



Embedded Code Generation *Tutorial*

Code Generation Workflow using PLECS STM32 TSP

Tutorial Version 1.0

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Introduction

In this tutorial you will continue to learn how to use STM32 microcontrollers (MCUs) with the PLECS Coder and the STM32 Target Support Package.

Before you begin

- Make sure you're familiar with the basic concepts introduced in the tutorials titled, "Introduction to PLECS STM32 Code Generation," and "Trigger Configuration using PLECS STM32 TSP". This is an advanced tutorial.
- We are going to continue to work with the STM32 NUCLEO-G474RE board [1]

Optionally, the following items are used in Exercise 2.1

- The RT Box Target Support Library: Follow the step-by-step instructions on configuring PLECS and the RT Box, as shown in the Quick Start guide of the RT Box User Manual [2]
- One PLECS RT Box 1
- One RT Box LaunchPad-Nucleo Interface Board [3], referred to as "Interface board," hereafter

If you don't have an RT Box, you could potentially use a second STM32 NUCLEO-G474RE board [1] to see how the controller works in real time, as shown in Exercise 2.2.



Note: Note that an RT Box is not necessary when running RT Box simulations offline (in PLECS), but you need to install the RT Box Target Support Library.

Exercise 1 Code Generation Workflow

In PLECS there is no need to create multiple model files for offline and real time simulations. During an offline simulation, the STM32 Target library blocks behave as regular PLECS blocks (from the PLECS schematic, right-click on any block and browse to **Subsystem + Look under mask** to explore the offline "Schematic" implementation). Therefore, the same PLECS model can be used for both offline and real time simulations.

In this exercise, let's look at the PLECS code generation workflow using a buck converter with a closed-loop controller.

Task 1.1 Open and Explore a Pre-built Buck Converter PLECS Model



Your Task: Locate and open the PLECS model `stm32_codegen_workflow_buck.plecs` from the reference files. This model is a of a buck converter with pre-built voltage and current control loops, as shown in Figures 1 and 2. Explore the model and start the simulation (**Ctrl + T**). Open the scope to observe the simulation results.



Note: This model contains model initialization commands that are accessible from the menu **Simulation + Simulation Parameters... + Initializations**.

This same Controller subsystem can be converted into a model that can be built on a STM32 MCU. This can be easily done by adding the required blocks from the STM32 Target library to the Controller subsystem.

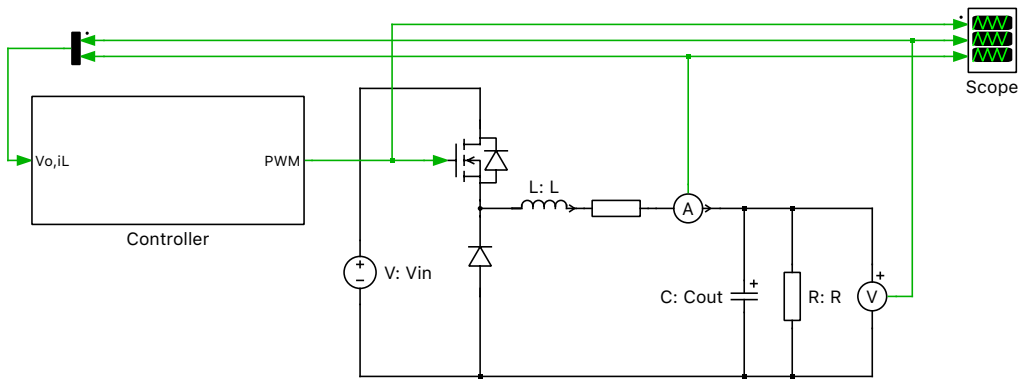


Figure 1: Top-level schematic of the buck converter circuit and the controller subsystem

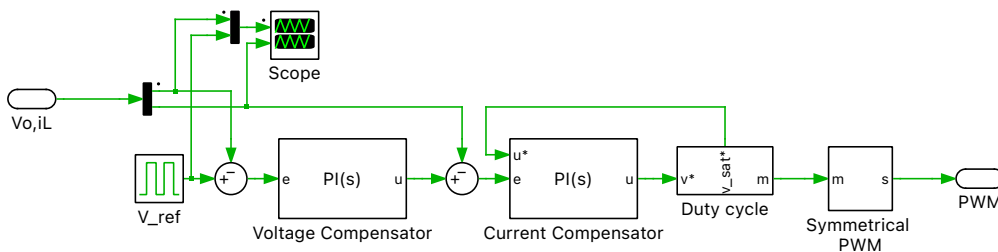


Figure 2: Controller of the buck converter circuit

Task 1.2 Modify the PLECS Model



Your Task:

- 1 From the main schematic, right-click on the “Controller” subsystem and select **Subsystem + Execution settings...**. In the configuration window select the check box **Enable code generation** and **Apply** the changes. This allows for just the controller subsystem to be built on the target device, without having to build the whole PLECS model.
- 2 Within the “Controller” subsystem, replace the "Vo, iL" signal inport block with an Analog In (Triggered) block from the **STM32 Target** library, as shown in Fig. 3, to bring the measurements of the output voltage and inductor current to the model environment.
- 3 The gate signals can be generated by a PWM block. The input to this block is a duty cycle in the range of [0, 1]. Therefore, delete the the "Symmetrical PWM" and "PWM" signal output blocks, and replace them with the PWM block from the **STM32 Target** library.
- 4 PWM block parameters:
 - Configure the **TIM Unit** as TIM8 and **Carrier frequency** appropriately from the **Main** tab of the PWM block parameter window.
 - Each TIM unit can independently generate a single PWM output or a complementary PWM pair on up to three PWM channels. From the **Channel 3** tab, choose the **Mode** as Single output, and set the **Port** as B, and the **Pin** as 9. Disable all other channels.
- 5 Analog In (Triggered) block parameters:
 - Since there are two analog inputs, the ADC block parameters can be vectorized. Choose the **ADC unit** as ADC2, and set the **Analog input channel** as [2, 17].
 - Since the STM32 MCU can only transmit or receive values between 0 to 3.3 V, the ADC input



6 Trigger configuration:

- 7** Finally, include a circuit to blink an LED as discussed in the “Introduction to PLECS STM32 Code Generation” tutorial and shown in Fig. 3.



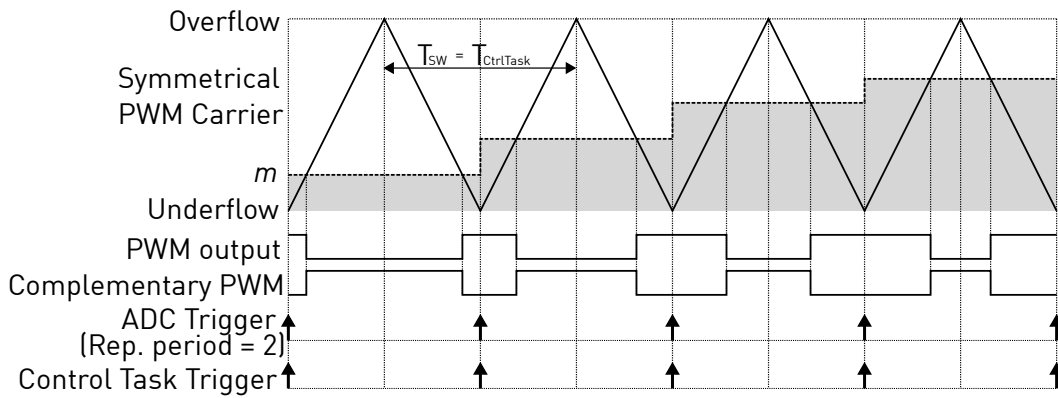


Figure 5: PWM carrier, ADC & Control Task Trigger schemes

Task 1.3 Configure the Coder Options, Parameter Inlining and External Mode



Your Task: In the **Coder Options** window, choose “Controller” under the **System** list on the left. In the **Scheduling** tab, set the **Discretization step size** to $1/f$ (f is the switching frequency). To make the output voltage reference tunable in real time, drag and drop the “V_ref” block into the **Exceptions** list window of the **Parameter Inlining** tab. In the **Target** tab, configure the code generation parameters for an STM32 G474RE, as explained in the “Introduction to PLECS STM32 Code Generation” tutorial. Next, from the **External Mode** sub-tab choose the communication option as JTAG and set the **Target buffer size** to 10000 [4].



At this stage, your model should be the same as the reference `stm32_codegen_workflow_1.plecs`. The Controller subsystem can now be directly built onto an STM32 MCU. Run the simulation of-line in PLECS and observe the simulation results.

Exercise 2 Real Time Example with a Plant

Prior to controlling a real power stage with the programmed MCU, the behavior of an embedded controller can be first validated using a Hardware-in-the-loop (HIL) simulation. PLECS RT Box can be used to perform a HIL simulation. If you don’t have a PLECS RT Box available to you, a second STM32 MCU can be used as a “Plant”, as explained in Exercise 2.2.

Exercise 2.1 HIL Simulation using a PLECS RT Box



Your Task: In this exercise let’s deploy the Controller subsystem onto an STM32 MCU, and verify its performance in real time by exchanging analog and digital signals with the PLECS RT Box.

- 1 Locate and open the PLECS model `stm32_codegen_workflow_plant.plecs` from the reference files. This model contains a “Plant_RT Box” subsystem of a pre-built buck converter. The buck converter from Exercise 1 has been modified to exchange analog and digital signals with the PLECS RT Box, by adding components from the PLECS RT Box library.
- 2 In the same PLECS model file from the end of Task 1.3, replace the existing circuit of the buck converter with the “Plant_RT Box” subsystem, as shown in Fig. 7.



Figure 6: RT Box and STM32 Nucleo board via the Interface board

3 Make the required hardware connections:

- Connect the STM32 G474RE NUCLEO board (the light blue board) to the RT Box via an RT Box NUCLEO Interface board (the green board), as shown in Fig. 6.
- On the STM32 G474RE board, set the jumper JP8 on to position 2-3, to select an external ADC reference (V_{ref+}) of 3.3 V.

4 Build the “Plant” on the RT Box: From the **System** tab of the **Coder + Coder options...** window, select “Plant”. Click the **Target** tab and select a target device. Then click **Build** to deploy the model to the target RT Box. If programmed correctly, the LED corresponding to “DO-31” of the RT Box NUCLEO Interface board should blink.

5 Flash the “Controller” on the STM32 board and connect to External Mode: From the **Coder Options** window, **Build** the “Controller” subsystem onto the STM32 MCU. Once the generated code is running on the STM32 target, **Connect** to the External Mode to update the scope of the Controller subsystem, as instructed in the “Introduction to PLECS STM32 Code Generation” tutorial. You should see the step response of the output voltage and inductor current in real time, as shown in Fig. 8.

6 Connect to External Mode of the RT Box: From the **System** tab of the **Coder + Coder options...** window, select “Plant”. Then, from the **External Mode** tab of the **Coder options...** window, **Connect** to the RT Box and **Activate autotriggering** to observe the RT Box results in the scope of the Plant subsystem in real time.



At this stage, your model should be the same as the reference `stm32_codegen_workflow_2.plecs`.

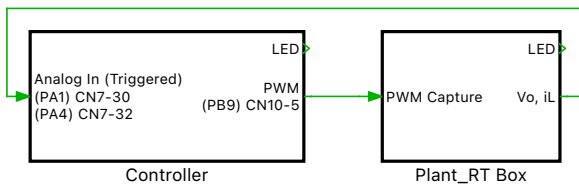


Figure 7: Top level schematic of the plant and the controller subsystems

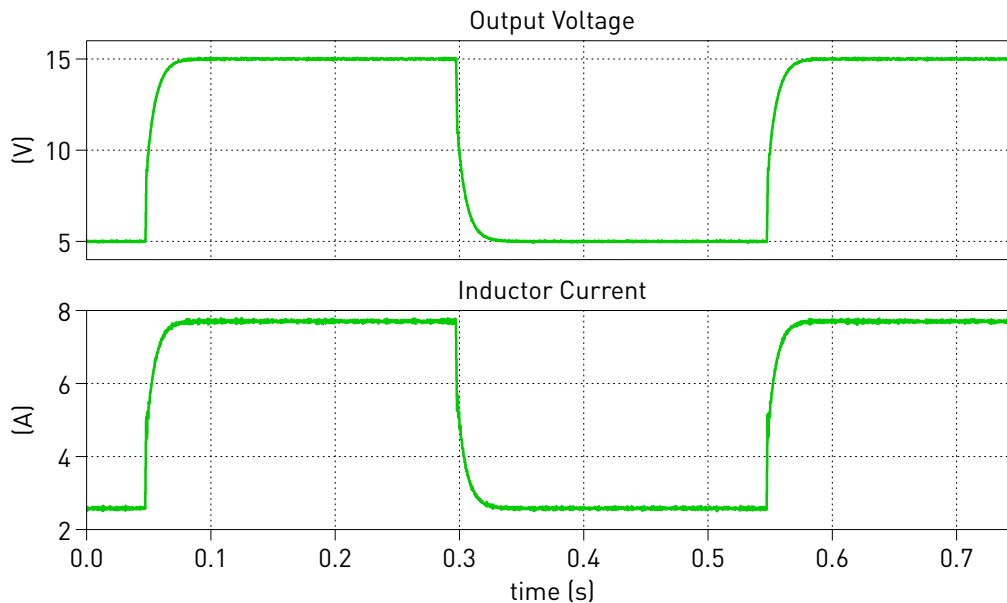


Figure 8: Output voltage and inductor current measurements in real time using the STM32 MCU

Exercise 2.2 HIL Simulation using a second STM32 MCU

If you don't have a PLECS RT Box available to you, a second STM32 MCU can be used as a "Plant". This MCU will be referred to as "Plant MCU" hereafter.



Your Task: In this exercise, let's deploy the Controller subsystem onto an STM32 MCU, referred to as "Controller MCU" hereafter, and verify its performance in real time by exchanging analog and digital signals with the Plant MCU.

- 1 Locate and open the PLECS model `stm32_codegen_workflow_plant.plecs` from the reference files. This model contains a "Plant_MCU" subsystem with an averaged model of the buck converter from Exercise 1. Components from STM32 library have also been included to exchange analog and digital signals with a second STM32 MCU.
- 2 In the same PLECS model file from the end of Task 1.3, replace the existing circuit of the buck converter with the "Plant_MCU" subsystem, as shown in Fig. 10.
- 3 Flash the Plant MCU:
 - First, connect the Plant MCU to the host computer through a USB cable, then from the **Coder Options** window, **Build** the "Plant" subsystem onto the Plant MCU.
 - If programmed correctly, the LED "LD2" on the STM32 board should blink.
- 4 Make the required hardware connections:
 - Next, disconnect the Plant MCU from the host computer, and connect the Controller MCU to the

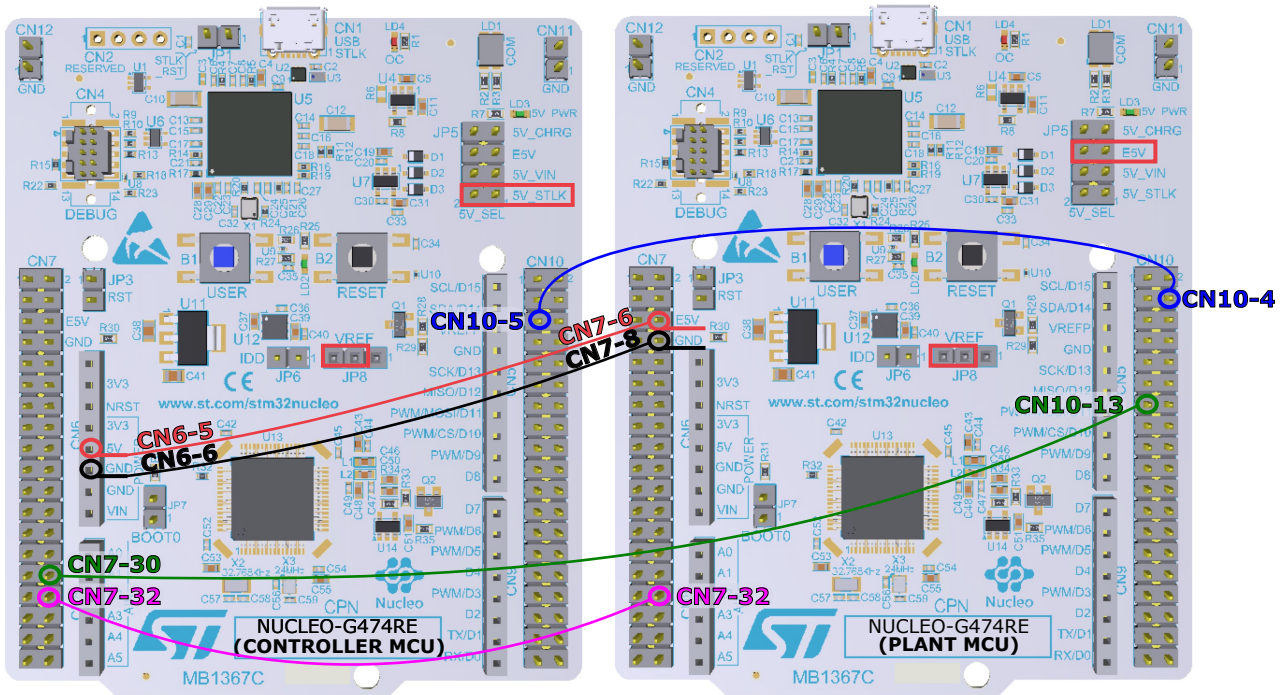


Figure 9: On the left is the Controller MCU and on the right is the Plant MCU

host computer through a USB cable. Then, connect the pins of the two MCUs according to Table 1 using jumper wires, as shown in Fig. 9.

- Flash the Controller MCU and connect to the External Mode: From the **Coder Options** window, **Build** the “Controller” subsystem onto the Controller MCU. Once the generated code is running on the STM32 target, **Connect** to the External Mode to update the scopes, as instructed in the “Introduction to PLECS STM32 Code Generation” tutorial. You should see the step response of the output voltage and inductor current in real time, as shown in Fig. 8

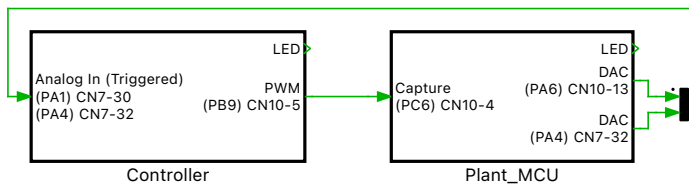


Figure 10: Top level schematic of the plant and the controller subsystems

At this stage, your model should be the same as the reference `stm32_codegen_workflow_3.plecs`.



Note: To update a scope at a desired step response, from the **External Mode** tab of the **Coder Options** window set the “Trigger channel”, “Sensitivity”, “Trigger level” and “Trigger delay” parameters appropriately. To see a larger time span, increase the “Decimation” parameter, and/or increase the “Target buffer size” from the **Target** tab + **External Mode** subtab.

Controller MCU	Plant MCU	Function
Set jumper JP8 to 2-3	Set jumper JP8 to 2-3	Select an external ADC reference (Vref+) of 3.3 V
	Set jumper JP5 to “E5V”	5 V supplied by the Controller MCU
Set jumper JP5 to “5V_STLK”		5 V supplied by the host PC via the USB port
CN6-5, 5 V	CN7-6, labeled E5V	5 V output
CN6-6, GND	CN7-8, labeled GND	GND
CN7-30 (PA1)	CN10-13 (PA6)	Sensed output voltage
CN7-32 (PA4)	CN7-32 (PA4)	Sensed inductor current
CN10-5 (PB9)	CN10-4 (PC6)	Generated PWM signals

Table 1: Connect the pins of the two MCUs using jumper wires

References

- [1] STMicroelectronics, NUCLEO-G474RE: <https://www.st.com/en/evaluation-tools/nucleo-g474re.html>
- [2] *RT Box User Manual*, Plexim GmbH, Online: <https://www.plexim.com/sites/default/files/rtboxmanual.pdf>
- [3] *RT Box LaunchPad-Nucleo Interface Board*, Plexim GmbH, Online: https://www.plexim.com/sites/default/files/launchpadnucleointerface_manual.pdf
- [4] STM32 Target Support User Manual: <https://plexim.com/sites/default/files/stm32manual.pdf>
- [5] STM32G4 Nucleo-64 boards (MB1367) User Manual: https://www.st.com/resource/en/user_manual/um2505-stm32g4-nucleo64-boards-mb1367-stmicroelectronics.pdf

Revision History:

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How to Contact Plexim:

☎	+41 44 533 51 00	Phone
	+41 44 533 51 01	Fax
✉	Plexim GmbH Technoparkstrasse 1 8005 Zurich Switzerland	Mail
@	info@plexim.com	Email
	http://www.plexim.com	Web

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