Mini Project
on

Designing and fabrication of an Analog PID Controller

Linear integrated circuit laboratory (EELR14)

Submitted by

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PID Controller

Abstract

This project endeavours to implement effective control mechanisms by compensating for present, past, and potential future errors using proportional, integral, and derivative control inputs.

The circuit design involves regulating a variable DC supply with IC 7815 to generate +15V and IC7660SAPAZ for generating -15V to power the op-amp (IC741). The schematic is divided into three sections: an input summer, a PID controller (comprising proportional, integral, and derivative circuits), and a plant with a gain of 0.5. The plant's output, fed to the input through an error generator (subtractor), is controlled by the PID controller, and the resulting output is amplified using the plant with a gain of 0.5.

An additional circuit for self-power generation operates within the range of 15V to 30V. To achieve a 2V target output, a 2V square wave input is maintained through a Schmitt Trigger whose upper and lower thresholds are maintained by the resistance divider circuit.

The project integrates theoretical concepts, practical implementation, and testing of proportional, integral, and derivative components. Its goal is to develop a fully functional Analog PID controller, poised to enhance control systems in diverse industrial applications.

1. Introduction

The concept of the project is to design and fabricate an Analog PID controller circuit specifically tailored for a given plant. A PID controller is a feedback control system widely used in industrial processes to regulate various parameters, ensuring the system's stability and optimal performance.

In the context of this project, the PID controller comprises three main components: proportional control, integral control, and derivative control. Proportional control responds to the present error, integral control addresses accumulated past errors, and derivative control considers the rate of change of the error. The combination of these three components allows for precise and dynamic control of the system.

The significance of this project lies in its practical application within industrial settings. PID controllers are crucial in processes, where maintaining a desired output or setpoint is essential. By customizing the Analog PID controller for a specific plant, the project aims to optimize control, reduce steady-state errors, and enhance the overall performance of the system. This type of tailored control system is particularly valuable in scenarios where digital controllers may not be suitable or where Analog control is preferred.

Importance: -

1. Precision Control: The precise and real-time control provided by PID controllers is essential in applications where maintaining specific conditions or setpoints is critical. This precision contributes to higher product quality and reliability.
2. Reduced Steady-State Errors: PID controllers are designed to minimize steady-state errors, ensuring that the system output closely follows the desired setpoint. This characteristic is vital in applications where maintaining consistency is paramount.
3. Versatility: PID controllers are versatile and applicable to a wide range of systems and industries. They find use in processes such as temperature control, motor speed regulation, fluid flow control, and more.

Challenges of the practical engineering applications: -

1. Tuning Difficulty: Tuning PID controllers for optimal performance requires a good understanding of the system dynamics. Finding the right combination of proportional, integral, and derivative gains can be a trial-and-error process.
2. Non-Linearity: Some processes may exhibit non-linear behaviour, making it challenging to design a PID controller that performs well across the entire operating range.
3. The selection of component ratings requires repeated iterative calculation due to changing effective resistances (R_{in} & R_{out}) across the circuit.

Ultimately, the successful design and fabrication of the Analog PID controller for the given plant can contribute to increased efficiency, improved stability, and enhanced control in industrial processes, making it a project with practical and real-world significance.

Objectives

- Variation of the output signal with varying K_p, K_d, and K_i.
- Variation of the output signal with varying Input signal threshold levels.
- Variation of the output signal with varying plant gain.

Note: Here K_p, K_d, and K_i correspond to Gains of Proportional, Differential, and Integral OpAmp based circuits.

2. Methodology

I. *Designing Proportional, Integrator, and Differentiator:*

- Initiated the circuit development by designing individual components such as the proportional amplifier, integrator, and differentiator.
- Utilized an Inverting Amplifier circuit and fixed the corresponding gains for each component.

II. *Summing Signals Using OpAmp as an Inverting Summer:*

- In the second stage, combined the signals from the proportional amplifier, integrator, and differentiator.
- Employed an OpAmp configured as an inverting summer to add these signals effectively.

III. *Passing Signal Through the Plant:*

- Passed the combined signal through the plant to obtain a stable output set at a constant 2 Volts.

IV. *Feedback Loop and Error Signal Generation:*

- Introduced a feedback loop by routing the output to an inverting subtractor.
- The inverting subtractor compared the input and output voltages, generating an error signal representing the difference.

V. *PID Controller Integration:*

- Fed the error signal into the PID (Proportional-Integral-Derivative) controller block.
- The PID controller adjusted the system parameters based on the error signal to optimize the output response.

VI. *Self-Power Generation Circuit:*

- Implemented a self-power generation circuit to ensure the availability of stable power.
- Accepted a DC input ranging between 15-30V.
- Utilized an IC7815 voltage regulator to provide a constant +15V supply.

VII. Generating -15V Supply:

- For the -15V supply, either employed a DC-DC coupler IC7660 or utilized a separate IC7915.

VIII. Function Generator for Reference Signal:

- Incorporated a function generator to generate a reference 2V square voltage required just before the PID controller block.
- This reference signal served as a baseline for the PID controller to compare against the system output.

IX. Observing System Response:

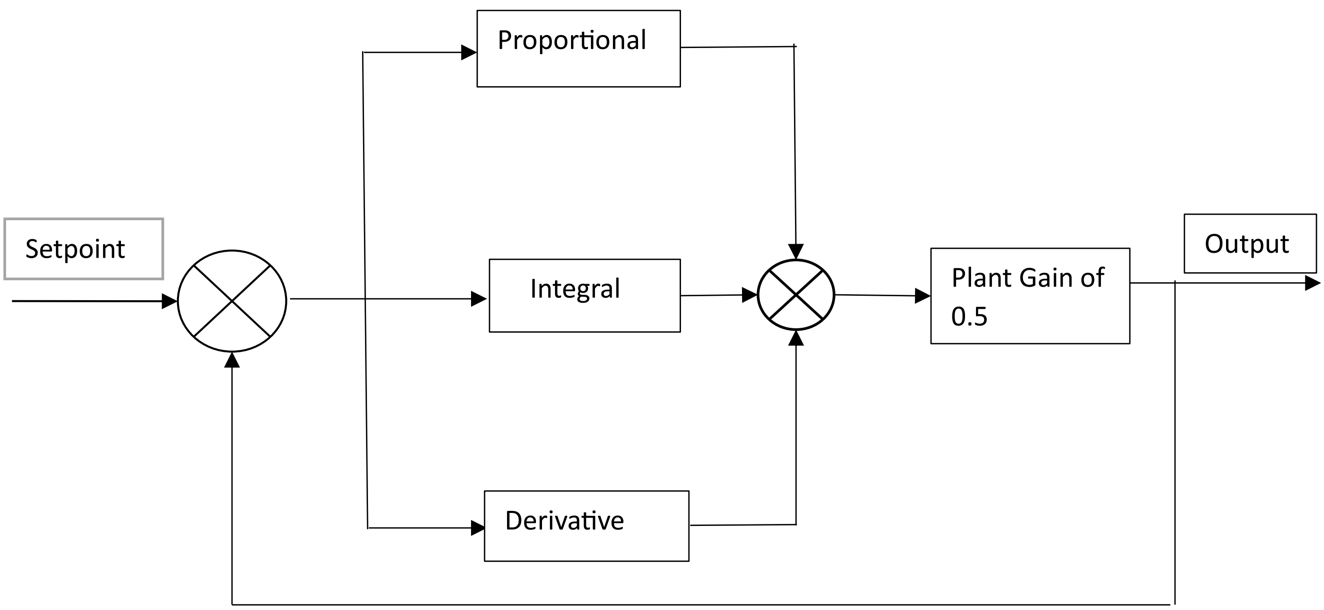
- Optionally, used a square wave with a maximum amplitude of 2V as an input.
- Observed changes in the output voltage, including overshoot, rise time, and peak time, when the fixed point was set at 2V.

X. Simulation Validation:

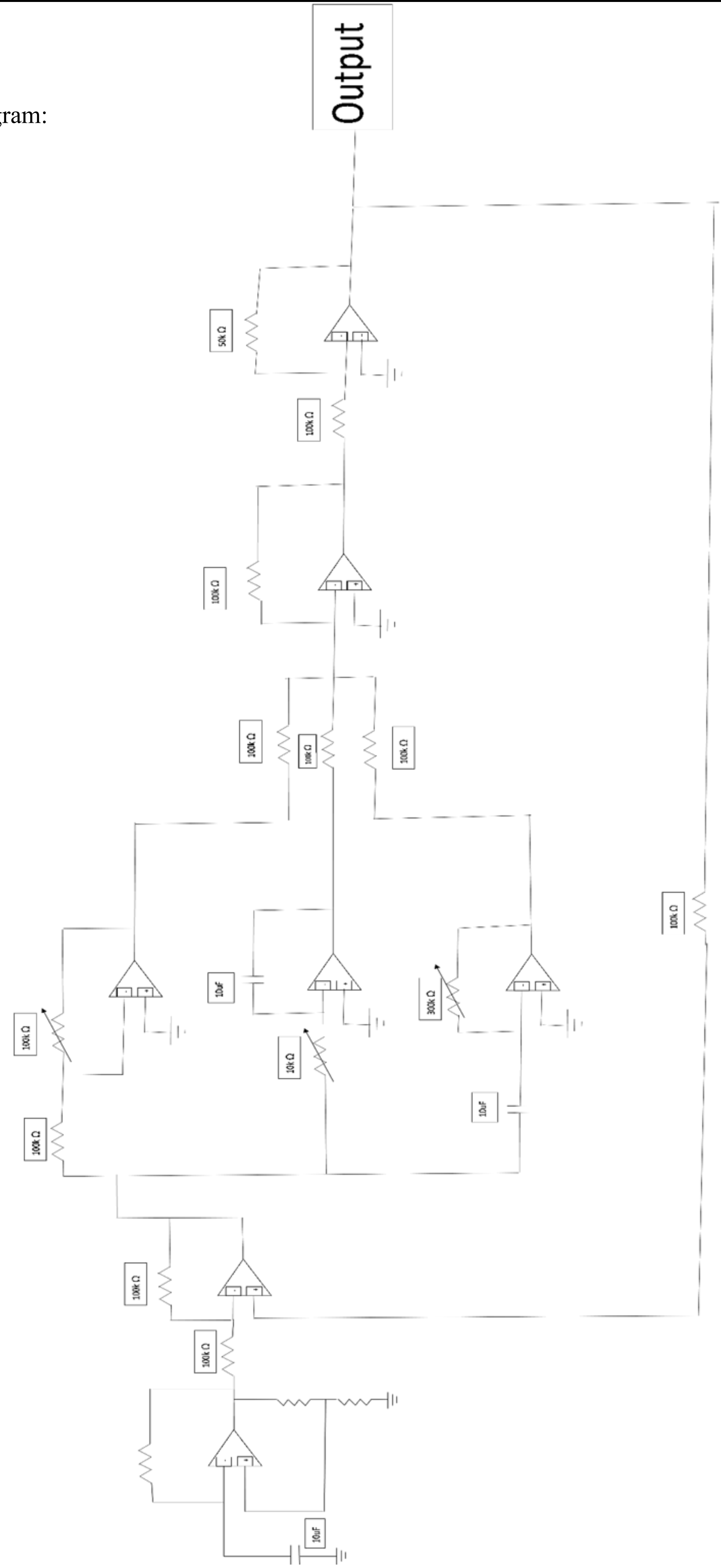
- Conducted cross-validation to compare and verify the simulation results with the obtained waveforms.
- Calculated and analyzed the discrepancies between simulated and observed values for various parameters, such as overshoot, under different system changes as outlined earlier.

By systematically following these steps, the circuit development process aimed to achieve a controlled and optimized system response for the given specifications.

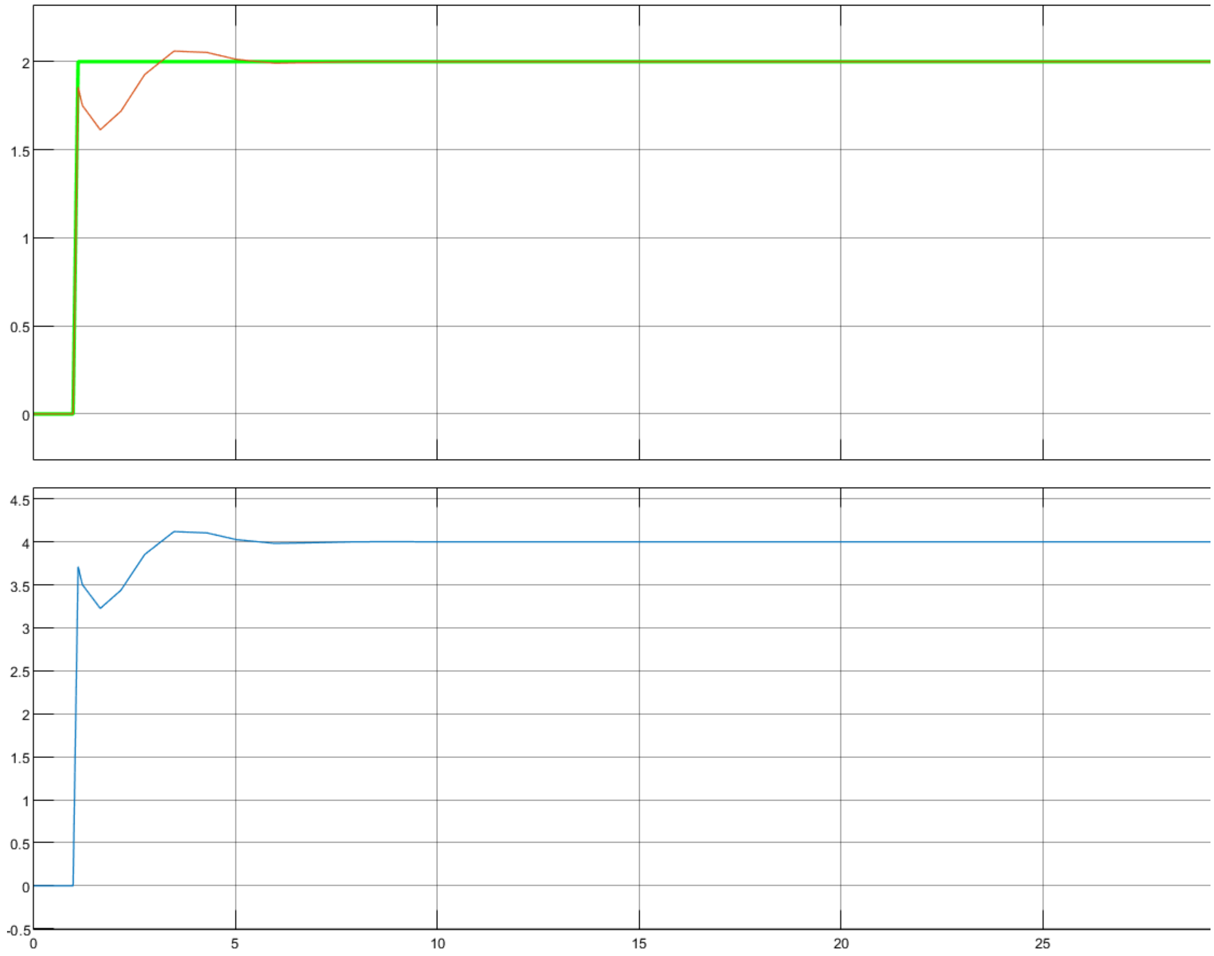
Block Diagram of Analog PID controller



Circuit Diagram:



MATLAB Simulation of the block Diagram: -



3. Design

Given Parameters: $K_i = 10$, $K_d = 3$, $K_p = 1$, and gain of plant as 0.5

Calculation of the R_d, R_i:

We have fixed the value of capacitance as 10µF for both the integral and derivative part, For that-

For R_d-

We have fixed the value of capacitance as 10µF, according to that,

$R_d \times C_d = K_d$

$R_d \times 10\mu F = 3$

$R_d = 300\ k\Omega$

For R_i-

$1/(R_i \times C_i) = K_i$

$R_i = 1/(K_i \times C_i)$

$R_i = 1/(10\times10\mu F)$

$R_i = 10\ k\Omega$

Transfer Function Representation: -

The transfer function of the PID Controller is given by: -

$$G(s) = K_p + K_i/s + K_d\, s = \frac{kd*s^2 + kp*s + ki}{s} = \frac{3*s^2 + 1*s + 10}{s}$$

4. Simulation and Experimental analysis

4.1 Simulation

A. <u>Simulating PID Controller Circuit:</u>

- Utilized MATLAB Simulink to simulate the PID controller circuit.
- Input for the simulation was generated using a square wave generator.
- The software's extensive component library facilitated the incorporation of necessary elements, and adjustments were made as needed.
- Waveforms were generated, enabling a detailed examination of the system's response.
- This step allowed us to identify and rectify circuit faults before moving forward with the physical implementation.

B. <u>Simulating Self-Generation Circuit:</u>

- Employed MATLAB Simulink for simulating the self-generation circuit, incorporating IC 7815 and a square wave generator circuit.
- The simulation aimed to validate the stability and performance of the self-power generation system.
- The software's capability to model complex systems ensured an accurate representation of the circuit's behavior.

C. <u>Parameters and Software Selection:</u>

- The MATLAB software was preferred due to its extensive library of components, allowing seamless integration of the required elements.
- The software provides a versatile platform where both PID controller and self-generation circuit simulations could be conducted effectively.
- Parameters such as input voltage (ranging from 2V to 4V), R_d, R_i , C_i , C_d, R_{p1} , R_{p2} , K_{plant} , R_{1sq} , R_{2sq} , and C_{sq} were varied during the simulations.
- Waveforms were generated for each parameter variation, and crucial performance metrics like overshoot, rise time, and others were measured.

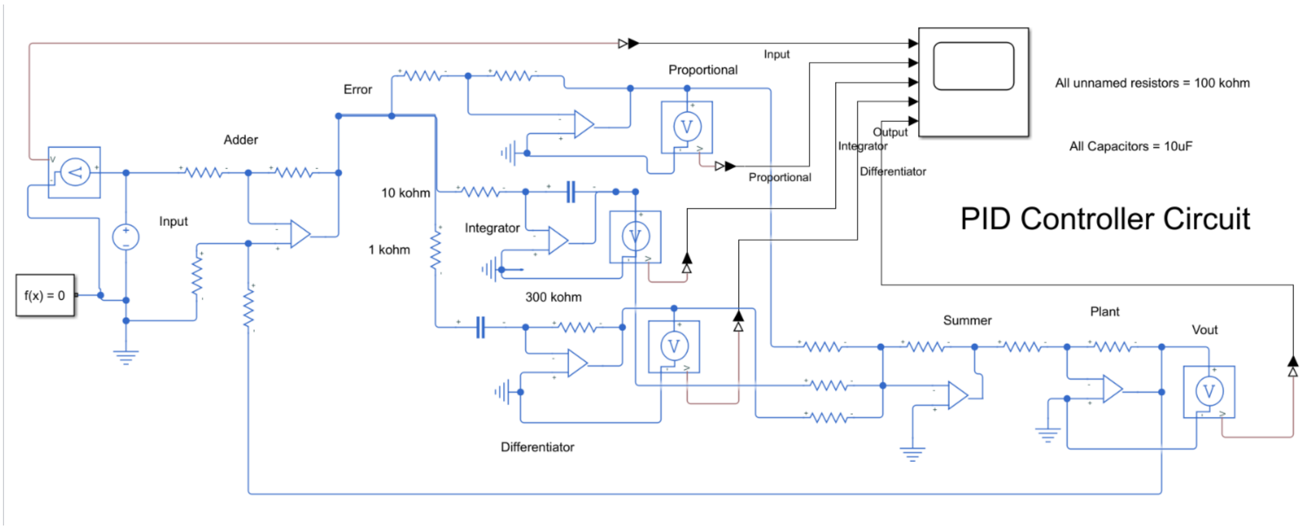
4.2 Experiment

Show the details process of experimental analysis, the deviation of component values from design and simulation, and Images of the experimental setup.

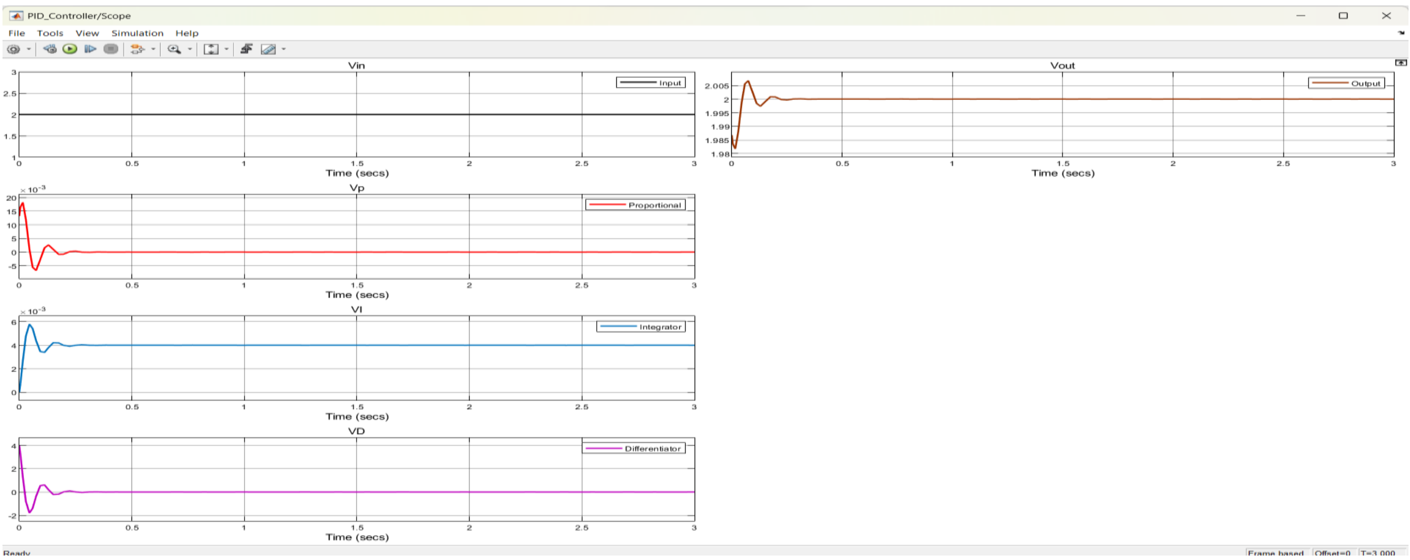
- The PCD design underwent simulation using the EASYEDA online software, allowing for a detailed examination of its real-world behavior.
- The parameters under consideration were systematically varied, and the corresponding waveforms were simulated.
- Key parameters such as overshoot, rise time, and other relevant metrics were measured to evaluate the performance of the physical circuit.

By combining simulation with both MATLAB Simulink and EASYEDA, we ensured a thorough analysis of the circuit's behavior in both virtual and real-world scenarios, facilitating the identification of potential issues and optimizations before the actual circuit implementation.

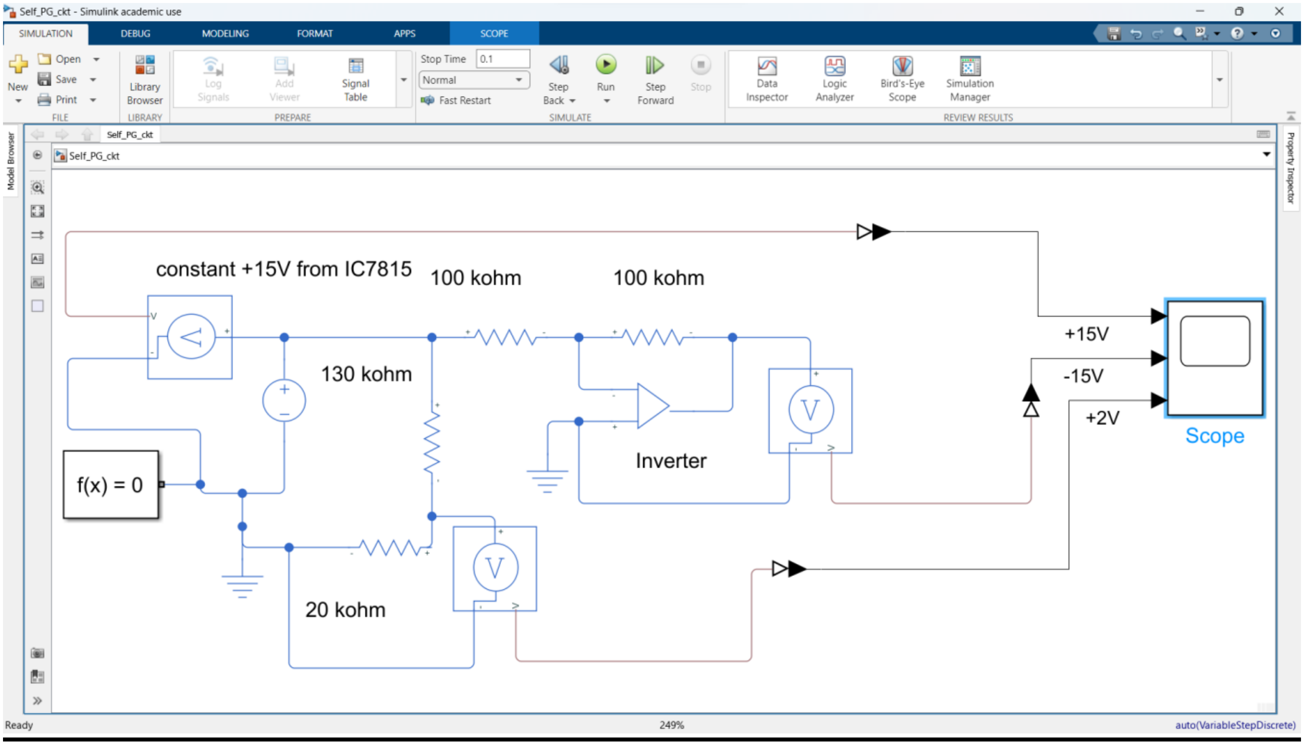
<u>MATLAB Simulation of Actual Circuit using OpAmps:-</u>



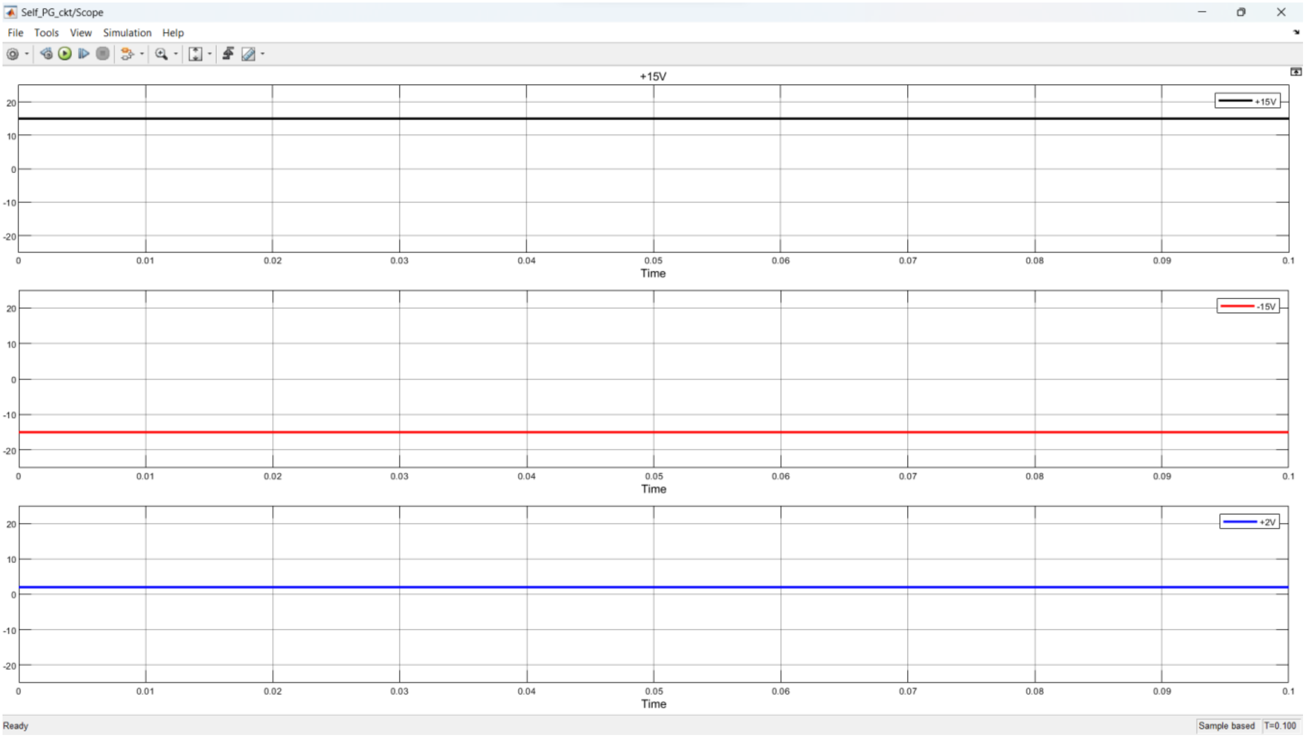
Corresponding Waveform-



Self-power generation circuit for signal conditioning:-

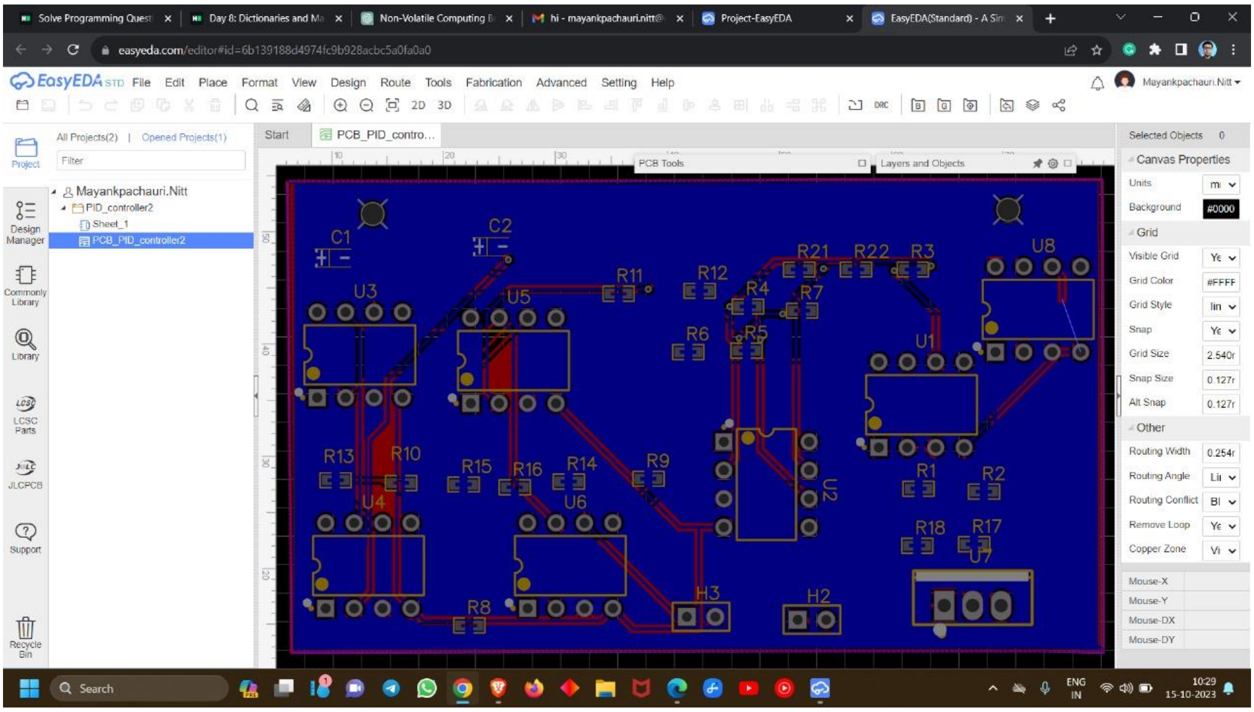


Corresponding Waveform-

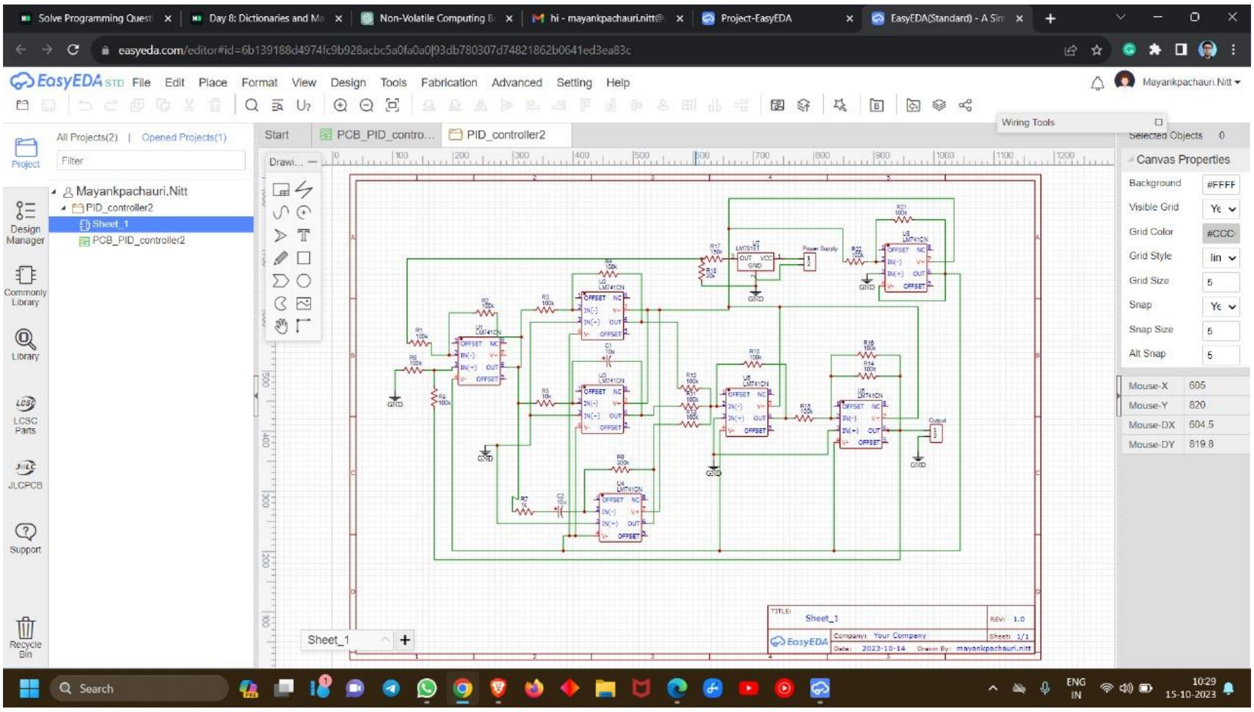


PCB Simulation using easyeda:-

PCB Schematic-

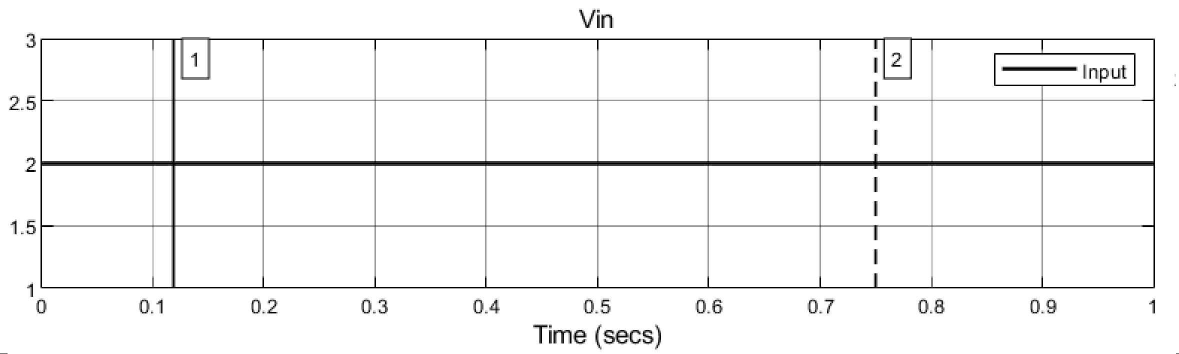


Final Circuit Diagram including Self-powering circuit-

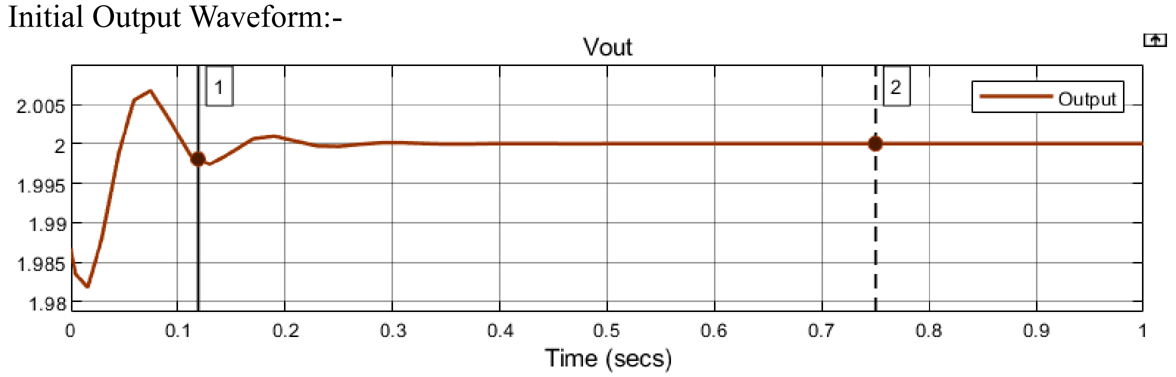


Simulation by varying parameters:-

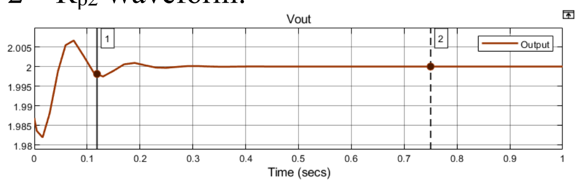
Initial Input Waveform:-



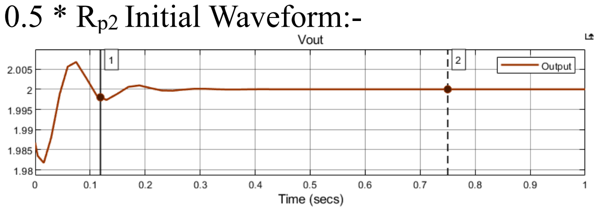
Initial Output Waveform:-



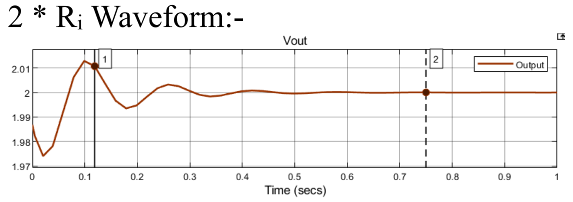
2 * R_{p2} Waveform:-



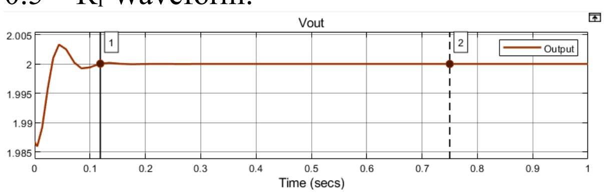
0.5 * R_{p2} Initial Waveform:-



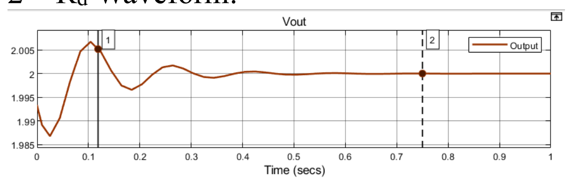
2 * R_i Waveform:-



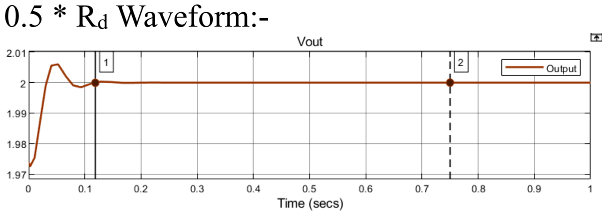
0.5 * R_i Waveform:-



2 * R_d Waveform:-



0.5 * R_d Waveform:-



5. Results and Discussion

A. Simulation and Experimental Analysis:

- The MATLAB Simulink simulations provided detailed waveforms for the PID controller circuit and the self-generation circuit.

- The EASYEDA online software allowed for PCB simulation, ensuring a thorough examination of the real-world behavior of the circuit.

B. Simulation of PID Controller:

- The PID controller, comprising proportional, integral, and derivative components, was simulated with varying parameters (Kp, Ki, Kd).
- Waveforms demonstrated the system's response to changes in input signal thresholds and plant gain.

C. Experimental Setup:

- The breadboard implementation of the entire circuit revealed a well-regulated supply and successful integration of the PID controller.
- Waveforms obtained during the experiment were compared with simulation results to assess the real-world performance.

D. Parameter Variation:

- Simulation results showcased the impact of varying parameters such as Rd, Ri, Ci, Cd, Rp1, Rp2, Kplant, R1sq, R2sq, and Csq on the system response.
- Experimental analysis confirmed the sensitivity of the circuit to changes in these parameters.

E. Comparison between Simulation and Experiment:

- Discrepancies between simulation and experimental results were observed, as expected in real-world scenarios.
- Deviations were logically justified, considering factors such as component tolerances, non-linearities, and practical limitations.

6. Conclusion

A. Controller Component Impact:

- Proportional controller effectively reduced transients.
- Derivative controller, sensitive to input changes, converted the triangular wave to a square wave.
- Integral controller exhibited a slow rise and decay time, contributing to system sluggishness.

B. Overall Performance:

- The fabricated Analog PID controller demonstrated output waveforms aligning closely with expectations.
- The combination of simulation and experimentation provided valuable insights into the practical behavior of the circuit.

C. Challenges and Considerations:

- Tuning PID controllers remains a challenge, requiring a good understanding of system dynamics.
- Non-linearities and variations in component ratings contributed to iterative calculations in the design process.

D. Significance of Analog PID Controller:

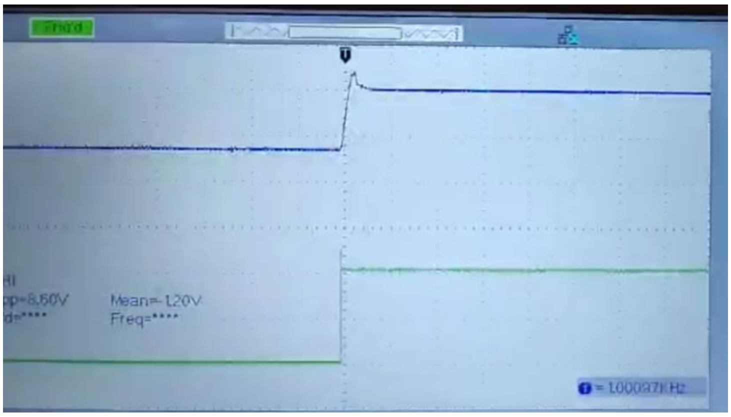
- The designed circuit holds practical significance in industrial applications, offering precision control and reduced steady-state errors.
- Versatility allows for adaptation to various systems, making it suitable for temperature control, motor speed regulation, and fluid flow control.

E. Future Considerations:

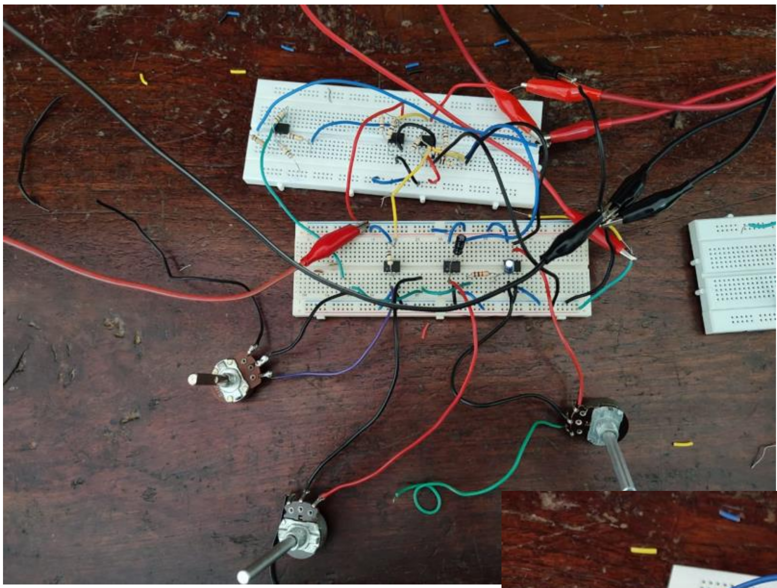
- Further refinements and optimizations may be explored to enhance the circuit's performance.
- Continued experimentation and tuning can address challenges associated with non-linear behavior and component variations.

In conclusion, the Analog PID controller project successfully integrated theoretical concepts, practical implementation, and testing. The combination of simulation and experimental analysis provided a comprehensive understanding of the circuit's behavior, paving the way for potential improvements and real-world applications in industrial control systems.

Breadboard Implementation of Entire Circuit:-



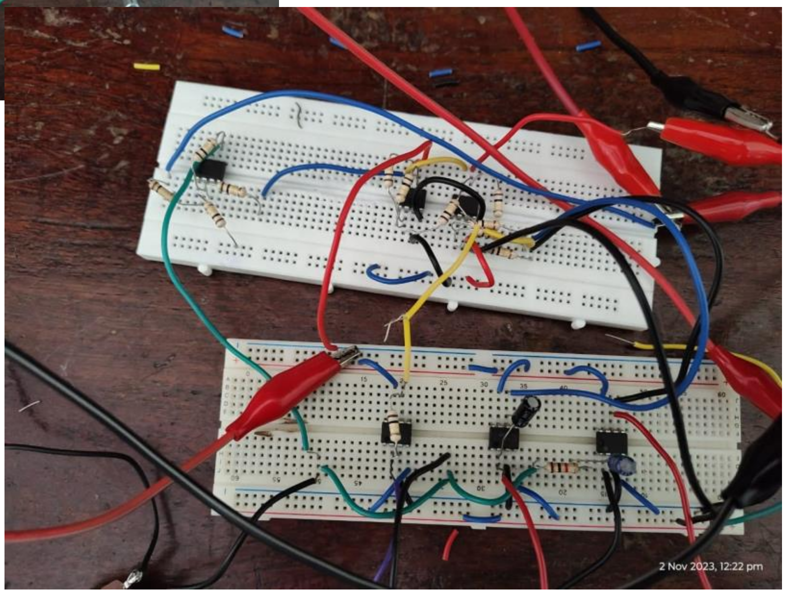
←---------------------Waveform at 2V change



←------------Supply + regulation

←-----------------------------PID

Zoomed image-----------------------→



7. Datasheets

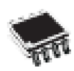
ST

UA741

GENERAL PURPOSE
SINGLE OPERATIONAL AMPLIFIER

- LARGE INPUT VOLTAGE RANGE
- NO LATCH-UP
- HIGH GAIN
- SHORT-CIRCUIT PROTECTION
- NO FREQUENCY COMPENSATION
- REQUIRED
- SAME PIN CONFIGURATION AS THE UA709

N
DIP8
(Plastic Package)



D
SO8
(Plastic Micropackage)

DESCRIPTION

The UA741 is a high performance monolithic operational amplifier constructed on a single silicon chip. It is intented for a wide range of analog applications.

- Summing amplifier
- Voltage follower
- Integrator
- Active filter
- Function generator

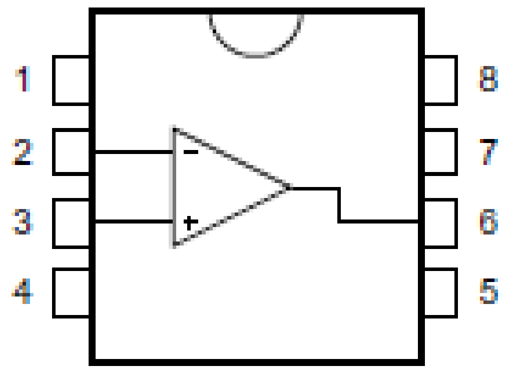
The high gain and wide range of operating voltages provide superior performances in integrator, summing amplifier and general feedback applications. The internal compensation network (6dB/octave) insures stability in closed loop circuits.

ORDER CODE

Part Number	Temperature Range	Package	
		N	D
UA741C	0°C, +70°C	•	•
UA741I	-40°C, +105°C	•	•
UA741M	-55°C, +125°C	•	•
Example : UA741CN			

N = Dual in Line Package (DIP)
D = Small Outline Package (SO) - also available in Tape & Reel (DT)

PIN CONNECTIONS (top view)



November 2001

ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	UA741M	UA741I	UA741C	Unit
V_{CC}	Supply voltage	±22			V
V_{id}	Differential Input Voltage	±30			V
V_i	Input Voltage	±15			V
P_{tot}	Power Dissipation [1)]	500			mW
	Output Short-circuit Duration	Infinite			
T_{oper}	Operating Free-air Temperature Range	-55 to +125	-40 to +105	0 to +70	°C
T_{stg}	Storage Temperature Range	-65 to +150			°C

1. Power dissipation must be considered to ensure maximum junction temperature (Tj) is not exceeded.

ELECTRICAL CHARACTERISTICS

V_{CC} = ±15V, T_{amb} = +25°C (unless otherwise specified)

Symbol	Parameter	Min.	Typ.	Max.	Unit
V_{io}	Input Offset Voltage ($R_s \leq 10k\Omega$) $T_{amb} = +25°C$ $T_{min} \leq T_{amb} \leq T_{max}$		1	5 6	mV
I_{io}	Input Offset Current $T_{amb} = +25°C$ $T_{min} \leq T_{amb} \leq T_{max}$		2	30 70	nA
I_{ib}	Input Bias Current $T_{amb} = +25°C$ $T_{min} \leq T_{amb} \leq T_{max}$		10	100 200	nA
A_{vd}	Large Signal Voltage Gain (V_o = ±10V, R_L = 2kΩ) $T_{amb} = +25°C$ $T_{min} \leq T_{amb} \leq T_{max}$	50 25	200		V/mV
SVR	Supply Voltage Rejection Ratio ($R_s \leq 10k\Omega$) $T_{amb} = +25°C$ $T_{min} \leq T_{amb} \leq T_{max}$	77 77	90		dB
I_{CC}	Supply Current, no load $T_{amb} = +25°C$ $T_{min} \leq T_{amb} \leq T_{max}$		1.7	2.8 3.3	mA
V_{icm}	Input Common Mode Voltage Range $T_{amb} = +25°C$ $T_{min} \leq T_{amb} \leq T_{max}$	±12 ±12			V
CMR	Common Mode Rejection Ratio ($R_S \leq 10k\Omega$) $T_{amb} = +25°C$ $T_{min} \leq T_{amb} \leq T_{max}$	70 70	90		dB

I_{OS}	Output short Circuit Current	10	25	40	mA
$\pm V_{opp}$	Output Voltage Swing $T_{amb} = +25°C$ $R_L = 10k\Omega$ $R_L = 2k\Omega$ $T_{min} \leq T_{amb} \leq T_{max}$ $R_L = 10k\Omega$ $R_L = 2k\Omega$	12 10 12 10	14 13		V
SR	Slew Rate $V_I = \pm 10V$, $R_L = 2k\Omega$, $C_L = 100pF$, unity Gain	0.25	0.5		V/µs
t_r	Rise Time $V_I = \pm 20mV$, $R_L = 2k\Omega$, $C_L = 100pF$, unity Gain		0.3		µs
K_{ov}	Overshoot $V_I = 20mV$, $R_L = 2k\Omega$, $C_L = 100pF$, unity Gain		5		%
R_i	Input Resistance	0.3	2		MΩ
GBP	Gain Bandwith Product $V_I = 10mV$, $R_L = 2k\Omega$, $C_L = 100pF$, $f = 100kHz$	0.7	1		MHz
THD	Total Harmonic Distortion $f = 1kHz$, $A_v = 20dB$, $R_L = 2k\Omega$, $V_o = 2V_{pp}$, $C_L = 100pF$, $T_{amb} = +25°C$		0.06		%
e_n	Equivalent Input Noise Voltage $f = 1kHz$, $R_s = 100\Omega$		23		$\frac{nV}{\sqrt{Hz}}$
Øm	Phase Margin		50		Degrees

National Semiconductor

May 2000

LM78XX
Series Voltage Regulators

LM78XX Series Voltage Regulators

General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

Features

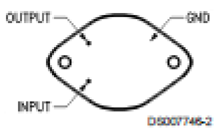
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

Voltage Range

LM7805C	5V
LM7812C	12V
LM7815C	15V

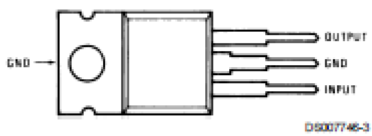
Connection Diagrams

Metal Can Package
TO-3 (K)
Aluminum



Bottom View
Order Number LM7805CK,
LM7812CK or LM7815CK
See NS Package Number KC02A

Plastic Package
TO-220 (T)



Top View
Order Number LM7805CT,
LM7812CT or LM7815CT
See NS Package Number T03B

Absolute Maximum Ratings (Note 3)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage	
(V_O = 5V, 12V and 15V)	35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range (T_A)	0°C to +70°C
Maximum Junction Temperature	
(K Package)	150°C
(T Package)	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package K	300°C
TO-220 Package T	230°C

Electrical Characteristics LM78XXC (Note 2)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

				5V			12V			15V			
Output Voltage				**5V**			**12V**			**15V**			**Units**
Input Voltage (unless otherwise noted)				**10V**			**19V**			**23V**			
Symbol	**Parameter**	**Conditions**		**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	Tj = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		$V_{MIN} \le V_{IN} \le V_{MAX}$			(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)		V
ΔV_O	Line Regulation	I_O = 500 mA	Tj = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}		(7 ≤ V_{IN} ≤ 25)			14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
			0°C ≤ Tj ≤ +125°C			50			120			150	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 1A	Tj = 25°C			50			120			150	mV
			ΔV_{IN}		(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)		V
			0°C ≤ Tj ≤ +125°C			25			60			75	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)		V
ΔV_O	Load Regulation	Tj = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ Tj ≤ +125°C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	Tj = 25°C			8			8			8	mA
			0°C ≤ Tj ≤ +125°C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		Tj = 25°C, I_O ≤ 1A				1.0			1.0			1.0	mA
		$V_{MIN} \le V_{IN} \le V_{MAX}$			(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN}≤ 27)			(17.9 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 500 mA, 0°C ≤ Tj ≤ +125°C				1.0			1.0			1.0	mA
		$V_{MIN} \le V_{IN} \le V_{MAX}$			(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN}≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
V_N	Output Noise Voltage	T_A =25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, Tj = 25°C or	62	80		55	72		54	70		dB
			I_O ≤ 500 mA 0°C ≤ Tj ≤ +125°C	62			55			54			dB
		$V_{MIN} \le V_{IN} \le V_{MAX}$			(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)		V
R_O	Dropout Voltage	Tj = 25°C, I_{OUT} = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ

Electrical Characteristics LM78XXC (Note 2) (Continued)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

			5V			12V			15V			
Output Voltage			**5V**			**12V**			**15V**			**Units**
Input Voltage (unless otherwise noted)			**10V**			**19V**			**23V**			
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
	Short-Circuit Current	Tj = 25°C		2.1			1.5			1.2		A
	Peak Output Current	Tj = 25°C		2.4			2.4			2.4		A
	Average TC of V_{OUT}	0°C ≤ Tj ≤ +125°C, I_O = 5 mA		0.6			1.5			1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	Tj = 25°C, I_O ≤ 1A		7.5		14.6			17.7			V

Note 1: Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

Note 2: All characteristics are measured with capacitor across the input of 0.22 μF, and a capacitor across the output of 0.1μF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_w ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 3: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For guaranteed specifications and the test conditions, see Electrical Characteristics.

Super Voltage Converters

The ICL7660S and ICL7660A Super Voltage Converters are monolithic CMOS voltage conversion ICs that guarantee significant performance advantages over other similar devices. They are direct replacements for the industry standard ICL7660 offering an **extended** operating supply voltage range up to 12V, with lower supply current. A **Frequency Boost pin** has been incorporated to enable the user to achieve lower output impedance despite using smaller capacitors. All improvements are highlighted in the "Electrical Specifications" section on page 3. **Critical parameters are guaranteed over the entire commercial and industrial temperature ranges.**

The ICL7660S and ICL7660A perform supply voltage conversions from positive to negative for an input range of 1.5V to 12V, resulting in complementary output voltages of -1.5V to -12V. Only two non-critical external capacitors are needed, for the charge pump and charge reservoir functions. The ICL7660S and ICL7660A can be connected to function as a voltage doubler and will generate up to 22.8V with a 12V input. They can also be used as a voltage multipliers or voltage dividers.

Each chip contains a series DC power supply regulator, RC oscillator, voltage level translator, and four output power MOS switches. The oscillator, when unloaded, oscillates at a nominal frequency of 10kHz for an input supply voltage of 5.0V. This frequency can be lowered by the addition of an external capacitor to the "OSC" terminal, or the oscillator may be over-driven by an external clock.

The "LV" terminal may be tied to GND to bypass the internal series regulator and improve low voltage (LV) operation. At medium to high voltages (3.5V to 12V), the LV pin is left floating to prevent device latchup.

In some applications, an external Schottky diode from V_{OUT} to CAP- is needed to guarantee latchup free operation (see Do's and Dont's section on page 8).

Features

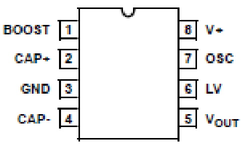
- Guaranteed Lower Max Supply Current for All Temperature Ranges
- Wide Operating Voltage Range: 1.5V to 12V
- 100% Tested at 3V
- Boost Pin (Pin 1) for Higher Switching Frequency
- Guaranteed Minimum Power Efficiency of 96%
- Improved Minimum Open Circuit Voltage Conversion Efficiency of 99%
- Improved SCR Latchup Protection
- Simple Conversion of +5V Logic Supply to ±5V Supplies
- Simple Voltage Multiplication $V_{OUT} = (-)nV_{IN}$
- Easy to Use; Requires Only Two External Non-Critical Passive Components
- Improved Direct Replacement for Industry Standard ICL7660 and Other Second Source Devices
- Pb-Free Available (RoHS Compliant)

Applications

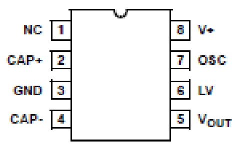
- Simple Conversion of +5V to ±5V Supplies
- Voltage Multiplication $V_{OUT} = \pm nV_{IN}$
- Negative Supplies for Data Acquisition Systems and Instrumentation
- RS232 Power Supplies
- Supply Splitter, $V_{OUT} = \pm V_S$

Pin Configurations

ICL7660S
(8 LD PDIP, SOIC)
TOP VIEW



ICL7660A
(8 LD PDIP, SOIC)
TOP VIEW



Electrical Specifications ICL7660S and ICL7660A, V+ = 5V, T_A = +25°C, OSC = Free running (see Figure 12, "ICL7660S Test Circuit" on page 7 and Figure 13 "ICL7660A Test Circuit" on page 7), unless otherwise specified.

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 9)	TYP	MAX (Note 9)	UNITS
Supply Current (Note 11)	I+	$R_L = \infty$, +25°C	-	80	160	µA
		0°C < T_A < +70°C	-	-	180	µA
		-40°C < T_A < +85°C	-	-	180	µA
		-55°C < T_A < +125°C	-	-	200	µA
Supply Voltage Range - High (Note 12)	$V+_H$	R_L = 10k, LV Open, $T_{MIN} < T_A < T_{MAX}$	3.0	-	12	V
Supply Voltage Range - Low	$V+_L$	R_L = 10k, LV to GND, $T_{MIN} < T_A < T_{MAX}$	1.5	-	3.5	V
Output Source Resistance	R_{OUT}	I_{OUT} = 20mA	-	60	100	Ω
		I_{OUT} = 20mA, 0°C < T_A < +70°C	-	-	120	Ω
		I_{OUT} = 20mA, -25°C < T_A < +85°C	-	-	120	Ω
		I_{OUT} = 20mA, -55°C < T_A < +125°C	-	-	150	Ω
		I_{OUT} = 3mA, V+ = 2V, LV = GND, 0°C < T_A < +70°C	-	-	250	Ω
		I_{OUT} = 3mA, V+ = 2V, LV = GND, -40°C < T_A < +85°C	-	-	300	Ω
		I_{OUT} = 3mA, V+ = 2V, LV = GND, -55°C < T_A < +125°C	-	-	400	Ω

Oscillator Frequency (Note 10)	f_{OSC}	C_{OSC} = 0, Pin 1 Open or GND	5	10	-	kHz
		C_{OSC} = 0, Pin 1 = V+	-	35	-	kHz
Power Efficiency	P_{EFF}	R_L = 5kΩ	96	98	-	%
		$T_{MIN} < T_A < T_{MAX}$ R_L = 5kΩ	95	97	-	-
Voltage Conversion Efficiency	$V_{OUT}EFF$	$R_L = \infty$	99	99.9	-	%

Electrical Specifications ICL7660S and ICL7660A, V+ = 5V, T_A = +25°C, OSC = Free running (see Figure 12, "ICL7660S Test Circuit" on page 7 and Figure 13 "ICL7660A Test Circuit" on page 7), unless otherwise specified. **(Continued)**

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 9)	TYP	MAX (Note 9)	UNITS
Oscillator Impedance	Z_{OSC}	V+ = 2V	-	1	-	MΩ
		V+ = 5V	-	100	-	kΩ
ICL7660A, V+ = 3V, T_A = 25°C, OSC = Free running, Test Circuit Figure 13, unless otherwise specified						
Supply Current (Note 13)	I+	V+ = 3V, $R_L = \infty$, +25°C	-	26	100	µA
		0°C < T_A < +70°C	-	-	125	µA
		-40°C < T_A < +85°C	-	-	125	µA
Output Source Resistance	R_{OUT}	V+ = 3V, I_{OUT} = 10mA	-	97	150	Ω
		0°C < T_A < +70°C	-	-	200	Ω
		-40°C < T_A < +85°C	-	-	200	Ω
Oscillator Frequency (Note 13)	f_{OSC}	V+ = 3V (same as 5V conditions)	5.0	8	-	kHz
		0°C < T_A < +70°C	3.0	-	-	kHz
		-40°C < T_A < +85°C	3.0	-	-	kHz

NOTES:

9. Parameters with MIN and/or MAX limits are 100% tested at +25°C, unless otherwise specified. Temperature limits established by characterization and are not production tested.
10. In the test circuit, there is no external capacitor applied to pin 7. However, when the device is plugged into a test socket, there is usually a very small but finite stray capacitance present, on the order of 5pF.
11. The Intersil ICL7660S and ICL7660A can operate without an external diode over the full temperature and voltage range. This device will function in existing designs that incorporate an external diode with no degradation in overall circuit performance.
12. All significant improvements over the industry standard ICL7660 are highlighted.
13. Derate linearly above 50°C by 5.5mW/°C.

8. References

1. "Analog Fabrication of PID Controller"
   https://core.ac.uk/download/pdf/53190057.pdf1
2. IC741 Datasheet – ST Microelectronics
3. IC7815 Datasheet
4. ICL7660SAPAZ Datasheet

Thank You