RFoF1P

Standalone System

Handbook V 1.0r2488

Schmid & Partner Engineering AG

August 3, 2020

Contents

Part I

General

0.1 Safety Instructions

The RF-over-Fiber (*RFoF1P*) system is a LASER Product designated as Class 1 during all procedures of operation. The *RFoF1P* system internally uses a CW power LASER capable of Class 3B operation. An internal safety circuit shuts down the power LASER within 0.1 ms if the optical link from the remote unit to the sensor is interrupted which allows the system to operate as a LASER Class 1 device. The *RFoF1P* system is easy to use device but as the system is internally operating with powerful invisible LASER radiation it is strongly recommended to read the following instructions before unpacking and first operating the system. Please refer to Chapter 1 if any of the below terminology is unclear.

- Permit only experienced personnel to operate the system.
- Do not override the safety optical safety return links by external bias (electrically or optically).
- Under no circumstances do attempt to defeat the connector interlocking mechanism (shutter and mating probe connector).
- Do not switch on the remote unit with the activation pin before the fiber optics (probe) have been connected.
- Do not leave the key of the key switch attached to the remote unit if not in use.
- Immediately shut down the system (remove activation pin) if an optical link error occurred. Inform support@speag.com about the error for further instructions.
- Under no circumstances operate a defective unit or a unit with broken or damaged cover seals.
- Do not open the remote unit, fiber optics housing, sleeves or the sensors at any time. It is dangerous and will cause system failure if one opens the cover of the remote unit, fiber or the sensor.
- In case of mechanical damage of the remote unit (in particular the shutter), the fiber-optical patch-cord or the *RFoF1P* probe, immediately deactivate the system by removing the activation pin. Inform "support@speag.com" about the damage and await further instructions.
- The system does not contain any user serviceable parts. Do not attempt any service or repair to the *RFoF1P* system yourself. For service or repair the system has to be returned to SPEAG.

Failure to adhere to the above instructions may result in hazardous exposure. Caution: the use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

0.1.1 LASER Specific Information

0.1.1.1 Accessible LASER Radiation

During operation the accessible radiation from the *RFoF1P* system is limited to LASER Class 1. Even in the event of a failure of the protective covers or sleeves the radiation from a *RFoF1P* system is limited to LASER Class 1 using an internal automatic power down mechanism of the LASER sources based on a continuous monitoring of the optical return link quality.

0.1.1.2 Non-Accessible Internal LASER Parameters

The *RFoF1P* system uses embedded Class 3B lasers with no human access. Inside the *Remote Unit* up to 3 mutually exclusively activated near-infrared power LASER sources are used to energise the connected *RFoF1P* probes:

Wavelength	808 nm
LASER power for classification	≤100 mW (≤55 mW calibrated)
Mode of operation	CW (continuous wave): automatic shutdown after link failure: ≤100 μs
Transverse Beam Mode	multi-mode

Inside the *Remote Unit* 1 near-infrared LASER source to energise the *TDS* probe serial number when a probe is connected:

Wavelength	845 nm
LASER power for classification	≤5 mW (calibrated)
Mode of operation	CW (continuous wave): automatic shutdown after link failure: ≤1000 uSec
Transverse beam mode	multi-mode

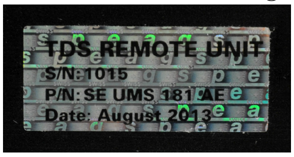
Inside the shutter handle of the *RFoF1P* probe 1 near-infrared LASER source (VCSEL) is present:

Wavelength	850 nm
LASER Power for classification	≤2 mW
Mode of operation	CW (continuous wave): automatic shutdown after link failure: ≤100 uSec
Transverse beam mode	multi-mode

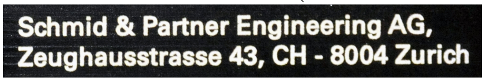
0.1.2 LASER Labeling

The below figures show the positions of the LASER safety relevant labelling of the *TDS Remote Unit*. Note that *RFoF1P* uses uses a standard *TDS Remote Unit*. The following labels are present on every *Remote Unit*:

1. Manufacturer Identification Label Part 1 (*Remote Unit* identification, Serial number, Part number and Manufacturing date)



2. Manufacturer Identification Label Part 2 (Manufacturer address)



3. Certification Label

4. Hazard Warning Symbol

5. Explanatory Label

Figure 1: Standalone *TDS Remote Unit* safety marking

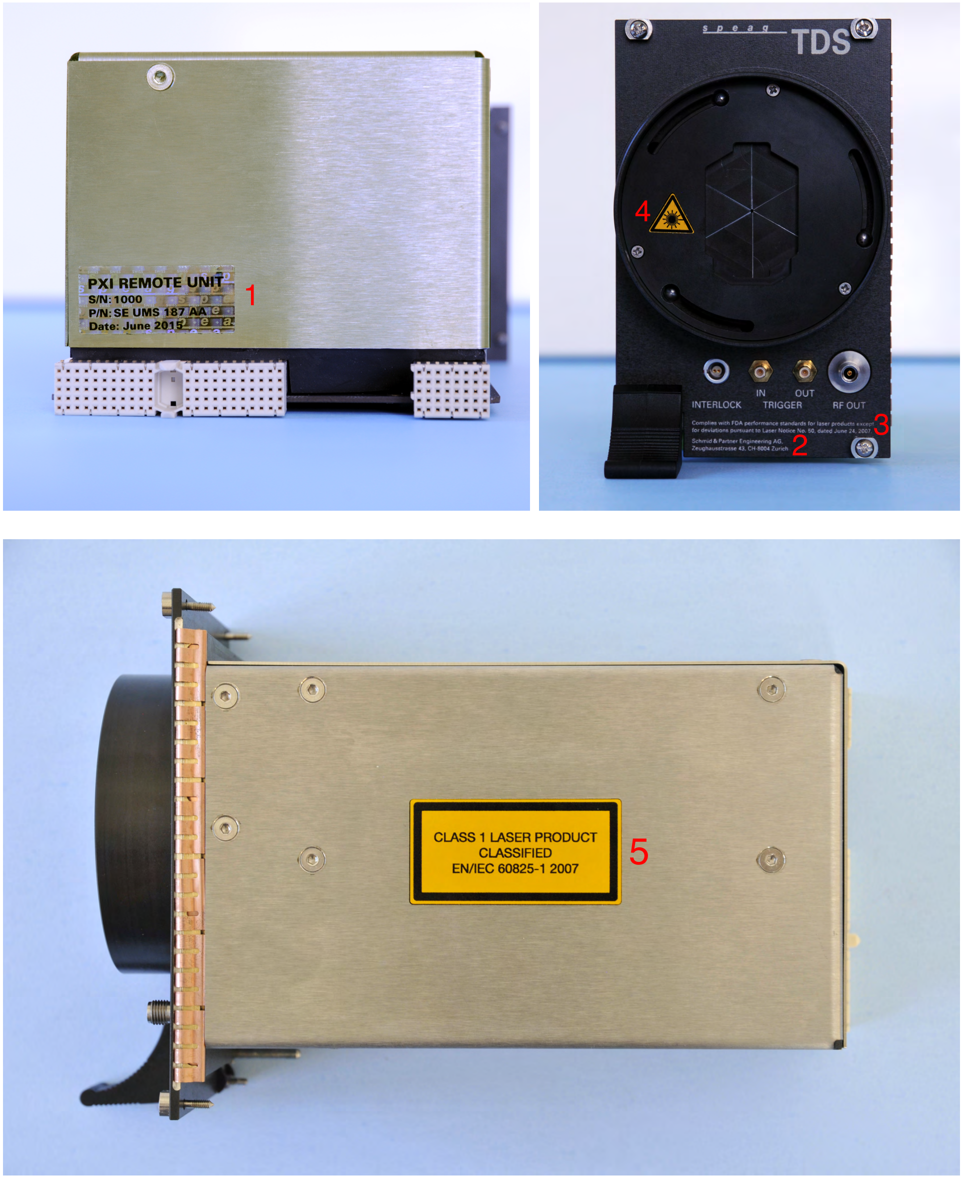


Figure 2: PXI *TDS Remote Unit* safety marking

0.2 Environmental Requirements

The *RFoF1P* system works best in the following environmental conditions:

- Temperature range: 10 °C - 30 °C.
- Humidity 30% - 90% non condensing.
- Atmospheric pressure 860 hPa - 1060 hPa

The probe calibrataion is valid for 22 °C ± 4 °C.

0.3 COPYRIGHT

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Switzerland

Visit our Web site: www.speag.com
Receive support: support@speag.com

0.4 About this Handbook

The *RFoF1P* Professional Handbook contains five parts: General, System Description, System Installation, *RFoF1P* Operation, and Remote Interface.

The System Description provides an overview of the *RFoF1P* hardware. Included are a hardware description, specifications, and service instructions to ensure correct operation.

System Installation is comprised of two parts: How to set up the hardware and how to install the software to control the *RFoF1P* system remotely from a PC.

RFoF1P Operation provides information on performing measurements with your *RFoF1P* system and applying the calibration factors delivered with your system.

The description of the Remote Interface provides details about the remote software command interface to control the *RFoF1P* system remotely from a PC.

If you have any questions related to matter beyond the scope of this handbook, do not hesitate to contact us by email (support@speag.com).

0.5 Declaration of CE Conformity

Schmid & Partner Engineering AG **s p e a g**

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info@speag.com, http://www.speag.com

Declaration of CE Conformity

Item / Configuration	TDS System: TDS Remote Unit 1– or 3–channel with TDS Probes E1TDSx, E1TDSz, E3TDS, E1TDSx SNI, E1TDSz SNI, H1TDSx, H1TDSz, H3TDS, H1TDSx SNI, H1TDSx SNI, RFoF1P
Type / Version No	SE UMS 180 A, SE UMS 180 B, SE UMS 181 A, SE UMS 181 B
Manufacturer / Origin	Schmid & Partner Engineering AG Zeughausstrasse 43 CH-8004 Zürich Switzerland
Contact	support@speag.com Tel. +41 44 245 9700

General

The TDS systems consist of a fully shielded remote unit (RU) powered by a separate USB power supply and a fully optical fiber coupled 1 or 3-channel detachable probe. The probe is powered optically by laser in the RU and the measured RF fields signals are transferred by laser from the probe to the RU. All interfaces of RF output and further control signals are available at RF connectors on the RU.

Electromagnetic Radiation

Radiating sources (radiating communication devices, test signal sources) will be operated together with the system. Such devices are not considered part of the system and therefore not covered by this declaration.

CE Conformity

We declare that the TDS system is compliant with the directives

2014/30/EU EMC

according to the harmonized standards

EN 55022 class A Emission
EN 61000-6-4 Immunity

and also with **2014/35/EU** Low Voltage
2006/25/EC Artificial Optical Radiation

according to the harmonized standard
EN 60825-1 2007 Class 1 Laser

In addition, the laser is certified as class 1 laser product under the requirements of
21 CFR (J) 1040.10 as per Laser Notice No. 50, dated June 24, 2007.

Date 30.3.2015

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Signature / Stamp F. Bomholt

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Part II

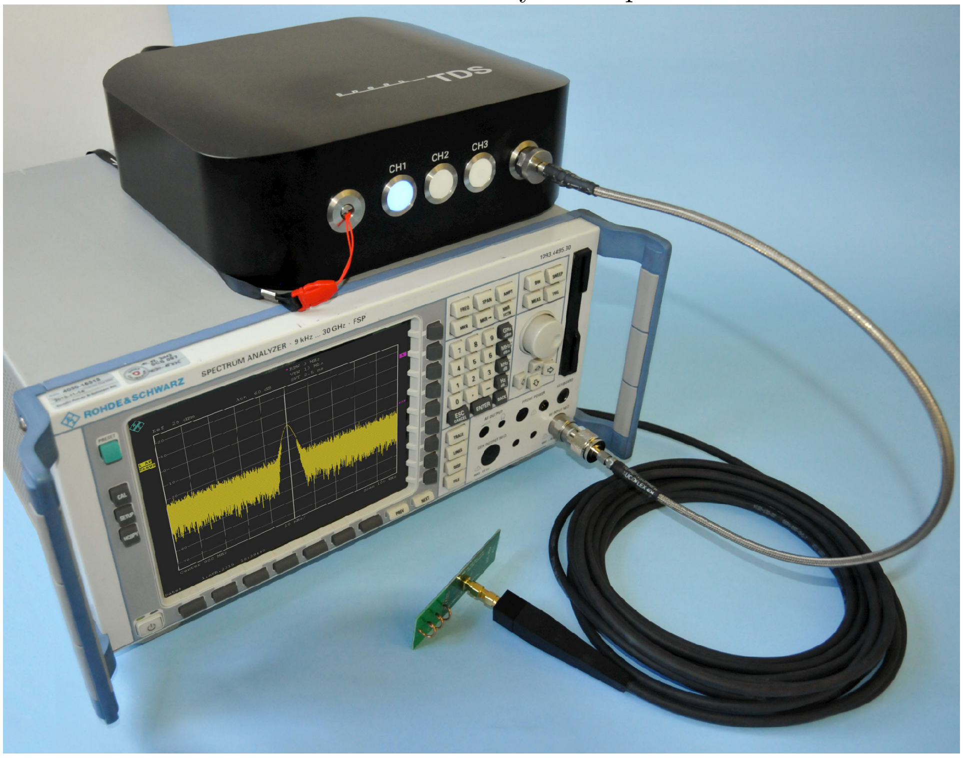
System Description

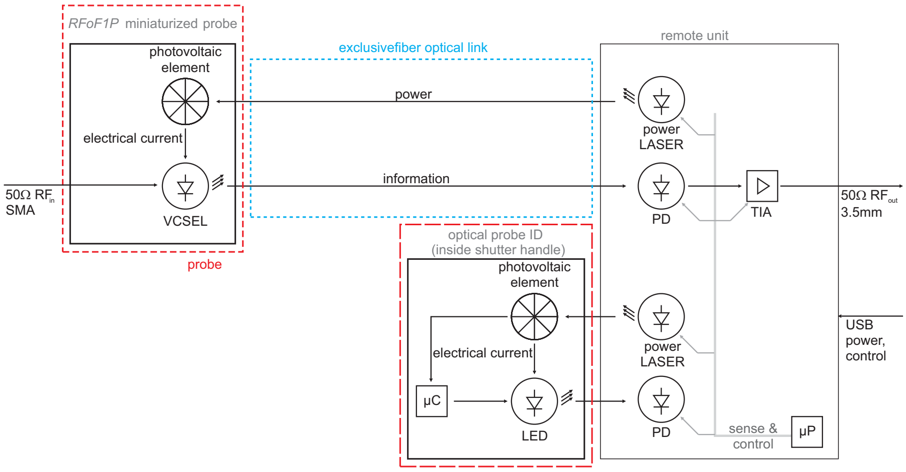
Chapter 1

Hardware Overview

1.1 *RFoF1P* System Overview

The main components of a *RFoF1P* system are the *RFoF1P* Probe and the Remote Unit which are interconnected by fibre optics:





The system uses direct laser modulation for signal transmission of the RF signal fed to the 50Ω SMA input of the probe. The *RFoF1P* probe and the *Remote Unit* are exclusively optically linked by fibre optics. A power laser is used to illuminate a photovoltaic converter inside the probe head via the fiber optics. The electrical energy from the photovoltaic cell drives a small current stabilized laser inside the sensor head. The input RF signal modulates the VCSEL's (vertical cavity surface emitting LASER) optical output power. This signal is then transmitted to the remote unit over an optical fibre. At the remote unit, the optical signal is demodulated again using a fast photodiode and the received RF signal is amplified by a transimpedance amplifier and made available using a standard 50Ω output to connect standard RF equipment.

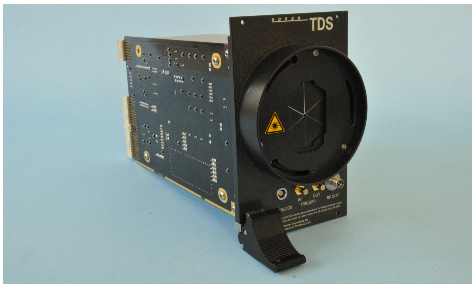
Basically, an *RFoF1P* system can be seen as a miniature, broad-band, electrically isolated link. The frequency dependent transfer function that gives the relation of the output from the remote unit and the input of the probe is available with the calibration certificate of the *RFoF1P* probes.

1.2 System Components

A *RFoF1P* system consist of the components listed in Table 1.1. Photographs of the system components are displayed in Figure 1.1.

(a) *TDS* Probe

(b) *TDS Remote Unit*

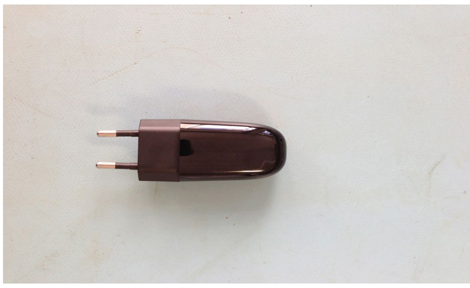


(c) *TDS* PXI *Remote Unit*

(d) PC 3.5 cable

(e) USB cable

Figure 1.1: Components of a *TDS* system.



(f) USB power supply

(g) Click Cleaner

(h) *Remote Unit* activation pin

Figure 1.1: Components of a *TDS* system (cont).

Item	Name	Description
a	*RFoF1P* probe	RF over Fiber link
b	*TDS Remote Unit*	Optical power source and RF opto-electrical converter
c	*TDS* PXI *Remote Unit*	Optical power source and RF opto-electrical converter (PXI version)
d	PC3.5 cable	Precision 3.5mm connector RF coaxial cable, 0.6m length
e	USB cable	Industrial USB cable, 4m length
f	USB power supply	USB power supply, $I_{max} = 1A$
g	ClickCleaner	Fiber optical connection cleaning device
h	Remote unit activation pin	Activation pin (key) for the remote unit

Table 1.1: Components of the *TDS* system.

1.3 Probe

The *RFoF1P* probe is a minituarized, remotely powered RF to optical media converter. The picture below illustrates it. All components are encapsulated in black plastic protective cover. The SMA input is the only user accessible part.

1.4 Remote Unit

RFoF1P is compatible with all standard *TDS Remote Units*. Two types of *TDS Remote Units* are available:

Single Channel Remote Unit The single channel *Remote Unit* acts as the optical power supply (via a near-infrared power LASER) to the *RFoF1P* probe. It further acts an opto-electrical converter for the optical signal returned from the *RFoF1P* probe.

Multi Channel Remote Unit The multi channel *Remote Unit* provides the same features as the single channel *Remote Unit*. In addition, it is equipped with 2 additional power LASER sources and an optical switch. The optical switch is used to multiplex up to 3 optical inputs onto the opto-electrical converter.

The below photographs show the front and rear views of the *Remote Unit* and provide a short description for all elements:

1. Activation Key Pin
2. Activation button and status LED for channel 1.
3. Activation button and status LED for channel 2.
4. Activation button and status LED for channel 3.
5. RF out connector (male 3.5 mm).

1. USB Type B connector.
2. Shutter with MU8 fibre optical connector.
3. *TDS Remote Unit* Instrument trigger input. This trigger can for instance be used to receive a trigger signal from a measurement receiver to indicate that the *Remote Unit* shall switch to a next measurement channel.
4. *TDS Remote Unit* Instrument trigger output. This trigger is intended to signal to a measurement receiver that the *Remote Unit* has completed a channel switching and hence the measurement receiver can perform an acquisition on the channel.
5. *TDS Remote Unit* Remote trigger input. This auxiliary trigger input can be used to synchronise the acquisition with another measurement instrument for instance a positioner system.

6. *TDS Remote Unit* Remote trigger output. This auxiliary trigger output can be used to synchronise the acquisition with another measurement instrument for instance a positioner system.
7. *TDS Remote Unit* Interlock input (optional). The isolated interlock input is currently unused. If configured internally (HW option) a 24V interlock signal is required to operate the remote unit, i.e., to switch on the power LASERs.

Chapter 2

System Handling

2.1 General

Caution – *RFoF1P* probes are miniaturised electro-optical devices. Even though SPEAG has put a lot of efforts into a robust packaging, handle both the *TDS Remote Unit* and probes with care. Note: Strong acceleration forces, e.g., from dropping the probes may cause permanent non-repairable damage to them.

2.2 Packing / Unpacking

2.2.1 Probe

The below description shows how to pack the *RFoF1P* probe. For unpacking simply reverse the order. It is recommended that during packing always the probe is first placed in the protective foam of the probe suitcase and removed as the last element during unpacking. Use the provided rubber caps to protect the SMA and the MU8 connectors from dust during transport.

Prepare and open the *RFoF1P* probe transport case. It is recommended to not yet disconnect the probe from the remote unit to protect the fibre optical connector during packing.

Please attach the provided plastic cap to the SMA connector to protect it from dust and dirt during transport. Insert the probe into the foam cutout as shown on the left. Make sure the probe is fully inserted.

Disconnect the probe from the *TDS Remote Unit*. Please attach the provided rubber cap to the MU8 connector to protect it from dust and dirt during transport.

Coil up the fibre optical patch-cord in few relatively loose turns in the foam cutout as shown on the left.

Insert the connector handle in the foam cutout. If the length does not fit re-adjust the coil radius of the fibre optical patch-cord.

2.2.2 Remote Unit

The components of the *TDS Remote Unit* and the accessories can be stored in the transport case as shown on the left.

2.3 Maintenance

2.3.1 General

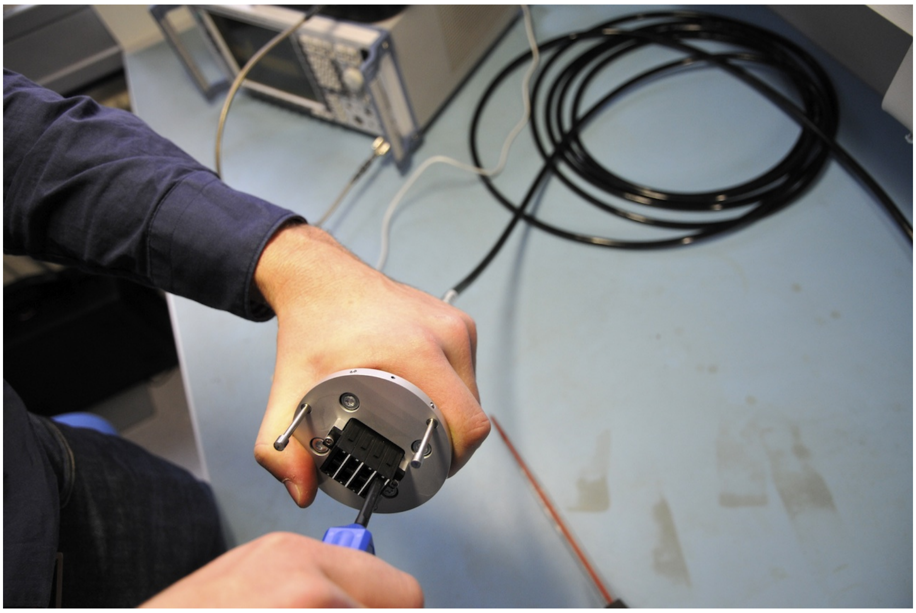
For maintaining LASER product safety, maintenance other than described below must be performed by the manufacturer of the *RFoF1P* system (Schmid & Partner Engineering AG, Zurich, Switzerland). The product does not require any scheduled maintenance to maintain compliance with Class 1 LASER safety. If the system is damaged, especially the housings of the probes, the remote unit or the sleeving of the fibre optics, or needs service or repair it has to be returned to Schmid&Partner Engineering AG, Zurich, Switzerland. Do not attempt any service or repair yourself. Do not open the housings or sleeves of any of the components of the *RFoF1P* system at any time.

2.3.2 Connector Life Cycle

Optical connectors in general have a limited number of mating cycles, until which the mating quality of the connectors is guaranteed (insertion loss uncertainty: $< \pm 0.3\,\mathrm{dB}$). For the MU8 connectors used in the *TDS* system, the number of mating cycles is 500 to 1000. We therefore recommend to plan out the use such that unnecessary connecting/disconnecting of probes is limited. SPEAG has designed the *RFoF1P* system in a way such that the fibre optics mating inside the shutter can be replaced at SPEAG in case a degradation of the connection is found. This would require the replacement of the *RFoF1P* probe cable and fibre optics inside the remote unit.

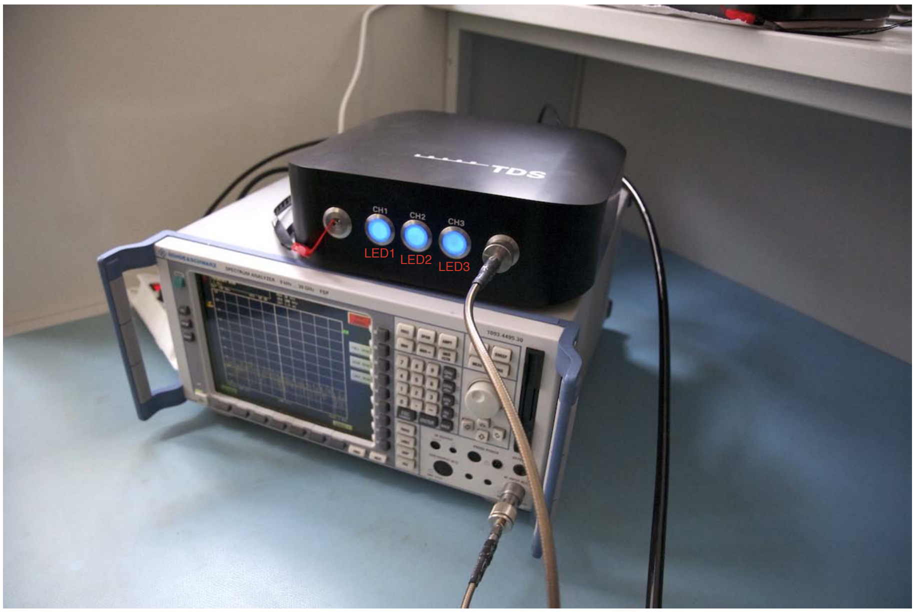
2.3.3 Cleaning of Optical Connectors

It is very important for a proper operation of the *RFoF1P* system that the fibre optical connector are cleaned before mating. The fibre optical connectors inside the shutter are protected from dust by the shutter system. User-access to the connectors for cleaning is not allowed due to LASER safety. SPEAG will clean those connectors during recalibration. The fibre optics inside at the cable connector can be cleaned using the ClickCleaner delivered with the remote unit. The number of cleaning cycles is 500. Please contact SPEAG if you require a spare ClickCleaner. To clean the connectors insert the ClickCleaner in every port of the MU8 adapter as shown below and push the blue part of the cleaner forward inside the connector. Repeat the process for all 8 ports:



2.4 TDS System Remote Unit LED States and Error Codes

The operational state of the *RFoF1P* system and error states are encoded using the lighting states of the 3 LEDs of the *TDS* Remote Unit:



Status: standby All three LEDs pulsating smoothly.

Status: channel activated LED of the active channel activated for channel activation time or continuous for continuous operation.

Error: no optical (probe) connector attached All LEDs flashing with 25% duty-cycle with 5 Hz period.

Error: serial number loop open All LEDs flashing with 50% duty-cycle with 5 Hz period.

Error: sensor loop feedback open during scan Single LED (of specific channel) flashing with 50% duty-cycle with 5 Hz period.

Error: no activation pin install LEDs displaying a moving light towards activation pin (3→2→1).

Part III

System Installation

Chapter 3

System Installation

3.1 Hardware Installation

This section provides a walkthrough for setting up the *RFoF1P* system hardware:

Remove the remote unit from the transport case as shown on the left.

In a typical setup the *TDS Remote Unit* is placed close to the measurements receiver, e.g., on top of a spectrum analyser as shown on the right. **Note: The *TDS* remote unit contains magnetic components and should not be brought close to strong static magnetic fields such as a Magnetic Resonance Imaging system.**

Place the USB power supply inside a power outlet socket. Connect the *Remote Unit* to the USB power supply using the included USB cable. Connect the USB cable with the Type B connector to the rear side of the *TDS Remote Unit*. The delivered cable provides an industrial grade USB connector (Neutrik), which has an automatic locking mechanism. To release the Type B USB connector, pull the metallic sleeve around the connector backwards to release the locking mechanism and then remove the cable.

Once the *Remote Unit* is powered all three LEDs will start flashing indicating a "Link Error" as no probe is connected yet.

The next steps describe how to connect the *RFoF1P* probe fiber optical connector to the *Remote Unit*. 1) align the marks on the *TDS Remote Unit* shutter and on the metal disc of the handle of the *RFoF1P* probe fiber optical cable. If the rotation of the disc is aligned with the shutter it is possible to insert the key pin against a spring load into the shutter. **Note: One of the pins has a wider diameter, incorrect alignment (rotation) of the cable connector will not allow to insert the probe.**

2) insert the pins against the spring load into the shutter until all three heads of the key pins are full inserted. If all three pin heads are inserted completely, it is possible to rotate the connector counter-clockwise.

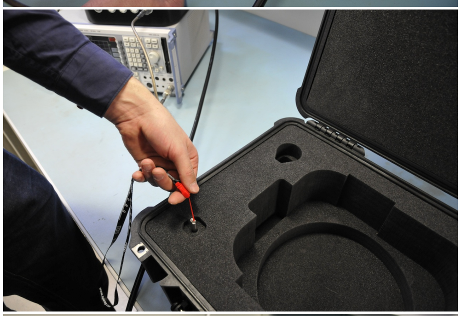
3) turn the connector and hence the key pins further counter-clockwise. The rotation opens the shutter incrementally. Once the rotation is initiated the key pins lock the cable to the shutter. This prevents removing the cable if the shutter is open. In the unlikely event of a failure of the electronic LASER shutdown mechanism this prevents direct visibility of LASER radiation.

4) Once the rotation is completed, the cable connector can be fully inserted into the shutter mating the cable's MU8 connector with the MU8 connector inside the shutter. **Please make sure that the cable connecter is inserted straight (fully orthogonal) into the *Remote Unit* housing)**

After connecting all cables to the rear side we recommend placing the *Remote Unit* as shown on the left. After the probe has been connected and the communication to the integrated serial number has been established the LEDs will display a moving light from right to left, identifying the missing activation pin.

Use the PC 3.5 mm cable delivered with the *TDS Remote Unit* and connect the female end to the 3.5 mm NMD connector at the front of the *Remote Unit*. To fasten the NMD connector turn the large nut counter-clockwise.

Connect the male end of the PC 3.5 mm cable to the RF in connector of your measurement receiver. (Use torque wrench for reliable mating.)



Insert the activation pin on the front left of the *TDS Remote Unit*.

After the pin is inserted the *Remote Unit* signals standby mode by "breathing" of the LEDs on the front. The *Remote Unit* is ready for use now.

3.2 Software Installation

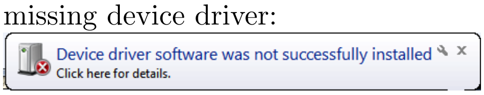
The *Remote Unit* can be controlled remotely via a Serial Communication over USB interface. The use of this interface has been tested under MS Windows XP and Windows 7 and MAC OS X 10.8. This section explains how to install the required driver and the prerequisites for a Remote Control of the *Remote Unit* using Python scripting.

3.2.1 Driver Installation under Windows

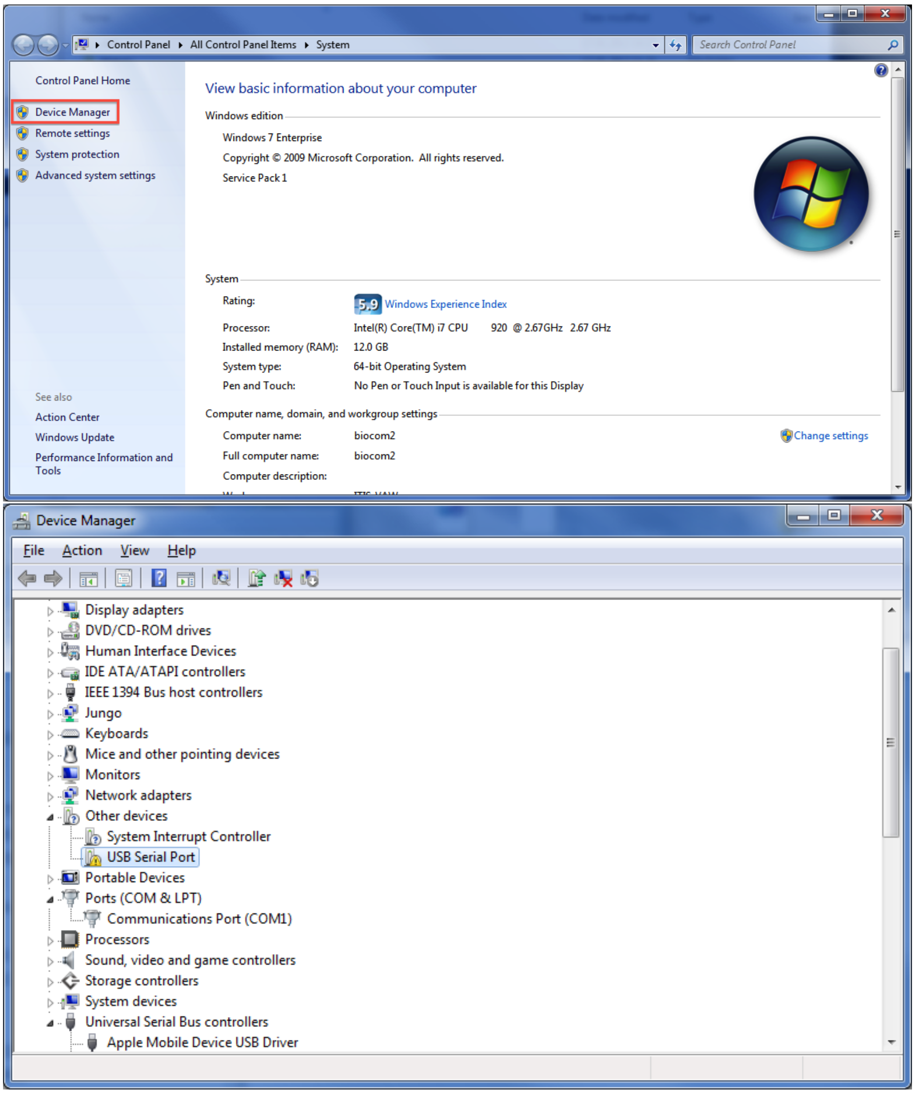
The following procedure describes the driver installation under Windows 7:

1. Download and extract the Virtual COM Port Driver package (for Windows 7) from the FTDI website: http://www.ftdichip.com/Drivers/VCP.htm.

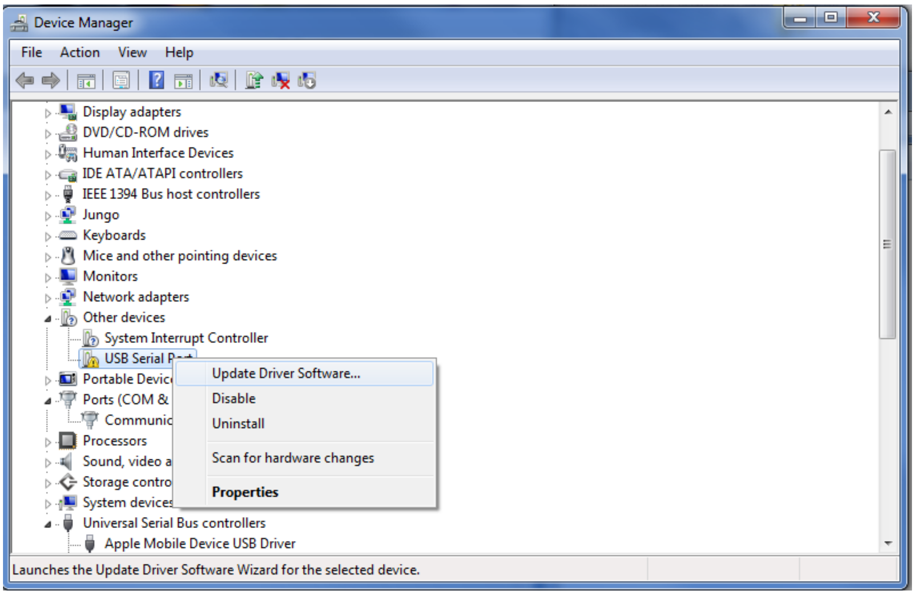
2. Connect the *Remote Unit* via the USB cable to your PC. Note: the USB port of your PC must be capable of providing $\geq$500mA. Most likely, the *Remote Unit* will not be immediately recognised due to the missing device driver:



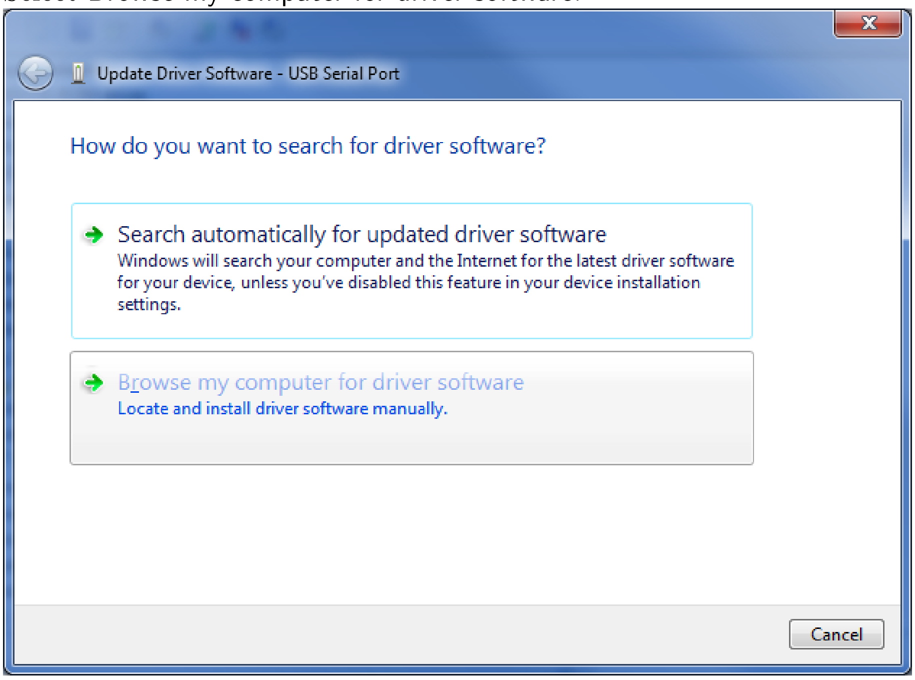
3. Open the MS Windows Device Manager. The device manager can be found under Control Panel — System of your PC:



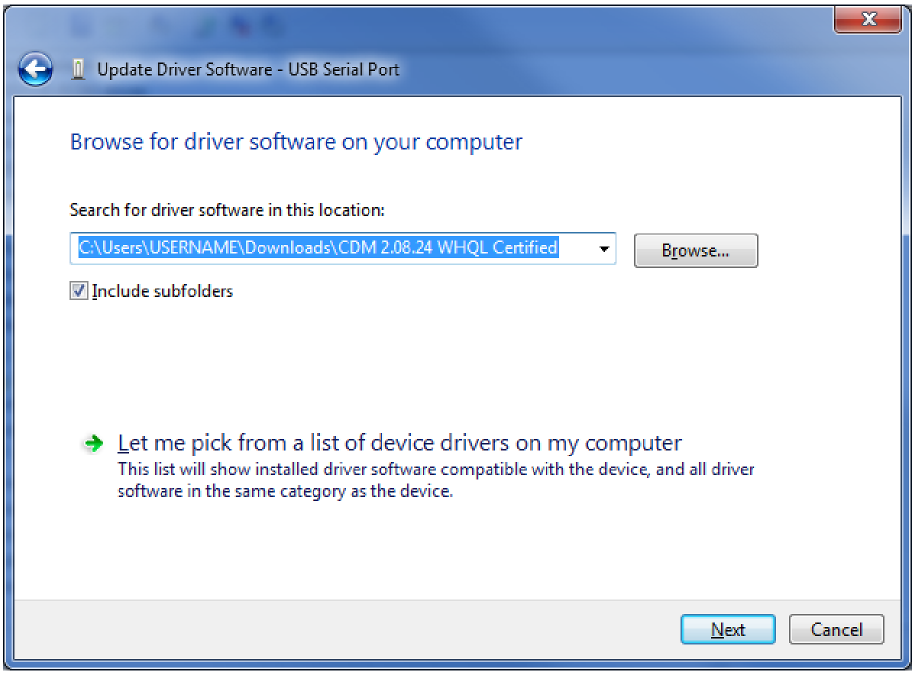
4. Identify a device called USB Serial Port under Other Devices. Right-click the device and select Update Driver Software:



5. Select Browse my computer for driver software:

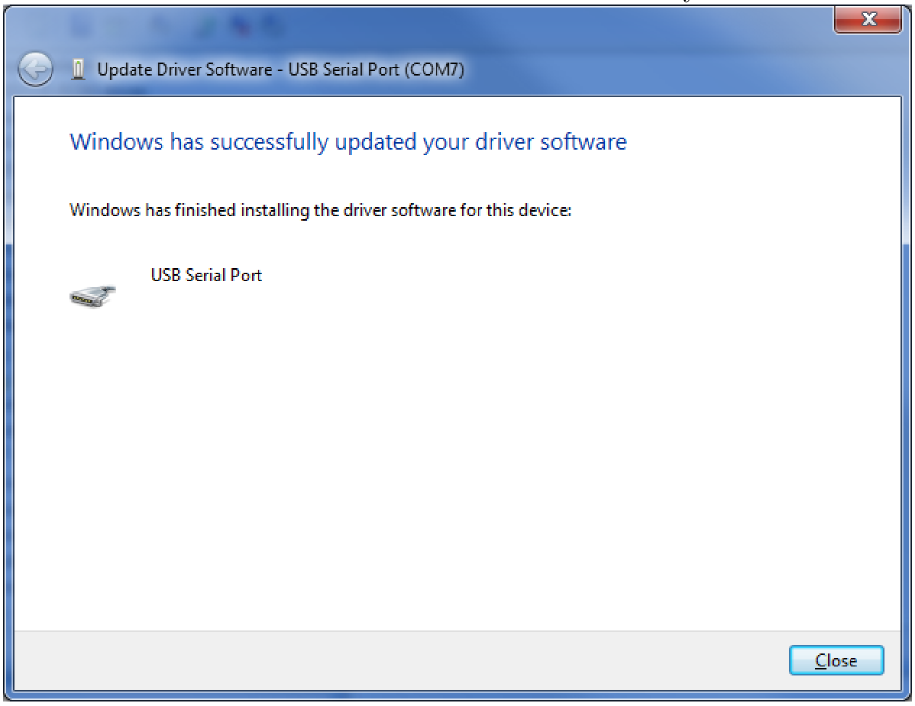


6. Navigate to the location where you downloaded and extracted the FTDI driver package:

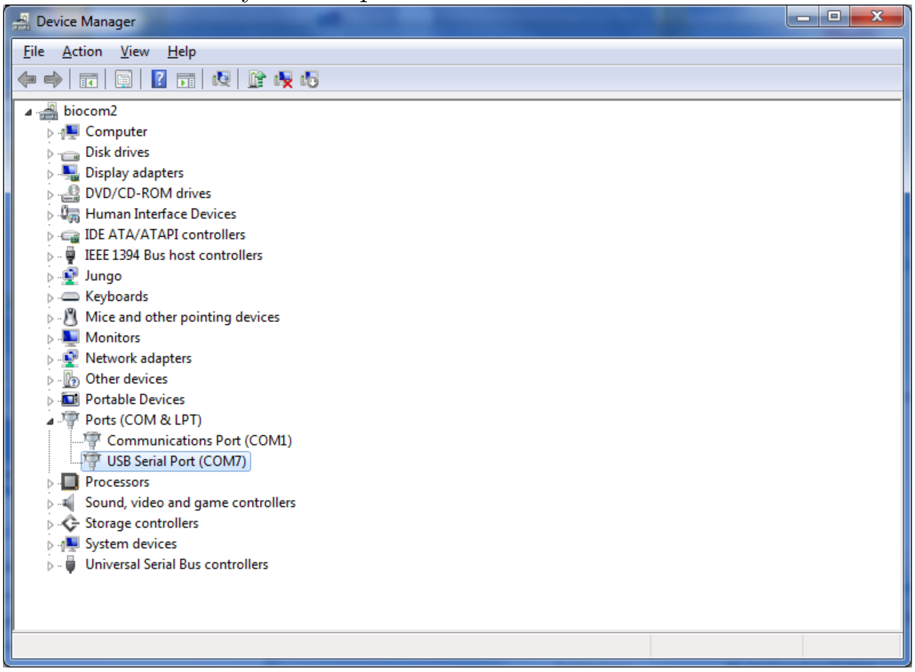


Make sure Include subfolders is ticked and click Next to install the driver.

7. You should be notified that the driver was successfully installed:



8. After the installation the *TDS Remote Unit* will be available as a new COM interface on your computer:

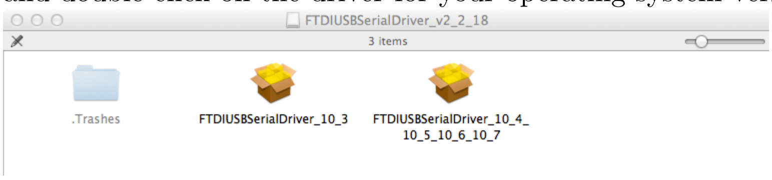


Note: the COM interface number depends on the USB port the *Remote Unit* is connected to. We recommend to always use the same port on the PC in order to maintain the same COM address. In rare cases when the *Remote Unit* COM interface appears unavailable the Windows COM driver stack may have locked up. In this case a reboot of the PC will resolve the issue.

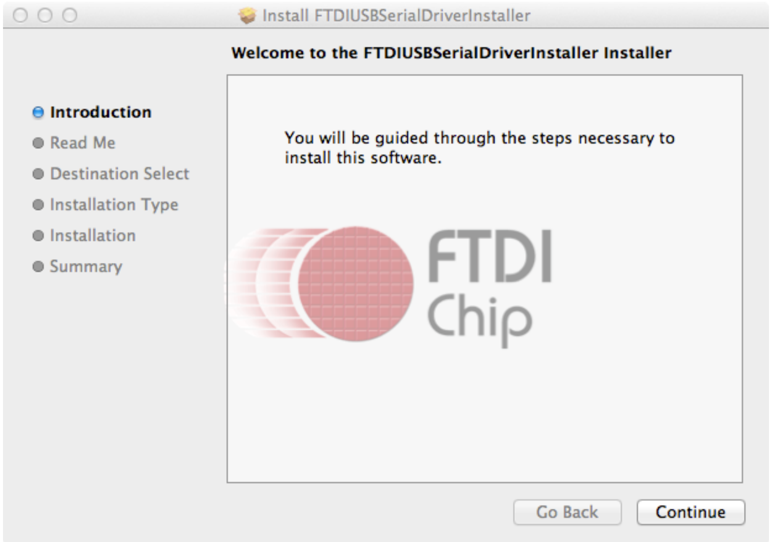
3.2.2 Driver Installation under MAC OS X

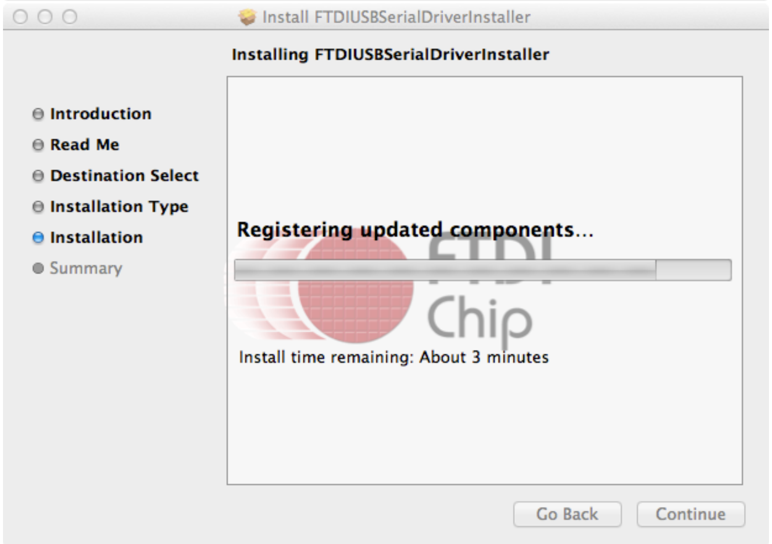
The following procedure describes the driver installation under MAC OS X 10.8:

- Download and extract the Virtual COM Port Driver package (.DMG, for MAC OS X) from the FTDI website: http://www.ftdichip.com/Drivers/VCP.htm and double click on the driver for your operating system version:



- The driver installation tool will start up. On most systems it will be sufficient to confirm all steps of the installation routine with Continue:



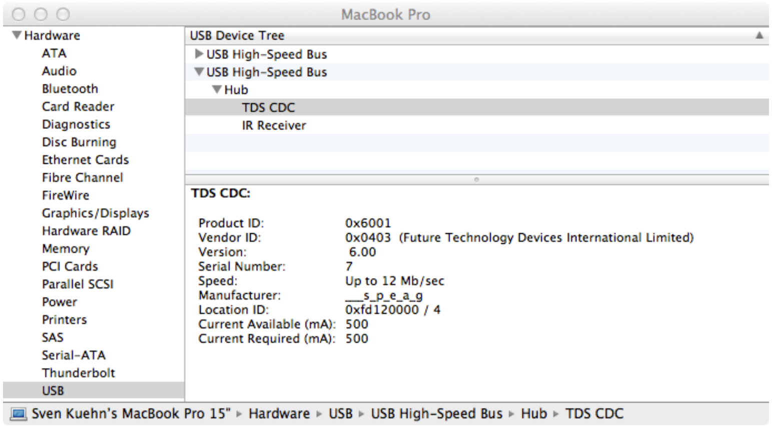


- Connect the *Remote Unit* via the USB cable to your MAC. Note: the USB port of your MAC must be capable of providing ≥500mA.

- You can verify that your *Remote Unit* was properly recognised as a COM interface by:

  – Open a terminal window and search tty COM interfaces via: `ls /dev/tty.*`:

– Alternatively, open the MAC OS X system report and identify your *Remote Unit* under USB as TDS CDC device:



3.2.3 Requirements for Instrument Control with Python

There are multiple ways to communicate to the *Remote Unit* via the serial interface, e.g., hyperterminal, direct serial interface, or using a VISA library. For simplicity we provide a Python module that allows the direct communication via the serial link, called TDSserial. The module is located on the USB memory drive delivered with your *TDS Remote Unit* in the folder Python. The TDSserial module requires the pyserial module present in your Python installation. We recommend installing a python distribution that includes the module, e.g., enthought (http://www.enthought.com) or PythonXY (http://code.google.com/p/pythonxy/). If the module pyserial is not present in your installation it can be obtained from:
http://pyserial.sourceforge.net.

Note: you can test if the pyserial module is present by executing: import serial in the Python command line shell.

Part IV

RFoF1P **Operation**

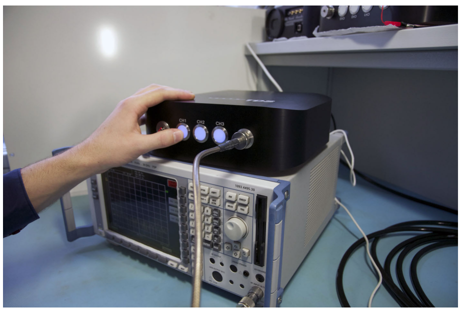
Chapter 4

RFoF1P Operation

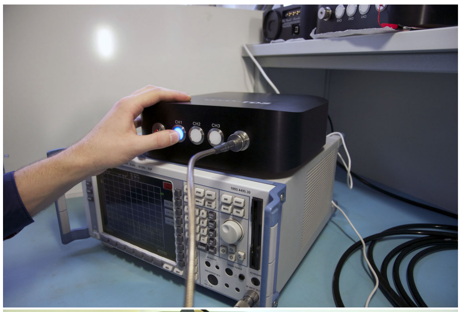
4.1 Using *RFoF1P*

The *RFoF1P* system is a very simple to use system - it just requires activation on CH1 channel of the *TDS Remote Unit*. **Note: *RFoF1P* probes and single channel *TDS Remote Unit* only support measurements on channel 1.** This section provides a short walk-through how to perform a manual measurement with your *RFoF1P* system.

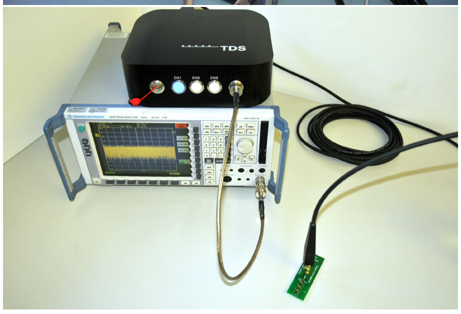
Set up your *RFoF1P* system as described in Section 3.1.



To activate the *RFoF1P* system on the desired channel press the corresponding button on the front side of the *Remote Unit*. Pressing the button button for <0.5 s will activate the channel for the measurement time programmed (see Chapter 5). Pressing the button for >0.5 s will activate the channel permanently (the 0.5 s transition is visualized by a short "off-cycle" of the channel's LED).



The LED of a channel lights up bright blue after activation



After activation the *RFoF1P* can be used for measurements. For information how to use the transfer function of *RFoF1P*, please refer to Section 4.2. For advanced remote control commands please refer to Chapter 5.

4.2 Application of the transfer function of *RFoF1P*

From link budget point of view, the *RFoF1P* probe can be regarded as an amplified wideband link. All *RFoF1P* sensors and paired *Remote Unit* are calibrated at SPEAG's calibration laboratory. Our calibration delivers the transfer function between an output power of the *Remote Unit* and the input power of the *RFoF1P* probe. This function in essence is the frequency dependent gain of the RFoF link defined as:

$$G_{RFoF} = P_{RUout} - P_{RFoFin} \tag{4.1}$$

with:

$$[G_{RFoF}] = dB \tag{4.2}$$

$$[P_{RUout}] = dBm \tag{4.3}$$

$$[P_{RFoFin}] = dBm \tag{4.4}$$

$$0dBm = 10 \cdot log_{10}(1mW) . \tag{4.5}$$

Based on the above equation a power ($[P_s] = dBm$) measured at the input of a measurement receiver the *TDS Remote Unit* is connected to, can be converted into input power to the *RFoF1P* by means of:

$$P_{RFoFin} = P_s - G_{RFoF} + ATT_{cable} \quad dBm \tag{4.6}$$

$$\tag{4.7}$$

Note: The Transfer Function of the *RFoF1P* system calibrates the transfer from the 3.5mm RF input of the *RFoF1P* probe to the RF output of the *Remote Unit*. It does not include the attenuation of any additional cables:

$$[ATT_{cable}] = dB \tag{4.8}$$

Part V

Remote Interface

Chapter 5

TDS Remote Command Interface

Table 5.1 show the remote SCPI command interface of the *TDS* system. Capital case letters in the command a mandatory, small case letters optional. Default arguments are identified by [].

Table 5.1: *TDS* system remote interface SCPI command list.

Command Level 1	Level 2	Level 3	Arguments	Functionality
*IDN?				Returns the identification of the *TDS Remote Unit* and the attached *TDS* probe.
*RST				Resets the *TDS Remote Unit*.
:FETCH?			([RF] | TIA | LASer | ADC),([DBM] | MW)	returns last measurments. for ADC the options are: ([MV]—RAW—HEX)
:Help?				list of commands
:INITiate			([ ] X | Y | Z | XY | XZ | YZ | XYZ | None)	inititates a scan. Default is the last channel setting
:READ?			([MW],DBM)	return RF-powers of last scan
:SENSe	:CHannels		(X | Y | Z | XY | XZ | YZ | XYZ | None)	configures channels for scan
:SENSe	:CHannels?			show channels configuration
:SENSe	:KEYTIMe		uint32	set scan-time [ms] for key-initiated scans [600..3600'000]

Continued on next page

Command			Arguments	Functionality
Level 1	Level 2	Level 3		
:SENSe	:KEYTIMe?			show current value of keytime
:SENSe	:MTIMe		uint32	set scan-time [ms] for remotely initiated scans [10..3600'000]. 0 means infinite duration
:SENSe	:MTIMe?			show current value of mtime
:SERVice	:ECHO		(OFF | ON)	turn echo on or off
:SERVice	:ECHO?			show echo status
:SERVice	:PROTOcol		([VISA] | LF | CR | CRLF)	set protocol
:SERVice	:PROTOcol?			show current protocol
:STATus?				returns highest priority error, and the program state. Then clears all errors.
:SYSTem	:INFO?			returns versions an so on
:SYSTem	:POWers?		([HUMan] | Line | MW | DBM)	returns current parameters
:SYSTem	:ADC?			returns parameters sampled by ADC
:SYSTem	:SENSor	:INFO?		returns info of the connected sensor
:SYSTem	:DATE		yy,mm,dd	set date of RTC
:SYSTem	:DATE?			query date of RTC
:SYSTem	:DTIME		yy,mm,dd, hh,mm,ss	set date and time of RTC
:SYSTem	:DTIME?			query date and time of of RTC
:SYSTem	:STACKS?			Show stacks of all threads
:SYSTem	:TIME		hh,mm,ss	set time of RTC
:SYSTem	:TIME?			query time of RTC
:SYSTem	:PXIslot?			query the address of the PXI slot
:TRIGger			(TP0 |TP1 | TP2 | TP3 | SMB | None), (TP0 | TP1 | TP2 | TP3 | SMB | [None])	configures triggers
:TRIGger?				show trigger configuration

Part VI

Application Notes

Chapter 6

Use of *RFoF1P* with High-Order Digital Modulations

6.1 Overview

Modulation is a fundamental property of all modern communications. It is the process of varying one or more characteristics (amplitude, phase or frequency) of a periodic waveform, called a carrier, with a modulating signal containing the information to be transmitted. In the case of digital communications, the carrier is modulated with a discrete signal (digital bit stream). The main goal of the modulation is to squeeze as much data as possible into the least amount of spectrum possible. That objective, known as spectral efficiency, measures how quickly data can be transmitted in an assigned channel bandwidth. In the urge to boost the spectral efficiency driven by ever increasing data speed requirements, higher and higher modulation orders are used. Signals used nowadays in modern satellite, cable and terrestrial communication systems are often modulated using quadrature modulating schemes. These schemes involve modulation of a pair of sine waves having 90 degrees phase offset. The output signal is an addition of the in-phase (I) and the quadrature (Q) components (as shown on Figure 6.1). A single carrier generated by a local oscillator is split into two paths. One of them is delayed with 1/4 of the carrier cycle time – equivalent to 90 degrees phase offset. The other one has no delay. Both carriers are amplitude modulated – one with the I signal, the other with the Q signal. As a next step both are added, resulting in a vector sum of the amplitude modulated I and Q signals as shown on Figure 6.2.

Both amplitude and phase in the I and Q branches can be modified in order to represent data symbols. This results in QAM (quadrature amplitude modulation). QAM modulation schemes are constantly evolving,

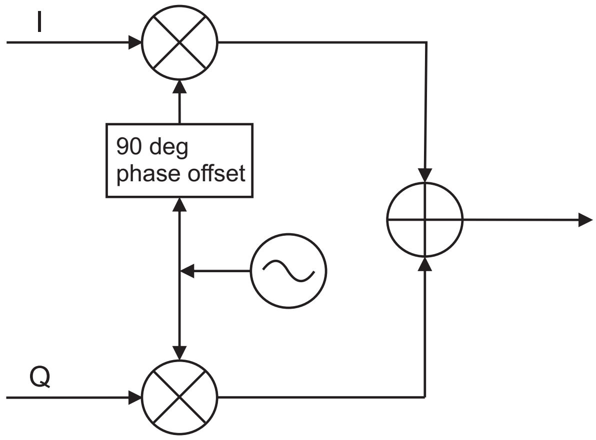


Figure 6.1: Block diagram of a quadrature modulator

starting from the "basic" QPSK (equivalent to 4QAM) used in 3G, going through 16QAM and 64QAM introduced in 4G and 256QAM, which was added in 802.11ac. Leading long-haul microwave equipment vendors have recently announced dependable long-distance transmissions using 1024 QAM [1]. 1024QAM is also been used in DVB-C2 [2] and is a candidate for the upcoming 802.11ax [3]. While these schemes present a significant improvement of the spectral efficiency, they are difficult to demodulate in the presence of noise, causing a serious engineering challenge on system level – both for transmitter and receiver. Such modulations require higher signal-to-noise ratios in combination with good linearity, making the design of communication channels tricky. In other words special care has to be taken to preserve the signal.

6.2 Constellation diagram

The constellation diagram is a common way to represent the modulated signal. It displays the signal in 2-dimensional complex scatter diagram with real and imaginary axis corresponding to the in-phase and quadrature components (Figure 6.2). The higher order modulation results in more constellation points (symbol landing points), as shown on Figure 6.3.

In the ideal channel every symbol is represented by a point (as shown on Figure 6.3). In non-ideal transmission channels, the symbols are not single dots, but rather clouds, with the corresponding error vector (demonstrated on Figure 6.4.

As long as the error is not significantly large, the receiver can recover the correct symbol using defined limits or decision boundaries. In real-

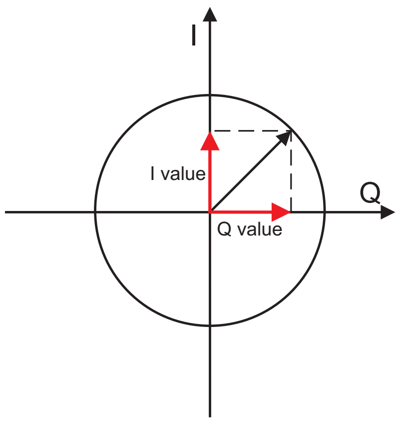
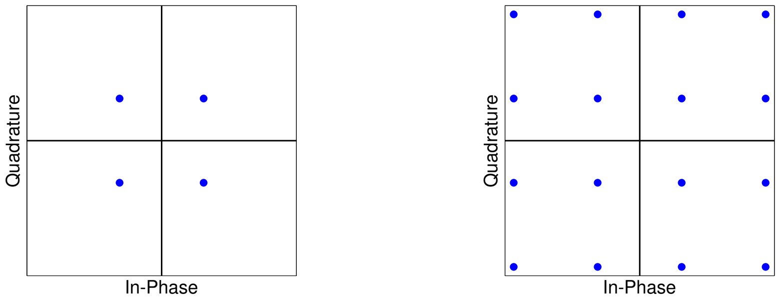


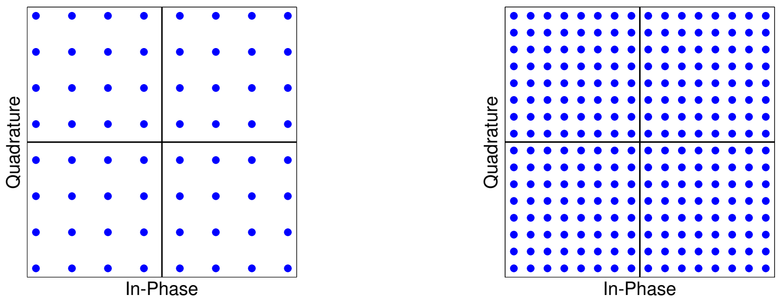
Figure 6.2: The resulting signal is represented as a vector sum of the in-phase (I) and quadrature (Q) components

life transmissions, there are many possible channel impairments forcing the points to land away from the target. One of the most common ones is additive noise. Figure 6.5 demonstrates the effect of Additive White Gaussian Noise (AWGN) to different modulations. Both signals are having Eb/No (energy per bit to noise power spectrum spectral density ratio) of 10dB. As the noise is white (flat power density over frequency) and Gaussian, it spreads the received symbols in a cloud around the ideal location. The closer the points are packed together in the cloud of received symbols, the better the signal quality. While in the case of QPSK, the data can be recovered without significant losses, the 64QAM is heavily influenced by the same noise levels. We see that the clouds surrounding the target landing points in 64QAM case are heavily overlapping, which means that bit erros will occur. This demonstrates that the channel qualities are getting more critical when increasing the modulation order.



(a) QPSK/4QAM

(b) 16QAM



(c) 64QAM

(d) 256QAM

Figure 6.3: Different order QAM modulation schemes

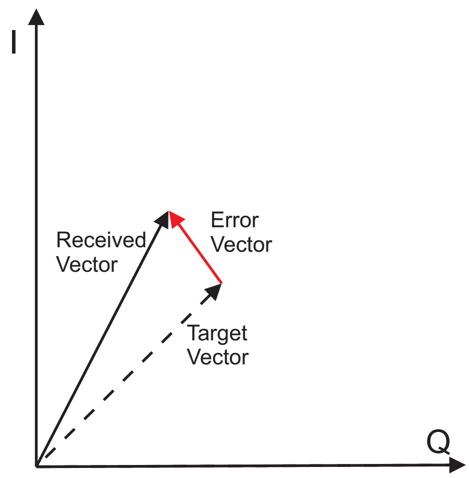
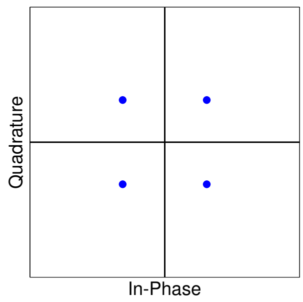
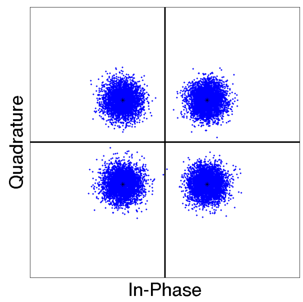


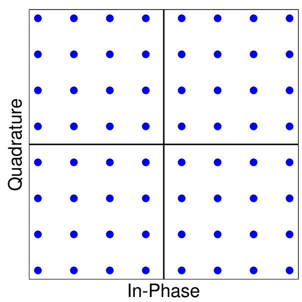
Figure 6.4: Graphical representation of the error vector



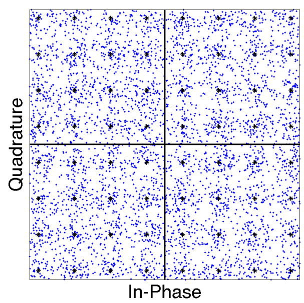
(a) QPSK without noise



(b) QPSK with noise



(c) 64QAM without nosie



(d) 64QAM with noise

Figure 6.5: Influence of the same amount of additive white Gaussian noise on two different QAM modulations. Eb/No for both modulations is 10dB. The target landing points are marked with black dots in the plots with noise. Note that the QPSK constellation points are well within the decision regions resulting in error-free data reconstruction, whereas the 64QAM case clearly shows that a lot of decision errors are present. The information in this case is severely damaged.

6.3 Constellation diagram measurements with National Instruments PXI VSA and *RFoF1P*

The best way to analyze the resulting transmission is by using a vector signal analyzer. Of course, we will need a vector signal generator capable of generating the high-order modulations we want to test. A simplified diagram of the setup is shown at Figure 6.7. All test equipment is placed in a National Instruments PXI chassis and is controlled by an external computer. In this setup, we use the PXI version of the TDS remote unit shown in Figure 6.6. The signal generator is NI PXIe-5644R VST and the signal analyzer is NI PXIe-5668R VSA.

Figure 6.6: TDS PXI Remote Unit.

Since the IQ constellation represents amplitude and phase, the shape of the constellation can be used to determine system or channel distortions and help pin down the cause. We generated real-life measurement data from the NI Modulation Analysis software (shown on Figure 6.8). We clearly see the influence of the noise in b) and the influence of the compression in c. Higher order modulations are usually resulting in high PAR (Peak-to-Average Ratio) levels. In order to properly transmit the signal, the channel has to remain linear in the whole dynamic range used by the signal. An impairment of the channel called gain compression happens when this linearity requirement is not fulfilled for the high amplitude symbols. It is causing rounding of the corner edges in both I and Q axes, where the channel is being driven to its limits. This is easiest to spot in the corners of the constellation (as shown on Figure 6.8(c)).

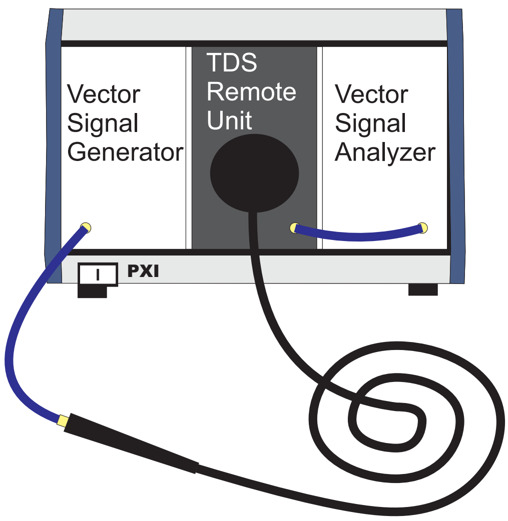
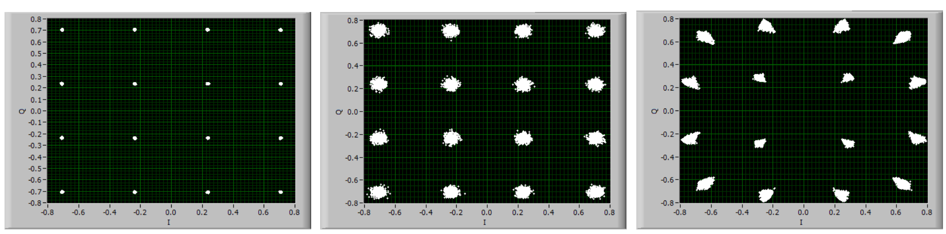


Figure 6.7: Simplified diagram of the setup used for the modulation analysis of *RFoF1P*. The signal generator provides a modulated signal at its output. This is transported using *RFoF1P* and delivered at the RF input of a vector signal analyzer. An external computer is used for control and visualization of the results.



(a) 16QAM with low noise (b) 16QAM with some noticeable noise (c) 16QAM with compression

Figure 6.8: Real-life measurement data showing AWGN noise and compression in the transmission channel

6.4 Modulation Error Ratio and Error Vector Magnitude

As we already saw different channel impairments can force the constellation points to fall away from its nominal position. In the extreme case of Figure 6.5 (d) the points go so far that bit errors are occurring. In the real-life networks, a figure of merit is needed to quantify a degraded link before an error occurs. Modulation Error Rate (MER) and Error Vector Magnitude (EVM) are widely spread ways to quantify the modulation quality [4]. MER is an aggregate quantity which includes all possible individual errors. In this sense it provides a single figure of merit which completely describes the performance of the transmission link. It is defined as:

$$MER = \frac{\sum_{j=1}^{N}(\tilde{I}_j^2 + \tilde{Q}_j^2)}{\sum_{j=1}^{N}\left[(I_j - \tilde{I}_j)^2 + (Q_j - \tilde{Q}_j)^2\right]} \tag{6.1}$$

,where

I_j is the I components of the j-th received symbol,

Q_j is the Q component of the j-th received symbol,

$\tilde{I}_j$ is the target I component of the j-th received symbol,

$\tilde{Q}_j$ is the target Q component of the j-th received symbol.

EVM is defined in [4] as:

$$EVM = \frac{\sqrt{\frac{1}{N}\sum_{j=1}^{N}\left[(I_j - \tilde{I}_j)^2 + (Q_j - \tilde{Q}_j)^2\right]}}{\mid V_{max} \mid} \tag{6.2}$$

,where

I_j is the I components of the j-th received symbol,

Q_j is the Q component of the j-th received symbol,

$\tilde{I}_j$ is the target I component of the j-th received symbol,

$\tilde{Q}_j$ is the target Q component of the j-th received symbol

V_{max} is the magnitude of the vector to the outermost state of the constellation.

EVM is closely related to MER. The only difference is that the EVM is referenced to the peak value, while the MER is referenced to the RMS value. In this sense the EVM and MER are proportional for a specific modulation and can be calculated from each other if the voltage ratio between the RMS and peak value are known. Both MER and EVM are reported in National Instrument's Modulation Analysis Toolkit (under the EVM Tab as shown in Fig 6.9) and can be used to evaluate the perfornmance of *RFoF1P* with real-life signals.

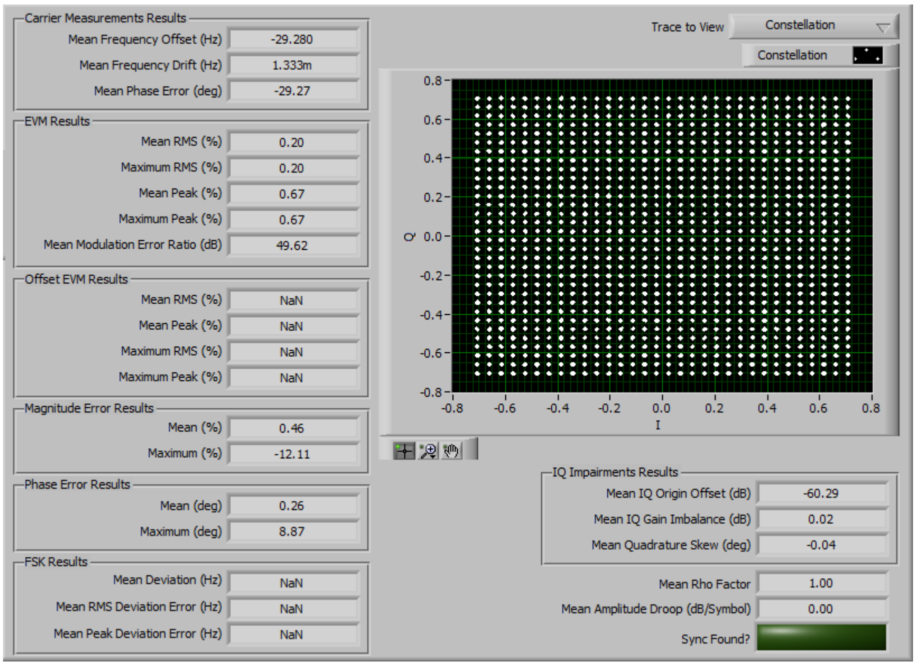
6.5 *RFoF1P* performance

Having all this background information, we run measurements with *RFoF1P* to evaluate its characteristics. The main goal is to examine *RFoF1P*'s capability to handle high order modulations typical for modern communication systems. Starting with a 64QAM we compare the performance of *RFoF1P* and a coaxial cable (Fig 6.9) . Since the coaxial cable has no active components, it will have a very low impact on the modulation. Yet it will degenerate the link quality over long distances due to natural attenuation. *RFoF1P* will have some immediate influence, but the important question is if this will cause any impairment of the signal transmission while *RFoF1P* will not. After inspection of the MER values in Figure 6.9, we see that there is a small degradation in MER, but this is negligible. The constellation diagram is properly transmitted without any noticeable distortions. Looking at 1024QAM, which puts much higher requirements on the link (Fig 6.10) again we notice some slight reduction of the MER. In fact, for both modulations we are covering the rather strict DOCSIS®3.1 requirement [6] of 40 dB MER with sufficient margin. These results prove that *RFoF1P* can be sucessfully used for transmitting modern signals with high order of modulation.

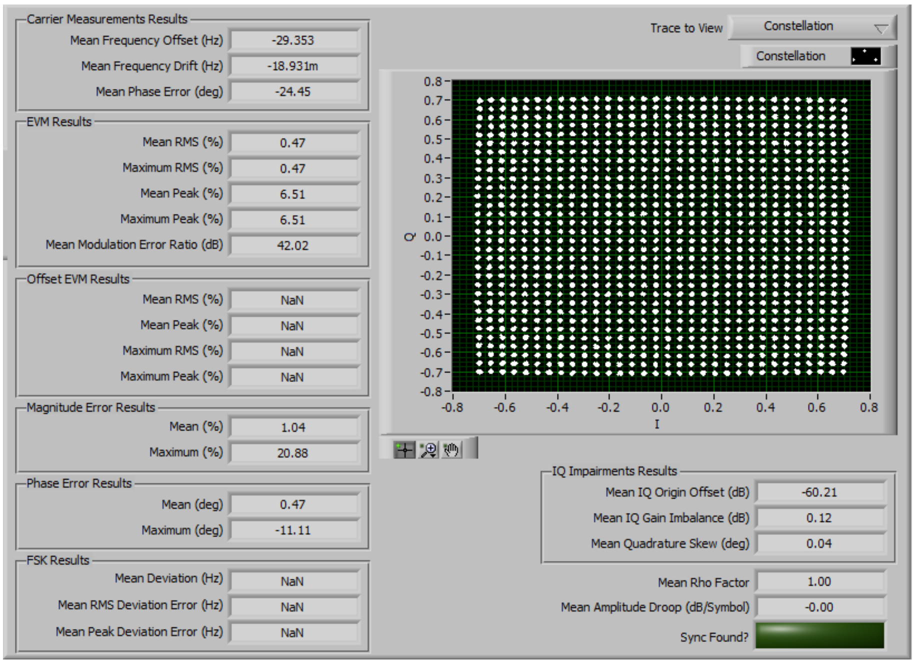
(a) 64QAM transmission over cable

(b) 64QAM transmission over *RFoF1P*

Figure 6.9: Comparison between 64QAM transmission with a coaxial cable and an *RFoF1P*.



(a) 1024QAM transmission over cable



(b) 1024QAM transmission over *RFoF1P*

Figure 6.10: Comparison between 1024QAM transmission with a coaxial cable and an *RFoF1P*. The MER is slightly increased, but stays on very high level, proving that *RFoF1P* is capable of handling such high order modulations.

6.6 AM-AM and AM-PM measurements

Another way to check the performance of an active transmission channel is to look at the influence of varying input amplitude to the output phase and amplitude. This is done by the so called AM-AM and AM-PM conversion measurements. In essence AM-AM is a measurement of the linearity of the system and shows the relation between input and output power. The AM-PM conversion on the other hand gives the amount of undesired phase deviation, caused by amplitude variations inherent in the system. It is usually defined as the phase change (in degrees) per increment of 1dB in the input power. Ideal channels will experience no phase deviations when the input power is changed. In real-life systems AM-PM conversion is a critical parameter, because unwanted phase deviations potentially can cause bit errors in the communication channel.

AM-AM and AM-PM conversion measurement can be easily performed using modern vector network analyzer, for example ZVA24 from Rohde & Schwarz. The setup is shown at Figure 6.11. The vector network analyzer performs a power sweep at a fixed frequency and measures output- amplitude and phase as a function of the input level. The steps to perform these measurements are described in [5].

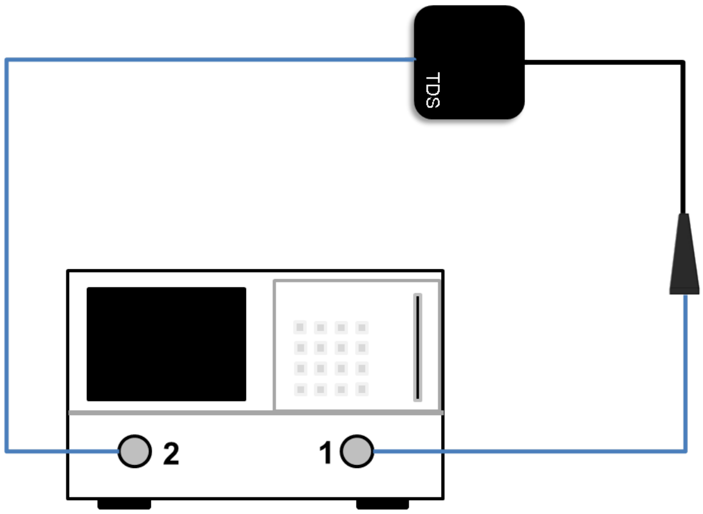
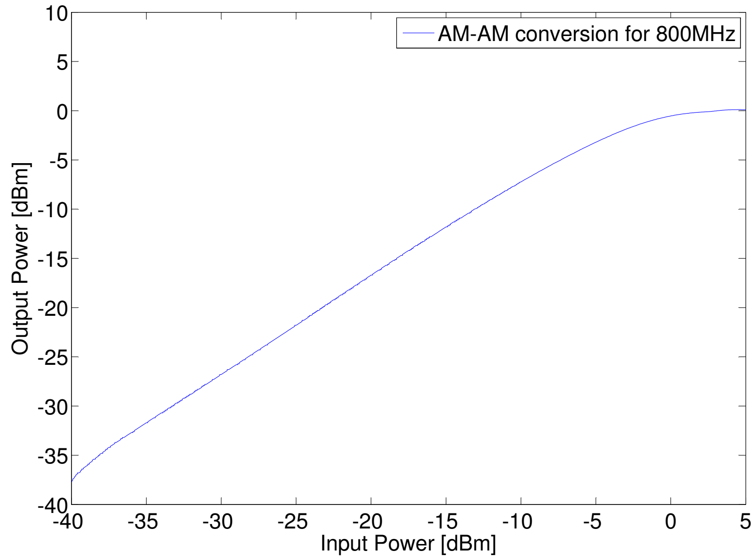
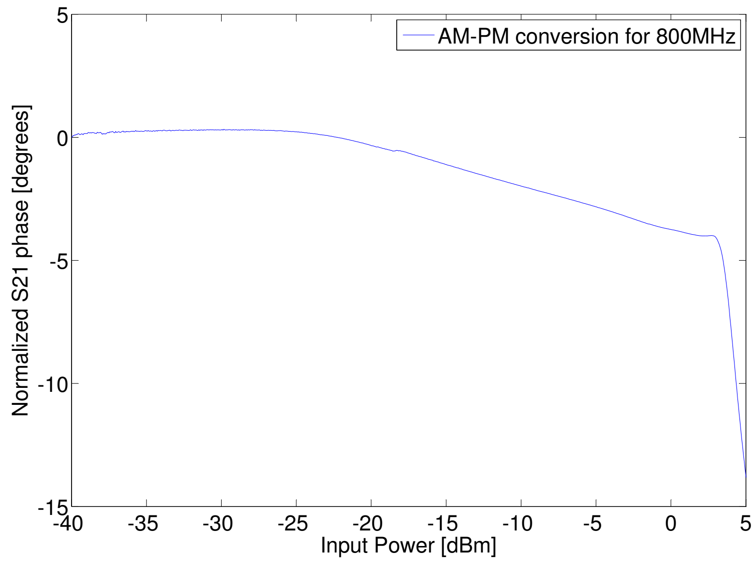


Figure 6.11: AM-AM and AM-PM test setup using a 2-port VNA. The remote unit of the *RFoF1P* system is connected to port 2 using a coaxial cable (in blue). The *RFoF1P* transducer in attached to port 1 using another coaxial cable.

Some typical results for *RFoF1P* are shown in Figure 6.12, demonstrating very good linearity and low phase deviation caused by input amplitude variations below the system compression point.



(a) AM-AM conversion of *RFoF1P*.



(b) AM-PM conversion of *RFoF1P*. *RFoF1P*

Figure 6.12: Typical results for AM-AM and AM-PM conversion measurements of *RFoF1P*. The link is performing very linear below the compression point at 0 dBm.

6.7 Discussion: Advantages of *RFoF1P* over coaxial cables

So far we demonstrated that the coaxial cable and *RFoF1P* are handling complex modulated signals in more or less the same way. Because *RFoF1P* is based on an optical fiber technology, it provides the following benefits compared to coaxial cables:

- Low attenuation:
  Compared the coaxial cables (even low-loss versions), optical fibers are offering much lower attenuations. High-grade low-loss coaxial cables have attenuation in the range of few dB/m, while the attenuation in modern optical fibers is maximum 3.5dB/km [7]. In other words, in setups with large distances between receiver and transmitter, the optical technology has a significant advantage. To overcome the high attenuation in the coaxial setup, traditionally additional amplifiers have been used, but these require complex setups with external feeding and can influence the purity of the modulation.

- Electromagnetic and radio frequency interference immunity:
  Coaxial cables are having some finite shielding effectiveness, which means that in electromagnetically harsh environments, these fields can leak through the outer shielding and disturb the transported signal, causing increased MER or EVM. Optical fibers, are inherently immune to electromagnetic interference and emit no radiation, due to the lack of any conductive materials in their construction. This is an important advantage in cases of routing weak signals through harsh EM environments (MRI, EMP, etc.) .

- Galvanic decoupling of receiver and transmitter:
  The optical fibers provide complete galvanic isolation between connected equipment, bringing additional protection for expensive measurement setups. This can be critical when remote outdoor installations are posing risks of thunderstrikes for example.

6.8 Conclusions

In this application note, we demonstrated with real-life measurements that *RFoF1P* can be successfully used to route modern high-order modulated signals. In this sense, it can act as a replacement of traditional coaxial links. Some imprtant advantages of *RFoF1P* over copper-based cables were listed above. These make *RFoF1P* the tool of choice when it comes to measurements and transport of modern communication signals over long distances, in EM harsh environments and when galvanic isolation of the fast communication link is paramount.

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[7] ISO/IEC 11801:2010 International Standard *Information technology - Generic cabling for customer premises*

Chapter 7

Sample Python scripts

7.1 Overview

Python™ is an object oriented open source programming language often used for scripting applications. It is easy-to-learn and with short development cycles. In addition, the scripts are clear to read. An important advantage is its very rich set of native libraries, including numerical and plotting modules for data analysis and visualisation and the possibility of expansion by creating custom-made modules, thus making the programming easier. In this application note, we list few example Python™ scripts demonstrating the use of remote commands to control a *TDS* system. The full list of all available commands can be found under Chapter 5.

7.2 Software Installation

7.2.1 Python™

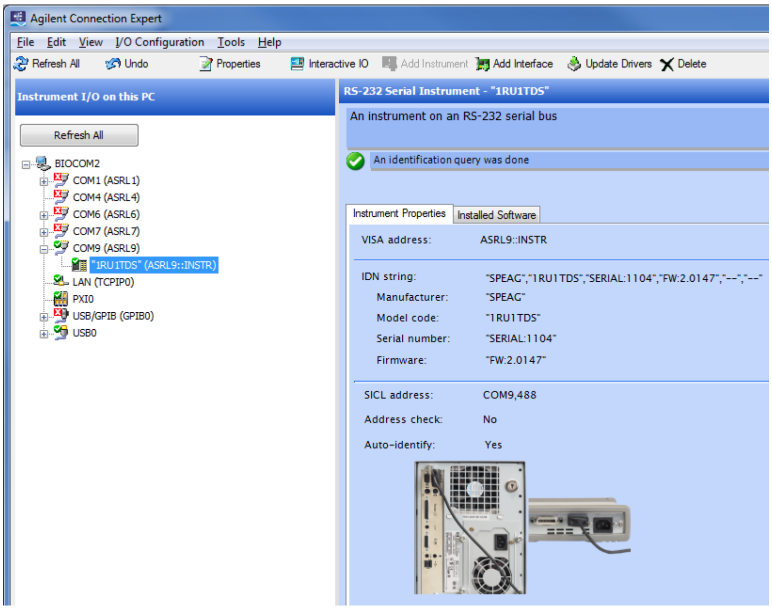
A working Python™ is required for running these sample scripts. One option is to install Enthought's Canopy distribution of Python™. The use of this distribution, however, is not mandatory. A good alternative can be the original Python™ distribution. It can be downloaded from http://www.python.org.

7.2.2 VISA library

Virtual Instrument Software Architecture (VISA) libraries are used for communicating with devices over GPIB, USB, and a variety of other buses. Agilent and National Instruments (NI) are some of the providers of these libraries. The Agilent software is called *Agilent IO Libraries*. The National Instuments software is called *National Instruments Measurement and Automation Explorer (NI MAX)*. Both are available for free download from the internet. Note that NI MAX is not a separate program and is distributed as a part of NI-VISA, NI-488.2, NI-DAQmx or other NI packages.

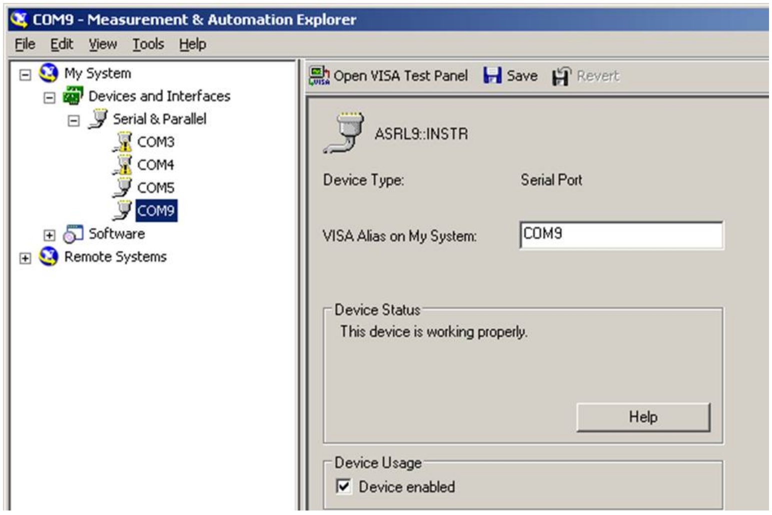
Agilent VISA

After a successful installation of Agilent's IO Libraries, the *TDS* Remote Unit should be identified as a COM device inside Agilent's Connection Expert. Details about the manufacturer, serial number and firmware version are displayed too. The screenshot below shows these:



National Instruments VISA

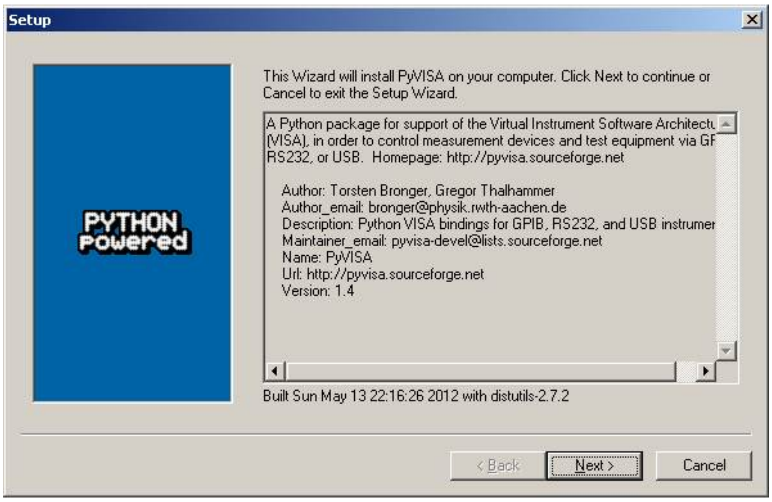
After a successful installation of the NI MAX, the *TDS* Remote Unit should be identified as a COM device. This is shown in the screenshot below:



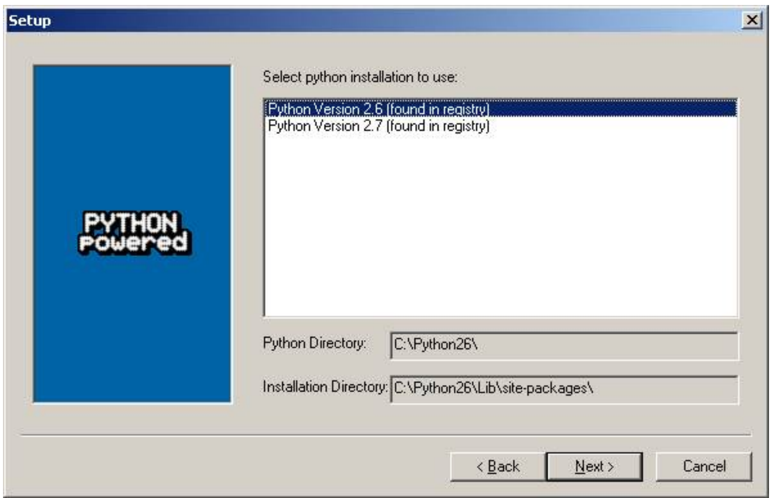
As seen on this picture, the VISA Alias assigned to the Remote Unit is COM9 and this is what we will use throughout this application note. Note that this might be different in your case.

7.2.3 PyVISA installation

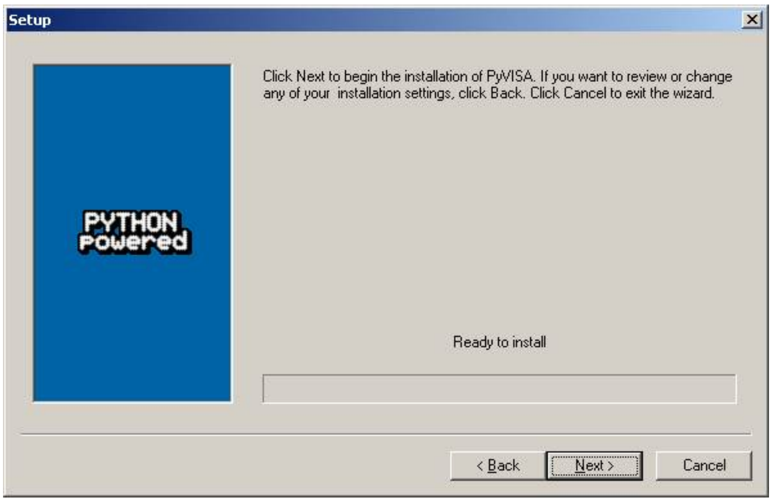
PyVISA is required to enable the control of the measurement equipment. This is a Python™ wrapper for the VISA library, needed for control of measurement devices and test equipment via GPIB, RS232, or USB. It can be downloaded from http://sourceforge.net/projects/pyvisa/ . After downloading the executable file, double-click on it. The following window will come up:



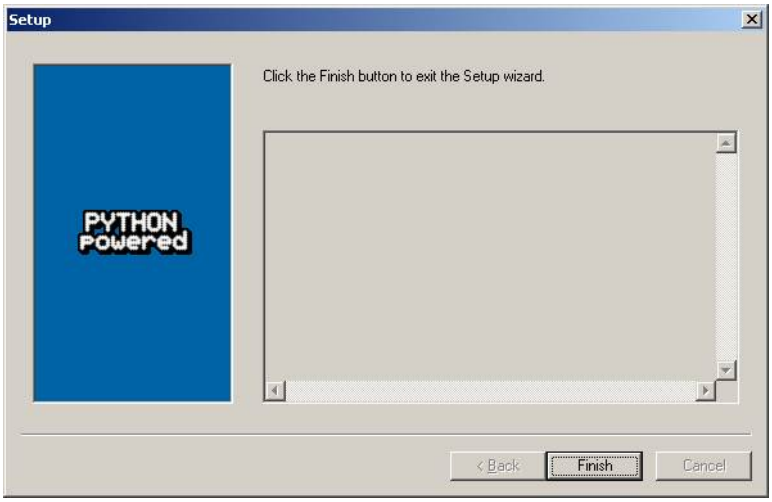
Click *Next*. On the following window, you should select which Python™ to be used for the PyVISA installation. If you have only one Python™ in your PC, this step is straightforward. However, if you run multiple Python™ versions, it is important to select the one which you intend to use for the instrument control. Note that PyVISA will be installed only for the selected Python™ installation.



Click *Next* to start the installation.



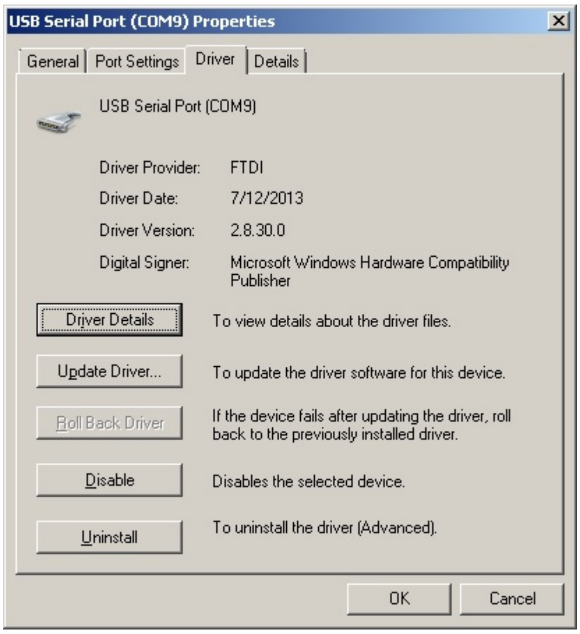
The installation is ready in few moments. Click *Finish* to exit the setup wizard.



Now, the software installation is ready and the first simple script can be run.

7.3 COM port

As mentioned in section 7.2.2 of this note, we assume that COM9 is the port assigned to the *TDS* remote unit. Please, check which COM port was assigned in your PC, since these are varying from system to system.This check can be done by using *Device Manager* in Windows as shown on the picture.

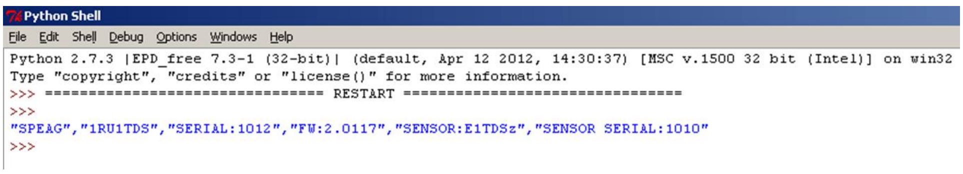


7.4 Reading IDN

In this first example, we start with asking the *TDS* Remote Unit for identification. Copy and paste the code given below into your Python™ editor and press F5 to save and run.

```
import visa # this imports visa

tds = visa.instrument('COM9',term_chars=visa.LF) # this creates the instrument
# variable tds, which is used for all further operations.

print tds.ask('*IDN?') # instead of separate write and read
# operations, we use ask() and print the result from it.
```

As a result, we get the IDN (type, serial number, firmware version) of the remote unit and the attached sensor printed in the Python™ console:

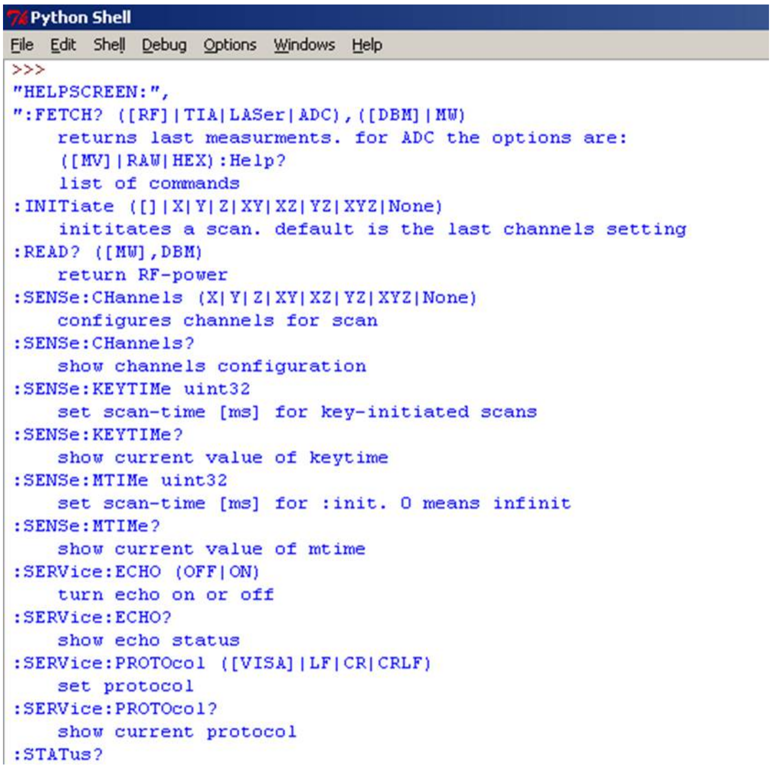


7.5 Getting help

This script is similar to the previous, but instead of asking for identification, we ask the Remote Unit to provide a help list of all commands. Copy and paste the code given below into your Python™ editor and press F5 to save and run.

```
import visa # this imports visa

tds = visa.instrument('COM9',term_chars=visa.LF) # this creates
# the instrument variable tds, which is used for all further operations.

print tds.ask('HELP?') # instead of separate write and read
# operations, we use ask() and print the result from it.
```

A long list with help for all possible commands will be displayed in the Python™ console.

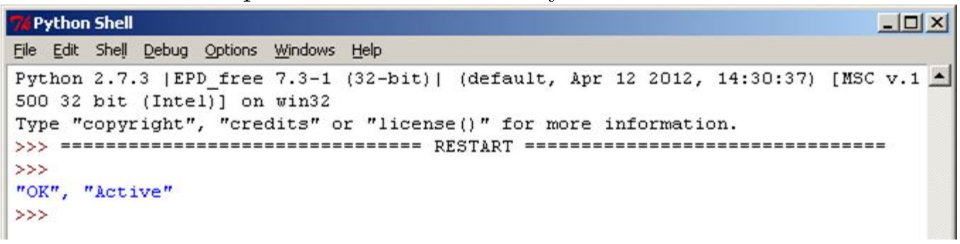


7.6 Checking the status of the system

In a similar to the previous examples manner, we ask the Remote Unit to report its status.

```
import visa # this imports visa

tds = visa.instrument('COM9',term_chars=visa.LF) # this creates
#the instrument variable tds, which is used for all further operations.

print tds.ask('STAT?') # instead of separate write and read
# operations, we use ask() and print the result from it.
```

The remote unit reports its status in the Python console:



The status of the *TDS* RU is OK, and we have an active connection to a probe.

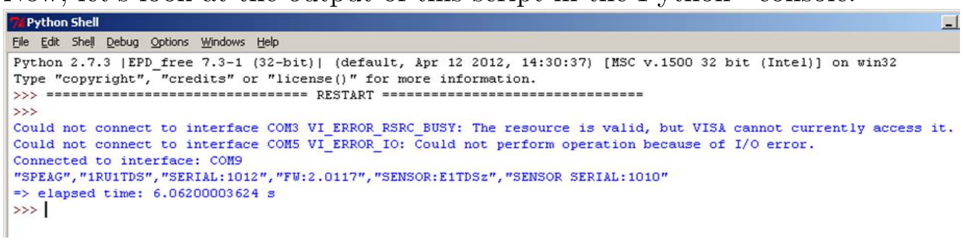
7.7 Automatic access to the *TDS* Remote Unit

This is a more advanced example, where we access the *TDS* Remote Unit without previously knowing the COM port assigned to it. For this, we send `*idn?` command to all COM ports and check the contents of the answer.

```
import visa
import sys
import time


instrumentlist = []  # the instument list is empty
start = time.time() # we start the timer
try: #try to list all attached visa interface
instrumentlistIF = visa.get_instruments_list()
except Exception, e:
    print "There was an error initializing the M&T interface: ", e
    instrumentlistIF = []

#try to connect to all interfaces and identify any attached instruments
for ii in instrumentlistIF:
    try:
        instrHandler = visa.instrument(ii, timeout=1, term_chars=visa.LF)
        instrumentIDN=instrHandler.ask("*IDN?")
```

```
    except Exception, e:
        print "Could not connect to interface", ii, e
        continue
    instrumentdata=instrumentIDN.split(",")
    instrumentdata.insert(0,ii)
    instrumentlist.append(instrumentdata)

# identify and connect to the first TDS Remote Unit in the list
# this is done by checking if we have SPEAG and RU1TDS in
# the instrument reply

for iiL in instrumentlist:
    if 'SPEAG' in iiL[1] and 'RU1TDS' in iiL[2]:
        try:
            TDSRUHandler = visa.instrument(iiL[0], timeout=1, term_chars=visa.L
            print "Connected to interface:", iiL[0]
        except Exception, e:
            print "Could not connect to TDS remote unit", iiL, e
            sys.exit()

try:
    print TDSRUHandler.ask("*IDN?")
except Exception, e:
    print "Could not connect to TDS remote unit", e
    sys.exit()

# print how much time it took to run this script
print '=> elapsed time: %s s' % (time.time()-start)
```

Now, let's look at the output of this script in the Python™ console.



Our PC has three VISA COM ports (COM3, COM5 and COM9), but only one of them is used by a *TDS* Remote Unit. The script tried communicating to all of these ports and identified COM9 as a *TDS* Remote Unit is COM9. This Remote Unit responded with its serial number and information about the connected sensor. The total run-time was printed at the end.