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Ingeniería eléctrica

TP N° 7: Operational Amplifier

Electronica II

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Objetives

Design an amplifier using an LM741 and carry out a frequency sweep.

- Design and build a square-wave oscillator with variable frequency between 1 kHz and 10 kHz, with 5 V output.

Introduction

Operational amplifiers

Operational amplifiers are fundamental integrated circuits in analog electronics. Their name comes from their original use in analog mathematical calculations (sums, subtractions, derivatives, integrals).

Ideal characteristics

- Infinite differential gain
- Infinite input impedance
- Zero output impedance
- Infinite bandwidth
- Instantaneous output without saturation

Modes of operation

Linear mode (with negative feedback):

Used as amplifiers of analog signals, precision comparators, filters, etc.

Examples: inverting amplifier, non-inverting amplifier, integrator, differentiator.

Switching mode (with positive feedback):

They behave as comparators: their output switches abruptly between the saturation voltages when the input crosses a certain threshold.

Examples: Schmitt triggers, square-wave oscillators, PWM generators.

Square-wave generation with op-amps

One of the most useful applications of op-amps is as a square-wave generator. This can be achieved with a relaxation oscillator that combines:

- An op-amp configured as a comparator
- An RC network that determines the frequency
- Positive feedback that imposes two trigger levels

Materials used

- Rigol DS1052t oscilloscope
  - 2 channels
  - 50 MHz
- Breadboard
- Power supply
- Op-amp
- Capacitor:
  - 2.2 nF
- Resistors:
  - 1 kΩ, 19 kΩ, 10 kΩ, 50 kΩ, 200 kΩ

Development

Amplifier with gain 20

Specifications of the statement

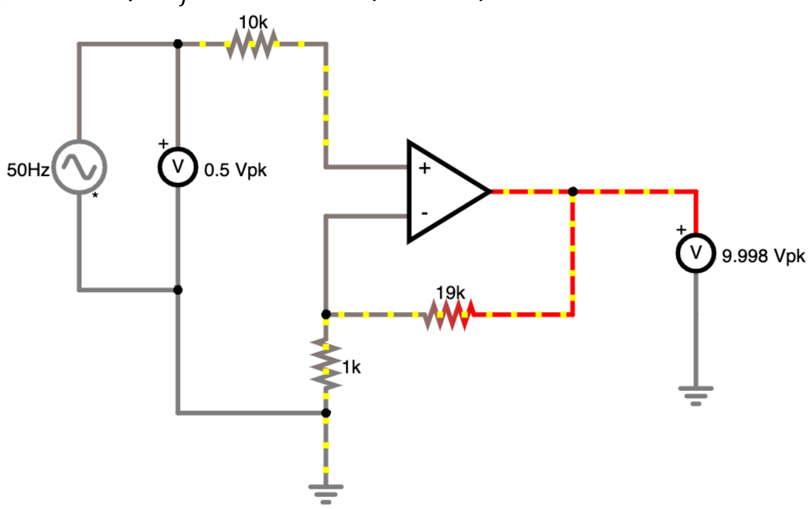
- Desired total gain: $A_V = 20$
- Amplifier : $\boldsymbol{LM741}$
- Input resistance : $Ri = \mathbf{10}\ \boldsymbol{k\Omega}$

The input impedance is approximately equal to the resistor connected in series with the non-inverting input (because the op-amp has very high input resistance).

For a non-inverting amplifier, the gain is:

$A_V = 1 + \frac{R_f}{R_1}$ with $A_V = 20 \rightarrow \frac{R_f}{R_1} = 19$

are choosen $R_1 = 1K\boldsymbol{\Omega}$ y $R_f = 19K\boldsymbol{\Omega} = (\mathbf{18} + \mathbf{1})\ \boldsymbol{K\Omega}$ commercial values are selected



Square-wave oscillator

Specifications of the statement

- Variable frequency: between 1 kHz and 10 kHz
- Output voltage: $V_{Out} = 5\ V$

A capacitor is used which charges and discharges through a resistor. The op-amp acts as a comparator with hysteresis, that is, with positive feedback.

Design formula

The oscillation frequency for this type of circuit is:

$$f = \frac{1}{2 \cdot R \cdot C \cdot Ln\left(\frac{1+\beta}{1-\beta}\right)}$$

Where:

- R: charging/discharging resistance of the capacitor
- C: timing capacitor
- β: hysteresis factor

$$\beta = \frac{R_1}{R_1 + R_2}$$

We start from the commonly used value $\beta = 0{,}5$, giving $Ln\left(\frac{1+\beta}{1-\beta}\right) = Ln(3)$

It is decide to use $R_1 = R_2 = 10\ K\boldsymbol{\Omega}$

$$f = \frac{0{,}455}{R \cdot C}$$

For $f = 1\ kHz \Rightarrow \quad R \cdot C = 455\ \mu s$

For $f = 10\ kHz \quad \Rightarrow \quad R \cdot C = 45{,}5\ \mu s$

Is choosen $C = 10nF$

For $f = 1\ kHz \Rightarrow \quad R = 45{,}5\ k\boldsymbol{\Omega}$

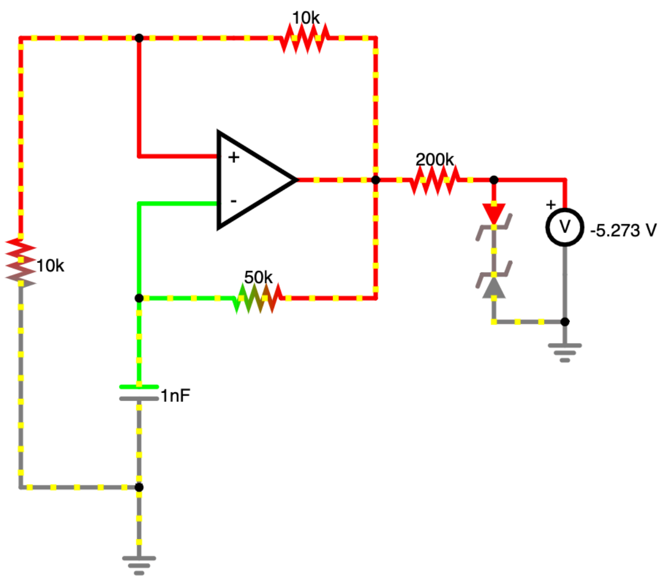
For $f = 10\ kHz \quad \Rightarrow \quad R = 4{,}55\ k\boldsymbol{\Omega}$

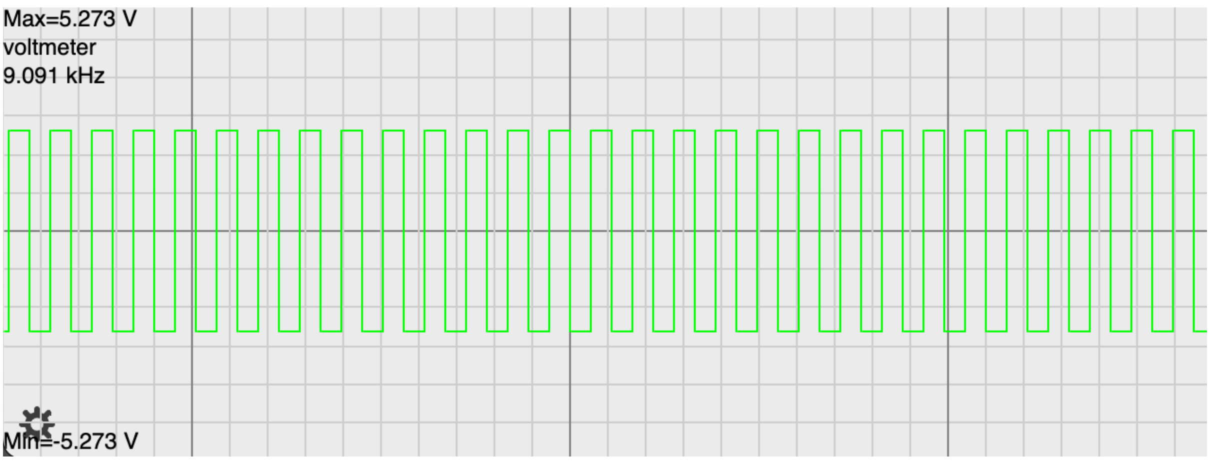
It is decided to use a potentiometer of $50\ k\boldsymbol{\Omega}$ and a fixed safety resistor of $4{,}7\ k\boldsymbol{\Omega}$.

We have therefore :

$$R_{Max} = (4{,}7\ + 50)k\boldsymbol{\Omega}$$

$$R_{Min} = 4{,}7\ k\boldsymbol{\Omega}$$





Laboratory development

Amplifier circuit simulation

The non-inverting amplifier stage was built first using an LM741 operational amplifier, with fixed gain of 20 through a feedback resistive network composed of resistors of and .

The op-amp was powered with ±15 V, and a 10 kΩ resistor was placed in series with the non-inverting input to set the input impedance.

Once the basic operation was verified, the LM741 was replaced by a TL081, without modifying the rest of the circuit, to compare the frequency behavior.

Measurement and signal analysis

A 500 mV peak sinusoidal signal generator was used, and the voltages were measured at the following points in the circuit:

- A (input): pure sine wave
- B (output): sine wave in phase with the input and with greater amplitude (confirming positive gain)

This confirms:

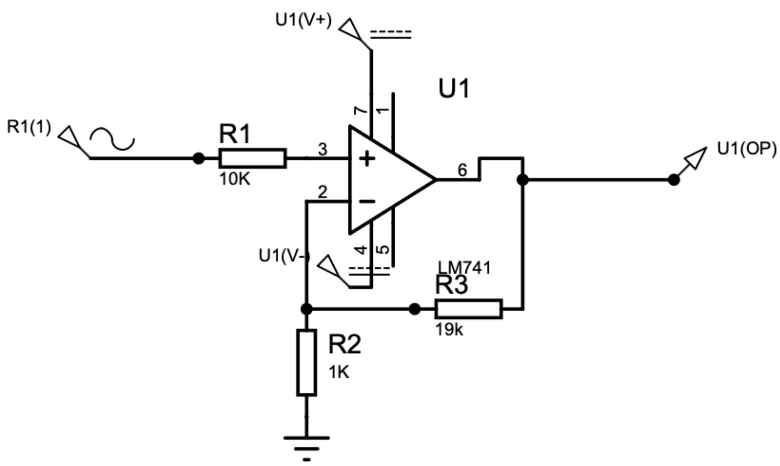
- The amplifier operates correctly with fixed gain
- There is no visible distortion at low frequency
- The output phase matches the input (as expected in a non-inverting configuration)

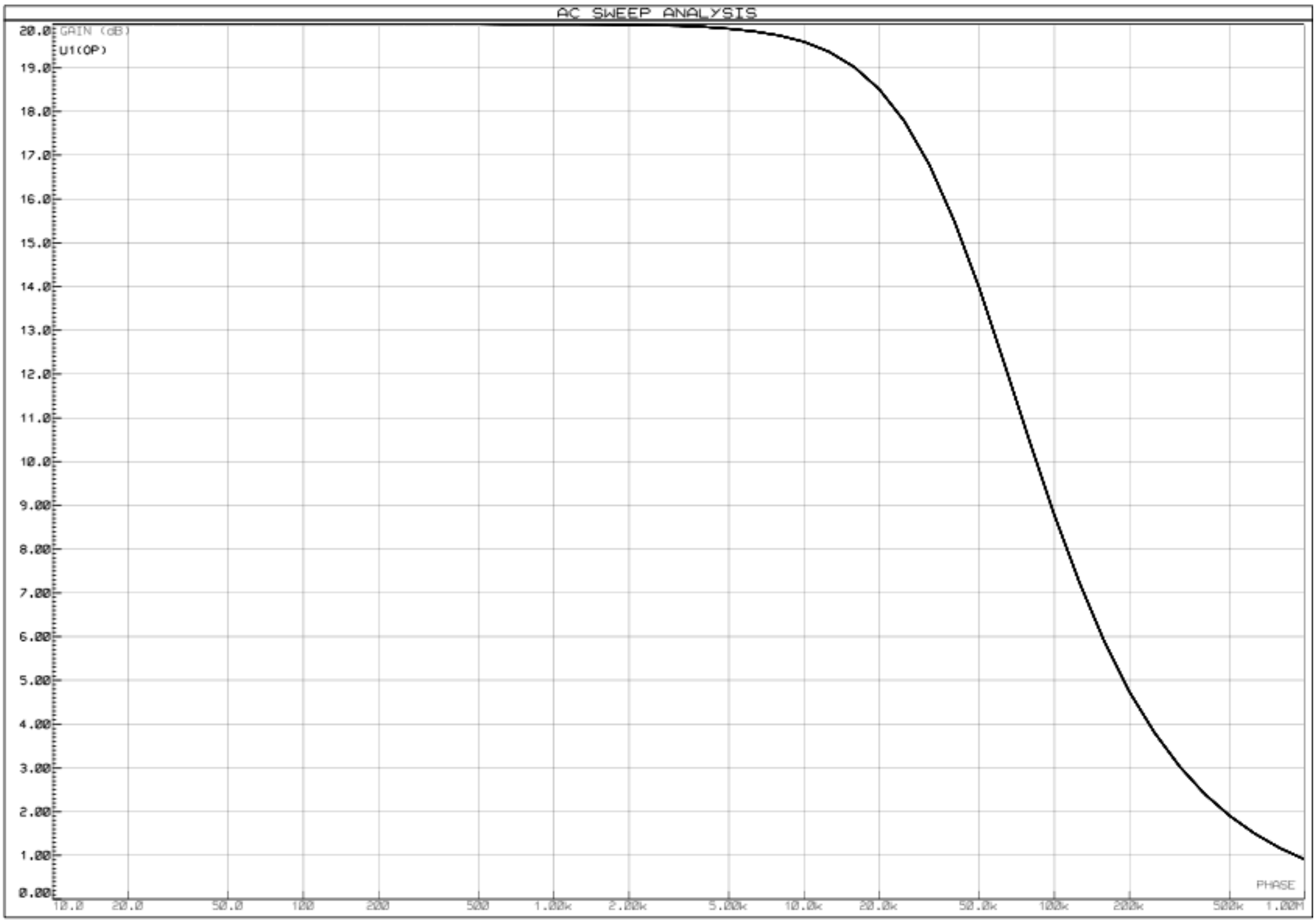
Frequency analysis

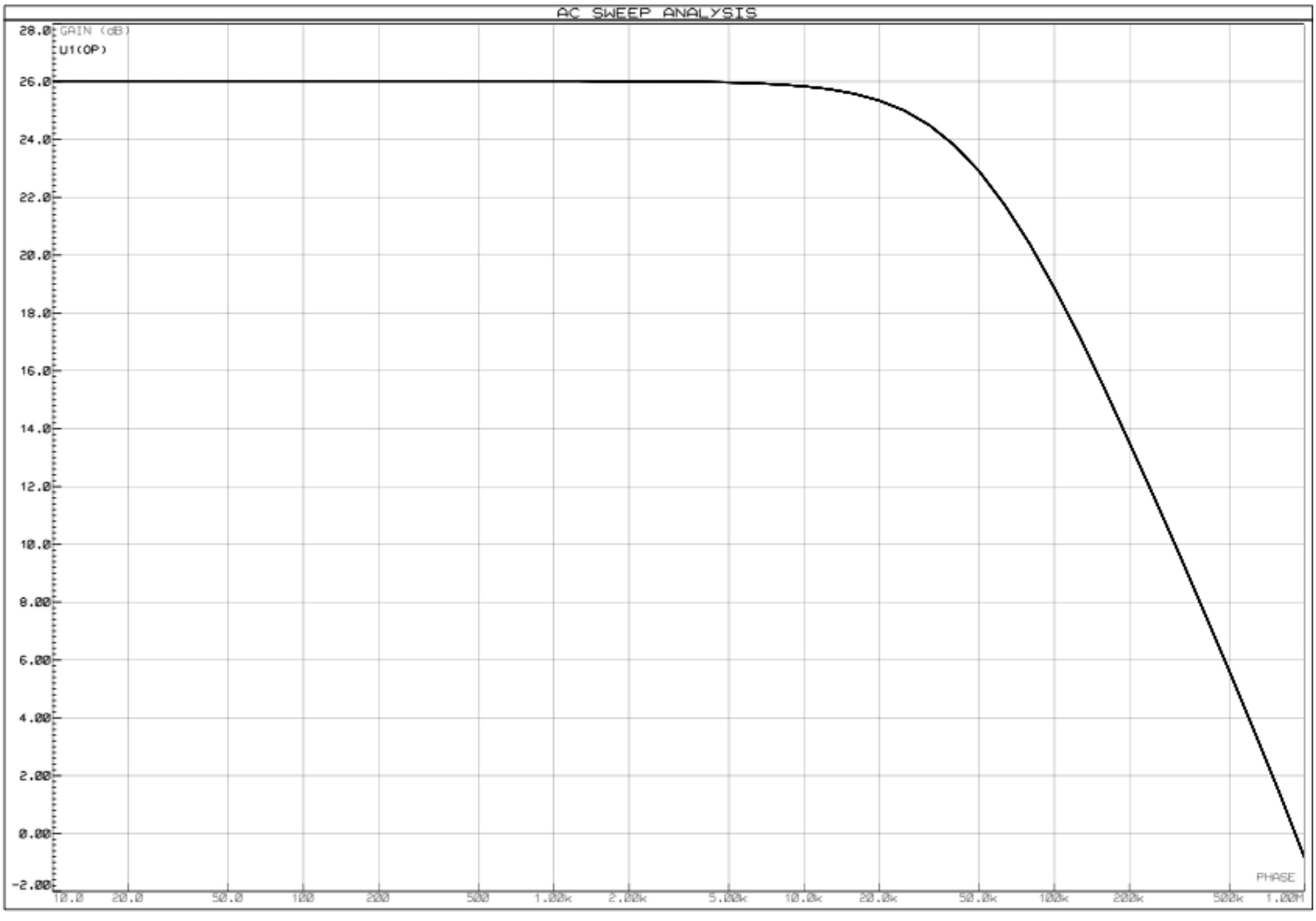
The bandwidth is obtained by identifying the cutoff frequency, defined as the point where the gain falls 3 dB below the maximum value in the flat region. This point marks the upper frequency limit at which the amplifier maintains linear behavior with the desired gain.

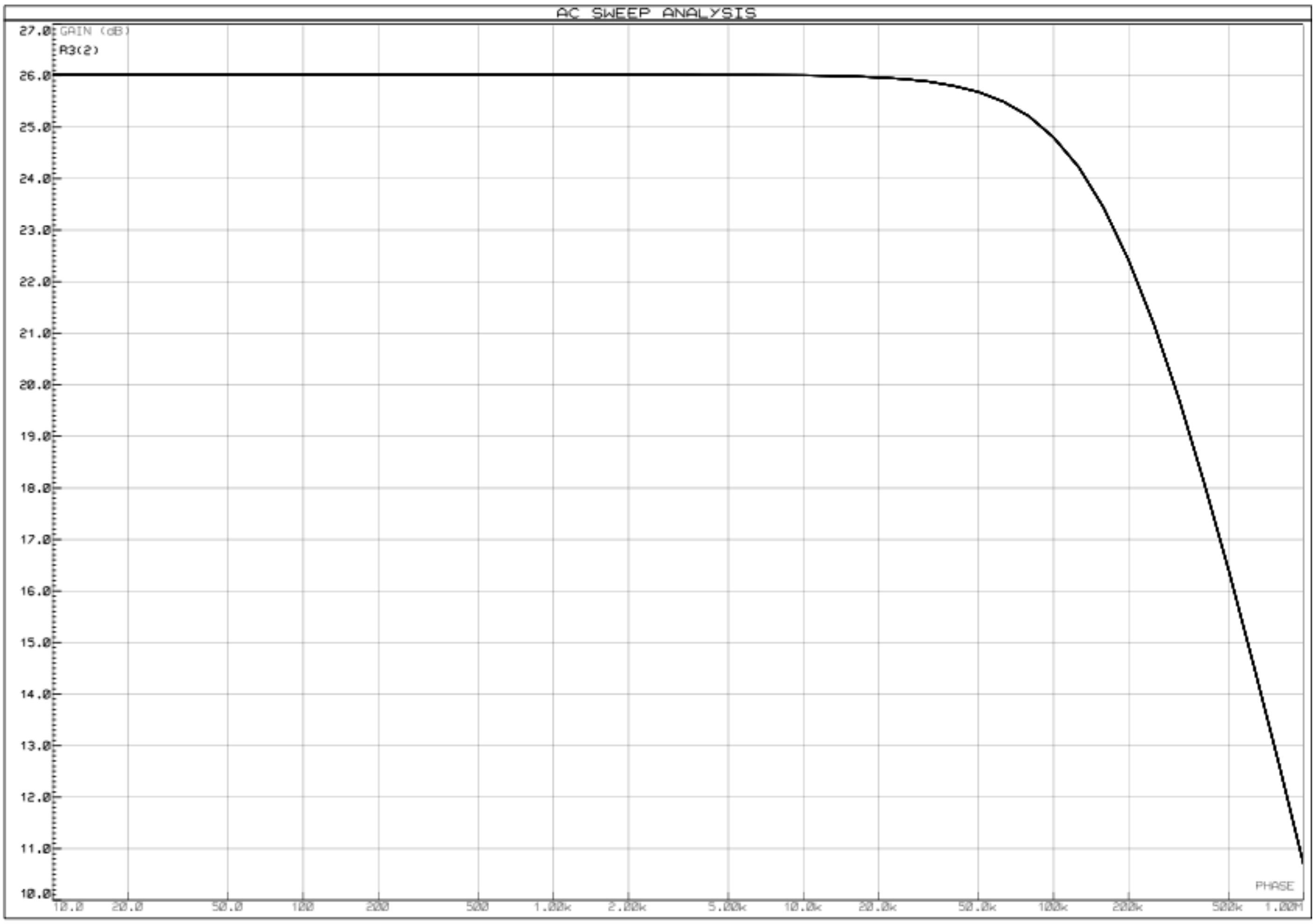
With LM741, the gain falls 3 dB at approximately 50 kHz.

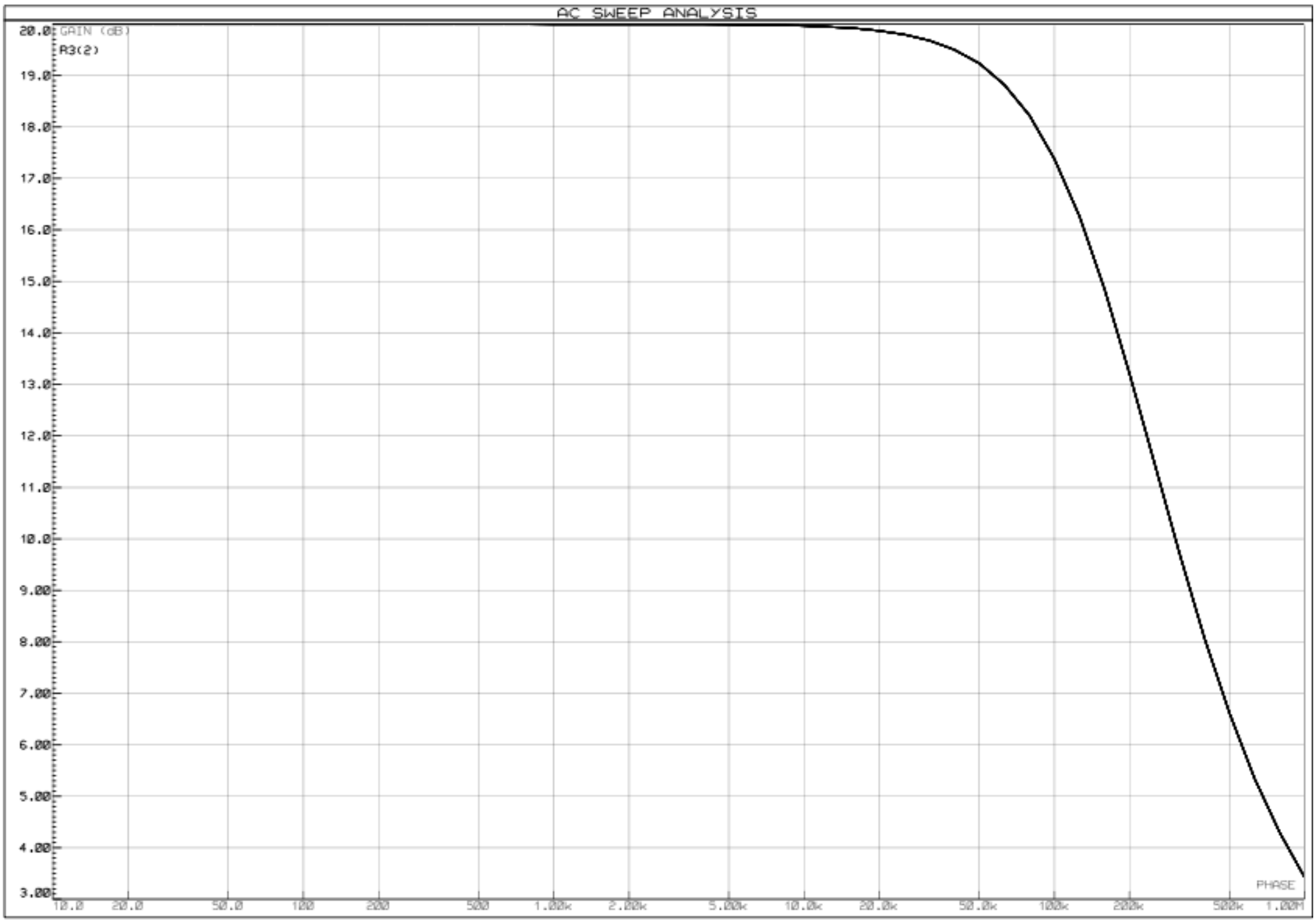
With TL081, the 3 dB drop occurs at 175 kHz.




AC SWEEP ANALYSIS
GAIN (dB)
U1(OP)
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
PHASE
10.0
20.0
50.0
100
200
500
1.00k
2.00k
5.00k
10.0k
20.0k
50.0k
100k
200k
500k
1.00M


AC SWEEP ANALYSIS
GAIN (dB)
U1(OP)
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.00
6.00
4.00
2.00
0.00
-2.00
PHASE
10.0
20.0
50.0
100
200
500
1.00k
2.00k
5.00k
10.0k
20.0k
50.0k
100k
200k
500k
1.00M


AC SWEEP ANALYSIS
GAIN (dB)
R3(2)
27.0
26.0
25.0
24.0
23.0
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
PHASE
10.0 20.0 50.0 100 200 500 1.00k 2.00k 5.00k 10.0k 20.0k 50.0k 100k 200k 500k 1.00M


AC SWEEP ANALYSIS
GAIN (dB)
R3(2)
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.00
8.00
7.00
6.00
5.00
4.00
3.00
PHASE
10.0 20.0 50.0 100 200 500 1.00k 2.00k 5.00k 10.0k 20.0k 50.0k 100k 200k 500k 1.00M

Oscillator circuit simulation

Se A square-wave oscillator circuit was built using an operational amplifier in comparator configuration with positive feedback.

Operation and analysis

The circuit generates a self-sustaining square wave, without the need for an external input signal. The capacitor connected to the inverting pin charges and discharges continuously through a resistor, and the positive feedback creates a hysteresis that forces the amplifier to alternate saturation at +Vcc and −Vcc, producing a square-wave signal.

The oscillation frequency depends on the RC product and on the values of the feedback resistors that set the switching thresholds (β).

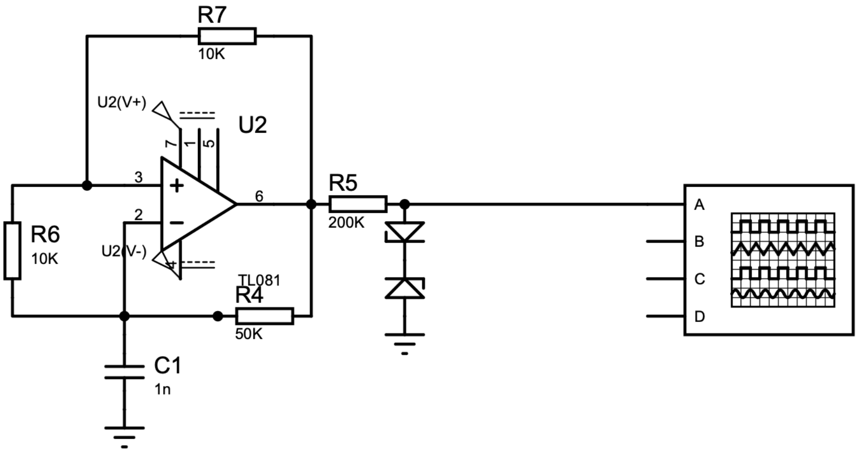
Measurement and results

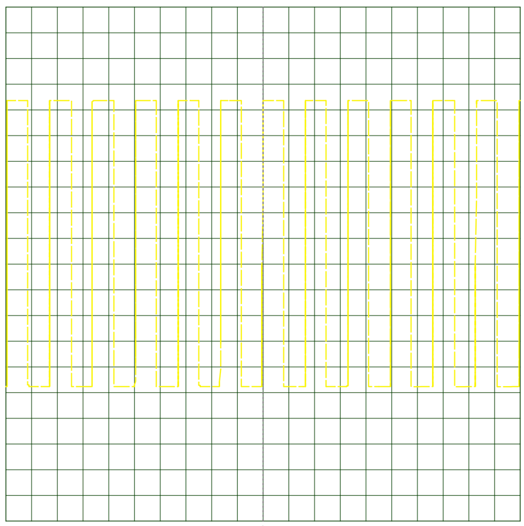
The waveforms were measured at the following points:

- Inverting input: triangular ramp (charging and discharging of the capacitor)
- Output: saturated square wave between +Vcc and −Vcc

It was observed that:

- The circuit oscillates stably
- The output wave is square and symmetrical
- The frequency can be adjusted by modifying the value of the resistor in series with the capacitor, or by replacing it with a potentiometer





Conclusion

In this work two circuits using operational amplifiers were analyzed and simulated: a non-inverting amplifier with fixed gain and a stable square-wave oscillator.

In the first part, a non-inverting amplifier with gain 20 was implemented, initially using an LM741 and then a TL081. It was observed that both operate correctly at low frequency, but the TL081 showed a larger bandwidth thanks to its higher gain-bandwidth product (GBW). Through the frequency sweep, it was verified that the cutoff frequency was approximately 50 kHz for the LM741 and 175 kHz for the TL081, which confirms the theory and highlights the importance of selecting a suitable op-amp according to the frequency requirements.

In the second part, a square-wave oscillator was built using positive feedback with hysteresis. The circuit oscillated correctly, generating a periodic signal without the need for an input signal.

References

Labcenter Electronics. (2024). *Proteus Design Suite 8.15* [Software de simulación electrónica]. https://www.labcenter.com

Floyd, T. L. (2012). *Principios de circuitos eléctricos* (9.ª ed.). Pearson Educación.

Falstad, P. (2023). *Circuit Simulator Applet* [Simulador en línea]. https://www.falstad.com/circuit/