Electrical Measurements Revisited — Experiences from Modernizing the Course

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Introduction

- to make an honest presentation, or a politically correct one?
- what the presentations are for?
- to say something which is **not** in the paper!
- otherwise the paper would be enough!
- so, an honest one!
- Electrical Measurements, sophomore class ...
- shared between at least three departments ...
- different teachers, different students, different **interests**, different views, lots of compromising ...
- result: patchwork shared among teachers that disagree
- the only common point: a lab with obsolete equipment
- an administrative opportunity no one thought about: to split the class into groups, customize as needed
- let's use it!

Introduction

- I'm in charge for the Department of Electronics
- motivated students, capable, with interest in hardware, making, creating, measuring, verifying . . .
- I believe in the use of computers!
- and I believe in free software . . .
- which I use in my everyday practice for everything . . .
- including automated measurement systems . . .
- so I could teach my students ("the kids") like they are my own kids, the best I can, topics I believe in
- to be capable, responsible, and independent
- so, let's start

Basic Principles

1. **real world principle**: to teach measurements on the equipment used in everyday practice, in the way they are performed in everyday practice
2. **up to date principle**: to use computers in the way they are used (or should be used) in everyday practice; forget about "a discipline that requires tedious work"; don't calculate by hand in the 21-st century, just to train muscles, not brain
3. **integrating principle**: students tend to treat courses as separate entities, pass the exam and forget approach; measurements are useful, measurements are needed; integrate the knowledge with other courses! support each other; illustrate the theory in practice!
4. **support excellence principle**: don't focus to average, or even worse, below average students; provide enough material to motivate the best students to go further, to improve! require only fundamental skills and topics to pass; encourage students to learn more if they are able and motivated!

Equipment

six benches, twelve students simultaneously in the lab, equippment:

1. Tektronix TDS 1002 + communication port
2. Agilent 33220A signal generator
3. Agilent E3630A triple output DC power source
4. an obsolete computer, Linux Mint MATE
5. two Fluke 111 multimeters
6. one DT-838 or RTO-1035N multimeter
7. protoboard
8. a set of elementary electronic components

mostly thanks to Tempus JEP 17028-02 project

Standard Workbench

Lab Exercises

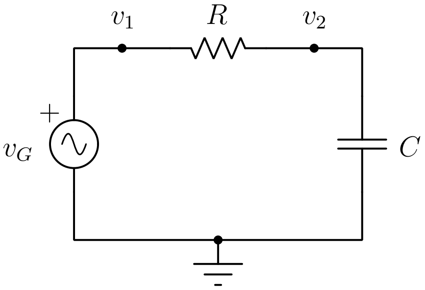
- 12 students simultaneously in the lab
- whenever possible, doing the same exercise
- two supervisors, competent
- already acquired knowledge: measurement of current, voltage, and resistance
- prerequisites are a sort of problem ...
- but with good students, not a real problem
- goal to illustrate concepts learned in Fundamentals of Electrical Engineering and Electric Circuit Theory
- good personal cooperation
- in parallel with Software Tools in Electronics course ...
- which I teach
- so the teachers agree!
- idea: to gain benefit for all courses involved!

Lab 1: Multimeter, DC Power Source, Protoboard

- not a big deal of measurement?
- well, just the opposite!
- practice, learn and remember, we won't get back!
- three voltmeters measuring the same voltage?
- yup! however, the readings are different!
- amazingly, the students were amazed!
- correlate the measurements, linear least squares, practice, Python Linux Mint MATE, look and feel similar to what students were familiar with
- measure resistance, protoboard, measure current and voltage, fith a line through the readings, linear least squares once again
- learn and **remember**! will be used later on!

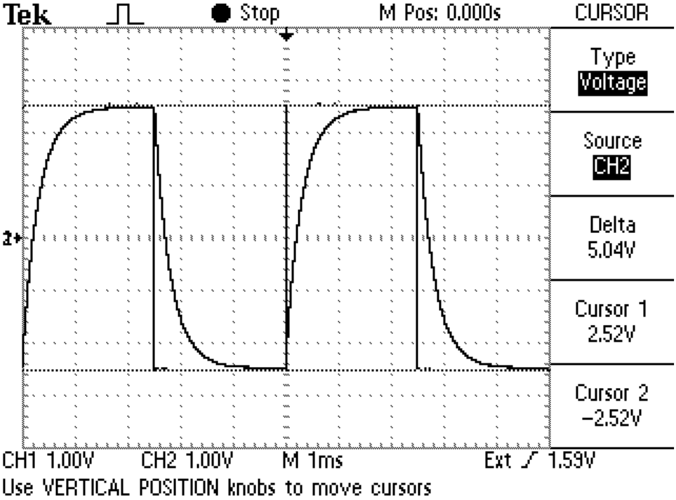
Lab 2: Oscilloscope and Signal Generator

- signal generator settings, manual: waveform type, voltage levels, period, frequency, duty ratio
- oscilloscope settings, manual; coupling, voltage scale, time scale, trigger
- synchronization methods
- assemble circuit, measure capacitance by measuring rise time



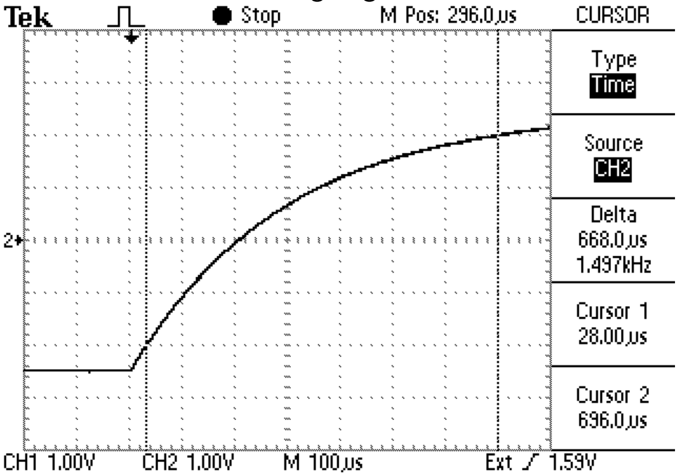
Lab 2: Oscilloscope and Signal Generator

capacitance measurement, waveform



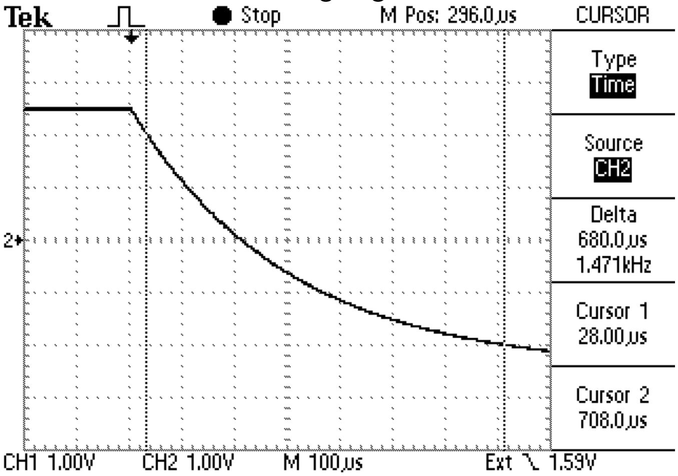
Lab 2: Oscilloscope and Signal Generator

capacitance measurement, rising edge



Lab 2: Oscilloscope and Signal Generator

capacitance measurement, falling edge

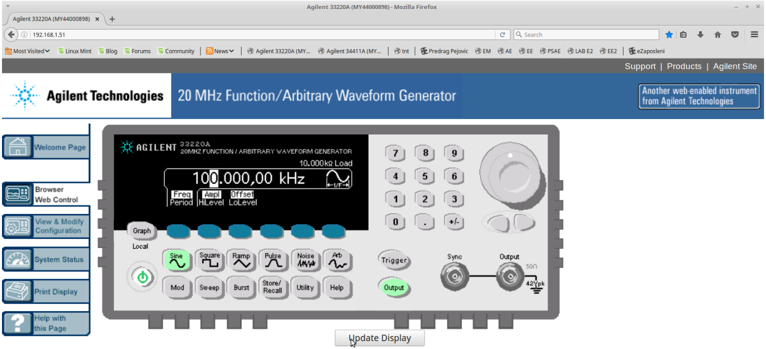


Lab 3: Control of Instruments Using a Computer, Automated Measurements, and Statistical Processing of Measurement Results

- really new!
- some experience in GNU/Linux assumed, very basic
- Python used to control instruments, not a prerequisite
- `ping`, verify connection, set IP address
- Agilent 33220A internal web server, web control of the instrument
- LXI compliant instruments, SCPI commands
- queries for the oscilloscope direct measurement
- statistical processing of measurement data, voltage average, 10 measurements manually, 100 and 1000 measurements automatically
- voltage divider, transfer curve, linear least squares
- the oscilloscope input impedance emerged as an auxiliary teaching topic

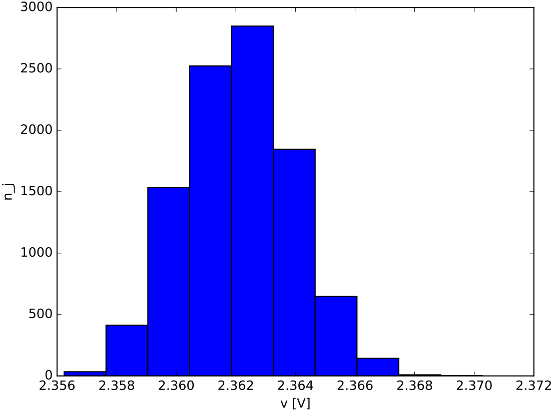
Lab 3: Control of Instruments Using a Computer, Automated Measurements, and Statistical Processing of Measurement Results

signal generator, browser control



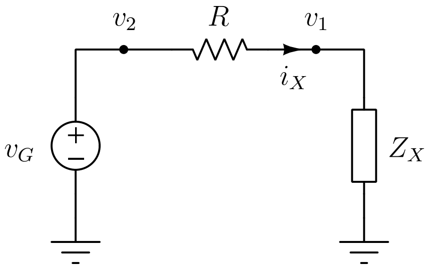
Lab 3: Control of Instruments Using a Computer, Automated Measurements, and Statistical Processing of Measurement Results

repeated voltage measurements, histogram



Lab 4: Impedance Measurement Using Oscilloscope

- relatively few new elements
- integrate previous exercises
- synchronized with Electric Circuit Theory course
- the circuit:



$$i_X = \frac{v_2 - v_1}{R}$$

Lab 4: Impedance Measurement Using Oscilloscope

just some formulas ...

- $R_X = R \, \dfrac{V_1}{V_2 - V_1}$
- $X_X = R \, \dfrac{V_1}{\sqrt{V_2^2 - V_1^2}}$
- $C_X = \dfrac{1}{2 \, \pi \, f \, R} \, \dfrac{\sqrt{V_2^2 - V_1^2}}{V_1}$
- $V_k, \; k \in \{1, \, 2\}$ RMS or Pk-2-Pk values? Different statistics! Students are able to see the difference!

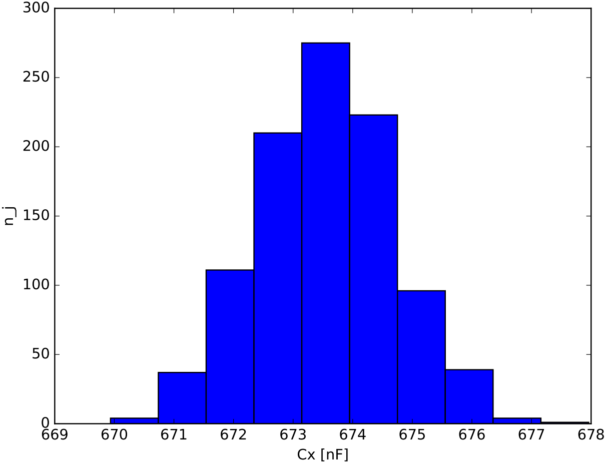
Lab 4: Impedance Measurement Using Oscilloscope

just some more formulas . . .

- capacitor, relate voltage and charge
- $q_{C0}[k] = \Delta t \sum_{0}^{k} i_C[k]$
- $q_0 = \frac{1}{n} \sum_{0}^{n-1} q_{C0}[k]$
- $q_C[k] = q_{C0}[k] - q_0$
- linear least squares assuming $q_C = C\, v_C$, determine C
- similar to determining R using voltage divider
- statistics?
- $q_C\,(v_C)$ curve?
- similar for inductors; ellipse?
- very few new elements
- however, turned out to be difficult!

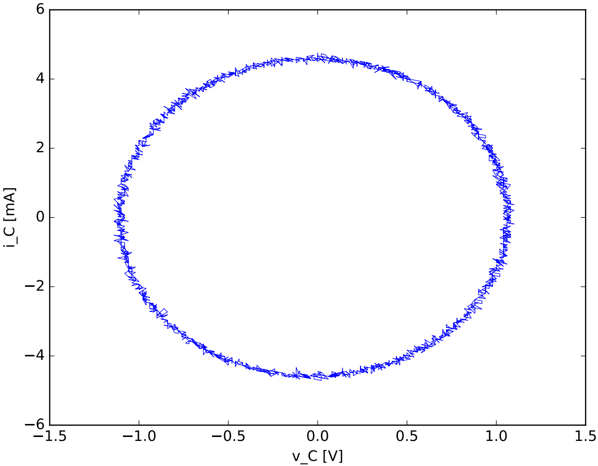
Lab 4: Impedance Measurement Using Oscilloscope

repeated capacitance measurement, RMS, histogram



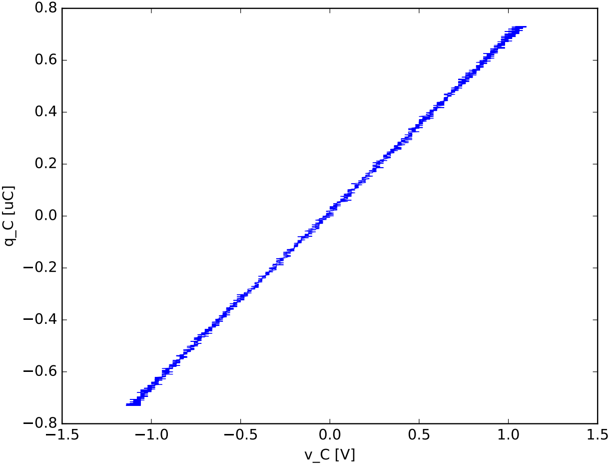
Lab 4: Impedance Measurement Using Oscilloscope

i_C versus v_C



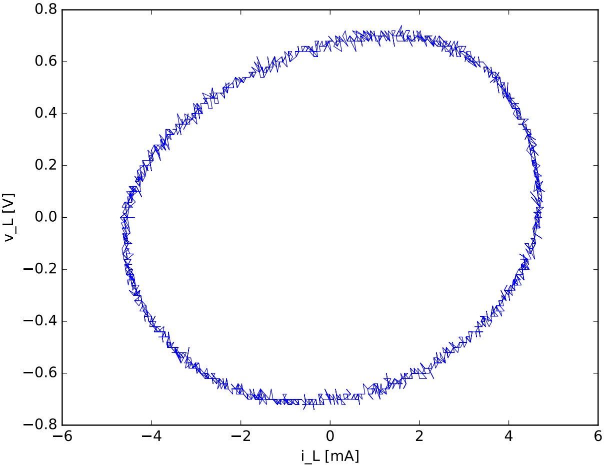
Lab 4: Impedance Measurement Using Oscilloscope

q_C versus v_C



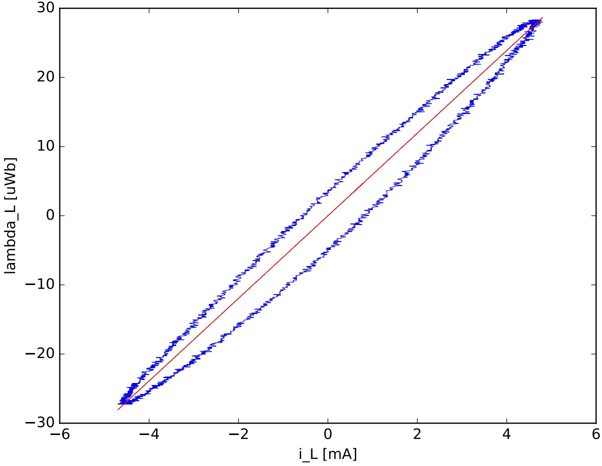
Lab 4: Impedance Measurement Using Oscilloscope

v_L versus i_L



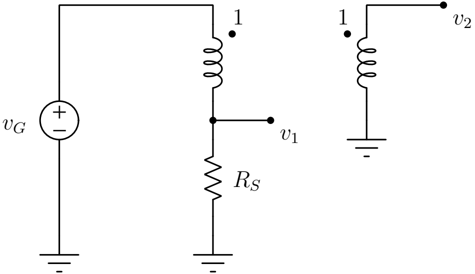
Lab 4: Impedance Measurement Using Oscilloscope

λ_L versus i_L



Lab 5: Analysis of Nonlinear Elements and Systems Using Oscilloscope

- theoretically demanding!
- how to measure magnetizing curve?
- careful in connecting!
- hysteresis curve
- mutual inductance
- dependence of mutual inductance on bias current



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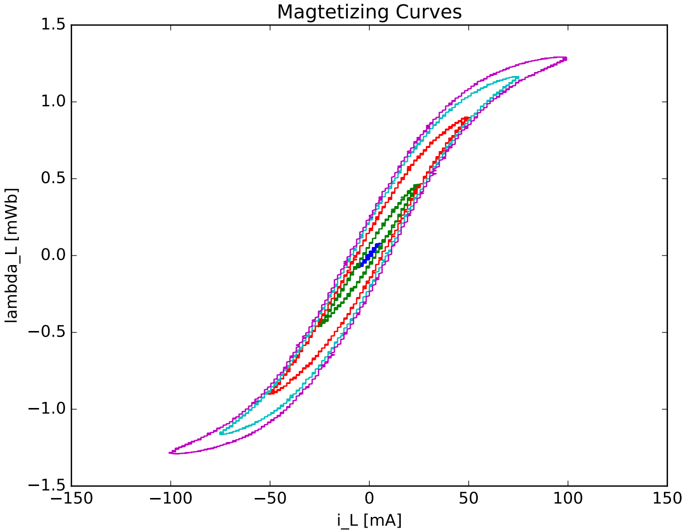

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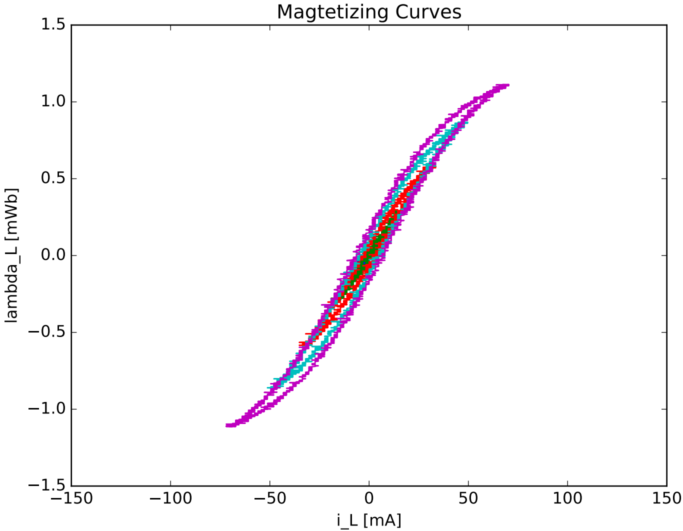

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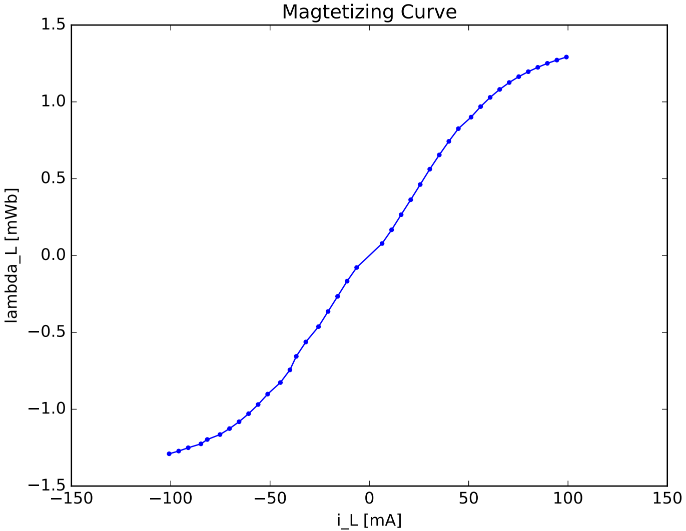

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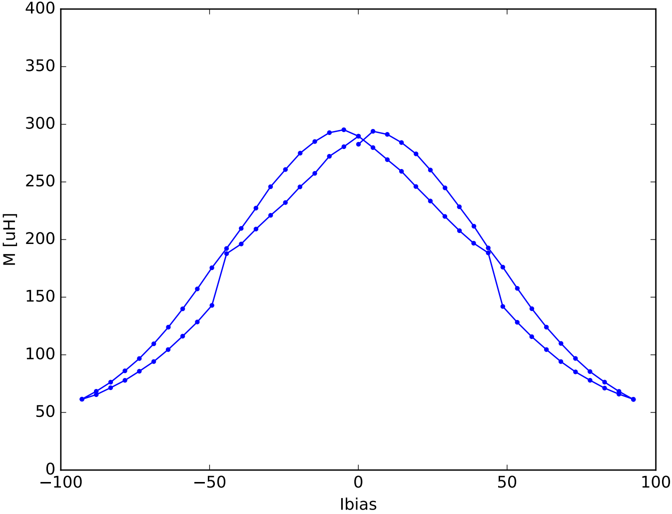

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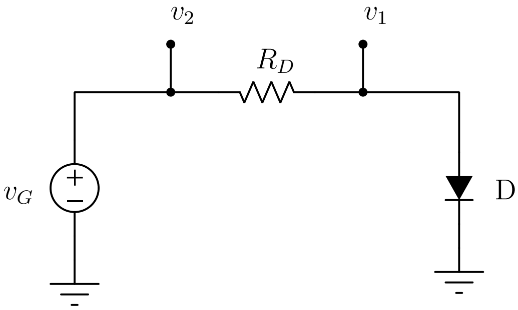

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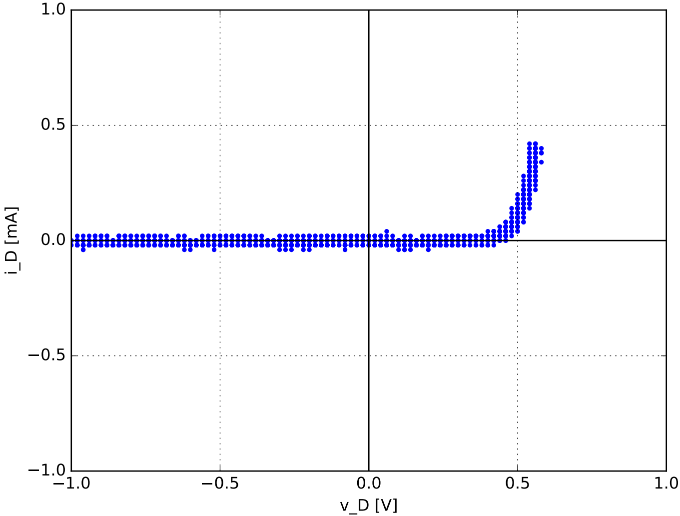

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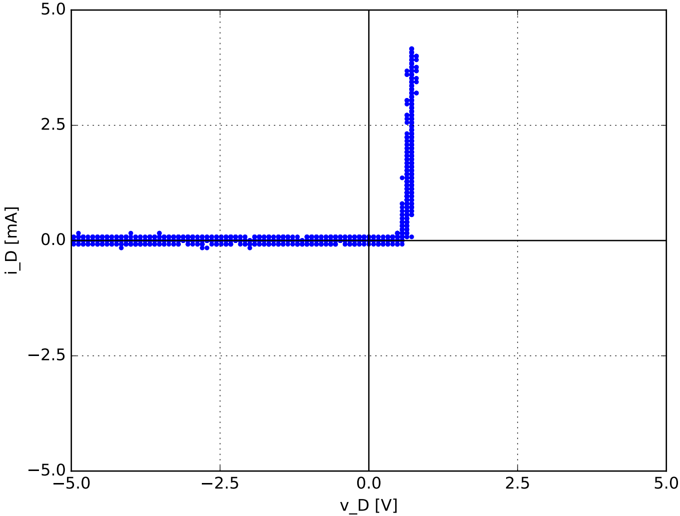

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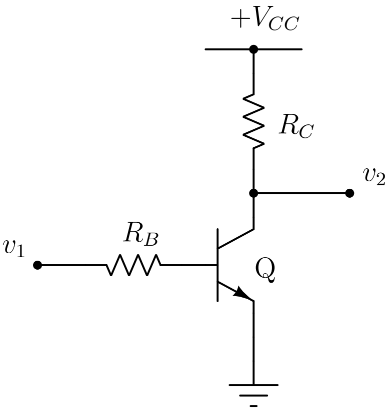
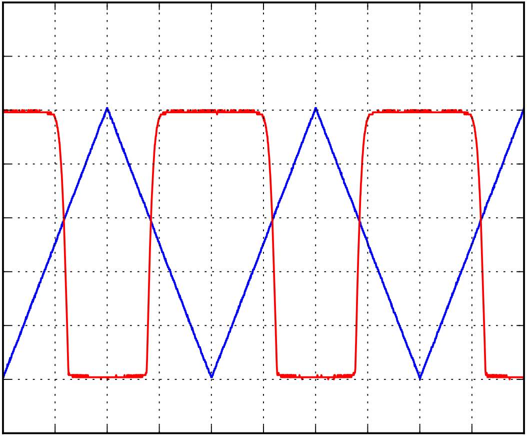


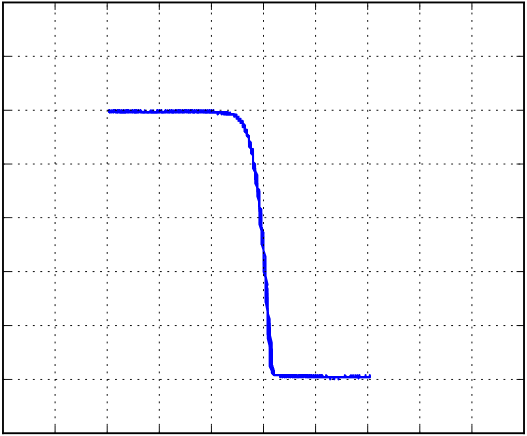
Lab 5: Analysis of Nonlinear Elements and Systems Using Oscilloscope

v_1 and v_2



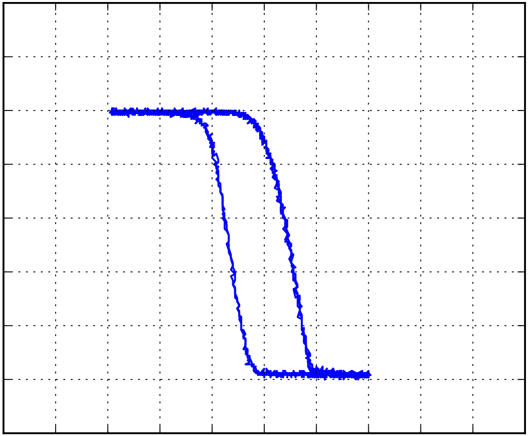
Lab 5: Analysis of Nonlinear Elements and Systems Using Oscilloscope

v_2 versus v_1, $f = 100\,\text{Hz}$



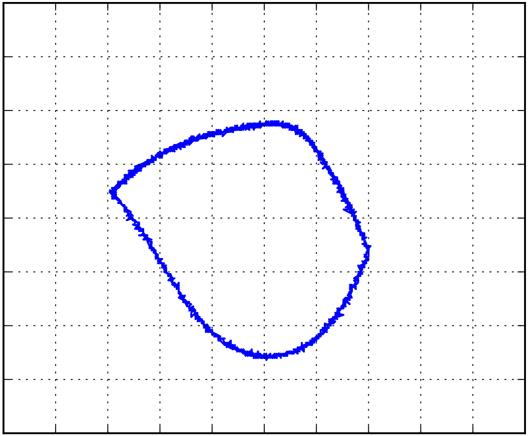
Lab 5: Analysis of Nonlinear Elements and Systems Using Oscilloscope

v_2 versus v_1, $f = 10\,\mathrm{kHz}$



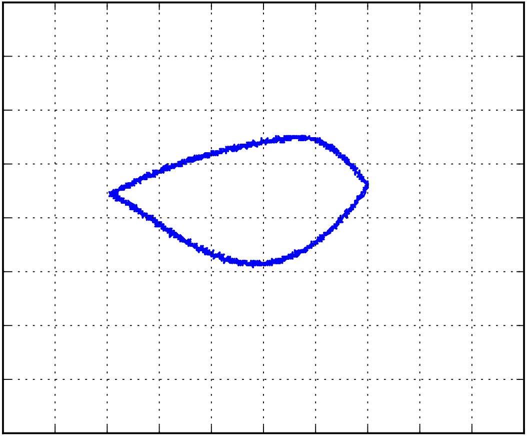
Lab 5: Analysis of Nonlinear Elements and Systems Using Oscilloscope

v_2 versus v_1, $f = 100\,\text{kHz}$

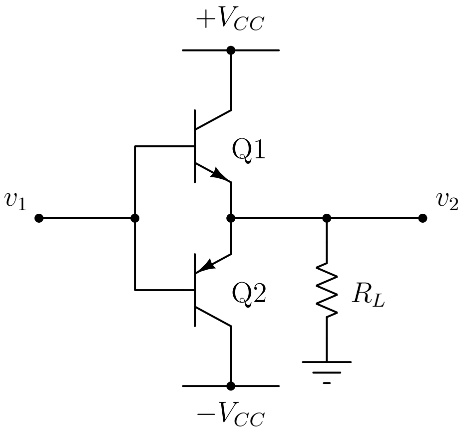


Lab 5: Analysis of Nonlinear Elements and Systems Using Oscilloscope

v_2 versus v_1, $f = 200\,\mathrm{kHz}$

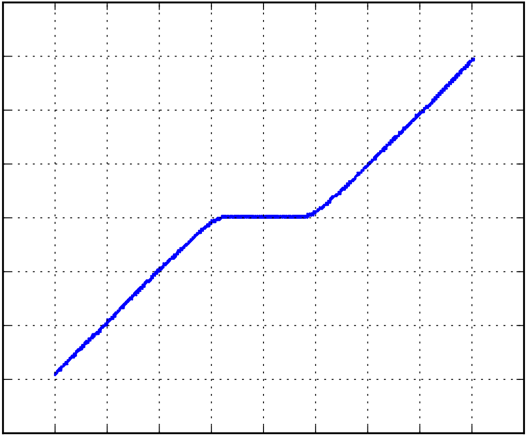


Lab 5: Analysis of Nonlinear Elements and Systems Using Oscilloscope



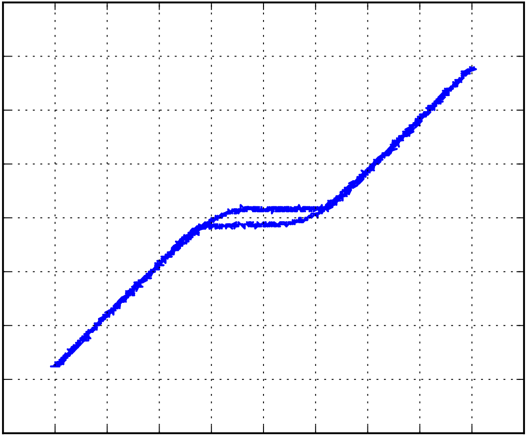
Lab 5: Analysis of Nonlinear Elements and Systems Using Oscilloscope

v_2 versus v_1, $f = 1\,\text{kHz}$



Lab 5: Analysis of Nonlinear Elements and Systems Using Oscilloscope

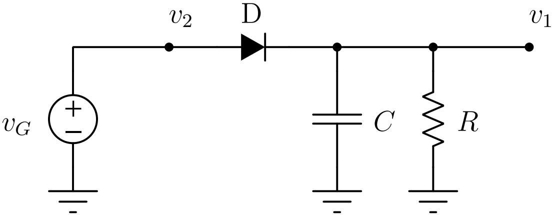
v_2 versus v_1, $f = 10\,\text{kHz}$



Lab 6: Measuring Parameters of AC Waveforms

- classical, common topic
- a little bit obsolete: I was not able to find to buy non-true-RMS instruments!
- still some educational value: diodes, real diodes, rectification, half-wave, full-wave
- both in voltmeters and ampere meters
- diode forward voltage drop, limitations at low voltages
- peak voltage detectors and their frequency response
- natural extension: envelope detector, link to Telecommunications course

Lab 6: Measuring Parameters of AC Waveforms



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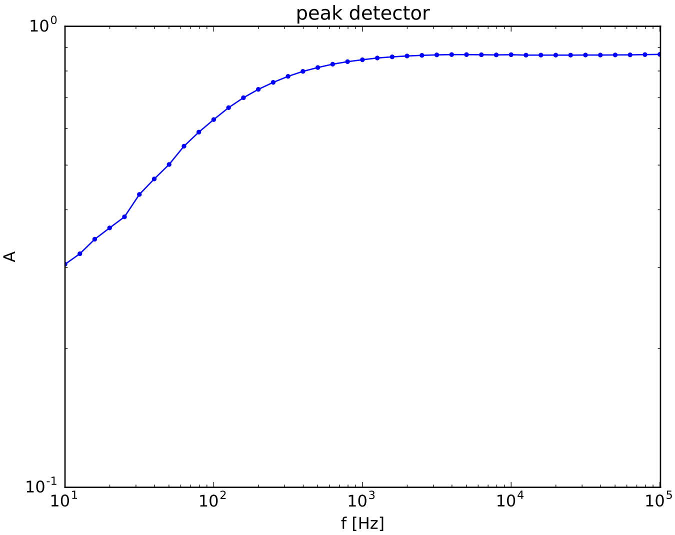

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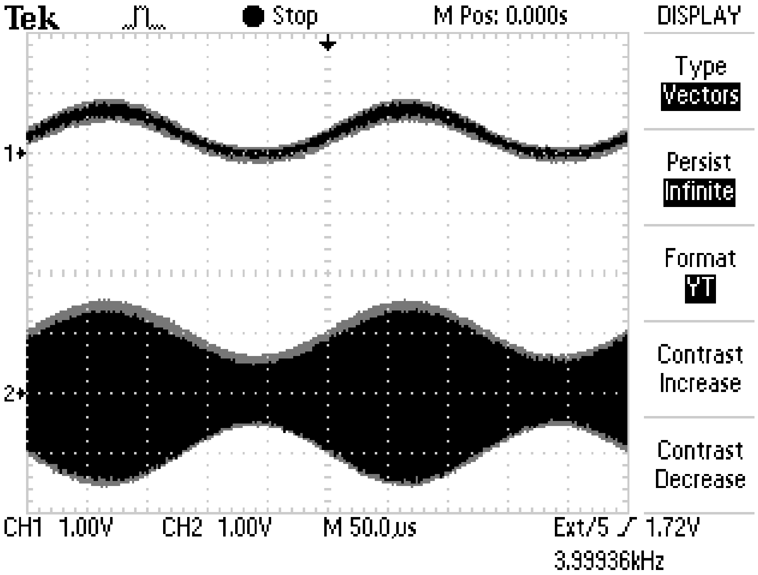
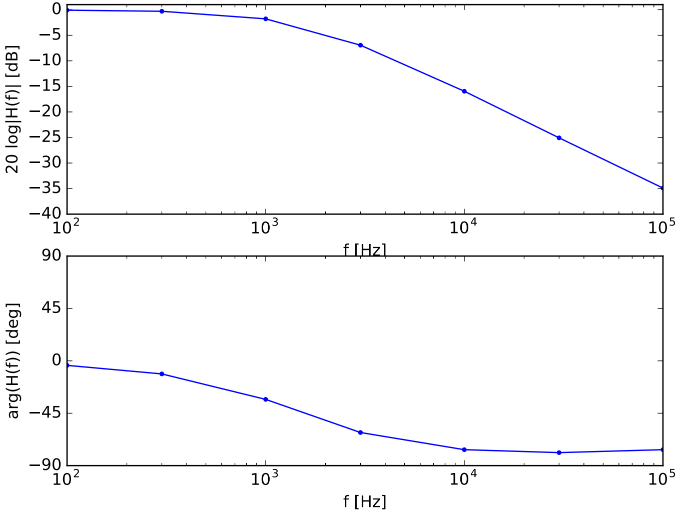


Lab 7: Frequency Response and AC bridges

- two topics: how are they related?
- they share the same course, which lacks spacetime
- frequency response: RC low-pass, RC high-pass, RLC band-pass
- bridge to Electric Circuit Theory
- aim: measure phase, emphasis on its **sign**
- manual measurements, especially phase
- frequency response of the oscilloscope input AC filter
- bridges are the classical topic
- De Sauty bridge, potentiometer to balance
- Maxwell bridge
- Wien bridge, to assemble and to measure frequency of the phase resonance

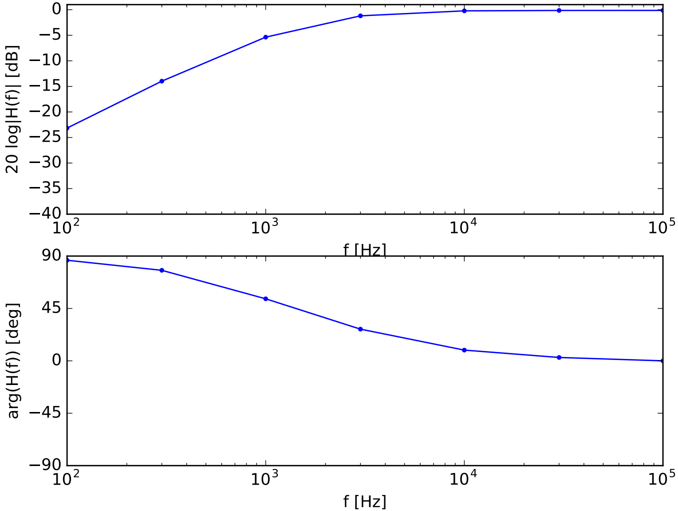
Lab 7: Frequency Response and AC bridges

frequency response of the low-pass filter



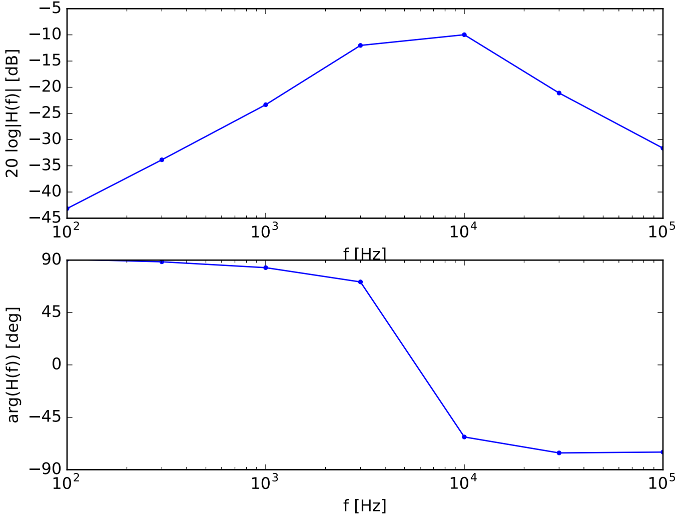
Lab 7: Frequency Response and AC bridges

frequency response of the high-pass filter



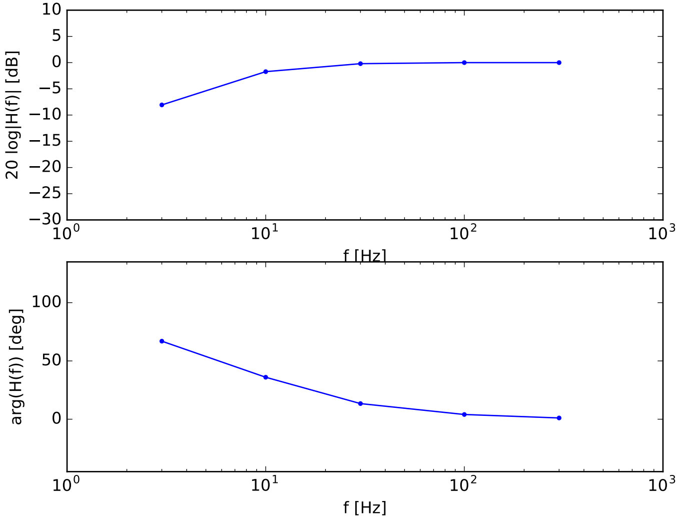
Lab 7: Frequency Response and AC bridges

frequency response of the band-pass filter



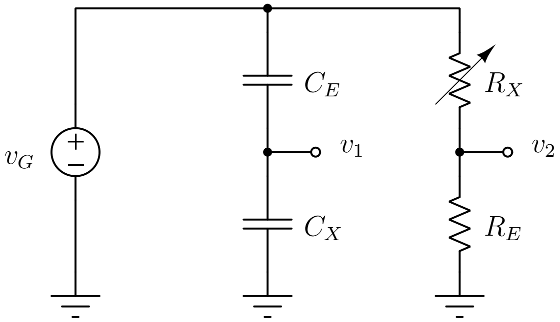
Lab 7: Frequency Response and AC bridges

frequency response of the oscilloscope input filter



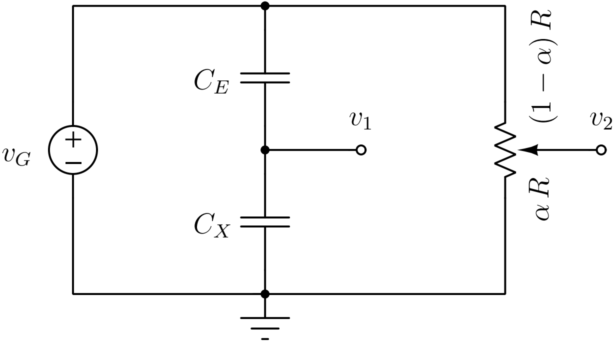
Lab 7: Frequency Response and AC bridges

De Sauty bridge, assemble and measure, protoboard



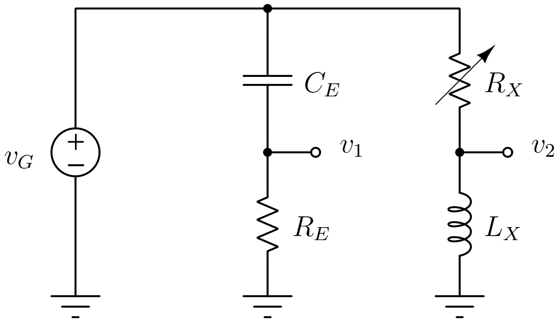
Lab 7: Frequency Response and AC bridges

De Sauty bridge with potentiometer, angle versus capacitance, no computing, assemble and measure, protoboard



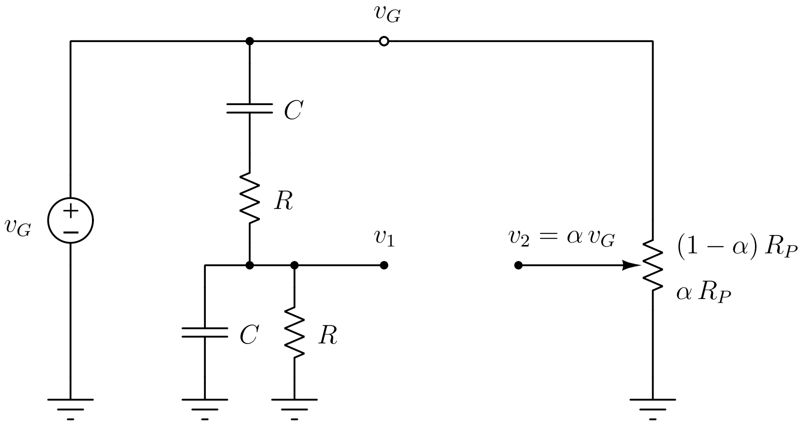
Lab 7: Frequency Response and AC bridges

Maxwell bridge, assemble and measure, protoboard



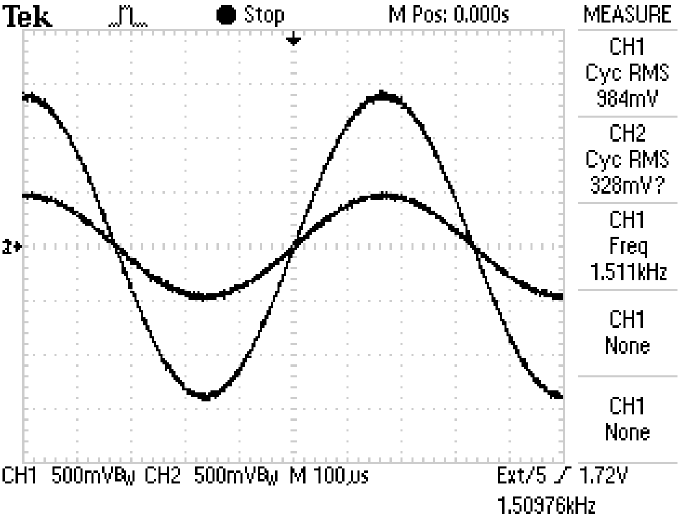
Lab 7: Frequency Response and AC bridges

Wien bridge, assemble and measure, protoboard



Lab 7: Frequency Response and AC bridges

Wien bridge, phase resonance

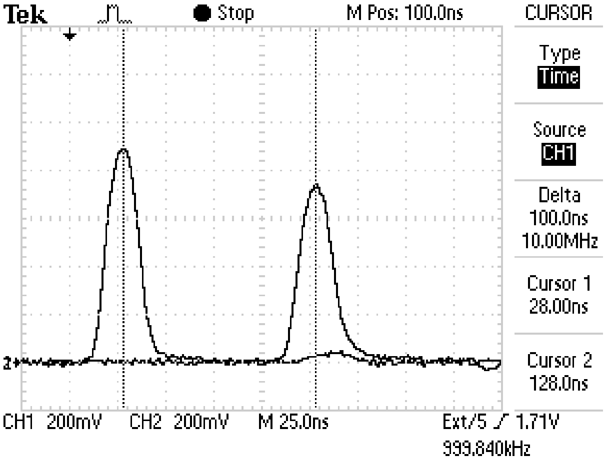


Lab 8: Measurements on Circuits with Distributed Parameters

- something really new
- to support Electric Circuit Theory course
- transmission lines are just a bunch of boring equations?
- never ever truly understood, at the end of the course, lack of time, boring, ...
- let's see the lines in real life
- a cable from an old computer network, recycled

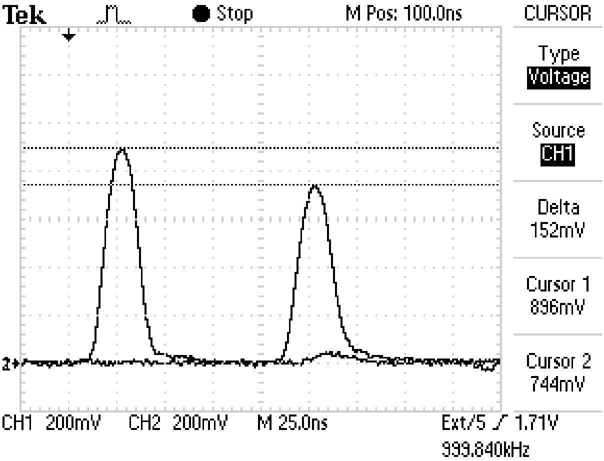
Lab 8: Measurements on Circuits with Distributed Parameters

propagation, delay



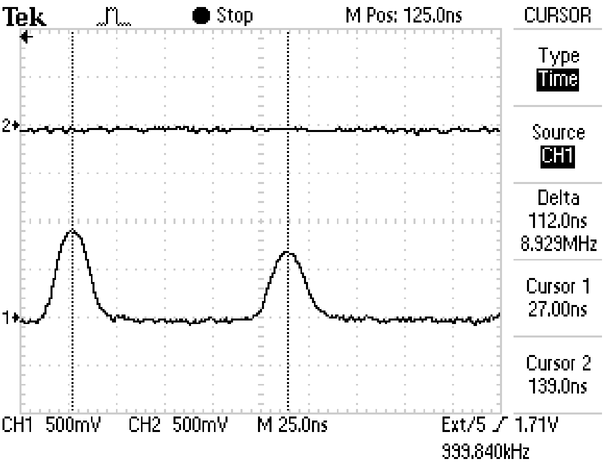
Lab 8: Measurements on Circuits with Distributed Parameters

propagation, attenuation



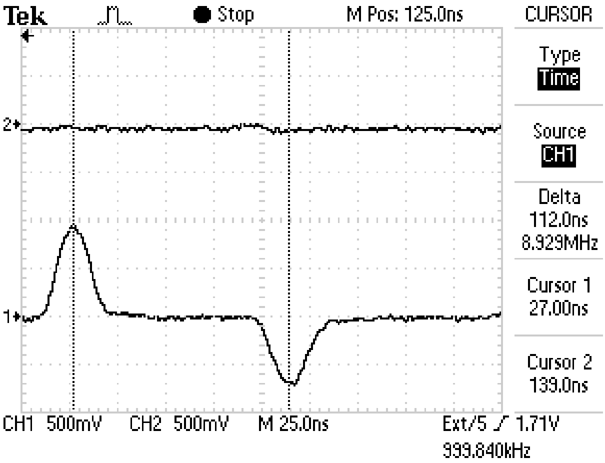
Lab 8: Measurements on Circuits with Distributed Parameters

reflection, open



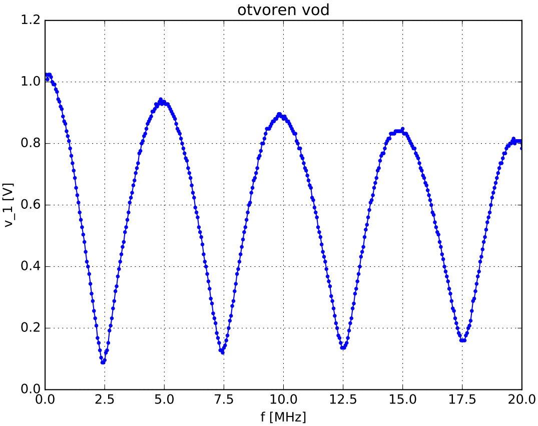
Lab 8: Measurements on Circuits with Distributed Parameters

reflection, short



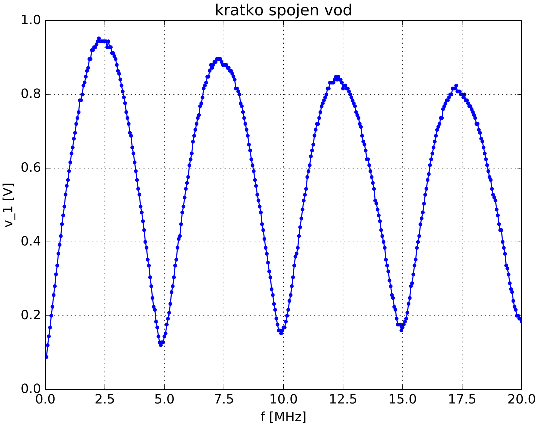
Lab 8: Measurements on Circuits with Distributed Parameters

voltage at the input versus frequency, open



Lab 8: Measurements on Circuits with Distributed Parameters

voltage at the input versus frequency, short



Experiences and Plans to Improve the Course

- something quite unexpected and new
- students worked hard during the lab sessions
- we had hard time to kick them out of the lab
- they **enjoyed** the lab!
- maybe a little bit too much
- questionnaire at the and, last minute idea
- 8 or 10 exercises?
- 80% voted for 10!
- really affirmative response

Grading

- 20% lab performance, during the exercises
- 20% lab performance, lab exam, the students are assigned to measure something, really close to the measurements they already did; however, this time they are alone, no pairs
- 60% written test
- really good results!
- almost all of the students already completed the exam with very good grades!

Conclusions

- a reformed course in Electrical Measurements presented
- customized to Electronics majors
- based on four principles
- computers heavily involved
- only free software!
- no donations, no dependence, everything open
- eight newly designed lab exercises
- understanding focused, not manual work
- everything available at http://tnt.etf.bg.ac.rs/~oe2em/
- success!
- students enjoyed the course!
- but even more surprising: teaching assistants and teacher enjoyed the course!