Function Generator using OpAmp

This project showcases DIY Function generator with satisfactory range and accuracy

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Semester 2 Project

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Abstract

Function generator are useful tools in academia and industries. Mostly they are avalaible in market. In this project we are trying to understand and study simple frequency generators with use of OpAmp. We usec generic OpAmp Ic LM741, which is single package and easy to understand with benefit of extensive acedemic experince.

Acknowledgement

We would like to thank to the our Head of Department - Dr. P. N. Gajjar sir for their faith in us and supporting us in everyway. Special thanks to our respected mentor Mr. D. B. Patel sir for their support, encouragement and supervision in every step of this project. We also thank to all our respected professors for their support to complete this project successfully.

We would also like to thank scientists and authors on whom work we build our work.

We are also grateful of our classmates for their help and support for this project work. We heartly appreciate their contribution and thank them too.

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1 Introduction

Function generator is circuit which generates periodic function with predictable frequencies with respect to time. Here, we will study only mono frequency generator but it can also generate superposed functions. Signals from Function generator comes in many forms but mostly it is either sinusoidal or square wave. We will generate sinusoidal, square and triangle wave as output.

We used basic circuits with few modification as our need. With use of IC LM741 we used OpAmp in our circuit.

For Sinusoidal wave we used Wein Bridge circuit, which is easy to understand and impliment. Also, wein bridge circuit is quite less noice compare to it's compitition RC phase shift Oscillator, which have more component than Wein bridge and more complicated to understand. For Square wave we used standard astable multivibrator cicuit, with little modification. Lastly, Triangle wave can be made from just attaching Integrator to our square wave output with some regulation.

Now, each circuit (this wave form generator) has different block, basically we divided whole circuit in there block. Main work for us is to combine all of this. We wandered across CMOS families, BJTs but finally we sattled into physical swith which is coupled for power transmission and also for output change.[2] [4][6]

2 Blocks

As told in introduction each circuit is in their blocks. First block for sine wave which is nothing but wien bridge circuit, second is sqaure which is astable multivibrator, third for triangular wave which integrator attached to second block (square wave block).

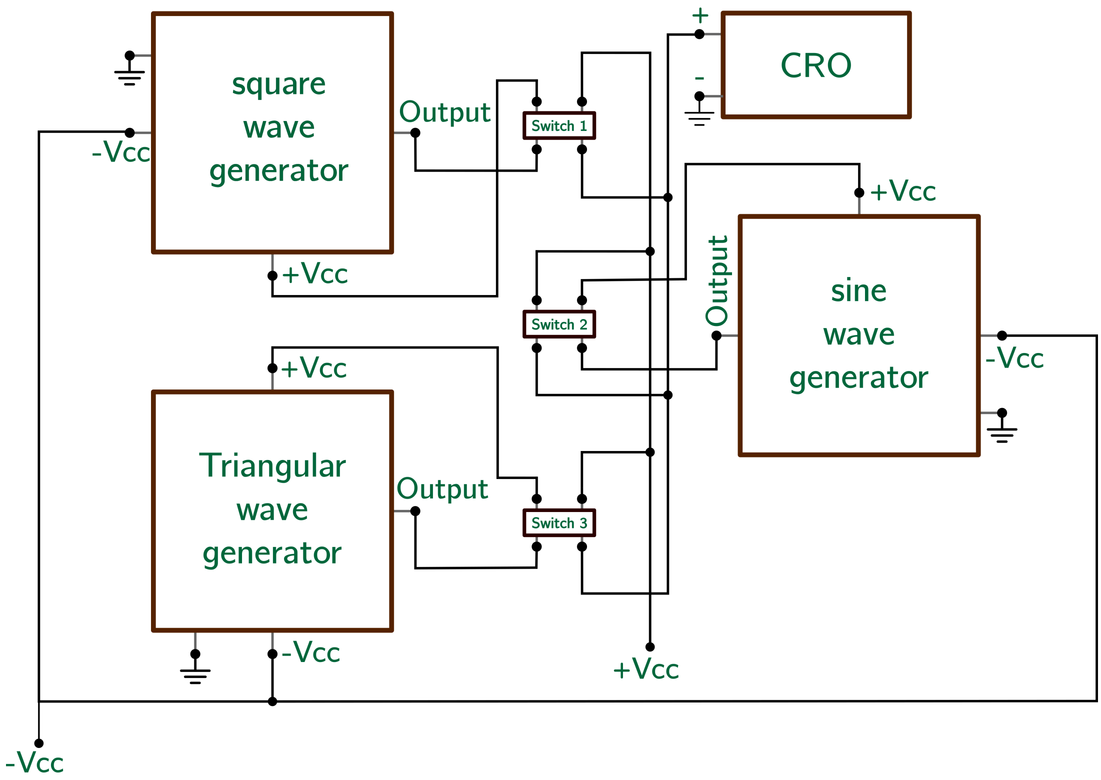

Figure 1: Block diagram of our function generator

2.1 Block 1: Sine wave generator

In first block, we have basic circuit of wein bridge. You can see in figure 1. In center we have OpAmp (IC LM741). This is amplifier with RC component attached with input and output. Here, at one end there is RC parallel component and at other end series RC component.

Here, frequency is given by,

$$f = \frac{1}{2\pi RC} \tag{1}$$

For sustaing oscilation gain must be 3 and for non inverting amplifier gain,

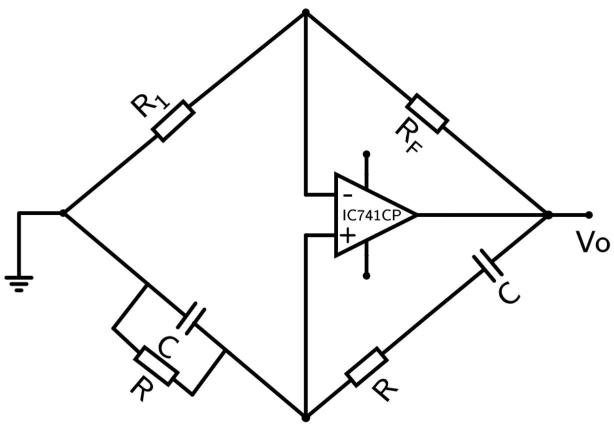

Figure 2: Wein bridge circuit

$$A = 1 + \frac{R_F}{R_1} = 3 \tag{2}$$

So, we get relation $R_F = R_1$

Here, you can see our block circuit, at the end we attached two zener diode for regulation to the output. As you can see OpAmp in IC LM741 package. Power supply given from 4 and 7 to 12V and -12V. We chose $R_1 = 12k\Omega$. By relation of R_1 and R_F, we got $R_F = 24k\Omega$.

For frequency range we used Potential with max range of $100k\Omega$. So, lowest and maximum frequency whould be (with constant capacitance at $50nF$),

$$f_{min} = \frac{1}{2\pi \times 100k \times 10n} \approx 159hz$$

$$f_{max} = \frac{1}{2\pi \times 100 \times 10n} \approx 159khz$$

So, frequency range would be $159hz$ to $159khz$

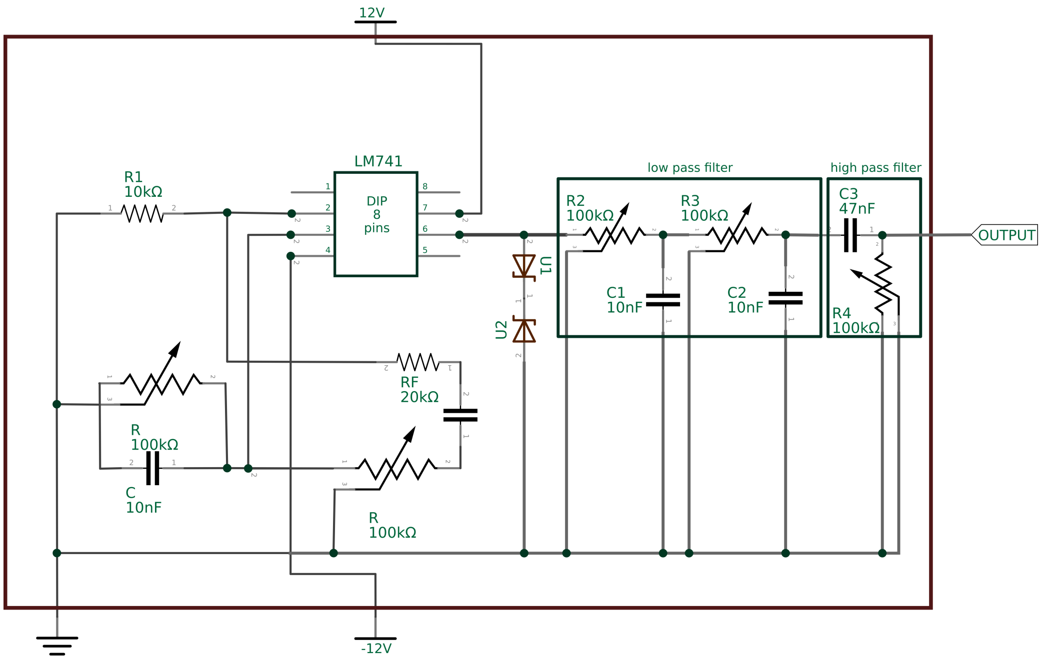

Figure 3: Our block 1, which consinst of IC741CP

2.2 Tuning sine wave generator

The output of sine wave generator can be little noisy. This will be reasonable as we will see it's working. Any sine wave generator will work as frequency extractor from DC or any AC levels. Since, Row signals have superposed waves in nearly all the spectrum, one have to rely on different filters and component which can attenuate desire frequency and theoretically minimize every other frequency.

In wien bridge, this is principle is mostly exploited. We have two RC components, one in series make low pass filter and secondly there is parallel component which work as high pass filter. In **figure** there is highlighted areas of both filters. Here, it is quite straight forward see that low pass will block higher frequency and high pass will vice versa. So, if we set both filter such that combination will give us some band (quite narrow band in fact). Center of this frequencies will cut off frequency of both filters. When wien bridge balances than this band of frequency will be resonated and give final output.

2.2.1 Series RC components in Wien bridge

Series RC component which works as low pass filter have this type of phenomenan, total V_{in} and V_{out} will be proportional to the to total reactance. With voltage divider low,

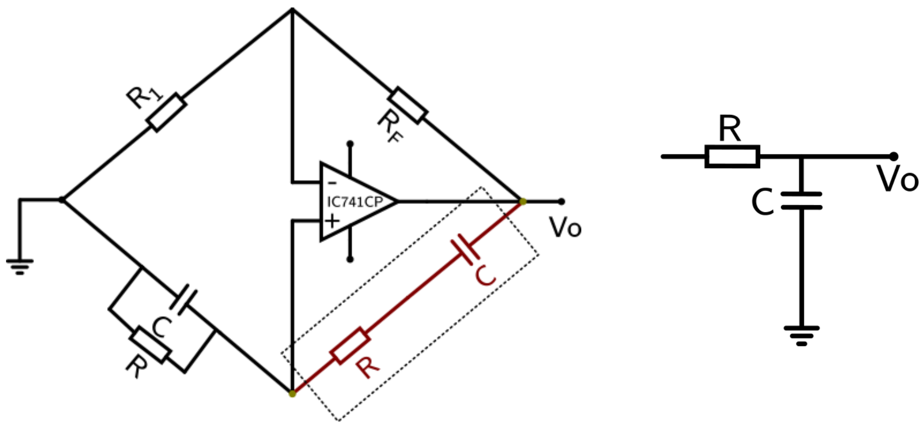

Figure 4: figure as shows low pass filter in wein bridge which is in series configuaration. Figure b suggest general way we can low pass filter

$$\frac{V_o}{V_i} = \frac{X_c}{R + X_c}$$

Where, X_c is reactance of capacitor valued as $\frac{-j}{wC}$. So,

$$\frac{V_o}{V_i} = \left(\frac{1}{1 + w^2 R^2 C^2} \right)^{\frac{1}{2}}$$

If we take w_0 as breakpoint or curoff point for our RC component than $w_0 = \frac{1}{RC}$. Here RC is time constant.

Graph of low pass shown in figure 12a. Where we can see frequency equals to $w = w_0$ at some point. Also, notice that even though we have cutoff frequency at w_0, there is enough frequencies around w_0. Basically filters always have some noise which does not filtered. Here, if you use higher order filter than this slope of voltage to frequency would be slightly higher. With sufficiently high order filter you can make abrupt change in frequency domain, but this comes with it's consequences. With higher order filters other noises dominates since we will have too much components. We will use second order filter here, which is quite balance in accuracy and component noise.

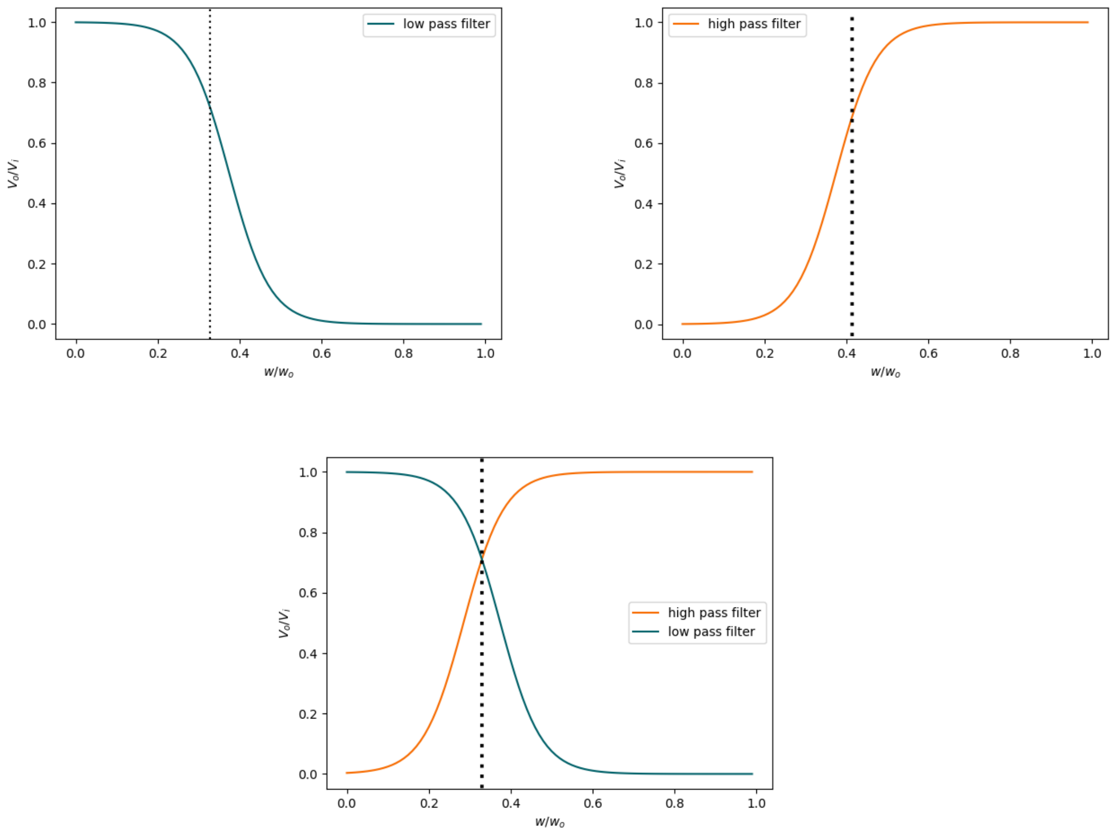

Figure 5: here, we have a) low pass filter, b) high pass filter and c) combination of high and low pass fiter

2.2.2 Parallel RC components in Wien bridge

Similarly to that of series RC components, we can define high pass filter as parallel RC component. In parallel circuit when frequency increases reactance decreases and total reactance decreases. So, consequently higher frequency pass and lower frequency will not. Reactance of high pass filter would be following,

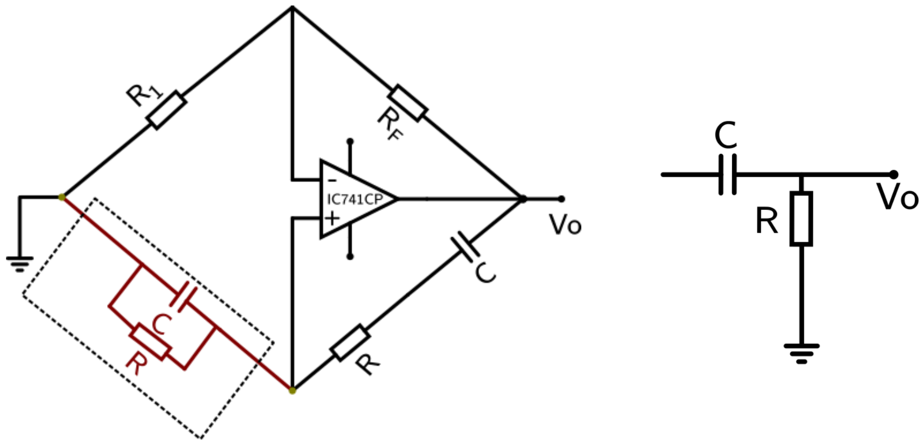

Figure 6: figure as shows high pass filter in wein bridge which is in parallel configuaration. Figure b suggest general way we can high pass filter

$$\frac{V_o}{V_i} = \frac{R}{R + X_c}$$

Again, X_c is capacitance reactance and valued at $-frac-jwC$

$$\frac{V_o}{V_i} = \left(\frac{R^2}{R^2 + \frac{1}{w^2 C^2}} \right)^{\frac{1}{2}}$$

This relationship is shown in figure 12b. With cutoff frequency at w_0. As we can see here also noise of unwanted frequency range are here.

2.2.3 Total signal and Error terms

In wien bridge we have both the low pass and high pass filters. So, total response of that shown in figure 12c. Here, we have gain frequencies in range between cutoff frequency. Since, this range amplify in non inverting amplifier and feedback. This frequency will resonant and becomes our output signal. From now on, we will say w_0 as resonant frequency. Final output in our theoretical studies will be this resonant frequency. Practically this frequency is observed with error frequencies.

Error terms in here will be in following cases. *1) since we have band, we get many frequency output from the band, which is quite distorted in itself.* and 2*) here working of filters are note up to expectation and we have noise from whole spectrum of frequency.* This is quite headache, unfortunately we have both the cases in our experiment.

2.2.4 Fourier analysis of Output signal

We can minimize this errors by using Fourier analysis of output signal. As one can say that DC level is made of superposed infinite number of waves with different wavelengths,

$$DC_{level} = \sum_{n}^{\infty}(a_n \cos(w_n t) + b_n \sin(w_n t))$$

Here, a_n and b_n are coefficients of Fourier series. What wein bridge does is extract desire frequency from DC level.

In our experiment we got distorted sine wave which means their is higher frequencies in effect. Also after some values of Potentiometer, there is just square signal. Another distortion occur was from lower frequencies manly $50Hz$ and around $300Hz$, which are making signal less stable and sometimes dominates resonant frequency.

For higher frequency, we got idea to put low pass filter around value of resonant frequency that would bring signal to more on resonant frequency. This is can be seen in block diagram of sine wave from figure 3 and figure below 7. This should give us better results ad we intended.

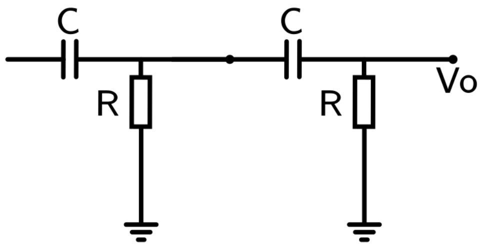

Figure 7: low pass filter at the output of our signal

For lower frequency, we have high pass filter, which eliminate those lower frequencies and stabilize our signal. This can be shown from block diagram figure 3 and figure 8.

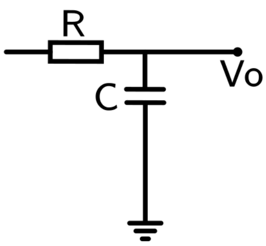

Figure 8: high pass filter at the output of our signal

2.2.5 Output of sine wave after tuning

The output which we expected from our upper analysis at different frequency is shown below in figure **??**. The frequency range of sine wave output is given below in table. You should know that this

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Real output is needed here with graph

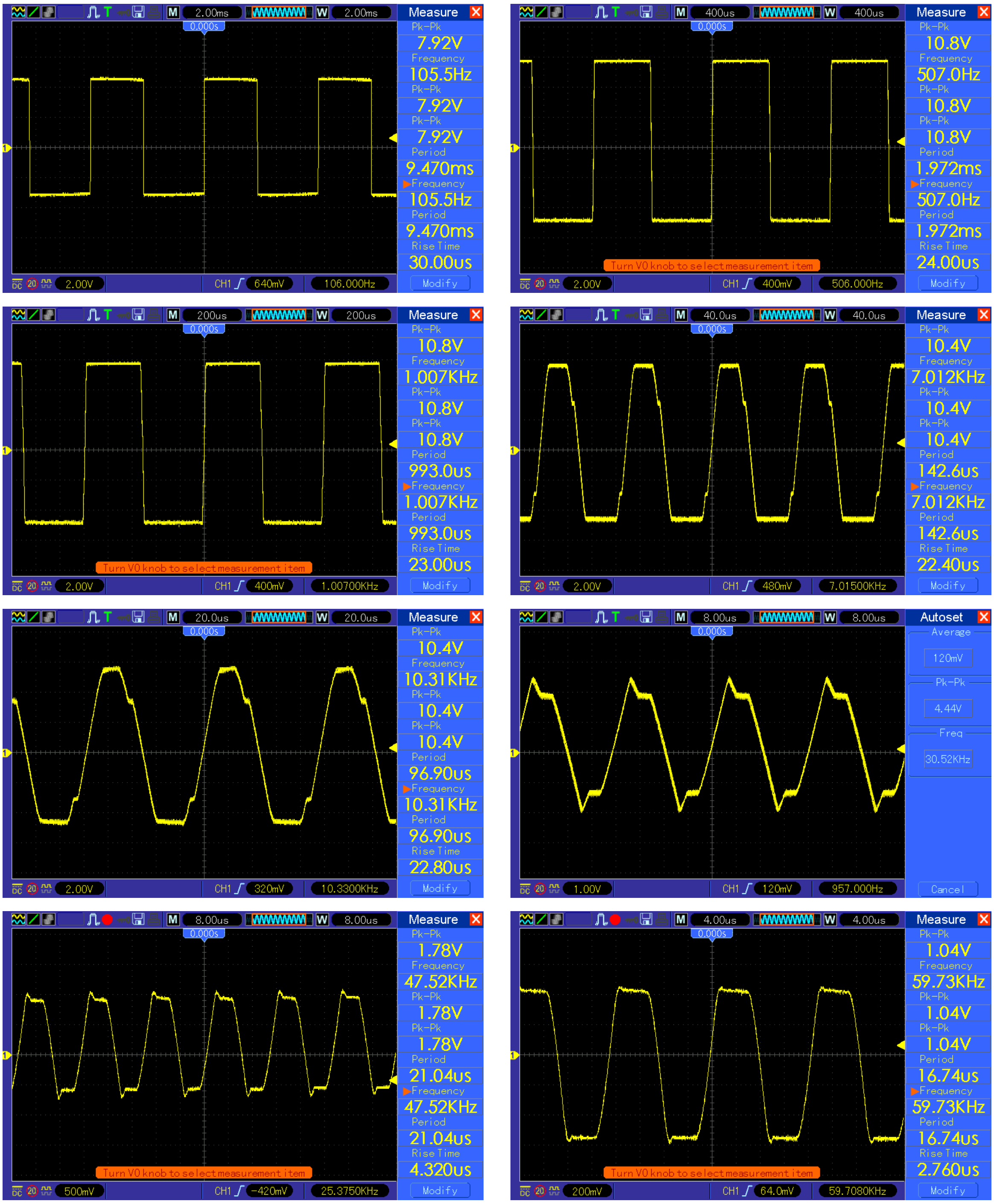

Figure 9: You can see all square wave outputs left to right respectevely 100Hz, 500Hz, 1kHz, 7kHz, 10kHz, 30kHz, 47kHz, 60kHz and 66kHz

$V_{out}p - p$ is after applying all the filters and tuning. Original output is quite large in peak to peak voltage around 5 times big.

2.3 Block 2: Square wave generator

As square wave generator we have basic astable multivibrator. This circuit works on scenario where output will have to stable state and it will swing between them, hence the name. When circuit is $+V_{sat}$, we will have high signal output and when circuit is $-V_{sat}$, we will have low signal output. So, we will have square wave as desired. The circuit for astable multivibrator is shown below.

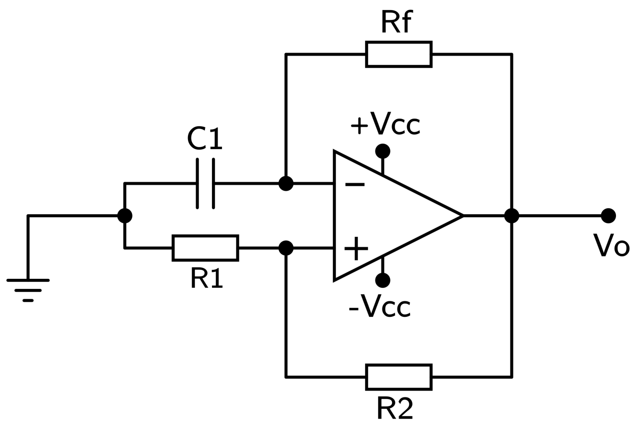

Figure 10: astable multivibrator circuit

Here, frequency would be,

$$f = \frac{1}{2RCln(\frac{2R_1+R_2}{R_2})} \tag{3}$$

If, we take $R_2 = 1.16R_1$ then,

$$f = \frac{1}{2RC} \tag{4}$$

Here, we took $R_1 = 10k\Omega$ and $R_2 = 11.6k\Omega$ such that $\frac{R_2}{R_1} = 1.16$. Also, you can see that we employed $100k\Omega$ in input terminals for accurate and reliable signal.

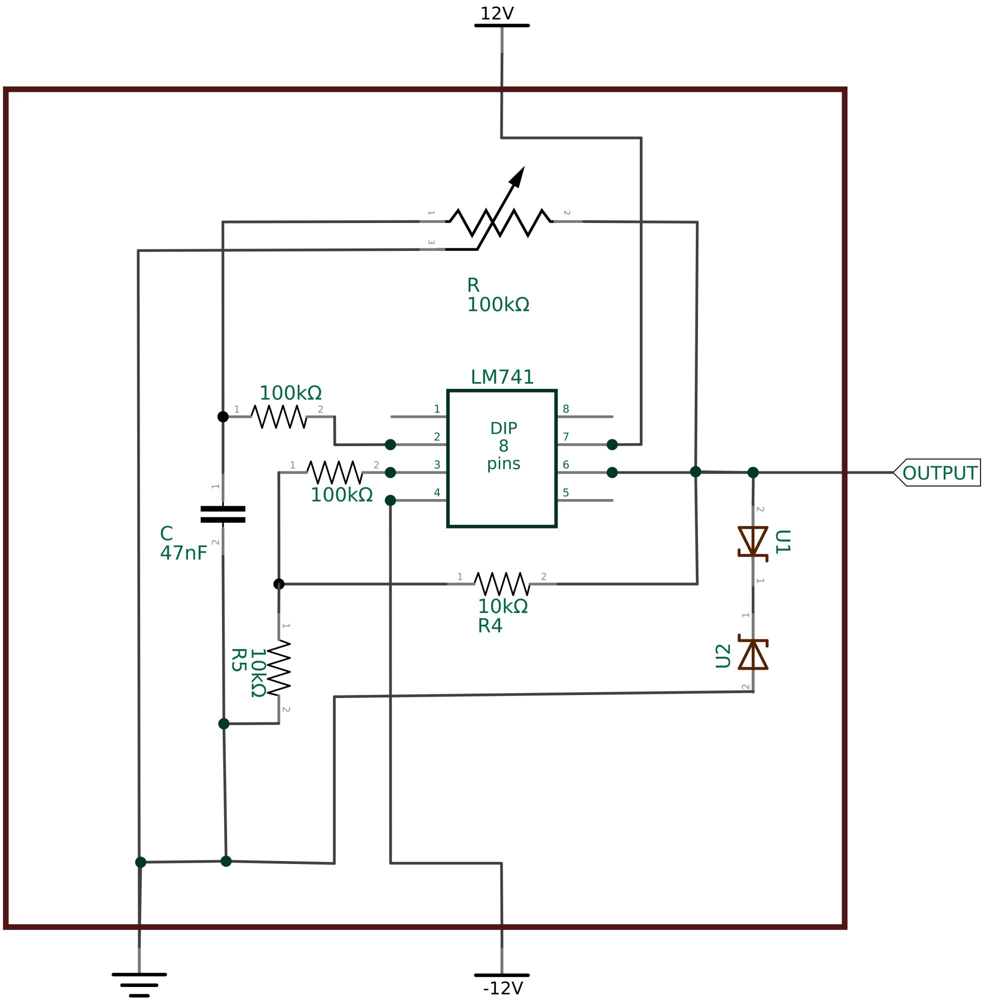

Figure 11: second block: square wave generator

Frequency range would be of (for constant capacitance at $47nF$) and here our R_1 and R_2 are equal at $10k\Omega$,

$$f_{min} = \frac{1}{2 \times 100k \times 47n \times ln(3)} \approx 97hz$$

$$f_{max} = \frac{1}{2 \times 100 \times 47n \times ln(3)} \approx 97khz$$

2.3.1 Problems in getting Square wave

Square wave is mostly (maybe lesser) immune to those porblem of sine wave generator but still it has serious problem. Mainly of slew rate problem, which is quite fundamental to OpAmp than particular circuit. For understanding this phenomena we should exploit inner working of OpAmp.

Let's define some phenomena before taking serious talk on output signals.

1) Transient state: After some initial stable state, if the system (for us the OpAmp) comes at another steady state, the intermediate state is called transient state.

2) Steady state: The state at which system has fix value of response (stable) which independent on time is called steady state (response).

3) Slew rate: State is maximum rate of change with respect to microsecond of time.

$$S = \left.\frac{dV}{dt}\right|_{max}$$

It is measured in $\frac{V}{\mu s}$. After seeing this, it's quite transparent to see the problem in our square wave generator. Also, the thing is slew rate is slop of signal with voltage and time domain. We can also see that it'll show us how gradual signal change from two steady state.

When signal is at $\pm V_{sat}$, it is at steady state. When it's changes signal goes into transient state. A fact that Slew rate is fundamental property IC (LM741 has slew rate around $.5V/\mu s$), which shows us how some IC is more reactive and some are not. This also defines Bandwidth some times. If we take high frequency which change so rapidly that slew rate can't keep up to signal than signal will not even change after some frequency value.

2.3.2 Output of square wave

In out project we have IC LM741 with slewrate of $0.5V/\mu s$. Which directly means that our square wave will not look square wave after some frequencies value. For example look at this results after some $10kHz$ it is deforming.

For better result, we can use OpAmp with higher slew rate. Typically *current feedback OpAmp* has higher response type, consequently higher slew rate (in the order of $4kV/\mu s$). Even for some voltage feedback OpAmp has higher Slew rate in range of $500V/\mu s$ to $3000V/\mu s$. Some ICs and it's slew rate value are shown in this table.

IC NAME	slew rate	gain bandwidth product	type
OPA 859QDSGRQ1	1.15 kV/μ s	900 MHz	voltage feedback
MAX 4212EUK+T	600 V/μs	300MHz	voltage feedback
AD 9631ARZ	1.3 kV/μs	110MHz	voltage feedback
BUF 634AIDR	3.75 kv/μs	240 MHz	voltage feedback
OPA 695IDGKT	4.3 kV/μs	1.7 GHz	current feedback
THS3001IDGN	6.5 kV/μ s	420 MHz	current feedback

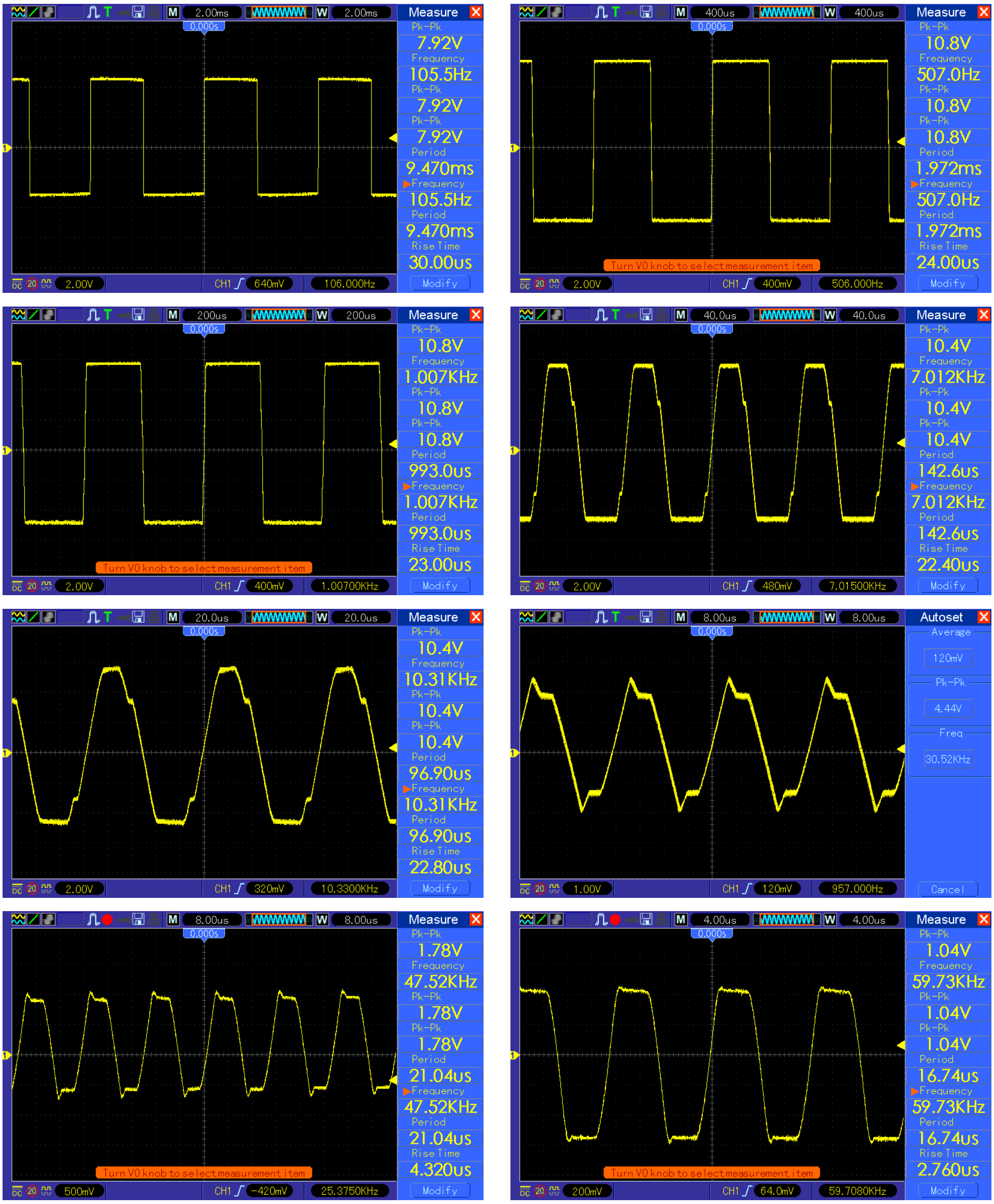

Figure 12: You can see all square wave outputs left to right respectevely 100Hz, 500Hz, 1kHz, 7kHz, 10kHz, 30kHz, 47kHz and 60kHz

Frequency to Output voltage is necessary too. Frequency to output voltage is in this relation. This gives out frequency range which is up to 60kHz. Data if this is given on appendix.

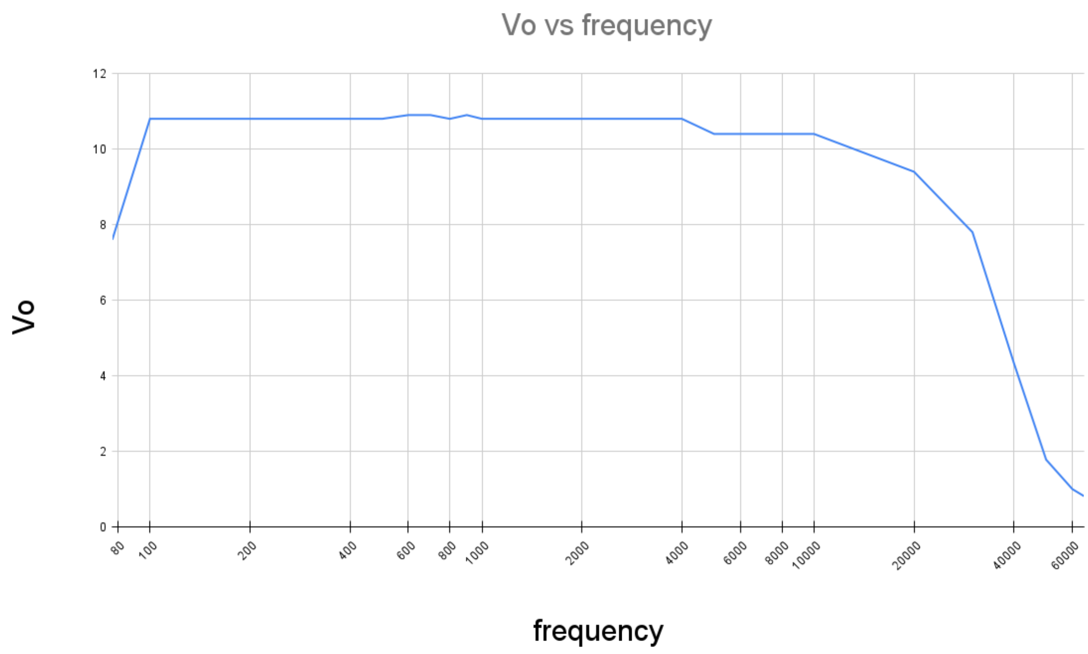

Figure 13: frequency to output voltage relation and maximum frequency in this oscillator

2.4 Block 3: Triangular Wave generator

We basically extend block 2 with integrator circuit. Which would give triangular wave as intended. Here, this integrator circuit differs from basic circuit that $100k\Omega$ as feedback resister is joined. Which would give better stability and accurate output. Circuit diagram is shown below,

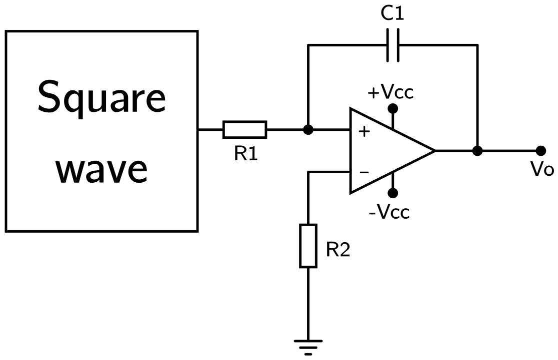

Figure 14: integrator circuit with square wave as input

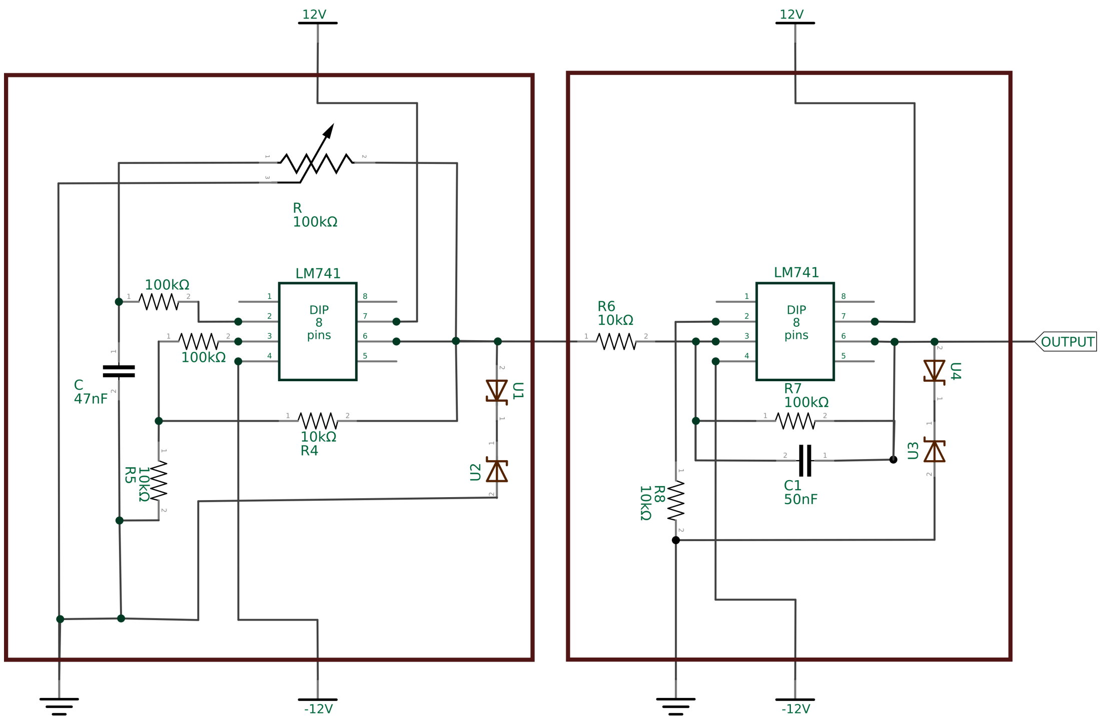

Figure 15: block 3: triangluar wave generator

Here, R_4 have to be $10R_3$. Frequency is give by same relation as block 2.

2.4.1 Working of Integrator

A Basic integrator is shown in figure 14. Which can modified as out need. Here basic passive components like capacitor and resistor used with OpAmp. The basic Integrator is made of inverting amplifier configuration. It has capacitor as feedback component. We used resistor of $100k\Omega$ in parallel to capacitor to stabilize integration operation. Since, capacitor as very low reactance at feedback. Here, inverting mode is employed so we have inverting input as virtual ground. Here, changing rate is determined by RC time constant. OpAmp produces ramp output till capacitor gets fully charged. The capacitor charges current decreases by the influence between the virtual ground and negative output.

2.4.2 Output of triangular wave.

Here, we have results of triangular waves as V_0 and frequency graph and practical data between them. You can see out practical data in appendix. All Output in CRO is shown in figure –refs{fig:tringout}.

Triangout

Triang graph v0 vs frequency

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3 connection and switching

For connection of all this block we have used DPST switch with. This have two poles, one for power controlling and other for output controlling. Basic diagram of this switch is drawn in figure below.

When switch is **ON** it will connect 1 terminals with common and complete the circuit. When switch is **OFF** (pulled condition), the circuit will open and we will not get connection.

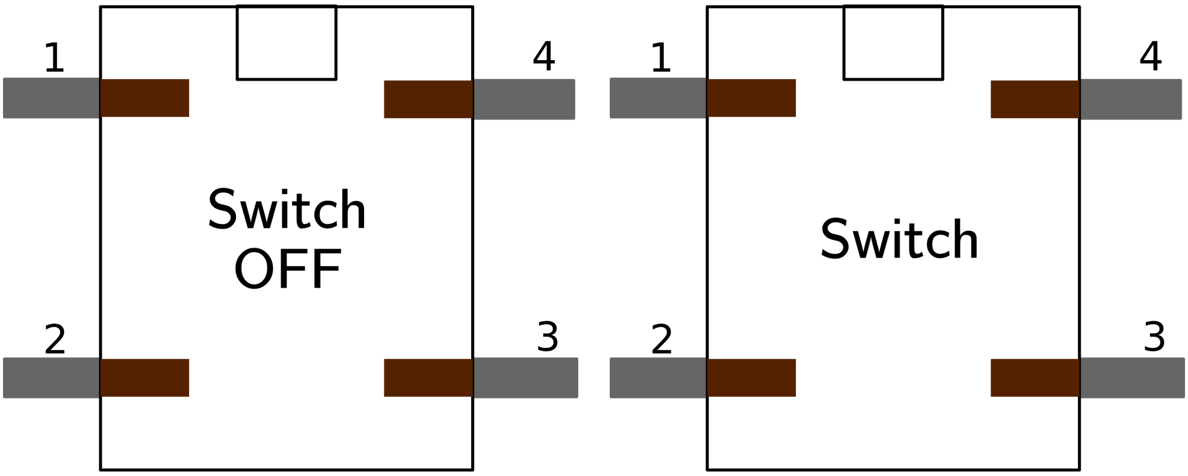


Figure 16: Here we have basic diagram of DPST switch, you can see how will switch connect internally for both on and off states. Figure a) is for switch on state and figure b) for off state

The +Vcc in common (upper common) is completely independent of Output terminal common (lower common). Which means switch can completely operate two tasks, which is when on it power the block and take output and give to CRO. You can see this is on block diagram in figure 1.

4 Appendix

4.1 Practical Data

We have taken some quantatitive work here for our project.

4.1.1 Sine wave data

Sine data

4.1.2 Square wave data

Frequency	V_o
77	7.6
100	10.8
200	10.8
300	10.8
400	10.8
500	10.8
600	10.9
700	10.9
800	10.8
900	10.9
1000	10.8
2000	10.8
3000	10.8
4000	10.8
5000	10.4
6000	10.4
7000	10.4
8000	10.4
9000	10.4
10000	10.4
20000	9.4
30000	7.8
40000	4.33
50000	1.78
60000	1
65000	0.816

4.1.3 Triangular data

Trian data

4.2 Used components in this project

We used standard components in this projects. For resistor we used ceramic resistor and ceramic capacitor for capacitor. As problem with availability 47nF capacitor is plastic

4.2.1 Ceramic resistor

A ceramic resistor is a fixed resistor used in electronic circuits. As name suggests the resistor's name suggest it is made from ceramic as substrate. Ceramic resistors are compact and versatile. Ceramic resistors are made by mixing ceramic powder with metallic oxide powder to form a paste. The paste is then shaped into a cylinder or rectangle and dried before being fired in a kiln. The firing process produces a dense, hard, and non-porous ceramic substrate that is stable at high temperatures and resistant to thermal shock.

Advantages of ceramic resistors: a) high power rating. That means they can be used in higher power use case scenario compare to other type of resistors.
b) As i said, ceramic resistor are compact and versatile.
c) very reliable and low with tolerances. They get lower drift over time and can be used in harsh scenarios.

4.2.2 Ceramics capacitor

As name suggest it is made of ceramic as its dielectric material. There are most common in making electronic circuits. Ceramic capacitors are made by applying a layer of ceramic material to a metal electrode, creating a sandwich-like structure. The electrodes are then connected to leads or terminals, forming the capacitor. The thickness of the ceramic layer determines the capacitor's capacitance value, with thinner layers resulting in lower capacitance values and thicker layers resulting in higher capacitance values.

Advantages of ceramic capacitor: a) ceramic capacitors can have high dielectric constant since ceramic have ceramic very low conductivity. This means it can store more energy in smaller package.
b) they are small and lightweight. This is quite needed in modern electronics circuits.
c) they are reliable in harsh conditions like extreme temperature variations, Making them suitable for almost every condition for electronic circuit purposes. They are also have very low drift with time making them suitable for long run.

We used 10nF capacitor of ceramic capacitor.

4.2.3 Polypropylene capacitor

Polyester film capacitors are film capacitors using a dielectric made of the thermoplastic polar polymer material polyethylene terephthalate (PET), trade names Hostaphan or Mylar, from the polyester family. They are manufactured both as metallized wound and stacked versions, as well as film/foil types. The dielectric films, depending on the desired dielectric strength, are drawn in a special process to an extremely thin thickness, and are then provided with electrodes. The electrodes of film capacitors may be metallized aluminum or zinc applied directly to the surface of the plastic film, or a separate metallic foil. Film capacitors, together with ceramic capacitors and electrolytic capacitors, are the most common capacitor types for use in electronic equipment, and are used in many AC and DC microelectronics and electronics circuits

We used 47nF capacitor of Polypropylene capacitor.

4.2.4 zener diode

A zener diode is a type of diode that is designed to operate in the reverse breakdown region of its voltage-current characteristics. This makes it useful as a voltage regulator in electronic circuits. The voltage across a zener diode is determined by the breakdown voltage, which is the voltage at which the diode starts to conduct in the reverse direction. Once the breakdown voltage is reached, the zener diode will conduct and maintain a relatively constant voltage across its terminals, regardless of changes in the applied voltage. This is main work of zener diode. It's straight voltage regulators with Fixed maximum voltage.

Here, we have 12 volt zener diode, which is adequate for our purpose and regulating small voltage variations.

If we take V_z as voltage across the zener diode, I_z as current through the diode, and R is the resistance of the load connected to the diode. In a typical voltage regulator circuit, the load resistance is known and fixed, so the voltage across the zener diode is determined by the current flowing through the diode. Current in reverse breakdown state,

$$I_z = \frac{V_z - V_r}{R}$$

where, V_r is the reverse voltage applied to the diode.

It can also be used as voltage clamper and voltage reference applications.

4.3 Data sheet of OpAmp we used (IC μ A741CP)

µA741, µA741Y
GENERAL-PURPOSE OPERATIONAL AMPLIFIERS

SLOS094B – NOVEMBER 1970 – REVISED SEPTEMBER 2000

- **Short-Circuit Protection**
- **Offset-Voltage Null Capability**
- **Large Common-Mode and Differential Voltage Ranges**
- **No Frequency Compensation Required**
- **Low Power Consumption**
- **No Latch-Up**
- **Designed to Be Interchangeable With Fairchild µA741**

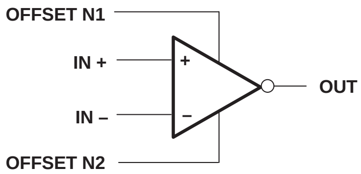
description

The µA741 is a general-purpose operational amplifier featuring offset-voltage null capability.

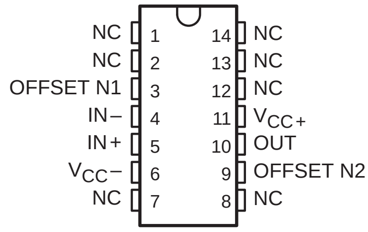
The high common-mode input voltage range and the absence of latch-up make the amplifier ideal for voltage-follower applications. The device is short-circuit protected and the internal frequency compensation ensures stability without external components. A low value potentiometer may be connected between the offset null inputs to null out the offset voltage as shown in Figure 2.

The µA741C is characterized for operation from 0°C to 70°C. The µA741I is characterized for operation from –40°C to 85°C.The µA741M is characterized for operation over the full military temperature range of –55°C to 125°C.

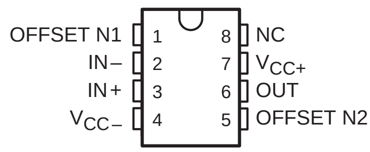
symbol



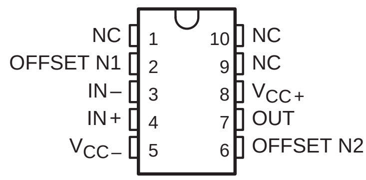
µA741M . . . J PACKAGE
(TOP VIEW)



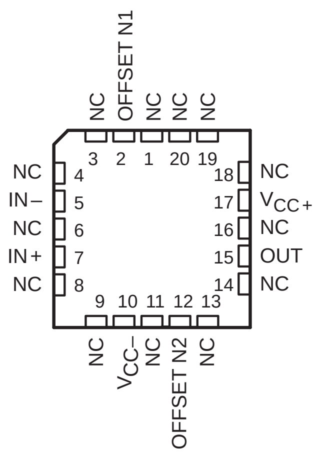
µA741M . . . JG PACKAGE
µA741C, µA741I . . . D, P, OR PW PACKAGE
(TOP VIEW)



µA741M . . . U PACKAGE
(TOP VIEW)



µA741M . . . FK PACKAGE
(TOP VIEW)



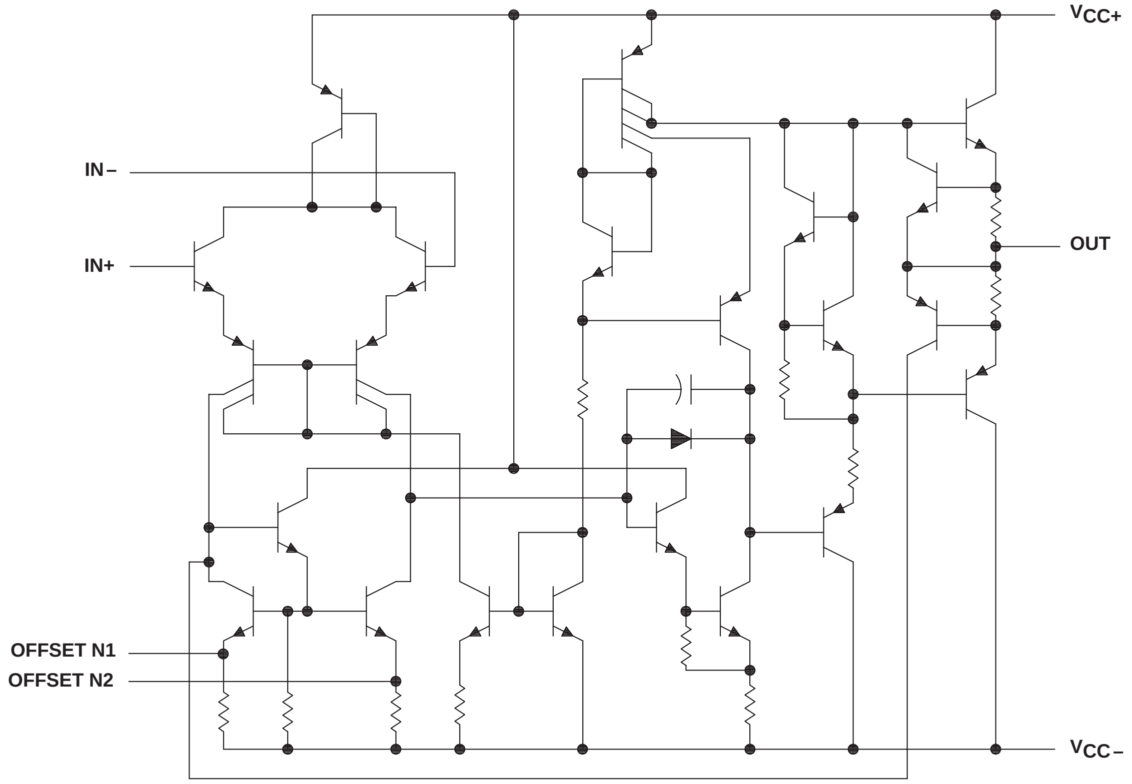
NC – No internal connection

AVAILABLE OPTIONS

T_A	PACKAGED DEVICES							CHIP FORM (Y)
	SMALL OUTLINE (D)	CHIP CARRIER (FK)	CERAMIC DIP (J)	CERAMIC DIP (JG)	PLASTIC DIP (P)	TSSOP (PW)	FLAT PACK (U)	
0°C to 70°C	µA741CD				µA741CP	µA741CPW		µA741Y
–40°C to 85°C	µA741ID				µA741IP			
–55°C to 125°C		µA741MFK	µA741MJ	µA741MJG			µA741MU	

The D package is available taped and reeled. Add the suffix R (e.g., µA741CDR).

schematic

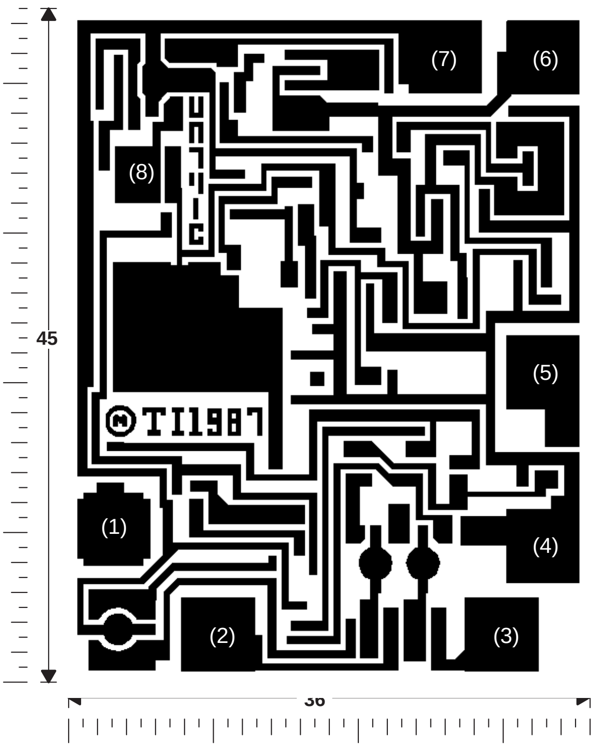


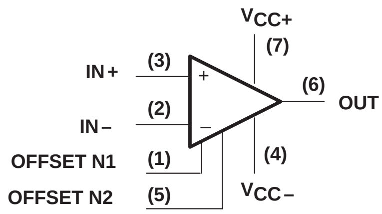
Component Count	
Transistors	22
Resistors	11
Diode	1
Capacitor	1

μA741Y chip information

This chip, when properly assembled, displays characteristics similar to the μA741C. Thermal compression or ultrasonic bonding may be used on the doped-aluminum bonding pads. Chips may be mounted with conductive epoxy or a gold-silicon preform.

BONDING PAD ASSIGNMENTS





CHIP THICKNESS: 15 TYPICAL

BONDING PADS: 4 × 4 MINIMUM

$T_J$max = 150°C.

TOLERANCES ARE ±10%.

ALL DIMENSIONS ARE IN MILS.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

		μA741C	μA741I	μA741M	UNIT
Supply voltage, V_{CC+} (see Note 1)		18	22	22	V
Supply voltage, V_{CC-} (see Note 1)		–18	–22	–22	V
Differential input voltage, V_{ID} (see Note 2)		±15	±30	±30	V
Input voltage, V_I any input (see Notes 1 and 3)		±15	±15	±15	V
Voltage between offset null (either OFFSET N1 or OFFSET N2) and V_{CC-}		±15	±0.5	±0.5	V
Duration of output short circuit (see Note 4)		unlimited	unlimited	unlimited	
Continuous total power dissipation		See Dissipation Rating Table			
Operating free-air temperature range, T_A		0 to 70	–40 to 85	–55 to 125	°C
Storage temperature range		–65 to 150	–65 to 150	–65 to 150	°C
Case temperature for 60 seconds	FK package			260	°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds	J, JG, or U package			300	°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	D, P, or PW package	260	260		°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES:
1. All voltage values, unless otherwise noted, are with respect to the midpoint between V_{CC+} and V_{CC-}.
2. Differential voltages are at IN+ with respect to IN–.
3. The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 V, whichever is less.
4. The output may be shorted to ground or either power supply. For the μA741M only, the unlimited duration of the short circuit applies at (or below) 125°C case temperature or 75°C free-air temperature.

DISSIPATION RATING TABLE

PACKAGE	$T_A \leq 25°C$ POWER RATING	DERATING FACTOR	DERATE ABOVE T_A	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ POWER RATING	$T_A = 125°C$ POWER RATING
D	500 mW	5.8 mW/°C	64°C	464 mW	377 mW	N/A
FK	500 mW	11.0 mW/°C	105°C	500 mW	500 mW	275 mW
J	500 mW	11.0 mW/°C	105°C	500 mW	500 mW	275 mW
JG	500 mW	8.4 mW/°C	90°C	500 mW	500 mW	210 mW
P	500 mW	N/A	N/A	500 mW	500 mW	N/A
PW	525 mW	4.2 mW/°C	25°C	336 mW	N/A	N/A
U	500 mW	5.4 mW/°C	57°C	432 mW	351 mW	135 mW

electrical characteristics at specified free-air temperature, $V_{CC\pm}$ = ±15 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	T_A†	μA741C			μA741I, μA741M			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	V_O = 0	25°C		1	6		1	5	mV
			Full range			7.5			6	
$\Delta V_{IO(adj)}$	Offset voltage adjust range	V_O = 0	25°C		±15			±15		mV
I_{IO}	Input offset current	V_O = 0	25°C		20	200		20	200	nA
			Full range			300			500	
I_{IB}	Input bias current	V_O = 0	25°C		80	500		80	500	nA
			Full range			800			1500	
V_{ICR}	Common-mode input voltage range		25°C	±12	±13		±12	±13		V
			Full range	±12			±12			
V_{OM}	Maximum peak output voltage swing	R_L = 10 kΩ	25°C	±12	±14		±12	±14		V
		R_L ≥ 10 kΩ	Full range	±12			±12			
		R_L = 2 kΩ	25°C	±10	±13		±10	±13		
		R_L ≥ 2 kΩ	Full range	±10			±10			
A_{VD}	Large-signal differential voltage amplification	R_L ≥ 2 kΩ	25°C	20	200		50	200		V/mV
		V_O = ±10 V	Full range	15			25			
r_i	Input resistance		25°C	0.3	2		0.3	2		MΩ
r_o	Output resistance	V_O = 0, See Note 5	25°C		75			75		Ω
C_i	Input capacitance		25°C		1.4			1.4		pF
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICR}$min	25°C	70	90		70	90		dB
			Full range	70			70			
k_{SVS}	Supply voltage sensitivity ($\Delta V_{IO}/\Delta V_{CC}$)	V_{CC} = ±9 V to ±15 V	25°C		30	150		30	150	μV/V
			Full range			150			150	
I_{OS}	Short-circuit output current		25°C		±25	±40		±25	±40	mA
I_{CC}	Supply current	V_O = 0, No load	25°C		1.7	2.8		1.7	2.8	mA
			Full range			3.3			3.3	
P_D	Total power dissipation	V_O = 0, No load	25°C		50	85		50	85	mW
			Full range			100			100	

† All characteristics are measured under open-loop conditions with zero common-mode input voltage unless otherwise specified. Full range for the μA741C is 0°C to 70°C, the μA741I is –40°C to 85°C, and the μA741M is –55°C to 125°C.

NOTE 5: This typical value applies only at frequencies above a few hundred hertz because of the effects of drift and thermal feedback.

operating characteristics, $V_{CC\pm}$ = ±15 V, T_A = 25°C

PARAMETER		TEST CONDITIONS		μA741C			μA741I, μA741M			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
t_r	Rise time	V_I = 20 mV, C_L = 100 pF,	R_L = 2 kΩ, See Figure 1		0.3			0.3		μs
	Overshoot factor				5%			5%		
SR	Slew rate at unity gain	V_I = 10 V, C_L = 100 pF,	R_L = 2 kΩ, See Figure 1		0.5			0.5		V/μs

electrical characteristics at specified free-air temperature, $V_{CC\pm} = \pm 15$ V, $T_A = 25°C$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	µA741Y			UNIT
			MIN	TYP	MAX	
V_{IO}	Input offset voltage	$V_O = 0$		1	6	mV
$\Delta V_{IO(adj)}$	Offset voltage adjust range	$V_O = 0$		±15		mV
I_{IO}	Input offset current	$V_O = 0$		20	200	nA
I_{IB}	Input bias current	$V_O = 0$		80	500	nA
V_{ICR}	Common-mode input voltage range		±12	±13		V
V_{OM}	Maximum peak output voltage swing	$R_L = 10$ kΩ	±12	±14		V
		$R_L = 2$ kΩ	±10	±13		
A_{VD}	Large-signal differential voltage amplification	$R_L \geq 2$ kΩ	20	200		V/mV
r_i	Input resistance		0.3	2		MΩ
r_o	Output resistance	$V_O = 0$, See Note 5		75		Ω
C_i	Input capacitance			1.4		pF
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICR}$min	70	90		dB
k_{SVS}	Supply voltage sensitivity ($\Delta V_{IO}/\Delta V_{CC}$)	$V_{CC} = \pm 9$ V to ±15 V		30	150	µV/V
I_{OS}	Short-circuit output current			±25	±40	mA
I_{CC}	Supply current	$V_O = 0$, No load		1.7	2.8	mA
P_D	Total power dissipation	$V_O = 0$, No load		50	85	mW

† All characteristics are measured under open-loop conditions with zero common-mode voltage unless otherwise specified.

NOTE 5: This typical value applies only at frequencies above a few hundred hertz because of the effects of drift and thermal feedback.

operating characteristics, $V_{CC\pm} = \pm 15$ V, $T_A = 25°C$

PARAMETER		TEST CONDITIONS	µA741Y			UNIT
			MIN	TYP	MAX	
t_r	Rise time	$V_I = 20$ mV, $R_L = 2$ kΩ, $C_L = 100$ pF, See Figure 1		0.3		µs
	Overshoot factor			5%		
SR	Slew rate at unity gain	$V_I = 10$ V, $R_L = 2$ kΩ, $C_L = 100$ pF, See Figure 1		0.5		V/µs

PARAMETER MEASUREMENT INFORMATION

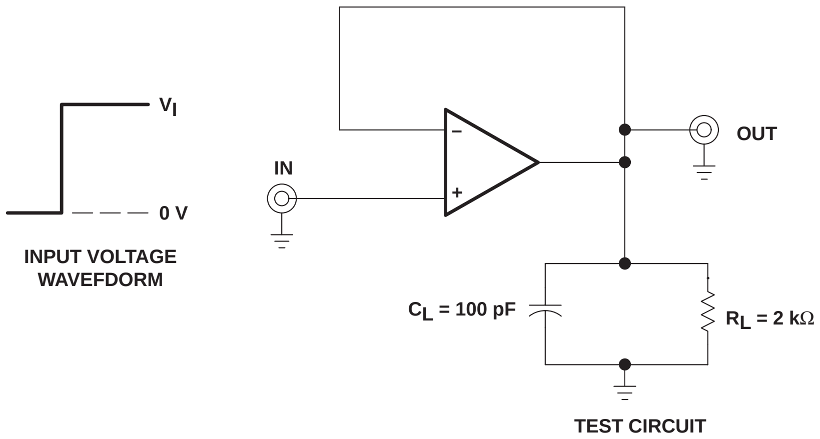


Figure 1. Rise Time, Overshoot, and Slew Rate

APPLICATION INFORMATION

Figure 2 shows a diagram for an input offset voltage null circuit.

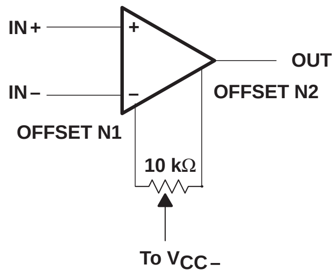


Figure 2. Input Offset Voltage Null Circuit

TYPICAL CHARACTERISTICS†

INPUT OFFSET CURRENT
vs
FREE-AIR TEMPERATURE

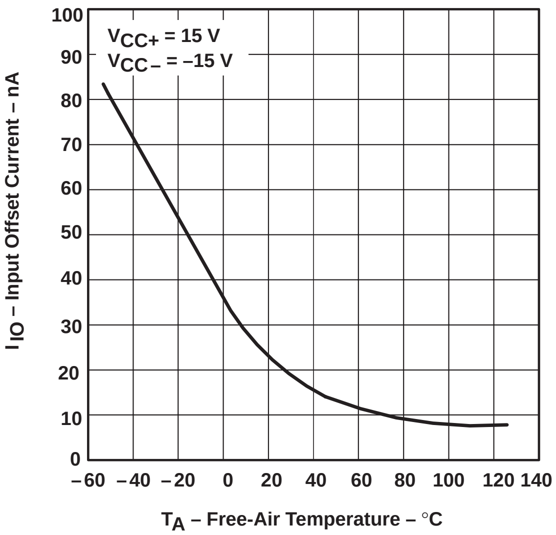


Figure 3

INPUT BIAS CURRENT
vs
FREE-AIR TEMPERATURE

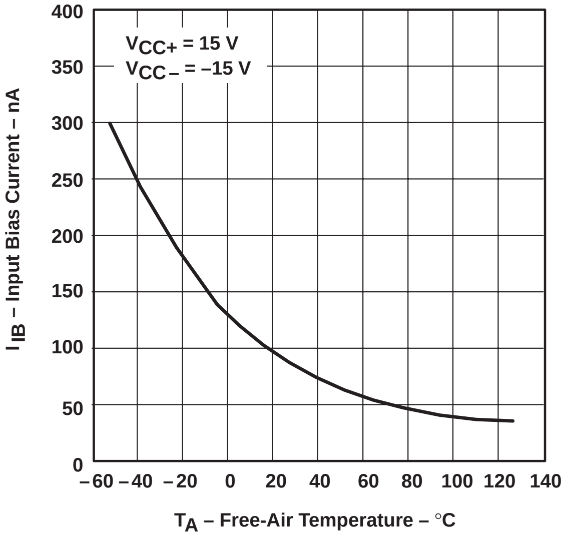


Figure 4

MAXIMUM PEAK OUTPUT VOLTAGE
vs
LOAD RESISTANCE

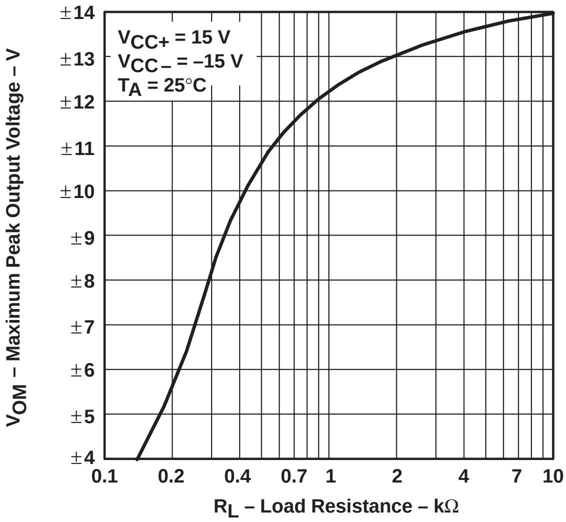


Figure 5

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS

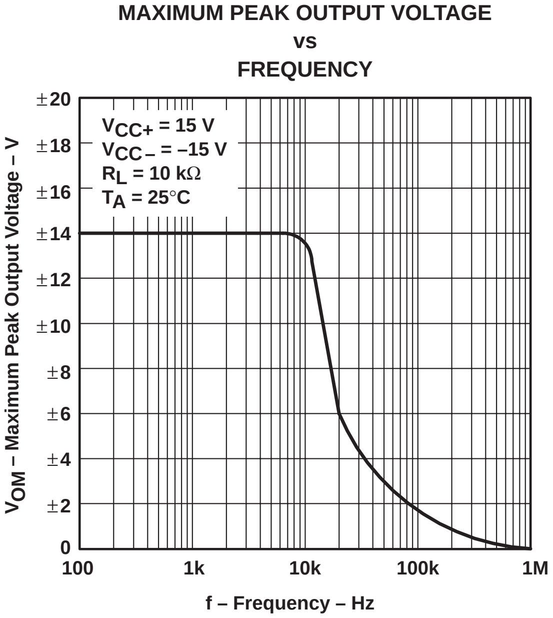


Figure 6

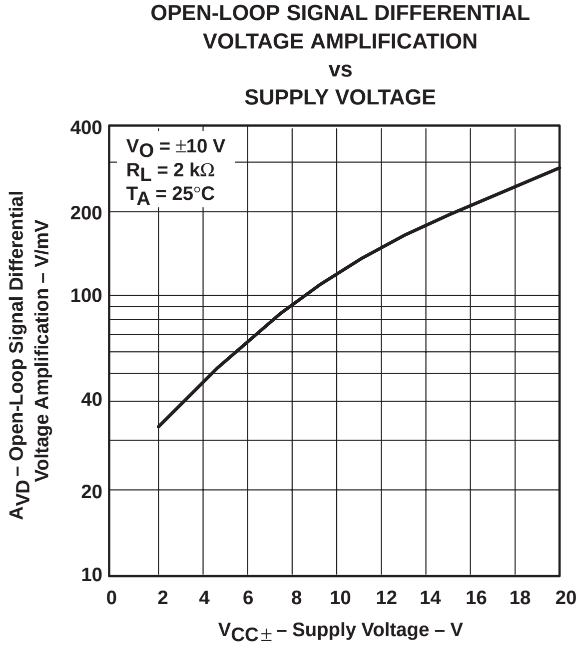
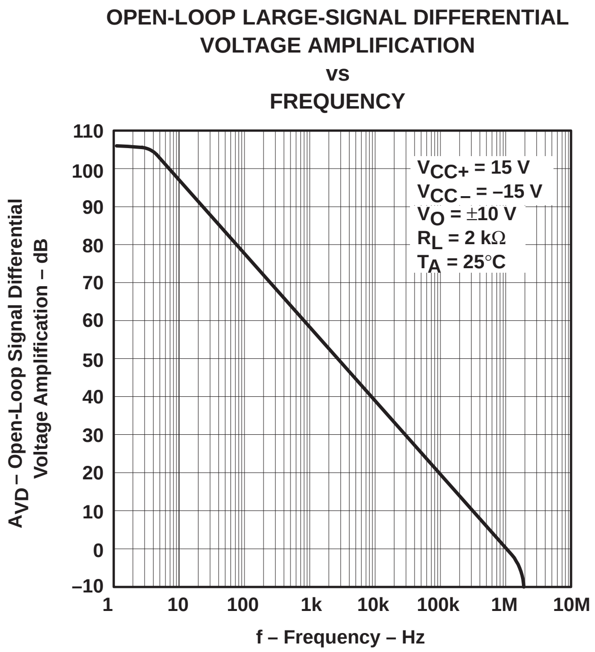


Figure 7



TYPICAL CHARACTERISTICS

COMMON-MODE REJECTION RATIO
vs
FREQUENCY

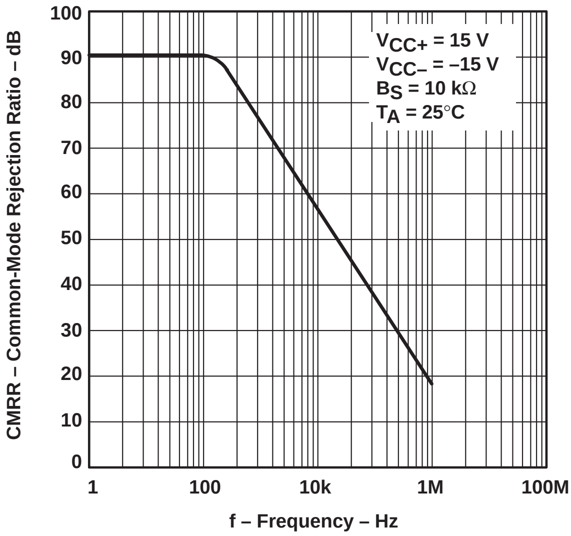


Figure 8

OUTPUT VOLTAGE
vs
ELAPSED TIME

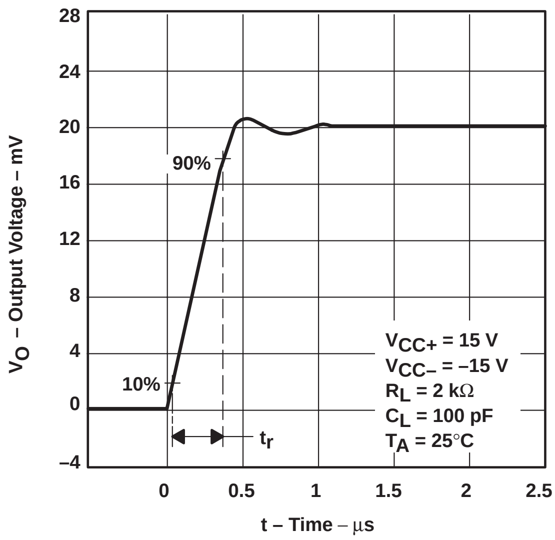


Figure 9

VOLTAGE-FOLLOWER
LARGE-SIGNAL PULSE RESPONSE

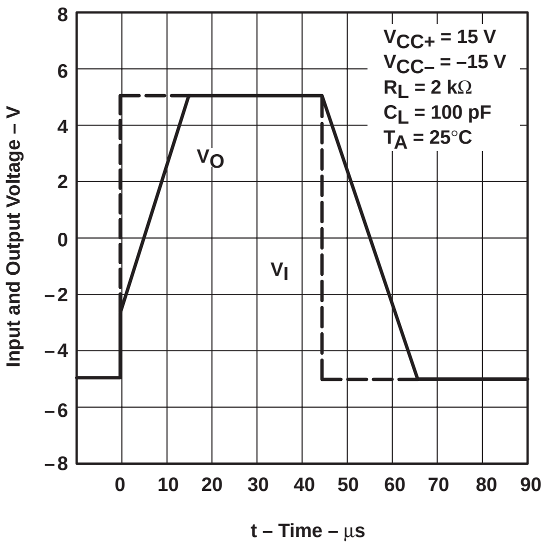


Figure 10

PACKAGING INFORMATION

Orderable Device	Status [1]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [2]	Lead/Ball Finish	MSL Peak Temp [3]
UA741CD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
UA741CDE4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
UA741CDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
UA741CDRE4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
UA741CJG	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI
UA741CJG4	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI
UA741CP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type
UA741CPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type
UA741CPSR	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
UA741CPSRE4	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
UA741MFKB	OBSOLETE	LCCC	FK	20		TBD	Call TI	Call TI
UA741MJ	OBSOLETE	CDIP	J	14		TBD	Call TI	Call TI
UA741MJB	OBSOLETE	CDIP	J	14		TBD	Call TI	Call TI
UA741MJG	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI
UA741MJGB	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI

[1] The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

[2] Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

[3] MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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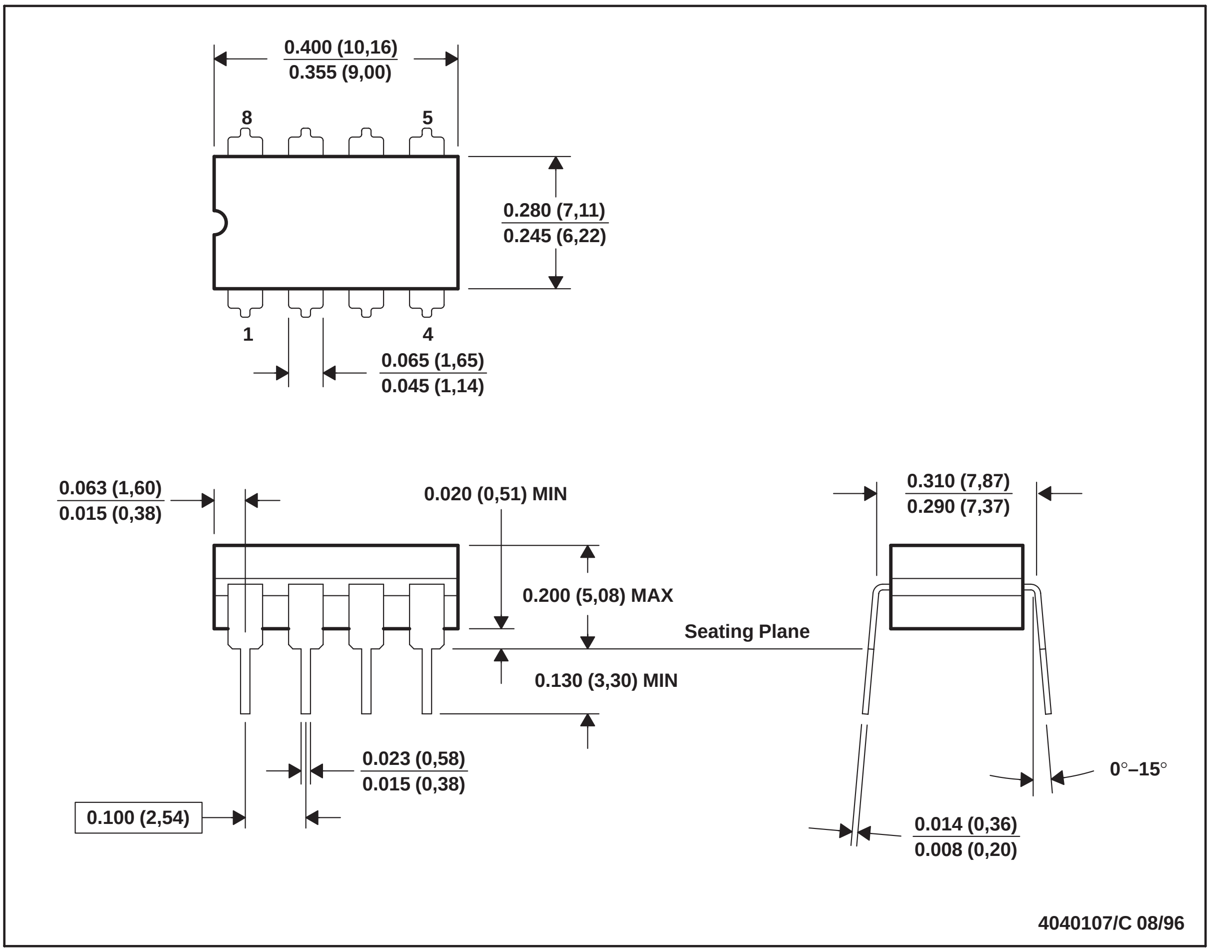
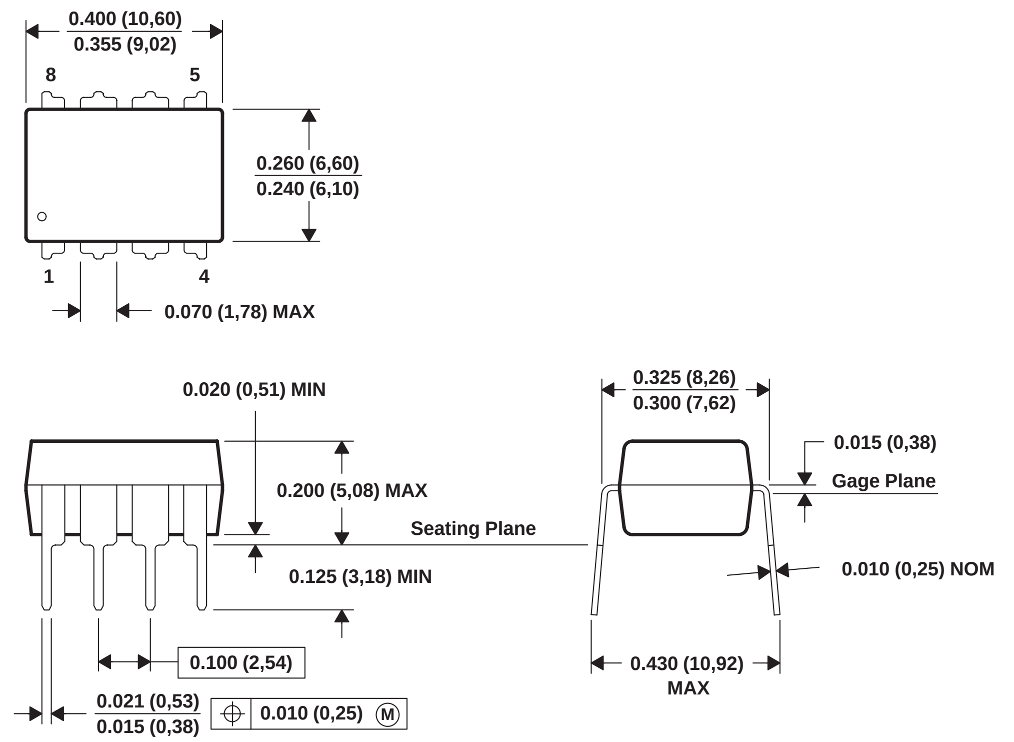
JG (R-GDIP-T8) **CERAMIC DUAL-IN-LINE**



NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. This package can be hermetically sealed with a ceramic lid using glass frit.
D. Index point is provided on cap for terminal identification.
E. Falls within MIL STD 1835 GDIP1-T8

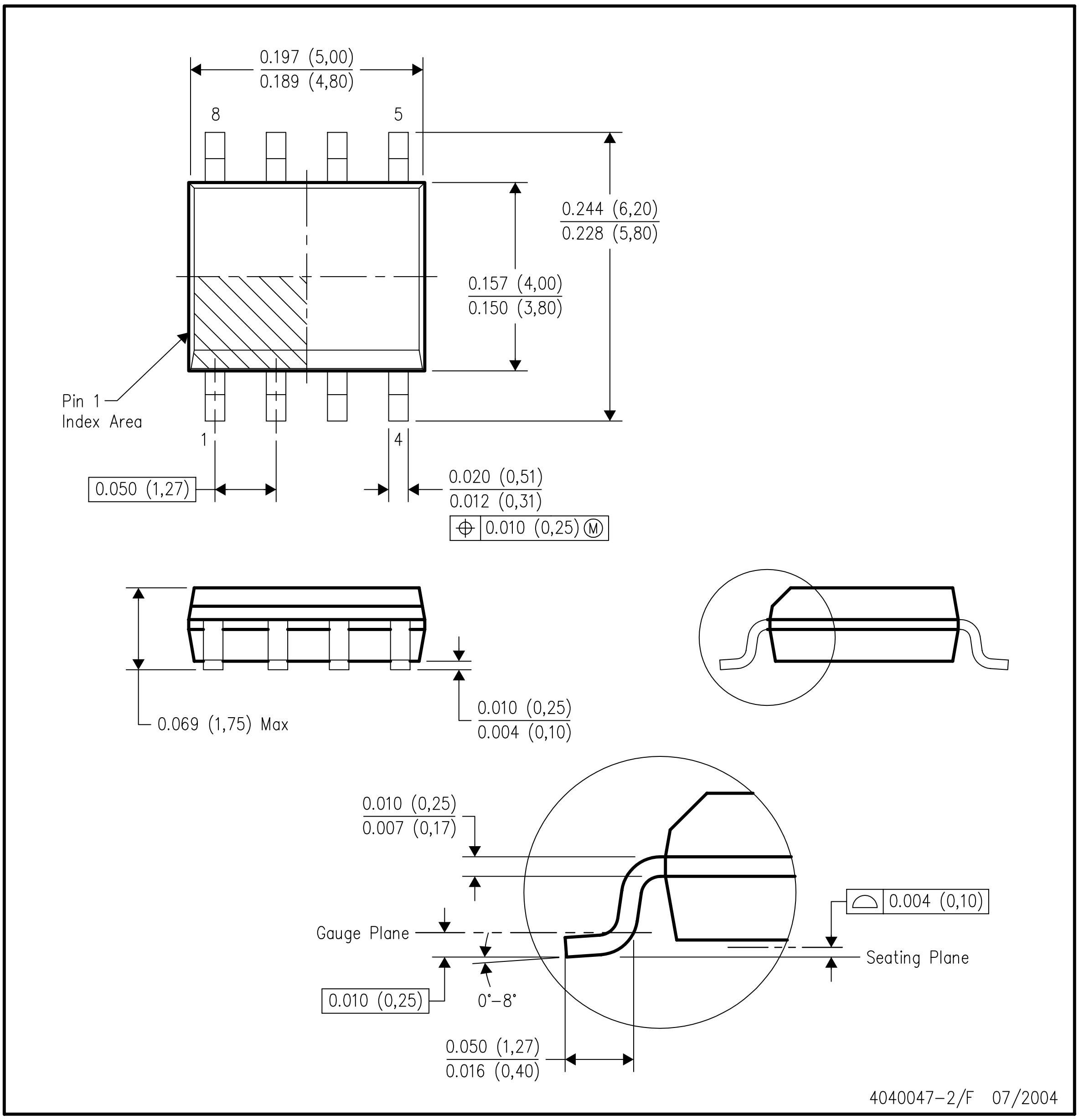
P (R-PDIP-T8) **PLASTIC DUAL-IN-LINE**



NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-001

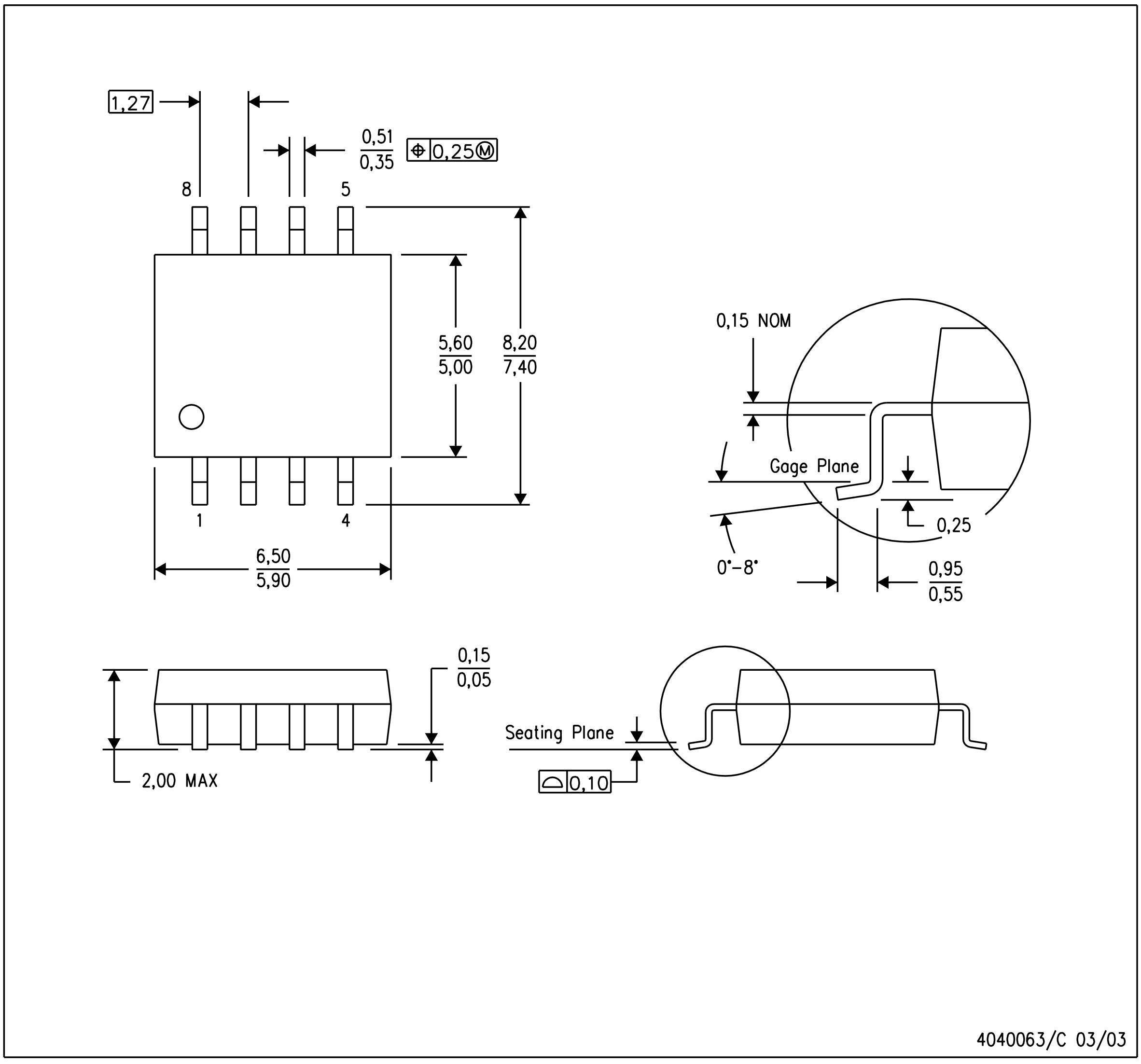
For the latest package information, go to http://www.ti.com/sc/docs/package/pkg_info.htm

D (R–PDSO–G8) PLASTIC SMALL–OUTLINE PACKAGE



NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion not to exceed 0.006 (0,15).
D. Falls within JEDEC MS–012 variation AA.

PS (R-PDSO-G8) **PLASTIC SMALL-OUTLINE PACKAGE**



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protrusion, not to exceed 0,15.

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4.4 Pspice simulations

We did Pspice simulation In `https://www.falstad.com/circuit/` [1] by Paul Falsted. Here are simlations result from different blocks. This outputs are for Potentiometer valued at $3.3k\Omega$. We gain peek to peek voltage value at $2.8917V$ for sine wave and $2.11V$ and 2.2 in square wave and triangular wave respectively. This figures are from matplotlib [5][3], since we could not get from falsted. We got accurate p-p voltages.

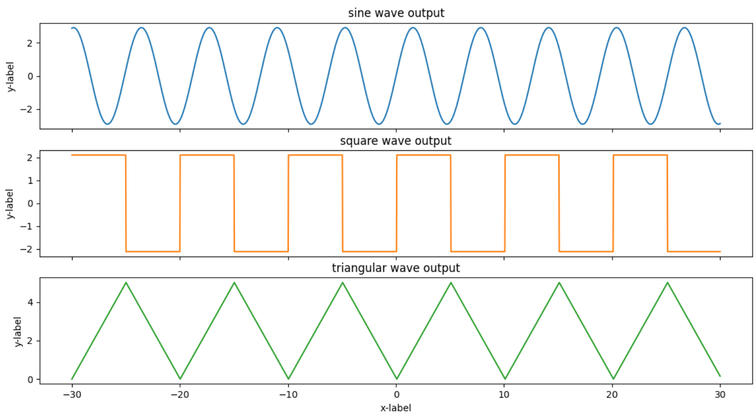

Figure 17: Outputs

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Brett, Allan Haldane, Jaime Fernández del Río, Mark Wiebe, Pearu Peterson, Pierre Gérard-Marchant, Kevin Sheppard, Tyler Reddy, Warren Weckesser, Hameer Abbasi, Christoph Gohlke, and Travis E. Oliphant. Array programming with NumPy. *Nature*, 585(7825):357–362, September 2020.

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