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Interfacing FlashRunner with CAN and CAN-FD buses

1. Introduction

This document aims to explain how a CAN or CAN-FD bus can be interfaced to FlashRunner High-Speed using its dedicated Active Module or to FlashRunner 2.0 and NXG using specific adapters, from both hardware and software points of view. CAN, which stands for Controller Area Network, is an automotive protocol used worldwide because of its robustness and flexibility. The development of this protocol started between 1980 and 1990 at Bosch and then it has become a standard for on-board diagnostics (OBD). Since the original CAN has some limitations in terms of bandwidth and performance, recently a new standard has been introduced in the market: the CAN-FD (Controller Area Network Flexible Data-Rate), which can reach a data rate up to 12 Mbps.

Using the solution developed by SMH Technologies, customers can now interface both CAN and CAN-FD buses with a single hardware solution. This system is designed to satisfy an increasing market demand for programming boards at the end-of-line stage where the case is mounted to the boards and only the CAN bus is accessible. Moreover, this system can be used to flash those devices that only have the CAN or CAN-FD bus as flashing port.

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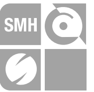

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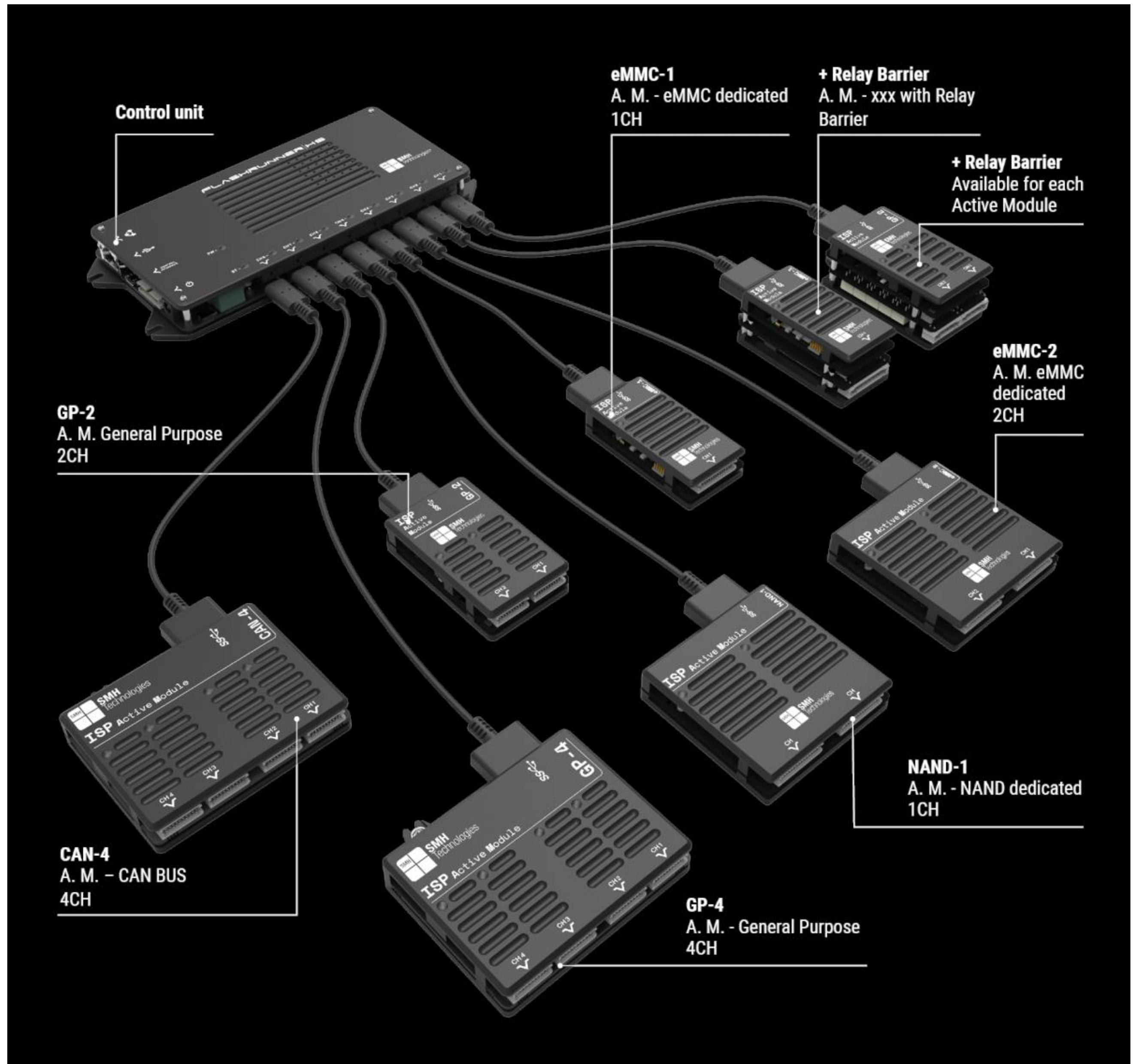
3. Hardware Setup

Before going deep into the CAN specifications, let us spend some words to describe FlashRunner and its unique characteristics. FlashRunner combines high-level programming performances and high modularity to obtain a Multi-end programming solution that fits the needs of Pre-Programming and In-System Programming equipment. A central management coordinates different technologies for each peripheral module: this organization reflects the Industry 4.0 concept, where a central intelligence creates smart networking and parallel independent process management, reaching high-quality levels and optimizing the production process. More info about FlashRunner can be found here.



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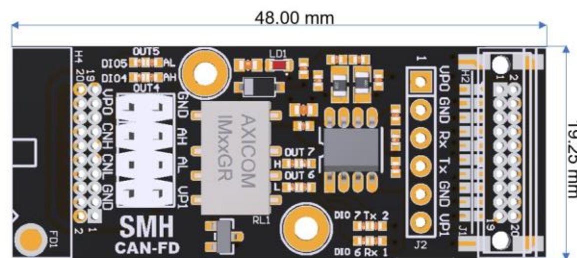
One of the available solutions is the CAN-4 Active Module shown on the right. This Active Module is specifically designed to allow both CAN and CAN-FD communications, up to 1Mbps for CAN and 12Mbps for CAN-FD which is the maximum frequency defined by the standard. This Active Module is named CAN-4 because it has four parallel independent communications channels. Each one of them is featured by a galvanically isolated transceiver to interface a CAN bus as required by the CAN and CAN-FD protocol specifications.
The CAN-4 module is designed with an additional interface board for the D-SUB 9-pin connectors which could be plugged into the module if needed.

Another available solution, suitable for compact integrations, is the Communication Adapter CAN: a small dedicated board that translates the FlashRunner output signals to the CAN differential bus. The adapter integrates a galvanically isolated transceiver and supports both CAN and CAN-FD, drawing its supply from the FlashRunner channel through VPROG0. It is offered in three connector configurations (wire wrapping, direct plug or peripheral cable interface) to match different integration needs.



For multi-channel production lines that require electrical separation between the programming system and the targets, SMH Technologies also offers the CAN/LIN Interface with Relay Barrier, available in 8-channel and 16-channel versions. It integrates the CAN/LIN transceivers together with a Relay Barrier that switches the targets in and out of the bus without affecting the rest of the line.

One of the main peculiarities of CAN bus protocol is that two differential lines are used to communicate. In fact, a CAN transceiver is required to transform these special signals into usable information by the programmer. This is the reason why SMH Technologies developed a dedicated Active Module to manage this protocol which is available only for FlashRunner.

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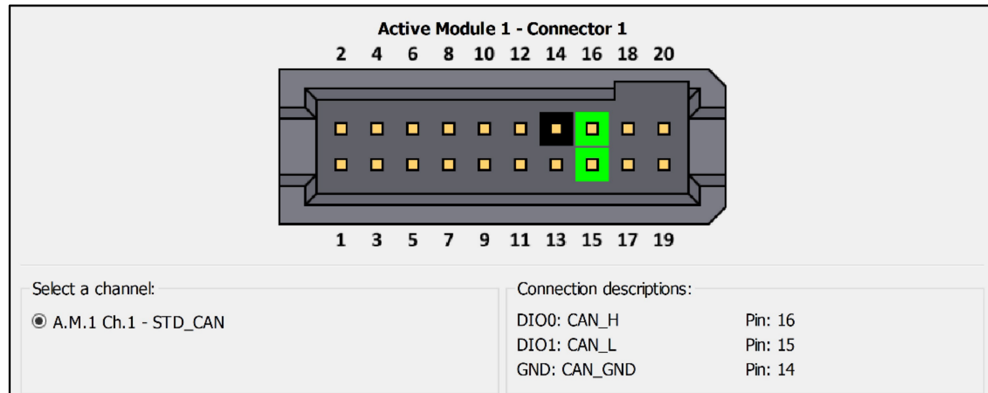
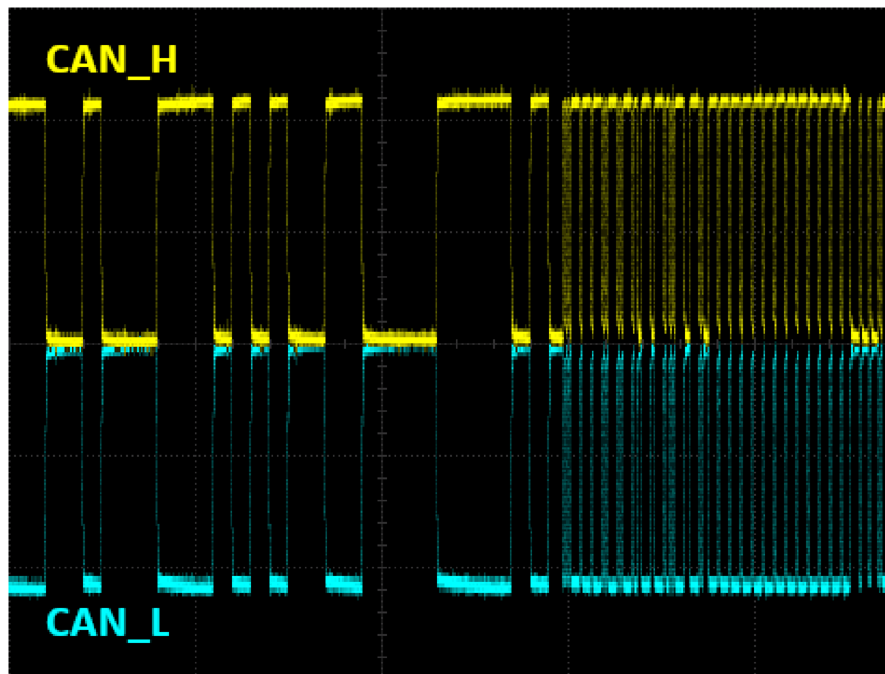


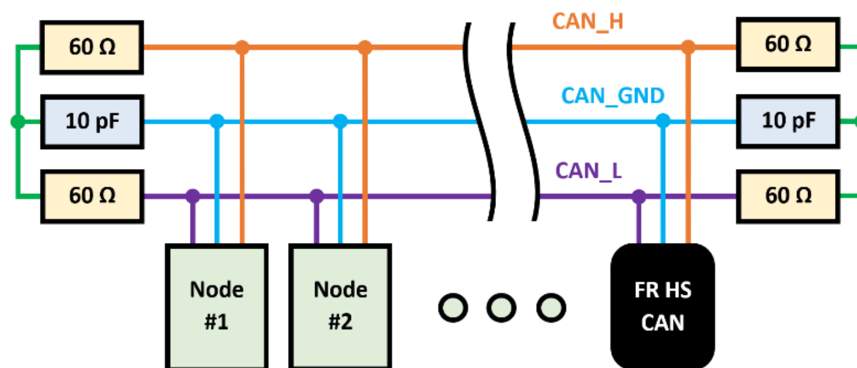
On the image above you can see the pinout of one connector mounted on the CAN-4 Active Module, and you can see that only three signals are present:

- **CAN_H** and **CAN_L**
  These are the two differential signals which actually carry the data.
- **CAN_GND**
  This is an optional signal which can be useful to have a common ground for the CAN bus nodes. We suggest to connect CAN_GND (when it is possible) to prevent high voltage differences that could damage the nodes connected to the network.
  This ground signal is galvanically isolated from FlashRunner.



From the capture above, it is possible to understand the meaning of “differential signals”. In fact, you can see that CAN_H and CAN_L have basically opposite levels and that the CAN bus only allows two valid states: **recessive** (when the voltage difference between CAN_H and CAN_L is about 0V) and **dominant** (when the voltage difference between CAN_H and CAN_L is higher than about 1V).

Another important aspect that customers should consider when realizing the hardware setup is that the CAN bus requires termination load resistors between CAN_H and CAN_L. This does not mean that a resistor must always be placed on the FlashRunner side, it depends on the network in which it is connected. What customers should check is if CAN bus specifications are satisfied. The best solution we suggest is the one shown in the image above where both sides of the network are terminated with 120 Ohm between CAN_H and CAN_L and each termination is split into two 60 Ohm resistors. The split termination improves electromagnetic emissions by adding a low-pass filter for the common-mode noise on the network.



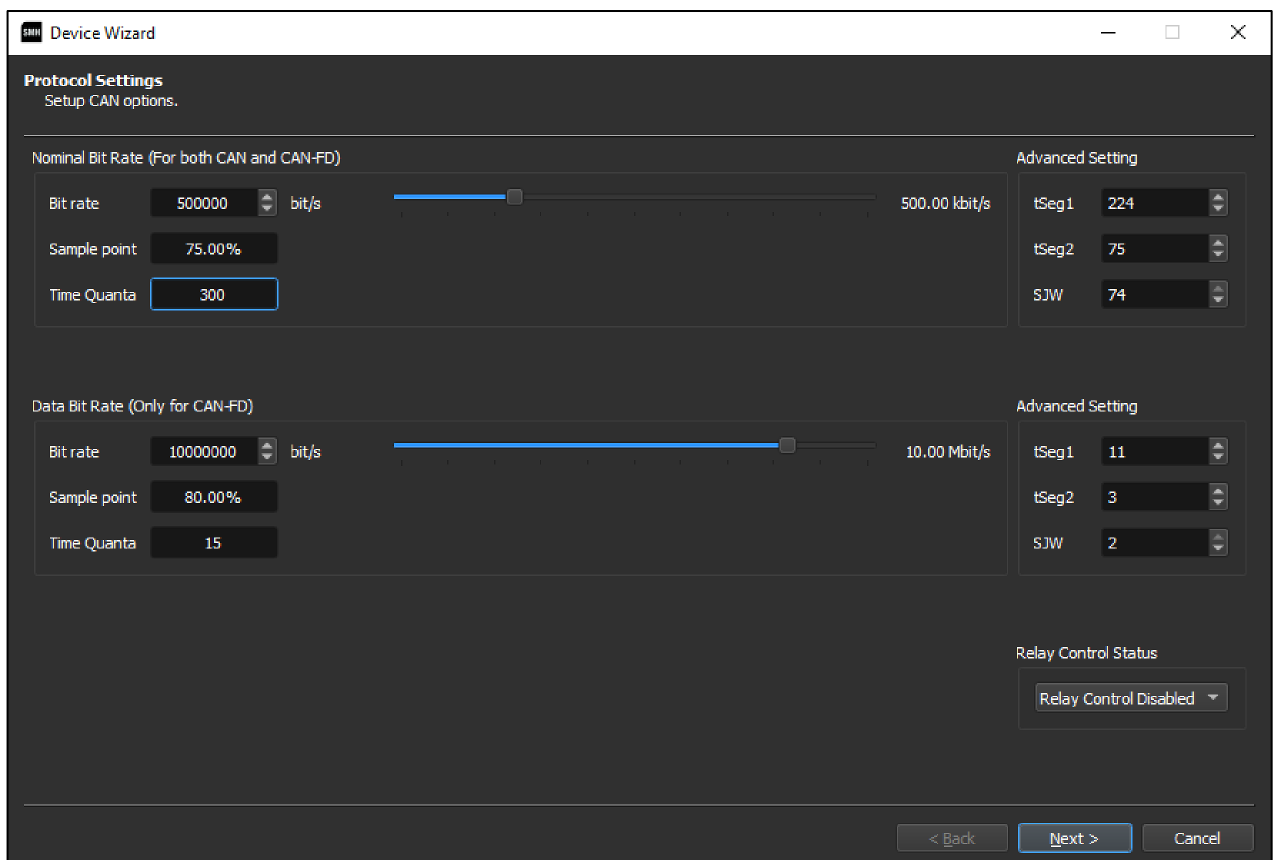
In the typical case when FlashRunner has to communicate with a single target, then it is highly probable that the user needs to place the resistors on both terminations as explained above. The customers also can ask us to mount these resistors on the CAN-4 Active Module when purchasing it.

4. Project Configuration

In the previous chapters we often mentioned CAN and CAN-FD and now it is time to explain the actual differences between them:

- **CAN**
  - One bit rate, up to 1 Mbps.
  - Maximum 8 bytes for each frame.
- **CAN-FD**
  - Two bit rates: the nominal bit rate that corresponds to the standard CAN specifications (up to 1 Mbps) and the data bit rate that is used only when transferring data and can reach up to 12 Mbps.
  - Maximum 64 bytes for each frame.

CAN and CAN-FD bit rates must be the same for all the nodes in the network.
Clarified that, now we can see how to configure a new project using the Workbench. So, just start creating a new project and select “STD_CAN” as device, this will lead you to the following window where you can select the bit rates to use for CAN and CAN-FD. This setting is fundamental to make the communication with other nodes work.



Moreover, there are also some advanced settings that allow you to configure the proper sample point according to your network characteristics. Default values are typically ok but, if you want to be punctilious, you can check that all the nodes share the same settings (or as close as possible).

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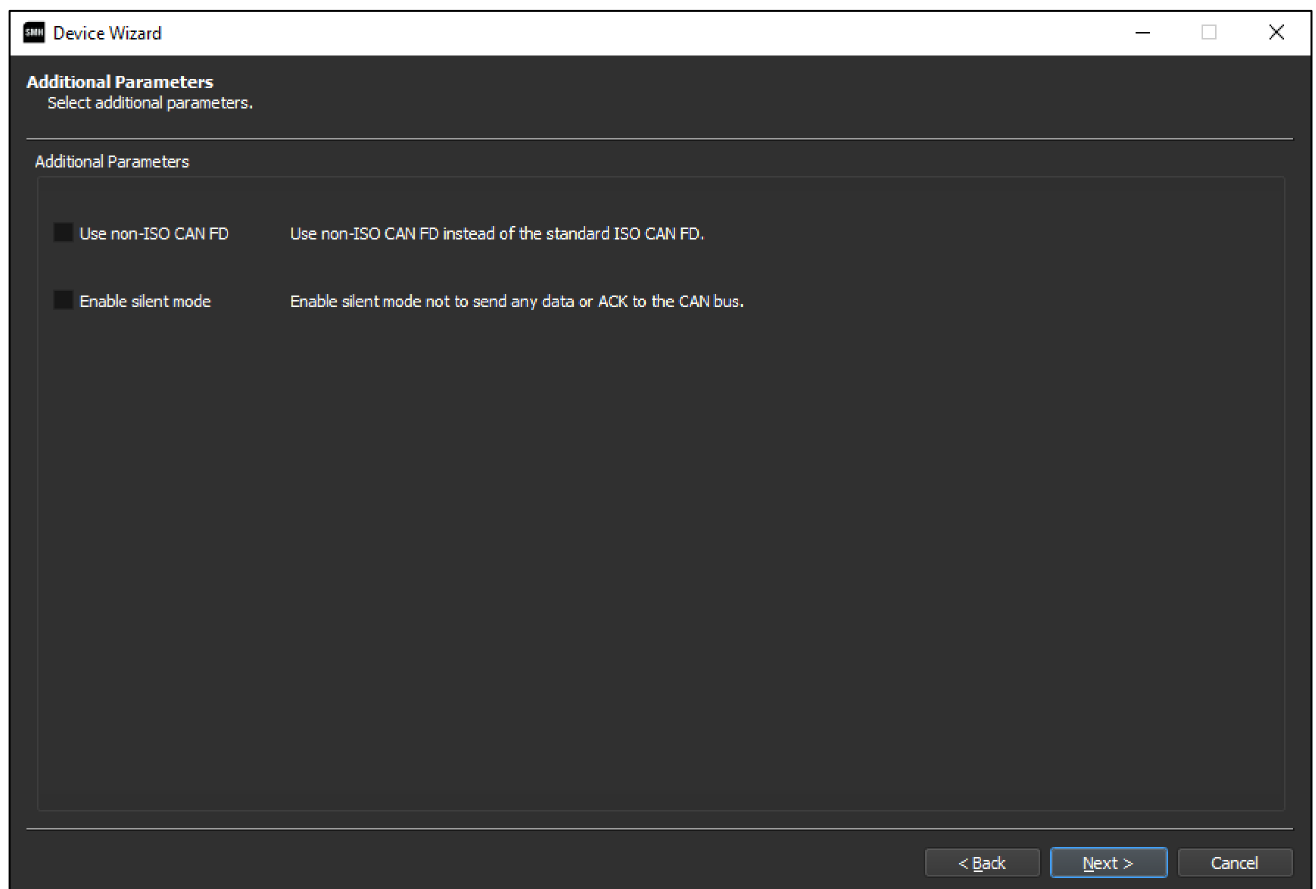
Warning: after generating the project file, it is not possible to manually edit these parameters from the textual project editor because if you edit them wrongly, then the project execution will fail. In fact, the driver checks if these parameters make sense during the TPSTART command. If you actually need to edit these parameters, please, edit the project using the wizard tool from the Workbench (shortcut: ctrl+alt+e).

From this page, it is also possible to enable or disable the Relay Barrier usage. This can be useful if customers want to totally isolate the target board from the FlashRunner when they are performing the functional test on the same station. Using the Relay Barrier we can connect the FlashRunner to the board when the relays are closed and cut off the programmer from the board when the relays are opened. If you need the Relay Barrier, you need to ask for that when purchasing the CAN-4 Active Module because it is an additional hardware plugin to the module.

On the next page, you will find some additional parameters that you can choose:

- **Use non-ISO CAN-FD**
  This should be enabled in case you need to use the non-ISO CAN-FD instead of the standard ISO CAN-FD. This could be required according to your network configuration.
- **Enable silent mode**
  This should be selected not to send any data or ACK to the CAN bus. This could be useful if you just need to monitor the communications on the bus without interfering.



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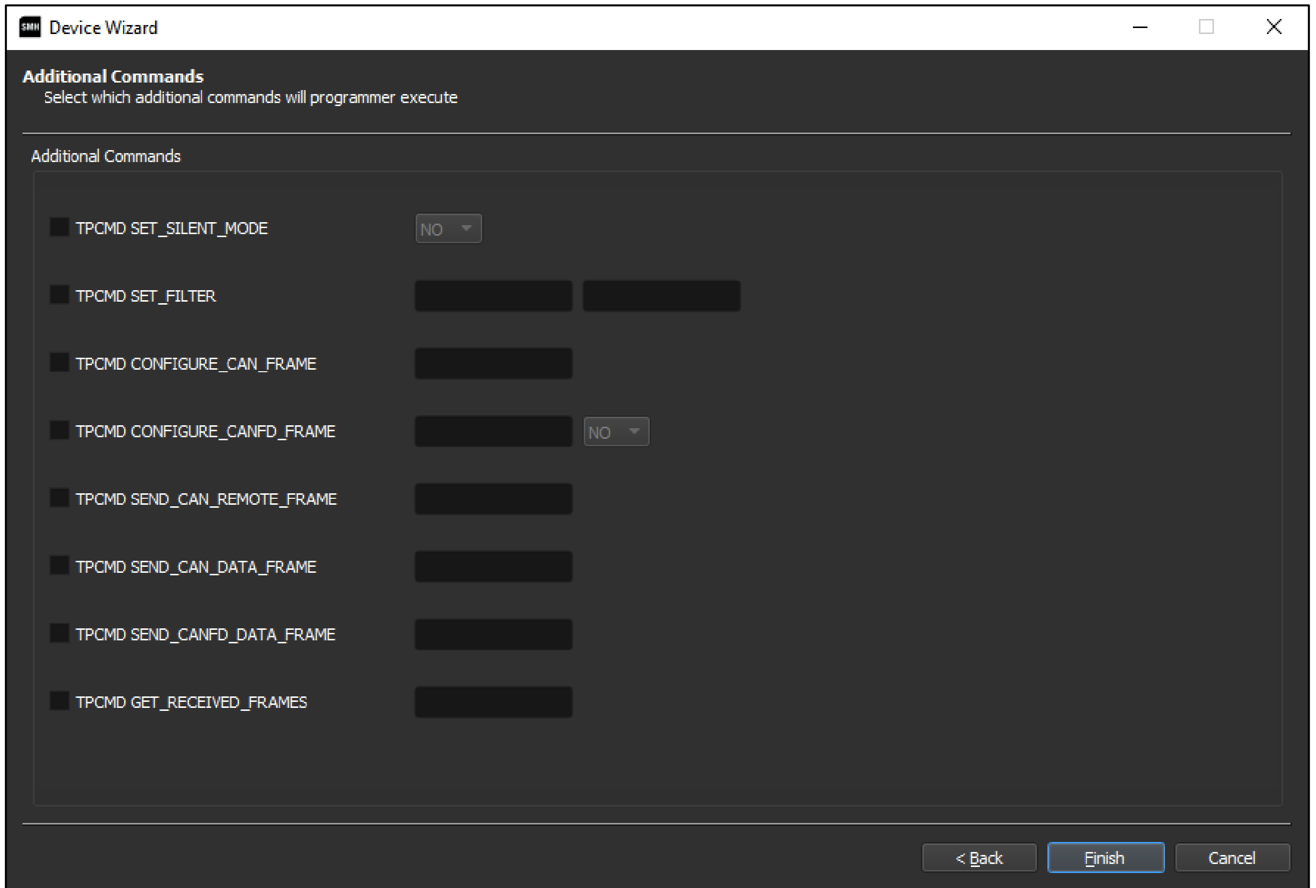
Going forward to the next page, you can find the list of commands that can be used to work with this general-purpose STD_CAN driver, their usage is deeply described in the following chapter.



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5. Custom Application

The STD_CAN driver aims to be as generic as possible, so we implemented low-level commands that can be integrated inside a more complex application. For example, the customer can call commands to send and receive CAN frames from his TestStand sequence using the DLL supplied by SMH Technologies. He can develop a high-level application using the low-level commands of this driver and perform any kind of operation: flashing, testing, calibrating, diagnosing, and much more.
Anyway, in case implementing an application in this way results too complex or not enough performing, SMH Technologies can also develop custom drivers to satisfy customers' requests.
Of course, if you need to flash a device with a CAN interface (such as Melexis or Elmos devices), SMH Technologies can you implementing a dedicated algorithm: in this way SMH Technologies will be able to guarantee you that the device works properly according to Silicon Producers' specifications and you do not have to worry about data retention problems.

This is the list of commands that are available for STD_CAN driver:

- **#TPCMD CONNECT**
  Activates the CAN transceiver and the FlashRunner channel starts working according to the settings chosen by the user on the previous parameters or commands.

- **#TPCMD DISCONNECT**
  Switches off the FlashRunner channel and the CAN transceiver, discarding all data received and ignoring all the upcoming communications.

- **#TPCMD SET_SILENT_MODE YES**
  Enables silent mode not to send any data or ACK to the CAN bus. This could be useful if you just need to monitor the communications on the bus without interfering.

- **#TPCMD SET_SILENT_MODE NO**
  Disables silent mode, so the FlashRunner can send data and ACK to the CAN bus.

- **#TPCMD SET_FILTER <Min_ID> <Max_ID>**
  Filters the received frames according to the range of IDs selected. The first parameter selects the minimum ID value and the second parameter selects the maximum ID. IDs can be expressed in both 11-bit format (standard format) or 29-bit format (extended format) and they must be written as a hexadecimal stream. See some examples below:

  ```
  #TPCMD SET_FILTER 2C7 4EF
  #TPCMD SET_FILTER 000 7FF
  #TPCMD SET_FILTER 0046A9C8 08AEF154
  ```

- **#TPCMD SET_FILTER <Fixed_ID>**
  Filters the received frames selecting only those frames which have the ID expressed by the parameter. The format to use is the same as the previous command.

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- **#TPCMD CONFIGURE_CAN_FRAME <ID>**
  Sets up the CAN frame to be sent. Using the first parameter, the user can select which ID to use for the frame. ID can be expressed in both 11-bit format (standard format) or 29-bit format (extended format) and they must be written as a hexadecimal stream. See some examples below:

```
#TPCMD CONFIGURE_CAN_FRAME 2C7
#TPCMD CONFIGURE_CAN_FRAME 0046A9C8
```

- **#TPCMD CONFIGURE_CANFD_FRAME <ID> <BitRateSwitch>**
  Sets up the CAN-FD frame to be sent. Using the first parameter, the user can select which ID to use for the frame. ID can be expressed in both 11-bit format (standard format) or 29-bit format (extended format) and they must be written as a hexadecimal stream. Using the second parameter, the user can choose to enable or disable the bit rate switch when transmitting data. See some examples below:

```
#TPCMD CONFIGURE_CANFD_FRAME 2C7 YES
#TPCMD CONFIGURE_CANFD_FRAME 0046A9C8 NO
```

- **#TPCMD SEND_CAN_REMOTE_FRAME <Data_Length>**
  Transmits a CAN remote frame with the value of data length expressed by the parameter (up to 8 bytes). Remote frames are always one-shot and are never registered as cyclic transmissions, regardless of any cyclic option previously set on CONFIGURE_CAN_FRAME. See some examples below:

```
#TPCMD SEND_CAN_REMOTE_FRAME 4
#TPCMD SEND_CAN_REMOTE_FRAME 8
```

- **#TPCMD SEND_CAN_DATA_FRAME <Data_Stream>**
  Transmits a CAN frame with the data expressed by the parameter (up to 8 bytes). If the most recent CONFIGURE_CAN_FRAME included a cyclic period, this command also registers the frame to be retransmitted at that period (see the Cyclic Frames chapter). See some examples below:

```
#TPCMD SEND_CAN_DATA_FRAME 54A938DE
#TPCMD SEND_CAN_DATA_FRAME DE6BE11AC1A032F0
```


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- **#TPCMD SEND_CANFD_DATA_FRAME <Data_Stream>**
  Transmits a CAN-FD frame with the data expressed by the parameter. Data stream can be up to 64-byte long and it must be one of the following values: 0, 1, 2, 3, 4, 5, 6, 7, 8, 12, 16, 20, 24, 32, 48, or 64. If the most recent CONFIGURE_CANFD_FRAME included a cyclic period, this command also registers the frame to be retransmitted at that period (see the Cyclic Frames chapter). See some examples below:

```
#TPCMD SEND_CANFD_DATA_FRAME 54A938DE
#TPCMD SEND_CANFD_DATA_FRAME DE6BE11AC1A032F0
#TPCMD SEND_CANFD_DATA_FRAME 54A938DEDE654A938DEBE11AC1A032F0
```

- **#TPCMD GET_RECEIVED_FRAMES**
  Returns the received frames. Frames are printed out in JSON format to be easily parsed by an application. This works like a FIFO: once a frame is returned, it is removed from FlashRunner memory. The same set of frames is also written to the FlashRunner log file in a compact tabular format with columns # | Protocol | ID | Good | Remote | ESI | DLC | Data Stream. See some examples below:

```
#1*TPCMD GET_RECEIVED_FRAMES
01|{
    "FRAME_1" : {
        "isGood" : true,
        "id" : "400",
        "protocol" : "CAN-FD",
        "errorStatusIndicator" : 0,
        "dataLength" : 16,
        "dataStream" : "12345678123456781234567812345678"
    }
}

01|{
    "FRAME_2" : {
        "isGood" : true,
        "id" : "7FE",
        "protocol" : "CAN-FD",
        "errorStatusIndicator" : 0,
        "dataLength" : 20,
        "dataStream" : "0001020300010203000102030001020300010203"
    }
}

01|{
    "FRAME_3" : {
        "isGood" : true,
        "id" : "10000000",
        "isRemoteFrame" : false,
        "protocol" : "CAN",
        "dataLength" : 5,
        "dataStream" : "A987654321"
    }
}
```


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As you can see above, the JSON element can have various fields:

- **FRAME_x**: is the name of the frame given by FlashRunner, where "x" is a number starting from 1 every time the command is called.
- **isGood**: indicates if the frame is ok (CRC checked successfully) or if it has been corrupted due to the overflow of the FIFO or to other external factors.
- **id**: indicate the ID of the frame. ID can be expressed in both 11-bit format (standard format) or 29-bit format (extended format) according to which format is actually used.
- **isRemoteFrame**: indicates if the frame is a remote frame or not (available only for CAN protocol).
- **protocol**: indicates if the frame has been sent using CAN or CAN-FD protocol.
- **dataLength**: indicates the number of bytes present on the dataStream. In case of remote frames, this indicates the data length requested.
- **dataStream**: contains the data stream expressed in hexadecimal. In case of remote frames, the data stream has no value because remote frames don't have data field.

Additional info:

1. In case no frames have been received before calling this command, the message "No frames received" will be returned.
2. When the FIFO is full of received frames, all the upcoming frames will be discarded; this information is reported both in the terminal output and in the FlashRunner log file as the warning "RX frames lost = x", where x is a decimal number. This message can be returned before any frame.
3. To flush the FIFO, you can use the disconnect command followed by the connect command.

- **#TPCMD GET_RECEIVED_FRAMES <Max_Frame_Count>**
  Returns the received frames as the previous command, the only difference is that using the parameter you can specify the maximum number of frames to return. For example, if you set the number to 1, then only the first received frame will be returned.

- **#TPCMD GET_RECEIVED_FRAMES_CSV**
  Same as GET_RECEIVED_FRAMES, but the terminal output is in CSV format (a header row followed by one row per frame). The tabular log entry is unchanged. See some examples below:

```
#1*TPCMD GET_RECEIVED_FRAMES_CSV
01|frameNum,isGood,id,isRemoteFrame,protocol,errorStatusIndicator,dataLength,dataStream
01|FRAME_1,true,400,false,CAN-FD,0,16,12345678123456781234567812345678
01|FRAME_2,true,7FE,false,CAN-FD,0,20,0001020300010203000102030001020300010203
01|FRAME_3,true,10000000,false,CAN,,5,A987654321
01|FRAME_4,true,1FFFFFFF,false,CAN,,8,0706050403020100
```

- **#TPCMD GET_RECEIVED_FRAMES_CSV <Max_Frame_Count>**
  Same as the previous command, with the parameter limiting the returned frames.

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6. Cyclic Frames

A common need in automotive applications is to emulate the periodic broadcast traffic typically generated by an ECU on a CAN or CAN-FD bus, such as engine speed every 10 ms or vehicle speed every 100 ms. The STD_CAN driver allows the FlashRunner to handle this cyclic transmission internally, so the host application does not need to maintain its own scheduling loop.
Cyclic transmission is enabled at frame configuration time by passing two additional optional parameters to the CONFIGURE_CAN_FRAME or CONFIGURE_CANFD_FRAME commands. Cyclic times must be a multiple of 50 ms and not lower than 50 ms; if specified, the execution time must be greater than or equal to the period. Up to 32 cyclic frames can be active at the same time across both protocols. This functionality adds three new commands and extends two existing ones:

- **#TPCMD CONFIGURE_CAN_FRAME <ID> <Cyclic_Period_ms>**
  Same as CONFIGURE_CAN_FRAME, with the additional parameter Cyclic_Period_ms. The next SEND_CAN_DATA_FRAME or SEND_CAN_REMOTE_FRAME transmits the first instance immediately and registers the frame to be retransmitted every Cyclic_Period_ms milliseconds, until CLEAR_CYCLIC_FRAMES, DISCONNECT or TPEND is called. See some examples below:

  ```
  #TPCMD CONFIGURE_CAN_FRAME 2C7 100
  ```

- **#TPCMD CONFIGURE_CAN_FRAME <ID> <Cyclic_Period_ms> <Cyclic_Exec_Time_ms>**
  Same as the previous form, with the additional parameter Cyclic_Exec_Time_ms: the cyclic transmission stops automatically after Cyclic_Exec_Time_ms milliseconds elapse from the first transmission. See some examples below:

  ```
  #TPCMD CONFIGURE_CAN_FRAME 2C7 100 500
  ```

- **#TPCMD CONFIGURE_CANFD_FRAME <ID> <BitRateSwitch> <Cyclic_Period_ms>**
  Same as CONFIGURE_CANFD_FRAME, with the additional parameter Cyclic_Period_ms. The next SEND_CANFD_DATA_FRAME transmits the first instance immediately and registers the frame to be retransmitted every Cyclic_Period_ms milliseconds, until CLEAR_CYCLIC_FRAMES, DISCONNECT or TPEND is called. See some examples below:

  ```
  #TPCMD CONFIGURE_CANFD_FRAME 2C7 YES 100
  ```

- **#TPCMD CONFIGURE_CANFD_FRAME <ID> <BitRateSwitch> <Cyclic_Period_ms> <Cyclic_Exec_Time_ms>**
  Same as the previous form, with the additional parameter Cyclic_Exec_Time_ms: the cyclic transmission stops automatically after Cyclic_Exec_Time_ms milliseconds elapse from the first transmission. See some examples below:

  ```
  #TPCMD CONFIGURE_CANFD_FRAME 2C7 YES 100 500
  ```

- **#TPCMD GET_CYCLIC_FRAMES**
  Prints the list of cyclic frames currently scheduled (protocol, ID, period, transmission counters and data payload) to the FlashRunner log file, which can be retrieved with the log download feature of the FlashRunner Workbench.

- **#TPCMD CLEAR_CYCLIC_FRAMES**
  Removes all the cyclic frames currently scheduled. The command returns the number of cyclic frames that have been removed.

- **#TPCMD CLEAR_CYCLIC_FRAMES <ID>**
  Removes only the cyclic frame matching the ID expressed by the parameter, leaving the others active. The ID format follows the CONFIGURE_*_FRAME convention. If both a CAN and a CAN-FD frame share the same ID, both are removed. See some examples below:

  ```
  #TPCMD CLEAR_CYCLIC_FRAMES 2C7
  ```

  Additional info:
  Up to 32 cyclic frames can be scheduled at the same time. Attempting to register a 33rd cyclic frame through a SEND_*_FRAME command returns the ERR_API_CYCLIC_FULL error and the SEND is aborted; the user should either clear one or more cyclic frames with CLEAR_CYCLIC_FRAMES or overwrite an existing entry by reconfiguring the same ID with new parameters.
  Enabling silent mode with SET_SILENT_MODE YES or calling DISCONNECT pauses cyclic transmission while keeping the cyclic table in place; SET_SILENT_MODE NO or a subsequent CONNECT resumes it. The execution time keeps counting while paused, so an entry whose execution time elapses during the pause is removed at resume. The TPEND command clears the cyclic table entirely, so cyclic transmissions never survive a programming session.

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7. Case Study

```
!ENGINEMASK 0x00000001
#LOADDRIVER libstd_can.so SMH GENERIC STD_CAN
#TCSETDEV VDDMIN 5000
#TCSETDEV VDDMAX 5000
!CRC 0x7751ADA7
#TCSETPAR CANFD_SJW 17
#TCSETPAR CANFD_TSEG1 56
#TCSETPAR CANFD_TSEG2 18
#TCSETPAR CAN_SJW 74
#TCSETPAR CAN_TSEG1 224
#TCSETPAR CAN_TSEG2 75
#TCSETPAR DATA_RATE 2000000
#TCSETPAR FPGA_FREQ 150000000
#TCSETPAR NonISO_CANFD NO
#TCSETPAR PROTCLK 500000
#TCSETPAR SILENT_MODE NO
#TCSETPAR CMODE CAN
#TPSTART
```

In this chapter, we show an example of an application using the STD_CAN driver and its cyclic transmission feature.

Let us start with the project file generated from the Workbench using 500 kbps as nominal bit rate and 2 Mbps as data bit rate. The application emulates an ECU that periodically broadcasts a CAN-FD frame with ID = 0x123 and listens for a frame with ID = 0x1E5 coming from another node on the bus.

To start, we send the connect command, which is mandatory to enable the communication:

```
#1*TPCMD CONNECT
```

We can then set up a filter to receive only the frames with ID = 0x1E5:

```
#1*TPCMD SET_FILTER 1E5
```

We configure the CAN-FD frame to be sent using ID = 0x123, bit rate switch enabled, and a cyclic period of 100 ms:

```
#1*TPCMD CONFIGURE_CANFD_FRAME 123 YES 100
```


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A single SEND_CANFD_DATA_FRAME both transmits the first frame and registers the cyclic schedule. From this point on, the FlashRunner re-emits the same frame every 100 ms without any further command from the host application:

```
#1*TPCMD SEND_CANFD_DATA_FRAME C1A0C1A0C1A0C1A0C1A0C1A0C1A0C1A0
```

The application can read the most recently received frame at any time, without maintaining its own polling loop, by calling:

```
#1*TPCMD GET_RECEIVED_FRAMES 1
```

The current state of the cyclic table can be inspected at any time through the FlashRunner log file:

```
#1*TPCMD GET_CYCLIC_FRAMES
```

When the application no longer needs the cyclic transmission, it can clear the cyclic table:

```
#1*TPCMD CLEAR_CYCLIC_FRAMES
```

You can also flush the RX FIFO by calling the following command sequence:

```
#1*TPCMD DISCONNECT
#1*TPCMD CONNECT
```

Warning: it is mandatory to call the #TPEND command at the end of the execution to free the memory of the FlashRunner and to clear any remaining cyclic frames (as it is for any other FlashRunner project).

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