Home-Constructed, Building Block Op-Amp Circuits for Analog Computers

Inverting Integrator

Introduction

Assuming the reader to be familiar with basic DC electronic theory, breadboards, ideal op-amp parameters, and a bit of calculus, the mission of this project is show him/her a circuit that performs integration! Below, is my home-constructed inverting integrator circuit. However, don't just take my word for it. Using this document as a guide, construct and test your own inverting integrator and see for yourself! Doing builds understanding! 😊 At the end of this document is a list of components and supplies used for this building block.

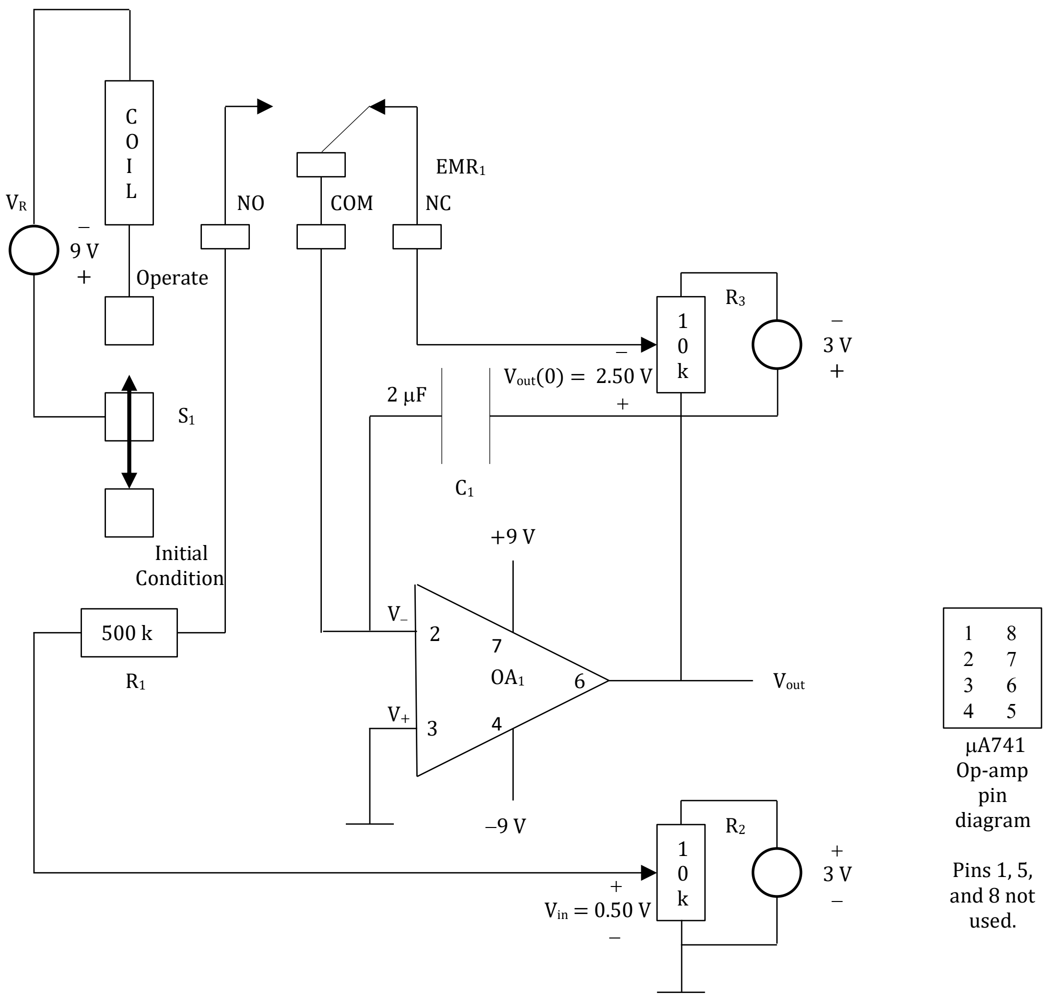

Figure 1: Inverting integrator diagram

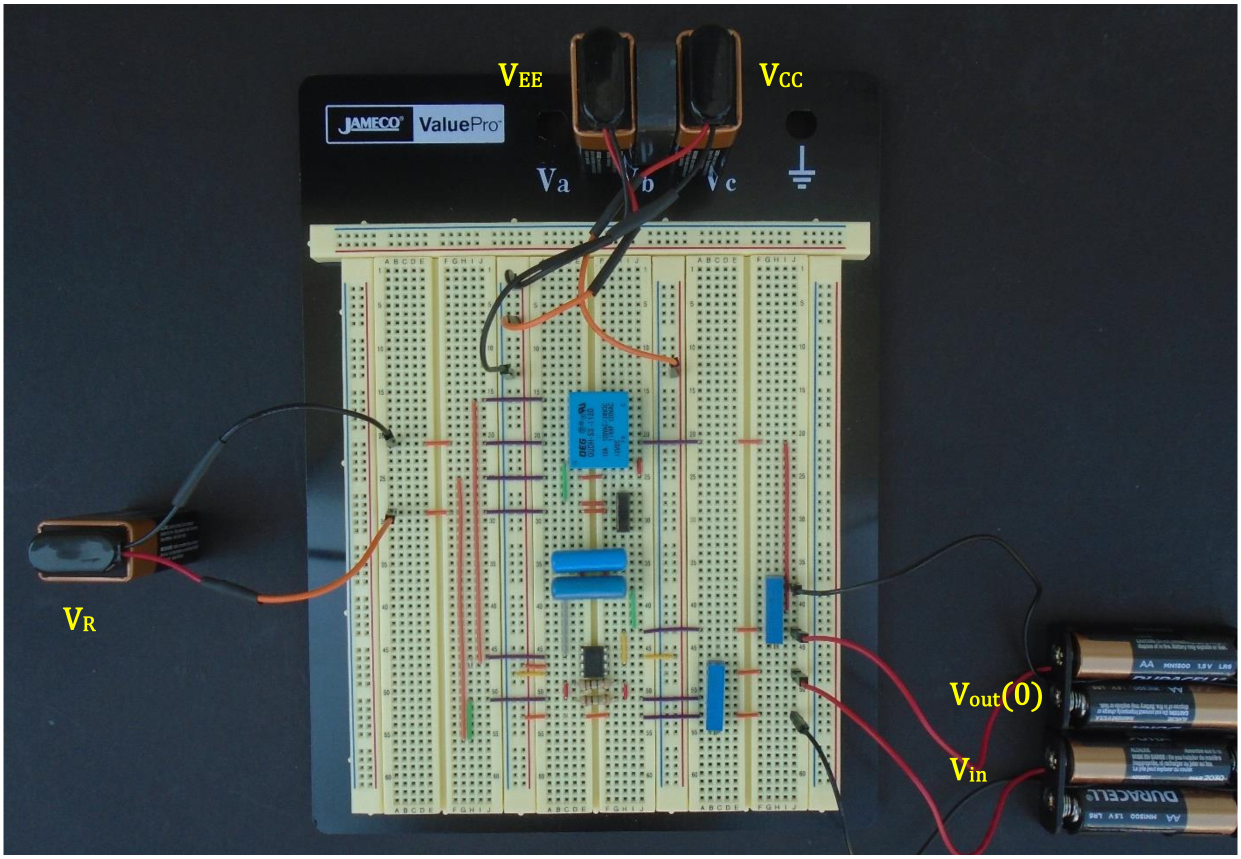

Figure 2: Photograph of inverting integrator breadboard layout

To see how this circuit integrates, I begin with a set of general current-voltage equations:

$$I_R = V_R/R,$$

where I_R is the current passing through the resistor.

Also,

$$I_C = dQ_C/dt = CdV_C/dt,$$

where Ic is the rate at which charge is deposited/removed from the capacitor. It is **NOT** charge passing through the capacitor! That would be a bad thing! ☹

Now, for a bit of op-amp circuit mathematics:

To start,

$$V_+ = V_- = 0 \text{ (virtual ground at pin 2)}$$

Determine I_{R1}:

$$I_{R1} = (V_{in} - 0)/R_1$$

$$I_{R1} = V_{in}/R_1$$

Determine I_{C1}

$$I_{C1} = C_1 dV_C/dt$$

$$I_{C1} = C_1 d(0 - V_{out})/dt$$

$$I_{C1} = -C_1 dV_{out}/dt$$

Since R_1 and C_1 are in series (no current should flow into pin 2 of the op-amp),

$$I_{C1} = I_{R1}$$

$$-C_1 dV_{out}/dt = V_{in}/R_1$$

$$dV_{out} = -1/(R_1C_1)V_{in}\,dt$$

$$\int_{V_{out}(0)}^{V_{out}} dV_{out} = -1/(R_1C_1)\int_0^t V_{in}dt$$

Integrating and inserting limits,

$$\boxed{V_{out} = -1/(R_1C_1)\int_0^t V_{in}\,dt + V_{out}(0) \qquad (1)}$$

Tada! So, there it is … integration! Notice the negative sign preceding the integral. Hence the term, inverting integrator!

Component nominal values: $R_1 = 500\ \text{k} = 0.5 \times 10^6\ \Omega$, $C_1 = 2 \times 10^{-6}$ C, $(R_1C_1 = 1\ \text{s})$, $V_{out}(0) = 2.50$ V, and $V_{in} = 0.50$ V.

After integrating and inserting component values, the nominal output voltage is

$$\boxed{V_{out} = (-0.50\ \text{V/s})\ t + 2.50\ \text{V} \qquad (2)}$$

Data

t (s)	V_{out} (V) Trial 1	V_{out} (V) Trial 2	V_{out} (V) Trial 3	V_{out} (V) Average
00.0	+2.50	+2.50	+2.50	+2.50
05.0	+0.62	+0.62	+0.59	+0.61
10.0	–1.98	–2.00	–1.96	–1.98
15.0	–4.38	–4.43	–4.46	–4.43

Table 1: Output voltage

Results

Using the above data, and using LinReg option on a TI-84 Plus calculator,

$$\boxed{V_{out} = (-0.47\ \text{V/s})\ t + 2.68\ \text{V with } r^2 = 0.996 \text{ (good fit!)} \qquad (3)}$$

Conclusion

This circuit performed as expected!

Any questions/comments regarding this building block may be addressed to:

Michael Cimorosi
Physics Instructor (adjunct)
Division of Physics, Engineering, Mathematics, and Computer Science
Delaware State University
Dover, DE
Email: mcimorosi@desu.edu.

Components

Circuit designation	Description
R_{1A}	1 MΩ = 1000 kΩ = 1000 k
R_{1B}	1 MΩ = 1000 kΩ = 1000 k
$R_1 = R_{1A} \| \| R_{1B}$	0.500 MΩ = 500 kΩ = 500 k (measured within 1%)
R_2	15-turn 10-k potentiometer
R_3	15-turn 10-k potentiometer
C_{1A}	1 µF (Polyester film)
C_{1B}	1 µF (Polyester film)
$C_1 = C_{1A} \| \| C_{1B}$	2 µF (measured within 1%)
OA_1	µA741 Op Amp *(assumed ideal)- OPA140 better option
EMR_1	Electromagnetic relay
S_1	SPDT slide switch
V_{CC}	+9 V (measured within 5%)
V_{EE}	–9 V (measured within 5%)
V_R	9 V relay voltage (measured within 5%)
V_{in}	+0.50 V (adjusted)
$V_{out(}0)$	+2.50 V (adjusted)

Miscellaneous Supplies

Item	Quantity
Fixed jumper wire kit	1
3-section breadboard	1
Digital multimeter	1
Timepiece	1
9-Volt batteries	2
1.5-Volt batteries	4
3-Volt battery case with leads	2
30-Volt (max) DC supply	1
Ti-84 Plus calculator	1
Magnet	1