 nm
G1	Infineon	TLS205B0EJV33	1	LDO 3.3 V/500 mA
L1, L2	Würth Elektronik	742792651	2	600R@100 MHz 1000 mA
R1, R2, R5	Yageo	RC0603FR-074K7L	3	4k7/100 mW/0603/1%
R3, R4	Yageo	AC0603JR-071KL	2	1 k/100 mW/0603/5%
R6	Vishay	CRCW0603510RFK	1	510R/100 mW/0603/1%
R7	Yageo	RC0603FR-07120RL	1	120R/100 mW/0603/1%
R8, R9	Bourns	CAT16A-2002F4LF	2	20k/63 mW/1206/1%
S1	Würth Elektronik	434121025816	1	WS-TASV Tact Switch
S2	Würth Elektronik	416131160808	1	WS-DISV 8p DIP Switch
U1	Infineon	XMC4700-F100K2048 AA	1	32-bit Arm® Cortex®-M4
U2	Infineon	TLE9351BVSJ	1	CAN FD Transceiver
X1	Würth Elektronik	62701021621	1	WR-BHD 10p 1.27 mm
X2, X3, X4	Würth Elektronik	61301221021	3	WR-PHD 12p 2.54 mm
X5, X6	Würth Elektronik	61300821021	2	WR-PHD 8p 2.54 mm
X7	N/A	N/A	1	Card edge header
Y1	Würth Elektronik	830108206909	1	12 MHz/8 pF/10 ppm
Y2	Würth Elektronik	830105946101	1	32.768 kHz/7 pF/20 ppm

6 PCB layout

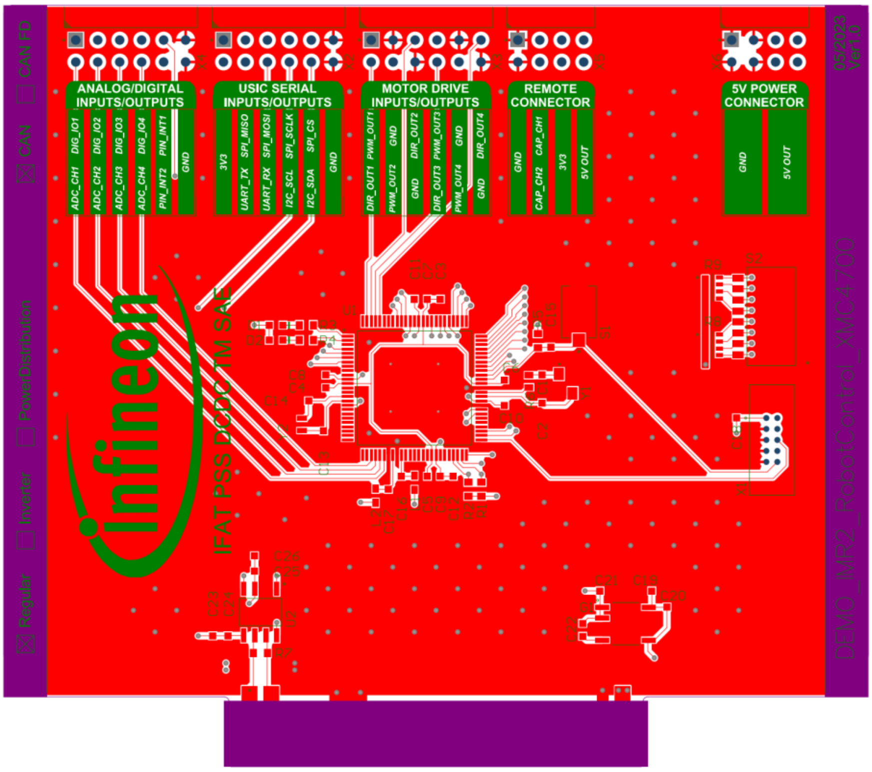

Figure 21 DEMO_IMR_MAINCTRL_V1 board top side

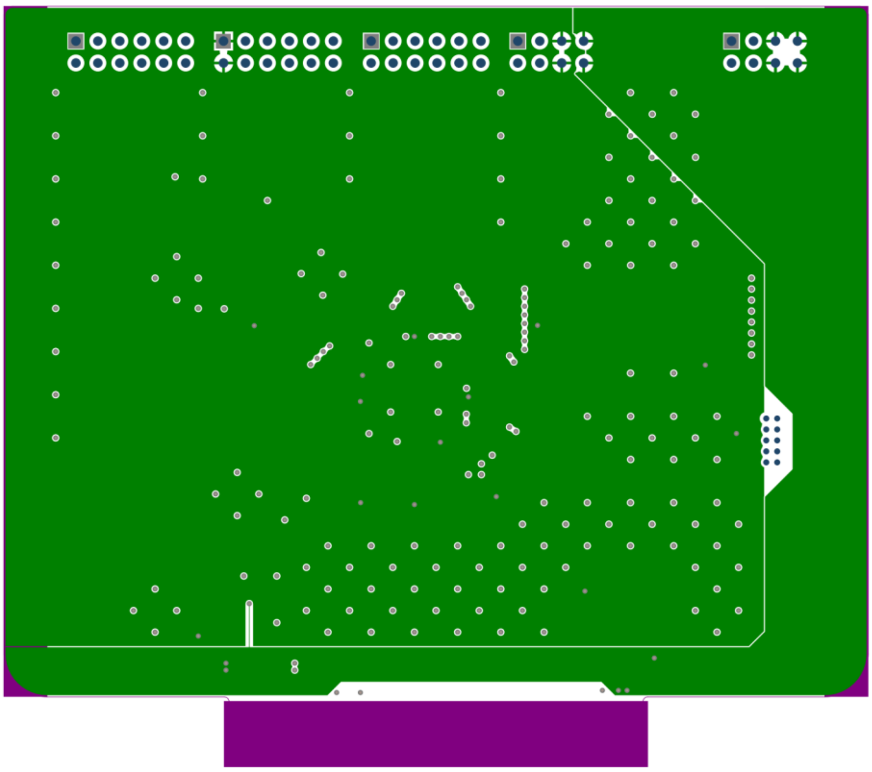

Figure 22 DEMO_IMR_MAINCTRL_V1 board first inner layer

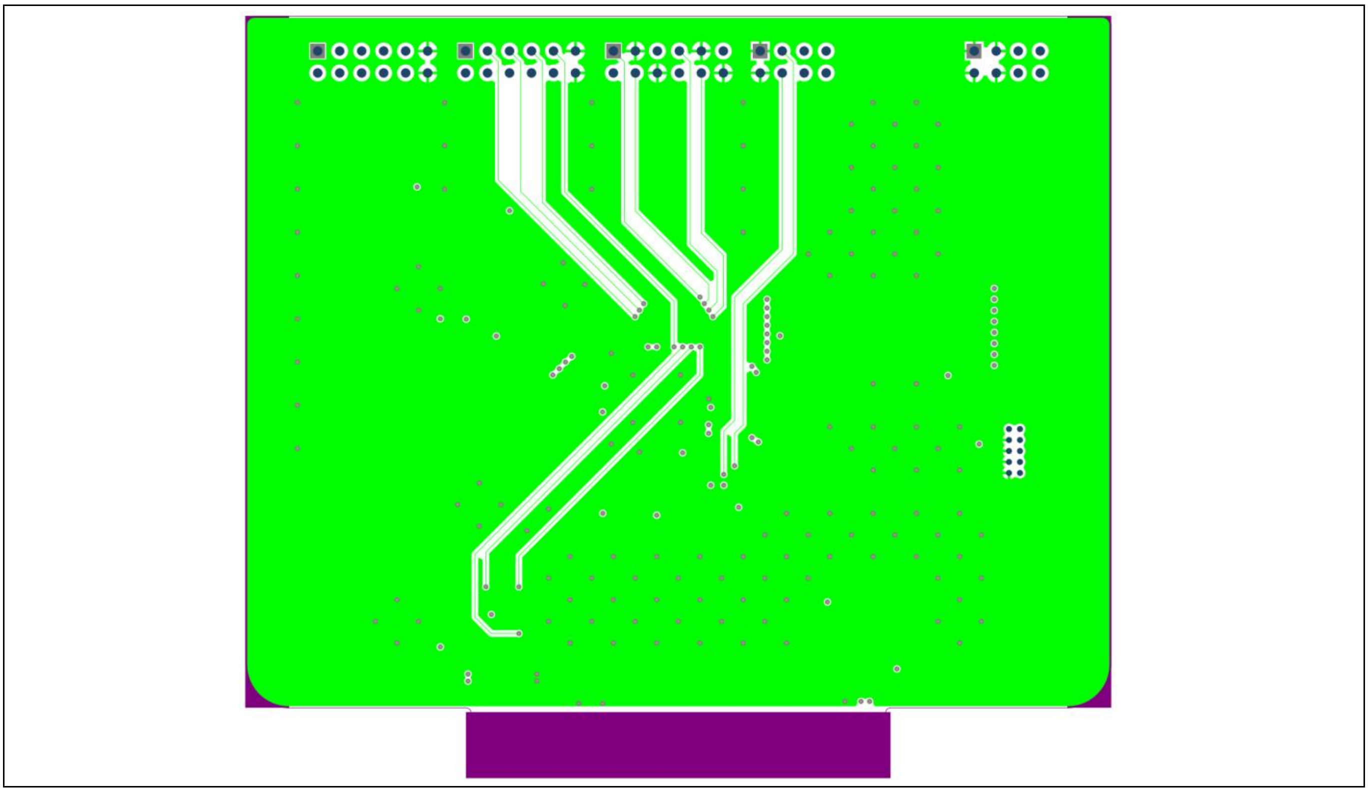

Figure 23 DEMO_IMR_MAINCTRL_V1 board second inner layer

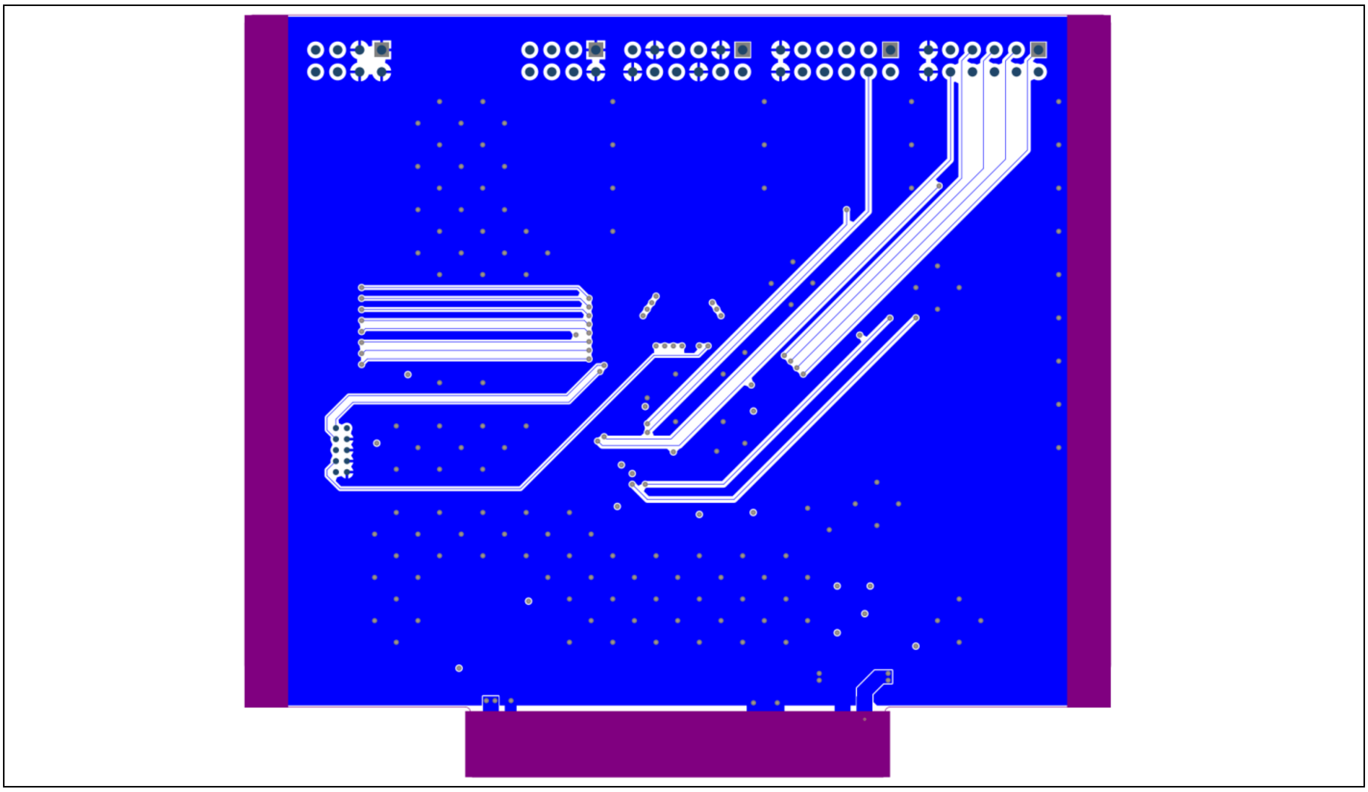

Figure 24 DEMO_IMR_MAINCTRL_V1 board bottom side

Appendices

A Schematics

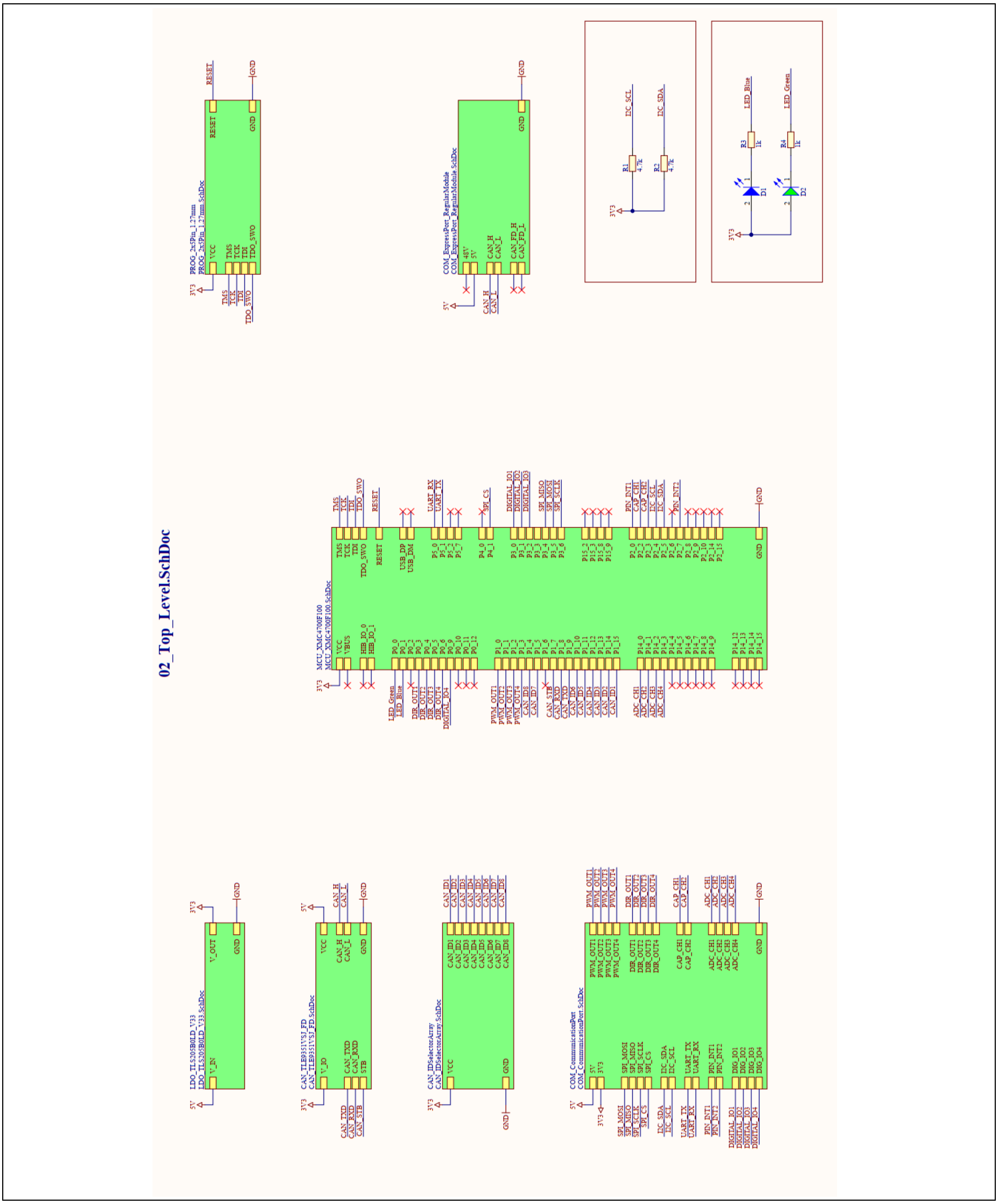

Figure 25 DEMO_IMR_MAINCTRL_V1 – 02_Top_Level.SchDoc

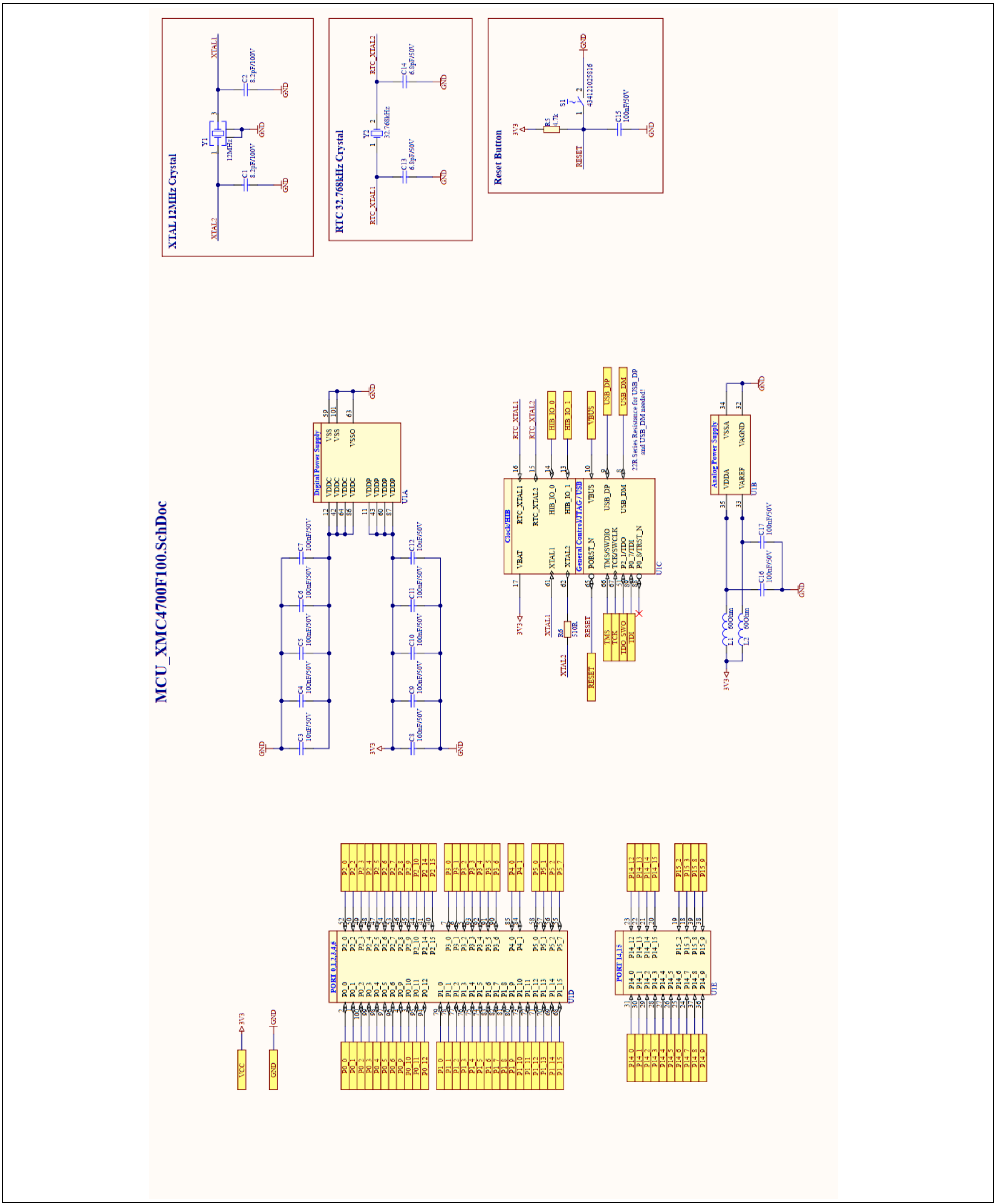

Figure 26 DEMO_IMR_MAINCTRL_V1 – MCU_XMC4700F100.SchDoc

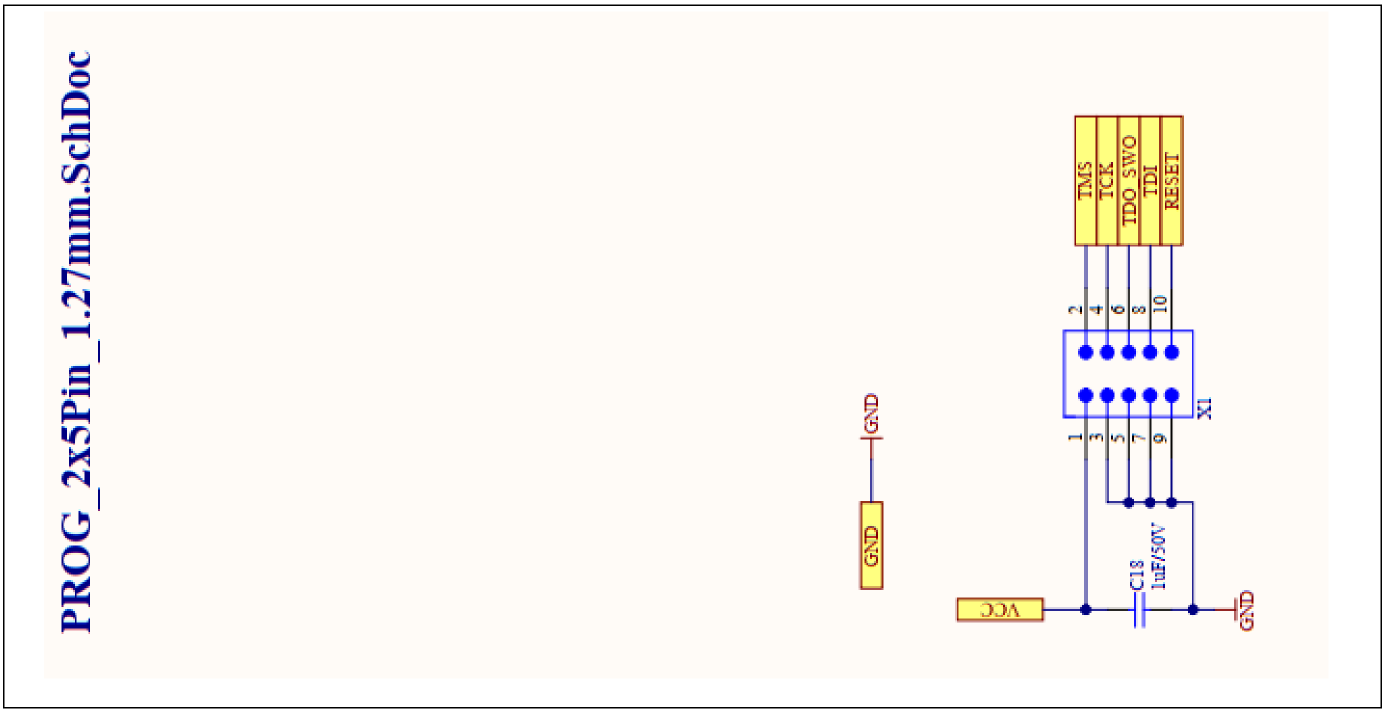

Figure 27 DEMO_IMR_MAINCTRL_V1 – PROG_2x5Pin_1.27mm.SchDoc

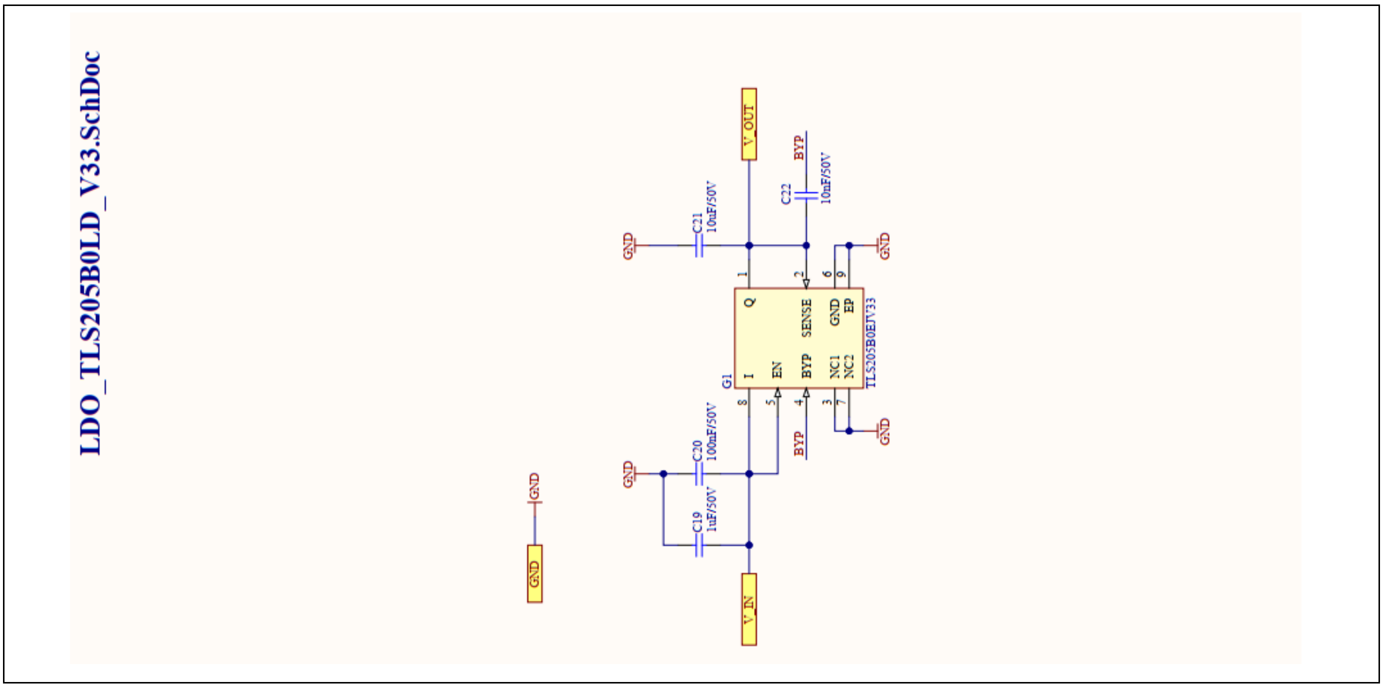

Figure 28 DEMO_IMR_MAINCTRL_V1 – LDO_TLS205B0LD_V33.SchDoc

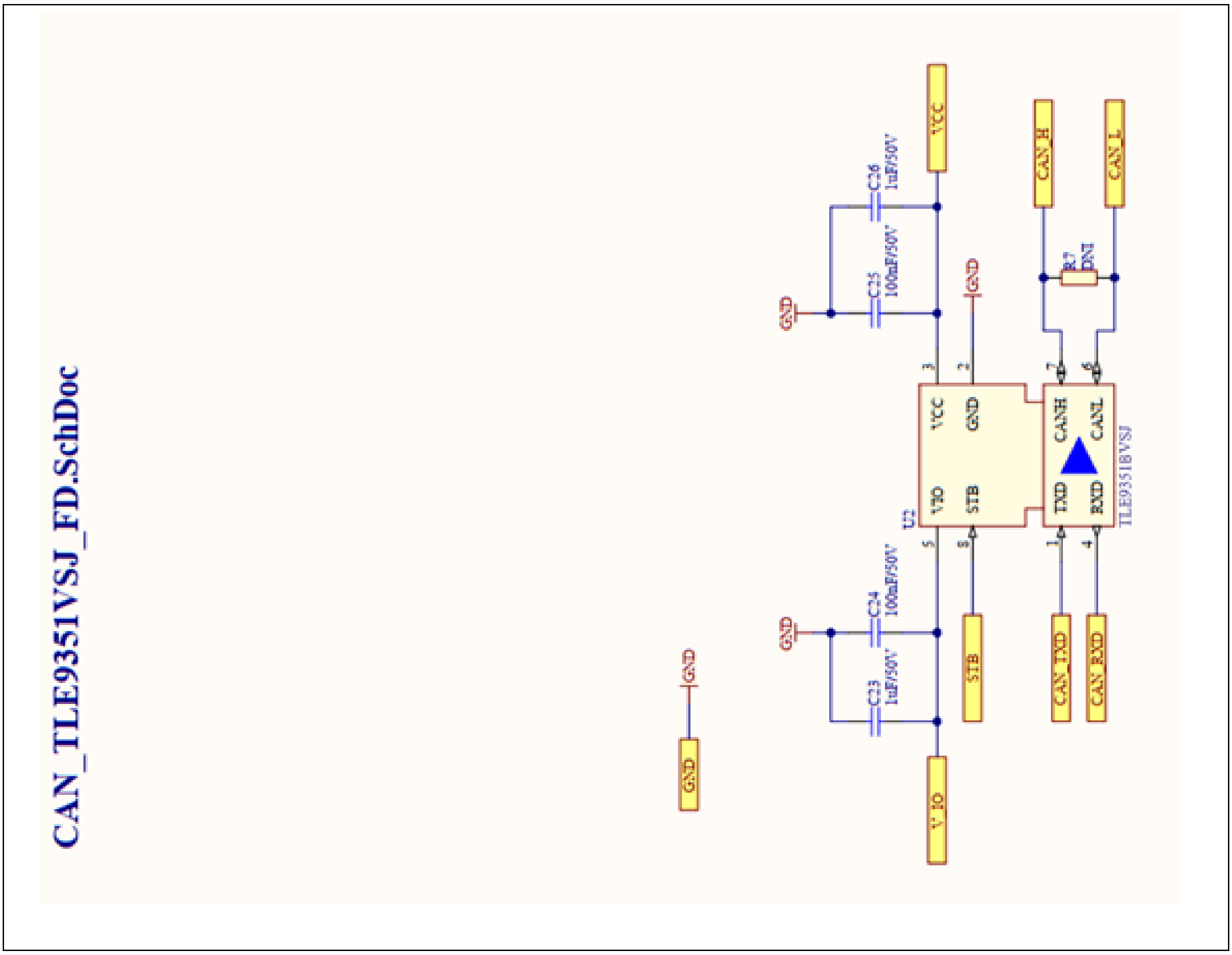

Figure 29 DEMO_IMR_MAINCTRL_V1 – CAN_TLE9351VSJ_FD.SchDoc

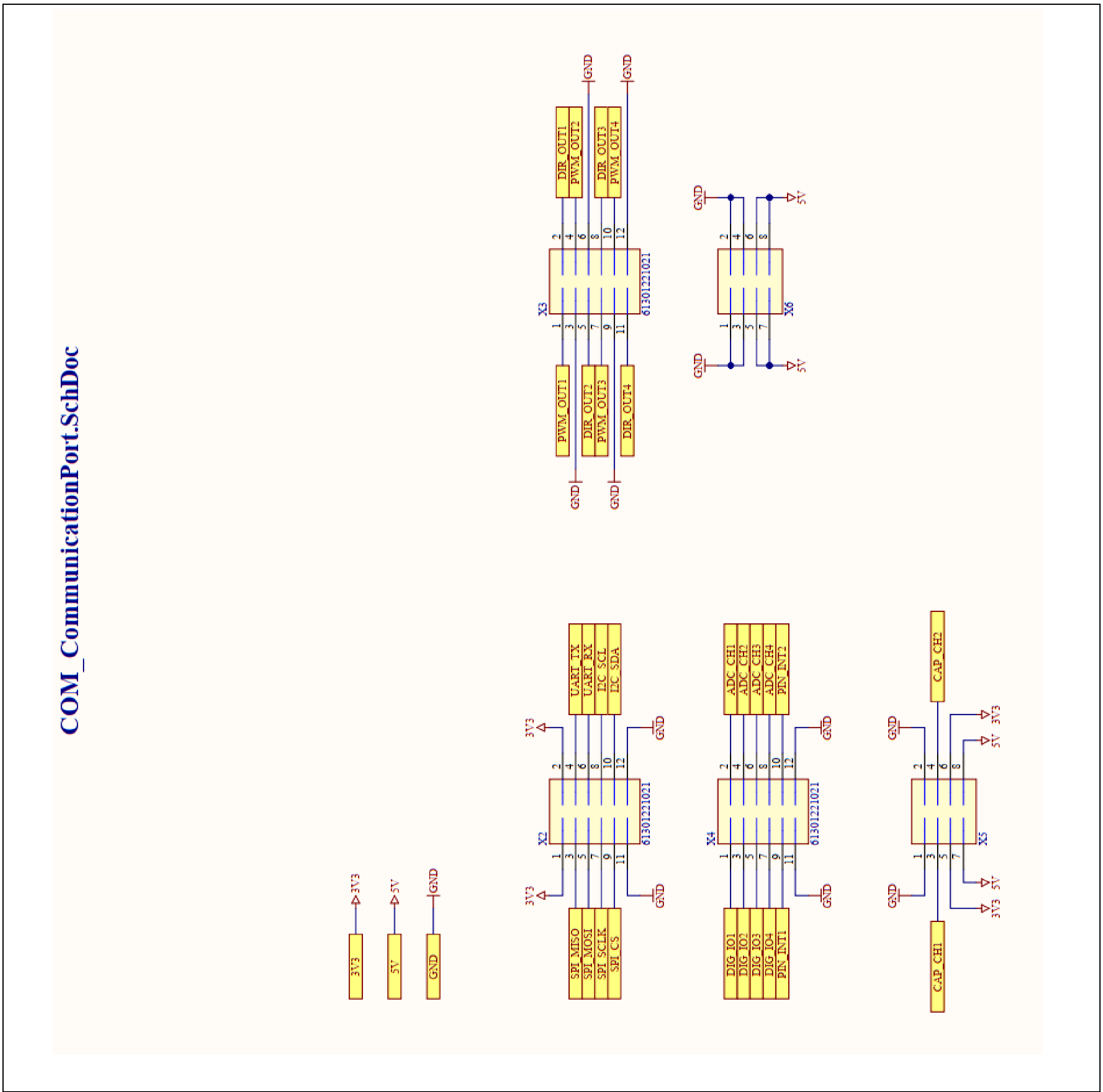

Figure 30 DEMO_IMR_MAINCTRL_V1 – COM_CommunicationPort.SchDoc

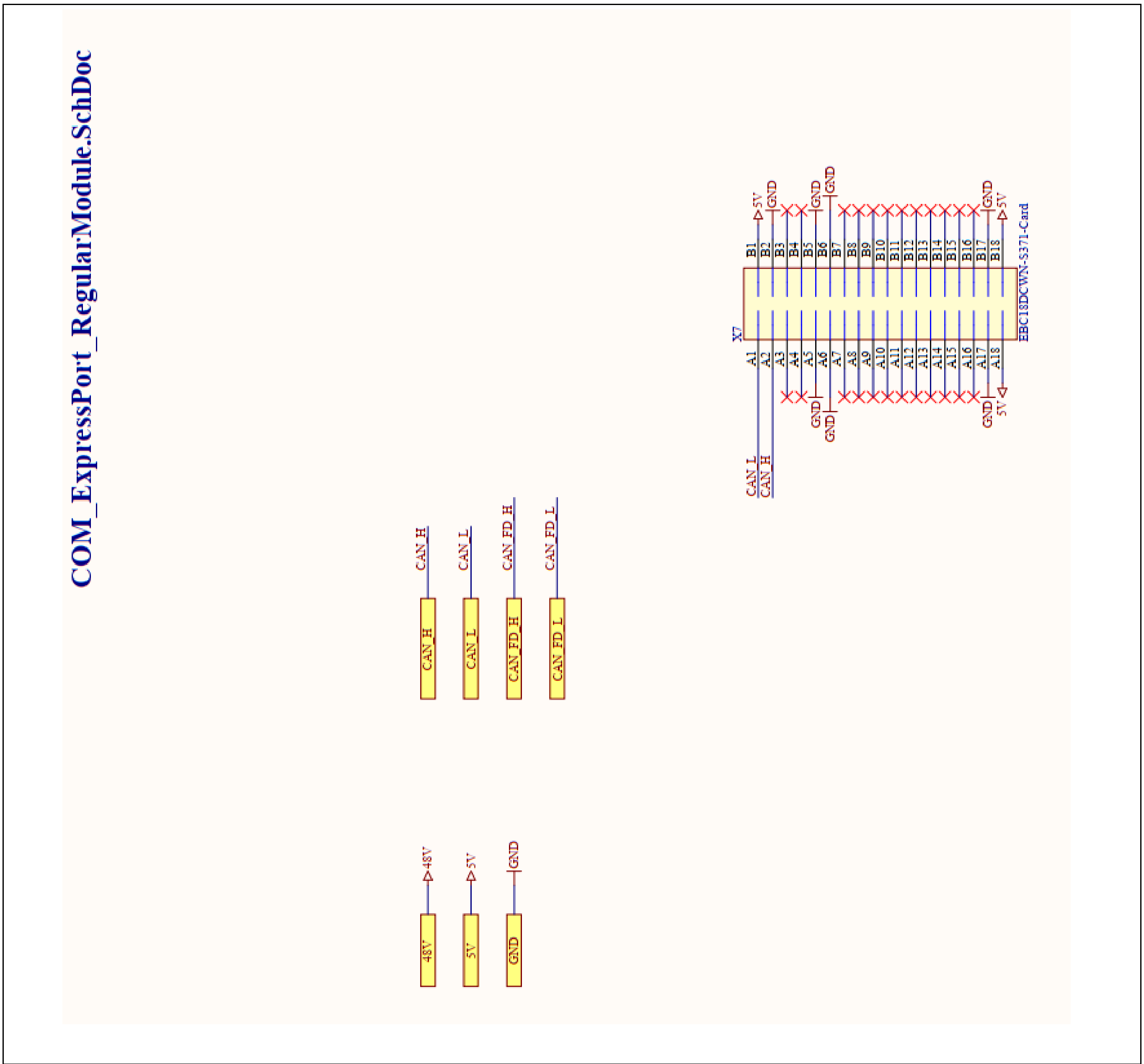

Figure 31 DEMO_IMR_MAINCTRL_V1 – COM_ExpressPort_RegularModule.SchDoc

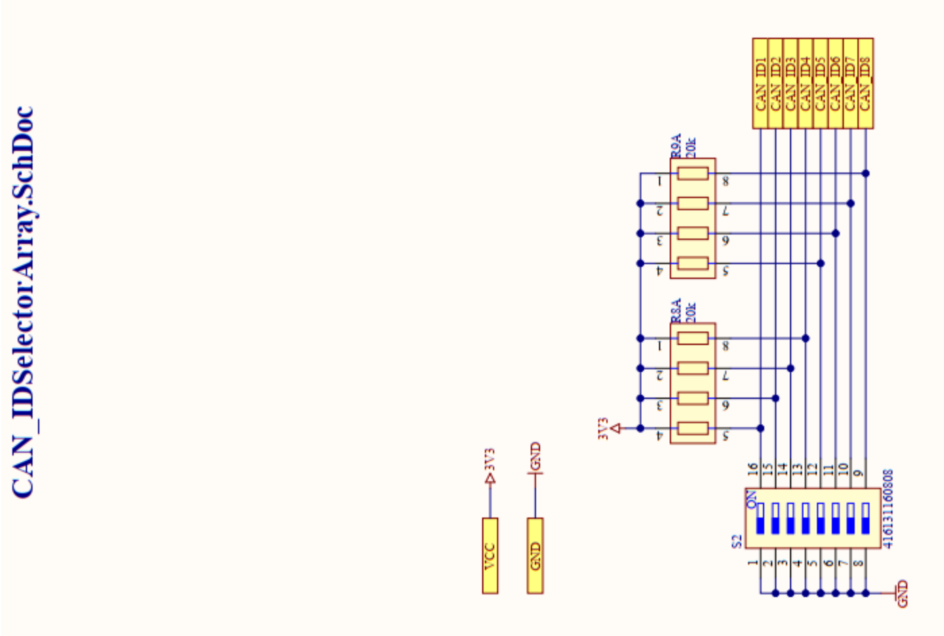

Figure 32 DEMO_IMR_MAINCTRL_V1 – CAN_IDSelectorArray.SchDoc

B Kinematics calculations

The direct and inverse kinematics for the robot were derived based on [12] and the following MATLAB code, using symbolic toolbox.

Code listing 1 **MATLAB code**

```
syms r beta gamma alpha l
Ti = -1/r * [cos(beta-gamma)/sin(gamma) sin(beta-gamma)/sin(gamma)
l*sin(beta-gamma-alpha)/sin(gamma)]
r = 0.05;               % wheel radius
lx=0.115;               % distance center to wheel x
ly=0.124;               % distance center to wheel x
l=sqrt(lx^2+ly^2);      % distance center to wheel
beta = pi/2;            % angle between robot x (forward) and wheel axis
gamma = -pi/4;          % angle of rollers on wheels

alpha = atan(lx/ly);

eval(Ti)
T=[20 -20 -4.24; 20 20 4.24; 20 20 -4.24; 20 -20 4.24]
Tp = inv(T'*T)*T'
```

References

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Glossary

AGV
automated guided vehicles

AMR
autonomous mobile robots

IMR
Infineon Mobile Robot (IMR)

LSB
least significant byte (LSB)

MSB
most significant byte (MSB)

Revision history

Document revision	Date	Description of changes
V 1.0	2024-04-08	Initial version
V 2.0	2025-04-25	Updated CAN communication Section, repository link, and onboard LEDs meaning

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