EtherCAT SDK User Manual

rt:labs

EtherCAT SDK User Manual

rt-labs AB

http://www.rt-labs.com

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DISCLAIMER

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Contents

Chapter 1

EtherCAT SDK Introduction

EtherCAT SDK is a complete toolset for developing and maintaining EtherCAT slaves. It includes the following components:

- **EtherCAT Slave Editor**: This component is used to specify the properties of EtherCAT slaves and to generate C source code for them.
- **EtherCAT Explorer**: This component is used to connect to running EtherCAT slaves, to do network exploration, logging and diagnostics.

Together with SOES EtherCAT Slave Stack the developer has an all-in-one tool for developing EtherCAT slaves in an efficient way, which makes it easy to support and maintain them throughout their life cycle.

EtherCAT SDK is available in the following two different packages:

- EtherCAT SDK Eclipse plug-in
- EtherCAT SDK stand-alone application

1 Requirements and Dependencies

1.1 Operating Systems

The EtherCAT Explorer component works only on Microsoft Windows operating systems (both 32 or 64 bit versions).

The EtherCAT Slave Editor works on GNU/Linux operating systems with GTK (64 bit versions) and on Microsoft Windows operation systems (both 32 or 64 bit versions).

1.2 Software Dependencies

The following software must be installed on a computer in order to run EtherCAT SDK:

- A Java Virtual Machine (JVM) version 8. The stand-alone version of EtherCAT SDK does not work with JVM:s version 9 or newer. The Eclipse plug-in version however should work in Eclipse hosts that are run by JVM 9.

  A JVM can be downloaded from the `Java web page`.

- To use the EtherCAT Explorer the WinPcap library must be installed. It can be downloaded from the `WinPcap web page`.

Note

WinPcap is installed as part of the Wireshark application, so if Wireshark is installed then WinPcap is already available on the computer.

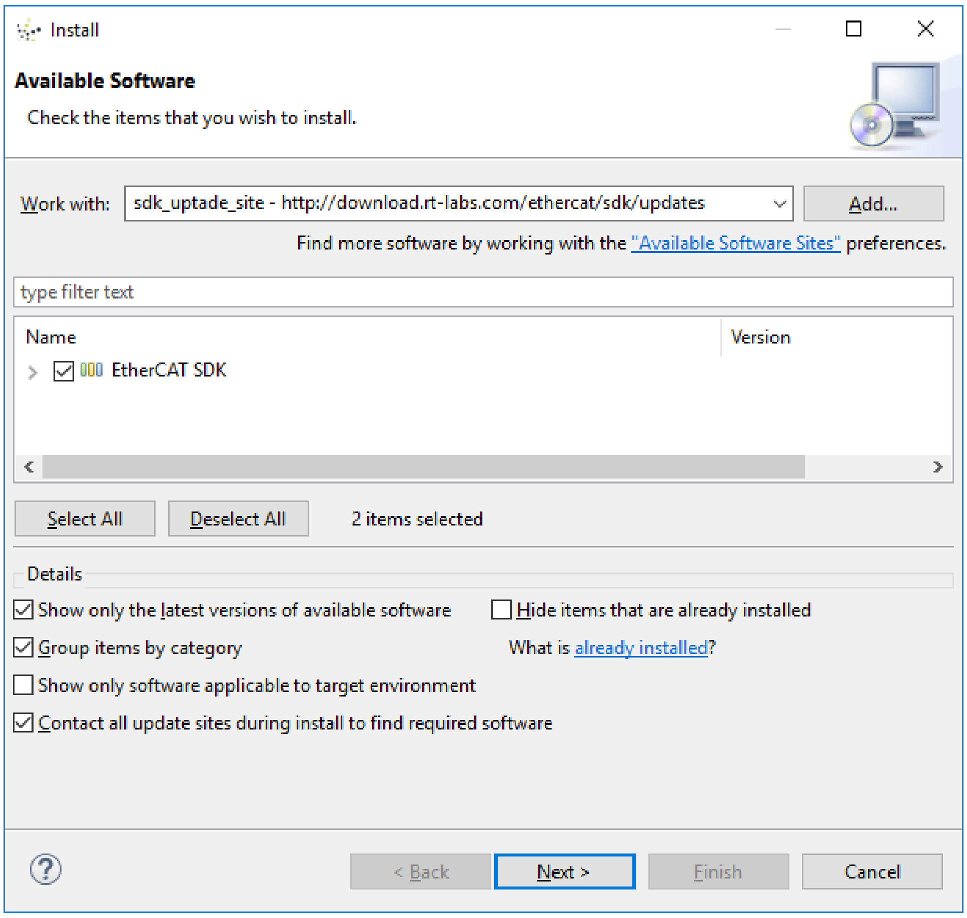
2 Download and Installation

2.1 EtherCAT SDK Eclipse Plug-in

To use EtherCAT SDK as a plug-in in an existing Eclipse installation, download and install it like an ordinary Eclipse plug-in.

Open **Help** > **Install new Software...**, enter the rt-labs download site hosting the plug-in:

```
http://download.rt-labs.com/ethercat/sdk/updates
```



Install

Available Software

Check the items that you wish to install.

Work with: sdk_uptade_site - http://download.rt-labs.com/ethercat/sdk/updates

Find more software by working with the "Available Software Sites" preferences.

type filter text

Name	Version
☑ EtherCAT SDK	

2 items selected

Details

- ☑ Show only the latest versions of available software
- ☐ Hide items that are already installed
- ☑ Group items by category
- What is already installed?
- ☐ Show only software applicable to target environment
- ☑ Contact all update sites during install to find required software

Figure 1.1: Enter Help > Install new software...

A license is required for the application to work. See section EtherCAT SDK License for instructions on how to obtain and install the license.

2.2 EtherCAT SDK Stand-Alone Application

Download the stand-alone EtherCAT SDK application from rt-labs download site in one of the following versions:

- `http://download.rt-labs.com/ethercat/sdk/ethercat-sdk-win32.↩ win32.x86.zip`
- `http://download.rt-labs.com/ethercat/sdk/ethercat-sdk-win32.↩ win32.x86_64.zip`
- `http://download.rt-labs.com/ethercat/sdk/ethercat-sdk-linux.↩ gtk.x86_64.zip`

Save the downloaded EtherCAT SDK zip file in a folder, unzip it and run the executable file (for example `ethercat-sdk.exe`) to start the application.

A license is required for the application to work. See section EtherCAT SDK License for instructions on how to obtain and install the license.

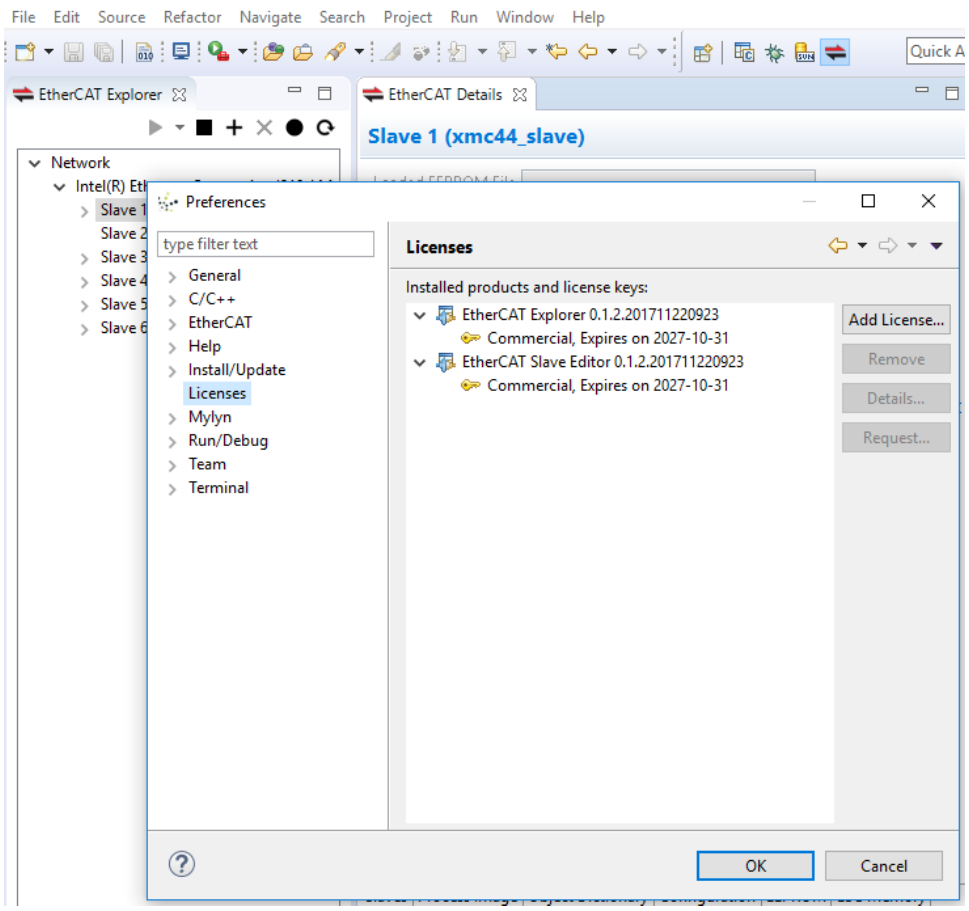
2.3 EtherCAT SDK License

A license is required to be able to generate slave code from the EtherCAT Slave Editor and to connect to an EtherCAT network with the EtherCAT Explorer. A time limited evaluation license can be obtained freely. A commercial license can be purchased from rt-labs.

A license file must be acquired and imported into the application license store. Use the Licenses$**$ preferences page to request a license file for an existing license, or to request a new evaluation license. This page is found at **Windows** $>$ **Preferences** $>$ **Licenses**.

There are two action that can be performed on this page:

1. Use **Request** to have a license file send to a given e-mail address.
   - If an existing license is available for the given e-mail address (commercial or evaluation), then that license is sent.
   - If no license is available for the given e-mail address, then an evaluation license is sent.
2. Use **Add License...** to import an existing license file into the license store, so that it is available to the application.



Licenses

Installed products and license keys:

- EtherCAT Explorer 0.1.2.201711220923
  - Commercial, Expires on 2027-10-31
- EtherCAT Slave Editor 0.1.2.201711220923
  - Commercial, Expires on 2027-10-31

Figure 1.2: The Licenses preference page is available at Windows > Preferences > Licenses.

3 Release Notes

3.1 Release 1.1.0

- Add support to import and export SSC excel spreadsheet
- Add support for SOES v3.0 and manual PDO mapping

3.2 Release 1.0.3

- The license component has been updated to support and check licenses that are specific for one computer.

3.3 Release 1.0.2

- The broken URL of the Nebula XYGraph dependency is updated. The Nebula XYGraph dependency has its version number set to a specific value.

3.4 Release 1.0.1

This release contains minor adjustments of the software.

1. Add the EtherCAT Explorer component to the stand-alone application. #186
2. Remove validation of item indices from the **Application** tab in the slave editor. #185
3. Compute the generated **Profile number** and **Add info** from **Device type** #187
4. Remove start modes that are only relevant for EAP networks. #188

3.5 Release 1.0.0

This is the first official release of the software.

Chapter 2

Slave Editor

1 Overview

The Slave Editor is an EtherCAT slave design tool supporting the developer in creating EtherCAT conforming slaves by providing all necessary outputs in an information aligned way and by providing a SOES EtherCAT slave stack application API for the application to use.

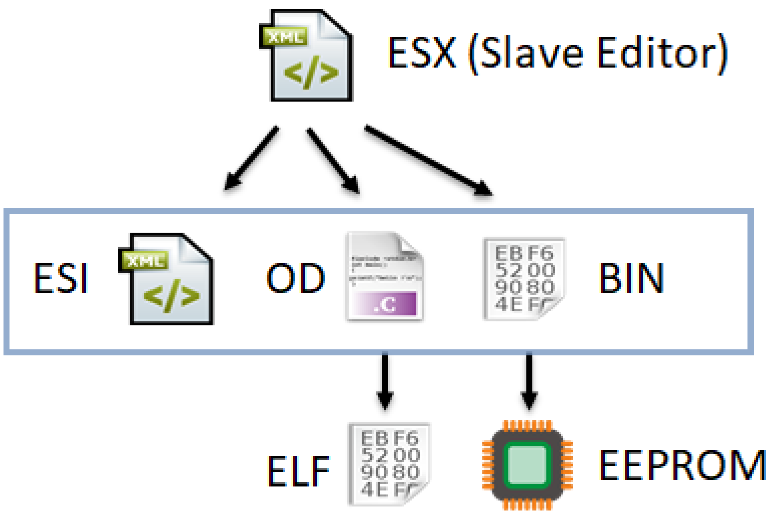
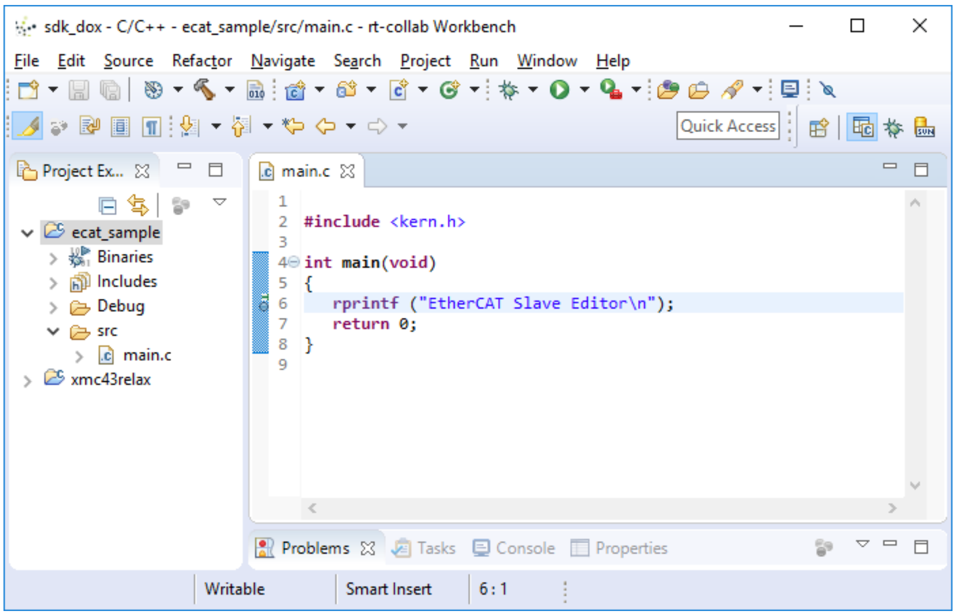


Figure 2.1: EtherCAT Slave Editor output objects ESI-file, C Object Dictionary and EEPROM image.

2 Start the Slave Editor

1. Start the stand-alone EtherCAT SDK or Workbench hosting the EtherCAT SDK plug-in.
2. Create or use an existing workspace
3. Create a new or use an existing project for Slave Editor output



```
#include <kern.h>

int main(void)
{
    rprintf ("EtherCAT Slave Editor\n");
    return 0;
}
```

Figure 2.2: Example with simple Hello World project

3 Create an EtherCAT Slave Editor Project

1. Go to the create new project wizard **File** > **New** > **Other...**
2. Select wizard **EtherCAT** > **EtherCAT Slave Description**

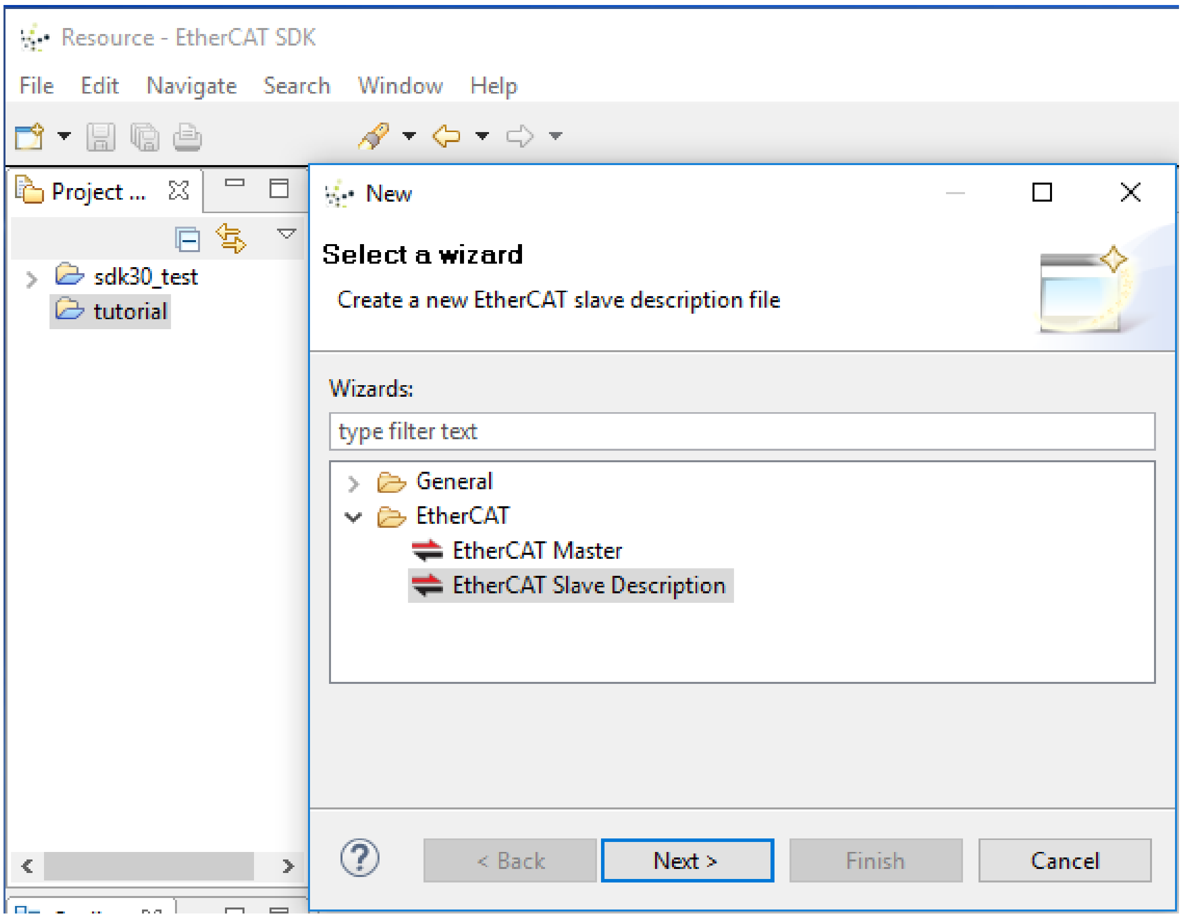
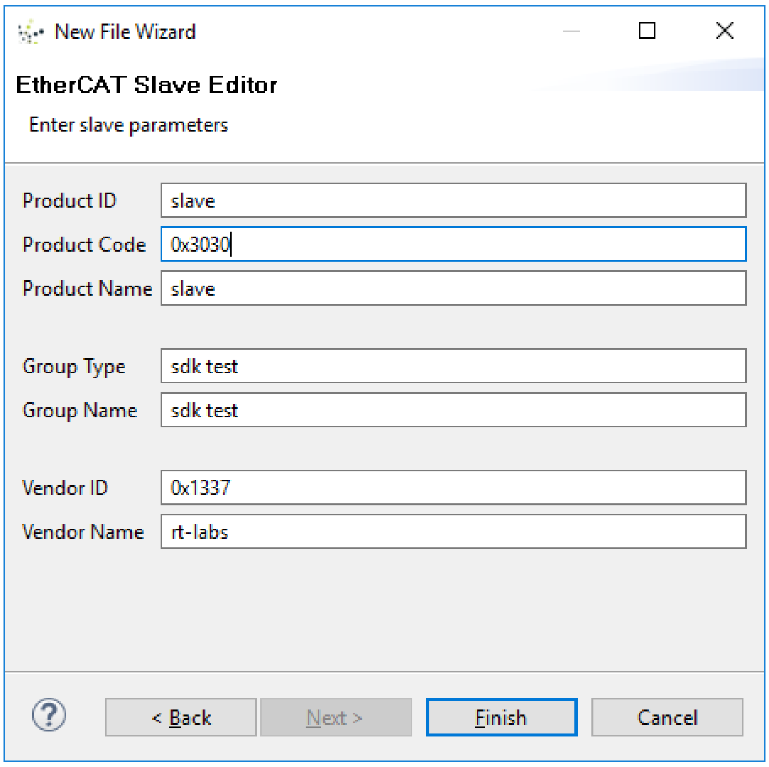


Figure 2.3: Select Wizard

3. Press Next and choose location for generated output.
4. Enter the EtherCAT slave information details, it is used to identify and present details of the slave device.



EtherCAT Slave Editor

Enter slave parameters

Product ID	slave
Product Code	0x3030
Product Name	slave
Group Type	sdk test
Group Name	sdk test
Vendor ID	0x1337
Vendor Name	rt-labs

Figure 2.4: Add slave information

(a) Product ID, Device type identity, not used for identification

(b) Product Code, Vendor specific product code, used for identification in conjunction with vendor id

(c) Product Name, Detailed name of device, not used for identification

(d) Group Type, Group for similar devices with slightly different features (The Slave Editor treat it as one device in one group)

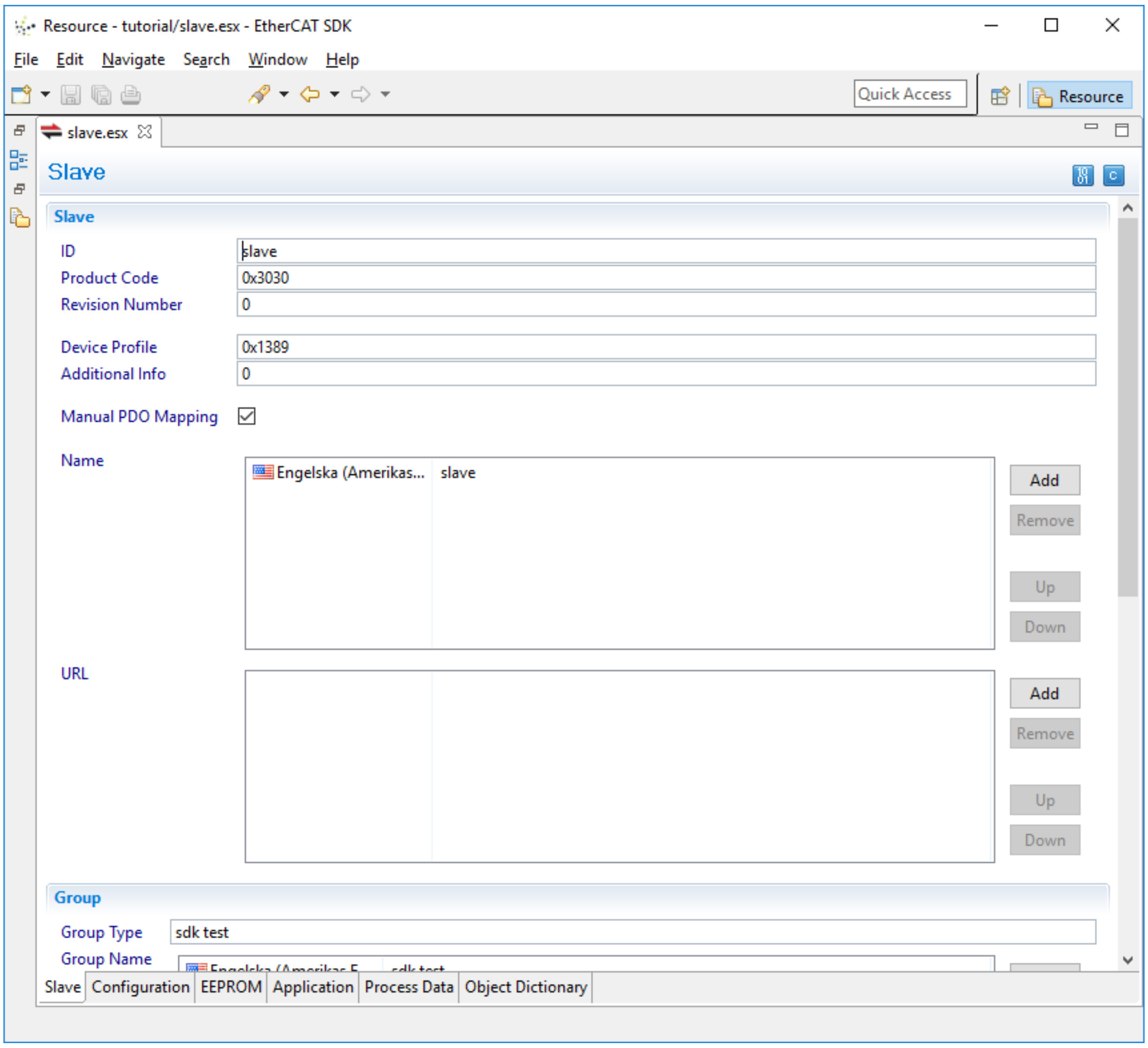
(e) Group Name, Name for this group (The Slave Editor treat it as one device in one group)

(f) Vendor ID, assigned by the EtherCAT Technology Group, used for identification in conjunction with product code

(g) Vendor Name, Vendor Name

5. Press finish to complete creating the EtherCAT Slave Editor project

4 Edit EtherCAT Slave Identity Information


Resource - tutorial/slave.esx - EtherCAT SDK
File Edit Navigate Search Window Help
Quick Access
Resource
slave.esx
Slave
Add
Remove
Up
Down
Slave Configuration EEPROM Application Process Data Object Dictionary

Slave

ID: slave
Product Code: 0x3030
Revision Number: 0
Device Profile: 0x1389
Additional Info: 0
Manual PDO Mapping: ☑
Name: Engelska (Amerikas... slave
URL:

Group

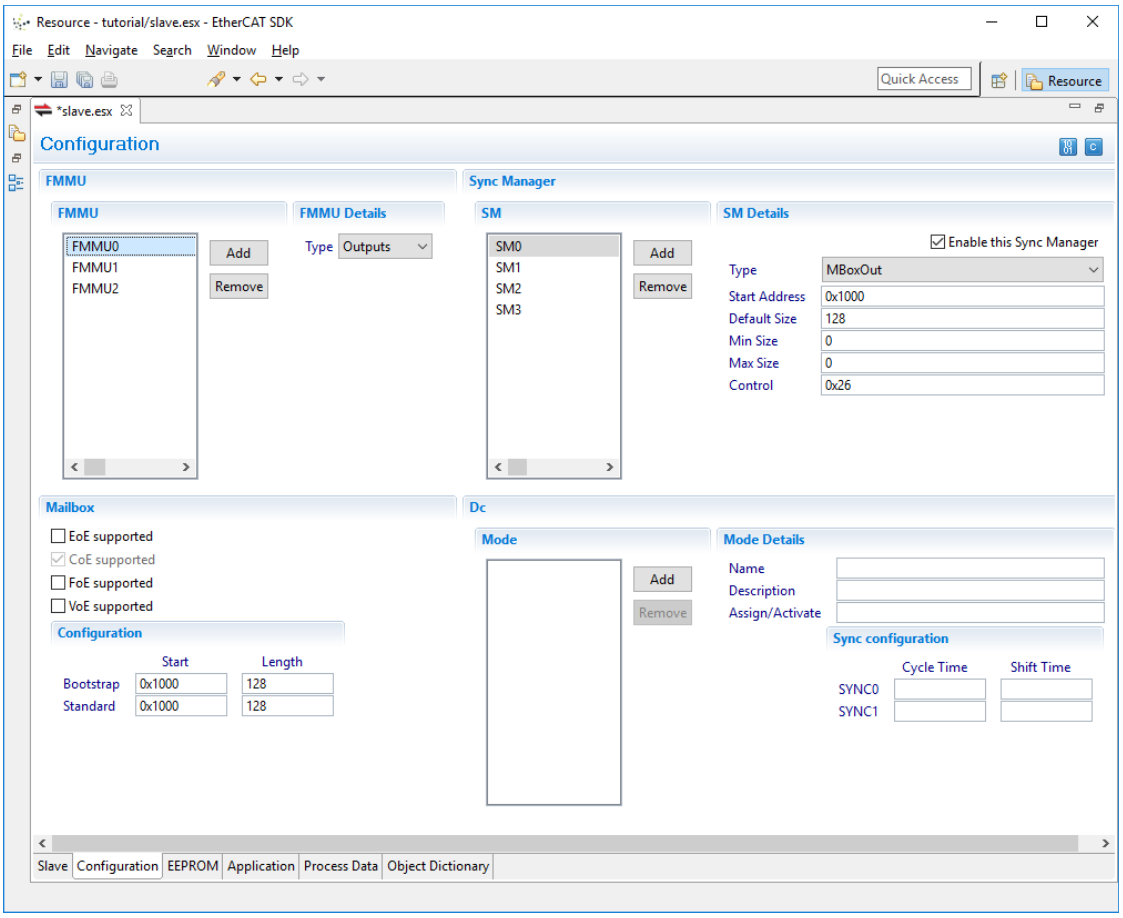
Group Type: sdk test
Group Name: Engelska (Amerikas E... sdk test

Figure 2.5: Slave Tab

Contains general slave information given when creating the EtherCAT Slave Editor project, here it is possible to add, update and remove given information and also add local language support where applicable. In addition, you can also

- Add what device profile the slave implements including additional information
- Select to enable "Manual PDO Mapping" which will display the hidden "Process Data Tab"
- Add URL, for further information on the device. Usually pointing to the vendors homepage where up to date ESI files can be downloaded
  - Company, Company URL
  - Description, URL to ESI files

5 Enter EtherCAT slave Data Link Layer Configuration


Resource - tutorial/slave.esx - EtherCAT SDK
File Edit Navigate Search Window Help
Quick Access
Resource
*slave.esx
Configuration
Add
Remove
Slave Configuration EEPROM Application Process Data Object Dictionary

FMMU

FMMU	FMMU Details
FMMU0	Type: Outputs
FMMU1	
FMMU2	

Sync Manager

SM: SM0, SM1, SM2, SM3

SM Details: ☑ Enable this Sync Manager

Type	MBoxOut
Start Address	0x1000
Default Size	128
Min Size	0
Max Size	0
Control	0x26

Mailbox

☐ EoE supported
☑ CoE supported
☐ FoE supported
☐ VoE supported

Configuration

	Start	Length
Bootstrap	0x1000	128
Standard	0x1000	128

Dc

Mode

Mode Details

Name	
Description	
Assign/Activate	

Sync configuration

	Cycle Time	Shift Time
SYNC0		
SYNC1		

Figure 2.6: Configuration TAB

Basic configuration of the EtherCAT slave Data Link Layer including device Mailbox, FMMU and SM. Settings here are shared among EEPROM and ESI-file.

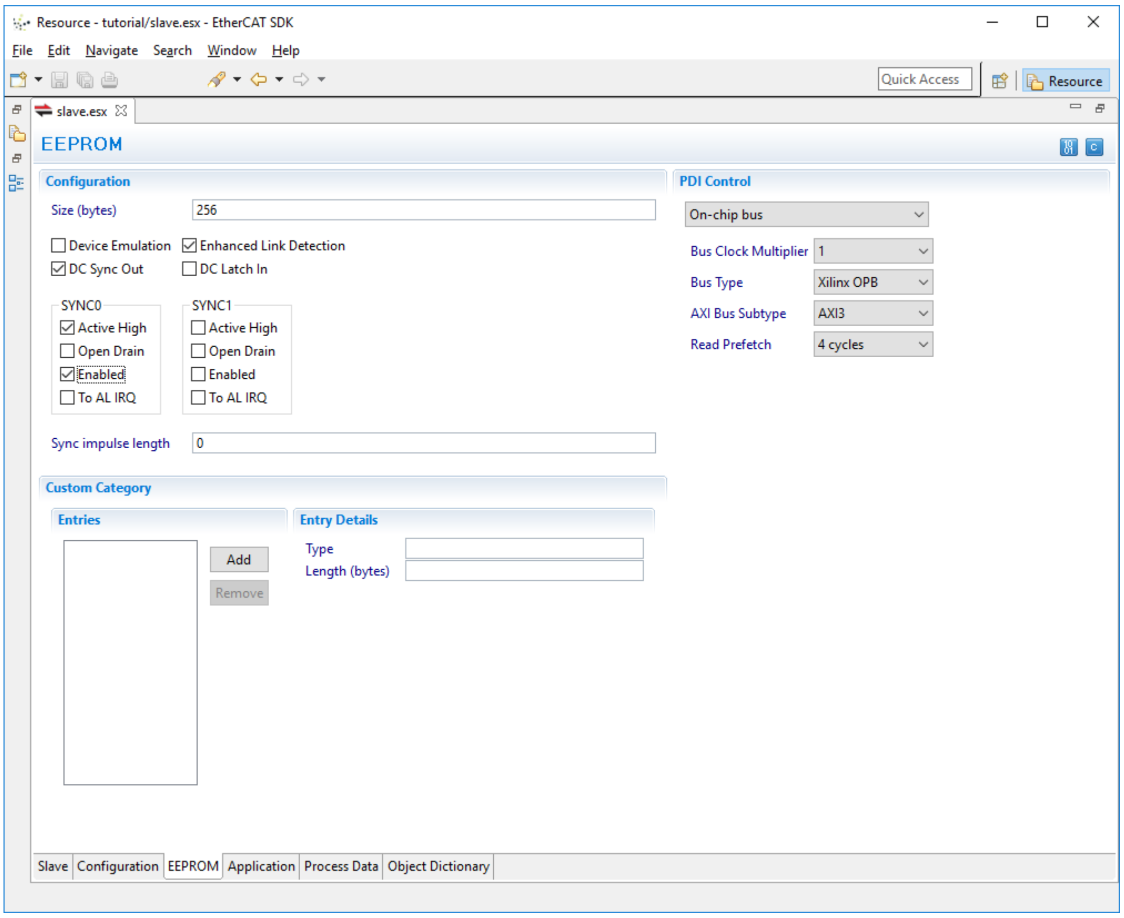
- Mailbox, description of available mailbox protocols
  - If a protocol is not selected it will not be defined or linked to the resulting application, except CoE that is mandatory
  - Bootstrap, address and length of bootstrap mailboxes, activate in bootstrap mode only.
  - Standard, address and length of standard mailboxes, standard mailbox settings are used during normal operations
- FMMU, definition of FMMU usage
  - Outputs, used for RxPDO
  - Inputs, used for TxPDO
  - MBoxState, FMMU used to poll Input MailboxState
- SM description of SyncManager including start address and direction
  - MBoxOut, Mailbox Data Master > Slave

- MBoxIn, Mailbox Data Slave > Master
- Outputs, Process Data Master > Slave
- Inputs, Process Data Slave > Master

• DC, description of synchronization mode for offline configuration

- Name, unique identifier of operation mode for configuration tool
- Description, vendor specific description of operation mode, recommended 'Free Run - no sync', 'SM Synchronous - synchronized on SyncManager event when process data is written' and 'DC-Synchronous - synchronized on DC event '
- Assign / Activate - value of latch and sync control registers
- Cycle Time - Cycle Time
- Shift Time - Shift offset

6 Enter EtherCAT slave EEPROM PDI Settings


Resource - tutorial/slave.esx - EtherCAT SDK
File Edit Navigate Search Window Help
Quick Access
Resource
slave.esx
Add
Remove
Slave Configuration EEPROM Application Process Data Object Dictionary

EEPROM

Configuration

Size (bytes) 256

☐ Device Emulation ☑ Enhanced Link Detection
☑ DC Sync Out ☐ DC Latch In

SYNC0
☑ Active High
☐ Open Drain
☑ Enabled
☐ To AL IRQ

SYNC1
☐ Active High
☐ Open Drain
☐ Enabled
☐ To AL IRQ

Sync impulse length 0

Custom Category

Entries

Entry Details
Type
Length (bytes)

PDI Control

On-chip bus

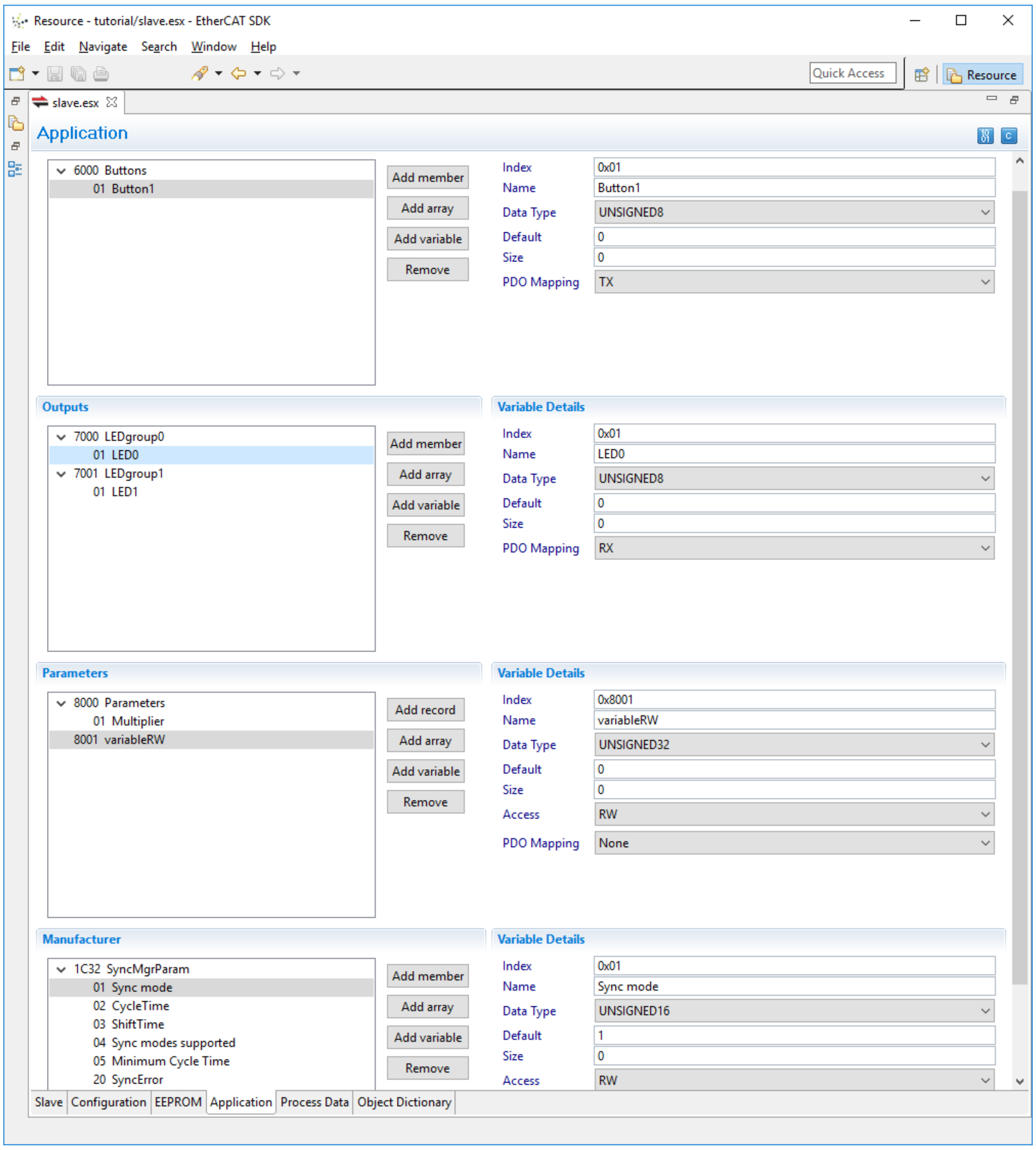
Bus Clock Multiplier 1
Bus Type Xilinx OPB
AXI Bus Subtype AXI3
Read Prefetch 4 cycles

Figure 2.7: EEPROM Tab

EEPROM only settings for the EtherCAT Slave Controller Configuration Area, required to boot the ESC properly (this is ESC dependent). Most EEPROM data are taken from already given information and not presented here.

- Configuration, initialization values for ESC PDI configuration registers. Consult the ESC manual for proper settings.
- PDI Control, initialization values for ESC PDI control registers. Consult the ESC manual for proper settings.
- Custom Category, add custom category header and allocate room for custom category data in the EEPROM. Data will not be populated.

7 Add EtherCAT Slave PDO and Configuration Parameters



Application

- 6000 Buttons
  - 01 Button1

Index	0x01
Name	Button1
Data Type	UNSIGNED8
Default	0
Size	0
PDO Mapping	TX

Outputs

- 7000 LEDgroup0
  - 01 LED0
- 7001 LEDgroup1
  - 01 LED1

Variable Details

Index	0x01
Name	LED0
Data Type	UNSIGNED8
Default	0
Size	0
PDO Mapping	RX

Parameters

- 8000 Parameters
  - 01 Multiplier
- 8001 variableRW

Variable Details

Index	0x8001
Name	variableRW
Data Type	UNSIGNED32
Default	0
Size	0
Access	RW
PDO Mapping	None

Manufacturer

- 1C32 SyncMgrParam
  - 01 Sync mode
  - 02 CycleTime
  - 03 ShiftTime
  - 04 Sync modes supported
  - 05 Minimum Cycle Time
  - 20 SyncError

Variable Details

Index	0x01
Name	Sync mode
Data Type	UNSIGNED16
Default	1
Size	0
Access	RW

Figure 2.8: Application TAB

Here the application defines process data, configuration parameters and manufacture specific data. If you selected "Manual PDO Mapping" you first create the object in this Tab and when the objects are created you go to the "Process Data Tab" to do the actual PDO mapping. Objects entered in the different areas will get indexes according to ranges specified by the MDP (Modular Device Profile). The suggested Index value can be changed by entering a different value in the text-box, for example when implementing a CiA 402 drive, all the Inputs and Outputs are in the 0x6000-0x6FFF range.

- 0x2000-0x5FFF, Manufacture Specific Area
- 0x6000-0x6FFF, Inputs Area, Objects that will be mapped to TxPDO
- 0x7000-0x7FFF, Outputs Area, Objects that will be mapped to RxPDO
- 0x8000-0x8FFF, Configuration Area, Configuration and settings objects. **TIP:** The EtherCAT master should write settings variables, the 0x8000 range, every time before making the state transition from PRE-OP to SAFE-OP.

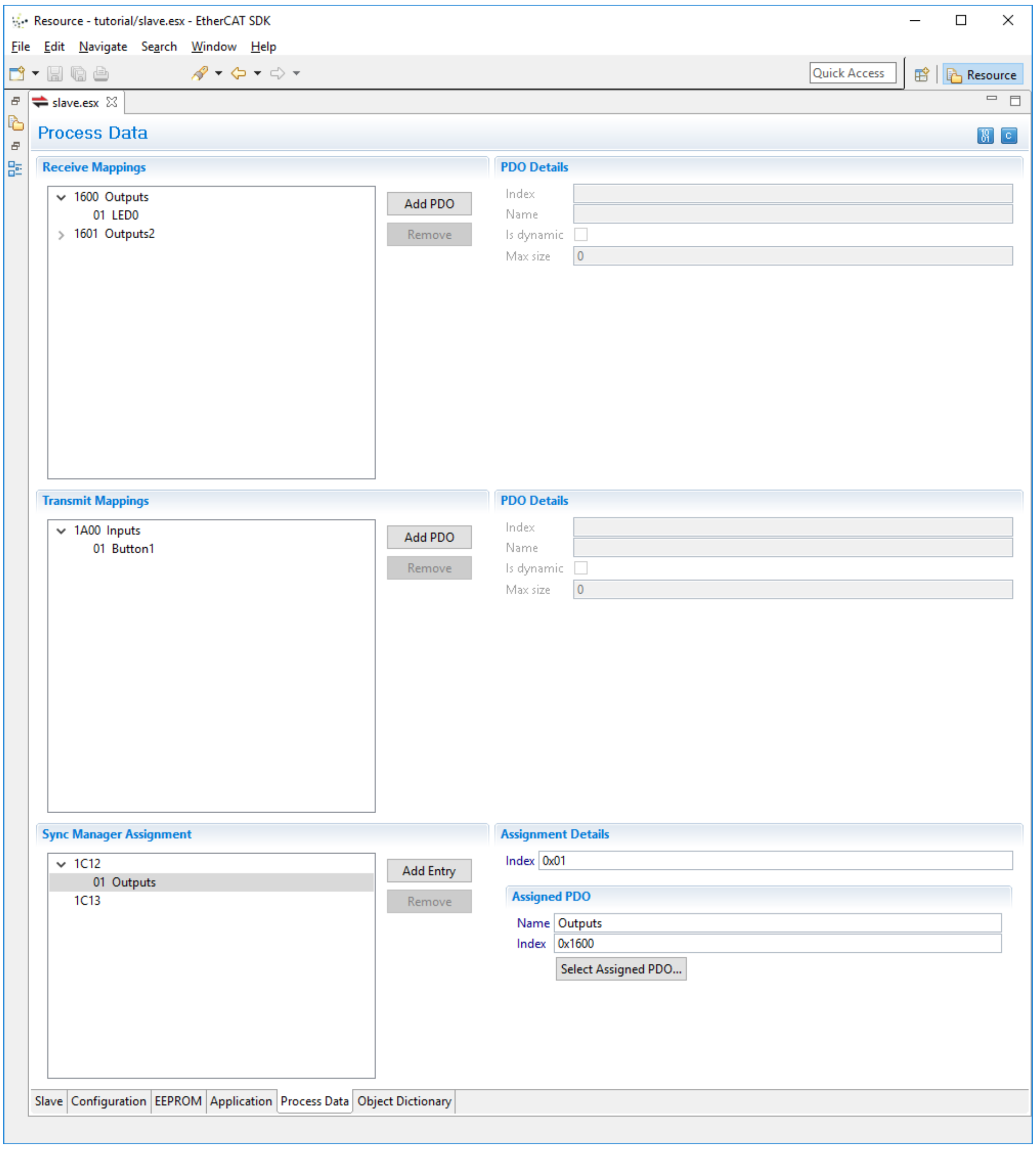
The application can specify objects of 3 types.

1. Record - a group of variables of same or different datatypes that belong together, a struct in C terms
2. Array - an array of variables of same datatype with a size describing number of elements, different datatypes may be used for the array.
3. Variable - a single variable of different datatypes

Properties for objects entered in the different areas

- General,
  - added object will automatically get assigned next free index in specified range.
  - index and sub index can be changed in the GUI by placing the cursor on the number and edited.
  - Add object properties via selected object details
    - Index value within allowed range
    - Name as string
    - Datatype from list of supported datatypes
    - Default value
    - Size, if applicable for selected datatype
    - PDO Mapping to allow the object to be included in specified the PDO Map
- Inputs,
  - object will automatically get the flag PDO Mapping TX set, can be changed manually.
- Outputs,
  - object will automatically get the flag PDO Mapping RX set, can be changed manually.
- Parameters,
  - N/A
- Manufacture,
  - N/A

8 Manual EtherCAT Slave PDO Mapping



Receive Mappings:

- 1600 Outputs
  - 01 LED0
- 1601 Outputs2

PDO Details: Index, Name, Is dynamic, Max size 0

Transmit Mappings:

- 1A00 Inputs
  - 01 Button1

PDO Details: Index, Name, Is dynamic, Max size 0

Sync Manager Assignment:

- 1C12
  - 01 Outputs
- 1C13

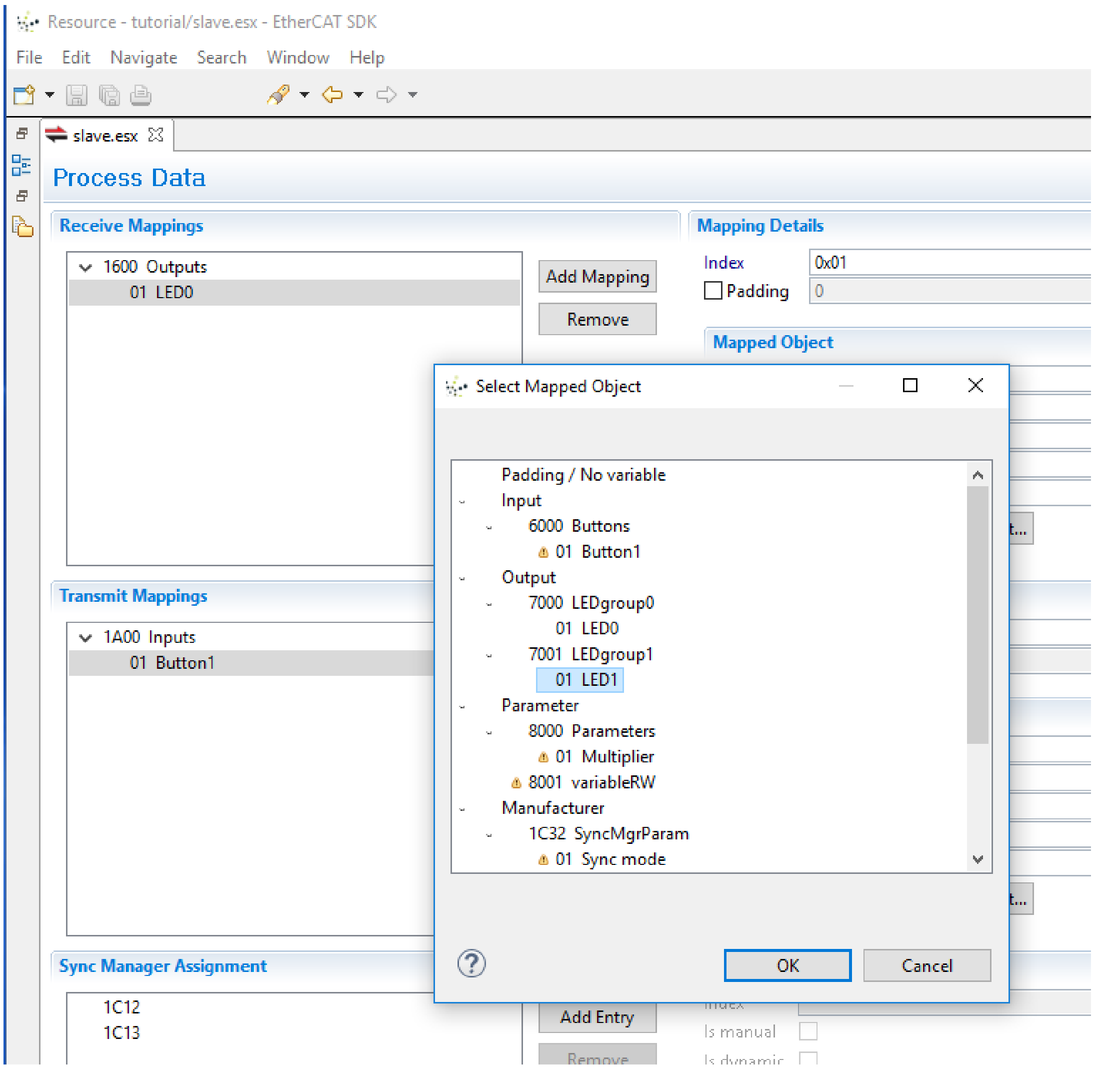
Assignment Details: Index 0x01

Assigned PDO: Name Outputs, Index 0x1600

Figure 2.9: Process Data TAB

The slave editor supports Manual PDO mapping in different ways. The supported options described below. **NOTE: To enable manual PDO mapping via the Process Data Tab, check the box "Manual PDO Mapping" in the Slave Tab**

Manual PDO mapping with automatic Sync Manager assignment. The user selects PDO objects to be included in either Receive Mappings or Transmit Mappings. The mapped objects are automatically added to the appropriate SyncManager.



```
1600 Outputs
    01 LED0

1A00 Inputs
    01 Button1

1C12
1C13
```

```
Padding / No variable
Input
    6000 Buttons
        01 Button1
Output
    7000 LEDgroup0
        01 LED0
    7001 LEDgroup1
        01 LED1
Parameter
    8000 Parameters
        01 Multiplier
    8001 variableRW
Manufacturer
    1C32 SyncMgrParam
        01 Sync mode
```

Figure 2.10: Automatic pdo mapping

1. Press button **Add PDO** for Receive Mappings (master outputs) or Transmit Mappings (master inputs)
2. Select a PDO and press button **Add Mapping** and select object to map to PDO. Objects that are not allowed, based on property PDO Mapping, are marked with a yellow triangle.
3. Fill the added PDO with more mapped objects via button **Add Mapping** or add another PDO via **Add PDO**

Manual PDO mapping with manual SyncManager Assignment

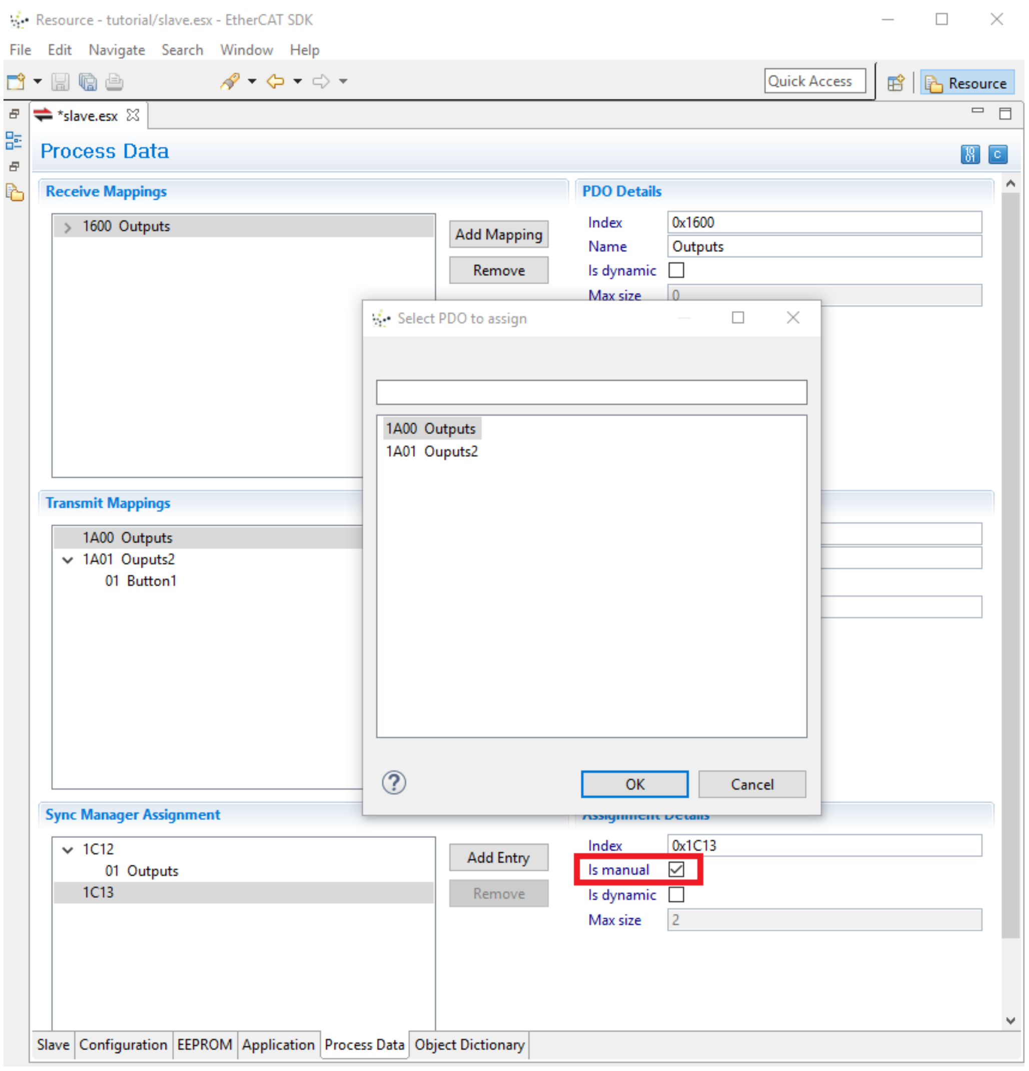
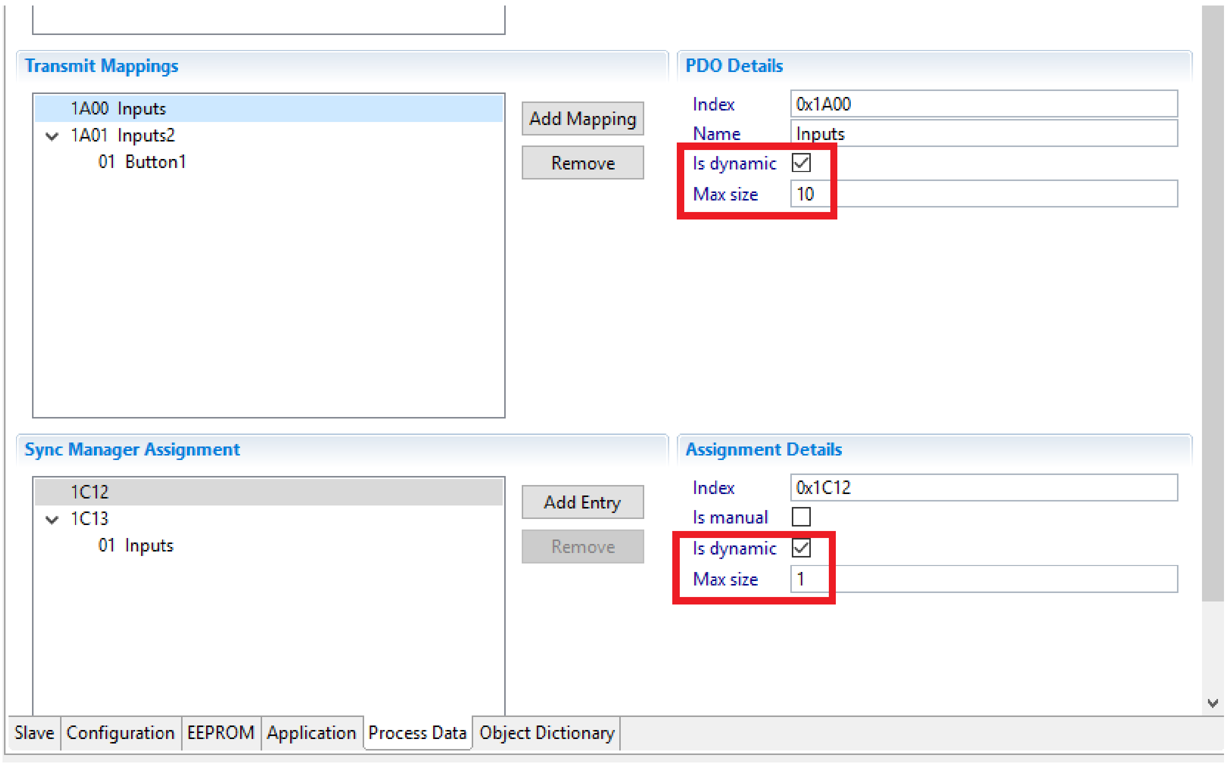


Figure 2.11: Manual PDO and SyncManager Assignment

1. Press button **Add PDO** for Receive Mappings or Transmit Mappings
2. Select Mapped Object. Objects that are not allowed, based on property PDO Mapping, are marked with a yellow triangle.
3. Fill the added PDO with more mapped objects via button **Add Mapping** or add another PDO via **Add PDO**
4. Assign PDO Mapping to SyncManager by selecting either SyncManager 1C12 for Receive Mappings (master outputs) or 1C13 for Transmit Mappings (master inputs)
5. Select Sync Manager and activate manual assignment by checking **"Is manual"**
6. **Add Entry** and select from possible PDO to assign

Create dynamic PDO object for run-time PDO mapping



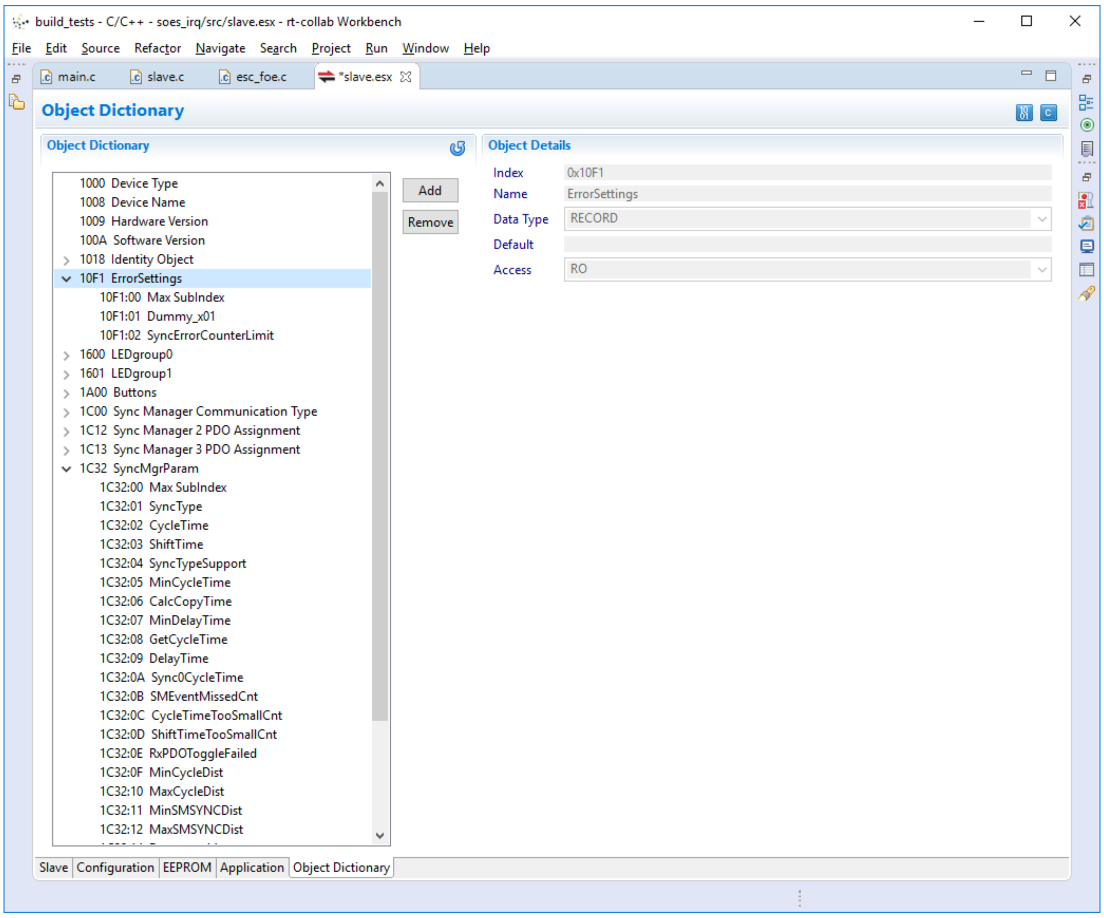
Index	0x1A00
Name	Inputs
Is dynamic	✓
Max size	10

Index	0x1C12
Is manual	☐
Is dynamic	✓
Max size	1

Figure 2.12: Create support dynamic PDO mapping

1. Select Sync Manager Assignment object or select or create a new PDO via **Add PDO**
2. Check **"Is dynamic"** and specify Max size to create an object that will be writable in run-time
3. The dynamic object can be filled with default mappings added via **Add Mapping** or be it can be empty
4. Dynamic objects can be filled and mapped by the master

9 Generate C Source Code, EEPROM and ESI-file


build_tests - C/C++ - soes_irq/src/slave.esx - rt-collab Workbench
File Edit Source Refactor Navigate Search Project Run Window Help
main.c
slave.c
esc_foe.c
*slave.esx
Object Dictionary
Add
Remove
Slave
Configuration
EEPROM
Application
Object Dictionary

Object Dictionary

```
1000  Device Type
1008  Device Name
1009  Hardware Version
100A  Software Version
> 1018  Identity Object
v 10F1  ErrorSettings
    10F1:00  Max SubIndex
    10F1:01  Dummy_x01
    10F1:02  SyncErrorCounterLimit
> 1600  LEDgroup0
> 1601  LEDgroup1
> 1A00  Buttons
> 1C00  Sync Manager Communication Type
> 1C12  Sync Manager 2 PDO Assignment
> 1C13  Sync Manager 3 PDO Assignment
v 1C32  SyncMgrParam
    1C32:00  Max SubIndex
    1C32:01  SyncType
    1C32:02  CycleTime
    1C32:03  ShiftTime
    1C32:04  SyncTypeSupport
    1C32:05  MinCycleTime
    1C32:06  CalcCopyTime
    1C32:07  MinDelayTime
    1C32:08  GetCycleTime
    1C32:09  DelayTime
    1C32:0A  Sync0CycleTime
    1C32:0B  SMEventMissedCnt
    1C32:0C  CycleTimeTooSmallCnt
    1C32:0D  ShiftTimeTooSmallCnt
    1C32:0E  RxPDOToggleFailed
    1C32:0F  MinCycleDist
    1C32:10  MaxCycleDist
    1C32:11  MinSMSYNCDist
    1C32:12  MaxSMSYNCDist
```

Object Details

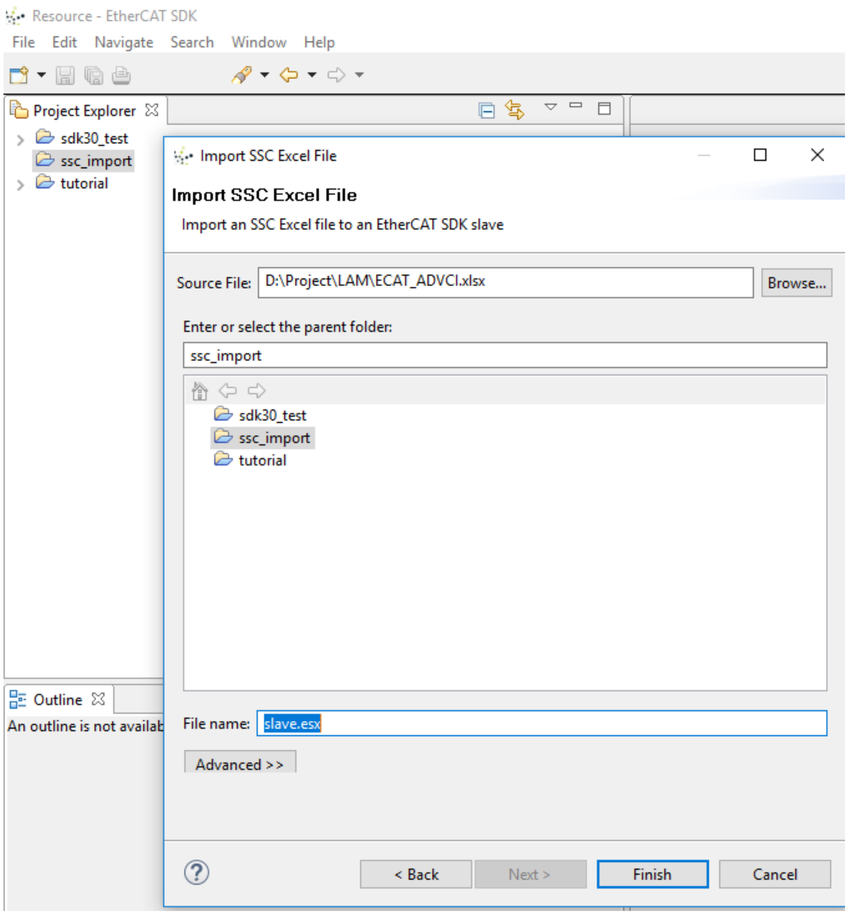
Index	0x10F1
Name	ErrorSettings
Data Type	RECORD
Default	
Access	RO

Figure 2.13: Object Dictionary Tab

Overview of the resulting Object Dictionary. The buttons in the right upper corner icon "IOIO" and icon "C" are used to generate the output. Code can be generated from any view.

- "IOIO"
  - ∗.bin, the EEPROM image. Targets using emulated EEPROM use objcopy to create a linkable object included in the target executable
  - ∗.xml, ESI file.
- "C" generate C source code.
  - utypes.h - user types created for the objects defined for the application
  - ecat_options.h - stack configuration parameters to setup hardware objects, parameters here override default parameters given in SOES options.h
  - <project name>_objectlist.c generated C object dictionary

10 Slave Editor SSC spreadsheet support



Import SSC Excel File

Import an SSC Excel file to an EtherCAT SDK slave

Source File: D:\Project\LAM\ECAT_ADVCI.xlsx

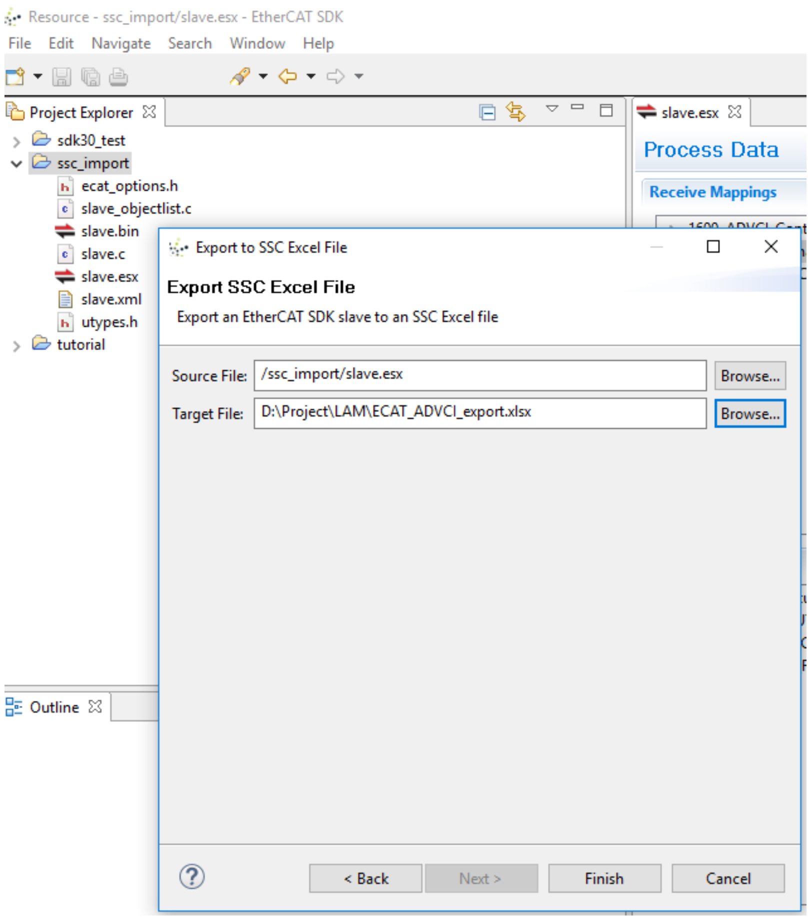
Enter or select the parent folder: ssc_import

File name: slave.esx

Figure 2.14: HowTo import SSC spreadsheet

Import spreadsheet

1. Start the stand-alone EtherCAT SDK or Workbench hosting the EtherCAT SDK plug-in.
2. Create or use an existing workspace
3. Create a new or use an existing project for Slave Editor output
4. Right click on created project and select Import
5. **Import > EtherCAT > EtherCAT Slave from SSC Excel File**
6. Browse for SSC Excel source file
7. Enter slave editor source file name
8. Press finish to complete creating the EtherCAT Slave Editor project
9. From here on it works as a standard Slave Editor project. **NOTE: The slave editor doesn't generate code for SSC**



Export SSC Excel File

Export an EtherCAT SDK slave to an SSC Excel file

Source File: /ssc_import/slave.esx Browse...

Target File: D:\Project\LAM\ECAT_ADVCI_export.xlsx Browse...

Figure 2.15: HowTo export SSC spreadsheet

Export spreadsheet

1. Right in Project Explorer and select Export
2. **Export > EtherCAT > EtherCAT Slave to SSC Excel File**
3. Browse for Slave Editor project file
4. Browse output folder and enter name of output SSC Excel source file
5. Press finish to complete exporting the EtherCAT Slave Editor project to SSC excel spreadsheet
6. **NOTE: The excel spreadsheet content can differ if it originates from a Slave Editor project or from an SSC excel spreadsheet since the Slave Editor don't support all entries in the spreadsheet. They can be added manually if needed**

Chapter 3

EtherCAT Explorer User Manual

1 Overview

EtherCAT Explorer is an EtherCAT network exploration, logging and diagnostics tool. Together with EtherCAT SDK Slave Editor and SOES EtherCAT Slave Stack, developers have an all-in-one tool for efficiently developing EtherCAT slaves that are easy to support and maintain throughout the life cycle.

2 Start the EtherCAT Explorer

1. Install WinPcap to use EtherCAT Explorer (WinPcap is part of Wireshark. If it is already installed there is no need to install again.)
2. Start the stand-alone EtherCAT SDK or workbench hosting the EtherCAT SDK plug-in.
3. Open the **EtherCAT Explorer** perspective, goto **Windows** > **Perspective** > **Open Perspective** > **Other...**.
4. Choose **EtherCAT Explorer**

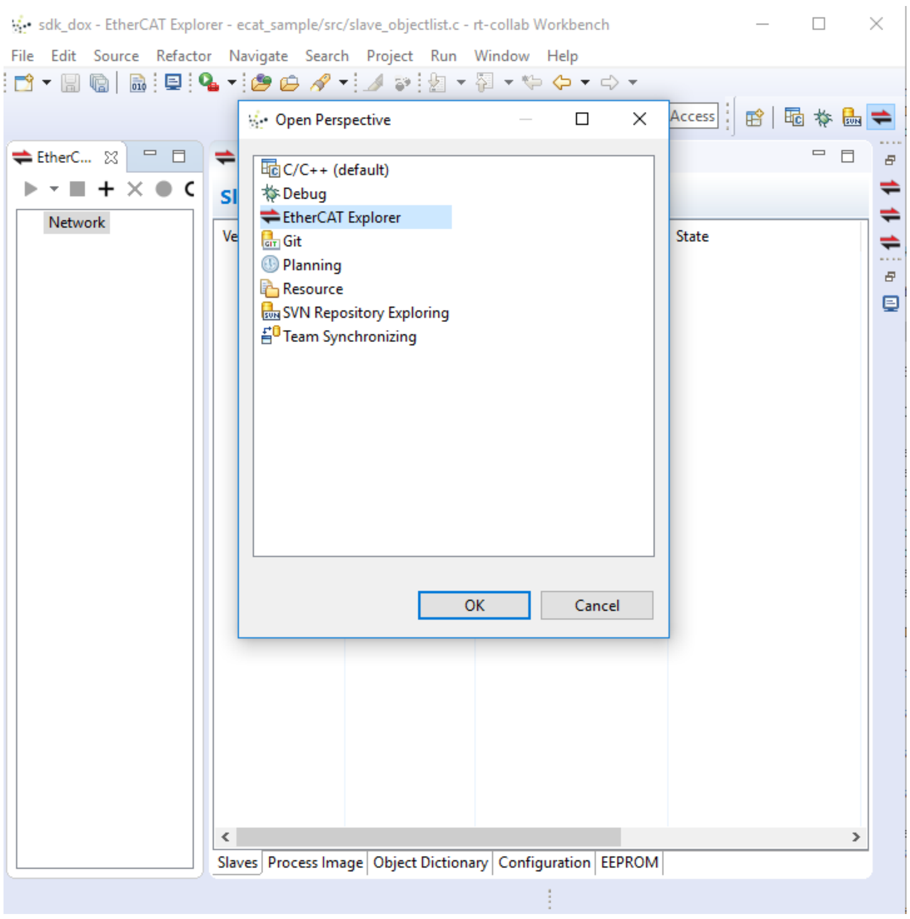
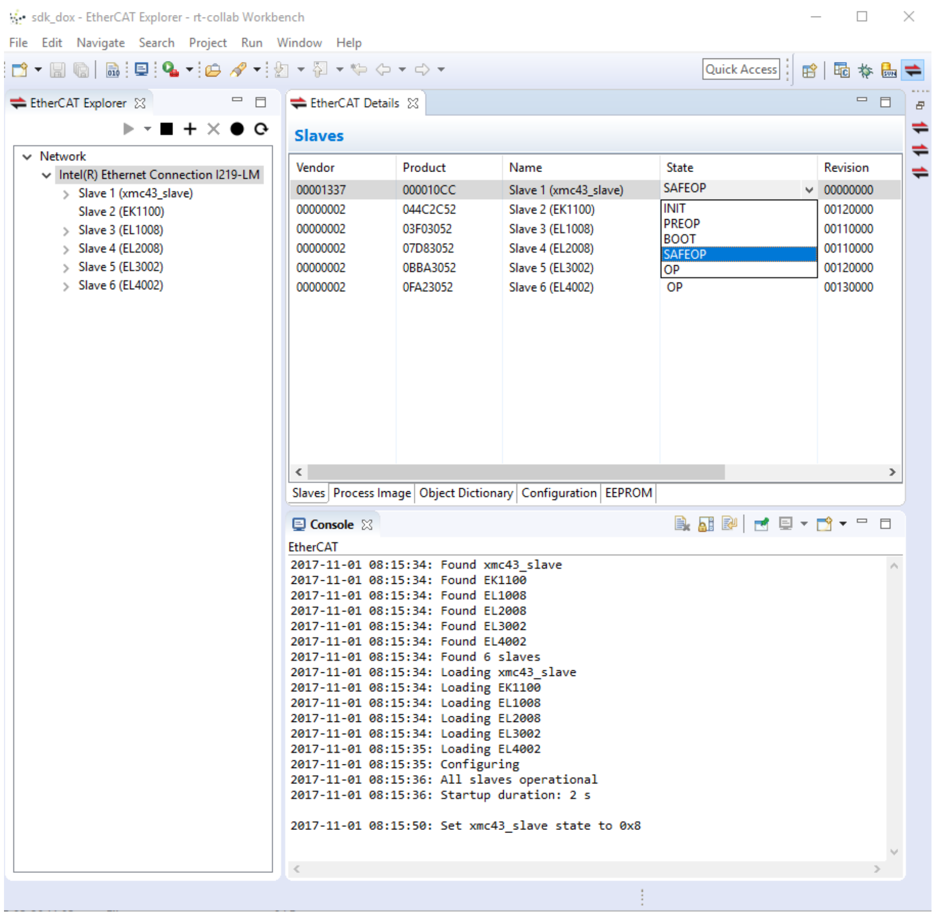


Figure 3.1: Open the EtherCAT Explorer perspective

3 Connect to an EtherCAT Network

Follow these instructions to configure and connect to an EtherCAT network.

1. To add a new EtherCAT master press the **+** button in the network tree-view toolbar
2. Select network interface and **Finish**
3. Start the network by pressing the **Play** arrow button
4. The slave network start is logged in the **Console** view
5. Individual slave information is presented in the columns. The **State** column can be edited, but the rest of the columns are read-only. Via state you can change individual slaves state from the drop-down list. No state change is validated and it have to be done in the correct sequence according to the EtherCAT state machine.
6. Starting, stopping, adding and removing masters in the network tree-view is handled by the buttons in the tree-view toolbar.



Vendor	Product	Name	State	Revision
00001337	000010CC	Slave 1 (xmc43_slave)	SAFEOP	00000000
00000002	044C2C52	Slave 2 (EK1100)		00120000
00000002	03F03052	Slave 3 (EL1008)		00110000
00000002	07D83052	Slave 4 (EL2008)		00110000
00000002	0BBA3052	Slave 5 (EL3002)		00120000
00000002	0FA23052	Slave 6 (EL4002)	OP	00130000

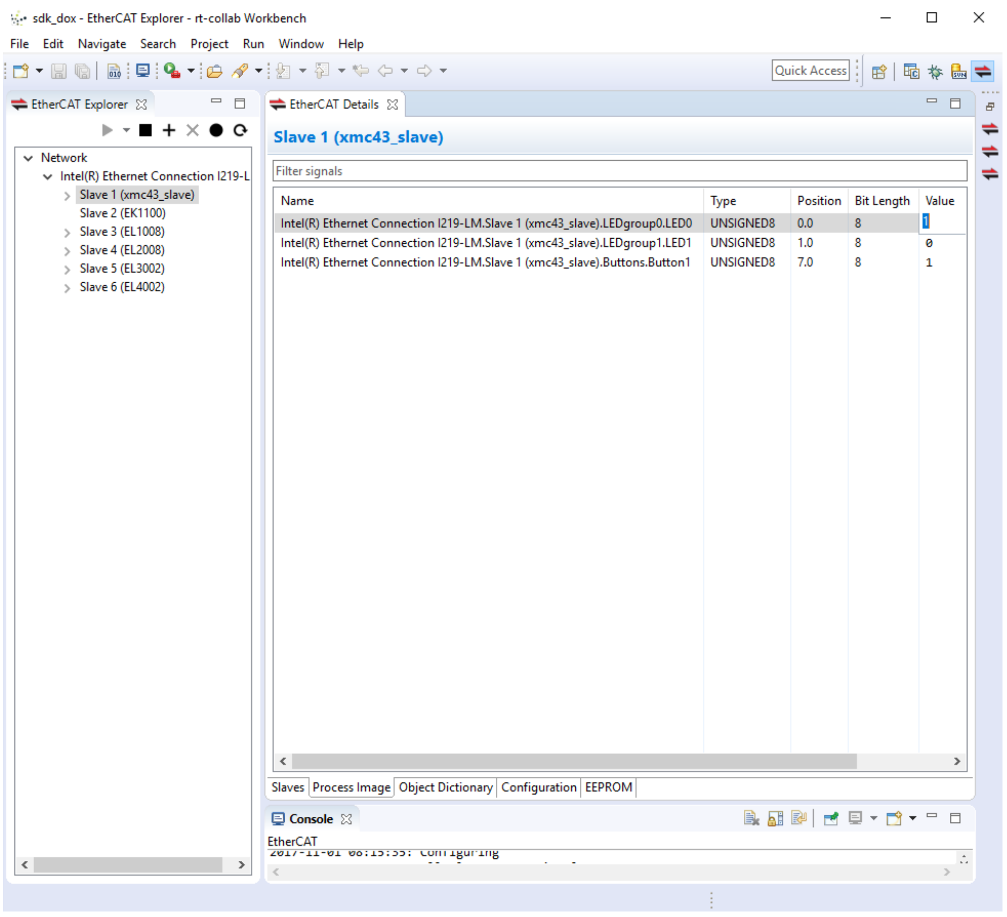
```
2017-11-01 08:15:34: Found xmc43_slave
2017-11-01 08:15:34: Found EK1100
2017-11-01 08:15:34: Found EL1008
2017-11-01 08:15:34: Found EL2008
2017-11-01 08:15:34: Found EL3002
2017-11-01 08:15:34: Found EL4002
2017-11-01 08:15:34: Found 6 slaves
2017-11-01 08:15:34: Loading xmc43_slave
2017-11-01 08:15:34: Loading EK1100
2017-11-01 08:15:34: Loading EL1008
2017-11-01 08:15:34: Loading EL2008
2017-11-01 08:15:34: Loading EL3002
2017-11-01 08:15:35: Loading EL4002
2017-11-01 08:15:35: Configuring
2017-11-01 08:15:36: All slaves operational
2017-11-01 08:15:36: Startup duration: 2 s

2017-11-01 08:15:50: Set xmc43_slave state to 0x8
```

Figure 3.2: EtherCAT Network Overview

4 Explore EtherCAT Network Process Data

Select the **Process Image** tab to monitor and control the EtherCAT network process data image, all PDO objects are listed by name, type, bit length and value. For outputs it is possible to enter and change values. PDO:s can be drag-and-dropped to views for logging, EtherCAT Trace, EtherCAT Watch and EtherCAT SDO Watch.



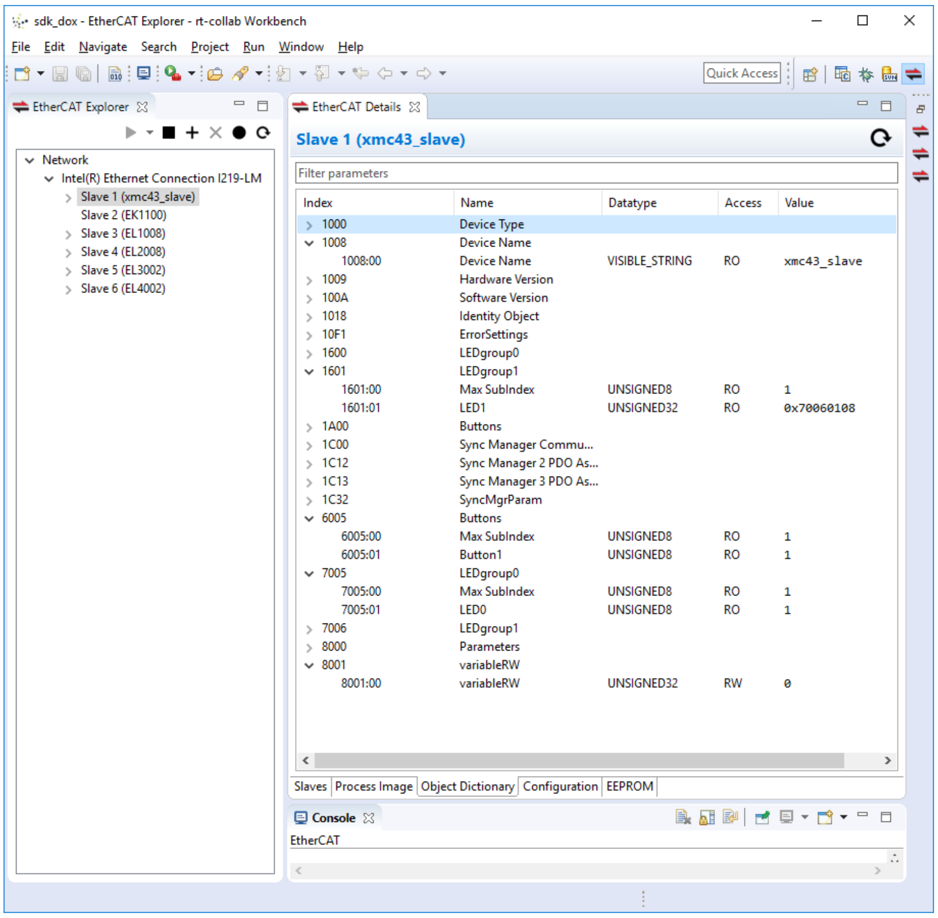
Name	Type	Position	Bit Length	Value
Intel(R) Ethernet Connection I219-LM.Slave 1 (xmc43_slave).LEDgroup0.LED0	UNSIGNED8	0.0	8	1
Intel(R) Ethernet Connection I219-LM.Slave 1 (xmc43_slave).LEDgroup1.LED1	UNSIGNED8	1.0	8	0
Intel(R) Ethernet Connection I219-LM.Slave 1 (xmc43_slave).Buttons.Button1	UNSIGNED8	7.0	8	1

```
2017-11-01 08:15:55: Configuring
```

Figure 3.3: Process Image view

5 Explore EtherCAT Slave Object Dictionary

Select **Object Dictionary** view to browse slaves Object Dictionary, select a slave in the network tree-view to populate the view, data is only read on-demand by pressing the **'Refresh'**-button in the top right corner.



- Network
  - Intel(R) Ethernet Connection I219-LM
    - Slave 1 (xmc43_slave)
    - Slave 2 (EK1100)
    - Slave 3 (EL1008)
    - Slave 4 (EL2008)
    - Slave 5 (EL3002)
    - Slave 6 (EL4002)

Slave 1 (xmc43_slave)

Index	Name	Datatype	Access	Value
1000	Device Type			
1008	Device Name			
1008:00	Device Name	VISIBLE_STRING	RO	xmc43_slave
1009	Hardware Version			
100A	Software Version			
1018	Identity Object			
10F1	ErrorSettings			
1600	LEDgroup0			
1601	LEDgroup1			
1601:00	Max SubIndex	UNSIGNED8	RO	1
1601:01	LED1	UNSIGNED32	RO	0x70060108
1A00	Buttons			
1C00	Sync Manager Commu...			
1C12	Sync Manager 2 PDO As...			
1C13	Sync Manager 3 PDO As...			
1C32	SyncMgrParam			
6005	Buttons			
6005:00	Max SubIndex	UNSIGNED8	RO	1
6005:01	Button1	UNSIGNED8	RO	1
7005	LEDgroup0			
7005:00	Max SubIndex	UNSIGNED8	RO	1
7005:01	LED0	UNSIGNED8	RO	1
7006	LEDgroup1			
8000	Parameters			
8001	variableRW			
8001:00	variableRW	UNSIGNED32	RW	0

```
EtherCAT
```

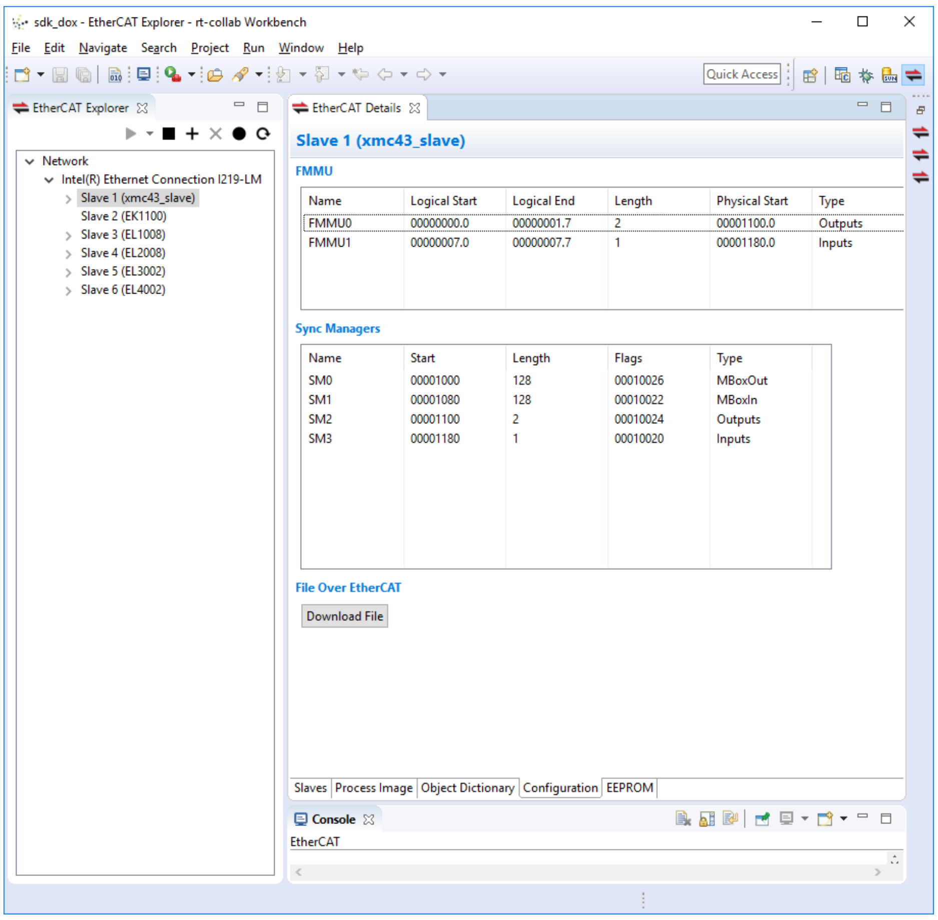
Figure 3.4: Object Dictionary view

6 Explore EtherCAT Slave Data Link Layer Configuration

Select Configuration for view of slaves' physical/logic mappings for the SyncManager and FMMU objects.

6.1 Write a file to EtherCAT slave

Press the **'Download File'**-button to transfer files to the slave over FoE (File Over EtherCAT). It will open a file browser dialog to select the file to transfer. The result of the transfer will be presented in the Console.



Slave 1 (xmc43_slave)

FMMU

Name	Logical Start	Logical End	Length	Physical Start	Type
FMMU0	00000000.0	00000001.7	2	00001100.0	Outputs
FMMU1	00000007.0	00000007.7	1	00001180.0	Inputs

Sync Managers

Name	Start	Length	Flags	Type
SM0	00001000	128	00010026	MBoxOut
SM1	00001080	128	00010022	MBoxIn
SM2	00001100	2	00010024	Outputs
SM3	00001180	1	00010020	Inputs

File Over EtherCAT

Figure 3.5: Configuration view

7 Manage EtherCAT Slave EEPROM

Select **EEPROM** view for slave EEPROM management. It supports Read and Write EEPROM online, Save and Load EEPROM images offline. It is possible to modify a read or loaded image by editing or adding EEPROM entries via the tree-view fields. However, the proper way to modify the EEPROM content, to keep slave identity information aligned, is by making the necessary changes in the EtherCAT Slave Editor.

7.1 Read online EEPROM

Select EtherCAT Slave in the tree-view. Press the **'Read EEPROM'**-button to populate the data view with EEPROM data read online.

7.2 Write Online EEPROM

Select EtherCAT Slave in the tree-view. Press the **'Write EEPROM'**-button to write the date to the slave.

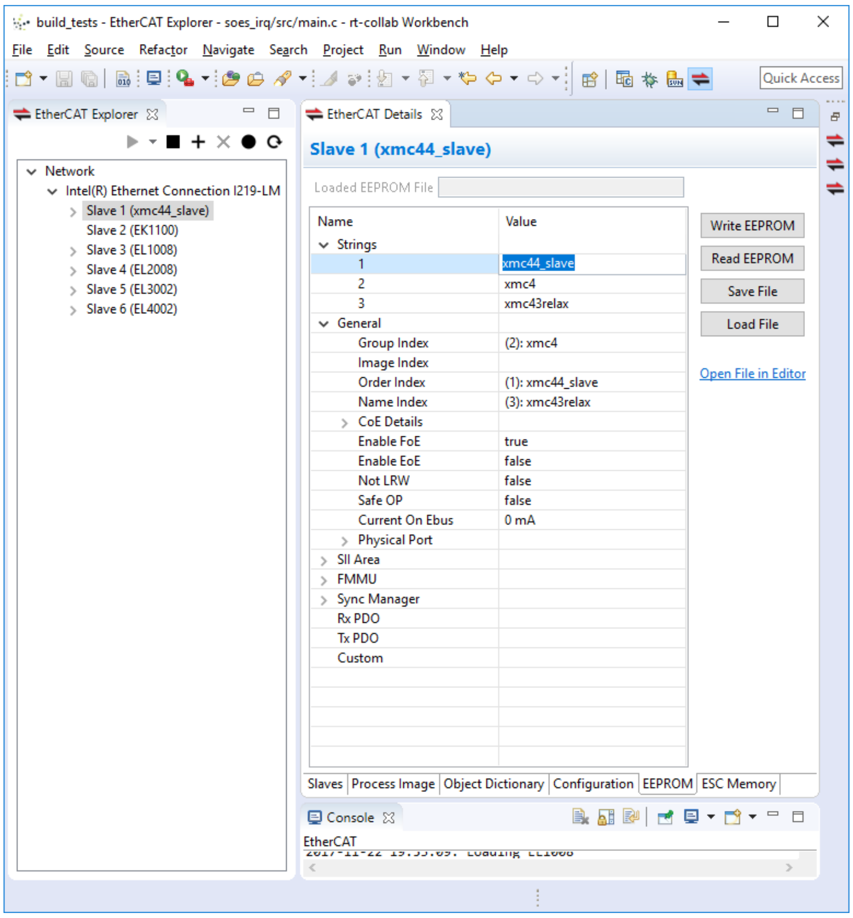
NOTE! A faulty EEPROM can cause problems starting the EtherCAT slave.

7.3 Save an EEPROM Image File

Press the **'Save File'**-button to write present data in data view to an image file on disk.

7.4 Load EEPROM image file

Press the **'Load File'**-button to load data to data view, the data view is write to the slave by Write EEP↩ ROM. A loaded file can be opened in the external linked editor if associated.


build_tests - EtherCAT Explorer - soes_irq/src/main.c - rt-collab Workbench

File Edit Source Refactor Navigate Search Project Run Window Help

Quick Access

EtherCAT Explorer

- Network
  - Intel(R) Ethernet Connection I219-LM
    - Slave 1 (xmc44_slave)
    - Slave 2 (EK1100)
    - Slave 3 (EL1008)
    - Slave 4 (EL2008)
    - Slave 5 (EL3002)
    - Slave 6 (EL4002)

EtherCAT Details

Slave 1 (xmc44_slave)

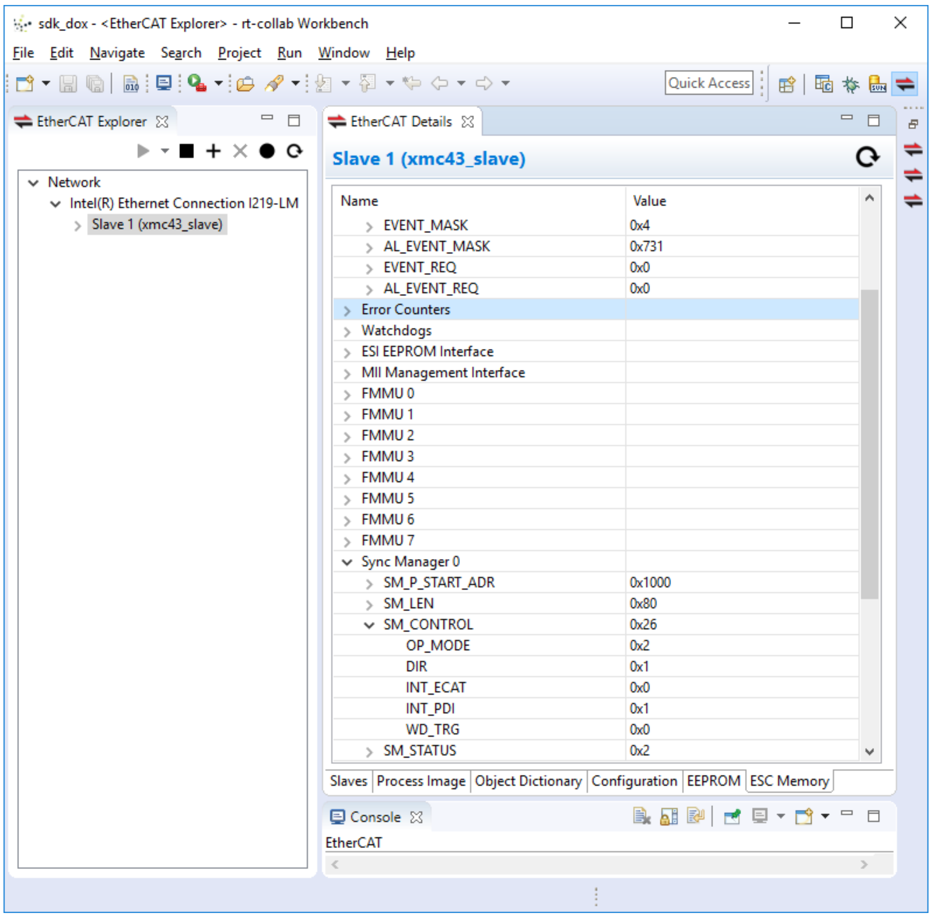
Loaded EEPROM File

Name	Value
Strings	
1	xmc44_slave
2	xmc4
3	xmc43relax
General	
Group Index	(2): xmc4
Image Index	
Order Index	(1): xmc44_slave
Name Index	(3): xmc43relax
CoE Details	
Enable FoE	true
Enable EoE	false
Not LRW	false
Safe OP	false
Current On Ebus	0 mA
Physical Port	
SII Area	
FMMU	
Sync Manager	
Rx PDO	
Tx PDO	
Custom	

Figure 3.6: EEPROM view

8 Explore EtherCAT Slave ESC Registers and RAM

Select **ESC Memory** for EtherCAT Slave Controller Register and RAM view, select a slave in the network tree-view to populate the view, data for expanded sections are read on-demand by pressing the **'Refresh'**-button in the top right corner.



Name	Value
EVENT_MASK	0x4
AL_EVENT_MASK	0x731
EVENT_REQ	0x0
AL_EVENT_REQ	0x0
Error Counters	
Watchdogs	
ESI EEPROM Interface	
MII Management Interface	
FMMU 0	
FMMU 1	
FMMU 2	
FMMU 3	
FMMU 4	
FMMU 5	
FMMU 6	
FMMU 7	
Sync Manager 0	
SM_P_START_ADR	0x1000
SM_LEN	0x80
SM_CONTROL	0x26
OP_MODE	0x2
DIR	0x1
INT_ECAT	0x0
INT_PDI	0x1
WD_TRG	0x0
SM_STATUS	0x2

Figure 3.7: ESC (EtherCAT Slave Controller) Register and RAM view

Chapter 4

EtherCAT Explorer Reference Manual

This document lists and describes the features of the EtherCAT Explorer application. It can be used as a specification document or a brief but detailed and technical user documentation.

1 Network Model

All functionality of the application is centred around an EtherCAT network model.

The model consists of a list of *masters*. Each master has information about how to start or connect to an EtherCAT master. It also contains a list of connected *slaves*.

Each slave has information about one embedded unit. The information included the following: Name, object dictionary data, process image data and slave state.

The model structure looks like this:

- Master 1
  - Slave 1
  - Slave 2
  - ...
- Master 2
- ...

A master can either be in the state *stopped* or in the state *started*. Commands can only be executed on a started master, and information can only be read from a started master. (Information that has been read from a started master is however still available in the GUI when the master has been stopped.)

When a master is started it scans the network for connected slaves. When a slave is found the master reads information about it into the model.

When the user exists the application the information about masters and slaves is saved to disk to be available the next time the application is started. This included the information about the current process image and object dictionary values.

1.1 Master Types

The application has support for two types of EtherCAT masters.

- **Local SOEM Masters:** These are masters that run locally on the PC, as part of the EtherCAT Explorer application itself. They use the SOEM EtherCAT master implementation.
- **Remote EAP Masters:** These are masters that run on a different computer. EtherCAT Explorer communicates with them using EAP (EtherCAT Automation Protocol) protocol.

2 Common Functionality in GUI Views

This section describes functionality which is common to many of the views in the application.

2.1 Display Number Base

Most values in lists and trees can be displayed in decimal, hexadecimal or binary base. This is select in a context pop-up menu which is accessed by right-clicking on the object values.

2.2 Copy Text from Tables and Trees

Most values in table and tree vies can be copied to the clipboard. This action is triggered in a context pop-up menu which is accessed by right-clicking on the object values.

3 SDO Data Reuse

Normally when EtherCAT Explorer starts a master and connect to the network it reads information from the slaves in the network. This information includes the structure and contents objects dictionaries of the slaves. But when a master has read this information once it can re-use it to make this startup procedure quicker.

Note

> This functionality is currently implemented only for EAP (Remote) EtherCAT masters. The reason for this is that the data transfer rate is generally lower from an EAP network making data reuse more useful.

The following start alternatives are available:

Clean Start (Read all data): This reads both the structure and values of the objects dictionary. This is the slowest start alternative, but it must be used if the structure of the object dictionary has changed. **Normal Start (Read only SDO values):** This assumes that the structure of the object dictionary is unchanged but refreshes all SDO values. **Quick Start (Skip reading SDO values):** This skips both reading the structure and the values of the object dictionary.

Warning

> If the **Normal Start** alternative is used when the object dictionary has changed since last update it can lead to serious problems! If the **Quick Start** alternative is used all SDO values will be stale. That is, they will have the values they had at the last refresh instead of the values they have when the master is started.

Slave matching∗∗: This data is reused if a slave on the network matches a saved slave. The following properties of the slaves must be identical for two slaves to match:

- Name
- Serial Number
- Revision Number
- Vendor ID

Measurements on some networks show that SDO data reuse can reduce the start-up time of an EAP master with 50 %.

4 EtherCAT Explorer View

This view consists of a list of the configured EtherCAT masters.

- The view has a toolbar with the following buttons:
  - Create new master
  - Delete selected master or slave. This can also be triggered by the **Del** key.
  - Start traffic logging for selected master
  - Refresh traffic logging for selected master
  - Start selected master and connect to the network. This button has a menu with three sub-buttons. The difference start modes that they trigger is described in section SDO Data Reuse.
- **F2** key opens a **Rename Master** dialog.

Note

When a master is renamed in loses its connection to all PDO:s and SDO:s that have been added to the watch views. The PDO:s and SDO:s have to be re-added.

- Masters can be expanded to show their connected slaves
- Slaves can be expanded to show the names of the slaves' PDO:s

5 EtherCAT Details View

This view consists of a number of tabs which each provides some information about and send commands to the slaves in the network.

This view has the following properties:

- It contains detailed information about one slave, or – in some tabs – information about all slaves of master.
- The active slave (or master) is selected in the EtherCAT Explorer View.
- It consists of a number of tabs that each displays some information about the selected slave.

5.1 Slaves Tab

This tab lists *all* slaves for the selected master. It displays basic properties that is read from each slave.

The user can change the slave state in a drop-down menu in the table. When the slave state is changed in the GUI a message is sent on the network to the slave instructing it to set the new state.

Note

> It is possible to instruct a slave to make an invalid state transitions. It this happens the slave might ignore the instruction or go to an error state.

If a slave reports that it is in an error state then that state is displayed in red.

5.2 Process Image Tab

This tab lists the PDO:s (Process Data Objects) of the selected slave, or for all slaves of a selected master.

The information in the view is periodically re-read from the slaves. More about information about data refresh can be found in section network_com.

PDO:s values that are not read-only can be edited by clicking on their value or selecting them and pressing **F2**. When a value has been edited a message is immediately sent to the slave to update its PDO value.

5.3 Object Dictionary Tab

This tab lists the SDO:s (Service Data Objects) of the selected slave.

The information in the view is read during master startup (unless a quick start mode is used). It can be re-read by using the **Refresh** button in the header of the tab.

SDO:s values that are not read-only can be edited by clicking on their value or selecting them and pressing **F2**. When a value has been edited a message is immediately sent to the slave to update its SDO value.

5.4 Configuration Tab

This tab displays data about the FMMU:s (Fieldbus Memory Management Unit) and the sync managers of the selected slave. This information is read during master startup.

It also has a button to initiate a File Over EtherCAT procedure. This lets the user select a file on the PC which will be transferred to the selected slave.

5.5 EEPROM Tab

This tab displays EEPROM memory. The EEPROM data is parsed and displayed in a tree view.

EEPROM can be read from and written to slaves in the network. EEPROM that is loaded into the tab can also be saved to a file in the file system.

If the CRC checksum of the loaded EEPROM file is not correct a warning message is displayed in the tab header.

When EEPROM has been saved to or loaded from a file the file name is displayed in the top of the view.

5.6 ESC Memory Tab

This tab displays ESC (EtherCAT Slave Controller) memory for the selected slave. The ESC data is parsed and displayed in a tree view.

Data in the view is read from the slave when the top-level categories in the view are expanded. If the read procedure takes a too long time (for example due to network problems) a progress information dialog is displayed.

The **Refresh** button in the tab header makes the application reload data for all expanded sections from the selected slave.

6 Watch View

The **Watch** views contains a list of PDO and SDO names, together with their current values. Values can be added to the view by using mouse drag-and-drop from the Process Image Tab or the Object Dictionary Tab in the **Details** view.

PDO values are refreshed continually. SDO values are refreshed only when the Object Dictionary Tab is refreshed.

The values in the view can be edited. This immediately sends write commands to the slave on the network.

The values in the views can be displayed in different number bases and they can be copied. This is done using the pop-up context menu.

7 Graph Views

This view contains a visual graph of how a set of PDO values change over time.

PDO:s can be added to the view by using mouse drag-and-drop from the Process Image Tab or the Object Dictionary Tab in the **Details** view.

8 EEPROM Editor

This components can be used to view and edit EEPROM data files, in the same way as in the EEPROM Tab of the EtherCAT Details View. The difference is that the EEPROM tab requires and connected slave to work, while the EEPROM Editor is separate from the Details view and the configured masters and slaves.

The editor also has full undo-redo functionality, which the EEPROM tab does not.

Chapter 5

SOES EtherCAT Slave Stack

1 Overview

The Simple Open EtherCAT Slave (SOES) is a library that provides user applications with means to access the EtherCAT fieldbus communication environment:

- EtherCAT State Machine
- Mailbox Interfaces
- Protocols
  - CoE
  - FoE
  - EoE

Required support for mailbox and protocols are examples when you need a slave stack to control the Application layer of EtherCAT. The PDI (Process Data Interface) used for such applications are either SPI (or similar) or an internal/external CPU interface

2 Getting Started

Goto `OpenEtherCATsociety/SOES on GitHub`, there you can find releases or current version.

Clone or download to the destination folder. SOES is split in 3 parts.

- soes - the generic part configured from the application
- application - the application API that configure the stack and control the execution
- soes HAL - hardware abstraction layer for the slave stack, not generic and complements the application configuration of the stack by providing necessary hardware configuration and functions

For a project, use generic SOES and pick one application and soes/hal as template that fits selected hardware and software platform. If the EtherCAT Slave Editor is used it will generate parts of the application, otherwise they have to be provide by the developer.

Project structure

- soes archive
  - SOES/soes
  - SOES/soes/include/sys/gcc/cc.h
- application binary
  - SOES/application
  - SOES/soes/hal

Under SOES/application a set of sample applications can be found to be used as reference designs for different platforms.

3 EtherCAT Slave Stack Initialization

The EtherCAT slave stack is setup with an ESC (EtherCAT Slave Controller) generic initialization function , ecat_slv_init. The esc_cfg_t argument passed to the stack is copied, except the user_arg, to stack internal variables and therefore can go out-of-scope.

There are 3 modes of operations for the stack

- Polling (Free-Run)
  - PDI interrupt is not enabled
  - SyncX interrupt are not enabled
  - AL Event are polled for events every ESC Read/Write to be handled by the stack
  - ecat_slv() get called regular to handle stack operations
- Mixed Polling/Interrupt (SM or DC Synchronous)
  - PDI interrupt is enabled
  - Only SM2 should be masked to generate PDI interrupt.
  - Sync0 interrupt is enabled if DC Synchronous
  - AL Event are polled for events every ESC Read/Write to be handled by the stack
  - ecat_slv_poll() get called regular to handle stack operations
  - DIG_process(DIG_PROCESS_WD_FLAG) get called regular to kick the software watchdog counter Or the hardware PDI interrupt watchdog should be activated
- Interrupt (SM or DC Synchronous)
  - PDI interrupt is enabled
  - In addition to SM2 add SMCHANGE, EEP(if EEPROM emulated), ALCONTROL, SM0 and SM1 to the mask to generate PDI interrupt.
  - Sync0 interrupt is enabled if DC Synchronous
  - AL Event are not polled for events
  - ecat_slv_worker() get called when an interrupt occur, preferably from a background task
  - DIG_process(DIG_PROCESS_WD_FLAG) get called regular to kick the software watchdog counter Or the hardware PDI interrupt watchdog should be activated

Structure configuration parameter

- User Input - Optional
- Stack parameter configuration - Mandatory
- Stack and Application interaction functions - Optional and Mandatory depending on mode of operations

```
static esc_cfg_t config =
{
   /* User input to stack */
   .user_arg = NULL, /* passed along to ESC_config and ESC_init */

   /* Mandatory input to stack */
   .use_interrupt = 1, /* flag telling the stack if the user application will use
                          interrupts, 0= Polling, 1 = Mixed Polling/Interrupt
                          and Interrupt */

   .watchdog_cnt = 100, /* non UNIT watchdog counter, for the application
                           developer to decide UNIT. This example set 100
                           cnt and by calling ecat_slv or
                           DIG_process(DIG_PROCESS_WD_FLAG) every 1ms,
                           it creates a watchdog running at ~100ms. */

   /* Optional input to stack for user application interaction with the stack
    * all functions given must be implemented in the application.
    */
   .set_defaults_hook = NULL, /* hook called after stack have loaded known
                                 default values, possible for application
                                 to load values not known in compile time
                                 or that need to be overwritten */
   .pre_state_change_hook = NULL, /* hook called before state transition */
   .post_state_change_hook = NULL, /* hook called after state transition */

   .application_hook = NULL, /* hook in application loop called when
                                DIG_process(DIG_PROCESS_APP_HOOK_FLAG) */
   .safeoutput_override = NULL, /* user override of default safeoutput when stack
                                   stop outputs */

   .pre_object_download_hook = NULL, /* hook called before object download,
                                        if hook return != 0 the download will not
                                        take place */
   .post_object_download_hook = NULL, /* hook called after object download */

   .rxpdo_override = NULL, /* user override of default rxpdo */
   .txpdo_override = NULL, /* user override of default txpdo */

   /* Mandatory input to stack for SM and DC synchronous applications */
   .esc_hw_interrupt_enable = NULL, /* callback to function that enable IRQ
                                       based on the Event MASK */
   .esc_hw_interrupt_disable = NULL, /* callback to function that disable IRQ
                                        based on the Event MASK */

   /* Mandatory input for emulated eeprom */
   .esc_hw_eep_handler = NULL /* callback to function that handle an emulated eeprom */

   /* Mandatory if Distributed Clocks get activated by the master */
   .esc_check_dc_handler = NULL /* Check DC synchronous settings, must be set if
                                  DC synchronisation activated, or state change
                                  PREOP->SAFEOP will fail.
};
```

The stack is setup but not running.

```
void main_run(void * arg)
{
...
   ecat_slv_init(&config);
```

4 EtherCAT Slave Stack API

4.1 DIG_process - Process Data Handler

Implements the watch-dog counter to count if the slave should make a state change to SAFEOP due to missing incoming SM2 events. Updates local I/O and run the application in the following order, call read EtherCAT outputs, execute user provided application hook and call write EtherCAT inputs.

- `#define DIG_PROCESS_INPUTS_FLAG 0x01`
- `#define DIG_PROCESS_OUTPUTS_FLAG 0x02`
- `#define DIG_PROCESS_WD_FLAG 0x04`
- `#define DIG_PROCESS_APP_HOOK_FLAG 0x08`

Parameters

in	*flags*	= User input what to execute

```
void DIG_process (uint8_t flags);
```

4.2 ecat_slv_worker - Non-synchronous Interrupt Handler

Handler for SM change, SM0/1, AL CONTROL and EEPROM events, the application control what interrupts that should be served and re-activated with event mask argument. Interrupts served here are not part of synchronization and is handle preferably by a background-task or similar. NOTE: No locking of ESC_read/ESC_write is done for slaves that rely on consecutive address/data being provided on ESC_read/ESC_write.

Parameters

in	*event_mask*	= Event mask for interrupts to serve and re-activate after served

```
void ecat_slv_worker (uint32_t event_mask);
```

4.3 ecat_slv_poll - Interrupt Polling Routine for Non-Synchronous Interrupt

Poll SM0/1, EEPROM and AL CONTROL events in a SM/DC synchronization application NOTE: No locking of ESC_read/ESC_write is done for slaves that rely on consecutive address/data being provided on ESC_read/ESC_write.

```
void ecat_slv_poll (void);
```

4.4 ecat_slv - All Polling Routine

Poll all events in a free-run application

```
void ecat_slv (void);
```

4.5 ecat_slv_init - Stack Initialization

Parameters

in	*config*	= User input how to configure the stack

```
void ecat_slv_init (esc_cfg_t * config);
```

5 EtherCAT Slave Stack HW Layer Implementation

5.1 EtherCAT HW Layer Polling Interrupts

When running in polling or mixed polling/interrupt mode AL Event must be polled. Best done in ESC_read and ESC_write

```
void ESC_read (uint16_t address, void *buf, uint16_t len)
{
   ESCvar.ALevent = <HW read ALevent>;
   memcpy (buf, ESCADDR(address), len);
}

void ESC_write (uint16_t address, void *buf, uint16_t len)
{
   ESCvar.ALevent = <HW read ALevent>;
   memcpy (ESCADDR(address), buf, len);
}
```

5.2 EtherCAT HW Layer Enable/Disable Interrupts

When running in mixed polling/interrupt or interrupt mode the EtherCAT HW layer should provide with function to enable and disable interrupts, those functions will be called by the EtherCAT slave stack with mask to enable/disable SM2 and DC events, DC if DC is active. The code below acts as pseudo code since access to ESC registers varies.

Example SM- or DC synchronous application only PDI interrupt is used

```
void ESC_interrupt_enable (uint32_t mask)
{
   AL_EVENT_MASK = mask;
}

void ESC_interrupt_disable (uint32_t mask)
{
   AL_EVENT_MASK &= ~mask;
}
```

Example DC synchronous application PDI and separate sync0 is used.

```
void ESC_interrupt_enable (uint32_t mask)
{
   AL_EVENT_MASK = mask;
   if(mask & dc_mask)
   {
       int_enable(SYNC0);
   ...
}
void ESC_interrupt_disable (uint32_t mask)
{
   AL_EVENT_MASK &= ~mask;
   if(mask & dc_mask)
   {
       int_disable(SYNC0);
   ...
}
```

5.3 EtherCAT HW Layer SYNC0 Interrupt

Sync0 used in DC synchronous is generated from a ESC internal block for Distributed Clocks, sync0 interrupts can be setup as a separate interrupt source or part of the PDI interrupt. In most cases it is used together with SM2 interrupts, therefor DIG_process allow to flag what parts it should execute. In this example sync0 is expected to happen after PDI isr SM2, SM2 handle DIG_process(DIG_PROCESS_↩ OUTPUTS_FLAG) copying the RxPDO to local variables. Sync0 finish with executing the application and writing the TxPDO for next frame, DIG_process(DIG_PROCESS_APP_HOOK_FLAG | DIG_PROCES↩ S_INPUTS_FLAG).

Example DC synchronous application with separate sync0 interrupt

```
void sync0_isr (void * arg)
{
    DIG_process(DIG_PROCESS_APP_HOOK_FLAG | DIG_PROCESS_INPUTS_FLAG);
}
```

5.4 EtherCAT HW Layer PDI Interrupt

PDI interrupt is a collection of interrupt sources, consult the ESC reference manual for details. Example, sync0 is handled by a separate interrupt, SM2 is mandatory when running an interrupt mode. Depending on software support the application can choose to poll AL event for non-synchronous interrupts when running mixed polling/interrupt mode Or run interrupt mode where no polling of AL event is used. The code below acts as pseudo code since access to ESC registers varies.

Example SM- or DC Synchronous application running mixed polling/interrupt mode

```
void pdi_isr (void * arg)
{
   /* High prio interrupt used for synchronization */
   if(ESCvar.ALevent & ESCREG_ALEVENT_SM2)
   {
      /* If DC sync is not active, run the application, all except for the Watchdog */
      if(ESCvar.dcsync == 0)
      {
         DIG_process(DIG_PROCESS_OUTPUTS_FLAG | DIG_PROCESS_APP_HOOK_FLAG |
               DIG_PROCESS_INPUTS_FLAG);
      }
      /* If DC sync is active, call output handler only */
      else
      {
         DIG_process(DIG_PROCESS_OUTPUTS_FLAG);
      }
   }
}
```

Example SM- or DC Synchronous application running interrupt mode, add separate handler for non-synchronous interrupts to minimize execution time of the interrupt. In this example a semaphore is used to start a low prio task.

```
void pdi_isr (void * arg)
{
```

```
...
   ESCvar.ALevent = AL_EVENT_MASK;
   /* High prio interrupt used for synchronization */
   if(ESCvar.ALevent & ESCREG_ALEVENT_SM2)
   {
      /* If DC sync is not active, run the application, all except for the Watchdog */
      if(ESCvar.dcsync == 0)
      {
         DIG_process(DIG_PROCESS_OUTPUTS_FLAG | DIG_PROCESS_APP_HOOK_FLAG |
               DIG_PROCESS_INPUTS_FLAG);
      }
      /* If DC sync is active, call output handler only */
      else
      {
         DIG_process(DIG_PROCESS_OUTPUTS_FLAG);
      }
   }
   /* Assume there is task support, handle low prio interrupts from back-ground
    * task not blocking for coming SM2 interrupts
    */
   if(ESCvar.ALevent & (ESCREG_ALEVENT_CONTROL | ESCREG_ALEVENT_SMCHANGE
         | ESCREG_ALEVENT_SM0 | ESCREG_ALEVENT_SM1 | ESCREG_ALEVENT_EEP))
   {
      /* Mask interrupts while servicing them */
      AL_EVENT_MASK &= ~(ESCREG_ALEVENT_CONTROL | ESCREG_ALEVENT_SMCHANGE
            | ESCREG_ALEVENT_SM0 | ESCREG_ALEVENT_SM1 | ESCREG_ALEVENT_EEP);
      /* Signal back-ground task */
      sem_signal(ecat_isr_sem);
   }
}
```

5.5 EtherCAT HW Layer Emulated EEPROM

Using emulated eeprom require a handler called by application code. The handler should call the generic EEP handler for incoming EEP interrupt and implement the HW parts for EEP write/EEP read. Example can be found for XMC4 targets under <SOES>/application. Normally the emulated EEPROM is loaded to RAM on start and flushed back to a NVM if needed, this must be implemented by the user in the eep hardware layer since the Slave Stack don't include support for it in the generic part.

```
void ESC_eep_handler(void)
{
   /* Handle incoming EEP interrupt  */
   EEP_process ();
   /* Implements read/write for volatile and non-volatile EEPROM data */
   EEP_hw_process();
}

static esc_cfg_t config =
{
..
   .esc_hw_eep_handler = ESC_eep_handler
..
};
```

5.6 EtherCAT HW Layer Initialization

The ESC hardware layer is possible to place in the SOES library or Application project, to handle both scenarios the EtherCAT slave stack pass the ESC configuration as parameter via ecat_slv_init to E↩SC_init. ESC config has an user_arg that can be used for miscellaneous information passed from the application to ESC hardware initialization. ESC_init should setup the hardware to serve the application with necessary functions. The code below acts as pseudo code since access to ESC registers varies.

Example SM- or DC Synchronous application running mixed polling/interrupt mode

```
void ESC_init (const esc_cfg_t * config)
{
    /* Setup PDI interrupt */
    int_connect (IRQ_PDI, pdi_isr, NULL);
    int_enable (IRQ_PDI);

    /* Set mask to disable all interrupts, the stack enables SM2 interrupt */
    AL_EVENT_MASK = 0;

    /* Setup sync0 interrupt if DC synchronous */
    int_connect (IRQ_SYNC0, sync0_isr, NULL);
    /* Let the stack enable the DC interrupt */
    int_disable(IRQ_SYNC0);
}
```

Example SM- or DC Synchronous application running interrupt mode, example implement an emulated EEPROM and require ESCREG_ALEVENT_EEP, no need to pass that event mask if EEPROM is connected via I2C.

```
/* Non-synchronous interrupt handler function */
static void isr_run(void * arg)
{
   while(1)
   {
      sem_wait(ecat_isr_sem);
      ecat_slv_worker(ESCREG_ALEVENT_CONTROL | ESCREG_ALEVENT_SMCHANGE
            | ESCREG_ALEVENT_SM0 | ESCREG_ALEVENT_SM1 | ESCREG_ALEVENT_EEP);
   }
}

void ESC_init (const esc_cfg_t * config)
{
    /* Create non-synchronous interrupt handler task and use a
     * semaphore for signalling
     */
    ecat_isr_sem = sem_create(0);
    task_spawn ("soes_isr", isr_run, 9, 2048, NULL);

    /* Setup PDI interrupt */
    int_connect (IRQ_PDI, pdi_isr, NULL);
    int_enable (IRQ_PDI);

    /* Set mask to enable non-synchronous interrupts to be able to operate,
     * let the stack enable SM2 interrupt.
     */
    AL_EVENT_MASK = (ESCREG_ALEVENT_SMCHANGE |
                     ESCREG_ALEVENT_EEP |
                     ESCREG_ALEVENT_CONTROL |
                     ESCREG_ALEVENT_SM0 |
                     ESCREG_ALEVENT_SM1);

    /* Setup sync0 interrupt if DC synchronous */
    int_connect (IRQ_SYNC0, sync0_isr, NULL);
    /* Let the stack enable the DC interrupt */
    int_disable(IRQ_SYNC0);
}
```

6 Implement the Application

If the EtherCAT Slave Editor is used it will generate parts of the application that needs to be implemented, otherwise the final linking of the application will fail with undefined reference errors. If no code generating tool is used one of the reference designs can be modified with desired data.

There are two types of stack interaction functions

- Overrides - are mutually exclusive, if set only the function provided by the application will execute.

- Hooks - are a complement to the code provided by SOES.

6.1 Handle Application Configuration Parameters

The EtherCAT slave stack give the developer possibility to verify, validate and take actions on SDO downloads, it is done with pre- and post SDO download hooks.

Pre SDO download handler:

It is possible to add a pre SDO download hook that will give the application a chance to validate and prevent the download from taking place.

Post SDO download handler:

It is possible to add a post SDO download hook that will give the application a chance to act on new data that have been downloaded.

```
uint32_t user_pre_dl_objecthandler ((uint16_t index,
      uint8_t subindex,
      void * data,
      size_t size,
      uint16_t flags)
{
   /* Prevent object from being written */
   if (index == 0x8001)
   {
      uint32_t value;
      memcpy(&value, data, size);
      if(value != OK_VALUE)
      {
         return ABORT_NOT_OK_SOMETHING;
      }
   }
   return 0;
}

void user_post_dl_objecthandler (uint16_t index, uint8_t subindex, uint16_t flags)
{
   /* Re-calculate PDO size on change */
   if (index == 0x1c12)act
      RXPDOsize = ESC_SM2_sml = sizeRXPDO();
   }
}

static esc_cfg_t config =
{
...
   .pre_object_download_hook = user_pre_dl_objecthandler,
   .post_object_download_hook = user_post_dl_objecthandler,
...
};

/* EtherCAT Slave Stack default code */
uint32_t ESC_pre_objecthandler (uint16_t index,
      uint8_t subindex,
      void * data,
      size_t size,
      uint16_t flags)
{
   int abort = 0;

   if (IS_RXPDO (index) || IS_TXPDO (index))
   {
      if (subindex > 0 && COE_maxSub (index) != 0)
      {
         abort = ABORT_SUBINDEX0_NOT_ZERO;
      }
   }
   else if (ESCvar.pre_object_download_hook)
   {
      abort = (ESCvar.pre_object_download_hook) (index,
            subindex,
            data,
            size,
            flags);
   }

   return abort;
}

void ESC_objecthandler (uint16_t index, uint8_t subindex, uint16_t flags)
{
   if (ESCvar.post_object_download_hook != NULL)
   {
      (ESCvar.post_object_download_hook)(index, subindex, flags);
   }
}
```

6.2 Handle Application IO

The EtherCAT Slave Stack provide two callback functions to be used with all RxPDO/TxPDO objects, the callbacks will be called accordingly when required and should be implemented by the application, void cb_get_inputs (void) and void cb_set_outputs (void).

The user also must declare the Application variable for, _Objects Obj.

```
/* Application variables */
_Objects    Obj;

void cb_get_inputs()
{
   Obj.Buttons.Button1 = gpio_get(GPIO_BUTTON1);
}
void cb_set_outputs()
{
   gpio_set(GPIO_LED1, Obj.LEDgroup0.LED0);
}

/* Function to update local I/O, call read ethercat outputs, call
 * write ethercat inputs. Implement watch-dog counter to count-out if we have
 * made state change affecting the App.state.
 */
void DIG_process (uint8_t flags)
{
...
   /* Handle Outputs */
   if ((flags & DIG_PROCESS_OUTPUTS_FLAG) > 0)
   {
...
         RXPDO_update();
...
         /* Set outputs */
         cb_set_outputs();
...
...
   /* Handle Inputs */
   if ((flags & DIG_PROCESS_INPUTS_FLAG) > 0)
   {
...
         /* Update inputs */
         cb_get_inputs();
         TXPDO_update();
...
}
```

SOES include a mandatory function for safe outputs, it is called by the stack when it stop outputs. The user should interact with this function providing a custom function to add local IO handling.

```
void APP_safeoutput (void)
{
...
   if(ESCvar.safeoutput_override != NULL)
   {
      (ESCvar.safeoutput_override)();
   }

}
```

6.3 Application State Machine Interactions

The EtherCAT slave stack give the developer possibility to verify, validate and take actions on state changes, it is done with pre- and post state change hooks.

Parameters

in	$*as$	= Combined info for requested and current state ((ALCONTROL $<<$ 4)| ALSTATUS)
in	$*an$	= Local value of AL Status in the stack state machine, will become the EtherCAT Slave AL Status when the state machine function finish.

```
void post_state_change_hook (uint8_t * as, uint8_t * an);
void post_state_change_hook (uint8_t * as, uint8_t * an);

\
void post_state_change_hook (uint8_t * as, uint8_t * an)
{
   /* Add specific step change hooks here */
   if ((*as == BOOT_TO_INIT) && (*an == ESCinit))
   {
      /* On upgrade finished verify the image and reset, else return and fail
       * the state change
       */
      upgrade_finished();
      /* If we return here */
      ESC_ALerror (ALERR_NOVALIDFIRMWARE);
      /* Upgrade failed, enter init with error */
      *an  = (ESCinit | ESCerror);
   }
   else if((*as == PREOP_TO_SAFEOP))
   {
      rprintf("boot PREOP_TO_SAFEOP\n");
      ESC_ALerror (ALERR_NOVALIDFIRMWARE);
      /* Stay in preop with error bit set */
      *an = (ESCpreop | ESCerror);
   }
#endif
}
static esc_cfg_t config =
{
...
   .application_hook = user_application,
...
};
```

6.4 Execute the Application

To execute the application accordingly when required, add an application hook serving as the user application entry point.

```
/* Function to update local I/O, call read ethercat outputs, call
```

```
 * write ethercat inputs. Implement watch-dog counter to count-out if we have
 * made state change affecting the App.state.
 */
void DIG_process (uint8_t flags)
{
   /* Call application */
   if ((flags & DIG_PROCESS_APP_HOOK_FLAG) > 0)
   {
...
      /* Call application callback if set */
      if (ESCvar.application_hook != NULL)
      {
         (ESCvar.application_hook)();
      }
   }
...
}
static esc_cfg_t config =
{
...
   .application_hook = user_application,
...
};
```

6.5 Initialization of Object Dictionary

When the stack initializes the Object Dictionary with given default values from _objectlist.c it only does it for data types less than or equal to 4 Bytes, this since the Object Dictionary implementation only provide 4 Bytes storage for default values. To handle this the user can provide a hook that will be called at the end when the stack initialize the default values; it also gives the possibility to modify or override given default values.

```
/* Function to set default values, called by stack set default function */
void init_default(void)
{
   /* Override given values */
#if SLAVE_TYPE_1
   Obj.Parameters.Multiplier = 100;
#else
   Obj.Parameters.Multiplier = 90;
#endif

   /* Initialize data types > 4 Bytes */
   Obj.datatyptest.real64_ro = 12345.67890;
   Obj.datatyptest.real64_rw = 67890.12345;
   Obj.datatyptest.int64_rw = UINT64_MAX;
   Obj.datatyptest.int64_ro = INT64_MAX;
   Obj.datatyptest.uint64_rw = UINT64_MAX;
   Obj.datatyptest.uint64_ro = UINT64_MAX;
}

static esc_cfg_t config =
{
...
   .application_hook = init_default,
...
};
```

7 Run the Application

For examples and references goto <SOES>/applications and <SOES>/soes/hal.

7.1 EtherCAT Slave Stack Polling

Configure not to use interrupts, call the EtherCAT stack handler periodically. This correspond to legacy use of SOES, soes_init , while(1) { soes(); }.

```
static esc_cfg_t config =
{
..
   .use_interrupt = 0,
..
};
void main_run(void * arg)
{
    ecat_slv_init(&config);
    while(1)
    {
        ecat_slv();
    }
}
```

7.2 EtherCAT Slave Stack Mixed Polling/Interrupt Mode

Configure to use interrupts, set interrupt enable/disable handlers, call the EtherCAT slave stack handler for polling non-synchronous interrupts periodically. Kick the watchdog supervising for incoming data from the EtherCAT Master

```
static esc_cfg_t config =
{
..
   .use_interrupt = 1,
   .esc_hw_interrupt_enable = ESC_interrupt_enable,
   .esc_hw_interrupt_disable = ESC_interrupt_disable,
..
};
void main_run(void * arg)
{
    ecat_slv_init(&config);
    while(1)
    {
        /* Kick watchdog with watchdog count intervals */
        DIG_process(DIG_PROCESS_WD_FLAG);
        ecat_slv_poll();
    }
}
```

7.3 EtherCAT Slave Stack Interrupt Mode

Configure to use interrupts, set interrupt enable/disable handlers, kick the watchdog supervising for incoming data from the EtherCAT Master

```
static esc_cfg_t config =
{
..
   .use_interrupt = 1,
   .esc_hw_interrupt_enable = ESC_interrupt_enable,
   .esc_hw_interrupt_disable = ESC_interrupt_disable,
..
};
void main_run(void * arg)
{
    ecat_slv_init(&config);
    while(1)
    {
        /* Kick watchdog with watchdog count intervals */
        DIG_process(DIG_PROCESS_WD_FLAG);
        task_delay(1)
    }
}
```

Configure to use interrupts, set interrupt enable/disable handlers, start the HW PDI interrupt watchdog supervising for incoming data from the EtherCAT Master

```
static void ecat_isr (void * arg)
{
...
   /* SM watchdog */
   if(ESCvar.ALevent & ESCREG_ALEVENT_WD)
   {
      uint16_t wd;
      /* Ack the WD IRQ */
      wd = WD_STAT_PDATA;
      /* Check if the WD have expired and if we're in OP */
      if(((wd & 0x1) == 0)  &&
         ((CC_ATOMIC_GET(ESCvar.App.state) & APPSTATE_OUTPUT) > 0))
      {
         ESC_ALstatusgotoerror((ESCsafeop | ESCerror), ALERR_WATCHDOG);
         AL_EVENT_MASK &= ~ESCREG_ALEVENT_WD;
      }
   }
...
}

void cb_state_change (uint8_t * as, uint8_t * an)
{
   if (*as == SAFEOP_TO_OP)
   {
      /* Enable watchdog interrupt */
      ESC_ALeventmaskwrite(ESC_ALeventmaskread() | ESCREG_ALEVENT_WD);
   }
}

static esc_cfg_t config =
{
..
   .use_interrupt = 1,
   .post_state_change_hook = cb_state_change,
   .esc_hw_interrupt_enable = ESC_interrupt_enable,
   .esc_hw_interrupt_disable = ESC_interrupt_disable,
..
};
void main_run(void * arg)
{
    ecat_slv_init(&config);
    for(;;)
    {
        /* Stack is run from interrupt context only, this task can be terminated
         * if supported by the OS.
         */
        task_delay(1000);
    }
}
```