An Automated System for Frequency Response Measurement Based on Free Software Tools

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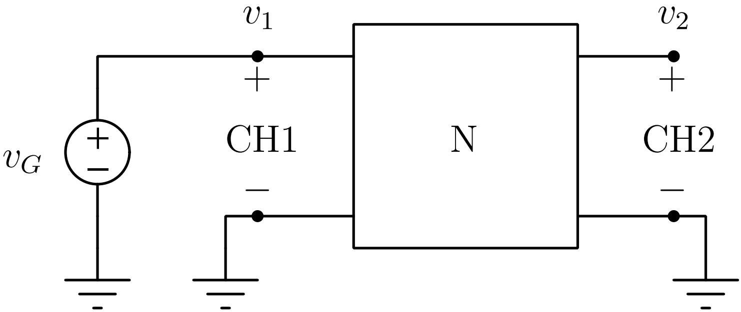
introduction

- we need frequency response … $\underline{H}(j\omega)$, $\underline{Z}(j\omega)$, $\underline{Y}(j\omega)$
- transmittance and immitance, total of 6, we cover 3 …
- important … communications, control systems, …
- Bode plot, Nyquist plot …
- measure manually?
- tedious, prone to error, people tend to avoid …
- automation?
- general purpose equipment
- exclusive use of free software
- equipment and software budget: $0\,\$ = 0\,£ = 0\,€ = 0$ …
- relied only upon what we already had …

the system

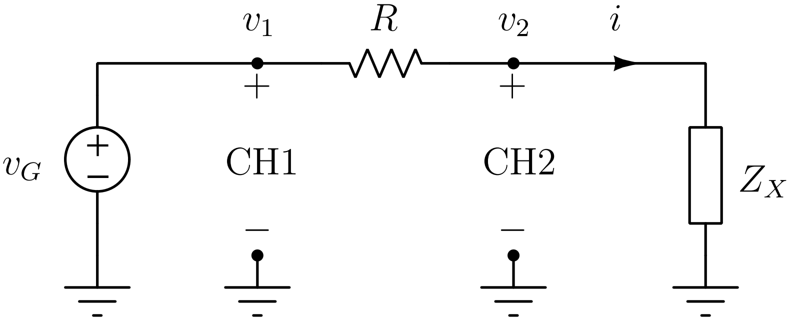
- waveform generator Agilent 33220A
- digital oscilloscope Tektronix TBS 1052B-EDU
- both instruments connectable, with SCPI commands!
- personal computer under Ubuntu or Mint
- Python and appropriate modules

transmittance ...



$$\underline{H}(j\omega) = \frac{\underline{V}_2}{\underline{V}_1}$$

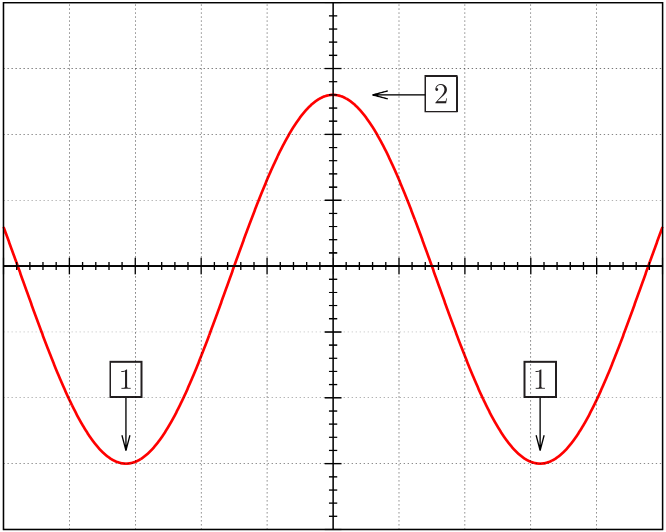
immittance . . .



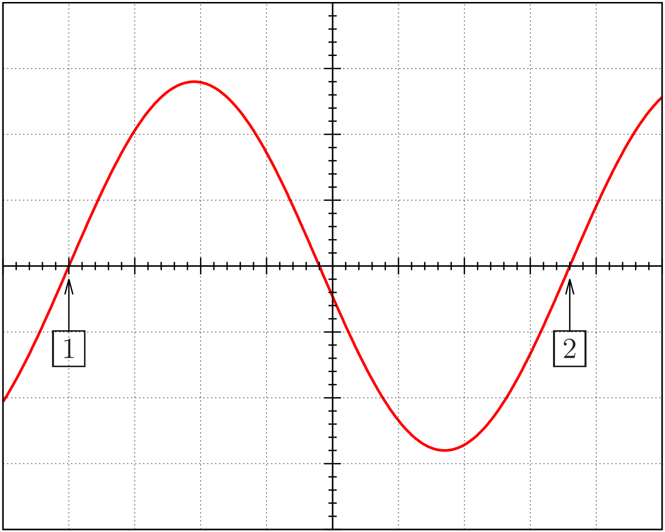
$$i = \frac{v_1 - v_2}{R}, \; \underline{Z}_X(j\omega) = \frac{\underline{V}_2}{\underline{I}}$$

the setup

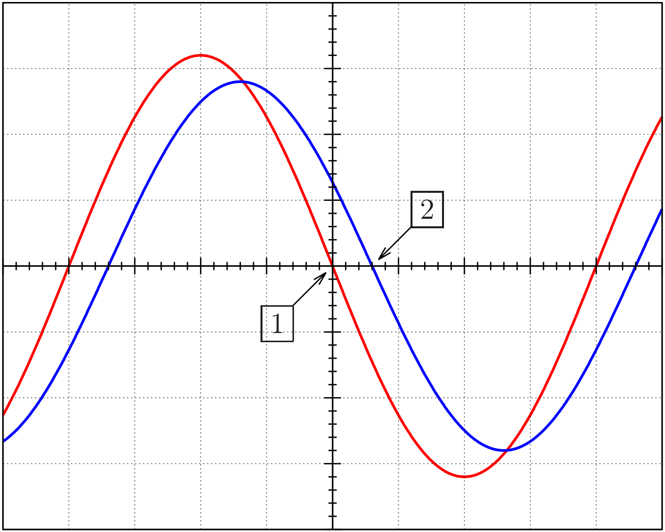
manual, measurement of the amplitude



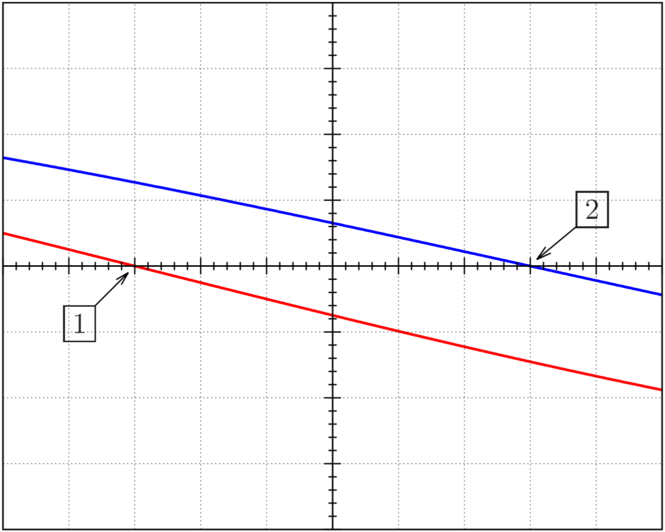
manual, measurement of the period



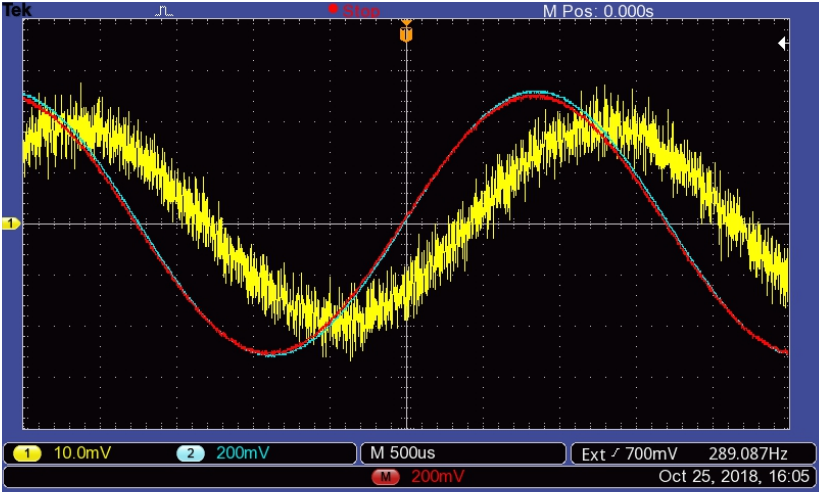
manual, measurement of the time delay



manual, measurement of the time delay



real life . . .


Tek
Stop
M Pos: 0.000s
1
1 10.0mV
2 200mV
M 500us
Ext 700mV
289.087Hz
M 200mV
Oct 25, 2018, 16:05

Plato, "Theory of Forms," versus oscilloscope

- Plato's waveforms:
  1. two samples to measure amplitude (twice, two signals to measure amplitude)
  2. two samples to measure period (in the case it is not already known)
  3. two samples to measure time delay
- in Plato's world of ideal (wave)forms we need the total of 8 samples to determine transmittance or immitance, or 6 samples if we already knew the frequency!
- but in the real life we have noise . . .
- . . . and 2500 samples per waveform per frame!
- filtering the noise out?
- good luck: we knew the frequency, we set it!

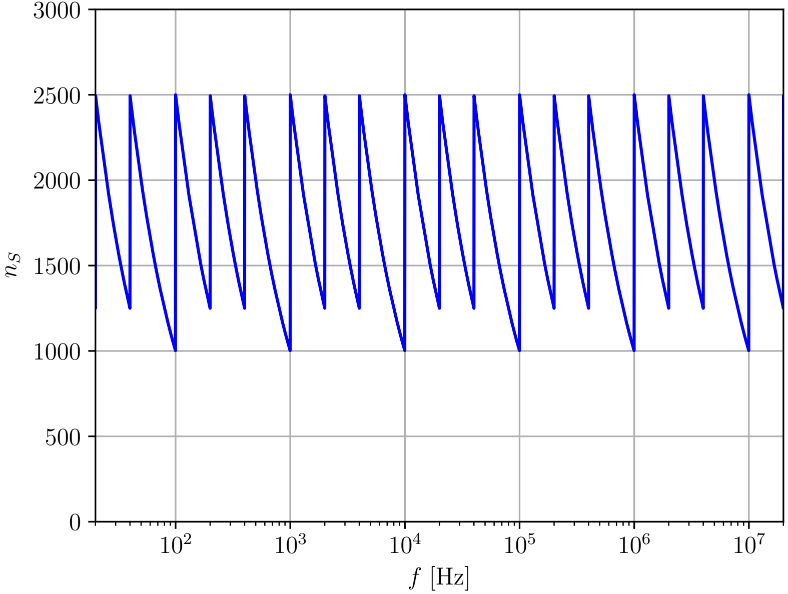
the algorithm

input data: frequency range, number of points per diagram, amplitude of the waveform generator voltage

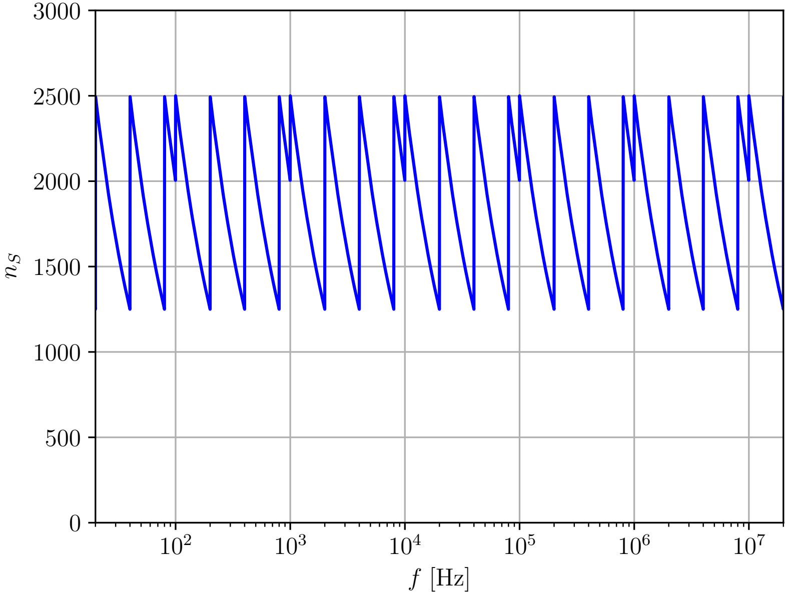
1. set the frequency
2. select the horizontal axis scale
3. select the vertical axes scale, autorange when needed, maximize resolution
4. select the number of samples to cover a whole number of periods, 1 or 2
5. get the samples
6. process the data point
7. loop back to the next data point

output data: transfer function diagram and the data used to plot the diagram

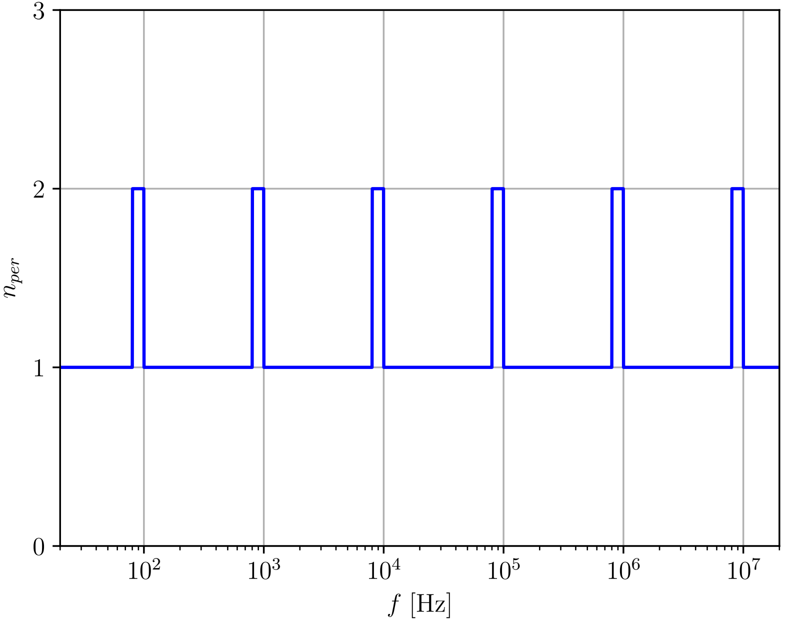
the algorithm: selecting the number of samples



already obsolete: a step forward . . .



already obsolete: a step forward . . .



data processing

- $k \in \{0, \dots n_S - 1\}$
- $c_k = 2\,\cos\left(2\,\pi\,n_{per}\,\frac{k}{n_S}\right)$
- $s_k = 2\,\sin\left(2\,\pi\,n_{per}\,\frac{k}{n_S}\right)$
- $X_C = \dfrac{1}{n_S}\displaystyle\sum_{k=0}^{n_S-1} x_k\,c_k$
- $X_S = \dfrac{1}{n_S}\displaystyle\sum_{k=0}^{n_S-1} x_k\,s_k$
- $X_m = \sqrt{X_C^2 + X_S^2}$
- $\varphi_x = \mathrm{atan2}\,(X_S,\,X_C)$
- the same for y_k sequence

computing the transfer function

- $|H(j\,\omega_0)| = \dfrac{Y_m}{X_m}$
- $\varphi_H = \varphi_y - \varphi_x$
- but $-\pi < \varphi_x, \, \varphi_y \leq \pi$
- defined this way $-2\,\pi < \varphi_H \leq 2\,\pi$
- reduction to $-\pi < \varphi_H \leq \pi$, phase adjustment?
- $\varphi_t = \varphi_y - \varphi_x$
- $\varphi_H = \begin{cases} \varphi_t, & -\pi < \varphi_t \leq \pi \\ \varphi_t - 2\,\pi, & \varphi_t > \pi \\ \varphi_t + 2\,\pi, & \varphi_t \leq -\pi. \end{cases}$
- and we are done! one point is done, at least ...
- iterrate ...

Python modules needed ...

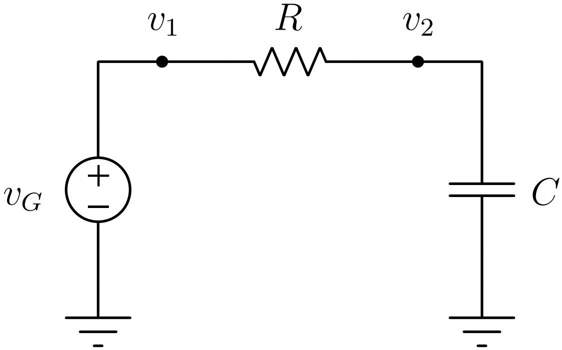
- `usbtmc`, to communicate with the oscilloscope and the waveform generator
- `numpy`, to perform computations and to store the data
- `matplotlib`, to do the plots
- maybe `os` and `sys` ...

a little bit arranged, though ...

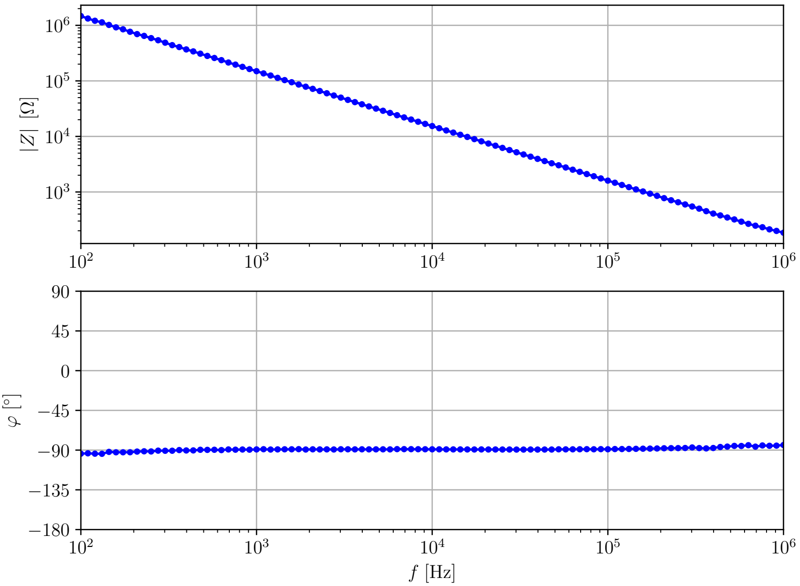
- `pylab`, just as an environment
- `oscusb`, available at
  http://tnt.etf.bg.ac.rs/~oe2em/oscusb.py

everything available at:
http://tnt.etf.bg.ac.rs/~oe2em/freqresp.zip

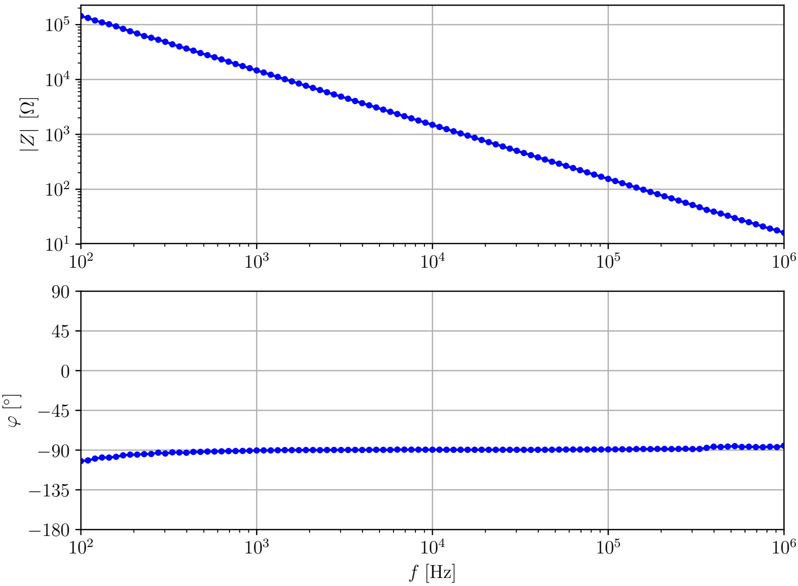
experimental results: capacitor impedance



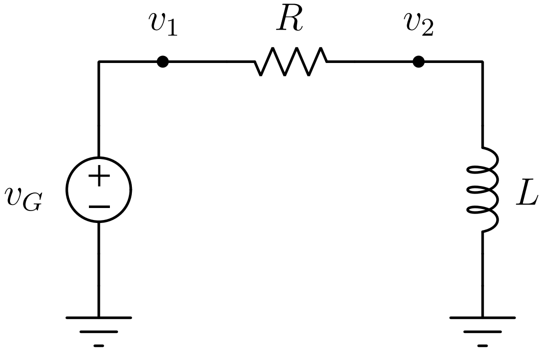
experimental results: capacitor, $C = 1\,\mathrm{nF}$



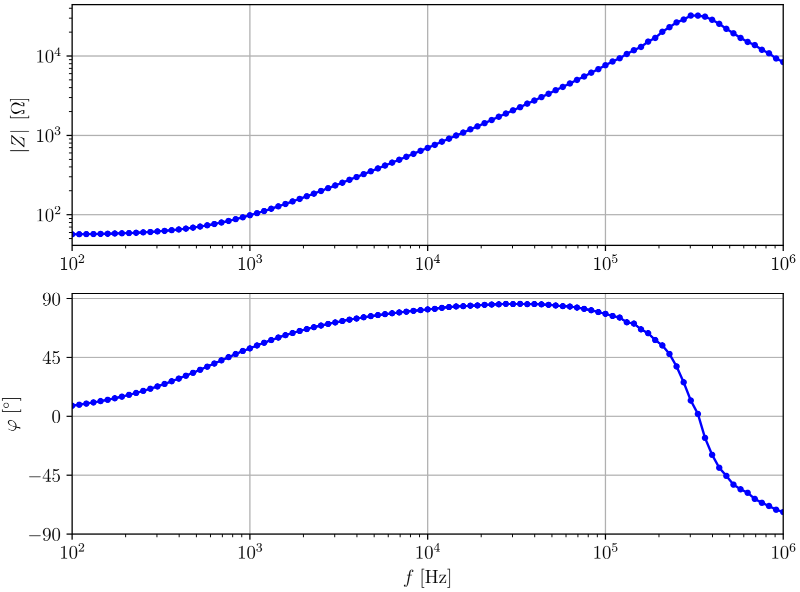
experimental results: capacitor, $C = 10\,\mathrm{nF}$



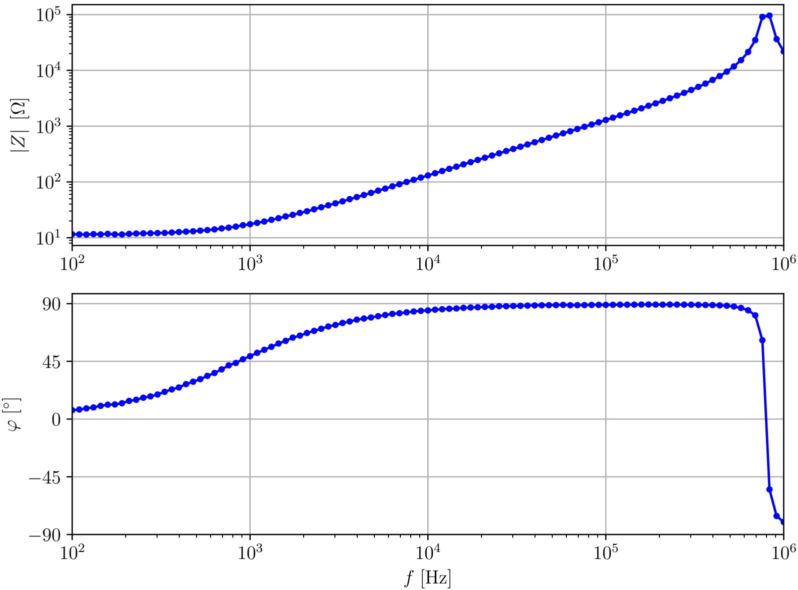
experimental results: inductor impedance



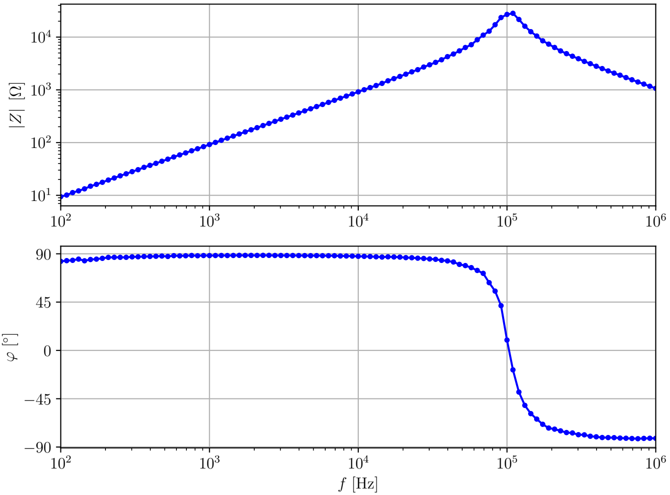
experimental results: inductor, $L = 10\,\mathrm{mH}$



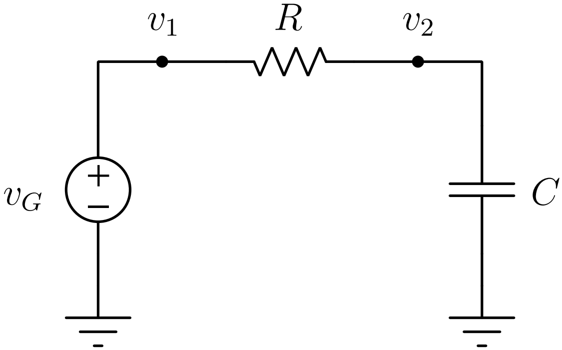
experimental results: inductor, $L = 100\,\mathrm{mH}$



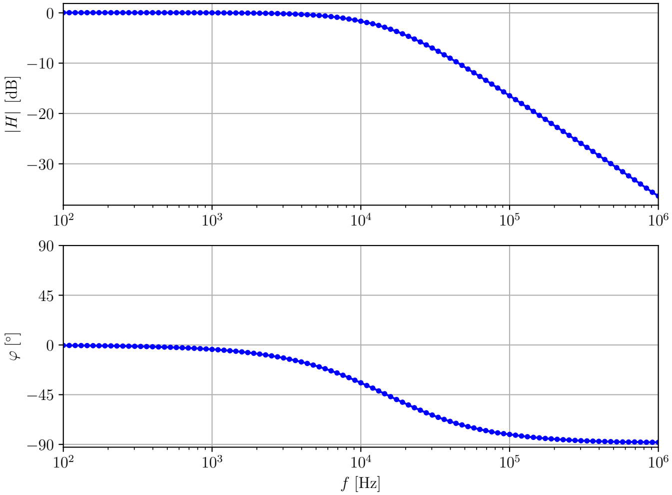
experimental results: inductor, ring core



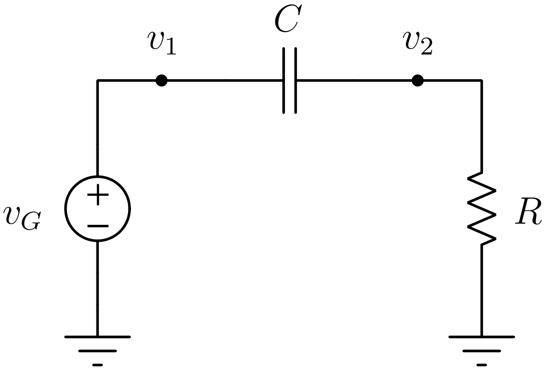
experimental results: low-pass filter



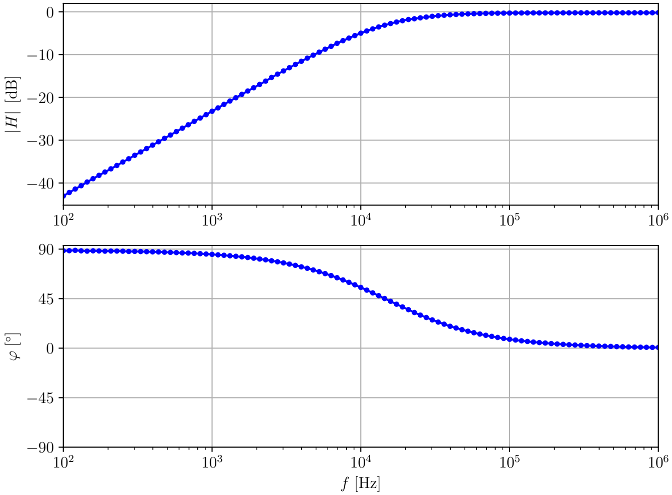
experimental results: low-pass filter



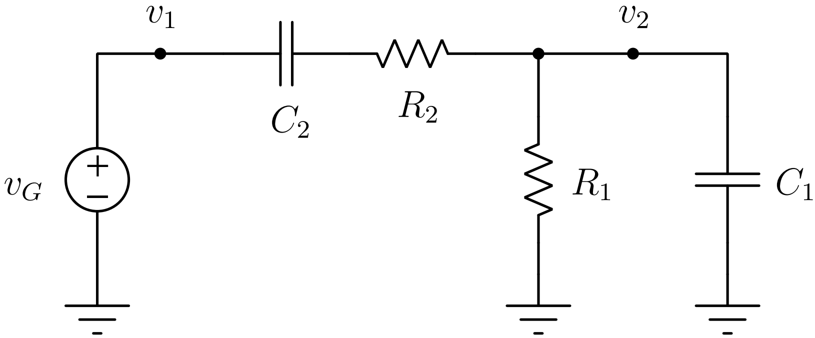
experimental results: high-pass filter



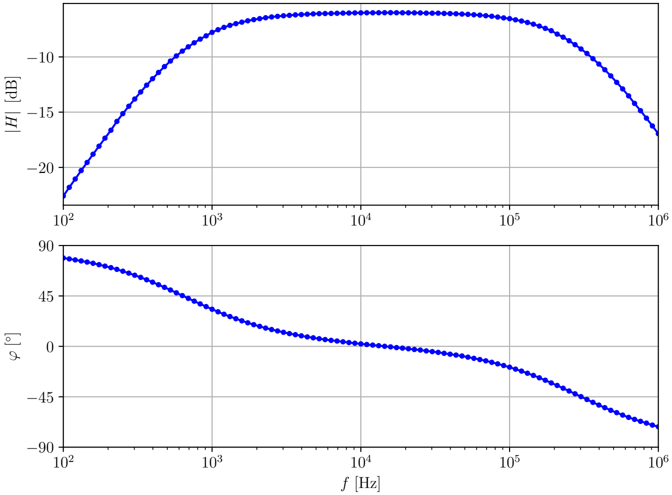
experimental results: high-pass filter



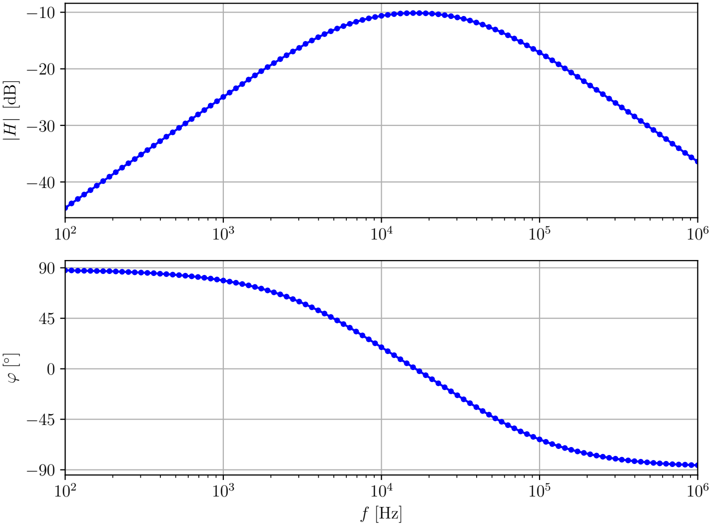
experimental results: band-pass filter



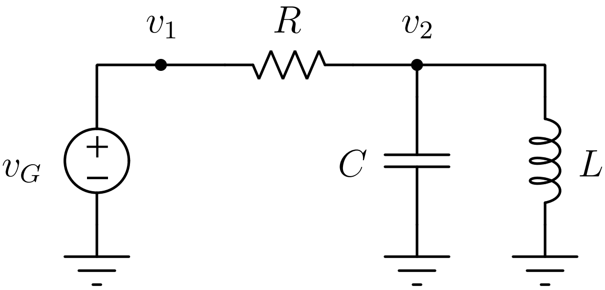
experimental results: band-pass filter



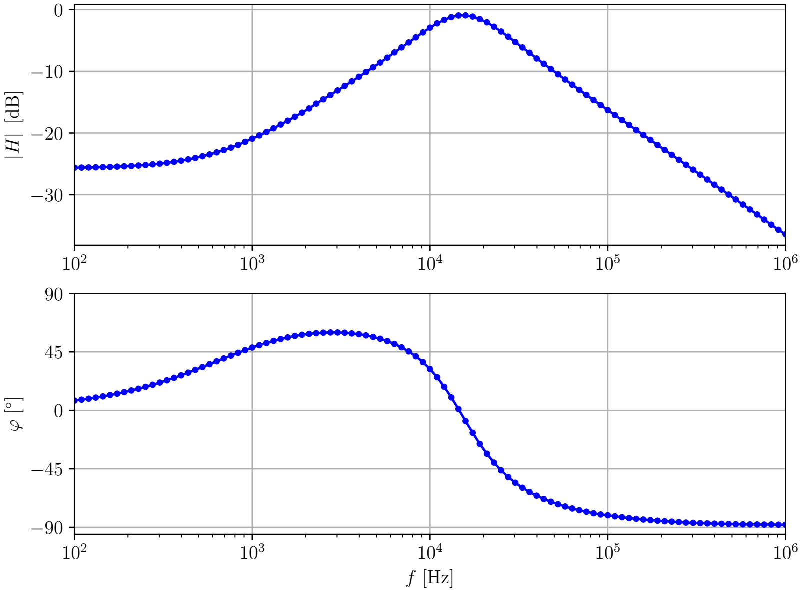
experimental results: band-pass, Wien bridge



experimental results: RLC bandpass filter

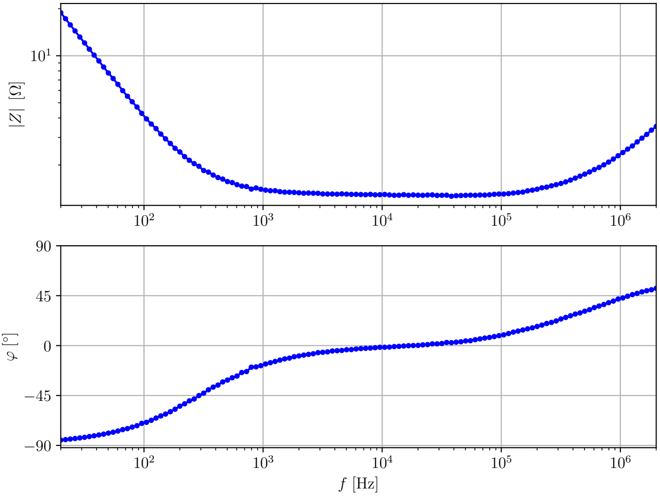


experimental results: RLC bandpass filter



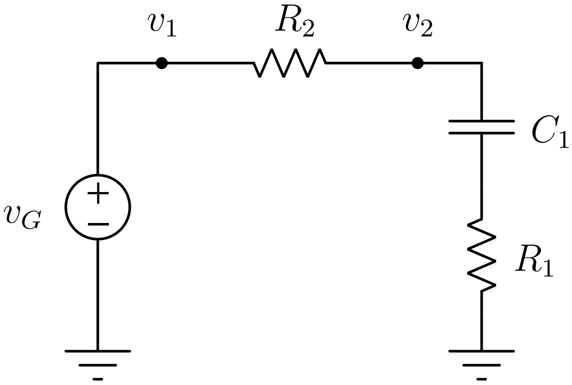
experimental results: impedance demonstration

electrolytic capacitor, 470 μF, electrolytic movie,
about 300 times speed up, yellow — voltage, red — current



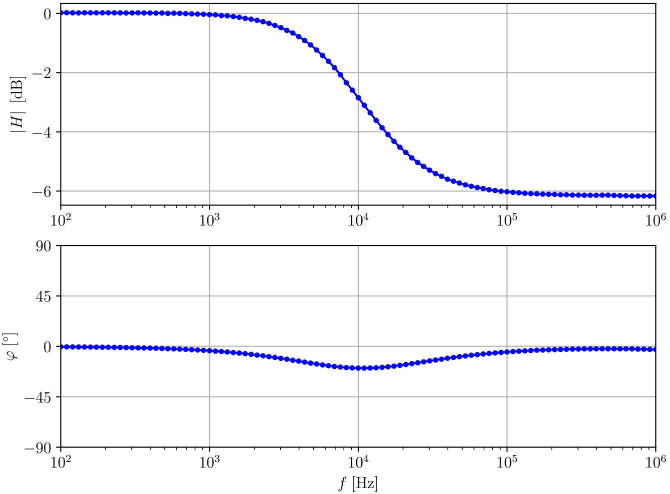
experimental results: transfer function movie

$R_1 = R_2 = 1\,\mathrm{k}\Omega$, $C = 10\,\mathrm{nF}$

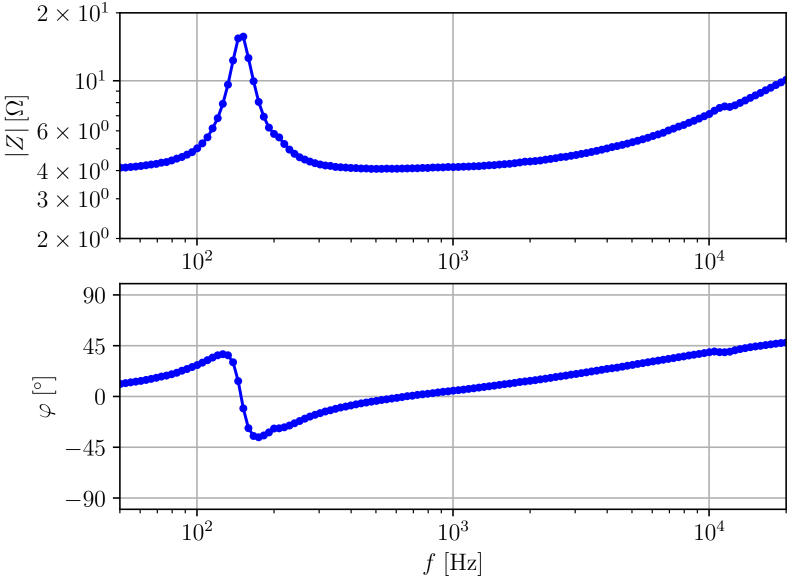


experimental results: transfer function movie

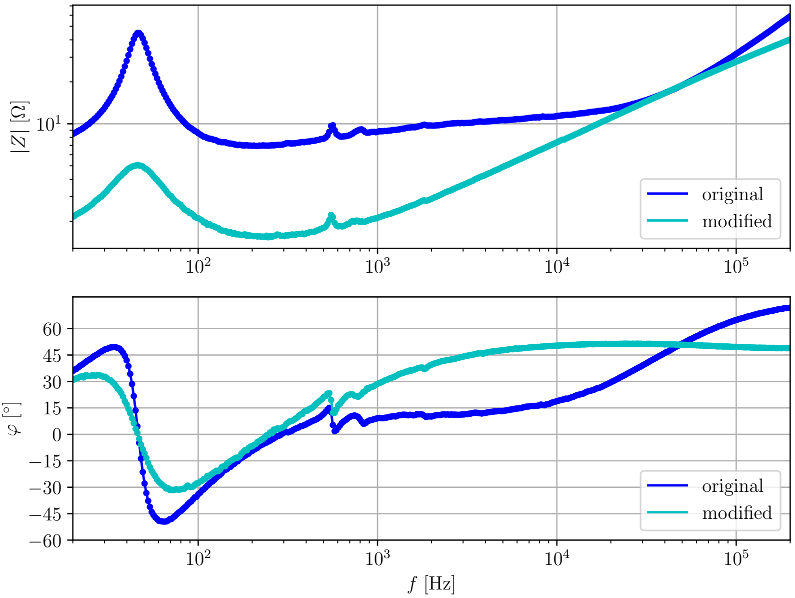
scaled movie, not scaled movie
yellow — output, cyan — input



experimental results: loudspeaker #1



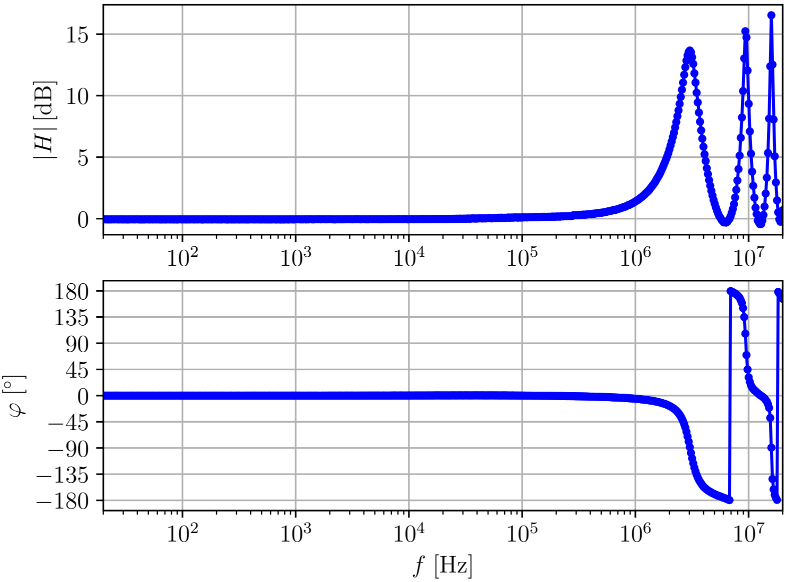
experimental results: loudspeaker #2



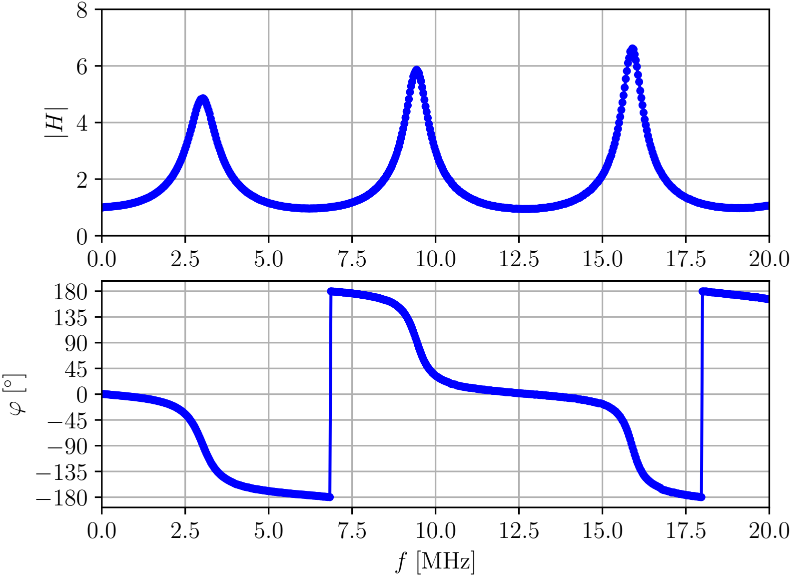
experimental results: loudspeaker #2

- 401 frequency points, 401 figures
- about 5000 samples per figure
- about 2 million of measurements!
- about 4 million of multiplications!
- and at least that many additions ...
- about million sin, cos
- about 800 arctan, atan2
- would you ever do that manually?
- **this IS a new quality: a method that could not be used before!**

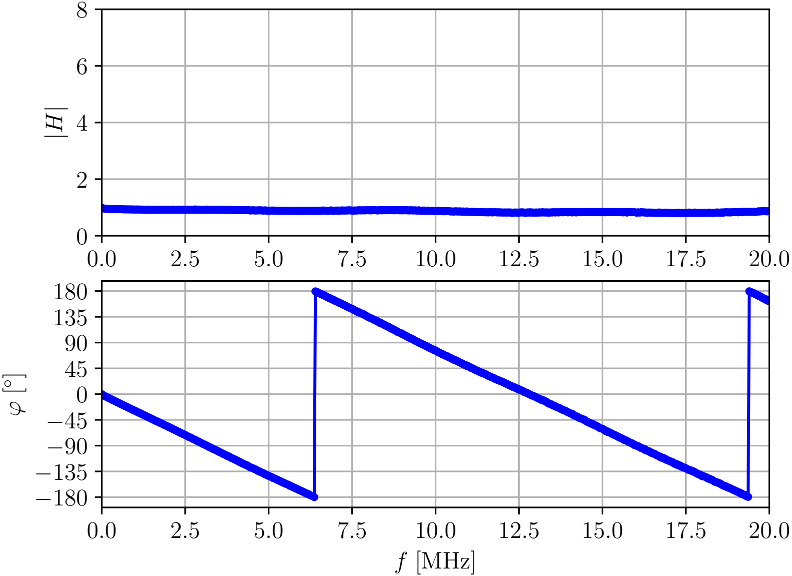
open transmission line, logarithmic



open transmission line, linear



properly terminated transmission line, linear



conclusions

- an automated system to measure frequency response ...
- both transmittance and immitance
- based upon 1^{st} harmonic Fourier analysis
- quite different than manual measurements ...
- taking all the samples into account ...
- the algorithm presented ...
- illustrated in examples ...
- useful to analyze parasitics ...
- entirely based on free software ...
- available: http://tnt.etf.bg.ac.rs/~oe2em/freqresp.zip
- in use: http://tnt.etf.bg.ac.rs/~oe2em/vezba-6.pdf