RT Box controlCARD Interface

User Manual January 2018

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Introduction

The PLECS RT Box is a powerful real-time simulator based on a 1 GHz Xilinx Zynq system on a chip (SOC). With its 64 digital and 32 analog I/O signals, the RT Box is well equipped for hardware-in-the-loop (HIL) testing as well as rapid control prototyping.

If employed for HIL testing, the RT Box typically emulates the power stage of a power electronic system. The power stage could be a simple DC/DC converter, an AC drive system or a complex multi-level inverter system. The device under test (DUT) is the control hardware connected to the RT Box. In such a setup, the complete controller can be tested without the real power stage.

To simplify the connection of external hardware and to provide convenient access to the RT Box inputs and outputs, Plexim offers a set of RT Box accessories.

The **controlCARD Interface** described in this document has two controlCARD slots which facilitate a simple connection of the RT Box with the 100-pin and 180-pin controlCARD modules from Texas Instruments (TI). It enables users to test control algorithms implemented on C2000 MCUs without developing their own interface hardware. The pinout of the controlCARD Interface board has been optimized for the following development kits:

- Piccolo controlCARDs (280049, 28027, 28035, 28075)
- Delfino controlCARDs (28335, 2837xD)
- Concerto controlCARDs (F28M35, F28M36)

The controlCARD Interface may also be used with other development boards compliant with the controlCARD pinout.

Interface Board Overview

The interface board provides a 100-pin socket for the older 100-pin controlCARDs, as well as a 180-pin socket for the newer modules. Fig. 2.1 shows the top view of the controlCARD interface board.

All RT Box output signals are buffered to protect the MCU from overvoltage, and local opamps provide a low-impedance source for the MCUs ADC inputs. The board provides access to three analog outputs labeled *AOUT-13 . . . 15* via BNC connectors. For status communication with the RT Box, the board features four sliding switches and four LEDs labeled *DIO-28 . . . DIO-31*.

Additionally, external JTAG adapters can be connected to the MCUs by means of two 14-pin headers labeled *JTAG-100, JTAG-180*. Each controlCARD is wired to an isolated CAN driver, allowing communication among the controlCARDs as well as external equipment. The board also provides a 64 kbit Serial Electrically Erasable PROM for user specific purposes.

ControlCARD Socket Pins

Tables 2.1 and 2.2 list the pin assignments of 100-pin and 180-pin controlCARD sockets and the RT Box signals.

A more detailed table, including the available processor functions at each pin for the supported controlCARDs, can be found in the Appendix.

Onboard Voltage Supply

Power to the controlCARD interface board can be supplied in two ways, by selecting the appropriate jumper terminals on the bottom right corner of the board. One way is to supply power directly from the RT Box. The second is

RT Box	100-pin		RT Box	RT Box	100-pin		RT Box
	1	**51**		DI23	**26**	**76**	DI22
	2	**52**			**27**	**77**	
	3	**53**		DI25	**28**	**78**	DI24
	4	**54**		DI27	**29**	**79**	DI26
	5	**55**		DI29	**30**	**80**	DI28
	6	**56**			**31**	**81**	
AO14	**7**	**57**	AO15		**32**	**82**	
	8	**58**			**33**	**83**	DO0
AO12	**9**	**59**	AO13		**34**	**84**	DO5
	10	**60**		DO6	**35**	**85**	DO7
AO10	**11**	**61**	AO11	DO4	**36**	**86**	
	12	**62**			**37**	**87**	
AO8	**13**	**63**	AO9		**38**	**88**	
	14	**64**			**39**	**89**	
AO6	**15**	**65**	AO7	DO2	**40**	**90**	DO3
	16	**66**			**41**	**91**	DO1
AO4	**17**	**67**	AO5		**42**	**92**	
	18	**68**			**43**	**93**	
AO2	**19**	**69**	AO3		**44**	**94**	
	20	**70**		DI31	**45**	**95**	DI30
AO0	**21**	**71**	AO1		**46**	**96**	
	22	**72**			**47**	**97**	
DI17	**23**	**73**	DI16		**48**	**98**	
DI19	**24**	**74**	DI18		**49**	**99**	
DI21	**25**	**75**	DI20		**50**	**100**	

Table 2.1: 100-pin controlCARD socket

RT Box	180-pin		RT Box
	1	**2**	
	3	**4**	
	5	**6**	
	7	**8**	
AO15	**9**	**10**	
AO13	**11**	**12**	AO14
	13	**14**	AO12
AO11	**15**	**16**	
AO9	**17**	**18**	AO10
	19	**20**	AO8
AO7	**21**	**22**	
AO5	**23**	**24**	AO6
AO3	**25**	**26**	AO4
AO1	**27**	**28**	AO2
	29	**30**	AO0
	31	**32**	
NC	**33...46**		NC
	47	**48**	
DI0	**49**	**50**	DI4
DI1	**51**	**52**	DI5
DI2	**53**	**54**	DI6
DI3	**55**	**56**	DI7
DI8	**57**	**58**	DI12
DI9	**59**	**60**	DI13
DI10	**61**	**62**	DO11
DI11	**63**	**64**	DO12

RT Box	180-pin		RT Box
	65	**66**	
	67	**68**	DO13
	69	**70**	DO14
	71	**72**	DO27
	73	**74**	DO26
DO25	**75**	**76**	
DO24	**77**	**78**	
DO23	**79**	**80**	
DO22	**81**	**82**	
	83	**84**	
	85	**86**	
	87	**88**	DI14
DO21	**89**	**90**	DI15
DO20	**91**	**92**	
	93	**94**	
	95	**96**	
	97	**98**	
	99	**100**	DO19
	101	**102**	DO18
	103	**104**	DO17
	105	**106**	DO16
	107	**108**	
NC	**109...118**		NC
	119	**120**	*RESET* (DO15)
	121	**122**	
NC	**123...180**		NC

Table 2.2: 180-pin controlCARD socket

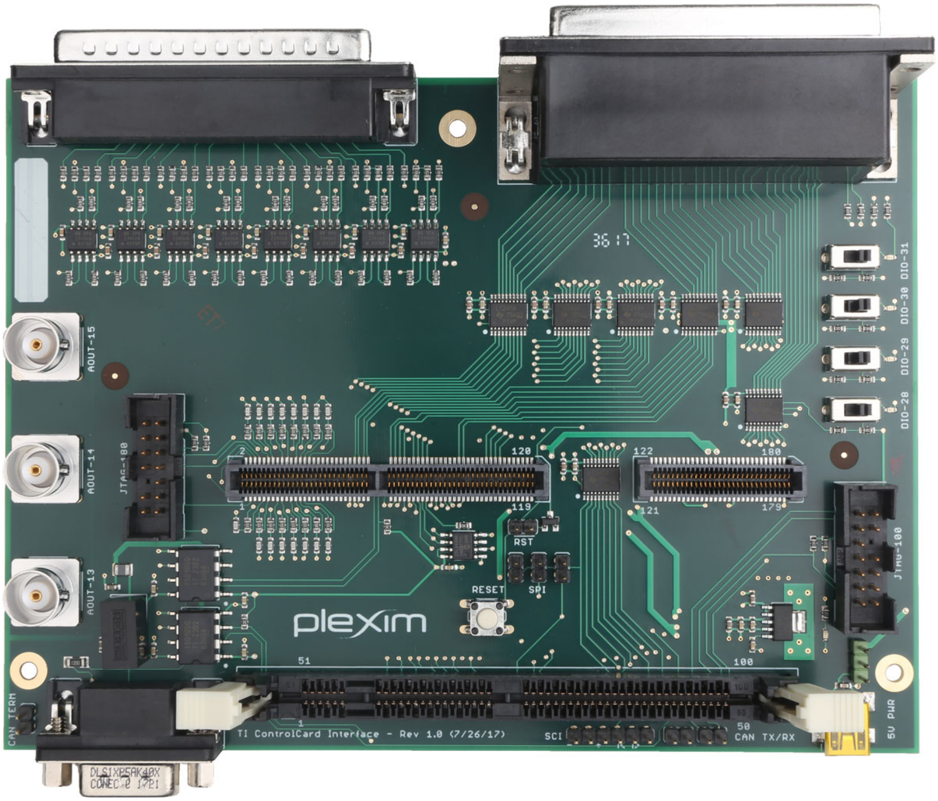

Figure 2.1: RT Box controlCARD Interface Board

through an external source using the USB connector labeled *5V PWR* . This allows the board to be used without the RT Box. The interface board contains a linear voltage regulator that steps down the 5 V supplied externally or by the RT Box to 3.3 V required by the controlCARD. A green LED on the lower right section of the board indicates power supply to the board.

Analog Output

All 16 analog outputs from the RT Box are routed to both 100-pin and 180-pin control card slots. It is possible to operate two cards at the same time, although the user must be aware that the sampling of one MCU could affect the measurements of the other. If both control card slots are populated, the analog signals must be shared by the controlCARDs. Three analog output channels *AOUT-13 . . . AOOUT-15* are also accessible at the BNC connectors.

All 16 analog output signals are passed through a rail-to-rail CMOS operational amplifier signal conditioning circuit for scaling the voltages to 0 V and 3.3 V, and for protecting the inputs of the MCU from damage by over-voltage.

Additionally, each analog channel routed to the 180-pin controlCARD socket is buffered with a capacitor (2200 pF) against ground, to lower the source impedance of the channel so that the sample and hold capacitor of the MCU can be charged quickly. A small resistance (56 Ω) is also placed in series to stabilize the driving opamp circuit.

The 100-pin controlCARD socket is excluded from this step and receives analog output signals directly after signal conditioning, as these resistors and capacitors are already populated on the 100-pin controlCARDS.

Fig. 2.2 shows the signal conditioning circuit.

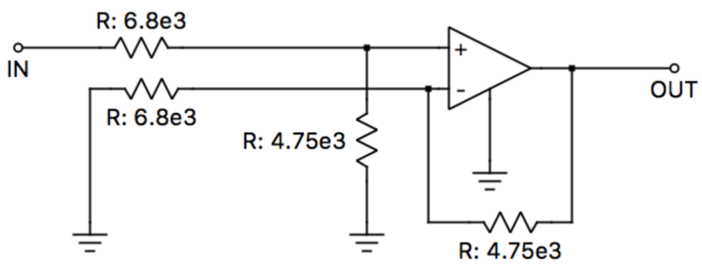

Figure 2.2: Analog Output Signal Conditioning Circuit

Digital I/O

Digital inputs DI0 . . . DI15 from the RT Box are connected to the 180-pin controlCARD socket. DI16 . . . DI31 are connected to the 100-pin controlCARD socket. Digital inputs DI28 . . . 31 can also be set via four sliding switches provided on the board labeled *DIO-28 . . . DIO-31*.

Digital outputs DO0 . . . DO7 are connected to the 100-pin controlCARD socket. DO11 . . . DO14, DO16 . . . 27 are connected to the 180-pin controlCARD socket. DO28 . . . DO31 are connected to four LEDs in the upper right section of the board labeled *DIO-28 . . . DIO-31*.

All the digital input and output signals are buffered through bus transceivers to protect the inputs of the MCU from voltages greater than 3.3 V.

DO15 is connected to the 180-pin controlCARDs MCU reset pin via $\overline{RST}$ jumper. If the jumper is set a low-level output at DO15 will reset the MCU. Do not set this jumper unless you wish to use this feature. Alternatively, the MCU can be reset using the push button labeled *RESET*.

CAN Communication

Two electrically isolated CAN transceivers provide CAN communication that can be accessed through a 9-pin D-SUB connector on the bottom left corner of the board. This allows communication among the controlCARDs, if populated together, as well as with external equipment.

Table 2.3 lists the pin assignments of the 9-pin D-SUB connector, 100-pin controlCARD and 180-pin controlCARD sockets.

100-pin	CAN Transceiver 1		9-pin connector	CAN Transceiver 2		180-pin
			1			
94	TX1	CAN_L	**2**	CAN_L	TX2	82
		GND	**3**	GND		
			4			
			5			
		GND	**6**	GND		
44	RX1	CAN_H	**7**	CAN_H	RX2	80
			8			
			9			

Table 2.3: CAN pin assignment

Note CAN_L and CAN_H signals on pins 2 and 7 respectively on the 9-pin D-SUB connector can be terminated with a 120 Ω resistor using the jumper labeled *CAN TERM* located on the bottom left corner of the board.

JTAG Headers

Tables 2.4 and 2.5 list the pin assignments of JTAG headers for the 100-pin controlCARD labeled *JTAG-100* and 180-pin controlCARD labeled *JTAG-180* respectively.

100-pin	Function	JTAG-100		Function	100-pin
49	TMS	**1**	**2**	$\overline{\text{TRST}}$	99
97	TDI	**3**	**4**	GND	
	3 V	**5**	**6**	NC	
98	TDO	**7**	**8**	GND	
48	TCK	**9**	**10**	GND	
48	TCK	**11**	**12**	GND	
100	EMU0	**13**	**14**	EMU1	50

Table 2.4: JTAG-100 pin assignment

180-pin	Function	JTAG-180		Function	180-pin
3	TMS	**1**	**2**	$\overline{\text{TRST}}$	4
8	TDI	**3**	**4**	GND	
	3 V	**5**	**6**	NC	
6	TDO	**7**	**8**	GND	
5	TCK	**9**	**10**	GND	
5	TCK	**11**	**12**	GND	
2	EMU0	**13**	**14**	EMU1	1

Table 2.5: JTAG-180 pin assignment

Demo Application

On user's request, Plexim can provide the demo model listed below.

- Field Oriented Control of a PMSM

To be able to work with this model, the user would have to purchase a TI F28379D controlCARD.

Software Requirements

The PLECS model can be executed on Windows, MAC or Linux machines with the following software installed:

- PLECS Standalone (version 4.0.4 or higher)
- PLECS Standalone Coder

However, the control preprogrammed for the TI controlCARD can only be flashed or updated on a Windows machine (32-bit or 64-bit) with the following additional software installed:

- C2Prog – Download from www.codeskin.com (only required to reflash the MCU).

A license is required to run PLECS and use the code generation feature. You can request this license from Plexim at www.plexim.com.

Loading the Firmware

The following section shows how to program the MCU to flash the demo application or perform an update. Please note that this section is applicable for Windows machines only.

Populate the controlCARD on the 180-pin connector on the controlCARD interface board and switch on the RT Box. Connect the JTAG/SCI USB port of the controlCARD to your PC.

Open the Windows Device Manager and confirm that TI Debug Probes are listed.

You may have to install the FTDI drivers if the port is not enumerated.

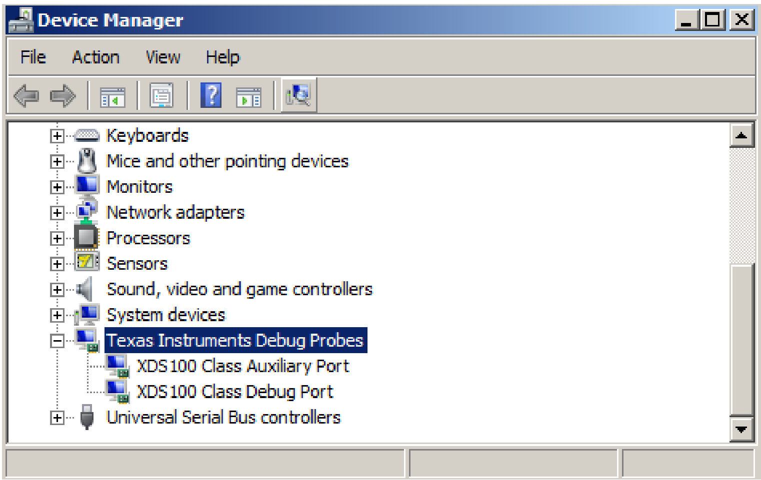

Figure 3.1: TI debug probes listed in device manager

The pre-compiled executable `FOC_Controlcard_28379D_cpu01.ehx` located in the demo package is used to begin. In C2Prog, select the file `FOC_Controlcard_28379D_cpu01.ehx` and configure the port to `XDS100v2`.

Click the **Program** button.

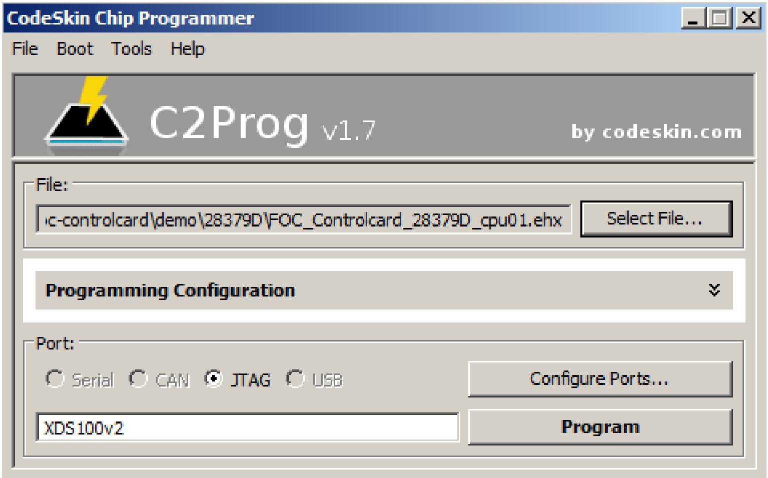

Figure 3.2: Flashing the controlCARD

Note The MCU can be reset using the push button labeled *RESET*.

Program the RT Box

This section describes the process of downloading a demo model to the RT Box. For general information about the RT Box and a manual on how to get started please also refer to the RT Box documentation available on the Plexim website at www.plexim.com.

Open the model `FOC_controlcard180_hil.plecs` located in the demo package. Familiarize yourself with the implementation of the subsystem PMSM and Inverter. Go to **Coder Options**. Select **PMSM and Inverter** and switch to the **Target** tab.

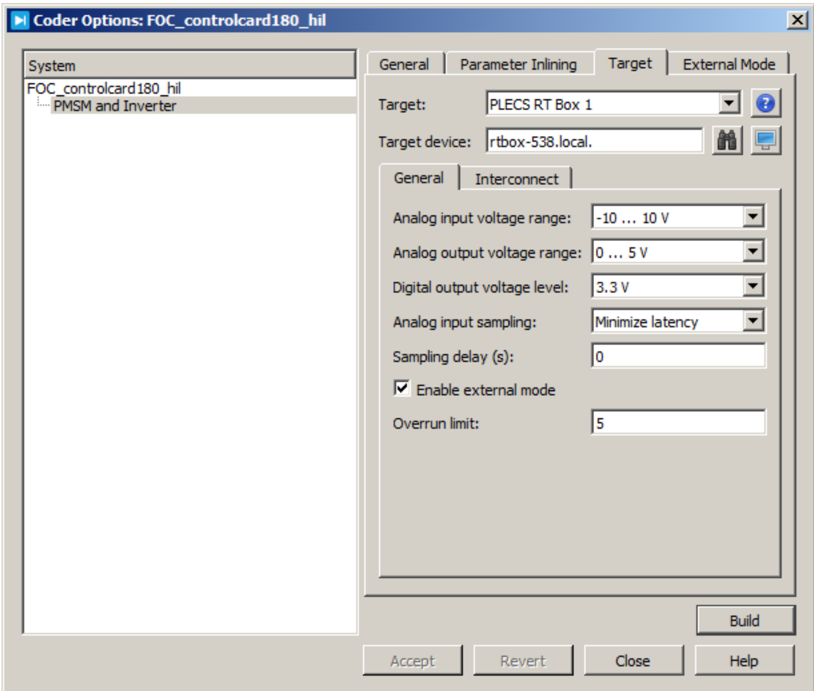

Figure 3.3: Programming the RT Box with the FOC Model

Select your **Target Device** from the drop-down list and click **Accept** and then **Build**. Your model is now compiled and downloaded to the RT Box automatically. Verify that the Blue **Running** LED on the RT Box is illuminated.

Connecting the External Mode

The External Mode enables access to the real-time simulation executed on the RT Box. It can be used to visualize all simulation signals via the model scopes.

Switch to the **External Mode** tab in the Coder Options and click **Connect** to start communication between PLECS and the model running on the RT Box. **Activate autotriggering** via the appropriate button.

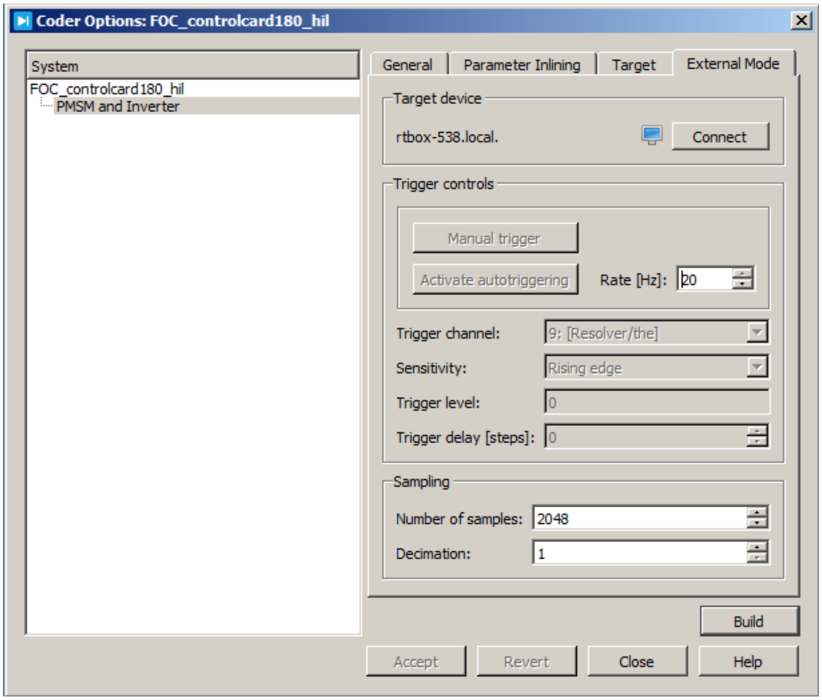

Figure 3.4: Connecting to the FOC Model via the External Mode

Flip Switch *DI29* to the left to enable the MCU drive control. Open the Scope **Scope** in the FOC model and analyze the control behavior.

RT Box Web Interface

The Web Interface provides information about the model running on the RT box as well as additional diagnostic options. It can be accessed by clicking on the icon under the *Target* or the *External Mode* tabs of the Coder Options dialog.

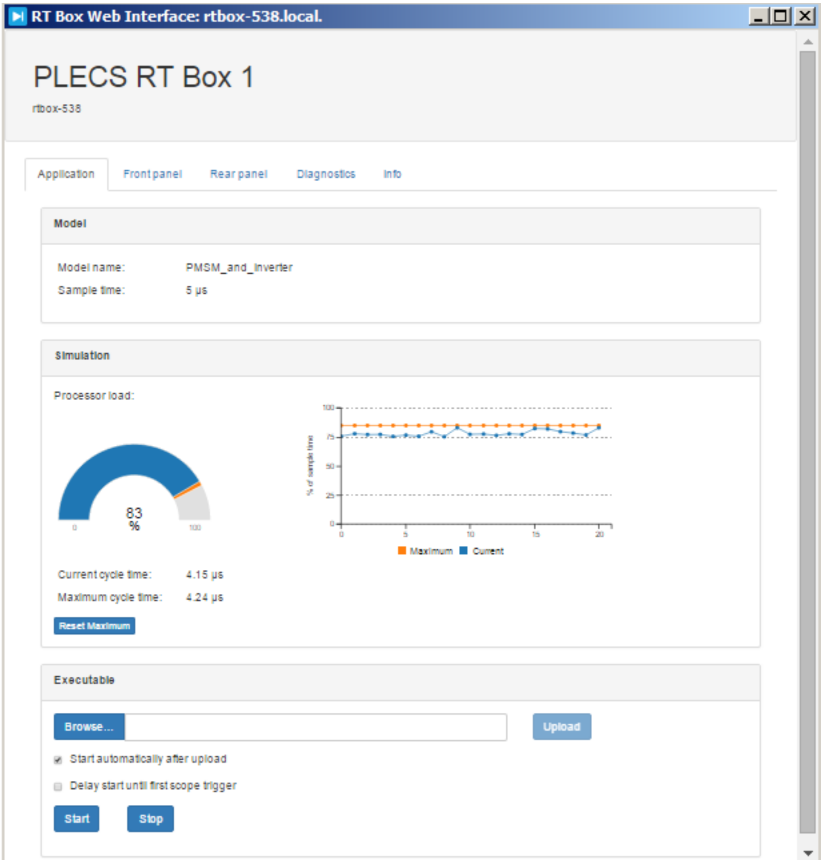

Figure 3.5: RT Box Web Interface

The processor load statistic reveals information about the time needed to calculate the model and therefore serves as a convenient tool to validate the chosen step size. Do not overload the processor and maintain a safety margin.

Note A model under actuation requires a higher processing time than an idle model. Additional processor load is required when using the external mode.

Description of Demo Projects

This section provides an overview of the FOC demo model and it's external signal availability.

Field Oriented Control of a PMSM

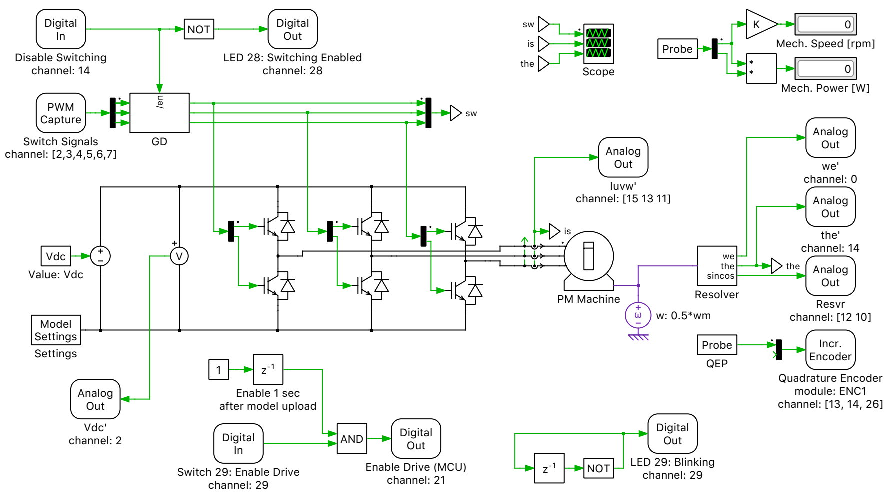

Figure 3.6: Field oriented control demo model

The project is based on a basic Field Oriented Control (FOC) application, with the embedded code controlling the switches of a three-phase inverter powering a permanent magnet (PM) machine.

The machine operates at Id= -200 A, Iq = 200 A, with a switching frequency of 20 kHz and a DC link voltage of 400 V.

The model outputs analog voltages for stator current measurements, the DC link voltage and the electrical angle (theta). The stator currents as well as theta can also be accessed directly via the BNC connectors. The rotor position and speed is made available using a quadrature encoder module via three digital outputs. The control algorithm generates six PWM signals controlling the inverter switches. Table 3.1 shows a detailed pin assignment for this demo model.

The speed of the motor can be changed in the PLECS model from 2500 rpm to 10000 rpm. At 10000 rpm, the motor is developing 50 kW.

A disable switching option in active high logic is implemented via DI14. LED 28 indicates if the switching signal is active. LED 29 blinks at a rate of 1 Hz while the model is running. Switch DI29 can be used to enable or disable the MCU drive. This information is forwarded to the MCU via DO21. Disconnect the $\overline{RST}$ jumper and use the push button labeled *RESET* to reset the MCU.

Feature	RT Box Channel	180-pin Socket
	AO0	30
Vdc	AO2	28
Isa	AO15	9
Isb	AO13	11
Isc	AO11	15
θ_e	AO14	12
	AO12	14
	AO10	18
ENC1A	DO13	68
ENC1B	DO14	70
ENC1I	DO26	74
PWM A H	DI2	53
PWM A L	DI3	55
PWM B H	DI4	50

PWM B L	DI5	52
PWM C H	DI6	54
PWM C L	DI7	56
Enable MCU	DO21	89
Disable PWM	DI14	88

Table 3.1: FOC I/O

Note Switch DI29 of the interface board enables or disables the MCU drive.

4

Appendix

The tables on the next pages provide more detailed information on the connectivity of the 180-pin controlCARD socket. For each controlCARD, the RT Box I/O is shown beside the controlCARD socket pins and the processor peripherals available at those pins.

TI F28379D ControlCard Pin Map

Function	RT Box	180-pin		RT Box	Function
JTAG-EMU1		**1**	**2**		JTAG-EMU0
JTAG-TMS		**3**	**4**		JTAG-TRSTn
JTAG-TCK		**5**	**6**		JTAG-TDO
		7	**8**		JTAG-TDI
ADC-A0	AO15	**9**	**10**		
ADC-A1	AO13	**11**	**12**	AO14	ADC-B0
		13	**14**	AO12	ADC-B1
ADC-A2	AO11	**15**	**16**		
ADC-A3	AO9	**17**	**18**	AO10	ADC-B2
		19	**20**	AO8	ADC-B3
ADC-A4	AO7	**21**	**22**		
ADC-A5	AO5	**23**	**24**	AO6	ADC-B4
ADCIN14	AO3	**25**	**26**	AO4	ADC-B5
ADCIN15	AO1	**27**	**28**	AO2	ADC-D0
		29	**30**	AO0	ADC-D1
	NC	**31...48**		NC	
PWM1A	DI0	**49**	**50**	DI4	PWM3A
PWM1B	DI1	**51**	**52**	DI5	PWM3B
PWM2A	DI2	**53**	**54**	DI6	PWM4A
PWM2B	DI3	**55**	**56**	DI7	PWM4B
PWM5A	DI8	**57**	**58**	DI12	PWM7A
PWM5B	DI9	**59**	**60**	DI13	PWM7B
PWM6A	DI10	**61**	**62**	DO11	PWM8A
PWM6B	DI11	**63**	**64**	DO12	PWM8B

Function	RT Box	180-pin		RT Box	Function
		65	**66**		
		67	**68**	DO13	QEP1A
		69	**70**	DO14	QEP1B
		71	**72**	DO27	QEP1S
		73	**74**	DO26	QEP1I
CAP1, SPISIMOB	DO25	**75**	**76**		
CAP2, SPISOMIB	DO24	**77**	**78**		
CAP3, SPICLKB	DO23	**79**	**80**		CANRX
CAP4, SPISTEB	DO22	**81**	**82**		CANTX
		83	**84**		
		85	**86**		
		87	**88**	DI14	OUT_P88, GPIO
GPIO	DO21	**89**	**90**	DI15	GPIO
GPIO	DO20	**91**	**92**		
		93	**94**		
		95	**96**		
		97	**98**		
		99	**100**	DO19	QEP2A
		101	**102**	DO18	QEP2B
		103	**104**	DO17	QEP2S
		105	**106**	DO16	QEP2I
	NC	**107...118**		NC	
		119	**120**	DO15	XRSn
	NC	**121...180**		NC	

Table 4.1: TI 28379D ControlCard pin map

TI F280049M controlCARD Pin Map

Function	RT Box	180-pin		RT Box	Function
JTAG-EMU1		**1**	**2**		JTAG-EMU0
JTAG-TMS		**3**	**4**		JTAG-TRSTn
JTAG-TCK		**5**	**6**		JTAG-TDO
		7	**8**		JTAG-TDI
ADC-A0, B15, C15, DACA	AO15	**9**	**10**		
ADC-A1, DACB	AO13	**11**	**12**	AO14	ADC-B0
		13	**14**	AO12	ADC-B1, A10, C10, PGA7_IN
ADC-A2, B6, PGA1_IN	AO11	**15**	**16**		
ADC-A3	AO9	**17**	**18**	AO10	ADC-B2, C6, PGA3_IN
		19	**20**	AO8	ADC-B3, VDAC
ADC-A4, B8, PGA2_IN	AO7	**21**	**22**		
ADC-A5	AO5	**23**	**24**	AO6	ADC-B4, C8, C3, PGA4_IN
ADC-A6, PGA5_IN	AO3	**25**	**26**	AO4	ADC-C0
ADC-A9	AO1	**27**	**28**	AO2	ADC-C1
		29	**30**	AO0	ADC-C2
	NC	**31...48**		NC	
PWM1A	DI0	**49**	**50**	DI4	PWM3A
PWM1B	DI1	**51**	**52**	DI5	PWM3B
PWM2A	DI2	**53**	**54**	DI6	PWM4A
PWM2B	DI3	**55**	**56**	DI7	PWM4B
PWM7A	DI8	**57**	**58**	DI12	PWM5A, TZ1
PWM7B	DI9	**59**	**60**	DI13	PWM6A, TZ2
PWM8A	DI10	**61**	**62**	DO11	PWMA, TZ3
PWM8B	DI11	**63**	**64**	DO12	PWMB, TZ4

Function	RT Box	180-pin		RT Box	Function
		65	**66**		
		67	**68**	DO13	QEP1A
		69	**70**	DO14	QEP1B
		71	**72**	DO27	QEP1S
		73	**74**	DO26	QEP1I
eCAP, SPISIMO	DO25	**75**	**76**		
eCAP, SPISOMI	DO24	**77**	**78**		
eCAP, SPICLK	DO23	**79**	**80**		CANRX
eCAP, SPISTE	DO22	**81**	**82**		CANTX
		83	**84**		
		85	**86**		
		87	**88**	DI14	GPIO
GPIO	DO21	**89**	**90**	DI15	GPIO
GPIO	DO20	**91**	**92**		
		93	**94**		
		95	**96**		
		97	**98**		
		99	**100**	DO19	QEP2A
		101	**102**	DO18	QEP2B
		103	**104**	DO17	QEPS
		105	**106**	DO16	QEPI
	NC	**107 . . . 118**		NC	
		119	**120**	DO15	XRSn
	NC	**121 . . . 180**		NC	

Table 4.2: TI F280049M controlCARD pin map

electrical engineering software

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