1. Introduction

1.1 Goal of the experimental lab

Aim of this lab is to

- Analyze the behavior and extract the equivalent two-port parameters of amplifier modules by measuring electrical signals at the external terminal of the amplifier module.
- Verify some deviations with respect to the behavior predicted by the approximated models presented in the lectures.

These analyses require the comparison between results of theoretical calculations (see the following "Homework" sections) and measurements. While the measurements are carried out by considering the module as a black-box (i.e. without the need to know details about its internal structure), the homework requires to know the internal structure of the amplifiers, which is described in Sec. 3.

At the end of this document you will also find a few tables and graphs to help you in the annotation of the measurements results and to be exploited as a preliminary draft for the preparation of the final report.

1.2 Modules and instrumentation tools

Circuits to be measured are pre-assembled on printed circuit boards. The present lab uses the module A2 of the board, which includes two amplifier stages, an inverting and a non-inverting one, as shown in the block diagram in Fig. 1. The detailed circuit scheme is reported at page 11.

The circuit configuration can be changed by using the switches (SW) on the board, as detailed in the description of each experiment. **The name and position (1/2) of each switch is indicated by a silkscreen on the PCB.** Connections to the outside can be arranged through coaxial connectors (input signals), bushings / terminals (power supplies, when required), and anchors at the measuring points (to connect the oscilloscope probes or other instruments).

The input signal (V_i) is provided through BNC connectors and a group of R-C-SW; the switch S1 is used to send the signal to the non-inverting or inverting module. The outputs of the two modules, selected by S2, go to the output group of R-C-SW and from these to the output terminal (V_u) according to the block diagram of Figure 1.

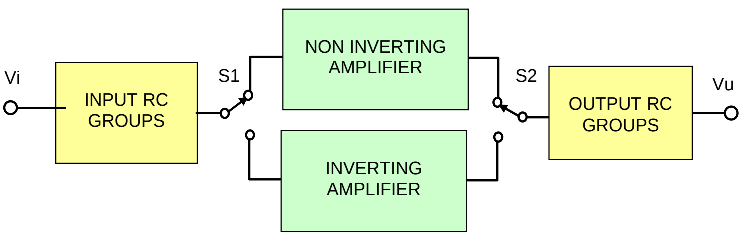


Figure 1: Block diagram of the A2 module

1.3 Dual power supply

The measurement benches are provided with double and triple power supplies. For this experience you must use a double power supply, arranged so as to provide with respect to ground a positive voltage of 12 V and a negative voltage of 12 V (cf. Figure 2).

A double (or dual) power supply contains two independent voltage sources, carried on two independent pairs of terminals (usually red for the positive and black for negative). Other terminals, marked GND (Ground or Earth usually green or white) are connected to the earth's power grid. Ground (zero potential node chosen as reference in the circuit) and earth (link to "land", generally through a stake into the ground on wetlands) are two different things, which should be considered as independent nodes. They can be connected together for electrical safety reasons, but the present experiences do not need to make connections between circuit ground (the reference node of the circuit) and ground (earth terminal connected to the mains).

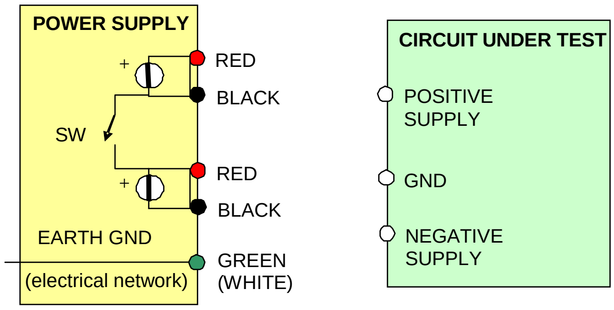


Figure 2: Power supply scheme

Power supply and circuit under test must be connected in such a way that the two independent generators of the power supply provide the circuit with a positive and a negative voltage with respect to ground.
The commands of the power supply are used to set the output voltage at the required value and the maximum current.
Voltages must be set to the correct value **before** connecting the circuit to be powered.
The current limitation acts in case of faults or errors, and must be set to a value such as not to damage the circuit.

For the present experience the **"tracking" mode** can be used for balanced power supply.

Tracking with series connection: in this *mode*, the two power supplies are connected in series, and the control of the master *power supply* adjusts the voltages of both. Generally, the activation of the tracking closes the switch SW (see Fig.2), and connects - inside the power supply - the positive terminal of a generator with the negative of the second one (corresponding to two adjacent terminals on front). This node has to be used as a reference potential, and is connected to the circuit ground. The tracking configuration should be used when tracking positive and negative voltages are identical.
These experiences do not use the ground terminals of the network.

This is the first lab that uses active circuits, which require power supply. Before connecting the power supply, set the output voltages to the desired value. The instruments on the power supply are generally not

Comment [PB1]: Nel generatore che c'e' al LED 9, ci sono due interruttori, uno indicato come "tracking" e uno come "serie/parallelo". E' possibile collegare i generatori in "tracking" e metterli in parallelo per aumentare l'erogazione di corrente.
Cosi' invece ho percepito che tracking e series fossero la stessa cosa e sono andato un po' nel pallone. Metterei ad esempio ***Tracking with series connection:*** in this *mode*, the two power supplies are connected in series, and the control of the master *power supply* adjusts the voltages of both. Using a series connection Generally, the activation of this mode closes the switch SW (see Fig.2), and connects - inside the power supply - the positive terminal of a generator with the negative of the second one (corresponding to two adjacent terminals on front).

accurate, so it may be worth checking the voltage with an external tool (tester or multimeter).
When using a signal generator one should always ask himself what level of output should be set. Too low voltages hamper the implementation of the measurements, while too high voltages may damage some components.

2 Measurements

2.1 Non-inverting amplifier: equivalent two-port parameters

Use the module labeled as “A2-amplificatore non invertente” (**A2 - non inverting amplifier**), and arrange it as indicated in the following. Fig. 3 shows the equivalent two-port circuit of the amplifier, that we intend to characterize.

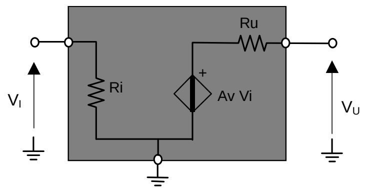


Figure 3: Amplifier two-port equivalent circuit

The nominal values for the amplifier to be characterized are:

A_v = 9.33 ± 10%

R_i = 11 kΩ ± 5%

R_u = 1 kΩ ± 5%

These data should be compared with the ones extracted from the experimental characterization (taking into account the quoted tolerances and the measurement errors).

How to connect the instruments. The BNC connector for the input signal is labeled as J1 on the board. The output signal terminal is labeled as J6 (ground on J7). The power supply is provided through the terminal J8. The positive and negative voltages must be set to 12 V.

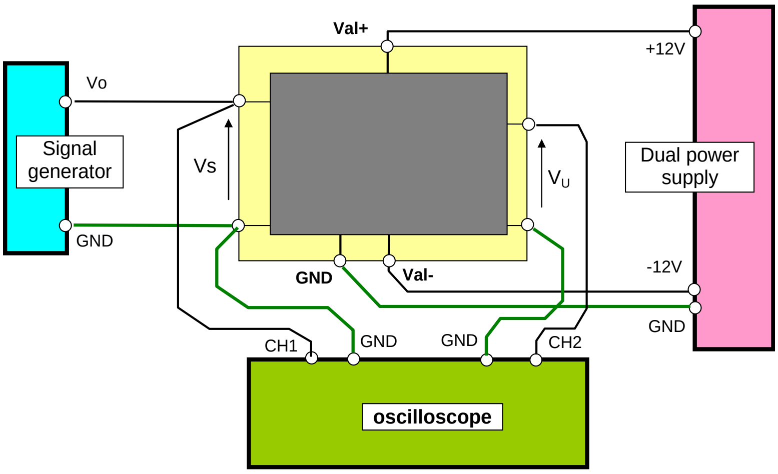


Figure 4: Connection scheme for the measurement of the amplifier

2.1.1 Gain measurement

Prepare the board so as to directly apply the generator voltage to the input of the module, with unloaded (open circuit) output (Figure 5).

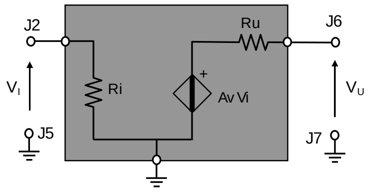


Figure 5: Non inverting amplifier scheme with terminals

Switch	Position on the board	notes
S1	2	
S2	2	
S3	2	close
S4	2	close
S5	2	close
S6	1	open
S7	1	open
S8	1	open
S9	1	open

Table 1 SW configuration for gain measurement

a) Apply to the input a sinusoidal signal with frequency 0.8 kHz, and peak-to-peak amplitude Vpp = 1 V
b) Connect the circuit input and output to two channels of the oscilloscope and measure the ratio $A_v = V_u/V_i$; evaluate A_v also in dB.

2.1.2 Measurement of the equivalent input resistance

A possible technique to measure the input resistance is as follows: one inserts a resistor in series to the generator (to perform a more precise measurement, it is preferable that the external resistance has a value of the same order of magnitude of the estimated value for the input resistance). The resistance forms a voltage divider with the input resistance of the module; a resistance is known (that one deliberately inserted), the other is unknown. From voltage measurements before and after the insertion of the known resistance, it is possible to determine the value of the unknown resistance.

Arrange the module in order to insert the resistance R9 of 10 kΩ (Figure 6) in series to the generator.

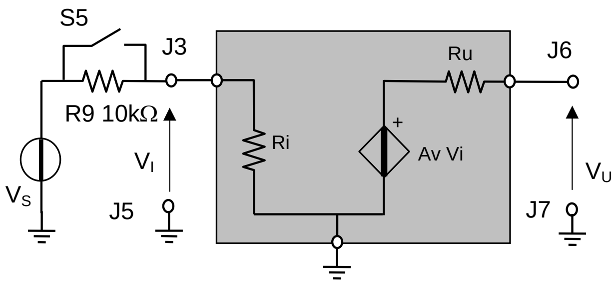


Figure 6: Inverting amplifier scheme with the configuration to be used for the measurement of R_i

switch	position on the board	notes
S1	2	
S2	2	
S3	2	close
S4	2	close
S5	1	R9 inserted
	2	R9 short circuited
S6	1	open
S7	1	open
S8	1	open
S9	1	open

Table 2 SW configuration for R_i measurement

a) Measure the AC output voltage once with R9 inserted and once with R9 short circuited (sinusoidal input with Vpp = 1 V, freq. 800 Hz)

b) From the measurements and from the value of R9, calculate the equivalent resistance of the amplifier (R_i).

The measurement is done on the output voltage, rather than on the input, to have higher values. The measurement can be performed with the multimeter (ACV) or with an oscilloscope (measure of the peak-to-peak voltage). The value of resistor R9 can be read on the component (using the color code).

2.1.3 Measurement of the equivalent output resistance

The theoretical approach to measure open circuit voltage and short circuit current cannot be applied froma practical standpoint: in fact, the short-circuit can drive the amplifier output in the nonlinear operating region (saturation), where the simplified linear model is no longer valid. However, it is possible to insert a load (such as to maintain the module in linearity – this can be checked out by observing the output signal with an oscilloscope), and measure the variation of the output voltage between the open circuit condition and the one with a load. Even here it is a matter to calculate one of the resistors of a voltage divider, given the voltages and the resistance of known value.

Arrange the module in order to insert the load resistance R10 of 1 kΩ in parallel to the output (Figure 7).

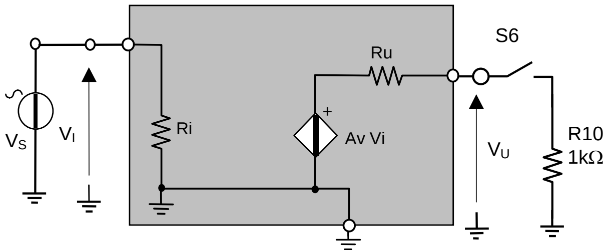


Figure 7: Inverting amplifier scheme with the configuration to be used for the measurement of R_u

switch	position on the board	notes
S1	2	
S2	2	
S3	2	close
S4	2	close
S5	2	lose
S6	1	R10 not connected
	2	R10 inserted
S7	1	open
S8	1	open
S9	1	open

Table 3 SW configuration for R_u measurement

a) Measure the output AC voltage under open circuit condition and with R10 inserted (sinusoidal input, Vpp = 1 V, freq. 800 Hz).
b) From the measurements and from the value of R9, calculate the equivalent output resistance of the amplifier (R_u).

2.2 Frequency response of the non-inverting amplifier with external RC filters.

Configure the "A2 – amplificatore non invertente" module according to Table 4.

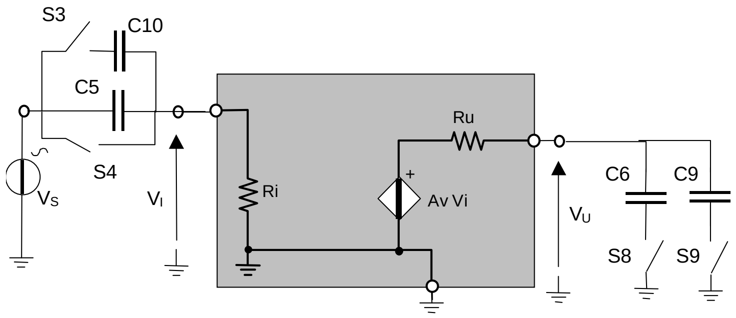


Figure 8: Non inverting amplifier scheme with indication of the SWs used to insert the external *RC* filters

switch	position on the board	notes
S1	2	
S2	2	
S3	2	C10=3.3 nF inserted
S4	1	C5=10 nF not short circuited
S5	2	closed
S6	1	open
S7	1	open
S8	2	C6=10 nF inserted
S9	1	C9=1 nF not inserted

Table 4 SW configuration for the frequency response measurements

a) Measure the amplifier gain Avs=Vu/Vs in the frequency range 300 Hz - 1 MHz, with two measurements for each decade; quote the results on the table and graph provided at the end of the document (note that the graph is a Bode diagram of the magnitude, with logarithmic frequency axis and magnitude in dB).

Set V_s to:

- Vpp = 1 V up to 30 kHz,
- Vpp = 0.2 V starting from 100kHz.

b) Compare the measurement results with the homework calculations.

2.3 Inverting amplifier: equivalent two-port parameters

Use the module labeled as "A2 -amplificatore invertente" (A2 – inverting amplifier), and configure it according to the following switch table.

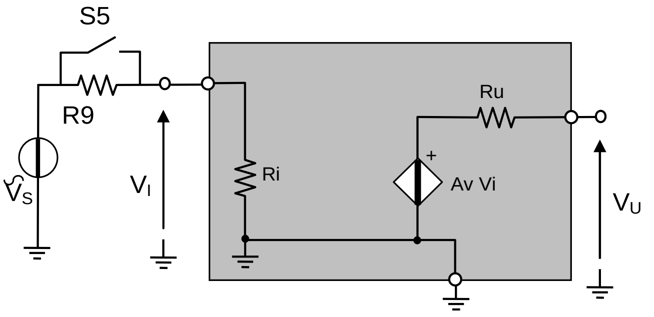


Figure 9: Measurement scheme for the inverting amplifier

switch	position on the board	notes
S1	1	
S2	1	
S3	1	open
S4	2	closed
S5	1	open
S6	1	open
S7	1	open
S8	1	open
S9	1	open

Table 5 RIMETTERE A POSTO SW configuration for the characterization of the inverting amplifier

By using an input sinusoidal signal

a) Check the phase inversion between V_s and V_u
b) Evaluate the amplifier gain at 1 kHz

c) Measure the equivalent input resistance R_i (with the same technique described in Sec. 2.1). Compare the measured value with the nominal one (15 kΩ ± 5%) and with the value computed from the analysis of the circuit scheme at pag 10 and 11.
d) Check that the equivalent output resistance R_u has a negligible value.

3 Homework

For some of the proposed measurements, it is required to carry out a comparison with results of calculations. The calculations should be made before the experimental lab, based on the circuit schemes and numerical values provided in this guide. Both nominal values and tolerances of the components are provided; the calculations can be performed using only the nominal values or trying to evaluate the range of possible outcomes based on tolerances.

The measurement result is in turn affected by errors for the imprecision of the instruments, and other causes. It is therefore reasonable to expect a discrepancy between the results of calculations and measurements (in fact, perfectly identical values cause confusion on the proper execution of the measures). The bars due to the tolerances of the components and those due to measurement errors must partially overlap. In the present lab it is not explicitly required to quantitatively check this correspondence, but it may be useful to express synthetic qualitative considerations.

Proposed analyses:

a) Evaluate the two-port equivalent circuit parameters for the non inverting amplifier described in Fig. 10 and the inverting amplifier described in Fig. 11.

b) Calculate the position of poles and zeros and the frequency response $|V_u/V_S|$ for the circuit in the configuration indicated in Table 4.

3.1 Inside the black-box

The amplifier modules used in this lab have been realized by exploiting feedback operational amplifiers. In the following you may find a detailed description of the circuits included in the modules in A2.

NOTE: The active components mounted on the boards can actually be different from the ones indicated in the scheme at pag. 11.

Internal scheme for the non-inverting amplifier stage (sections 2.1 and 2.2).

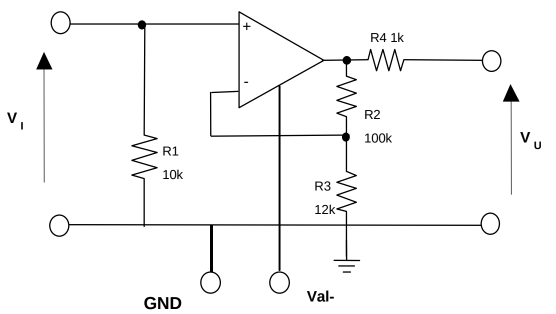


Figure 10: Internal scheme of the non-inverting amplifier

Comment [PB2]: Ho modificato i pedici delle resistenze per uniformarli con lo schema completo a pag.11

Internal scheme for the inverting amplifier stage (section 2.3).

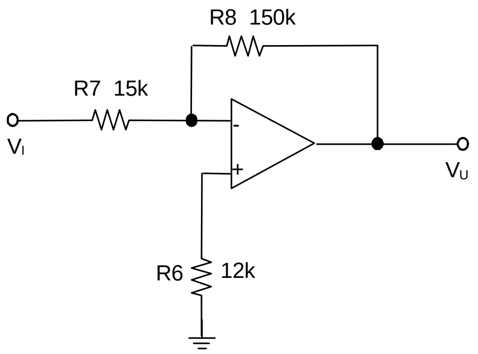
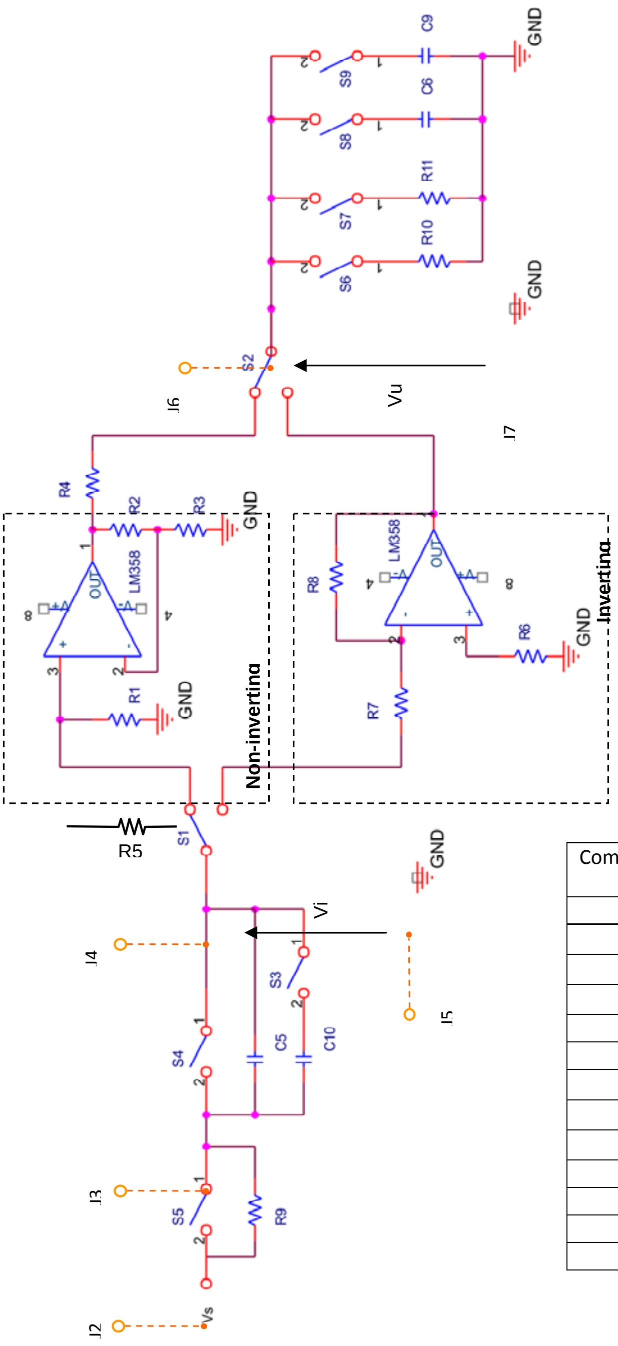


Figure 11: Internal scheme of the inverting amplifier

Complete scheme of the board A2

Comment [PB3]: Ho aggiunto la tabella al fondo con i valori dei componenti, forse può semplificare la vita agli studenti in laboratorio ed evitare qualche pasticci nei calcoli



Component	Nominal value
R_1	10 kΩ
R_2	100 kΩ
R_3	12 kΩ
R_4	1 kΩ
R_6	12 kΩ
R_7	15 kΩ
R_8	150 kΩ
R_9	10 kΩ
R_{10}	1 kΩ
C_5	10 nF
C_6	10 nF
C_9	1 nF
C_{10}	3.3 nF

4 Draft for the final report

Electronic Lab 1: Measurements of Amplifiers

Date:

4.1.1 Group ……..; components:

First Name	Last name	Signature

4.1.2 Used instruments

Instrument	Make and model	Characteristics
Waveform generator		
Oscilloscope		
Power supply		
Pre-assembled circuit board		

4.1.3 Synthetic description of the lab goals

4.1.4 Measure of the equivalent two-port circuit of amplifier stages

Gain at 800 Hz

	Measured	Theoretical acceptable range (from given values of components)
A_v (rapporto)		
A_v (in dB)		

Input equivalent resistance

	Measured	Theoretical acceptable range (from given values of components)
V_u (R9 short circuited)		---------
V_u (R9 inserted)		---------
R9 value		---------

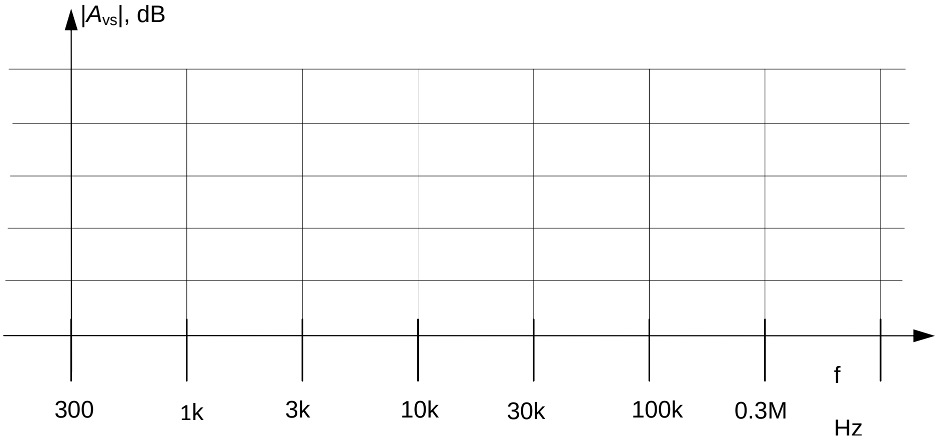
R_i value		

Output equivalent resistance

	Measured	Theoretical acceptable range (from given values of components)
V_u (R10 not connected)		-------------
V_u (R10 inserted)		-------------
R10 value		-------------
R_u value		

4.1.5 Frequency response of the amplifier with external RC filters.

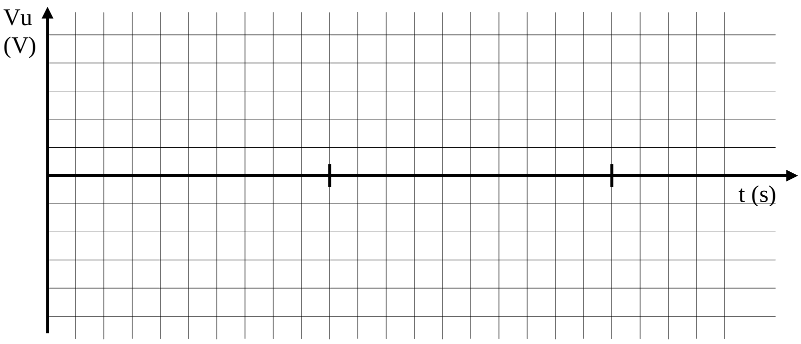
frequency (Hz)	pulsation (rad/s)	$\|A_{vs}\|$ (dB) calculated	$\|A_{vs}\|$ (dB) measured
300			
1k			
3k			
10k			
30k			
100k			
300k			
1M			



Bode plot of the voltage gain magnitude

4.1.6 Inverting amplifier

Check of the phase inversion



A_v measurement

	Measured
A_v	

$\boldsymbol{R_i}$ measurement

	Measured	Calculated
R_i value		