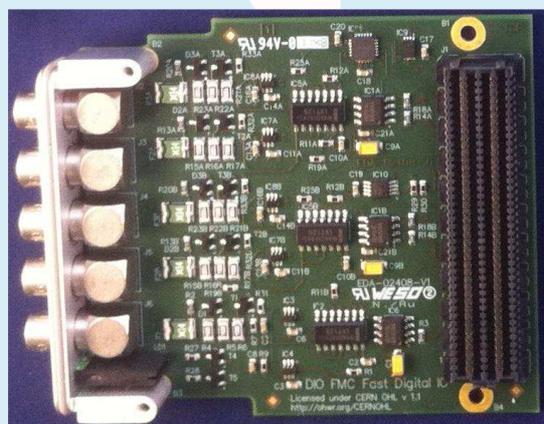


# Production Test Suite for the FMC-DIO-5chTTLa board

## User Manual

Revision 0.2



## REVISION TABLE

Revision	Date	Author	Comments
0.1	9/4/2012	Richard R. Carrillo, Seven Solutions S.L.	Initial version
0.2	26/4/2012	Richard R. Carrillo, Seven Solutions S.L.	New error messages added and some tests changes.

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## 1) INTRODUCTION

The FMC-DIO-5chTTLa board is a 5-channel digital Input/Output (I/O) module which can be attached to the SPEC board (Simple PCIe FPGA Mezzanine Card Carrier) by means of a FMC connector. The I/O channels (ports) are accessed through LEMO 00 connectors and are TTL (transistor-transistor logic) compatible (supplying 3.3V). This board also includes programmable voltage threshold (when the ports are configured as inputs), a configurable 50ohm termination resistor in each port, 2 LEDs (light-emitting diodes), a temperature measurement integrated circuit (IC) and a 64Kbit Electrically-Erasable Programmable Read-Only Memory (EEPROM).

This board was initially designed for testing White Rabbit functionality as part of the SPEC Demonstration Package for White Rabbit.

Production Test Suite (PTS) is the environment designed to test the functionality of boards after manufacture. PTS was originally intended for testing boards specifically designed for the Open Hardware Repository. These tests try to check that the boards have been correctly soldered and assembled and that the printed circuit board (PCB) is correctly fabricated in terms of electrical connectivity.

It is important to note that PTS refers only to the functionality testing of the boards and it is not covering any verification or validation tests of the design. Moreover, PTS can not completely assure a correct fabrication process, for example, some intermittent failures caused by flaws in the manufacture may not be detected.

This document describes how PTS can be used to test the FMD-DIO-5chTTLa board.

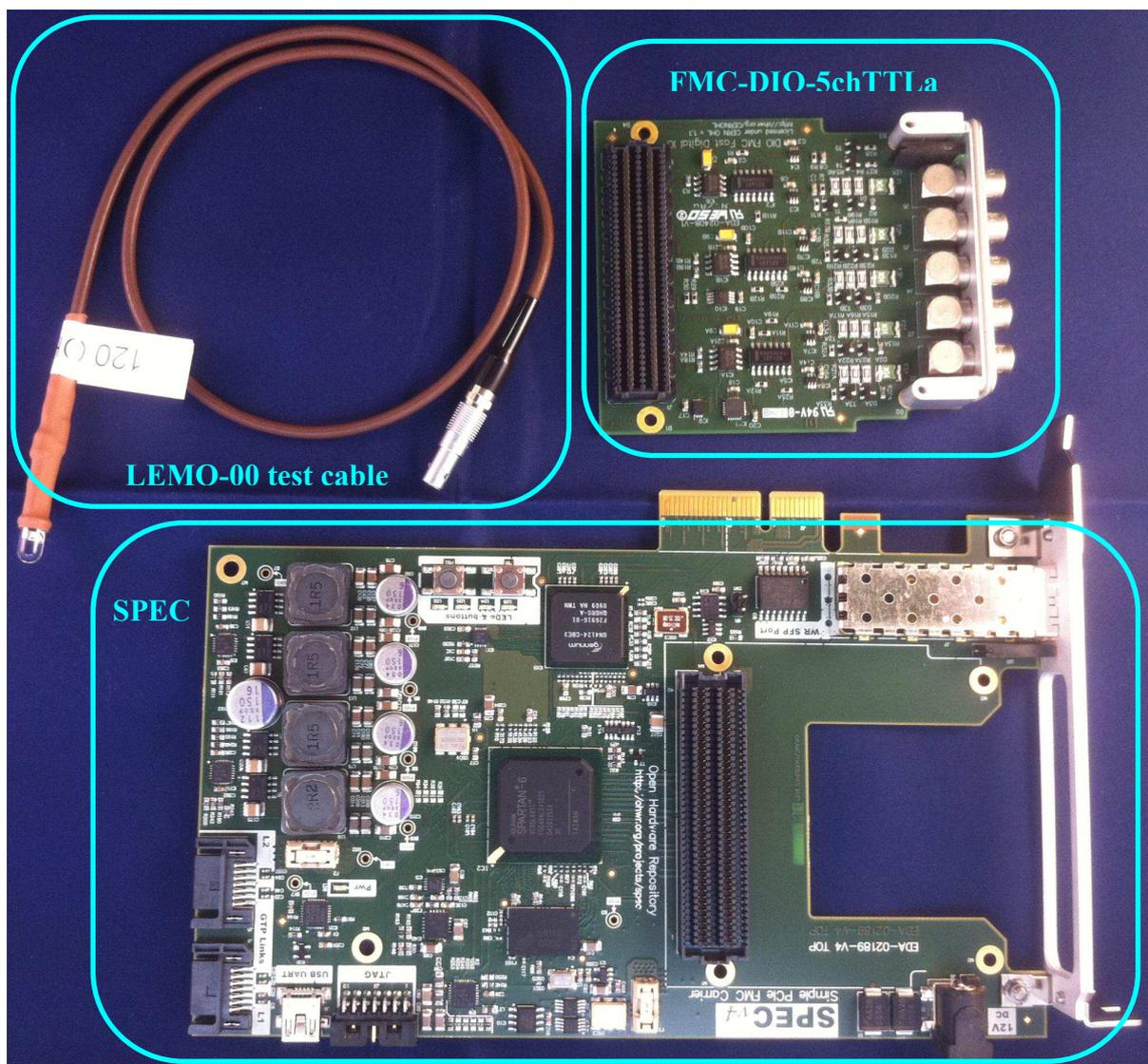
## 2) FMC-DIO-5CHTTLA PTS REQUIREMENTS

In order to use PTS to test the FMC-DIO-5chTTLa board some hardware and software elements must be used.

### **a) Hardware**

- A computer including at least a free 4-lane PCIe slot (x4) or larger.
- The FMC-DIO-5chTTLa board to be tested.

- A Simple PCIe FPGA Mezzanine Card Carrier (SPEC). This board is a 4-lane PCIe carrier for FPGA Mezzanine Cards (VITA 57). It incorporates a FMC connector in which the FMC-DIO-5chTTLa board is connected.
- 4 LEMO-00 cables and 3 LEMO-00 Y couplers. It may be required one LEMO 00 test cable (plug and indicator LED attached). The reader is referred to section 4) for instructions on how to construct this cable.



**Figure 1: Specific hardware required**

## **b) Software**

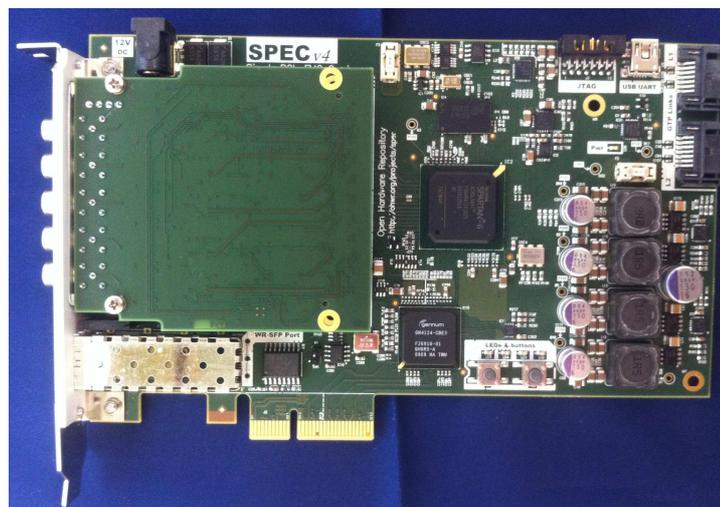
- Ubuntu Linux with kernel 2.6.38 or higher.
- Python 2.7 or higher.
- The TPS environment installed.
- *gnurabbit* driver installed.

## **3) TEST PROCEDURE**

### **a) Hardware installation**

Before executing the PTS tests the boards must be properly installed in the computer:

- 1) Before starting the hardware installation, it is recommended to wear an antistatic wrist band to avoid electrostatic discharges when handling the boards.
- 2) Mount the FMC-DIO-5chTTLA board on the FMC connector of the SPEC board as indicated in Figure 2. The FMC-DIO-5chTTLA board can be mechanically fixed to the SPEC board using spacers and screws.



**Figure 2: FMC-DIO-5chTTLa assembly**

- 3) Confirm that the computer is switched off (cord unplugged or power-supply switch off) and plug the assembled SPEC board into a PCIe slot as indicated in Figure 3.



**Figure 3: SPEC board inserted into a PCIe slot**

- 4) Switch on the computer and verify that the power LED in the SPEC board is on.

### ***b) PTS execution***

Before executing the tests, the TPS environment, a Python interpreter and the *gnurabbit* driver should have been previously installed (and the corresponding kernel module loaded). If the module is not loaded after booting (check it with `lsmod`), it can be loaded executing:

```
insmod <pts dir>/gnurabbit/kernel/rawrabbit.ko vendor=0x10dc device=0x18d
```

See section 2)b)

- 1) After the computer has finished booting and a user has logged in, open a terminal (if necessary) and change the current directory to the PTS root directory.
- 2) Execute: `sudo ./fmc dio5chttla.sh`

Next, the program should ask for the serial number of the board. Type the number in the barcode sticker of the FMC-DIO-5chTTLa board and press enter. The program will ask for an extra serial number (used in case the manufacturer has a different barcode system). Type the extra barcode number, or if there is no extra barcode, just press ENTER. The execution of the tests will start. Refer to the next subsection on how to proceed in each test.

- 3) Wait for the tests to finish and finally check the results. If any of the tests generated an error or warning message, it will be displayed in the screen. In case of error, review the whole test process and repeat the tests one more time for the same board. If during the second execution of tests you do not get any error or warning messages, it is recommended that you repeat the tests again with the same initial conditions to ensure that it is not an intermittent problem. If the error persists, check the log files to obtain detailed information about what occurred during the execution (see UsersManualProductionTestSuite.pdf), the reader is referred to the subsection 3)e) in order to elucidate the potential causes of the reported errors
- 4) Shut down the Linux system and switch off the computer power supply to repeat this process with another board.

### **c) List of tests**

The test procedure for the FMC-DIO-5chTTLa board is composed of 6 tests summarized in Table 1.

<b>Test number</b>	<b>Short description</b>	<b>User intervention</b>
00	Check EEPROM and DAC presence and temperature-sensor operation	No
01	Check board LEDs (LEDs and LED circuit working)	Yes
02	Check board ports as output (port driver, port electrical connectivity and LVDS-to-LVCMOS IC working)	Yes*
03	Check board ports as inputs (DAC and LVDS comparator working)	No
04	Check output-enable circuit of board ports	No
05	Check termination resistors of board ports	No

**Table 1: List of tests**

\* The user is required to plug the interconnection cables in the five ports and to unplug them when the test is completed. In some rare cases the user is required to manually measure the port outputs.

## Test00

This test is intended to check the FMC-DIO-5chTTLa-board EEPROM and DAC presence and temperature-sensor operation

**Conditions:** To execute this test completely, the FMC-DIO-5chTTLa-board presence line, the I2C bus and the OneWire bus must work properly.

### Procedure details:

- Load SPEC-board firmware (the FPGA is configured using the bit stream contained in the *spec\_top.bin* file).
- Test mezzanine presence line (check if the FMC-DIO-5chTTLa-board is correctly plugged in the FMC connector of the SPEC board). The successful completion of this presence test is not decisive, that is, other errors could result in a wrong presence test outcome.
- Initialize the board and its peripherals.
- Check that I2C devices (EEPROM -24AA64T- and DAC -DAC5578-) are present.
- Check that OneWire device (temperature sensor -DS18B20-) is present and responds.
- Check temperature sensor unique ID and store it in the log files.
- Check temperature acquisition and store it in the log files.

## Test01

This test is intended to check the FMC-DIO-5chTTLa-board LEDs (LED and LED circuit working)

**Conditions:** To execute this test completely, the FMC-DIO-5chTTLa-board presence line must work properly.

### Procedure details:

- Load SPEC-board firmware (the FPGA is configured using the bit stream contained in the *spec\_top.bin* file).
- Test mezzanine presence line (check if the FMC-DIO-5chTTLa-board is correctly plugged in the FMC connector of the SPEC board). The successful completion of this presence test is not decisive, that is, other errors could result in a wrong presence test outcome.

- Alternately blink the two FMC-DIO-5chTTLa-board LEDs.

The user must check that the two LEDs are blinking (see Figure 4) and answer Y (yes) or N (no) to the program.



**Figure 4: FMC-DIO-5chTTLa-board LEDs**

## Test02

This test is intended to check FMC-DIO-5chTTLa-board ports as output (port driver, port electrical connectivity and LVDS-to-LVCMOS IC working).

**Conditions:** To execute this test completely, the FMC-DIO-5chTTLa-board presence line must work properly.

### Procedure details:

- Load SPEC-board firmware (the FPGA is configured using the bit stream contained in the *spec\_top.bin* file).
- Test mezzanine presence line (check if the FMC-DIO-5chTTLa-board is correctly plugged in the FMC connector of the SPEC board). The successful completion of this presence test is not decisive, that is, other errors could result in a wrong presence test outcome.
- Check FMC-DIO-5chTTLa-board ports as output. It tries to use the board DAC to automatically find any operation problem.
- If the board DAC does not work, the test oscillates the state of FMC-DIO-5chTTLa-board ports.

In some rare cases, the user is required to check the state oscillation of the ports. The user must connect one LEMO-00 test cable (see subsection 2)a)) to each FMC-DIO-5chTTLa-board port or alternatively connect the same test cable to each port at least during 2 second when the program requests it as indicated in Figure 5. The user must check that the cable LED blinks (in all the ports) and then answer Y (yes) or N (no) to the program.



Figure 5: LEMO-00 connector plugged in the first FMC-DIO-5chTTLa-board port (port 0)

### Test03

This test is intended to check FMC-DIO-5chTTLa-board ports as inputs (DAC and LVDS comparator working).

**Conditions:** To execute this test completely, the FMC-DIO-5chTTLa-board ports must work as outputs (test02 passed) and the I2C bus and the FMC-DIO-5chTTLa-board presence line must work properly (test00 passed).

#### Procedure details:

- Load SPEC-board firmware (the FPGA is configured using the bit stream contained in the *spec\_top.bin* file).
- Test mezzanine presence line (check if the FMC-DIO-5chTTLa-board is correctly plugged in the FMC connector of the SPEC board). The successful completion of this presence test is not decisive, that is, other errors could result in a wrong presence test outcome.
- Check the voltage of all ports (by means of the DAC and LVDS comparator) when the port output is set to 0 and also when it is set to 1.

### Test04

This test is intended to check the output-enable circuit of FMC-DIO-5chTTLa-board ports (current-driver circuit working).

**Conditions:** To execute this test completely, the FMC-DIO-5chTTLa-board ports must work as outputs (test02 passed), the I2C bus and the FMC-DIO-5chTTLa-board presence line must work properly (test00 passed) and the FMC-DIO-5chTTLa-board ports must work as inputs (test03 passed).

### **Procedure details:**

- Load the SPEC-board firmware (the FPGA is configured using the bit stream contained in the *spec\_top.bin* file).
- Test mezzanine presence line (check if the FMC-DIO-5chTTLa-board is correctly plugged in the FMC connector of the SPEC board). The successful completion of this presence test is not decisive, that is, other errors could result in a wrong presence test outcome.
- Check the voltage of all ports (by means of the DAC and LVDS comparator) when port output is set to 1 and when port output enable is set to 0.

### **Test05**

This test is intended to check the termination resistors of the FMC-DIO-5chTTLa-board ports (termination-resistor-activation circuit working).

**Conditions:** To execute this test completely, the FMC-DIO-5chTTLa-board ports must work as outputs (test02 passed), the I2C bus and the FMC-DIO-5chTTLa-board presence line must work properly (test00 passed) and the FMC-DIO-5chTTLa-board ports must work as inputs (test03 passed).

### **Procedure details:**

- Load the SPEC-board firmware (the FPGA is configured using the bit stream contained in the *spec\_top.bin* file).
- Test mezzanine presence line (Check if the FMC-DIO-5chTTLa-board is correctly plugged in the FMC connector of the SPEC board). The successful completion of this presence test is not decisive, that is, other errors could result in a wrong presence test outcome.
- Check the voltage of all ports (by means of the DAC and LVDS comparator) when the port output is set to 1 and the port termination resistor is enabled.

### ***d) Individual execution of tests***

As an alternative, any of the six tests can be executed individually:

- 1) Follow the first step of subsection 3)b)

- 2) Change the current directory to the python directory of FMC-DIO-5chTTLA board in the PTS.

```
cd <pts dir>/test/fmcdio5chttla/python
```

- 3) Execute: `sudo ./test0x.py` where x is a number in the [0,5] interval. The test results will be displayed in the screen.
- 4) Follow steps 3) and 4) of subsection 3)b)

### **e) Test result message list**

This section describes all the potential messages which can be generated during the execution of PTS of the FMC-DIO-5chTTLA board. These messages can reveal the cause of a test failure.

#### **Error messages**

##### **DIOERR00: PRESENT line is not asserted in FMC. Is the fmc-dio-5chttla correctly inserted into the carrier?**

The PRESENT line of the FMC connector is not asserted. This line is used to state that an adequate board is connected in the FMC connector of the SPEC board (carrier).

**Possible causes:**

- FMC-DIO-5chTTLA-board is not correctly connected.
- Faulty electrical connectivity in the PRESENT line circuit or FMC connector.
- FPGA configured with an incorrect bit stream file.

##### **DIOERR01: I2C core is not enabled**

The internal flags corresponding to the I2C core are not active.

**Possible causes:**

- FPGA configured with an incorrect bit stream file.

##### **DIOERR02: No I2C device found**

No device has responded to any address in the I2C bus.

**Possible causes:**

- I2C bus is not working properly. Check for short-circuits in any of the bus lines.

### **DIOERR03: Device not found. Only x I2C devices found**

The DAC or the EEPROM does not respond to their expected address.

#### **Possible causes:**

- Wrong address configuration. If the number of devices found (x) is 3, check the list of devices (addresses) found in the generated log files. For those devices (addresses) which are not listed, check their address configuration lines (chip soldering and FMC GA0 and GA1 lines connectivity).
- Faulty electrical connection. If the number of devices found (x) is less than 3, check the list of devices (addresses) found in the generated log files. For those devices (addresses) which are not listed, check their I2C lines and power pins (chip soldering).

### **I2C device EEPROM (24AA64T) at addr 0x50 produced the error: DIOERR04: x**

This error message is reserved for future uses.

#### **Possible causes:**

- None

### **I2C device DAC (DAC5578) at addr 0x48 produced the error: DIOERR05: x**

The DAC did not respond correctly during the configuration process.

#### **Possible causes:**

- An incorrect DAC IC is mounted.
- Defective DAC IC soldering (I2C lines and power-supply pins of DAC).

The message x may give an extra clue about the error cause.

### **I2C device DAC (DAC5578) at addr 0x48 produced the error: DIOERR06: x**

The DAC did not respond correctly to the set-channel voltage commands.

#### **Possible causes:**

- An incorrect DAC IC is mounted.
- Defective DAC IC soldering (I2C lines and power-supply pins of DAC).

The message x may give an extra clue about the error cause.

### **Error in I2C bus. (Addr: x): DIOERR07: Device not initialized**

The I2C-device access library has not been properly initialized. This error should never be reported when executing the original FMC-DIO-5chTTLa-board tests.

#### **Possible causes:**

- Test-program programming bug.

### **I2C device DAC (DAC5578) at addr 0x48 produced the error: DIOERR08: x**

The DAC did not respond correctly to the get channel-voltage configuration commands.

#### **Possible causes:**

- An incorrect DAC IC is mounted.
- Defective DAC IC soldering (I2C lines and power-supply pins of DAC).

The message x may give an extra clue about the error cause.

### **Error in OneWire bus. (Addr: x): DIOERR09: y**

The OneWire device DS1820 did not respond correctly during the process for obtaining the chip unique ID (first commands).

#### **Possible causes:**

- An incorrect IC is mounted.
- Defective chip soldering (OneWire line and power-supply pins of DS1820).
- Electrical connectivity problems (short-circuits or open-circuits) in the OneWire line (FMC connector, OneWire pull-up resistors).

The message y may give an extra clue about the error cause.

### **Error in OneWire bus. (Addr: x): DIOERR10: Device not initialized**

The OneWire-device access library has not been properly initialized. This error should never be reported when executing the original FMC-DIO-5chTTLa-board tests.

#### **Possible causes:**

- Test-program programming bug.

### **Error in OneWire bus. (Addr: x): DIOERR11: y**

The OneWire device DS1820 did not respond correctly during the process for obtaining the temperature.

#### **Possible causes:**

- An incorrect IC is mounted.
- Defective chip soldering (OneWire line and power-supply pins of DS1820).

The message y may give an extra clue about the error cause.

### **TSTERR00: Operation of fmc-dio-5chttla-board LEDs failed**

The user answered "N" indicating that the FMC-DIO-5chTTLa-board LEDs did not operate properly.

#### **Possible causes:**

- Soldering problems of the LED circuit (LED, current-limiting resistor or switch transistor).

- Electrical connectivity problems in the LED activation lines of the FMC connector.

### **TSTERR01: Operation of fmc-dio-5chttla-board ports as output failed**

The user answered “N” indicating that the FMC-DIO-5chTTLa-board ports did not provide the correct voltage to turn on and off the test-cable LEDs.

#### **Possible causes:**

- Soldering problems (short-circuits and open-circuits) of the corresponding LEMO 00 connectors, corresponding lines (fuses) or voltage clamping components (short-circuits).
  - Soldering problems of the corresponding port driver IC and the LVDS-to-LVCMOS IC.
  - Electrical connectivity problems of the corresponding port control lines of the FMC connector.
- Execute test03 to obtain more information which could be useful to isolate the problem.

### **TSTERR02: Proper voltage reading not obtained in ports: [x] when output enable=1**

Apparently the voltage obtained in the ports x is out of the expected range when the port output is set to a high or low level. Alternatively, a misleading wrong voltage could have been measured due to a DAC or comparator operation problem.

#### **Possible causes:**

- Something is connected to the LEMO-00 connectors of the ports. Ensure that nothing is connected to the ports while executing test03.
- Soldering problems (short-circuits) of the corresponding LEMO-00 connectors, corresponding lines (fuses) or voltage clamping components.
- Soldering problems of the corresponding port driver IC or the LVDS-to-LVCMOS IC.
- Soldering problems of the DAC or the corresponding voltage comparator.
- Electrical connectivity problems of the corresponding port control lines of the FMC connector.
- An incorrect port current-driver IC is mounted.

Check the log files to obtain more information about what caused the error.

Check the results of test02 to isolate the problem.

### **TSTERR03: Proper voltage reading not obtained in ports: [x] when output enable=0**

Apparently the voltage obtained in the ports x is out of the expected range when the port output is set to a high level, the termination resistor is disabled and the output-enable circuit is disabled.

Alternatively, a misleading wrong voltage could have been measured due to a DAC or comparator operation problem.

#### **Possible causes:**

- Soldering problems of the corresponding port driver IC or the LVDS-to-LVCMOS IC.
- Soldering problems of the DAC or the corresponding voltage comparator.

- Electrical connectivity problems of the corresponding port control lines of the FMC connector. Check the log files to obtain more information about what caused the error. Check the results of test03 to isolate the problem.

#### **TSTERR04: Proper voltage reading not obtained in ports: [x] when termination resistors enabled**

Apparently the voltage obtained in the ports x is out of the expected range when the port output is set to a high level and the termination resistor is enabled. Alternatively, a misleading wrong voltage could have been measured due to a DAC or comparator operation problem.

##### **Possible causes:**

- Soldering problems (short-circuits) of the corresponding LEMO-00 connectors, corresponding lines (fuses) or port input-voltage clamping components.
- Soldering problems of the corresponding port driver IC or the LVDS-to-LVCMOS IC.
- Soldering problems of the DAC or the corresponding voltage comparator.
- Electrical connectivity problems of the corresponding port control lines of the FMC connector.
- An incorrect port current-driver IC is mounted.

Check the log files to obtain more information about what caused the error.

Check the results of test03 to isolate the problem.

#### **TSTERR05: No communication could be performed between any two ports**

No communication could be established between any of the board ports (when the interconnection cables are plugged). That is, the test could not find a port working as input and another as output.

##### **Possible causes:**

- The interconnection cables are not connected to the LEMO 00 ports while executing test02
- Soldering problems (short-circuits and open-circuits) of the corresponding LEMO 00 connectors, corresponding lines (fuses) or voltage clamping components (short-circuits).
- Soldering problems of the corresponding port driver IC or the LVDS-to-LVCMOS IC.
- Soldering problems of the DAC or the corresponding voltage comparator.
- Electrical connectivity problems of the corresponding port control lines of the FMC connector.

Check the log files to obtain more information about what caused the error.

#### **TSTERR06: Ports x appear no to be correctly connected**

No communication could be established through ports x (when the interconnection cables are plugged). That is, the test could use ports x neither as input nor output to communicate with the rest of the ports.

##### **Possible causes:**

- Some of the interconnection cables are not correctly connected to the LEMO 00 ports while executing test02

- Soldering problems (open-circuits) of the corresponding LEMO 00 connectors or corresponding lines (fuses).
  - Soldering problems of the corresponding port driver IC or the LVDS-to-LVCMOS IC.
  - Soldering problems of the DAC or the corresponding voltage comparator.
  - Electrical connectivity problems of the corresponding port control lines of the FMC connector.
- Check the log files to obtain more information about what caused the error.

## Warning messages

### **TSTWRN00: Strangely-low voltage value obtained in ports: [x] when output=1**

Apparently the voltage measured in the ports x is unusually low (but still within the operating range) when the port output is set to a high level.

#### **Possible causes:**

- Something is connected to the LEMO-00 connectors of the ports. Ensure that nothing is connected to the ports while executing test03.
- Soldering problems of the termination-resistor activation circuit (switching transistor)
- Electrical connectivity problems of the corresponding port termination-resistor control lines of the FMC connector.
- An incorrect port current-driver IC is mounted.

Check the log files to obtain more information about what caused the error.

### **TSTWRN01: Strangely-high voltage value obtained in ports: [x] when output=0**

Apparently the voltage measured in the ports x is unusually high (but still within the operating range) when the port output is set to a low level.

#### **Possible causes:**

- Electrical connectivity problems of the corresponding port control lines of the FMC connector.
- An incorrect port current-driver IC is mounted.

Check the log files to obtain more information about what caused the error.

### **TSTWRN02: Strangely-high voltage value obtained in ports: [x] when output enable=0**

Apparently the voltage measured in the ports x is unusually high (but still within the operating range) when the port output-enable circuit is disabled.

#### **Possible causes:**

- Electrical connectivity problems of the corresponding port control lines of the FMC connector.
- An incorrect port current-driver IC is mounted.

Check the log files to obtain more information about what caused the error.

### **TSTWRN03: Strangely-low voltage value obtained in ports: [x] when termination resistors enabled**

Apparently the voltage measured in the ports x is unusually low (but still within the operating range) when the port output is set to a high level and the termination resistor is enabled.

#### **Possible causes:**

- Something is connected to the LEMO-00 connectors of the ports. Ensure that nothing is connected to the ports while executing test05.
- Electrical connectivity problems of the corresponding port termination-resistor control lines of the FMC connector.
- An incorrect port current-driver IC is mounted.

Check the log files to obtain more information about what caused the error.

### **TSTWRN04: Strangely-high voltage value obtained in ports: [x] when termination resistors enabled**

Apparently the voltage measured in the ports x is unusually high (but still within the operating range) when the port output is set to a high level and the termination resistor is enabled.

#### **Possible causes:**

- Soldering problems of the termination-resistor activation circuit (switching transistor or resistors)
- An incorrect port current-driver IC is mounted.

Check the log files to obtain more information about what caused the error.

### **TSTWRN05: Strange temperature value measured**

Apparently the temperature measured through the OneWire temperature acquisition I.C. is out of a reasonable range.

#### **Possible causes:**

- The test is run in extreme temperature conditions.
- Board overheating.
- Faulty temperature acquisition I.C.

Check the log files to obtain the concrete temperature value measured.

## **4) LEMO 00 TEST CABLE**

This section describes how to build the test cable required for test02.

### **a) Overview**

In order to conduct the test02, the user must check that the correct voltage pulses are present in the 5 FMC-DIO-5chTTLa-board ports (LEMO-00 connectors) when this test program is being executed. This can be achieved using an oscilloscope and measuring the minimum and maximum voltage level in each port (about 0V and 3.3V respectively). However, a faster and simpler manner is to connect a LED in series with a 120ohm resistor to each port. To ease this process, the test cable presented in Figure 1 can be built.

### **b) List of materials**

The main electrical component required to build the test cable are listed in Table 2. Neither the resistor value nor the LED type is critical. However, the maximum current rating of the FMC-DIO-5chTTLa-board port driver must not be exceeded. The type of LED has been chosen to have a low forward voltage drop (about 1.8V). The already assembled 1m cable has been chosen to ease our test cable building.

<b>Description</b>	<b>Manufacturer</b>	<b>Manufacturer code</b>	<b>RS components code</b>
Assembled 1m cable with 2 LEMO 00 plugs	Lemo	MSB.00.250.LTE100	168-3836
Carbon resistor 0.25W 5% 120ohm axial-lead	RS	707-7599	707-7599
AlGaAs LED 5mm (red)	Avago Technologies	HLMP-D155	826-509

**Table 2: Test-cable component list**

### **c) Cable building**

Cut the assembled 1m LEMO cable and strip off about 2cm of the outer jacket. Cut half of one of the LED leads and solder the resistor to the remaining part as indicated in Figure 6.



**Figure 6: Test-cable building**

Solder the LED and resistor to the cable end considering the LED polarity. Isolate the conductors and optionally cover the union with heat shrink tubing. The resulting cable should be similar to that presented in Figure 1.

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