

DIGITAL STORAGE OSCILLOSCOPES

Electronic Measurements Lab

Massimo Ortolano
2018

POLITECNICO DI TORINO

© 2011–2018 Massimo Ortolano

Dipartimento di Elettronica e Telecomunicazioni (DET)

Politecnico di Torino

Corso Duca degli Abruzzi, 24

10129 Torino

Italy

Email: massimo.ortolano@polito.it

This work is licensed under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc-sa/3.0/> or send a letter to Creative Commons, 444 Castro Street, Suite 900, Mountain View, California, 94041, USA.



Preliminaries

In this lab you will practice with digital storage oscilloscopes (DSOs). Have a look at your workbench, you will need the following laboratory equipment (check [here](#) for specifications), components and cables:

- Bench DC power supply
- Signal generator board (LED product)
- Bench function generator
- Digital storage oscilloscope
- Breadboard
- 1 banana plug to banana plug cable (figure 1 shows a banana plug)
- 1 three-wire power cable (figure 2)
- 2 BNC male to BNC male cables (figure 3 shows a cable of this type and figure 4 shows the detail of a BNC male connector)
- 1 crocodile clips to BNC male cable (figure 5 shows a crocodile clip)
- 1 attenuating oscilloscope probe (figure 6 shows an example probe and figure 7 shows a detail of the probe body)



Figure 1: A banana plug.



Figure 2: Three-wire power cable for the signal generator board.

(Preliminaries)



Figure 3: A BNC male to BNC male cable.



Figure 4: Detail of a BNC male connector.



Figure 5: A crocodile (*alligator* in the US) clip.



Figure 6: An oscilloscope probe.



Figure 7: Oscilloscope probe body.

(Preliminaries)

Part I

Basic usage

1 Getting started

1.1 A quick tour of the oscilloscope front panel

Power up the oscilloscope, and take a look at the oscilloscope's front panel. Knobs and keys are divided in three main sections: *vertical*, *horizontal* and *trigger*. There are also other miscellaneous controls.

Vertical In this area you will find the vertical controls, one set of controls for each vertical channel. The biggest knob can be used to change the vertical scale. Look at the front-panel or at the read-out: what are the minimum and maximum values (expressed in V/div) of the vertical scale? Try the vertical position knob (◆ position): what happens to the corresponding trace? The vertical menu key calls up a menu with the following main submenus: *Coupling* (*DC*, *AC* or *GND*), *BW limit* (the bandwidth of a vertical channel can be limited to 20 MHz to improve the display of noisy signals), *Vertical scale adjustment* (fine/coarse) and *Probe* (1×, 10× etc.). Check the different options. **Warning:** In the following, be sure that the probe type is set to 1×, otherwise voltage readings will be wrong. Be sure, too, that the vertical scale adjustment is set to coarse.

Horizontal In this area you will find the horizontal (time-base) controls. The biggest

knob can be used to change the horizontal scale. Look at the front-panel or at the read-out: what are the minimum and maximum values (expressed in s/div) of the horizontal scale? Try the horizontal position knob ($\blacktriangleleft\blacktriangleright$ position). Since there are no input signals, you will not see any change in the traces; look at the read-out, instead: what happens? The horizontal menu key calls up a menu which allows the selection of a waveform segment to display (more in §4.5). **Warning:** In the following, be sure that the time-base is set to *Main*, in order to display the entire waveform. Be sure, too, that the trigger position indicator (\downarrow or \blacksquare) is centred horizontally: if not, centre it by rotating the horizontal position knob.

Trigger In this area you will find the trigger controls, which allow you to set the trigger operating mode and level (more in §2.3).

Miscellaneous controls These include run controls (e.g. the *Run/Stop* key and the *Run single* key) which allow the user to start or stop an acquisition or to run single acquisitions. Other keys allow to change the acquisition mode or the sampling mode (*Acquire*), to activate cursors (*Cursors*) or to run automated measurements (*Measure*).

1.2 Powering the signal generator board

The signal generator board requires a 12 V dual symmetrical power supply:

- 1 Turn on the DC power supply. Set the switches on the front panel to select the *tracking/series* mode of operation: in this mode of operation the output voltage of the *slave* section is equal to that of the *master* section and the two main outputs are connected in series internally.
- 2 By turning the voltage adjustment knob of the *master* section, adjust the output voltage to 12 V. **Warning:** Adjust the output voltage of the laboratory power supply before making *any* connection to the signal generator board.
- 3 Turn off the DC power supply. Using the three-wire power cable, connect the signal generator board to the power supply: red, 12 V; black, -12 V; and green, 0 V. **Warning:** Do not connect the green cable to the power supply's earth ground! The green cable *must* be connected to the common point between the two main power outputs (figure 8).
- 4 Turn on the power supply.

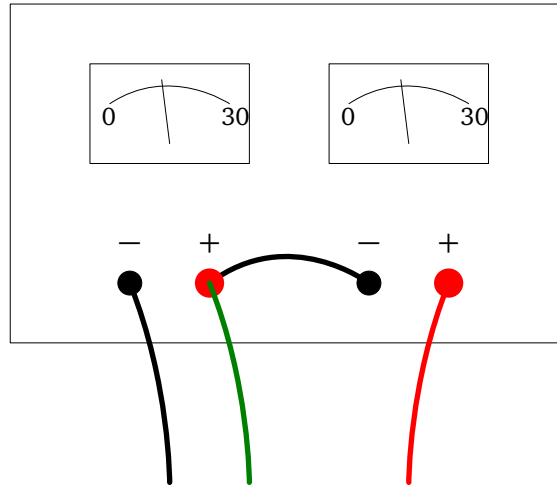


Figure 8: Powering the signal generator board: at the end of §1.2, the power-supply set-up should look like the above. (§1.2)

2 Oscilloscope's settings

2.1 Traces

- 1 Turn on the CH1 trace and turn off CH2.
- 2 Set the trigger mode to *Auto*, the trigger source to *CH1* and the trigger coupling to *AC*. Set the trigger level around 0V.
- 3 Set CH1 input coupling to *AC*. Centre the trace vertically on the screen.
- 4 Connect CH1 to the signal generator board with a BNC male to BNC male cable, to get signal A0 (output A, signal no. 0 on the display).
- 5 Set vertical scale for CH1 in order to expand the trace as much as possible within the display limits (the trace should occupy most of the vertical scale).
- 6 Set the horizontal scale in order to expand a waveform period as much as possible within the display limits (a single period should occupy most of the horizontal scale).

2.2 Acquisition modes

A DSO can have several different acquisition modes, e.g. *sample*, *peak detect*, *average*. The sample mode is typically the default acquisition mode at turn-on. The acquisition mode can be changed by pressing the *Acquire* key. The peak-detect mode can be useful to detect random spikes, while the average mode can be useful to reduce the effect of noise and obtain a thinner trace.

- 1 With the oscilloscope set as in §2.1, change the acquisition mode to average. See what happens when changing the number of averages.

2.3 Trigger

- 1 Turn on the CH1 trace and turn off CH2.
- 2 Set the trigger mode to *Auto*, the trigger source to *CH1* and the trigger coupling to *DC*. Set the trigger level around 0 V.
- 3 Set CH1 input coupling to *DC*. Centre the trace vertically on the screen.
- 4 Connect CH1 to signal A4.
- 5 Set CH1 vertical scale in order to expand the trace as much as possible within the display limits (the trace should occupy most of the vertical scale).
- 6 Set the horizontal scale in order to expand a waveform period as much as possible within the display limits (a single period should occupy most of the horizontal scale).
- 7 What happens if you change the trigger level?
- 8 Change the trigger slope from the trigger menu: what happens?
- 9 Change the trigger source to *CH2*: what happens?
- 10 Change the trigger mode to *Normal*: what happens?
- 11 Change the trigger source back to *CH1*: what happens?

3 Basic measurements

3.1 Amplitude measurements

- 1 Set the oscilloscope as in §2.1. Set the acquisition mode to average and the number of averages to 64.
- 2 Measure the peak-to-valley signal amplitude with the aid of the screen graticule.
- 3 Measure the peak-to-valley signal amplitude by using the cursors.
- 4 Measure the peak-to-valley signal amplitude by using the oscilloscope's automatic measurement mode, if available.
- 5 Determine the uncertainties of the above measurements (check the oscilloscope specifications).

3.2 Period and frequency measurements

- 1 Measure the period T of the signal with the aid of the screen graticule and calculate the corresponding frequency $f = 1/T$.
- 2 Measure the signal period and frequency by using the cursors.
- 3 Measure the signal period and frequency by using the oscilloscope's automatic measurement mode, if available.
- 4 Determine the uncertainties of the above measurements (check the oscilloscope's specifications).

3.3 Phase measurements

- 1 Turn on both CH1 and CH2.
- 2 Set the trigger mode to *Auto*, the trigger source to *CH1* and the trigger coupling to *AC*. Set the trigger level around 0 V.
- 3 Set the input coupling of both channels to *AC*. Centre both traces vertically on the screen (be precise, otherwise you will get a measurement error).
- 4 Connect the two oscilloscope channels to signals A0 and B0.
- 5 Set the vertical scales of both channels in order to expand the traces as much as possible within the display limits.
- 6 Set the horizontal scale in order to expand a waveform period as much as possible within the display limits.
- 7 Determine the phase shift $\Delta\varphi$ between the two signals according to the definition given in figure 9.
- 8 Determine the uncertainty of the phase shift.

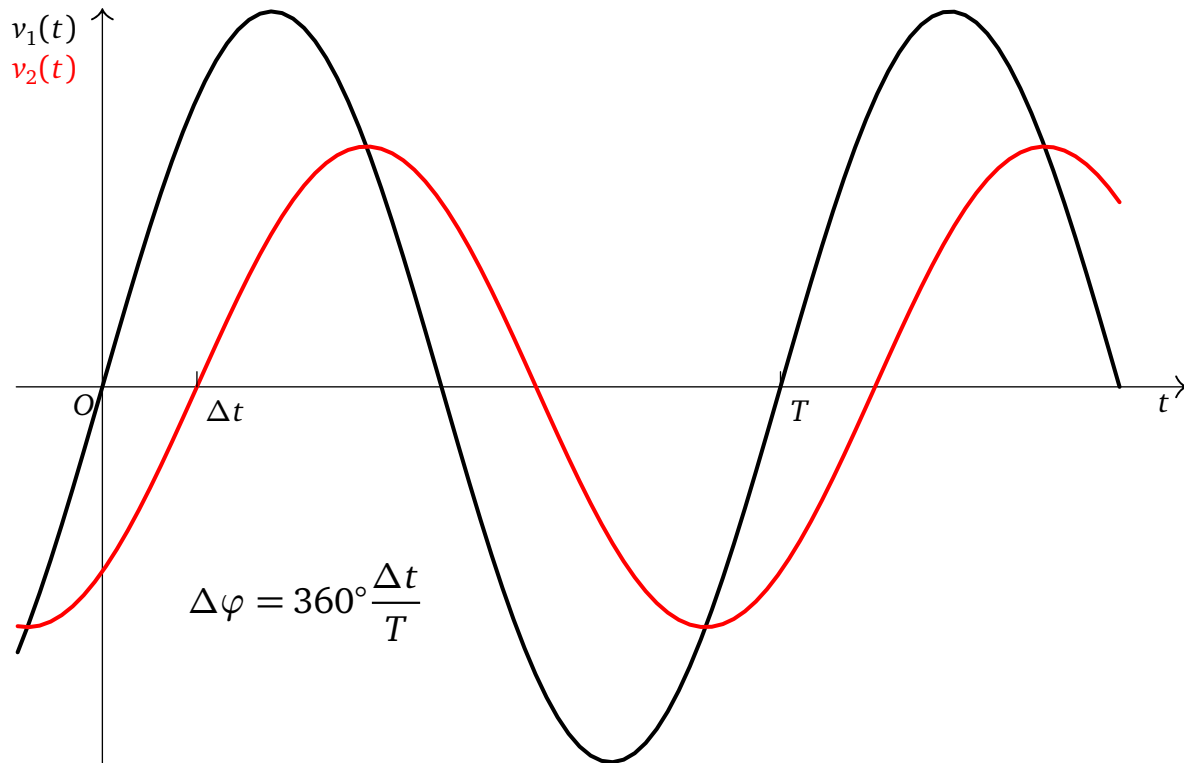


Figure 9: Phase measurements: Δt is the time interval (with sign) between two nearby zero crossings; here, if signal 1 is taken as reference, Δt should be considered negative because the output signal *lags* (i.e. it is delayed) with respect to the input one.

4 Pulse wave measurements

4.1 Period

- 1 Turn on the CH1 trace and turn off CH2.
- 2 Set the trigger mode to *Auto*, the trigger source to *CH1* and the trigger coupling to *DC*. Set the trigger level around 0V.
- 3 Set CH1 input coupling to *DC*. Centre the trace vertically on the screen.
- 4 Connect CH1 to signal B4.
- 5 Set CH1 vertical scale in order to expand the trace as much as possible within the display limits (the trace should occupy most of the vertical scale).
- 6 Set the horizontal scale in order to expand a waveform period as much as possible within the display limits (a single period should occupy most of the horizontal scale; change the horizontal position for best results).
- 7 Measure the signal period T using the graticule, the cursors and the automated measurement mode.
- 8 Determine the uncertainty of T for each measurement.

4.2 Pulse width

- 1 Set the horizontal scale to expand the pulse as much as possible within the display limits. If necessary, change the horizontal position too.
- 2 Measure the pulse width t_w using the graticule, the cursors and the automated measurement mode.
- 3 Determine the uncertainty of t_w for each measurement.

4.3 Duty factor

- 1 From the results of §4.1 and §4.2, calculate the duty factor $d = t_w/T$.
- 2 Determine the uncertainty of d .
- 3 The duty factor can also be measured with the following method. Set the oscilloscope as in §4.1 and determine d as the ratio of the pulse divisions to the period divisions. Determine the uncertainty of d in this second measurement. Are the two measurements compatible?

4.4 Levels and DC component

- 1 Measure the voltage V_L corresponding to the pulse low level (recall that CH1 input coupling should be set to *DC*).
- 2 Measure the voltage V_H corresponding to the pulse high level.
- 3 From V_L , V_H and the duty factor d measured in §4.3, calculate the DC component of the pulse wave, that is, its mean value over a period:

$$V_{\text{dc}} = \frac{1}{T} \int_{t_0}^{t_0+T} v(t) dt,$$

where t_0 is an arbitrary initial time.

- 4 If you change the CH1 input coupling from *DC* to *AC*, the trace on the screen will shift vertically by the amount $-V_{\text{dc}}$. Measure the DC component in this way and check if this result is compatible with the one above.

4.5 Rise and fall times

- 1 Set the horizontal scale to expand the pulse rising edge as much as possible within the display limits. If necessary, change the horizontal position too. To expand the rising edge, you can also use the Window Zone/Window submenus of the horizontal menu.
- 2 Measure the pulse rise time.
- 3 Set the horizontal scale to expand the pulse falling edge as much as possible within the display limits. If necessary, change the horizontal position too.
- 4 Measure the pulse falling time.

Part II

Other measurements, oscilloscope probe

5 Step response of an *RC* low-pass filter

5.1 Assembling the circuit

- 1 Calculate the nominal cut-off frequency f_H and the nominal step-response rise-time t_r for the circuit of figure 10.
- 2 Assemble the circuit of figure 10 on the breadboard. Figure 11 shows a possible way of assembling the circuit.

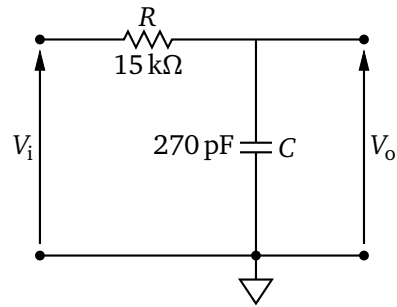


Figure 10: Circuit diagram of the RC filter.

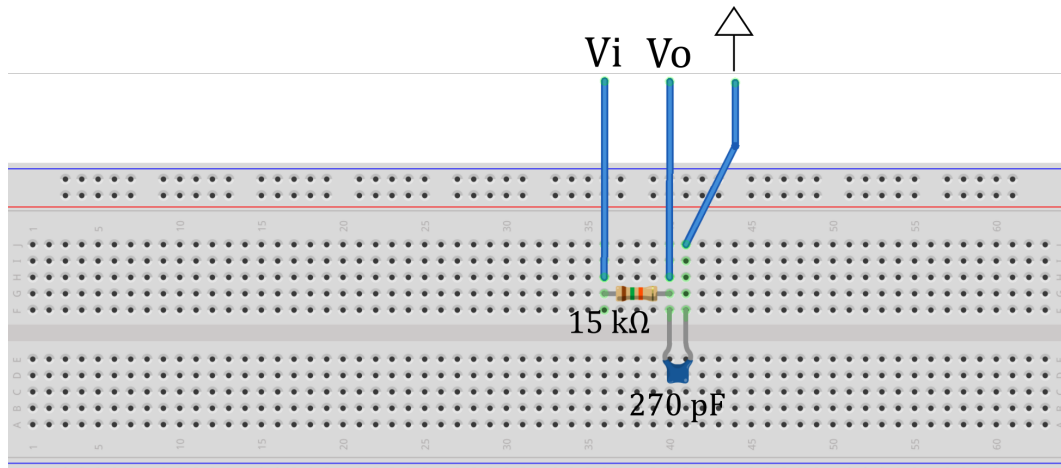


Figure 11: A possible way of assembling the RC filter of figure 10.

5.2 Rise-time and cut-off frequency (Coaxial cable)

- 1 Using a BNC-to-BNC cable, a BNC T adapter (figure 12) and a coaxial cable with crocodile clips, connect the function generator output to the oscilloscope CH1 input and then to the circuit input (V_i). **Warning:** Recall that the black clip is the ground.
- 2 Using a coaxial cable with crocodile clips, connect the circuit output (V_o) to the oscilloscope CH2 input.
- 3 Set the input coupling of both inputs to DC.
- 4 Using a BNC-to-BNC cable, connect the trigger output of the bench function generator to the external trigger input of the oscilloscope. Set the trigger source to *External*.
- 5 Set the function generator output for a square wave with a frequency of 1 kHz.
- 6 Measure the step-response rise time and calculate the cut-off frequency from the formula $f_H = 0.35/t_r$. Compare these values with those obtained in §5.1. Do they agree? How do you explain the result obtained?



Figure 12: A BNC T adapter

5.3 Rise-time and cut-off frequency (Oscilloscope probe)

- 1 Disconnect the coaxial cable from the circuit output and the CH2 input and replace it with an oscilloscope probe (1 : 10 attenuation).
- 2 Compensate the probe (ask for a suitable screwdriver).
- 3 Measure the step-response rise time and calculate the cut-off frequency from the formula $f_H = 0.35/t_r$. Compare these values with those obtained in §5.1. Is there any difference with the values obtained in §5.2?
- 4 Correct the values obtained in the previous point for the errors caused by the oscilloscope intrinsic rise time and by the function generator output resistance. State if these errors are negligible or not.

6 Frequency response of the RC low-pass filter

A generic linear time-invariant filter (figure 13) is characterised by a transfer function

$$H(j2\pi f) = \frac{V_o}{V_i},$$

where V_i is the complex phasor associated with a sinusoidal input voltage at frequency f , and V_o is the phasor associated with the corresponding sinusoidal output voltage.

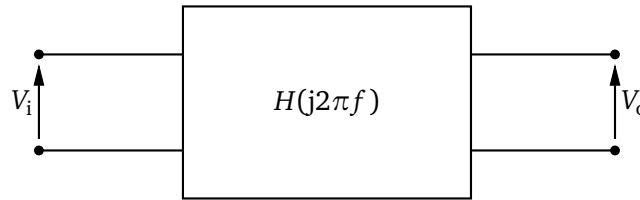


Figure 13

$H(j2\pi f)$ is thus a complex number which changes with f . The Bode plots are graphical representations of the quantities $G(f) = 20 \log |H(j2\pi f)|$ and $\varphi(f) = \arg H(j2\pi f)$ as a function of frequency (figure 14). $G(f)$ is the magnitude of the transfer function, expressed in decibel (dB), and $\varphi(f)$ is the phase. The frequency axis is logarithmic.

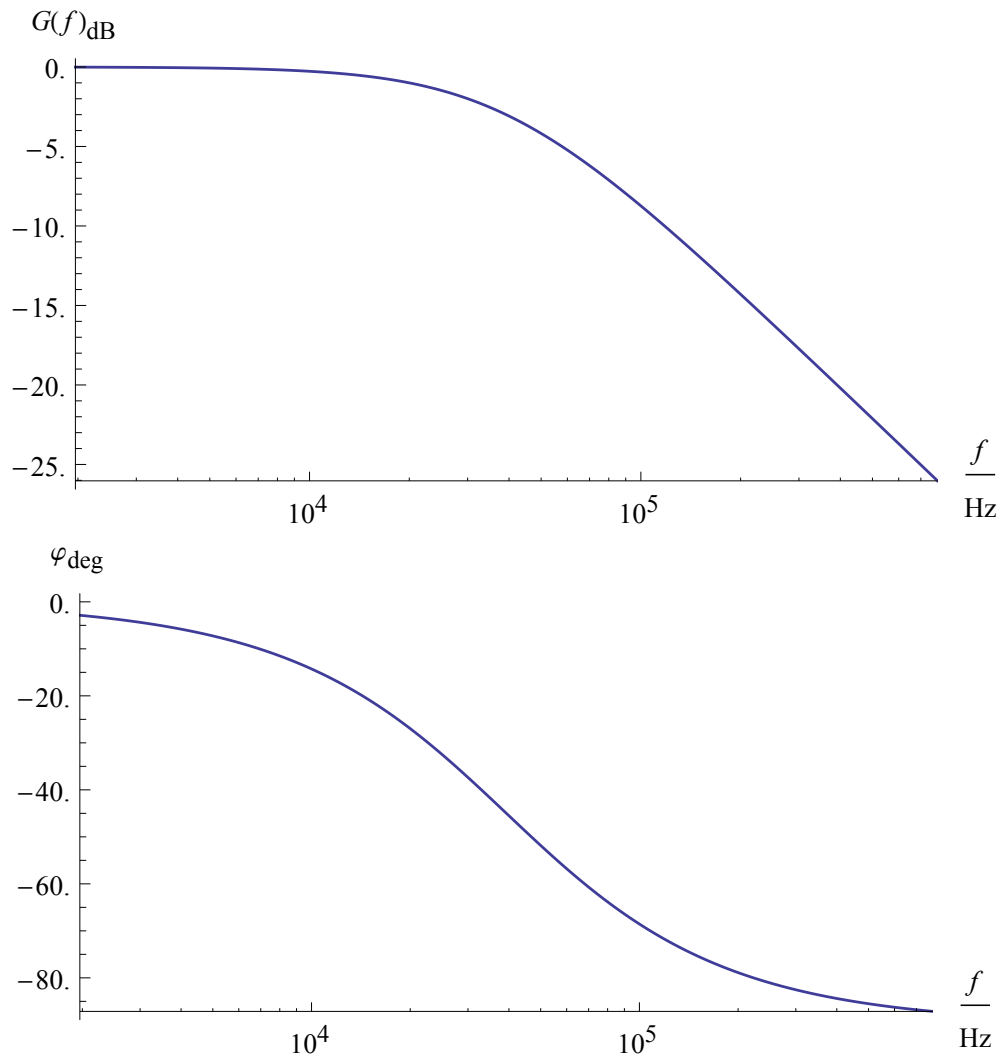


Figure 14: Example Bode plots.

- 1 Measure $G(f)$ and $\varphi(f)$ for the filter assembled in §5 over a frequency range from 500 Hz to 500 kHz (see also figure 15 for a definition of the parameters). I suggest to make measurements at the following frequency points, but you can also make other choices: 500 Hz, 800 Hz, 1200 Hz, 2000 Hz, 3000 Hz, 5 kHz, 8 kHz, 12 kHz, 20 kHz, 30 kHz, 50 kHz, 80 kHz, 120 kHz, 200 kHz, 300 kHz and 500 kHz.
- 2 Search the -3 dB cut-off frequency by continuously varying the input frequency; compare this value with the one obtained in §5.3.
- 3 Draw the Bode plot of the measured frequency response.

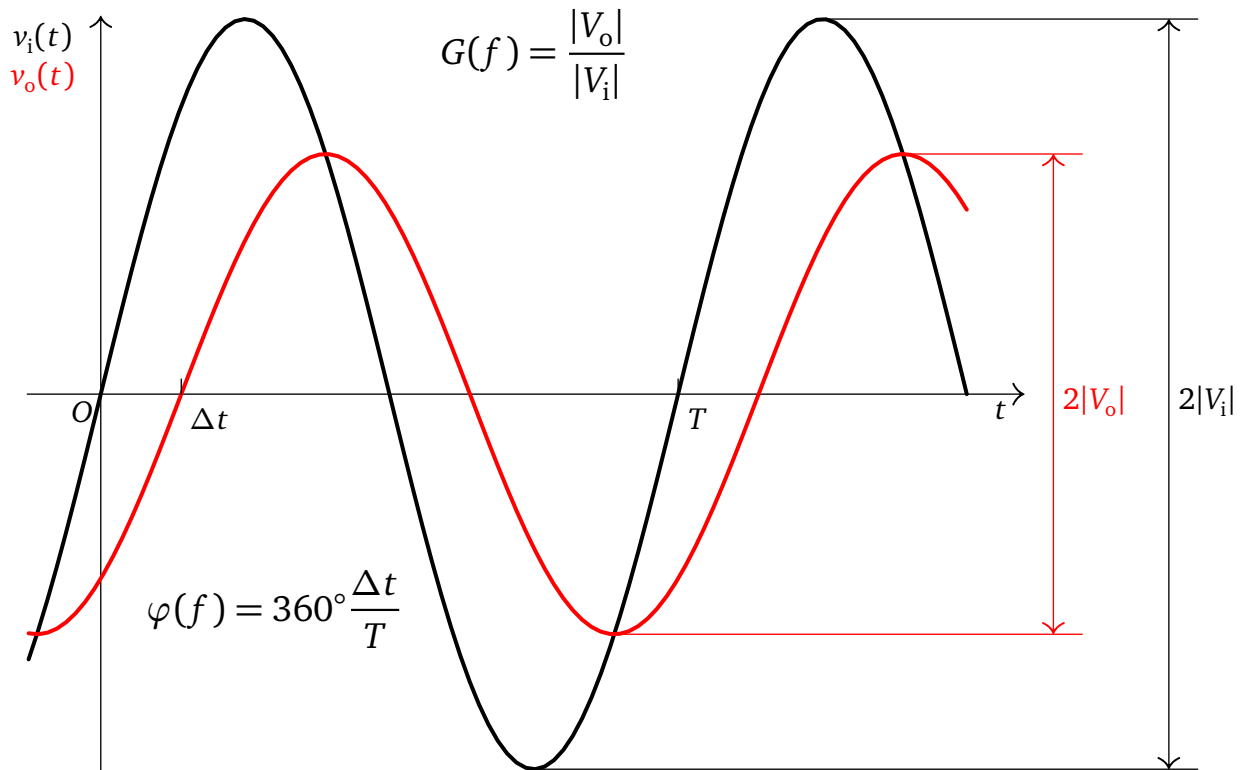


Figure 15: This figure shows an example of input (black) and output (red) voltage waveforms. Δt is the time interval (with sign) between two nearby zero crossings. Here Δt should be considered negative because the output signal *lags* (i.e. it is delayed) with respect to the input one.

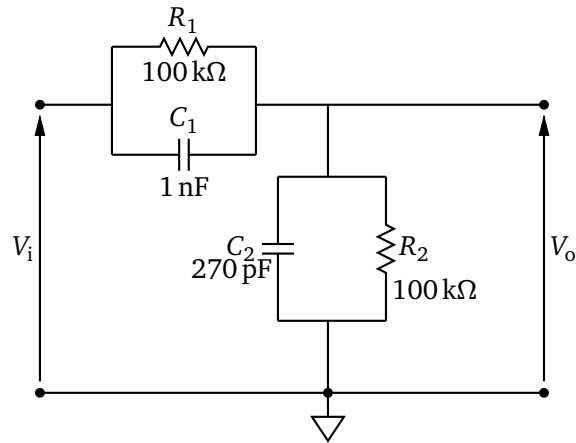


Figure 16

7 An “uncompensated” voltage divider

- 1 Assemble the circuit of figure 16. Figure 17 shows a possible way of assembling the circuit.
- 2 Measure the frequency response (magnitude and phase) of the assembled circuit over a frequency range from 200 Hz to 20 kHz. I suggest to make measurements at the following frequency points, but you can also make other choices: 200 Hz, 350 Hz, 630 Hz, 1.1 kHz, 2 kHz, 3.5 kHz, 6.3 kHz, 11 kHz and 20 kHz.
- 3 Draw the Bode plot and compare it with the theoretical one (homework).

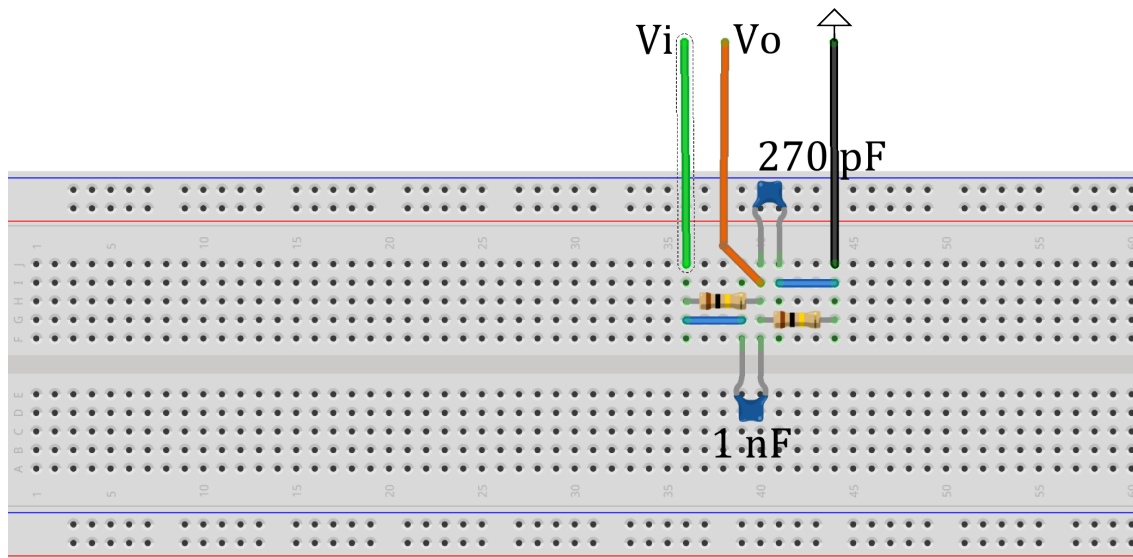


Figure 17: A possible way of assembling the voltage divider of figure 17.