EVALUATION OF AN OSCILLOSCOPE TRAINING COURSE

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Abstract: At Delft University of Technology a half-day (4 hours) oscilloscope practical training course has been developed to support two activities in the start of the freshman year. The first is an introductory lecture on Instrumentation and Measurement and the second is a series of hands-on laboratory activities offered to students throughout the academic year. The target group, therefore, is freshman students, whose prior knowledge of electrical engineering is mainly determined by an introductory circuit course and the high school curriculum on physics.The objectives, structure and results of the designed course are presented here.

1 COURSE OBJECTIVES

The training courses are the “hands-on” part of the broad introductory lectures on Instrumentation and Measurement in the first year for Electrical Engineering students. A one-afternoon training course has been designed around the oscilloscope, since this is the most versatile and common instrument for all electrical engineers.

Besides the practical support of the measurement theory, as at that stage already has been discussed in the lectures, the following more general objectives are pursued in the training course:

1. Providing basic **measurement skills** and understanding of instrument use, such as **calibration** (probes). After the course the student should be familiar with the use of an oscilloscope and some other basic lab instruments on actual signals. This experience has to be used in other practical work, like the signal- and digital systems lab training courses, in the months to follow.
2. Creating and stimulating awareness about the limiting instrument **specifications**, such as bandwidth, and the **potential of misuse**.
3. Confronting students with some **common measurement errors**, e.g. grounding problems and input- and output impedance loading.
4. Stimulating the student to **interprete** his/her measurement results.

2 “REAL” OR “VIRTUAL” INSTRUMENTS ?

In our view the benefits of virtual instruments come with the level of the user.

Introductory teaching on Instrumentation and Measurement should be, therefore, associated with practical training on real instruments. These instruments should show the beginning engineer that basic, well-defined measurement, functions can be distinguished and for accurate measurements the right instrument should be choosen. Instruments like an oscilloscope, a voltmeter and signal generators are the **basic tools** for electrical engineers.

3 ANALOG OR DIGITAL?

Traditionally these basic instruments were analog instruments. More modern instruments have the essential functions implemented digitally. In digital signal processing functions can be added and instruments can be combined, resulting in complex data acquisition systems. Nevertheless, analog-to-digital and digital-to-analog conversions are always necessary to interface to the real world.

Fig. 1 Basic instrumentation

The sampling and quantization phenomena associated with AD conversion can add a level of complexity that can not be overcome by the beginning Electrical Engineering student, distracting the attention from the actual operation principles of that instrument. Therefore, in order to keep the student with his/her feet on the ground, we think that the digital nature of an instrument should not be dominantly visible in this course.

Direct user control of the commonly used functions of an instrument (by actual buttons and switches) and direct feedback (on a display) allows fast and easy operation for the beginner. This allows the students complete the measurements in time and feeling more familiar with the instrument. After this, the logic behind groups of "soft-keys" in menus should be more obvious to the student.

4 VIRTUAL INSTRUMENT AND VIRTUAL LAB ?

The experience gained with real instruments brings the student to the level at which a virtual instrument can subsequently be introduced. Proper interpretation of the instrument specifications is also required to make more responsible use of the various hardware and software tools and to select and operate virtual instruments with their many signal-handling options. Moreover, it may be helpful at a later stage to appreciate the merits of a virtual instrument.

The latest developments in measurement software, like LabView 6i or HP VEE , allow control of instruments over the internet. Using this software, this practical training course could also be done partly on remote "virtual lab" setups, even from the students computer at home. In our view this is not a good approach for an introductory course, since there is no interaction with a teacher. Also real "hands-on" courses are much appreciated by students in the first year. The potential of such "virtual lab-courses" will be investigated in our more advanced courses to follow.

5 INSTRUMENTS

A modern digital oscilloscope (Tektronix TDS 210) is used, however no accent is given on the digital nature of the scope itself, since digital signal processing theory is not discussed yet. This scope features controls for the main functions and also a menu-organised operating panel for the more advanced functions. It has a 200 MHz bandwidth, which is typical to what can nowadays be found as general purpose oscilloscope in the profession. Another instruments used in the course are a low-cost Aplab 2011A 10MHz waveform generator.

6 COURSE DESCRIPTION

The course is designed in such a way that the student is confronted with limiting instrument specifications and features. The students work in groups of two, starting at a very simple level.

At three specific checkpoints, usually after completion of a more difficult task the students are required to show their results to the lab assistant:

1. First a step-by-step guide through the main settings has to be followed to get acquainted with the instrument. For each step there are questions that have to be answered. A typical example is shown in Fig. 2.
2. The student has to go through a calibration routine, using the on-scope square wave test signal as shown in Fig.3. The unique combination of a particular scope plus the probe that is calibrated

for that particular scope is emphasised. The peak-to-peak voltage voltage should be also measured here to verify the correct setting of the probe attenuation factor.

3. Bandwidth and trigger are introduced using a measurement of the rise/fall time of a pulse from a signal generator. As an example an explanation of Triggering features is shown in Fig.4
4. Peak-to-peak-, Mean- and RMS voltages should be measured using both the display cursors and the built-in menu functions, using an external signal source as shown in Fig.5. Here the student is reminded that the display of an oscilloscope is very suitable for qualitative analysis of dynamic signals, but is not designed for high-resolution readout of a particular voltage level.
5. Measurement errors by resistive as well as capacitive loading are demonstrated using the oscilloscope with probes and a simple blackbox RC-network and a signal generator. From the DC, LF an HF response the students have to calculate values of the components inside this black-box. As an example the manual page of this task is printed in Fig.6.

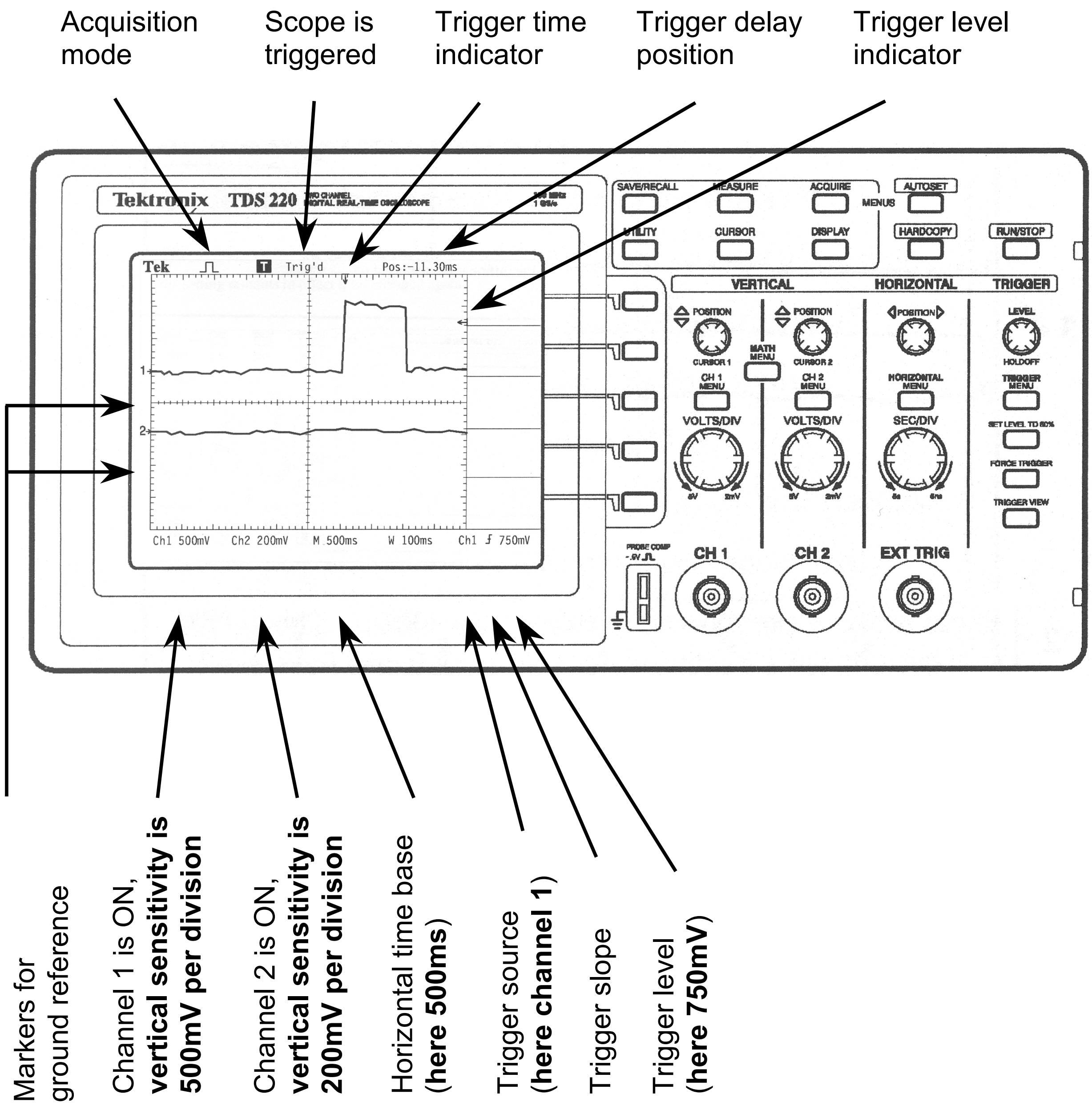
For each step there are questions that have to be answered. The potential of misuse of the attenuating probe received a relatively large attention. During the course the students are confronted with earth- and signal ground and safety problems and also with the limited performance of the low-cost signal generator. Problems associated with the sampling nature of the scope cannot always be ignored and are explained at the end of the course.

7 RESPONSE

This training course was offered twice during two consecutive academic years to about 180 students in total (1999/2000: 5 groups of about 20 students and 2000/2001: 4 groups of about 20 students). The general response was favourable. The students appreciated the detailed step by step approach and the emphasis on proper instrument operation. The calibration of the probe and the measurement of the RC network proved to be a convenient starting point for discussing complex impedances. Most students needed about 3 to 3-1/2 hours to finish. The students who were familiar with oscilloscopes (a small minority nowadays) needed about two hours and a half. The many questions also kept the attention of the more experienced students.

The course was designed to be included in the beginning of our Electrical Engineering curriculum, but can also be used for students of other disciplines, with minor changes and additional theory from the lectures.

Getting started (3): What the display indicates



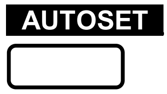
Question 2. *Connect a probe to the coaxial connector of channel 1. Next, the probe tip to the probe calibration source, called "probe comp". Select channel 1 as the triggering source. Give the horizontal sweep setting to display a single period of the test signal.*

Fig.2 Settings of the scope.

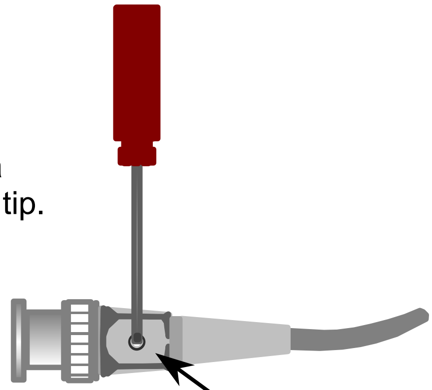
Correct use of the probe (1): Calibrating the probe

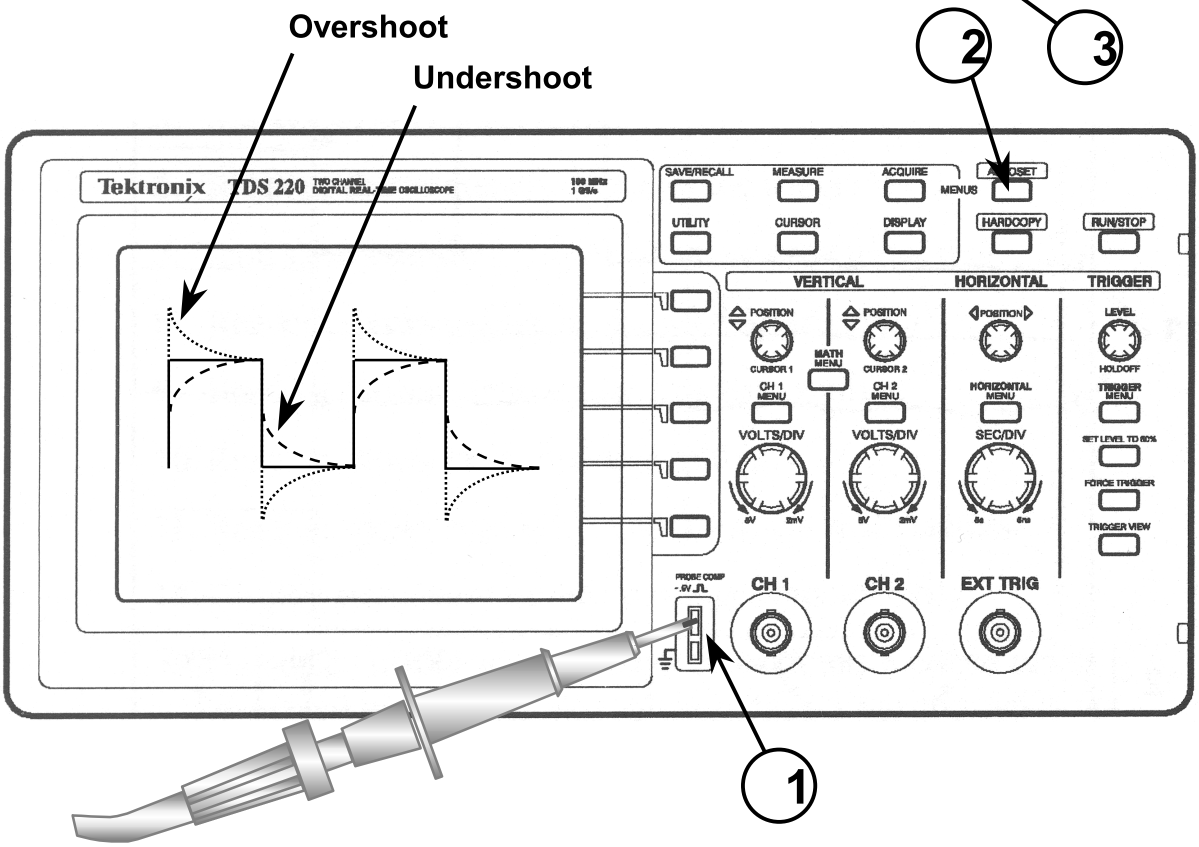
① **Connect the probe(s) tip(s) to the calibration source. Do not forget to connect the alligator clip to the ground of the calibration source.**

② **Let the scope 'choose' the right settings to display the signal traces on the display:**



③ **Now compensate the probe.**
Depending on the type of probe connected there is a small screw near the BNC connector or near the probe tip. Turn this screw gently until there is no overshoot or undershoot visible on the display. *Use the special plastic adjustment tool supplied with the probe. Never use an ordinary metal-blade screwdriver.*





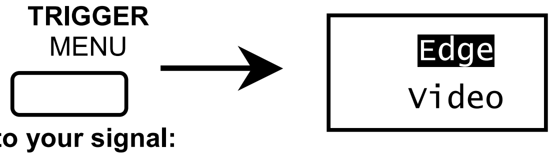
Question 4. *Draw the equivalent circuit of the probe plus input of the scope.*
Tip: Look in the book "Data acquisitie", chapter 4.

Fig. 3 Probe calibration

What the main controls do (2): Triggering

① **Check section 'Getting started (3)' on the triggering indicators (level, time and delay).**

② **To adjust triggering press**



③ **Now adjust the triggering according to your signal:**

Trigger slope: Selects triggering on the rising or falling slope

Trigger source: CH1, CH2, Ext(ernal source) or AC line

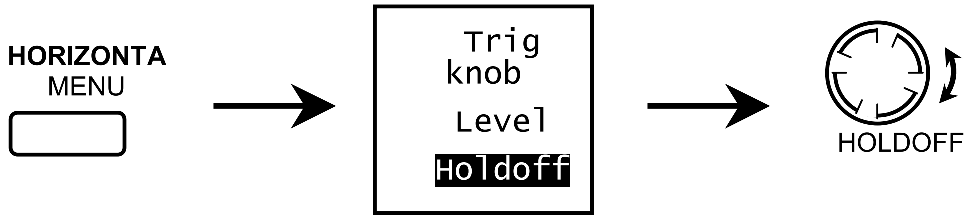
Trigger mode:

- Normal: The scope will only trigger if there is a trigger event
- Single: Is used to display one-time events: makes a single scan whenever the first trigger event occurs, or when the button "Force Trigger" is pressed. After the single scan, the display is frozen until the user presses "Force Trigger" again or switches to a different triggering mode.
- Auto: When the signal is unknown, the scope will adjust the trigger settings itself, until a suitable trigger signal is found: there is always a trigger and a display. *CAUTION: the scope's trigger event can be on a different event than the event you would like to trigger on!*

Trigger coupling:

- AC: Used if the signal of interest has large DC offset components
- DC: Passes all signal components (both DC and AC)
- Noise reject: Useful if the signal has a lot of spikes
- HF reject: Attenuates frequencies above 80kHz
- LF reject: Attenuates frequencies below 30kHz

④ If necessary, use trigger holdoff if the signal has multiple trigger level crossings per period, e.g. pulse trains or burst signals. This normally causes unstable displaying. Holdoff makes it possible to ignore the unwanted triggers for a user-defined time interval:



Question 7a. *Explain in which applications auto triggering does not work?*

7a1. *Finding small unwanted switch pulses ("glitches") in digital circuits*

7a2. *Measuring and testing analogue circuits using periodic input signal.*

7a3. *Monitoring of signals on a network cable.*

Question 7b. *If you have a signal described by $f(t)= 10+0.2\cos 100\pi t+0.4\sin 2\cdot 10^5\pi t$, explain what the best coupling, rejection and timebase settings are: 7b1. To display the 50Hz signal component 7b2. To display the high frequency (10^5Hz) component*

Fig 4. Triggering explained

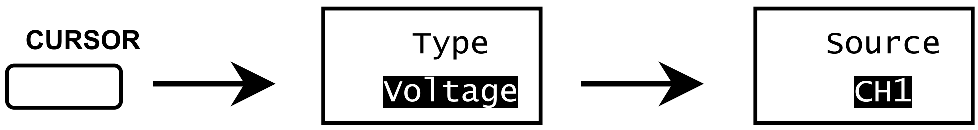
Measurements (1): Peak-to-peak voltage $V_{p\text{-}p}$

① **After trying the various settings on your scope in the previous sections, make sure the settings of your scope are reset to the factory defaults and that your probes are properly calibrated:**

- Reset your scope to the factory settings. Also see 'Getting started (1)'.
- Hook the probe onto channel 1 to the calibration source, and don't forget to check the attenuation setting (e.g. 10:1).
- *Adjust the display in such a way that only the BOTTOM of the probe calibration signal is completely visible, with the highest possible vertical sensitivity (thus, the lowest possible voltage setting per division).*

***Question 8a**. Note the vertical voltage setting, the vertical position and time base.*

- Now check the signal trace with a *cursor* to see if the calibration is accurate enough: First select the following:



- Now, adjust the cursors using the *vertical position* knobs to the following: place one cursor on the signal bottom which is flat and place the other cursor at the beginning of the signal bottom, which most likely shows some curvature, either over- or undershoot.

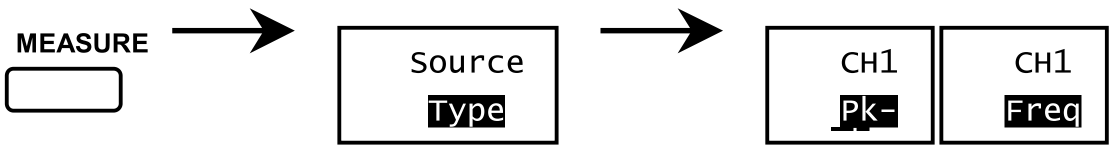
***Question 8b1**. Make sure the over/undershoot is less than 3mV. Tip: If the signal contains a lot of noise, you can decrease the noise level by averaging of the signal, found under the menu button "Acquire". Show the results to the 'student assistent'.*

***Question 8b2**. Repeat the same calibration check for channel 2.*

***Question 8c**. Use the two cursors to measure the peak-to-peak voltage $V_{p\text{-}p}$.*

***Question 8d**. Now set the cursor type to 'time' and determine the signal frequency f_s. Write these values down.*

② After determining the peak-to-peak voltage and frequency by hand (the hard way), now it's time to check your values with those of the oscilloscope. Use the following key setting, and make sure there is at least one full period of the calibration signal visible in your display:



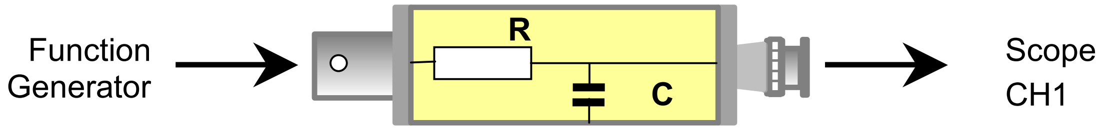
***Question 8e**. Compare $V_{p\text{-}p}$ and f_s read by the scope to your values. Explain any differences.*

***Question 8f**. Measure the mean value, peak-to-peak value and RMS values of the probe calibration signal. Compare the signal to those in Table 4.1 in "Data Acquisitie". What type of signal is the calibration signal? Now calculate the crest factor CF.*

Fig 5 Peak-to-peak voltage measurement exercise

Measurements (4): Step response

① In this experiment you will need the circuit box, which contains a low-pass RC network (i.e. high-frequency signals are blocked.) The layout of the box is shown in the figure below. During the measurement, the approximate values of both R and C will be determined, using the scope.



As a first step, the value of R will be determined now. Assume that for DC signals, the oscilloscope has an input resistance of 1MΩ.

③ Connect the function generator to the oscilloscope using a coaxial cable.

④ Set the function generator to provide a low freqency sine-wave of a few Hertz. This allows C to be ignored.

Question 11a. *Measure the peak-to-peak amplitude of the low-frequency signal.*

⑤ Now place the circuit box on CH1 of the oscilloscope and connect the input of the box to the function generator using a coaxial cable.

Question 11b. *Again measure the peak-to-peak amplitude of the signal.*

Question 11c. *From the ratio of 11a and 11b, determine the value of R.*
(This is the easiest when you draw the equivalent circuit, so you can see which two values you've measured.)

In the second step, the value of C will be determined.

⑥ Set the generator to provide a 1.5kHz square wave, with symmetry off, offset off and level 1x.

⑦ Set the oscilloscope timebase to 50μs/div.

Question 11d. *Measure the peak-to-peak amplitude and the time τ (the so-called time constant). This is the time elapsed for the signal to rise from 0% to 63% of the maximum amplitude. Explain how you measured τ.*

Question 11g. *Assuming τ=RC, calculate the value of C in the circuit box.*

⑧ Connect the probe to CH1, with an attenuation factor of 10x. Use the coaxial adapter and gender changer to connect the probe to the circuit box.

Question 11e. *Again measure the peak-to-peak amplitude and τ.*

Question 11f. *Explain the difference in results.*

Fig.6 Black-box measurement exercise