Pixhawk Pilot Support Package (PSP) User Guide

Version 2.1

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MathWorks

Pilot Engineering Group

1 Product Description

The Pixhawk Pilot Support Package (PSP) feature allows users to use Simulink models to generate code targeted for the Pixhawk FMUv2 (Flight Management Unit). The PSP provides the ability to incorporate the Pixhawk Toolchain for complete firmware build and download to the px4fmu Version 2 unit. It does not provide exact function behavior blocks for other services running on the Pixhawk (e.g. Attitude Estimation using EFK or SOF). The user will need to use blocks from the base Simulink or possibly the Aerospace blockset for simulating their flight control system model. Once the flight control system (FCS) has been successfully modeled, simulated and verified, the Pixhawk Target can be used to deploy the control system onto the PX4 hardware.

The Pixhawk Simulink blocks allows users to access sensor data and other calculations available to be used in their Simulink model at runtime. Generated code can then be compiled and executed on the Pixhawk platform controlling a multi-rotor airframe.

1.1 Basic Software Environment Description

The Pixhawk Pilot Support Package is based off of a forked version of the official Pixhawk Firmware. This forked version can be found here.
https://github.com/darenlee/PixhawkPSP_Firmware/tree/PSP_R2016AB

During the PSP installation process, a download script will automatically clone this repository. This forked version is roughly based off of the 1.3.4 tag
https://github.com/PX4/Firmware/releases/tag/v1.3.4

A NuttX application called "px4_simulink_app" is created using this PSP and code generation tools. This application follows the same code structure and format depicted here.
http://dev.px4.io/tutorial-hello-sky.html

This Pilot Support Package has been tested with the Pixhawk FMUv2 which can be configured to run different CMake configurations through the installation process. We have tested the "default" configuration and "ekf2" but we also allow you to specify your own custom CMake configuration.

Since this package is generating code for a Simulink PX4 module, our PSP adapts the Simulink code generation and compilation process to fit into the Pixhawk build environment by making use of CMake. A CMake command is executed compile the Pixhawk Firmware to invoke compilation.

Ideally, one should be familiar with the embedded software environment of the PX4 platform prior to using this Pilot Support Package. For more information on this, refer to the later sections that go into details about the code generation process as well as the PSP installation section.

1.2 Acronyms/Definitions

Pixhawk (PX4) – the Flight Controller Unit providing various sensor value inputs and PWM outputs as well as an ARM Cortex-M4 microprocessor for flight control and management.
PSP – Pilot Support Package. MathWorks software offering customized feature development or updates that are not yet available in the officially released version of MATLAB/Simulink.
TLC – Target Language Compiler
BTI – Built Tool Integration
FMU – Flight Management Unit
PWM – Pulse Width Modulation
RC – Radio Control
Tx/Rx – Transmitter/Receiver
ESC – Electronic Speed Controller
NED – North-East-Down

1.3 Contact Information

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2 Document History

Date	Version	Author	Description
1 Oct 2014	1.0	SEK	Initial version.
22 April 2015	1.2	DL	updates
Nov 2015	1.3	DL	updates
Nov 2015	1.3.1	DL	update CSC fix
Aug 2016	1.3.4	DL	Beta updates
Dec 2016	2.0	SEK	Updates to support package blocks, etc…
Feb 2017	2.1	DL	Bug fixes, R2016b release

3 System Requirements

3.1 MATLAB/Simulink Toolboxes

To generate code from a Simulink model, the following products are needed:
- MATLAB R2016a / R2016b
- Simulink
- Simulink Coder
- Embedded Coder
- Aerospace Blockset is needed for some of the example models

3.2 Required (Windows)

- PX4 Toolchain Installer v1.4 for Windows

To successfully work with the PX4 and deploy the generated firmware to the Pixhawk this additional software is needed

- Pixhawk Toolchain
- CMake (tested with CMake 3.6.0)
- QGroundControl (Optional : Tested on 2.7.1 and 2.8.0)

NOTE (Windows): The Pixhawk Toolchain must be fully installed prior to running the Pixhawk PSP. Please ensure that no Firmware directory exists already.

3.3 Required (Linux)

- Git
- arm-none-eabi-gcc (GNU Tools for ARM Embedded Processors) 4.8.4
- Python 2.7.6 / 2.7.12 (tested on both)
    - Additional Python Package: `sudo apt-get install python python-tk`
- CMake (tested with 3.5.1)
- Other software (see installation details **Section 4.2**)

NOTE (Linux): Compilation of the firmware can actually fail on newer versions of the arm-none-eabi-gcc. All tests with the Pixhawk PSP were conducted on version arm-gcc 4.8.4. Similarly, the Simulink code generation process can fail too without obtaining the latest version of Python.

For more detail on how to use QGroundControl with the PixhawkPSP please refer to 5.4 Using QGroundControl with Pixhawk PSP............**Error! Bookmark not defined.**

4 Installation

This PSP is supported on Win64 and Linux platforms.

Platform	**Installation Program**
Windows-7 64	Pixhawk-<MATLAB_VERSION>_v1.x_win64-Install.exe
Linux 64	Pixhawk-<MATLAB_VERSION>_v1.x_glnxa64-Install

It is IMPORTANT for you to install the PX4 Toolchain software on your machine FIRST. The Pixhawk PSP installer needs to know the Root directory of the Pixhawk Toolchain since it modifies some of its files. The PSP installer is responsible for modifying the tool chain files to fetch files from a forked PX4 repository containing firmware source files. This forked repository contains modifications that are needed to interface with the PSP.

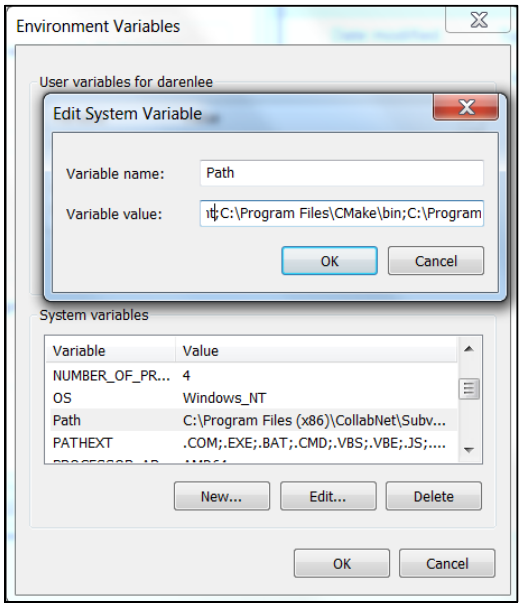
4.1 Pixhawk Toolchain Install (Windows)

You should download and install the Pixhawk Toolchain from http://www.pixhawk.org/ under the Downloads section.
This PSP was tested with version 1.4 found here:
http://www.inf.ethz.ch/personal/lomeier/downloads/px4_toolchain_installer_v14_win.exe
For the Pixhawk Toolchain installation:

- Launch the installation program for your operating system.
- Read and accept the licensing agreement
- Specify the location for the Toolchain installation. It is recommended that you choose the default of "**c:\px4**"

You may also need to install a USB driver if you are using Windows. See the Pixhawk Downloads page for more information HERE.

Before proceeding to the next steps for firmware building please also download CMake.
https://CMake.org/download/
Version 3.6.0 is recommended as this was used to test with the PSP. You will also need to add CMake to your Windows path as shown below:


Environment Variables

User variables for darenlee

Edit System Variable

Variable name: Path

Variable value: ıt;C:\Program Files\CMake\bin;C:\Program

System variables

Variable	Value
NUMBER_OF_PR...	4
OS	Windows_NT
Path	C:\Program Files (x86)\CollabNet\Subv...
PATHEXT	.COM;.EXE;.BAT;.CMD;.VBS;.VBE;.JS;....

After downloading and installing the Pixhawk Toolchain you will want to install the Pixhawk PSP described below.

4.2 Pixhawk Toolchain Install (Linux)

As opposed to the Windows version of the installation, the embedded GCC compiler is assumed to be already installed. There is no pre-packaged "toolchain" to download like the Windows version. Assuming that the correct Linux packages are installed (see software requirements above) the only step that is needed here is to clone the Git repository containing the correct firmware version and then build it. The installer will ask you to select a directory to specify where this firmware will be placed.

Special Notes:

- As mentioned in the beginning of this document, it is highly suggested to use the GCC-ARM version 4.8 compiler. The commands to do this are listed below.
- In Ubuntu, you may will need write access sudo permissions for your MATLAB installer. This means the ability to write files/folders in the MATLAB directory. You may need to enable write permissions or else the installation can fail. To see an example of how one can enable write permissions please see the notes here: http://superuser.com/questions/19318/how-can-i-give-write-access-of-a-folder-to-all-users-in-linux
  Enable this option on the location of where you wish to install the PSP folder (ie: `usr/local/MATLAB/<MATLAB_RELASE>/toolbox/psp`)
- You might need to also install a python package for pop-up window UI support. This can be obtained via:
  `sudo apt-get install python python-tk`

Below are a set of commands that fetches all the correct packages to support version GCC-ARM 4.8 as well as other utilities (Cmake, Python, etc). This has been tested on Ubuntu. You may need to modify these commands depending on what existing packages you may or may not have. These instructions come from these pages here:
http://dev.px4.io/starting-installing-linux.html
http://dev.px4.io/starting-installing-linux-boutique.html

```
#recommended from install guide
sudo usermod -a -G dialout $USER

#install CMakeand other px4 tools
sudo add-apt-repository ppa:george-edison55/CMake-3.x -y
sudo apt-get update
sudo apt-get install python-argparse git-core wget zip \
    python-empy qtcreator CMake build-essential genromfs -y
# simulation tools
sudo apt-get install ant protobuf-compiler libeigen3-dev libopencv-dev openjdk-8-jdk
openjdk-8-jre clang-3.5 lldb-3.5 -y


#recommended from install guide
sudo apt-get remove modemmanager

sudo apt-get update

#Get python
sudo apt-get install python-serial openocd \
    flex bison libncurses5-dev autoconf texinfo build-essential \
    libftdi-dev libtool zlib1g-dev

#Get GCC ARM Compiler version 4.8
pushd .
cd ~
wget https://launchpadlibrarian.net/186124160/gcc-arm-none-eabi-4_8-2014q3-20140805-
linux.tar.bz2
tar -jxf gcc-arm-none-eabi-4_8-2014q3-20140805-linux.tar.bz2
```

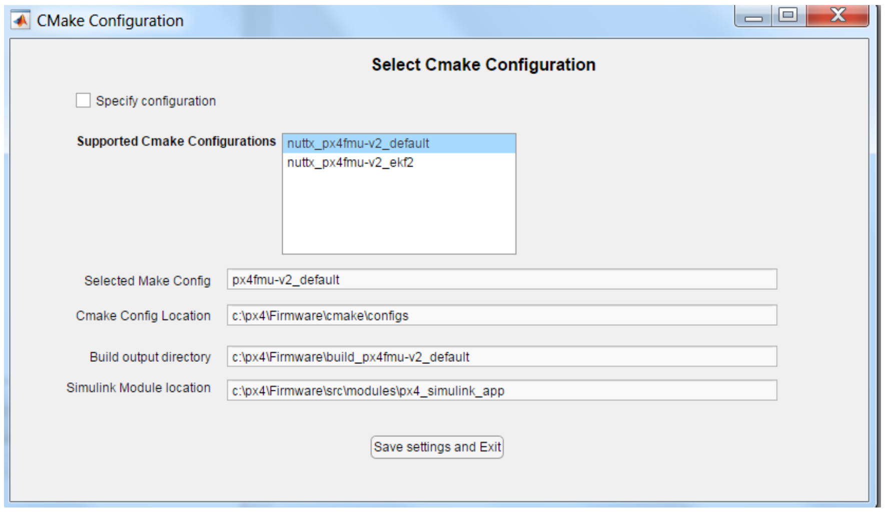
```
exportline="export PATH=$HOME/gcc-arm-none-eabi-4_8-2014q3/bin:\$PATH"
if grep -Fxq "$exportline" ~/.profile; then echo nothing to do ; else echo $exportline
>> ~/.profile; fi
. ~/.profile
Popd

#Get 32-bit libraries
sudo apt-get install libc6:i386 libgcc1:i386 gcc-4.8-base:i386 libstdc++5:i386
libstdc++6:i386
```

4.3 Pixhawk Toolchain MathWorks PSP Install (Linux/Windows)

For the Pixhawk PSP installation:

1) Launch the installation program (e.g. pixhawk-R2015b-v1.3.1_win64-Install.exe)
2) Read and accept the licensing agreement
3) Specify the MATLAB Root directory of your R2016b/R2016a installation. For example c:\MATLAB\R2016a (Windows) or /usr/local/MATLAB/R2016a/ (Linux)
4) Specify the Pixhawk Toolchain Root directory (e.g. c:\px4). On Windows this is where your PX4 Toolchain is installed. On Linux this directory is a folder location that you specify where the PX4 firmware will be placed.
5) The Installer will verify the MATLAB Version and the Pixhawk Toolchain directory.
6) It will launch MATLAB in the background and run a script to finish the installation (this will take some time, please wait for the ***Next>*** button to show in the installer dialog).

7) You will then be prompted to select a particular Firmware configuration.


CMake Configuration

Select Cmake Configuration

☐ Specify configuration

Supported Cmake Configurations: nuttx_px4fmu-v2_default, nuttx_px4fmu-v2_ekf2

Selected Make Config: px4fmu-v2_default

Cmake Config Location: c:\px4\Firmware\cmake\configs

Build output directory: c:\px4\Firmware\build_px4fmu-v2_default

Simulink Module location: c:\px4\Firmware\src\modules\px4_simulink_app

As mentioned in an earlier section, this screen allows you to select which CMake configuration you want to use in the build process. Default and EKF2 are the ones that come with the Pixhawk Firmware but a user can also specify their own custom configuration by using the "Specify configuration" tick-box. You are also free to edit and customize these configurations as needed which you can find within '<px4_directory>\Firmware\CMake\configs'.

NOTES: The next steps after this install process will require you to compile the firmware. If you compiled a firmware configuration and want to switch to a different configuration, you may need to perform a 'make clean' on the build output directory or delete it. The Build output directory is listed in the above user interface diagram. In this example it is located in 'c:\px4\Firmware\build_px4fmu-v2_default'. This is the output of compilation of the firmware.

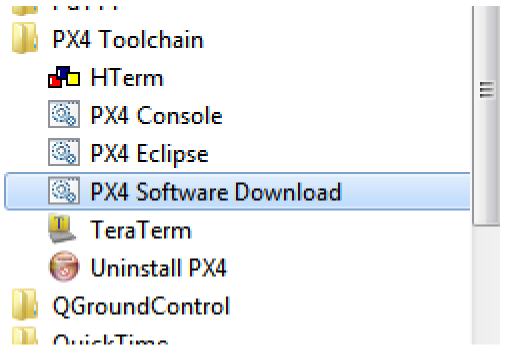
8) If the installation script fails, a MATLAB command window will show any errors that may have occurred. If this happened, please copy and paste this window content and email it back to the Pilot Team for help.

9) After installation on a Windows-7 machine, you may get a pop-up dialog asking if the software installed correctly. Simply answer 'Yes' to this dialog. This is just an artifact of using an installer that works on a Win32 machine as well.

The PSP will install itself in the <matlabroot>\toolbox\psp\pixhawk directory. The Simulink Pixhawk Blockset and MATLAB Pixhawk Toolchain BTI functions are now installed and ready to use. You should copy the example models out of the <matlabroot>\toolbox\psp\pixhawk\examples directory to your own working directory.

4.4 Toolchain Firmware Download and Compilation (Windows)

One last step before being able to use the PSP is to perform a Pixhawk software update and pre-compiling source firmware source files. This is done by choosing the "PX4 Software Download" option in the PX4 Toolchain application Windows folder menu:



This download script has been modified in the PSP installer to download from a Github repository containing a forked stable copy of the PX4 FMU firmware. This stable-release will be revisited from time to time by MathWorks Pilot Engineering to ensure appropriate updates are applied from the official firmware when necessary (ie: bug fixes, feature updates). Please contact us regarding any discrepancies between the forked and the official repo. In this version of the PSP, we are using work based off of the '1.3.4 tag' release.

IMPORTANT: Please ensure that the instructions followed so far are with a fresh install of the PX4 tool chain. Sometimes git-related errors can occur if the Firmware directory is already populated with files and will fail to clone files from the repository.

After you do an initial software download you need to build the necessary target files. This can take up to half-hour or longer. This should only need to be done once.

1) Choose the "PX4 Console" option from the Windows PX4 Toolchain start menu.
2) Once the MINGW32 window appears, change directory to Firmware. e.g. cd Firmware
3) Build all the modules: make <CMake_CONFIG>
   Where <CMake_CONFIG> will depend on which configuration you selected during the PSP installation. For instance, if you plan to use the ekf2, you would use
   ```
   make px4fmu-v2_ekf2
   ```
   Or the default configuration
   ```
   make px4fmu-v2_default
   ```

This process can take up to 20-30 minutes. Wait until the Firmware has been built. On some Windows machines, it has been observed that there is a chance that this build can fail due to parallel build issues. You may see error messages along the lines of "unable to rename file" or some permission settings. If it gets stuck in this state, exit out by using CTRL+C and run the same make command as in step 3). The build procedure will resume where it left off so it will not perform a "make clean" and start from scratch.
NOTE: Disabling virus scanner has been observed to also dramatically decreased the chances of this happening. Please temporarily disable virus scanning utilities during this process

4.5 Firmware Download and Compilation (Linux)

After downloading the correct packages and installing the Pixhawk PSP, the next steps are:

1) Depending on which folder you selected for specifying the Px4 directory in the installation process you will want to navigate to that directory and run the shell script inside. This script will grab a forked version of the PX4 firmware.

<selected directory during PSP install>/px4/toolchain/msys/1.0/px4_download_software.sh

Where <selected directory>/ is the directory you specified in **step 4)** for section ***4.3***

This should begin to clone a repository <selected directory>/Firmware

It is important to note that the /Firmware folder should NOT exist prior to running this shell script or the Git clone can fail to retrieve all the files.

2) Once downloading has been completed

Build all the modules: make <CMake_CONFIG>
Where <CMake_CONFIG> will depend on which configuration you selected during the PSP installation. For instance, if you plan to use the ekf2, you would use
```
make px4fmu-v2_ekf2
```
Or the default configuration
```
make px4fmu-v2_default
```

5 Getting Started

5.1 Pixhawk Environment

Using the default firmware available for the Pixhawk, you should test to make sure your hardware is correctly configured and works as intended. This includes the correct motor wiring, placement of the PX4 module and any other sensors you may be using. You can use QGroundControl to download and flash the necessary firmware for this test.

You can launch a serial terminal program like TerraTerm or PuTTY and connect to the PX4 and manually run the built-in commands using the nuttx shell. NuttX is the OS that is delivered with the Pixhawk toolchain and will be used for running the code generated from your Simulink models.

You can find out which "Builtin" Apps your firmware has by typing "?" at the nuttx shell prompt "nsh>"

```
nsh> ?
help usage:  help [-v] [<cmd>]
   df kill mkrd rm unset ? echo losetup mh rmdir usleep
   cat exec ls mount set xd cd exit mb mv  sh cp free
   mkdir mw sleep cmp help mkfatfs ps test dd hexdump
```

```
      mkfifo pwd umount

    Builtin Apps:
      sercon
      serdis
      adc
      attitude_estimator_ekf
      bl_update
      blinkm
      boardinfo
      commander
      …
```

Some useful commands are:

1) esc_calib – to calibrate your ESCs through the command line interface

```
     usage:
     [-d <device>]   PWM output device (defaults to
                                        /dev/pwm_output)
     [-l <pwm>]      Low PWM value in us (default: 1000us)
     [-h <pwm>]      High PWM value in us (default: 2000us)
     [-c <channels>] Supply channels (e.g. 1234)
     [-m <chanmask>] Directly supply channel mask (e.g. 0xF)
     [-a]            Use all outputs
```

2) pwm – to test out your PWM outputs

```
usage:
pwm
arm|disarm|rate|failsafe|disarmed|min|max|test|info  ...

       arm                        Arm output
       disarm                     Disarm output

       rate ...                   Configure PWM rates
       [-g <channel group>]     Channel group that should
                                update at the alternate rate
         [-m <chanmask> ]       Directly supply channel mask
         [-a]                   Configure all outputs
         -r <alt_rate>          PWM rate (50 to 400 Hz)

       failsafe ...             Configure failsafe PWM values
       disarmed ...             Configure disarmed PWM values
       min ...                  Configure minimum PWM values
       max ...                  Configure maximum PWM values
         [-c <channels>]        Supply channels (e.g. 1234)
         [-m <chanmask> ]       Directly supply channel mask
                                 (e.g. 0xF)
         [-a]                   Configure all outputs
         -p <pwm value>         PWM value

       test ...                 Directly set PWM values
         [-c <channels>]        Supply channels (e.g. 1234)
         [-m <chanmask> ]       Directly supply channel mask
                                 (e.g. 0xF)
         [-a]                   Configure all outputs
         -p <pwm value>         PWM value

       info          Print information about the PWM device

         -v                     Print verbose information
         -d <device>            PWM output device (defaults
to /dev/pwm_output)
```

3) tests – run various built-in test on the pixhawk hardware

```
nsh> tests help
Available tests:
  led
  int
  float
  sensors
  gpio
  hrt
  ppm
  servo
  ppm_loopback
  adc
  jig_voltages
  uart_loopback
  uart_baudchange
  uart_send
  uart_console
  hott_telemetry
  tone
  sleep
  time
  perf
  all
  jig
  param
  bson
  file
  file2
  mixer
```

```
rc
conv
mount
mtd
mathlib
help
```

4) top – will list all the NuttX processes running at the time (press ‘q’ to quit)

```
Processes: 11 total, 2 running, 9 sleeping
CPU usage: 37.36% tasks, 0.48% sched, 62.16% idle
Uptime: 904.233s total, 561.039s idle

 PID COMMAND                   CPU(ms) CPU(%)
USED/STACK PRIO(BASE) STATE
   0 Idle Task                  561039 62.162     0/
0   0 (  0)  READY
   1 hpwork                      26060  2.799   748/
1992 192 (192)  w:sig
   2 lpwork                       6784  0.675   628/
1992  50 ( 50)  READY
  85 top                           116  1.158  1244/
1696 100 (100)  RUN
   7 nshterm                       121  0.000   884/
1192 100 (100)  w:sem
   9 px4io                        9444  0.965   796/
1992 240 (240)  w:sem
  26 sensors_task                38995  4.440  1364/
1992 250 (250)  w:sem
  38 px4SimTermTask                  1  0.000   524/
2040 100 (100)  w:sem
  29 attitude_estimator_ekf     191254 20.945
13004/13992 250 (250)  w:sem
  40 px4SimBaseTask              49428  5.501  1164/
2552 100 (100)  w:sem
  42 px4SimSchedTask              7819  0.868  1028/
2040 100 (100)  READY
```

5) SD card logging – useful for logging data to the SD Card

```
sdlog2: usage: sdlog2 {start|stop|status} [-r <log
rate>] [-b <buffer size>] -e -a -t -x
        -r      Log rate in Hz, 0 means unlimited rate
        -b      Log buffer size in KiB, default is 8
        -e      Enable logging by default (if not, can
be started by command)
```

```
        -a      Log only when armed (can be still
overriden by command)
        -t      Use date/time for naming log
directories and files
        -x      Extended logging
```

5.2 Firmware Startup Preparation

Executing the default firmware, there are several processes that get executed at system startup. When deploying a custom flight control system you will need to suppress the execution of these processes and instead, run the application generated by Simulink. This is done by a start-up script put on the micro-SD card used on the PX4. In this way you can control which flight control software you want to run just by changing the contents of this script.

The script's filename is **rc.txt**. It should be copied to the SD-card directory **/etc**. A script sample has been provided by the PSP installation and can be found in your Pixhawk Toolchain installation directory: **c:\px4\Firmware\etc**. By copying this file to your SD-card in the folder **/etc** the Pixhawk will execute the ***px4_simulink_app*** at system startup. This app is built into the firmware that is flashed onto your PX4 hardware at Simulink Model build time. Simply renaming this file (e.g. rc.txt to rc.txt.simulink) on the SD-card will allow boot-up of the default flight control software.

NOTE: Newer release of the Pixhawk firmware has changed how the boot-up tone is played by moving it to the 'commander' application. Because we are not using the commander application and instead running our own boot sequence from the SD card, you will not hear the boot-up sound. You can manually add a tone alarm sequence in the rc.txt file to indicate successful boot-up.

More information can be found on the Pixhawk website HERE.
www.pixhawk.org/dev/system_startup.

The Pixhawk firmware relies on a publisher-subscriber communication architecture for Inter-Process communication on the PX4. This mechanism is implemented by the uORB or micro-Object-Request-Broker application. It provides the infrastructure that allows threads and applications to share data between each other. Data is exchanged between participants in what is known as "topics". Any task can register themselves as a publisher or subscriber of a particular topic. Topic information is exchanged in defined common "C" structures.

More information on uORB can be found here:
http://pixhawk.org/firmware/apps/uorb.

In order for the firmware to properly function, the uorb task must be executed upon startup (uorb start). Many of the Simulink Blocks that generate code interacting with the PX4 hardware rely on the uORB mechanism.

The next section will talk more about how the Pixhawk Pilot Support Package creates the ***px4_simulink_app*** application from generated code.

5.3 Simulink Code Generation and Compilation

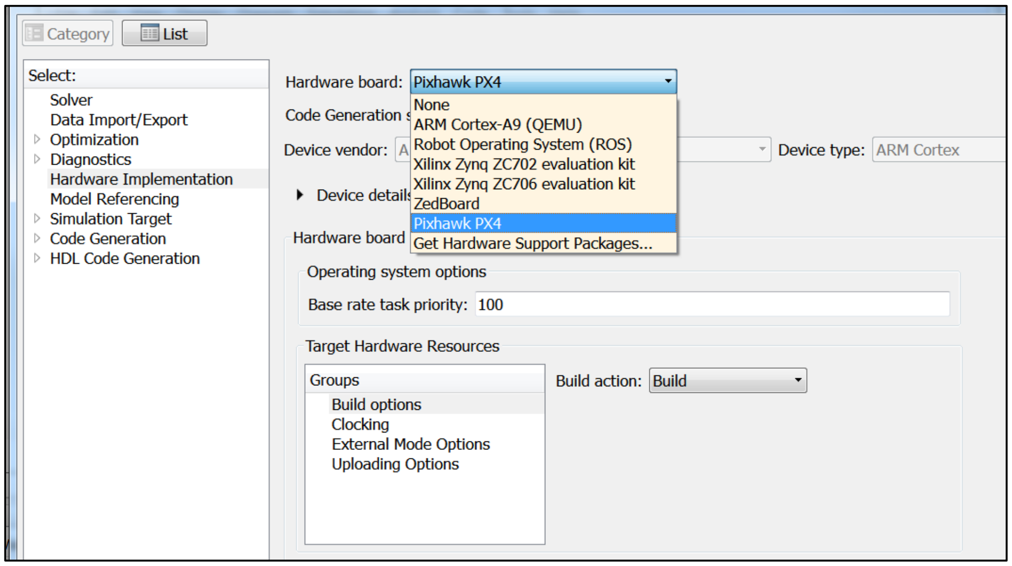
The Pixhawk target uses MathWorks Build Tool Integration (BTI) to allow MATLAB to invoke the ARM-GCC compiler to build ***px4_simulink_app***. The system target file needs to be ert.tlc (Embedded Real-Time) which is available with Embedded Coder. The user is then able to choose the hardware and toolchain. If the target hardware is set to 'Pixhawk', then the appropriate toolchain (Pixhawk) will be chosen automatically.

Newer version of the Pixhawk firmware now uses a CMake build process. We have adapted this version of the PSP to take advantage of this. This is separated into different parts:

1) Code generation of Simulink Model
2) Compilation of the Simulink model into object files. Note that if this process fails it means code that was generated was not compilable and will no longer proceed further with the CMake process below. Step 4.4 / 4.5 must be completed for this to succeed.
3) Transfer generated code to \px4\Firmware\src\modules\px4_simulink_app along with a *CMakelist.txt* which describes the necessary source files, include paths and compiler options inherited from Build Tool Integration.
4) Invoke CMake commands to build the entire firmware. Since we already built the firmware in step 4.4 and 4.5 this process should advance more quickly, the only difference being that CMake will now integrate our newly added Simulink generated code for ***px4_simulink_app***
5) The firmware image (*.px4 file) will be placed in \px4\Firmware\build_px4fmu-v2_default\
6) If the download option was also selected, user will be prompted to plug in the Pixhawk FMU to upload the firmware

5.3.1 Simulink Settings

In order for the model to target the PX4 hardware, the Simulink model must be configured to use the appropriate code generation options. Go to the Hardware Implementation page and select Pixhawk PX4 to do this. Note that in previous releases this selection was done in the Code Generation panel, but nowit has moved into Hardware Implementation. The code generation panel should automatically update the labeled items one through four (1-4) to select the correct compiler and build configurations.



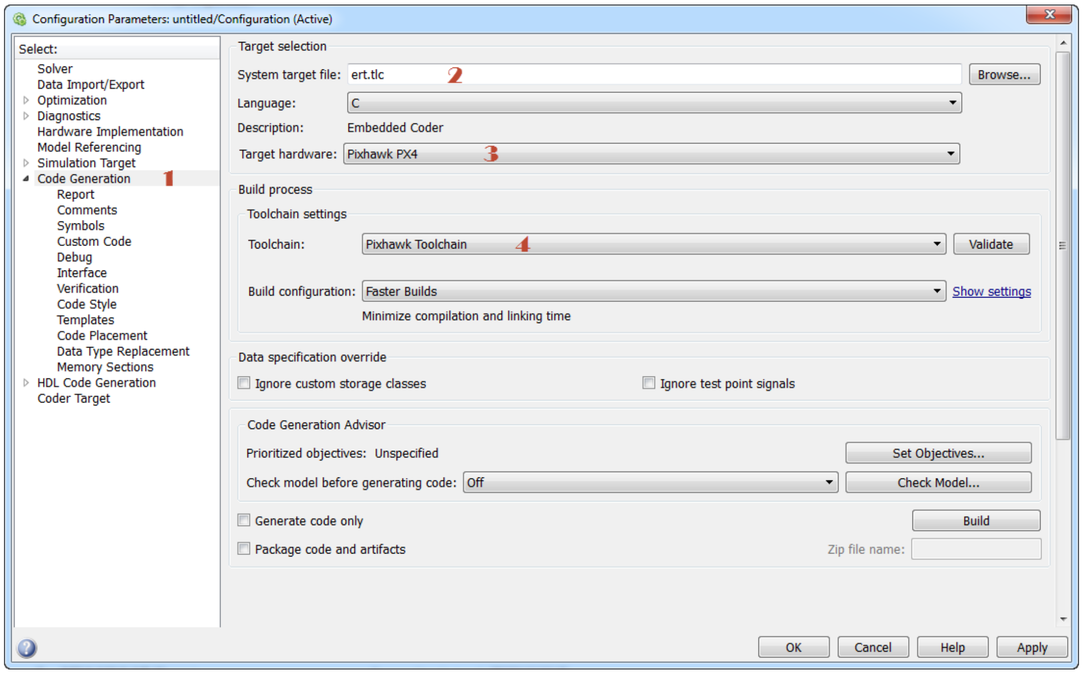
Hardware board: Pixhawk PX4

Device vendor: A

Device type: ARM Cortex

Base rate task priority: 100

Build action: Build



System target file: ert.tlc

Language: C

Description: Embedded Coder

Target hardware: Pixhawk PX4

Toolchain: Pixhawk Toolchain

Build configuration: Faster Builds

Minimize compilation and linking time

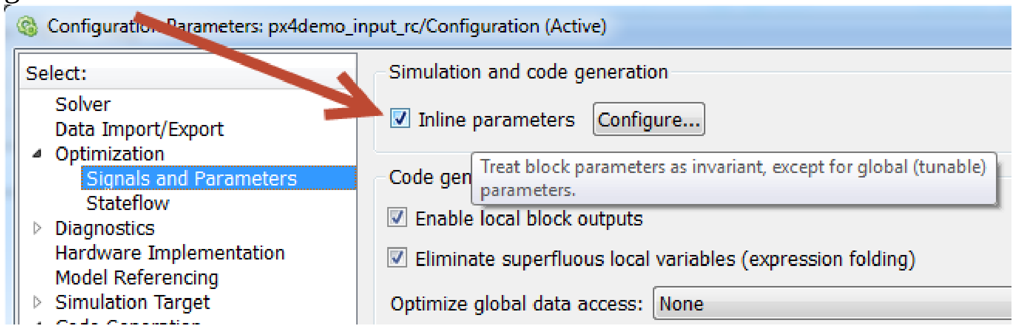
Prioritized objectives: Unspecified

Check model before generating code: Off

There are a few other settings which are required for this version of the PSP. These are:

1) Solver Type should be set for Fixed-Step (for embedded code generation)

2) Model Optimization Option **Inline Params** must be '**on**' for Pixhawk code generation



Configuration Parameters: px4demo_input_rc/Configuration (Active)

Select:
- Solver
- Data Import/Export
- Optimization
  - Signals and Parameters
  - Stateflow
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target

Simulation and code generation

☑ Inline parameters [Configure...]

Treat block parameters as invariant, except for global (tunable) parameters.

Code gen

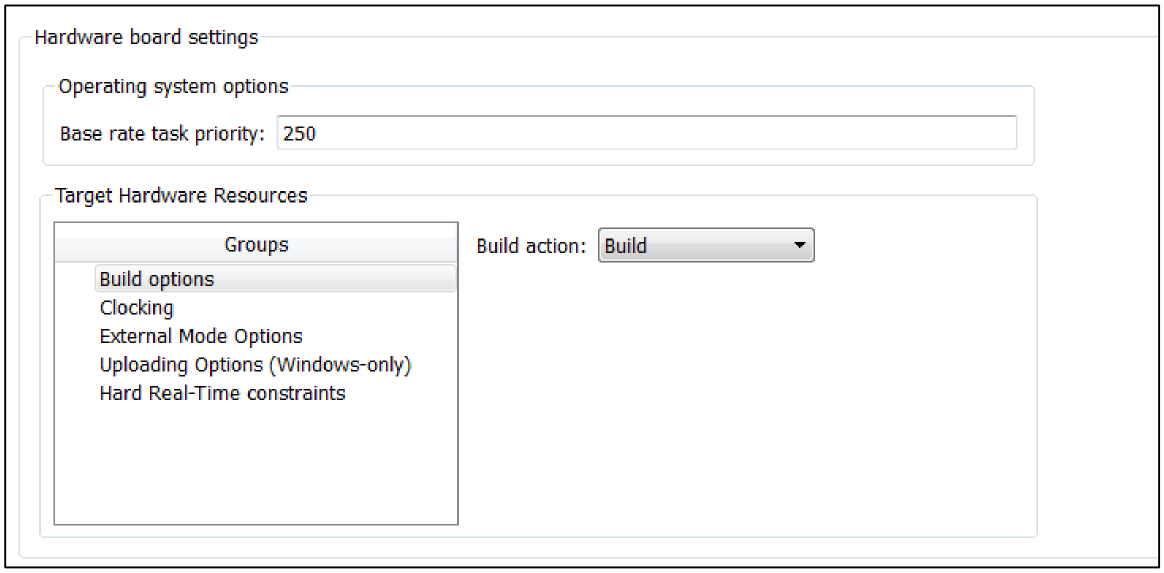
☑ Enable local block outputs

☑ Eliminate superfluous local variables (expression folding)

Optimize global data access: None

Inline parameters setting is highly recommended due to the limited resources in global memory and constraints on the Pixhawk target. Inline parameters places all model parameters (ie: gains) as "inline" constants or variables on the function stack rather. You will receive an error if this setting is not adjusted in your model.

5.3.2 Target Hardware Resource Options



Hardware board settings

Operating system options

Base rate task priority: 250

Target Hardware Resources

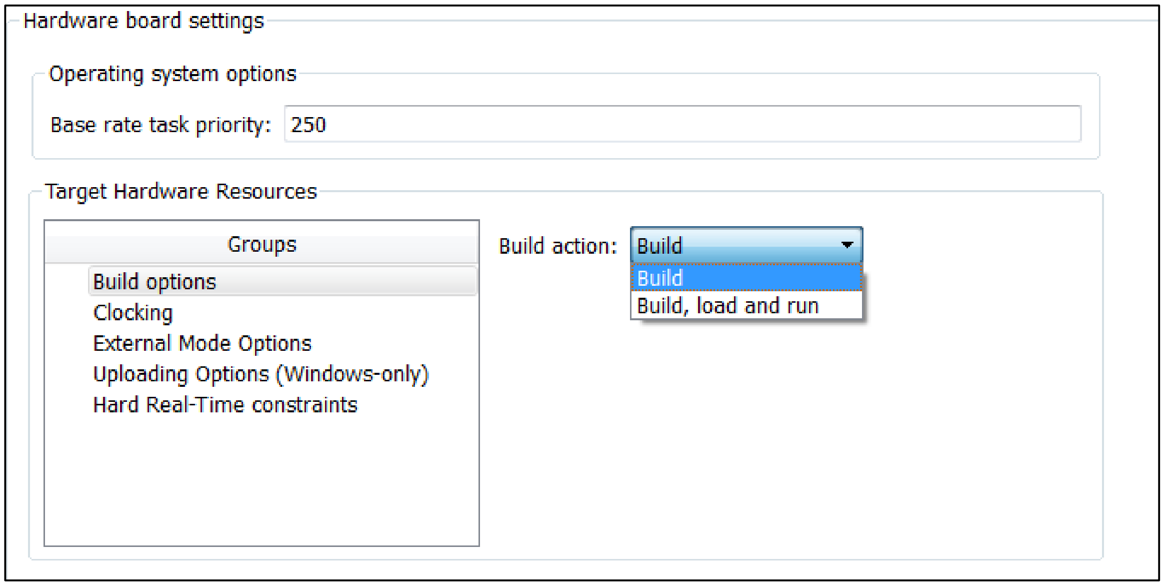
Groups
- Build options
- Clocking
- External Mode Options
- Uploading Options (Windows-only)
- Hard Real-Time constraints

Build action: Build

Under the Hardware Implementation pane there are several Target Hardware Resource Options. These are explained in detail below.

1) Base rate task priority:
   - When the generated code begins executing, several threads are spawned, one being the base-rate thread which runs at the model's base sample rate. The priority of this thread can be adjusted if needed.

2) Build Options:
   - Build – selecting this will just build the Pixhawk firmware image in `/px4/Firmware/Build/` but not actually upload it to the Pixhawk FMU
   - Build, load and run – this will build and upload to the Pixhawk FMU. How it decides to upload is dictated by the “Uploading Options”


Hardware board settings

Operating system options

Base rate task priority: 250

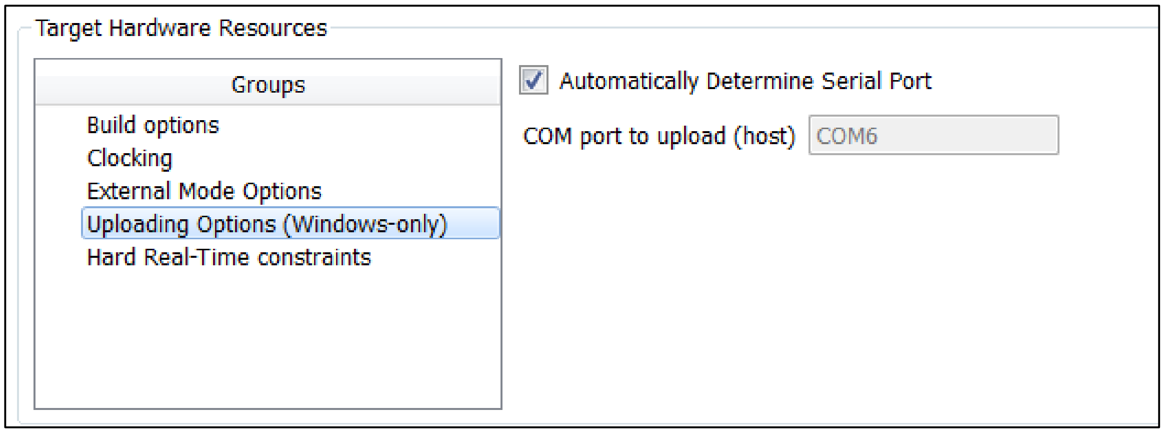
Target Hardware Resources

Build action: Build

3) Clocking: Currently not modifiable. Typically, this parameter is utilized by Processor-in-the-Loop. This feature is currently not implemented in the Pixhawk PSP

4) External Mode Options – Please see the external mode chapter documentation. These options configure which serial port settings to use to setup external mode communication.

5) Uploading Options (Windows Only) – For uploading to the Pixhawk FMU, we can either force it to connect to a port manually or we can tell MATLAB to search for the correct COM port and connect automatically. Once MATLAB determines the COM port it will continue using it without having to search again or until the COM port value changes for connecting to the PX4 FMU.


Target Hardware Resources

Groups
- Build options
- Clocking
- External Mode Options
- Uploading Options (Windows-only)
- Hard Real-Time constraints

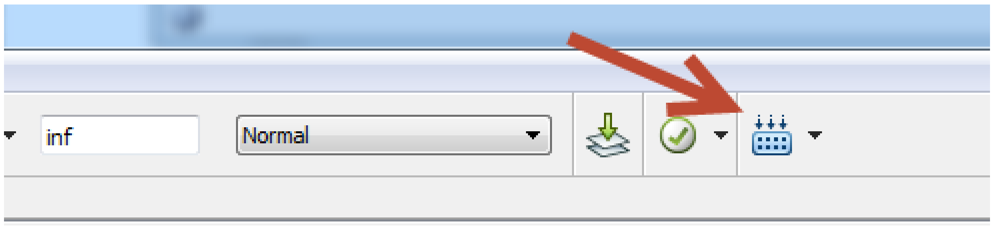
[✓] Automatically Determine Serial Port

COM port to upload (host): COM6

5.3.3 Building the Firmware

NOTE: please ensure putty or any connection to the Nutshell terminal is closed before attempting an upload!

The firmware for model can be generated by pressing the 'Build' icon on the toolbar:

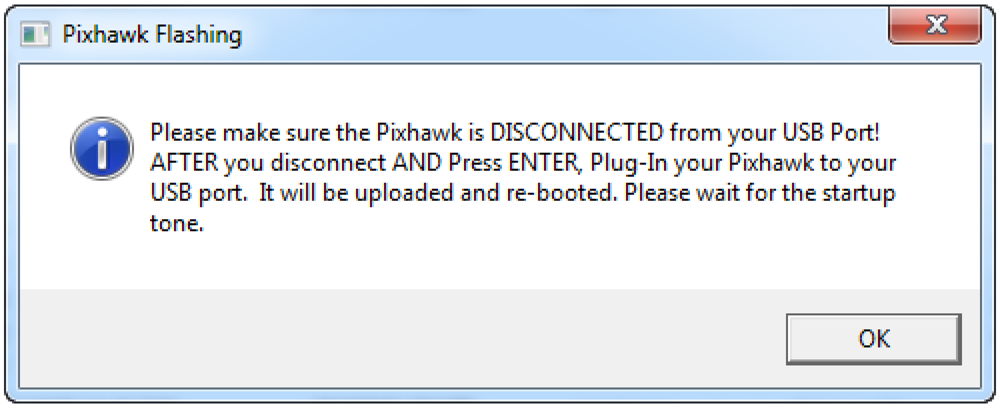


The firmware will then start to build, starting with the generated code then along with the rest of the Pixhawk Firmware using CMake.

5.3.3.1 Build, Download and Run

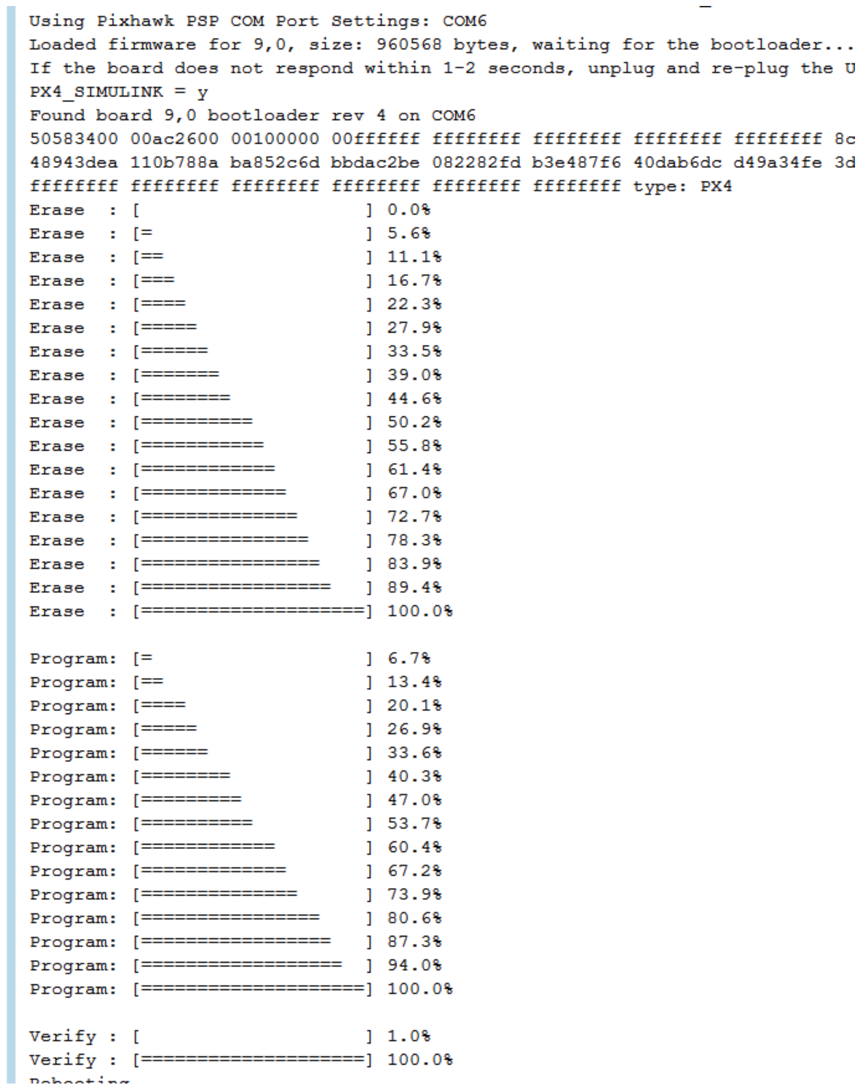
If the "Build, Download and Run" option was selected in the hardware implementation panel then the next chain of events will occur after the build process is completed:

The Diagnostic Window will show the progress of the build process. When the firmware is ready and the 'Build, Load, Run" option is selected, the user will be promoted to make sure that the pixhawk is NOT currently plugged into the computer USB port (see pop-up dialog below). Press OK on this pop-up dialog, then plug in the pixhawk into the USB port. This will start the flashing process. When the process is complete, the PX4 will re-boot and you should hear the start-up tune.



Please make sure the Pixhawk is DISCONNECTED from your USB Port! AFTER you disconnect AND Press ENTER, Plug-In your Pixhawk to your USB port. It will be uploaded and re-booted. Please wait for the startup tone.

A successful upload using the "Build, Load and Run" option looks something like this in the Simulink Diagnostic Viewer



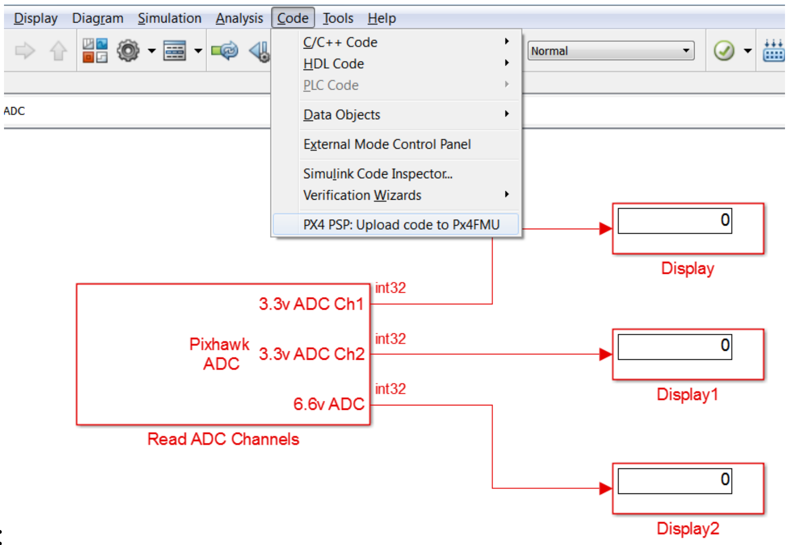
```
Using Pixhawk PSP COM Port Settings: COM6
Loaded firmware for 9,0, size: 960568 bytes, waiting for the bootloader...
If the board does not respond within 1-2 seconds, unplug and re-plug the U
PX4_SIMULINK = y
Found board 9,0 bootloader rev 4 on COM6
50583400 00ac2600 00100000 00ffffff ffffffff ffffffff ffffffff ffffffff 8c
48943dea 110b788a ba852c6d bbdac2be 082282fd b3e487f6 40dab6dc d49a34fe 3d
ffffffff ffffffff ffffffff ffffffff ffffffff ffffffff type: PX4
Erase  : [                    ] 0.0%
Erase  : [=                   ] 5.6%
Erase  : [==                  ] 11.1%
Erase  : [===                 ] 16.7%
Erase  : [====                ] 22.3%
Erase  : [=====               ] 27.9%
Erase  : [======              ] 33.5%
Erase  : [=======             ] 39.0%
Erase  : [========            ] 44.6%
Erase  : [==========          ] 50.2%
Erase  : [===========         ] 55.8%
Erase  : [============        ] 61.4%
Erase  : [=============       ] 67.0%
Erase  : [==============      ] 72.7%
Erase  : [===============     ] 78.3%
Erase  : [================    ] 83.9%
Erase  : [=================   ] 89.4%
Erase  : [====================] 100.0%

Program: [=                   ] 6.7%
Program: [==                  ] 13.4%
Program: [====                ] 20.1%
Program: [=====               ] 26.9%
Program: [======              ] 33.6%
Program: [========            ] 40.3%
Program: [=========           ] 47.0%
Program: [==========          ] 53.7%
Program: [============        ] 60.4%
Program: [=============       ] 67.2%
Program: [==============      ] 73.9%
Program: [================    ] 80.6%
Program: [=================   ] 87.3%
Program: [==================  ] 94.0%
Program: [====================] 100.0%

Verify : [                    ] 1.0%
Verify : [====================] 100.0%
Rebooting
```

5.3.3.2 Build Only

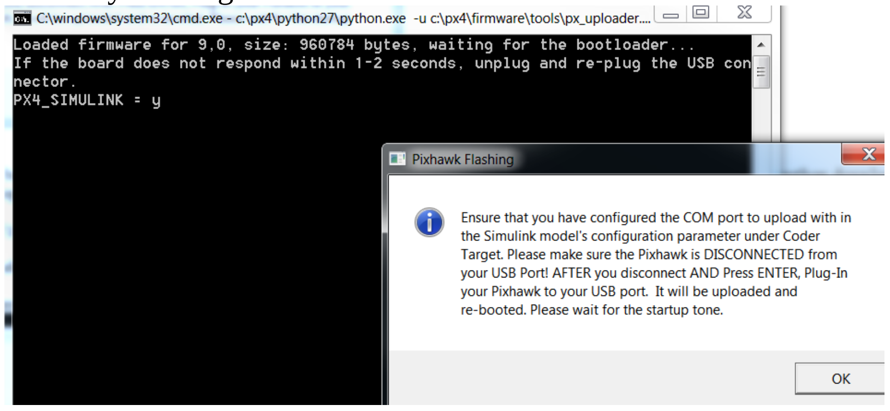
If the “Build” option was selected then Simulink will proceed no further after the firmware image has been built. The next steps are left to the user to upload the firmware manually. One can manually upload the firmware by entering a command in the Mingw environment by opening the Px4 Console and typing in:

```
python -u /c/px4/firmware/tools/px_uploader.py --port
"COM6" /c/px4/firmware/build/px4fmu-
v2_default.build/firmware.px4
```

Note that in the above example COM6 happened to be the COM port for my Windows machine which is connected to the Px4FMU. Also, pay attention to the above path as it may differ from yours depending on where the Px4 firmware was installed.
A more convenient/equivalent option is to use a built-in drop-down menu we have added in which will effectively execute this command for you without typing it



manually in MingW:


C:\windows\system32\cmd.exe - c:\px4\python27\python.exe -u c:\px4\firmware\tools\px_uploader....
Pixhawk Flashing
OK

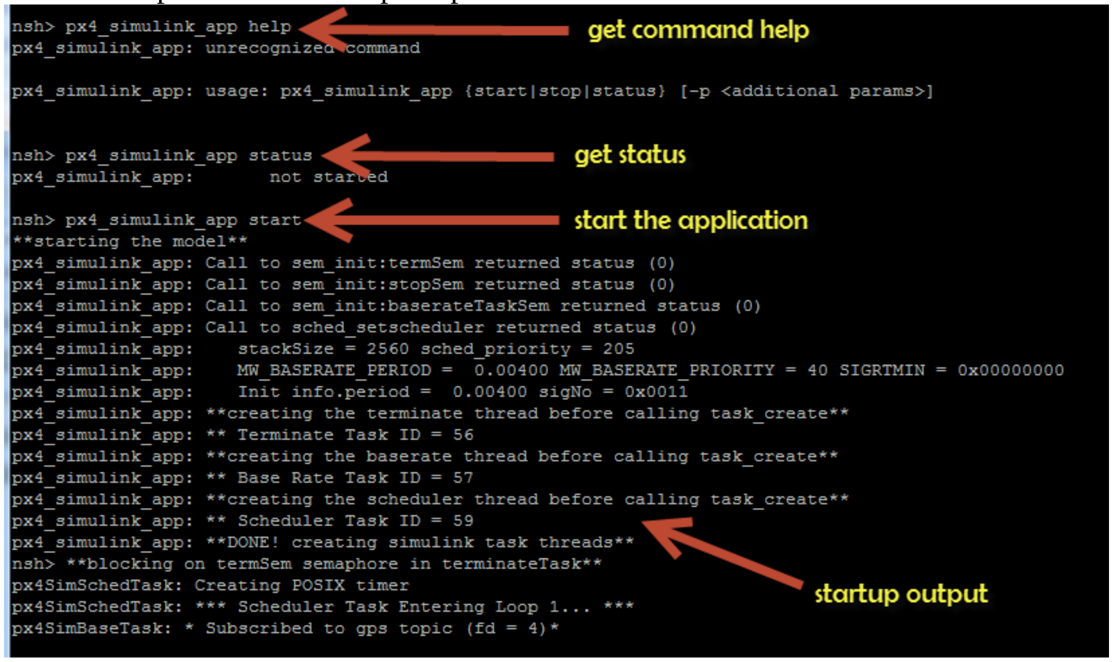
```
Loaded firmware for 9,0, size: 960784 bytes, waiting for the bootloader...
If the board does not respond within 1-2 seconds, unplug and re-plug the USB con
nector.
PX4_SIMULINK = y
```

Ensure that you have configured the COM port to upload with in the Simulink model's configuration parameter under Coder Target. Please make sure the Pixhawk is DISCONNECTED from your USB Port! AFTER you disconnect AND Press ENTER, Plug-In your Pixhawk to your USB port. It will be uploaded and re-booted. Please wait for the startup tone.

This is found under the Code menu > PX4 PSP: Upload code to Px4FMU. You will be prompted with a pop-up menu prior to programming the device. Using this method can be useful after you have performed a “build-only” and want to upload the firmware on to the Pixhawk.

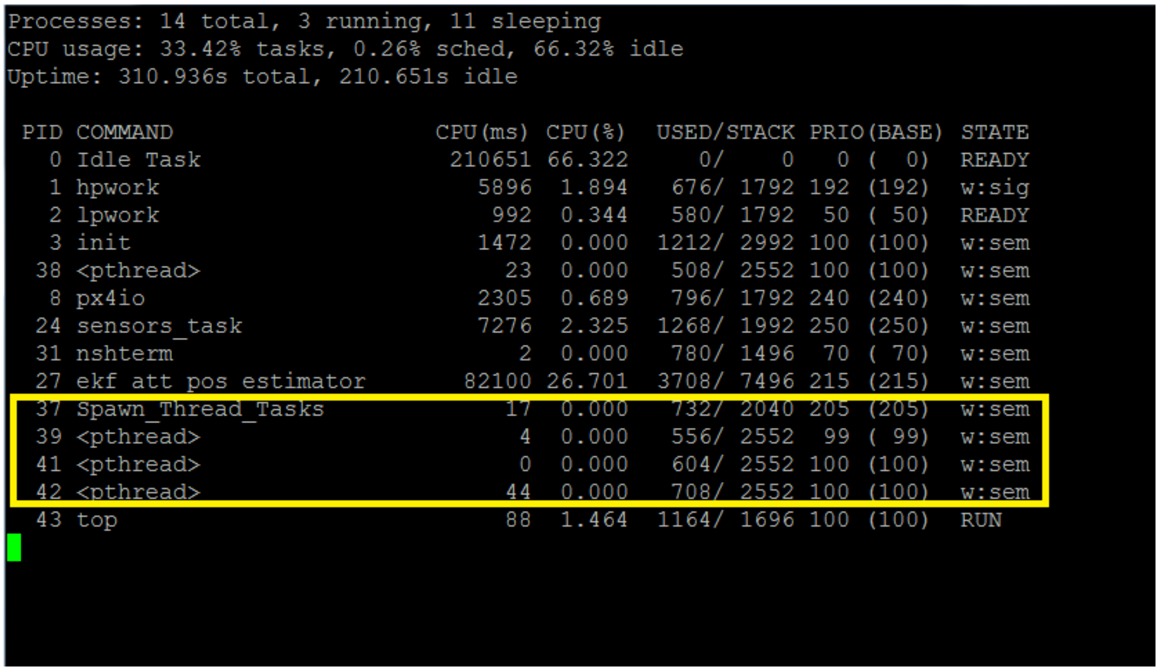
5.3.4 Firmware and Code Generation structure

The Pixhawk PSP generates source code from the model, creates a binary which is then added as a built-in command in the NuttX OS running on the pixhawk. The build-in command is called ***px4_simulink_app*** and it has a command line interface to control its start and stop condition. This application should be included as part of the boot-up script.



```
nsh> px4_simulink_app help
px4_simulink_app: unrecognized command

px4_simulink_app: usage: px4_simulink_app {start|stop|status} [-p <additional params>]


nsh> px4_simulink_app status
px4_simulink_app:       not started

nsh> px4_simulink_app start
**starting the model**
px4_simulink_app: Call to sem_init:termSem returned status (0)
px4_simulink_app: Call to sem_init:stopSem returned status (0)
px4_simulink_app: Call to sem_init:baserateTaskSem returned status (0)
px4_simulink_app: Call to sched_setscheduler returned status (0)
px4_simulink_app:    stackSize = 2560 sched_priority = 205
px4_simulink_app:    MW_BASERATE_PERIOD =  0.00400 MW_BASERATE_PRIORITY = 40 SIGRTMIN = 0x00000000
px4_simulink_app:    Init info.period =  0.00400 sigNo = 0x0011
px4_simulink_app: **creating the terminate thread before calling task_create**
px4_simulink_app: ** Terminate Task ID = 56
px4_simulink_app: **creating the baserate thread before calling task_create**
px4_simulink_app: ** Base Rate Task ID = 57
px4_simulink_app: **creating the scheduler thread before calling task_create**
px4_simulink_app: ** Scheduler Task ID = 59
px4_simulink_app: **DONE! creating simulink task threads**
nsh> **blocking on termSem semaphore in terminateTask**
px4SimSchedTask: Creating POSIX timer
px4SimSchedTask: *** Scheduler Task Entering Loop 1... ***
px4SimBaseTask: * Subscribed to gps topic (fd = 4)*
```

During execution the ***px4_simulink_app*** will spawn a task called “Spawn_Thread_Tasks”. When the application initializes it spawns a task which is used to spawn several threads. These threads are the following: base rate thread, subrate thread, a scheduler thread or a terminate thread. The number of subrate threads are dictated by the number of sample-times you have in the model and if the model is set to multi-tasking.



```
Processes: 14 total, 3 running, 11 sleeping
CPU usage: 33.42% tasks, 0.26% sched, 66.32% idle
Uptime: 310.936s total, 210.651s idle

 PID COMMAND                   CPU(ms) CPU(%)  USED/STACK PRIO(BASE) STATE
   0 Idle Task                  210651 66.322     0/    0   0 (  0)  READY
   1 hpwork                       5896  1.894   676/ 1792 192 (192)  w:sig
   2 lpwork                        992  0.344   580/ 1792  50 ( 50)  READY
   3 init                         1472  0.000  1212/ 2992 100 (100)  w:sem
  38 <pthread>                      23  0.000   508/ 2552 100 (100)  w:sem
   8 px4io                        2305  0.689   796/ 1792 240 (240)  w:sem
  24 sensors_task                 7276  2.325  1268/ 1992 250 (250)  w:sem
  31 nshterm                         2  0.000   780/ 1496  70 ( 70)  w:sem
  27 ekf_att_pos_estimator       82100 26.701  3708/ 7496 215 (215)  w:sem
  37 Spawn_Thread_Tasks             17  0.000   732/ 2040 205 (205)  w:sem
  39 <pthread>                       4  0.000   556/ 2552  99 ( 99)  w:sem
  41 <pthread>                       0  0.000   604/ 2552 100 (100)  w:sem
  42 <pthread>                      44  0.000   708/ 2552 100 (100)  w:sem
  43 top                            88  1.464  1164/ 1696 100 (100)  RUN
```

When the application has ended these threads will terminate along with the "Spawn_Thread_Task".

The source file `nuttxinitialize.c` is responsible for spawning these threads, semaphores and so forth to execute the generated code at the specified sample rates in the Simulink model. This source file can be found in `\toolbox\psp\pixhawk\src`

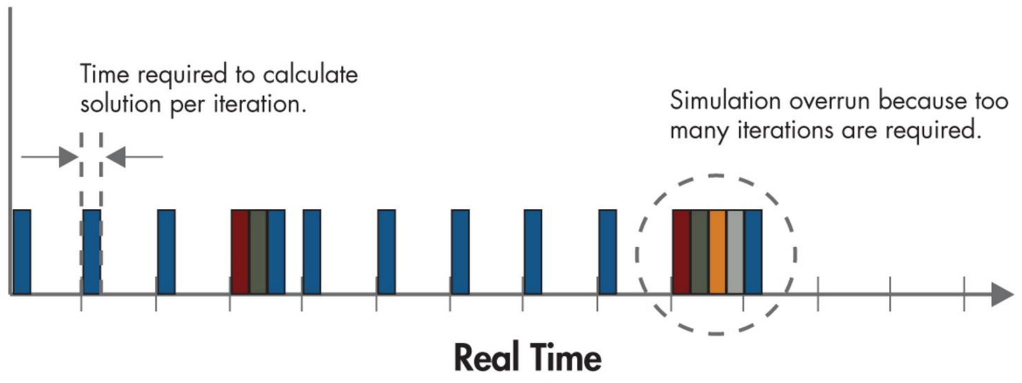
In the previous versions of the Pixhawk PSP we would spawn a thread called schedlerTask which would setup a semaphore that waits on a POSIX timer using functions such as `timer_create.` Using this method, it was observed that there was jitter in the pace of execution. While this jitter was not enough to cause instability in the system, it was enough to warrant an update. We now employ a High-Resolution Timer (HRT) which was observed to have less jitter to post the base-rate semaphore which is used to set the execution pace of the base-rate thread. To read more about this go here:

https://pixhawk.org/dev/accurately_timed_operations

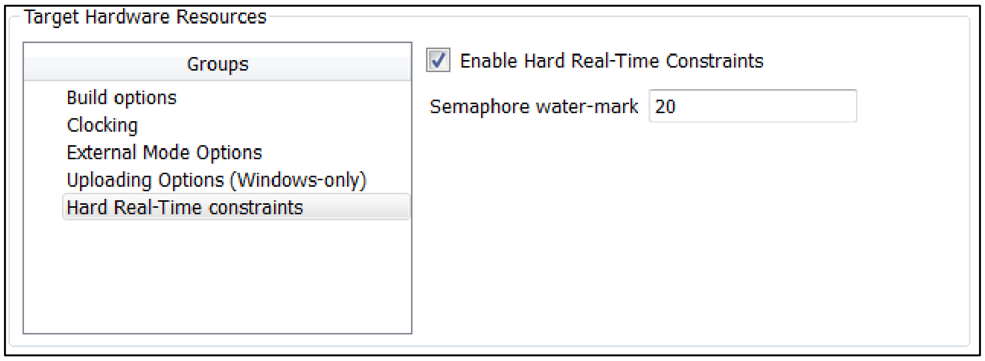
5.3.5 Hard Real-Time Constraints

It is highly recommended to NOT use this during flight tests as there is a chance the system will auto-shut down in midflight.

In the R2016a/R2016b PSP release, a new feature has been added in here to allow users to determine if the flight algorithm is able to meet scheduling deadlines by examining task over-run occurrences. By definition, task over-run means that the generated code was not able to complete a call complete it's task in the specified sample time set by the Simulink model. This is illustrated below:


Time required to calculate solution per iteration.
Simulation overrun because too many iterations are required.
Real Time

When enabling Hard Real-Time constraints, the generated code will auto-shut down and report to the Nuttshell terminal when task over-run crosses a certain threshold.


Target Hardware Resources

Groups
- Build options
- Clocking
- External Mode Options
- Uploading Options (Windows-only)
- Hard Real-Time constraints

[✓] Enable Hard Real-Time Constraints

Semaphore water-mark: 20

This threshold is dictated by the semaphore water-mark. In the above settings, we allow task over-run to occur at a maximum of 20 times before the application shuts down. The water-mark is here to account for more flexibility in instances where model initialization may have taken longer than a single sample period and causes brief semaphore wind-up but the generated code step function is still able to meet the scheduling deadline.

General use-cases for this feature include:

- Use this to help determine if your flight algorithm does not perform in real time and be able to quantify the severity
- It is highly recommended to NOT use this during flight tests as there is a chance the system will auto-shut down in midflight. You will be warned prior to compiling the Simulink model that this option has been enabled

- Useful for observe transient semaphore wind-up due to initialization

- This is only used to measure against the base (ie: fastest) sample-rate. As such, you may want to use this option with a simplified model with a single-rate that you plan to run that section of the algorithm on. With this option enabled, examine ‘`baseRateTask(void *arg)` to see the instrumentation code we introduce to measure for overrun.

Tips for running at faster periods in real-time include:

- Run with ‘faster runs’ configuration (-o3 optimizations)
- Reduce the complexity in the model
- Think of better ways of partitioning the model to different sample-rates – this will split the model into different threads. For instance, try moving a section of the model which does not need to run as fast as the base-sample rate into a slower sample rate. This will make that part of the model run less frequently and places it in a lower priority thread
- Use fixed-point instead of floating point math if necessary to ease computational complexity

5.4 Using QGroundControl with Pixhawk PSP for sensor calibration

QGroundControl is a utility which can interact with your Pixhawk FMU through calibration routines, mission planning and parameter adjustments. This utility uses Mavlink serial connection to communicate back to the host computer. For more information on QGroundControl please refer to their website: http://qgroundcontrol.com/

QGroundControl has had many different releases which may or may not work with the Pixhawk PSP. Only versions 2.7.1 and 2.8.0 have been tested with the PSP. When running px4_simulink_app we recommend disabling several applications such as the commander and mavlink. This is done because

- We currently do not generate code to interact with Mavlink. We also sometimes require the serial port to be free to access for other things (ie: generic UART communication)

- The commander application has full control over the motors/actuators. Because px4_simulink_app was intended to replace the commander application as the main flight controls system, we disable this app. This unfortunately means that QGroundControl cannot be used simultaneously while px4_simulink_app is running if the commander application is disabled.

The QGroundControl calibration procedure calculates sensor offset and compensation needed for stable flight orientation. These parameters are stored in /fs/mtd_params which is persistent readable/writable memory. To learn more about reading/writing parameters please see http://dev.px4.io/advanced-configurations.html

If you wish run through a calibration routine with QGroundControl, you can follow these steps.

Step 1: Remove the SD card and start the FMU

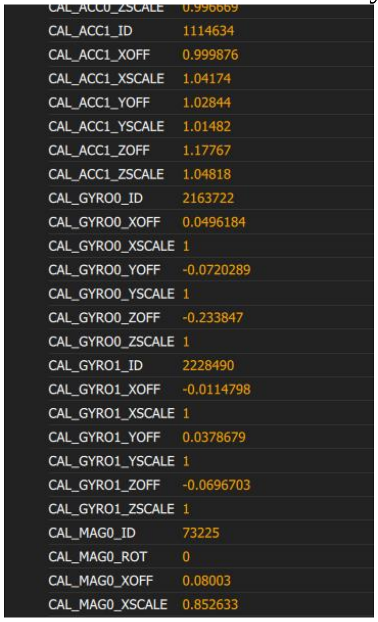
By removing the SD card we force the FMU to load the default applications such as commander/navigator/Mavlink, etc. This will allow you to use QGroundControl to connect to it in a later step.

Step 2: Start Calibration Routine in QGroundControl (tested on 2.7.1 and 2.8.0)

You should now be able to connect to the FMU with QGroundControl and begin the calibration routine as described here:
https://donlakeflyer.gitbooks.io/qgroundcontrol-user-guide/content/SetupView/Sensors.html

Step 3: Examine Parameters

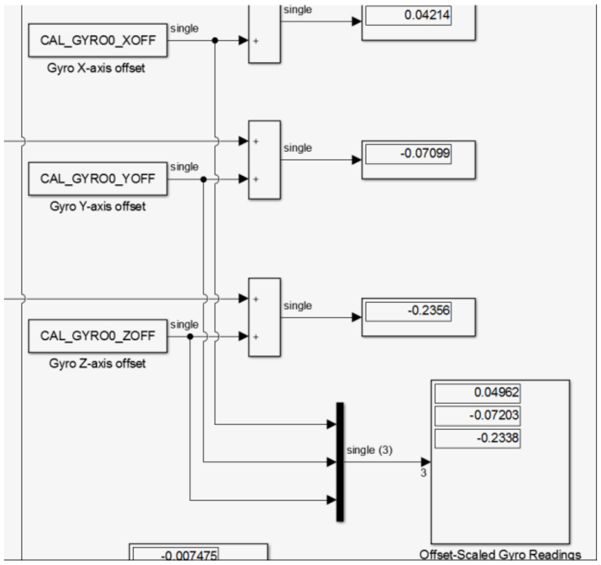
The calibration routine will update several parameters which will be needed by the attitude estimation / sensor system on the Pixhawk



```
CAL_ACC0_ZSCALE  0.996669
CAL_ACC1_ID      1114634
CAL_ACC1_XOFF    0.999876
CAL_ACC1_XSCALE  1.04174
CAL_ACC1_YOFF    1.02844
CAL_ACC1_YSCALE  1.01482
CAL_ACC1_ZOFF    1.17767
CAL_ACC1_ZSCALE  1.04818
CAL_GYRO0_ID     2163722
CAL_GYRO0_XOFF   0.0496184
CAL_GYRO0_XSCALE 1
CAL_GYRO0_YOFF   -0.0720289
CAL_GYRO0_YSCALE 1
CAL_GYRO0_ZOFF   -0.233847
CAL_GYRO0_ZSCALE 1
CAL_GYRO1_ID     2228490
CAL_GYRO1_XOFF   -0.0114798
CAL_GYRO1_XSCALE 1
CAL_GYRO1_YOFF   0.0378679
CAL_GYRO1_YSCALE 1
CAL_GYRO1_ZOFF   -0.0696703
CAL_GYRO1_ZSCALE 1
CAL_MAG0_ID      73225
CAL_MAG0_ROT     0
CAL_MAG0_XOFF    0.08003
CAL_MAG0_XSCALE  0.852633
```

Step 4: Access Parameters in Simulink

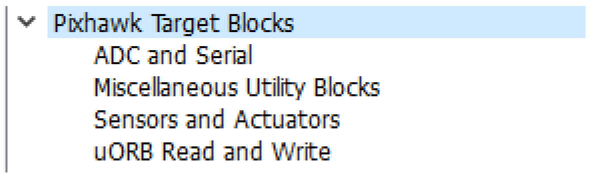
These parameters are also accessible in Simulink generated application px4_simulink_app using the Custom Storage Class (CSC) method in one of our example models. Reboot your Pixhawk FMU after the above calibration step with the modified rc.txt file via SD card insertion. Here is a snap-shot of this example model running in external mode where we display several parameters from the above list.



Please refer to section **5.6.1** for a more detailed description of this model and using CSCs.

5.5 Simulink Block Library

A few Simulink Blocks have been provided for the user to interface to the hardware of the PX4. These allow for **code generation** only and do not provide for plant modeling behavior. It is recommended that your control model be a Model Block in your Simulink simulation model and then be re-used in your implementation model which would tie in these hardware interface blocks. The library filename is called pixhawk_sllib.slx and will be available in your Simulink Library browser under **Pixhawk Target Blocks**. It consists of four (4) sub-libraries: 1) ADC and Serial Port, 2) Misc Utility Blocks, 3) Sensors and Actuators and 4) uORB Read/Write Blocks.



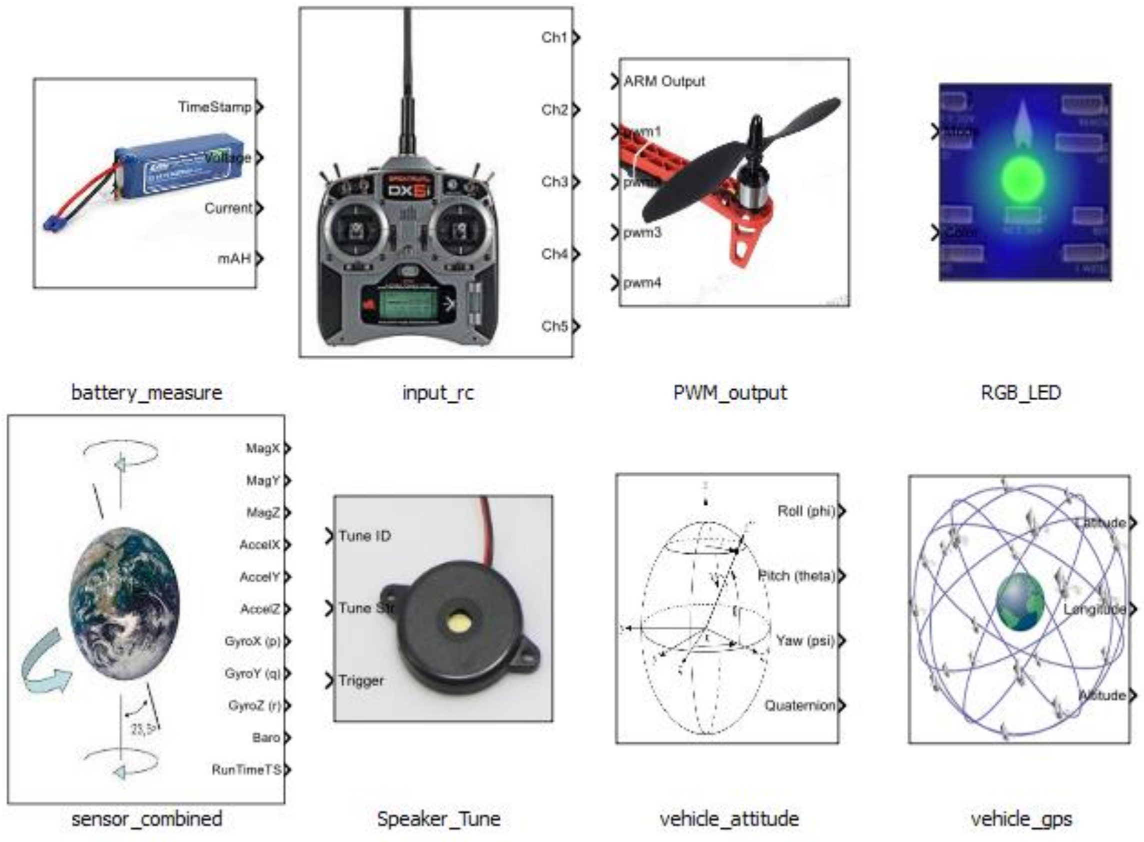
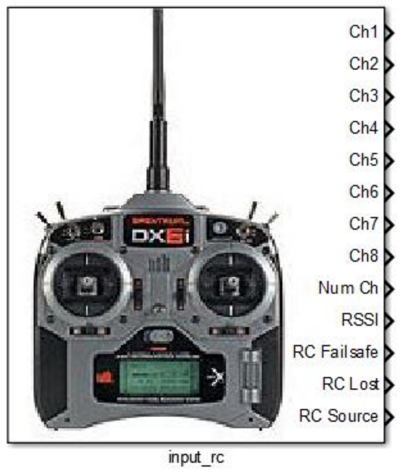
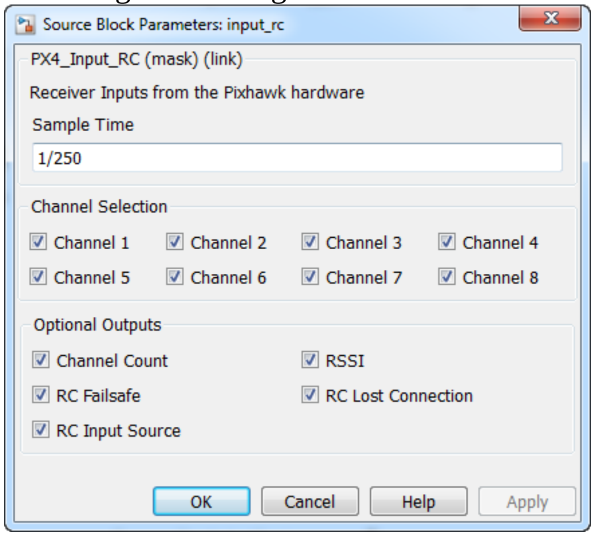


Figure 1 Sensors and Actuator Blocks

5.5.1 Pixhawk Target Block: input_rc

This block allows the user to access the signals coming from the RC transmitter.





PX4_Input_RC (mask) (link)

Receiver Inputs from the Pixhawk hardware

Sample Time

1/250

Channel Selection

[✓] Channel 1 [✓] Channel 2 [✓] Channel 3 [✓] Channel 4
[✓] Channel 5 [✓] Channel 6 [✓] Channel 7 [✓] Channel 8

Optional Outputs

[✓] Channel Count [✓] RSSI
[✓] RC Failsafe [✓] RC Lost Connection
[✓] RC Input Source

The user has the ability to choose which channels are available as outputs from this block and also some optional outputs. These include

1) Channels 1 through 8

    a. uint16 data type indicating the PWM (in usec) value from the controller
    b. measured pulse widths for each of the supported channels
2) Channel Count
    a. uint32 data type of the number of channels which are detector by the PX4
3) RC Failsafe
    a. boolean data types indicating that the RC Tx is sending the FailSafe signal (if equipped and properly setup)
    b. explicit failsafe flag: true on TX failure or TX out of range , false otherwise.
    c. Only the true state is reliable, as there are some (PPM) receivers on the market going into failsafe without telling us explicitly.
4) RC Input Source
    a. Enumeration data type indicating which source the RC input is from.
    b. Valid values are found in the ENUM file: RC_INPUT_SOURCE_ENUM.m

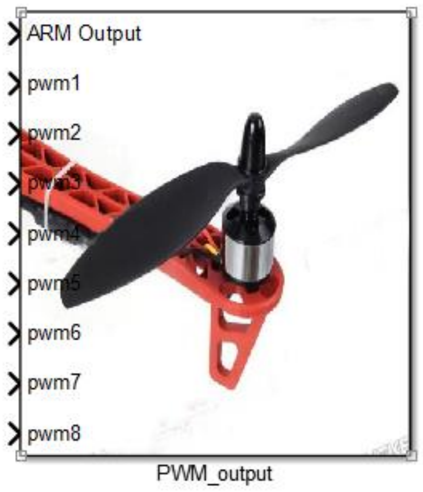
```
RCINPUT_SOURCE_UNKNOWN        (0)
RCINPUT_SOURCE_PX4FMU_PPM     (1)
RCINPUT_SOURCE_PX4IO_PPM      (2)
RCINPUT_SOURCE_PX4IO_SPEKTRUM (3)
RCINPUT_SOURCE_PX4IO_SBUS     (4)
```

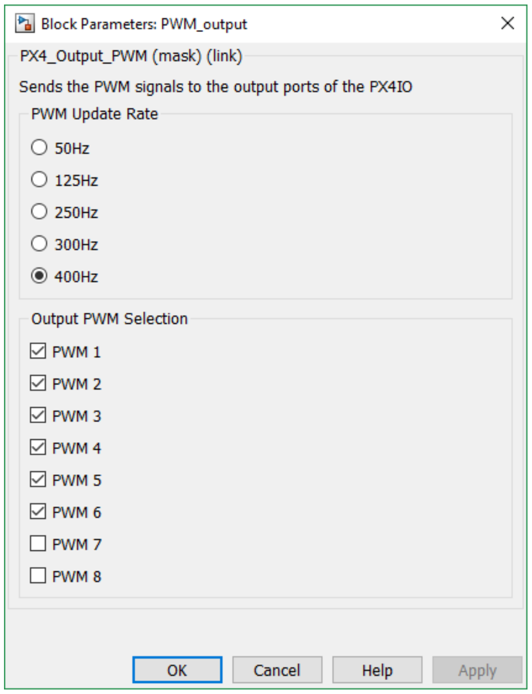
5) RSSI - Receive signal strength index
    a. receive signal strength indicator (RSSI): < 0: Undefined, 0: no signal, 255: full reception
6) RC Lost Connection
    a. boolean data type indicating RC receiver connection status
    b. True, if no frame has arrived in the expected time, false otherwise.
    c. True usally means that the receiver has been disconnected, but can also indicate a radio link loss on "stupid" systems.
    d. Will remain false, if a RX with failsafe option continues to transmit frames after a link loss.

Sample Model: px4demo_input_rc.slx

5.5.2 Pixhawk Target Block: PWM_output

This block allows the user to send the appropriate PWM signals out to the PX4 outputs. These are usually connected to the ESCs which control the motor speeds.




Block Parameters: PWM_output

PX4_Output_PWM (mask) (link)

Sends the PWM signals to the output ports of the PX4IO

PWM Update Rate

- ○ 50Hz
- ○ 125Hz
- ○ 250Hz
- ○ 300Hz
- ● 400Hz

Output PWM Selection

- ☑ PWM 1
- ☑ PWM 2
- ☑ PWM 3
- ☑ PWM 4
- ☑ PWM 5
- ☑ PWM 6
- ☐ PWM 7
- ☐ PWM 8

In order for the flight control to arm (enable) the output from the software side, the ARM Output input must be held high (boolean TRUE). Only then will the PWM values be sent out the PX4 hardware ports. This is usually a function of the RC Tx in combination with other flight modes programmed in the Simulink model by the user.

The block has 8 available ports (data type uint16) which can be selectively chosen. These correspond to the 8 PWM output ports on the px4fmu hardware.

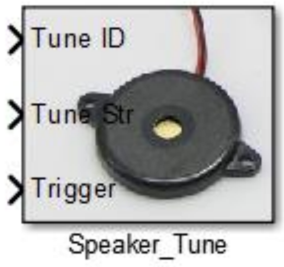
The PWM unit value is in micro-seconds (usec) which corresponds to the pulse width (1500 is 1500 usec or 1.5 milli-seconds).

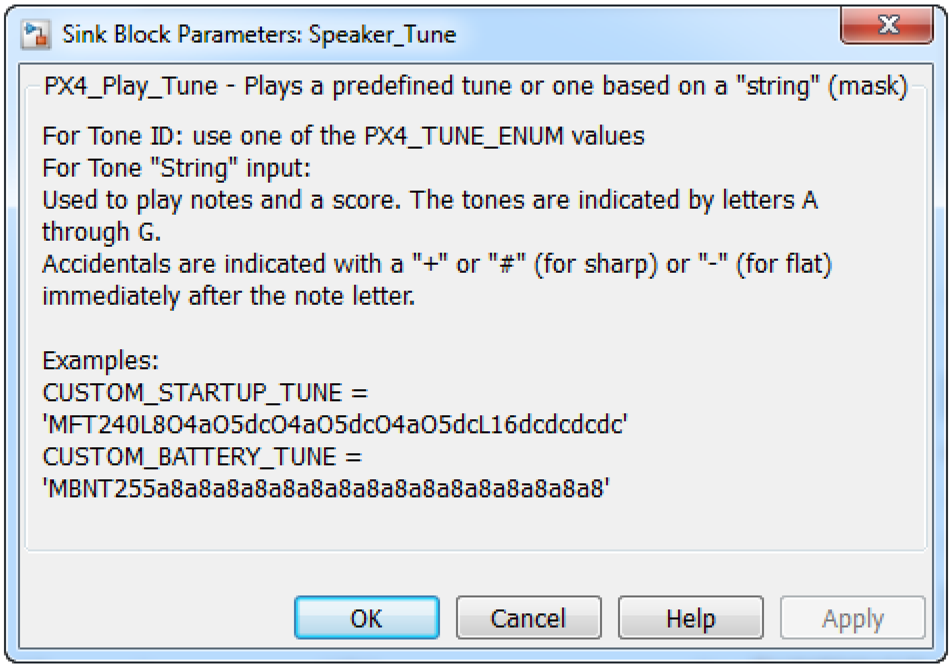
The PWM update rate is set to 400Hz at startup of the px4_simulink_app (or what the user sets in the block dialog). Available PWM update rates are: 50, 125, 250, 300 and 400Hz.

The px4_simulink_app will also set an idle value of 900 usec at startup and when the ARM port is set to low (boolean FALSE) so that the ESC controllers do not time-out.

5.5.3 Pixhawk Target Block: Speaker_Tune

This block allows the user to control the various tunes that can be emitted by the mini-speaker connected to the px4fmu.





PX4_Play_Tune - Plays a predefined tune or one based on a "string" (mask)

For Tone ID: use one of the PX4_TUNE_ENUM values
For Tone "String" input:
Used to play notes and a score. The tones are indicated by letters A through G.
Accidentals are indicated with a "+" or "#" (for sharp) or "-" (for flat) immediately after the note letter.

Examples:
CUSTOM_STARTUP_TUNE =
'MFT240L8O4aO5dcO4aO5dcO4aO5dcL16dcdcdcdc'
CUSTOM_BATTERY_TUNE =
'MBNT255a8a8a8a8a8a8a8a8a8a8a8a8a8a8a8a8'

This block accepts 3 input signals.

i. Tune ID : This is an enumeration data type of pre-defined "tunes" that can be played.

Enumeration members for class 'PX4_TUNE_ENUM':

STOP_TUNE
STARTUP_TUNE
ERROR_TUNE
NOTIFY_POSITIVE_TUNE
NOTIFY_NEUTRAL_TUNE
NOTIFY_NEGATIVE_TUNE
ARMING_WARNING_TUNE

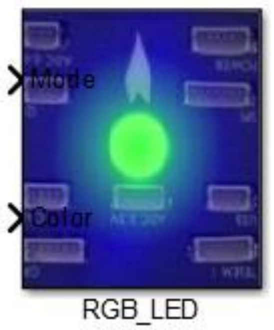
BATTERY_WARNING_SLOW_TUNE
BATTERY_WARNING_FAST_TUNE
GPS_WARNING_TUNE
ARMING_FAILURE_TUNE
PARACHUTE_RELEASE_TUNE

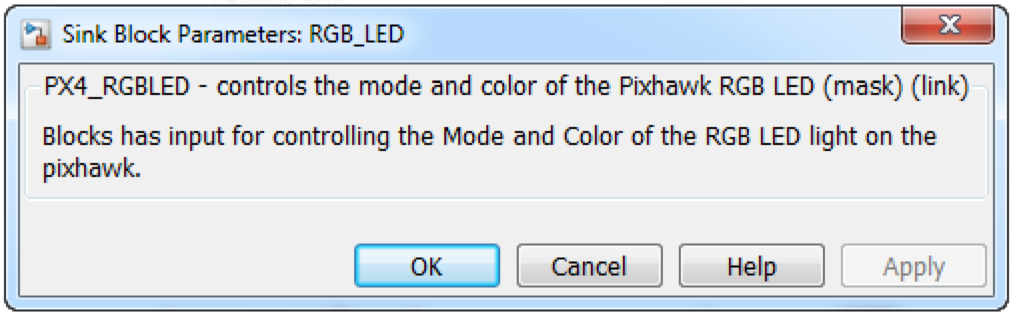
ii. Tune Str : This is for defining a custom tune to be played. The user can use a constant block that define the string to play.
iii. Trigger : This is a trigger signal that indicates when to play the predefined Tune (if Trigger value goes to 1) or the custom Tune (if Trigger value goes to 2). The change in tune will only be *triggered* by a change in this value.

Please see the example model px4demo_tune.slx.

5.5.4 Pixhawk Target Block: RGB_LED

This block gives the user control over various lighting modes of the RGB LED available on the PX4 hardware.





PX4_RGBLED - controls the mode and color of the Pixhawk RGB LED (mask) (link)

Blocks has input for controlling the Mode and Color of the RGB LED light on the pixhawk.

This block accepts 2 inputs: Mode and Color. These are enumeration data types. You can find out what values are valid in the MATLAB command window by typing:

```
>> enumeration('RGBLED_COLOR_ENUM')
```

```
Enumeration members for class 'RGBLED_COLOR_ENUM':
    COLOR_OFF
    COLOR_RED
    COLOR_YELLOW
```

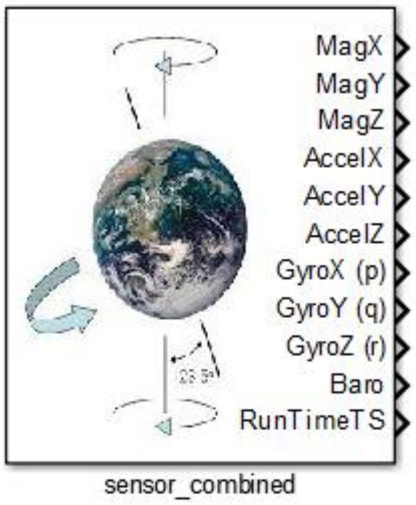
COLOR_PURPLE
COLOR_GREEN
COLOR_BLUE
COLOR_WHITE
COLOR_AMBER
COLOR_DIM_RED
COLOR_DIM_YELLOW
COLOR_DIM_PURPLE
COLOR_DIM_GREEN
COLOR_DIM_BLUE
COLOR_DIM_WHITE
COLOR_DIM_AMBER

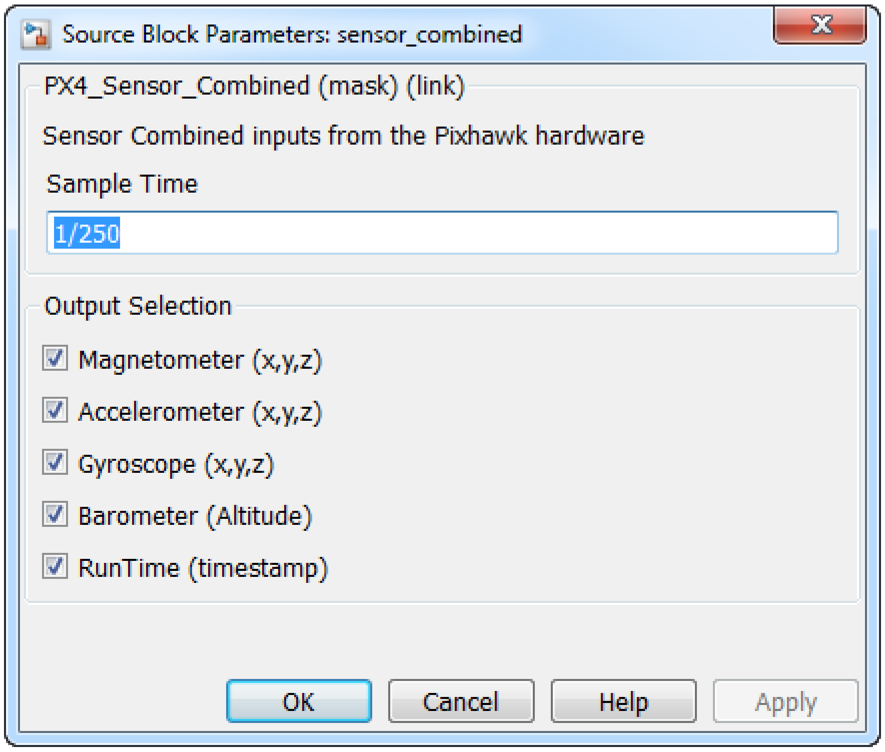
Enumeration members for class 'RGBLED_MODE_ENUM':
MODE_OFF
MODE_ON
MODE_BLINK_SLOW
MODE_BLINK_NORMAL
MODE_BLINK_FAST
MODE_BREATHE
MODE_PATTERN

Look at the sample Simulink model: px4demo_rgbled.slx for an example of how to use this block.

5.5.5 Pixhawk Target Block: sensor_combined

This block enables access to the various sensors available on the px4fmu-v2 hardware. The user can use these signals in the Simulink control model. The sample time needs to be provided in the mask dialog. Optional output ports can also be selected. Refer to the sample model: px4demo_attitude_control.slx




Source Block Parameters: sensor_combined

PX4_Sensor_Combined (mask) (link)

Sensor Combined inputs from the Pixhawk hardware

Sample Time

1/250

Output Selection

[✓] Magnetometer (x,y,z)

[✓] Accelerometer (x,y,z)

[✓] Gyroscope (x,y,z)

[✓] Barometer (Altitude)

[✓] RunTime (timestamp)

Signal definitions:

- Magnetometer (x,y,z) - single values – Magnetic field in NED body frame, in Gauss
- Accelerometer (x,y,z) - single values – Acceleration in NED body frame, in m/s^2
- Gyroscope (p,q,r) - single values – Angular velocity in radians per second

- Barometer (Altitude) - single value – Barometric pressure, already temperature compensated (millibars)
- RunTime (timestamp) - double value – Timestamp in microseconds since boot, from gyro

The sensor_combined block needs to have the px4io service running on the PX4 hardware in order to get valid signal values.

Refer to the sample model: px4demo_attitude_control.slx

5.5.6 Pixhawk Target Block: vehicle_attitude

This block gives access to the running service that calculates the vehicle's attitude. A uORB topic (vehicle_attitude (attitude measurements)) publisher MUST be running in order for this block to provide valid signal values. The method used is based on the CMake Configuration the user has chosen at installation time.

http://dev.px4.io/advanced-switching_state_estimators.html

https://github.com/darenlee/PixhawkPSP_Firmware/tree/PSP_R2016AB/src/modules

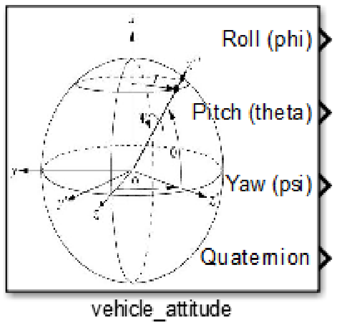
One of these MUST be running on the px4fmu in order for this block to return valid values. For example:

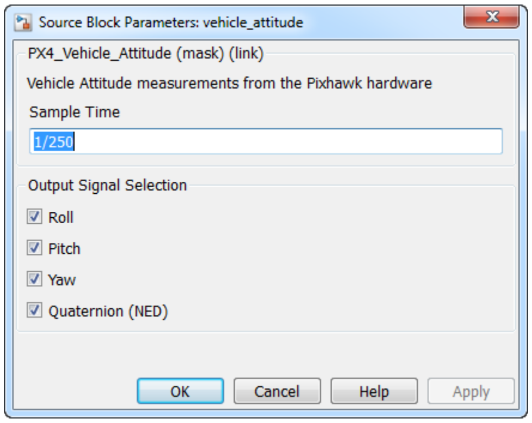
px4fmu-v2_ekf2: *EKF-Extended Kalman Filter for attitude estimation*

px4fmu-v2_default: *SO(3)-attitude estimation by using accelerometer, gyroscopes and magnetometer*

Refer to the sample model: px4demo_attitude_control.slx. If you want to switch to a different method, you must first re-run the PixhawkPSP script in the <matlabroot>\toolbox\psp\pixhawk folder. The corresponding firmware must be built as well. See the above section on Firmware Build.

Attitude in NED (North-East-Down) body frame in SI units.




Source Block Parameters: vehicle_attitude

PX4_Vehicle_Attitude (mask) (link)

Vehicle Attitude measurements from the Pixhawk hardware

Sample Time

1/250

Output Signal Selection

☑ Roll

☑ Pitch

☑ Yaw

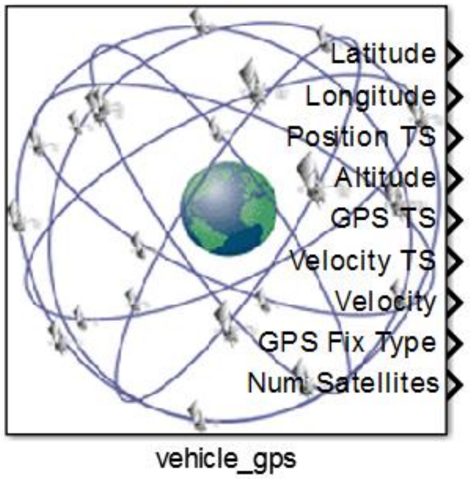
☑ Quaternion (NED)

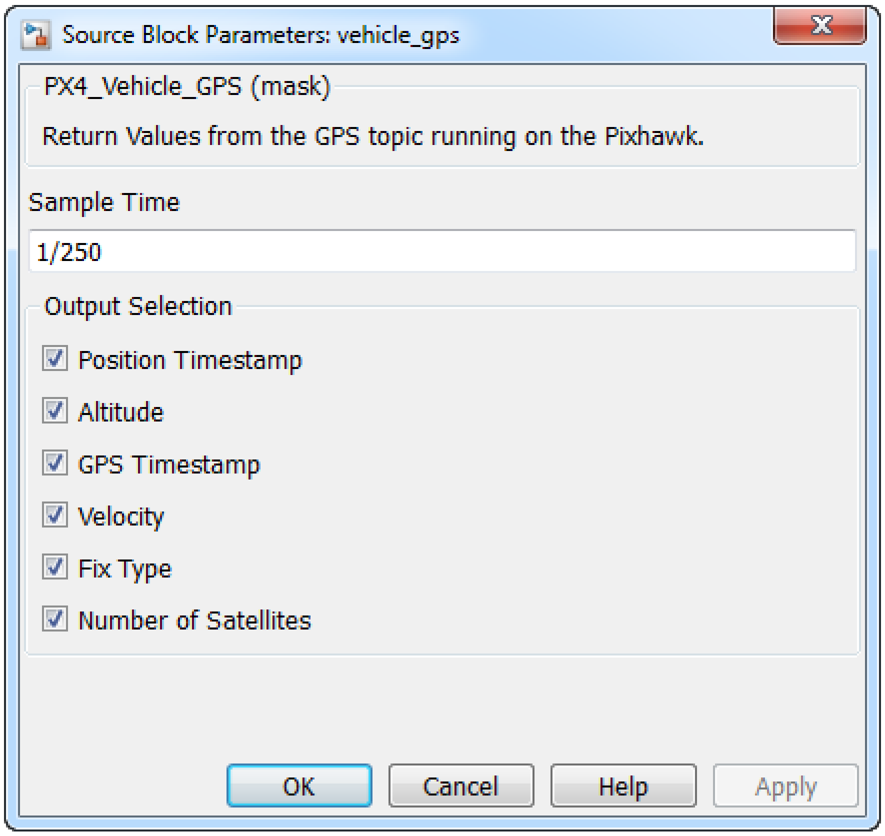
Signal definitions:

7) Roll – single value, Roll angle (rad, Tait-Bryan, NED)
8) Pitch – single value, Pitch angle (rad, Tait-Bryan, NED)
9) Yaw – single value, Yaw angle (rad, Tait-Bryan, NED)
10) Quaternion (NED) – single values (optional based on the uORB publisher)

5.5.7 Pixhawk Target Block: vehicle_gps

This block will provide GPS signals from the uORB topic publisher: vehicle_gps_position. You must ensure that you have the gps topic executed as part of the start-up script in order to get valid signal values.
Refer to the sample model: px4demo_gps.slx





Source Block Parameters: vehicle_gps

PX4_Vehicle_GPS (mask)

Return Values from the GPS topic running on the Pixhawk.

Sample Time

1/250

Output Selection

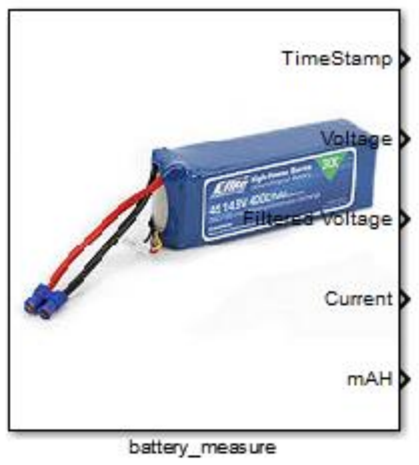
- [✓] Position Timestamp
- [✓] Altitude
- [✓] GPS Timestamp
- [✓] Velocity
- [✓] Fix Type
- [✓] Number of Satellites

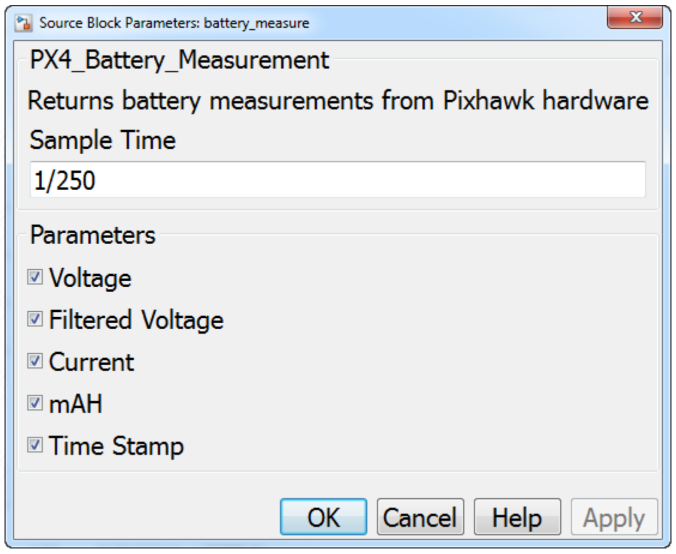
Signal definitions:

- Latitude – (int32) global coordinate given in 1e-7 degrees
- Longitude – (int32) global coordinate given in 1e-7 degrees
- Position TS – (double) timestamp for position information
- Altitude – (int32) in 1e-3 meters (millimeters) above MSL (mean sea level)
- GPS TS – (double) timestamp (microseconds in GPS format). This is the timestamp that comes from the GPS module.
- Velocity TS – (double) timestamp for velocity information
- Velocity – (single) GPS ground speed in meters/second
- GPS Fix Type – (uint8) 0-1 = No fix, 2 = 2D fix, 3= 3D fix
- Num Satellites – (uint8) the number of satellites used in calculations

5.5.8 Pixhawk Target Block: Battery_measure

This block allows the user to monitor the health of the connected battery. It returns battery level measurements from the uORB topic publisher “battery_status”.




Source Block Parameters: battery_measure

PX4_Battery_Measurement

Returns battery measurements from Pixhawk hardware

Sample Time

1/250

Parameters

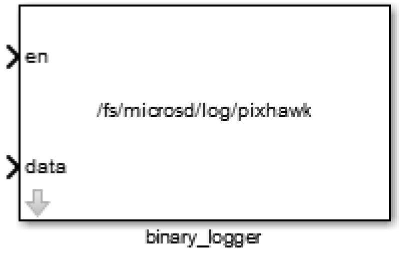
[✓] Voltage
[✓] Filtered Voltage
[✓] Current
[✓] mAH
[✓] Time Stamp

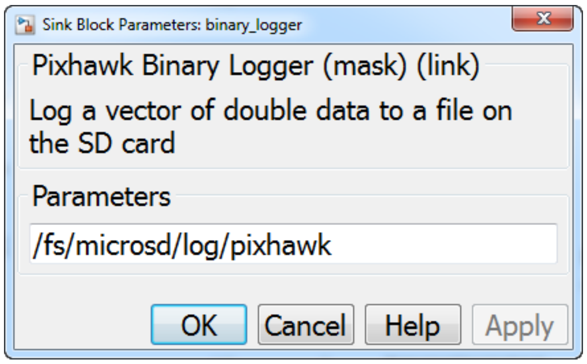
The user has the ability to choose which telemetry data are available as outputs from this block.

Signal definitions:

- Voltage – (double) Battery voltage in volts
- Filtered Voltage – (single) Filtered battery voltage in volts
- Current – (single) Battery current in amperes
- mAH – (single) Discharged amount in mAh
- Timestamp– (int32) timestamp of measurement

5.5.9 Pixhawk Target Block: Binary Logger





Pixhawk Binary Logger (mask) (link)

Log a vector of double data to a file on the SD card

Parameters

/fs/microsd/log/pixhawk

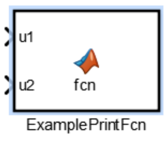
Log a vector of double data to a file on the SD card. The first enable port must trigger high and then low during the execution of the program for a successful write to disk space. If the enable port does not fall low before the generated code is finished executing the file will be still considered 'open' and not accessible. In order for proper SD card data writing ensure that the above directory path points to some place in /fs/microsd/

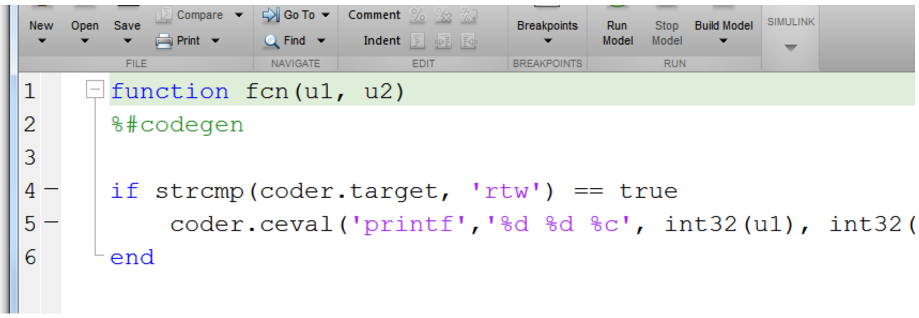
The data input can be a vector signal concatenated together to allow for multiple signal logging. The signals all need to have the same data type (single).

The format of the log file has a header followed by the binary logged data.

Note that an example model has been provided to showcase data logging and reading/extraction. Under the examples look for px4demo_log.slx to see how one can use the logging block and use the `px4_read_binary_file` function to read in the logged data file found on the SD card.

5.5.10 Pixhawk Target Block: Example Print Function



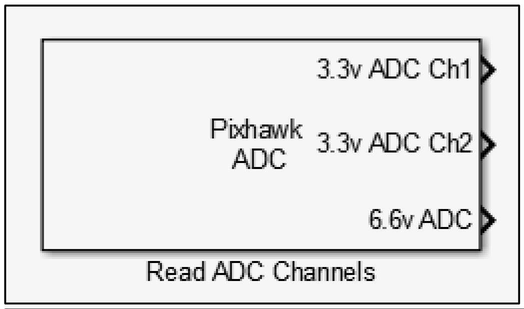


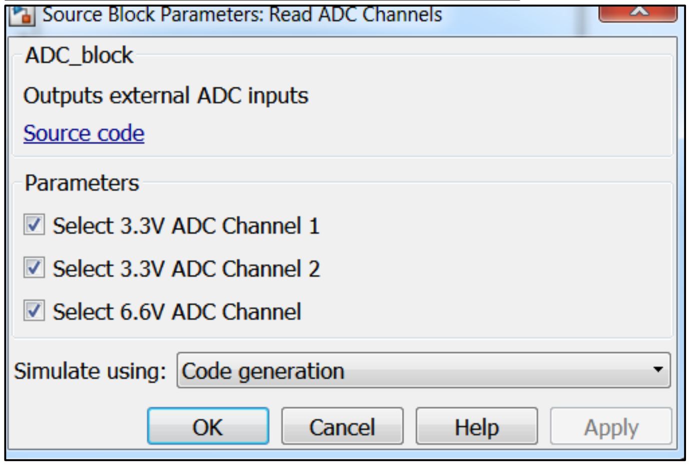
```
function fcn(u1, u2)
%#codegen

if strcmp(coder.target, 'rtw') == true
    coder.ceval('printf','%d %d %c', int32(u1), int32(
end
```

Print signal data content to the PX4 Nuttx console terminal. Note that this block should be treated as an "example" block and the print message can be constructed anyway the user sees fit. The coder.ceval( ) is a MATLAB Coder function used to evaluate the printf ( ) statement to pass in two values. Please note that there is a bug in Nuttx in which sometimes floating numbers cannot be properly displayed. Please use warnx( ) instead of printf( ) of this as a work-around.

5.5.11 Pixhawk Target Block: Read ADC Channels

This block allows one to access the three available external ADC channels on the Pixhawk.




Source Block Parameters: Read ADC Channels

ADC_block

Outputs external ADC inputs

Source code

Parameters

- [✓] Select 3.3V ADC Channel 1
- [✓] Select 3.3V ADC Channel 2
- [✓] Select 6.6V ADC Channel

Simulate using: Code generation

The user has the ability to choose which ADC channel as outputs from this block from the 3.3V and 6.6V Analog Input. Note that Channel 1 and 2 corresponds to pin 14 and 15 respectively for the 3.3V ADC. Please see this link for the labelling of the pins:

https://pixhawk.org/modules/pixhawk

Signal definitions:

- 3.3V Analog to digital conversion – (int32)
- 3.3V Analog to digital conversion – (int32)
- 6.6V Analog to digital conversion (int32)

5.5.12 Pixhawk Target Block: uORB Write

This block allows one to write arbitrary data to a uORB Topic provided that the topic exists and the structure elements are properly defined. The block assumes that the topic exists and is defined in the MSG folder here (ie: C:\px4\Firmware\msg). The block will generate code to include the appropriate header file of the uORB topic. For instance, if the topic is 'TOPIC_NAME' in the first entry, then the header file to be included:

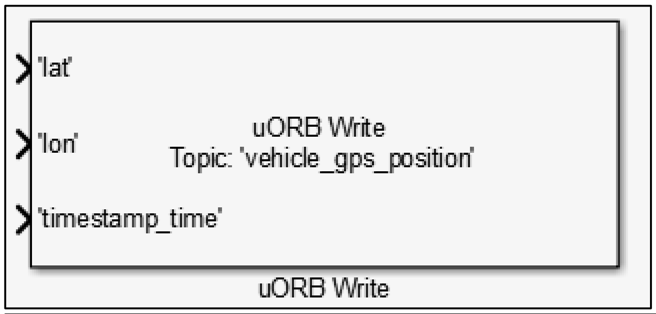
```
#include <uORB/topics/TOPIC_NAME.h>
```

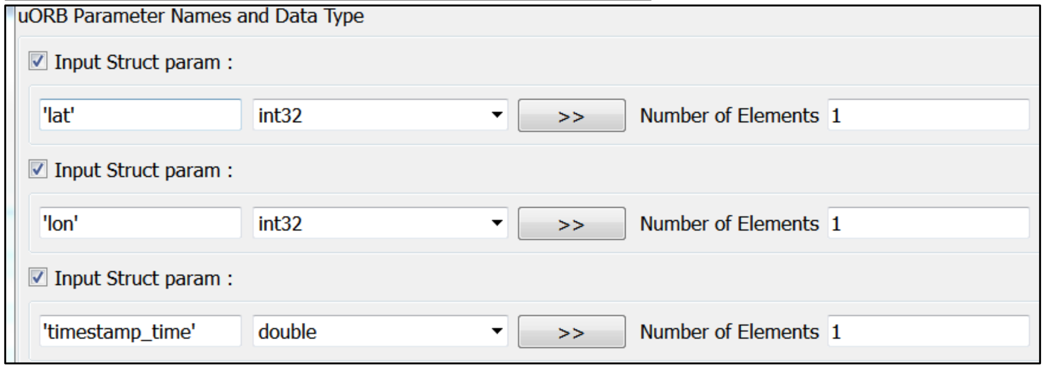
Similarly, the syntax for invoking the uORB Topic and creating its structure will look like this:

```
struct TOPIC_NAME_s
orb_publish(ORB_ID(TOPIC_NAME), other_param1,
other_param2)
```

And so on. Please ensure that the topic is well defined and the header / source files are in the right location.

To specify the struct elements to write to for the uORB topic click on the tick-boxes and specify the name of the element, the data type and the number of elements to be greater than one if the struct element is a vector. You can check the dimension and data type by opening the corresponding .msg file button which will search for the matching file name in the \px4\Firmware\msg folder.




uORB Parameter Names and Data Type

☑ Input Struct param :

'lat' | int32 | >> | Number of Elements 1

☑ Input Struct param :

'lon' | int32 | >> | Number of Elements 1

☑ Input Struct param :

'timestamp_time' | double | >> | Number of Elements 1

This block at initialization time will first advertise the topic and then subsequently publish data from the input signal lines. Note that only a maximum of five struct elements are accessible at the moment. The next release will explore a more flexible method of accessing uORB topics.

Signal definitions:

- To be defined by the user

5.5.13 Pixhawk Target Block: uORB Read / Function-Call Trigger

This block allows one to read arbitrary data from a uORB Topic provided that the topic exists and the structure elements are properly defined. This block will also allow one to trigger a function-call signal that will be able to asynchronously execute generated code when new data from the topic is available. The block cannot act in these two modes simultaneously.

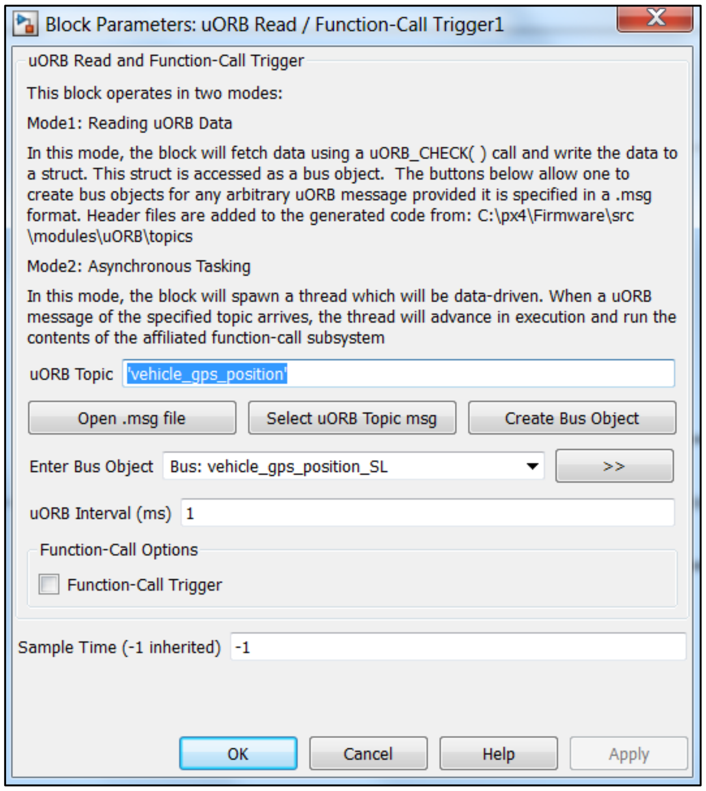
The block assumes that the topic exists and is defined in the MSG folder here (ie: C:\px4\Firmware\msg). The block will always generate code to include the appropriate header file of the uORB topic. For instance, if the topic is 'TOPIC_NAME' in the first entry, then the header file to be included:

```
#include <uORB/topics/TOPIC_NAME.h>
```

Similarly, the syntax for invoking the uORB Topic and creating its structure will look like this:

```
struct TOPIC_NAME_s

orb_read(ORB_ID(TOPIC_NAME), other_param1, other_param2,
etc…)
```

And so on. Please ensure that the topic is well defined and the header / source files are in the right location.


Block Parameters: uORB Read / Function-Call Trigger1

uORB Read and Function-Call Trigger

This block operates in two modes:

Mode1: Reading uORB Data

In this mode, the block will fetch data using a uORB_CHECK( ) call and write the data to a struct. This struct is accessed as a bus object. The buttons below allow one to create bus objects for any arbitrary uORB message provided it is specified in a .msg format. Header files are added to the generated code from: C:\px4\Firmware\src\modules\uORB\topics

Mode2: Asynchronous Tasking

In this mode, the block will spawn a thread which will be data-driven. When a uORB message of the specified topic arrives, the thread will advance in execution and run the contents of the affiliated function-call subsystem

uORB Topic 'vehicle_gps_position'

Enter Bus Object Bus: vehicle_gps_position_SL

uORB Interval (ms) 1

Function-Call Options

Function-Call Trigger

Sample Time (-1 inherited) -1

The general steps for using this block for reading topics are:

1) Selecting a Topic

This is done with the 2nd button select "uORB Topic msg" which opens up the 'msg' directory for you to choose a topic. Only topics which are not treated as C++ objects are supported, an error message will appear if such topics are chosen. For more details on this see Chapter 7 on Limitations for a work-around.

2) Creating a bus object

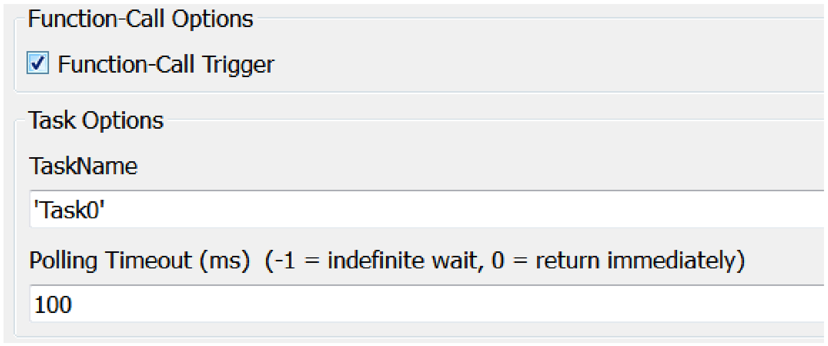
A Simulink bus object is created from the topic in the .msg file. Because uORB topics are more or less C-structs (except when they are treated as a C++ struct with object properties) we have the ability to map structs to bus objects. A bus object will appear in your MATLAB workspace for you to start using. When clicking this button, the data type output of this block gets automatically assigned to this newly created bus object, however, you are also free to choose your own as needed.

3) Setting uORB read interval

When reading from a topic, you will also want to specify polling rates (uORB interval) in milliseconds. Some topics can only provide data at a maximum rate, please ensure that the polling rate choice does not exceed this.

The general steps for using this block for asynchronous events are as follows:

1) Select Function-Call Trigger


Function-Call Options

☑ Function-Call Trigger

Task Options

TaskName

'Task0'

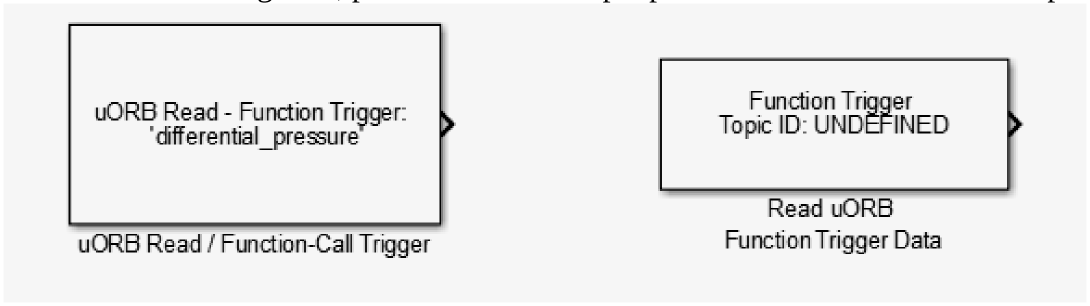
Polling Timeout (ms) (-1 = indefinite wait, 0 = return immediately)

100

2) Set poll timeout and Task Name

The sample rate at which this block executes at is not applicable when the block is in Triggered Function-Call mode since the block behaves asynchronously in this configuration. A Task Name and a polling-time out needs to be specified when in Triggered Function-Call mode. A new thread is spawned which will be responsible for running the generated code assosciated with the fucntion-trigger signal. This thread will wait for new topic data by polling on the topic.

When reading your topic inside the function call trigger block you'll want to use another library block "uORB Function-Call Read" we provide to do this. These blocks were meant to be used together, please see the example px4demo_fcn_call_uorb_example.slx


uORB Read - Function Trigger: 'differential_pressure'
uORB Read / Function-Call Trigger
Function Trigger
Topic ID: UNDEFINED
Read uORB
Function Trigger Data

Signal definitions:

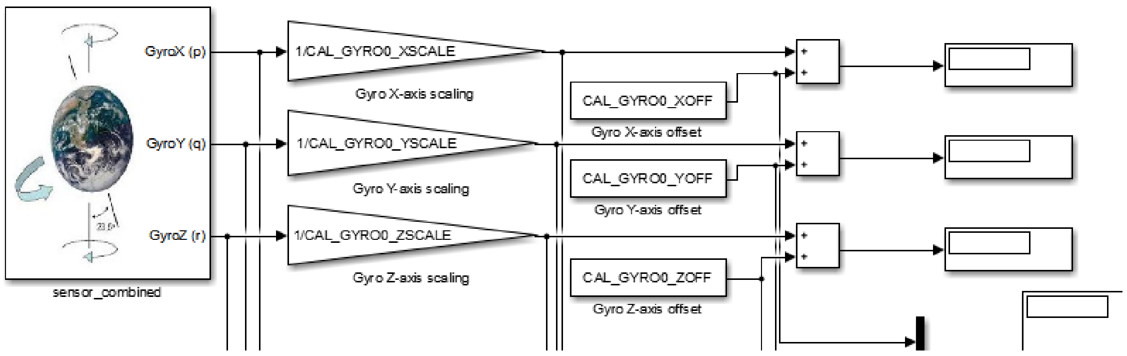
- To be defined by the user based on bus object

5.6 Example Models

There are several simple "test" models available for you to make sure everything is correctly installed and working. It is recommended to try one of these initial test models before trying a complete flight control system model.

IMPORTANT: Simulink does not allow a user to 'Build' under the matlabroot (e.g. c:\MATLAB\R2015b\matlab\toolbox\psp\pixhawk\examples) directory. Therefore it is recommended to COPY the example models to a user working directory outside the MATLAB root. There is a copy of these models made at the c:\px4\SimulinkExamples directory when the PSP is installed. The user can navigate to this directory to work with the Simulink example models.

5.6.1 px4demo_Parameter_CSC_example.slx



The Pixhawk Px4FMUv2 uses many parameters to store and access during various operations. Much of these include sensor/actuator calibration data and are stored in flash memory which is accessible by MTD via NuttX.

You can see the list of default parameters here:
https://pixhawk.org/firmware/parameters
Guide to configuring parameters:
http://dev.px4.io/advanced-configurations.html

The Pixhawk PSP allows you to access these parameters using Embedded Coder's Custom Storage Class feature. A parameter is first defined in the MATLAB workspace with specific parameter properties which is then accessed in the generated code.

To make use of this, use the following syntax:

```
Pixhawk_CSC.Parameter( CELL_ARRAY )
```

Where CELL_ARRAY is a MATLAB cell array composed of a value (int32 or single) and a string of the parameter. For instance:

```
CAL_GYRO0_XSCALE  =  Pixhawk_CSC.Parameter(  {single(1),
'CAL_GYRO0_XSCALE'}  )
```

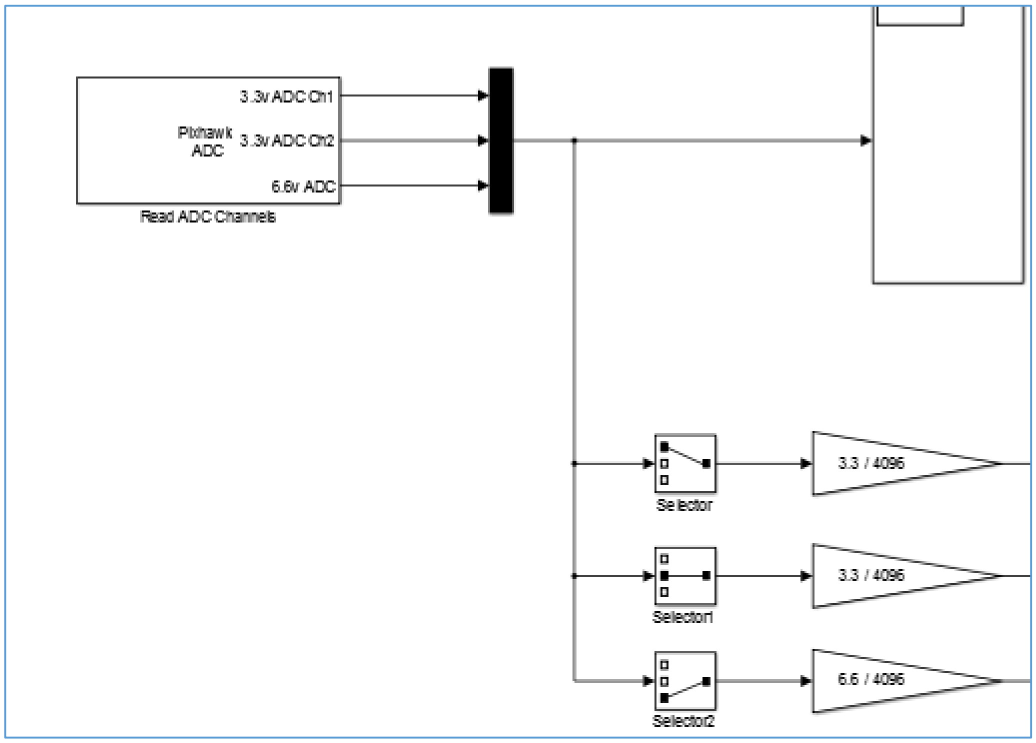
Parameters can either be int32 or single/floating precision. Please ensure you select the correct data type and the the string name matches.

Note that for the model below, all parameters have been defined in the model callback function

NOTE: This model is to be demonstrated using external mode

5.6.2 px4demo_ADC_example.slx

Select the different ADC channels through the options in the block. This block was written as a system object.

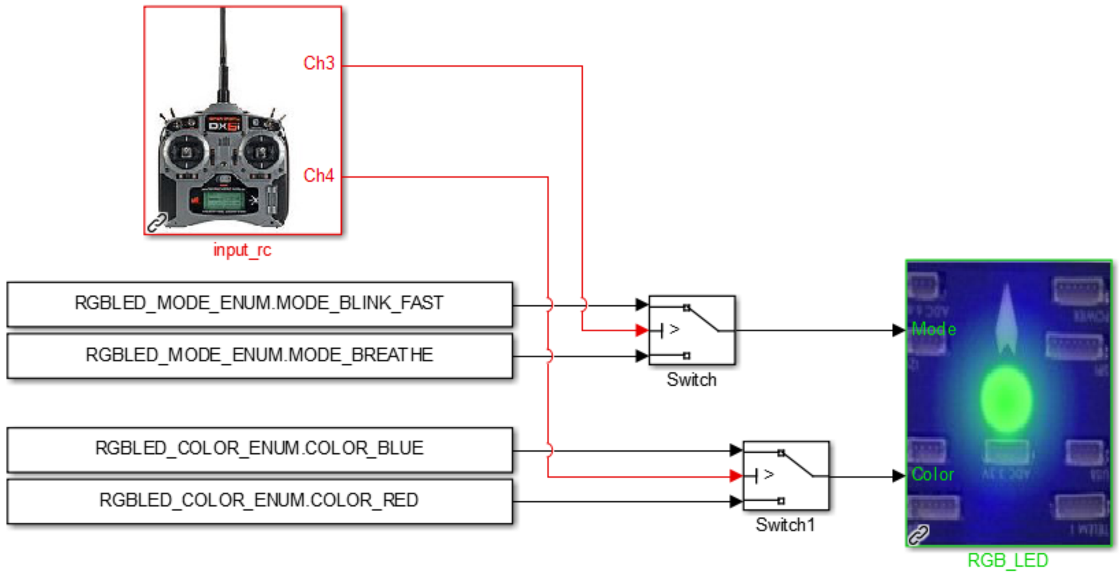


System objects are another alternate method of block authoring. The source code is written as MATLAB class. To view the source code, a link is provided in the block description.

NOTE: This model is to be demonstrated using external mode

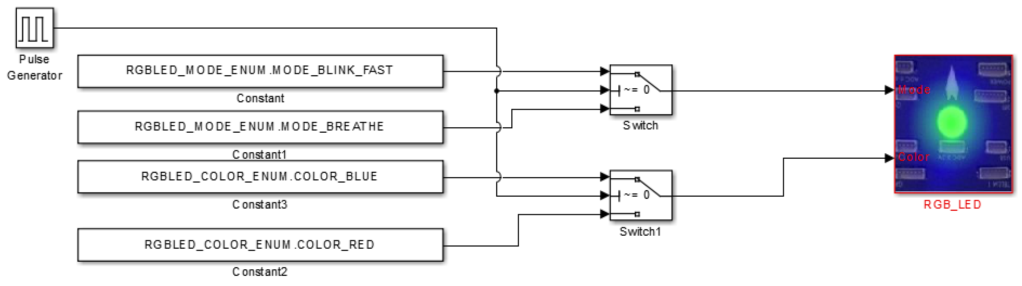
5.6.3 px4demo_input_rc.slx

This model will test the RC transmitter block. Use the RC Transmitter to control the color and mode of the RGB LED on the pixhawk. Channel 3 is typically the "Thrust" or the left vertical joystick control. Channel 4 is typically the "Yaw" or the right horizontal joystick control.


Ch3
Ch4
input_rc
RGBLED_MODE_ENUM.MODE_BLINK_FAST
RGBLED_MODE_ENUM.MODE_BREATHE
RGBLED_COLOR_ENUM.COLOR_BLUE
RGBLED_COLOR_ENUM.COLOR_RED
Switch
Switch1
Mode
Color
RGB_LED

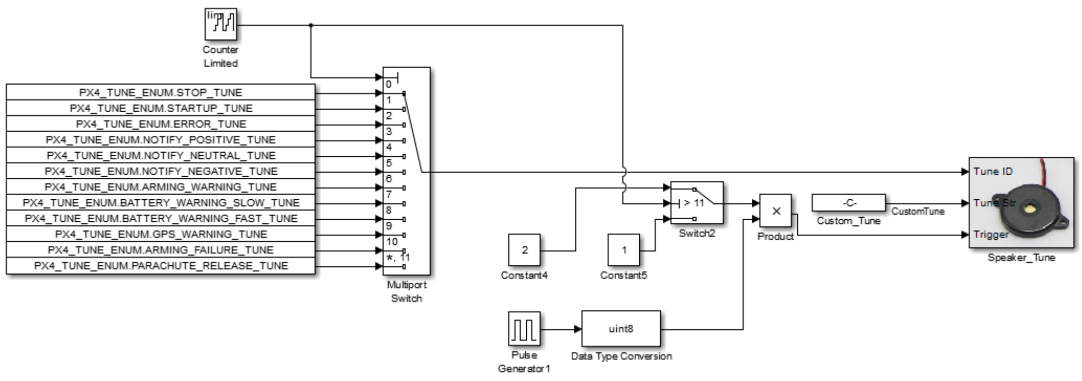
5.6.4 px4demo_rgbled.slx

A simple model that show how to program the RGB_LED library block. Every second the RGB LED changes from blinking-fast blue color to "breathing" red color.


Pulse Generator
RGBLED_MODE_ENUM.MODE_BLINK_FAST
Constant
RGBLED_MODE_ENUM.MODE_BREATHE
Constant1
RGBLED_COLOR_ENUM.COLOR_BLUE
Constant3
RGBLED_COLOR_ENUM.COLOR_RED
Constant2
Switch
Switch1
Mode
Color
RGB_LED

5.6.5 px4demo_tune.slx

To test various tunes, this model plays all the pre-defined tunes plus a user-custom tune cycling every 10 seconds.


Counter Limited
PX4_TUNE_ENUM.STOP_TUNE
PX4_TUNE_ENUM.STARTUP_TUNE
PX4_TUNE_ENUM.ERROR_TUNE
PX4_TUNE_ENUM.NOTIFY_POSITIVE_TUNE
PX4_TUNE_ENUM.NOTIFY_NEUTRAL_TUNE
PX4_TUNE_ENUM.NOTIFY_NEGATIVE_TUNE
PX4_TUNE_ENUM.ARMING_WARNING_TUNE
PX4_TUNE_ENUM.BATTERY_WARNING_SLOW_TUNE
PX4_TUNE_ENUM.BATTERY_WARNING_FAST_TUNE
PX4_TUNE_ENUM.GPS_WARNING_TUNE
PX4_TUNE_ENUM.ARMING_FAILURE_TUNE
PX4_TUNE_ENUM.PARACHUTE_RELEASE_TUNE
0
1
2
3
4
5
6
7
8
9
10
*, 11
Multiport Switch
2
Constant4
1
Constant5
> 11
Switch2
×
Product
-C-
Custom_Tune
CustomTune
Tune ID
Tune Str
Trigger
Speaker_Tune
Pulse Generator1
uint8
Data Type Conversion

5.6.6 px4demo_gps.slx

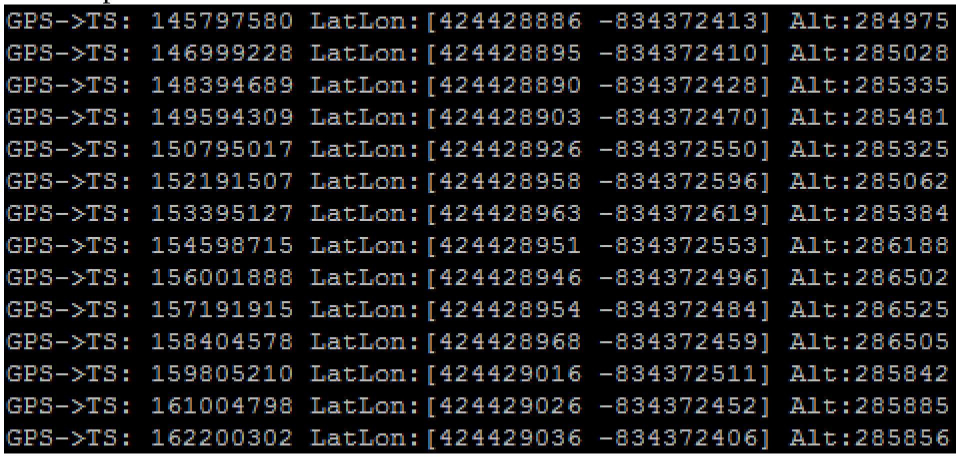
A test model has been provided to test out the GPS Block. This model will print out information to a terminal window once a second and the RGB LED will "breathe" Green. You will need to establish a serial terminal connection to the PX4 hardware with a program such as TerraTerm or PuTTY. If you do not manually start the ***px4_simulink_app*** (rather have it start at boot-up time), then you will need to stop it, then re-start it with these commands (since there is no stdout console available at boot-up time the printf statements in the code can't output any text):

```
nsh> px4_simulink_app stop
```

then

```
nsh> px4_simulink_app start
```

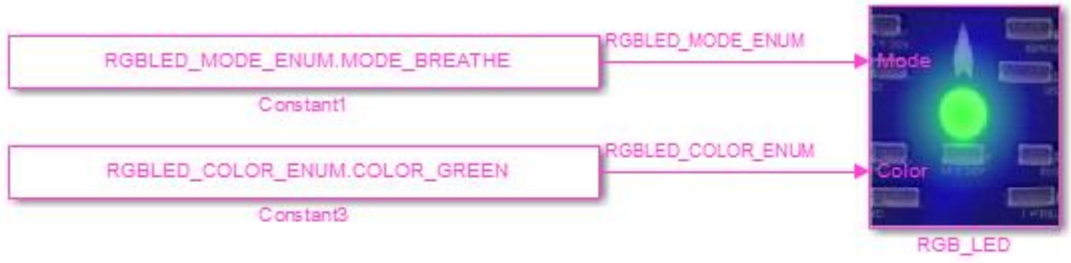
The output will look similar to this:

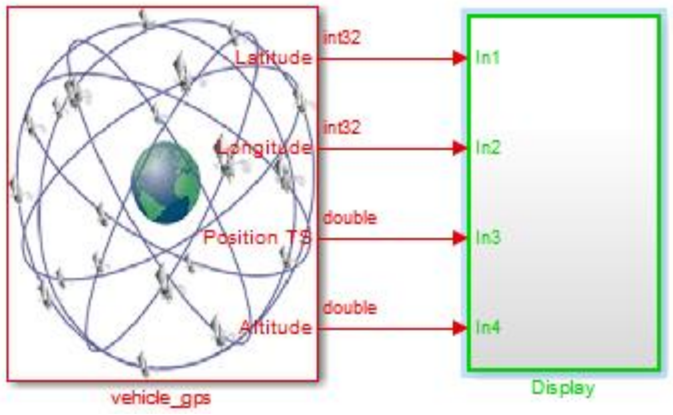


```
GPS->TS: 145797580 LatLon:[424428886 -834372413] Alt:284975
GPS->TS: 146999228 LatLon:[424428895 -834372410] Alt:285028
GPS->TS: 148394689 LatLon:[424428890 -834372428] Alt:285335
GPS->TS: 149594309 LatLon:[424428903 -834372470] Alt:285481
GPS->TS: 150795017 LatLon:[424428926 -834372550] Alt:285325
GPS->TS: 152191507 LatLon:[424428958 -834372596] Alt:285062
GPS->TS: 153395127 LatLon:[424428963 -834372619] Alt:285384
GPS->TS: 154598715 LatLon:[424428951 -834372553] Alt:286188
GPS->TS: 156001888 LatLon:[424428946 -834372496] Alt:286502
GPS->TS: 157191915 LatLon:[424428954 -834372484] Alt:286525
GPS->TS: 158404578 LatLon:[424428968 -834372459] Alt:286505
GPS->TS: 159805210 LatLon:[424429016 -834372511] Alt:285842
GPS->TS: 161004798 LatLon:[424429026 -834372452] Alt:285885
GPS->TS: 162200302 LatLon:[424429036 -834372406] Alt:285856
```

The top-level model is simple. The Display Subsystem has a MATLAB Block which shows how to print information (text strings) to the console if you want to include some debug outputs in your model. User should be careful not to run any standard output to the console at the high base rate, but rather put it in a slower rate (e.g. 1

second sample time) as illustrated with the different colors in the model (Red = fast rate, Green = slow rate).

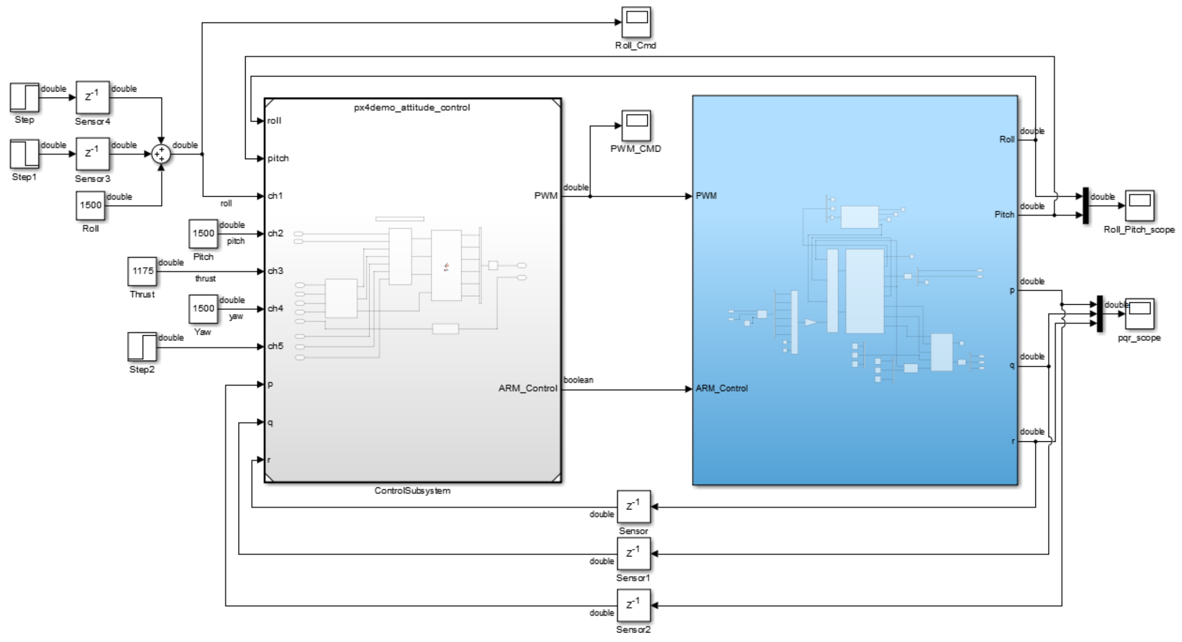




5.6.7 px4demo_attitude_plant.slx

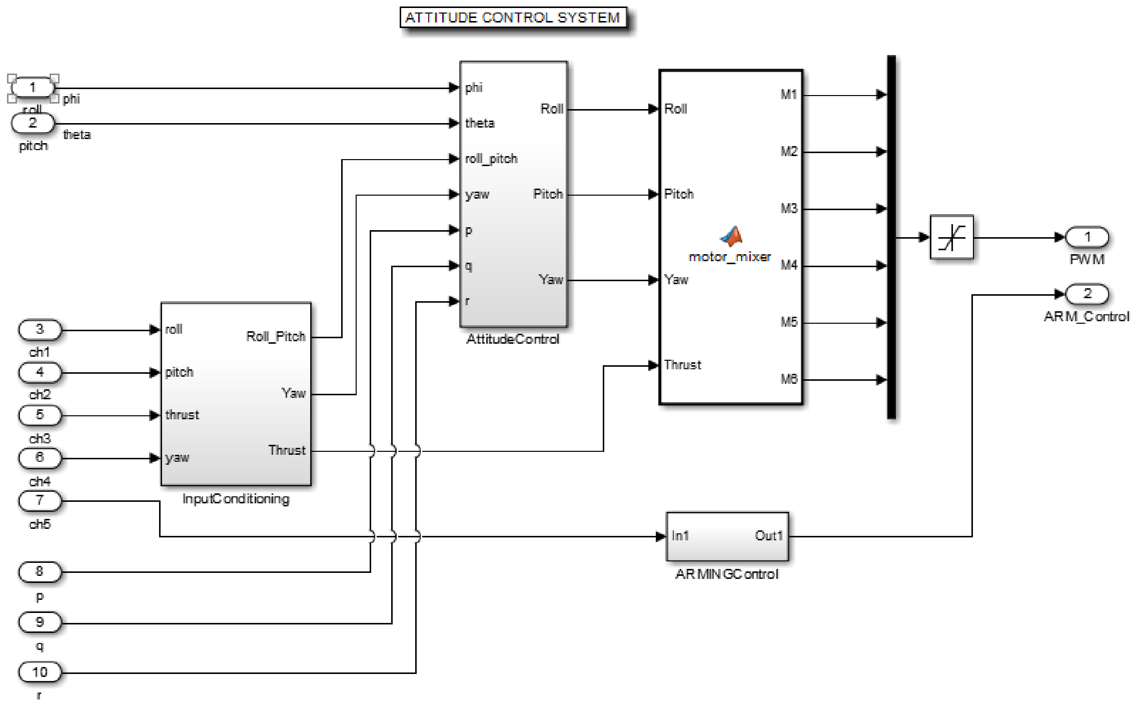
In order to design and simulation your flight control you will need a test-bench model. It is recommended that you create your test bench model that will provide the stimulus and plant/environment/feedback behavior for your flight control and use a Model (Reference) Block for your control system model.

Here is an example of a model to simulate an attitude control system:



5.6.8 px4demo_attitude_control.slx

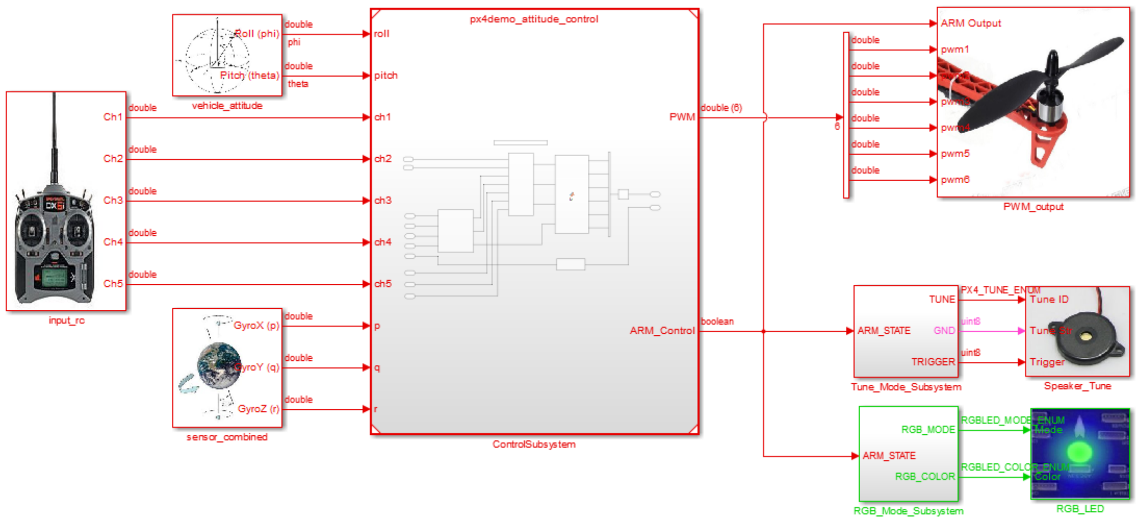
This model contains the heart of the attitude flight control model. It should have the identical configuration parameters as the parent model.



5.6.9 px4demo_attitude_system.slx

After the flight control system has been successfully simulated, it can be used in an "implementation" model that the user can use to generate code and deploy to the Pixhawk PX4 hardware.

Here is the same Control Model referenced in a system model for deployment. The RED/GREEN colors indicate the different sample rates of the model (RED = 250Hz, GREEN = 2Hz).



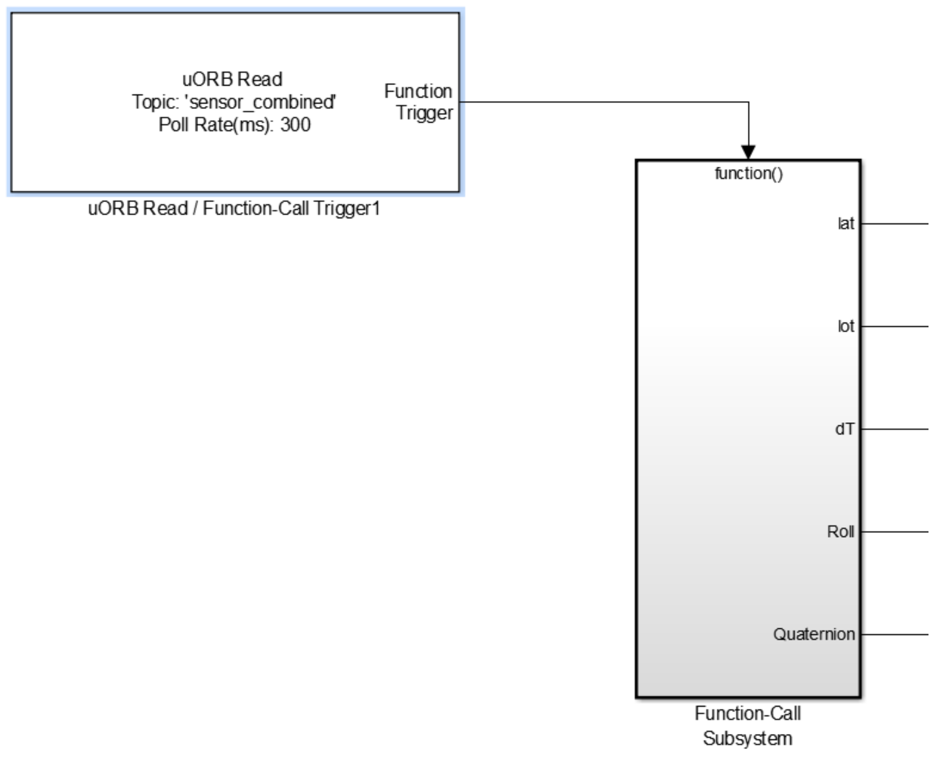
5.6.10 px4demo_fcn_call_uorb_example.slx

This model demonstrates a function-call subsystem approach to modeling using triggered subsystems. This can be used to model this type of control architecture seen here:

https://github.com/PX4/Firmware/blob/master/src/modules/mc_att_control/mc_att_control_main.cpp

In this scheme, the control algorithm is driven by sensor updates. A variable is used to keep track of the time between updates such that the control terms such as Derivative and Integral can be computed accurately. Although these sensor updates are configured to come in at regular intervals, this approach accounts for any small differences in time due to jitter imprecision.

Inside the function-call subsystem, we read out the data from the sensor update event from a source block. The data can then be subsequently processed upon reception of the data. Because of this control structure, this event-driven control logic is considered to be asynchronous. If you check the sample times of the model you can see that this subsystem is configured this way.

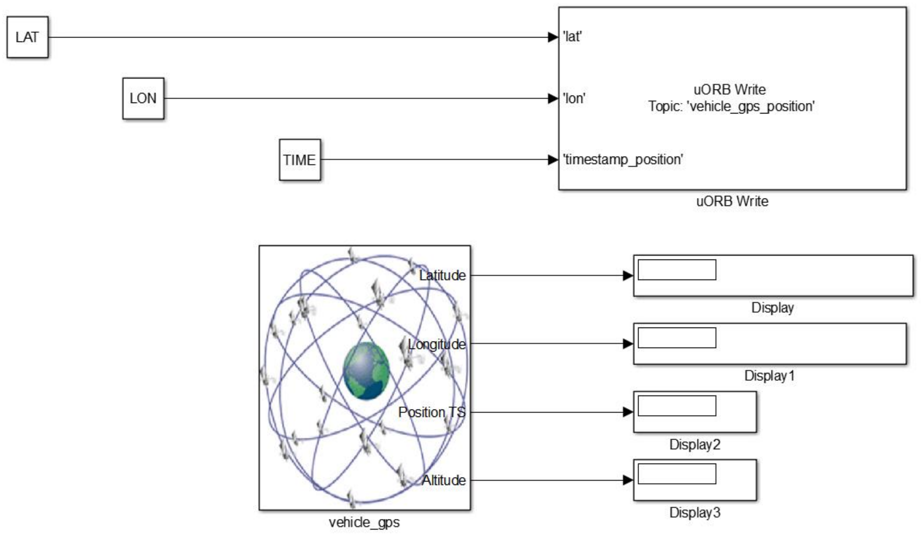


NOTE: This model is to be demonstrated using external mode

5.6.11 px4demo_write_uorb_example.slx

This model demonstrates how one can write data to uORB topics. The uORB write block writes to the struct elements 'lat','lon' and 'timestamp' to the GPS topic. The GPS block then outputs the same value we are writing to by first advertising the GPS topic and then publishing data. You can define whatever topic to write to and its individual struct elements

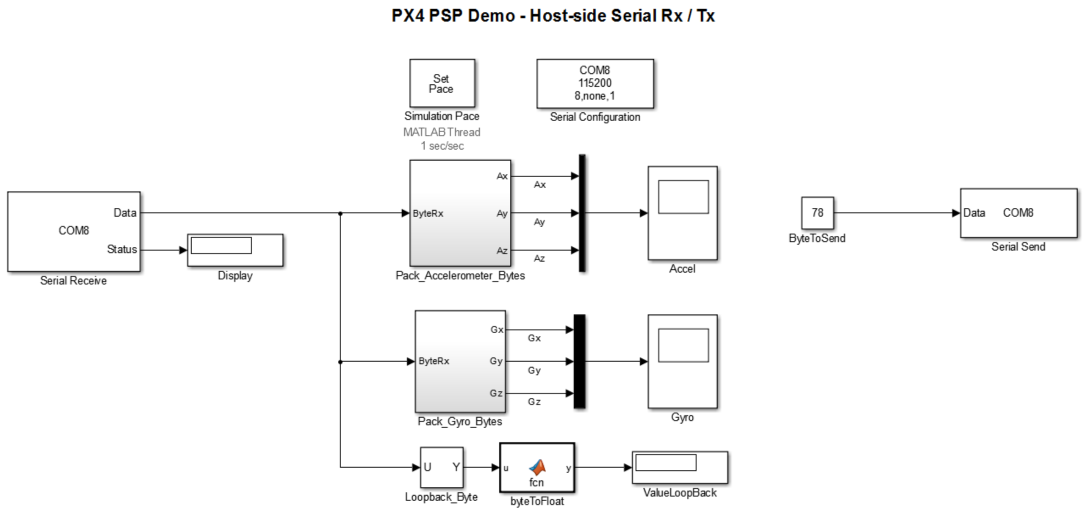
1) Define LAT, LON and TIME in the MATLAB work-space with assigned values. Ensure they are matching data types to what the block expects.
2) Run in external mode
3) Tune values LAT, LON and TIME and watch the values change in the display from the output of the GPS block



NOTE: This model is to be demonstrated using external mode

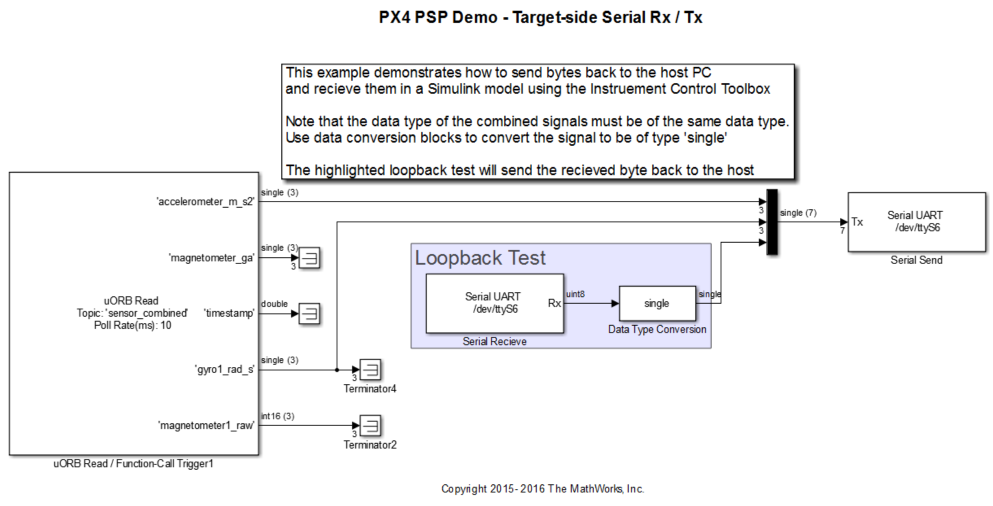
5.6.12 Serial Communication

Two models have been provided to demonstrate how to setup serial communication px4demo_HostSerial_TxRx.slx



This model does not undergo code generation, it resides on the host PC and is responsible for sending/receiving data to the Pixhawk Px4FMU over serial. The scopes will show accelerometer and gyro readings. A loopback display block is used to show the value that we send to the Pixhawk is sent back.

px4demo_Serial_TxRx.slx


PX4 PSP Demo - Target-side Serial Rx / Tx

This example demonstrates how to send bytes back to the host PC
and recieve them in a Simulink model using the Instrument Control Toolbox

Note that the data type of the combined signals must be of the same data type.
Use data conversion blocks to convert the signal to be of type 'single'

The highlighted loopback test will send the recieved byte back to the host

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This model is the one that will be deployed the Pixhawk FMU. It will fetch data from a uORB topic and send it off over serial (ttyS6). Loopback data is received and sent back into the serial send block.

6 Building your own custom Simulink Block

There are several reasons you may want to consider building your own Simulink block. The most common reason is the need to interface generated code with custom code. This could be to interface with driver code which talks to various sensors/actuators or to send data over to another interface. Whatever the reason may be, MATLAB and Simulink offers many ways to accomplish the same goal here.

6.1.1 S-Function Approach

All the blocks in this Pilot Support Package were created by writing S-functions with TLC and System Objects.

There are many ways to create S-Functions and the accompanying TLC code.

- Write it by hand along with the TLC from scratch
- Use S-function builder
- Use Legacy Code Tool to interface to existing hand-written code.
- Use a combination of all of the above. S-function builder or Legacy Code Tool can be used to create a starting point for you to start modifying the S-function MEX source file as well as the TLC.

We have provided an example in this version of the PSP (C-MEX and TLC) for users to learn from. Please See:

\examples\BlockCreation\

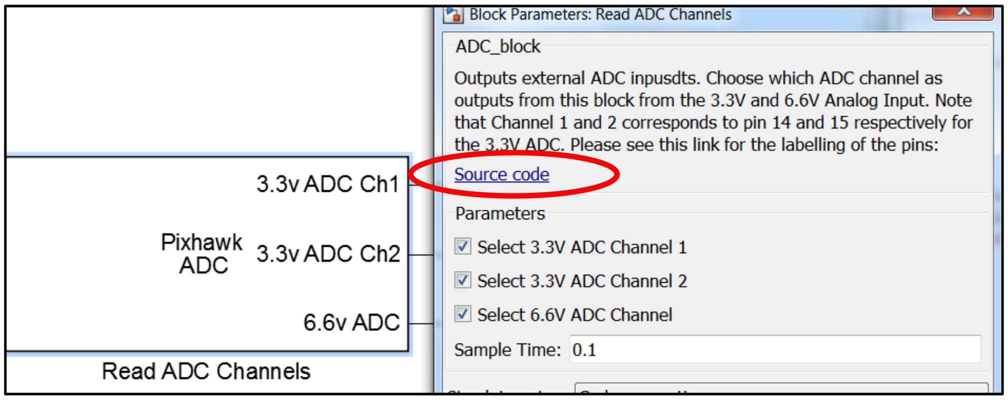
Apply the MEX command on the sfun_px4_battery_example.cpp block to generate a valid MEX file for the S-function. Use this block as an example as to how to create blocks with S-Functions.

For more documentation on S-Functions, please see:
http://www.mathworks.com/help/releases/R2016a/rtw/block-authoring.html

6.1.2 MATLAB Function blocks and System Objects

The logging block was written using a MATLAB Function block. MATLAB Coder syntax is used to describe the interface to hand-code. Please examine the contents of this block for more information on how this was accomplished

Another method that exists is through the use of System Objects. These types of blocks make use of MATLAB Coder's capability of transforming MATLAB Code into C-code. System Objects are written using an object-oriented approach. Please see the ADC and Serial blocks as examples of how to write such blocks.



ADC_block

Outputs external ADC inpusdts. Choose which ADC channel as outputs from this block from the 3.3V and 6.6V Analog Input. Note that Channel 1 and 2 corresponds to pin 14 and 15 respectively for the 3.3V ADC. Please see this link for the labelling of the pins:

Parameters

☑ Select 3.3V ADC Channel 1
☑ Select 3.3V ADC Channel 2
☑ Select 6.6V ADC Channel

Sample Time: 0.1

Click on the 'Source code' hyperlink to open up the MATLAB System Object code for these types of blocks.

For more information on MATLAB Coder and System Objects, please also see:

https://www.mathworks.com/help/simulink/ug/creating-an-example-model-that-uses-a-matlab-function-block.html

https://www.mathworks.com/help/simulink/slref/coder.ceval.html

https://www.mathworks.com/help/simulink/system-objects.html

7 Limitations

Also, the supplied Simulink blocks do not support any simulation behavior. These are merely there to provide code generation to interface the control system to the actual hardware drivers necessary in the firmware. It is advised that you use **Model Referencing** to separate your control system so that you can re-use the model in your simulation as well as the implementation model (used for code generation).

Currently, the optimization option "**Inline Parameters**" must be turned on. This eliminates the use of global data being created which has shown to cause compilation errors due to limited global memory space.

7.1.1 Support for HIL / Mavlink

We currently do not support interactions with HIL or Mavlink with the px4_simulink_app. This is something we wish to investigate in the future and will require significant changes / updates to the way we generate code for this application. Additional code will need to be added to each of the blocks to allow routing of signals when in a HIL environment. If you have suggestions or contributions to help in this area, please feel free to reach out to MathWorks Pilot Engineering.

7.1.2 Supporting C++ uORB Message Data Structures

The current uORB read block is only able to convert uORB messages into Simulink bus objects if the topic is not treated as a C++ object. Several messages are treated as a C++ object where the data structure will not be compatible in C. At the moment, we only generate C code for ***px4_simulink_app***. This means that thing such as memcopies or memory layout cannot be assumed to be contagious. Here's an example of a uORB topic that uses C++ notation.

Message File: **battery_status.msg**

```
uint64 timestamp        # microseconds since system boot, needed to integrate
float32 voltage_v       # Battery voltage in volts, 0 if unknown
float32 voltage_filtered_v  # Battery voltage in volts, filtered, 0 if unknown
float32 current_a       # Battery current in amperes, -1 if unknown
float32 current_filtered_a  # Battery current in amperes, filtered, 0 if unknown
float32 discharged_mah      # Discharged amount in mAh, -1 if unknown
float32 remaining       # From 1 to 0, -1 if unknown
int32 cell_count        # Number of cells
bool connected          # Wether or not a battery is connected
#bool is_powering_off       # Power off event imminent indication, false if
unknown


uint8 BATTERY_WARNING_NONE = 0       # no battery low voltage warning active
uint8 BATTERY_WARNING_LOW = 1        # warning of low voltage
uint8 BATTERY_WARNING_CRITICAL = 2   # alerting of critical voltage

uint8 warning    # current battery warning
```

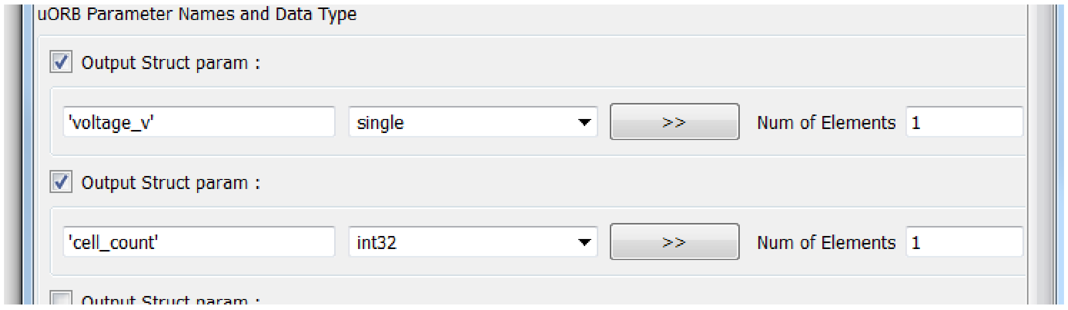
The header file which gets generated looks something like this:
C:\px4\Firmware\build_px4fmu-v2_default\src\modules\uORB\topics\battery_status.h

```
#ifdef __cplusplus
struct __EXPORT battery_status_s {
#else
struct battery_status_s {
#endif
	uint64_t timestamp;
	float voltage_v;
	float voltage_filtered_v;
	float current_a;
	float current_filtered_a;
	float discharged_mah;
	float remaining;
	int32_t cell_count;
	bool connected;
	uint8_t warning;
#ifdef __cplusplus
	static const uint8_t BATTERY_WARNING_NONE = 0;
	static const uint8_t BATTERY_WARNING_LOW = 1;
	static const uint8_t BATTERY_WARNING_CRITICAL = 2;

#endif
};
```

Because the battery_status uORB topic was written in C++ we see non-C struct notation with `BATTERY_WARNING_NONE`, `BATTERY_WARNING_LOW` and `BATTERY_WARNING_CRITICAL`. Because the PixhawkPSP generates C code we cannot assume instantiate this struct and copy data elements such as `BATTERY_WARNING_NONE` over like a normal C struct without getting a compiler error. These variables must be treated as a 'singleton' or global.

We have provided a block which is similar to the uORB read block in the current library but supports the ability to access struct elements from a C++ uORB object, however, the ability to actually read the global elements is not supported. Please look at the example inside: **\blocks\ExtraLibSupport**

Example:


uORB Parameter Names and Data Type

☑ Output Struct param :

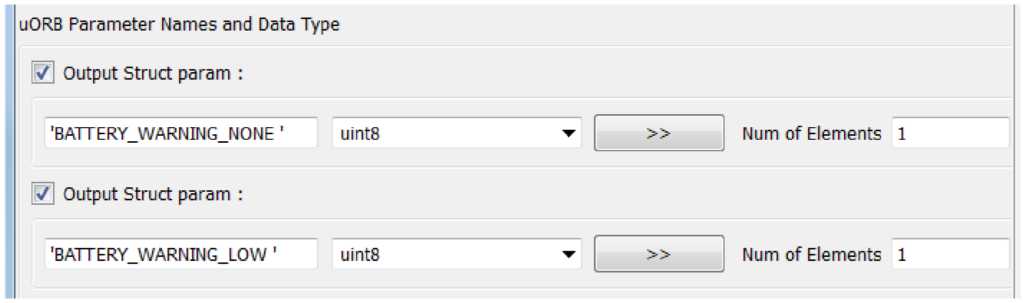
'voltage_v' | single | >> | Num of Elements 1

☑ Output Struct param :

'cell_count' | int32 | >> | Num of Elements 1

☐ Output Struct param :

However, attempting to do this:


uORB Parameter Names and Data Type

[✓] Output Struct param :

'BATTERY_WARNING_NONE ' uint8 >> Num of Elements 1

[✓] Output Struct param :

'BATTERY_WARNING_LOW ' uint8 >> Num of Elements 1

Will result in compiler error. Therefore, the official shipped version of the uORB read block that uses bus objects will reject these types of data structures completely while this version of the block will still allow you to use any data structure.

If you wish to support the C++ global member variables such as the one in the example above, you will probably need to write your own block that does a copy of data from a C++ struct into local C variables. This function/code could live inside a C++ source file and gets used only if the topic will contain C++ data-structures. Consult the previous chapter on block creation for more tips on how to do this as well. This may be addressed in a future version of the PSP.

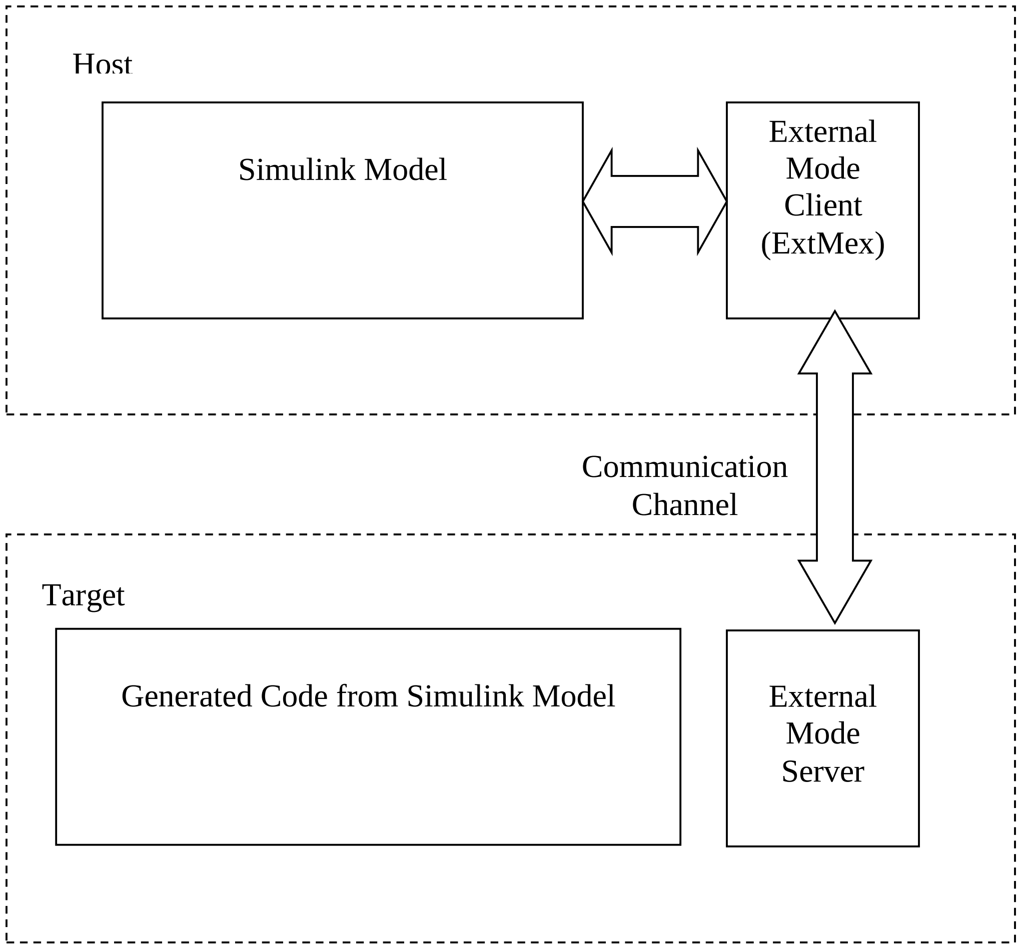
8 Updating to a new version of Pixhawk PSP

There may be times when a new version of the Pixhawk PSP will need to be installed. This could be based on newer versions of Simulink being released, bug fixes, new blocks or enhancements of both the base product and the PSP.

If you run into any issues with the use of this PSP please contact your MathWorks sales representative or Pilot Engineering group directly. Do not go through technical support for issues with this PSP. Do go through technical support for issues related to MATLAB/Simulink outside the scope of this PSP.

9 Using External Mode with the Pixhawk PSP

9.1 What is External Mode?



External mode is a way in which one can examine execution and “tune” the generated code from your standard desktop environment. This feature comes with Embedded Coder and can greatly enhance debugging capabilities or interactive testing through tuning of model parameters. For instance, suppose you wanted to know the output value of a certain signal at each time step of the simulation. One could implement this by modifying the generated code to execute a “printf” of that signal value manually or create a block to do this (we actually provide this for you), however, this can be cumbersome. External mode can alleviate this by not only displaying the value of the signal from the generated code in a scope in the Simulink environment, but it also enables you to log that signal and record it to your host PC as a MAT file as well. One way to think of external mode is that your Simulink model now becomes a “user-interface” that interacts with the generated code during execution, instead of the play button playing a simulation on your host machine the play button now begins execution of embedded code.

This mode is not to be confused with Hardware-in-the-Loop or Processor-in-the-Loop. External mode works by establishing a communication channel between the host PC and the embedded system you are targeting. MathWorks provides all the necessary source files for both TCP/IP and Serial communication – in the case with the Px4FMU we are using serial communication.

The generated code and the Simulink infrastructure have the necessary source files and shared libraries to do this for you without having you manually modify the code itself. For more information, please see:
http://www.mathworks.com/help/rtw/ug/external-mode-communication_f1028013.html

9.2 Some important considerations:

External mode can be a potentially taxing process since it needs to transfer data back and forth to the PC as well as wait for user commands to start/stop execution of the model as well as tuning of parameters. Because of the limited resources on the Px4FMU, it is highly recommended to NOT use external mode for flight tests. Due to limited RAM on the system, the amount of data transferred back must be reduced considerably at each execution time-step, therefore, some special modifications to some user settings must be made. More detail will be covered on this down below.

Note that if you are just interested in logging data rather than viewing data as the system is running and tuning parameters then you may want to consider data logging. A Simulink block is being developed for this in the Pixhawk Library browser.

Important Note: Recent testing has confirmed that external mode does not operate correctly with the telemetry radios. Data comes in very sporadically and in long intervals. We are looking into this and will provide an update to address the issue, in the mean-time, please use USB for serial connection for external mode.

10 External Mode Tutorial Part 1:

10.1 Viewing Signals from the generated Code

Serial port setup:

Before running External Mode, you should be familiar with the serial ports offered by the hardware. The Px4FMUv2 comes with a variety of different options. To see which serial ports you may want to use consult these pages here:
https://pixhawk.org/users/wiring
https://pixhawk.org/dev/wiring

Note: some serial ports are reserved and cannot/should not be used, such as ttyS0 which is a serial debug console port. Please consult above links for information on this.

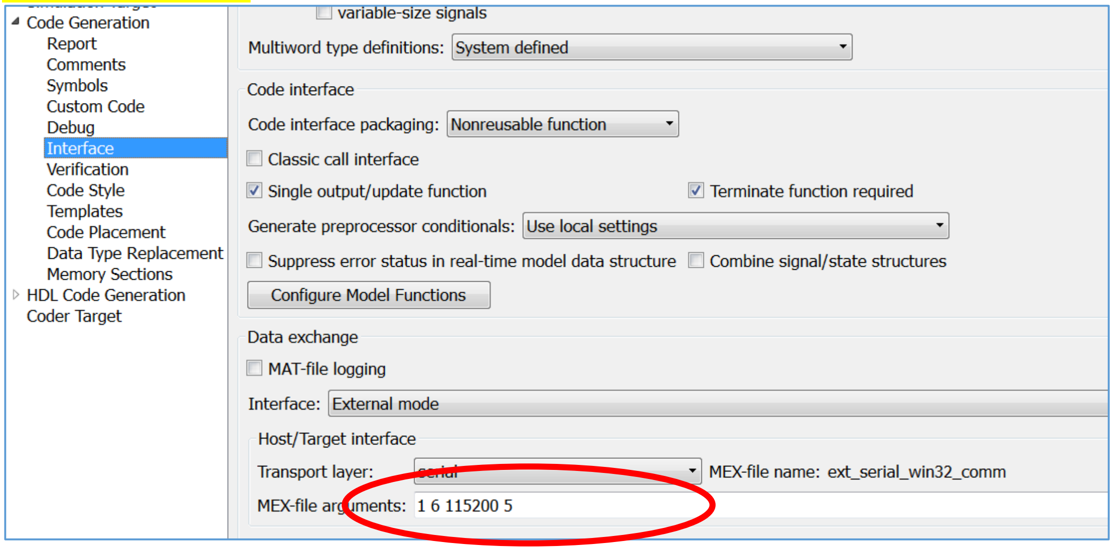
Suppose you wanted to use the standard USB programming cable for external mode. In this case, ttyACM0 becomes a free serial port to be used by external mode and ttyS6 be a serial console shell. Here is one example of one would modify their rc.txt file to do this:

```
#sercon - in the latest release sercon already gets called
usleep 1000
uorb start
usleep 1000
#nshterm /dev/ttyACM0 & #Disable the USB serial console
usleep 1000
px4io start
usleep 1000
#commander start
#usleep 1000
#mavlink start -d /dev/ttyS1 -b 115200
#usleep 5000
#dataman start
#usleep 1000
#navigator start
#usleep 1000
sh /etc/init.d/rc.sensors
usleep 1000
#sh /etc/init.d/rc.logging
#usleep 1000
#gps start
#usleep 1000
#attitude_estimator_ekf start - the latest release does not use this anymore
ekf_att_pos_estimator start
usleep 1000
#attitude_estimator_so3 start
#usleep 1000
#mavlink start -d /dev/ttyS3 -b 115200
mtd start
usleep 1000
param load /fs/mtd_params
usleep 1000
rgbled start
usleep 1000
#px4_simulink_app start #disable automatic starting up of the model
nshterm /dev/ttyS6 & #this will make ttyS6 the serial console
exit
```

In the above example, ttyS6 (serial port 4) and the USB port we typically use to access the serial console is now a free serial port we can use to establish data exchange in external mode. Note that in the example I am doing in this tutorial, I have ttyS6 connected to a USB FTDI connector which will allow my Windows machine to access the serial shell over USB. Other options could include using the telemetry radios to establish external mode which would be different serial ports than the ones mentioned here.–

10.2 Model Configuration Setup:

The next step after choosing a serial port is to now configure Simulink to use the port of choice. Open up the model
ext_mode_intro.slx



variable-size signals

Multiword type definitions: System defined

Code interface

Code interface packaging: Nonreusable function

Classic call interface

✓ Single output/update function ✓ Terminate function required

Generate preprocessor conditionals: Use local settings

Suppress error status in real-time model data structure Combine signal/state structures

Data exchange

MAT-file logging

Interface: External mode

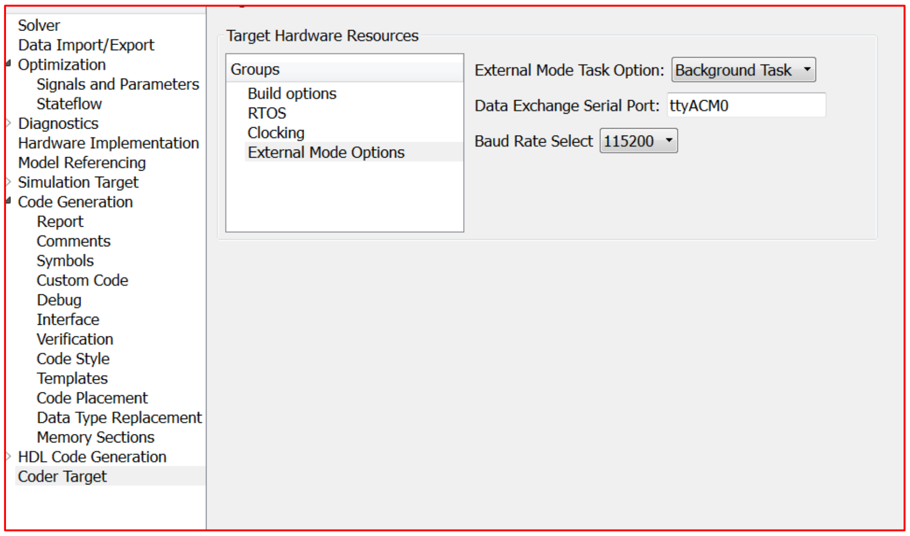
Host/Target interface

Transport layer: serial MEX-file name: ext_serial_win32_comm

MEX-file arguments: 1 6 115200 5

To configure Windows to talk to the Px4FMU, click on the interfaces section in Code Generation, then click on Interface, then under MEX-file Arguments you want to type in the following syntax
1 <COMPORT#> <BAUDRATE> <TIMEOUT>
The '1' value in the front is to indicate that the generated code will wait for the host before starting execution. This is highly recommended.
<COMPORT#> - this is the COM port of the USB connection which connects the PC and the Px4FMU
<BAUDRATE> - Specify a baud rate here. Note that radios are set to run on 57600
<TIMEOUT> - Specify the amount of time it takes to wait for establishing a connection before timing out. 5 seconds should be sufficient

Next, we want to configure the generated code to use the correct serial port on the firmware. In this example, this is ttyACM0



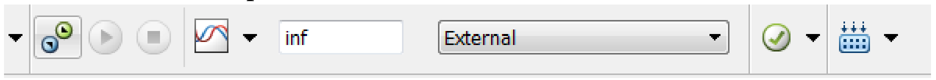
External Mode Task Option: Background Task
Data Exchange Serial Port: ttyACM0
Baud Rate Select 115200

Click on the Coder Target menu and then select external mode options. Click on the Baud Rate Select button drop-down to select a baud rate and specify the data exchange serial port as 'ttyACM0'

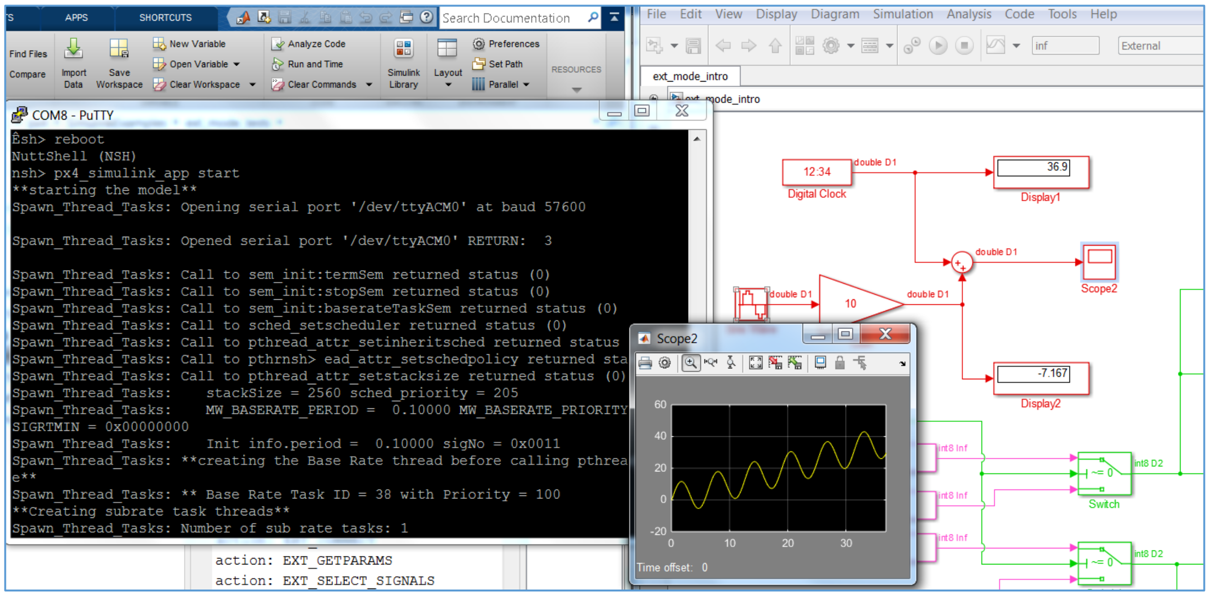
10.3 *Running the example model*

The next step is to run the model. This involves a couple of steps:

1) Pressing the build button (ctrl+B) to generate code, compile it, and then having it transferred to the PX4FMU
2) Running the model. Open up the serial shell to access the command line and start the model by typing 'px4_simulink_app start'
   The model will not actually begin execution yet until receiving a start packet from external mode, this is done in the next step
3) Ensure that the drop-down menu is set to 'External'

   After, click on the "Connect To Target" button on the left of the above diagram. This will establish connection after a few seconds. Finally, press the green play button to the right. You will now be able to see data appear in the Simulink model in the generated code.



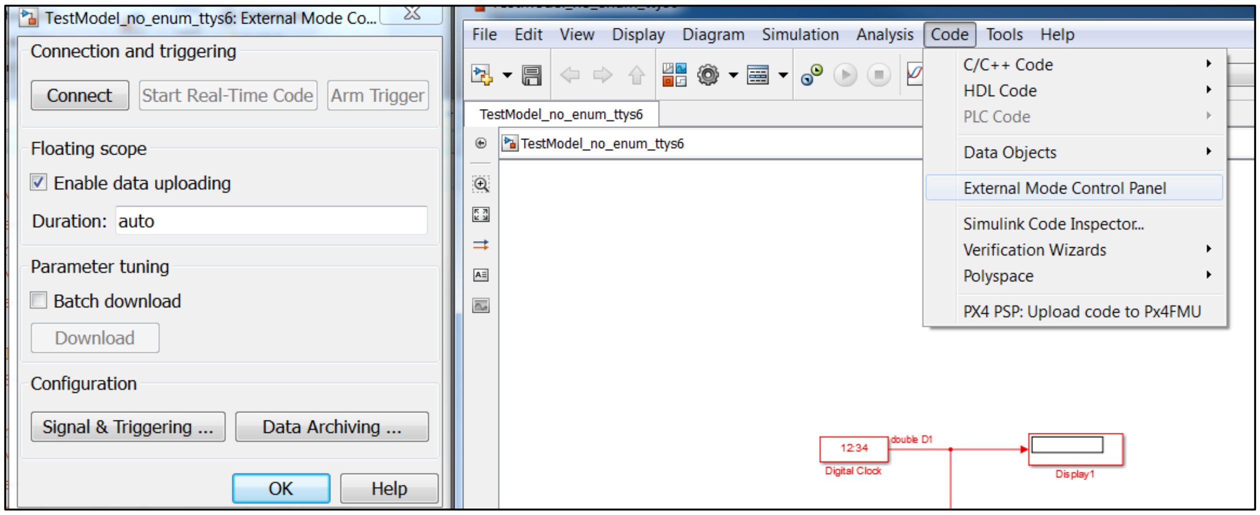
```
Êsh> reboot
NuttShell (NSH)
nsh> px4_simulink_app start
**starting the model**
Spawn_Thread_Tasks: Opening serial port '/dev/ttyACM0' at baud 57600

Spawn_Thread_Tasks: Opened serial port '/dev/ttyACM0' RETURN:  3

Spawn_Thread_Tasks: Call to sem_init:termSem returned status (0)
Spawn_Thread_Tasks: Call to sem_init:stopSem returned status (0)
Spawn_Thread_Tasks: Call to sem_init:baserateTaskSem returned status (0)
Spawn_Thread_Tasks: Call to sched_setscheduler returned status (0)
Spawn_Thread_Tasks: Call to pthread_attr_setinheritsched returned status
Spawn_Thread_Tasks: Call to pthrnsh> ead_attr_setschedpolicy returned sta
Spawn_Thread_Tasks: Call to pthread_attr_setstacksize returned status (0)
Spawn_Thread_Tasks:    stackSize = 2560 sched_priority = 205
Spawn_Thread_Tasks:    MW_BASERATE_PERIOD =  0.10000 MW_BASERATE_PRIORITY
SIGRTMIN = 0x00000000
Spawn_Thread_Tasks:    Init info.period =  0.10000 sigNo = 0x0011
Spawn_Thread_Tasks: **creating the Base Rate thread before calling pthrea
e**
Spawn_Thread_Tasks: ** Base Rate Task ID = 38 with Priority = 100
**Creating subrate task threads**
Spawn_Thread_Tasks: Number of sub rate tasks: 1
```

```
action: EXT_GETPARAMS
action: EXT_SELECT_SIGNALS
```

4) To stop the generated code, press the stop button in the model. **If you wish to run external mode again, type 'reboot' at the serial console as well**. There is currently a limitation in which external mode code has some issues being treated as re-entrant. This will be fixed in the future – for now, **please reboot the Px4FMU in-between external mode runs.**

11 External Mode Tutorial Part 2: External Mode Control Panel

As mentioned earlier, the PX4FMU runs on a resource constrained environment. External mode can be process intensive at times depending on the circumstances. For instance, if you have a model which contains many (10-30) scopes the amount of data transferred can impact real-time performance. To assist with real-time execution of code, external mode has been automatically configured to run as a back-ground task by default. This option appears in the External Mode Control panel and doesn't need to be changed by the user. Due to limited memory, the amount of data that can be transferred back needs to be adjusted. This setting dictates a buffer size on the Px4 for each signal you are logging.


TestModel_no_enum_ttys6: External Mode Co...

Connection and triggering

Connect | Start Real-Time Code | Arm Trigger

Floating scope

[✓] Enable data uploading

Duration: auto

Parameter tuning

[ ] Batch download

Download

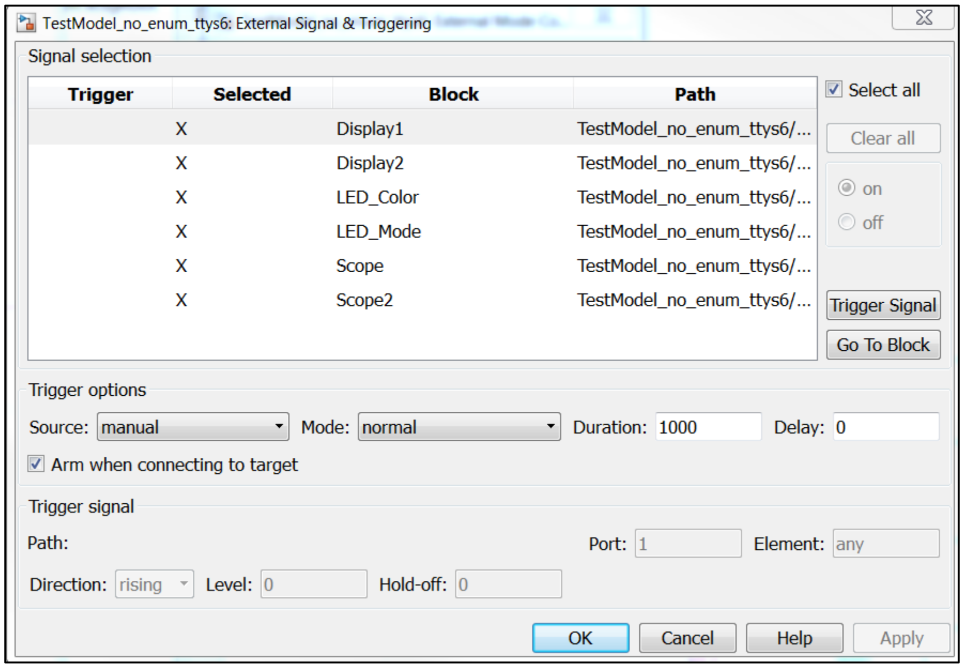
Configuration

Signal & Triggering ... | Data Archiving ...

OK | Help

File Edit View Display Diagram Simulation Analysis Code Tools Help
TestModel_no_enum_ttys6
C/C++ Code
HDL Code
PLC Code
Data Objects
External Mode Control Panel
Simulink Code Inspector...
Verification Wizards
Polyspace
PX4 PSP: Upload code to Px4FMU
12:34
Digital Clock
double D1
Display1

When clicking on the "Signal & Triggering" button you get access to all the signals that are attached to display ports. Signals marked with an X are available for viewing in external mode which you can enable/disable with the "ON" and "OFF" radial button on the right. The diagram below has the "select all" option enabled so all display/scopes will be viewable.


TestModel_no_enum_ttys6: External Signal & Triggering

Signal selection

Trigger	Selected	Block	Path
	X	Display1	TestModel_no_enum_ttys6/...
	X	Display2	TestModel_no_enum_ttys6/...
	X	LED_Color	TestModel_no_enum_ttys6/...
	X	LED_Mode	TestModel_no_enum_ttys6/...
	X	Scope	TestModel_no_enum_ttys6/...
	X	Scope2	TestModel_no_enum_ttys6/...

[✓] Select all

Clear all

[✓ on] off

Trigger Signal

Go To Block

Trigger options

Source: manual Mode: normal Duration: 1000 Delay: 0

[✓] Arm when connecting to target

Trigger signal

Path: Port: 1 Element: any

Direction: rising Level: 0 Hold-off: 0

OK | Cancel | Help | Apply

The 'Duration' value specifies the buffer size to send back to Simulink. The default value of 10000 is rather large, so in this example we have scaled it back down to 1000. A large value can impact performance of external mode – the real-time code can still run but external mode may not report back on time. Since external mode runs on a lower priority task the generated code from Simulink takes more precedence and can potentially delay external mode's transfer of data to the host machine. To avoid this, choosing a low duration value such as 1000 or 500 samples can help greatly.

Duration value dictates how many samples you'll see at each time step in the Simulink model. Duration value does not apply to all sample times, since it is based on the base-sample rate. In other words, choosing a value of 1000 means one will receive 1000 data 'ticks' of base-rate data. Here is an example:

Suppose we have a model and its fastest-sample time is 250 Hz (Ts = 0.004 seconds) and a slower rate 25 Hz (Ts = 0.04 seconds)
Suppose we choose a duration value of 400:
This means if we hook a scope up to a 250 Hz signal we will see 400 sample points appear at a time in external mode. Or in other words, (400*0.004 = 1.6 seconds) 1.6 seconds of data will appear at a time.

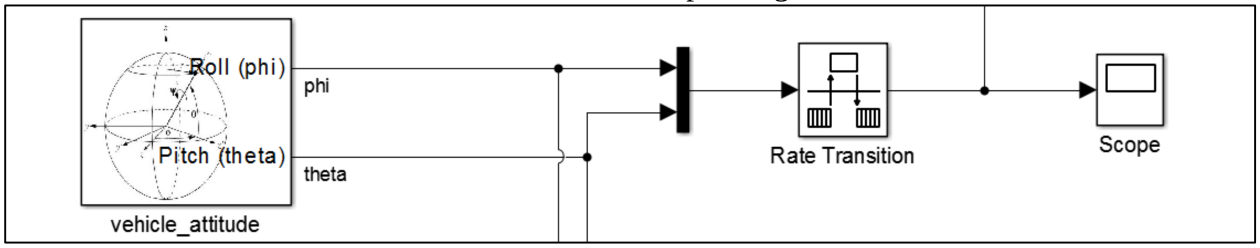
For the lower sample rate (25 Hz), 1.6 seconds of data yields 40 data points (1.6/0.04 = 40) at a time rather than 400

One should be careful to not choose a duration time that is too low. For instance, suppose I chose a duration time of 1. This means:

250 Hz: Any scope hooked up to this will give you one sample at a time
1*0.004 = 0.004 seconds of data
0.004 / 0.04 = 0 (round to floor)
A duration size must be selected which is big enough such that each time external mode delivers data back to the PC it has enough sample points for signals running on a lower sample-rate. If we chose a duration value of 1 only the 250 Hz signal will display data and the other signals will show no data (default value of zero)

11.3 *Tips for logging fast-rate signals*

Sometimes, depending on the model, there will be a noticeable delay when receiving data. This can occur if the signal if you are trying to log is running at a fast sample rate. External mode may deliver data back to the PC at a slower than desirable rate. One way to get-around this is to use a rate transition block to view a signal running at a fast rate at a slower rate. You will get less data back but this will help alleviate slow-downs – considerations and trade-offs will need to be made depending on the situation



In this example I specify a sample rate of the sensor block to 250 Hz.
If you just want sensor data, you can just hook up a scope and start logging away, however, keep in mind that you will not get real-time performance. This means that the

Simulink timer assosicated with the base-rate ticks will not keep up with real-time. Data coming in from the sensors will still update/react to physical stimuli but the time stamp of data will not be in real-time (ie: 2-3 times slower). Other sample rates will suffer as a result and not run on schedule. Performance is affected at the cost of getting more data back into the host PC.
Adding in the rate transition to slow down the sampling will help greatly as shown above.

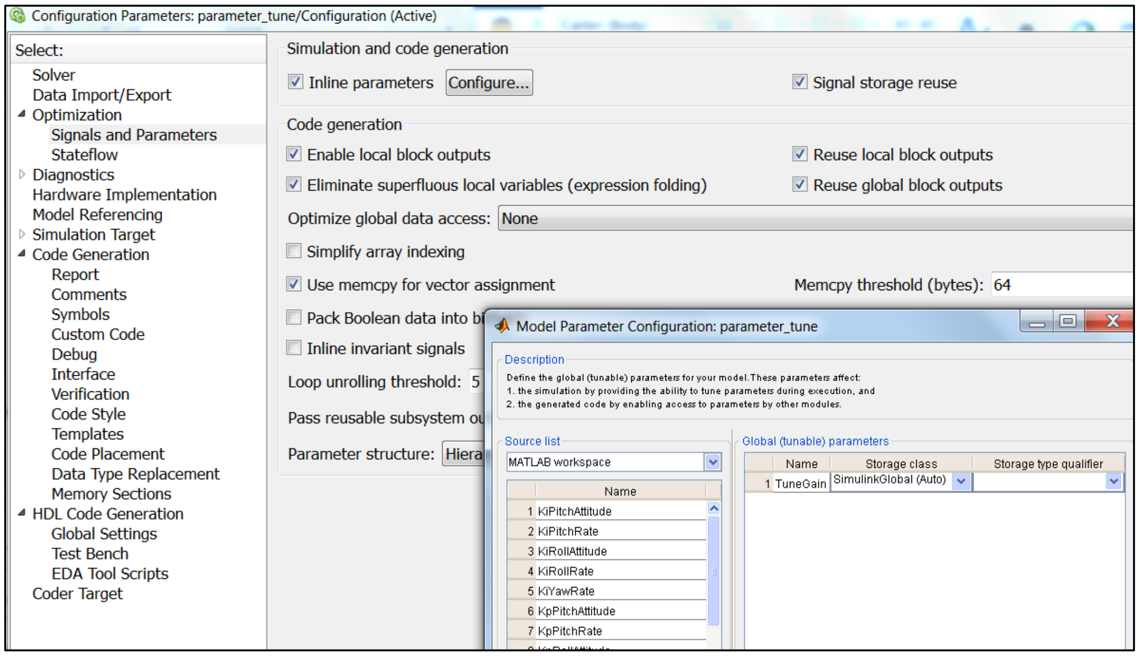
px4demo_attitude_system_multi_task.slx

11.4 Background Task vs Normal EXT Mode Behavior

This model has already been configured to use a background task and already uses a lot of the tips described in the above steps. With background tasking, the base-rate task is not encumbered by having to run external mode tasks at the same time, instead, EXT mode is now running in the background on another task being paced at 10 Hz. This can greatly help with real-time performance. Sometimes you may want to use the default behavior if you only have a single sample-time running at a slow rate - if you want data to come in faster or as fast as the model's sample-time then you'll want to use default behavior. On the other hand, if your model is running with multiple rates at varying speeds, you will want to pick the back-ground task option

12 External Mode Tutorial Part 3: Tuning parameters

Tuning parameters is one way to adjust values of the generated code Simulink while execution. In order for this to be possible, parameters must be set to tunable. Tunable parameters allow parameters to be exposed in the generated code as a global value such that an external program can have more control over it rather than having it inlined.
Due to resource constraints in global memory, parameters all Pixhawk PSP models are set to inline and will error out if you disable the inline parameter option. You can, however, select certain parameters to allow for tuning. This is done by clicking on the configure button in this menu
Configuration Parameters -> signals and parameters -> inline parameters -> configure
The example model for this section is : parameter_tune.slx



Configuration Parameters: parameter_tune/Configuration (Active)

Select:
- Solver
- Data Import/Export
- Optimization
  - Signals and Parameters
  - Stateflow
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target
- Code Generation
  - Report
  - Comments
  - Symbols
  - Custom Code
  - Debug
  - Interface
  - Verification
  - Code Style
  - Templates
  - Code Placement
  - Data Type Replacement
  - Memory Sections
- HDL Code Generation
  - Global Settings
  - Test Bench
  - EDA Tool Scripts
- Coder Target

Simulation and code generation
- ✓ Inline parameters [Configure...]
- ✓ Signal storage reuse

Code generation
- ✓ Enable local block outputs
- ✓ Reuse local block outputs
- ✓ Eliminate superfluous local variables (expression folding)
- ✓ Reuse global block outputs
- Optimize global data access: None
- ☐ Simplify array indexing
- ✓ Use memcpy for vector assignment
- Memcpy threshold (bytes): 64
- ☐ Pack Boolean data into bi
- ☐ Inline invariant signals
- Loop unrolling threshold: 5
- Pass reusable subsystem ou
- Parameter structure: Hiera

Model Parameter Configuration: parameter_tune

Description
Define the global (tunable) parameters for your model. These parameters affect:
1. the simulation by providing the ability to tune parameters during execution, and
2. the generated code by enabling access to parameters by other modules.

Source list: MATLAB workspace

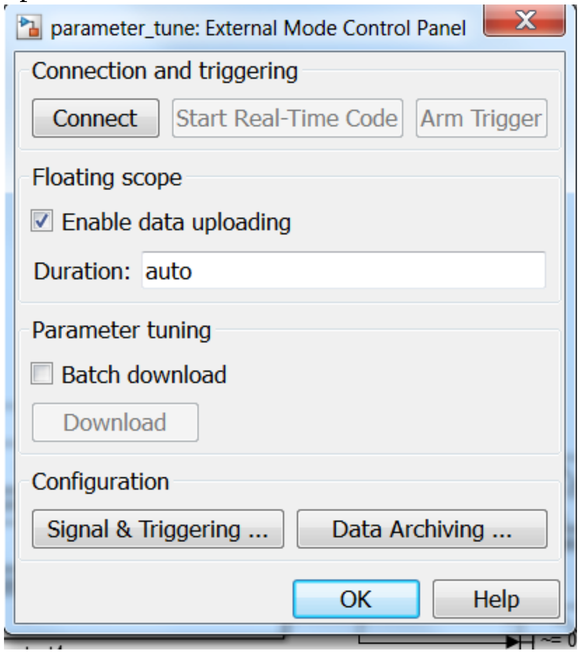
	Name
1	KiPitchAttitude
2	KiPitchRate
3	KiRollAttitude
4	KiRollRate
5	KiYawRate
6	KpPitchAttitude
7	KpPitchRate

Global (tunable) parameters

	Name	Storage class	Storage type qualifier
1	TuneGain	SimulinkGlobal (Auto)	

From this menu, you can now select parameters you wish to tune. Note that a parameter that requires tuning must have a parameter which exists in the base-workspace. In this example, the parameter is 'TuneGain' which has been selected.

To change the value of this parameter while the Simulink model is running, change the value in the base MATLAB workspace, to update the model and then bring up the External Mode Control panel



parameter_tune: External Mode Control Panel

Connection and triggering
[Connect] [Start Real-Time Code] [Arm Trigger]

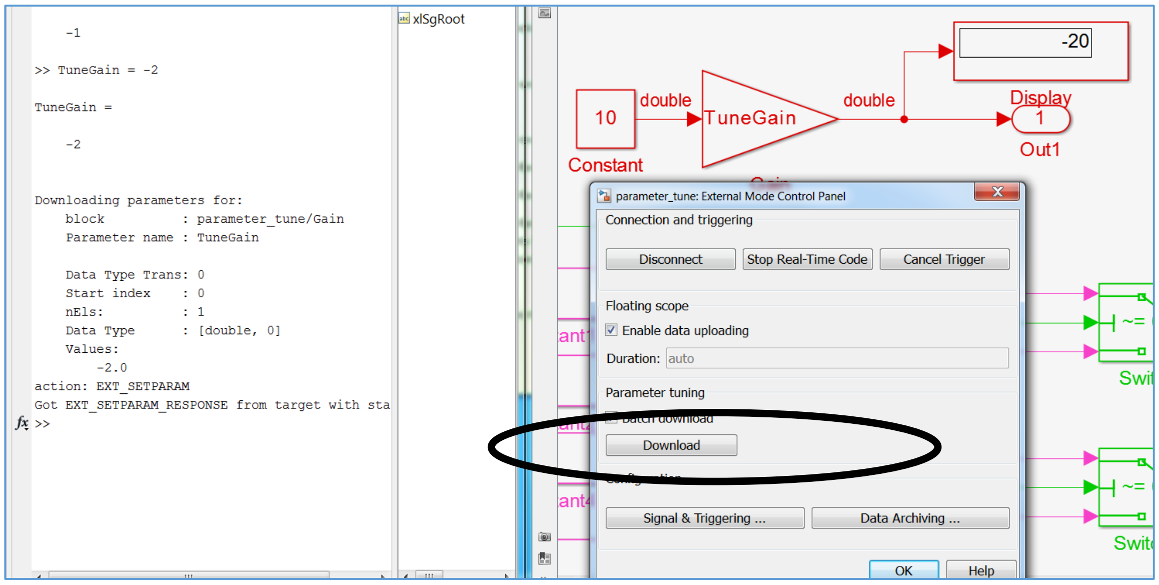
Floating scope
- ✓ Enable data uploading
- Duration: auto

Parameter tuning
- ☐ Batch download
- [Download]

Configuration
[Signal & Triggering ...] [Data Archiving ...]

[OK] [Help]

Now, press the "Download" button to push updated parameter values onto the generated code with "Batch download" selected



```
    -1

>> TuneGain = -2

TuneGain =

    -2


Downloading parameters for:
    block           : parameter_tune/Gain
    Parameter name  : TuneGain

    Data Type Trans: 0
    Start index    : 0
    nEls:          : 1
    Data Type      : [double, 0]
    Values:
        -2.0
action: EXT_SETPARAM
Got EXT_SETPARAM_RESPONSE from target with sta
>>
```

If you have multiple parameters that change, clicking the download button will also update those parameters in one-shot. In the above example I change the TuneGain from -1 to -2 and the generated code receives this update immediately afterwards. **Note a faster method is to also update the model diagram by pressing CTRL+D after changing a parameter in the MATLAB command prompt.**