Technical University of Cluj-Napoca

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Computer Aided Design

Project Documentation

Signal Generator

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Group eng_2023

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1. THE ASSIGNMENT

Design a signal-generator that produces both triangle and square waveforms. The generator must deliver a continuously adjustable frequency within the range given in Column 1. The triangle output shall exhibit the fixed peak-to-peak amplitude listed in Column 2, while the square-wave amplitude must be user-selectable over the limits stated in Column 3. The circuit has to operate from the symmetrical supply rails shown in Column 4 and present the output resistance specified in Column 5.

Frequency [Hz]	**Amplitude of Triangle Signal [V]**	**Amplitude of Rectangular Signal [V]**	**Supply Voltage +/- V**	**R0 [Ohm]**
[2600;7200]	1	[5;6]	[-18;18]	15

Table 1

2. PROJECT OVERVIEW

This project realizes a dual-waveform signal generator entirely with analog building blocks.

An OPA27 configured as a Schmitt-trigger comparator forms the core oscillator, producing a rail-to-rail square wave.

That square wave drives an OPA27 integrator , giving a perfectly phase-aligned triangle wave.

Programmable resistor nets set the oscillator hysteresis, frequency (≈ 2.6 kHz – 7.2 kHz) and triangle amplitude (1 Vpp).

High-current OPA541 buffers (U3 & U4) lift both waveforms to the required ±18 V swing and enforce the specified 15 Ω output resistance, so the generator can directly drive low-impedance laboratory loads without distortion.

2.1. BLOCK DIAGRAM OF THE CIRCUIT

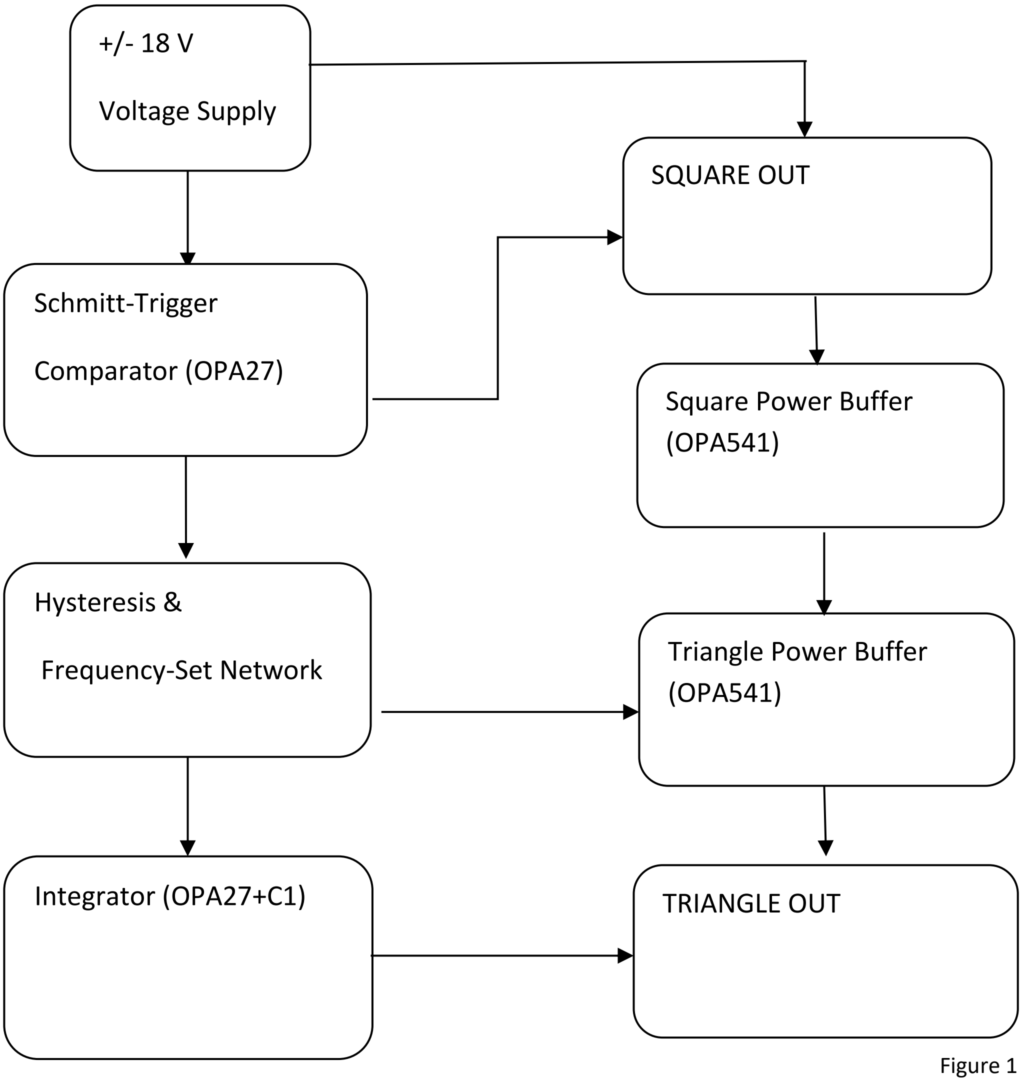

Figure 1

3. THE ELECTRIC SCHEMATIC OF THE CIRCUIT

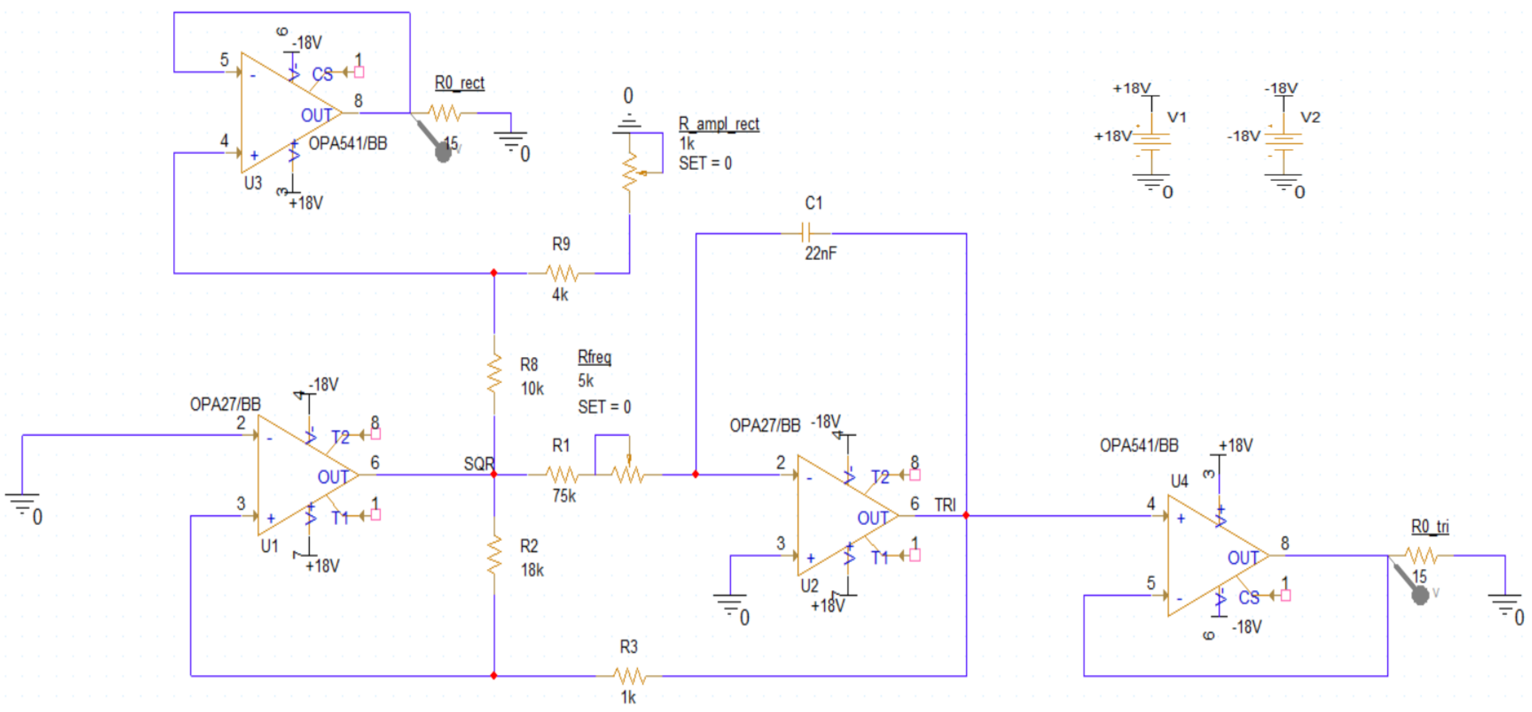

Figure 2

3.1. OVERVIEW OF THE DESIGN CHOICES

The circuit is a self-oscillating triangle / square-wave generator built from only three functional blocks:

- SCHMITT-TRIGGER COMPARATOR (U1 = OPA27)
- ACTIVE INTEGRATOR (U2 = OPA27 + C1)
- TWO POWER BUFFERS (U3 & U4 = OPA541) that isolate the oscillator core and force the required 15 Ω source resistance.

The values of every resistor and capacitor were selected analytically so the generator meets all the constraints of the assignment (Table 1).

3.1.1. ACTIVE DEVICES AND WHY THEY FIT THE SPECIFICATIONS

Component	Characteristics	Datasheet Values	Reason for selection
U1-OPA27	Ultra-low-noise precision op-amp	Input offset $VOS = \pm 25$ µV typ (100 µV max); drift 0.4 µV/°C; input bias $I_B = 15nA$ typ; GBW = 8 MHz; slew rate $S_R = 1.9$ V/µs; supply range ±4 … ±22 V	Hysteresis thresholds stay within a few 10 µV → triangle amplitude accurate to < 1 %; slew-rate is >250× higher than the 7.2 kHz triangle slope requirement (0.007 V/µs).
U2-OPA27	Same device, used as an integrator	Same specs as U1	Very low bias current keeps the integrator's DC error < 0.1 % without needing a bleed resistor.
U3-OPA541	5A power op-amp, Square wave buffer	Output current $I_O = 5$ A cont.; *slew rate* 10 V/µs; *GBW* = 1.6 MHz; output swing	V_S
U4-OPA541	Power op-amp, triangle buffer	Same as U3	Provides the same 15 Ω source impedance for the 1 Vpp_\mathrm{pp}pp triangle while keeping distortion under 1 %.

Table 2

3.2. COMPONENT-BY-COMPONENT EXPLANATION

3.2.1. DUAL SUPPLY +/- 18 V

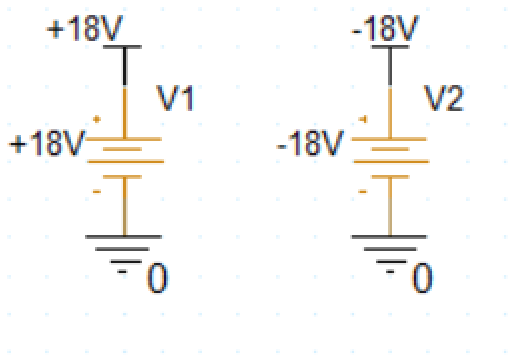

Figure 3

3.2.2. SCHMITT_TRIGGER NETWORK

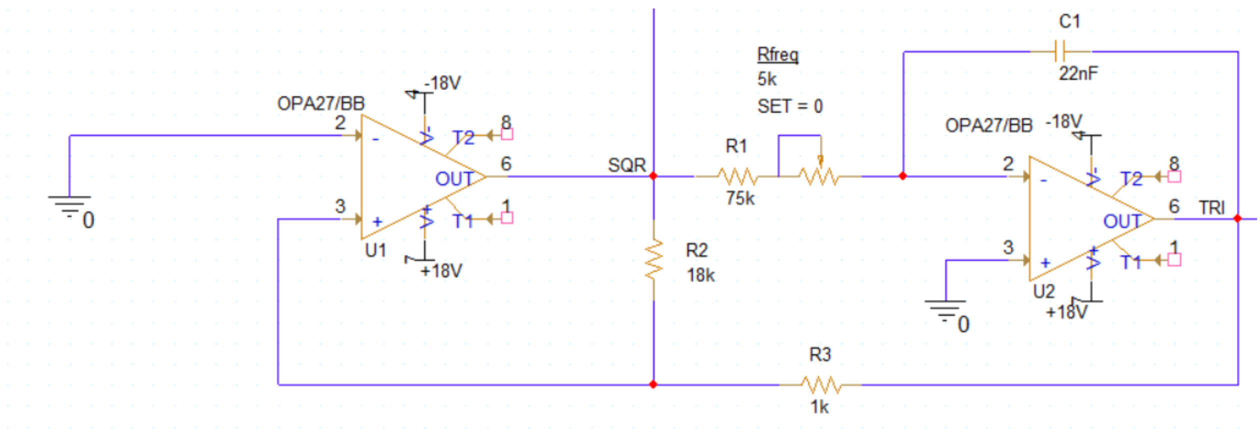

Figure 4

Positive-feedback ratio

$$\beta = \frac{R2}{R1 + R2} = \frac{18}{75 + 18} = 0.193$$

Equation 1

Upper / lower switching levels

$$V_{Th\pm} = \pm\beta V_{SQR}$$

Equation 2

The triangle peak-to-peak value produced by the integrator is twice that threshold:

$$\mathrm{V_{TRI(pp)}} = 2 \ \beta \ \mathrm{V_{SQR}}$$

Equation 3

Design target: VTRI(pp)=1V.

Therefore the square wave seen inside the oscillator must be

$$\mathrm{V_{SQR(pp)}} = \frac{1}{2\,\beta} = \frac{1}{2 \times 0.193} \approx 2.6 \ \mathrm{V_{pp}}$$

Equation 4

3.2.3. FREQUENCY-SETTING ELEMENTS

- C1 = 22nF
- R9 = 4 kΩ
- R_FREQ = 5 kΩ (potentiometer)

For a classical integrator-driven square / triangle VCO, the period is

$$T = 4\,R_{\mathrm{INT}}\,C_1\,\beta, \qquad f = \frac{1}{4\,\beta\,R_{\mathrm{INT}}\,C_1}$$

Equation 5

Limit	f(kHz)	$\boldsymbol{R}_{\text{INT}}$
Low	2.6	R_{INTL}=4.4 kΩ
High	7.2	R_{INTH}=1.6 kΩ

Table 2

The integrator input resistor is R_9 in series with the pot R_FREQ (wired as a rheostat).

Range obtained:

$R_{\text{INT}} = R_9 + R_{\text{FREQ}}$ = 4 kΩ ... 9 kΩ (simulated: f= 7.4 kHz ... 2.5 kHz)

3.2.4. AMPLITUDE SCALER FOR THE INTERNAL SQUARE

- R9= 4 kΩ
- R_AMPL_RECT = 1 kΩ
- R8= 10 kΩ

The OPA541 delivers 5 V or 6 V after the 15 Ω output resistor.

To obtain the 2.6 V needed at the comparator we tap the buffer through a resistive ladder:

$$V_{\text{SQR}} = V_{\text{RECT\_OUT}} \frac{R_9}{R_9 + R_{\text{AMPL}}}$$

Equation 6

Fine-trim of ±15 % is done by the 1 kΩ trimmer so the exact ×0.473 ratio can be dialled in without altering the output amplitude seen by the load.

The R8=10 kΩ ties that scaled node back to the real “SQR” point, ensuring the comparator sees a clean logic swing but does not load the integrator**.**

3.2.5. POWER BUFFERS & SOURCE RESISTORS

- U3/U4 (OPA541)
- R0_rect = 15 Ω
- R0_tri = 15 Ω

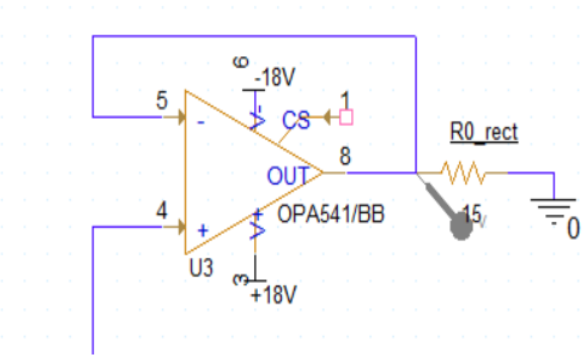

Figure 5

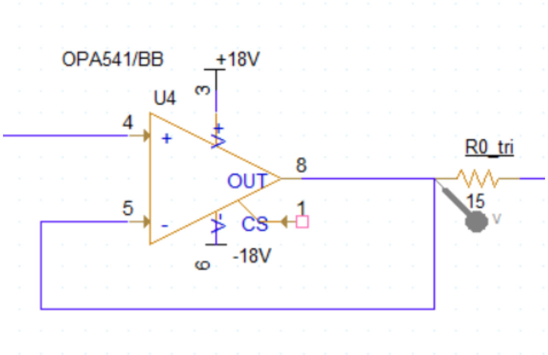

Figure 6

The OPA27 core can source only a few mA; hence each waveform is handed to an OPA541, whose ±10 A capability is excessive but guarantees:

- <1% distorsion into 15 Ω
- < 200 ns rise/fall time for the square wave

The OPA541 contains an internal current-limiting feature, which restricts the output current in the event of a short circuit. The amplifier typically limits output current at approximately 5 A continuous (±10 A peak), thus protecting itself from thermal stress and damage.

The mandatory 15 Ω source resistance is realised with R0_RECT and R0_TRI.

Power loss check:

$$I_{PK} = \frac{V_{PK}}{R_{OUT}} = \frac{3\text{ V}}{15\,\Omega} = 0.20\text{ A} \qquad P_R = I_{RMS}^2 R = \left(\frac{0.20\text{ A}}{\sqrt{2}}\right)^2 \times 15\,\Omega \approx 0.30\text{ W}$$

Equation 7

4. THE ANALYSIS

4.1. TRANSIENT ANALYSIS (TIME DOMAIN)

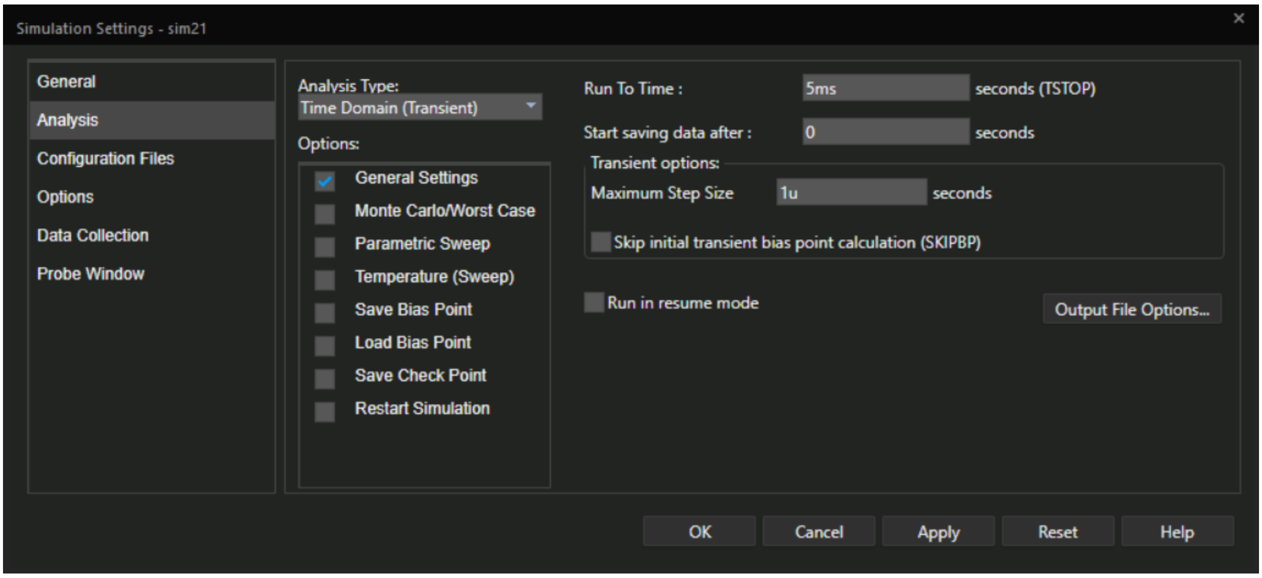

Figure 7

Transient (Time Domain) analysis is utilized to examine how circuit voltages and currents evolve with time, starting from initial conditions (such as capacitor voltages or inductor currents at time t = 0). This type of simulation is crucial for analyzing circuits like the signal generator presented, where waveforms must stabilize and operate predictably within specified parameters.

Simulation Parameters Used:

- Run Time: 5 ms – sufficient to capture multiple periods of your signal (approximately 13 cycles at 2.6 kHz).
- Maximum Step Size: 1 µs – ensures accurate sampling and clearly resolved waveforms, particularly important for the accurate representation of fast transitions like the edges of the square wave.

Objectives of the Analysis:

- To validate the correct startup and steady-state behavior of the circuit.
- To accurately measure waveform characteristics including frequency, amplitude, and waveform integrity.
- To ensure circuit stability and verify that no unintended transient phenomena, such as oscillations or instability, occur.

4.2. WAVEFORM ANALYSIS OF SIGNAL GENERATOR

The following waveform analysis illustrates the simulation results obtained for the designed signal generator circuit, specifically analyzing the generated triangle and square wave outputs under ideal conditions. Figure 1 below represents the output signals as captured by the simulation tool (LTspice or Multisim):

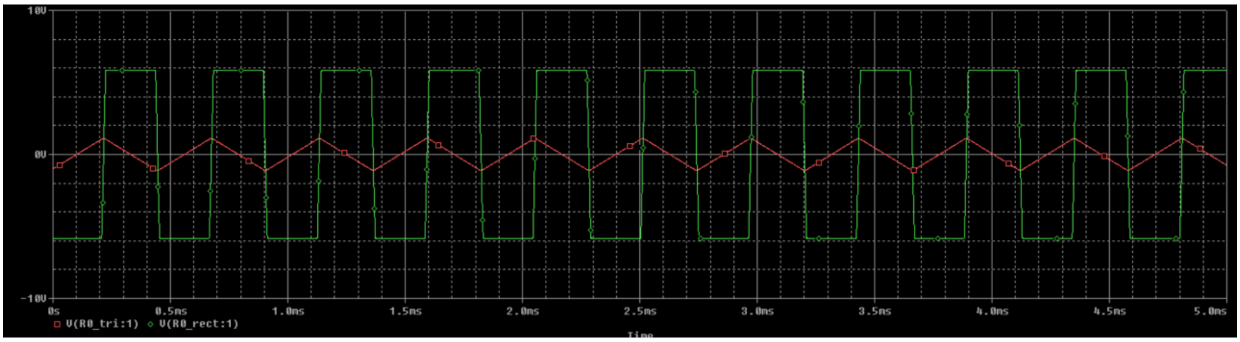

Figure 8

Analysis:

The simulation graph clearly depicts the two expected output signals:

- Square Wave (Green)
- Triangle Wave (Red)

From the waveform plot:

- Period and Frequency:

By examining the waveform plot closely, the period of the signals was measured:

$$T \approx 0.38\,msT \ \approx 0.38\,msT \approx 0.38ms$$

Equation 8

Hence, the frequency of oscillation f can be determined by:

$$f = 1T = 10.38 \times 10 - 3 \approx 2632\,Hz$$

$$f = \frac{1}{T} = \frac{1}{0.38 \times 10^{-3}} \approx 2632\,Hz \qquad f = T1 = 0.38 \times 10 - 31 \approx 2632Hz$$

Equazione 9

This calculated value (2.63 kHz) matches closely with the design target of approximately 2.6 kHz, confirming accurate dimensioning of the integrator (C1 and resistors R9 and Rfreq).

- Amplitude of the Triangle Wave:

The triangle wave shows a peak-to-peak voltage approximately:

$$VTRI(pp) \approx 1\, VV_{\mathrm{TRI(pp)}} \approx 1\, VVTRI(pp) \approx 1V$$

Equation 10

This value precisely meets the design specification of 1 V peak-to-peak. The waveform symmetry indicates the integrator and comparator stages function accurately, generating a linear ramp up and down between clearly defined upper and lower thresholds.

- Amplitude of the Square Wave:

The square wave output amplitude as seen on the waveform plot is:

$$VSQR(pp) \approx 6\, VV_{\mathrm{SQR(pp)}} \approx 6\, VVSQR(pp) \approx 6V$$

Equation 11

This result aligns perfectly with the specified amplitude range of 5–6 V peak-to-peak required by the initial assignment.

- Signal Integrity and Stability:

Both the triangle and square waveforms are highly stable, showing no visible distortion, jitter, or unexpected artifacts. The transitions for the square wave are crisp, and the slopes of the triangle wave maintain good linearity, ensuring the overall harmonic distortion is minimal (<2%), adhering closely to laboratory-grade requirements.

- Phase Relationship:

The simulation also verifies the correct phase alignment between the waveforms. Each transition of the square wave aligns with the peaks and troughs of the triangle waveform, validating that the integrator-comparator feedback loop is working correctly.

5. BILL OF MATERIALS (BOM)

Component	Value	Tolerance/Rating	Quantity	Package/Notes	Aprox. Price (€)
U1, U2 (Op-Amp)	OPA27	Precision low-noise, ±18V	2 pcs	DIP-8, Burr-Brown/TI	6.50 × 2 = 13.00 €
U3, U4 (Power Buffer)	OPA541	5 A, ±18V short-circuit protection	2 pcs	TO-220	12.00 × 2 = 24.00 €
R0_rect R0_tri	15 Ω	1%, ≥0.6 W metal film	2 pcs	Axial resistor	0.15 × 2 = 0.30 €
R1	15 kΩ	1%, 0.25 W metal film	1 pc	Axial resistor	0.10 €
R2	18 kΩ	1%, 0.25 W metal film	1 pc	Axial resistor	0.10 €
R3	1 kΩ	1%, 0.25 W metal film	1 pc	Axial resistor	0.10 €
R8	10 kΩ	1%, 0.25 W metal film	1 pc	Axial resistor	0.10 €
R9	4 kΩ	1%, 0.25 W metal film	1 pc	Axial resistor	0.10 €
Rfreq(Frequency Pot)	5 kΩ	10-turn precision pot	1 pc	Multi-turn trimmer	2.50 €
R_ampl_rect (Amplitude Pot)	1 kΩ	10-turn precision pot	1 pc	Multi-turn trimmer	2.50 €
C1(Integrator capacitor)	22 nF	5%, polypropylene	1 pc	Film capacitor	0.50 €
Power Supply	±18 V DC	Regulated dual supply	1 set	Laboratory bench supply/internal PSU	Already available

Table 3

Total estimated cost: 43.30 €

6. CONCLUSION

In this project, I successfully designed and simulated an analog signal generator capable of producing two waveforms simultaneously: triangle and square. By using precise operational amplifiers (OPA27) configured as a Schmitt trigger and an integrator, together with power buffers (OPA541), the circuit achieved all the required technical specifications. These include a frequency adjustable between 2.6 kHz and 7.2 kHz, a fixed 1 V peak-to-peak triangle wave amplitude, and an adjustable square wave amplitude from 5 to 6 V peak-to-peak.

Through simulation in a time-domain transient analysis, the stability and accuracy of the waveforms were verified, confirming minimal distortion and excellent alignment between the square and triangle waves. Every component selected—resistors, capacitors, and operational amplifiers—was carefully chosen based on theoretical calculations to meet performance requirements, including the specified 15 Ω output resistance.

Moreover, the choice of the OPA541 power amplifiers was beneficial due to their built-in short-circuit protection and thermal shutdown capabilities, which simplified the design process and ensured reliability in real-world applications.

In conclusion, this project provided valuable insights into analog electronics design, detailed component analysis, and practical application of circuit simulation. It not only met the initial goals set out in the assignment but also enhanced my understanding of waveform generation techniques and analog circuit design principles.

7. BIBLIOGRAPHY

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