# TDS

Time Domain Sensor

Standalone System

# Handbook V 1.0r2486

Schmid & Partner Engineering AG

August 3, 2020

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# Part I

# General

## 0.1 Safety Instructions

The Time-Domain Sensor (*TDS*) system is a LASER Product designated as Class 1 during all procedures of operation. The *TDS* 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 *TDS* 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 *TDS* 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 *TDS* 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 *TDS* system is limited to LASER Class 1. Even in the event of a failure of the protective covers or sleeves the radiation from a *TDS* 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 *TDS* 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 to energise the *TDS* sensors heads when a probe is connected:

| | |
|---|---|
| Wavelength | 808 nm |
| LASER power for classification | $\leq$100 mW ($\leq$55 mW calibrated) |
| Mode of operation | CW (continuous wave):<br>automatic shutdown after link failure: $\leq$100 $\mu$s |
| 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 | $\leq$5 mW (calibrated) |
| Mode of operation | CW (continuous wave):<br>automatic shutdown after link failure: $\leq$1000 uSec |
| Transverse beam mode | multi-mode |

Inside the *TDS* probe 1 near-infrared LASER source (VCSEL) is present:

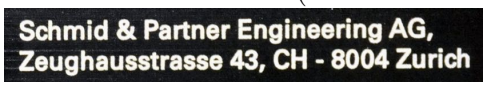
| | |
|---|---|
| Wavelength | 850 nm |
| LASER Power for classification | ≤2 mW |
| Mode of operation | CW (continuous wave):<br>automatic shutdown after link failure: ≤100 uSec |
| Transverse beam mode | multi-mode |

### 0.1.2 LASER Labeling

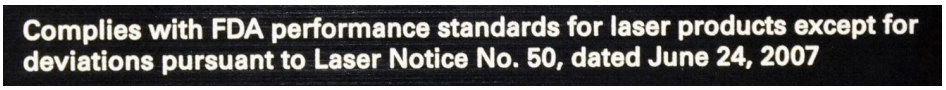
The below figures show the positions of the LASER safety relevant labelling of the standalone *TDS Remote Unit* and the PXI version of the *TDS Remote Unit*. The following labels are present on every *Remote Unit*. The exact locations are shown on Figure 1 and Figure 2.

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

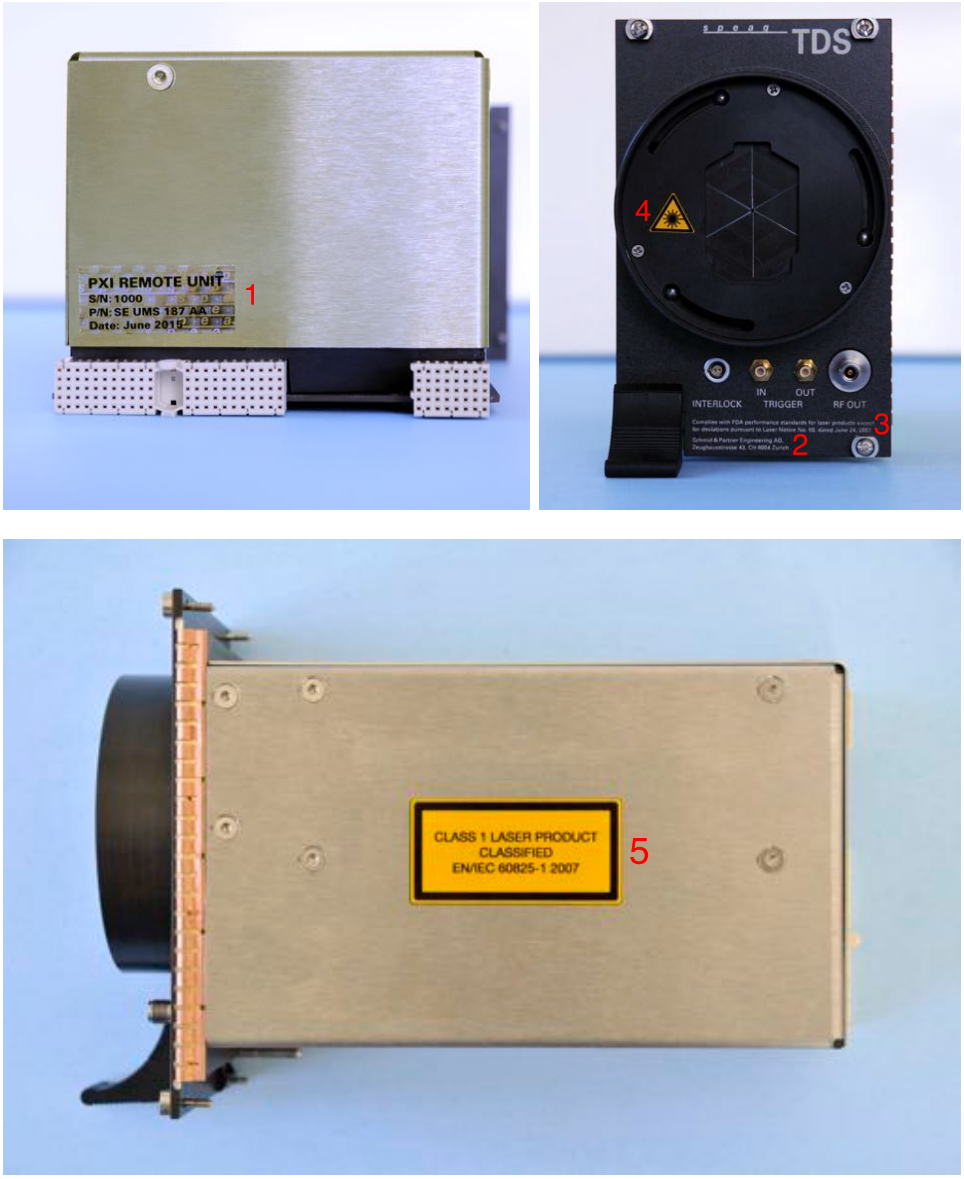



Figure 2: PXI *TDS Remote Unit* safety marking

## 0.2 Environmental Requirements

The *TDS* 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

**Note:** The probe tip is fully sealed, so it can be used inside liquids. This is valid only for the tip, not for the entire probe.

## 0.3 COPYRIGHT

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Receive support: support@speag.com

## 0.4 About this Handbook

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

The System Description provides an overview of the *TDS* 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 *TDS* system remotely from a PC.

*TDS* Operation provides information on performing measurements with your *TDS* 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 *TDS* 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

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

**Declaration of CE Conformity**

| | |
|---|---|
| Item / Configuration | TDS System:<br>TDS Remote Unit 1– or 3–channel<br>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<br>Zeughausstrasse 43<br>CH-8004 Zürich<br>Switzerland |
| Contact | support@speag.com<br>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

**Signature / Stamp** F. Bomholt

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# Part II

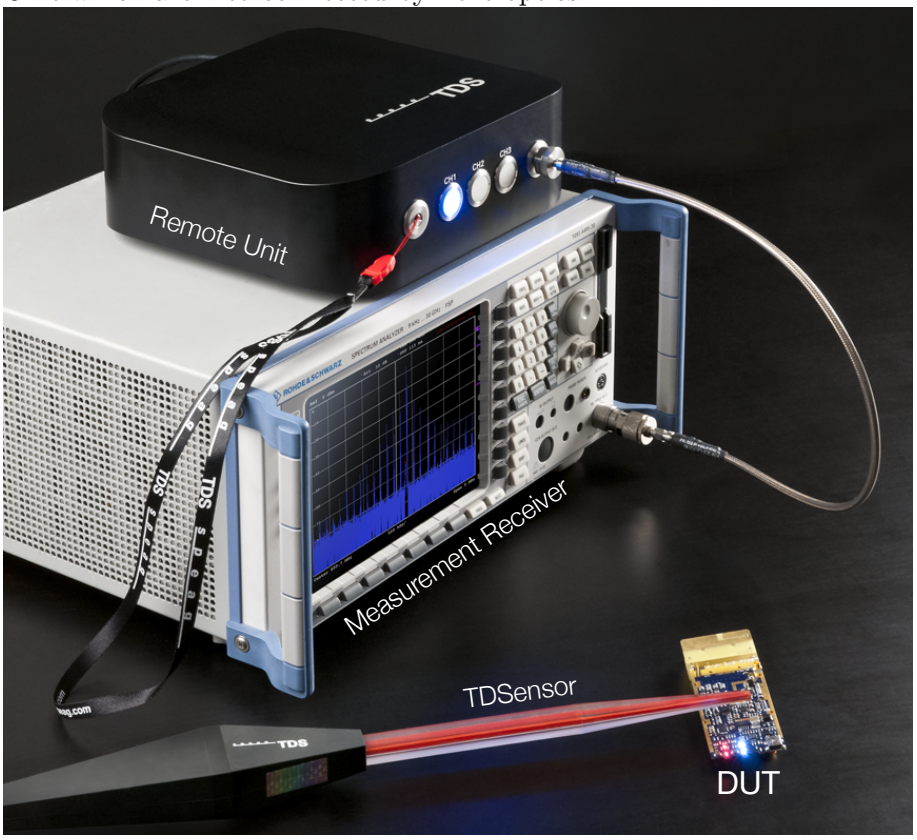
# System Description

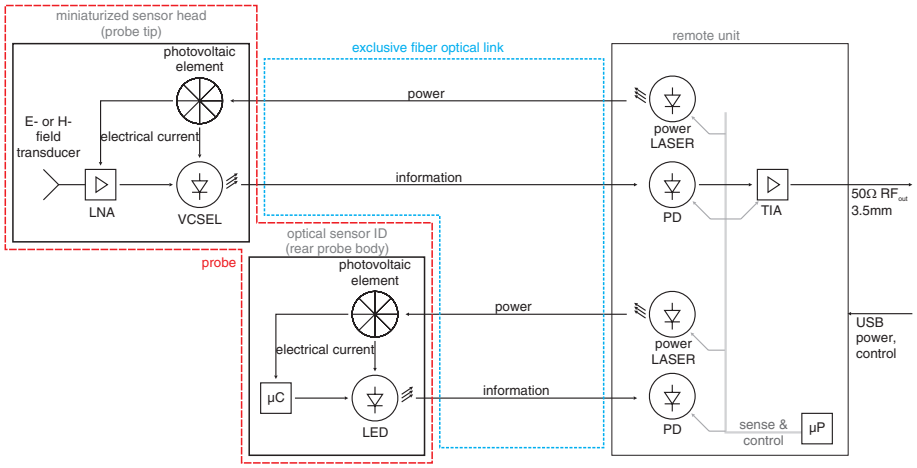
# Chapter 1

# Hardware Overview

## 1.1 *TDS* System Overview

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






The system uses direct laser modulation for signal transmission and electrically small transducers to pick up the E- or H-field. Both devices are exclusively optically linked by fibre optics. A power laser is used to illuminate a photovoltaic converter inside the sensor head via the fiber optics. The electrical energy from the photovoltaic cell drives a small laser and a low-noise amplifier inside the sensor head. The H-field is detected using an electrically small loop antenna and the E-field by a small dipole, respectively. The detected signal modulates the VCSEL (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 measurement equipment such as an oscilloscope or a spectrum analyser.

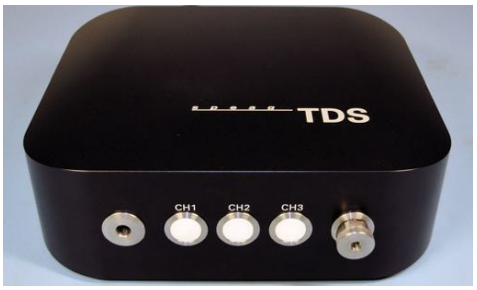
Basically, a *TDS* system can be seen as a miniature, broad-band, optically isolated antenna. The antenna factor, the frequency dependent transfer function that converts the output from the remote unit in dBm to an H-field (in dBA/m) or an E-field (in dBV/m) is made available with the calibration certificate of the TDS probes.

## 1.2 System Components

A *TDS* 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* Sniffer Probe



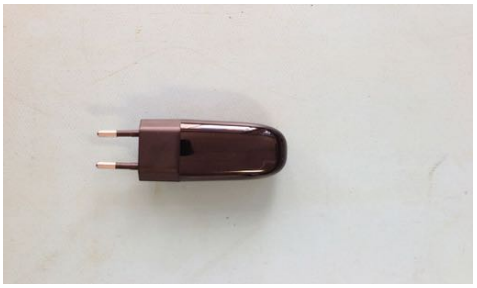

(c) *TDS Remote Unit*

(d) *TDS* PXI *Remote Unit*

(e) PC 3.5 cable

(f) USB cable

Figure 1.1: Components of a *TDS* system.



(g) USB power supply

(h) Click Cleaner

(i) *Remote Unit* activation pin

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

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

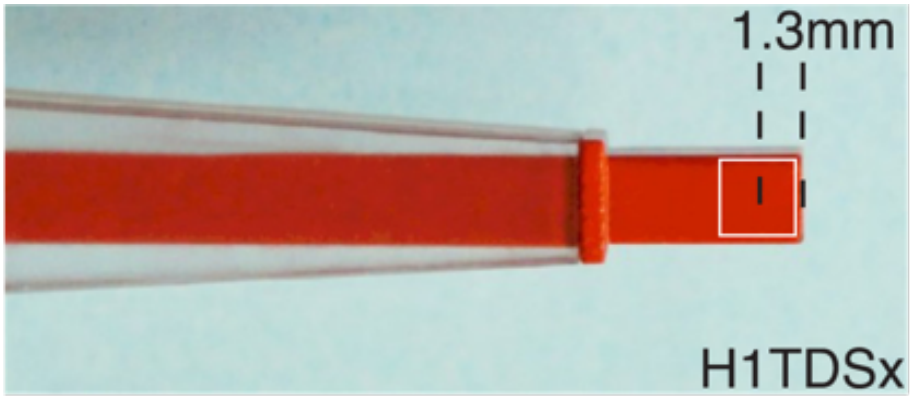
Table 1.1: Components of the *TDS* system.

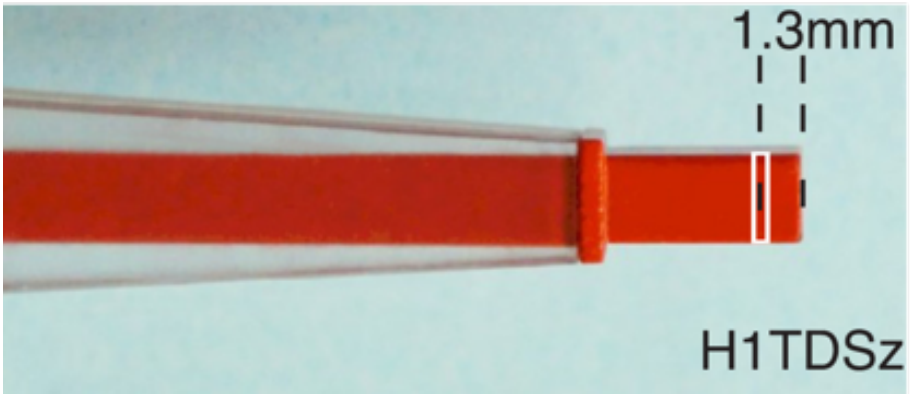
## 1.3 Probes

Eight types of *TDS* probes are available, four full-sized *TDS* probes (E1TDSx, E1TDSz, H1TDSx and H1TDSz) and four *TDS* sniffer probes (E1TDSx SNI, E1TDSz SNI, H1TDSx SNI and H1TDSz SNI). The details of the probes are described in the sections below.

### 1.3.1 H-Field Probes

*TDS* H-field probes can be identified by a probe tip coloured in red. The below figure illustrates the location of the miniature loop sensors with respect to the tip of the *TDS* H-field probes:



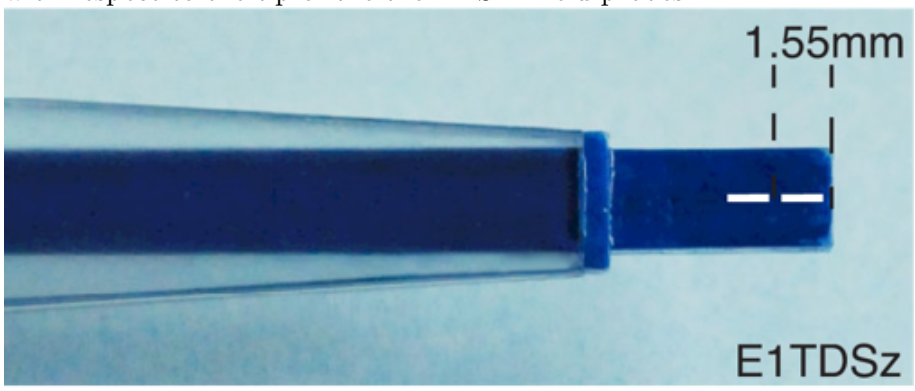



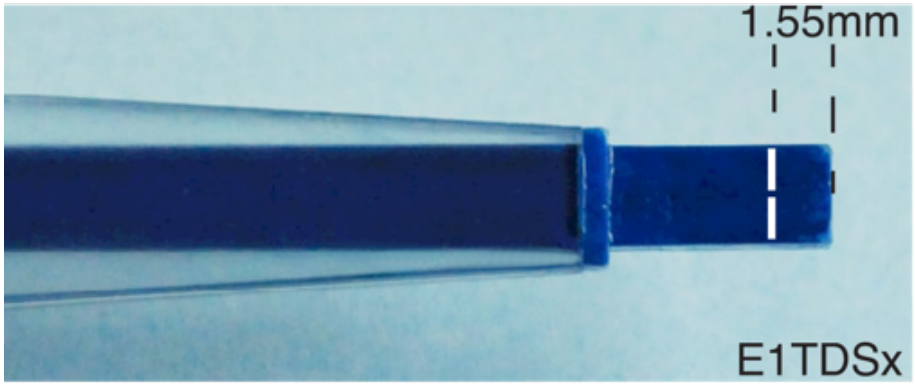

The loop of the H1TDSz sensor is just a visualisation as it is actually oriented orthogonal to the viewing plane. Both loop types are centred in the *TDS* probe tip centre. The tip to loop sensing centre distance is 1.3 mm in both cases.

The picture below illustrates the pick-up directions for H1TDSx and H1TDSz probes. Note the orientation of the label with the serial number of the *TDS* probe:

### 1.3.2 E-Field Probes

*TDS* E-field probes can be identified by a probe tip coloured in blue. The below figure illustrates the location of the miniature dipole sensors (in white) with respect to the tip of the the *TDS* E-field probes:

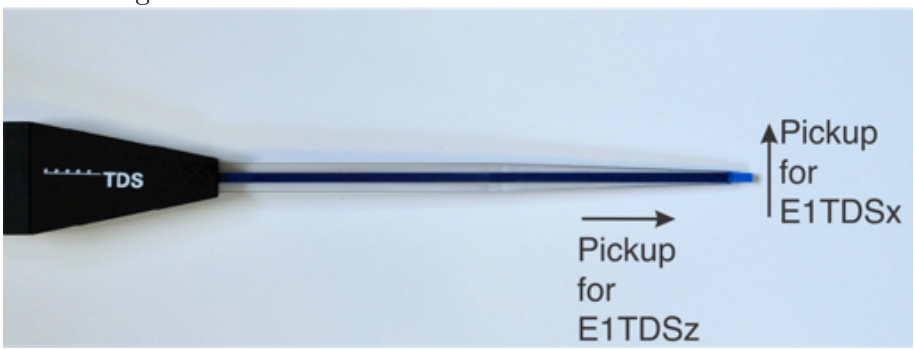



The dipoles of the E1TDS sensors are centred in the *TDS* probe tip centre. The tip to dipole centre distance is in both case 1.55 mm.

The picture below illustrates the pick-up directions for E1TDSx and E1TDSz probes. Note the orientation of the white *TDS* label and the

SPEAG logo::




## 1.4 Remote Unit

Two main types of *TDS Remote Unit* 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 H1TDS and E1TDS single channel sensors. It further acts a opto-electrical converter for the optical sensor signal returned from the sensor.

**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, i.e., the multi-channel remote unit allows the usage of multi-channel TDS probes.

These two types of *TDS Remote Units* are available in standalone and in PXI format.

The below photographs show the front and rear views of the standalone *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.

The photographs below show the front and the back of the PXI *Remote Unit* and provides a short description for all elements:

1. Shutter with MU8 fibre optical connector
2. 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.
3. *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.
4. *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.
5. RF out connector (female 3.5 mm).

# Chapter 2

# System Handling

## 2.1 General

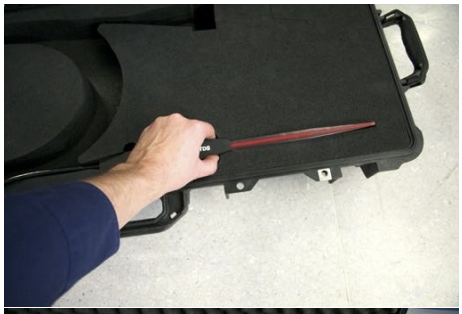
Caution – *TDS* probes are miniaturised electro-optical devices. Even though SPEAG has put a lot of efforts into a robust packaging, handle both the *TDS Remote Unit* and probes with care. Note: Strong acceleration forces, e.g., from dropping the probes make cause permanent non-repairable damage to them.

## 2.2 Packing / Unpacking

### 2.2.1 Probe

The below description shows how to pack the *TDS* 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.

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



Insert the probe into the foam cutout as shown on the left. Make sure the probe is fully inserted in the foam.

Disconnect the probe from the *TDS Remote Unit*.

Coil up the fibre optical patch-cord in 7 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 you may either use one of the secondary cutouts or 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 *TDS* 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 *TDS* system at any time.

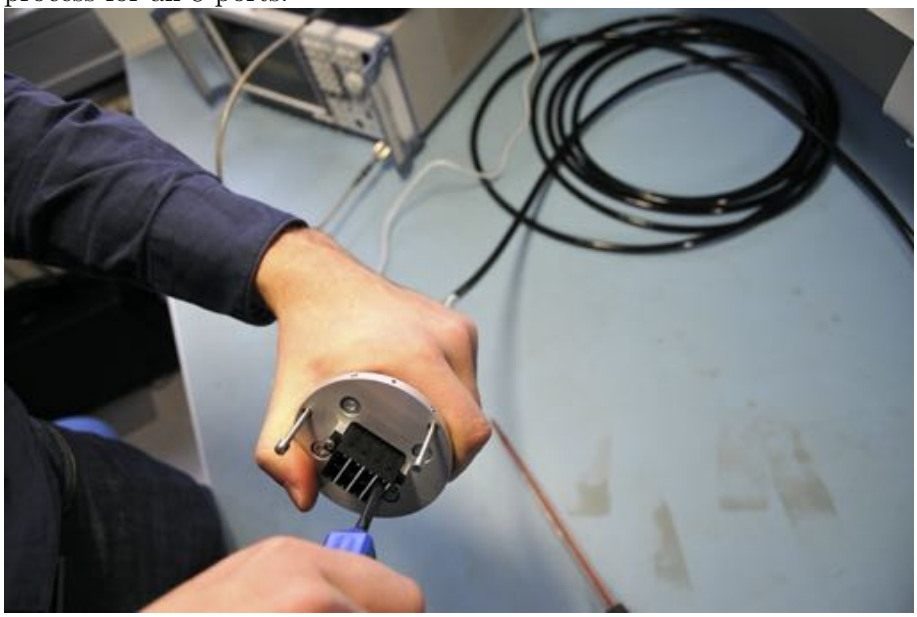
### 2.3.2 Connector Life Cycle

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 measurements such that unnecessary connecting/disconnecting of probes is limited. SPEAG has designed the *TDS* 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 *TDS* probe cable and fibre optics inside the remote unit.

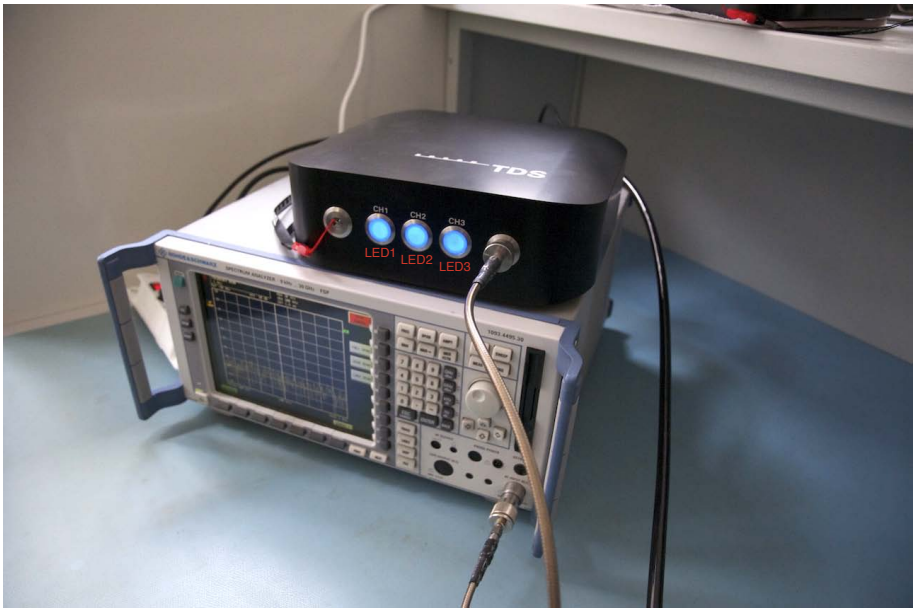
### 2.3.3 Cleaning of Optical Connectors

It is very important for a proper operation of the *TDS* 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 *TDS* 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

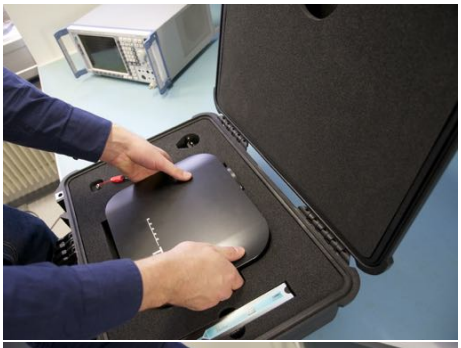
# System Installation

# Chapter 3

# System Installation

## 3.1 Hardware Installation

This section provides a walkthrough for setting up the *TDS* 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 *TDS* 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 *TDS* 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.

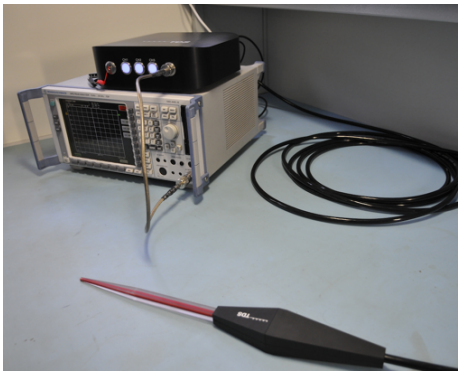
4) Once the rotation is completed, the cable connector can be fully inserted into the shutter mating the cable's MU8 connector with the MU8 connector inside the shutter. **Please make sure that the cable connecter is inserted straight (fully orthogonal) into the *Remote Unit* housing)**

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

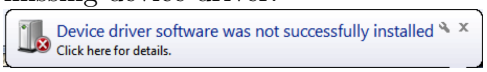
The *Remote Unit* can be controlled remotely via a Serial Communication over USB interface. The use of this interface has been tested under MS Windows XP and Windows 7 and MAC OS X 10.8. This section explains how to install the required driver and the prerequisites for a Remote Control of the *Remote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

### 3.2.1 Driver Installation under Windows

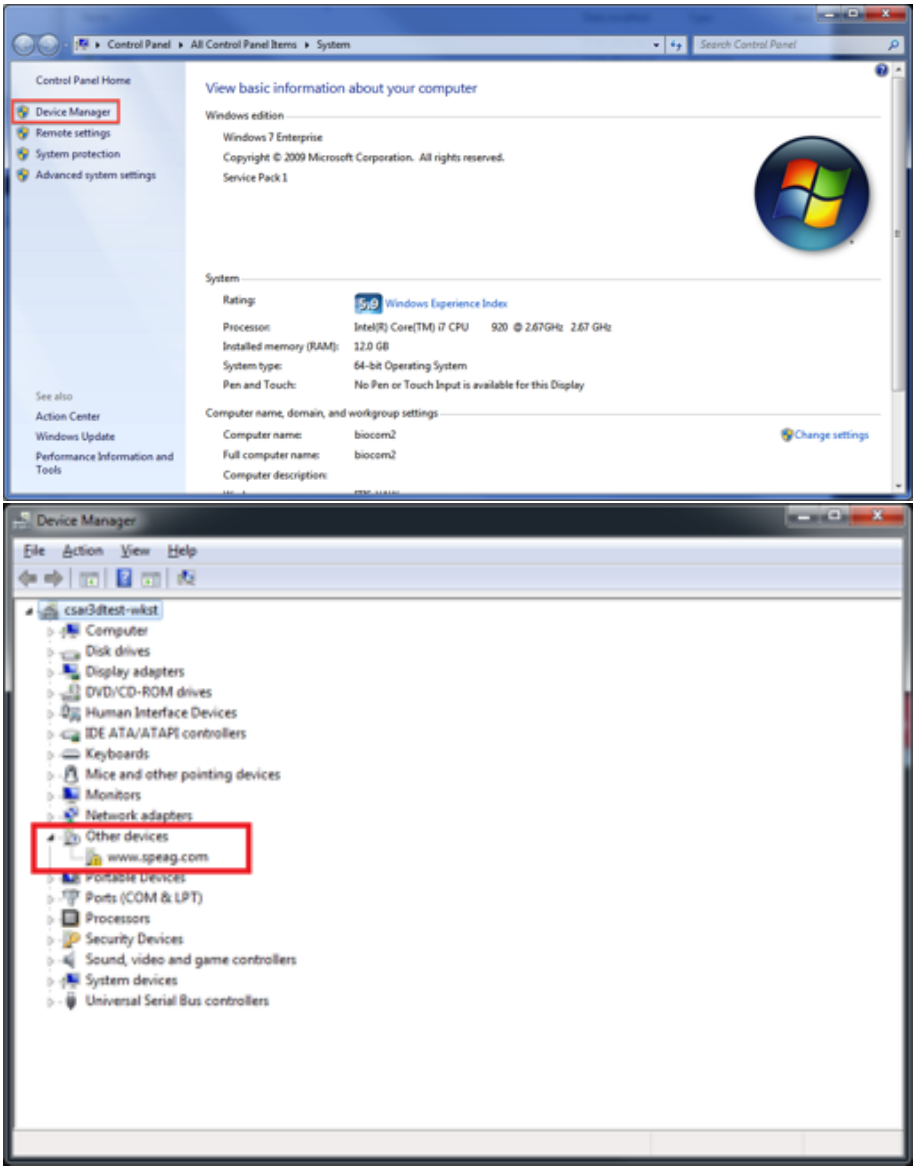
The following procedure describes the driver installation under Windows 7:

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

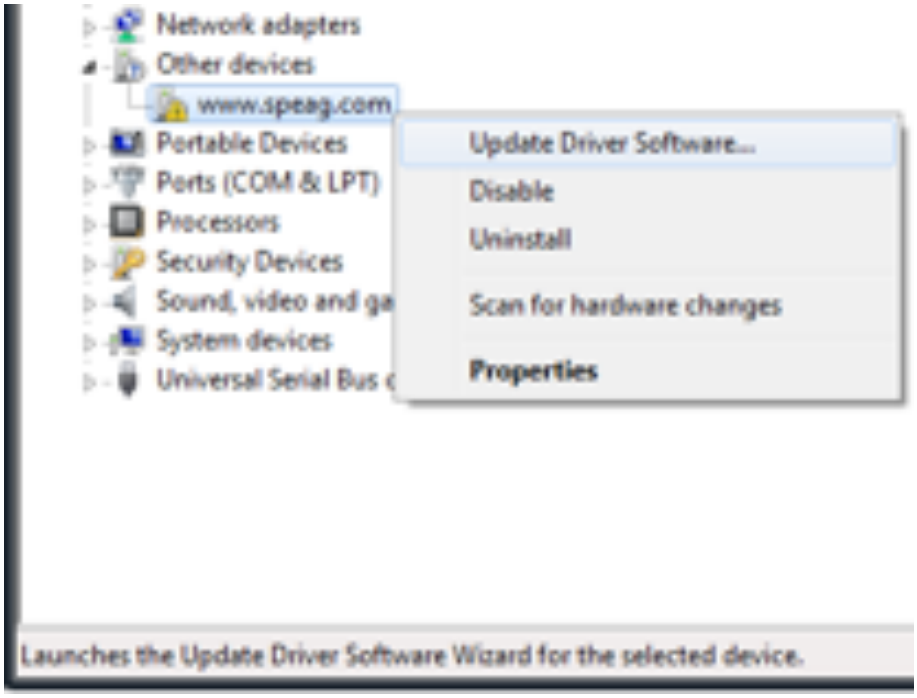
2. Connect the *Remote Unit* via the USB cable to your PC. Note: the USB port of your PC must be capable of providing ≥500mA. Most likely, the *Remote Unit* will not be immediately recognised due to the missing device driver:



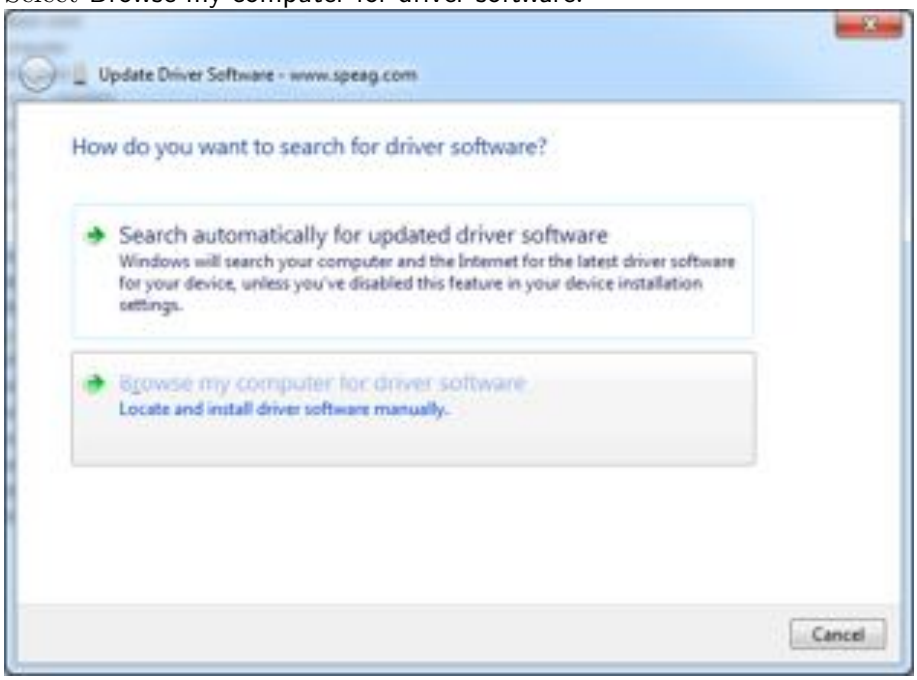

3. Open the MS Windows Device Manager. The device manager can be found under Control Panel — System of your PC:



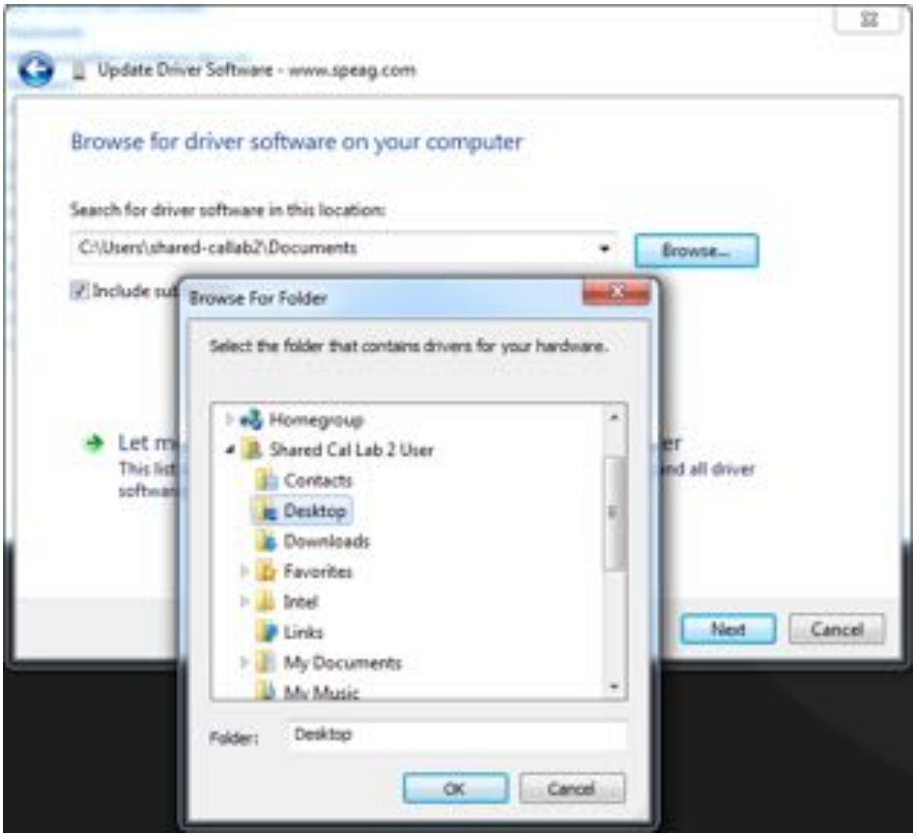

4. Identify a device called USB Serial Port under Other Devices. Right-click the device and select Update Driver Software:




5. Select Browse my computer for driver software:



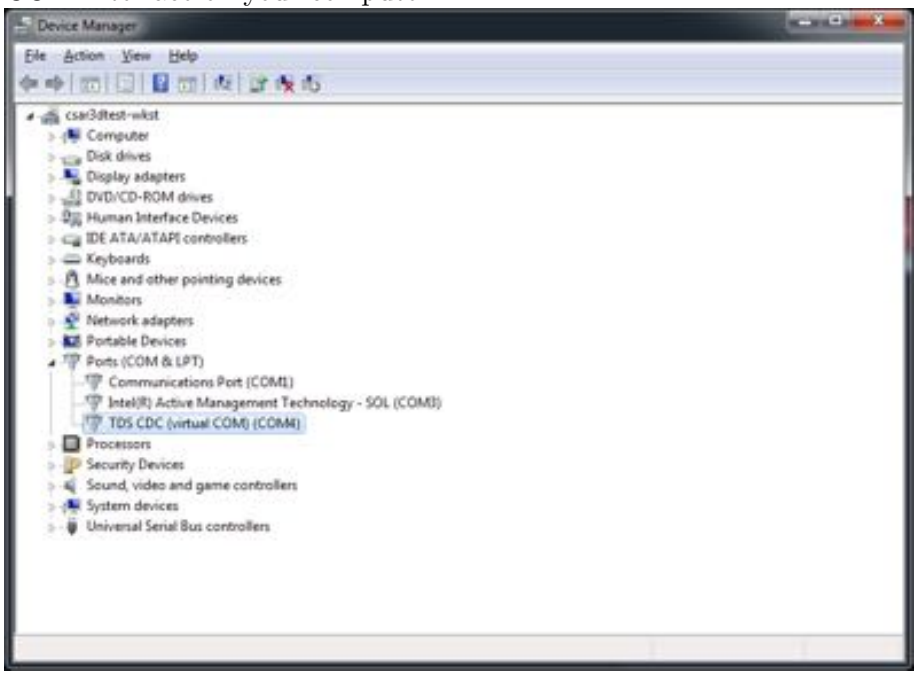

6. Navigate to the location where you downloaded and extracted the FTDI driver package:




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:



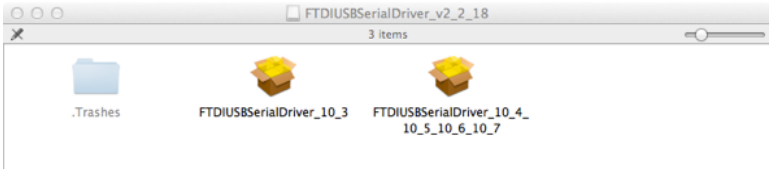

**Note: the COM interface number depends on the USB port the *Remote Unit* is connected to. We recommend to always use the**

**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.

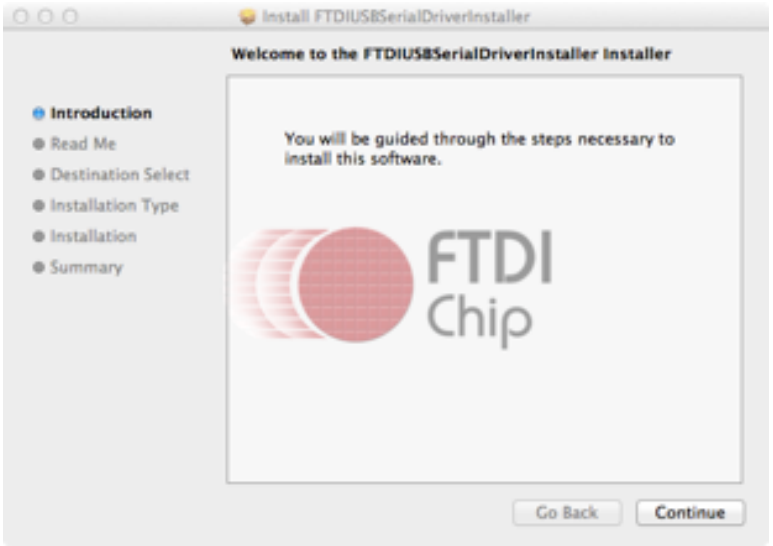
### 3.2.2 Driver Installation under MAC OS X

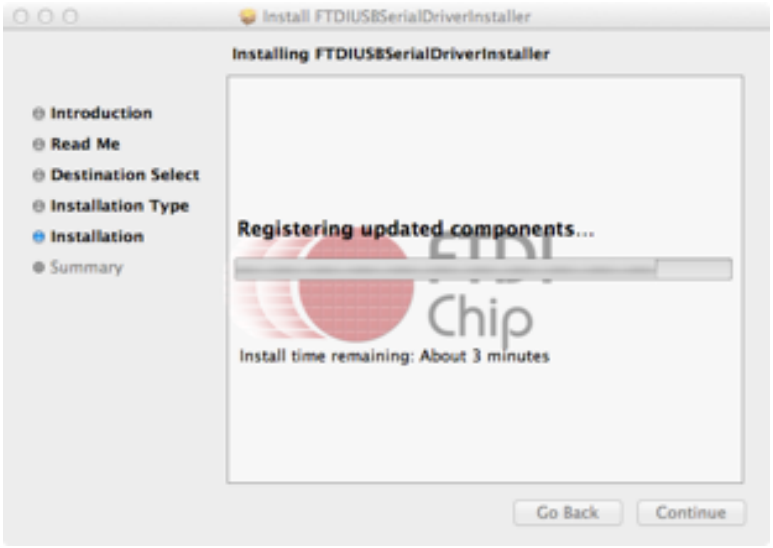
The following procedure describes the driver installation under MAC OS X 10.8:

- 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:

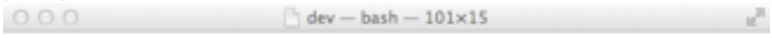


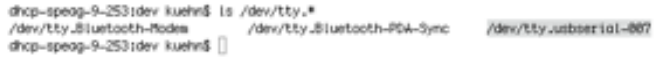



- Connect the *Remote Unit* via the USB cable to your MAC. Note: the USB port of your MAC must be capable of providing ≥500mA.

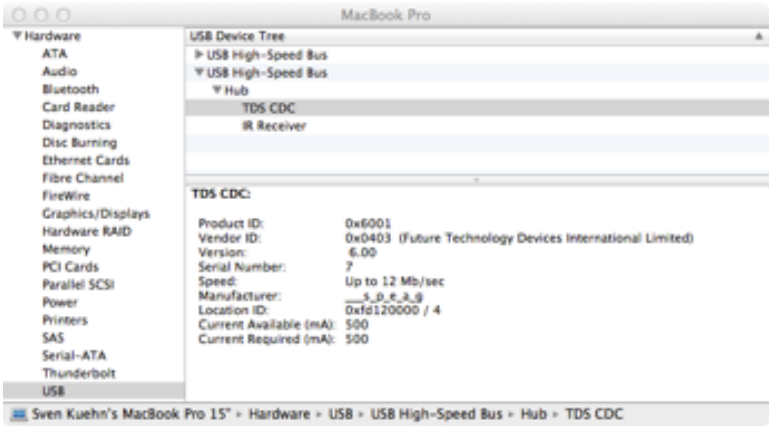
- You can verify that your *Remote Unit* was properly recognised as a COM interface by:

  – 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:



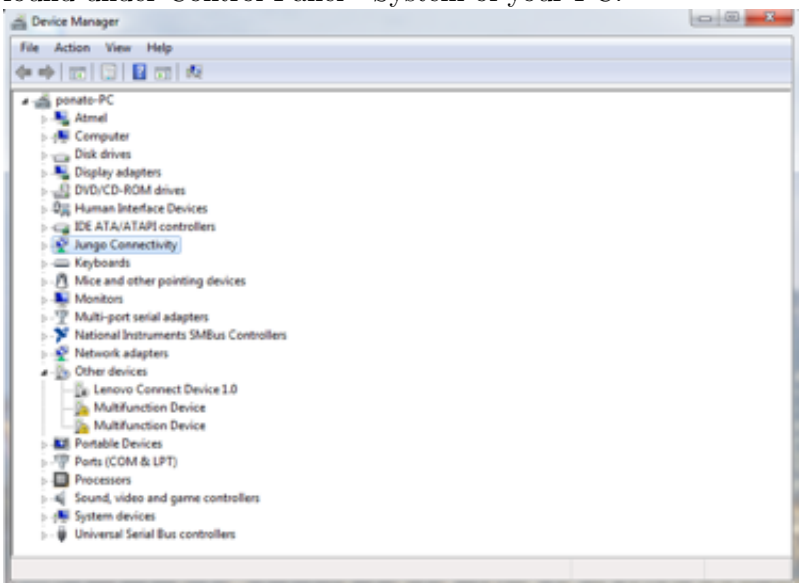

### 3.2.3 PXI TDS Remote Unit driver installation

#### 3.2.3.1 Windows 7

The following procedure describes the driver installation under Windows 7:

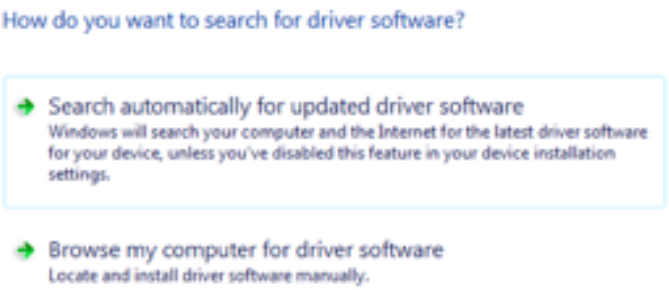
1. Mount the Remote Unit PXI inside an NI PXI Chassis. Connect the NI PXIe with your PC and start up all devices.

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

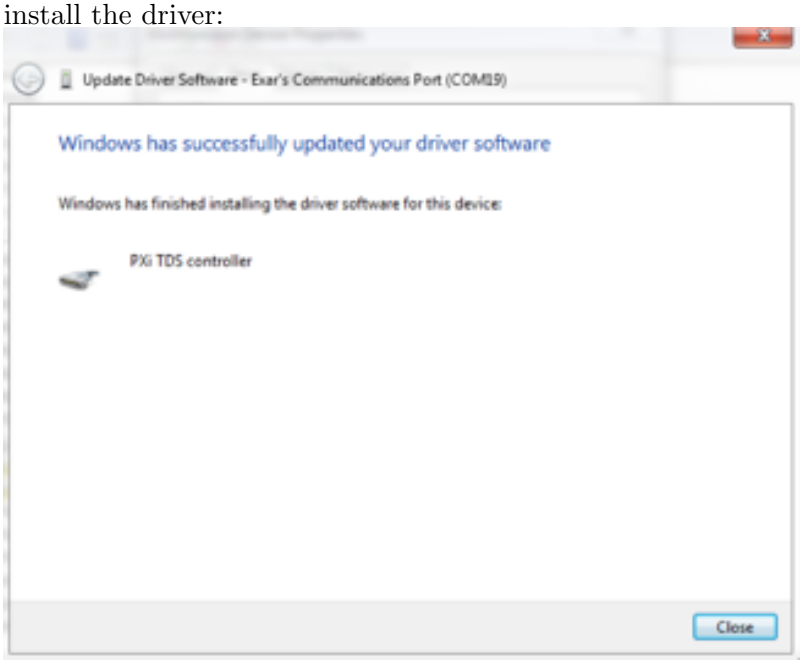



3. Identify two devices called Multifunction Device under Other Devices. Right-click on the devices and select Update Driver Software.

4. Select Browse my computer for driver software:

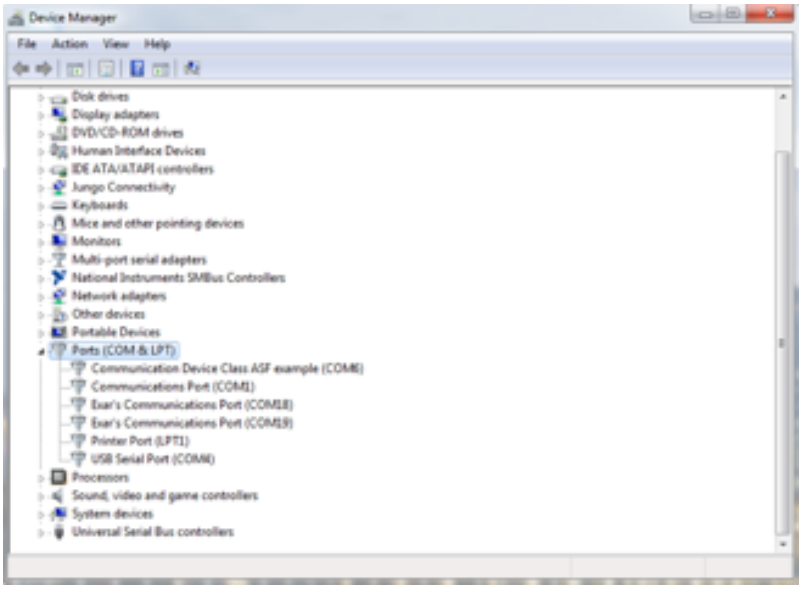



5. Navigate to the location of NextFreePort_14.7 (`\RemoteUnit\PXI\PCIVEN_1C0D&DEV_0001TDSEXAR\NextFreePort_14.7-1c0d0001`) and install the driver:




6. Repeat these steps for the second Multifunction Device.

7. After the successful installation the TDS PXI Remote Unit will be available as a new COM interface (Exar's) on your computer:

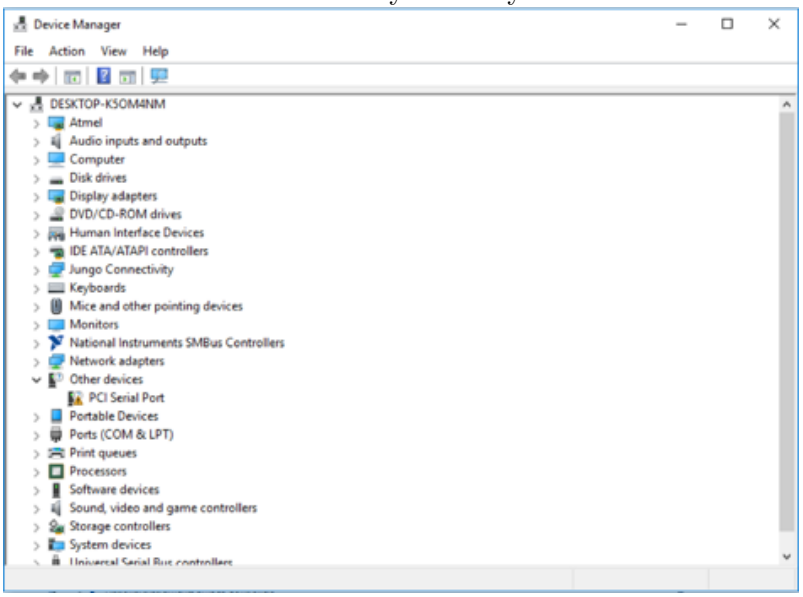



#### 3.2.3.2 Windows 10

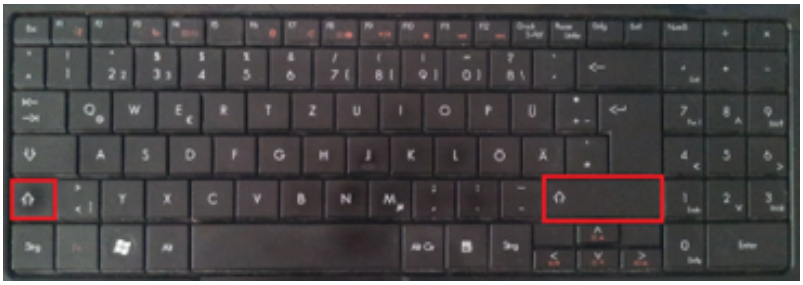
The following procedure describes the driver installation under Windows 10:

1. Mount the Remote Unit PXI inside an NI PXI Chassis. Connect the NI PXIe with the your PC and start up all devices.

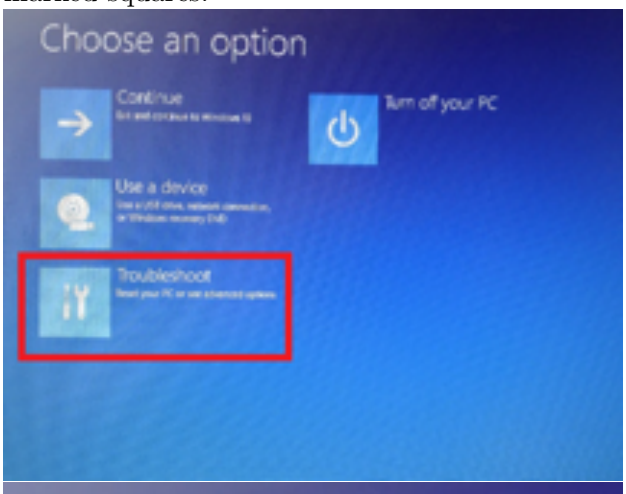
2. Open the MS Windows Device Manager. The device manager can be found under Control Panel - System of your PC:

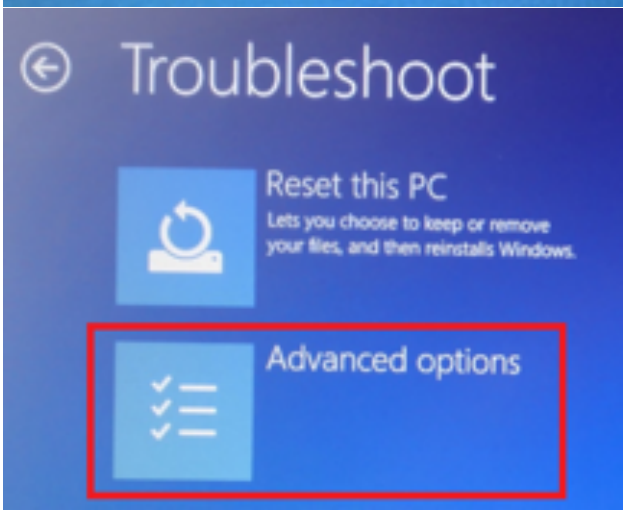


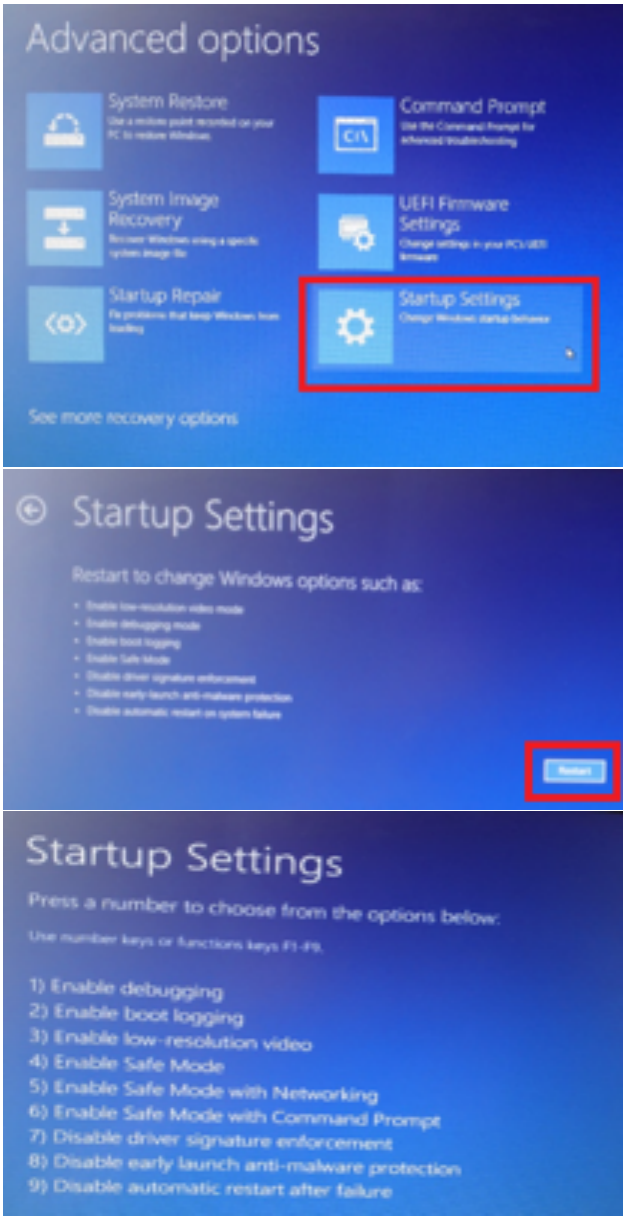

3. Press and Hold the Shift-Button on the Keyboard and restart the Computer:



4. The Computer boots now to the boot options menu. Follow the red marked squares:



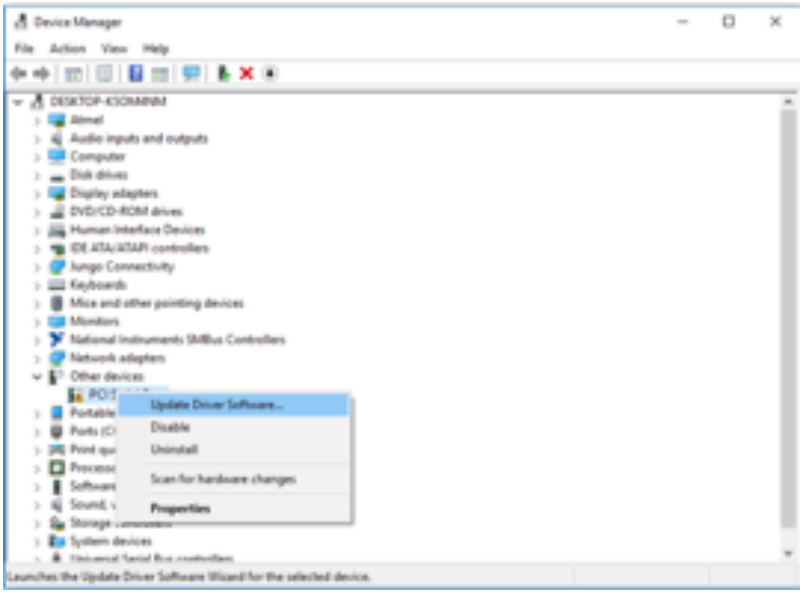





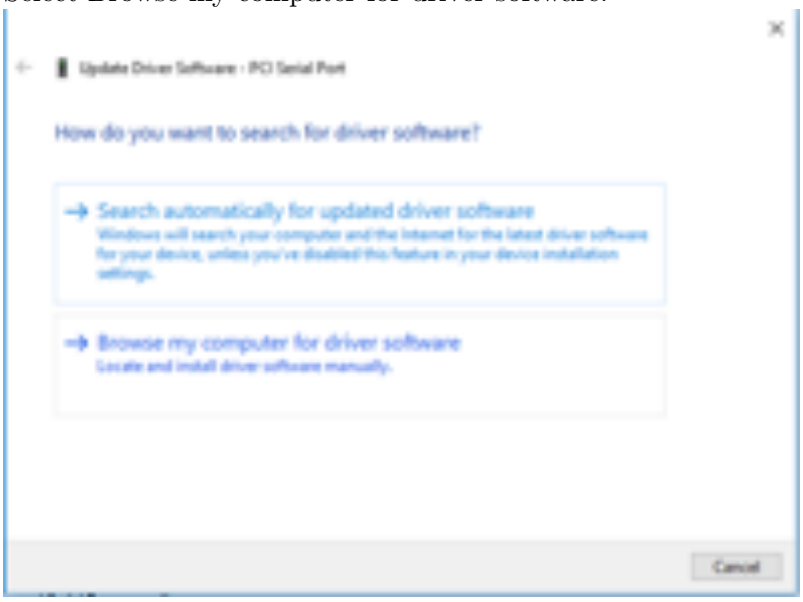

5. Press F7 on the keyboard and the computer will restart

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

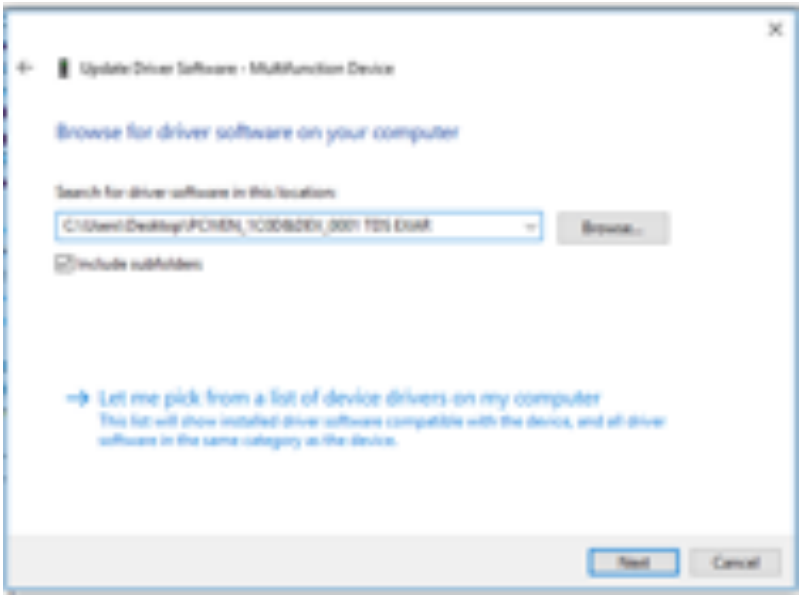
7. Identify two devices called Multifunction Device under Other Devices. Rigth-click on the devices and select Update Driver Software:



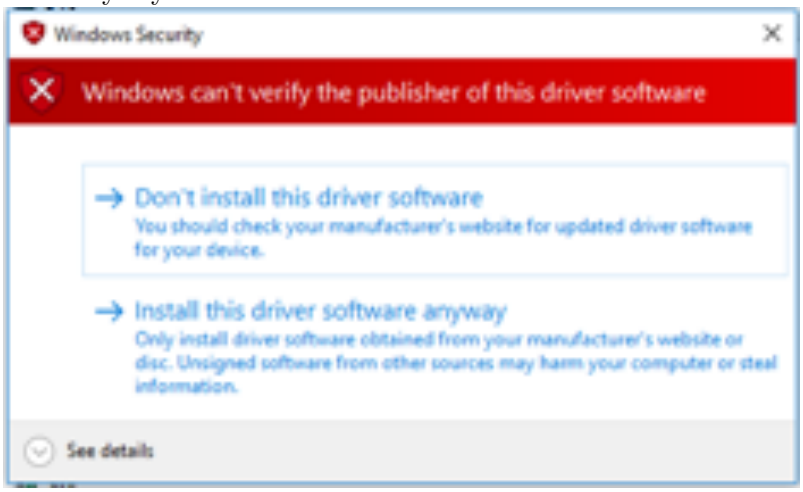

8. Select Browse my computer for driver software:



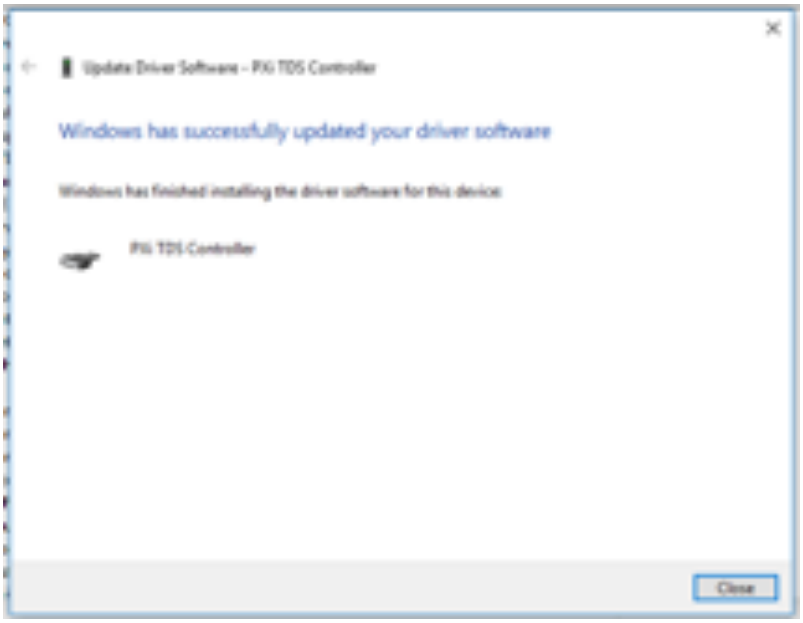

9. Navigate to the location where you downloaded and extracted the NextFreePort_14.7. This is provided by SPEAG. Press Next.



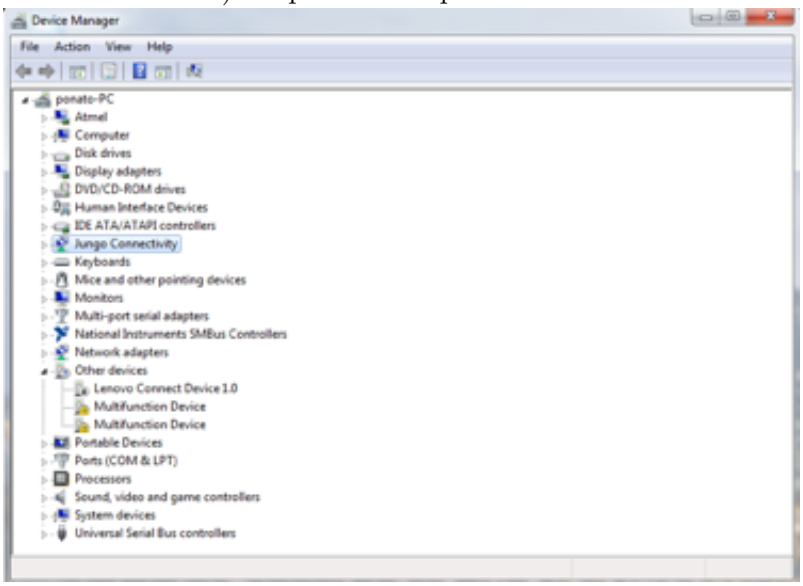

10. Windows will ask to install the Driver. Press "Install this driver software anyway".



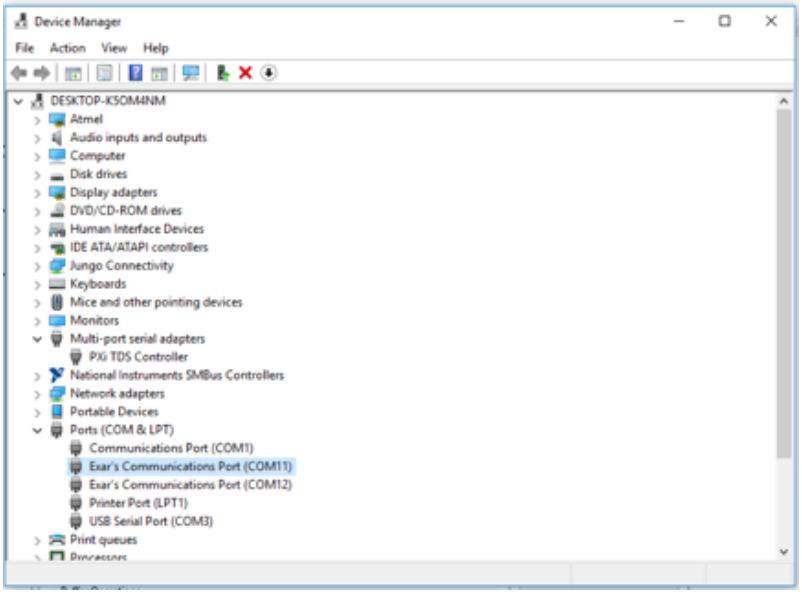

11. Windows will confirm the successful installation.




12. Now there are two new Devices visible in the Device Manager. (Multifunction Device). Repeat the steps 1 to 6 for both Devices:




13. After the successful installation the TDS PXI Remote Unit will be available as a new COM interface (Exar's) on your computer:




### 3.2.4 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

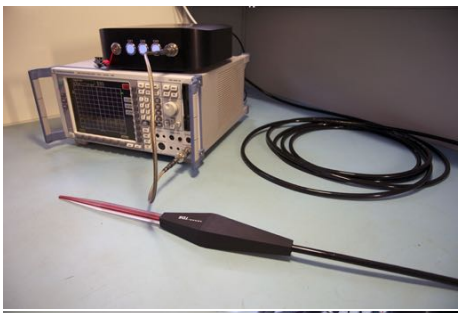
# *TDS* Operation

# Chapter 4

# *TDS* Operation

## 4.1 Taking a Measurement with *TDS*

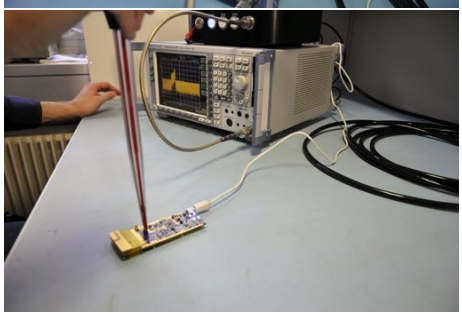
The *TDS* system is a very simple to use system. Taking a manual measurement with it just requires activation on the desired probe channel. **Note: 1D *TDS* probes and single channel *TDS Remote Unit* only support measurements on channel 1.** This section provides a short walk-through how to perform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



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

To activate the *TDS* 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



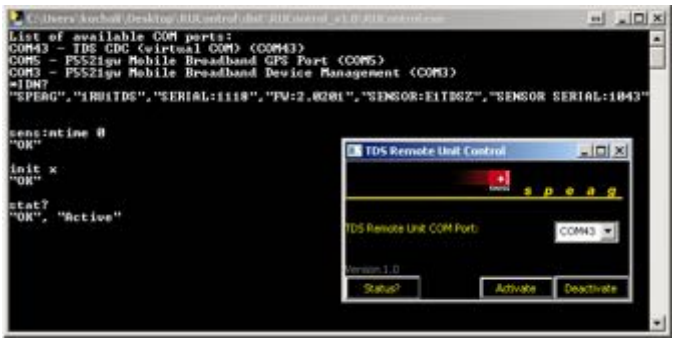
After activation the TDS can be used for measurements. For information on conversion of the output signal of the remote unit to a calibrated E- or H-field please refer to Section 4.4. For advanced remote control commands please refer to Chapter 5.

## 4.2 Manual control of PXI *TDS* Remote Units

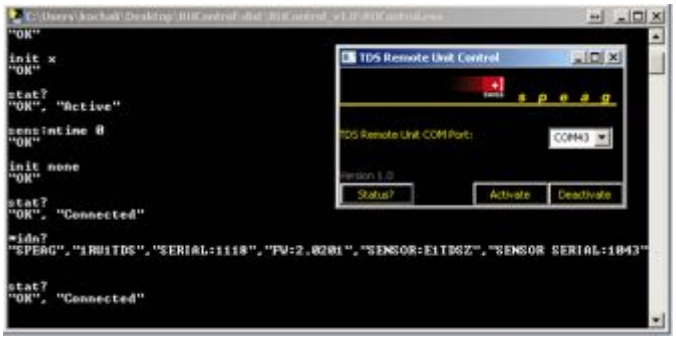
To save space the PXI version of the *TDS* Remote Unit doesn't have any physical buttons. Switching on and off the probes connected to such remote units can be done using a small program called RUControl, delivered by SPEAG. This program is compatible with all available *TDS* Remote Units (PXI and non-PXI). It doesn't require any Python™ installation and talks directly to the COM port of the Remote Unit. To run it, locate and double-click the RUControl.exe. It will open up two windows: one with console output and one with the GUI. Upon startup the console window lists all available COM ports with short description for each. By looking at the description, the user can pick the right port - the one used by the *TDS* remote unit. It can be selected from the dropdown menu in the GUI.

Pressing the Activate and Deactivate buttons is switching on and off thE *TDS* sensor. Upon the first activation of the sensor the type and serial

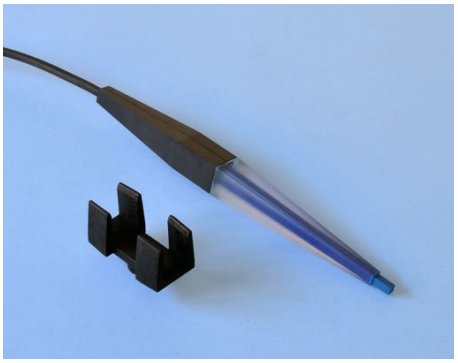
number of the Remote Unit and the probe connected to it are printed in the console window.




The Status? button shows the current state of the Remote Unit.

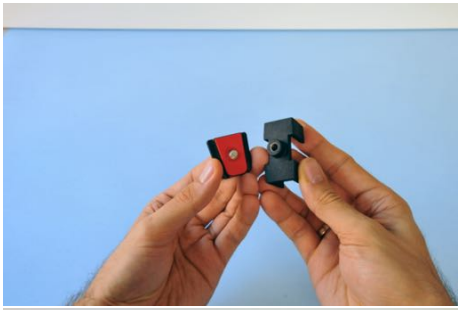



## 4.3 Using *TDS* SNI probes with third-party tripods



When performing near-field measurements, the distance and the orientation of the measurement probes with respect to the DUT are vital for accurate readings. Holding the probe in hand might not give satisfactory results. This is the reason why all *TDS* SNI probes are delivered with a small plastic clip, which can be used to attach the probes to positioners (for example camera tripods). Please note that many tripods on the market are made of metal or contain metal parts. This will influence the accuracy of the measurements, so try to choose a tripod which is constructed of non-metallic, non-reflective materials that will not distort the measurement results. *TDS* SNI probes are pretty light, so there is no need for heavy-duty tripods.

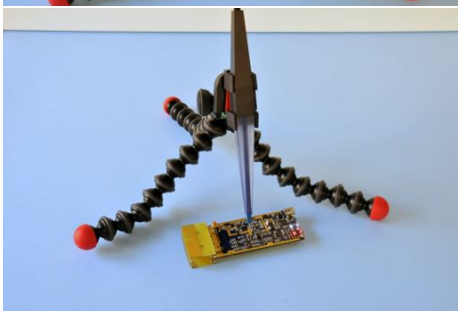
In the pictures below, we demonstrate how to attach the *TDS* SNI probe to a small plastic tabletop tripod.



Start with attaching the *TDS* SNI clip to the adaptor plate of the tripod. The clip has a 1/4-20 UNC thread, which will fit in most consumer tripods. Please, don't tighten the adaptor screw too hard, since the thread of the clip (and the clip itself) is plastic and might be damaged.

Next, place and secure the adaptor plate in the tripod head. Most tripods have a lever or some type of clicking mechanism for securing.

Then place the *TDS* SNI probe inside the clip. Once the probe is in, the spring force of the clip will keep it tight in place.



Now, the *TDS* SNI probe can be placed in the desired position by adjusting the tripod.

## 4.4 Application of Antenna (Calibration) Factors

*TDS* probe can be regarded as miniaturised antennas for E- or H-field measurements. All *TDS* sensors and paired *Remote Unit* are calibrated at SPEAG's calibration laboratory. Besides validation of the sensor per-

formance our calibration delivers the transfer function between an output power of the *Remote Unit* and the measured field (E or H) at the tip of the *TDS* probe. The method is similar to the well established antenna factor. Antenna factors are always provided for the main receiving direction of a probe. The antenna factor is a frequency dependent quantity.

The antenna factor for H-field *TDS* probes is given in terms of:

$$[AF_H] = dB\frac{(A/m)^2}{mW} = dBA/m - dBm \tag{4.1}$$

and for E-field *TDS* probes in terms of:

$$[AF_E] = dB\frac{(V/m)^2}{mW} = dBV/m - dBm \tag{4.2}$$

with:

$$\begin{aligned} 0dBA/m &= 20 \cdot log_{10}(1A/m) && (4.3)\\ 0dBV/m &= 20 \cdot log_{10}(1V/m) && (4.4)\\ 0dBm &= 10 \cdot log_{10}(1mW)\,. && (4.5) \end{aligned}$$

The *AF* of the *TDS* system calibrates the transfer from the tip of *TDS* probe to the RF output of the *Remote Unit*. It does not include the attenuation of the cable:

$$[ATT_{cable}] = dB \tag{4.6}$$

Based on the above equation a power ($[P_s] = dBm$) measured at the input of a spectrum analyser the *TDS Remote Unit* is connected to, can be converted into a H-field:

$$\begin{aligned} H_{dBA/m} &= AF_H + ATT_{cable} + P_s \quad dBA/m && (4.7)\\ H &= 10^{\frac{H_{dBA/m}}{20}} \quad A/m && (4.8) \end{aligned}$$

or into an E-field for a ETDS probe:

$$\begin{aligned} E_{dBV/m} &= AF_E + ATT_{cable} + P_s \quad dBV/m && (4.9)\\ E &= 10^{\frac{E_{dBV/m}}{20}} \quad V/m. && (4.10) \end{aligned}$$

# 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 | | | Arguments | Functionality |
|---|---|---|---|---|
| Level 1 | Level 2 | Level 3 | | |
| *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

# MRI Polarization Detection

## 6.1 Introduction

This application note describes the use of *TDS* for polarization identification of the field inside an MRI machine. The most important qualitative descriptor of the MRI RF coil is the B1-field distribution in the imaging volume of interest. B1 is the RF magnetic field vector rotating in a plane orthogonal to the static magnetic field (B0). For most efficient imaging it is important that the B1 vector is rotating in a right-handed frame, circularly polarized and homogeneous throughout the imaging volume. This field component is usually called B1+ and is responsible for the nutation of the spins [1]. The other B1-field components in the B1 reference system (B1-, rotating in left left-handed frame and $B1_z$ polarized parallel to B0) are considered parasitic. To achieve a proper B1 field mapping, two *TDS* standalone systems are connected to a USB oscilloscope from TiePie Engineering. A Python™ script is provided to acquire and process the data from the oscilloscope. After a successful installation, the software identifies the polarization by comparing the signals detected by the *TDS* probes. These signals are equalized and used to construct a Lissajous figure. The relative measurement uncertainties in terms of the axial ratio and the relative phase of the $\mathbf{B1_x}$ and $\mathbf{B1_y}$ (polarisation ellipse parameter) are better than 0.4 dB and 3°, respectively.The absolute B-field measurement uncertainty is better than $\pm\mathbf{1\,dB}$.

## 6.2 Measurement concept

The basic measurement equipment setup of the MRI B1-field measurement system is shown in Fig 6.1. Two H1TDSx probes oriented 90 degree to each other capture the $B1_x$ and $B1_y$ field in the MRI system's coordinate frame (Fig 6.2). Based on the RF-over-fiber principle, the RF signal proportional to the B1-field is transmitted via fiber-optics to the TDS remote units. Two

TDS remote units are used to retrieve the RF signal from the optical carrier and provide it at a standard 50Ω 3.5 mm output. The RF outputs of the remote units are sampled using a fast coherent dual-channel oscilloscope and the discrete $B1_x(n)$ and $B1_y(n)$ data is streamed to a PC's memory for digital post-processing.

Since the dominant RF signal present in MRI is the carrier at the typical Larmor frequencies (≈64 MHz for 1.5 T and ≈128 MHz for 3.0 T systems) any additional down-conversion or filtering has not been foreseen. The only filtering is coming from the inherent high-pass filter integrated in the TDS H1TDSx probe and the remote unit which efficiently suppresses the reception of the gradient fields.

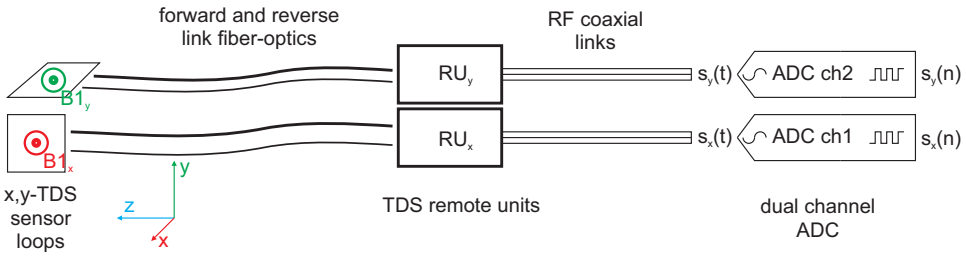



Figure 6.1: Measurement setup for B1-field mapping.

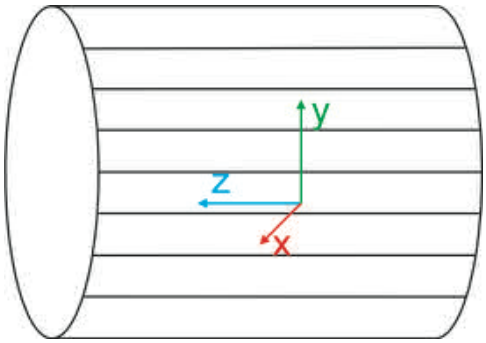



Figure 6.2: Selected coordinate frame in the MRI RF transmit coil.

The HS5 oscilloscope is capable of sampling up to 500 MS/s on a single channel, or 200 MS/s in a dual-channel configuration. This feature can be used to extract the actual RF carrier at approximately 64 or 128 MHz. For the actual extraction of the axial ratio and phase between the $B1_x$ and $B1_y$ fields we perform a digital downconversion by subsampling (see Fig 6.3). For 64 MHz we use a subsampling frequency of 3 MHz and for 128 MHz we use a subsampling frequency of 2.5 MHz. These sampling frequencies allow

carrier frequency ranges from 63.0 – 64.5 MHz and 127.5 – 128.75 MHz to be aliased into the ADC sampling baseband. The aforementioned bandwidths are sufficient to cover MRI system carrier frequencies of the MRI test systems and the full bandwidths of typical MRI pulse sequences. For other carrier frequencies the subsampling frequencies can be easily adapted. After the digital downconversion of the RF signals we perform a complex-valued FFT on both channels extracting the spectral information ($\overline{S}_{x/y}(f)$). Using the Fourier space for the post-processing has the advantage that it is very robust against the typical pulsed signal shapes of the B1-signals. From the spectral contents of both channels we extract the baseband carrier frequency ($f_c$). Over an averaging bandwidth ($f_a$) centred at $f_c$ we then extract the relative phases and axial ratio of $\overline{S}_x(f)$ and $\overline{S}_y(f)$ and display those parameters in terms of axial ratio, relative phase and the resulting polarisation ellipse.

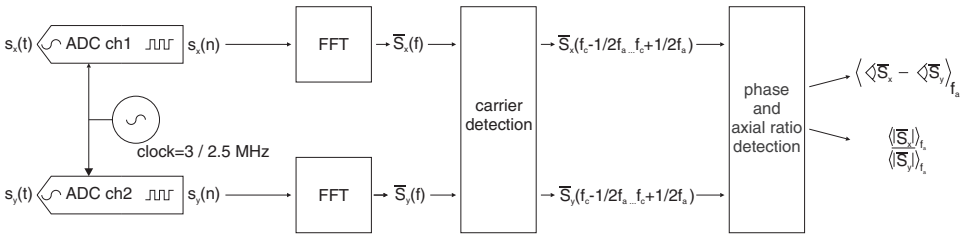



Figure 6.3: Schematic diagram of the digital post-processing for the extraction of the axial ratio and phase between $B1_x$ and $B1_y$.

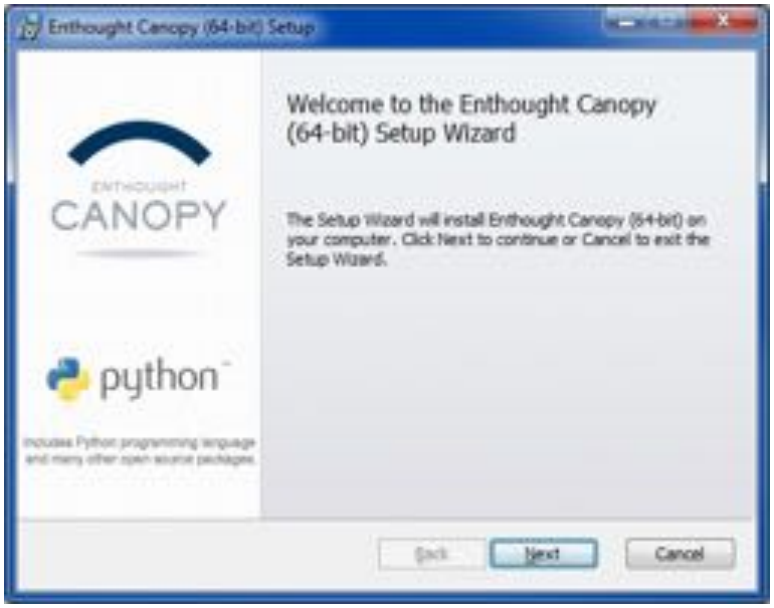
## 6.3 Software

The script for control and read-out of the *TDS* sensors and the HS5 oscilloscope is using the Python™ scripting language. The same software implements the post-processing algorithm described above and provides a graphical user interface (GUI) for measurement control and visualisation. The GUI provides graphical information about the time-domain MRI signal waveform the axial ratio and phase between $B1_x$ and $B1_y$ as well as a visualisation in terms of the polarisation ellipse. The provided MRIgui.py Python™ script requires Enthought Canopy environment to work. In addition, the drivers for the HS5 handyscope have to be installed prior to running the Python script.

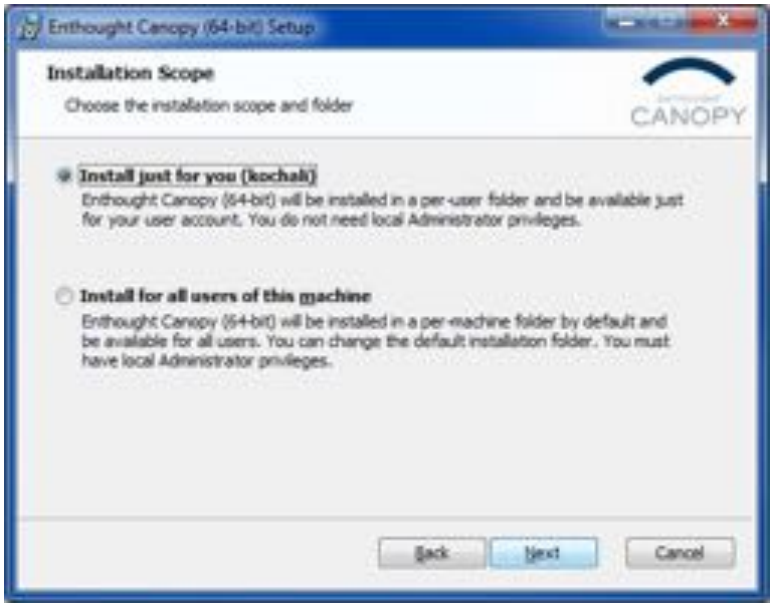
### 6.3.1 Enthought Canopy installation

This section contains a summary of the installation of Enthought Canopy environment. For more detailed instruction visit: http://docs.enthought.com/

canopy/quick-start/install_windows.htm.
To start with the installation, go to https://www.enthought.com/downloads/ and download Canopy Express Installer. Depending on your system architecture, you should choose either the 32-bit or the 64-bit version. Double-click on the downloaded file. Verify that the publisher is listed as Enthought and click Run. The first window of the install wizard should be as the one shown below. Click Next.




Read the license terms, click "I accept the terms in the License Agreement" and then click Next. In the following window, you will be asked if you want to make Canopy available to all users, or only to the current user.

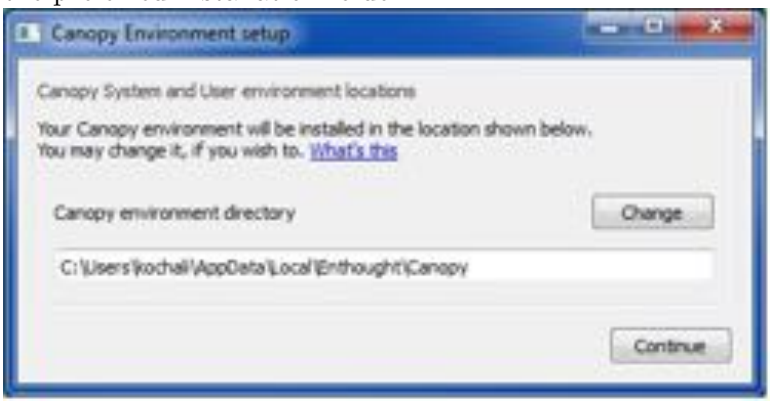


- If you install it only for the current user, it will be stored under this account and will not be available to other users. The location of the installation folder is operating system dependent and is listed in the following table. Please replace Canopy with Canopy32 in the paths below in case a 32-bit version of the software is used.

| **OS** | **Path** |
|---|---|
| Windows XP | C:\Documents and Settings \<username>\Local Settings\Application Data\Enthought\Canopy\App |
| Windows Vista/7/8/10 | C:\Users\<username>\AppData\Local\Enthought \Canopy\App |

- If you choose to make Canopy available to all users you can select the installation directory. The default installation path is C:\Program Files\Enthought

Click "Install" and begin the installation process. The process may take several minutes depending on your system configuration. Once the installation process is complete, the last step is to set up your Python environment. Check-mark "Launch Canopy when setup exits" and the configuration of the Python environment will start automatically. Alternatively, you can launch the Canopy GUI from the Start Menu. When this is done Canopy will ask for the preferred installation folder.




The default installation folder for the Canopy User Python environment depends on the version of Windows you are using and is shown in the following table.

| **OS** | **Path** |
|---|---|
| Windows XP | C:\Documents and Settings\<username>\Local Settings\Application Data\Enthought\Canopy\User |
| Windows Vista/7/8/10 | C:\Users\<username>\AppData\Local\Enthought \Canopy\User |

For the 32-bit version of Canopy, replace the path Enthought\Canopy with Enthought\Canopy32 in the table above.

After the Python™ environment is installed, Canopy prompts you to make it the default Python™ environment. We recommend answering Yes.

Before running the provided MRIgui.py script in Canopy make sure that the PyLab backend is the correct one. Open Canopy from the Start Menu and go to the Python Tab under Edit->Preferences in the Canopy Editor. The right backend should be *Interactive(wx)* and not to the default *Interactive(Qt4)*.

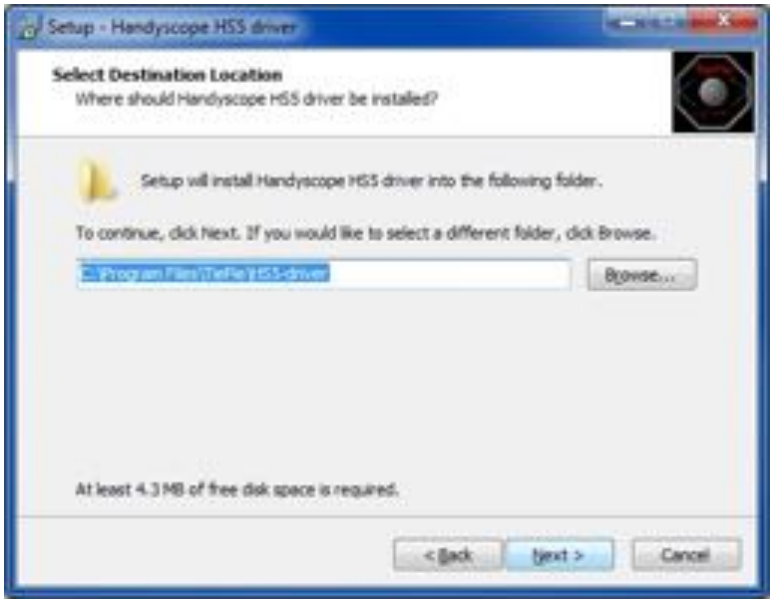
At this point Canopy has been set up and is ready to use.

### 6.3.2 HS5 USB handyscope installation

This section contains a summary of the driver installation for TiePie's HS5 Handyscope. For more detailed instruction check *Instrument Manual Handyscope HS5.pdf* available on the CD-ROM which came with the instrument or from http://www.tiepie.com.
The installation of the USB driver is done in two steps. Firstly, the driver has to be pre-installed by the driver setup program. This makes sure that all required files are located in a place where Windows can find them. It is important that during this first stage, the HS5 is not plugged in any of the USB ports of the PC. Later, when the pre-installation is ready and the instrument is plugged in, Windows will detect the new hardware and will complete the installation of the required drivers.

To start with the installation, go to http://www.tiepie.com/en/products /Oscilloscopes/Handyscope_HS5/Download and download the USB driver. Double-click on the downloaded file, verify that the publisher is TiePie engineering and click Next from the dialog window. If the instrument is connected, you will get a warning to disconnect it before you continue with the installation.

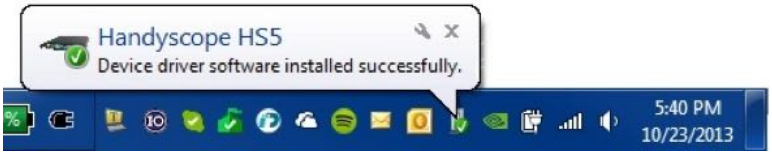
In the next dialog window you have the option to change the default installation folder for the driver.




The installation should take few minutes, depending on your computer configuration. After successful installation, you should see the following window.

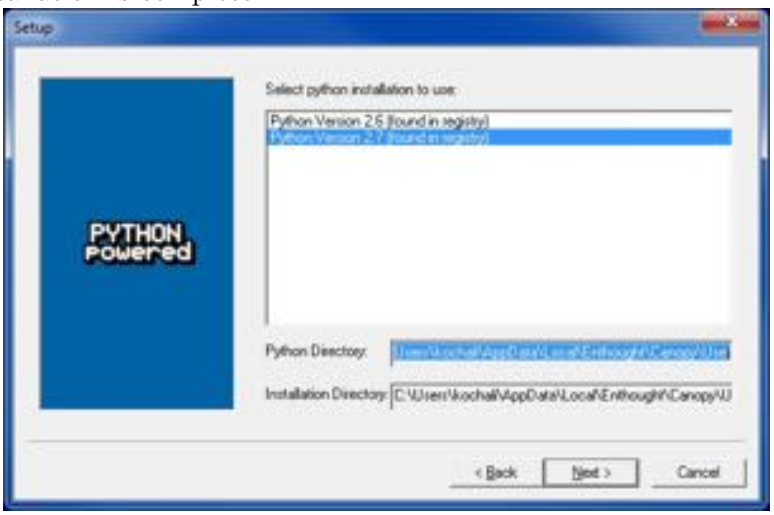
Now, the driver has been pre-installed and the Handyscope HS5 can be connected to the computer via USB. When this is done, Windows will report that it has detected new hardware. Depending on the Windows version, the New Hardware Wizard will show a number of windows with different information about the found hardware. Once ready, Windows will report that the driver is installed. Note that when the Handyscope HS5 is plugged into a different USB port, some Windows versions will treat it as a different

hardware and will attempt to install the driver again.




To complete our HS5 installation, we need to copy the LibTiePie SDK library. The latest version of the dll is available for download from http://www.tiepie.com/en/products /Oscilloscopes/Handyscope_HS5 /Download. Depending on your system architecture, you should choose either the 32-bit or the 64-bit version. For a 32-bit installation, copy the libtiepie.dll to <windir>\system32\in your PC. For a 64-bit installation, this folder is <windir>\system\.

Now, when we have the Python™ environment and the Handyscope installed, it is time to connect these two using PyLibTiePie. The latest version is available for download from http://www.tiepie.com/en/products /Oscilloscopes/Handyscope_HS5/Download. Depending on your system architecture, you should choose either the 32-bit or the 64-bit version. Double-click on the downloaded exe file. The installation will search for installed Python™ environments in your PC. Make sure that you select Canopy - this can be easily identified by looking at the Python™ Directory. Click Next and the installation is complete.




## 6.4 Hardware

### 6.4.1 Required hardware

The followoing table lists the hardware needed for this application example.

| Item | Name | Quantity |
|---|---|---|
| 1 | *TDS* H1TDSx probe | 2 |
| 2 | *TDS* Remote Unit | 2 |
| 3 | PC3.5 cable | 2 |
| 4 | BNC to SMA(3.5mm) adapter | 2 |
| 5 | BNC 50Ω Feed-through terminator | 2 |
| 6 | USB cable | 2 |
| 7 | USB power supply | 2 |
| 8 | Remote unit activation pin | 2 |
| 9 | TiePie HS5 USB oscilloscope | 1 |
| 10 | *TDS* probe holder for MRI | 1 |
| 11 | Laptop/Desktop | 1 |

### 6.4.2 Hardware Setup

Figure 6.4 shows a simplified block diagram of the setup. The *TDS* probes are connected to *TDS* remote units. The outputs of the remote units are fed to ch.1 and ch.2 of the HS5 handyscope, using 50 Ω feed-through terminators. The signals are sampled in the HS5 and the data is transferred to the PC over USB.
**Note:** It is very important to connect the *TDS* probes and Remote units to the corresponding channel of the TiePie oscilloscope (as shown on Figure 6.4). Please, check the labels on the probes and Remote units. Channel 1 of the oscilloscope corresponds to the X-component and channel 2 - to the Y-component. Following the labels will ensure correct identification of the rotational direction of the field inside the MRI.

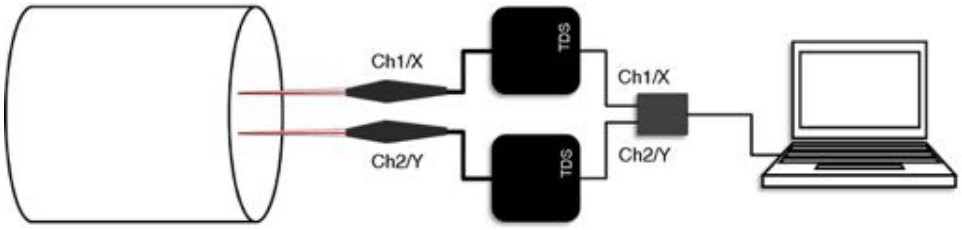
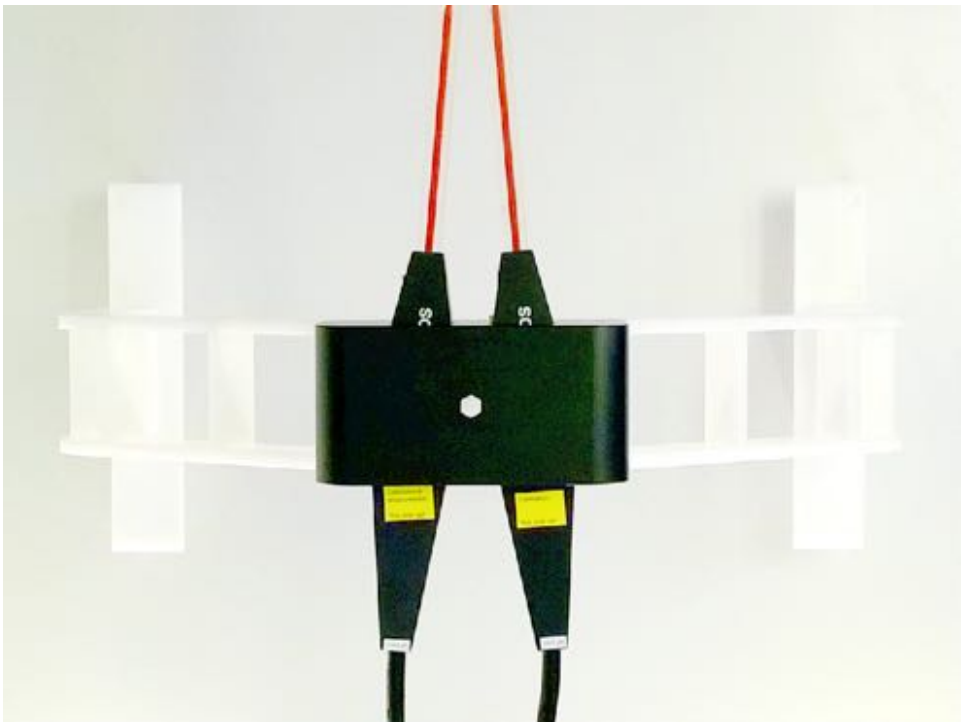



Figure 6.4: Simplified block diagram of the hardware setup

The probes are mounted inside an MRI birdcage usingone of the specially designed *TDS* holders for MRI - shown in the pictures below. Two different types are available - one for horizontal, one for vertical placement.

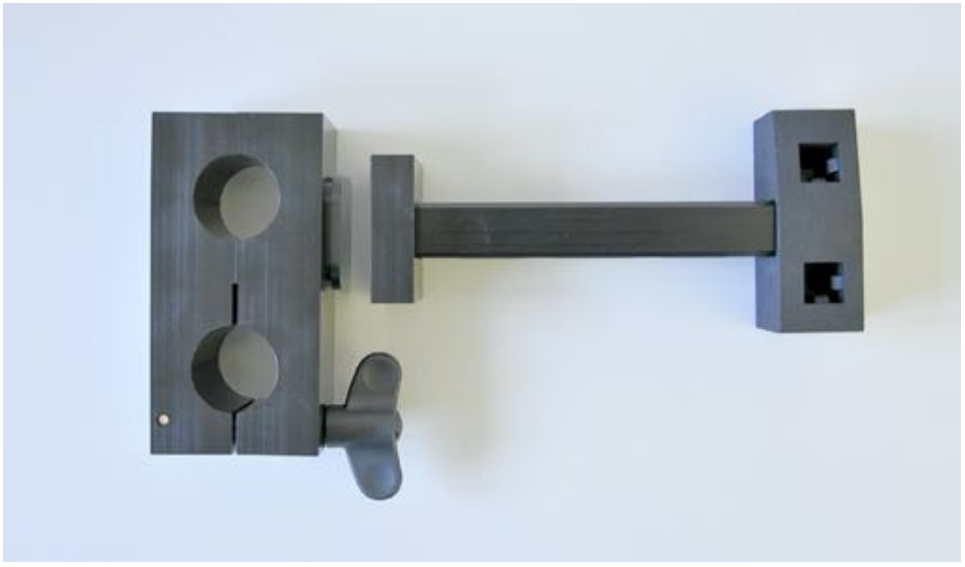
**Horizontal holder**



The holder has two interchangeable attachments - one which holds the probes in the same orientation (used during imbalance compensation) and one which holds them with 90 degrees offset (used during polarization measurement). The imbalance compensation attachment is shown on the left side of the picture below. The measurement attachment is on the right side.

### Vertical holder

The holder constist of two separate parts. The first one is attached directly to the legs of the Dual Cylinder plantom. The second one is snapped to the first one with a simple click mechanism and holds the probes, both during calibration and measurement.



To minimize the influence of the mismatch from the non-50Ω HS5 input, the cables from the *TDS* remote units are connected through 50Ω feed-through terminators.

**Note:** The probes and the fiber-optics are fully compatible and tested with MRI environments up to 9 T. The *TDS* probes are provided with 8 m long fiber cables, such that the equipment that is not compatible with the strong static or gradient magnetic fields in the vicinity of an MRI machine, i.e., the remote units and HS5 oscilloscope can be placed outside the MRI environment. Only the *TDS* probes should be inside the birdcage.

## 6.5 Performing measurements

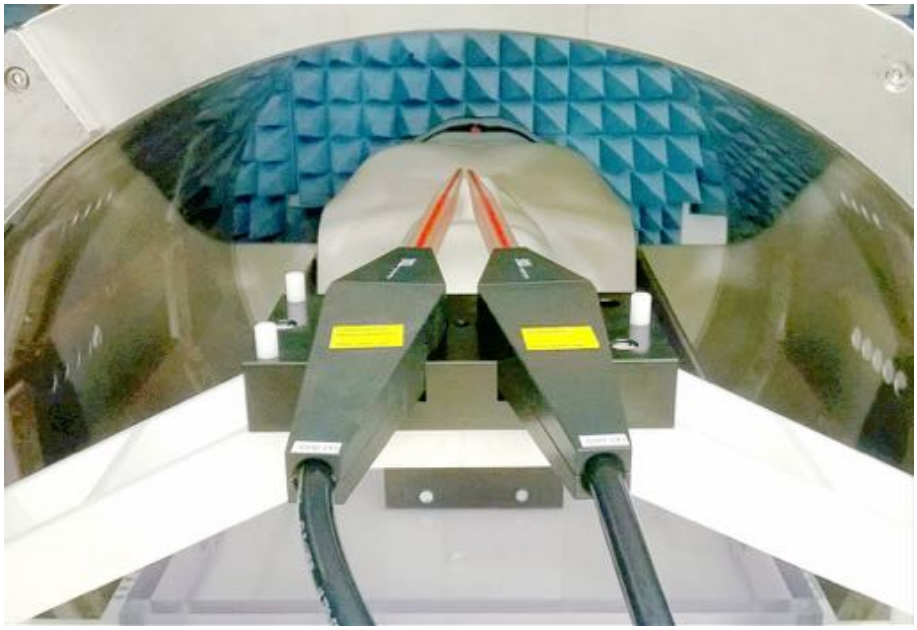
Unzip and copy the provided package to a location on your harddisk. Then run Canopy from *Start -> All Programs -> Enthought Canopy*. Start the MRIgui.py script from "Run File" under the Run menu. If everything is installed properly, you should not see any warnings or errors in the Python™ console window.

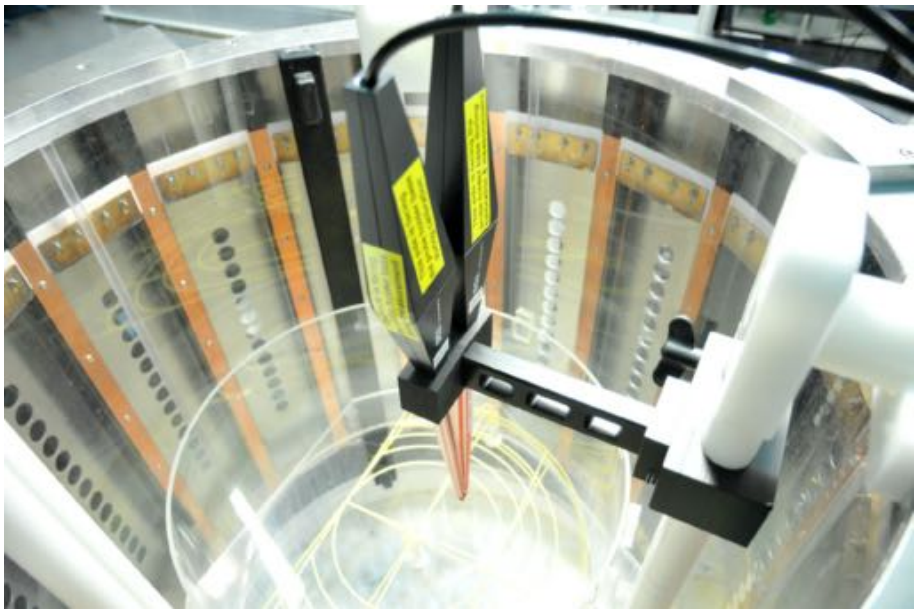
### 6.5.1 Channel Imbalance Compensation

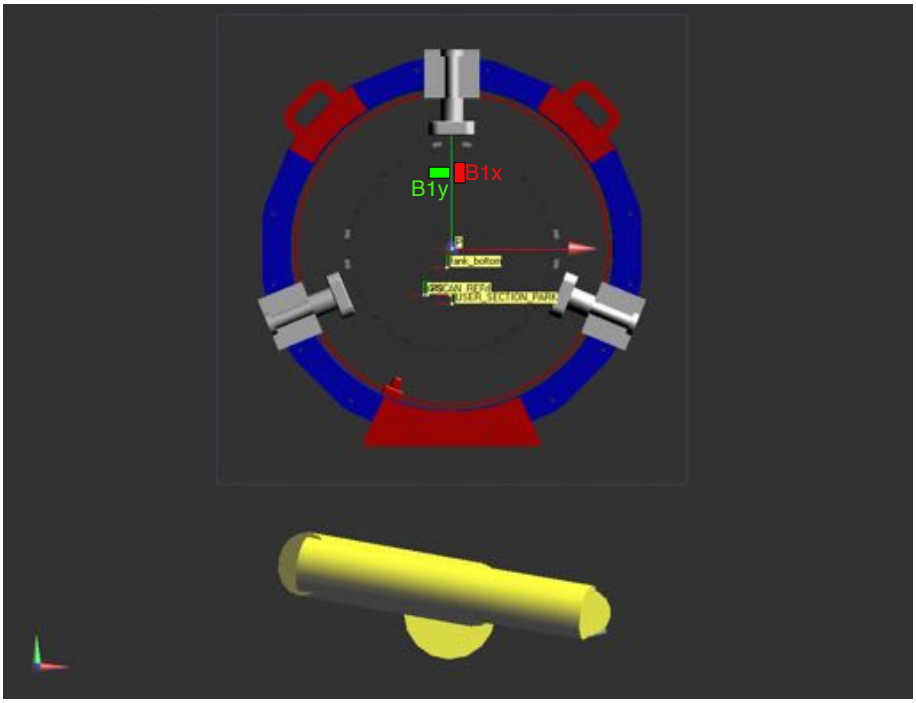
During the channel imbalance compensation of the setup, we aim to equalize the gain and phase imbalance of the the two measurement branches. This step considerably lowers the relative measurement uncertainty. To perform a successful compensation, take the following steps:

**STEP 1:** Place the probes inside the birdcage using the MRI holder with the imbalance compensation attachment (for the horizontal holder).

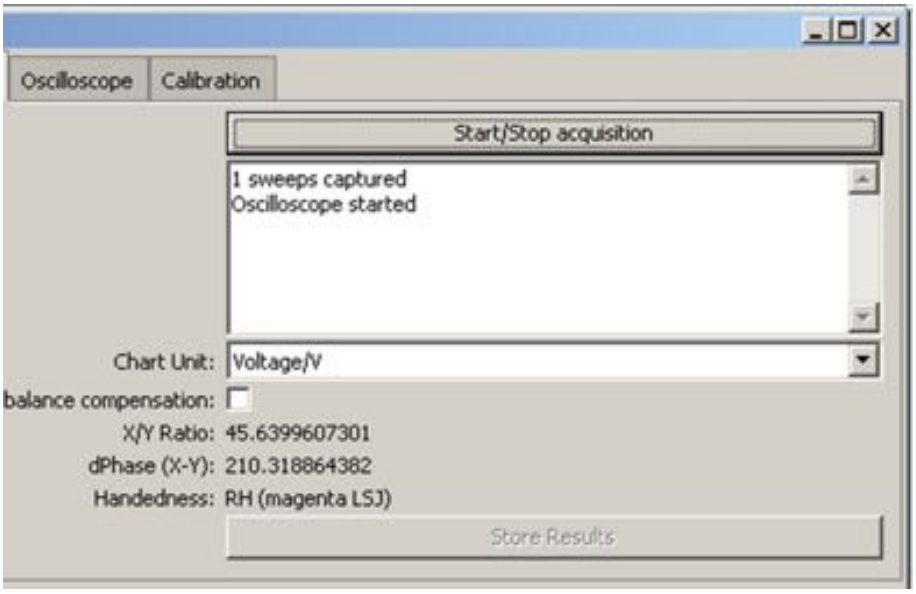
This attachment ensures that the probes are put in similar condition - from amplitude and phase point of view. For the vertical holder, just follow the text on the labels and place the probes in the same orientation. Turn on the MRI RF signal.

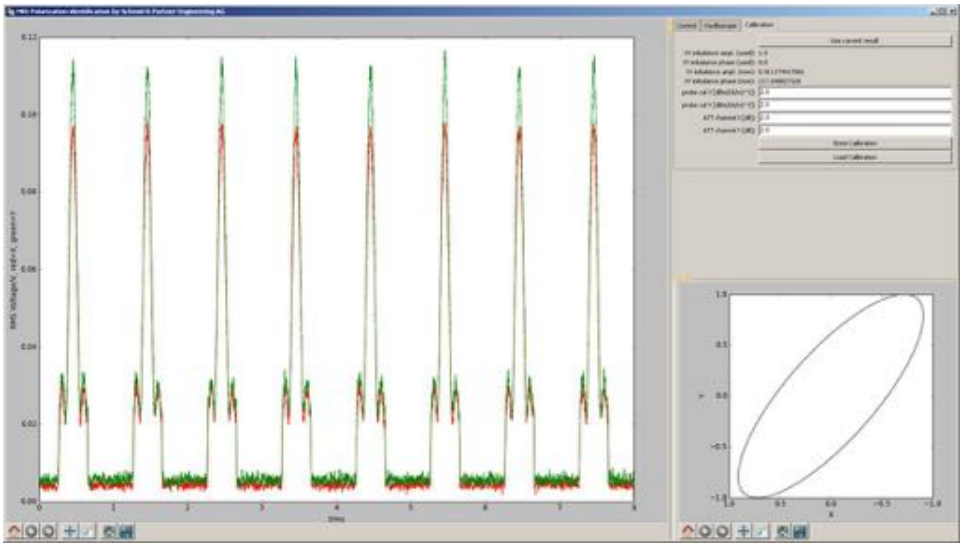




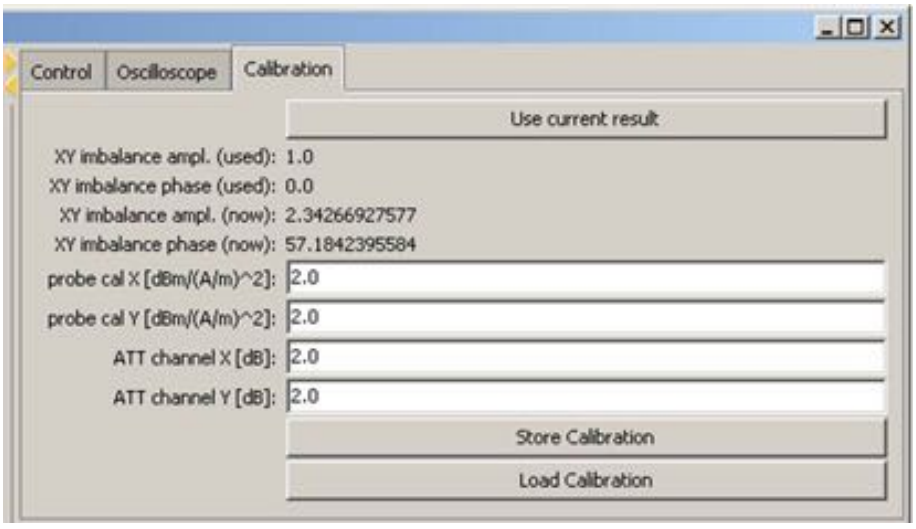



**STEP 2:** Once the GUI is loaded, press *Start/Stop Acquisition* from the Control tab. The acquisition will start and the sweep counter in the window below will be increasing. The displayed data will be updated after each new sweep.



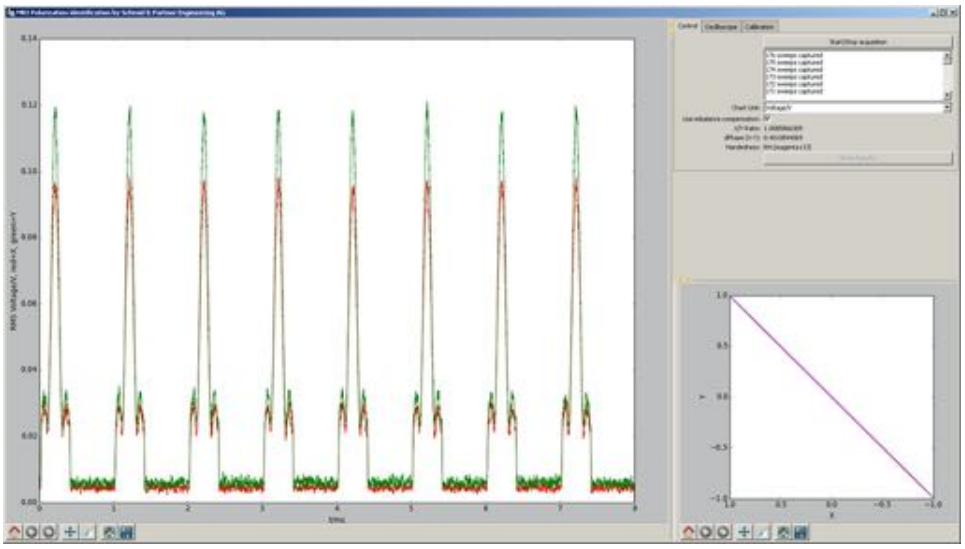


**STEP 3:** Now, go to the *Calibration* tab. The current imbalance between the *TDS* probes is shown under *XY imbalance phase/amplitude (now)*. These numbers should be relatively stable. If they are, you can press *Use Current Result*. Please, note that typically the amplitude should have little imbalance, but the phase may have significantly more.

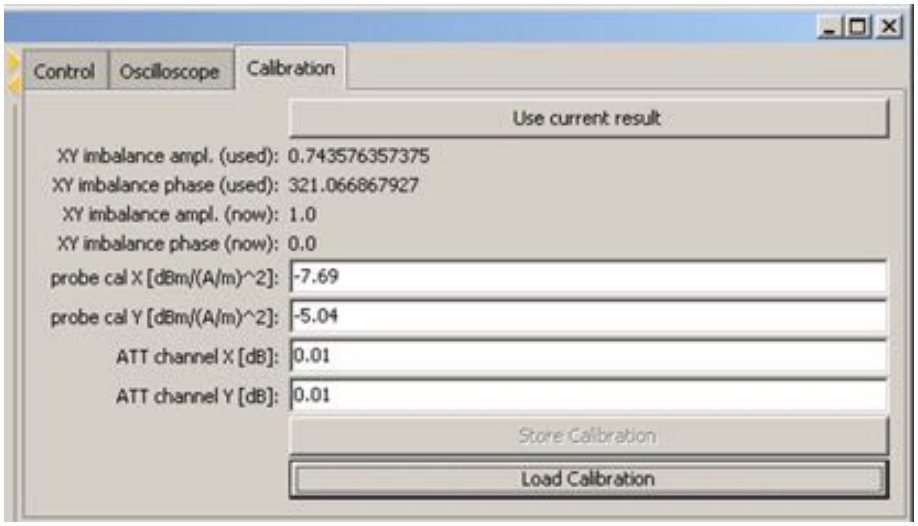



Now, the compensation is done. The script calculates the difference between the two *TDS* branches in terms of phase and magnitude. Applying these differences during a measurement ensures that the amplitude and phase offsets between the branches are zeroed. For a quick verification of this zeroing, you can go to the *Control* tab and check the *Use Imbalance Compensation*. Since, the probes are placed in very similar conditions, the script should show similar result to the one below. The *X/Y Ratio* should be very close to 1 and the *dPhase (X-Y)* should be almost 0 degrees. The

Lissajous plot should be a line (or an ellipse very close to a line), with a 45 degrees tilt.

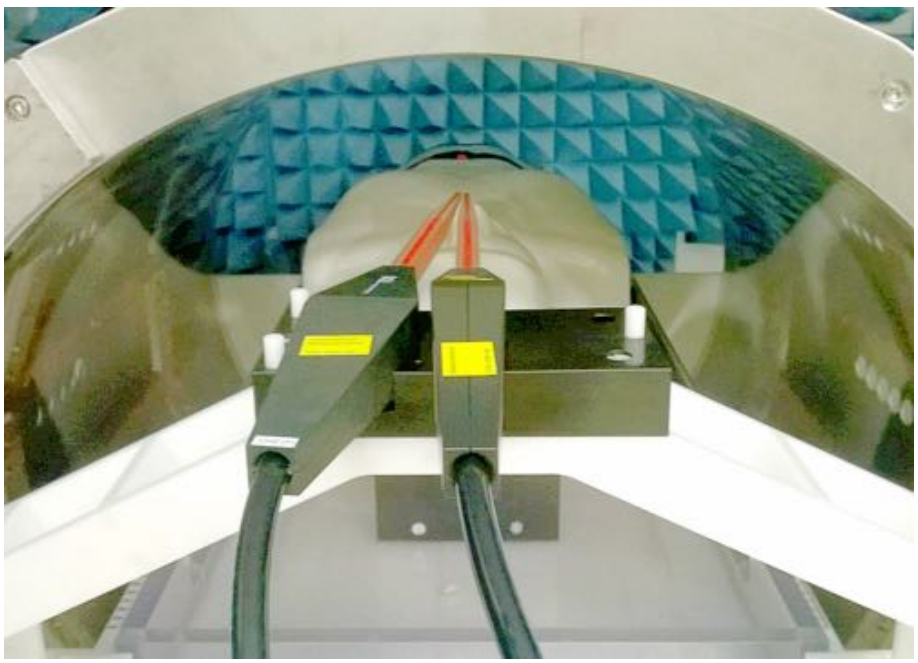


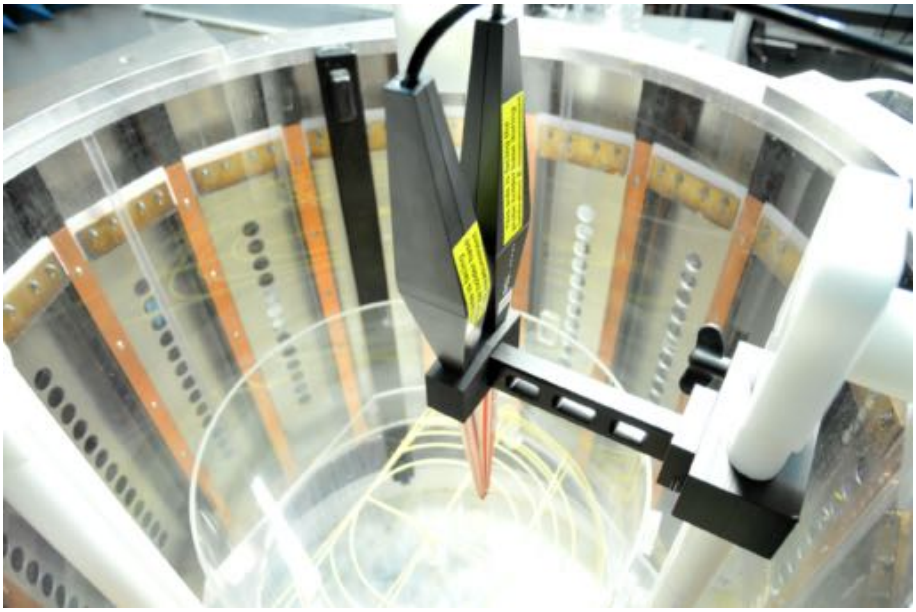
At this stage, the system can be used for polarization estimation. However, if absolute field strength is of interest, the user must fill in the probe calibration factors for X and Y. These values are frequency dependent and are available from the calibration certificate of the probes - check the sensitivity response for the corresponding frequency. Due to some changes of the format of the calibration certificates, the signs of the AF values in the certificates might have to be inverted. The unit of the AF should be used for guidance. The users can also take into account the attenuation in the cables between the *TDS* Remote Units and the TiePie Oscilloscope. These should be put under *ATT channel X/Y*. The coefficients (including imbalance, calibration and attenuation) can be stored as *.cal.mat file and later re-loaded using the *Store Calibration* and *Load Calibration buttons*.



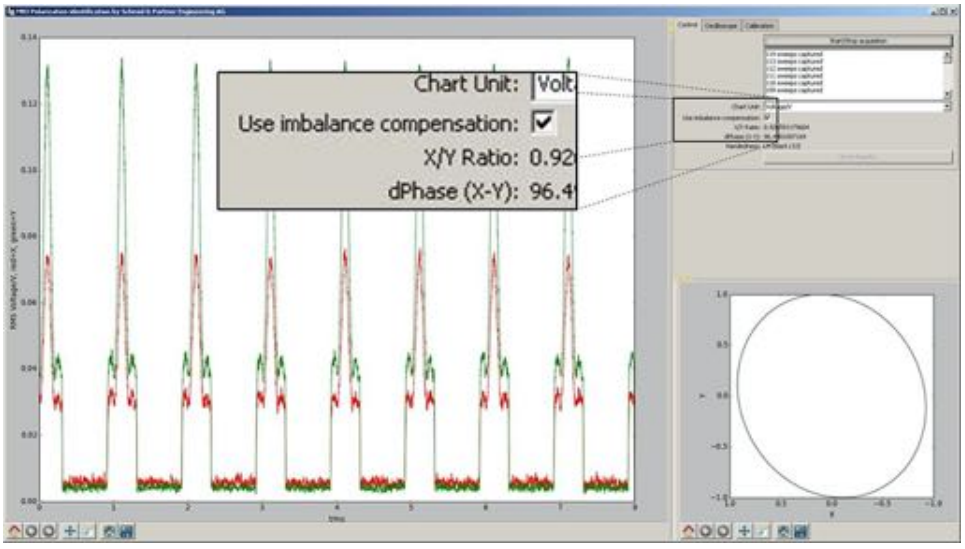

### 6.5.2 Measurement

Place the probes inside the birdcage using the MRI holder with the measurement attachment for the horizontal holder. For the vertical holder, just rotate one of the probes 90 degrees along its axis.





Don't forget to click on *Use Imbalance Compensation* to take into account the previously performed imbalance compensation. Below, you can find a sample result, including the corresponding Lissajous figure in the lower right corner of the window. Depending on the orientation of the polarization, the color of this figure will change. Magenta corresponds to RH (right-handed), and black - to LH (left-handed) polarization.




**Note:** The data plotted by the GUI is RMS (root mean square) filtered. When the Chart Unit is set to Voltage/V, the displayed traces (Red for X- and Green for Y-component) are data from the oscilloscope, with no coefficients applied on it.When the Chart Unit is H-field/(A/m), the displayed

data is absolute field strength and is compensated using all coefficients from the Calibration tab.

# Bibliography

[1] M. Murbach, *EMF Risk Assessment: Exposure Assessment and Safety Considerations in MRI and other Environments,* Ph.D. dissertation ETH Nr. 21514, ETH Zurich, Zurich, Switzerland, Jan. 2013.

# Chapter 7

# Phase Measurements using *TDS* and a Vector Network Analyzer

## 7.1 Overview

Modern Network Analyzers are measuring both magnitude and phase of the wave quantities and use these values to calculate complex S-parameters. Since *TDS* is preserving the phase of the signal, it can be used together with a Vector Network Analyzer to perform complex transfer function measurements, or shortly S21 in the case of a two-port DUT. In this application note, we describe how to use *TDS* to perform such measurements with a specific focus on the phase of S21, also called insertion phase.

## 7.2 Test Setup

For this example, we will use a *TDS* system to measure the phase change along a stripline. The hardware needed for this measurement example is listed in the table below.

| Item | Name |
|---|---|
| 1 | *TDS* probe (E- or H-field) |
| 2 | *TDS* Remote Unit |
| 3 | Vector Network Analyzer (min. 2-port) |
| 4 | Microstripline |
| 5 | 50Ω terminator |
| 6 | Adaptors, cables |

Figure 7.1 shows how to connect the equipment. Note that for this mea-

surement, both E- and H-field probes can be used. Please, keep in mind the field distribution around the stripline shown on Fig. 7.2 in order to obtain the correct coupling to the probe.

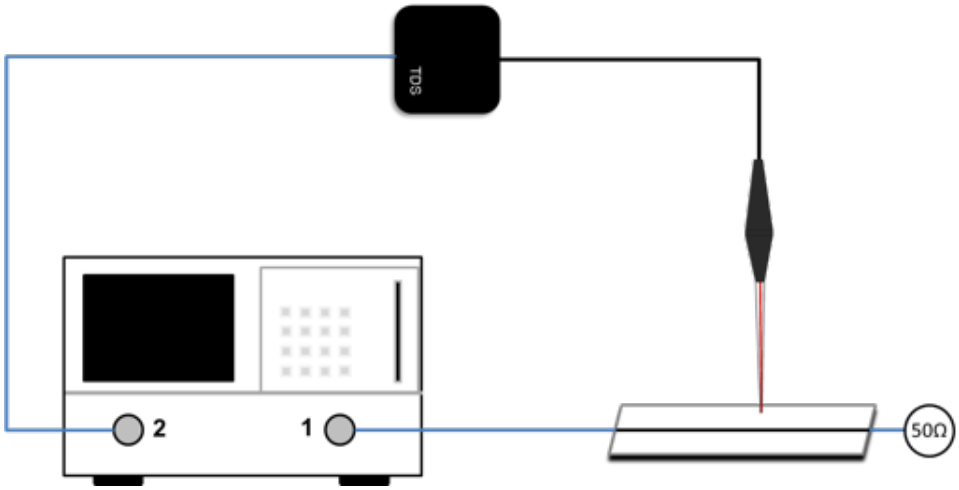



Figure 7.1: VNA measurement setup for S21 measurements using *TDS*

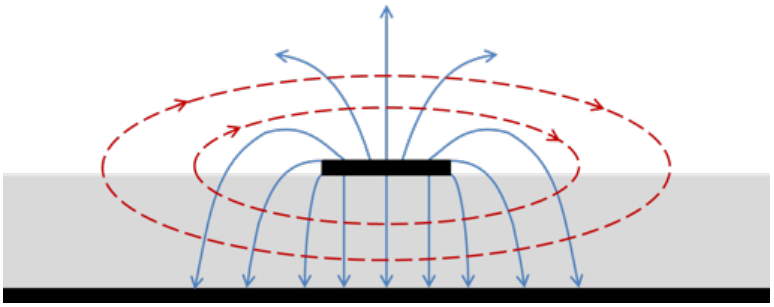


Figure 7.2: Field distribution of quasi TEM mode for a microstrip line. The E-field lines are in blue and the H-field lines are in red.

## 7.3 Calibration

In this specific example a modified VNA calibration is required. The standard 2-port calibration performed at the input of the mictorstrip line and

the ouput of the *TDS* Remote Unit has to be modified by adding some offset. This is done to compensate for the electrical delay introduced by *TDS* (shown as a blue dashed line on Fig. 7.3).

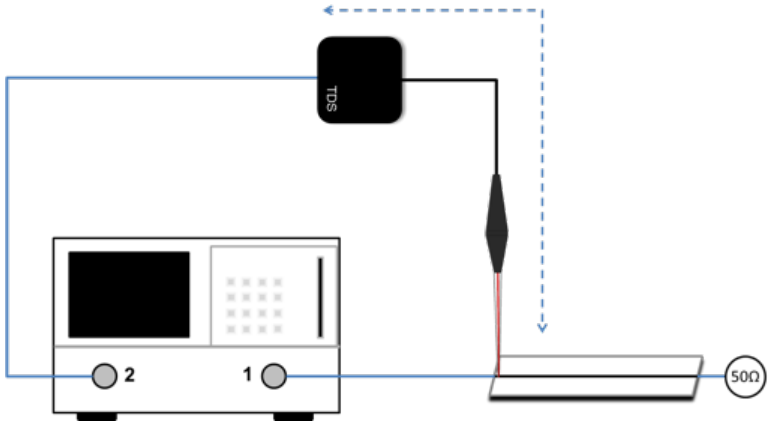



Figure 7.3: Calibration setup for compensating the additional delay introduced by *TDS* (shown in blue dashed line).

In most modern VNAs the electrical length compensation is implemented as a separate function. By activating it, the instument will automatically calculate and apply the correct time delay. This function is called in different ways by different equipment providers - some common names are Auto Port Extension, Auto Length, Auto Reference Delay Compensation. Please, consult the manual of your VNA for more details.

To perform a successful calibration, take the following steps:
**STEP 1:** Perform a standard 2-port VNA calibration with calibration planes at the input of the microstrip and the RF output of the *TDS* Remote Unit.
**STEP 2:** Connect the *TDS* system according to Fig. 7.3. Here the probe is kept on top of the stripline, close to the beginning of the stripline. Consult Fig. 7.2 in order to get correct coupling between the probe and the stripline.
**STEP 3:** While maintaining this probe placement, perform Auto Length compensation from the VNA.
**STEP 4:** Apply the calculated offset. This position of the probe will be used as a reference for the next measurements.

Usually phase delay is displayed in a linear phase format as a function of frequency. This display shows values between -180 and +180 degrees. The linear phase delay can be unwrapped, forcing the phase to be displayed linearly without the typical sawtooth character. This makes it easier to follow and draw conclusions, especially in the cases when the phase values are close to ±180 degrees. Most VNA offer this functionality. Please, consult the manual of your VNA for more details on this.

## 7.4 Conversion between phase delay and mechanical length

For an ideal non-dispersive DUT, the phase of the complex forward transmission coefficient S21 is a linear function of the frequency, described by the following formula [1]:

$$\varphi = -360^\circ \cdot f \cdot \tau \tag{7.1}$$

, where $\tau$ is the electrical delay time and $f$ is the frequency. It can be directly calculated from the mechanical length (L) of the DUT, using the effective permittivity ($\varepsilon_{eff}$) and the speed of light (C) [1].

$$\tau = \frac{L \cdot \sqrt{\varepsilon_{eff}}}{C} \tag{7.2}$$

Combining equations (7.1) and (7.2) shows that the phase change along a non-dispersive transmission line is a linear function of the mechanical length. It can be calculated using commercial software packages [2] for transmission line design. For the chosen PCB thickness, copper width and thickness, substrate dielectric constant and given frequency, the program can calculate the relation between electrical and physical length. In other words, this calculation provides the relation between the path along which the probe is moved and degrees of phase change for the specific microstrip design.
Our setup can be used to confirm these calculations. Firstly, we put the probe in the same position which was used during the Auto Length adjustment. Then we physically move the probe along the stripline towards its end (as shown on Figure 7.4) and record the VNA readings. By doing this we introduce additional length to the DUT, resulting in phase change.

We can look at a single frequency (1GHz for example) and plot the resulting data. The comparison between calculated and actually measured values is shown on Figure 7.5.

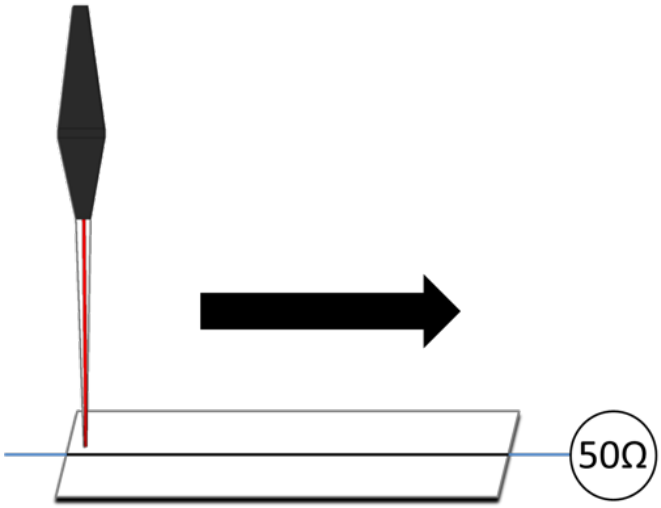



Figure 7.4: Moving the *TDS* probe along the stripline introduces phase change

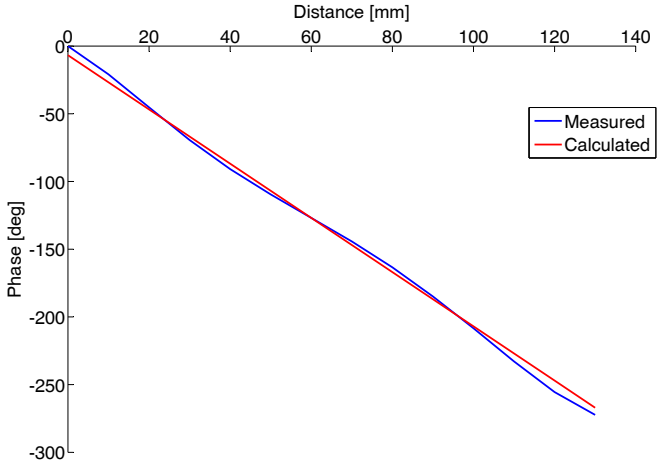



Figure 7.5: Relation between phase change and distance for the tested microstripline

## 7.5 Phase change as a function of the frequency

Now, instead of using a single frequency, we can look at the frequency range from 200MHz to 500MHz. We can move the probe in steps of 10mm and

take a measurement sweep for each position. The resulting phase is plotted on Figure 7.6. The dashed lines are representing the targets calculated using equations (7.1) and (7.2). Commercially available software [2] was used for to calculate $\varepsilon_{eff}$ in equation (7.2).

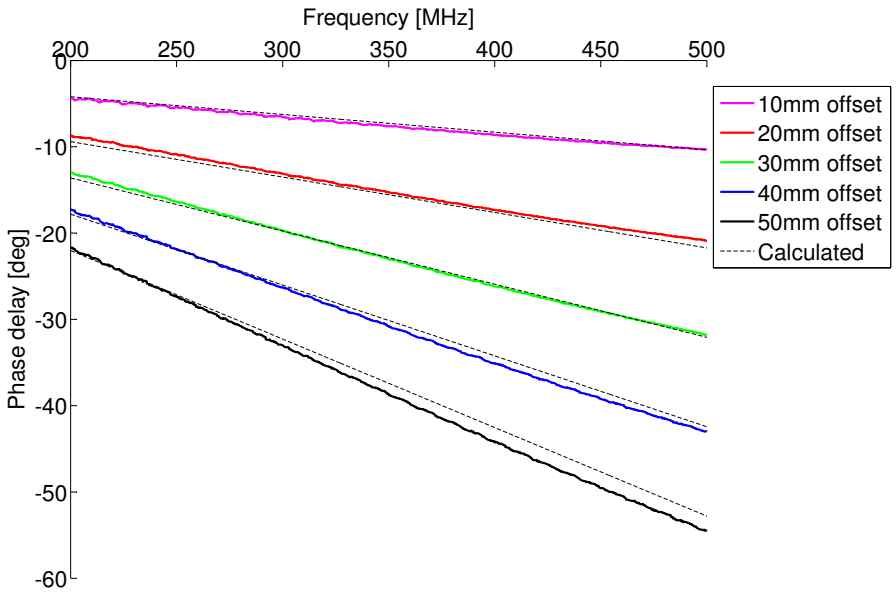



Figure 7.6: Measured phase change as a function of the frequency for different probe positions

The top curve (pink) is for the position closest to the beginning of the stripline. The black one is for the position closest to the end of the stripline. As expected the phase has a negative slope with respect to frequency due to the electrical length of the device. In other words, the longer device will result in a steeper slope. The change of phase as a function of frequency is pretty much linear. Since the tested microstripline is not an ideal transmission line, we are observing some dispersion, but this is not significant.

# Bibliography

[1] M. Hiebel, *Fundamentals of Vector Network Analysis* ISBN 978-3-939837-06-0, Rohde & Schwarz GmbH & Co. KG Munich, Germany, 2011.

[2] TX-Line, National Instruments / AWR, *Analysis and Synthesis of Transmission Lines*. Download available from: http://www.awrcorp.com/products/optional-products/tx-line-transmission-line-calculator

# Chapter 8

# Sample Python scripts

## 8.1 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.

## 8.2 Software Installation

### 8.2.1 Python™

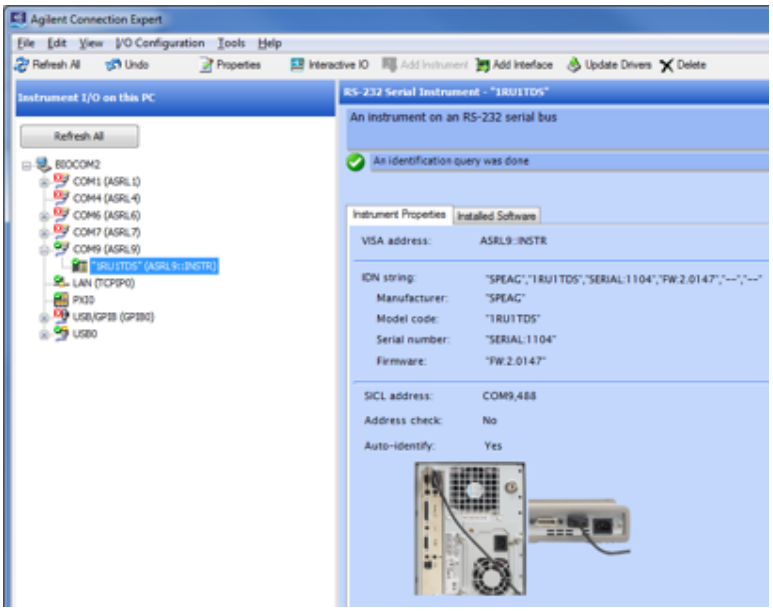
A working Python™ is required for running these sample scripts. One option is to install Enthought's Canopy distribution of Python™. The use of this distribution, however, is not mandatory. A good alternative can be the original Python™ distribution. It can be downloaded from http://www.python.org.

### 8.2.2 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:



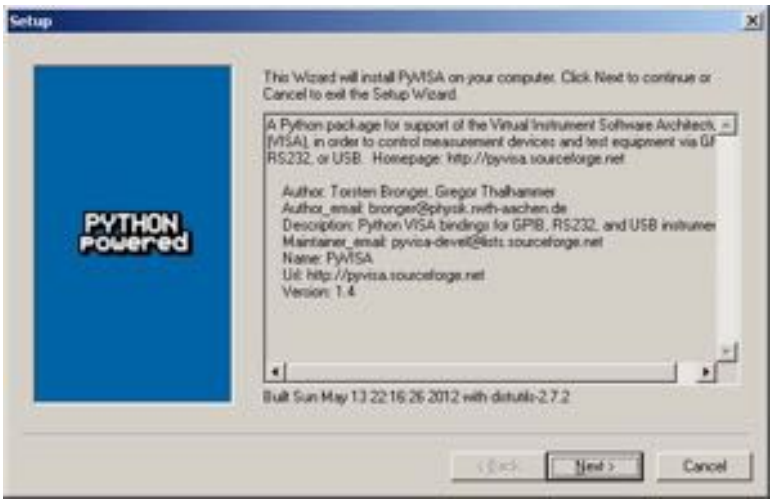

### National Instruments VISA

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:

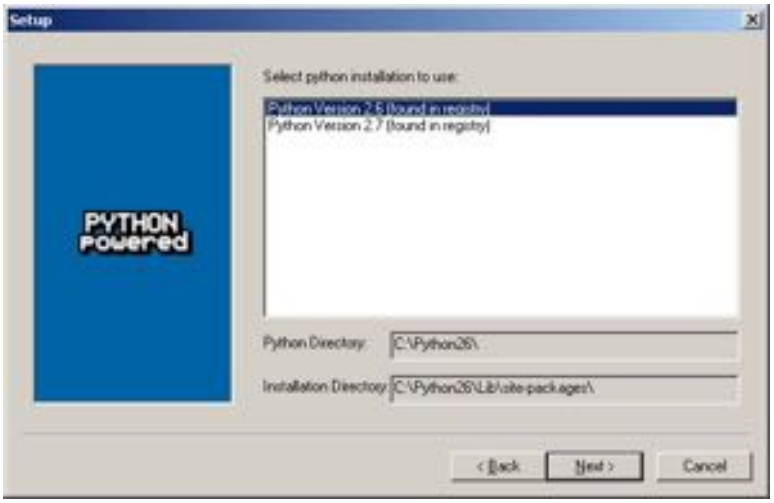
As seen on this picture, the VISA Alias assigned to the Remote Unit is COM9 and this is what we will use throughout this application note. Note that this might be different in your case.

### 8.2.3 PyVISA installation

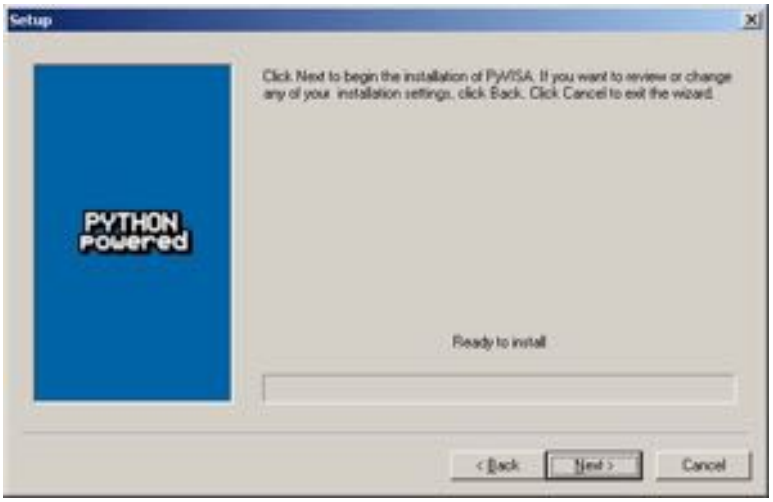
PyVISA is required to enable the control of the measurement equipment. This is a Python™ wrapper for the VISA library, needed for control of measurement devices and test equipment via GPIB, RS232, or USB. It can be downloaded from http://sourceforge.net/projects/pyvisa/ . After downloading the executable 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.

## 8.3 COM port

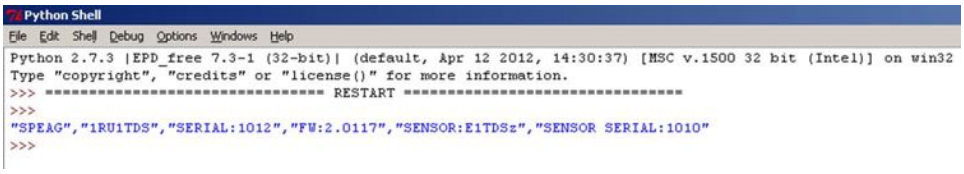
As mentioned in section 8.2.2 of this note, we assume that COM9 is the port assigned to the *TDS* remote unit. Please, check which COM port was assigned in your PC, since these are varying from system to system.This check can be done by using *Device Manager* in Windows as shown on the picture.

## 8.4 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:

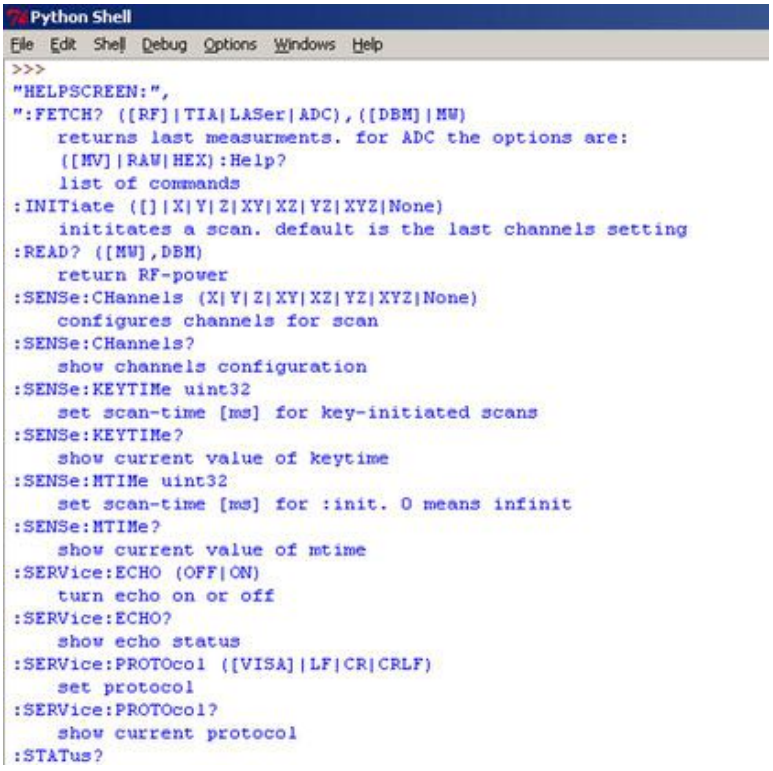


## 8.5 Getting help

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.

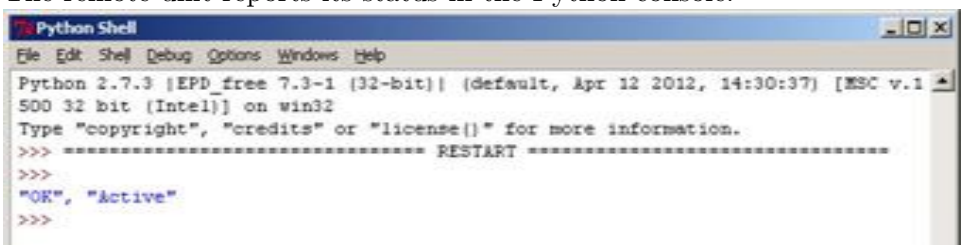



## 8.6 Checking the status of the system

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.

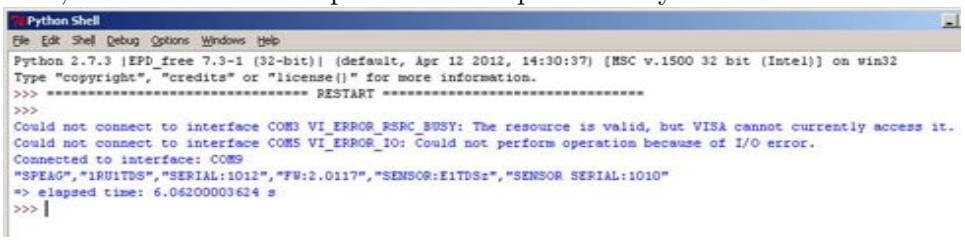
## 8.7 Automatic access to the *TDS* Remote Unit

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.

# Chapter 9

# EMC Sniffing Application Scenario Using TDS SNI Where Conventional EMC Probes Are Non-Compliant

*This application note aims to demonstrate the practical advantages of TDS SNI over conventional, conductive EMC probes in a real use case. It focuses on the aspect of RF EM transparency, i.e. the possibility to conduct an accurate near field measurement without perturbing the electrical or magnetic fields under test. To show this, two different experimental setups have been arranged, one to demonstrate the field perturbation of a conventional metallic probe, and one to highlight that a conventional probe can induce unintentional EM interference in an electronic circuit.*

## 9.1 Electromagnetic Field Perturbation Effects

The experimental setup for the evaluation of the RF EM transparency of near-field EMC probes is shown in Fig 9.1. A H1TDSx H-field probe mounted on a fixed support is used as a reference probe that detects the 900 MHz carrier transmitted by the device under test (DUT). The signal measured with the *TDS* probe is continuously monitored on a spectrum analyzer.

After approaching the DUT with a medium size loop (10 mm) conventional EMC probe (Fig 9.2) the field variation detected by the reference probe has been recorded. Fig 9.3 shows the field compression (blue trace) due to the screening effect of the conventional EMC probe approaching the reference probe. Similarly, the experiment has been repeated approaching the same DUT with *TDS SNI* monitored by the H1TDSx reference probe

(Fig 9.4). Fig 9.5 shows that the 900 MHz transmitted field does not exhibit any amplitude variation.

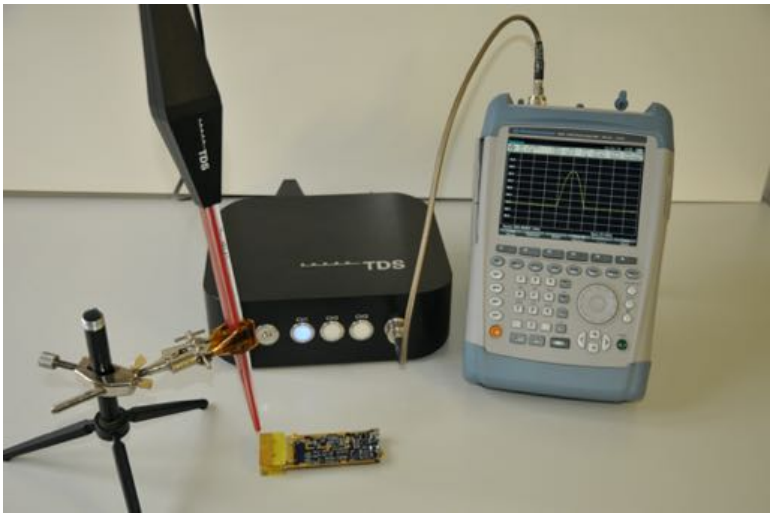



Figure 9.1: *Experimental setup to evaluate the RF EM field perturbation induced by a conventional EMC probe. Shown is a SPEAG H1TDSx H-field probe used as reference probe mounted on a support bracket, a 900 MHz transmitter device and a spectrum analyzer.*

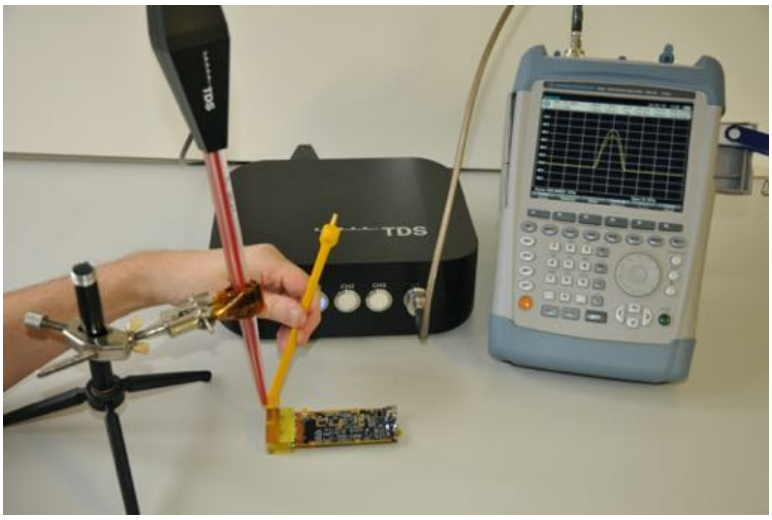



Figure 9.2: *A 10 mm H-field conventional EMC probe close to the reference probe perturbs the detected field. An amplitude reduction of the detected carrier is observed.*

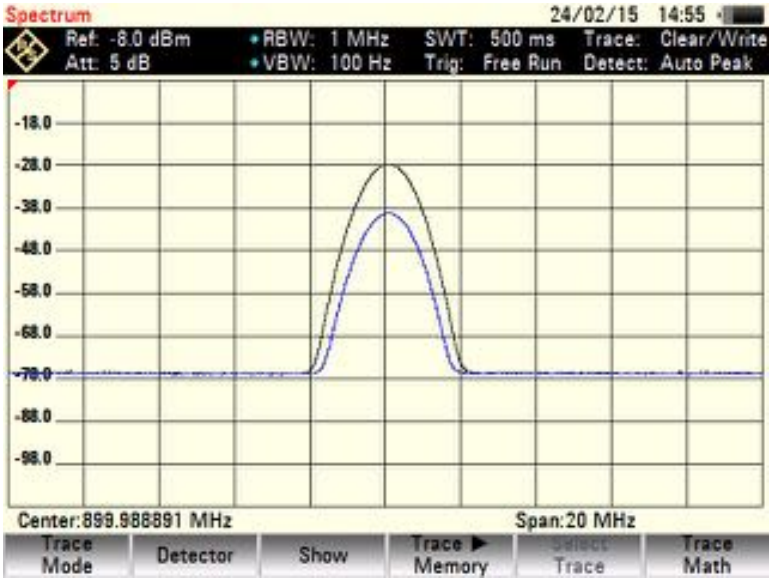



Figure 9.3: *The field perturbation effect of the 10 mm conventional EMC probe on the 900 MHz carrier becomes evident comparing the black (reference) and the blue curves (with conventional EMC probe present).*

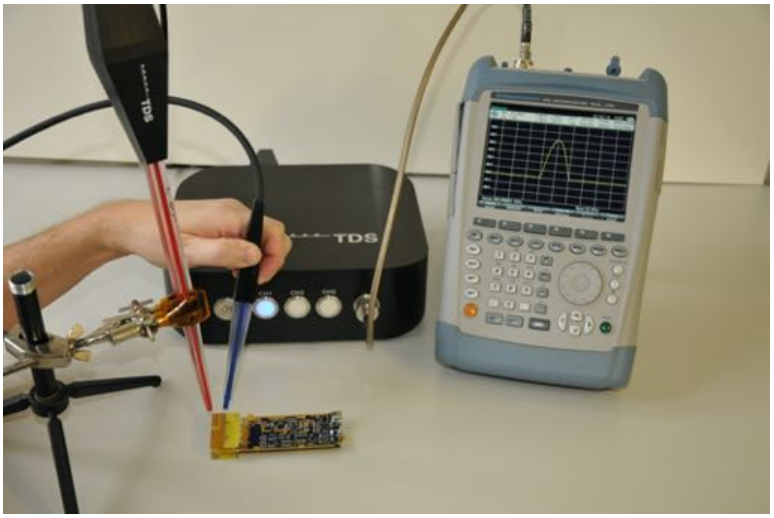



Figure 9.4: *Absence of field perturbation when approaching the reference probe with a TDS SNI EMC probe.*

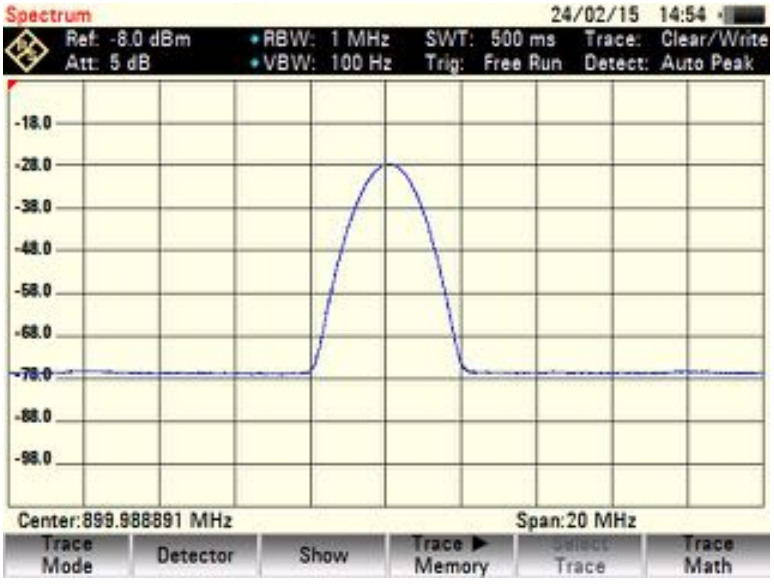



Figure 9.5: *The 900 MHz carrier, unperturbed after having approached the reference probe with TDS SNI .*

## 9.2 Signal Distortion Effects

The introduction of a conventional, conductive EMC probe close to the components and traces of an electronic circuit can affect the circuit behavior by re-routing the electromagnetic signals under test all over the PCB. Using the 900 MHz transmitter previously described a second experiment has been arranged. It demonstrates that by placing a conventional EMC probe we could induce unlocking of the PLL of the DUT. In this test the tip of a conventional EMC probe has been positioned close to the PLL circuitry (Fig 9.6). In this way the RF signal emitted by the antenna is routed via the conductive probe to the PLL in the middle of the PCB. Fig 9.7 shows the induced oscillation, due to the feedback of the output RF signal into the PLL. The same positioning of *TDS SNI* (Fig 9.8), does not affect the circuit behaviour, due to the absence of conductive materials (Fig 9.9).

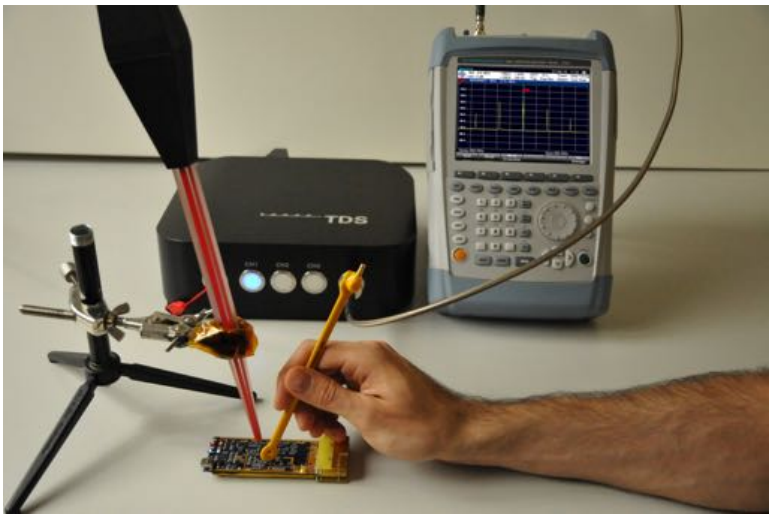



Figure 9.6: *A 10 mm conventional EMC probe positioned close to the PLL circuit of the DUT. The conductive probe elements route the RF energy picked up at the transmitter into the PLL circuitry.*

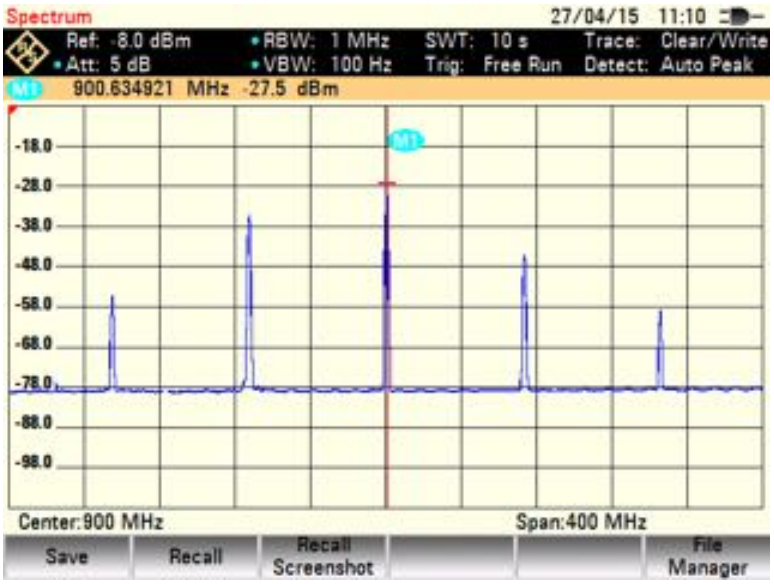



Figure 9.7: *The presence of the conventional EMC probe causes artificial spurious emissions, invalidating the EMC measurement.*

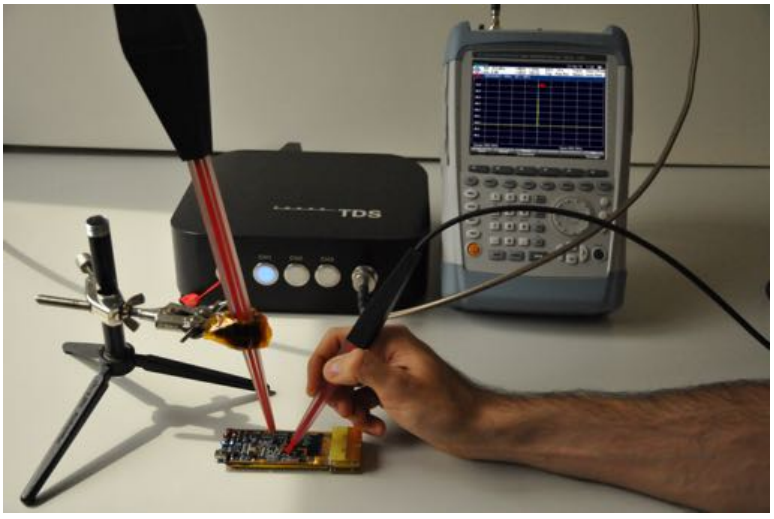



Figure 9.8: *A TDS SNI EMC probe positioned close to the PLL circuit of the DUT. The near-field probe does not affect the circuit behaviour due to absence of conductive material.*

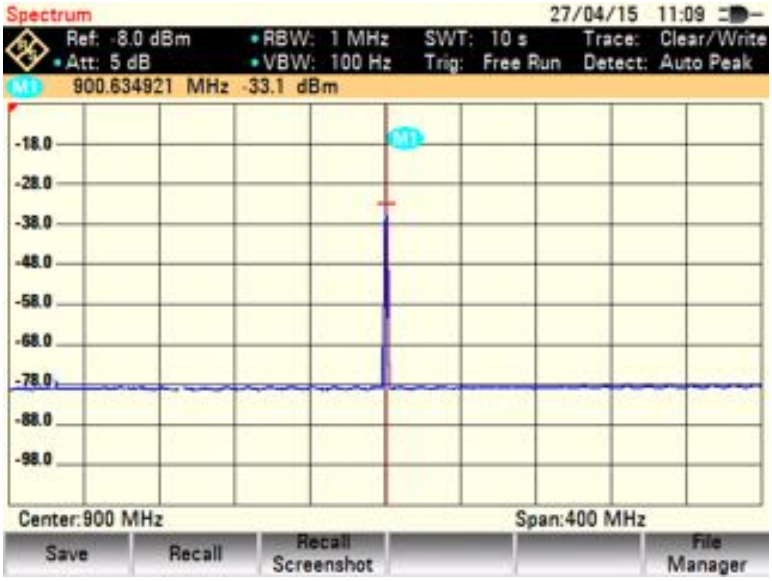



Figure 9.9: *The clean 900 MHz signal of the DUT measured with TDS SNI.*

## 9.3 Summary: Applicability of TDS SNI and Conventional EMC Probes for EMC Near-field Sniffing

As demonstrated in this application note, investigating realistic EMC sniffing scenarios, conventional EMC probes can impose strong limitations with respect to their general applicability for EMC and signal integrity near-field sniffing. Being metallic, conventional EMC probes introduce a strong, artificial and unpredictably EM boundary condition. The shielding effect of conventional probes may remove EMC and signal integrity problems that are present without the probe. Likewise, radio-frequency energy routed along the conductive parts of conventional probes may introduce EMC and signal integrity problems that are not present without the probe. Only the full RF transparency of *TDS SNI* near-field EMC probes ensures a general applicability and true results in EMC near-field sniffing applications.

# Part VII

# Appendixes

# Chapter 10

# Conversion between Antenna Factors in dBm and V

Section 4.4 of this manual explains how to use the provided antenna factors for calculation of the actual field on the tip of a *TDS* probe. This explanation assumes that the measurement receiver is reporting dBm values. However, sometimes, the reported unit might be Volts. In this appendix, we explain how to modify the provided antenna factors for this case. We assume that a HTDS probe is used. In other words, the measured field is in A/m. The V/m case (or ETDS) is using the same calculation.

The power at the 3.5mm connector the *TDS* Remote Unit can be expressed as:

$$P = \frac{U^2}{Z_0} \tag{10.1}$$

where

$\boldsymbol{U}$ is the output voltage in Volts

$\boldsymbol{Z_0}$ is $50\boldsymbol{\Omega}$

This can be re-written in logarithmic form as:

$$10 \cdot log_{10} P_W = 10 \cdot log_{10} U^2 - 10 \cdot log_{10} Z_0 \tag{10.2}$$

$$10 \cdot log_{10} P_{mW} = 20 \cdot log_{10} U - 10 \cdot log_{10} 50 + 10 \cdot log_{10} 1000 \tag{10.3}$$

In terms of AF, this equation will be:

$$AF_{dB((A/m)^2/mW)} = AF_{dB((A/m)/V)} + 10 \cdot log_{10} 50 - 30 \tag{10.4}$$

Since we are interested in having an AF expressed in (A/m)/V, the formula will be:

$$AF_{(A/m)/V} = 10^{\frac{AF_{dB((A/m)^2/mW)} - 10 \cdot log_{10} 50 + 30}{20}} \tag{10.5}$$

# Chapter 11

# Antenna Factor Calculation Example

The values of the Antenna Factor (AF) listed in the calibration certificate are calculated only for certain frequencies. However, using the provided polynomial coefficients, the users can calculate the AF for every desired frequency within the calibrated range. This appendix shows an example calculation, which can be applied both for *E*- or *H*- *TDS* probes. We will use the following polynomial coefficients from an *H*-field probe certificate to build the AF curve:

| **Coefficient** | **Value** |
|---|---|
| T6 | 6.94329462888430E-01 |
| T5 | -4.65397006314600E+01 |
| T4 | 1.23748320968528E+03 |
| T3 | -1.69712049204748E+04 |
| T2 | 1.27748564107909E+05 |
| T1 | -5.03227602778675E+05 |
| T0 | 8.13427962218824E+05 |

The polynomial formula is listed in the calibration certificate:

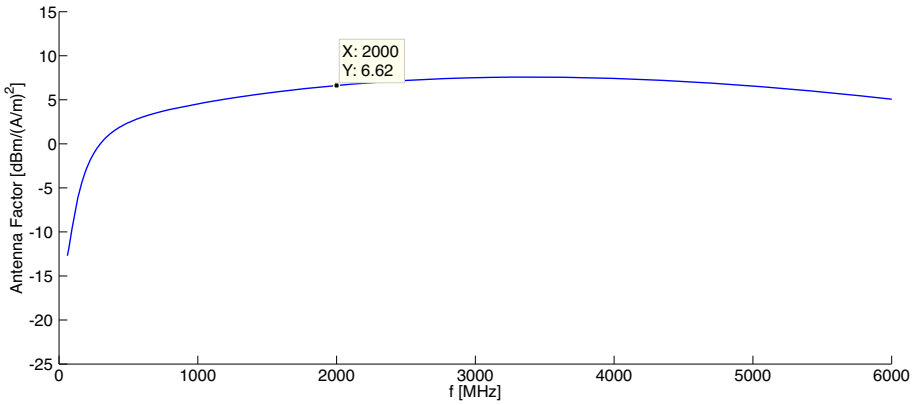
$$AF_H = \sum_{n=0}^{6} T_n \cdot (log_{10}(f))^n \tag{11.1}$$

Using it, the resulting polynomial will be:

$$
\begin{aligned}
AF_H = 6.94329462888430E-01 \cdot (log_{10}(f))^6 \\
-4.65397006314600E+01 \cdot (log_{10}(f))^5 \\
+1.23748320968528E+03 \cdot (log_{10}(f))^4 \\
-1.69712049204748E+04 \cdot (log_{10}(f))^3 \\
+1.27748564107909E+05 \cdot (log_{10}(f))^2 \\
-5.03227602778675E+05 \cdot (log_{10}(f)) \\
+8.13427962218824E+05
\end{aligned}
$$

, where $f$ is the frequency in $Hz$

This polynomial can be used in programs like Matlab™ or Python™ to calculate the Antenna Factor for all calibrated frequencies. The result looks like this (for an H-field *TDS* probe) and is included in the calibration certificate:




We can put a marker for example on 2000MHz. The value of the $AF_H$ for this frequency is 6.62 $dBm/(A/m)^2$. It can be used for further calculations according to section 4.4 of this manual.