Appendices

1. Study results about the wheel form done by Kojiro Iizuka, Yoshinori Sato, Yoji Kuroda and Takashi Kubota (1a and 1b)
2. Extract of the Hyperion product catalogue
3. List of the first material bought for making the first battery charge and discharge tests
4. Test record of the cell voltage measuring circuit
5. CD with the datasheets of electronic devices
    - 5a) 12V DC-motor from Maxon (A-max 26) with gear & encoder
    - 5b) 12V DC-motor from Maxon (A-max 19) with gear & encoder
    - 5c) Charging unit 1210i from Hyperion (user manual)
    - 5d) Balancer LBA10 from Hyperion (user manual)
    - 5e) MOSFET transistor K2936
    - 5f) Operational amplifier LMV324
    - 5g) Comparator LMV339
    - 5h) Operational amplifier LM324
    - 5i) Comparator LM339
    - 5j) Quad 2-input NOR gate M74HC02
    - 5k) Relay from the company Finder (Series 66)
    - 5l) Relay from the company Omron (LY2)
    - 5m) A/D-converter MAX197
    - 5n) Current sensor LTSR 6-NP (LEM)
    - 5o) Quad RS latch 74HC279
    - 5p) Quad 2-input AND gate MM74HC08
    - 5q) Temperature sensor LM35

Appendix 1a

Study on Wheeled Forms of Lunar Robots for Traversing Soft Terrain

by Kojiro Iizuka, Yoshinori Sato, Yoji Kuroda and Takashi Kubota

Study on Wheeled Forms of Lunar Robots for Traversing Soft Terrain

Kojiro IIzuka, Yasuharu Kunii and Takashi Kubota

Abstract— **Lunar rovers are required to move on rough terrains such as in craters and rear cliffs where it is scientifically very important to explore. Recently, wheel typed rovers are popular for planetary exploration missions. However, there is a problem that the wheel typed rovers have possibility of stack. Therefore, this paper investigates a mechanism of kinetic behavior between the wheels of the exploration rovers and soil. The important parameters are extracted by considering the mechanism. This paper proposes an elastic wheel by considering the important parameters. The elastic wheel has the surface which can be changed flexibly toward rough terrain. Running experiments on soil which imitated regolith are carried out to observe the traversability of the elastic wheel using slip ratio and sinkage.**

I. INTRODUCTION

Robots are considered to be one of the most important mission devices for planetary explorations and will be expected to move on planetary surfaces to collect precise information regarding the origin and maturing. In the Mars mission by NASA in 1997, the micro robot Sojourner moved and explored on the surface of Mars. Sojourner sent the important data and detailed pictures to the earth.

The Sojourner mission showed the importance of moving exploration[1]. In planetary exploration, robots are required to move on rough terrains such as in craters and rear cliffs where it is scientifically very important to explore. Further, robots must avoid tip-over and stack even though they move on rough terrains. At past, in lunar missions, Lunokhod[Russian] and LRV[NASA] traveled long distance on regolith for explorations. These robots were so large and heavy (about 800[kg]). On soil, the movement of robots with heavy load is better. In future missions, however, heavy robots are not realistic because of the limit of payload, cost and capacity etc. Therefore, the future robots have to do downsizing. But it is difficult for small robots like Sojourner to move on soil, because it is hard to get effective impulse from soil. Therefore, this paper focuses on robots with the middle scale and middle load (a few 10[kg]) and constructs high performance for running on soil.

To investigate the running condition, it is needed to study the interaction between wheel and soil. However, the mechanism is not clear yet. Therefore, this paper investigates the kinematics behavior of lunar robots with tire-soil mechanism.

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This paper defines the mechanism, where the running condition is bad when the circular wheel is running on slope. The reasons are extracted from the mechanism. To solve the problems is to increase the traversability of the exploration robots for exploring the lunar surface. This paper proposes a new wheel form for solving these problems.

In section II, the interaction between wheel and soil is modeled on slope. Important parameters for running wheel are extracted from the model. Then, a new wheel form is designed in section III. Section IV presents the running experiments and results. Section V is for the conclusion of this paper.

II. INTERACTION BETWEEN WHEEL AND SOIL

A. Dynamic Action of Soil

The lunar surface is covered with regolith, the lunar ground is soft and it is easy to slide. Regolith is made of the fragment broken from the moon and other heaven bodies. Moreover, the regolith was suffered from the chemical change for granule phenomenon. And the regolith is different from weathering soil of the Earth. On such a surface, a normally wheel can not produce the traction easily for the movement. Therefore, the exploration robots need to install "lug" for increasing the traction force. In case of the wheel which has lugs, the behavior of subsidence characteristics, the shearing strength of soil, the transformation by shearing and friction characteristics need for the consideration of the interaction between wheel and soil.

B. Wheeled Type on the Lunar Surface

When robots explore the surface of the moon, the environment is vacuum and is exposed to the space radiation. Moreover, the temperature difference between day and night is intense. In such environments, tires which are generally used on the Earth can not be used. Therefore, the wheels of metal are used for lunar robots.

C. Model of Interaction between Wheel and Soil

Some researchers have studied robots with interaction between wheel and soil on a flat terrain[4][6][9][10][11]. However they do not study the model on a slope. This paper cosiders the interaction model between wheel and soil on a slope as shown in Fig.1.

The line which the wheel runs on slope is shown as "soil surface". $r\omega$ and V_ω denote the revolution and velocity of the wheel. W_t means the parallel load of the wheel to soil surface. Z_s denotes the sinkage at a slope. θ is used to show the part of the wheel into soil. θ_1 indicates the inserted angle into soil and θ_2 indicates the escaped angle.

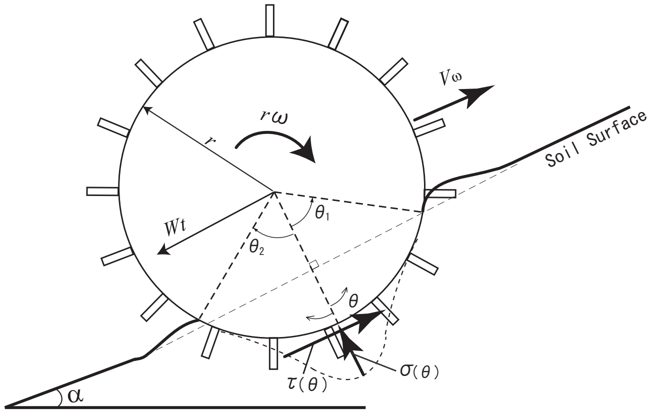

Fig. 1. Interaction Model between Wheel and Soil on Slope

D. Traction Load

In case of the slope, the traction load which is increased by gravity occurs to the wheel. If the slope for running increases, the traction load increases.

E. Stress at Contact Surface

If it is assumed that soil shows the hardening behavior of distortion by shearing stress when a wheel is moving, a shearing stress in an angle θ can be written as follows.

$$\tau(\theta) = (c + \sigma(\theta)) \tan\phi)(1 - \exp^{-\frac{j(\theta)}{K}}) \qquad (1)$$

c : adhesive power
j : shearing strain
ϕ : internal friction angle

The slip ratio λ is defined by the following formula here.

$$\lambda = \begin{cases} 1 - \dfrac{V_\omega}{r\omega} & : drive(r\omega \geq V\omega) \\ 1 - \dfrac{r\omega}{V_\omega} & : brake(r\omega \leq V_\omega) \end{cases} \qquad (2)$$

where,

r : the radius of a wheel
ω : angular velocity of a wheel
V_ω : moving speed of a wheel

Moreover, the sinkage Z_s can be written as follows.

$$Z_s = r(1 - \cos(\theta_1)) \qquad (3)$$

Fig.2 shows the interaction between soil and the wheel when the wheel sinks. θ_f and θ_e denote the original angle. θ_0 is the angle of direction of gravity. θ_β is the inserted angle after sinking. α' is an angle of slope after sinking. In other words, to increase slope for running means that the wheel sinks. Moreover, if the angle of slope for running is bigger, the traction load becomes large. α' can be written as follows.

$$\alpha' = \tan^{-1} \times B \qquad (4)$$

where,

$$B = \left(\frac{\sin(\theta_0 + \theta_f - \frac{\pi}{2} + \theta_\beta) - \sin(\theta_0 - \theta_e - \frac{\pi}{2} + \theta_\beta)}{\cos(\theta_0 + \theta_f - \frac{\pi}{2} + \theta_\beta) - \cos(\theta_0 - \theta_e - \frac{\pi}{2} + \theta_\beta)} \right)$$

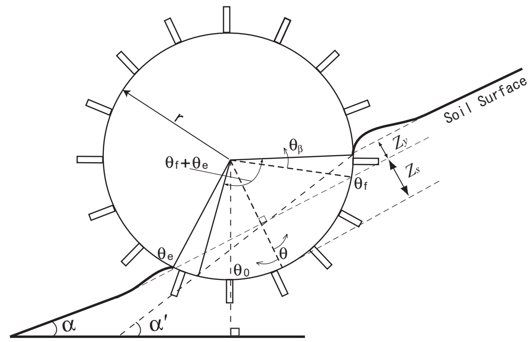

Fig. 2. Running Slope changed by rotation of Wheel

F. Traction Force produced by Wheel

The traction force of wheel DP is expressed by the total of force working the wheel. Therefore, the traction force is expressed by intergrating a shearing stress $\tau(\theta)$ and a normal stress $\sigma(\theta)$ is intergrated using contacted area of wheel and soil. Then, the traction force DP is written as follows using the wheel radius r and the wheel width b.

$$DP = rb \left\{ \int_{\theta_1}^{\theta_2} \tau(\theta) \cos\theta d\theta - \int_{\theta_1}^{\theta_2} \sigma(\theta) \sin\theta d\theta \right\} + L_j b \lambda \int_{\theta_1}^{\theta_2} R_b \cos\theta d\theta \qquad (5)$$

where,

L_j : $length\ \ of\ \ lugs$
R_b : $pressure\ \ given\ \ lugs$

G. Important Parameters for Traversability

The running mechanism can be described in Fig.3 from the interactional model between wheel and soil. On the slope, the wheel has traction load. When the wheel has traction load, the velocity for moving of the wheel decreases. To decrease the velocity of moving means that the wheel slips. Even if the wheel slips, the soil under the wheel make discharged by lug installed on surface of the wheel. To discharge the soil under the wheel means the wheel sinks into soil. The slope for running increases, when the wheel sinks into soil. To move on the steep slope leads to the increase of the traction load. By repeating this mechanism during running, the running condition becomes so bad on the slope. This paper believes that there are problems on bad running condition of the circular forms of wheels. The stress on the circular wheel is high. Therefore, the circular wheels are easy to sink into soil and stack. As a method to solve this problem, in generally, the following schemes are candidates. 1) To decrease the load of space robots. 2) To size up the diameter of wheel. Whereas those methods can decrease the stress of the circular wheel, the stress distribution of wheel can not change. The stess distribution of the circular wheel is not uniform. Therefore, even if the stess of wheel decreases, the sinkage behaior of wheel is not changed unless the load of wheel is light extremely. Moreover, robots which are light extremely are not reality for acting on the moon. This paper defines that important points are the low stress and the uniform stress distribution.

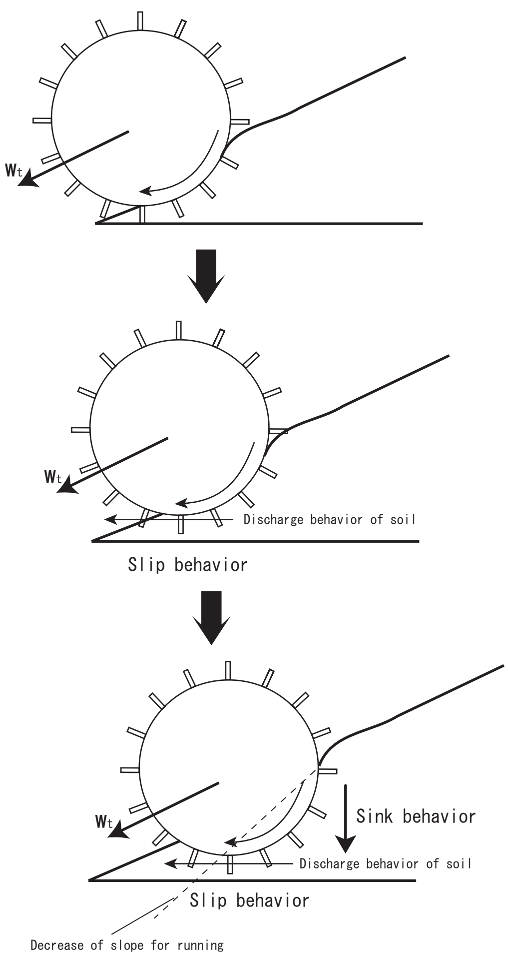

Fig. 3. Mechanism between Wheel and Soil on Slope

III. Consideration of Wheeled Forms

A. Wheel of Low Stress

The wheel of low stress exists the vehicles on the earth.

The vehicles[13][14] with the wheel of low stress on the earth are shown in Fig.4 and Fig.5. Those vehicles can move rough terrain or soft ground. The wheels of those vehicles have low stress and the low stress distribution. The traversibility of this low stress wheel is good, but this one can not use on the moon. It is important to select the material of wheels for use of the moon.

Fig. 4. Wheel for Agriculture [New Holland HFT Japan, Inc.]

Fig. 5. Vehicles with Low Stress on the earth[Mswing, Inc.]

B. Consideration of Wheel for lunar robots

This paper proposes a wheel for lunar robots. The wheel is shown in Fig.6. The proposed wheel has elastic metallic material. The material of the wheel is Copper Beryllium. Young's modulus and bending stress of Copper Beryllium are stronger than other elastic metallic materials. The diameter of the proposed wheel is 200[mm], the width is 100[mm]. In addition, the proposed wheel has the 10 lugs at 35[deg] interval. The wheel can extract effects of the low stress and low stress distributiion.

C. Hardening Effect by New Wheel

The stress distribution of the elastic wheel is shown in Fig.7. The stress distribution of the elastic wheel proposed by this paper is uniform. Uniform stress distribution can harden soil on wide area under the wheel. To harden soil on wide area means that the repulsion given to lugs from soil increases. As a result, the traversability of robots is high.

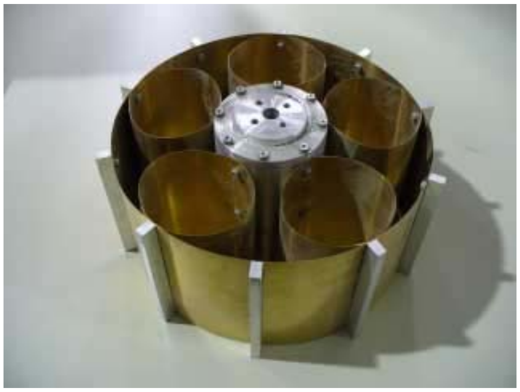

Fig. 6. Elastic Wheel made with Copper Beryllium

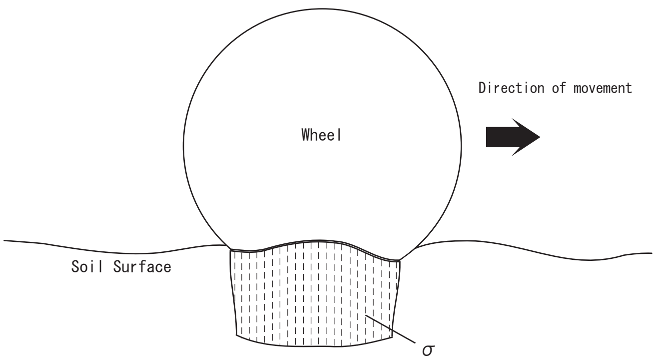

Fig. 7. Stress Distribution of Elastic Wheel

IV. EXPERIMENTS

A. Experimental System

The overview of the experimental system is shown in Fig.8. In this experiment, the simulant is used as soil, whose the particle specific gravity is 2.83, the minimum density is 1.39 [g/cm 3], the adhesive power is 5.0 [kPa] and the internal friction angle 36.7 [deg]. The depth of the simulant is 0.07 [m]. And the simulant is dry by the heater. The experimental system is composed of some mechanics and some sensors as shown in Fig.9. Here, one wheel, the parallel link, the stator, the guide rail, the load balance and the balance box are used. The parallel link is attached between the axis for the wheel and the load balance. The road balance runs on the guide rail. As sensors, there are differential transformer to measure the distance and two encoders. The differential trans-former measures the horizontal position of a wheel. The measurable distance of the differential transformer is within 20 [mm]. The vertical position of a wheel can be calculated by the rotary encoder. The velocity of the wheel is calculated by using vertical and horizontal position, and time. The rotation of wheel can be obtained from encoder. Therefore, the slip ratio is calculated using the velocity and the rotation. The sinkage is obtained from the present position and position of the original surface of the soil. Moreover, the wheel load can be set by some weight into the balance box.

Fig. 8. Overview of Experimental System

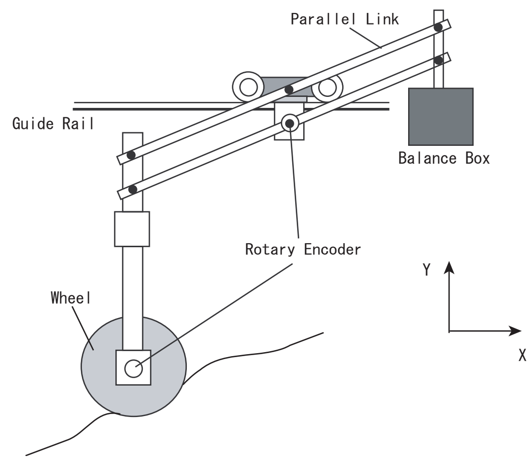

Fig. 9. Experimental Setup

1) Experimental Conditions: In the experiment, the wheel load, the speed of wheel and slope angle can be changed as parameters. Experimental parameters are shown in TABLE 1.

TABLE 1: Experimental Parameters

Load	2 [kg]
Speed	0.1 [m/s]
Slope	0, 5, 15, 20 [deg]

2) Measurement Item: The measurement items in this experiment are shown below. The initial shearing strength of soil is measured by the default of soil. Moreover, the shearing strength after running are measured for observing hardening effect.

- initial shearing strength of soil
- rotation angle of wheel
- wheel position

3) Wheels for Experiment: In the experiments, two kinds of wheels are used as below;

- Circular wheel
- Elastic wheel

B. Experimental Results

The running condition of the elastic wheel on slope is shown in Fig.10. The slope is 15 [deg]. In the case that circluar wheel runs on slope, the slipping phenomenon remarkably increases. However, the running condition of the elastic wheel is good. The elasic wheel is not easy to sink because of having the structure of low stress and wide hardening area. Therefore, the slipping phenomenon of the elastic wheel is not easy to increase. Moreover, the small sliping phenomene means that the sinkage of the wheel is small. If the sinkage of the wheel is small, the traction load hanging the wheel is small. The shearing stress is shown in Fig.11. The shearing stress were measured by the vane shearing tester. The shearing stress of both wheels after running became larger than before running. However, the rise of the shearing stress of the circular wheel was small. After hardening, the lugs of the circular wheel destroyed on hardened soil. On the other hands, the rise of shearing stress of the elastic wheel after running was larger than the circular wheel. Because of the hardened area is wide, the soil under the elastic wheel is not easy to destroy. Fig.12 and Fig.13 show the slip ratio and the sinkage of each wheel at 0 [deg]. The slip ratio and the sinkage of both wheels are small. Both wheels are good condition at 0[deg]. Fig.14 shows the slip ratio of each wheels at 20 [deg] slope. The slip ratio of the elastic wheel was smaller than the circular wheel. The effect of low stress and wide hardening area appeared. Moreover, on the results of slip raito of elastic wheel, there were constant lines. These lines show the constant condition without the rise of slip ratio. On these experiments, the elastic wheel proposed by this paper has 10 lugs. If the elastic wheel has more lugs, the traversability of this wheel will be increased. Fig.15 shows the sinkage of the of each wheels at 20 [deg] slope. The sinkage of the elastic wheel is smaller than the circular wheel. The elastic wheel was not easy to sink because of this one was low stress. The results of slip ratio are shown in Fig.16 on each slope. The slip ratio of the elastic wheel is smaller than the circular wheel about 0.1 on each slope. The elastic wheel has high performance compared with the cicular wheel. From these results, the wheels with low stress like the elastic wheel are effective for traversing on soften ground like regolith.

V. CONCLUSION

In this paper, wheeled forms of the lunar robots on slope were discussed. From the theoretical approach, the important parameters on traversability on the slope were extracted. The extracted parameters are "low stress" and "hardening effect". In this paper, the wheel with low stress using elastic material were developed for traversing lunar surface. From the experimental results, to combine these effects are effective for traversability.

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start

10[s]

20[s]

40[s]

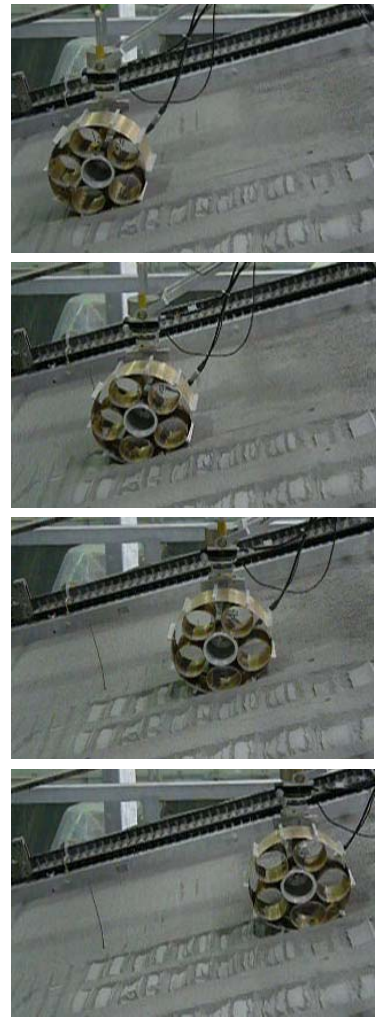

Fig. 10. Running View of Elastic Wheel (15[deg])

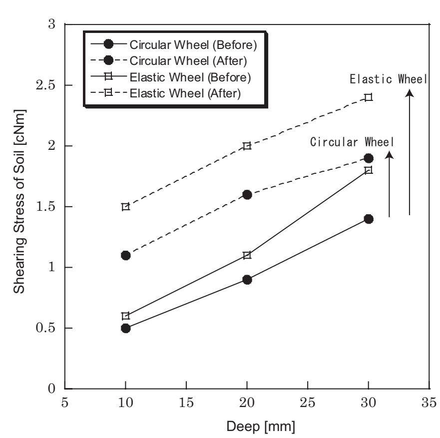

Fig. 11. Shearing Strength before and after running

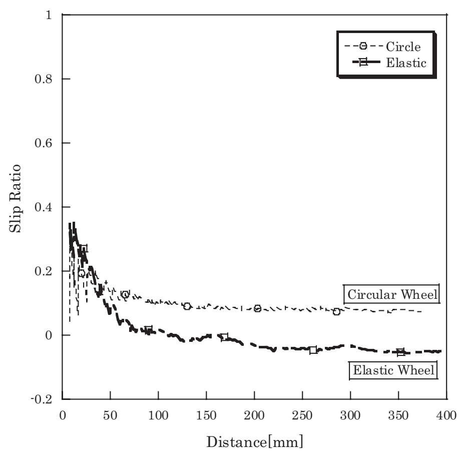

Fig. 12. Experimental Result:Slip Ratio(2[kg], 0[deg], 0.1[m/s])

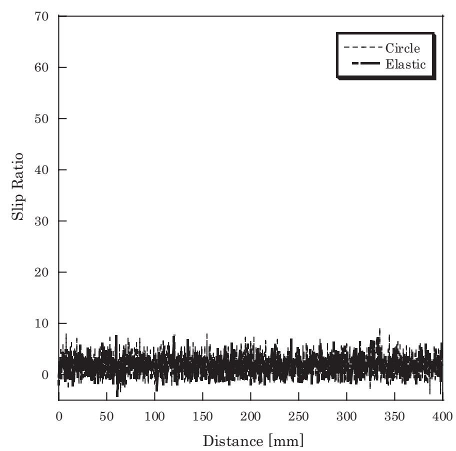

Fig. 13. Experimental Result:Sinkage(2[kg], 0[deg], 0.1[m/s])

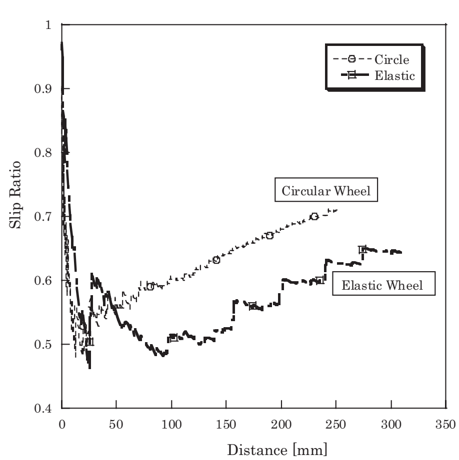

Fig. 14. Experimental Result:Slip Ratio(2[kg], 20[deg], 0.1[m/s])

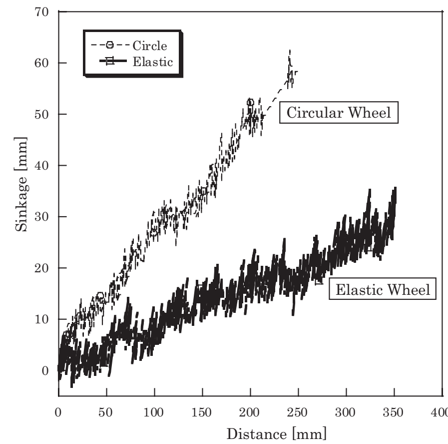

Fig. 15. Experimental Result:Sinkage(2[kg], 20[deg], 0.1[m/s])

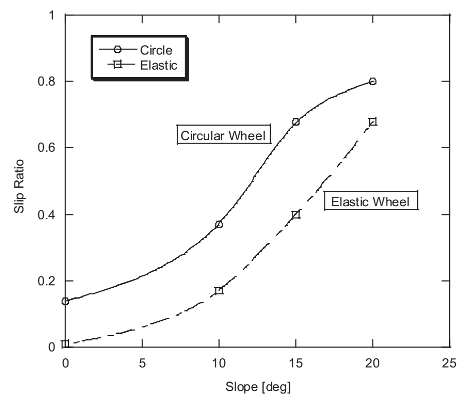

Fig. 16. Experimental Result(2[kg], 0.1[m/s])

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Appendix 1b

Study on Wheel of Exploration Robot on Sandy Terrain

by Kojiro Iizuka, Yoshinori Sato, Yoji Kuroda and Takashi Kubota

Study on Wheel of Exploration Robot on Sandy Terrain

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***Abstract*— In future planetary exploration missions, robots are required to traverse over very rough terrain. On the surface of the moon there are covered with soils, which is named regolith. Regolith is easy to slide. Any stack may occur to the robots that are running on the regolith. Some reseachers have studied the mobility system for robots. However the optimal and robust mobility systems have not been developed yet. For avoiding stack, this paper proposes a new wheel system, considering the characteristic of soil made a new wheel.**

I. Introduction

Robots are considered to be one of the most important mission devices for planetary explorations and will be expected to move on planetary surfaces to collect precise information regarding the origin and maturing. In the Mars mission by NASA in 1997, the micro robot Sojourner moved and explored on the surface of Mars. Sojourner sent the important data and detailed pictures to the earth.

The Sojourner mission showed the importance of moving exploration[1]. In planetary exploration, robots are required to move on rough terrains such as in craters and rear cliffs where it is scientifically very important to explore. Further, robots must avoid tip-over and stack even though they move on rough terrains. At past, in lunar missions, Lunokhod[Russian] and LRV[NASA] traveled long distance on regolith for explorations. These robots were so large and heavy (about 800[kg]). On soil, the movement of robots with heavy load is better. In future missions, however, heavy robots are not realistic because of the limit of payload, cost and capacity etc. Therefore, the future robots have to do downsizing. But small robots like Sojourner are difficult to move on soil because it is difficult to get effective impulse from soil. Therefore, this paper focuses on robots with the middle scale and middle load (a few 10[kg]) and constructs high performance for running on soil.

To investigate the running condition, it is needed to study the interaction between wheel and soil. However, the mechanism is not clear yet. Therefore, this paper investigates the kinematics behavior of lunar robots with tire-soil mechanism. Then two important parameters are extracted for running wheel on regolith. A new wheel form is designed by considering these parameters. Some experiments using the proposed wheel are performed to observe the traversability.

In section II, the interaction between wheel and soil is modeled on slope. Important parameters for running wheel are extracted from the model. Then, a new wheel form is designed in section III. Section IV shows the running experiments and results. Section V is for the conclusion of this paper.

II. Interaction between wheel and soil

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B. Wheeled Type on the Lunar Surface

When robots explore the surface of the moon, the environment is vacuum and is exposed to the space radiation. Moreover, the temperature difference between day and night is intense. In such an environment, tires which are generally used on the Earth can not be used. Therefore, the rigid wheels of metal are used for lunar robots.

C. Model of Interaction between Wheel and Soil

Some researchers have studied robots with interaction between wheel and soil on a flat terrain[4][6][9][10][11]. However they do not study the model on a slope. This paper cosiders the interaction model between wheel and soil on a slope as shown in Fig.1.

The line which the wheel runs on a flat is shown as "Flat Line". Z_f denotes the sinkage at a flat and Z_s denotes the sinkage at a slope. Z_f and Z_s mean the distance from the bottom line of the wheel. θ_0 indicates the vertical angle. θ_1 indicates the inserted angle into soil and θ_2 indicates the escaped angle.

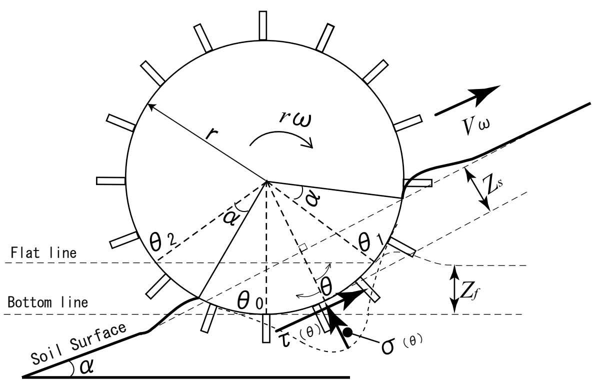

Fig. 1. Interaction Model between Wheel and Soil on Slope

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c	:	adhesive power
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where

r	:	the radius of a wheel
ω	:	angular velocity of a wheel
V_ω	:	moving speed of a wheel

The range of θ on the flat is from θ_1 to θ_2. However, the range of θ on the slope is from $(\theta_1+\alpha)$ to $(\theta_2-\alpha)$, because the angle of slope is α. Moreover, the sinkage Z_s can be written as follows.

$$Z_s = r(1 - \cos(\theta_1 + \alpha)) \tag{3}$$

The inserted angle on the slope is larger than the angle on the flat and the escape angle is small. If the angle of slope is bigger, the minus traction becomes large. Because the resistance of the movement increases by the angle of slop, and the supported force for wheel decreases by the small escaped angle.

E. Force Load on Wheel

A perpendicular force N can be expressed by intergrateing that a shearing stress $\tau(\theta)$ and a nomal stress $\sigma(\theta)$ using contacted area of wheel and soil. Then, a perpendicular force N is written as follows using the wheel radius r the and wheel width b.

$$N = rb\left\{\int_{\theta_1+\alpha}^{\theta_2-\alpha}\sigma(\theta)\cos\theta d\theta + \int_{\theta_1+\alpha}^{\theta_2-\alpha}\tau(\theta)\sin\theta d\theta\right\} \tag{4}$$

The traction force of wheel DP is expressed by the total of force working the wheel. Therefore, the traction force is expressed by intergrating a shearing stress $\tau(\theta)$ and a normal stress $\sigma(\theta)$ is intergrated using contacted area of wheel and soil. Then, the traction force DP is written as follows using the wheel radius r and the wheel width b.

$$DP = rb\left\{\int_{\theta_1+\alpha}^{\theta_2-\alpha}\tau(\theta)\cos\theta d\theta - \int_{\theta_1+\alpha}^{\theta_2-\alpha}\sigma(\theta)\sin\theta d\theta\right\} \tag{5}$$

However, a force of the range of $(\theta_1 - \alpha)$ - (θ_0) is the running resistence. The running resistence is written as follows.

$$R = rb\int_0^{\theta_1+\alpha}\sigma(\theta)\sin\theta d\theta \tag{6}$$

F. Important Parameters for Traversability

The traction force of wheel is expressed by the function of the slip ratio λ and the inserted angle θ_1, and the escaped angle θ_2. Since the inserted angle θ_1 and the escaped angle θ_2 can be expressed with the sinkage Z_s, and the traction DP is expressed by the function of the slip ratio λ, and the sinkage Z_s.

$$DP = f(\lambda, Z_s) \tag{7}$$

The slip ratio λ and the sinkage z are important for traversability of wheel. The slip ratio is determined by the shearing stress.

If the wheel becomes impossible to run on slope, when the interaction between wheel and soil becomes smaller than the opposite force worked by the gravity. Moreover, when the running condition is not good, the slip ratio increases. To increase the slip ratio means the shearing stress increases. However, the shearing behavior is necessary to get impellent of wheel. The important thing is the balance of "strength of soil and shearing stress". When the amount of soil moved by shearing stress becomes large, the sinkage increases. Further, the large sinkage means that the inserted angle increases. As the inserted angle grows, the running resistance becomes large. Then, the traction force of wheel is small. However, if the shearing stress does not increase, the slip ratio and the traction force can be kept constantly. It is necessary to increase the shearing stress of soil so that the shearing stress should not increase. Moreover, the shearing strength of soil can increase with " hardening effect ". Hardening effect is occurred by wheel load. Therefore, this paper considers the wheel forms using " hardening effect " and " shearing effect ".

III. Consideration of Wheeled Forms

A. Hardening Effect

When the soil under the wheel is pressured by a load of the wheel, the density of soil increases. As a result, the hardening effect is caused by a load of wheel. To understand the distribution of the normal stress needs to harden the soil effectively. The method to harden the soil effectively is to increase the area contacting with the soil. Therefore, this paper proposes a pentagon typed wheel(Fig.2). The pentagon typed has the flat surface. The distribution of the normal stress is stabilized by the flat surface. The reason why the type of pentagon was selected is bellow.

1) A surface of pentagon is larger than a surface of polygon over pentagon.
2) An angle of the pentagon forms is larger than an angle of polygon below pentagon.

The distribution of the normal stress is stabilized by large surface. Moreover, if the angle of polygon is large, the soil is not easy to destroy. The type of pentagon is selected by balance of these points. In case of pentagon typed wheel, the distribution of the normal stress σ can be shown in the following expression[12].

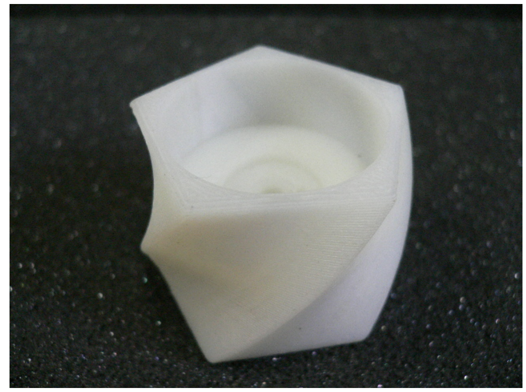

Fig. 2. Picture of Pentagon typed Wheel

$$\sigma = \frac{q}{\pi}(2\epsilon + \sin\epsilon) \tag{8}$$

where

Load of wheel	:	q
Parameter for stress	:	ϵ

The distribution of the normal stress is shown in Fig.3. The pentagon typed wheel effectively causes the hardening effect.

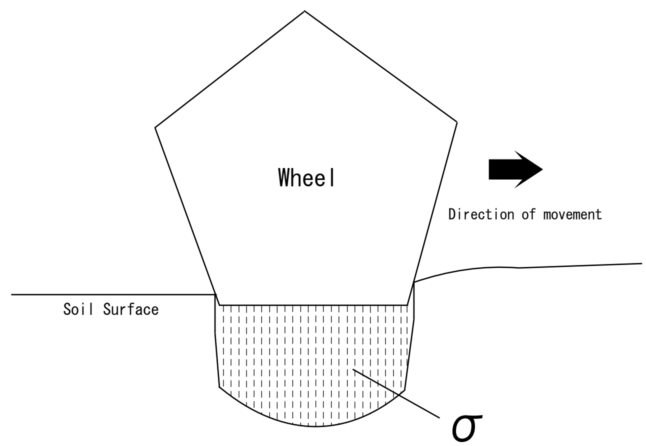

Fig. 3. Ditribution of Normal Stress promoted by Pentagon typed Wheel

B. Shearing Effect

The wheel with lugs is shown in Fig.4 as a form using the effect of the shearing stress. At the rotation of wheel, the lugs push soil. To push soil can generate impellent for travel of the wheel. Figure 5 shows the condition of lug into soil. When lugs run into soil, the movement of soil occurs. Soil is destroyed over shearing strength of soil. At this time, lugs are given the reaction force from soil. And the reaction force becomes impellent for wheel. However, the movement of soil means the destruction of soil. Soil is cultivated by lugs. Therefore, the shearing strength of soil decreases, and the reaction force from soil decreases gradually. Therefore, the wheel slips more and more so that this behavior is repeated.

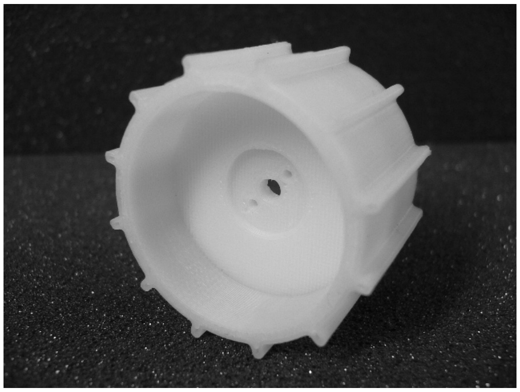

Fig. 4. Normal Wheel with Lugs

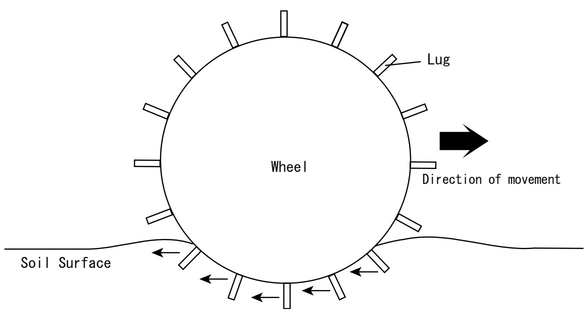

Fig. 5. Effect of Shearing Stress

C. *Combined Effect of Hardening and Shearing*

The new type of wheel which can combine the effect of hardening and shearing is shown in Fig.6. The soil is softened by the rotations of wheel. On the soft soil, the wheel cannot obtain enough impellent. Therefore, this paper proposes a new wheel which combines the hardening effect and the shearing effect. The combined wheel has the structure, which is added lugs on the surface of the pentagon typed wheel. Here, the two typed combined wheels are developed. One has 16 lugs. The other has 4 lugs. The combined wheel with 16 lugs is installed like the normal wheel with lugs. And, on the combined wheel with 4 lugs, the shearing force is demonstrated after the wheel hardens the soil. The mechanism of the combined wheel is shown in Fig.7. The soil is hardened by the wheel load. Then, the lugs push the hardened soil. Therefore, the reaction force is effectively translated to lugs.

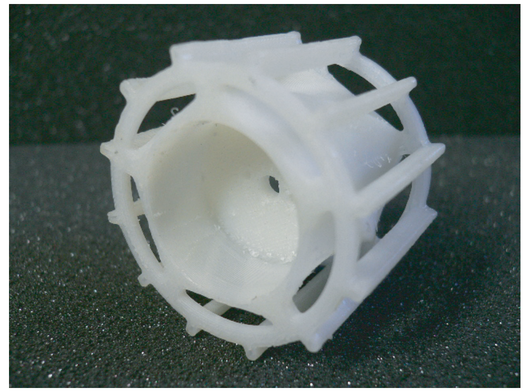

Fig. 6. Picture of Combined Wheel

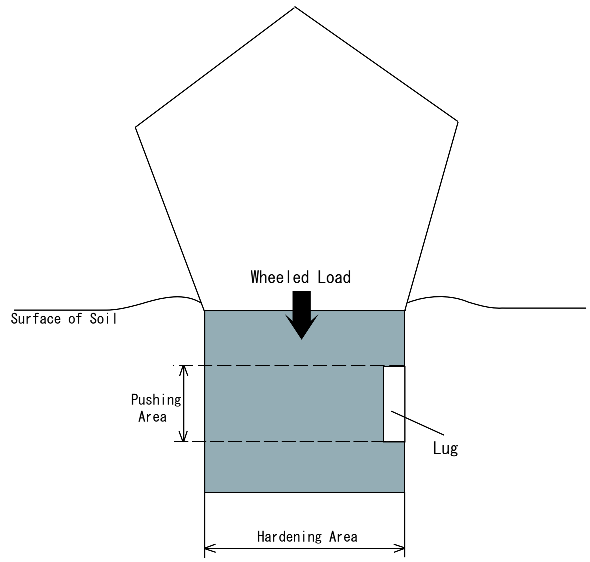

Fig. 7. Model of Combained Wheel

IV. Experiments

A. *Experimental System*

The overview of the experimental system is shown in Fig.8. In this experiment, the simulant is used as soil, whose the particle specific gravity is 2.83, the minimum density is 1.39 [g/cm 3], the adhesive power is 5.0 [kPa] and the internal friction angle 36.7 [deg]. The depth of the simulant is 0.07 [m]. And the simulant is dry by the heater. The experimental system is composed of some mechanics and some sensors as shown in Fig.9. Here, one wheel, the parallel link, the stator, the guide rail, the load balance and the balance box are used. The parallel link is attached between the axis for the wheel and the load balance. The road balance runs on the guide rail. As sensors, there are differential transformer to measure the distance and two encoders. The differential trans-former measures the horizontal position of a wheel. The measurable distance of the differential trans-former is within 20 [mm]. The vertical position of a wheel can be calculated by the rotary encoder. The velocity of the wheel is calculated by using vertical and horizontal position, and time. The rotation of wheel can be obtained from encoder. Therefore, the slip ratio is calculated using the velocity and the rotation. The sinkage is obtained from the present position and position of the original surface of the soil. Moreover, the wheel load can

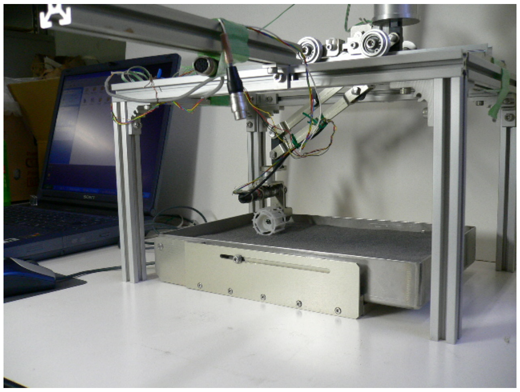

Fig. 8. Overview of Experimental System

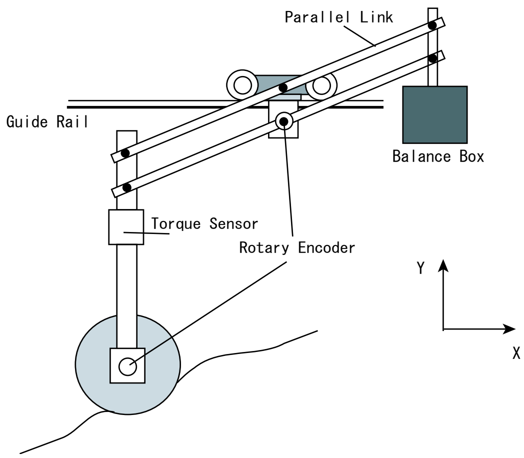

Fig. 9. Experimental Setup

be set by some weight into the balance box.

1) Experimental Conditions: In the experiment, the wheel load, the speed of wheel and slope angle can be changed as parameters. Experimental parameters are shown in TABLE 1.

TABLE 1: Experimental Parameter

Load	23, 32 [g]
Speed	0.01, 0.04 [m/s]
Slope	0, 10, 15 [deg]

2) Measurement Item: The measurement items in this experiment are shown below. The initial shearing strength of soil is measured by the default of soil. Moreover, the shearing strength after running are measured for observing hardening effect.

- initial shearing strength of soil
- rotation angle of wheel
- wheel position

3) Wheels for Experiment: In the experiments, four kinds of wheels are used as below;

- Normal wheel with lugs (Normal)
- Pentagon typed wheel (Pentagon)
- Combined wheel with 16 lugs (Combined A)
- Combined wheel with 4 lugs (Combined B)

Fig. 10. The Track of Pentagon typed Wheel

B. Experimental Results

The track of pentagon typed wheel is shown in Fig.10. The destruction of soil has not occurred after running. On each wheel, the shearing strength before and after running were measured by the vane shearing tester (TABLE 2). On the normal wheel with lugs, the shearing strength decreased after running. On other wheels, the shearing strength after running was stronger than before running. This phenomenon means that the hardening effect was occurred by the surface of the pentagon typed wheel.

Figure 11 shows the slip ratio at 0 [deg] and 40[mm/s]. The slip ratio of all wheels is steady tendency. The slip ratio of the pentagon typed wheel is higher than the other wheels. The surface of the pentagon typed wheel is the surface like parabolic. However, the wheel without lugs cannot obtain the large impellent. The impellent of twist wheel is only the friction force. Therefore, the slip ratio of the pentagon typed wheel is larger than the other wheels.

At 15 [deg] slope, the slip ratio is shown in Fig.12. The slip ratio of the pentagon typed wheel and the normal wheel with lugs have up tendency. Moreover, the slip ratio of the combined wheels have steady tendency. Since the results, the traversability of wheel cannot get effective impellent by only hardening effect of soil. However, the traversability of wheel can be improved by combining the effect of hardening and shearing.

TABLE 2: The Shearing Strength of Soil

Kind of wheel	Before Running	After Running	Tendency
Normal	0.43[cNm]	0.30[cNm]	↘
Pentagon	0.40[cNm]	0.53[cNm]	↗
Combined A	0.43[cNm]	0.47[cNm]	↗
Combined B	0.43[cNm]	0.50[cNm]	↗

V. Conclusion

In this paper, wheeled forms of the lunar robot on slope soil were discussed. From the theoretical approach, this paper extracted the important parameters. These parameters are ”hardening effect” and ”shearing effect”. From the experimental results, to combine these effects are effective for traversability.

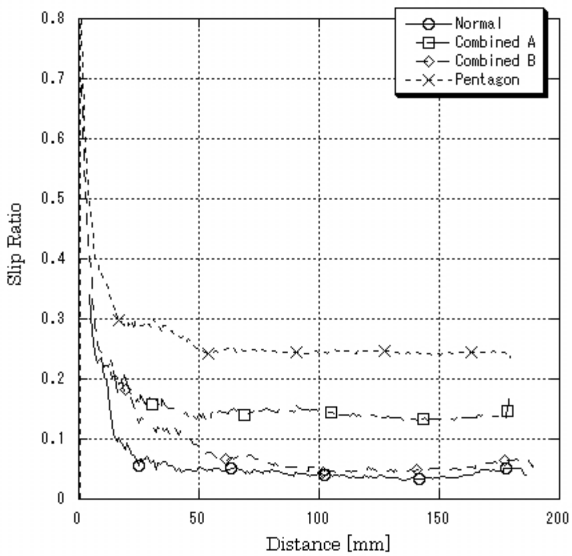

Fig. 11. Experimental Result (5[kg], 10[mm/s], 0[deg])

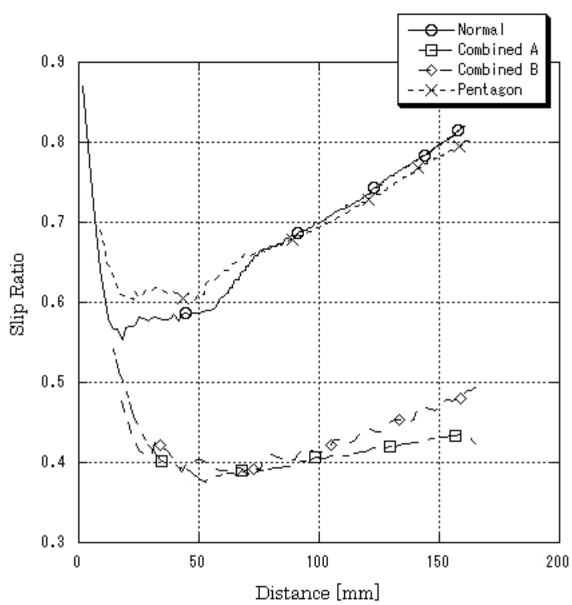

Fig. 12. Experimental Result (5[kg], 40[mm/s], 15[deg])

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Appendix 2

Extract of the Hyperion product catalogue

Spring Catalog 2007

Hyperion VX LiPo packs

The Hyperion VX lipos is the Blue Series. VX stands for 'Voltage Xtreme' and that is exactly what we are talking about here.

To many modellers, the lipo market is a jungle. What factory makes the same cells as this or that brand of packs, why are some packs so cheap etc. Here are a few of the typical questions we hear:

''Will I really ever need all the power of high quality lipo packs such as the Hyperion VX?''

It can be answered quickly, if you will excuse this simple analogy: Two cars can both travel at a 100 km/h at a straight road. The question is what happens when you want to go over a mountain? A good, powerful car would continue to drive 100 km/h even uphill. A less powerful car would loose speed and before you know it, you are going 60 km/h with the gas pedal all pressed down.

Which car would you rather be driving?

''Other brands of lipos claim 25C continous discharge - are the Hyperion packs inferior to those packs?''

The VX packs from Hyperion are the newest and best battery chemistry available on the planet Earth today. They ARE capable of 25C discharge with high retained capacity. However, running ANY battery at it's maximum possible discharge rate involves a shortened life in battery cycles. As such, Hyperion feels that such ratings are irresponsible, because many users will not notice the ''fine print'' cautions on the websites of other makers.

However, we do have users that use our VX-packs way beyond 20 or 25C. We have feedback from competition pilots that they are getting bursts of over 50C discharges in F5B models. Their use consists of very short runs of motor time, a pause, then another run, etc. While such use is not recommended nor covered by warranty, if you are a competition pilot it is really good to know that a lipo pack capable of over 270Amps weighing just 400gr exists.

Product number	*Product*	*MSRP (EUR)*
HP-LVX0300-2S	**Hyperion VX - 2S 300mAh, 6.0A Continuous (20-30C)** *Weight: 20gr, Size: 23.5 x 51 x 10 mm, No balance connector*	***19,30***
HP-LVX0300-3S	**Hyperion VX - 3S 300mAh, 6.0A Continuous (20-30C)** *Weight: 29gr, Size: 23.5 x 51 x 14 mm, No balance connector*	***25,73***
HP-LVX0400-2S	**Hyperion VX - 2S 400mAh, 8.0A Continuous (20-30C)** *Weight: 27.0gr, Size: 36.5 x 65 x 8 mm*	***23,16***
HP-LVX0400-3S	**Hyperion VX - 3S 400mAh, 8.0A Continuous (20-30C)** *Weight: 40.0gr, Size: 37.5 x 65 x 12 mm*	***27,02***
HP-LVX0800-2S	**Hyperion VX - 2S 800mAh, 16.0A Continuous (20-30C)** *Weight: 47.0gr, Size: 36 x 65 x 10 mm*	***26,53***
HP-LVX0800-3S	**Hyperion VX - 3S 800mAh, 16.0A Continuous (20-30C)** *Weight: 62.0gr, Size: 36 x 65 x 14 mm*	***38,27***
HP-LVX1200-2S	**Hyperion VX - 2S 1200mAh, 24.0A Continuous (20-30C)** *Weight: 67gr, Size: 30.5 x 100 x 11 mm*	***28,46***
HP-LVX1200-3S	**Hyperion VX - 3S 1200mAh, 24.0A Continuous (20-30C)** *Weight: 99gr, Size: 30.5 x 100 x 16 mm*	***41,33***
HP-LVX1500-2S	**Hyperion VX - 2S 1500mAh, 30.0A Continuous (20-30C)** *Weight: 80gr, Size: 31 x 100 x 13.5 mm*	***34,57***
HP-LVX1500-3S	**Hyperion VX - 3S 1500mAh, 30.0A Continuous (20-30C)** *Weight: 118gr, Size: 31 x 100 x 20 mm*	***50,98***
HP-LVX1800-2S	**Hyperion VX - 2S 1800mAh, 36.0A Continuous (20-30C)** *Weight: 91gr, Size: 31 x 100 x 15 mm*	***41,33***
HP-LVX1800-3S	**Hyperion VX - 3S 1800mAh, 36.0A Continuous (20-30C)** *Weight: 136gr, Size: 33 x 100 x 23 mm*	***59,66***
HP-LVX1800-4S	**Hyperion VX - 4S 1800mAh, 36.0A Continuous (20-30C)** *Weight: 176gr, Size: 33 x 100 x 30 mm*	***77,03***
HP-LVX2000-2S	**Hyperion VX - 2S 2000mAh, 40.0A Continuous (20-30C)** *Weight: 107gr, Size: 31 x 109 x 15 mm*	***48,08***
HP-LVX2000-3S	**Hyperion VX - 3S 2000mAh, 40.0A Continuous (20-30C)** *Weight: 161gr, Size: 31 x 109 x 27 mm*	***70,27***
HP-LVX2000-4S	**Hyperion VX - 4S 2000mAh, 40.0A Continuous (20-30C)** *Weight: 200gr, Size: 31 x 109 x 29 mm*	***93,59***

Hyperion VX LiPo packs (continued)

Product number	Product	MSRP (EUR)
HP-LVX2100-2S	**Hyperion VX - 2S 2100mAh, 42.0A Continuous (20-30C)** *Weight: 118gr, Size: 39 x 121 x 12 mm*	***51,94***
HP-LVX2100-4S	**Hyperion VX - 4S 2100mAh, 42.0A Continuous (20-30C)** *Weight: 222gr, Size: 40 x 121 x 24 mm*	***100,19***
HP-LVX2200-2S	**Hyperion VX - 2S 2200mAh, 44.0A Continuous (20-30C)** *Weight: 117gr, Size: 34 x 108 x 17 mm*	***52,10***
HP-LVX2200-3S	**Hyperion VX - 3S 2200mAh, 44.0A Continuous (20-30C)** *Weight: 173gr, Size: 34 x 108 x 24.5 mm*	***77,03***
HP-LVX2200-4S	**Hyperion VX - 4S 2200mAh, 44.0A Continuous (20-30C)** *Weight: 221gr, Size: 34 x 108 x 33 mm*	***103,24***
HP-LVX2500-2S	**Hyperion VX - 2S 2500mAh, 50.0A Continuous (20-30C)** *Weight: 136gr, Size: 39.5 x 121 x 13 mm*	***66,41***
HP-LVX2500-3S	**Hyperion VX - 3S 2500mAh, 50.0A Continuous (20-30C)** *Weight: 203gr, Size: 40 x 121 x 20 mm*	***96,33***
HP-LVX2500-4S	**Hyperion VX - 4S 2500mAh, 50.0A Continuous (20-30C)** *Weight: 258gr, Size: 40 x 121 x 27 mm*	***128,49***
HP-LVX2500-5S	**Hyperion VX - 5S 2500mAh, 50.0A Continuous (20-30C)** *Weight: 320gr, Size: 40 x 121 x 34 mm*	***159,04***
HP-LVX3300-2S	**Hyperion VX - 2S 3300mAh, 66.0A Continuous (20-30C)** *Weight: 175gr, Size: 46 x 142 x 13 mm*	***77,03***
HP-LVX3300-3S	**Hyperion VX - 3S 3300mAh, 66.0A Continuous (20-30C)** *Weight: 260gr, Size: 46 x 142 x 20 mm*	***114,66***
HP-LVX3300-4S	**Hyperion VX - 4S 3300mAh, 66.0A Continuous (20-30C)** *Weight: 335gr, Size: 46 x 142 x 26 mm*	***153,25***
HP-LVX3300-5S	**Hyperion VX - 5S 3300mAh, 66.0A Continuous (20-30C)** *Weight: 420gr, Size: 46 x 142 x 32 mm*	***191,85***
HP-LVX3700-2S	**Hyperion VX - 2S 3700mAh, 74.0A Continuous (20-30C)** *Weight: 192gr, Size: 46 x 142 x 15 mm*	***82,82***
HP-LVX3700-3S	**Hyperion VX - 3S 3700mAh, 74.0A Continuous (20-30C)** *Weight: 287gr, Size: 46 x 142 x 21.5 mm*	***122,38***
HP-LVX3700-4S	**Hyperion VX - 4S 3700mAh, 74.0A Continuous (20-30C)** *Weight: 368gr, Size: 46 x 142 x 28 mm*	***161,94***
HP-LVX3700-5S	**Hyperion VX - 5S 3700mAh, 74.0A Continuous (20-30C)** *Weight: 460gr, Size: 46 x 142 x 34.5 mm*	***200,53***
HP-LVX4350-2S	**Hyperion VX - 2S 4350mAh, 87.0A Continuous (20-30C)** *Weight: 235gr, Size: 44 x 160 x 16 mm*	***93,75***
HP-LVX4350-3S	**Hyperion VX - 3S 4350mAh, 87.0A Continuous (20-30C)** *Weight: 349gr, Size: 47 x 160 x 23 mm*	***141,19***
HP-LVX4350-4S	**Hyperion VX - 4S 4350mAh, 87.0A Continuous (20-30C)** *Weight: 440gr, Size: 44 x 160 x 31 mm*	***186,70***
HP-LVX4350-5S	**Hyperion VX - 5S 4350mAh, 87.0A Continuous (20-30C)** *Weight: 557gr, Size: 47 x 160 x 39 mm*	***238,16***
HP-LVX4350-6S	**Hyperion VX - 6S 4350mAh, 87.0A Continuous (20-30C)** *Weight: 652gr, Size: 44 x 160 x 46 mm*	***287,37***
HP-LVX5000-2S	**Hyperion VX - 2S 5000mAh, 100.0A Continuous (20-30C)** *Weight: 268gr, Size: 44 x 160 x 18.5 mm*	***121,73***
HP-LVX5000-3S	**Hyperion VX - 3S 5000mAh, 100.0A Continuous (20-30C)** *Weight: 400gr, Size: 47 x 160 x 27 mm*	***182,68***
HP-LVX5000-4S	**Hyperion VX - 4S 5000mAh, 100.0A Continuous (20-30C)** *Weight: 511gr, Size: 44 x 160 x 36.5 mm*	***243,79***
HP-LVX5000-5S	**Hyperion VX - 5S 5000mAh, 100.0A Continuous (20-30C)** *Weight: 642gr, Size: 47 x 160 x 45 mm*	***304,74***
HP-LVX5000-6S	**Hyperion VX - 6S 5000mAh, 100.0A Continuous (20-30C)** *Weight: 755gr, Size: 44 x 160 x 53.5 mm*	***363,59***

Hyperion CL LiPo packs

The Hyperion CL lipo packs is the red series. The CL-series offers CAPACITY and LIGHT lipo packs.

The CL-series is 'C-rated' slightly lower than the VX-series. The CL-series takes aim at the sports pilot who wants long flight times, long battery life and low weight. Hyperion recommends a 16-22C load with the exception of the incredible new 350mAh packs and 950mAh packs in this line.

Both of these new smaller packs are still comparably very light, but yet so advanced that they are capable of up to 25C discharge, taking indoor flying to new levels of power-to-weight ratios. The CL-350mAh 2S packs are awesome in their performance.

Each pack (like the VX-series) offer a multi-connector that allows tapping into each cell individually to check cell voltage and re-balance when necessary, and supports the Hyperion LBA10 Cell Balance Adapter. Note that Hyperion packs may be charged via the main wires like any other lithium pack, but that the multi-connector also gives you additional diagnostic and charge safety options.

All CL Series packs come with high-quality, flexible silicone cabling sized appropriately for expected current draw, and foam end caps to reduce chances of impact damage.

Product number	*Product*	*MSRP (EUR)*
HP-LCL0350-2S	**Hyperion CL - 2S 350mAh, 9.1A Continuous (26C)** *Weight: 25.6gr, Size: 34 x 60 x 7 mm*	***24,76***
HP-LCL0350-3S	**Hyperion CL - 3S 350mAh, 9.1A Continuous (26C)** *Weight: 36.9gr, Size: 34 x 60 x 10.3 mm*	***34,90***
HP-LCL0950-2S	**Hyperion CL - 2S 950mAh, 24.7A Continuous (26C)** *Weight: 62.2gr, Size: 33 x 75 x 12 mm*	***33,77***
HP-LCL0950-3S	**Hyperion CL - 3S 950mAh, 24.7A Continuous (26C)** *Weight: 90.0gr, Size: 33 x 75 x 19 mm*	***48,40***
HP-LCL2100-2S	**Hyperion CL - 2S 2100mAh, 33.6A Continuous (16-22C)** *Weight: 102gr, Size: 34 x 102 x 12 mm*	***44,06***
HP-LCL2100-3S	**Hyperion CL - 3S 2100mAh, 33.6A Continuous (16-22C)** *Weight: 149gr, Size: 34 x 102 x 19 mm*	***65,45***
HP-LCL2100-4S	**Hyperion CL - 4S 2100mAh, 33.6A Continuous (16-22C)** *Weight: 205gr, Size: 34 x 102 x 26 mm*	***78,96***
HP-LCL2500-2S	**Hyperion CL - 2S 2500mAh, 50.0A Continuous (16-22C)** *Weight: 142gr, Size: 44 x 145 x 11 mm*	***57,09***
HP-LCL2500-3S	**Hyperion CL - 3S 2500mAh, 50.0A Continuous (16-22C)** *Weight: 207gr, Size: 44 x 145 x 16 mm*	***84,43***
HP-LCL2500-4S	**Hyperion CL - 4S 2500mAh, 50.0A Continuous (16-22C)** *Weight: 271gr, Size: 44 x 145 x 22 mm*	***109,99***
HP-LCL2500-5S	**Hyperion CL - 5S 2500mAh, 50.0A Continuous (16-22C)** *Weight: 335gr, Size: 44 x 145 x 27 mm*	***137,33***
HP-LCL2500-6S	**Hyperion CL - 6S 2500mAh, 50.0A Continuous (16-22C)** *Weight: 401gr, Size: 44 x 145 x 33 mm*	***165,96***
HP-LCL3200-2S	**Hyperion CL - 2S 3200mAh, 64.0A Continuous (16-22C)** *Weight: 177gr, Size: 44 x 145 x 14 mm*	***72,36***
HP-LCL3200-3S	**Hyperion CL - 3S 3200mAh, 64.0A Continuous (16-22C)** *Weight: 260gr, Size: 44 x 145 x 21 mm*	***106,14***
HP-LCL3200-4S	**Hyperion CL - 4S 3200mAh, 64.0A Continuous (16-22C)** *Weight: 341gr, Size: 44 x 145 x 27 mm*	***138,94***
HP-LCL3200-5S	**Hyperion CL - 5S 3200mAh, 64.0A Continuous (16-22C)** *Weight: 425gr, Size: 44 x 145 x 34 mm*	***173,51***
HP-LCL3200-6S	**Hyperion CL - 6S 3200mAh, 64.0A Continuous (16-22C)** *Weight: 515gr, Size: 44 x 145 x 41 mm*	***208,41***
HP-LCL4000-2S	**Hyperion CL - 2S 4000mAh, 64.0A Continuous (16-22C)** *Weight: 225gr, Size: 42 x 143 x 17 mm*	***86,84***
HP-LCL4000-3S	**Hyperion CL - 3S 4000mAh, 80.0A Continuous (20C)** *Weight: 328gr, Size: 42 x 143 x 25 mm*	***129,29***
HP-LCL4000-4S	**Hyperion CL - 4S 4000mAh, 80.0A Continuous (20C)** *Weight: 436gr, Size: 42 x 148 x 33 mm*	***169,82***

Hyperion CL LiPo packs (continued)

Product number	Product	MSRP (EUR)
HP-LCL4000-5S	**Hyperion CL - 5S 4000mAh, 80.0A Continuous (20C)** *Weight: 542gr, Size: 42 x 148 x 42 mm*	***212,27***
HP-LCL4000-6S	**Hyperion CL - 6S 4000mAh, 80.0A Continuous (20C)** *Weight: 642gr, Size: 42 x 148 x 50 mm*	***255,69***
HP-LCL4200-3S	**Hyperion CL - 3S 4200mAh, 67.2A Continuous, (2100-2P 16-22C)** *Weight: 294gr, Size: 34 x 102 x 40 mm*	***119,48***
HP-LCL4200-4S	**Hyperion CL - 4S 4200mAh, 67.2A Continuous, (2100-2P 16-22C)** *Weight: 384gr, Size: 34 x 102 x 51 mm*	***157,11***
HP-LCL4200-5S	**Hyperion CL - 5S 4200mAh, 67.2A Continuous, (2100-2P 16x22C)** *Weight: 475gr, Size: 34 x 102 x 67 mm*	***192,65***
HP-LCL4800-2S	**Hyperion CL - 2S 4800mAh, 96.0A Continuous (20C)** *Weight: 264gr, Size: 44 x 147 x 20 mm*	***100,35***
HP-LCL4800-3S	**Hyperion CL - 3S 4800mAh, 96.0A Continuous (20C)** *Weight: 388gr, Size: 44 x 147 x 30 mm*	***150,52***
HP-LCL4800-4S	**Hyperion CL - 4S 4800mAh, 96.0A Continuous (20C)** *Weight: 515gr, Size: 44 x 150 x 40 mm*	***196,83***
HP-LCL4800-5S	**Hyperion CL - 5S 4800mAh, 96.0A Continuous (20C)** *Weight: 636gr, Size: 44 x 150 x 50 mm*	***247,01***
HP-LCL4800-6S	**Hyperion CL - 6S 4800mAh, 96.0A Continuous (20C)** *Weight: 755gr, Size: 44 x 150 x 60 mm*	***297,18***

Spring Catalog 2007

NEW - Hyperion EOS 1210i 12S CHARGER, with Terminal Capacity Selection and Speed 2C Rate

Highlights:	*MSRP:*
• *Dimensions: 6cm tall x 15.5cm front/back x 14.5cm wide* • *Weight: 640gr* • *Lipos: 2 - 12S*	***154,38*** *Product number:* **HP-EOS1210i** Price in EUR including 19% VAT

The EOS 1210i is an extremely powerful (180W, 10A max), versatile, easy-to-use charger with special features for speed charging lithium packs up to 12S! 2C rates are possible - in addition to Terminal Capacity Selection - allowing you to charge and fly lithium polymer packs* in as little as 27 minutes. NiCd and NiMH packs of up to 30 cells, and lead-acid batteries to 12V are also supported. Output Charge Cord/Connector set included ($3.50 value)

Monitor the individual cell voltages on the LCD screen of EOS1210i while you balance your lithium packs with LBA 10 and optional cable #HP-EOSLBA10-DPC. Network two LBA 10 together with NET Adapter pack #HP-EOSLBA10-MSC, and you can charge two packs of same cell type and capacity (such as 6S and 6S) at the same time, and every cell in both packs will be balanced to the other when charging is done, for packs from 7S to 12S!

HP-EOS1210I-SEN is the Temperature sensor for EOS1210i. It plugs into a dedicated port and allows you to specify a pack termperature at which charging will be stopped, and/or monitor pack temp during the charge.

Hyperion EOS 5i Speed 5S / 14N charger - with dataport

Highlights:

- *Versatile and easy to use*
- *Connectivity with LBA10 balancer*

Special price:

49,00

Regular price:

~~(64,16)~~

Product number:

HP-EOS5i-DP

Price in EUR including 19% VAT

This price is only available while stock lasts.

NEW! Hyperion EOS 5i DP - Speed 5S14N CHARGER with DataPort for LBA10

The EOS 5i DP [SPEED 5S14N] is a versatile, easy-to-use charger with special features for fast charging, discharging and cycling NiCd and NiMH packs of up to 14 cells, Lithium packs to 5S, and lead-acid batteries to 12V.

New Function! You can monitor the individual cell voltages on the LCD screen of EOS5iDP while you balance your lithium packs with LBA 10, using optional cable HP-EOSLBA10-DPC

NEW - Hyperion EOS 5i DP 12V / 220V input CHARGER, with DataPort for LBA10

Highlights:

- *Very versatile charger for both 220V and 12V*
- *Identical in features with Hyperion EOS5i-DP*

MSRP:

90,05

Product number:

HP-EOS5i-DP-AD

Price in EUR including 19% VAT

The EOS 5i DP AC/DC is a versatile, easy-to-use charger with special features for fast charging, discharging and cycling NiCd and NiMH packs of up to 14 cells, Lithium packs to 5S, and lead-acid batteries to 12V.

Of course, the AC/DC part means that you can charge directly from AC wall supply while at home or from a 12V DC battery while at the field.

Spring Catalog 2007

EOS LBA10 Balance Charge Adapter 2S~6S 10A Max

Highlights:

- *New balance unit from Hyperion*
- *Charge with 10A*
- *Network 2 LBA10 for 12S balancing*

MSRP:

36,99

Product number:

HP-EOSLBA10

Price in EUR including 19% VAT

New Hyperion EOS LBA10A Net - The Most Powerful, Versatile Balance-Safety Adapter for Lithium Packs. Max 6S, 10A rating - Network 2 units for 7S~12S balancing.

The Hyperion EOS Lithium Balance Adapter 10 (LBA10) is the newest, most feature-packed and reliable lithium balancer on the market today, and comes at a bargain price. Simply put, it is the most powerful, versatile, and safest way to charge your lithium packs today. A single LBA10 provides three ways to balance your lithium packs from 2S to 6S, at a maximum of up to 10-ampere rate!

Or, you can network two LBA 10 together with NET cable and adapter pack #HP-EOSLBA10-MSC. Set one LBA10 to Master and one to Slave mode. Series the LBA input leads together, and connect to a charger with appropriate S rating. Now you can charge two packs of same cell type and capacity (such as 6S and 6S) at the same time, and every cell in both packs will be balanced to the other when charging is done. Connect the packs in series and fly, with balanced packs from 7S to 12S in this way!

Or, say you have two 5S chargers, and want to charge two 5S packs to connect and fly as 10S. Use each LBA10 in Master mode, and connect each to a separate charger and battery. When charging is finished, Connect the two LBA10 together in Master-Slave configuration, and connect them to the just-charged lithium packs. The LBA10 will work together until every cell in the two packs are balanced together, then automatically shut down. Takes only a few minutes. Now series the packs together and fly in peace!

Each LBA 10 comes with balance harnesses for 2S and 3S packs. For 4S to 6S packs, get the appropriate optional harnesses from these part numbers:

HP-EOSLBA10-MC-H4SHP-EOSLBA10-MC-H5SHP-EOSLBA10-MC-H6S

The LBA 10 also has a DataPort (use optional cable HP-EOSLBA10-DPC) which will allow you to monitor the individual cell voltages while you balance, using the LCD screen of any HYPERION charger which has DataPort option. (DP Chargers available on about Oct1, 2006)

Connection wires for EOS-LBA10 Lipo balancer

Product number	*Product*	*MSRP (EUR)*
HP-EOSLBA10-DPC	**LBA10 Balancer DataPort Cable**	***3,54***
HP-EOSLBA10-MSC	**LBA10 NET Cable/Adapter Set**	***5,15***
HP-EOSLBA-MC-P4	**MALE PACK SIDE for 2S~4S**	***2,57***
HP-EOSLBA-MC-P5	**MALE PACK SIDE for 5S**	***2,57***
HP-EOSLBA10-MC-H2S	**LBA 10 Balance Harness 2S, Std**	***2,89***
HP-EOSLBA10-MC-H3S	**LBA 10 Balance Harness 3S, Std.**	***3,38***
HP-EOSLBA10-MC-H4S	**LBA 10 Balance Harness 4S, Std.**	***3,70***
HP-EOSLBA10-MC-H5S	**LBA 10 Balance Harness 5S, Std.**	***3,86***
HP-EOSLBA10-MC-H6S	**LBA 10 Balance Harness 6S, Std.**	***3,86***
HP-EOSLBA10-EH-H2S	**LBA 10 JST EH Harness 2S**	***3,70***
HP-EOSLBA10-EH-H3S	**LBA 10 JST EH Harness 3S**	***3,70***
HP-EOSLBA10-EH-H4S	**LBA 10 JST EH Harness 4S**	***3,86***
HP-EOSLBA10-EH-H5S	**LBA 10 JST EH Harness 5S**	***4,18***
HP-EOSLBA10-EH-H6S	**LBA 10 JST EH Harness 6S**	***4,34***
HP-EOSLBA10-XH-H2S	**LBA 10 JST XH Harness H2S**	***3,70***
HP-EOSLBA10-XH-H3S	**LBA 10 JST XH Harness H3S**	***3,70***
HP-EOSLBA10-XH-H4S	**LBA 10 JST XH Harness H4S**	***3,86***
HP-EOSLBA10-XH-H5S	**LBA 10 JST XH Harness H5S**	***4,18***
HP-EOSLBA10-XH-H6S	**LBA 10 JST XH Harness H6S**	***4,34***

Appendix 3

List of material bought for making the first battery charge/discharge tests

Material to buy for first charge/discharge tests

- **Batteries**: 2x Hyperion CL-4S 4800mAh, 96.0A Continuous (20C)
  Weight: 515gr, Size: 44 x 150 x 40 mm

Product number: **HP-LCL4800-4S**

MSRP: 196,83 €

Remark: This picture is from the CL-5S 4800mAh

- **Charger**: 1x EOS 1210i; charge: 180W, 10A; discharge: 50W, 5A
  640gr; 6cm tall x 15.5cm front/back x 14.5cm wide
  DC input voltage between 12V and 15V

Product number: **HP-EOS1210i**

MSRP: 154.38 €

1x temperature sensor, range 10℃ to 55℃
For monitoring pack temperature on charger and stop charging at given temperature.

Product number: **HP-EOS1210i-SEN**

MSRP: 12.86 €

Remark: All prices in EUR including 19% VAT

Material to buy for first charge/ discharge tests (continued)

- **Balancer**: 2x EOS 1210i, 180W, 10A max

Product number: **HP-EOSLBA10**
MSRP: 36.99 €

2x balance harnesses for 4S batteries
For connecting 4S batteries

Product number: **HP-EOSLBA10-MC-H4S**
MSRP: 3.70 €

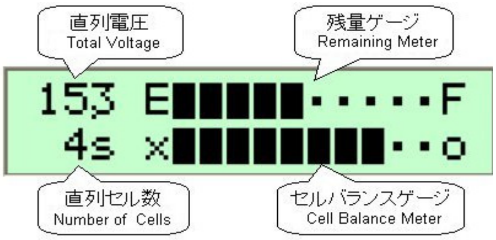
1x data port cable
For monitoring cell voltage on charger

Product number: **HP-EOSLBA10-DPC**
MSRP: 3.54 €

1x network cable/adapter set
To connect the two balancer together

Product number: **HP-EOSLBA10-MSC**
MSRP: 5.15 €

- **Cellmeter**: 1x CellMeter-8



Remark: How I saw, the cell meter is quite expensive. It allows displaying the voltage of each cell. I just found Japanese sites and therefore just poor information about it.

Remark: All prices in EUR including 19% VAT

Appendix 4

Test record of the cell voltage measuring circuit

Test record - cell voltag measuring circuit

No.	Description	Conditions	Measurand(s)	Result	Status
1	Verification of short circuits	no supply voltage	-	no short circuit on 5V supply	**OK**
2	Checking the supply voltage of all ICs	ciruit supplied with +5Vdc; ICs not plugged in	supply of each IC	all components supplied correctly	**OK**
3	Setting reference voltage to 1.92V (1.92V = 0.6*3.2V)	ciruit supplied with +5Vdc	voltage given by the potentiometer	voltage adjusted to 1.92V by adapting the resistance value	**OK**
Take away supply voltage of +5Vdc and plug in the ICs (LM324 and LM339). Reconnect the power supply of +5Vdc.					
Rem:	*For all the following test the circuit stays supplied with +5Vdc.*				
Connect the two battery packs in series. Connect them with the CellMeter8 for allowing displaying each cell voltage. Than connect the batteries with the circuit.					
4*	Test of the cell voltage measure. The gain of each amplifier have to be 0.6.	batteries connected to the circuit	Uout of each op-amp and each cell voltage	one amplifier has a gain of 0.665 (results see table below)	**KO**
5	Check of the functionality of the comparators (part one)	reference voltage of 1.92V	Uout of comparators	Uout = +5Vdc	**OK**
Increase reference voltage given by the potentiometer until it's higher than 0.6 times the voltage one cell, but if possible lower than the voltage of another cell (·0.6)					
6	Check of the functionality of the comparators (part two)	reference voltage at 2.35V ($Ucell_{min}$ = 2.324V and $Ucell_{max}$ = 2.574V)	Uout of comparators	Uout = 0Vdc as soon as the reference voltage is higher than 0.6 times the voltage of one cell	**OK**

*

Cell voltages		Uout of the op-amps	Gain of the amplifier (G = Uout / Ucell)
1. CellMeter:	2. Multimeter:	Multimeter:	Designated gain G = 0.6
cell1 3.88V	cell1 3.874V	cell1 2.363V	cell1: G = 0.610
cell2 3.88V	cell2 3.879V	cell2 2.375V	cell2: G = 0.612
cell3 3.90V	cell3 3.892V	cell3 2.377V	cell3: G = 0.611
cell4 3.89V	cell4 3.886V	cell4 2.387V	cell4: G = 0.614
cell5 3.90V	cell5 3.906V	cell5 2.378V	cell5: G = 0.609
cell6 3.88V	cell6 3.873V	cell6 2.574V	cell6: G = 0.665
cell7 3.88V	cell7 3.878V	cell7 2.326V	cell7: G = 0.600
cell8 3.89V	cell8 3.887V	cell8 2.324V	cell8: G = 0.598

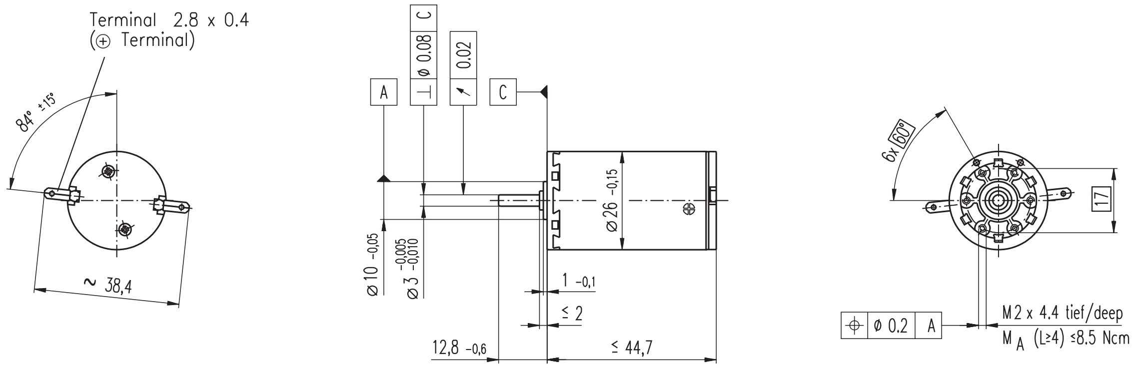
As we can see, for the cells 1 to 5 the average error is only about +0.011 (+1.8% , which is acceptable. For the cells 7 and 8 the error is nearly 0. Only the gain for the 6th cell is 0.065 to high, which corresponds to an error of +10.8%. This is too high and inadmissible. This error is due to the tolerances of the components (measuring device, resistances (±5%) etc.)

Appendix 5

CD with the datasheets of electronic devices

A-max 26 ∅26 mm, Graphite Brushes, 11 Watt

High*Power*



M 1:2

Stock program
Standard program
Special program (on request)

Order Number

Motor Data		110935	110936	110937	110938	110939	110940	110941	110942	110943	110944	110945
Values at nominal voltage												
1 Nominal voltage	V	6.0	7.2	12.0	15.0	18.0	24.0	30.0	36.0	42.0	48.0	48.0
2 No load speed	rpm	9110	9850	8010	8320	7950	8820	7020	7250	7850	7450	6000
3 No load current	mA	140	128	56.7	47.3	37.0	31.7	18.9	16.9	15.5	12.7	9.67
4 Nominal speed	rpm	7560	8230	6030	6150	5830	6730	4910	5160	5770	5340	3860
5 Nominal torque (max. continuous torque)	mNm	5.53	6.30	14.2	16.5	17.2	17.2	17.6	17.7	17.6	17.5	17.7
6 Nominal current (max. continuous current)	A	1.08	1.08	1.08	1.03	0.846	0.704	0.455	0.394	0.365	0.300	0.244
7 Stall torque	mNm	54.4	59.6	66.6	70.3	69.8	77.6	60.5	63.1	68.4	63.2	50.6
8 Starting current	A	9.32	9.07	4.80	4.19	3.30	3.04	1.51	1.35	1.36	1.04	0.672
9 Max. efficiency	%	68	70	76	77	78	79	78	79	79	79	77
Characteristics												
10 Terminal resistance	Ω	0.644	0.794	2.50	3.58	5.46	7.90	19.9	26.6	30.9	46.0	71.4
11 Terminal inductance	mH	0.0402	0.0509	0.227	0.332	0.528	0.770	1.90	2.57	2.99	4.34	6.68
12 Torque constant	mNm / A	5.84	6.57	13.9	16.8	21.2	25.5	40.1	46.7	50.3	60.6	75.2
13 Speed constant	rpm / V	1640	1450	689	569	451	374	238	205	190	158	127
14 Speed / torque gradient	rpm / mNm	180	176	124	122	116	116	118	117	116	120	121
15 Mechanical time constant	ms	27.1	23.6	17.5	16.7	16.2	15.7	15.4	15.3	15.2	15.2	15.2
16 Rotor inertia	gcm²	14.3	12.8	13.5	13.1	13.2	13.0	12.5	12.5	12.5	12.1	12.0

Specifications

Thermal data

17	Thermal resistance housing-ambient	13.2 K / W
18	Thermal resistance winding-housing	3.2 K / W
19	Thermal time constant winding	12.4 s
20	Thermal time constant motor	772 s
21	Ambient temperature	-30 ... +85°C
22	Max. permissible winding temperature	+125°C

Mechanical data (ball bearings)

23	Max. permissible speed	10400 rpm
24	Axial play	0.1 - 0.2 mm
25	Radial play	0.025 mm
26	Max. axial load (dynamic)	5 N
27	Max. force for press fits (static)	75 N
28	Max. radial loading, 5 mm from flange	20.5 N

Mechanical data (sleeve bearings)

23	Max. permissible speed	10400 rpm
24	Axial play	0.1 - 0.2 mm
25	Radial play	0.012 mm
26	Max. axial load (dynamic)	1.7 N
27	Max. force for press fits (static)	80 N
28	Max. radial loading, 5 mm from flange	5.5 N

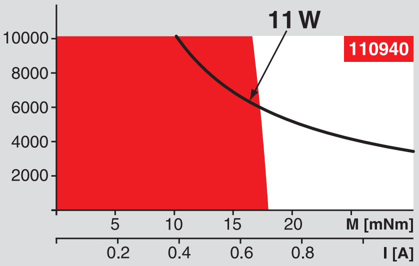
Other specifications

29	Number of pole pairs	1
30	Number of commutator segments	13
31	Weight of motor	117 g

Values listed in the table are nominal.
Explanation of the figures on page 47.

Option
Sleeve bearings in place of ball bearings
Pigtails in place of terminals

Operating Range



Comments

Continuous operation
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

Short term operation
The motor may be briefly overloaded (recurring).

Assigned power rating

maxon Modular System

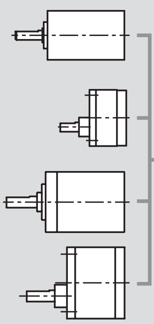
Overview on page 16 - 21

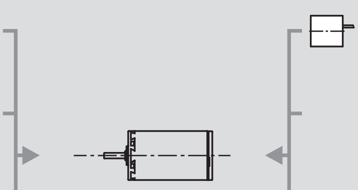
Planetary Gearhead
∅26 mm
0.5 - 2.0 Nm
Page 226

Spur Gearhead
∅30 mm
0.07 - 0.2 Nm
Page 227

Planetary Gearhead
∅32 mm
0.4 - 6.0 Nm
Page 228 / 229 / 232

Spur Gearhead
∅38 mm
0.1 - 0.6 Nm
Page 234



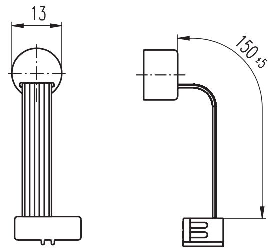


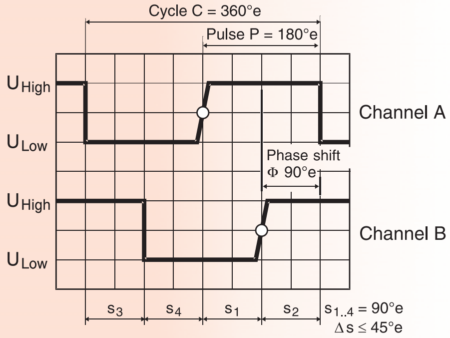
Encoder MEnc
∅13 mm
16 CPT, 2 channels
Page 262

Recommended Electronics:

LSC 30/2	Page 268
ADS 50/5	268
ADS_E 50/5	269
EPOS 24/5	286
EPOS P 24/5	287
MIP 10	289
Notes	**18**

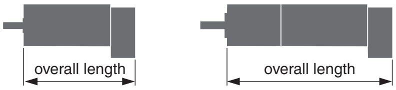
Encoder MEnc 13, 16 Counts per turn, 2 Channels





Stock program
Standard program
Special program (on request)

	Order Number
	110778
Type	
Counts per turn	16
Number of channels	2
Max. operating frequency (kHz)	20



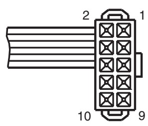
Combination

+ Motor	Page	+ Gearhead	Page	Overall length [mm] / ● see: + Gearhead
RE 13, 0.75 W	56 / 57			27.0 / 29.4
RE 13, 0.75 W	57	GP 13, 0.05 - 0.15 Nm	209	●
RE 13, 0.75 W	57	GP 13, 0.2 - 0.35 Nm	210	●
RE 13, 2 W	60 / 61			39.2 / 41.6
RE 13, 2 W	61	GP 13, 0.05 - 0.15 Nm	209	●
RE 13, 2 W	61	GP 13, 0.2 - 0.35 Nm	210	●
RE 13, 1.5 W	64 / 65			30.3 / 32.7
RE 13, 1.5 W	65	GP 13, 0.05 - 0.15 Nm	209	●
RE 13, 1.5 W	65	GP 13, 0.2 - 0.35 Nm	210	●
RE 13, 3 W	68 / 69			42.5 / 44.9
RE 13, 3 W	69	GP 13, 0.05 - 0.15 Nm	209	●
RE 13, 3 W	69	GP 13, 0.2 - 0.35 Nm	210	●
RE 16, 3.2 W	73			46.5
RE 16, 3.2 W	73	GP 16, 0.06 - 0.18 Nm	214	●
RE 16, 3.2 W	73	GP 16, 0.1 - 0.3 Nm	215	●
RE 16, 4.5 W	75			49.5
RE 16, 4.5 W	75	GP 16, 0.06 - 0.18 Nm	214	●
RE 16, 4.5 W	75	GP 16, 0.1 - 0.3 Nm	215	●
A 2516, 0.8 W	86			24.7
A 2516, 0.8 W	86	GS 16, 0.01 - 0.03 Nm	211	●
A 2516, 0.8 W	86	GS 16, 0.01 - 0.03 Nm	212	●
A 2516, 0.8 W	86	GS 16, 0.06 - 0.1 Nm	213	●
A 2520, 1.2 W	87			25.6
A 2520, 1.2 W	87	GP 19, 0.1 - 0.3 Nm	217	●
GM 20, 1.2 W	88	GS 20 (integriert)	88	28.5
A-max 16	102/104			33.5
A-max 16	102/104	GS 16, 0.01 - 0.03 Nm	211/212	●
A-max 16	102/104	GS 16, 0.06 - 0.1 Nm	213	●
A-max 16	102/104	GP 16, 0.06 - 0.18 Nm	214	●
A-max 16	102/104	GP 16, 0.1 - 0.3 Nm	215	●
A-max 19	106/108			36.4 / 39.0
A-max 19	106/108	GP 19, 0.1 - 0.3 Nm	217	●
A-max 19	106/108	GS 20, 0.06 - 0.25 Nm	218	●
A-max 19	106/108	GP 22, 0.5 - 2.0 Nm	221/222	●
A-max 19	106/108	GS 24, 0.1 Nm	225	●
A-max 22	110/112			39.0
A-max 22	110/112	GP 22, 0.1 - 0.6 Nm	219/220	●
A-max 22	110/112	GP 22, 0.5 - 2.0 Nm	221/222	●
A-max 22	110/112	GS 24, 0.1 Nm	225	●
A-max 26	113-119			51.8
A-max 26	113-119	GP 26, 0.5 - 2.0 Nm	226	●
A-max 26	113-119	GS 30, 0.07 - 0.2 Nm	227	●
A-max 26	113-119	GP 32, 0.4 - 2.0 Nm	228	●
A-max 26	113-119	GP 32, 0.75 - 6.0 Nm	228/229	●
A-max 26	113-119	GS 38, 0.1 - 0.6 Nm	234	●

Technical Data

Supply voltage V_{CC}	3.8 - 24 V
Output signal V_{CC} = 5 VDC	TTL compatible
Phase shift	90°e ± 45°e
Power input at V_{CC} 5 VDC	max. 8 mA
Inertia of the magnetic disc	0.07 gcm²
Operating temperature range	-20 ... +80°C

Pin Allocation



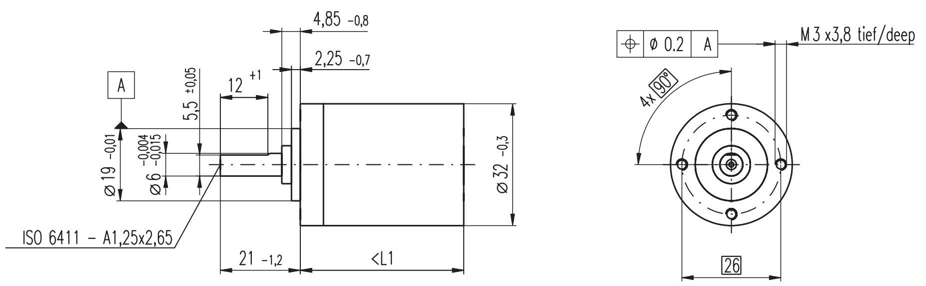
1 Motor+
2 V_{CC}
3 Channel A
4 Channel B
5 GND
6 Motor-

Pin type DIN 41651
(Type 3M 89110-0101HA)
flat band cable AWG 28

Planetary Gearhead GP 32 C ∅32 mm, 1.0 - 6.0 Nm

Ceramic Version

maxon gear



M 1:2

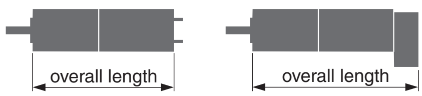
Technical Data

Planetary Gearhead	straight teeth
Output shaft	stainless steel
Shaft diameter as option	8 mm
Bearing at output	ball bearing
Radial play, 5 mm from flange	max. 0.14 mm
Axial play	max. 0.4 mm
Max. radial load, 10 mm from flange	140 N
Max. permissible axial load	120 N
Max. permissible force for press fits	120 N
Sense of rotation, drive to output	=
Recommended input speed	< 8000 rpm
Recommended temperature range	-20 ... +100°C
Extended area as option	-35 ... +100°C

Option: Low-noise version

Stock program
Standard program
Special program (on request)

	Order Number		166930	166933	166938	166939	166944	166949	166954	166959	166962	166967	166972	166977
	Gearhead Data													
1	Reduction		3.7 : 1	14 : 1	33 : 1	51 : 1	111 : 1	246 : 1	492 : 1	762 : 1	1181 : 1	1972 : 1	2829 : 1	4380 : 1
2	Reduction absolute		26/7	676/49	529/16	17576/343	13824/125	421824/1715	86112/175	19044/25	10123776/8575	8626176/4375	495144/175	109503/25
3	Max. motor shaft diameter	mm	6	6	3	6	4	4	3	3	4	4	3	3
	Order Number		166931	166934		166940	166945	166950	166955	166960	166963	166968	166973	166978
1	Reduction		4.8 : 1	18 : 1		66 : 1	123 : 1	295 : 1	531 : 1	913 : 1	1414 : 1	2189 : 1	3052 : 1	5247 : 1
2	Reduction absolute		24/5	624/35		16224/245	6877/56	101062/343	331776/625	36501/40	2425488/1715	536406/245	1907712/625	839523/160
3	Max. motor shaft diameter	mm	4	4		4	3	3	4	3	3	3	3	3
	Order Number		166932	166935		166941	166946	166951	166956	166961	166964	166969	166974	166979
1	Reduction		5.8 : 1	21 : 1		79 : 1	132 : 1	318 : 1	589 : 1	1093 : 1	1526 : 1	2362 : 1	3389 : 1	6285 : 1
2	Reduction absolute		23/4	299/14		3887/49	3312/25	389376/1225	20631/35	279841/256	9345024/6125	2066688/875	474513/140	6436343/1024
3	Max. motor shaft diameter	mm	3	3		3	3	4	3	3	4	3	3	3
	Order Number			166936		166942	166947	166952	166957		166965	166970	166975	
1	Reduction			23 : 1		86 : 1	159 : 1	411 : 1	636 : 1		1694 : 1	2548 : 1	3656 : 1	
2	Reduction absolute			576/25		14976/175	1587/10	359424/875	79488/125		1162213/686	7962624/3125	457056/125	
3	Max. motor shaft diameter	mm		4		4	3	4	3		3	4	3	
	Order Number			166937		166943	166948	166953	166958		166966	166971	166976	
1	Reduction			28 : 1		103 : 1	190 : 1	456 : 1	706 : 1		1828 : 1	2623 : 1	4060 : 1	
2	Reduction absolute			138/5		3588/35	12167/64	89401/196	158171/224		2238912/1225	2056223/784	3637933/896	
3	Max. motor shaft diameter	mm		3		3	3	3	3		3	3	3	
4	Number of stages		1	2	2	3	3	4	4	4	5	5	5	5
5	Max. continuous torque	Nm	1	3	3	6	6	6	6	6	6	6	6	6
6	Intermittently permissible torque at gear output	Nm	1.25	3.75	3.75	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
7	Max. efficiency	%	80	75	75	70	70	60	60	60	50	50	50	50
8	Weight	g	118	162	162	194	194	226	226	226	258	258	258	258
9	Average backlash no load	°	0.7	0.8	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	Mass inertia	gcm²	1.5	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
11	Gearhead length L1	mm	26.4	36.3	36.3	43.0	43.0	49.7	49.7	49.7	56.4	56.4	56.4	56.4

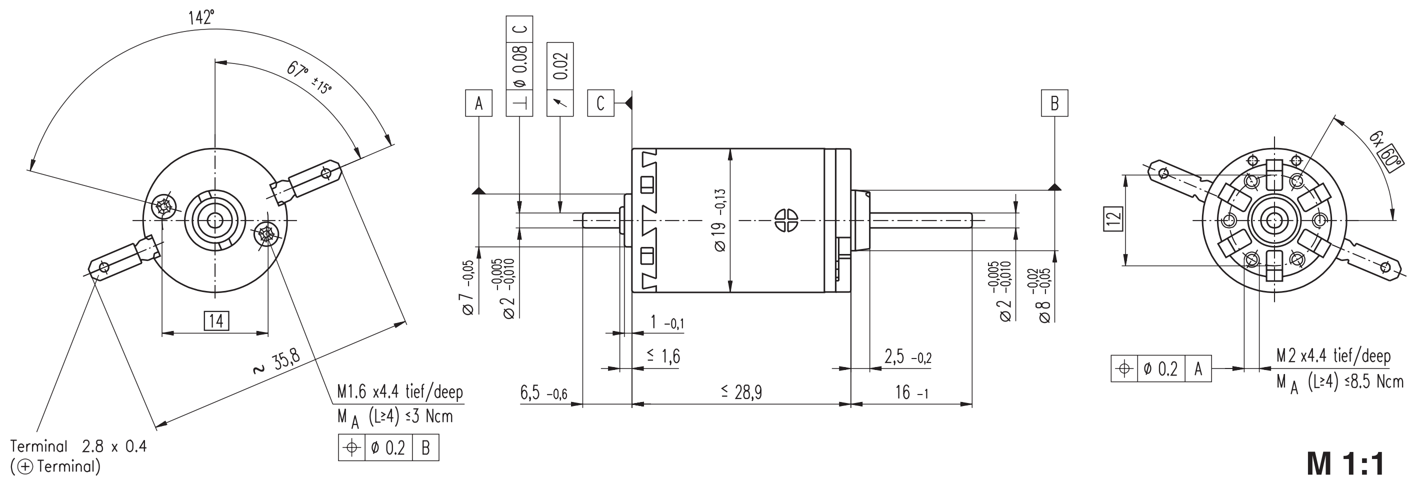


Combination

+ Motor	Page	+ Tacho / Brake	Page	Overall length [mm] = Motor length + gearhead length + (tacho / brake) + assembly parts											
A-max 26	113-120			71.2	81.1	81.1	87.8	87.8	94.5	94.5	94.5	101.2	101.2	101.2	101.2
A-max 26	113-119	MEnc 13	262	78.3	88.2	88.2	94.9	94.9	101.6	101.6	101.6	108.3	108.3	108.3	108.3
A-max 26	114-120	MR	246	80.0	89.9	89.9	96.6	96.6	103.3	103.3	103.3	110.0	110.0	110.0	110.0
A-max 26	114-120	Enc 22	252	85.6	95.5	95.5	102.2	102.2	108.9	108.9	108.9	115.6	115.6	115.6	115.6
A-max 26	114-120	HED_ 5540	254/256	90.0	99.9	99.9	106.6	106.6	113.3	113.3	113.3	120.0	120.0	120.0	120.0
A-max 32	121/123			89.4	99.3	99.3	106.0	106.0	112.7	112.7	112.7	119.4	119.4	119.4	119.4
A-max 32	122/124			88.0	97.9	97.9	104.6	104.6	111.3	111.3	111.3	118.0	118.0	118.0	118.0
A-max 32	122/124	MR	247	99.2	109.1	109.1	115.8	115.8	122.5	122.5	122.5	129.2	129.2	129.2	129.2
A-max 32	122/124	HED_ 5540	254/256	108.8	118.7	118.7	125.4	125.4	132.1	132.1	132.1	138.8	138.8	138.8	138.8
RE-max 29	143-146			71.2	81.1	81.1	87.8	87.8	94.5	94.5	94.5	101.2	101.2	101.2	101.2
RE-max 29	144/146	MR	246	80.0	89.9	89.9	96.6	96.6	103.3	103.3	103.3	110.0	110.0	110.0	110.0
EC 32, 80 W	162			86.5	96.4	96.4	103.1	103.1	109.8	109.8	109.8	116.5	116.5	116.5	116.5
EC 32, 80 W	162	HED_ 5540	254/256	104.9	114.8	114.8	121.5	121.5	128.2	128.2	128.2	134.9	134.9	134.9	134.9
EC 32, 80 W	162	Res 26	264	106.6	116.5	116.5	123.2	123.2	129.9	129.9	129.9	136.6	136.6	136.6	136.6
EC-max 22, 25 W	175			75.0	84.9	84.9	91.6	91.6	98.3	98.3	98.3	105.0	105.0	105.0	105.0
EC-max 22, 25 W	175	MR	245	84.7	94.6	94.6	101.3	101.3	108.0	108.0	108.0	114.7	114.7	114.7	114.7
EC-max 22, 25 W	175	AB 20	298	110.0	119.9	119.9	126.6	126.6	133.3	133.3	133.3	140.0	140.0	140.0	140.0
EC-max 30, 40 W	176			68.5	78.4	78.4	85.1	85.1	91.8	91.8	91.8	98.5	98.5	98.5	98.5
EC-max 30, 40 W	176	MR	247	80.7	90.6	90.6	97.3	97.3	104.0	104.0	104.0	110.7	110.7	110.7	110.7
EC-max 30, 40 W	176	HEDL 5540	254	89.1	99.0	99.0	105.7	105.7	112.4	112.4	112.4	119.1	119.1	119.1	119.1
EC-max 30, 40 W	176	AB 20	298	100.6	110.5	110.5	117.2	117.2	123.9	123.9	123.9	130.6	130.6	130.6	130.6
EC-max 30, 40 W	176	HEDL 5540 / AB 20	254/298	121.2	131.1	131.1	137.8	137.8	144.5	144.5	144.5	151.2	151.2	151.2	151.2
EC-power 22, 90 W	183			75.1	85.0	85.0	91.7	91.7	98.4	98.4	98.4	105.1	105.1	105.1	105.1
EC-power 22, 120 W	184			92.5	102.4	102.4	109.1	109.1	115.8	115.8	115.8	122.5	122.5	122.5	122.5
MCD EPOS, 60 W	295			146.5	156.4	156.4	163.1	163.1	169.8	169.8	169.8	176.5	176.6	176.7	176.8
MCD EPOS P, 60 W	295			146.5	156.4	156.4	163.1	163.1	169.8	169.8	169.8	176.5	176.6	176.7	176.8

May 2007 edition / subject to change

A-max 19 ∅19 mm, Precious Metal Brushes CLL, 1.5 Watt, CE approved



M 1:1

- Stock program
- Standard program
- Special program (on request)

Order Number

Motor Data			110090	110091	110092	110093	110094	110095	110096	110097	110098
	Values at nominal voltage										
1	Nominal voltage	V	1.2	2.4	3.0	4.8	6.0	7.2	9.0	12.0	18.0
2	No load speed	rpm	6360	7150	6210	6180	6080	6120	6120	6140	6580
3	No load current	mA	88.0	51.9	34.1	21.2	16.6	13.9	11.1	8.39	6.17
4	Nominal speed	rpm	5030	4380	2490	2430	2360	2320	2310	2300	2670
5	Nominal torque (max. continuous torque)	mNm	1.34	2.49	3.62	3.59	3.63	3.55	3.54	3.51	3.42
6	Nominal current (max. continuous current)	A	0.840	0.840	0.831	0.513	0.407	0.335	0.267	0.200	0.139
7	Stall torque	mNm	6.50	6.53	6.13	6.01	6.01	5.80	5.79	5.72	5.85
8	Starting current	A	3.69	2.09	1.36	0.832	0.655	0.53	0.423	0.314	0.23
9	Max. efficiency	%	72	72	71	71	71	71	71	71	71
	Characteristics										
10	Terminal resistance	Ω	0.325	1.15	2.20	5.77	9.17	13.6	21.3	38.2	78.2
11	Terminal inductance	mH	0.0186	0.0587	0.121	0.314	0.506	0.719	1.12	1.98	3.87
12	Torque constant	mNm / A	1.76	3.13	4.50	7.23	9.19	10.9	13.7	18.2	25.4
13	Speed constant	rpm / V	5430	3050	2120	1320	1040	873	698	525	376
14	Speed / torque gradient	rpm / mNm	1000	1120	1040	1050	1040	1080	1090	1100	1160
15	Mechanical time constant	ms	26.7	24.4	23.7	23.6	23.5	23.7	23.7	23.8	24.1
16	Rotor inertia	gcm²	2.54	2.07	2.18	2.14	2.16	2.09	2.09	2.06	1.99

Specifications

Thermal data

17	Thermal resistance housing-ambient	21.3 K / W
18	Thermal resistance winding-housing	10.5 K / W
19	Thermal time constant winding	11 s
20	Thermal time constant motor	362 s
21	Ambient temperature	-30 ... +65°C
22	Max. permissible winding temperature	+85°C

Mechanical data (sleeve bearings)

23	Max. permissible speed	10000 rpm
24	Axial play	0.05 - 0.15 mm
25	Radial play	0.012 mm
26	Max. axial load (dynamic)	1 N
27	Max. force for press fits (static)	80 N
	(static, shaft supported)	480 N
28	Max. radial loading, 5 mm from flange	2.7 N

Mechanical data (ball bearings)

23	Max. permissible speed	10000 rpm
24	Axial play	0.05 - 0.15 mm
25	Radial play	0.025 mm
26	Max. axial load (dynamic)	3.3 N
27	Max. force for press fits (static)	45 N
	(static, shaft supported)	480 N
28	Max. radial loading, 5 mm from flange	11.9 N

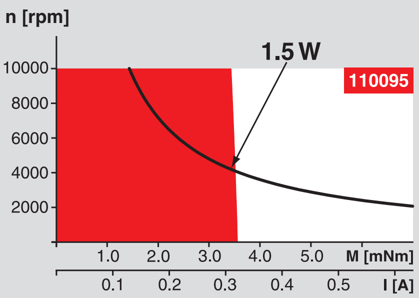
Other specifications

29	Number of pole pairs	1
30	Number of commutator segments	9
31	Weight of motor	34 g
	CLL = Capacitor Long Life	

Values listed in the table are nominal.
Explanation of the figures on page 47.

Option
Ball bearings in place of sleeve bearings
Pigtails in place of terminals
Without CLL

Operating Range



Comments

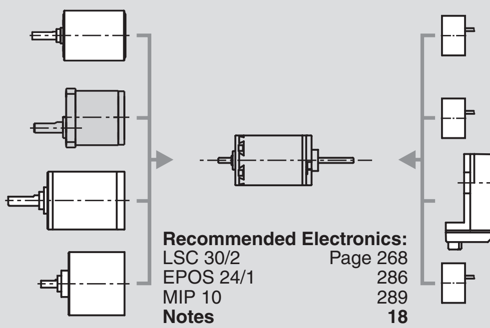
Continuous operation
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

Short term operation
The motor may be briefly overloaded (recurring).

Assigned power rating

maxon Modular System

Overview on page 16 - 21



Planetary Gearhead
∅19 mm
0.1 - 0.3 Nm
Page 217

Spur Gearhead
∅20.3 mm
0.06 - 0.25 Nm
Page 218

Planetary Gearhead
∅22 mm
0.1 - 2.0 Nm
Page 219 / 221 / 222

Spur Gearhead
∅24 mm
0.1 Nm
Page 225

Recommended Electronics:

LSC 30/2	Page 268
EPOS 24/1	286
MIP 10	289
Notes	**18**

Encoder MR
32 CPT,
2 / 3 channels
Page 247

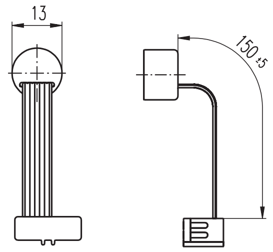
Encoder MR
128 / 256 / 512 CPT,
2 / 3 channels
Page 248

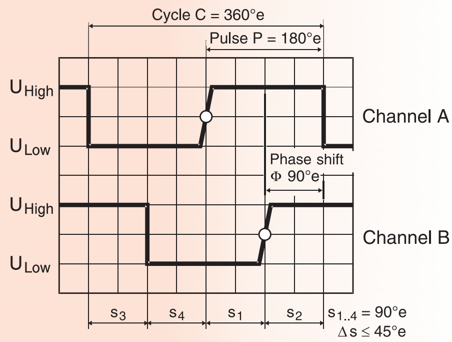
Encoder Enc
22 mm
100 CPT, 2 channels
Page 253

Encoder MEnc
∅13 mm
16 CPT, 2 channels
Page 262

May 2007 edition / subject to change

Encoder MEnc 13, 16 Counts per turn, 2 Channels



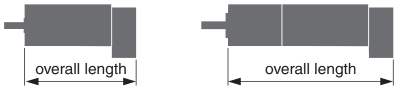


Stock program
Standard program
Special program (on request)

Order Number

110778

Type	
Counts per turn	16
Number of channels	2
Max. operating frequency (kHz)	20

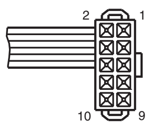


Combination

+ Motor	Page	+ Gearhead	Page	Overall length [mm] / ● see: + Gearhead
RE 13, 0.75 W	56 / 57			27.0 / 29.4
RE 13, 0.75 W	57	GP 13, 0.05 - 0.15 Nm	209	●
RE 13, 0.75 W	57	GP 13, 0.2 - 0.35 Nm	210	●
RE 13, 2 W	60 / 61			39.2 / 41.6
RE 13, 2 W	61	GP 13, 0.05 - 0.15 Nm	209	●
RE 13, 2 W	61	GP 13, 0.2 - 0.35 Nm	210	●
RE 13, 1.5 W	64 / 65			30.3 / 32.7
RE 13, 1.5 W	65	GP 13, 0.05 - 0.15 Nm	209	●
RE 13, 1.5 W	65	GP 13, 0.2 - 0.35 Nm	210	●
RE 13, 3 W	68 / 69			42.5 / 44.9
RE 13, 3 W	69	GP 13, 0.05 - 0.15 Nm	209	●
RE 13, 3 W	69	GP 13, 0.2 - 0.35 Nm	210	●
RE 16, 3.2 W	73			46.5
RE 16, 3.2 W	73	GP 16, 0.06 - 0.18 Nm	214	●
RE 16, 3.2 W	73	GP 16, 0.1 - 0.3 Nm	215	●
RE 16, 4.5 W	75			49.5
RE 16, 4.5 W	75	GP 16, 0.06 - 0.18 Nm	214	●
RE 16, 4.5 W	75	GP 16, 0.1 - 0.3 Nm	215	●
A 2516, 0.8 W	86			24.7
A 2516, 0.8 W	86	GS 16, 0.01 - 0.03 Nm	211	●
A 2516, 0.8 W	86	GS 16, 0.01 - 0.03 Nm	212	●
A 2516, 0.8 W	86	GS 16, 0.06 - 0.1 Nm	213	●
A 2520, 1.2 W	87			25.6
A 2520, 1.2 W	87	GP 19, 0.1 - 0.3 Nm	217	●
GM 20, 1.2 W	88	GS 20 (integriert)	88	28.5
A-max 16	102/104			33.5
A-max 16	102/104	GS 16, 0.01 - 0.03 Nm	211/212	●
A-max 16	102/104	GS 16, 0.06 - 0.1 Nm	213	●
A-max 16	102/104	GP 16, 0.06 - 0.18 Nm	214	●
A-max 16	102/104	GP 16, 0.1 - 0.3 Nm	215	●
A-max 19	106/108			36.4 / 39.0
A-max 19	106/108	GP 19, 0.1 - 0.3 Nm	217	●
A-max 19	106/108	GS 20, 0.06 - 0.25 Nm	218	●
A-max 19	106/108	GP 22, 0.5 - 2.0 Nm	221/222	●
A-max 19	106/108	GS 24, 0.1 Nm	225	●
A-max 22	110/112			39.0
A-max 22	110/112	GP 22, 0.1 - 0.6 Nm	219/220	●
A-max 22	110/112	GP 22, 0.5 - 2.0 Nm	221/222	●
A-max 22	110/112	GS 24, 0.1 Nm	225	●
A-max 26	113-119			51.8
A-max 26	113-119	GP 26, 0.5 - 2.0 Nm	226	●
A-max 26	113-119	GS 30, 0.07 - 0.2 Nm	227	●
A-max 26	113-119	GP 32, 0.4 - 2.0 Nm	228	●
A-max 26	113-119	GP 32, 0.75 - 6.0 Nm	228/229	●
A-max 26	113-119	GS 38, 0.1 - 0.6 Nm	234	●

Technical Data	
Supply voltage V_{CC}	3.8 - 24 V
Output signal V_{CC} = 5 VDC	TTL compatible
Phase shift	90°e ± 45°e
Power input at V_{CC} 5 VDC	max. 8 mA
Inertia of the magnetic disc	0.07 gcm²
Operating temperature range	-20 ... +80°C

Pin Allocation

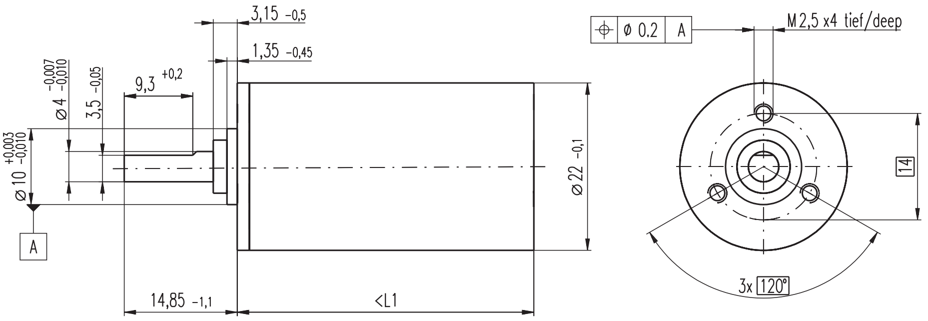


1	Motor+
2	V_{CC}
3	Channel A
4	Channel B
5	GND
6	Motor-

Pin type DIN 41651
(Type 3M 89110-0101HA)
flat band cable AWG 28

Planetary Gearhead GP 22 C ∅22 mm, 0.5 - 2.0 Nm

Ceramic Version



M 1:1

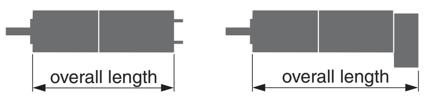
Technical Data

Planetary Gearhead	straight teeth
Output shaft	stainless steel, hardened
Bearing at output	ball bearing
Radial play, 10 mm from flange	max. 0.2 mm
Axial play	max. 0.2 mm
Max. radial load, 10 mm from flange	70 N
Max. permissible axial load	100 N
Max. permissible force for press fits	100 N
Sense of rotation, drive to output	=
Recommended input speed	< 8000 rpm
Recommended temperature range	-20 ... +100°C
Extended area as option	-35 ... +100°C

Stock program
Standard program
Special program (on request)

Order Number		143971	143974	143980	143986	143990	143996	144002	144004	144011	144017	144023
Gearhead Data												
1 Reduction		3.8 : 1	14 : 1	53 : 1	104 : 1	198 : 1	370 : 1	590 : 1	742 : 1	1386 : 1	1996 : 1	3189 : 1
2 Reduction absolute		15/4	225/16	3375/64	87723/845	50625/256	10556001/28561	59049/100	759375/1024	158340015/114244	285012027/142805	1594323/500
3 Max. motor shaft diameter	mm	4	4	4	3.2	4	3.2	4	4	3.2	3.2	4
Order Number		143972	143975	143981	143987	143991	143997	144003	144006	144012	144018	144024
1 Reduction		4.4 :1	16 : 1	62 : 1	109 : 1	231 : 1	389 : 1	690 : 1	867 : 1	1460 : 1	2102 : 1	3728 : 1
2 Reduction absolute		57/13	855/52	12825/208	2187/20	192375/832	263169/676	1121931/1625	2885625/3328	3947535/2704	7105563/3380	30292137/8125
3 Max. motor shaft diameter	mm	3.2	3.2	3.2	4	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Order Number		143973	143976	143982	143988	143992	143998	144005	144007	144013	144019	144025
1 Reduction		5.4 : 1	19 : 1	72 : 1	128 : 1	270 : 1	410 : 1	850 : 1	1014 : 1	1538 : 1	2214 : 1	4592 : 1
2 Reduction absolute		27/5	3249/169	48735/676	41553/325	731025/2704	6561/16	531441/625	10965375/10816	98415/64	177147/80	14348907/3125
3 Max. motor shaft diameter	mm	2.5	3.2	3.2	3.2	3.2	4	2.5	3.2	4	4	2.5
Order Number			143977	143983	143989	143993	143999		144008	144014	144020	
1 Reduction			20 : 1	76 : 1	157 : 1	285 : 1	455 : 1		1068 : 1	1621 : 1	2458 : 1	
2 Reduction absolute			81/4	1215/16	19683/125	18225/64	5000211/10985		273375/256	601692057/371293	135005697/54925	
3 Max. motor shaft diameter	mm		4	4	2.5	4	3.2		4	3.2	3.2	
Order Number			143978	143984		143994	144000		144009	144015	144021	
1 Reduction			24 : 1	84 : 1		316 : 1	479 : 1		1185 : 1	1707 : 1	2589 : 1	
2 Reduction absolute			1539/65	185193/2197		2777895/8788	124659/260		41668425/35152	15000633/8788	3365793/1300	
3 Max. motor shaft diameter	mm		3.2	3.2		3.2	3.2		3.2	3.2	3.2	
Order Number			143979	143985		143995	144001		144010	144016	144022	
1 Reduction			29 : 1	89 : 1		333 : 1	561 : 1		1249 : 1	1798 : 1	3027 : 1	
2 Reduction absolute			729/25	4617/52		69255/208	2368521/4225		1038825/832	373977/208	63950067/21125	
3 Max. motor shaft diameter	mm		2.5	3.2		3.2	3.2		3.2	3.2	3.2	
4 Number of stages		1	2	3	3	4	4	4	5	5	5	5
5 Max. continuous torque	Nm	0.5	0.6	1.2	1.2	1.8	1.8	1.8	2.0	2.0	2.0	2.0
6 Intermittently permissible torque at gear output	Nm	0.8	0.9	1.9	1.9	2.7	2.7	2.7	3.0	3.0	3.0	3.0
7 Max. efficiency	%	84	70	59	59	49	49	49	42	42	42	42
8 Weight	g	42	55	68	68	81	81	81	94	94	94	94
9 Average backlash no load	°	1.0	1.2	1.6	1.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0
10 Mass inertia	gcm²	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
11 Gearhead length L1*	mm	25.4	32.2	39.0	39.0	45.8	45.8	45.8	52.6	52.6	52.6	52.6

*L1 - 2.8 mm for calculating the overall length



Combination

+ Motor	Page	+ Tacho / Brake	Page	Overall length [mm] = Motor length + gearhead length + (tacho / brake) + assembly parts										
A-max 19	105/106			51.6	58.4	65.2	65.2	72.0	72.0	72.0	78.8	78.8	78.8	78.8
A-max 19, 1.5 W	106	MR	247/248	56.7	63.5	70.3	70.3	77.1	77.1	77.1	83.9	83.9	83.9	83.9
A-max 19, 1.5 W	106	Enc 22	253	66.0	72.8	79.6	79.6	86.4	86.4	86.4	93.2	93.2	93.2	93.2
A-max 19, 1.5 W	106	MEnc 13	262	59.1	65.9	72.7	72.7	79.5	79.5	79.5	86.3	86.3	86.3	86.3
A-max 19, 2.5 W	107/108			54.2	61.0	67.8	67.8	74.6	74.6	74.6	81.4	81.4	81.4	81.4
A-max 19, 2.5 W	108	MR	247/248	58.5	65.3	72.1	72.1	78.9	78.9	78.9	85.7	85.7	85.7	85.7
A-max 19, 2.5 W	108	Enc 22	253	68.6	75.4	82.2	82.2	89.0	89.0	89.0	95.8	95.8	95.8	95.8
A-max 19, 2.5 W	108	MEnc 13	262	61.7	68.5	75.3	75.3	82.1	82.1	82.1	88.9	88.9	88.9	88.9
A-max 22	109-112			54.6	61.4	68.2	68.2	75.0	75.0	75.0	81.8	81.8	81.8	81.8
A-max 22	110/112	MR	247/248	59.6	66.4	73.2	73.2	80.0	80.0	80.0	86.8	86.8	86.8	86.8
A-max 22	110/112	Enc 22	253	69.0	75.8	82.6	82.6	89.4	89.4	89.4	96.2	96.2	96.2	96.2
A-max 22	110/112	MEnc 13	262	61.7	68.5	75.3	75.3	82.1	82.1	82.1	88.9	88.9	88.9	88.9
RE-max 21	135/136			51.6	58.4	65.2	65.2	72.0	72.0	72.0	78.8	78.8	78.8	78.8
RE-max 21, 3.5 W	136	MR	247/248	56.7	63.5	70.3	70.3	77.1	77.1	77.1	83.9	83.9	83.9	83.9
RE-max 21	137/138			54.2	61.0	67.8	67.8	74.6	74.6	74.6	81.4	81.4	81.4	81.4
RE-max 21, 6 W	138	MR	247/248	58.5	65.3	72.1	72.1	78.9	78.9	78.9	85.7	85.7	85.7	85.7
RE-max 24	139-142			54.6	61.4	68.2	68.2	75.0	75.0	75.0	81.8	81.8	81.8	81.8
RE-max 24	140/142	MR	247/248	59.6	66.4	73.2	73.2	80.0	80.0	80.0	86.8	86.8	86.8	86.8

May 2007 edition / subject to change

2SK2936

Silicon N Channel MOS FET
High Speed Power Switching

HITACHI

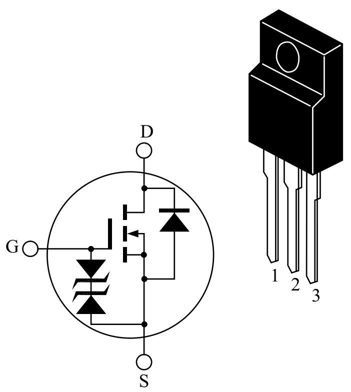
ADE-208-559B (Z)
3rd. Edition
Jun 1998

Features

- Low on-resistance
  R_{DS} =0.010 Ω typ.
- High speed switching
- 4V gate drive device can be driven from 5V source

Outline

TO–220CFM



1. Gate
2. Drain
3. Source

Absolute Maximum Ratings (Ta = 25°C)

Item	Symbol	Ratings	Unit
Drain to source voltage	V_{DSS}	60	V
Gate to source voltage	V_{GSS}	±20	V
Drain current	I_D	45	A
Drain peak current	$I_{D(pulse)}$ Note1	180	A
Body-drain diode reverse drain current	I_{DR}	45	A
Avalanche current	I_{AP} Note3	45	A
Avalanche energy	E_{AR} Note3	173	mJ
Channel dissipation	Pch Note2	35	W
Channel temperature	Tch	150	°C
Storage temperature	Tstg	–55 to +150	°C

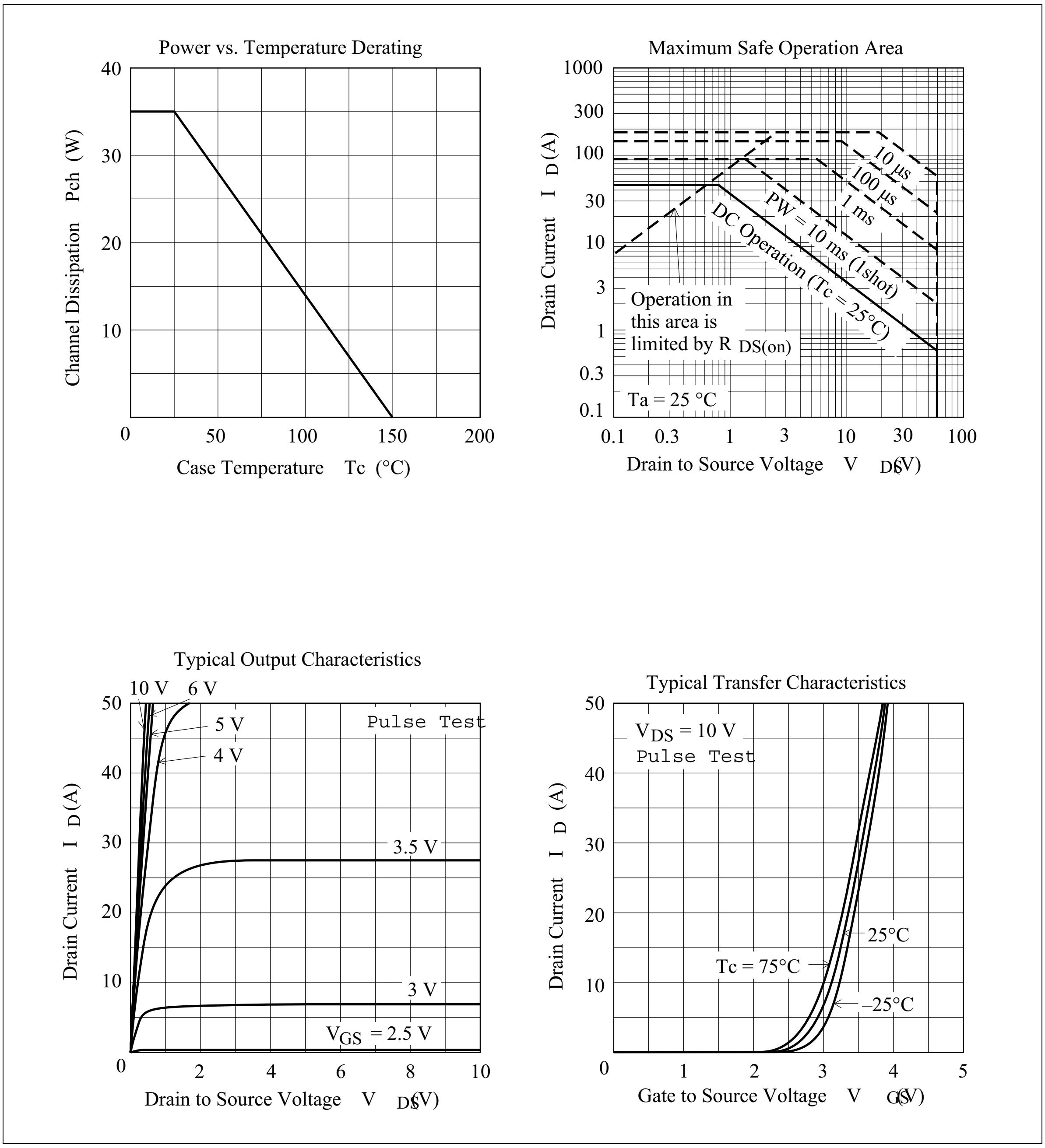
Note: 1. PW ≤ 10µs, duty cycle ≤ 1 %
2. Value at Tc = 25°C
3. Value at Tch = 25°C, Rg ≥ 50Ω

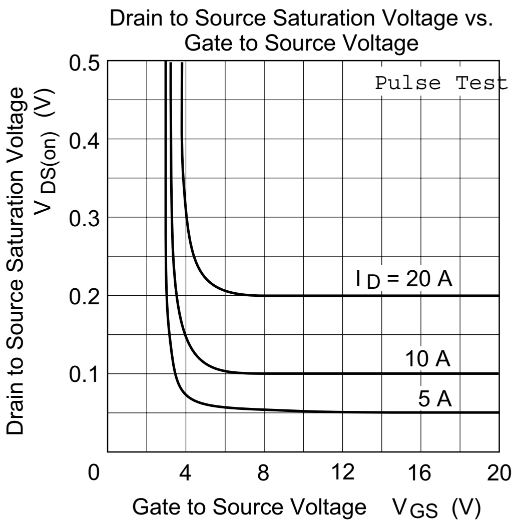
Electrical Characteristics (Ta = 25°C)

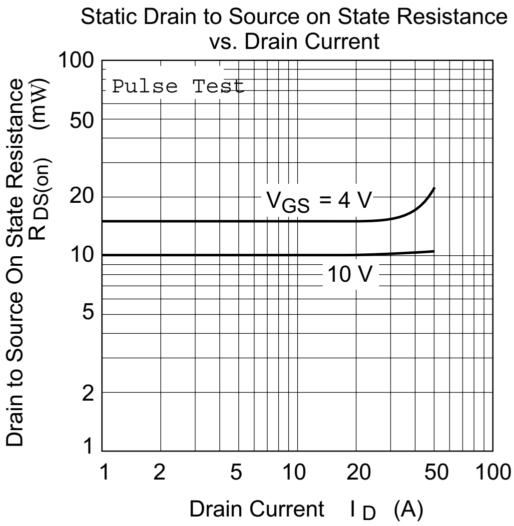
Item	Symbol	Min	Typ	Max	Unit	Test Conditions
Drain to source breakdown voltage	$V_{(BR)DSS}$	60	—	—	V	I_D = 10mA, V_{GS} = 0
Gate to source breakdown voltage	$V_{(BR)GSS}$	±20	—	—	V	I_G = ±100μA, V_{DS} = 0
Gate to source leak current	I_{GSS}	—	—	±10	μA	V_{GS} = ±16V, V_{DS} = 0
Zero gate voltege drain current	I_{DSS}	—	—	10	μA	V_{DS} = 60 V, V_{GS} = 0
Gate to source cutoff voltage	$V_{GS(off)}$	1.5	—	2.5	V	I_D = 1mA, V_{DS} = 10V
Static drain to source on state resistance	$R_{DS(on)}$	—	0.010	0.013	Ω	I_D = 20A, V_{GS} = 10V Note4
	$R_{DS(on)}$	—	0.015	0.025	Ω	I_D = 20A, V_{GS} = 4V Note4
Forward transfer admittance	$\|y_{fs}\|$	24	40	—	S	I_D = 20A, V_{DS} = 10V Note4
Input capacitance	Ciss	—	2200	—	pF	V_{DS} = 10V
Output capacitance	Coss	—	1050	—	pF	V_{GS} = 0
Reverse transfer capacitance	Crss	—	320	—	pF	f = 1MHz
Turn-on delay time	$t_{d(on)}$	—	25	—	ns	I_D = 20A, V_{GS} = 10V
Rise time	t_r	—	200	—	ns	V_{GS} = 10V, I_D = 20A
Turn-off delay time	$t_{d(off)}$	—	320	—	ns	R_L = 1.5Ω
Fall time	t_f	—	240	—	ns	
Body–drain diode forward voltage	V_{DF}	—	0.95	—	V	I_F = 45A, V_{GS} = 0
Body–drain diode reverse recovery time	t_{rr}	—	60	—	ns	I_F = 45A, V_{GS} = 0 diF/ dt =50A/μs

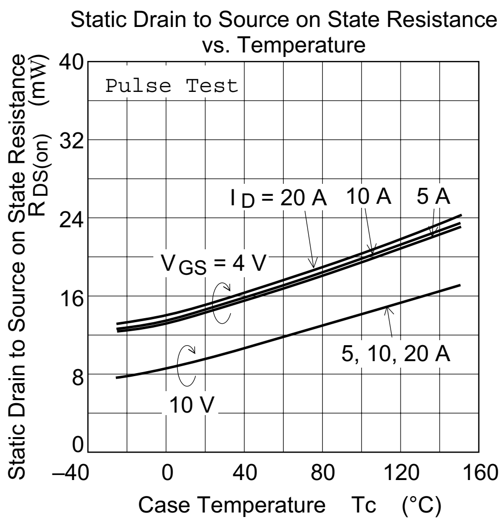
Note: 4. Pulse test

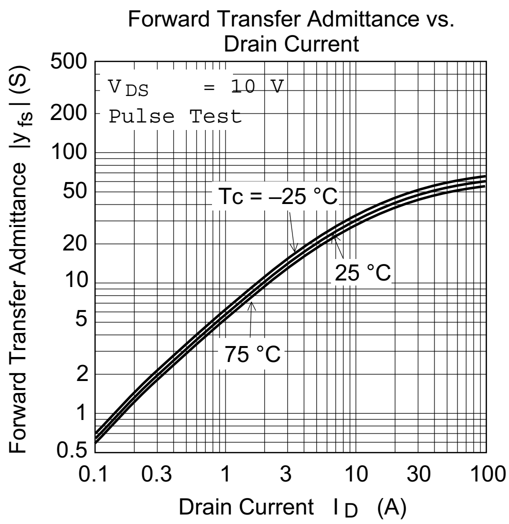
Main Characteristics

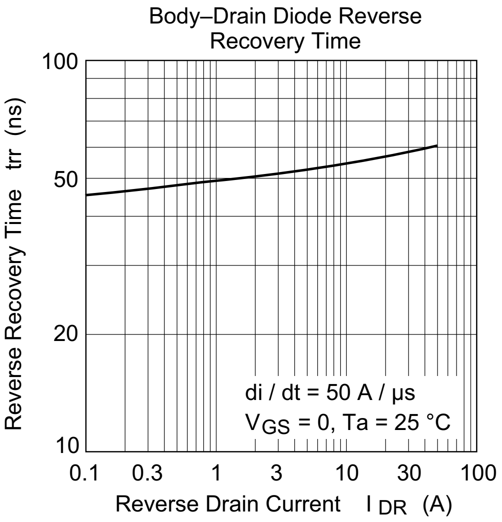


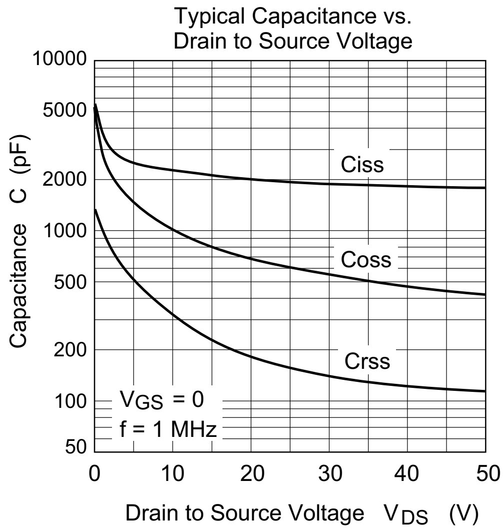

Drain to Source Saturation Voltage vs.
Gate to Source Voltage
Pulse Test
I D = 20 A
10 A
5 A
Drain to Source Saturation Voltage V DS(on) (V)
0.5
0.4
0.3
0.2
0.1
0
4
8
12
16
20
Gate to Source Voltage V GS (V)

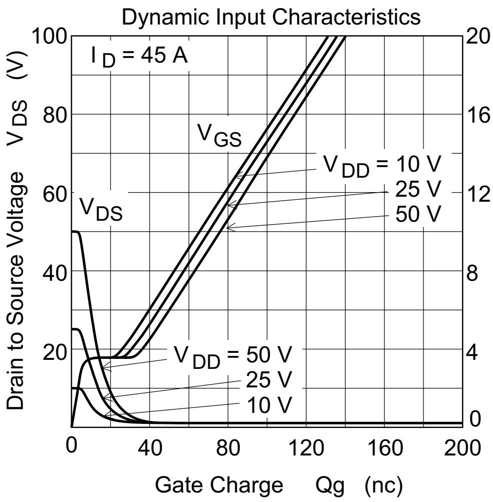

Static Drain to Source on State Resistance
vs. Drain Current
Pulse Test
V GS = 4 V
10 V
Drain to Source On State Resistance R DS(on) (mW)
100
50
20
10
5
2
1
1
2
5
10
20
50
100
Drain Current I D (A)

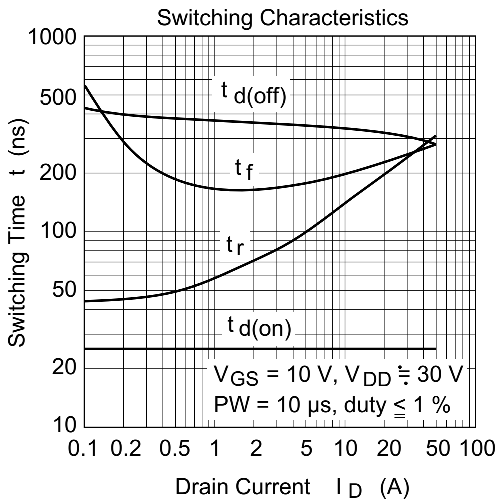

Static Drain to Source on State Resistance
vs. Temperature
Pulse Test
I D = 20 A
10 A
5 A
V GS = 4 V
5, 10, 20 A
10 V
Static Drain to Source on State Resistance R DS(on) (mW)
40
32
24
16
8
0
–40
0
40
80
120
160
Case Temperature Tc (°C)


Forward Transfer Admittance vs.
Drain Current
V DS = 10 V
Pulse Test
Tc = –25 °C
25 °C
75 °C
Forward Transfer Admittance |y fs| (S)
500
200
100
50
20
10
5
2
1
0.5
0.1
0.3
1
3
10
30
100
Drain Current I D (A)

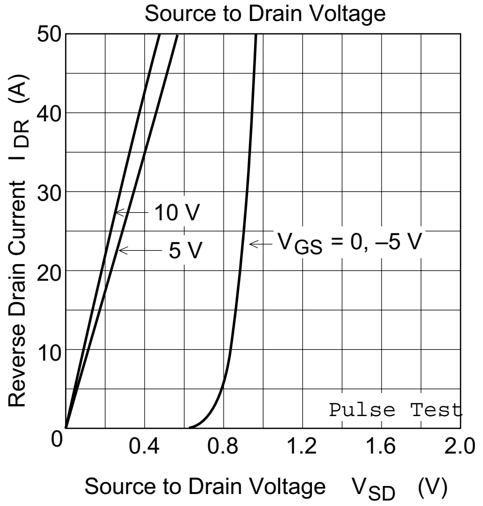

Body–Drain Diode Reverse Recovery Time
Reverse Recovery Time trr (ns)
Reverse Drain Current I DR (A)
di / dt = 50 A / μs
VGS = 0, Ta = 25 °C


Typical Capacitance vs. Drain to Source Voltage
Capacitance C (pF)
Drain to Source Voltage VDS (V)
Ciss
Coss
Crss
VGS = 0
f = 1 MHz

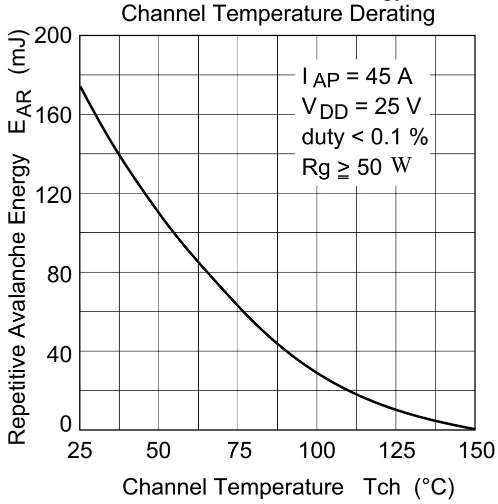

Dynamic Input Characteristics
Drain to Source Voltage VDS (V)
Gate to Source Voltage VGS (V)
Gate Charge Qg (nc)
I D = 45 A
VGS
VDS
VDD = 10 V
25 V
50 V
VDD = 50 V
25 V
10 V


Switching Characteristics
Switching Time t (ns)
Drain Current I D (A)
t d(off)
t f
t r
t d(on)
VGS = 10 V, VDD ≒ 30 V
PW = 10 μs, duty ≤ 1 %

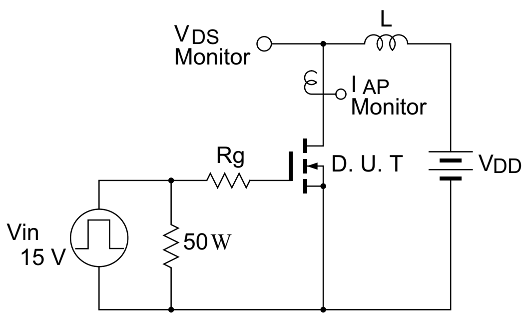
Reverse Drain Current vs.
Source to Drain Voltage



Maximum Avalanche Energy vs.
Channel Temperature Derating

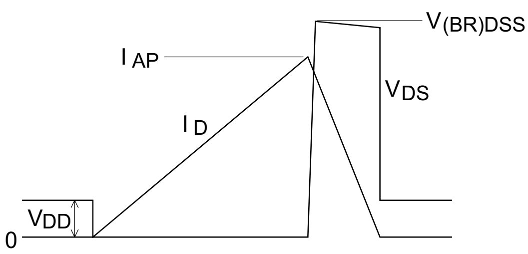


Avalanche Test Circuit

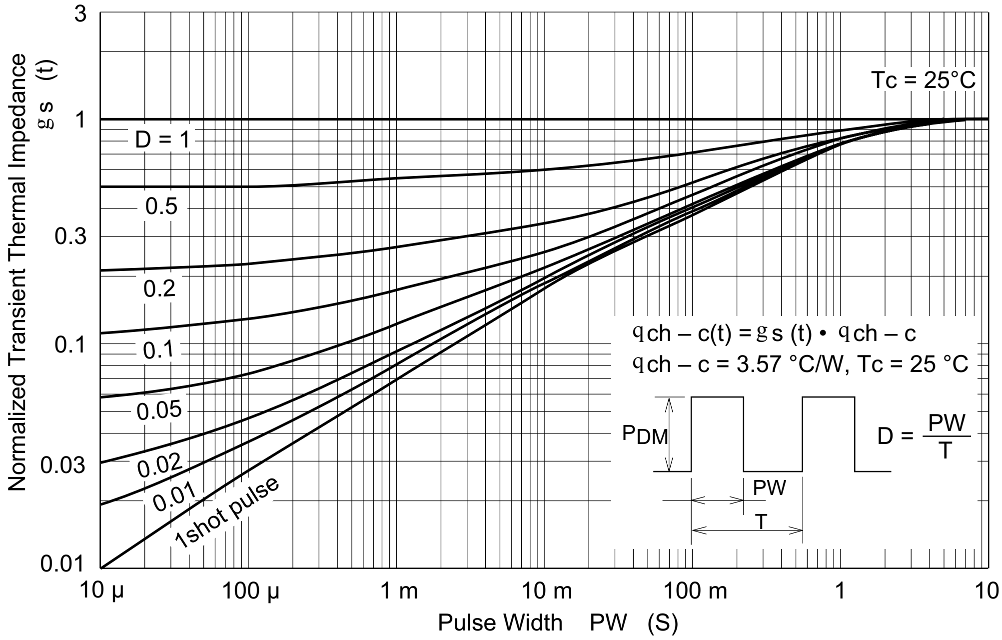


Avalanche Waveform

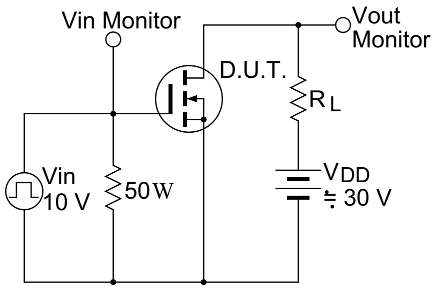
$$E_{AR} = \frac{1}{2} \cdot L \cdot I_{AP}^{2} \cdot \frac{V_{DSS}}{V_{DSS} - V_{DD}}$$



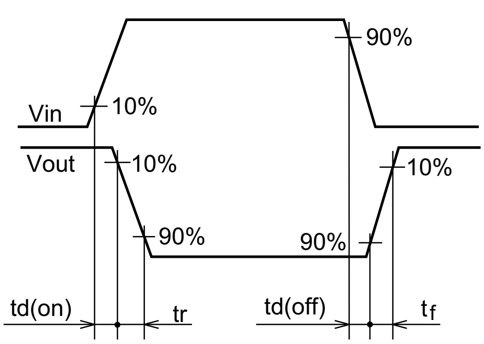
Normalized Transient Thermal Impedance vs. Pulse Width



Switching Time Test Circuit

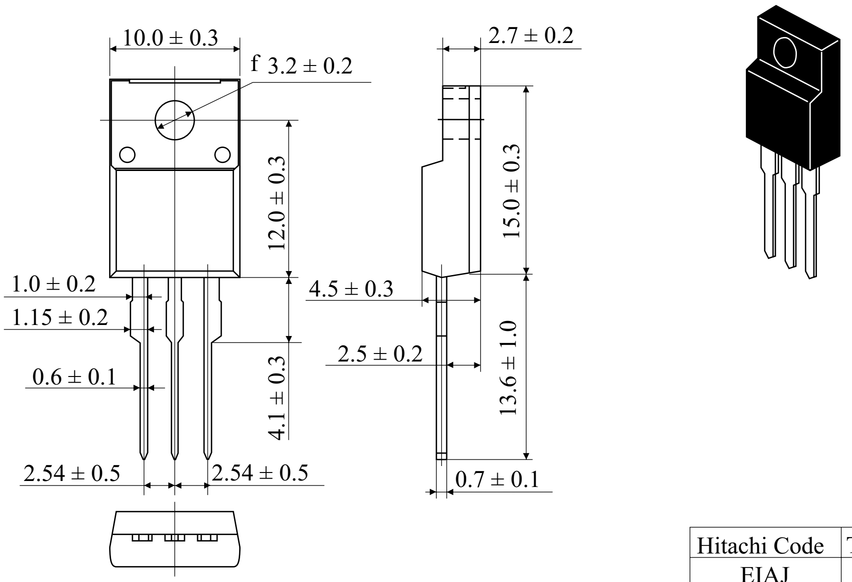


Waveform



Package Dimentions

Unit: mm



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National Semiconductor

August 2000

LMV321 / LMV358 / LMV324 Single/Dual/Quad General Purpose, Low Voltage, Rail-to-Rail Output Operational Amplifiers

General Description

The LMV358/324 are low voltage (2.7–5.5V) versions of the dual and quad commodity op amps, LM358/324, which currently operate at 5–30V. The LMV321 is the single version.

The LMV321/358/324 are the most cost effective solutions for the applications where low voltage operation, space saving and low price are needed. They offer specifications that meet or exceed the familiar LM358/324. The LMV321/358/324 have rail-to-rail output swing capability and the input common-mode voltage range includes ground. They all exhibit excellent speed-power ratio, achieving 1 MHz of bandwidth and 1 V/µs of slew rate with low supply current.

The LMV321 is available in space saving SC70-5, which is approximately half the size of SOT23-5. The small package saves space on pc boards, and enables the design of small portable electronic devices. It also allows the designer to place the device closer to the signal source to reduce noise pickup and increase signal integrity.

The chips are built with National's advanced submicron silicon-gate BiCMOS process. The LMV321/358/324 have bipolar input and output stages for improved noise performance and higher output current drive.

Features

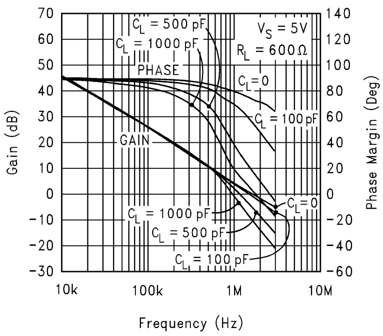
(For V^+ = 5V and V^- = 0V, Typical Unless Otherwise Noted)

- ☐ Guaranteed 2.7V and 5V Performance
- ☐ No Crossover Distortion
- ☐ Space Saving Package SC70-5 2.0x2.1x1.0mm
- ☐ Industrial Temp.Range −40˚C to +85˚C
- ☐ Gain-Bandwidth Product 1MHz
- ☐ Low Supply Current
  - LMV321 130µA
  - LMV358 210µA
  - LMV324 410µA
- ☐ Rail-to-Rail Output Swing
  - @ 10kΩ Load V^+−10mV
  - V^-+65mV
- ☐ V_{CM} −0.2V to V^+−0.8V

Applications

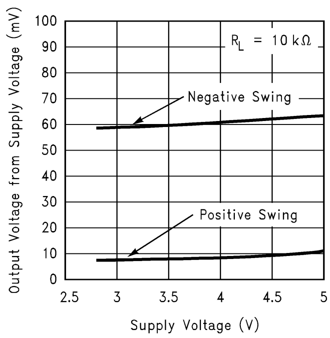
- Active Filters
- General Purpose Low Voltage Applications
- General Purpose Portable Devices

Gain and Phase vs Capacitive Load



DS100060-45

Output Voltage Swing vs Supply Voltage



DS100060-67

Absolute Maximum Ratings (Note 1)

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

ESD Tolerance (Note 2)	
Machine Model	100V
Human Body Model	
LMV358/324	2000V
LMV321	900V
Differential Input Voltage	± Supply Voltage
Supply Voltage ($V^+–V^-$)	5.5V
Output Short Circuit to V^+	(Note 3)
Output Short Circuit to V^-	(Note 4)
Soldering Information	
Infrared or Convection (20 sec)	235˚C
Storage Temp. Range	−65˚C to 150˚C
Junction Temp. (T_j, max) (Note 5)	150˚C

Operating Ratings (Note 1)

Supply Voltage	2.7V to 5.5V
Temperature Range	
LMV321, LMV358, LMV324	$−40˚C \leq T_J \leq 85˚C$
Thermal Resistance (θ_{JA})(Note 10)	
5-pin SC70-5	478˚C/W
5-pin SOT23-5	265˚C/W
8-Pin SOIC	190˚C/W
8-Pin MSOP	235˚C/W
14-Pin SOIC	145˚C/W
14-Pin TSSOP	155˚C/W

2.7V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25˚C, V^+ = 2.7V, V^- = 0V, V_{CM} = 1.0V, V_O = $V^+/2$ and R_L > 1 MΩ.

Symbol	Parameter	Conditions	Typ (Note 6)	Limit (Note 7)	Units
V_{OS}	Input Offset Voltage		1.7	7	mV max
TCV_{OS}	Input Offset Voltage Average Drift		5		μV/˚C
I_B	Input Bias Current		11	250	nA max
I_{OS}	Input Offset Current		5	50	nA max
CMRR	Common Mode Rejection Ratio	$0V \leq V_{CM} \leq 1.7V$	63	50	dB min
PSRR	Power Supply Rejection Ratio	$2.7V \leq V^+ \leq 5V$ V_O = 1V	60	50	dB min
V_{CM}	Input Common-Mode Voltage Range	For CMRR≥50dB	−0.2	0	V min
			1.9	1.7	V max
V_O	Output Swing	R_L = 10kΩ to 1.35V	V^+ -10	V^+ -100	mV min
			60	180	mV max
I_S	Supply Current	LMV321	80	170	μA max
		LMV358 Both amplifiers	140	340	μA max
		LMV324 All four amplifiers	260	680	μA max

2.7V AC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25˚C, V^+ = 2.7V, V^- = 0V, V_{CM} = 1.0V, V_O = V^+/2 and R_L > 1 MΩ.

Symbol	Parameter	Conditions	Typ (Note 6)	Limit (Note 7)	Units
GBWP	Gain-Bandwidth Product	C_L = 200 pF	1		MHz
Φ_m	Phase Margin		60		Deg
G_m	Gain Margin		10		dB
e_n	Input-Referred Voltage Noise	f = 1 kHz	46		$\frac{nV}{\sqrt{Hz}}$
i_n	Input-Referred Current Noise	f = 1 kHz	0.17		$\frac{pA}{\sqrt{Hz}}$

5V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25˚C, V^+ = 5V, V^- = 0V, V_{CM} = 2.0V, V_O = V^+/2 and R_L > 1 MΩ. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Typ (Note 6)	Limit (Note 7)	Units
V_{OS}	Input Offset Voltage		1.7	7 **9**	mV max
TCV_{OS}	Input Offset Voltage Average Drift		5		μV/˚C
I_B	Input Bias Current		15	250 **500**	nA max
I_{OS}	Input Offset Current		5	50 **150**	nA max
CMRR	Common Mode Rejection Ratio	0V ≤ V_{CM} ≤ 4V	65	50	dB min
PSRR	Power Supply Rejection Ratio	2.7V ≤ V^+ ≤ 5V V_O = 1V V_{CM} = 1V	60	50	dB min
V_{CM}	Input Common-Mode Voltage Range	For CMRR≥50dB	−0.2	0	V min
			4.2	4	V max
A_V	Large Signal Voltage Gain (Note 8)	R_L = 2kΩ	100	15 **10**	V/mV min
V_O	Output Swing	R_L = 2kΩ to 2.5V	V^+ -40	V^+ -300 **V^+ -400**	mV min
			120	300 **400**	mV max
		R_L = 10kΩ to 2.5V	V^+ -10	V^+ -100 **V^+ -200**	mV min
			65	180 **280**	mV max
I_O	Output Short Circuit Current	Sourcing, V_O = 0V	60	5	mA min
		Sinking, V_O = 5V	160	10	mA min
I_S	Supply Current	LMV321	130	250 **350**	μA max
		LMV358 Both amplifiers	210	440 **615**	μA max
		LMV324 All four amplifiers	410	830 **1160**	μA max

5V AC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25˚C, V^+ = 5V, V^- = 0V, V_{CM} = 2.0V, V_O = $V^+/2$ and R_L > 1 MΩ. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Typ (Note 6)	Limit (Note 7)	Units
SR	Slew Rate	(Note 9)	1		V/µs
GBWP	Gain-Bandwidth Product	C_L = 200 pF	1		MHz
Φ_m	Phase Margin		60		Deg
G_m	Gain Margin		10		dB
e_n	Input-Referred Voltage Noise	f = 1 kHz,	39		$\frac{nV}{\sqrt{Hz}}$
i_n	Input-Referred Current Noise	f = 1 kHz	0.21		$\frac{pA}{\sqrt{Hz}}$

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and the test conditions, see the Electrical Characteristics.

Note 2: Human body model, 1.5 kΩ in series with 100 pF. Machine model, 0Ω in series with 200 pF.

Note 3: Shorting output to V^+ will adversely affect reliability.

Note 4: Shorting output to V^- will adversely affect reliability.

Note 5: The maximum power dissipation is a function of $T_{J(max)}$, θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is P_D = $(T_{J(max)}-T_A)/\theta_{JA}$. All numbers apply for packages soldered directly into a PC board.

Note 6: Typical values represent the most likely parametric norm.

Note 7: All limits are guaranteed by testing or statistical analysis.

Note 8: R_L is connected to V^-. The output voltage is 0.5V ≤ V_O ≤ 4.5V.

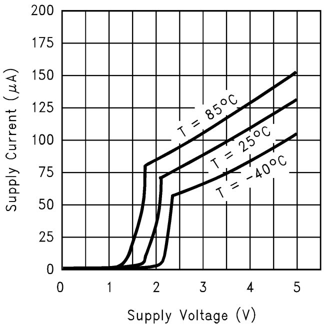
Note 9: Connected as voltage follower with 3V step input. Number specified is the slower of the positive and negative slew rates.

Note 10: All numbers are typical, and apply for packages soldered directly onto a PC board in still air.

Typical Performance Characteristics

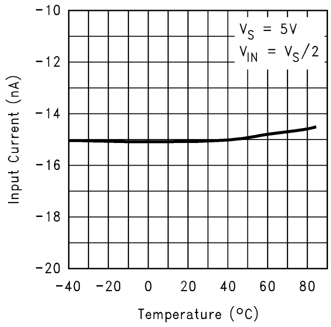
Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C.

Supply Current vs Supply Voltage (LMV321)



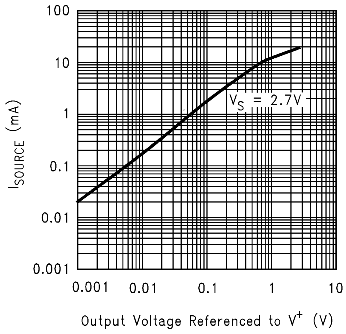
DS100060-73

Input Current vs Temperature



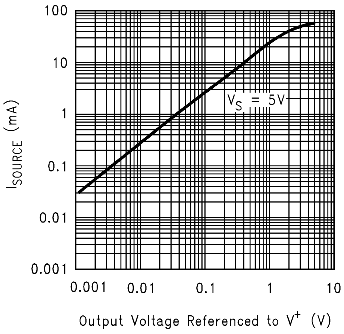
DS100060-A9

Sourcing Current vs Output Voltage



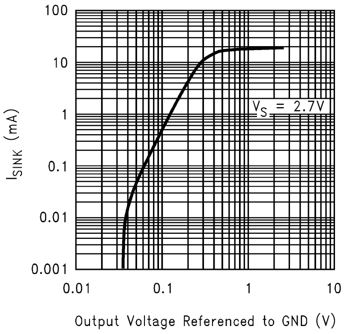
DS100060-69

Sourcing Current vs Output Voltage



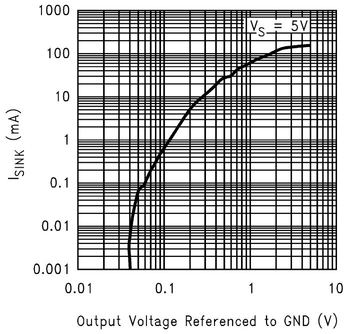
DS100060-68

Sinking Current vs Output Voltage



DS100060-70

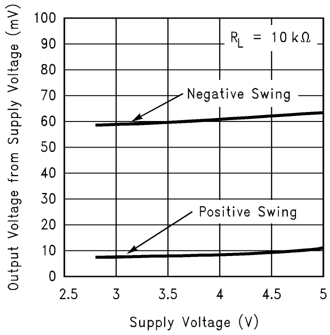
Sinking Current vs Output Voltage



DS100060-71

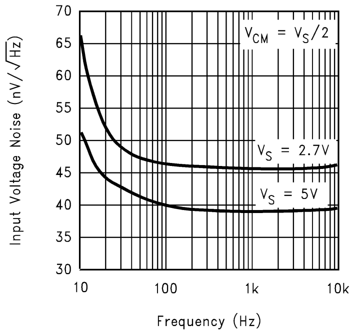
Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

Output Voltage Swing vs Supply Voltage



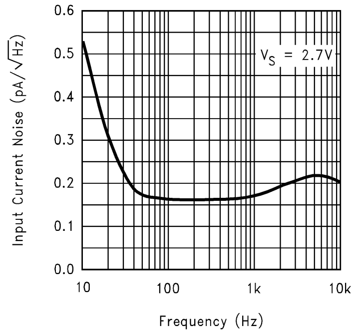
DS100060-67

Input Voltage Noise vs Frequency



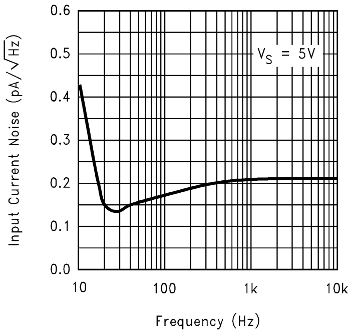
DS100060-56

Input Current Noise vs Frequency



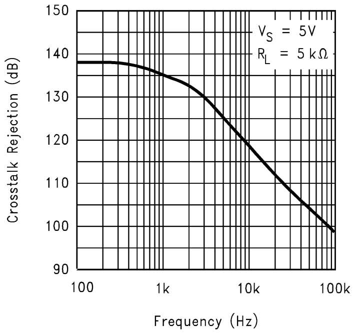
DS100060-60

Input Current Noise vs Frequency



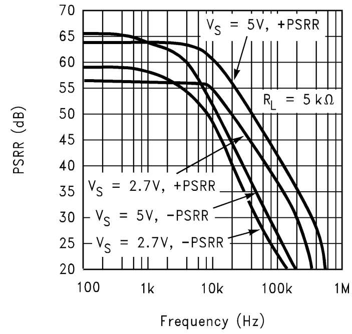
DS100060-58

Crosstalk Rejection vs Frequency



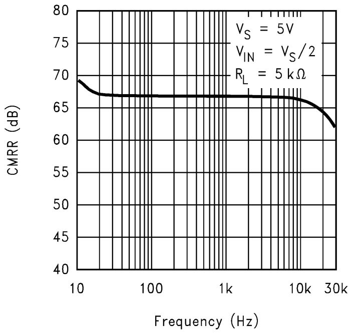
DS100060-61

PSRR vs Frequency



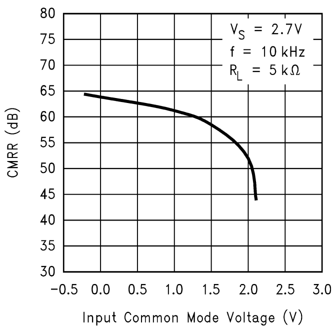
DS100060-51

CMRR vs Frequency



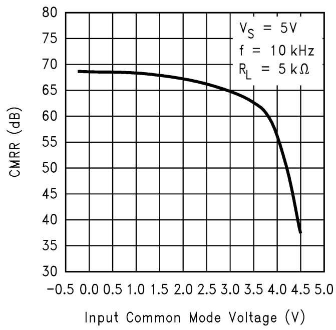
DS100060-62

CMRR vs Input Common Mode Voltage



DS100060-64

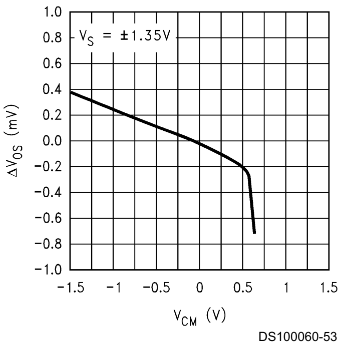
CMRR vs Input Common Mode Voltage



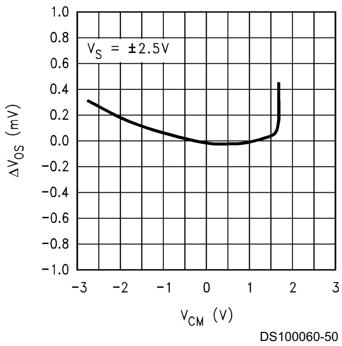
DS100060-63

Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

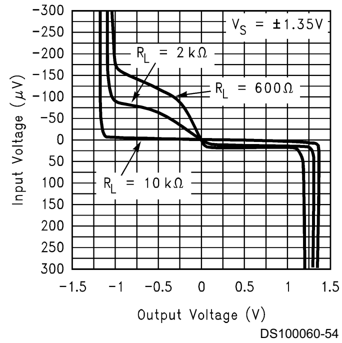
Δ V_{OS} vs CMR



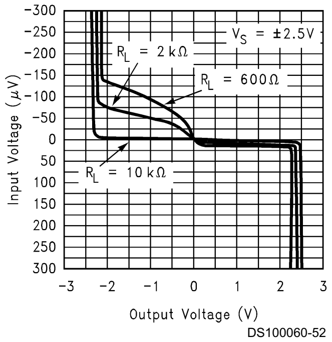
Δ V_{OS} vs CMR



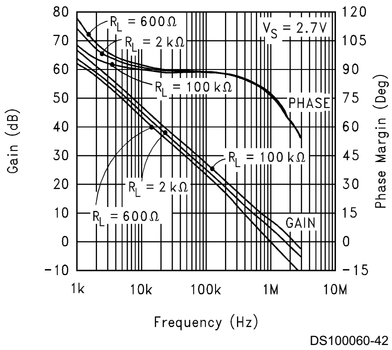
Input Voltage vs Output Voltage



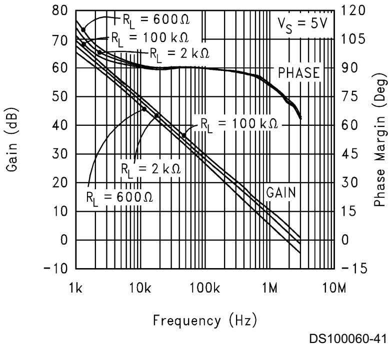
Input Voltage vs Output Voltage



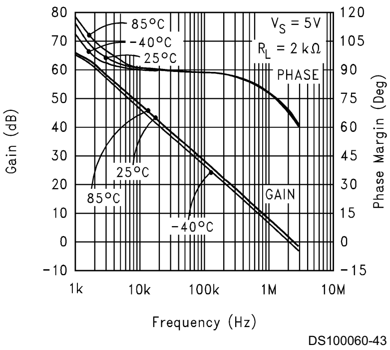
Open Loop Frequency Response



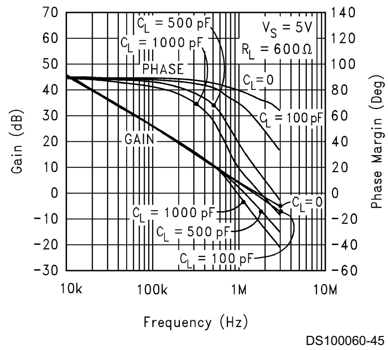
Open Loop Frequency Response



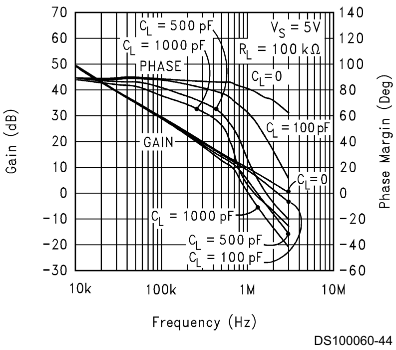
Open Loop Frequency Response vs Temperature



Gain and Phase vs Capacitive Load

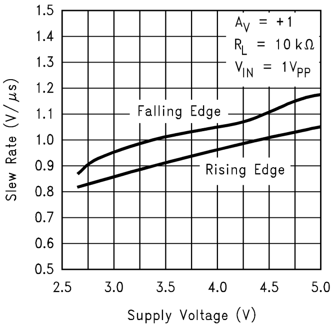


Gain and Phase vs Capacitive Load



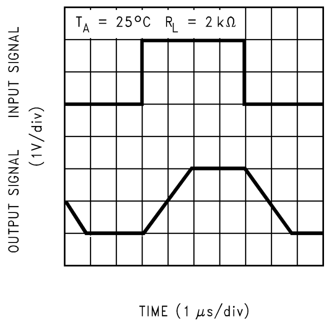
Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

Slew Rate vs Supply Voltage



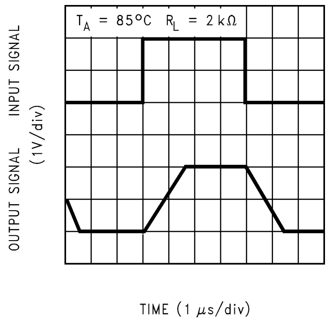
DS100060-57

Non-Inverting Large Signal Pulse Response



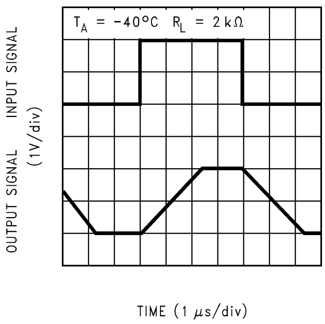
DS100060-88

Non-Inverting Large Signal Pulse Response



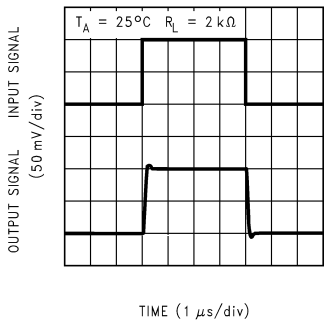
DS100060-A1

Non-Inverting Large Signal Pulse Response



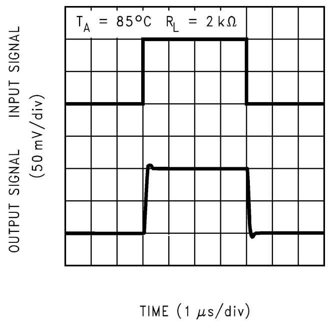
DS100060-A0

Non-Inverting Small Signal Pulse Response



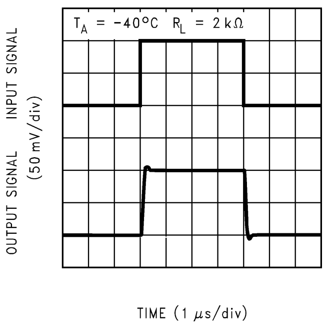
DS100060-89

Non-Inverting Small Signal Pulse Response



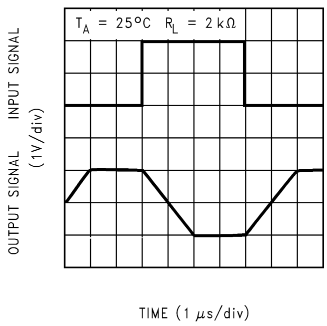
DS100060-A2

Non-Inverting Small Signal Pulse Response



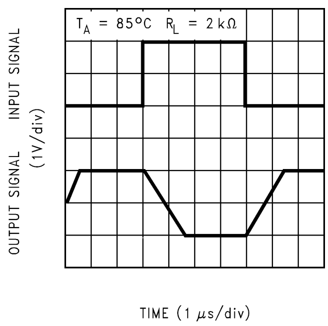
DS100060-A3

Inverting Large Signal Pulse Response



DS100060-90

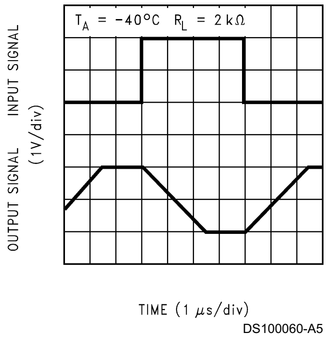
Inverting Large Signal Pulse Response



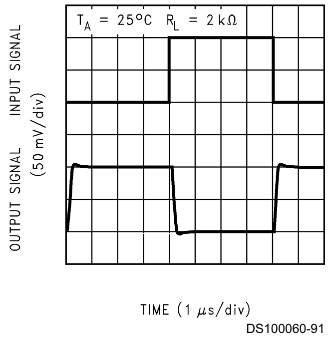
DS100060-A4

Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

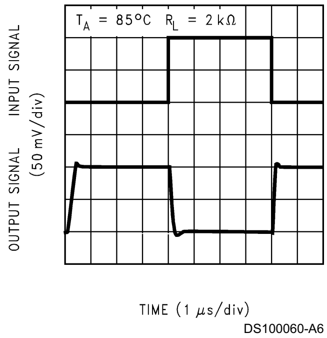
Inverting Large Signal Pulse Response



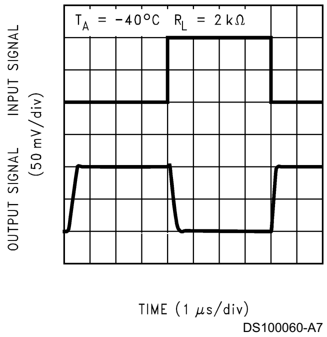
Inverting Small Signal Pulse Response



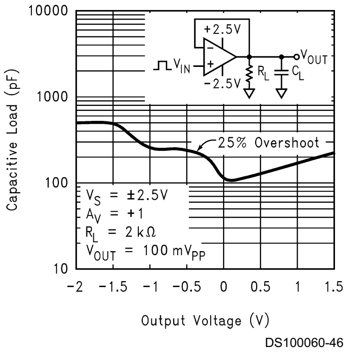
Inverting Small Signal Pulse Response



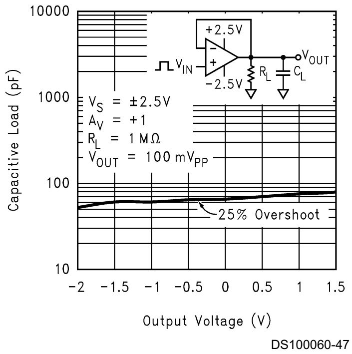
Inverting Small Signal Pulse Response



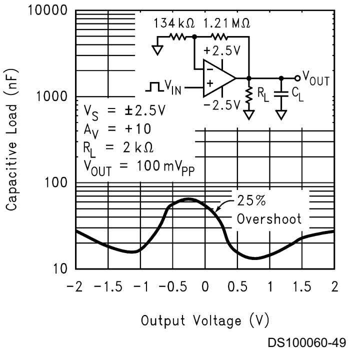
Stability vs Capacitive Load



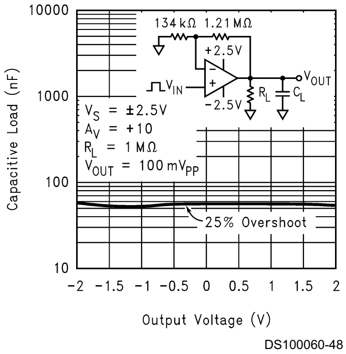
Stability vs Capacitive Load



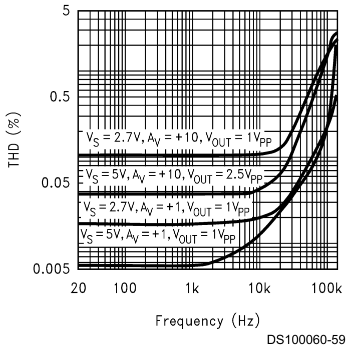
Stability vs Capacitive Load



Stability vs Capacitive Load

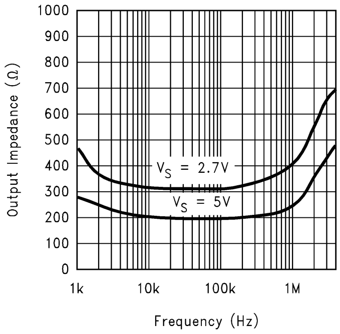


THD vs Frequency



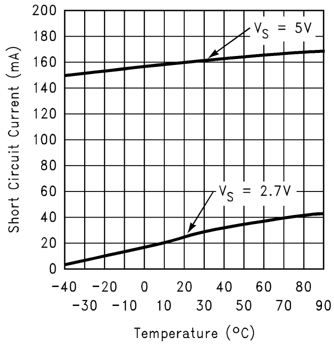
Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

Open Loop Output Impedance vs Frequency



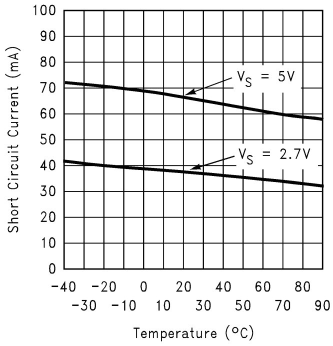
DS100060-55

Short Circuit Current vs Temperature (Sinking)



DS100060-65

Short Circuit Current vs Temperature (Sourcing)



DS100060-66

Application Notes

1.0 Benefits of the LMV321/358/324

Size. The small footprints of the LMV321/358/324 packages save space on printed circuit boards, and enable the design of smaller electronic products, such as cellular phones, pagers, or other portable systems. The low profile of the LMV321/358/324 make them possible to use in PCMCIA type III cards.

Signal Integrity. Signals can pick up noise between the signal source and the amplifier. By using a physically smaller amplifier package, the LMV321/358/324 can be placed closer to the signal source, reducing noise pickup and increasing signal integrity.

Simplified Board Layout. These products help you to avoid using long pc traces in your pc board layout. This means that no additional components, such as capacitors and resistors, are needed to filter out the unwanted signals due to the interference between the long pc traces.

Low Supply Current. These devices will help you to maximize battery life. They are ideal for battery powered systems.

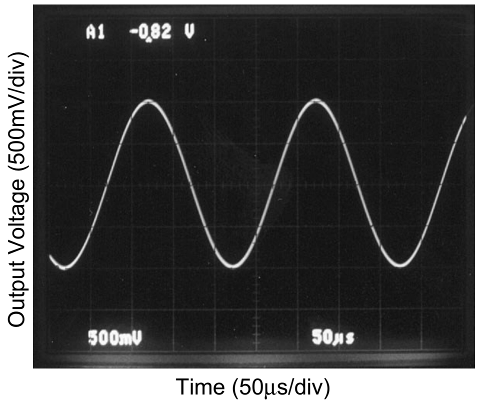
Low Supply Voltage. National provides guaranteed performance at 2.7V and 5V. These guarantees ensure operation throughout the battery lifetime.

Rail-to-Rail Output. Rail-to-rail output swing provides maximum possible dynamic range at the output. This is particularly important when operating on low supply voltages.

Input Includes Ground. Allows direct sensing near GND in single supply operation.

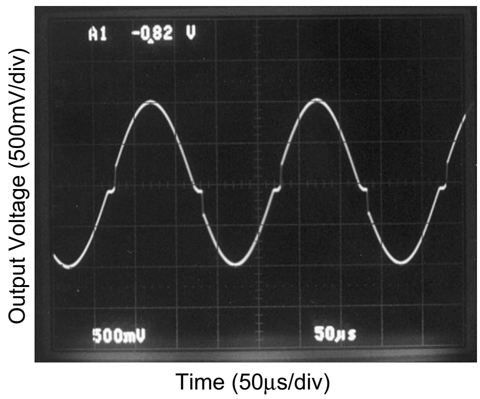
The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than −0.3V (at 25˚C). An input clamp diode with a resistor to the IC input terminal can be used.

Ease of Use & No Crossover Distortion. The LMV321/358/324 offer specifications similar to the familiar LM324. In addition, the new LMV321/358/324 effectively eliminate the output crossover distortion. The scope photos in *Figure 1* and *Figure 2* compare the output swing of the LMV324 and the LM324 in a voltage follower configuration, with V_S= ± 2.5V and R_L (= 2kΩ) connected to GND. It is apparent that the crossover distortion has been eliminated in the new LMV324.



DS100060-97

FIGURE 1. Output Swing of LMV324



DS100060-98

FIGURE 2. Output Swing of LM324

2.0 Capacitive Load Tolerance

The LMV321/358/324 can directly drive 200 pF in unity-gain without oscillation. The unity-gain follower is the most sensitive configuration to capacitive loading. Direct capacitive loading reduces the phase margin of amplifiers. The combination of the amplifier's output impedance and the capacitive load induces phase lag. This results in either an underdamped pulse response or oscillation. To drive a heavier capacitive load, circuit in *Figure 3* can be used.

Application Notes (Continued)

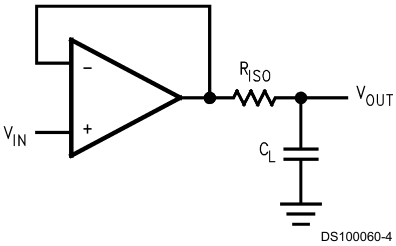


FIGURE 3. Indirectly Driving A Capacitive Load Using Resistive Isolation

In *Figure 3* , the isolation resistor R_{ISO} and the load capacitor C_L form a pole to increase stability by adding more phase margin to the overall system. The desired performance depends on the value of R_{ISO}. The bigger the R_{ISO} resistor value, the more stable Vout will be. *Figure 4* is an output waveform of *Figure 3* using 620Ω for R_{ISO} and 510 pF for C_L..

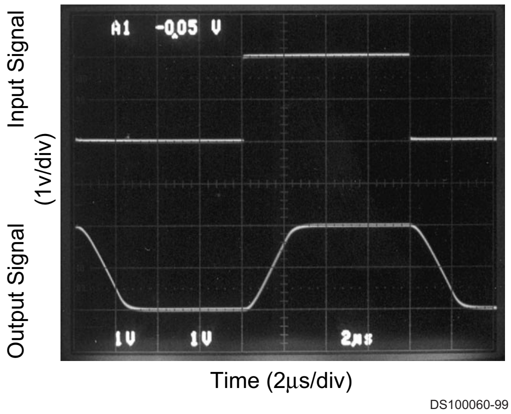


FIGURE 4. Pulse Response of the LMV324 Circuit in Figure 3

The circuit in *Figure 5* is an improvement to the one in *Figure 3* because it provides DC accuracy as well as AC stability. If there were a load resistor in *Figure 3*, the output would be voltage divided by R_{ISO} and the load resistor. Instead, in *Figure 5*, R_F provides the DC accuracy by using feed-forward techniques to connect V_{IN} to R_L. Caution is needed in choosing the value of R_F due to the input bias current of the LMV321/358/324. C_F and R_{ISO} serve to counteract the loss of phase margin by feeding the high frequency component of the output signal back to the amplifier's inverting input, thereby preserving phase margin in the overall feedback loop. Increased capacitive drive is possible by increasing the value of C_F . This in turn will slow down the pulse response.

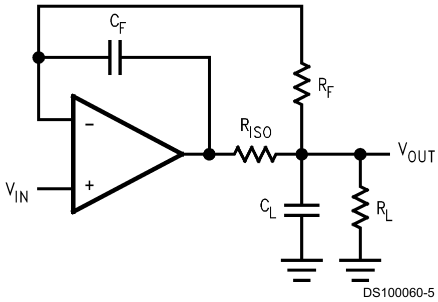


FIGURE 5. Indirectly Driving A Capacitive Load with DC Accuracy

3.0 Input Bias Current Cancellation

The LMV321/358/324 family has a bipolar input stage. The typical input bias current of LMV321/358/324 is 15 nA with 5V supply. Thus a 100 kΩ input resistor will cause 1.5 mV of error voltage. By balancing the resistor values at both inverting and non-inverting inputs, the error caused by the amplifier's input bias current will be reduced. The circuit in *Figure 6* shows how to cancel the error caused by input bias current.

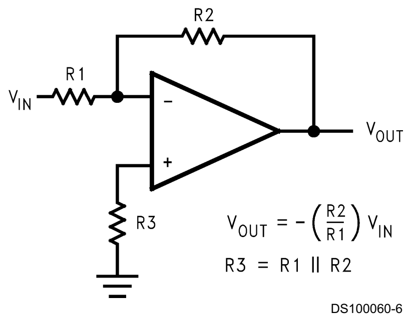


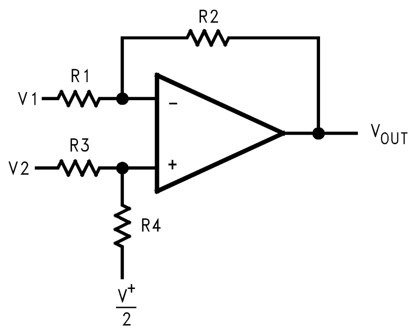
FIGURE 6. Cancelling the Error Caused by Input Bias Current

4.0 Typical Single-Supply Application Circuits

4.1 Difference Amplifier

The difference amplifier allows the subtraction of two voltages or, as a special case, the cancellation of a signal common to two inputs. It is useful as a computational amplifier, in making a differential to single-ended conversion or in rejecting a common mode signal.

Application Notes (Continued)



DS100060-7

$$V_{OUT} = \left(\frac{R1 + R2}{R3 + R4}\right)\frac{R4}{R1}V_2 - \frac{R2}{R1}V_1 + \left(\frac{R1 + R2}{R3 + R4}\right)\frac{R3}{R1} \bullet \frac{V^+}{2}$$

for $R1 = R3$ and $R2 = R4$

$$V_{OUT} = \frac{R2}{R1}\left(V_2 - V_1\right) + \frac{V^+}{2}$$

DS100060-19

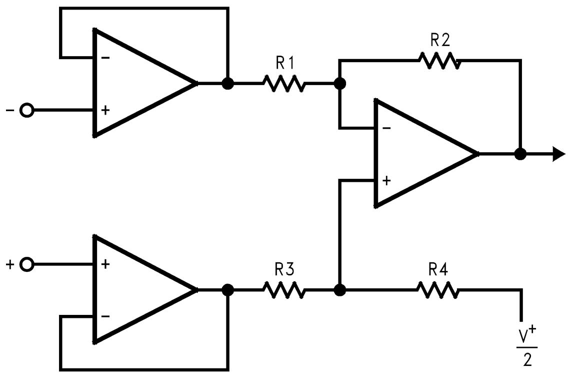
FIGURE 7. Difference Amplifier

4.2 Instrumentation Circuits

The input impedance of the previous difference amplifier is set by the resistors R_1, R_2, R_3, and R_4. To eliminate the problems of low input impedance, one way is to use a voltage follower ahead of each input as shown in the following two instrumentation amplifiers.

4.2.1 Three-op-amp Instrumentation Amplifier

The quad LMV324 can be used to build a three-op-amp instrumentation amplifier as shown in *Figure 8*.



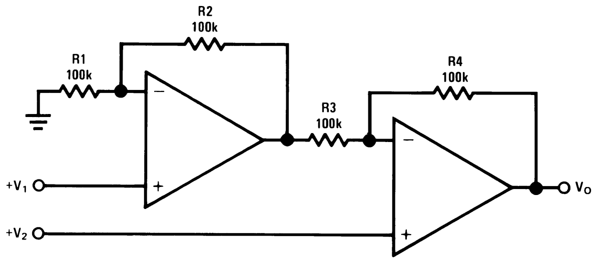
DS100060-85

FIGURE 8. Three-op-amp Instrumentation Amplifier

The first stage of this instrumentation amplifier is a differential-input, differential-output amplifier, with two voltage followers. These two voltage followers assure that the input impedance is over 100 MΩ. The gain of this instrumentation amplifier is set by the ratio of R_2/R_1. R_3 should equal R_1, and R_4 equal R_2. Matching of R_3 to R_1 and R_4 to R_2 affects the CMRR. For good CMRR over temperature, low drift resistors should be used. Making R_4 slightly smaller than R_2 and adding a trim pot equal to twice the difference between R_2 and R_4 will allow the CMRR to be adjusted for optimum.

4.2.2 Two-op-amp Instrumentation Amplifier

A two-op-amp instrumentation amplifier can also be used to make a high-input-impedance dc differential amplifier (*Figure 9*) . As in the three-op-amp circuit, this instrumentation amplifier requires precise resistor matching for good CMRR. R4 should equal to R1 and R3 should equal R2.



DS100060-11

$$V_O = \left(1 + \frac{R4}{R3}\right)\left(V_2 - V_1\right), \text{ where } R1 = R4 \text{ and } R2 = R3$$

As shown: $V_O = 2\left(V_2 - V_1\right)$

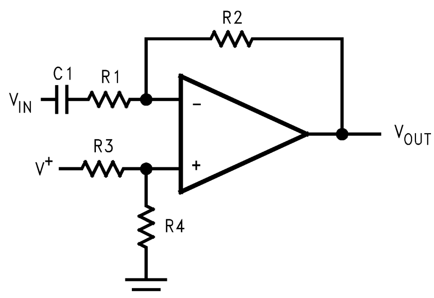
DS100060-35

FIGURE 9. Two-Op-amp Instrumentation Amplifier

4.3 Single-Supply Inverting Amplifier

There may be cases where the input signal going into the amplifier is negative. Because the amplifier is operating in single supply voltage, a voltage divider using R_3 and R_4 is implemented to bias the amplifier so the input signal is within the input common-mode voltage range of the amplifier. The capacitor C_1 is placed between the inverting input and resistor R_1 to block the DC signal going into the AC signal source, V_{IN}. The values of R_1 and C_1 affect the cutoff frequency, fc $= 1/2\pi R_1C_1$.

As a result, the output signal is centered around mid-supply (if the voltage divider provides $V^+/2$ at the non-inverting input). The output can swing to both rails, maximizing the signal-to-noise ratio in a low voltage system.



DS100060-13

$$V_{OUT} = -\frac{R2}{R1}V_{IN}$$

DS100060-20

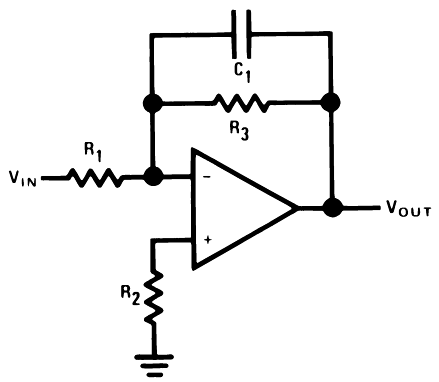
FIGURE 10. Single-Supply Inverting Amplifier

4.4 Active Filter

4.4.1 Simple Low-Pass Active Filter

The simple low-pass filter is shown in *Figure 11*. Its low-frequency gain ($\omega \rightarrow 0$) is defined by $-R_3/R_1$. This allows low-frequency gains other than unity to be obtained. The filter has a -20dB/decade roll-off after its corner frequency fc. R_2 should be chosen equal to the parallel combination of R_1 and R_3 to minimize errors due to bias current. The frequency response of the filter is shown in *Figure 12*.

Application Notes (Continued)



DS100060-14

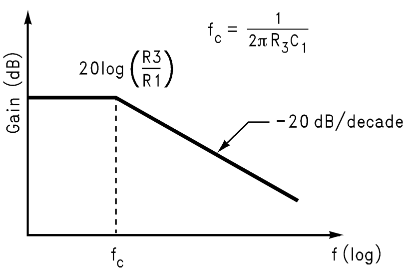
$$A_L = -\frac{R_3}{R_1}$$

$$f_c = \frac{1}{2\pi R_3 C_1}$$

$$R_2 = R_1 \parallel R_3$$

DS100060-37

FIGURE 11. Simple Low-Pass Active Filter



DS100060-15

FIGURE 12. Frequency Response of Simple Low-Pass Active Filter in Figure 11

Note that the single-op-amp active filters are used in to the applications that require low quality factor, Q(≤ 10), low frequency (≤ 5 kHz), and low gain (≤ 10), or a small value for the product of gain times Q (≤ 100). The op amp should have an open loop voltage gain at the highest frequency of interest at least 50 times larger than the gain of the filter at this frequency. In addition, the selected op amp should have a slew rate that meets the following requirement:

SlewRate ≥ 0.5 x ($\omega_H V_{OPP}$) x 10^{-6} V/μsec

where ω_H is the highest frequency of interest, and V_{opp} is the output peak-to-peak voltage.

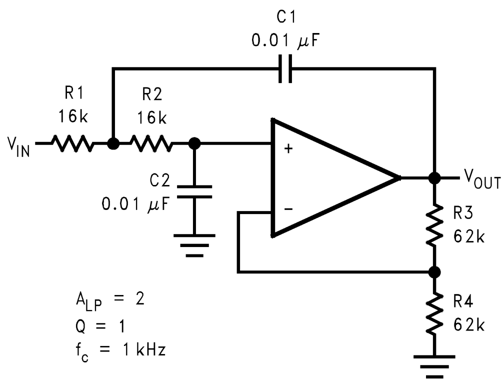
4.4.2 Sallen-Key 2nd-Order Active Low-Pass Filter

The Sallen-Key 2nd-order active low-pass filter is illustrated in *Figure 13*. The dc gain of the filter is expressed as

$$A_{LP} = \frac{R_3}{R_4} + 1 \quad (1)$$

Its transfer function is

$$\frac{V_{OUT}}{V_{IN}}(S) = \frac{\frac{1}{C_1 C_2 R_1 R_2} A_{LP}}{S^2 + S\left(\frac{1}{C_1 R_1} + \frac{1}{C_1 R_2} + \frac{1}{C_2 R_2} - \frac{A_{LP}}{C_2 R_2}\right) + \frac{1}{C_1 C_2 R_1 R_2}} \quad (2)$$



DS100060-16

FIGURE 13. Sallen-Key 2nd-Order Active Low-Pass Filter

The following paragraphs explain how to select values for R_1, R_2, R_3, R_4, C_1, and C_2 for given filter requirements, such as A_{LP}, Q, and f_c.

The standard form for a 2nd-order low pass filter is

$$\frac{V_{OUT}}{V_{IN}}(S) = \frac{A_{LP}\,\omega_c^2}{S^2 + \left(\frac{\omega_c}{Q}\right)S + \omega_c^2} \quad (3)$$

where

Q: Pole Quality Factor

ω_C: Corner Frequency

Comparison between the *Equation (2)* and *Equation (3)* yields

$$\omega_c^2 = \frac{1}{C_1 C_2 R_1 R_2} \quad (4)$$

$$\frac{\omega_c}{Q} = \frac{1}{C_1 R_1} + \frac{1}{C_1 R_2} + \frac{1}{C_2 R_2} - \frac{A_{LP}}{C_2 R_2} \quad (5)$$

To reduce the required calculations in filter design, it is convenient to introduce normalization into the components and design parameters. To normalize, let $\omega_C = \omega_n$ = 1rad/s, and $C_1 = C_2 = C_n$ = 1F, and substitute these values into *Equation (4)* and *Equation (5)*. From *Equation (4)*, we obtain

$$R_1 = \frac{1}{R_2} \quad (6)$$

From *Equation (5)*, we obtain

$$R_2 = \frac{1 \pm \sqrt{1 - 4Q^2(2 - A_{LP})}}{2Q} \quad (7)$$

For minimum dc offset, V+ = V-, the resistor values at both inverting and non-inverting inputs should be equal, which means

$$R_1 + R_2 = \frac{R_3 R_4}{R_3 + R_4} \quad (8)$$

From *Equation (1)* and *Equation (8)*, we obtain

$$R_3 = (R_1 + R_2)A_{LP} \quad (9)$$

Application Notes (Continued)

$$R_4 = \left(\frac{A_{LP}}{A_{LP}-1}\right)(R_1 + R_2) \tag{10}$$

The values of C_1 and C_2 are normally close to or equal to

$$C = \frac{10}{f_c}\,\mu F$$

As a design example:

Require: $A_{LP} = 2$, Q = 1, fc = 1KHz

Start by selecting C1 and C2. Choose a standard value that is close to

$$C = \frac{10}{f_c}\,\mu F$$

$$C_1 = C_2 = \frac{10}{1 \times 10^3}\,\mu F = 0.01\,\mu F$$

From *Equations (6), (7), (9), (10)*,

$R_1 = 1\Omega$

$R_2 = 1\Omega$

$R_3 = 4\Omega$

$R_4 = 4\Omega$

The above resistor values are normalized values with ω_n=1rad/s and $C_1 = C_2 = C_n$ = 1F. To scale the normalized cut-off frequency and resistances to the real values, two scaling factors are introduced, frequency scaling factor (k_f) and impedance scaling factor (k_m).

$$k_f = \frac{\omega_c}{\omega_n} = \frac{2\pi \times 1 \times 10^3}{1} = 2\pi \times 10^3$$

$$k_m k_f = \frac{Cn}{C1}$$

$$k_m = 1.59 \times 10^4$$

Scaled values:

$R_2 = R_1 = 15.9\ k\Omega$

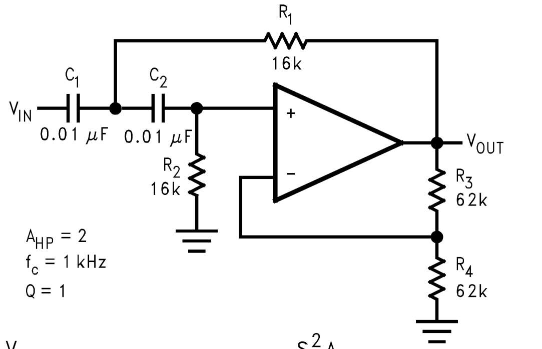
$R_3 = R_4 = 63.6\ k\Omega$

$C_1 = C_2 = 0.01\ \mu F$

An adjustment to the scaling may be made in order to have realistic values for resistors and capacitors. The actual value used for each component is shown in the circuit.

4.4.3 2nd-order High Pass Filter

A 2nd-order high pass filter can be built by simply inter-changing those frequency selective components (R_1, R_2, C_1, C_2) in the Sallen-Key 2nd-order active low pass filter. As shown in *Figure 14*, resistors become capacitors, and capacitors become resistors. The resulted high pass filter has the same corner frequency and the same maximum gain as the previous 2nd-order low pass filter if the same components are chosen.



$$\frac{V_{OUT}}{V_{IN}}(S) = \frac{S^2 A_{HP}}{S^2 + S\left(\frac{1}{C_1 R_2} + \frac{1}{C_2 R_2} + \frac{(1 - A_{HP})}{C_1 R_1}\right) + \frac{1}{C_1 C_2 R_1 R_2}}$$

Where $A_{HP} = 1 + \frac{R_3}{R_4}$

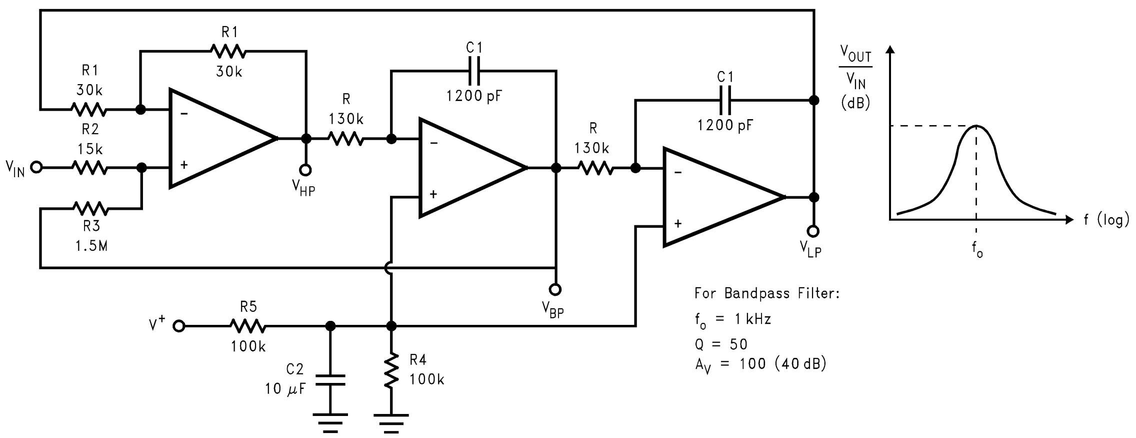
DS100060-83

FIGURE 14. Sallen-Key 2nd-Order Active High-Pass Filter

4.4.4 State Variable Filter

A state variable filter requires three op amps. One convenient way to build state variable filters is with a quad op amp, such as the LMV324 (*Figure 15*).

This circuit can simultaneously represent a low-pass filter, high-pass filter, and bandpass filter at three different outputs. The equations for these functions are listed below. It is also called ″Bi-Quad″ active filter as it can produce a transfer function which is quadratic in both numerator and denominator.



DS100060-39

FIGURE 15. State Variable Active Filter

Application Notes (Continued)

$$V_{LP} = \left(\frac{2R_3}{R_2 + R_3}\right) \frac{\frac{1}{R^2C^2}}{S^2 + \frac{1}{\left(\frac{R_2+R_3}{2R_2}\right)RC} S + \frac{1}{R^2C^2}} V_{IN}$$

$$V_{HP} = \left(\frac{2R_3}{R_2 + R_3}\right) \frac{S^2}{S^2 + \frac{1}{\left(\frac{R_2+R_3}{2R_2}\right)RC} S + \frac{1}{R^2C^2}} V_{IN}$$

$$V_{BP} = \left(\frac{2R_3}{R_2 + R_3}\right) \frac{\left(\frac{1}{RC}\right)S}{S^2 + \frac{1}{\left(\frac{R_2+R_3}{2R_2}\right)RC} S + \frac{1}{R^2C^2}} V_{IN}$$

where for all three filters,

$$Q = \frac{R_2 + R_3}{2R_2} \qquad (11)$$

$$\omega_0 = \frac{1}{RC} \quad \text{(resonant frequency)} \qquad (12)$$

A design example for a bandpass filter is shown below:

Assume the system design requires a bandpass filter with f_O = 1 kHz and Q = 50. What needs to be calculated are capacitor and resistor values.

First choose convenient values for C_1, R_1 and R_2:

$$C_1 = 1200\text{ pF}$$

$$2R2 = R_1 = 30\text{ k}\Omega$$

Then from *Equation (11)*,

$$R_3 = R_2(2Q-1)$$

$$R_3 = 15\text{ k}\Omega \times (2 \times 50-1)$$

$$= 1.5\text{ M}\Omega$$

From *Equation (12)*,

$$R = \frac{1}{\omega_0 C_1}$$

$$R = \frac{1}{(2\pi \times 10^3)(1.2 \times 10^{-9})}$$

$$= 132.7\text{ k}\Omega$$

From the above calculated values, the midband gain is $H_0 = R_3/R_2$ = 100 (40dB). The nearest 5% standard values have been added to *Figure 15*.

4.5 Pulse Generators and Oscillators

A pulse generator is shown in *Figure 16*. Two diodes have been used to separate the charge and discharge paths to capacitor C.

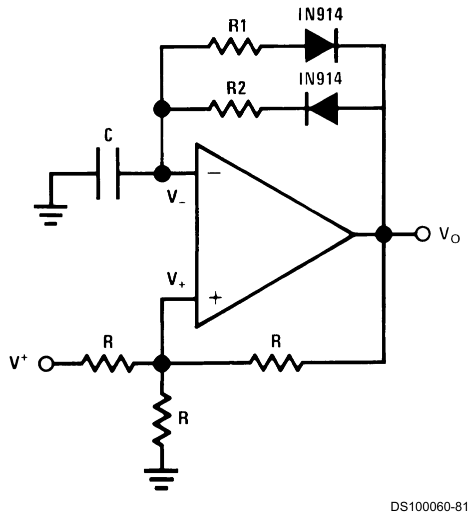
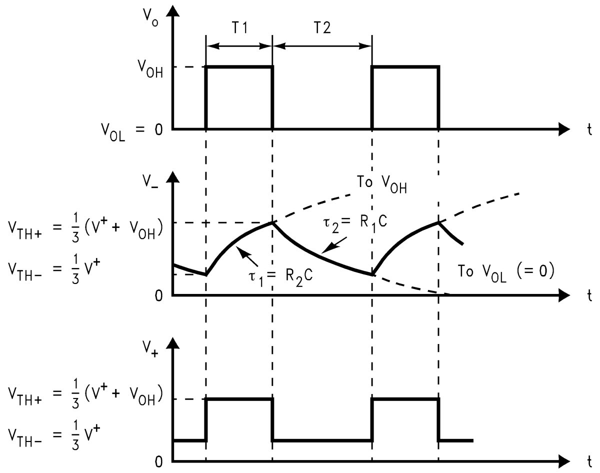


FIGURE 16. Pulse Generator

When the output voltage V_O is first at its high, V_{OH}, the capacitor C is charged toward V_{OH} through R_2. The voltage across C rises exponentially with a time constant $\tau = R_2C$, and this voltage is applied to the inverting input of the op amp. Meanwhile, the voltage at the non-inverting input is set at the positive threshold voltage (V_{TH+}) of the generator. The capacitor voltage continually increases until it reaches V_{TH+}, at which point the output of the generator will switch to its low, V_{OL} (=0V in this case). The voltage at the non-inverting input is switched to the negative threshold voltage (V_{TH-}) of the generator. The capacitor then starts to discharge toward V_{OL} exponentially through R_1, with a time constant $\tau = R_1C$. When the capacitor voltage reaches V_{TH-}, the output of the pulse generator switches to V_{OH}. The capacitor starts to charge, and the cycle repeats itself.

Application Notes (Continued)



$$T_1 = R_2C \ln \frac{3V_{OH} - V_{OL} - V^+}{2V_{OH} - V^+} \text{ and } T_2 = R_1C \ln \frac{3V_{OL} - V_{OH} - V^+}{2V_{OL} - V^+}$$

When $V_{OL} = 0V$

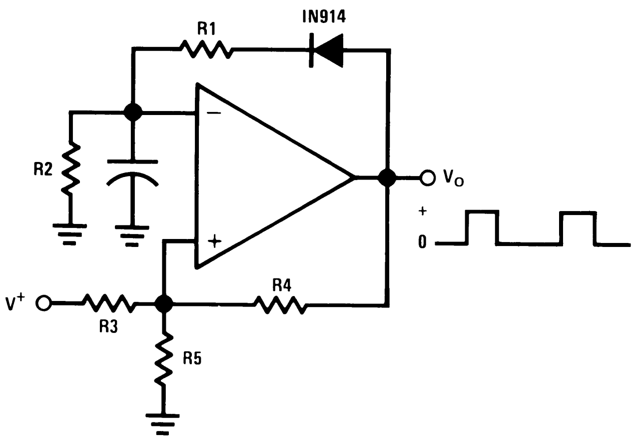
$$T_1 = R_2C \ln \frac{3V_{OH} - V^+}{2V_{OH} - V^+} \text{ and } T_2 = R_1C \ln \left(1 + \frac{V_{OH}}{V^+}\right)$$

DS100060-86

FIGURE 17. Waveforms of the Circuit in Figure 16

As shown in the waveforms in *Figure 17*, the pulse width (T_1) is set by R_2, C and V_{OH}, and the time between pulses (T_2) is set by R_1, C and V_{OL}. This pulse generator can be made to have different frequencies and pulse width by selecting different capacitor value and resistor values.

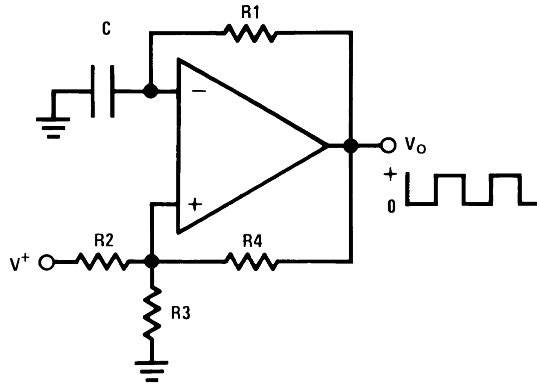
Figure 18 shows another pulse generator, with separate charge and discharge paths. The capacitor is charged through R1 and is discharged through R_2.



DS100060-77

FIGURE 18. Pulse Generator

Figure 19 is a squarewave generator with the same path for charging and discharging the capacitor.



DS100060-76

FIGURE 19. Squarewave Generator

4.6 Current Source and Sink

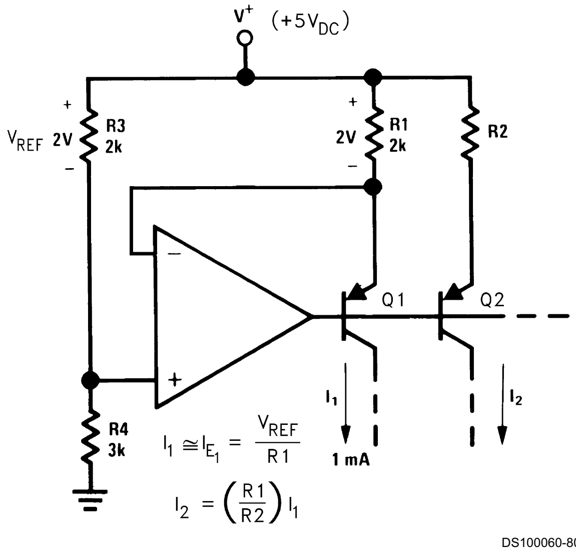
The LMV321/358/324 can be used in feedback loops which regulate the current in external PNP transistors to provide current sources or in external NPN transistors to provide current sinks.

4.6.1 Fixed Current Source

A multiple fixed current source is show in *Figure 20*. A voltage (V_{REF} = 2V) is established across resistor R_3 by the voltage divider (R_3 and R_4). Negative feedback is used to cause the voltage drop across R_1 to be equal to V_{REF}. This controls the emitter current of transistor Q_1 and if we neglect the base current of Q_1 and Q_2, essentially this same current is available out of the collector of Q_1.

Large input resistors can be used to reduce current loss and a Darlington connection can be used to reduce errors due to the β of Q_1.

The resistor, R_2, can be used to scale the collector current of Q_2 either above or below the 1 mA reference value.



DS100060-80

FIGURE 20. Fixed Current Source

Application Notes (Continued)

4.6.2 High Compliance Current Sink

A current sink circuit is shown in *Figure 21*. The circuit requires only one resistor (R_E) and supplies an output current which is directly proportional to this resistor value.

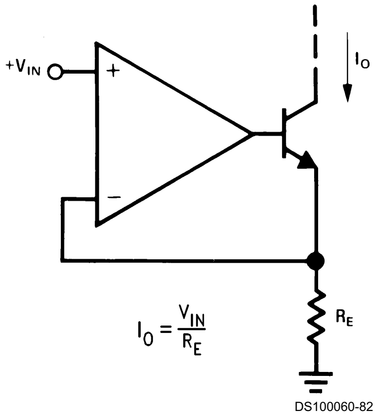


FIGURE 21. High Compliance Current Sink

4.7 Power Amplifier

A power amplifier is illustrated in *Figure 22*. This circuit can provide a higher output current because a transistor follower is added to the output of the op amp.

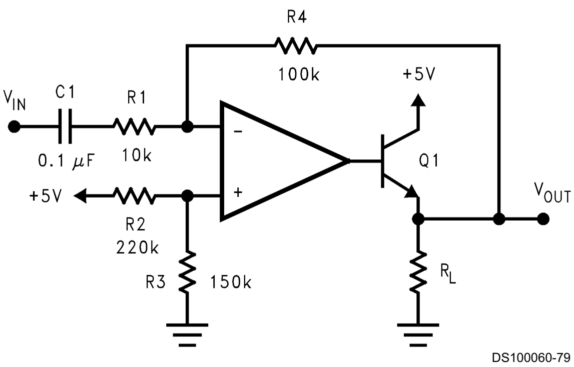


FIGURE 22. Power Amplifier

4.8 LED Driver

The LMV321/358/324 can be used to drive an LED as shown in *Figure 23*.

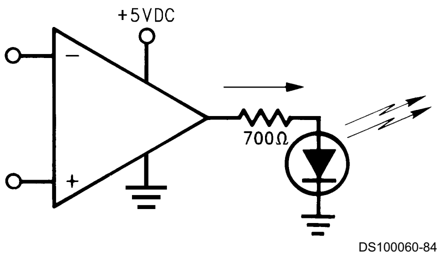


FIGURE 23. LED Driver

4.9 Comparator with Hysteresis

The LMV321/358/324 can be used as a low power comparator. *Figure 24* shows a comparator with hysteresis. The hysteresis is determined by the ratio of the two resistors.

$$V_{TH+} = V_{REF}/(1+R_1/R_2)+V_{OH}/(1+R_2/R_1)$$

$$V_{TH-} = V_{REF}/(1+R_1/R_2)+V_{OL}/(1+R_2/R_1)$$

$$V_H = (V_{OH}-V_{OL})/(1+R_2/R_1)$$

where

V_{TH+}: Positive Threshold Voltage

V_{TH-}: Negative Threshold Voltage

V_{OH}: Output Voltage at High

V_{OL}: Output Voltage at Low

V_H: Hysteresis Voltage

Since LMV321/358/324 have rail-to-rail output, the ($V_{OH}-V_{OL}$) equals to V_S, which is the supply voltage.

$$V_H = V_S/(1+R_2/R_1)$$

The differential voltage at the input of the op amp should not exceed the specified absolute maximum ratings. For real comparators that are much faster, we recommend you to use National's LMV331/393/339, which are single, dual and quad general purpose comparators for low voltage operation.

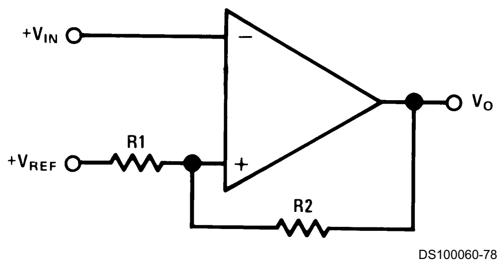
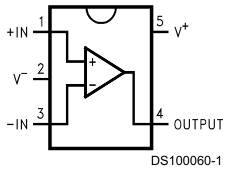


FIGURE 24. Comparator with Hysteresis

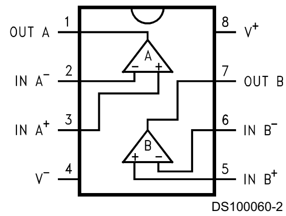
Connection Diagrams

5-Pin SC70-5/SOT23-5



Top View

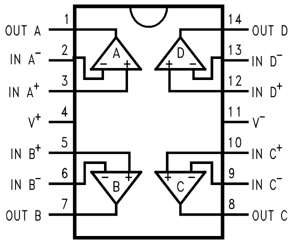
8-Pin SO/MSOP



Top View

Connection Diagrams (Continued)

14-Pin SO/TSSOP



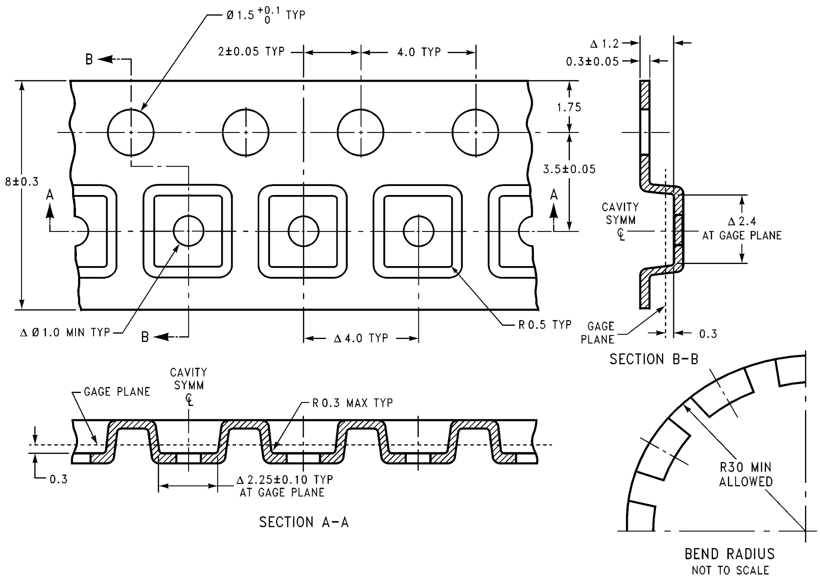
DS100060-3

Top View

Ordering Information

Package	Temperature Range Industrial −40˚C to +85˚C	Packaging Marking	Transport Media	NSC Drawing
5-Pin SC70-5	LMV321M7	A12	1k Units Tape and Reel	MAA05
	LMV321M7X	A12	3k Units Tape and Reel	
5-Pin SOT23-5	LMV321M5	A13	1k Units Tape and Reel	MA05B
	LMV321M5X	A13	3k Units Tape and Reel	
8-Pin Small Outline	LMV358M	LMV358M	Rails	M08A
	LMV358MX	LMV358M	2.5k Units Tape and Reel	
8-Pin MSOP	LMV358MM	LMV358	1k Units Tape and Reel	MUA08A
	LMV358MMX	LMV358	3.5k Units Tape and Reel	
14-Pin Small Outline	LMV324M	LMV324M	Rails	M14A
	LMV324MX	LMV324M	2.5k Units Tape and Reel	
14-Pin TSSOP	LMV324MT	LMV324MT	Rails	MTC14
	LMV324MTX	LMV324MT	2.5k Units Tape and Reel	

SC70-5 Tape and Reel Specification



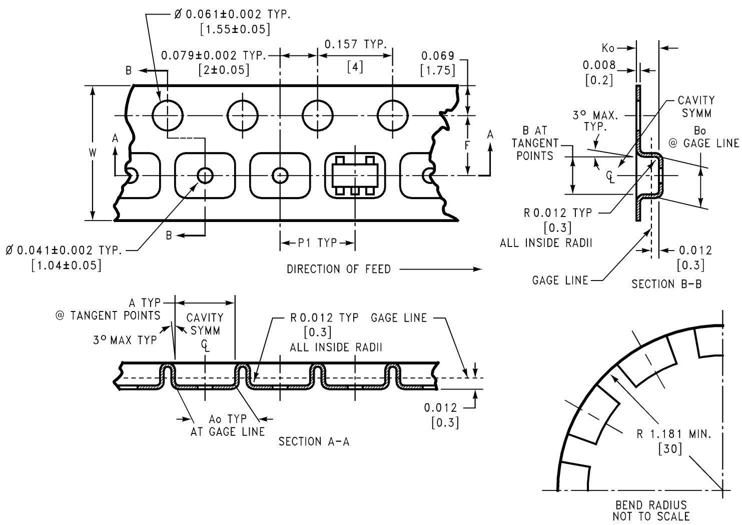
DS100060-B3

SOT-23-5 Tape and Reel Specification

TAPE FORMAT

Tape Section	# Cavities	Cavity Status	Cover Tape Status
Leader	0 (min)	Empty	Sealed
(Start End)	75 (min)	Empty	Sealed
Carrier	3000	Filled	Sealed
	250	Filled	Sealed
Trailer	125 (min)	Empty	Sealed
(Hub End)	0 (min)	Empty	Sealed

TAPE DIMENSIONS

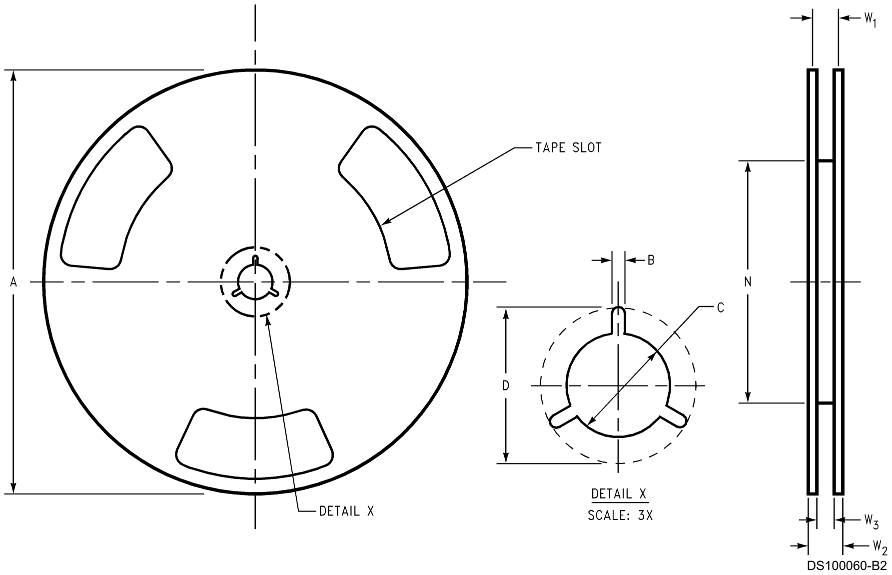


DS100060-B1

8 mm	0.130 (3.3)	0.124 (3.15)	0.130 (3.3)	0.126 (3.2)	0.138 ±0.002 (3.5 ±0.05)	0.055 ±0.004 (1.4 ±0.11)	0.157 (4)	0.315 ±0.012 (8 ±0.3)
Tape Size	DIM A	DIM Ao	DIM B	DIM Bo	DIM F	DIM Ko	DIM P1	DIM W

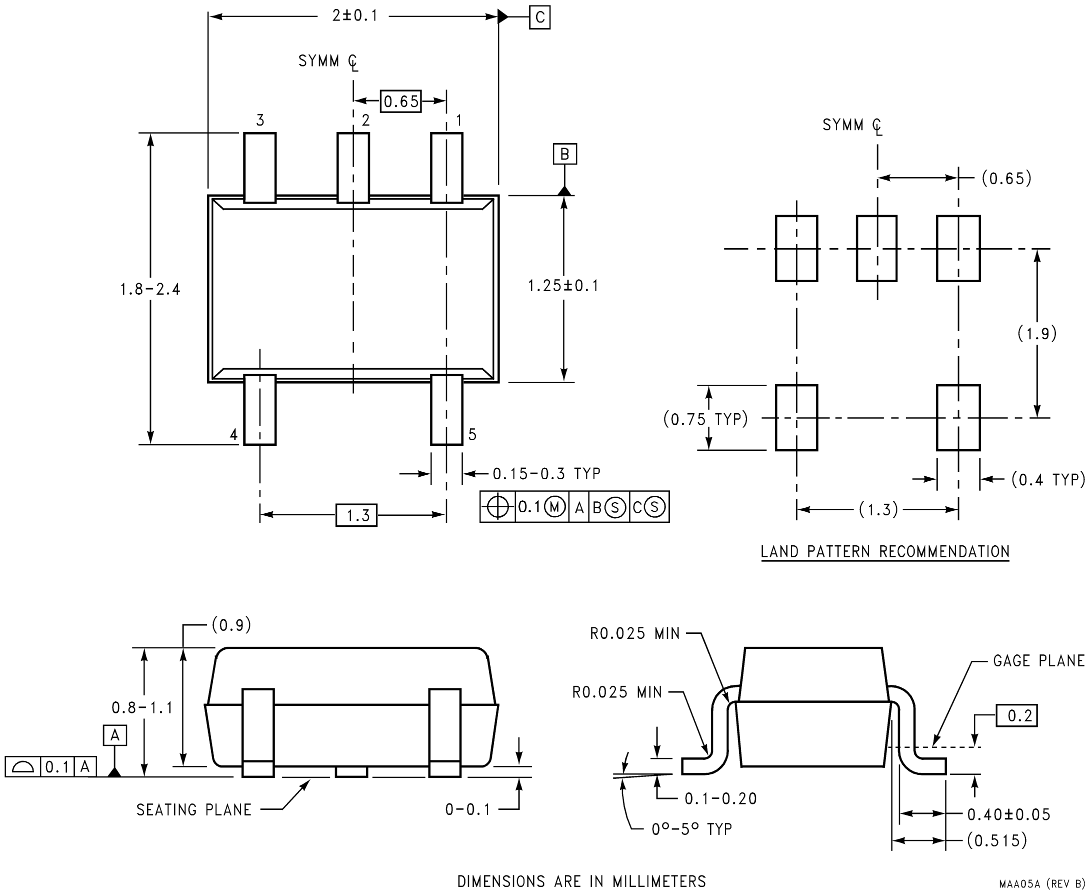
SOT-23-5 Tape and Reel Specification (Continued)

REEL DIMENSIONS



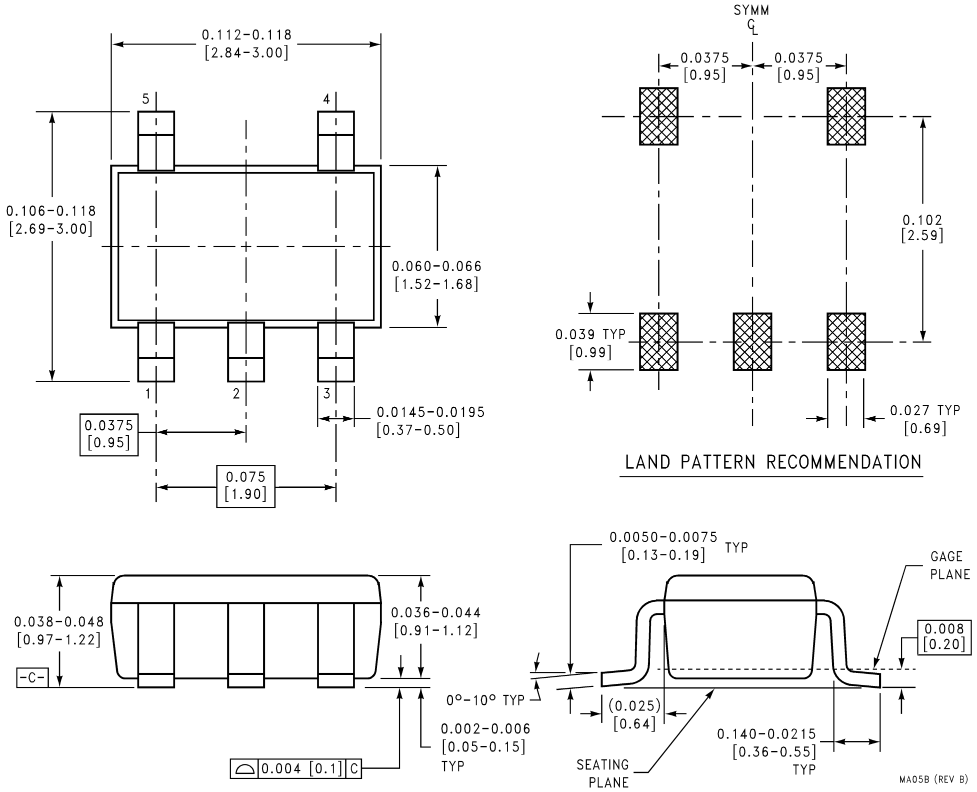
8 mm	7.00 330.00	0.059 1.50	0.512 13.00	0.795 20.20	2.165 55.00	0.331 + 0.059/−0.000 8.40 + 1.50/−0.00	0.567 14.40	W1+ 0.078/−0.039 W1 + 2.00/−1.00
Tape Size	A	B	C	D	N	W1	W2	W3

Physical Dimensions inches (millimeters) unless otherwise noted

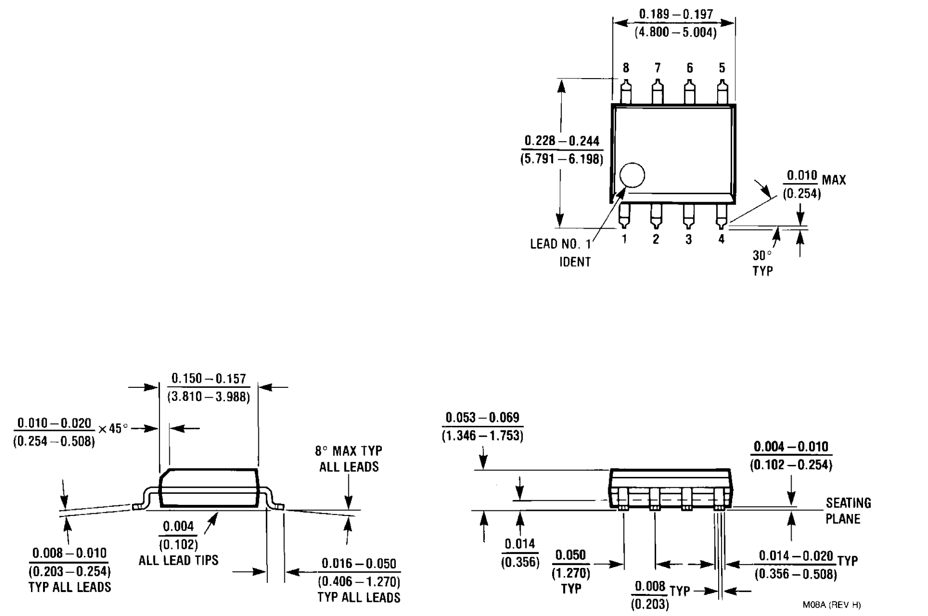


5-Pin SC70-5 Tape and Reel
Order Number LMV321M7 and LMV321M7X
NS Package Number MAA05A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

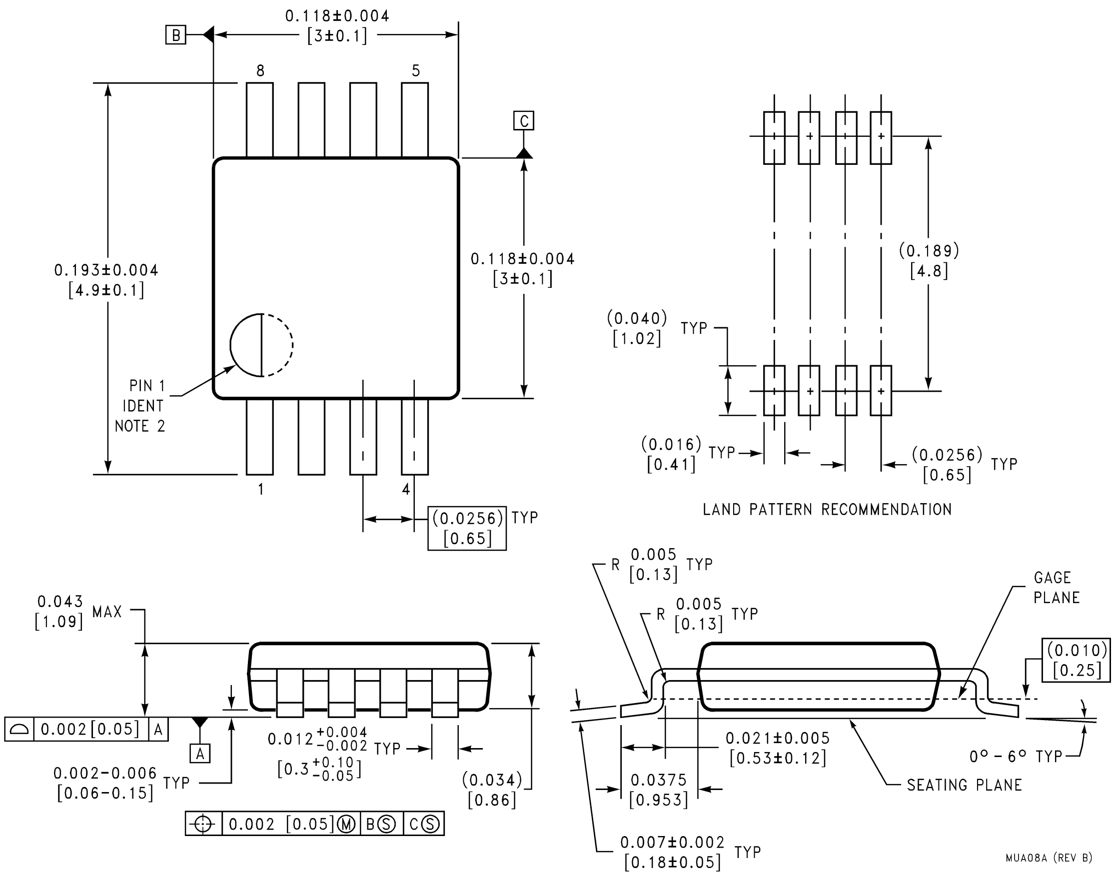


5-Pin SOT23-5 Tape and Reel
Order Number LMV321M5 and LMV321M5X
NS Package Number MA05B



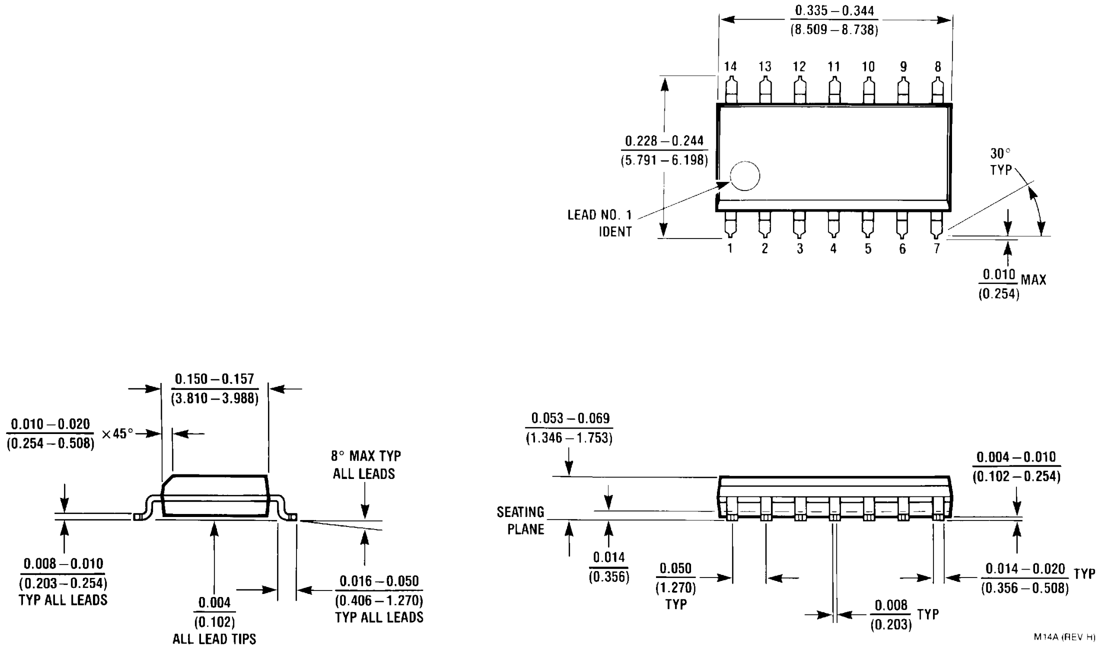
8-Pin Small Outline
Order Number LMV358M and LMV358MX
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



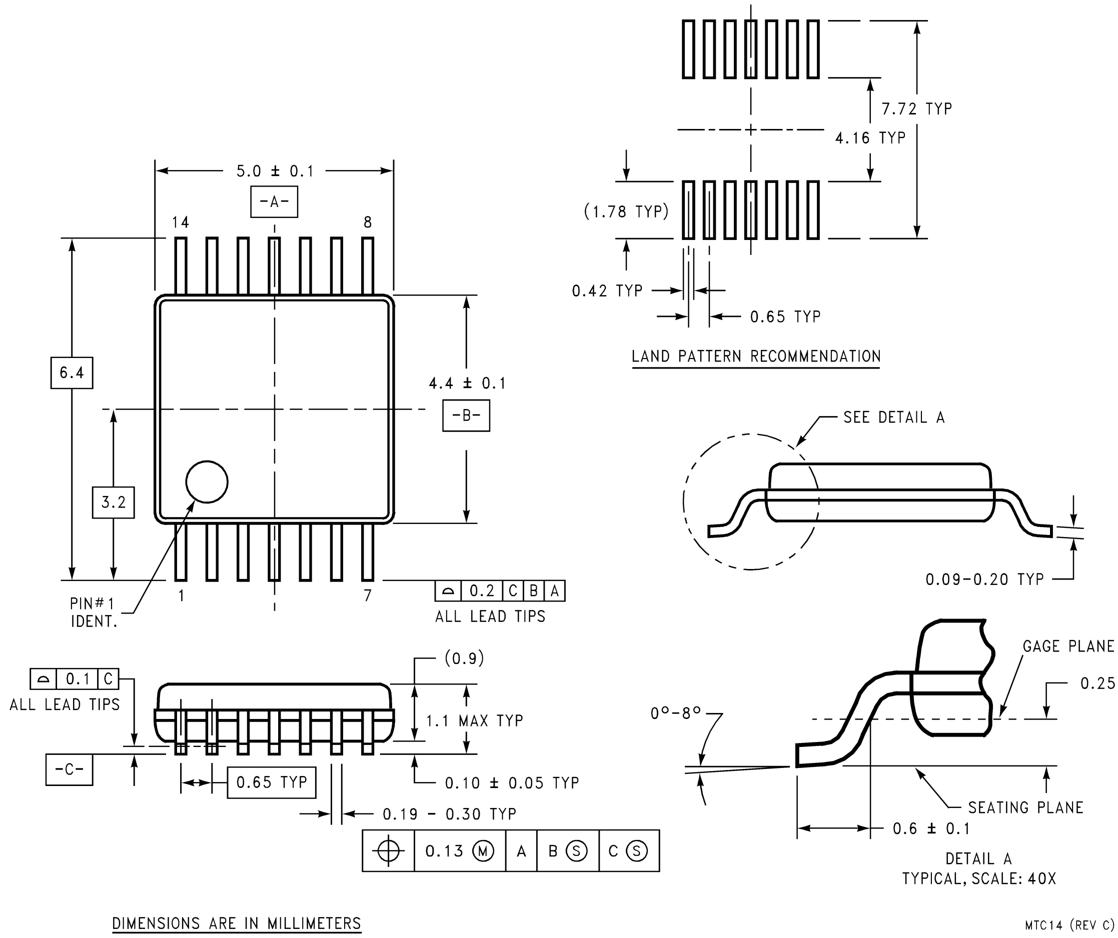
8-Pin MSOP
Order Number LMV358MM and LMV358MMX
NS Package Number MUA08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



14-Pin Small Outline
Order Number LMV324M and LMV324MX
NS Package Number M14A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



14-Pin TSSOP
Order Number LMV324MT and LMV324MTX
NS Package Number MTC14

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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National Semiconductor

August 2000

LMV331 Single / LMV393 Dual / LMV339 Quad General Purpose, Low Voltage, TinyPack Comparators

General Description

The LMV393 and LMV339 are low voltage (2.7-5V) versions of the dual and quad comparators, LM393/339, which are specified at 5-30V. The LMV331 is the single version, which is available in space saving SC70-5 and SOT23-5 packages. SC70-5 is approximately half the size of SOT23-5.

The LMV393 is available in 8-pin SOIC and 8-pin MSOP. The LMV339 is available in 14-pin SOIC and 14-pin TSSOP.

The LMV331/393/339 is the most cost-effective solution where space, low voltage, low power and price are the primary specification in circuit design for portable consumer products. They offer specifications that meet or exceed the familiar LM393/339 at a fraction of the supply current.

The chips are built with National's advanced Submicron Silicon-Gate BiCMOS process. The LMV331/393/339 have bipolar input and output stages for improved noise performance.

Features

(For 5V Supply, Typical Unless Otherwise Noted)

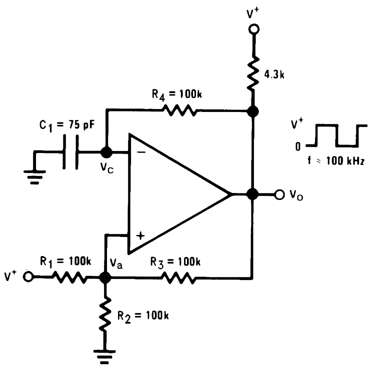
- Space Saving SC70-5 Package (2.0 x 2.1 x 1.0 mm)
- Space Saving SOT23-5 Package (3.00 x 3.01 x1.43 mm)
- Guaranteed 2.7V and 5V Performance
- Industrial Temperature Range −40˚C to +85˚C
- Low Supply Current 60µA/Channel
- Input Common Mode Voltage Range Includes Ground
- Low Output Saturation Voltage 200 mV

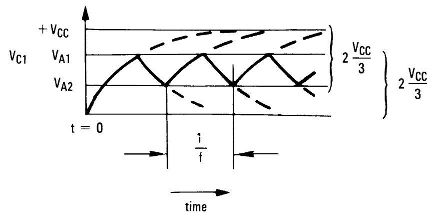
Applications

- Mobile Communications
- Notebooks and PDA's
- Battery Powered Electronics
- General Purpose Portable Device
- General Purpose Low Voltage Applications

Typical Applications

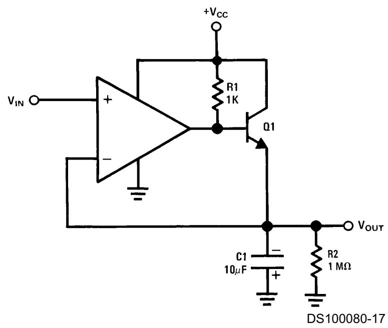
Squarewave Oscillator





DS100080-24

DS100080-8



DS100080-17

Positive Peak Detector

 DS100080

Absolute Maximum Ratings (Note 1)

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

ESD Tolerance (Note 2)	
Human Body Model	
LMV331/ 393/ 339	800V
Machine Model LMV331/339/393	120V
Differential Input Voltage	± Supply Voltage
Voltage on any pin (referred to V^- pin)	5.5V
Soldering Information	
Infrared or Convection (20 sec)	235°C
Storage Temp. Range	−65°C to +150°C
Junction Temperature (Note 3)	150°C

Operating Ratings(Note 1)

Supply Voltage	2.7V to 5.0V
Temperature Range	
LMV393, LMV339, LMV331	$-40°C \leq T_J \leq +85°C$
Thermal Resistance (θ_{JA})	
M Package, 8-pin Surface Mount	190°C/W
M Package, 14-pin Surface Mount	145°C/W
MTC Package, 14-pin TSSOP	155°C/W
MAA05 Package, 5-pin SC70-5	478°C/W
M05A Package 5 -pin SOT23-5	265°C/W
MM Package, 8-pin Mini Surface Mount	235°C/W

2.7V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25°C, V+ = 2.7V, V− = 0V. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Typ (Note 4)	**LMV331/ 393/339 Limit** (Note 5)	Units
V_{OS}	Input Offset Voltage		1.7	7	mV max
TCV_{OS}	Input Offset Voltage Average Drift		**5**		μV/°C
I_B	Input Bias Current		10	250 **400**	nA max
I_{OS}	Input Offset Current		5	50 **150**	nA max
V_{CM}	Input Voltage Range		−0.1		V
			2.0		V
V_{SAT}	Saturation Voltage	$I_{sink} \leq 1mA$	200		mV
I_O	Output Sink Current	$V_O \leq 1.5V$	23	5	mA min
I_S	Supply Current	LMV331	40	100	μA max
		LMV393 Both Comparators	70	140	μA max
		LMV339 All four Comparators	140	200	μA max
	Output Leakage Current		.003	**1**	μA max

2.7V AC Electrical Characteristics

T_J = 25°C, V+ = 2.7V, R_L = 5.1 kΩ, V− = 0V.

Symbol	Parameter	Conditions	Typ (Note 4)	Units
t_{PHL}	Propagation Delay (High to Low)	Input Overdrive =10 mV	1000	ns
		Input Overdrive =100 mV	350	ns
t_{PLH}	Propagation Delay (Low to High)	Input Overdrive =10 mV	500	ns
		Input Overdrive =100 mV	400	ns

5V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25˚C, V+ = 5V, V− = 0V. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Typ (Note 4)	LMV331/ 393/339 Limit (Note 5)	Units
V_{OS}	Input Offset Voltage		1.7	7 **9**	mV max
TCV_{OS}	Input Offset Voltage Average Drift		5		μV/˚C
I_B	Input Bias Current		25	250 **400**	nA max
I_{OS}	Input Offset Current		2	50 **150**	nA max
V_{CM}	Input Voltage Range		−0.1		V
			4.2		V
A_V	Voltage Gain		50	20	V/mV min
V_{sat}	Saturation Voltage	$I_{sink} \leq 4$ mA	200	400 **700**	mV max
I_O	Output Sink Current	$V_O \leq 1.5V$	84	10	mA
I_S	Supply Current	LMV331	60	120 **150**	μA max
		LMV393 Both Comparators	100	200 **250**	μA max
		LMV339 All four Comparators	170	300 **350**	μA max
	Output Leakage Current		.003	**1**	μA max

5V AC Electrical Characteristics

T_J = 25˚C, V+ = 5V, R_L = 5.1 kΩ, V− = 0V.

Symbol	Parameter	Conditions	Typ (Note 4)	Units
t_{PHL}	Propagation Delay (High to Low)	Input Overdrive =10 mV	600	ns
		Input Overdrive =100 mV	200	ns
t_{PLH}	Propagation Delay (Low to High)	Input Overdrive =10 mV	450	ns
		Input Overdrive =100 mV	300	ns

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and the test conditions, see the Electrical characteristics.

Note 2: : Human body model, 1.5kΩ in series with 100 pF. Machine model, 200Ω in series with 100 pF.

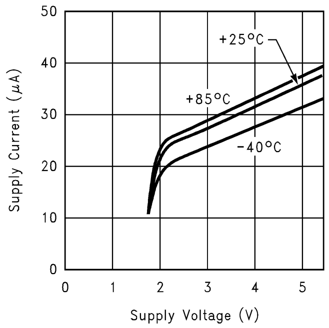
Note 3: The maximum power dissipation is a function of $T_{J(max)}$, θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(max)} - T_A)/\theta_{JA}$. All numbers apply for packages soldered directly into a PC board.

Note 4: Typical Values represent the most likely parametric norm.

Note 5: All limits are guaranteed by testing or statistical analysis.

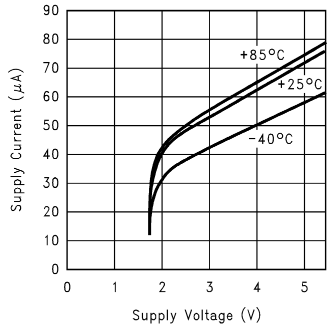
Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C

Supply Current vs Supply Voltage Output High (LMV331)



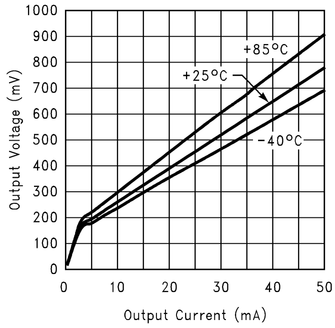
DS100080-34

Supply Current vs Supply Voltage Output Low (LMV331)



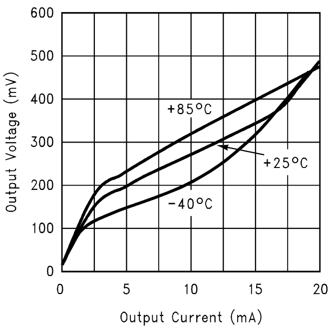
DS100080-33

Output Voltage vs Output Current at 5V Supply



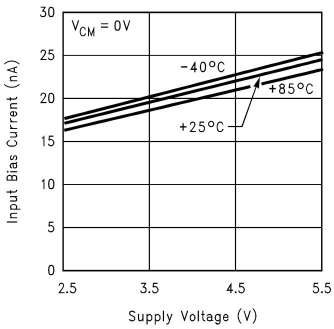
DS100080-37

Output Voltage vs Output Current at 2.7 Supply



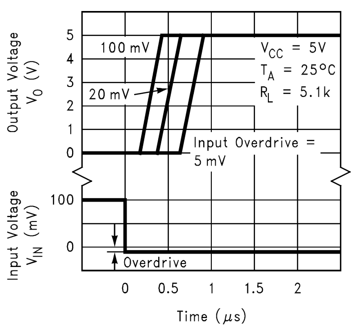
DS100080-38

Input Bias Current vs Supply Voltage



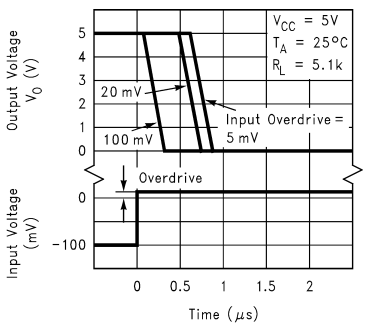
DS100080-36

Response Time vs Input Overdrives Negative Transition



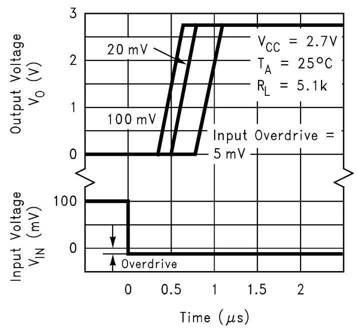
DS100080-42

Response Time for Input Overdrive Positive Transition



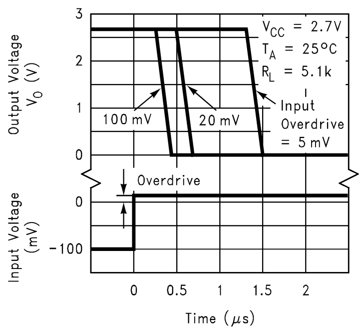
DS100080-43

Response Time vs Input Overdrives Negative Transition



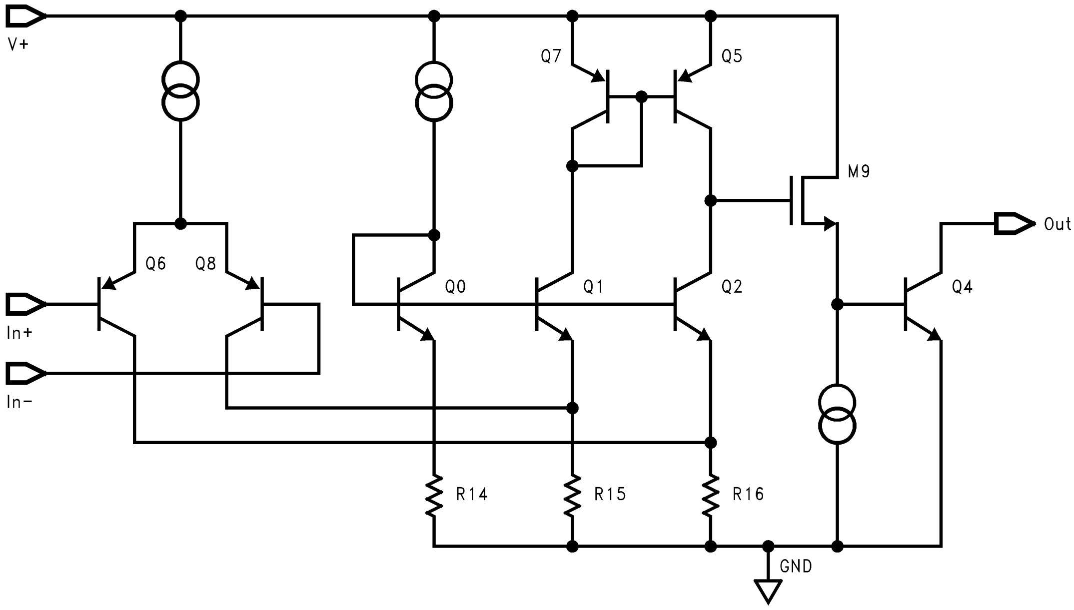
DS100080-41

Response Time for Input Overdrive Positive Transition



DS100080-40

Simplified Schematic



DS100080-47

Application Circuits

Basic Comparator

A basic comparator circuit is used for converting analog signals to a digital output. The LMV331/393/339 have an open-collector output stage, which requires a pull-up resistor to a positive supply voltage for the output to switch properly. When the internal output transistor is off, the output voltage will be pulled up to the external positive voltage.

The output pull-up resistor should be chosen high enough so as to avoid excessive power dissipation yet low enough to supply enough drive to switch whatever load circuitry is used on the comparator output. On the LMV331/393/339 the pull-up resistor should range between 1k to 10kΩ.

The comparator compares the input voltage (V_{in}) at the non-inverting pin to the reference voltage (V_{ref}) at the inverting pin. If V_{in} is less than V_{ref}, the output voltage (V_o) is at the saturation voltage. On the other hand, if V_{in} is greater than V_{ref}, the output voltage (V_o) is at $V_{cc.}$.

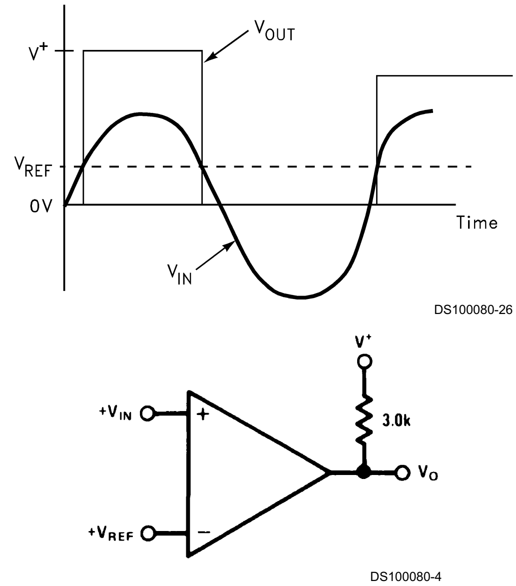


FIGURE 1. Basic Comparator

Comparator with Hysteresis

The basic comparator configuration may oscillate or produce a noisy output if the applied differential input voltage is near the comparator's offset voltage. This usually happens when the input signal is moving very slowly across the comparator's switching threshold. This problem can be prevented by the addition of hysteresis or positive feedback.

Inverting Comparator with Hysteresis

The inverting comparator with hysteresis requires a three resistor network that are referenced to the supply voltage V_{cc} of the comparator. When Vin at the inverting input is less than V_a, the voltage at the non-inverting node of the comparator ($V_{in} < V_a$), the output voltage is high (for simplicity assume V_o switches as high as V_{cc}). The three network resistors can be represented as $R_1//R_3$ in series with R_2. The lower input trip voltage V_{a1} is defined as

$$V_{a_1} = \frac{V_{CC}\ R_2}{(R_1 \| R_3) + R_2}$$

When V_{in} is greater than Va (V_{in} V_a), the output voltage is low very close to ground. In this case the three network resistors can be presented as $R_2//R_3$ in series with R_1. The upper trip voltage V_{a2} is defined as

$$V_{a2} = \frac{V_{CC}(R_2 // R_3)}{R_1 + (R_2 // R_3)}$$

The total hysteresis provided by the network is defined as

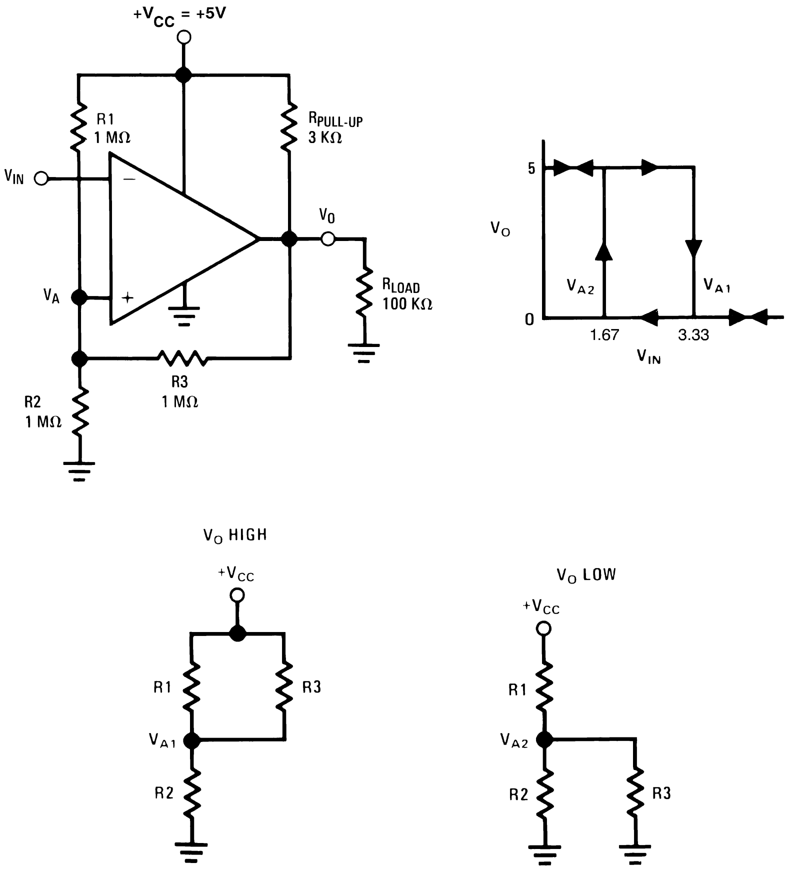
$$\Delta V_a = V_{a1} - V_{a2}$$

To assure that the comparator will always switch fully to V_{cc} and not be pulled down by the load the resistors values should be chosen as follow:

$$R_{pull\text{-}up} << R_{load}$$

and $R_1 > R_{pull\text{-}up}$.

Application Circuits (Continued)



DS100080-25

FIGURE 2. Inverting Comparator with Hysteresis

Non-Inverting Comparator with Hysteresis

Non inverting comparator with hysteresis requires a two resistor network, and a voltage reference (V_{ref}) at the inverting input. When V_{in} is low, the output is also low. For the output to switch from low to high, V_{in} must rise up to V_{in1} where V_{in1} is calculated by

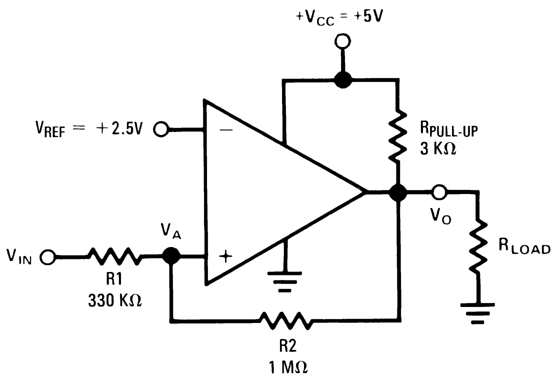
$$V_{in1} = \frac{V_{ref}(R_1 + R_2)}{R_2}$$

When V_{in} is high, the output is also high, to make the comparator switch back to it's low state, V_{in} must equal V_{ref} before V_a will again equal V_{ref}. V_{in} can be calculated by:

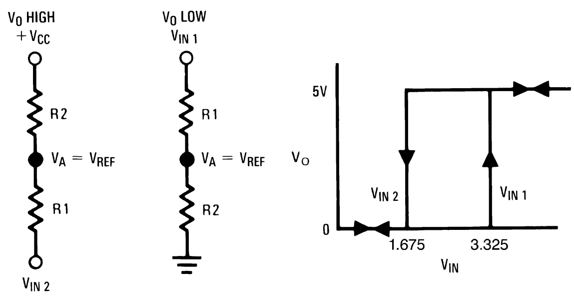
$$V_{in2} = \frac{V_{ref}(R_1 + R_2) - V_{CC} R_1}{R_2}$$

The hysteresis of this circuit is the difference between V_{in1} and V_{in2}.

$$\Delta V_{in} = V_{cc} R_1 / R_2$$



DS100080-22

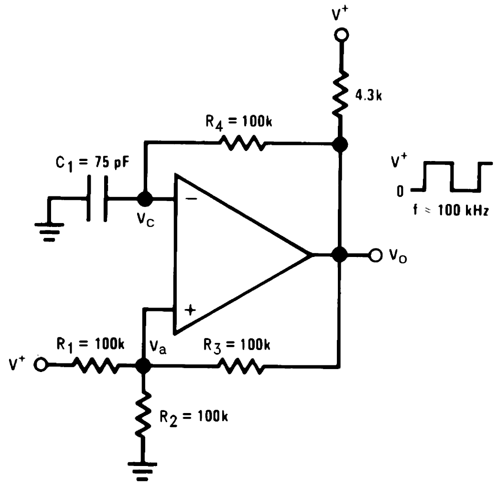


DS100080-23

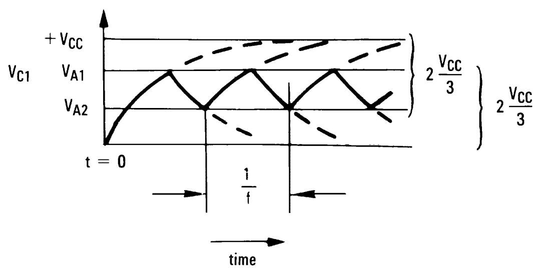
Application Circuits (Continued)

Square Wave Oscillator

Comparators are ideal for oscillator applications. This square wave generator uses the minimum number of components. The output frequency is set by the RC time constant of the capacitor C_1 and the resistor in the negative feedback R_4. The maximum frequency is limited only by the large signal propagation delay of the comparator in addition to any capacitive loading at the output, which would degrade the output slew rate.



DS100080-8



DS100080-24

FIGURE 5. Squarewave Oscillator

To analyze the circuit, assume that the output is initially high. For this to be true, the voltage at the inverting input V_c has to be less than the voltage at the non-inverting input V_a. For V_c to be low, the capacitor C_1 has to be discharged and will charge up through the negative feedback resistor R_4. When it has charged up to value equal to the voltage at the positive input V_{a1}, the comparator output will switch.

V_{a1} will be given by:

$$V_{a1} = \frac{V_{CC} R_2}{R_2 + (R_1 // R_2)}$$

If:

$$R_1 = R_2 = R_3$$

Then:

$$V_{a1} = 2V_{cc}/3$$

When the output switches to ground, the value of V_a is reduced by the hysteresis network to a value given by:

$$V_{a2} = V_{cc}/3$$

Capacitor C_1 must now discharge through R_4 towards ground. The output will return to its high state when the voltage across the capacitor has discharged to a value equal to V_{a2}.

For the circuit shown, the period for one cycle of oscillation will be twice the time it takes for a single RC circuit to charge up to one half of its final value. The time to charge the capacitor can be calculated from

$$V_C = V_{max} \; e^{\frac{-t}{RC}}$$

Where V_{max} is the max applied potential across the capacitor = $(2V_{cc}/3)$

and $V_C = Vmax/2 = V_{CC}/3$

One period will be given by:

$$1/freq = 2t$$

or calculating the exponential gives:

$$1/freq = 2(0.694)\, R_4\, C_1$$

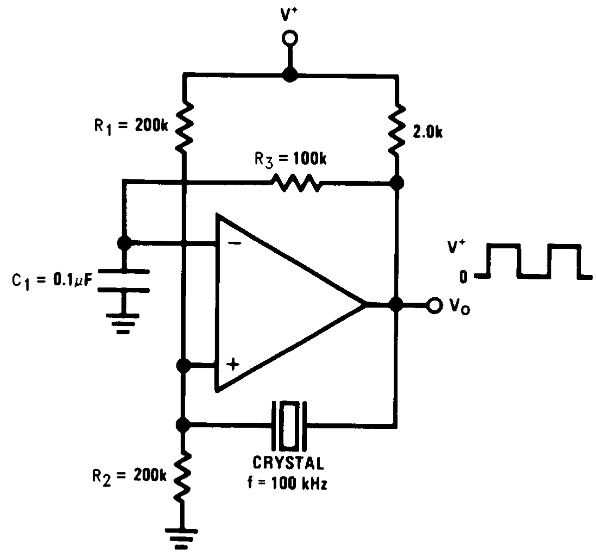
Resistors R_3 and R_4 must be at least two times larger than R_5 to insure that V_o will go all the way up to V_{cc} in the high state. The frequency stability of this circuit should strictly be a function of the external components.

Free Running Multivibrator

A simple yet very stable oscillator that generates a clock for slower digital systems can be obtained by using a resonator as the feedback element. It is similar to the free running multivibrator, except that the positive feedback is obtained through a quartz crystal. The circuit oscillates when the transmission through the crystal is at a maximum, so the crystal in its series-resonant mode.

The value of R_1 and R_2 are equal so that the comparator will switch symmetrically about $+V_{cc}/2$. The RC constant of R_3 and C_1 is set to be several times greater than the period of the oscillating frequency, insuring a 50% duty cycle by maintaining a DC voltage at the inverting input equal to the absolute average of the output waveform.

When specifying the crystal, be sure to order series resonant with the desired temperature coefficient



DS100080-7

FIGURE 6. Crystal controlled Oscillator

Application Circuits (Continued)

Pulse generator with variable duty cycle:

The pulse generator with variable duty cycle is just a minor modification of the basic square wave generator. Providing a separate charge and discharge path for capacitor C_1 generates a variable duty cycle. One path, through R_2 and D_2 will charge the capacitor and set the pulse width (t_1). The other path, R_1 and D_1 will discharge the capacitor and set the time between pulses (t_2).

By varying resistor R_1, the time between pulses of the generator can be changed without changing the pulse width. Similarly, by varying R_2, the pulse width will be altered without affecting the time between pulses. Both controls will change the frequency of the generator. The pulse width and time between pulses can be found from:

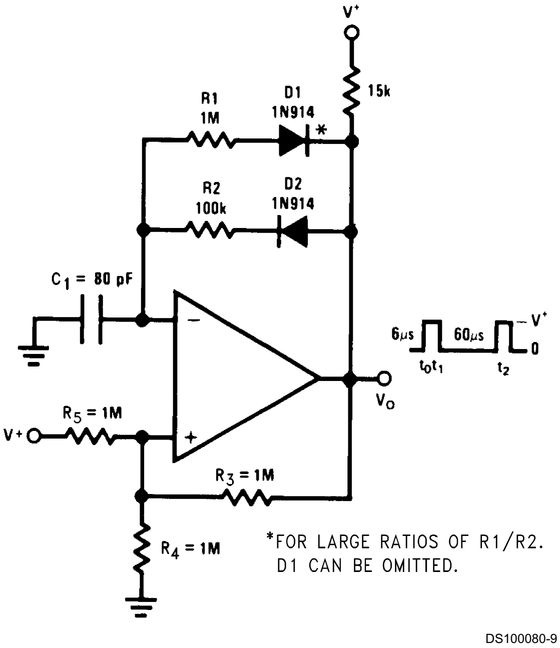


FIGURE 7. Pulse Generator

$$V_1 = V_{max}\left(1 - e^{-t_1/R_4C_1}\right) \quad \text{rise time}$$

$$V_1 = V_{max} \quad e^{-t_2/R_5C_1} \quad \text{fall time}$$

Where

$$V_{max} = \frac{2\,V_{CC}}{3}$$

and

$$V_1 = \frac{V_{max}}{3} = \frac{V_{CC}}{3}$$

Which gives

$$\frac{1}{2} = e^{-t_1/R_4C_1}$$

t_2 is then given by:

$$\frac{1}{2} = e^{-t_2/R_5C_1}$$

Solving these equations for t_1 and t_2

$$t_1 = R_4C_1 \ln 2$$

$$t_2 = R_5C_1 \ln 2$$

These terms will have a slight error due to the fact that V_{max} is not exactly equal to 2/3 V_{CC} but is actually reduced by the diode drop to:

$$V_{max} = \frac{2}{3}(V_{CC} - V_{BE})$$

$$\frac{1}{2(1 - V_{BE})} = e^{-t_1/R_4C_1}$$

$$\frac{1}{2(1 - V_{BE})} = e^{-t_2/R_5C_1}$$

Positive Peak Detector:

Positive peak detector is basically the comparator operated as a unit gain follower with a large holding capacitor from the output to ground. Additional transistor is added to the output to provide a low impedance current source. When the output of the comparator goes high, current is passed through the transistor to charge up the capacitor. The only discharge path will be the 1M ohm resistor shunting C1 and any load that is connected to the output. The decay time can be altered simply by changing the 1M ohm resistor. The output should be used through a high impedance follower to a avoid loading the output of the peak detector.

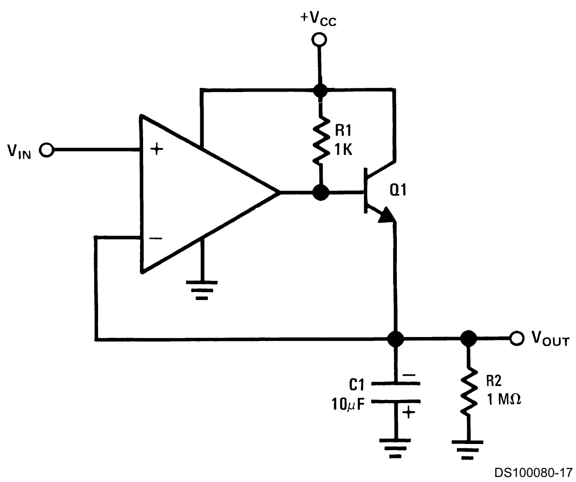


FIGURE 8. Positive Peak Detector

Negative Peak Detector:

For the negative detector, the output transistor of the comparator acts as a low impedance current sink. The only discharge path will be the 1 MΩ resistor and any load impedance used. Decay time is changed by varying the 1 MΩ resistor

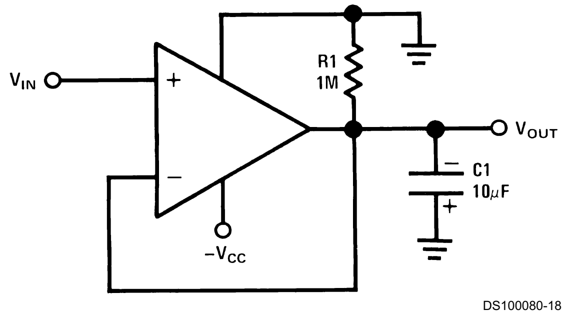


FIGURE 9. Negative Peak Detector

Application Circuits (Continued)

Driving CMOS and TTL

The comparator's output is capable of driving CMOS and TTL Logic circuits.

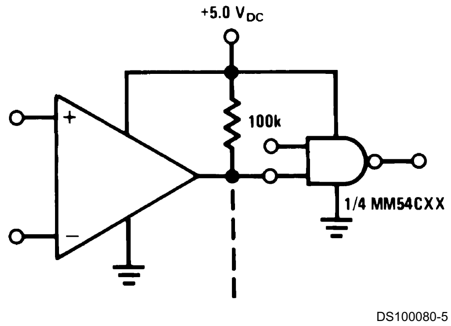


FIGURE 10. Driving CMOS

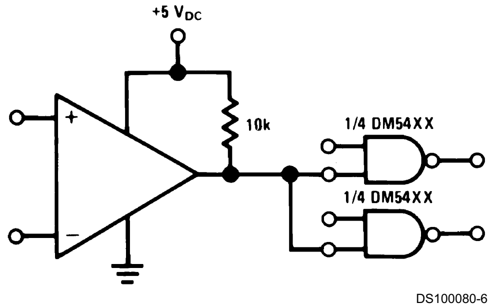


FIGURE 11. Driving TTL

AND Gates

The comparator can be used as three input AND gate. The operation of the gate is as follow:

The resistor divider at the inverting input establishes a reference voltage at that node. The non-inverting input is the sum of the voltages at the inputs divided by the voltage dividers. The output will go high only when all three inputs are high, casing the voltage at the non-inverting input to go above that at inverting input. The circuit values shown work for a ″0″ equal to ground and a ″1″ equal to 5V.

The resistor values can be altered if different logic levels are desired. If more inputs are required, diodes are recommended to improve the voltage margin when all but one of the inputs are high.

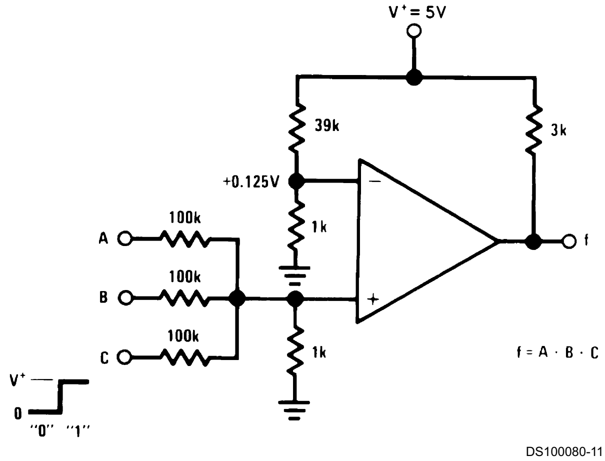


FIGURE 12. AND Gate

OR Gates

A three input OR gate is achieved from the basic AND gate simply by increasing the resistor value connected from the inverting input to V_{cc}, thereby reducing the reference voltage.

A logic ″1″ at any of the inputs will produce a logic ″1″ at the output.

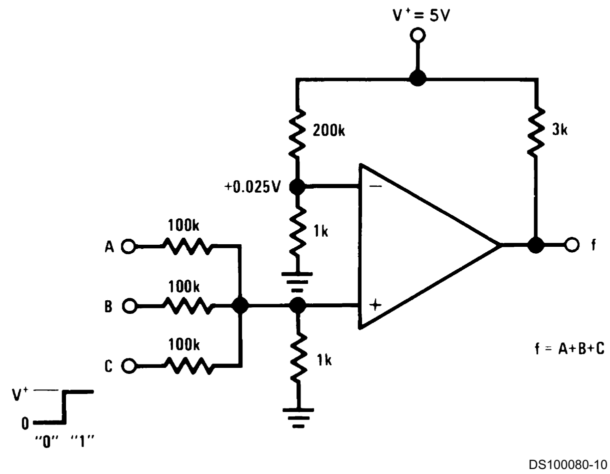


FIGURE 13. OR Gate

ORing the Output

By the inherit nature of an open collector comparator, the outputs of several comparators can be tied together with a pull up resistor to V_{cc}. If one or more of the comparators outputs goes low, the output V_o will go low.

Application Circuits (Continued)

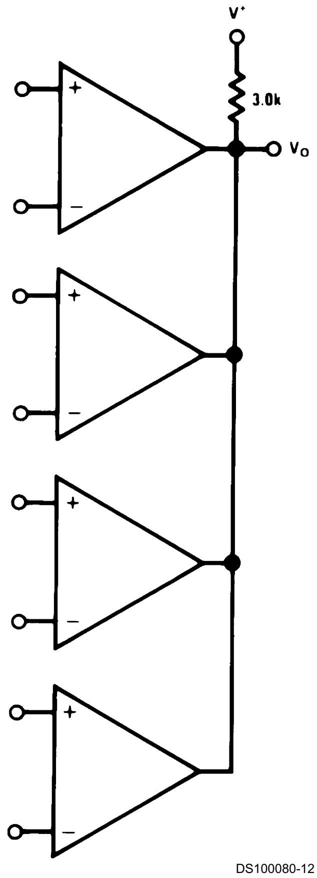


FIGURE 14. ORing the Outputs

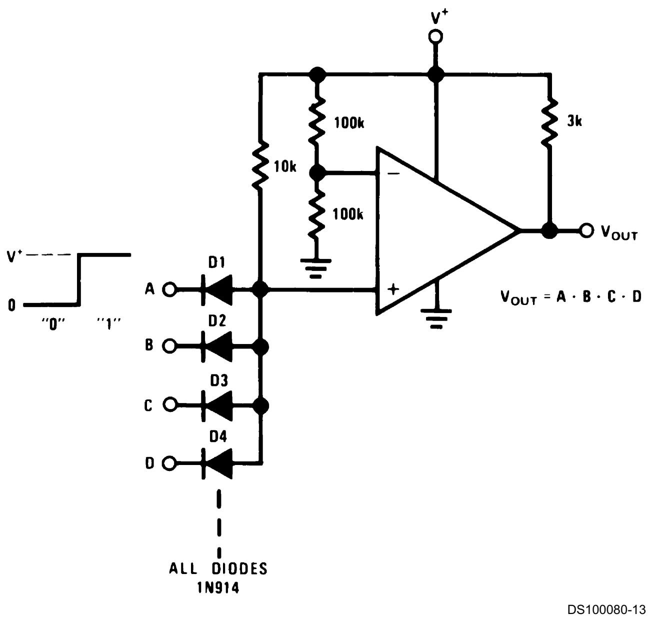
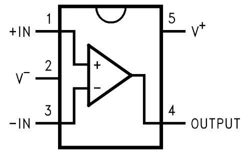


FIGURE 15. Large Fan-In AND Gate

Connection Diagrams

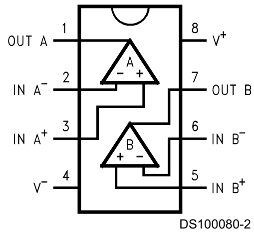
Application Circuits (Continued)

5-Pin SC70-5/SOT23-5



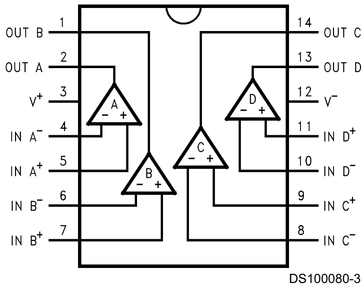
Top View

8-Pin SO/MSOP



Top View

14-Pin SO/TSSOP

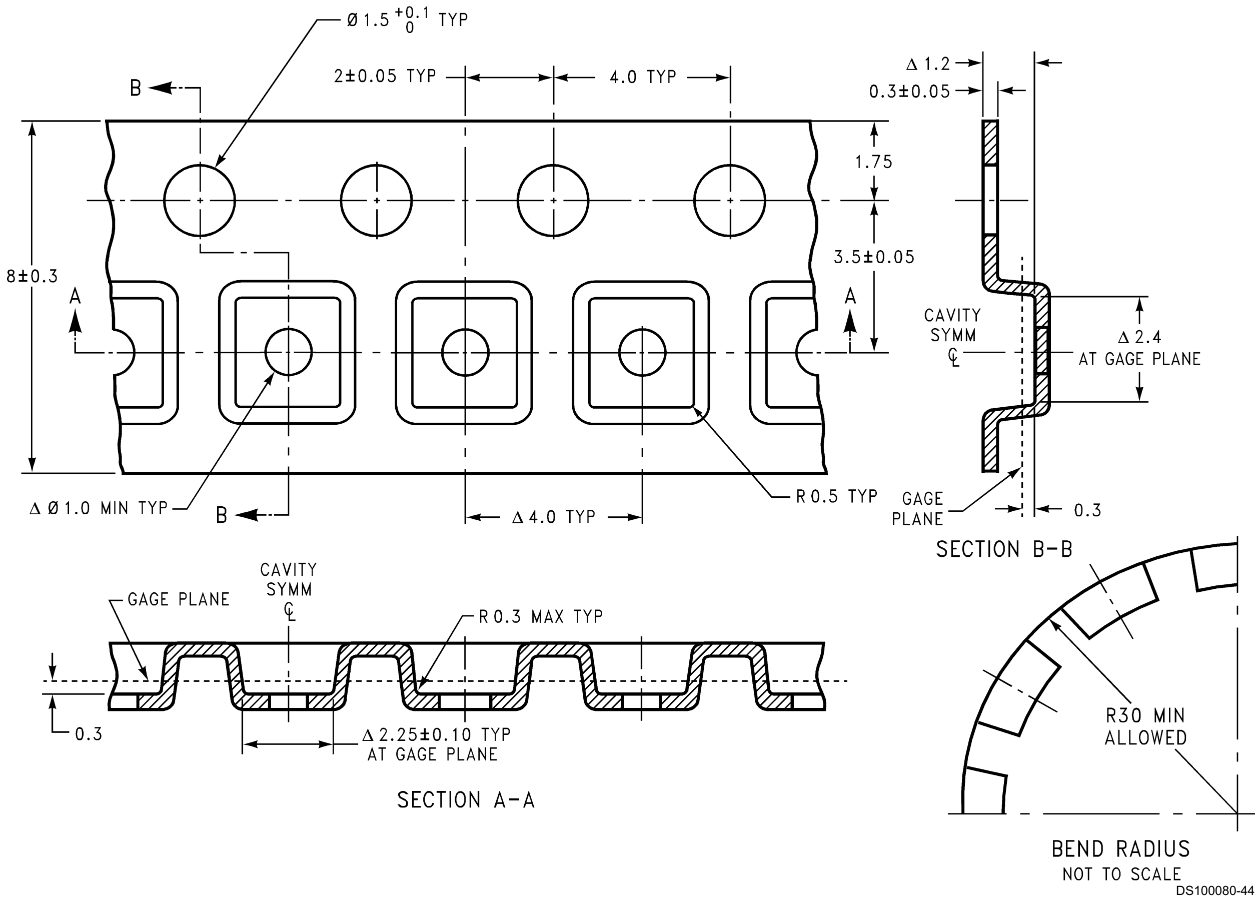


Top View

Ordering Information

Package	Temperature Range Industrial −40˚C to +85˚C	Packaging Marking	Transport Media	NSC Drawing
5-pin SC70-5	LMV331M7	C13	1k Units Tape and Reel	MAA05
	LMV331M7X	C13	3k Units Tape and Reel	
5-pin SOT23-5	LMV331M5	C12	1k Units Tape and Reel	MA05B
	LMV331M5X	C12	3k Units Tape and Reel	
8-pin Small Outline	LMV393M	LMV393M	Rails	M08A
	LMV393MX	LMV393M	2.5k Units Tape and Reel	
8-pin MSOP	LMV393MM	LMV393	1k UnitsTape and Reel	MUA08A
	LMV393MMX	LMV393	3.5k Units Tape and Reel	
14-pin Small Outline	LMV339M	LMV339M	Rails	M14A
	LMV339MX	LMV339M	2.5k Units Tape and Reel	
14-pin TSSOP	LMV339MT	LMV339MT	Rails	MTC14
	LMV339MTX	LMV339MT	2.5k Units Tape and Reel	

SC70-5 Tape and Reel Specification



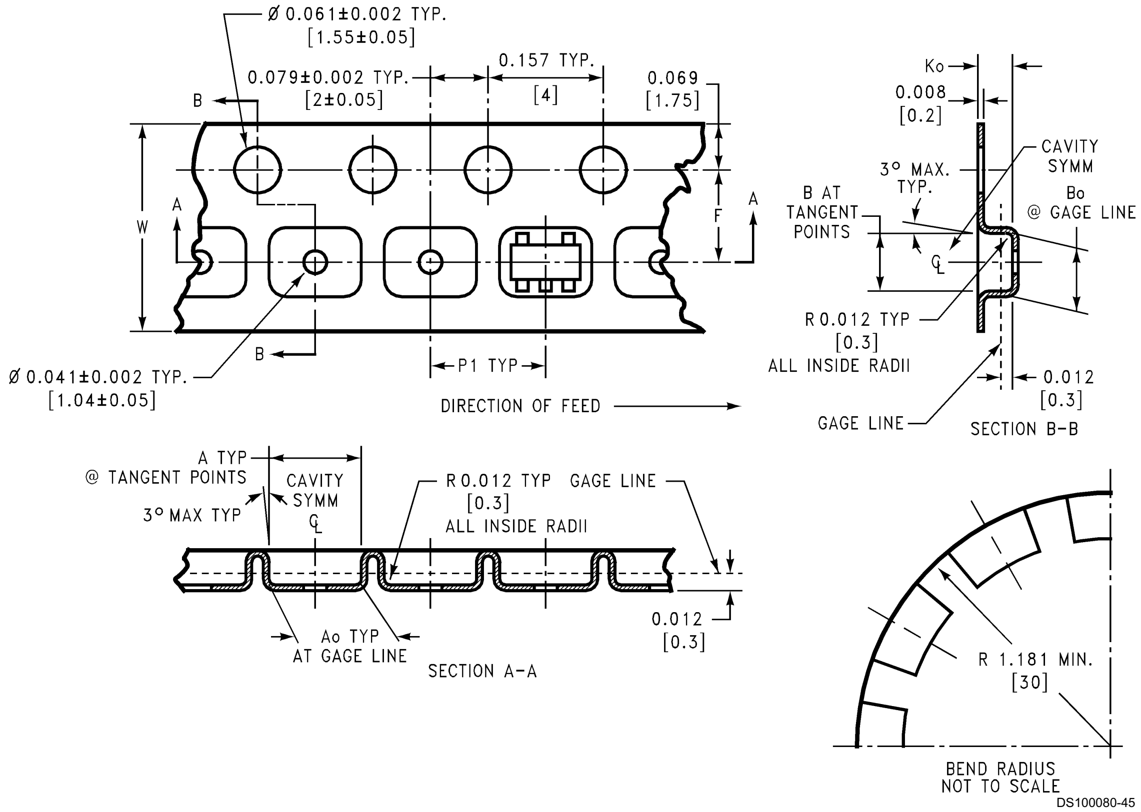
SOT-23-5 Tape and Reel Specification

TAPE FORMAT

Tape Section	# Cavities	Cavity Status	Cover Tape Status
Leader	0 (min)	Empty	Sealed
(Start End)	75 (min)	Empty	Sealed
Carrier	3000	Filled	Sealed
	250	Filled	Sealed
Trailer	125 (min)	Empty	Sealed
(Hub End)	0 (min)	Empty	Sealed

SOT-23-5 Tape and Reel Specification (Continued)

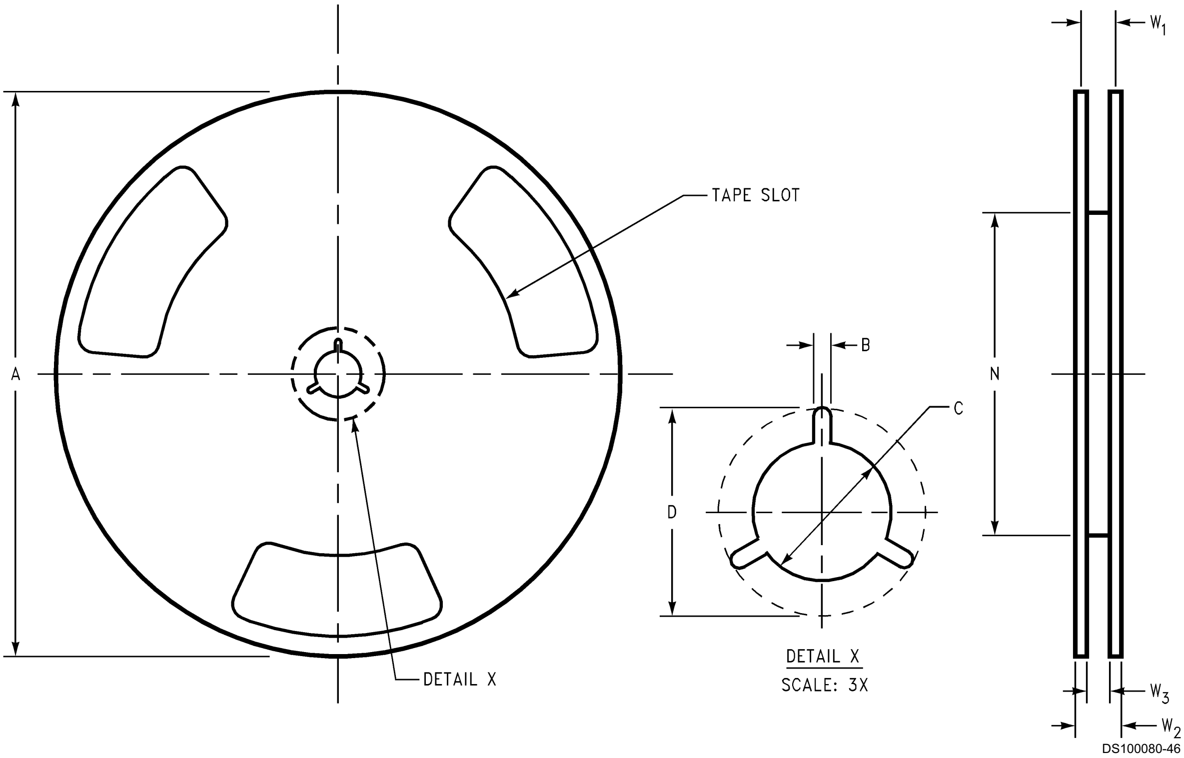
TAPE DIMENSIONS



8 mm	0.130 (3.3)	0.124 (3.15)	0.130 (3.3)	0.126 (3.2)	0.138 ±0.002 (3.5 ±0.05)	0.055 ±0.004 (1.4 ±0.11)	0.157 (4)	0.315 ±0.012 (8 ±0.3)
Tape Size	DIM A	DIM Ao	DIM B	DIM Bo	DIM F	DIM Ko	DIM P1	DIM W

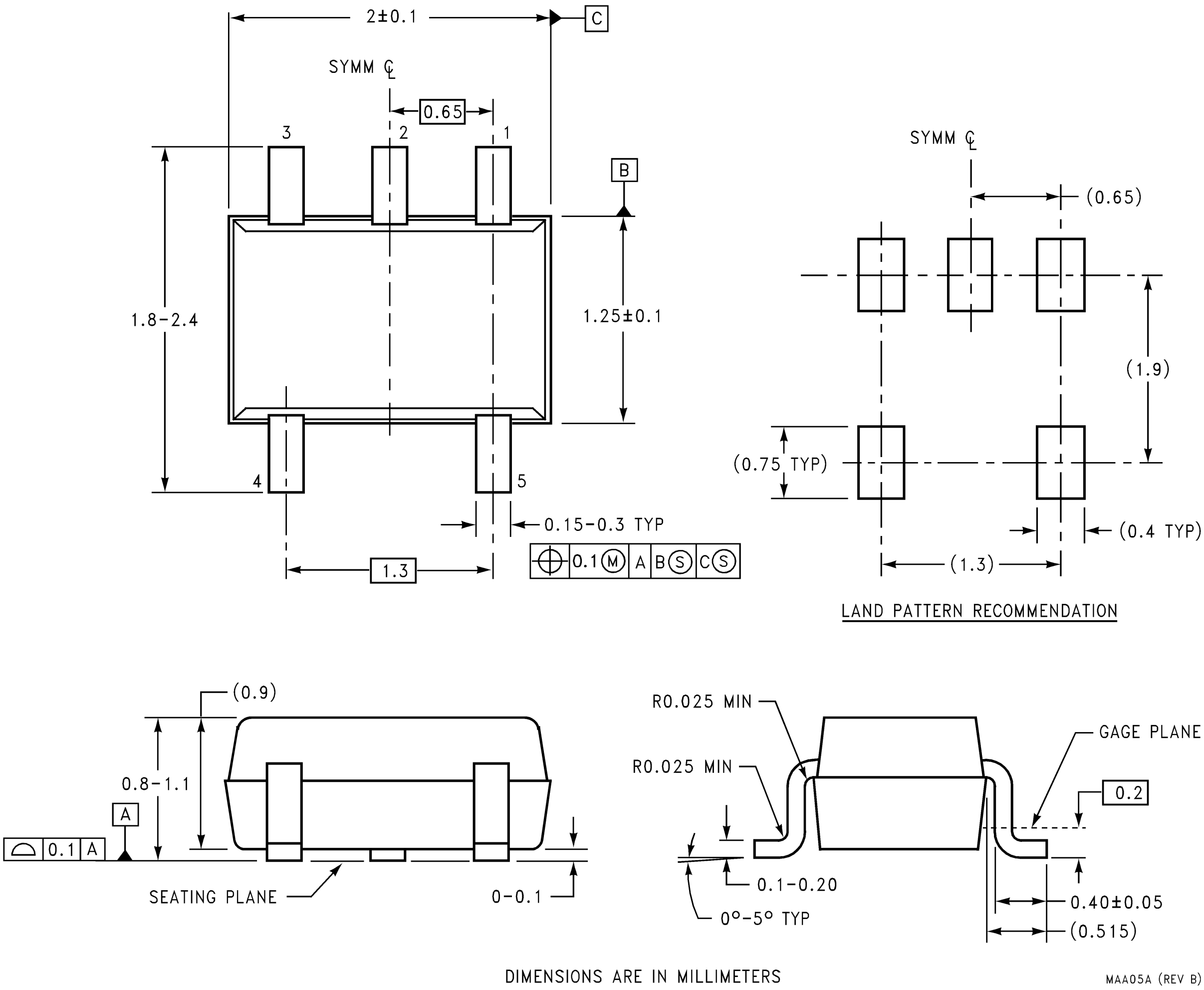
SOT-23-5 Tape and Reel Specification (Continued)

REEL DIMENSIONS



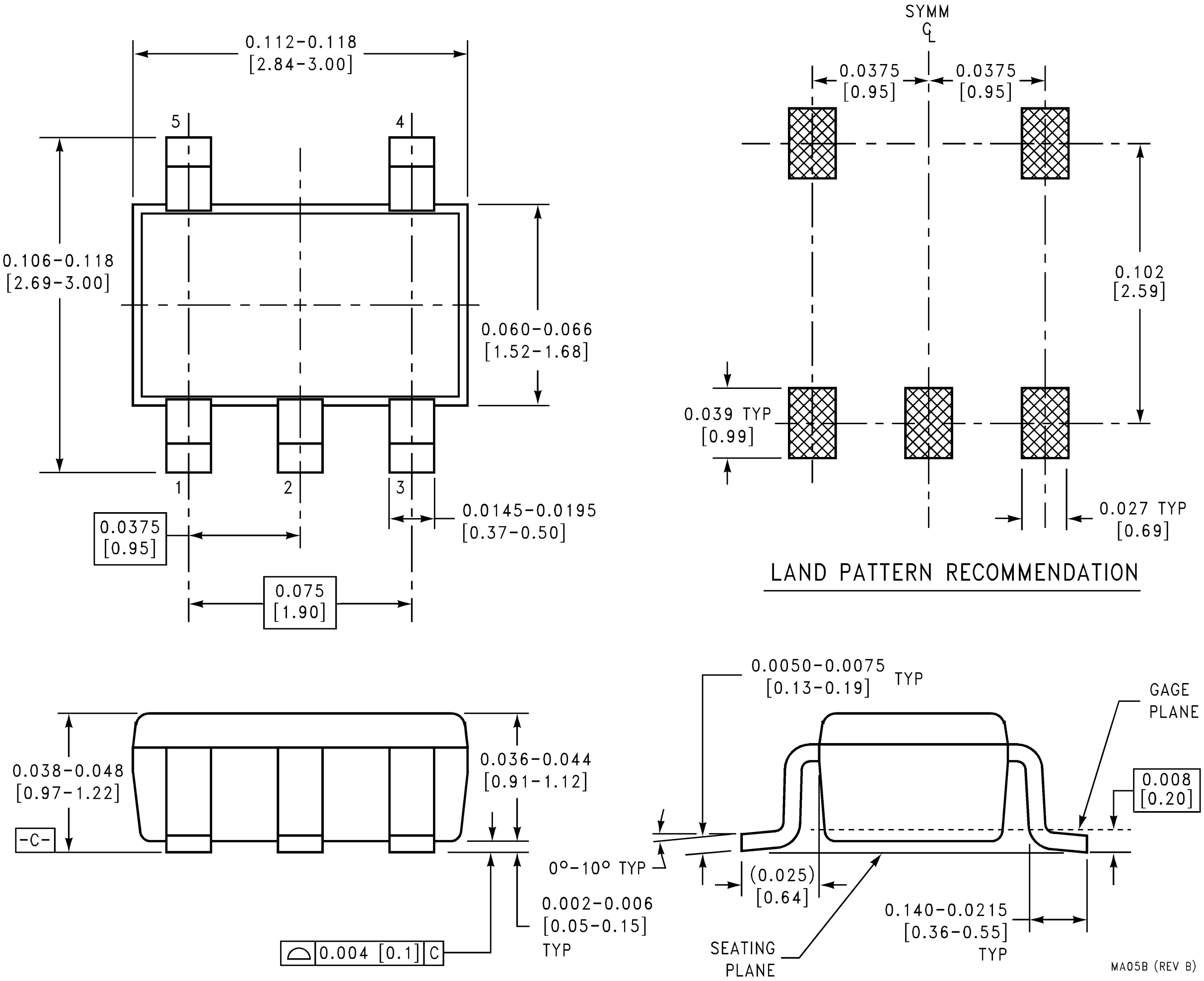
8 mm	7.00 330.00	0.059 1.50	0.512 13.00	0.795 20.20	2.165 55.00	0.331 + 0.059/−0.000 8.40 + 1.50/−0.00	0.567 14.40	W1+ 0.078/−0.039 W1 + 2.00/−1.00
Tape Size	A	B	C	D	N	W1	W2	W3

Physical Dimensions inches (millimeters) unless otherwise noted



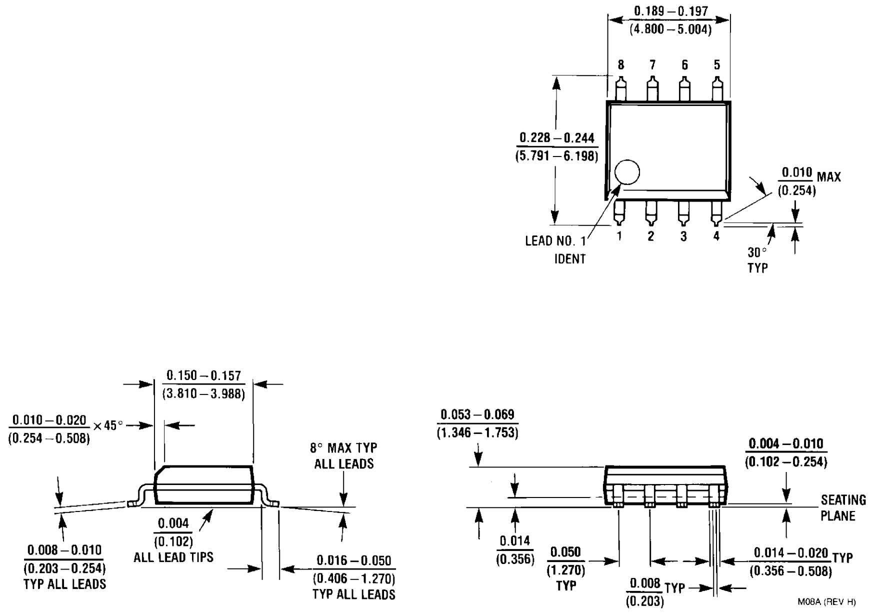
5-Pin SC70-5 Tape and Reel
Order Number LMV331M7 and LMV331M7X
NS Package Number MAA05A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



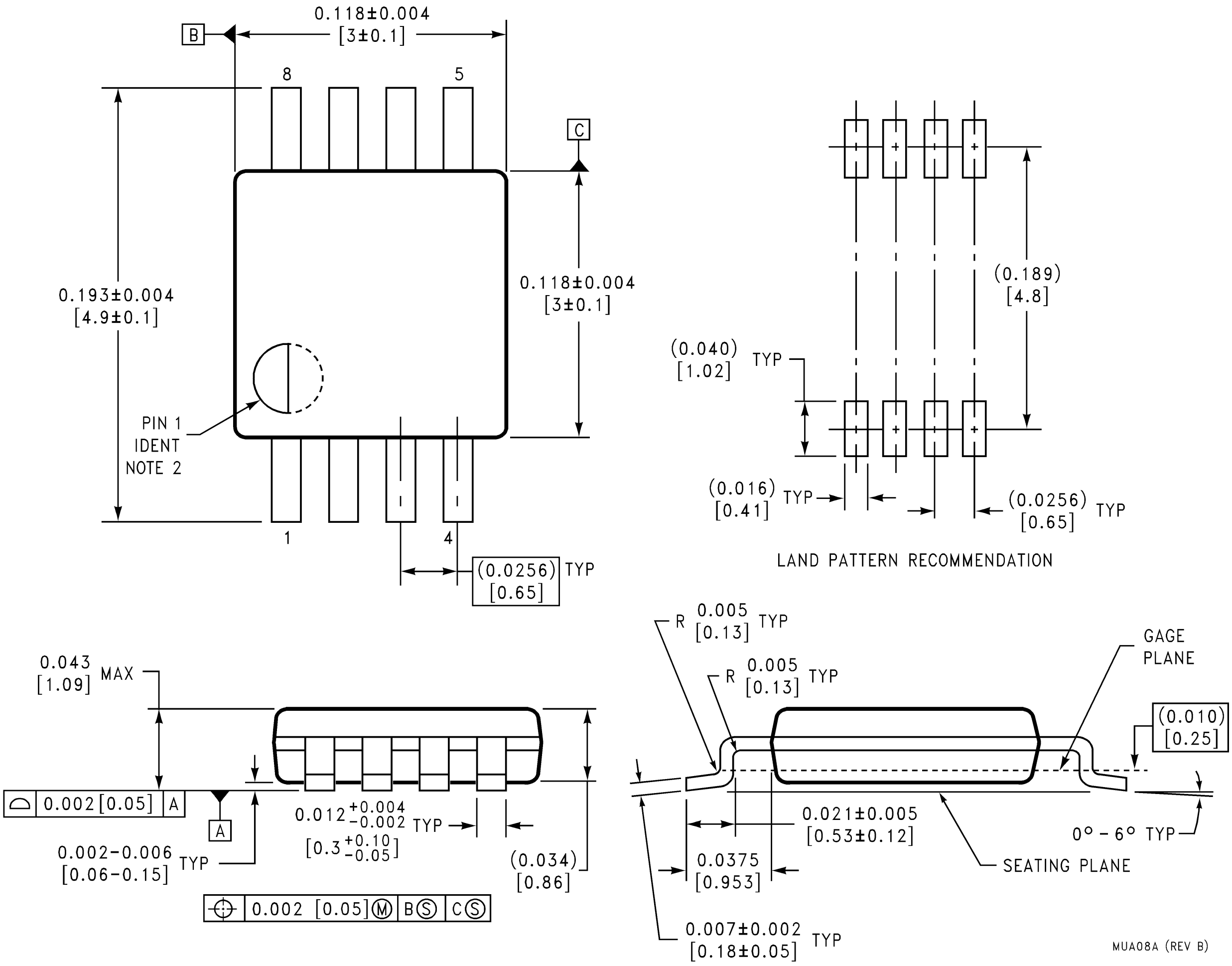
5-Pin SOT23-5 Tape and Reel
Order Number LMV331M5 and LMV331M5X
NS Package Number MA05B

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



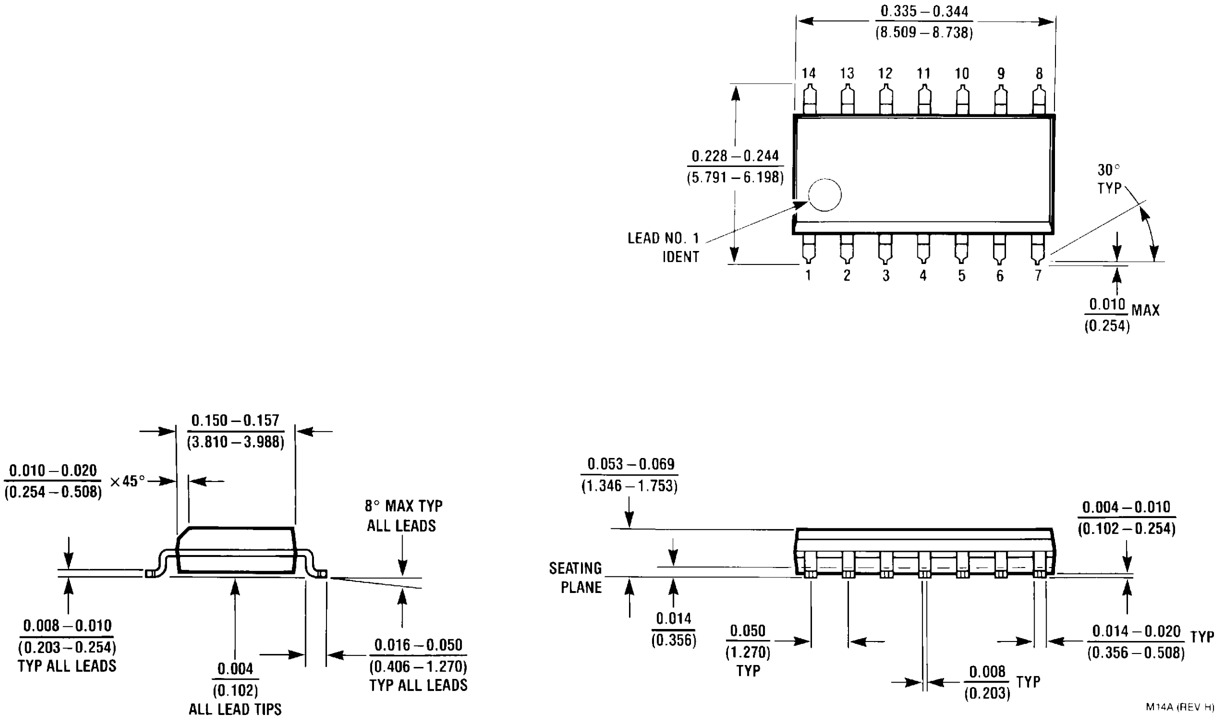
8-Pin Small Outline
Order Number LMV393M and LMV393MX
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



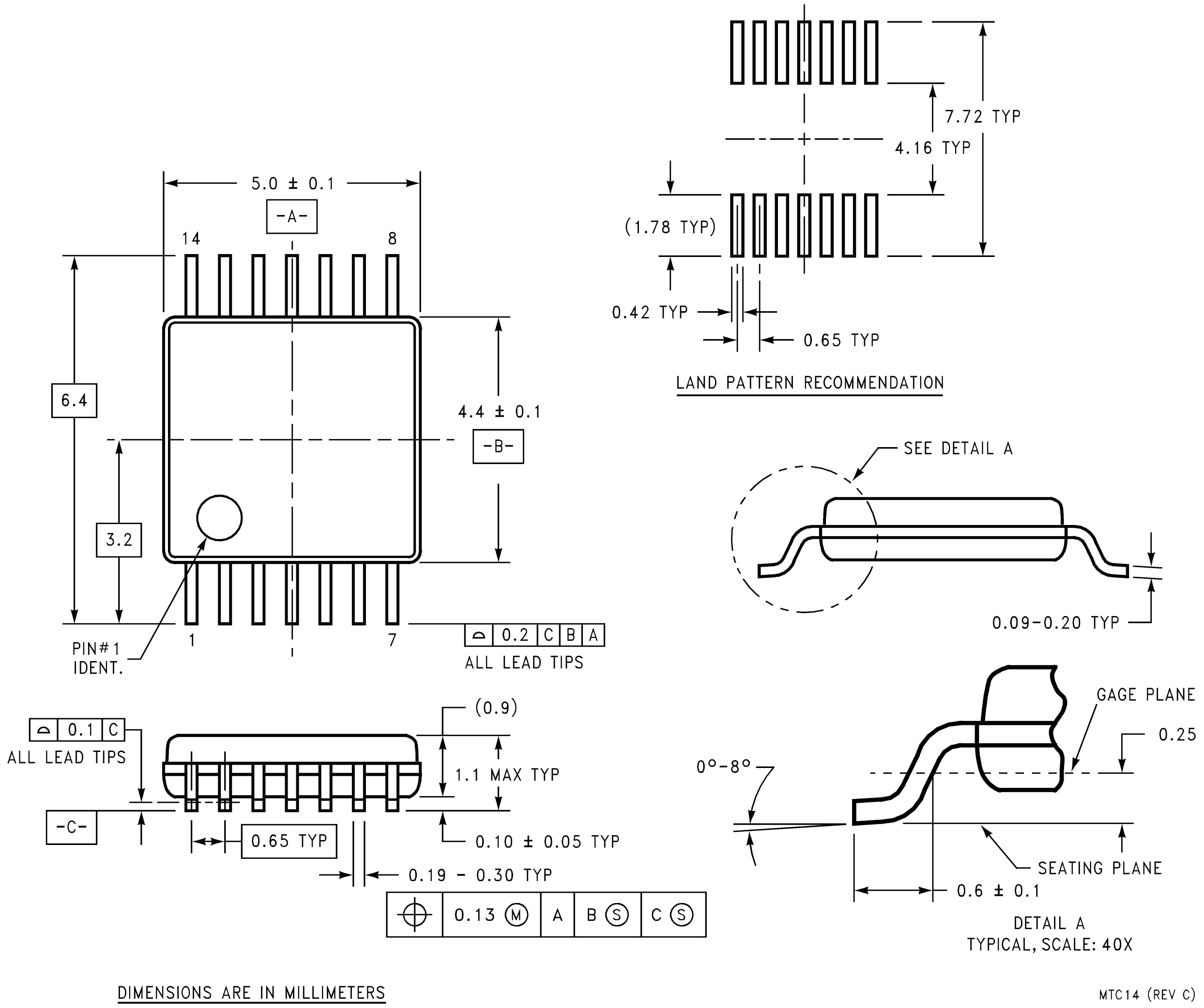
8-Pin MSOP
Order Number LMV393MM and LMV393MMX
NS Package Number MUA08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



14-Pin Small Outline
Order Number LMV339M and LMV339MX
NS Package Number M14A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



14-Pin TSSOP
Order Number LMV339MT and LMV339MTX
NS Package Number MTC14

LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT AND GENERAL COUNSEL OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

National Semiconductor

August 2000

LM124/LM224/LM324/LM2902
Low Power Quad Operational Amplifiers

General Description

The LM124 series consists of four independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM124 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage
- The unity gain cross frequency is temperature compensated
- The input bias current is also temperature compensated

Advantages

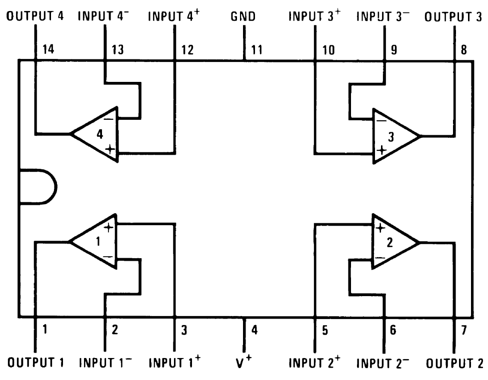
- Eliminates need for dual supplies
- Four internally compensated op amps in a single package
- Allows directly sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features

- Internally frequency compensated for unity gain
- Large DC voltage gain 100 dB
- Wide bandwidth (unity gain) 1 MHz (temperature compensated)
- Wide power supply range:
  Single supply 3V to 32V
  or dual supplies ±1.5V to ±16V
- Very low supply current drain (700 µA) — essentially independent of supply voltage
- Low input biasing current 45 nA (temperature compensated)
- Low input offset voltage 2 mV and offset current: 5 nA
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing 0V to V^+ – 1.5V

Connection Diagrams

Dual-In-Line Package

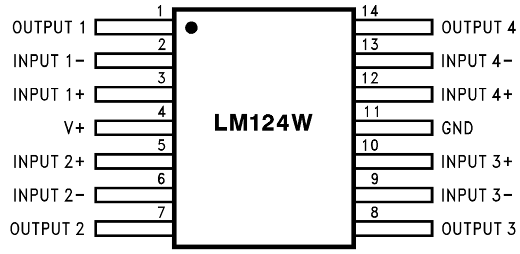


Top View

Order Number LM124J, LM124AJ, LM124J/883 (Note 2)**, LM124AJ/883** (Note 1)**, LM224J, LM224AJ, LM324J, LM324M, LM324MX, LM324AM, LM324AMX, LM2902M, LM2902MX, LM324N, LM324AN, LM324MT, LM324MTX or LM2902N LM124AJRQML and LM124AJRQMLV**(Note 3)

See NS Package Number J14A, M14A or N14A

Connection Diagrams (Continued)



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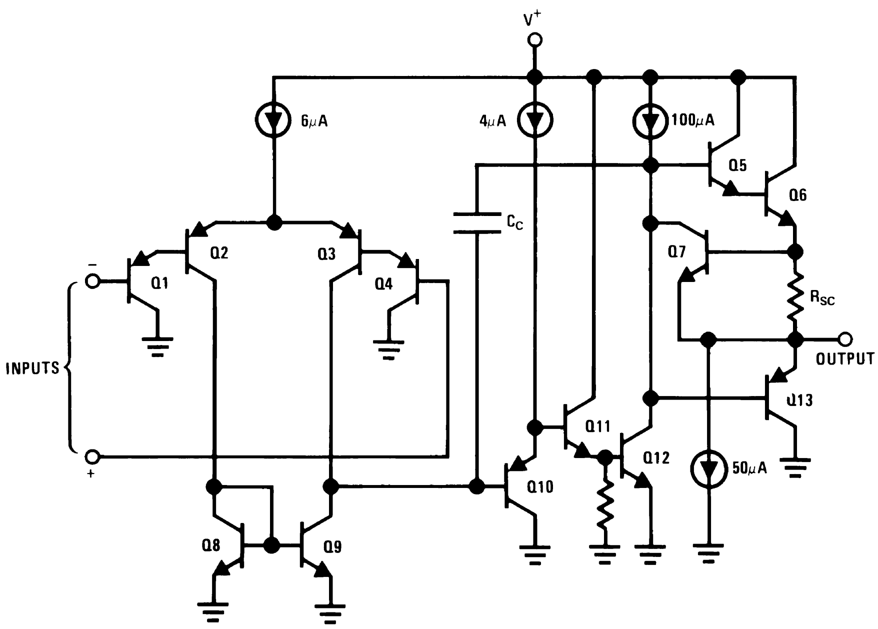
Order Number LM124AW/883, LM124AWG/883, LM124W/883 or LM124WG/883
LM124AWRQML and LM124AWRQMLV(Note 3)
See NS Package Number W14B
LM124AWGRQML and LM124AWGRQMLV(Note 3)
See NS Package Number WG14A

Note 1: LM124A available per JM38510/11006

Note 2: LM124 available per JM38510/11005

Note 3: See STD Mil DWG 5962R99504 for Radiation Tolerant Device

Schematic Diagram (Each Amplifier)



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Absolute Maximum Ratings (Note 12)

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

	LM124/LM224/LM324 LM124A/LM224A/LM324A	LM2902
Supply Voltage, V^+	32V	26V
Differential Input Voltage	32V	26V
Input Voltage	−0.3V to +32V	−0.3V to +26V
Input Current		
(V_{IN} < −0.3V) (Note 6)	50 mA	50 mA
Power Dissipation (Note 4)		
Molded DIP	1130 mW	1130 mW
Cavity DIP	1260 mW	1260 mW
Small Outline Package	800 mW	800 mW
Output Short-Circuit to GND		
(One Amplifier) (Note 5)		
$V^+ \leq 15V$ and T_A = 25˚C	Continuous	Continuous
Operating Temperature Range		−40˚C to +85˚C
LM324/LM324A	0˚C to +70˚C	
LM224/LM224A	−25˚C to +85˚C	
LM124/LM124A	−55˚C to +125˚C	
Storage Temperature Range	−65˚C to +150˚C	−65˚C to +150˚C
Lead Temperature (Soldering, 10 seconds)	260˚C	260˚C
Soldering Information		
Dual-In-Line Package		
Soldering (10 seconds)	260˚C	260˚C
Small Outline Package		
Vapor Phase (60 seconds)	215˚C	215˚C
Infrared (15 seconds)	220˚C	220˚C

See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.

ESD Tolerance (Note 13)	250V	250V

Electrical Characteristics

V^+ = +5.0V, (Note 7), unless otherwise stated

Parameter	Conditions	LM124A			LM224A			LM324A			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 8) T_A = 25˚C		1	2		1	3		2	3	mV
Input Bias Current (Note 9)	$I_{IN(+)}$ or $I_{IN(-)}$, V_{CM} = 0V, T_A = 25˚C		20	50		40	80		45	100	nA
Input Offset Current	$I_{IN(+)}$ or $I_{IN(-)}$, V_{CM} = 0V, T_A = 25˚C		2	10		2	15		5	30	nA
Input Common-Mode Voltage Range (Note 10)	V^+ = 30V, (LM2902, V^+ = 26V), T_A = 25˚C	0		V^+−1.5	0		V^+−1.5	0		V^+−1.5	V
Supply Current	Over Full Temperature Range $R_L = \infty$ On All Op Amps V^+ = 30V (LM2902 V^+ = 26V) V^+ = 5V		 1.5 0.7	 3 1.2		 1.5 0.7	 3 1.2		 1.5 0.7	 3 1.2	mA
Large Signal Voltage Gain	V^+ = 15V, $R_L \geq 2k\Omega$, (V_O = 1V to 11V), T_A = 25˚C	50	100		50	100		25	100		V/mV
Common-Mode	DC, V_{CM} = 0V to V^+ − 1.5V,	70	85		70	85		65	85		dB

Electrical Characteristics (Continued)

$V^+ = +5.0V$, (Note 7), unless otherwise stated

Parameter	Conditions	LM124A			LM224A			LM324A			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Rejection Ratio	$T_A = 25°C$										
Power Supply Rejection Ratio	$V^+ = 5V$ to $30V$ (LM2902, $V^+ = 5V$ to $26V$), $T_A = 25°C$	65	100		65	100		65	100		dB
Amplifier-to-Amplifier Coupling (Note 11)	f = 1 kHz to 20 kHz, $T_A = 25°C$ (Input Referred)		−120			−120			−120		dB
Output Current — Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$	20	40		20	40		20	40		mA
Output Current — Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$	10	20		10	20		10	20		mA
	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 200$ mV, $T_A = 25°C$	12	50		12	50		12	50		μA
Short Circuit to Ground	(Note 5) $V^+ = 15V$, $T_A = 25°C$		40	60		40	60		40	60	mA
Input Offset Voltage	(Note 8)			4			4			5	mV
V_{OS} Drift	$R_S = 0\Omega$		7	20		7	20		7	30	μV/°C
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$			30			30			75	nA
I_{OS} Drift	$R_S = 0\Omega$		10	200		10	200		10	300	pA/°C
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$		40	100		40	100		40	200	nA
Input Common-Mode Voltage Range (Note 10)	$V^+ = +30V$ (LM2902, $V^+ = 26V$)	0		V^+-2	0		V^+-2	0		V^+-2	V
Large Signal Voltage Gain	$V^+ = +15V$ (V_OSwing = 1V to 11V) $R_L \geq 2$ kΩ	25			25			15			V/mV
Output Voltage Swing — V_{OH}	$V^+ = 30V$ (LM2902, $V^+ = 26V$), $R_L = 2$ kΩ	26			26			26			V
	$R_L = 10$ kΩ	27	28		27	28		27	28		V
Output Voltage Swing — V_{OL}	$V^+ = 5V$, $R_L = 10$ kΩ		5	20		5	20		5	20	mV
Output Current — Source	$V_O = 2V$, $V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$	10	20		10	20		10	20		mA
Output Current — Sink	$V_O = 2V$, $V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$	10	15		5	8		5	8		mA

Electrical Characteristics

$V^+ = +5.0V$, (Note 7), unless otherwise stated

Parameter	Conditions	LM124/LM224			LM324			LM2902			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 8) $T_A = 25°C$		2	5		2	7		2	7	mV
Input Bias Current (Note 9)	$I_{IN(+)}$ or $I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		45	150		45	250		45	250	nA
Input Offset Current	$I_{IN(+)}$ or $I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		3	30		5	50		5	50	nA
Input Common-Mode Voltage Range (Note 10)	$V^+ = 30V$, (LM2902, $V^+ = 26V$), $T_A = 25°C$	0		$V^+-1.5$	0		$V^+-1.5$	0		$V^+-1.5$	V

Electrical Characteristics (Continued)

$V^+ = +5.0V$, (Note 7), unless otherwise stated

Parameter		Conditions		LM124/LM224 Min	LM124/LM224 Typ	LM124/LM224 Max	LM324 Min	LM324 Typ	LM324 Max	LM2902 Min	LM2902 Typ	LM2902 Max	Units
Supply Current		Over Full Temperature Range $R_L = \infty$ On All Op Amps											mA
		$V^+ = 30V$ (LM2902 $V^+ = 26V$)			1.5	3		1.5	3		1.5	3	
		$V^+ = 5V$			0.7	1.2		0.7	1.2		0.7	1.2	
Large Signal Voltage Gain		$V^+ = 15V$, $R_L \geq 2k\Omega$, (V_O = 1V to 11V), $T_A = 25°C$		50	100		25	100		25	100		V/mV
Common-Mode Rejection Ratio		DC, V_{CM} = 0V to $V^+ - 1.5V$, $T_A = 25°C$		70	85		65	85		50	70		dB
Power Supply Rejection Ratio		V^+ = 5V to 30V (LM2902, V^+ = 5V to 26V), $T_A = 25°C$		65	100		65	100		50	100		dB
Amplifier-to-Amplifier Coupling (Note 11)		f = 1 kHz to 20 kHz, $T_A = 25°C$ (Input Referred)			−120			−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$		20	40		20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$		10	20		10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 200$ mV, $T_A = 25°C$		12	50		12	50		12	50		μA
Short Circuit to Ground		(Note 5) $V^+ = 15V$, $T_A = 25°C$			40	60		40	60		40	60	mA
Input Offset Voltage		(Note 8)				7			9			10	mV
V_{OS} Drift		$R_S = 0\Omega$			7			7			7		μV/°C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$				100			150		45	200	nA
I_{OS} Drift		$R_S = 0\Omega$			10			10			10		pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$			40	300		40	500		40	500	nA
Input Common-Mode Voltage Range (Note 10)		$V^+ = +30V$ (LM2902, $V^+ = 26V$)		0		V^+−2	0		V^+−2	0		V^+−2	V
Large Signal Voltage Gain		$V^+ = +15V$ (V_OSwing = 1V to 11V) $R_L \geq 2$ kΩ		25			15			15			V/mV
Output Voltage Swing	V_{OH}	$V^+ = 30V$	$R_L = 2$ kΩ	26			26			22			V
		(LM2902, $V^+ = 26V$)	$R_L = 10$ kΩ	27	28		27	28		23	24		V
	V_{OL}	$V^+ = 5V$, $R_L = 10$ kΩ			5	20		5	20		5	100	mV
Output Current	Source	$V_O = 2V$	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$	10	20		10	20		10	20		mA
	Sink		$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$	5	8		5	8		5	8		mA

Note 4: For operating at high temperatures, the LM324/LM324A/LM2902 must be derated based on a +125˚C maximum junction temperature and a thermal resistance of 88˚C/W which applies for the device soldered in a printed circuit board, operating in a still air ambient. The LM224/LM224A and LM124/LM124A can be derated based on a +150˚C maximum junction temperature. The dissipation is the total of all four amplifiers — use external resistors, where possible, to allow the amplifier to saturate of to reduce the power which is dissipated in the integrated circuit.

Note 5: Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V^+. At values of supply voltage in excess of +15V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.

Note 6: This input current will only exist when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistors becoming forward biased and thereby acting as input diode clamps. In addition to this diode action, there is also lateral NPN parasitic transistor action

Electrical Characteristics (Continued)

on the IC chip. This transistor action can cause the output voltages of the op amps to go to the V+voltage level (or to ground for a large overdrive) for the time duration that an input is driven negative. This is not destructive and normal output states will re-establish when the input voltage, which was negative, again returns to a value greater than −0.3V (at 25˚C).

Note 7: These specifications are limited to $-55^\circ C \le T_A \le +125^\circ C$ for the LM124/LM124A. With the LM224/LM224A, all temperature specifications are limited to $-25^\circ C \le T_A \le +85^\circ C$, the LM324/LM324A temperature specifications are limited to $0^\circ C \le T_A \le +70^\circ C$, and the LM2902 specifications are limited to $-40^\circ C \le T_A \le +85^\circ C$.

Note 8: $V_O \simeq 1.4V$, $R_S = 0\Omega$ with V^+ from 5V to 30V; and over the full input common-mode range (0V to $V^+ - 1.5V$) for LM2902, V^+ from 5V to 26V.

Note 9: The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.

Note 10: The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V (at 25˚C). The upper end of the common-mode voltage range is $V^+ - 1.5V$ (at 25˚C), but either or both inputs can go to +32V without damage (+26V for LM2902), independent of the magnitude of V^+.

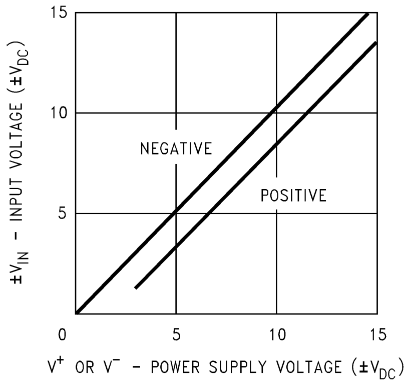
Note 11: Due to proximity of external components, insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequencies.

Note 12: Refer to RETS124AX for LM124A military specifications and refer to RETS124X for LM124 military specifications.

Note 13: Human body model, 1.5 kΩ in series with 100 pF.

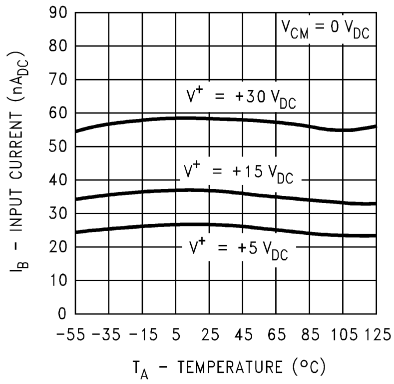
Typical Performance Characteristics

Input Voltage Range



00929934

Input Current



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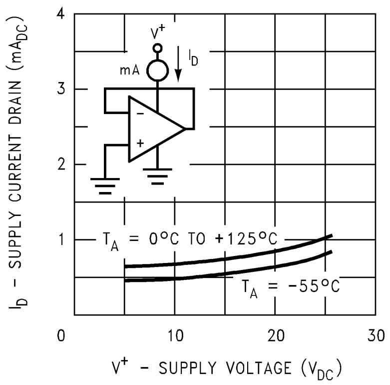
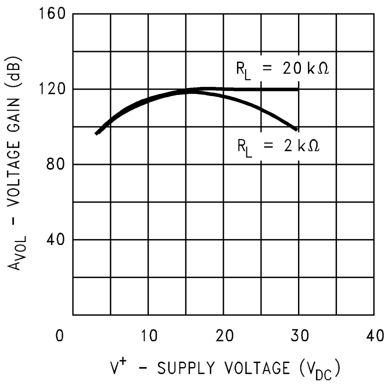
Supply Current



00929936

Voltage Gain



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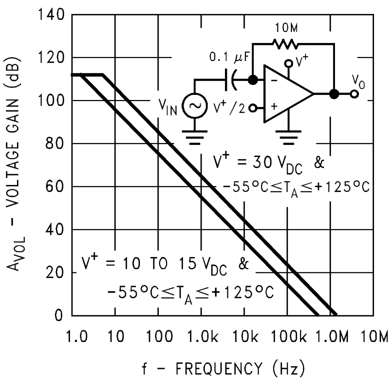
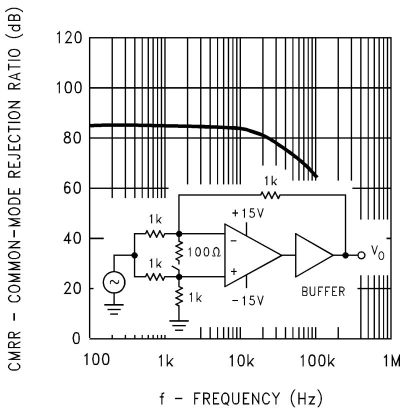
Typical Performance Characteristics (Continued)

Open Loop Frequency Response



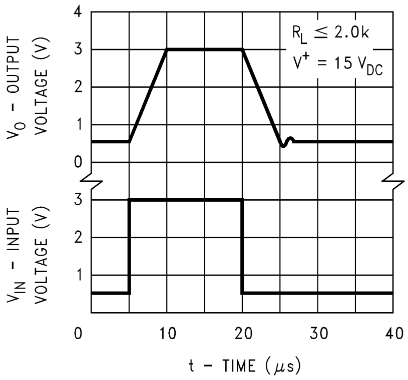
00929938

Common Mode Rejection Ratio



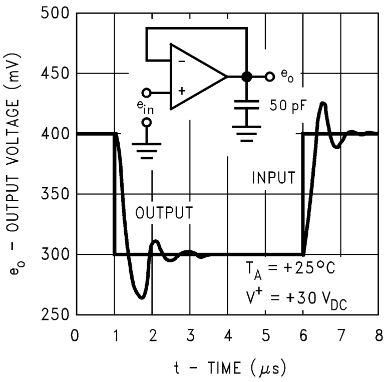
00929939

Voltage Follower Pulse Response



00929940

Voltage Follower Pulse Response (Small Signal)



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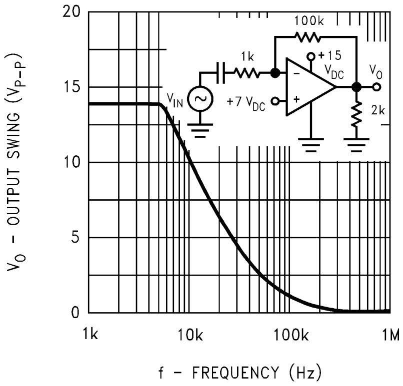
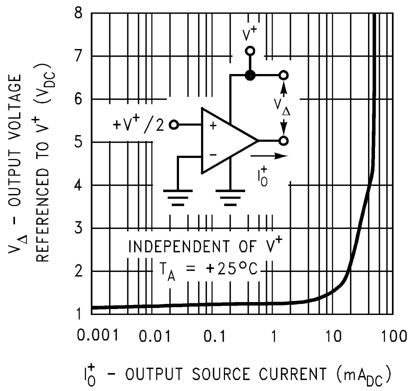
Large Signal Frequency Response



00929942

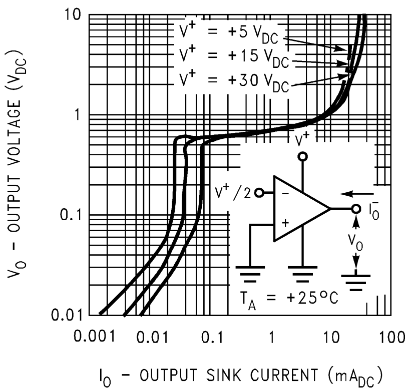
Output Characteristics Current Sourcing



00929943

Typical Performance Characteristics (Continued)

Output Characteristics Current Sinking



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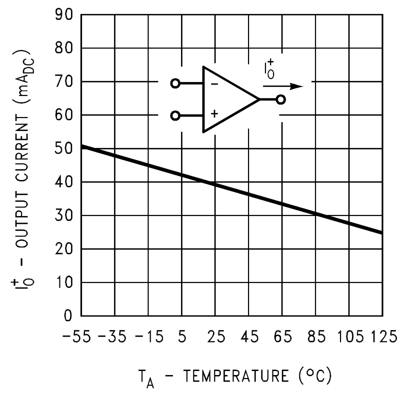
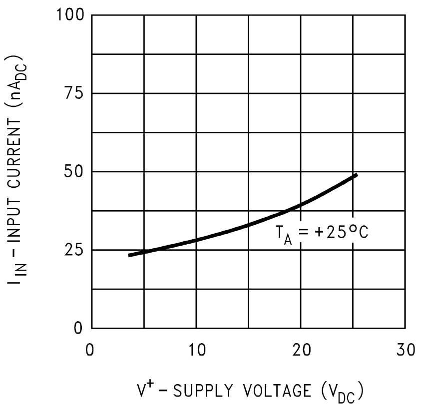
Current Limiting



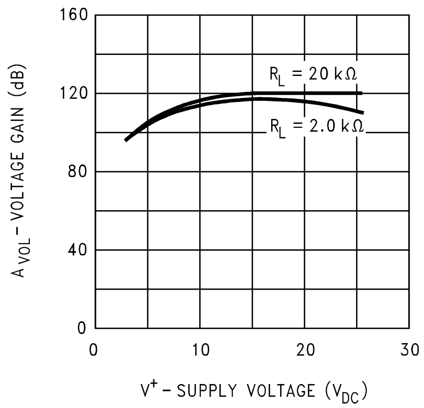
00929945

Input Current (LM2902 only)



00929946

Voltage Gain (LM2902 only)



00929947

Application Hints

The LM124 series are op amps which operate with only a single power supply voltage, have true-differential inputs, and remain in the linear mode with an input common-mode voltage of 0 V_{DC}. These amplifiers operate over a wide range of power supply voltage with little change in performance characteristics. At 25˚C amplifier operation is possible down to a minimum supply voltage of 2.3 V_{DC}.

The pinouts of the package have been designed to simplify PC board layouts. Inverting inputs are adjacent to outputs for all of the amplifiers and the outputs have also been placed at the corners of the package (pins 1, 7, 8, and 14).

Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Large differential input voltages can be easily accommodated and, as input differential voltage protection diodes are not needed, no large input currents result from large differential input voltages. The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than −0.3 V_{DC} (at 25˚C). An input clamp diode with a resistor to the IC input terminal can be used.

To reduce the power supply drain, the amplifiers have a class A output stage for small signal levels which converts to class B in a large signal mode. This allows the amplifiers to both source and sink large output currents. Therefore both NPN and PNP external current boost transistors can be used to extend the power capability of the basic amplifiers. The output voltage needs to raise approximately 1 diode drop above ground to bias the on-chip vertical PNP transistor for output current sinking applications.

For ac applications, where the load is capacitively coupled to the output of the amplifier, a resistor should be used, from the output of the amplifier to ground to increase the class A bias current and prevent crossover distortion.

Where the load is directly coupled, as in dc applications, there is no crossover distortion.

Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50 pF can be accommodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if larger load capacitance must be driven by the amplifier.

Application Hints (Continued)

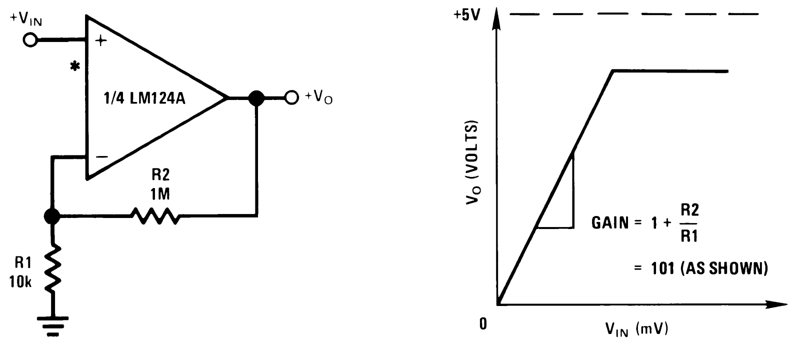
The bias network of the LM124 establishes a drain current which is independent of the magnitude of the power supply voltage over the range of from 3 V_{DC} to 30 V_{DC}.

Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive junction temperatures. Putting direct short-circuits on more than one amplifier at a time will increase the total IC power dissipation to destructive levels, if not properly protected with external dissipation limiting resistors in series with the output leads of the amplifiers. The larger value of output source current which is available at 25˚C provides a larger output current capability at elevated temperatures (see typical performance characteristics) than a standard IC op amp.

The circuits presented in the section on typical applications emphasize operation on only a single power supply voltage. If complementary power supplies are available, all of the standard op amp circuits can be used. In general, introducing a pseudo-ground (a bias voltage reference of $V^+/2$) will allow operation above and below this value in single power supply systems. Many application circuits are shown which take advantage of the wide input common-mode voltage range which includes ground. In most cases, input biasing is not required and input voltages which range to ground can easily be accommodated.

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$)

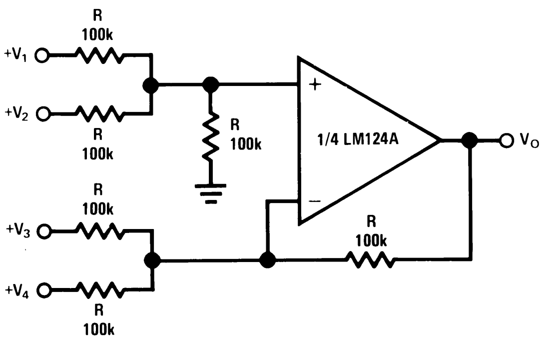
Non-Inverting DC Gain (0V Input = 0V Output)



00929905

*R not needed due to temperature independent I_{IN}

DC Summing Amplifier ($V_{IN'S} \geq 0\ V_{DC}$ and $V_O \geq V_{DC}$)

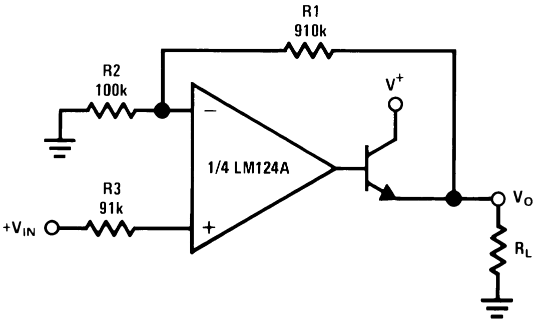


00929906

Where: $V_0 = V_1 + V_2 - V_3 - V_4$

$(V_1 + V_2) \geq (V_3 + V_4)$ to keep $V_O > 0\ V_{DC}$

Power Amplifier



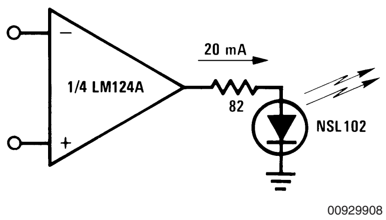
00929907

$V_0 = 0\ V_{DC}$ for $V_{IN} = 0\ V_{DC}$

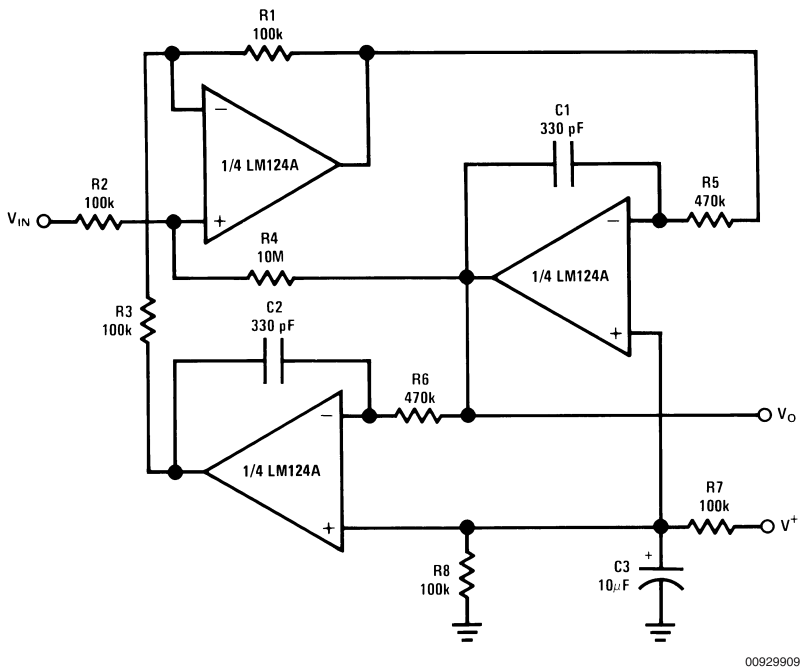
$A_V = 10$

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

LED Driver

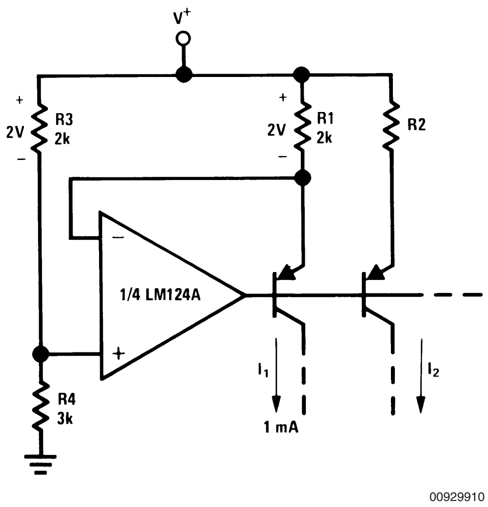


"BI-QUAD" RC Active Bandpass Filter



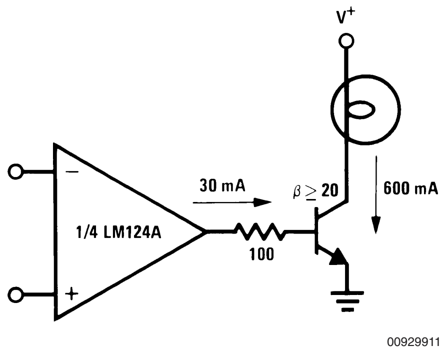
$f_o = 1$ kHz
Q = 50
$A_V = 100$ (40 dB)

Fixed Current Sources



$$I_2 = \left(\frac{R1}{R2}\right) I_1$$

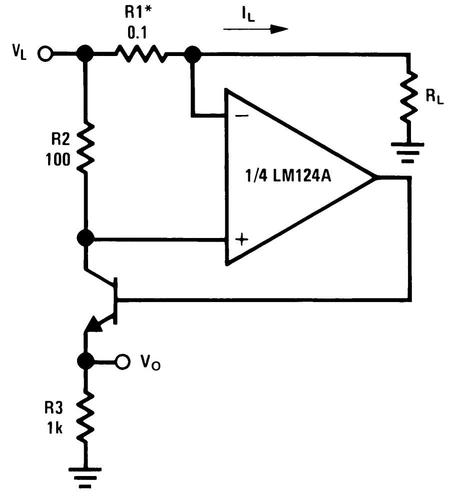
Lamp Driver



Typical Single-Supply Applications

(V^+ = 5.0 V_{DC}) (Continued)

Current Monitor



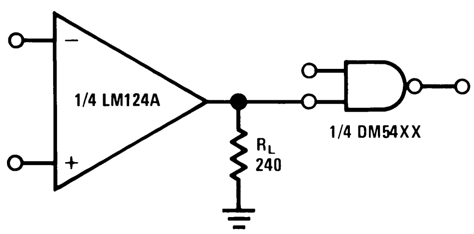
00929912

$$V_O = \frac{1V(I_L)}{1A}$$

$$V_L \leq V^+ - 2V$$

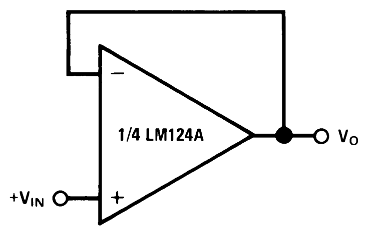
*(Increase R1 for I_L small)

Driving TTL



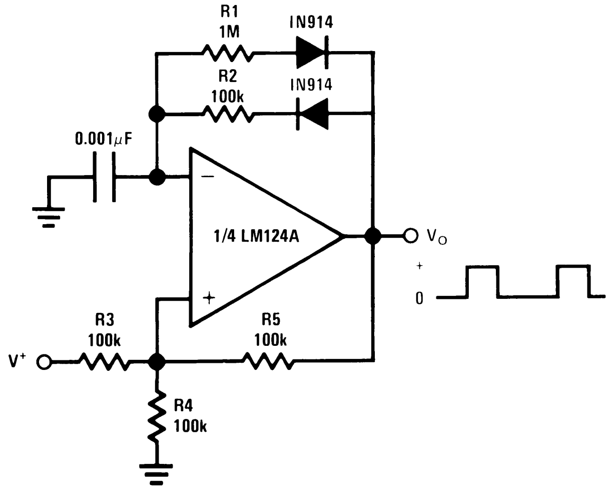
00929913

Voltage Follower



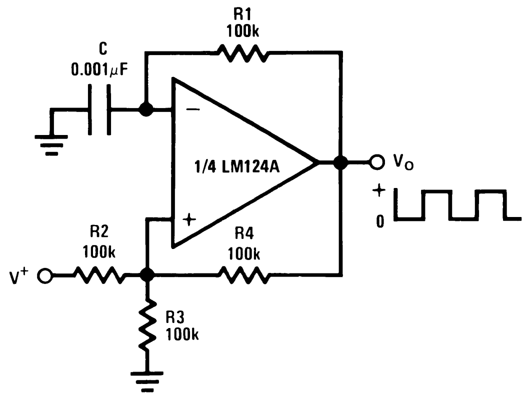
00929914

Pulse Generator



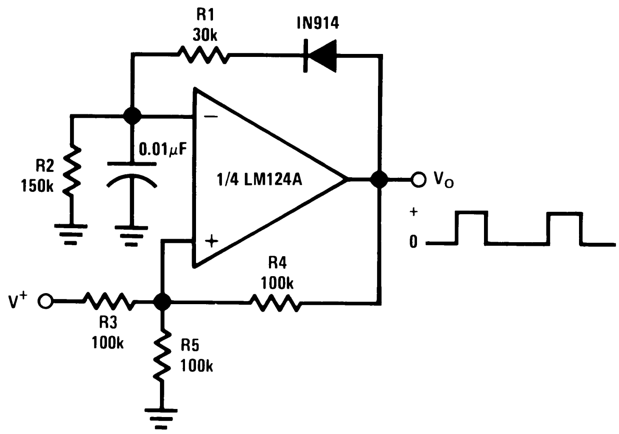
00929915

Squarewave Oscillator



00929916

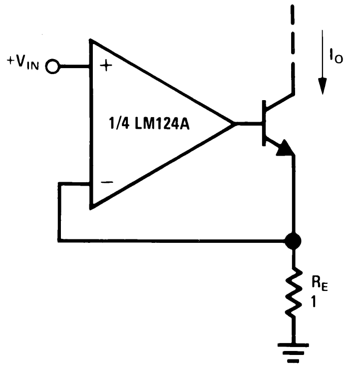
Pulse Generator



00929917

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

High Compliance Current Sink



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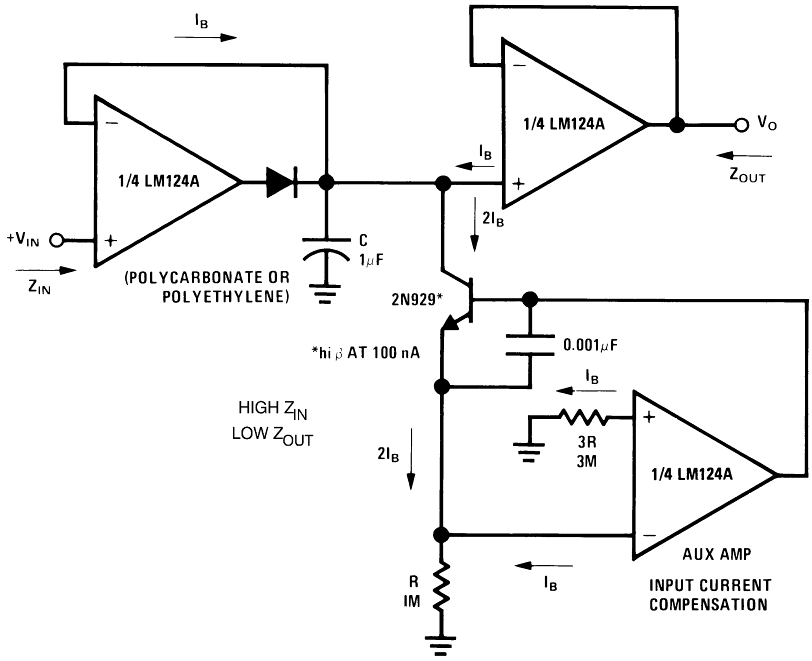
I_O = 1 amp/volt V_{IN}
(Increase R_E for I_o small)

Low Drift Peak Detector



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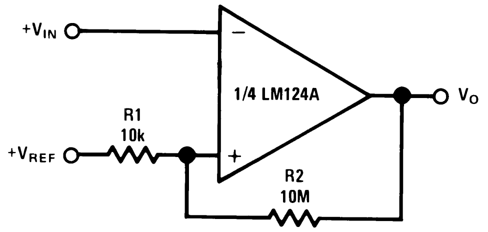
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

Comparator with Hysteresis



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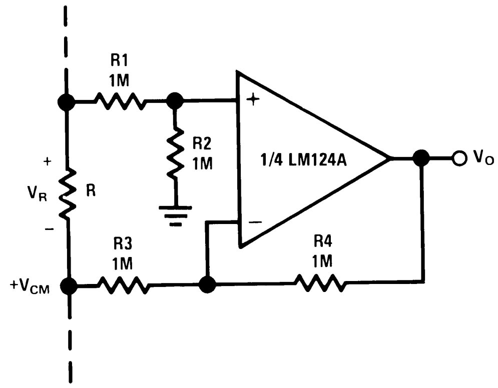
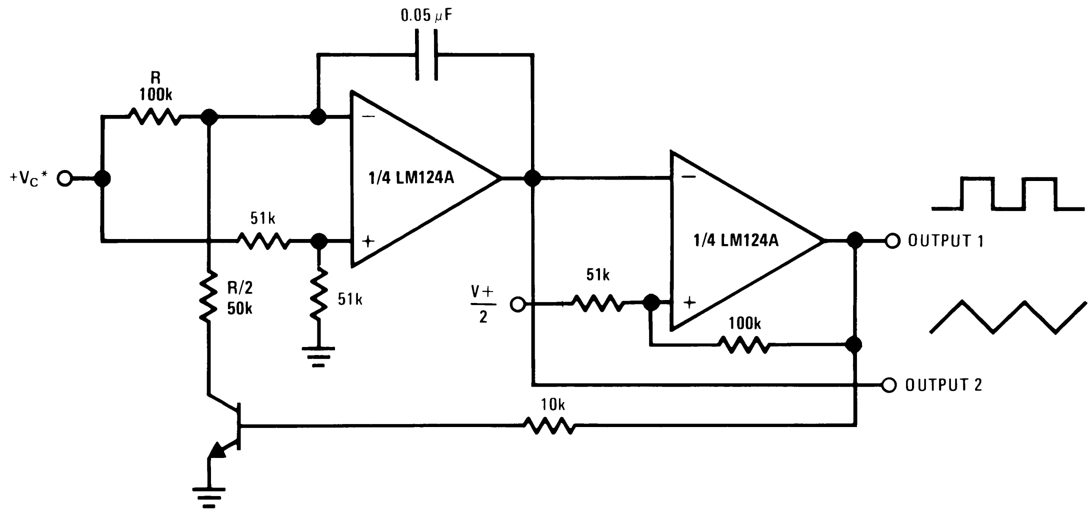
Ground Referencing a Differential Input Signal



00929921

$V_O = V_R$

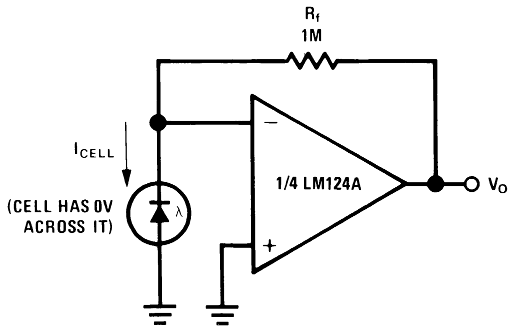
Voltage Controlled Oscillator Circuit



00929922

*Wide control voltage range: $0\ V_{DC} \leq V_C \leq 2\ (V^+ - 1.5\ V_{DC})$

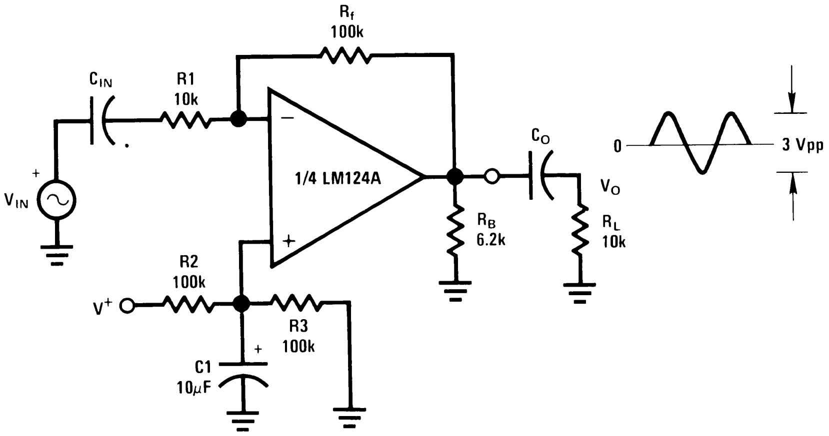
Photo Voltaic-Cell Amplifier



00929923

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

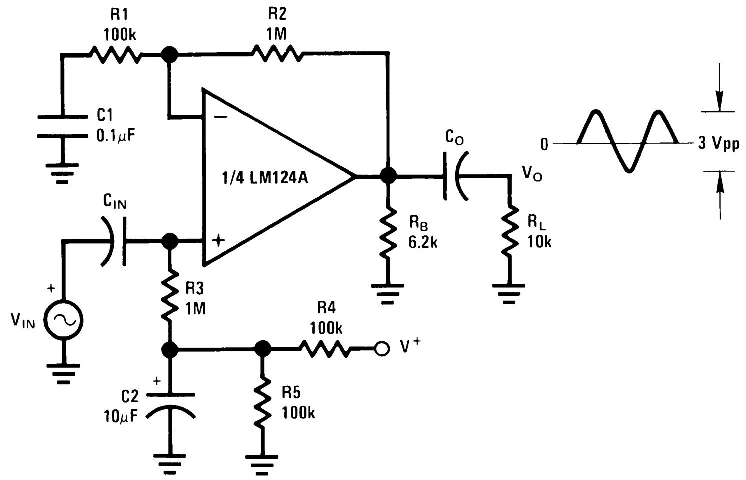
AC Coupled Inverting Amplifier



00929924

$$A_V = \frac{R_f}{R1} \text{ (As shown, } A_V = 10\text{)}$$

AC Coupled Non-Inverting Amplifier



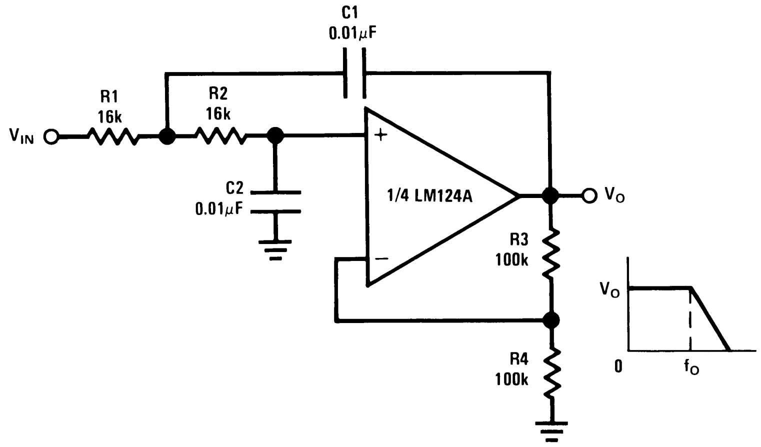
00929925

$$A_V = 1 + \frac{R2}{R1}$$

$A_V = 11$ (As shown)

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

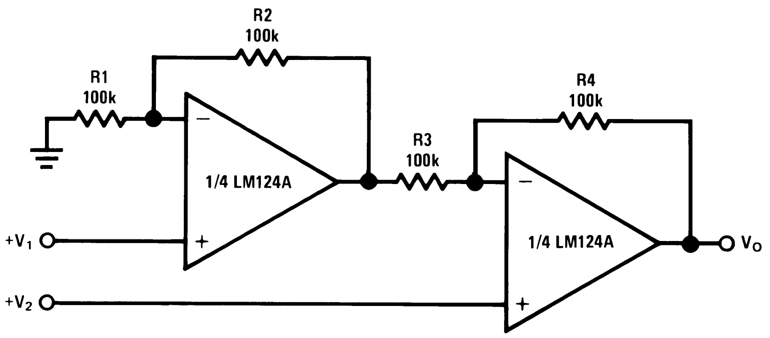
DC Coupled Low-Pass RC Active Filter



00929926

$f_O = 1$ kHz
$Q = 1$
$A_V = 2$

High Input Z, DC Differential Amplifier



00929927

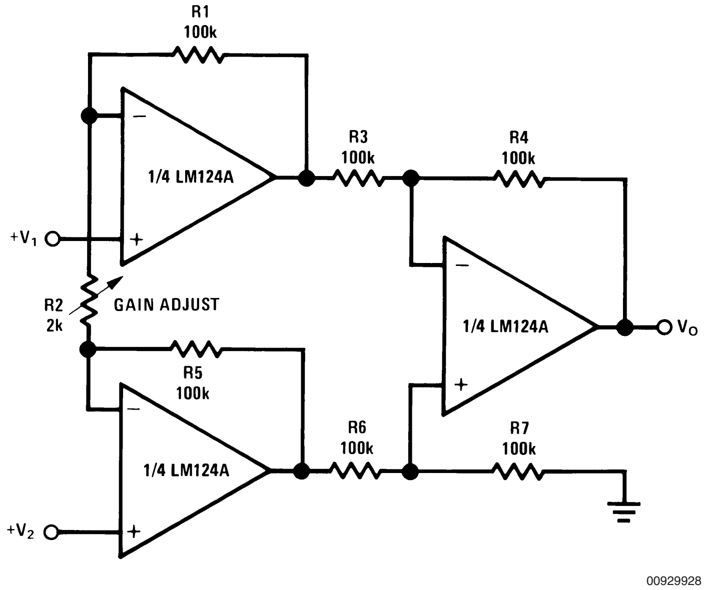
For $\frac{R1}{R2} = \frac{R4}{R3}$ (CMRR depends on this resistor ratio match)

$V_O = 1 + \frac{R4}{R3}(V_2 - V_1)$

As shown: $V_O = 2(V_2 - V_1)$

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

High Input Z Adjustable-Gain DC Instrumentation Amplifier

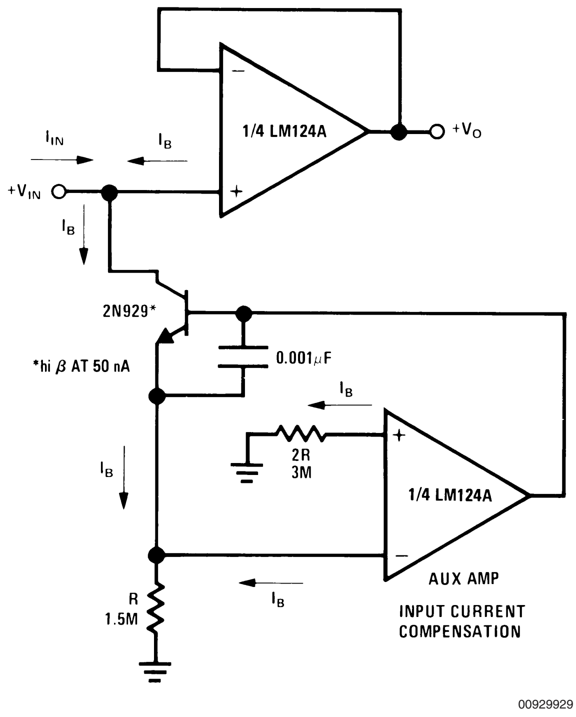


If R1 = R5 & R3 = R4 = R6 = R7 (CMRR depends on match)

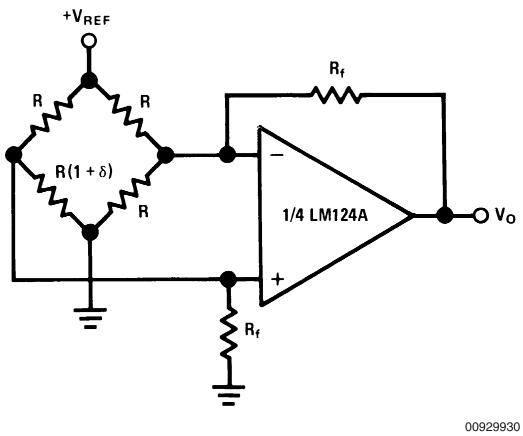
$$V_O = 1 + \frac{2R1}{R2}(V_2 - V_1)$$

As shown $V_O = 101\ (V_2 - V_1)$

Using Symmetrical Amplifiers to Reduce Input Current (General Concept)



Bridge Current Amplifier

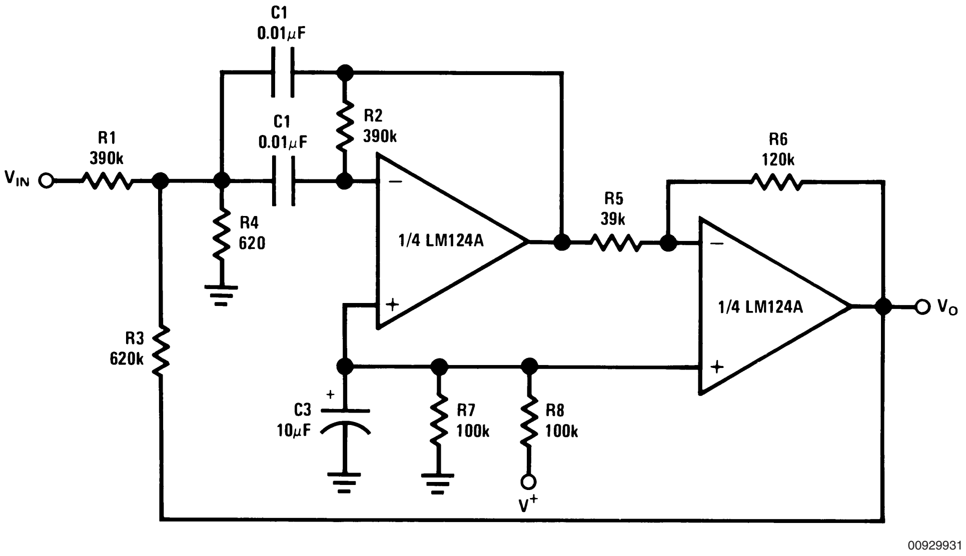


For $\delta << 1$ and $R_f >> R$

$$V_O \cong V_{REF}\left(\frac{\delta}{2}\right)\frac{R_f}{R}$$

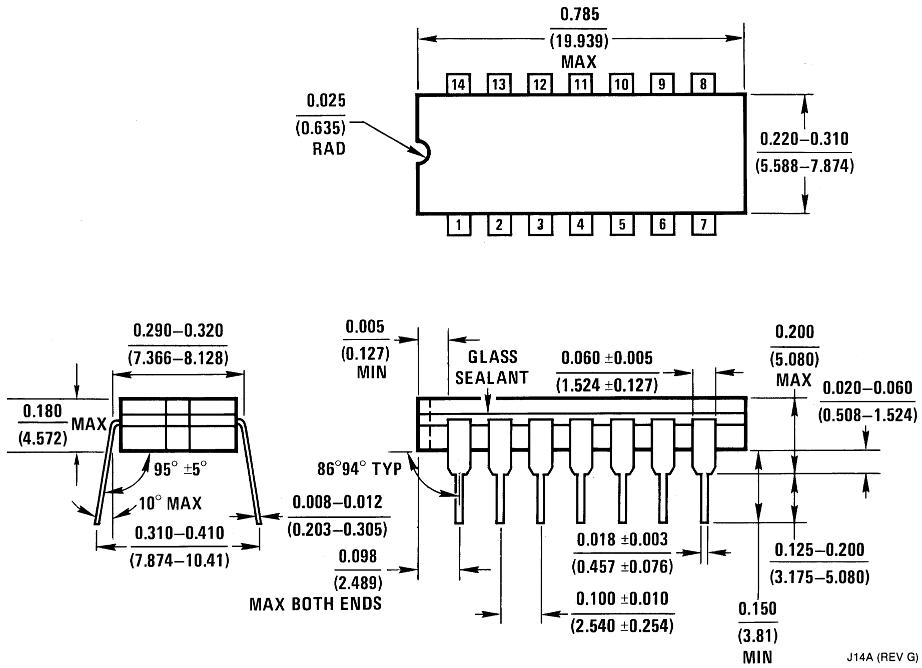
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

Bandpass Active Filter

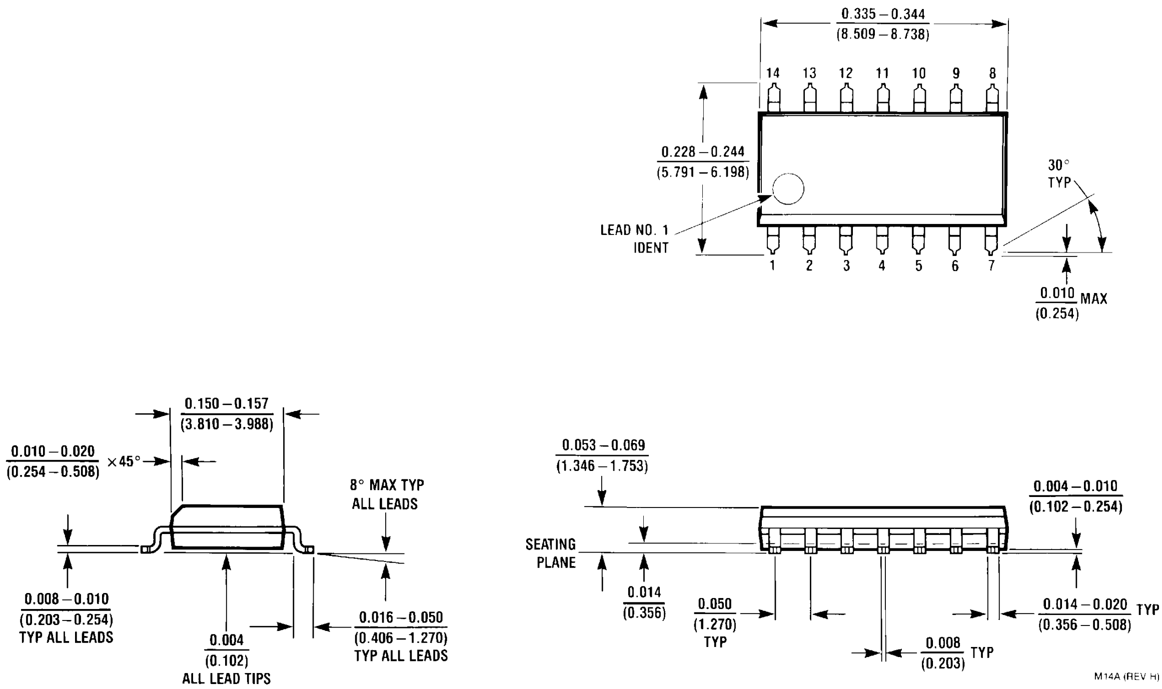


$f_O = 1$ kHz
Q = 25

Physical Dimensions inches (millimeters) unless otherwise noted

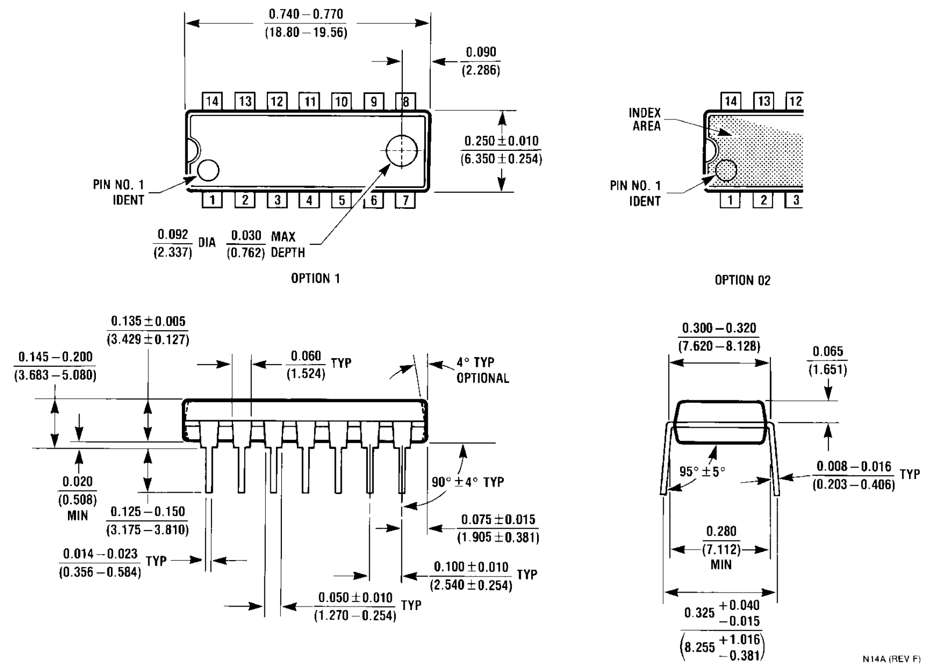


Ceramic Dual-In-Line Package (J)
Order Number JL124ABCA, JL124BCA, JL124ASCA, JL124SCA, LM124J, LM124AJ, LM124AJ/883, LM124J/883, LM224J, LM224AJ or LM324J
NS Package Number J14A

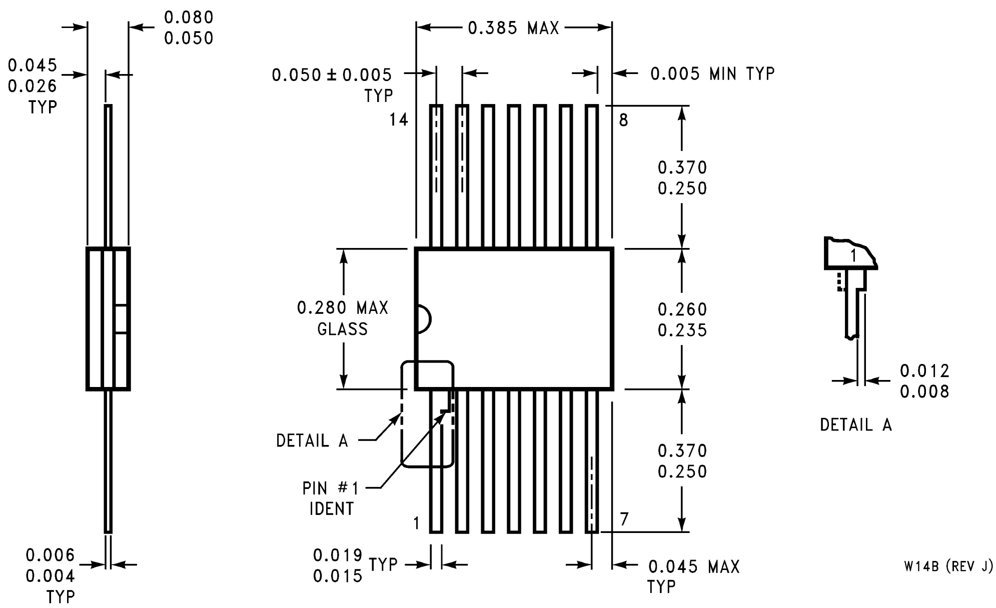


MX S.O. Package (M)
Order Number LM324M, LM324MX, LM324AM, LM324AMX, LM2902M or LM2902MX
NS Package Number M14A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

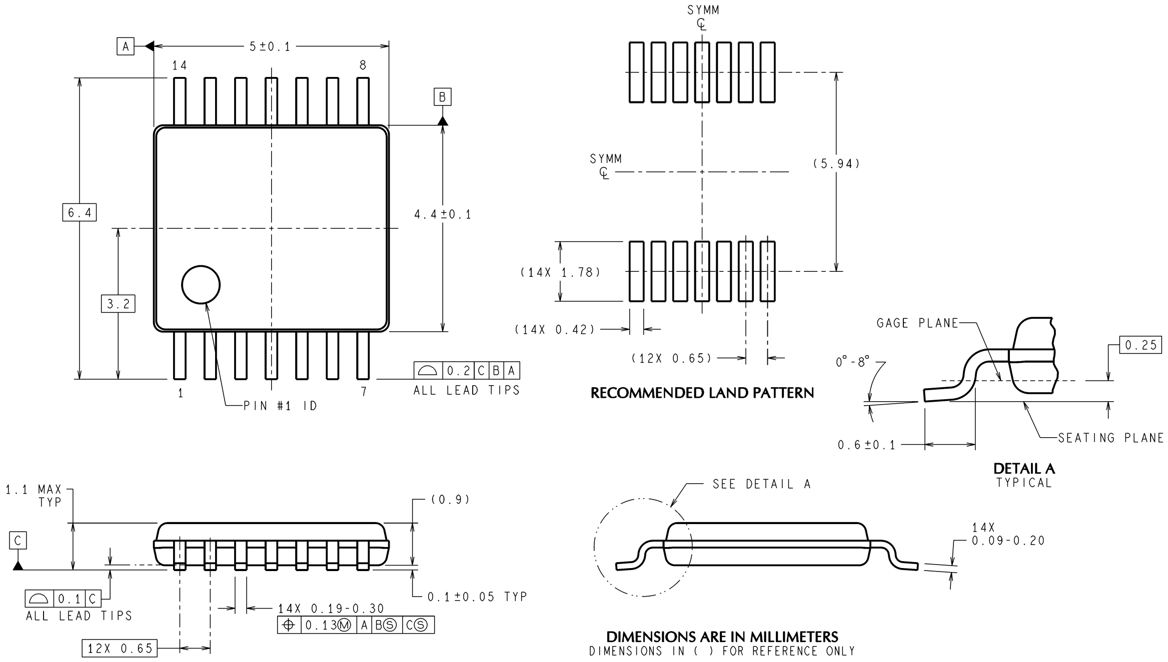


Molded Dual-In-Line Package (N)
Order Number LM324N, LM324AN or LM2902N
NS Package Number N14A



Ceramic Flatpak Package
Order Number JL124ABDA, JL124ABZA, JL124ASDA, JL124BDA, JL124BZA, JL124SDA, LM124AW/883, LM124AWG/883, LM124W/883 or LM124WG/883
NS Package Number W14B

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



MTC14 (Rev D)

14-Pin TSSOP
Order NumberLM324MT or LM324MTX
NS Package Number MTC14

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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National Semiconductor

November 1994

LM139/LM239/LM339/LM2901/LM3302 Low Power Low Offset Voltage Quad Comparators

General Description

The LM139 series consists of four independent precision voltage comparators with an offset voltage specification as low as 2 mV max for all four comparators. These were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. These comparators also have a unique characteristic in that the input common-mode voltage range includes ground, even though operated from a single power supply voltage.

Application areas include limit comparators, simple analog to digital converters; pulse, squarewave and time delay generators; wide range VCO; MOS clock timers; multivibrators and high voltage digital logic gates. The LM139 series was designed to directly interface with TTL and CMOS. When operated from both plus and minus power supplies, they will directly interface with MOS logic— where the low power drain of the LM339 is a distinct advantage over standard comparators.

Advantages

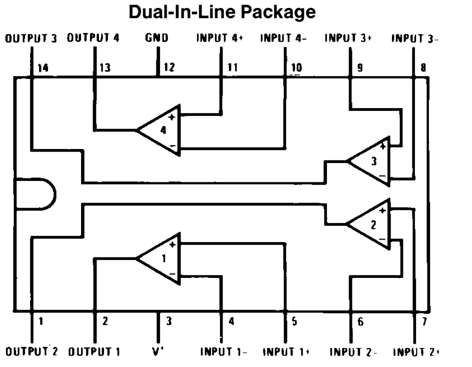
- High precision comparators
- Reduced V_{OS} drift over temperature
- Eliminates need for dual supplies
- Allows sensing near GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features

- Wide supply voltage range
  - LM139 series, 2 V_{DC} to 36 V_{DC} or $\pm$1 V_{DC} to $\pm$18 V_{DC}
  - LM139A series, LM2901 2 V_{DC} to 28 V_{DC}
  - LM3302 or $\pm$1 V_{DC} to $\pm$14 V_{DC}
- Very low supply current drain (0.8 mA) — independent of supply voltage
- Low input biasing current 25 nA
- Low input offset current $\pm$5 nA and offset voltage $\pm$3 mV
- Input common-mode voltage range includes GND
- Differential input voltage range equal to the power supply voltage
- Low output saturation voltage 250 mV at 4 mA
- Output voltage compatible with TTL, DTL, ECL, MOS and CMOS logic systems

Connection Diagrams

Dual-In-Line Package



TOP VIEW

TL/H/5706–2

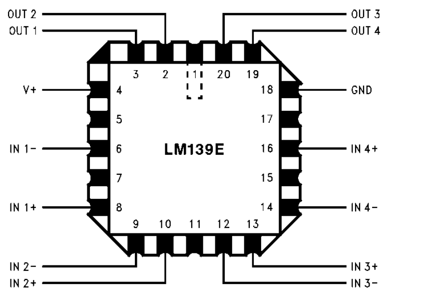
Order Number LM139J, LM139J/883*, LM139AJ, LM139AJ/883, LM239J, LM239AJ, LM339J, See NS Package Number J14A**

Order Number LM339AM, LM339M or LM2901M See NS Package Number M14A

Order Number LM339N, LM339AN, LM2901N or LM3302N See NS Package Number N14A

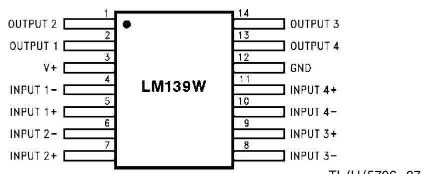
*Available per JM38510/11201

**Available per SMD# 5962-8873901



TL/H/5706–26

Order Number LM139AE/883 or LM139E/883 See NS Package Number E20A



TL/H/5706–27

Order Number LM139AW/883 or LM139W/883* See NS Package Number W14B

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 10)

	LM139/LM239/LM339 LM139A/LM239A/LM339A LM2901	LM3302
Supply Voltage, V^+	36 V_{DC} or ± 18 V_{DC}	28 V_{DC} or ± 14 V_{DC}
Differential Input Voltage (Note 8)	36 V_{DC}	28 V_{DC}
Input Voltage	-0.3 V_{DC} to $+36$ V_{DC}	-0.3 V_{DC} to $+28$ V_{DC}
Input Current ($V_{IN} < -0.3$ V_{DC}), (Note 3)	50 mA	50 mA
Power Dissipation (Note 1)		
Molded DIP	1050 mW	1050 mW
Cavity DIP	1190 mW	
Small Outline Package	760 mW	
Output Short-Circuit to GND, (Note 2)	Continuous	Continuous
Storage Temperature Range	$-65°C$ to $+150°C$	$-65°C$ to $+150°C$
Lead Temperature (Soldering, 10 seconds)	260°C	260°C

	LM139/LM239/LM339 LM139A/LM239A/LM339A LM2901	LM3302
Operating Temperature Range		$-40°C$ to $+85°C$
LM339/LM339A	0°C to $+70°C$	
LM239/LM239A	$-25°C$ to $+85°C$	
LM2901	$-40°C$ to $+85°C$	
LM139/LM139A	$-55°C$ to $+125°C$	
Soldering Information		
Dual-In-Line Package		
Soldering (10 seconds)	260°C	260°C
Small Outline Package		
Vapor Phase (60 seconds)	215°C	215°C
Infrared (15 seconds)	220°C	220°C

See AN-450 ''Surface Mounting Methods and Their Effect on Product Reliability'' for other methods of soldering surface mount devices.

ESD rating (1.5 kΩ in series with 100 pF)	600V	600V

Electrical Characteristics ($V^+ = 5$ V_{DC}, $T_A = 25°C$, unless otherwise stated)

Parameter	Conditions	LM139A			LM239A, LM339A			LM139			LM239, LM339			LM2901			LM3302			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 9)		1.0	2.0		1.0	2.0		2.0	5.0		2.0	5.0		2.0	7.0		3	20	mV_{DC}
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$ with Output in Linear Range, (Note 5), $V_{CM} = 0V$		25	100		25	250		25	100		25	250		25	250		25	500	nA_{DC}
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$		3.0	25		5.0	50		3.0	25		5.0	50		5	50		3	100	nA_{DC}
Input Common-Mode Voltage Range	$V^+ = 30$ V_{DC} (LM3302, $V^+ = 28$ V_{DC}) (Note 6)	0		$V^+ - 1.5$	0		$V^+ - 1.5$	0		$V^+ - 1.5$	0		$V^+ - 1.5$	0		$V^+ - 1.5$	0		$V^+ - 1.5$	V_{DC}
Supply Current	$R_L = \infty$ on all Comparators, $R_L = \infty$, $V^+ = 36V$, (LM3302, $V^+ = 28$ V_{DC})		0.8	2.0		0.8 1.0	2.0 2.5		0.8 1.0	2.0 2.5		0.8 1.0	2.0 2.5		0.8 1.0	2.0 2.5		0.8 1.0	2.0 2.5	mA_{DC} mA_{DC}
Voltage Gain	$R_L \geq 15$ kΩ, $V^+ = 15$ V_{DC} $V_o = 1$ V_{DC} to 11 V_{DC}	50	200		50	200		50	200		50	200		25	100		2	30		V/mV
Large Signal Response Time	V_{IN} = TTL Logic Swing, V_{REF} = 1.4 V_{DC}, $V_{RL} = 5$ V_{DC}, $R_L = 5.1$ kΩ,		300			300			300			300			300			300		ns
Response Time	$V_{RL} = 5$ V_{DC}, $R_L = 5.1$ kΩ, (Note 7)		1.3			1.3			1.3			1.3			1.3			1.3		μs
Output Sink Current	$V_{IN(-)} = 1$ V_{DC}, $V_{IN(+)} = 0$, $V_O \leq 1.5$ V_{DC}	6.0	16		6.0	16		6.0	16		6.0	16		6.0	16		6.0	16		mA_{DC}

Electrical Characteristics ($V^+ = 5\ V_{DC}$, $T_A = 25°C$, unless otherwise stated) (Continued)

Parameter	Conditions	LM139A			LM239A, LM339A			LM139			LM239, LM339			LM2901			LM3302			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Saturation Voltage	$V_{IN(-)} = 1\ V_{DC}$, $V_{IN(+)} = 0$, $I_{SINK} \leq 4$ mA		250	400		250	400		250	400		250	400		250	400		250	500	mV_{DC}
Output Leakage Current	$V_{IN(+)} = 1\ V_{DC}$, $V_{IN(-)} = 0$, $V_O = 5\ V_{DC}$		0.1			0.1			0.1			0.1			0.1			0.1		nA_{DC}

Electrical Characteristics ($V^+ = 5.0\ V_{DC}$, Note 4)

Parameter	Conditions	LM139A			LM239A, LM339A			LM139			LM239, LM339			LM2901			LM3302			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 9)			4.0			4.0			9.0			9.0		9	15			40	mV_{DC}
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$			100			150			100			150		50	200			300	nA_{DC}
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$ with Output in Linear Range, $V_{CM} = 0V$ (Note 5)			300			400			300			400		200	500			1000	nA_{DC}
Input Common-Mode Voltage Range	$V^+ = 30\ V_{DC}$ (LM3302, $V^+ = 28\ V_{DC}$) (Note 6)	0		$V^+ - 2.0$	0		$V^+ - 2.0$	0		$V^+ - 2.0$			$V^+ - 2.0$	0		$V^+ - 2.0$	0		$V^+ - 2.0$	V_{DC}
Saturation Voltage	$V_{IN(-)} = 1\ V_{DC}$, $V_{IN(+)} = 0$, $I_{SINK} \leq 4$ mA			700			700			700			700		400	700			700	mV_{DC}
Output Leakage Current	$V_{IN(+)} = 1\ V_{DC}$, $V_{IN(-)} = 0$, $V_O = 30\ V_{DC}$, (LM3302, $V_O = 28\ V_{DC}$)			1.0			1.0			1.0			1.0			1.0			1.0	μA_{DC}
Differential Input Voltage	Keep all V_{IN}'s $\geq 0\ V_{DC}$ (or V^-, if used), (Note 8)			36			36			36			36			36			28	V_{DC}

Note 1: For operating at high temperatures, the LM339/LM339A, LM2901, LM3302 must be derated based on a 125°C maximum junction temperature and a thermal resistance of 95°C/W which applies for the device soldered in a printed circuit board, operating in a still air ambient. The LM239 and LM139 must be derated based on a 150°C maximum junction temperature. The low bias dissipation and the "ON-OFF" characteristic of the outputs keeps the chip dissipation very small ($P_D \leq 100$ mW), provided the output transistors are allowed to saturate.

Note 2: Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground, the maximum output current is approximately 20 mA independent of the magnitude of V^+.

Note 3: This input current will only exist when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistors becoming forward biased and thereby acting as input diode clamps. In addition to this diode action, there is also lateral NPN parasitic transistor action on the IC chip. This transistor action can cause the output voltages of the comparators to go to the V^+ voltage level (or to ground for a large overdrive) for the time duration that an input is driven negative. This is not destructive and normal output states will re-establish when the input voltage, which was negative, again returns to a value greater than $-0.3\ V_{DC}$ (at 25°)C.

Note 4: These specifications are limited to $-55°C \leq T_A \leq +125°C$, for the LM139/LM139A. With the LM239/LM239A, all temperature specifications are limited to $-25°C \leq T_A \leq +85°C$, the LM339/LM339A temperature specifications are limited to $0°C \leq T_A \leq +70°C$, and the LM2901, LM3302 temperature range is $-40°C \leq T_A \leq +85°C$.

Note 5: The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the reference or input lines.

Note 6: The input common-mode voltage or either input signal voltage should not be allowed to go negative by more than 0.3V. The upper end of the common-mode voltage range is $V^+ - 1.5V$ at 25°C, but either or both inputs can go to $+30\ V_{DC}$ without damage (25V for LM3302), independent of the magnitude of V^+.

Note 7: The response time specified is a 100 mV input step with 5 mV overdrive. For larger overdrive signals 300 ns can be obtained, see typical performance characteristics section.

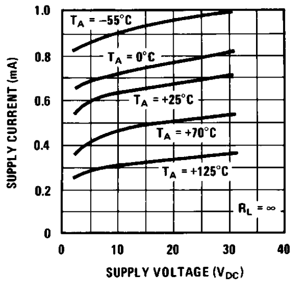
Note 8: Positive excursions of input voltage may exceed the power supply level. As long as the other voltage remains within the common-mode range, the comparator will provide a proper output state. The low input voltage state must not be less than $-0.3\ V_{DC}$ (or $0.3\ V_{DC}$ below the magnitude of the negative power supply, if used) (at 25°C).

Note 9: At output switch point, $V_O \cong 1.4\ V_{DC}$, $R_S = 0\Omega$ with V^+ from $5\ V_{DC}$ to $30\ V_{DC}$; and over the full input common-mode range ($0\ V_{DC}$ to $V^+ - 1.5\ V_{DC}$), at 25°C. For LM3302, V^+ from $5\ V_{DC}$ to $28\ V_{DC}$.

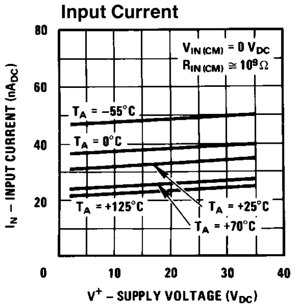
Note 10: Refer to RETS139AX for LM139A military specifications and to RETS139X for LM139 military specifications.

Typical Performance Characteristics LM139/LM239/LM339, LM139A/LM239A/LM339A, LM3302

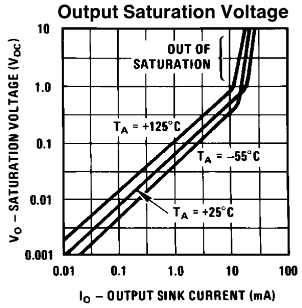
Supply Current



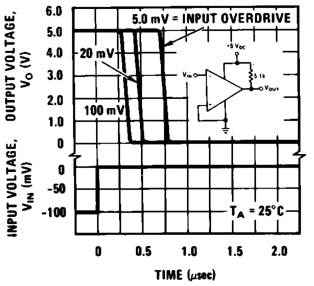
Input Current



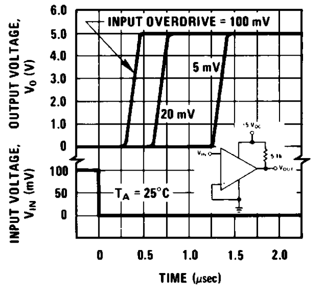
Output Saturation Voltage



Response Time for Various Input Overdrives—Negative Transition



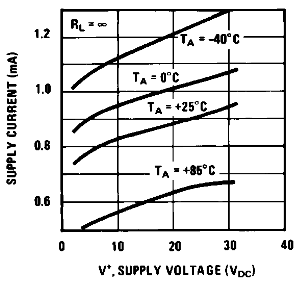
Response Time for Various Input Overdrives—Positive Transition



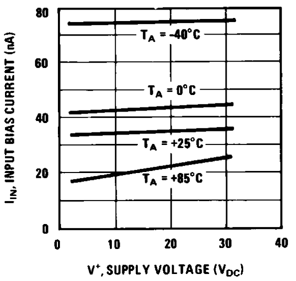
TL/H/5706–6

Typical Performance Characteristics LM2901

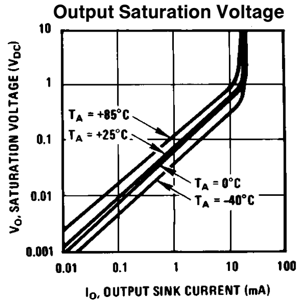
Supply Current



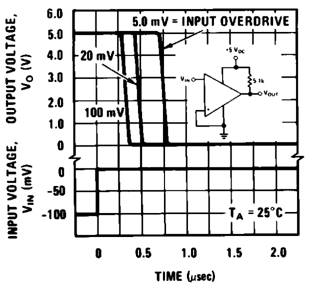
Input Current



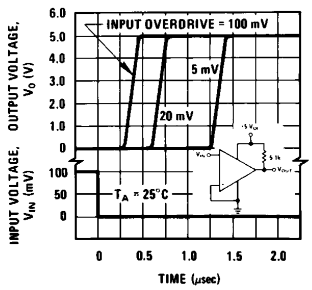
Output Saturation Voltage



Response Time for Various Input Overdrives-Negative Transition



Response Time for Various Input Overdrives-Positive Transition



TL/H/5706–7

Application Hints

The LM139 series are high gain, wide bandwidth devices which, like most comparators, can easily oscillate if the output lead is inadvertently allowed to capacitively couple to the inputs via stray capacitance. This shows up only during the output voltage transition intervals as the comparator changes states. Power supply bypassing is not required to solve this problem. Standard PC board layout is helpful as it reduces stray input-output coupling. Reducing this input resistors to $< 10\ k\Omega$ reduces the feedback signal levels and finally, adding even a small amount (1 to 10 mV) of positive feedback (hysteresis) causes such a rapid transition that oscillations due to stray feedback are not possible. Simply socketing the IC and attaching resistors to the pins will cause input-output oscillations during the small transition intervals unless hysteresis is used. If the input signal is a pulse waveform, with relatively fast rise and fall times, hysteresis is not required.

All pins of any unused comparators should be grounded.

The bias network of the LM139 series establishes a drain current which is independent of the magnitude of the power supply voltage over the range of from 2 V_{DC} to 30 V_{DC}.

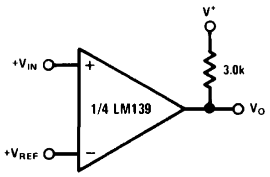
It is usually unnecessary to use a bypass capacitor across the power supply line.

The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than -0.3 V_{DC} (at 25°C). An input clamp diode can be used as shown in the applications section.

The output of the LM139 series is the uncommitted collector of a grounded-emitter NPN output transistor. Many collectors can be tied together to provide an output OR'ing function. An output pull-up resistor can be connected to any available power supply voltage within the permitted supply voltage range and there is no restriction on this voltage due to the magnitude of the voltage which is applied to the V^+ terminal of the LM139A package. The output can also be used as a simple SPST switch to ground (when a pull-up resistor is not used). The amount of current which the output device can sink is limited by the drive available (which is independent of V^+) and the β of this device. When the maximum current limit is reached (approximately 16 mA), the output transistor will come out of saturation and the output voltage will rise very rapidly. The output saturation voltage is limited by the approximately 60Ω R_{SAT} of the output transistor. The low offset voltage of the output transistor (1 mV) allows the output to clamp essentially to ground level for small load currents.

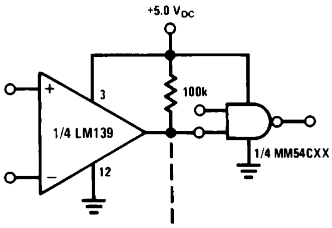
Typical Applications ($V^+ = 5.0\ V_{DC}$)

Basic Comparator



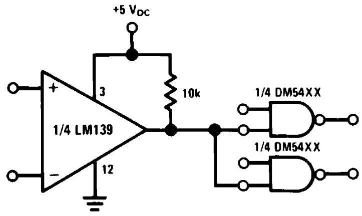
TL/H/5706–3

Driving CMOS



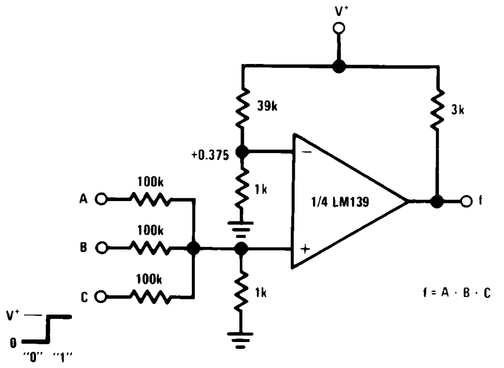
TL/H/5706–4

Driving TTL



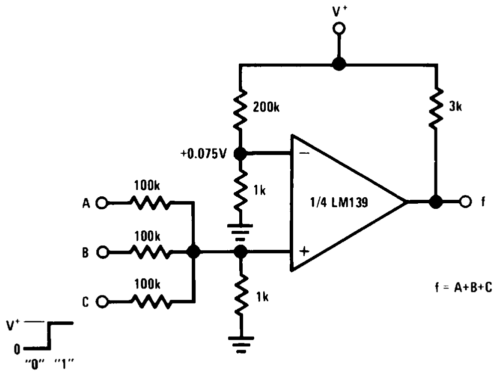
TL/H/5706–5

AND Gate



TL/H/5706–8

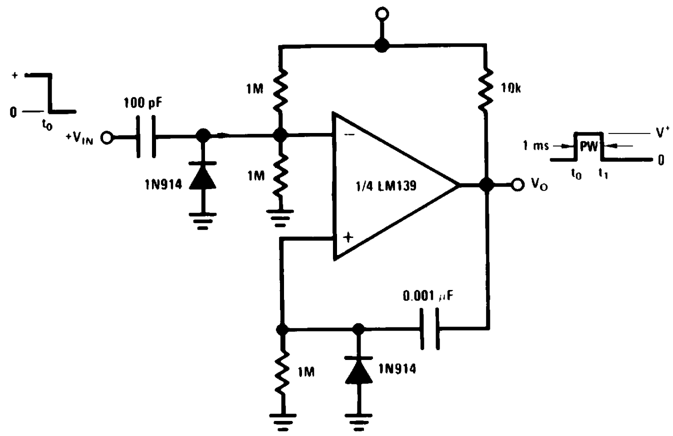
OR Gate



TL/H/5706–9

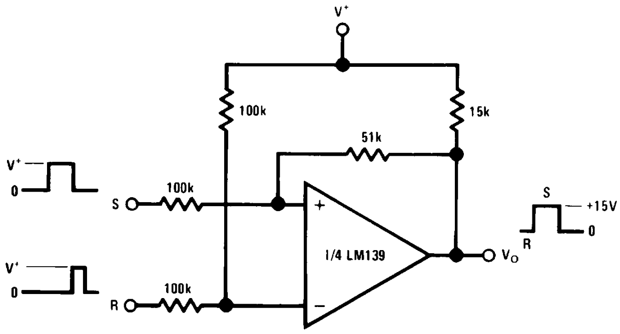
Typical Applications ($V^{+} = 15\ V_{DC}$) (Continued)

One-Shot Multivibrator



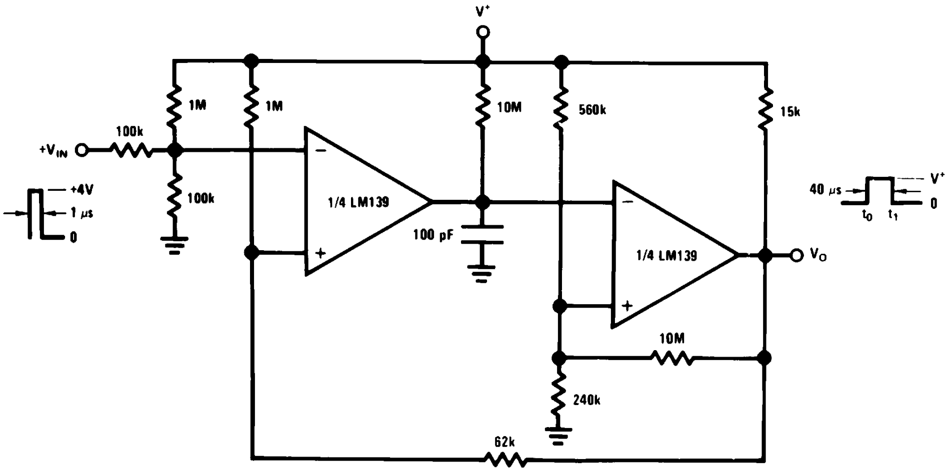
TL/H/5706–10

Bi-Stable Multivibrator



TL/H/5706–11

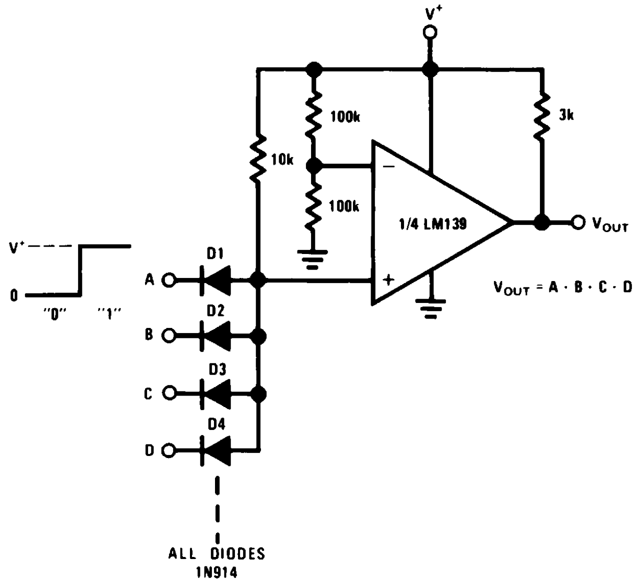
One-Shot Multivibrator with Input Lock Out



TL/H/5706–12

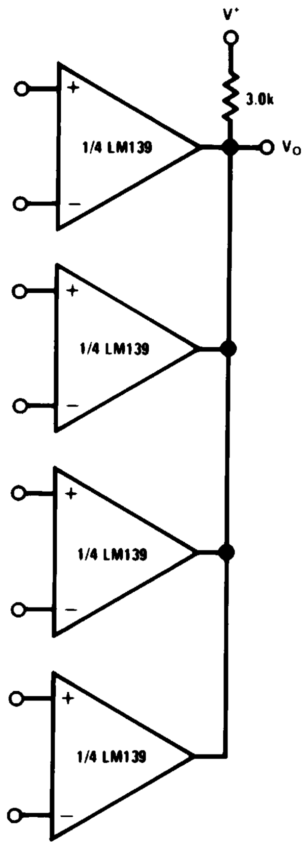
Typical Applications ($V^+ = 15\ V_{DC}$) (Continued)

Large Fan-In AND Gate



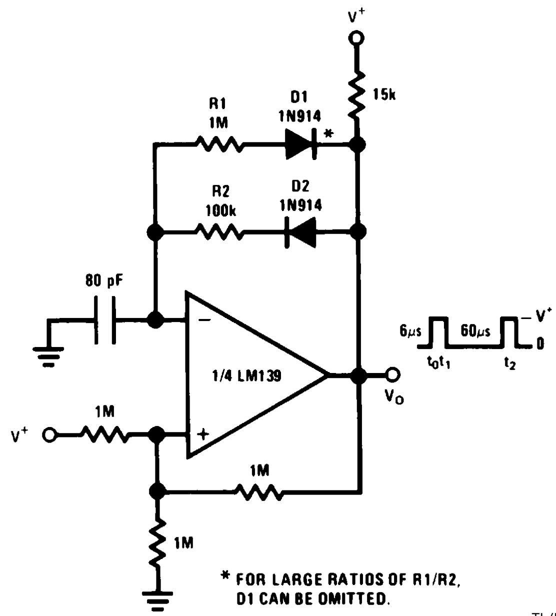
TL/H/5706–13

ORing the Outputs



TL/H/5706–15

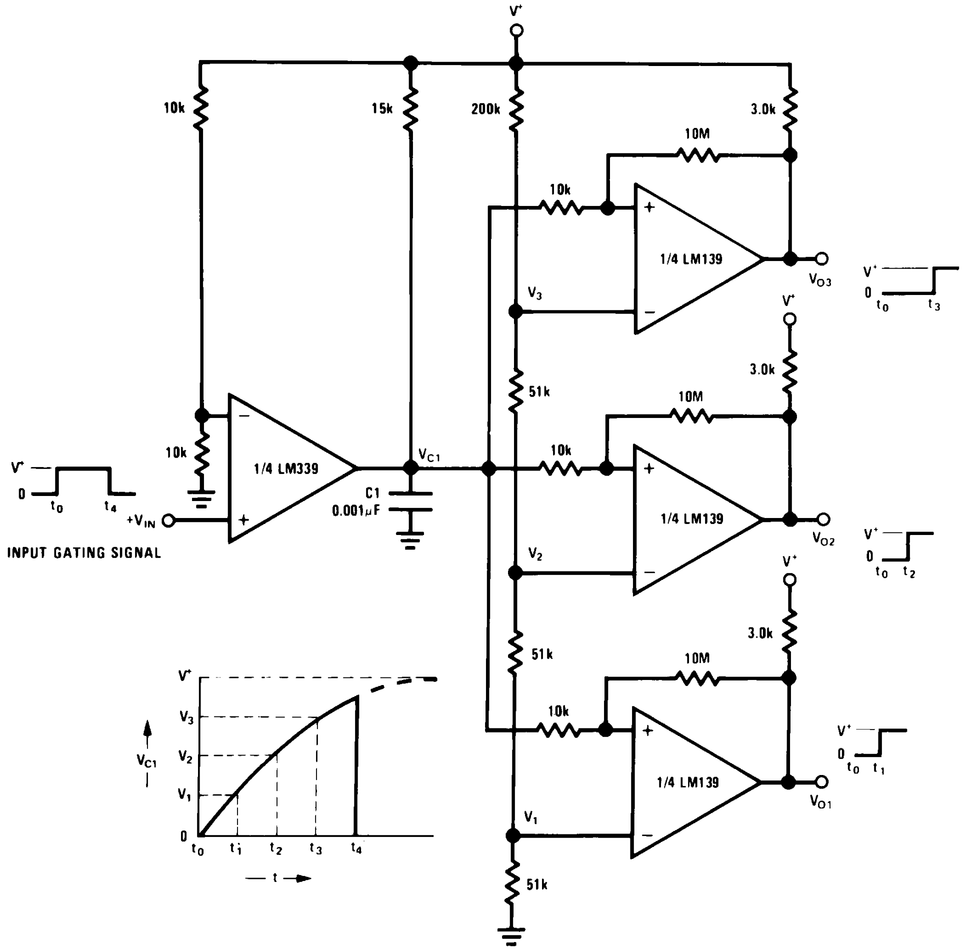
Pulse Generator



TL/H/5706–17

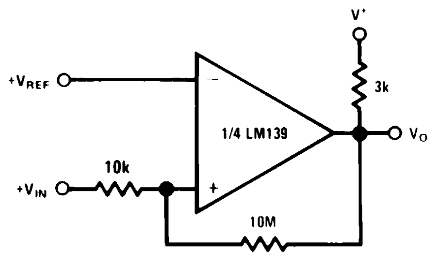
Typical Applications ($V^+ = 15\ V_{DC}$) (Continued)

Time Delay Generator



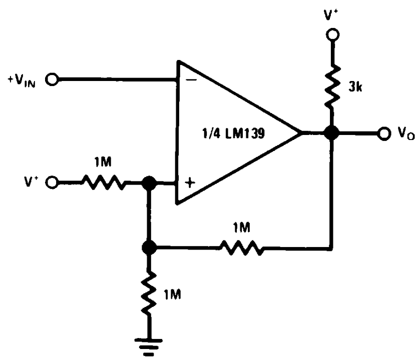
TL/H/5706–14

Non-Inverting Comparator with Hysteresis



TL/H/5706–18

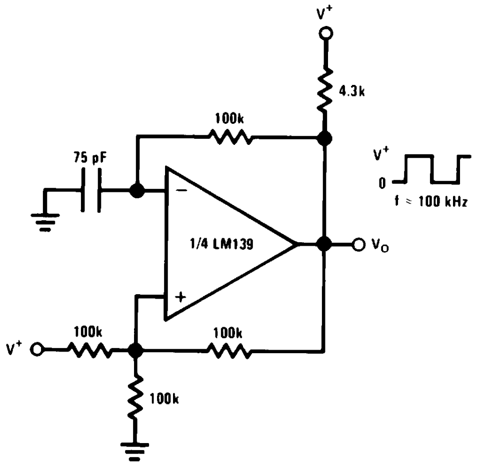
Inverting Comparator with Hysteresis



TL/H/5706–19

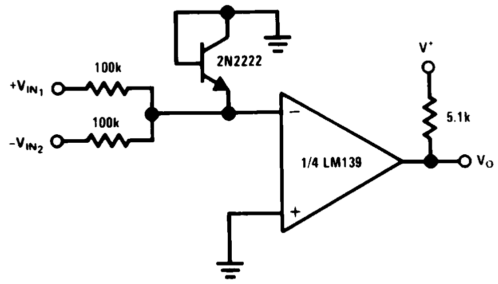
Typical Applications ($V^{+} = 15\ V_{DC}$) (Continued)

Squarewave Oscillator



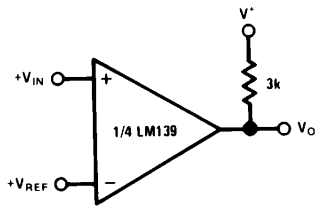
TL/H/5706–16

Comparing Input Voltages of Opposite Polarity



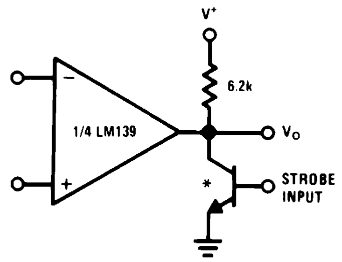
TL/H/5706–20

Basic Comparator



TL/H/5706–21

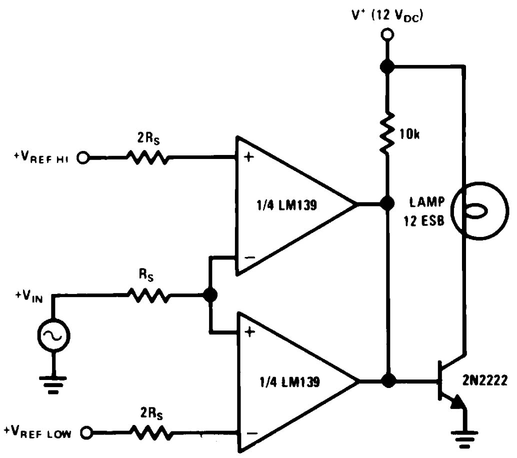
Output Strobing



TL/H/5706–22

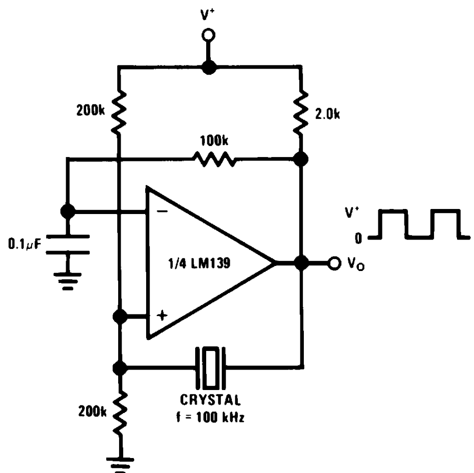
*Or open-collector logic gate without pull-up resistor

Limit Comparator



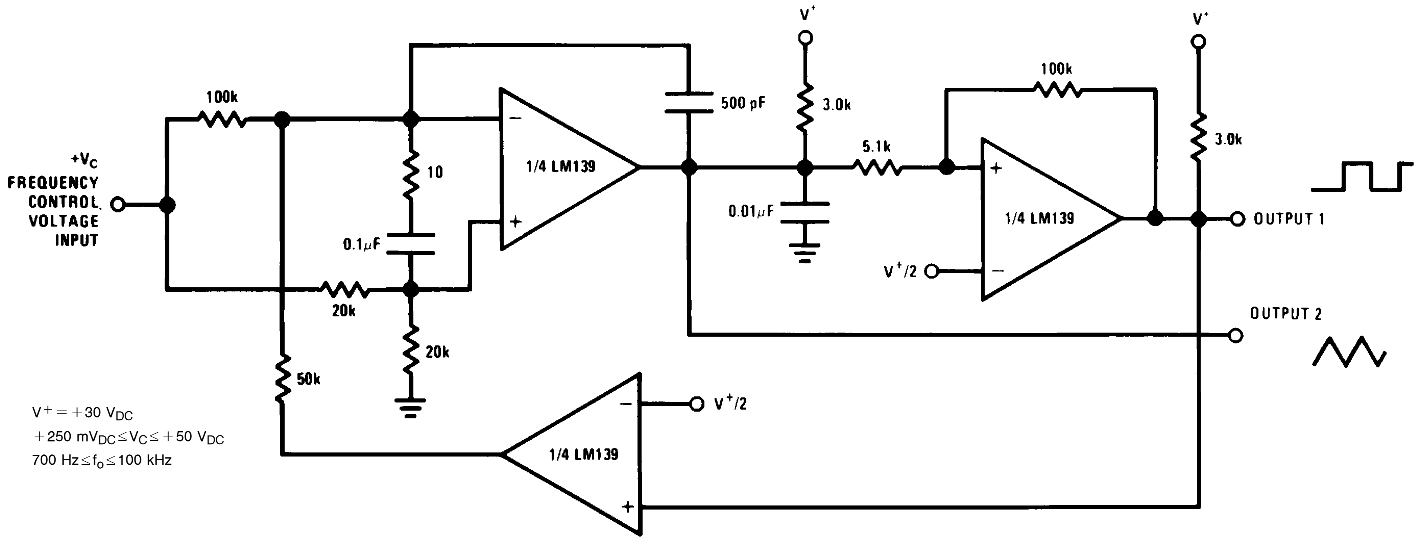
TL/H/5706–24

Crystal Controlled Oscillator



TL/H/5706–25

Two-Decade High-Frequency VCO



$V^{+} = +30\ V_{DC}$

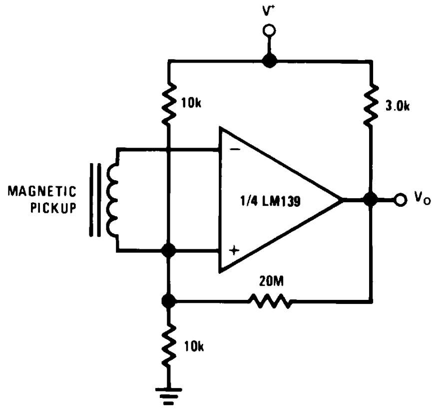
$+250\ mV_{DC} \le V_C \le +50\ V_{DC}$

$700\ Hz \le f_o \le 100\ kHz$

TL/H/5706–23

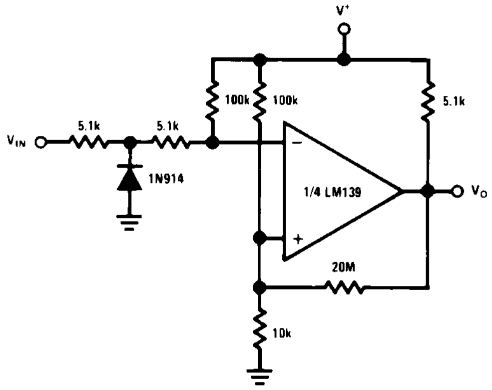
Typical Applications ($V^{+} = 5\ V_{DC}$) (Continued)

Transducer Amplifier



TL/H/5706–28

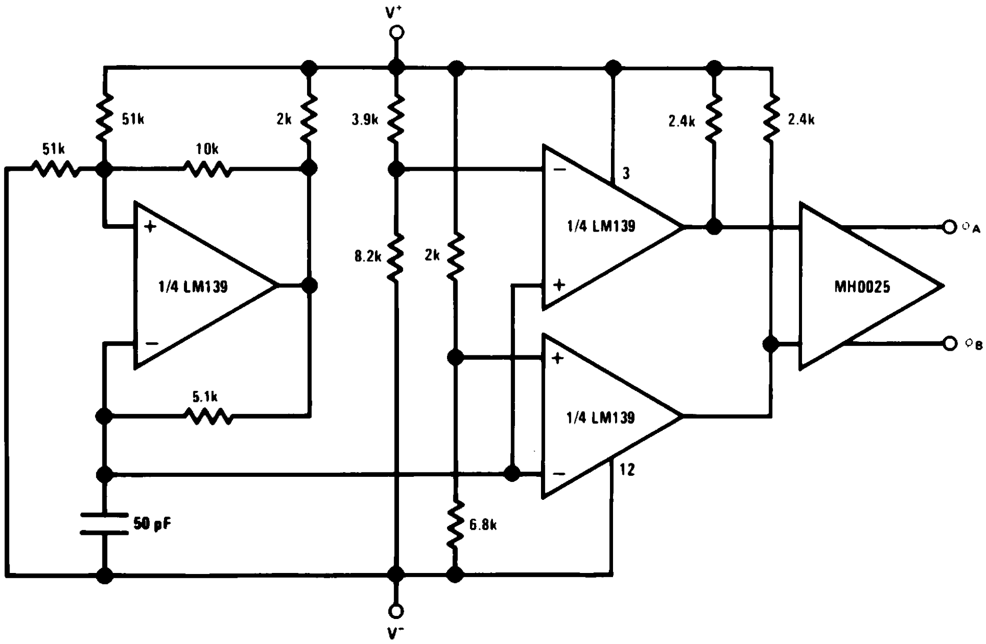
Zero Crossing Detector (Single Power Supply)



TL/H/5706–30

Split-Supply Applications ($V^{+} = +15\ V_{DC}$ and $V^{-} = -15\ V_{DC}$)

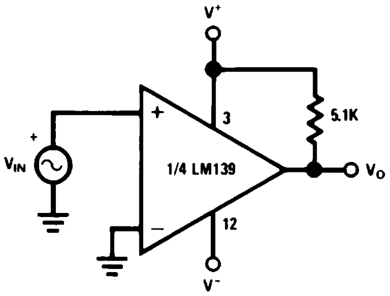
MOS Clock Driver



TL/H/5706–31

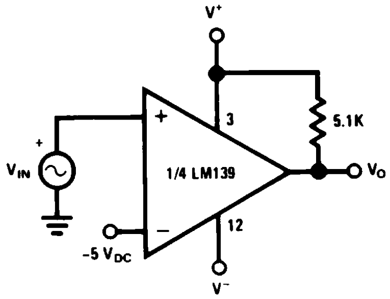
Split-Supply Applications ($V^{+} = +15\ V_{DC}$ and $V^{-} = -15\ V_{DC}$) (Continued)

Zero Crossing Detector



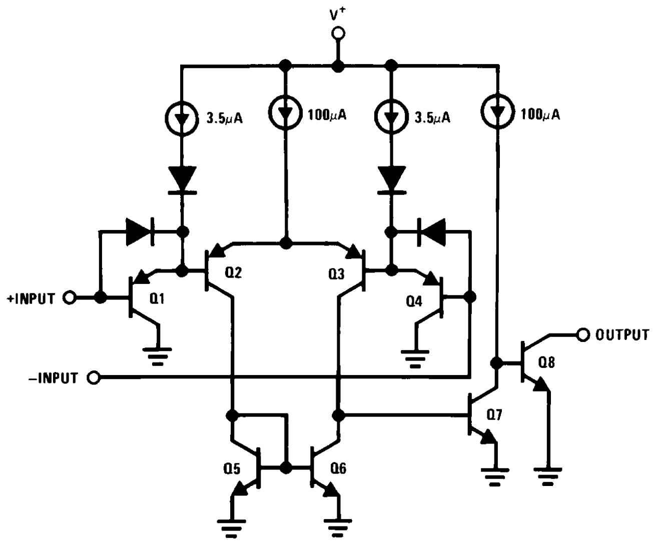
TL/H/5706–32

Comparator With a Negative Reference



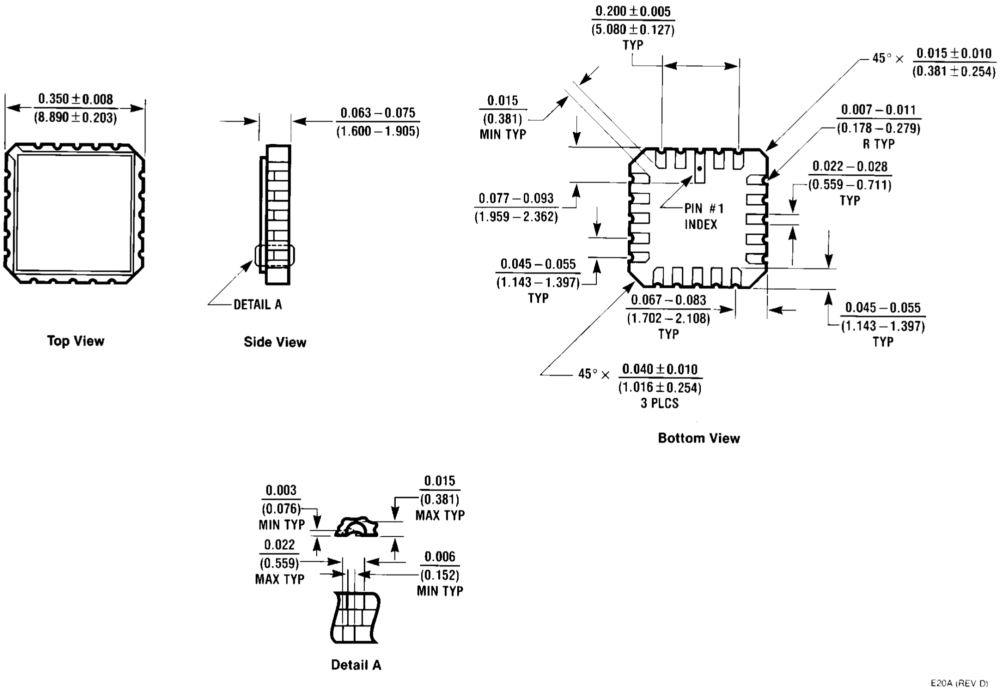
TL/H/5706–33

Schematic Diagram

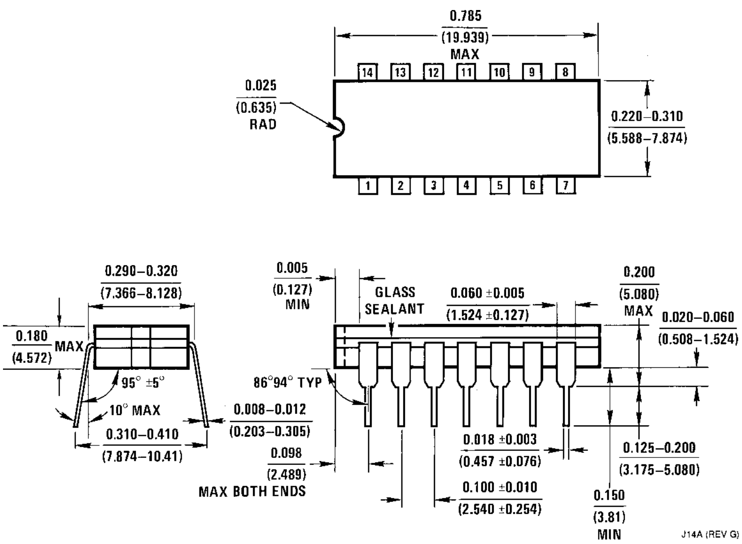


TL/H/5706–1

Physical Dimensions inches (millimeters)

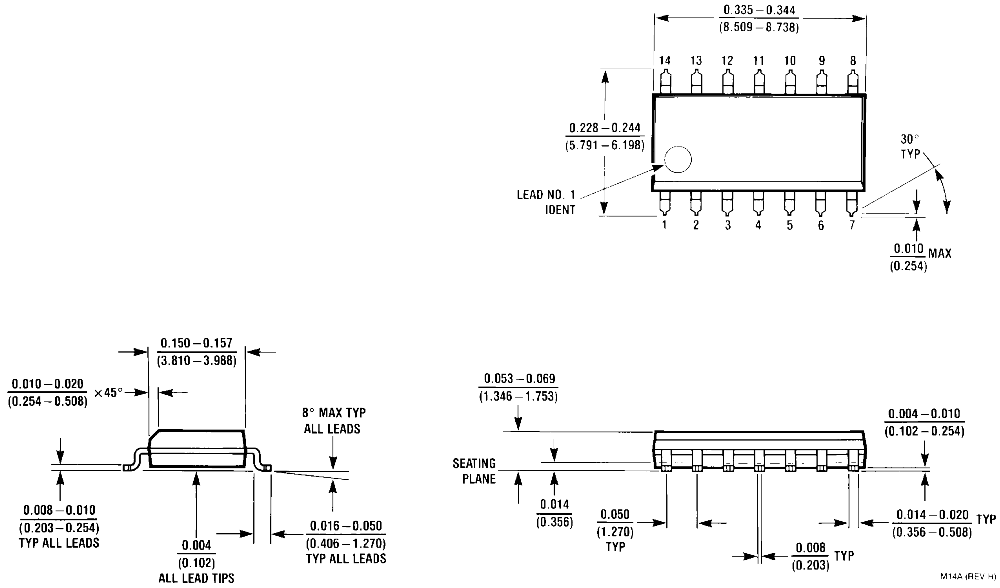


Order Number LM139AE/883 or LM139E/883
NS Package Number E20A

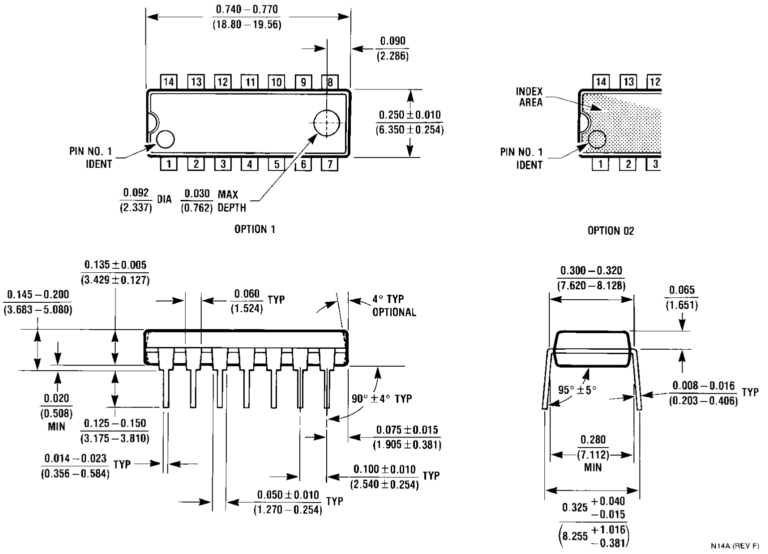


Ceramic Dual-In-Line Package (J)
Order Number LM139J, LM139J/883, LM139AJ,
LM139AJ/883, LM239J, LM239AJ, LM339J
NS Package Number J14A

Physical Dimensions inches (millimeters) (Continued)

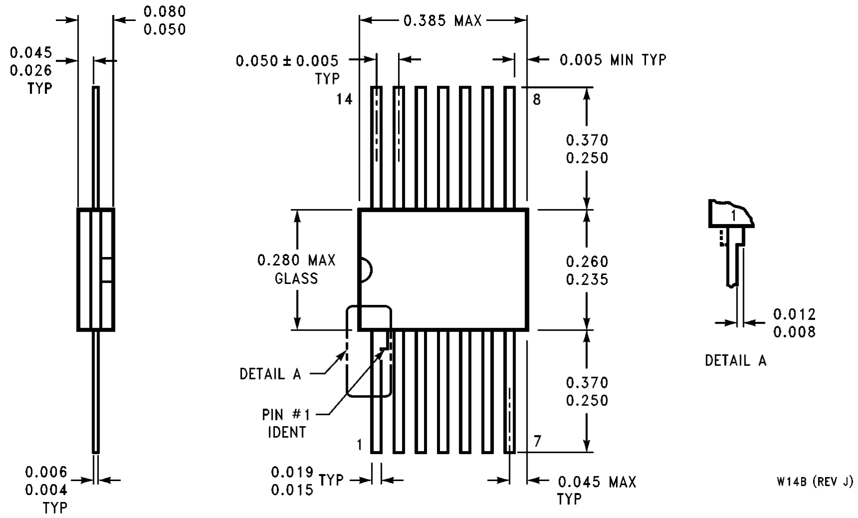


S.O. Package (M)
Order Number LM339AM, LM339M or LM2901M
NS Package Number M14A



Molded Dual-In-Line Package (N)
Order Number LM339N, LM339AN, LM2901N or LM3302N
NS Package Number N14A

Physical Dimensions inches (millimeters) (Continued)



Order Number LM139AW/883 or LM139W/883
NS Package Number W14B

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
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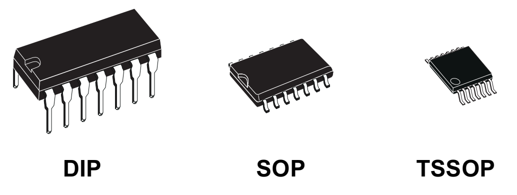
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
Fax: 81-043-299-2408

QUAD 2-INPUT NOR GATE

- HIGH SPEED:
  t_{PD} = 8ns (TYP.) at V_{CC} = 6V
- LOW POWER DISSIPATION:
  I_{CC} = 1μA(MAX.) at T_A=25°C
- HIGH NOISE IMMUNITY:
  V_{NIH} = V_{NIL} = 28 % V_{CC} (MIN.)
- SYMMETRICAL OUTPUT IMPEDANCE:
  $|I_{OH}|$ = I_{OL} = 4mA (MIN)
- BALANCED PROPAGATION DELAYS:
  $t_{PLH} \cong t_{PHL}$
- WIDE OPERATING VOLTAGE RANGE:
  V_{CC} (OPR) = 2V to 6V
- PIN AND FUNCTION COMPATIBLE WITH 74 SERIES 02



ORDER CODES

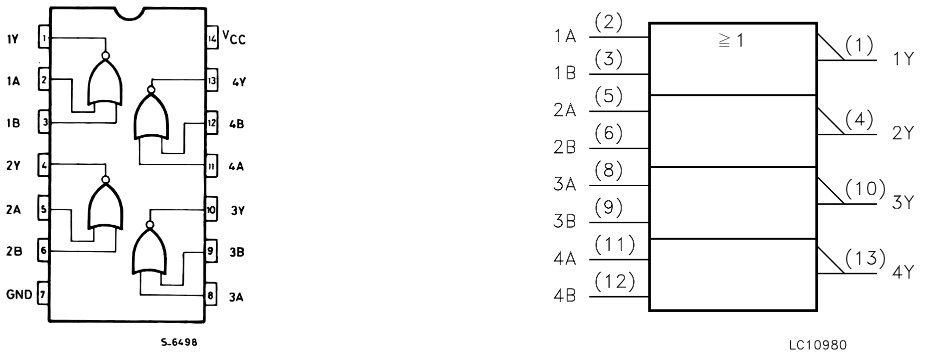
PACKAGE	TUBE	T & R
DIP	M74HC02B1R	
SOP	M74HC02M1R	M74HC02RM13TR
TSSOP		M74HC02TTR

DESCRIPTION

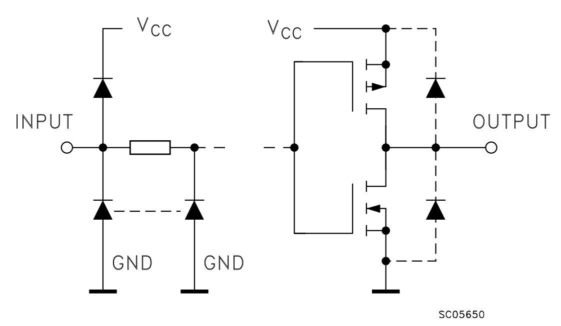
The M74HC02 is an high speed CMOS QUAD 2-INPUT NOR GATE fabricated with silicon gate C^2MOS technology.
The internal circuit is composed of 3 stages including buffer output, which enables high noise immunity and stable output.

All inputs are equipped with protection circuits against static discharge and transient excess voltage.

PIN CONNECTION AND IEC LOGIC SYMBOLS



INPUT AND OUTPUT EQUIVALENT CIRCUIT



PIN DESCRIPTION

PIN No	SYMBOL	NAME AND FUNCTION
2, 5, 8, 11	1A to 4A	Data Inputs
3, 6, 9, 12	1B to 4B	Data Inputs
1, 4, 10, 13	1Y to 4Y	Data Outputs
7	GND	Ground (0V)
14	V_{CC}	Positive Supply Voltage

TRUTH TABLE

A	B	Y
L	L	H
L	H	L
H	L	L
H	H	L

ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_{CC}	Supply Voltage	-0.5 to +7	V
V_I	DC Input Voltage	-0.5 to V_{CC} + 0.5	V
V_O	DC Output Voltage	-0.5 to V_{CC} + 0.5	V
I_{IK}	DC Input Diode Current	± 20	mA
I_{OK}	DC Output Diode Current	± 20	mA
I_O	DC Output Current	± 25	mA
I_{CC} or I_{GND}	DC V_{CC} or Ground Current	± 50	mA
P_D	Power Dissipation	500(*)	mW
T_{stg}	Storage Temperature	-65 to +150	°C
T_L	Lead Temperature (10 sec)	300	°C

Absolute Maximum Ratings are those values beyond which damage to the device may occur. Functional operation under these conditions is not implied
(*) 500mW at 65 °C; derate to 300mW by 10mW/°C from 65°C to 85°C

RECOMMENDED OPERATING CONDITIONS

Symbol	Parameter		Value	Unit
V_{CC}	Supply Voltage		2 to 6	V
V_I	Input Voltage		0 to V_{CC}	V
V_O	Output Voltage		0 to V_{CC}	V
T_{op}	Operating Temperature		-55 to 125	°C
t_r, t_f	Input Rise and Fall Time	V_{CC} = 2.0V	0 to 1000	ns
		V_{CC} = 4.5V	0 to 500	ns
		V_{CC} = 6.0V	0 to 400	ns

DC SPECIFICATIONS

Symbol	Parameter	Test Condition		Value							Unit
		V_{CC} (V)		T_A = 25°C			-40 to 85°C		-55 to 125°C		
				Min.	Typ.	Max.	Min.	Max.	Min.	Max.	
V_{IH}	High Level Input Voltage	2.0		1.5			1.5		1.5		V
		4.5		3.15			3.15		3.15		
		6.0		4.2			4.2		4.2		
V_{IL}	Low Level Input Voltage	2.0				0.5		0.5		0.5	V
		4.5				1.35		1.35		1.35	
		6.0				1.8		1.8		1.8	
V_{OH}	High Level Output Voltage	2.0	I_O=-20 µA	1.9	2.0		1.9		1.9		V
		4.5	I_O=-20 µA	4.4	4.5		4.4		4.4		
		6.0	I_O=-20 µA	5.9	6.0		5.9		5.9		
		4.5	I_O=-4.0 mA	4.18	4.31		4.13		4.10		
		6.0	I_O=-5.2 mA	5.68	5.8		5.63		5.60		
V_{OL}	Low Level Output Voltage	2.0	I_O=20 µA		0.0	0.1		0.1		0.1	V
		4.5	I_O=20 µA		0.0	0.1		0.1		0.1	
		6.0	I_O=20 µA		0.0	0.1		0.1		0.1	
		4.5	I_O=4.0 mA		0.17	0.26		0.33		0.40	
		6.0	I_O=5.2 mA		0.18	0.26		0.33		0.40	
I_I	Input Leakage Current	6.0	$V_I = V_{CC}$ or GND			± 0.1		± 1		± 1	µA
I_{CC}	Quiescent Supply Current	6.0	$V_I = V_{CC}$ or GND			1		10		20	µA

AC ELECTRICAL CHARACTERISTICS (C_L = 50 pF, Input $t_r = t_f$ = 6ns)

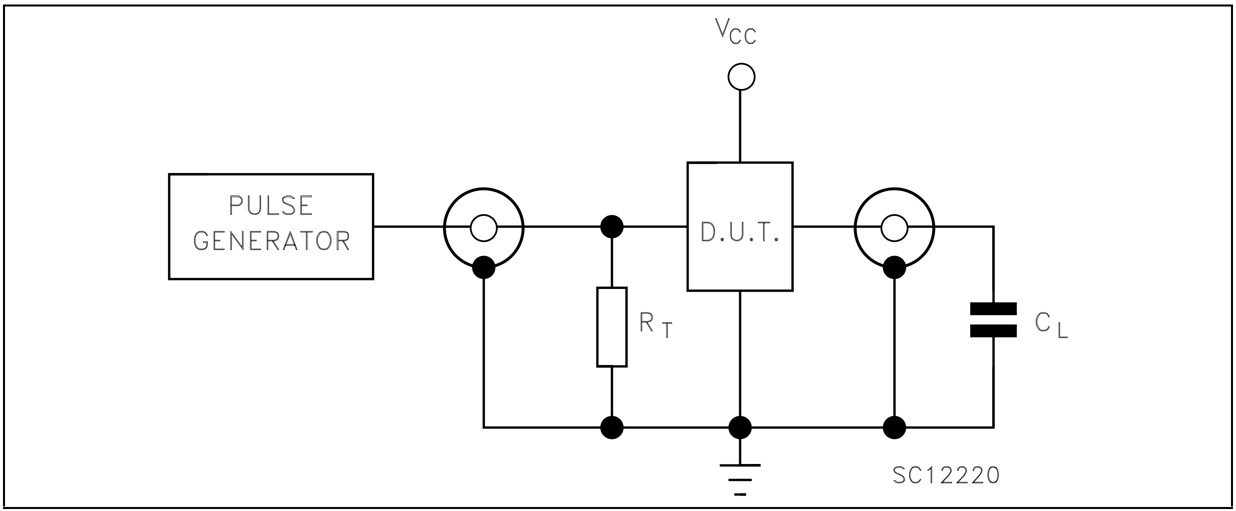
Symbol	Parameter	Test Condition		Value							Unit
		V_{CC} (V)		T_A = 25°C			-40 to 85°C		-55 to 125°C		
				Min.	Typ.	Max.	Min.	Max.	Min.	Max.	
t_{TLH} t_{THL}	Output Transition Time	2.0			30	75		95		110	ns
		4.5			8	15		19		22	
		6.0			7	13		16		19	
t_{PLH} t_{PHL}	Propagation Delay Time	2.0			27	75		95		110	ns
		4.5			9	15		19		22	
		6.0			8	13		16		19	

CAPACITIVE CHARACTERISTICS

Symbol	Parameter	Test Condition		Value							Unit
		V_{CC} (V)		T_A = 25°C			-40 to 85°C		-55 to 125°C		
				Min.	Typ.	Max.	Min.	Max.	Min.	Max.	
C_{IN}	Input Capacitance	5.0			5	10		10		10	pF
C_{PD}	Power Dissipation Capacitance (note 1)	5.0			21						pF

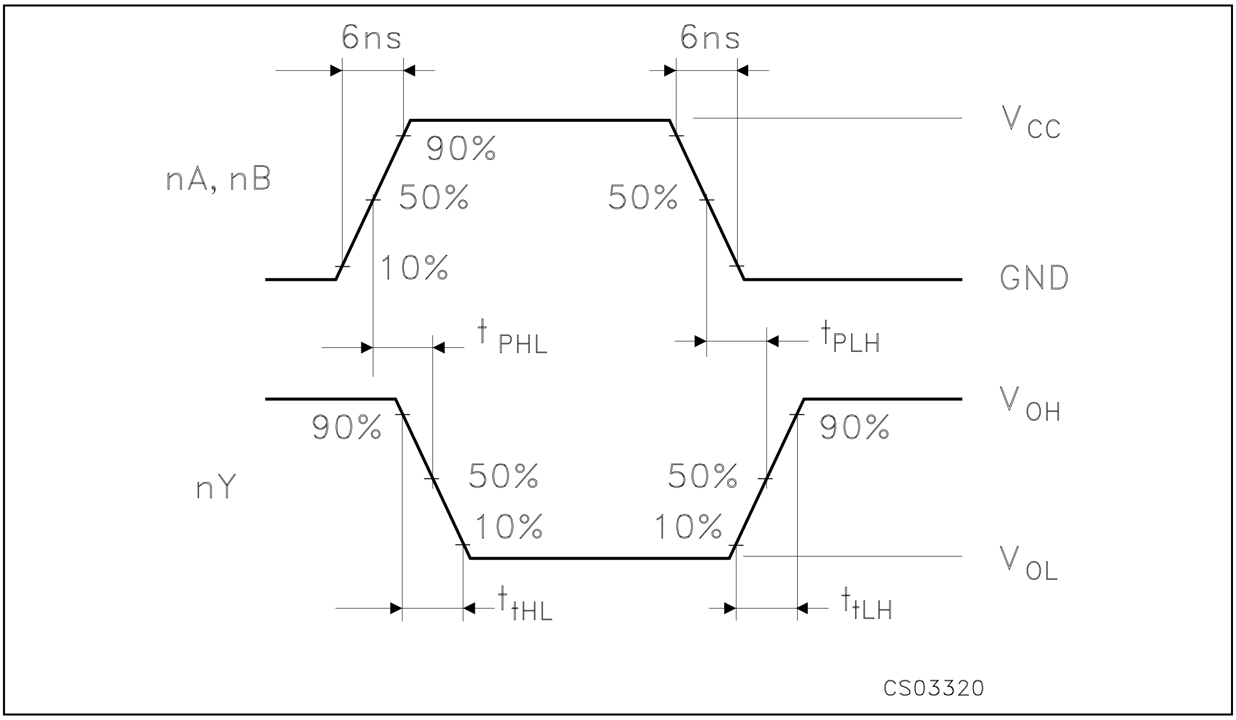
1) C_{PD} is defined as the value of the IC's internal equivalent capacitance which is calculated from the operating current consumption without load. (Refer to Test Circuit). Average operating current can be obtained by the following equation. $I_{CC(opr)} = C_{PD} \times V_{CC} \times f_{IN} + I_{CC}/4$ (per gate)

TEST CIRCUIT



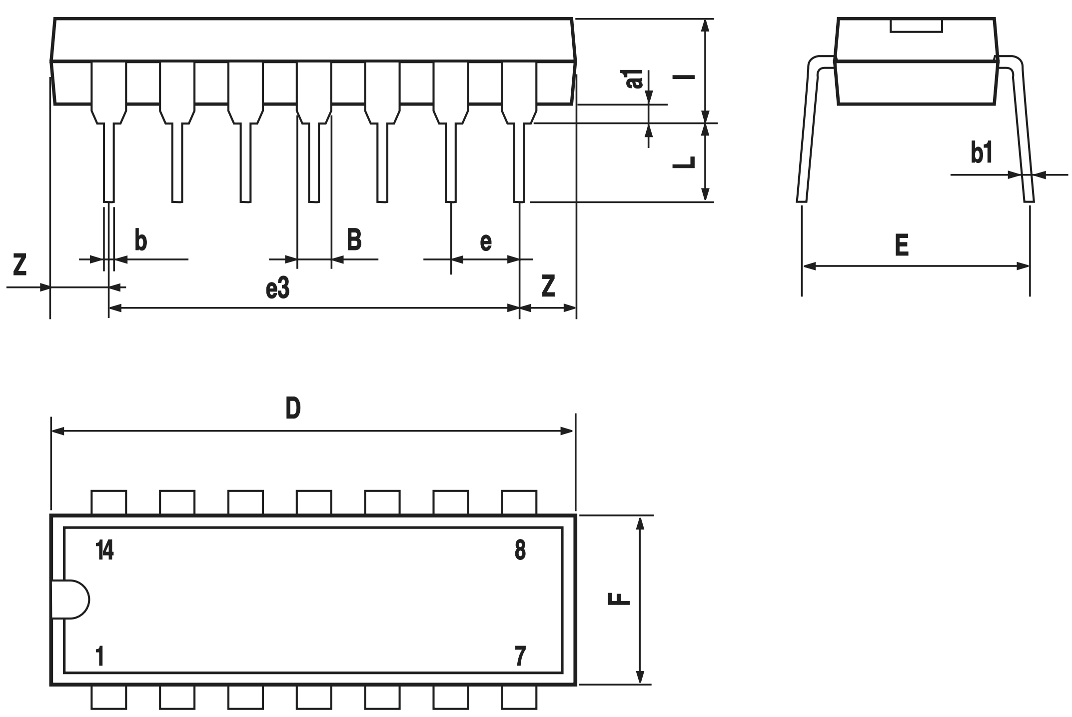
C_L = 50pF or equivalent (includes jig and probe capacitance)
R_T = Z_{OUT} of pulse generator (typically 50Ω)

WAVEFORM : PROPAGATION DELAY TIMES(f=1MHz; 50% duty cycle)



Plastic DIP-14 MECHANICAL DATA

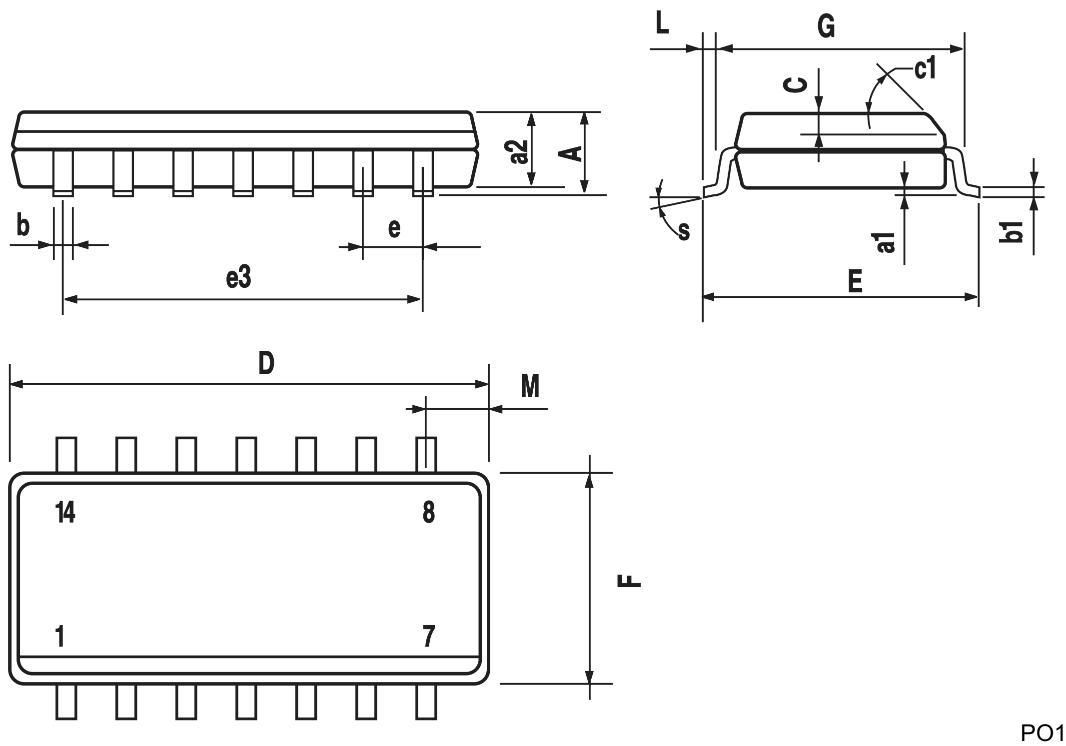
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
a1	0.51			0.020		
B	1.39		1.65	0.055		0.065
b		0.5			0.020	
b1		0.25			0.010	
D			20			0.787
E		8.5			0.335	
e		2.54			0.100	
e3		15.24			0.600	
F			7.1			0.280
I			5.1			0.201
L		3.3			0.130	
Z	1.27		2.54	0.050		0.100



P001A

SO-14 MECHANICAL DATA

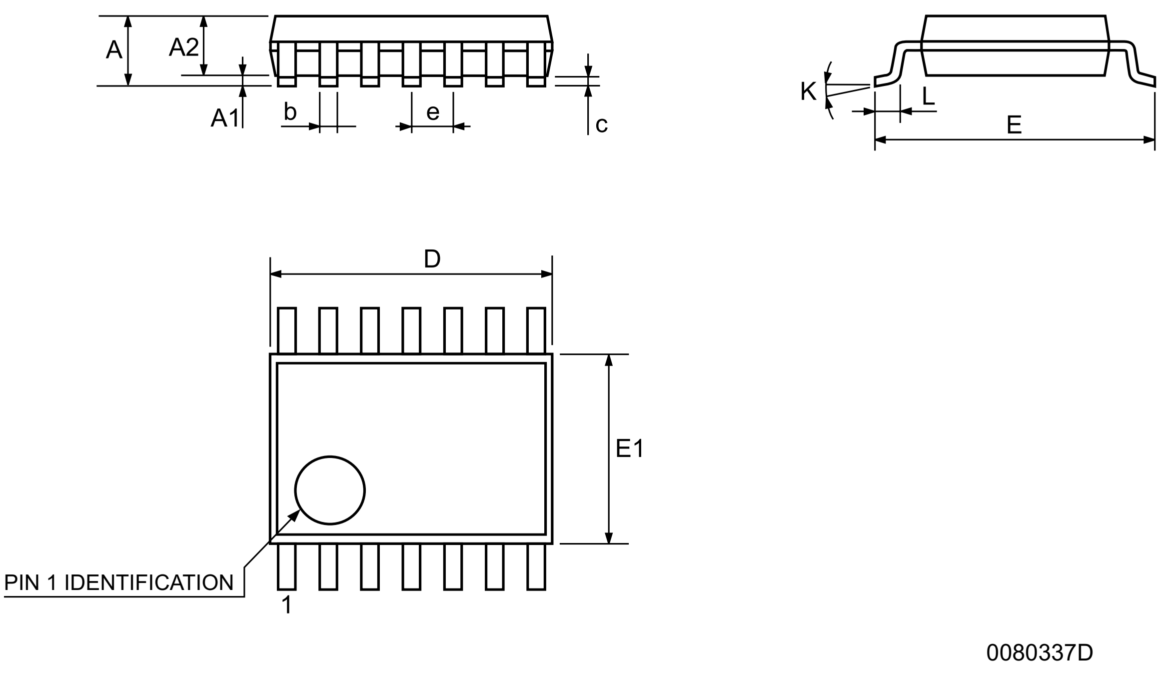
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A			1.75			0.068
a1	0.1		0.2	0.003		0.007
a2			1.65			0.064
b	0.35		0.46	0.013		0.018
b1	0.19		0.25	0.007		0.010
C		0.5			0.019	
c1	45° (typ.)					
D	8.55		8.75	0.336		0.344
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		7.62			0.300	
F	3.8		4.0	0.149		0.157
G	4.6		5.3	0.181		0.208
L	0.5		1.27	0.019		0.050
M			0.68			0.026
S	8° (max.)					



PO13G

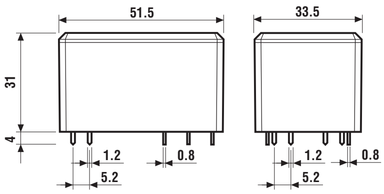
TSSOP14 MECHANICAL DATA

DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A			1.2			0.047
A1	0.05		0.15	0.002	0.004	0.006
A2	0.8	1	1.05	0.031	0.039	0.041
b	0.19		0.30	0.007		0.012
c	0.09		0.20	0.004		0.0089
D	4.9	5	5.1	0.193	0.197	0.201
E	6.2	6.4	6.6	0.244	0.252	0.260
E1	4.3	4.4	4.48	0.169	0.173	0.176
e		0.65 BSC			0.0256 BSC	
K	0°		8°	0°		8°
L	0.45	0.60	0.75	0.018	0.024	0.030

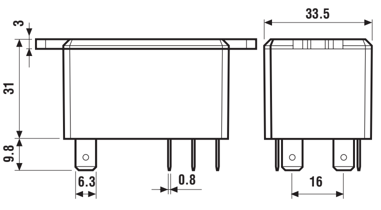


Features

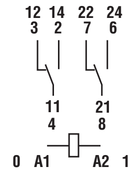
	66.22	66.82	66.82-xx07
2 Pole Changeover (DPDT) **30 A Power relay** **66.22** PCB connections & mount **66.82** Faston 250 connections - Flange mount **66.82-xx07** Faston 250 connections - 35 mm rail mount • Reinforced insulation between coil and contacts according to EN 60335-1; 8 mm creepage and clearance distances • AC coils & DC coils • Cadmium Free option available	 • 30 A rated contacts • PCB mount - bifurcated terminals	 • 30 A rated contacts • Flange mount • Faston 250 connections	 • 30 A rated contacts • 35 mm rail mount • Faston 250 connections

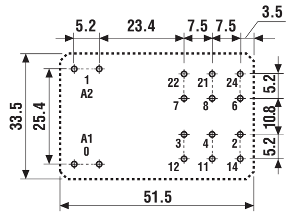


66.22

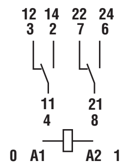


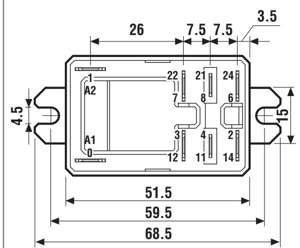
66.82-xxxx

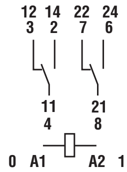


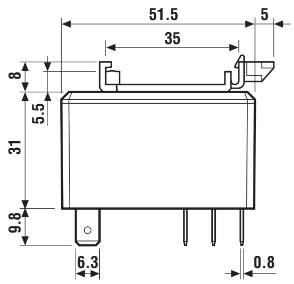


Copper side view









For UL Horsepower and Pilot Duty ratings
See "General technical information" page V

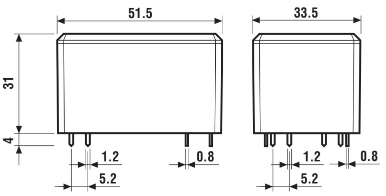
		66.22	66.82	66.82-xx07
Contact specification				
Contact configuration		2 CO (DPDT)	2 CO (DPDT)	2 CO (DPDT)
Rated current/Maximum peak current	A	30/50 (NO) - 10/20 (NC)	30/50 (NO) - 10/20 (NC)	30/50 (NO) - 10/20 (NC)
Rated voltage/Maximum switching voltage	V AC	250/440	250/440	250/440
Rated load AC1	VA	7,500 (NO) - 2,500 (NC)	7,500 (NO) - 2,500 (NC)	7,500 (NO) - 2,500 (NC)
Rated load AC15 (230 V AC)	VA	1,200 (NO)	1,200 (NO)	1,200 (NO)
Single phase motor rating (230 V AC)	kW	1.5 (NO)	1.5 (NO)	1.5 (NO)
Breaking capacity DC1: 30/110/220 V	A	25/0.7/0.3 (NO)	25/0.7/0.3 (NO)	25/0.7/0.3 (NO)
Minimum switching load	mW (V/mA)	1,000 (10/10)	1,000 (10/10)	1,000 (10/10)
Standard contact material		AgCdO	AgCdO	AgCdO
Coil specification				
Nominal voltage (U_N)	V AC (50/60 Hz)	6 - 12 - 24 - 110/115 - 120/125 - 230 - 240		
	V DC	6 - 12 - 24 - 110 - 125		
Rated power AC/DC	VA (50 Hz)/W	3.6/1.7	3.6/1.7	3.6/1.7
Operating range	AC	$(0.8…1.1)U_N$	$(0.8…1.1)U_N$	$(0.8…1.1)U_N$
	DC	$(0.8…1.1)U_N$	$(0.8…1.1)U_N$	$(0.8…1.1)U_N$
Holding voltage	AC/DC	$0.8\ U_N/0.5\ U_N$	$0.8\ U_N/0.5\ U_N$	$0.8\ U_N/0.5\ U_N$
Must drop-out voltage	AC/DC	$0.2\ U_N/0.1\ U_N$	$0.2\ U_N/0.1\ U_N$	$0.2\ U_N/0.1\ U_N$
Technical data				
Mechanical life AC/DC	cycles	$10 \cdot 10^6$	$10 \cdot 10^6$	$10 \cdot 10^6$
Electrical life at rated load AC1	cycles	$100 \cdot 10^3$	$100 \cdot 10^3$	$100 \cdot 10^3$
Operate/release time	ms	8/15	8/15	8/15
Insulation between coil and contacts (1.2/50 μs)	kV	6 (8 mm)	6 (8 mm)	6 (8 mm)
Dielectric strength between open contacts	V AC	1,500	1,500	1,500
Ambient temperature range	°C	–40…+70	–40…+70	–40…+70
Environmental protection		RT II	RT II	RT II
Approvals (according to type)		CE, cULus, VDE		

Features

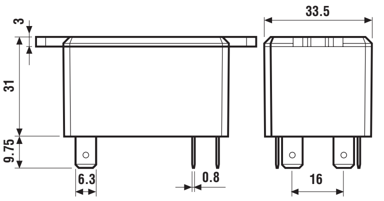
2 Pole NO (DPST-NO)
30 A Power relay

66.22-x300 **PCB mount**
66.82-x300 **Faston 250 connections - Flange mount**
66.82-x307 **Faston 250 connections - 35 mm rail mount**

- Reinforced insulation between coil and contacts according to EN 60335-1; 8 mm creepage and clearance distances
- AC coils & DC coils
- Cadmium Free option available



66.22-0300

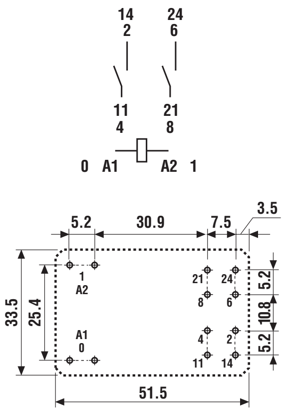


66.82-0300

For UL Horsepower and Pilot Duty ratings See "General technical information" page V

66.22-x300

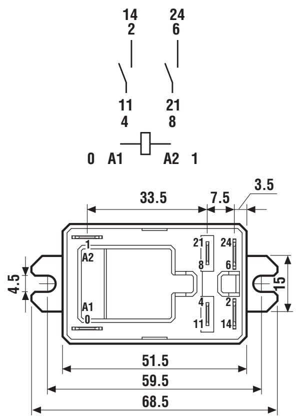
- 30 A rated contacts
- PCB mount - bifurcated terminals



Copper side view

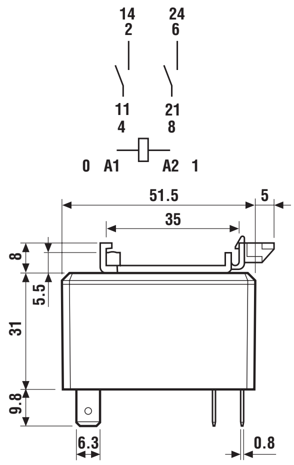
66.82-x300

- 30 A rated contacts
- Flange mount
- Faston 250 connections



66.82-x307

- 30 A rated contacts
- 35 mm rail mount
- Faston 250 connections



		66.22-x300	66.82-x300	66.82-x307
Contact specification				
Contact configuration		2 NO (DPST-NO)	2 NO (DPST-NO)	2 NO (DPST-NO)
Rated current/Maximum peak current	A	30/50	30/50	30/50
Rated voltage/Maximum switching voltage	V AC	250/440	250/440	250/440
Rated load AC1	VA	7,500	7,500	7,500
Rated load AC15 (230 V AC)	VA	1,200	1,200	1,200
Single phase motor rating (230 V AC)	kW	1.5	1.5	1.5
Breaking capacity DC1: 30/110/220 V	A	25/0.7/0.3	25/0.7/0.3	25/0.7/0.3
Minimum switching load	mW (V/mA)	1,000 (10/10)	1,000 (10/10)	1,000 (10/10)
Standard contact material		AgCdO	AgCdO	AgCdO
Coil specification				
Nominal voltage (U_N)	V AC (50/60 Hz)	6 - 12 - 24 - 110/115 - 120/125 - 230 - 240		
	V DC	6 - 12 - 24 - 110 -125		
Rated power AC/DC	VA (50 Hz)/W	3.6/1.7	3.6/1.7	3.6/1.7
Operating range	AC	(0.8…1.1)U_N	(0.8…1.1)U_N	(0.8…1.1)U_N
	DC	(0.8…1.1)U_N	(0.8…1.1)U_N	(0.8…1.1)U_N
Holding voltage	AC/DC	0.8 U_N/0.5 U_N	0.8 U_N/0.5 U_N	0.8 U_N/0.5 U_N
Must drop-out voltage	AC/DC	0.2 U_N/0.1 U_N	0.2 U_N/0.1 U_N	0.2 U_N/0.1 U_N
Technical data				
Mechanical life AC/DC	cycles	$10 \cdot 10^6$	$10 \cdot 10^6$	$10 \cdot 10^6$
Electrical life at rated load AC1	cycles	$100 \cdot 10^3$	$100 \cdot 10^3$	$100 \cdot 10^3$
Operate/release time	ms	8/10	8/10	8/10
Insulation between coil and contacts (1.2/50 μs)	kV	6 (8 mm)	6 (8 mm)	6 (8 mm)
Dielectric strength between open contacts	V AC	1,500	1,500	1,500
Ambient temperature range	°C	–40…+70	–40…+70	–40…+70
Environmental protection		RT II	RT II	RT II
Approvals (according to type)				

Ordering information

Example: 66 series relay, Faston 250 (6.3x0.8 mm) with top flange mount, 2 CO (DPDT) 30 A contacts, 24 V DC coil.

						A	B	C	D
6 6	.	8	2	. 9	. 0 2 4	. 0	0	0	0

Series

Type
2 = PCB
8 = Faston 250 (6.3x0.8 mm) with top flange mount

No. of poles
2 = 2 CO (DPDT) 30 A

Coil version
8 = AC (50/60 Hz)
9 = DC

Coil voltage
See coil specifications

A: Contact material
0 = Standard AgCdO
1 = AgNi

B: Contact circuit
0 = CO (nPDT)
3 = NO (nPST)

D: Special versions
0 = Standard
1 = Wash tight (RT III) for 66.22 only
3 = Wash tight (RT III) + top 35 mm rail (EN 50022) mount for 66.82 only
7 = Top 35 mm rail (EN 50022) mount for 66.82 only

C: Options
0 = None

Selecting features and options: only combinations in the same row are possible.
Preferred selections for best avaliability are shown in **bold.**

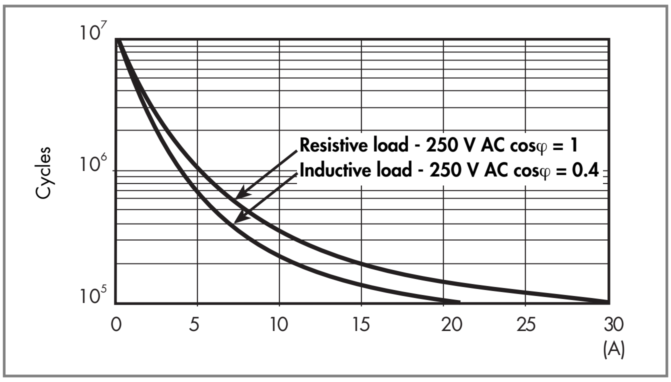
Type	Coil version	A	B	C	D
66.22	AC-DC	**0** - 1	**0** - 3	**0**	0 - **1**
66.82	AC-DC	**0** - 1	**0** - 3	**0**	**0** - 3 - 7

Technical data

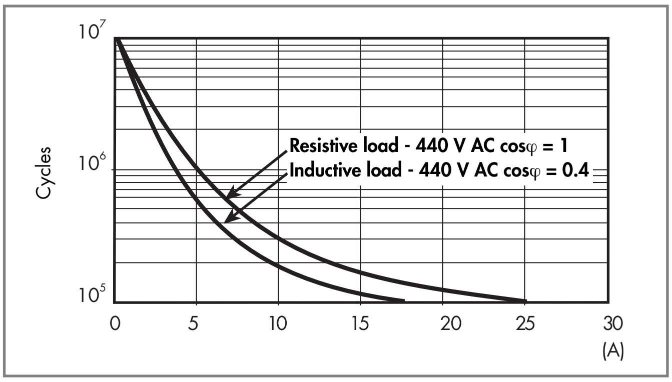
Insulation according to EN 61810-1:2004			
Nominal voltage of supply system	V AC	230/400	
Rated insulation voltage	V AC	400	
Pollution degree		3	
Insulation between coil and contact set			
Type of insulation		Reinforced (8 mm)	
Overvoltage category		III	
Rated impulse voltage	kV (1.2/50 μs)	6	
Dielectric strength	V AC	4,000	
Insulation between adjacent contacts			
Type of insulation		Basic	
Overvoltage category		III	
Rated impulse voltage	kV (1.2/50 μs)	4	
Dielectric strength	V AC	2,500	
Insulation between open contacts			
Type of disconnection		Micro-disconnection	
Dielectric strength	V AC/kV (1.2/50 μs)	1,500/2	
Conducted disturbance immunity			
Burst (5...50)ns, 5 kHz, on A1 - A2		EN 61000-4-4	level 4 (4 kV)
Surge (1.2/50 μs) on A1 - A2 (differential mode)		EN 61000-4-5	level 4 (4 kV)
Other data			
Bounce time: NO/NC	ms	7/10	
Vibration resistance (10...150)Hz: NO/NC	g	20/19	
Shock resistance	g	20	
Power lost to the environment — without contact current	W	2.3	
Power lost to the environment — with rated current	W	5	
Recommended distance between relays mounted on PCB	mm	≥ 10	

Contact specification

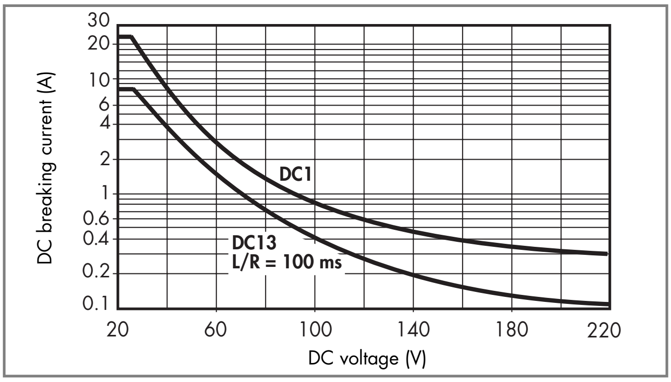
F 66 - Electrical life (AC) v contact current
250 V (normally open contact)



F 66 - Electrical life (AC) v contact current
440 V (normally open contact)



H 66 - Maximum DC1 breaking capacity



- When switching a resistive load (DC1) having voltage and current values under the curve, an electrical life of ≥ $100 \cdot 10^3$ can be expected.
- In the case of DC13 loads, the connection of a diode in parallel with the load will permit a similar electrical life as for a DC1 load.
  Note: the release time for the load will be increased.

Coil specifications

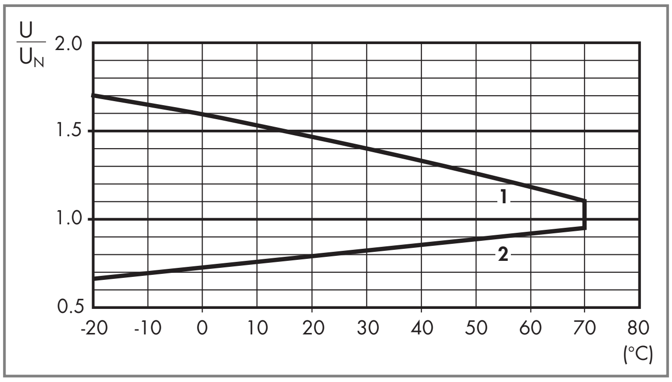
DC coil data

Nominal voltage U_N	Coil code	Operating range U_{min}	U_{max}	Resistance R	Rated coil consumption I at U_N
V		V	V	Ω	mA
6	**9**.006	4.8	6.6	21	283
12	**9**.012	9.6	13.2	85	141
24	**9**.024	19.2	26.4	340	70.5
110	**9**.110	88	121	7,000	15.7
125	**9**.125	100	137.5	9,200	13.6

AC coil data

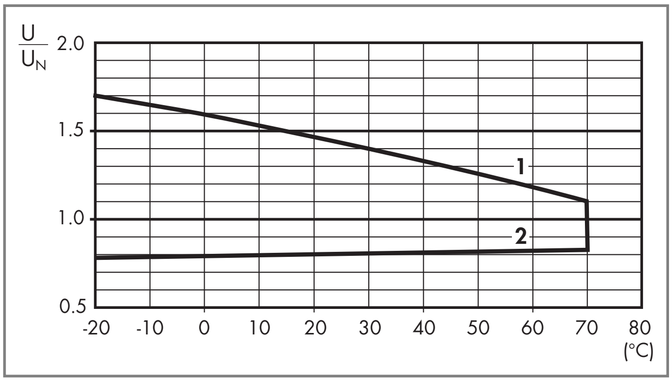
Nominal voltage U_N	Coil code	Operating range U_{min}	U_{max}	Resistance R	Rated coil consumption I at U_N (50Hz)
V		V	V	Ω	mA
6	**8**.006	4.8	6.6	3	600
12	**8**.012	9.6	13.2	11	300
24	**8**.024	19.2	26.4	50	150
110/115	**8**.110	88	126	930	32.6
120/125	**8**.120	96	137	1,050	30
230	**8**.230	184	253	4,000	15.7
240	**8**.240	192	264	5,500	15

R 66 - DC coil operating range v ambient temperature



1 - Max. permitted coil voltage.
2 - Min. pick-up voltage with coil at ambient temperature.

R 66 - AC coil operating range v ambient temperature



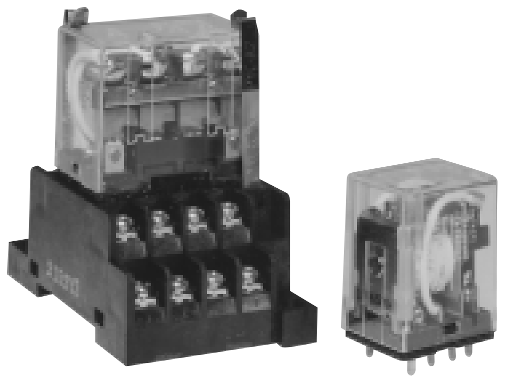
1 - Max. permitted coil voltage.
2 - Min. pick-up voltage with coil at ambient temperature.

OMRON

General Purpose Relay

LY

- Arc barrier equipped
- High dielectric strength (2,000 VAC)
- Long dependable service life assured by AgCdO contacts
- Choose models with single or bifurcated contacts, LED indicator, diode surge suppression, push-to-test button, or RC circuit
- All models meet UL and CSA approvals; VDE, LR, and SEV approved versions are available



Ordering Information

To Order: Select the part number and add the desired coil voltage rating (e.g., LY1-*DC6*).

Type	Terminal	Contact form	**Part number**					
			Single contact			Bifurcated contact		
			Standard bracket mounting	Upper mounting bracket	Lower mounting bracket	Standard bracket mounting	Upper mounting bracket	Lower mounting bracket
Standard	Plug-in/solder	SPDT	**LY1**	**LY1F**	**LY1S**	—	—	—
		DPDT	**LY2**	**LY2F**	**LY2S**	**LY2Z**	**LY2ZF**	**LY2ZS**
		3PDT	**LY3**	**LY3F**	**LY3S**	—	—	—
		4PDT	**LY4**	**LY4F**	**LY4S**	—	—	—
	PCB	SPDT	**LY1-0**	—	—	—	—	—
		DPDT	**LY2-0**	—	—	**LY2Z-0**	—	—
		3PDT	**LY3-0**	—	—	—	—	—
		4PDT	**LY4-0**	—	—	—	—	—
LED indicator	Plug-in/solder	SPDT	**LY1N**	—	—	—	—	—
		DPDT	**LY2N**	—	—	**LY2ZN**	—	—
		3PDT	**LY3N**	—	—	—	—	—
		4PDT	**LY4N**	—	—	—	—	—
Diode surge suppression		SPDT	**LY1-D**	—	—	—	—	—
		DPDT	**LY2-D**	—	—	**LY2Z-D**	—	—
		3PDT	**LY3-D**	—	—	—	—	—
		4PDT	**LY4-D**	—	—	—	—	—
LED indicator and diode surge suppression		SPDT	**LY1N-D2**	—	—	—	—	—
		DPDT	**LY2N-D2**	—	—	**LY2ZN-D2**	—	—
		4PDT	**LY4N-D2**	—	—	—	—	—
RC circuit		SPDT	**LY1-CR**	—	—	—	—	—
		DPDT	**LY2-CR**	—	—	**LY2Z-CR**	—	—
LED indicator and RC circuit		SPDT	**LY1N-CR**	—	—	—	—	—
		DPDT	**LY2N-CR**	—	—	**LY2ZN-CR**	—	—

Note: 1. Types with specifications other than those listed are available. Contact your OMRON Sales representative.
2. To order connecting sockets and mounting tracks, see “Accessories” section.

Ordering Information, continued

Type	Terminal	Contact form	Part number					
			Single contact			Bifurcated contact		
			Standard bracket mounting	Upper mounting bracket	Lower mounting bracket	Standard bracket mounting	Upper mounting bracket	Lower mounting bracket
Push-to-test button	Plug-in/solder	SPDT	**LY1I4**	—	—	—	—	—
		DPDT	**LY2I4**	—	—	**LY2ZI2**	—	—
		3PDT	**LY3I4**	—	—	—	—	—
		4PDT	**LY4I4**	—	—	—	—	—
LED indicator and push-to-test button	Plug-in/solder	DPDT	**LY2I4N**	—	—	**LY2ZI2N**	—	—
		4PDT	**LY4I4N**	—	—	—	—	—

Note: 1. Types with specifications other than those listed are available. Contact your OMRON Sales representative.
2. To order connecting sockets and mounting tracks, see “Accessories” section.

■ ACCESSORIES

Connecting Sockets

To Order: Select the appropriate part numbers for sockets, clips, and mounting tracks (if required) from the following charts.

Track mounted sockets

Relay	Socket*	Relay hold-down clip		Mounting track
		Standard	RC circuit	
SPDT DPDT	**PTF08A-E**	**PYC-A1**	**Y92H-3**	**PFP-100N/PFP-50N** & **PFP-M** or **PFP-100N2** **PFP-S** (Option spacer)
3PDT	**PTF11A**			
4PDT	**PTF14A-E**			

* Track mounted socket can be used as a front connecting socket.

Back connecting sockets

Relay	Solder terminal socket	Wire wrap terminal socket	Relay hold-down clip				Socket Mounting Plate			
			Standard	Push-to-test	RC circuit	Mtg. plate	1	10	12	18
SPDT DPDT	**PT08**	**PT08QN**	**PYC-P**	**PYC-P2**	**PYC-1**	**PYC-S**	**PYP-1**	–	–	**PYP-18**
3PDT	**PT11**	**PT11QN**					**PTP-1-3**	–	**PTP-12**	–
4PDT	**PT14**	**PT14QN**					**PTP-1**	**PTP-10**	–	–

Note: Types PYP-18, PTP-12 and PTP-10 may be cut to any desired length.

Relay	PC terminal socket	Relay hold-down clip		
		Standard	Push-to-test	RC circuit
SPDT DPDT	**PT08-0**	**PYC-P**	**PYC-P2**	**PYC-1**
3PDT	**PT11-0**			
4PDT	**PT14-0**			

Specifications

■ CONTACT DATA

Load	Single contact				Bifurcated contact	
	SPDT		DPDT, 3PDT, 4PDT		DPDT	
	Resistive load (p.f. = 1)	Inductive load (p.f. = 0.4) (L/R = 7 ms)	Resistive load (p.f. = 1)	Inductive load (p.f. = 0.4) (L/R = 7 ms)	Resistive load (p.f. = 1)	Inductive load (p.f. = 0.4) (L/R = 7 ms)
Rated load	15 A at 110 VAC 15 A at 24 VDC	10 A at 110 VAC 7 A at 24 VDC	10 A at 110 VAC 10 A at 24 VDC	7.5 A at 110 VAC 5 A at 24 VDC	5 A at 110 VAC 5 A at 24 VDC	4 A at 110 VAC 4 A at 24 VDC
Contact material	AgCdO					
Carry current	15 A		10 A		7 A	
Max. operating voltage	250 VAC 125 VDC					
Max. operating current	15 A		10 A		7 A	
Max. switching capacity	1,700 VA 360 W	1,100 VA 170 W	1,100 VA 240 W	830 VA 120 W	550 VA 120 W	440 VA 100 W
Min. permissible load	100 mA, 5 VDC				10 mA, 5 VDC	

■ COIL DATA

1- and 2-pole types – AC

Rated voltage (V)	Rated current (mA)		Coil resistance (Ω)	Coil inductance (ref. value) (H)		Pick-up voltage	Dropout voltage	Maximum voltage	Power consumption (VA, W)
	50 Hz	60 Hz		Armature OFF	Armature ON	(% of rated voltage)			
6	214.10	183	12.20	0.04	0.08	80% max.	30% min.	110%	Approx. 1.00 to 1.20 (60 Hz)
12	106.50	91	46	0.17	0.33				
24	53.80	46	180	0.69	1.30				
50	25.70	22	788	3.22	5.66				
100/110	11.70/12.90	10/11	3,750	14.54	24.60				Approx. 0.90 to 1.10 (60 Hz)
110/120	9.90/10.80	8.40/9.20	4,430	19.20	32.10				
200/220	6.20/6.80	5.30/5.80	12,950	54.75	94.07				
220/240	4.80/5.30	4.20/4.60	18,790	83.50	136.40				

1- and 2-pole types – DC

Rated voltage (V)	Rated current (mA)	Coil resistance (Ω)	Coil inductance (ref. value) (H)		Pick-up voltage	Dropout voltage	Maximum voltage	Power consumption (VA, W)
			Armature OFF	Armature ON	(% of rated voltage)			
6	150	40	0.16	0.33	80% max.	10% min.	110%	Approx. 0.90
12	75	160	0.73	1.37				
24	36.90	650	3.20	5.72				
48	18.50	2,600	10.60	21				
100/110	9.10/10	11,000	45.60	86.20				

Note: 1. The rated current and coil resistance are measured at a coil temperature of 23°C (73°F) with tolerances of +15%, -20% for AC rated current, and ±15% for DC rated coil resistance.
2. The AC coil resistance and inductance are reference values at 60 Hz.
3. The performance characteristics are measured at a coil temperature of 23°C (73°F).
4. Class B coil insulation is available.

■ COIL DATA(continued)

3-pole type – AC

Rated voltage (V)	Rated current (mA)		Coil resistance (Ω)	Coil inductance (ref. value) (H)		Pick-up voltage	Dropout voltage	Maximum voltage	Power consumption (VA, W)
	50 Hz	60 Hz		Armature OFF	Armature ON	(% of rated voltage)			
6	310	270	6.70	0.03	0.05	80% max.	30% min.	110%	Approx. 1.60 to 2.00 (60 Hz)
12	159	134	24	0.12	0.21				
24	80	67	100	0.44	0.79				
50	38	33	410	2.24	3.87				
100/110	15.90/18.30	13.60/15.60	2,300	10.50	18.50				
120	17.30	14.8	2,450	11.50	20.60				
200/220	10.50/11.60	9.00/9.90	8,650	34.80	59.50				
240	9.40	8	10,400	38.60	74.60				

3-pole type – DC

Rated voltage (V)	Rated current (mA)	Coil resistance (Ω)	Coil inductance (ref. value) (H)		Pick-up voltage	Dropout voltage	Maximum voltage	Power consumption (VA, W)
			Armature OFF	Armature ON	(% of rated voltage)			
6	234	25.70	0.11	0.21	80% max.	10% min.	110%	Approx. 1.40
12	112	107	0.45	0.98				
24	58.60	410	1.89	3.87				
48	28.20	1,700	8.53	13.90				
100/110	12.70/13	8,500	29.60	54.30				

4-pole type – AC

Rated voltage (V)	Rated current (mA)		Coil resistance (Ω)	Coil inductance (ref. value) (H)		Pick-up voltage	Dropout voltage	Maximum voltage	Power consumption (VA, W)
	50 Hz	60 Hz		Armature OFF	Armature ON	(% of rated voltage)			
6	386	330	5	0.02	0.04	80% max.	30% min.	110%	Approx. 1.95 to 2.50 (60 Hz)
12	199	170	20	0.10	0.17				
24	93.60	80	78	0.38	0.67				
50	46.80	40	350	1.74	2.88				
100/110	22.50/25.50	19/21.80	1,800	10.50	17.30				
120	19.00	16.40	2,200	9.30	19				
200/220	11.50/13.10	9.80/11.20	6,700	33.10	57.90				
240	11.00	9.50	9,000	33.20	63.40				

4-pole type – DC

Rated voltage (V)	Rated current (mA)	Coil resistance (Ω)	Coil inductance (ref. value) (H)		Pick-up voltage	Dropout voltage	Maximum voltage	Power consumption (VA, W)
			Armature OFF	Armature ON	(% of rated voltage)			
6	240	25	0.09	0.21	80% max.	10% min.	110%	Approx. 1.50
12	120	100	0.39	0.84				
24	69	350	1.41	2.91				
48	30	1,600	6.39	13.60				
100/110	15/15.90	6,900	32	63.70				

Note:
1. The rated current and coil resistance are measured at a coil temperature of 23°C (73°F) with tolerances of +15%, -20% for AC rated current, and ±15% for DC rated coil resistance.
2. The AC coil resistance and inductance are reference values at 60 Hz.
3. The performance characteristics are measured at a coil temperature of 23°C (73°F).
4. Class B coil insulation is available.

■ CHARACTERISTICS

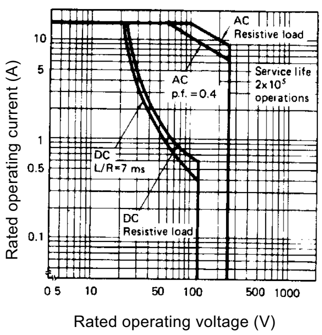
Contact resistance		50 mΩ max.
Operate time		25 ms max.
Release time		25 ms max.
Operating frequency	Mechanically	18,000 operations/hour
	Under rated load	1,800 operations/hour
Insulation resistance		100 MΩ min. (at 500 VDC)
Dielectric strength		2,000 VAC, 50/60 Hz for 1 minute 1,000 VAC, 50/60 Hz for 1 minute between contacts of same polarity
Vibration	Mechanical durability	10 to 55 Hz, 1.00 mm (0.04 in) double amplitude
	Malfunction durability	10 to 55 Hz, 1.00 mm (0.04 in) double amplitude
Shock	Mechanical durability	1,000 m/s^2 (approx. 100 G)
	Malfunction durability	200 m/s^2 (approx. 20 G)
Ambient temperature	Operating	-40° to 70°C (-40° to 158°F)
Humidity		35 to 85% RH
Service Life	Mechanically	AC: 50 million operations min. (at operating frequency of 18,000 operations/hour) DC: 100 million operations min. (at operating frequency of 18,000 operations/hour)
	Electrically	See “Characteristic Data”
Weight		SPDT, DPDT: Approx. 40 g (1.41 oz), 3PDT: Approx. 50 g (1.76 oz) 4PDT: Approx. 70 g (2.47 oz)

Note: Data shown are of initial value.

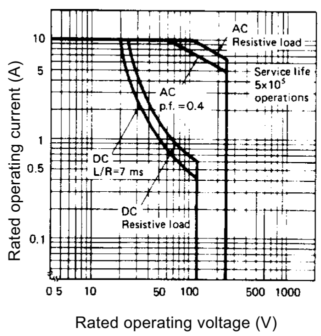
■ CHARACTERISTIC DATA

Maximum switching capacity

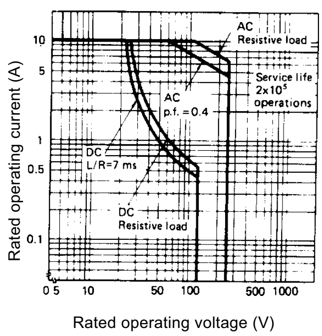
LY1



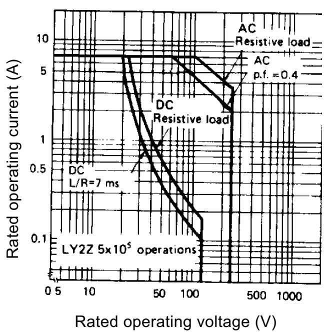
LY2



LY3, LY4

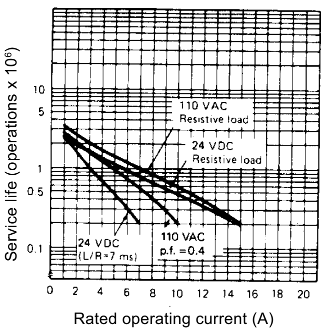


LY2Z

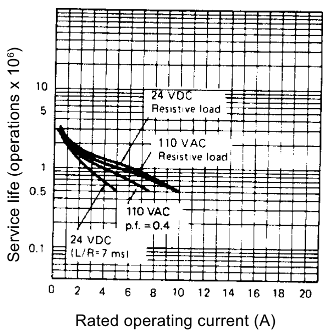


Electrical service life

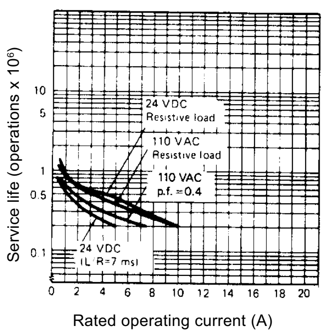
LY1



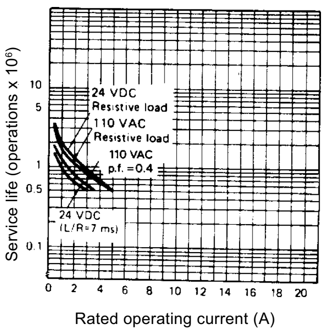
LY2



LY3, LY4



LY2Z

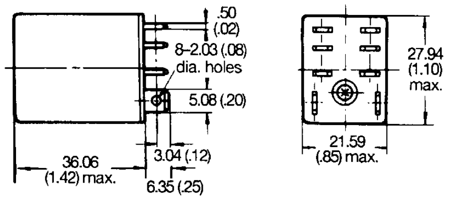


Dimensions

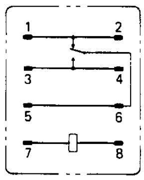
Unit: mm (inch)

■ RELAYS

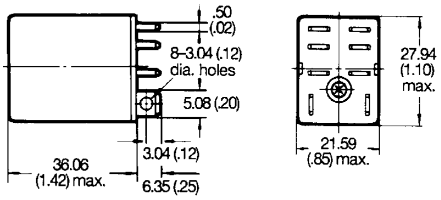
LY1



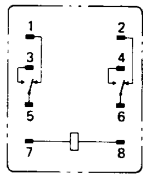
Terminal arrangement (Bottom view)



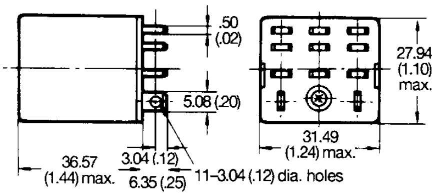
LY2



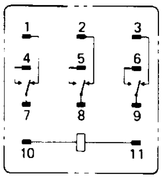
Terminal arrangement (Bottom view)



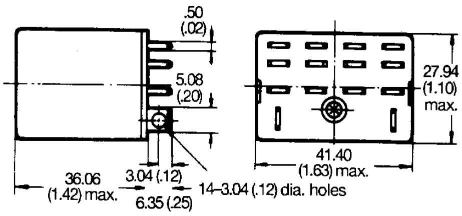
LY3



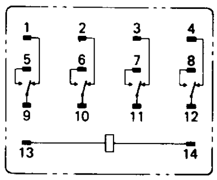
Terminal arrangement (Bottom view)



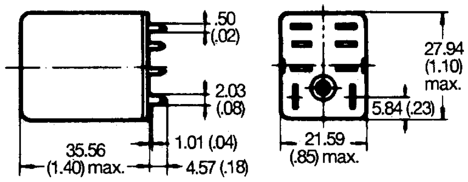
LY4



Terminal arrangement (Bottom view)

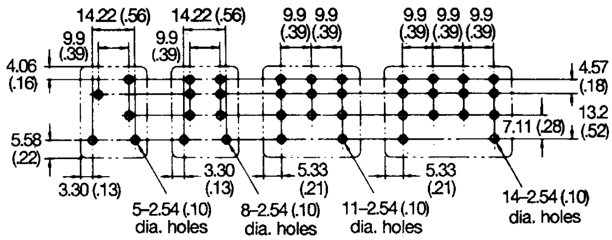


LY1-0, LY2-0, LY3-0, LY4-0



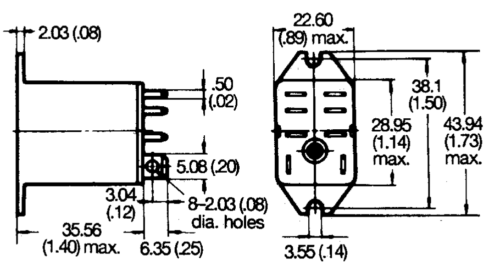
Note: The above drawing shows LY2-0. With LY1-0, dimension "*" should read as 6.35 (.25).

Mounting holes for LY1-0, LY2-0, LY3-0, LY4-0 (Bottom view)

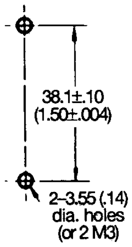


SPDT DPDT 3PDT 4PDT

LY1F, LY2F

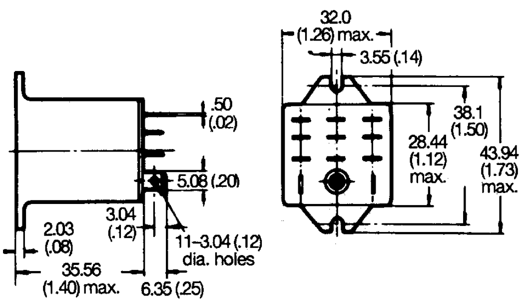


Mounting holes

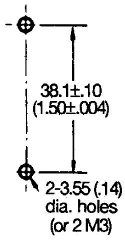


Note: The above drawing shows LY1F. With LY2F, dimension "*" should read as eight 3.05 mm (0.12 in) dia. holes.

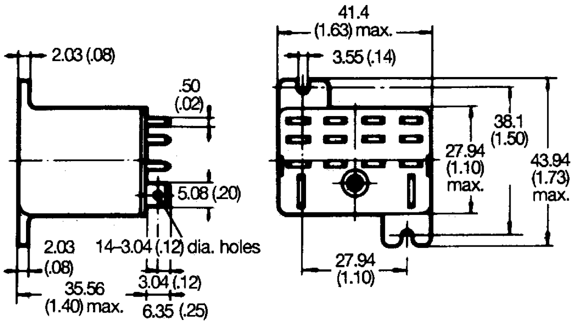
LY3F



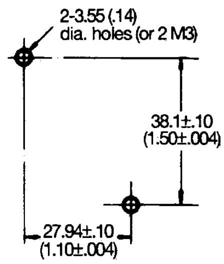
Mounting holes



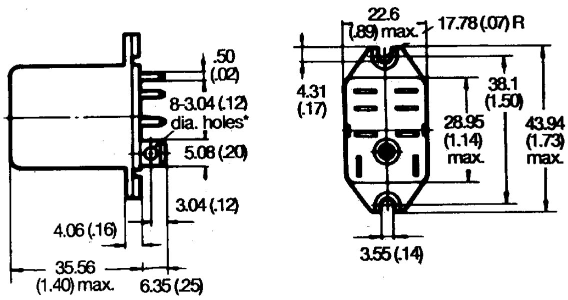
LY4F



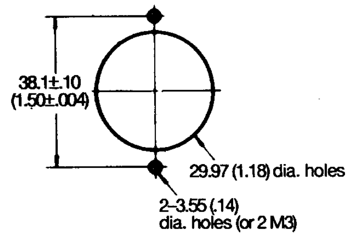
Mounting holes



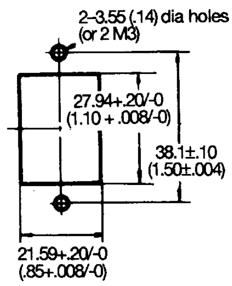
LY1S, LY2S



Round hole

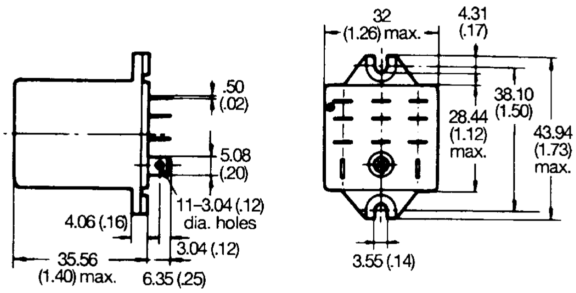


Rectangular hole

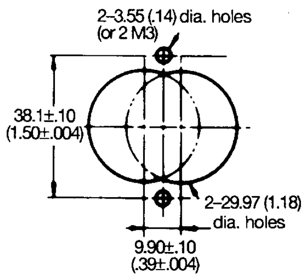


Note: The above drawing shows LY2S-US. With LY1S-US, dimension "*" should read as eight 2.03 mm (0.08 in) dia. holes.

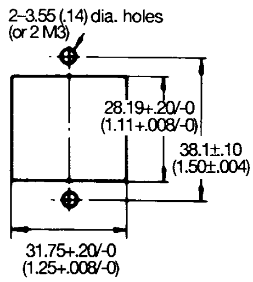
LY3S



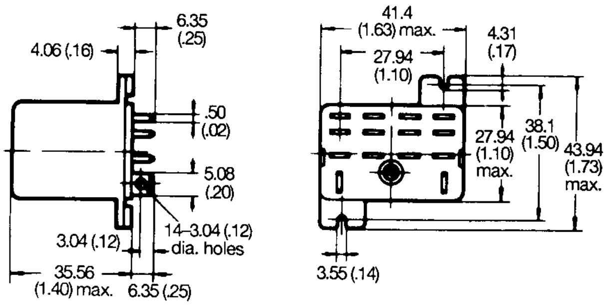
Round hole



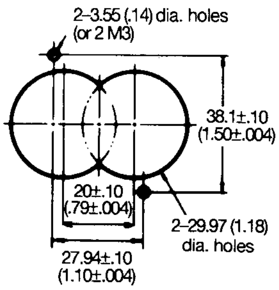
Rectangular hole



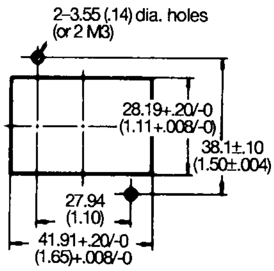
LY4S



Round hole



Rectangular hole

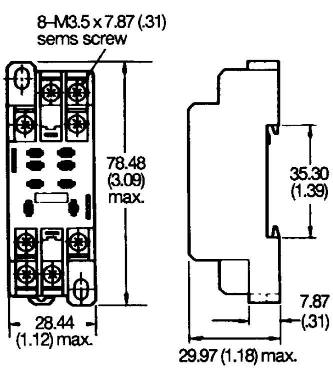


■ ACCESSORIES

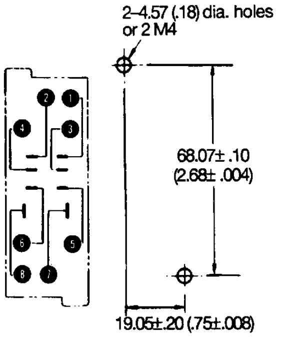
Unit: mm (inch)

Track mounted sockets (UL File No. E87929) (CSA Report No. LR31928)

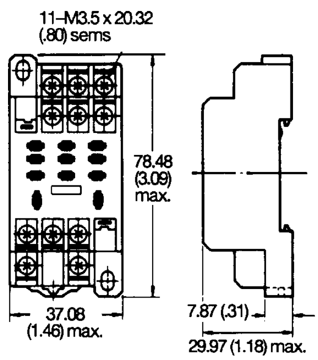
PTF08A-E



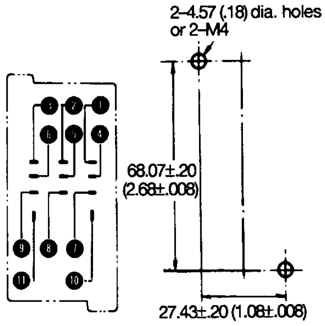
Terminal arrangement/ mounting holes
(Top view)



PTF11A

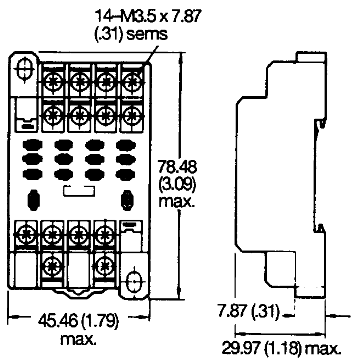


Terminal arrangement/ mounting holes
(Top view)

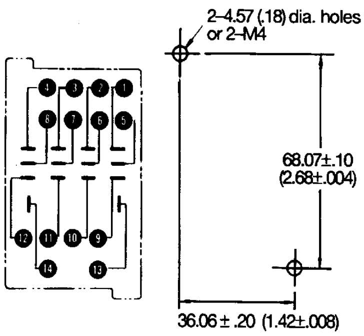


Track mounting sockets (UL File No. E87929) (CSA Report No. LR31928)

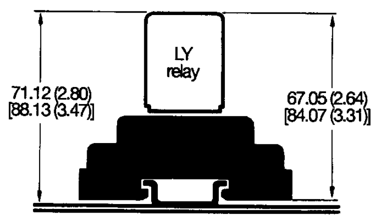
PTF14A-E



Terminal arrangement/ mounting holes
(Top view)



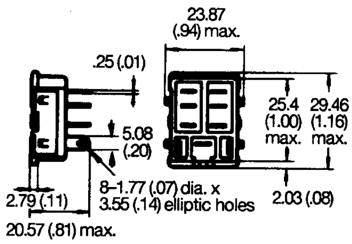
Mounting height of relay with socket
(Applies to all PTF□A sockets)



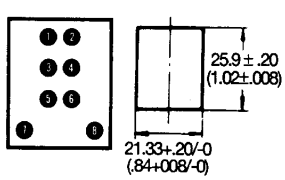
Note: 1. UL/CSA does not apply to wire wrap (Q) type sockets.
2. Values in brackets for LY□CR.

Back connecting socket (UL File No. E87929) (CSA Report No. LR31928)

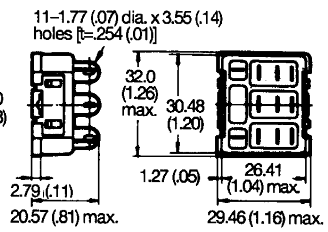
PT08



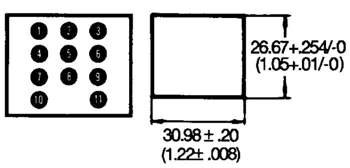
Terminal arrangement
(Bottom view)



PT11

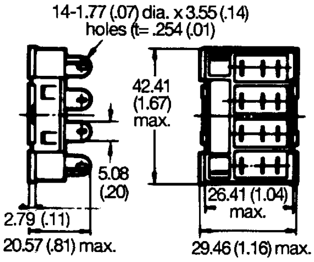


Terminal arrangement
(Bottom view)

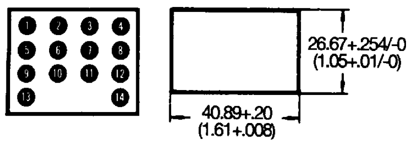


Back connecting socket (UL File No. E87929) (CSA Report No. LR31928)

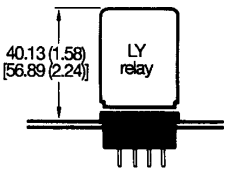
PT14



Terminal arrangement
(Bottom view)



Mounting height of relay with socket
(Applies to all PT sockets)

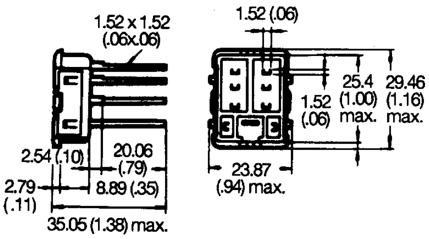


PT

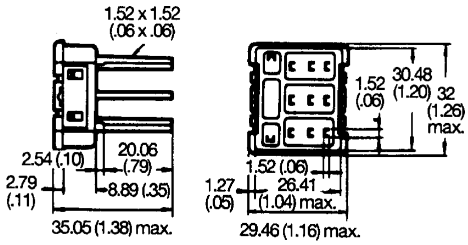
Note: Values in brackets for LY□CR.

Back connecting socket (UL File No. E87929) (CSA Report No. LR31928)

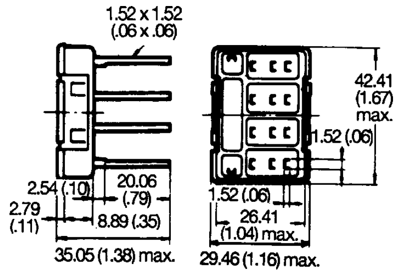
PT08QN
Panel cut-out and terminal arrangement are the same as Type PT08.



PT11QN
Panel cut-out and terminal arrangement are the same as Type PT11.

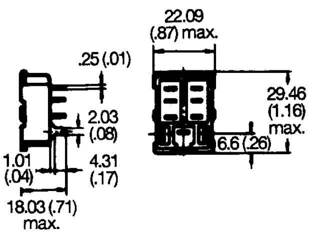


PT14QN
Panel cut-out and terminal arrangement are the same as Type PT14.

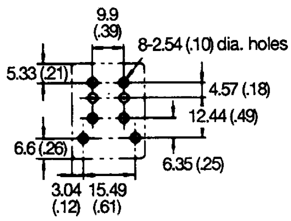


Back connecting socket (UL File No. E87929) (CSA Report No. LR31928)

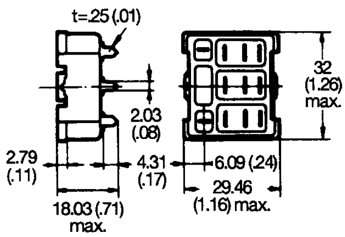
PT08-0
Terminal arrangement is the same as Type PT08.



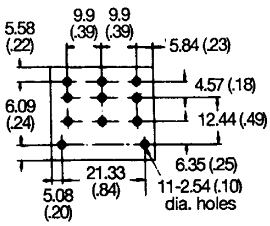
Mounting holes
(Bottom view)



PT11-0
Terminal arrangement is the same as Type PT11.

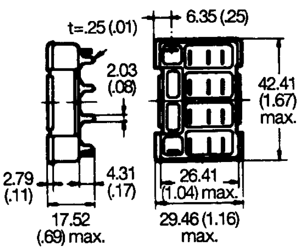


Mounting holes
(Bottom view)

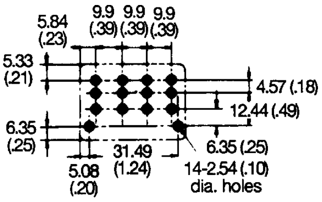


Back connecting socket (UL File No. E87929) (CSA Report No. LR31928)

PT14-0
Terminal arrangement is the same as Type PT14.



Mounting holes
(Bottom view)

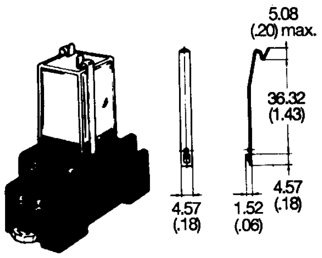


■ ACCESSORIES (continued)

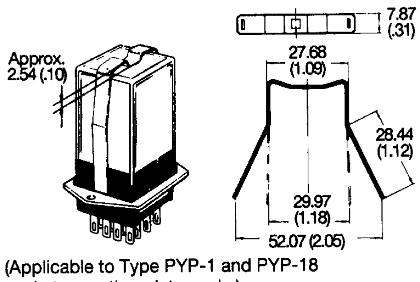
Unit: mm (inch)

Relay hold-down clips

PYC-A1
For PTF□A socket

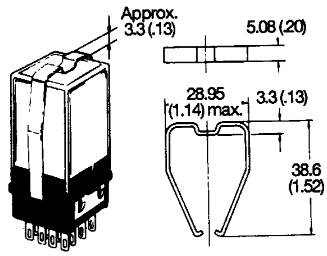


PYC-S
For relay mounting plates
(Applicable to Type PYP-1 and PYP-18 socket mounting plates only.)



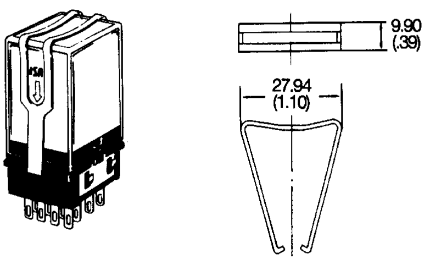
(Applicable to Type PYP-1 and PYP-18 socket mounting plates only.)

PYC-P
For PT□ socket

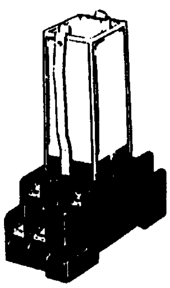


Relay hold-down clips

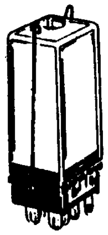
PYC-P2
For push-to-test button type with PT□ socket



Y92H-3
For RC circuit type

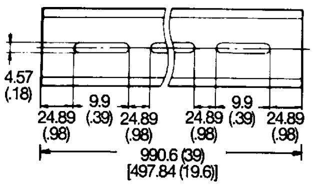


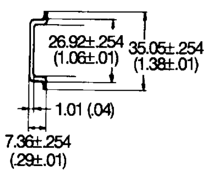
PYC-1
For RC circuit type



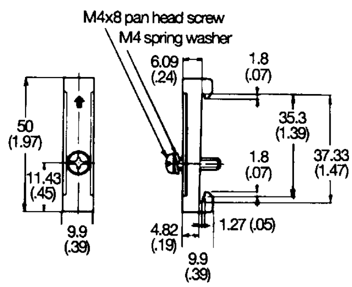
Mounting track/end plate/spacer

PFP-100N/PFP-50N mounting track

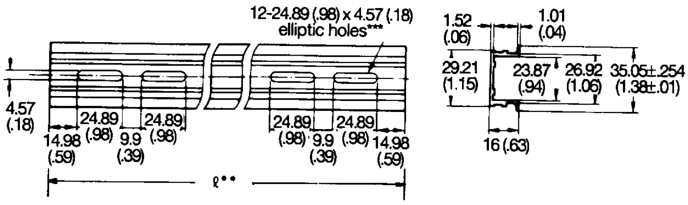




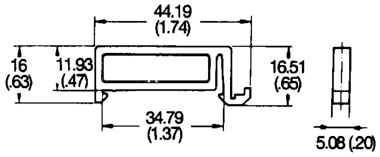
PFP-M end plate



PFP-100N2 mounting track



PFP-S spacer

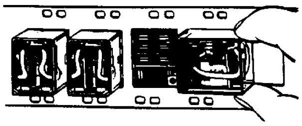


* This dimension is 14.99 mm (0.59 in) on both ends in the case of PFP-100N, but on one end in the case of PFP-50N.

** L = Length
PFP-50N .... L = 497.84 mm (19.60 in)
PFP-100N .... L = 990.60 mm (39.00 in)
PFP-100N2 .... L = 990.60 mm (39.00 in)

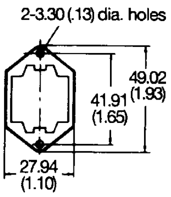
*** A total of twelve 24.89 x 4.57 mm (0.98 x 0.18 in) elliptic holes are provided, with six holes cut from each end of the track at a pitch of 9.91 (0.39) between holes.

Socket mounting plates [t=1.52 (.06)]

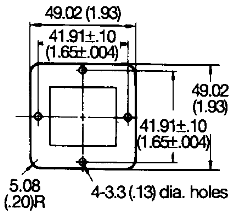


	Number of socket specs.			
Socket needed	1	10	12	18
PT08, PT08QN	PYP-1	–	–	PYP-18
PT11, PT11QN	PTP-1-3	–	PTP-1-2	–
PT14, PT14QN	PTP-1	PTP-10	–	–

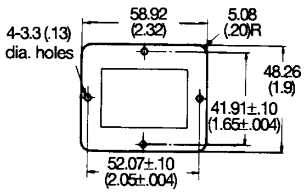
PYP-1



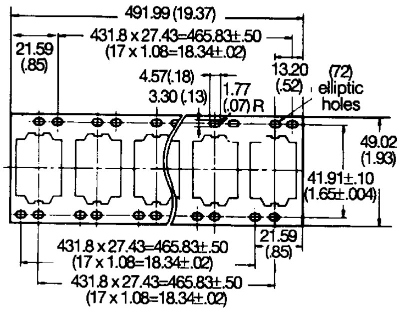
PTP-1-3



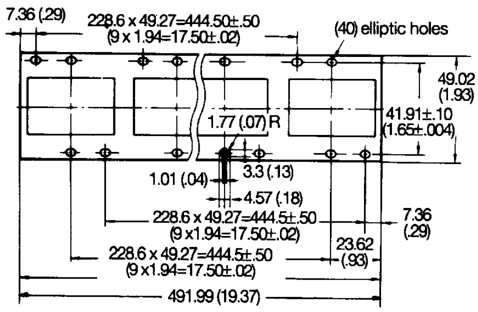
PTP-1



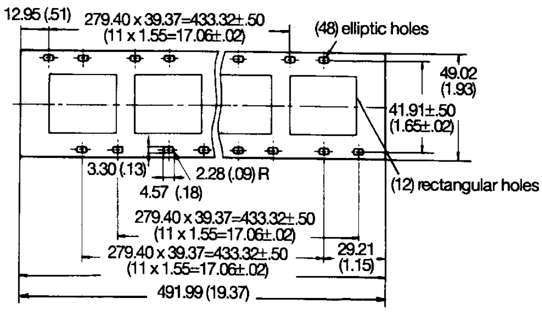
PYP-18



PTP-10



PTP-12



■ RELAY OPTIONS

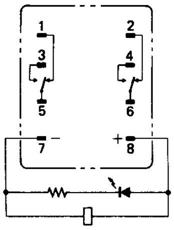
LED Indicator

Specifications and dimensions same as the Standard Type with the following exception. With the LED indicator type, the rated current is approximately 0 to 5.0 mA higher than the Standard Type.

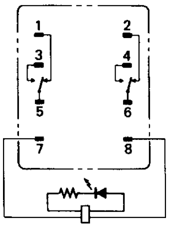
Terminal arrangement/Internal connections (Bottom view)

LY2N

DC coil rating type



AC coil rating type

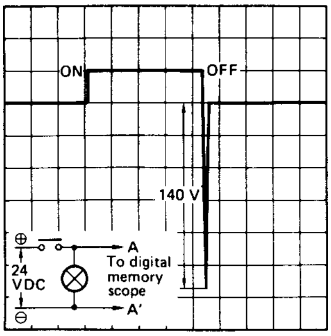


Note: 1. The coil terminals 10 and 11 of Type LY3N become (-) and (+) and terminals 13 and 14 of Type LY4N become (-) and (+), respectively.
2. Pay special attention to the polarities when using the DC type.

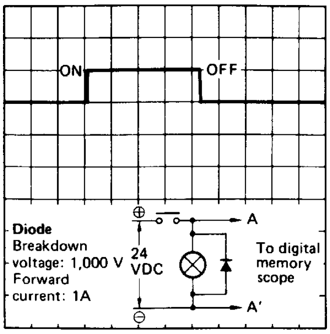
Diode Surge Suppression

Specifications and dimensions same as the Standard Type with the following exception. Ambient operating temperature: -25° to 40°C (-13° to 104°F)

Without Diode



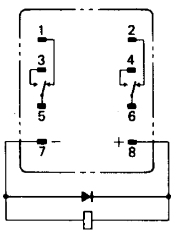
With Diode



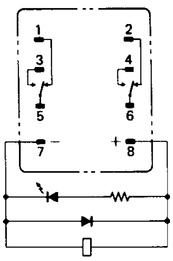
Terminal arrangement/Internal connections (Bottom view)

LY2(N)-D(2)

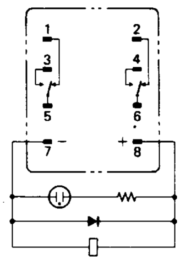
LY2-D
6, 12, 24, 48
100/110 VDC



LY2N-D2
6, 12, 24, 48 VDC



LY2N-D2
100/110 VDC



Note: 1. Pay special attention to the polarities when using the DC type.
2. The release time is somewhat longer, but satisfies the standard specifications of 25 ms.
3. The reverse-breakdown voltage of the diode is 1,000 VDC.
4. Available on DC versions only.

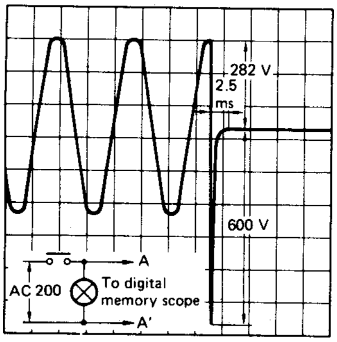
■ RELAY OPTIONS

RC Circuit

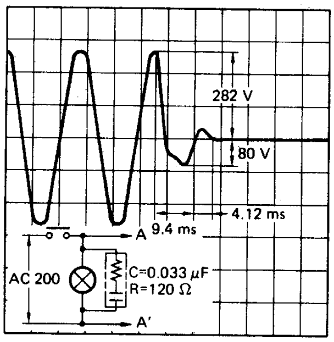
Specifications and dimensions same as the Standard Type with the following exceptions.

Characteristic Data

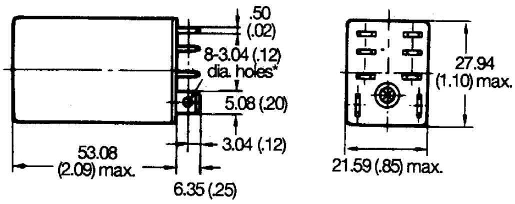
Without RC circuit



With RC circuit

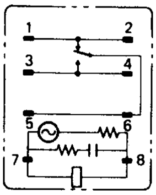


LY1-CR, LY2(Z)-CR

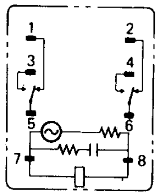


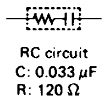
Terminal arrangement/Internal connections (Bottom view)

LY1-CR



LY2(Z)-CR





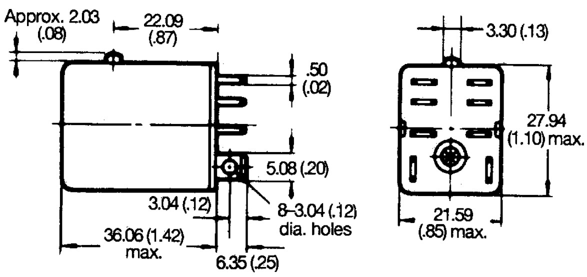
Note: 1. The above drawing shows LY2(Z)-CR. With LY1-CR, "*" should read eight 2.03 mm (0.08 in) dia. holes.
2. Available on AC versions only.

Push-to-test Button

Specifications and dimensions same as the Standard Type with the following exceptions.

LY□12

LY112, LY212



Note: Type LY112 has the same dimensions and appearances as Type LY212 shown except that dimension "*" is 2.03 mm (0.08 in) dia. holes

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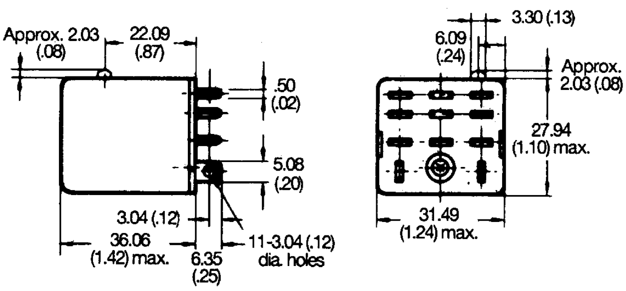
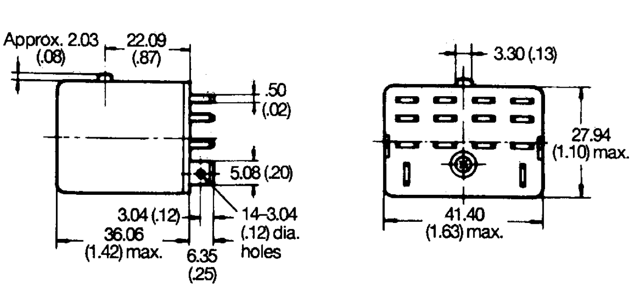
LY312



LY412



■ APPROVALS

UL recognized type (File No. E41643)

Type	Contact form	Coil ratings	Contact ratings
LY□	SPDT	6 to 240 VAC 6 to 120 VDC	15 A, 240 VAC (Inductive) 15 A, 28 VDC (Resistive) TV-5 (ACTV) 1/2 HP, 120 VAC (Motor)
LY□	DPDT		13 A, 120 VAC (Resistive) 12 A, 240 VAC (Inductive) 10 A, 28 VDC (Resistive) TV-3 (ACTV) 1/2 HP, 120 VAC (Motor)
LY□	3PDT 4PDT		10 A, 240 VAC (Inductive) 10 A, 28 VDC (Resistive) 1/2 HP, 240 VAC (Motor)

CSA certified type (File No. LR31928)

Type	Contact form	Coil ratings	Contact ratings
LY□	SPDT	6 to 240 VAC 6 to 120 VDC	15 A, 120 VAC (Inductive) 10 A, 240 VAC (Inductive) 15 A, 28 VDC (Resistive) TV-5 (ACTV)
LY□	DPDT		13 A, 28 VDC (Resistive) 12 A, 120 VAC (Inductive) 10 A, 240 VAC (Inductive) 1/3 HP, 120 VAC (Motor) TV-3 (ACTV)
LY□	3PDT 4PDT		10 A, 240 VAC (Inductive) 10 A, 28 VDC (Resistive)

VDE approved type (File No. 9903 [SPDT, DPDT & 3PDT], File No. 9947 [4PDT])

Type	Contact form	Coil ratings	Contact ratings
LY□-VD	SPDT	6, 12, 24, 50, 110, 220 VAC and 6, 12, 24, 48, 110 VDC	10 A, 220 VAC (Resistive) 10 A, 28 VDC (Resistive) 7 A, 220 VAC (Inductive) 7 A, 28 VDC (Inductive)
LY□-VD	DPDT 3PDT 4PDT		7 A, 220 VAC (Resistive) 7 A, 28 VDC (Resistive) 4 A, 220 VAC (Inductive) 4 A, 28 VDC (Inductive)

LR (Lloyd's Register) approved type (File No. 562KOB-204523)

Type	Contact form	Coil ratings	Contact ratings
LY□	DPDT 4PDT	6 to 240 VAC 6 to 110 VDC	7.5 A, 230 VAC (Inductive) 5 A, 24 VDC (Inductive)

SEV listed type (File No. D7 91/82 [2- & 4-pole], D 91/204a [1- & 3-pole])

Type	Contact form	Coil ratings	Contact ratings
LY□-SV	SPDT	6 to 240 VAC 6 to 110 VDC	15 A, 220 VAC (Resistive) 15 A, 24 VDC (Resistive)
LY□-SV	DPDT 3PDT 4PDT		10 A, 220 VAC (Resistive) 10 A, 24 VDC (Resistive)

Note: 1. The rated values approved by each of the safety standards (e.g., UL, CSA, VDE, and SEV) may be different from the performance characteristics individually defined in this catalog.
2. In the interest of product improvement, specifications are subject to change.

19-0381; Rev 1; 6/96

EVALUATION KIT MANUAL AVAILABLE

MAXIM

Multi-Range (±10V, ±5V, +10V, +5V), Single +5V, 12-Bit DAS with 8+4 Bus Interface

MAX197

General Description

The MAX197 multi-range, 12-bit data-acquisition system (DAS) requires only a single +5V supply for operation, yet accepts signals at its analog inputs that may span both above the power-supply rail and below ground. This system provides 8 analog input channels that are independently software programmable for a variety of ranges: ±10V, ±5V, 0V to +10V, or 0V to +5V. This increases effective dynamic range to 14 bits, and provides the user flexibility to interface 4mA-to-20mA, ±12V, and ±15V powered sensors to a single +5V system. In addition, the converter is overvoltage tolerant to ±16.5V; a fault condition on any channel will **not** affect the conversion result of the selected channel. Other features include a 5MHz bandwidth track/hold, a 100ksps throughput rate, software-selectable internal or external clock and acquisition, 8+4 parallel interface, and an internal 4.096V or an external reference.

A hardware $\overline{SHDN}$ pin and two programmable power-down modes (STBYPD, FULLPD) are provided for low-current shutdown between conversions. In STBYPD mode, the reference buffer remains active, eliminating start-up delays.

The MAX197 employs a standard microprocessor (µP) interface. A three-state data I/O port is configured to operate with 8-bit data buses, and data-access and bus-release timing specifications are compatible with most popular µPs. All logic inputs and outputs are TTL/CMOS compatible.

The MAX197 is available in 28-pin DIP, wide SO, SSOP, and ceramic SB packages.

For a different combination of ranges (±4V, ±2V, 0V to 4V, 0V to 2V), see the MAX199 data sheet. For 12-bit bus interface, see the MAX196 and MAX198 data sheets.

Applications

Industrial-Control Systems
Robotics
Data-Acquisition Systems
Automatic Testing Systems
Medical Instruments
Telecommunications

Functional Diagram appears at end of data sheet.

Features

- ♦ **12-Bit Resolution, 1/2LSB Linearity**
- ♦ **Single +5V Operation**
- ♦ **Software-Selectable Input Ranges: ±10V, ±5V, 0V to 10V, 0V to 5V**
- ♦ **Fault-Protected Input Multiplexer (±16.5V)**
- ♦ **8 Analog Input Channels**
- ♦ **6µs Conversion Time, 100ksps Sampling Rate**
- ♦ **Internal or External Acquisition Control**
- ♦ **Internal 4.096V or External Reference**
- ♦ **Two Power-Down Modes**
- ♦ **Internal or External Clock**

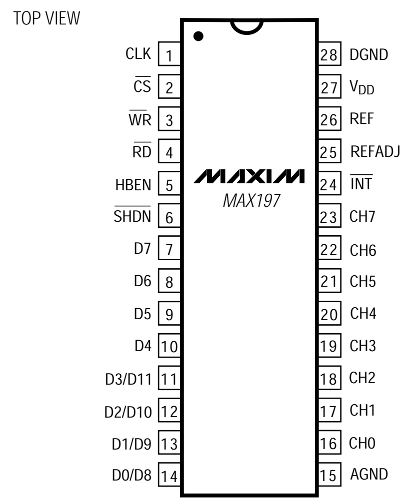
Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX197ACNI	0°C to +70°C	28 Narrow Plastic DIP
MAX197BCNI	0°C to +70°C	28 Narrow Plastic DIP
MAX197ACWI	0°C to +70°C	28 Wide SO
MAX197BCWI	0°C to +70°C	28 Wide SO
MAX197ACAI	0°C to +70°C	28 SSOP
MAX197BCAI	0°C to +70°C	28 SSOP
MAX197BC/D	0°C to +70°C	Dice*

Ordering Information continued at end of data sheet.

**Dice are specified at TA = +25°C, DC parameters only.*

Pin Configuration



DIP/SO/SSOP/Ceramic SB

ABSOLUTE MAXIMUM RATINGS

V_{DD} to AGND .... -0.3V to +7V
AGND to DGND .... -0.3V to +0.3V
REF to AGND .... -0.3V to (V_{DD} + 0.3V)
REFADJ to AGND .... -0.3V to (V_{DD} + 0.3V)
Digital Inputs to DGND .... -0.3V to (V_{DD} + 0.3V)
Digital Outputs to DGND .... -0.3V to (V_{DD} + 0.3V)
CH0–CH7 to AGND .... ±16.5V
Continuous Power Dissipation (T_A = +70°C)
Narrow Plastic DIP (derate 14.29mW/°C above +70°C) 1143mW
Wide SO (derate 12.50mW/°C above +70°C) 1000mW
SSOP (derate 9.52mW/°C above +70°C) 762mW
Narrow Ceramic SB (derate 20.00mW/°C above +70°C) .. 1600mW

Operating Temperature Ranges
MAX197_C_ _ .... 0°C to +70°C
MAX197_E_ _ .... -40°C to +85°C
MAX197_M_ _ .... -55°C to +125°C
Storage Temperature Range .... -65°C to +150°C
Lead Temperature (soldering, 10sec) .... +300°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 in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{DD} = 5V ±5%; unipolar/bipolar range; external reference mode, V_{REF} = 4.096V; 4.7µF at REF pin; external clock, f_{CLK} = 2.0MHz with 50% duty cycle; T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
ACCURACY (Note 1)							
Resolution				12			Bits
Integral Nonlinearity	INL	MAX197A				±1/2	LSB
		MAX197B				±1	
Differential Nonlinearity	DNL					±1	LSB
Offset Error		Unipolar	MAX197A			±3	LSB
			MAX197B			±5	
		Bipolar	MAX197A			±5	
			MAX197B			±10	
Channel-to-Channel Offset Error Matching		Unipolar			±0.1		LSB
		Bipolar			±0.5		
Gain Error (Note 2)		Unipolar	MAX197A			±7	LSB
			MAX197B			±10	
		Bipolar	MAX197A			±7	
			MAX197B			±10	
Gain Temperature Coefficient (Note 2)		Unipolar			3		ppm/°C
		Bipolar			5		
DYNAMIC SPECIFICATIONS (10kHz sine-wave input, ±10Vp-p, f_{SAMPLE} = 100ksps)							
Signal-to-Noise + Distortion Ratio	SINAD		MAX197A	70			dB
			MAX197B	69			
Total Harmonic Distortion	THD	Up to the 5th harmonic			-85	-78	dB
Spurious-Free Dynamic Range	SFDR			80			dB
Channel-to-Channel Crosstalk		50kHz, V_{IN} = ±5V (Note 3)			-86		dB
Aperture Delay		External CLK mode/external acquisition control			15		ns
Aperture Jitter		External CLK mode/external acquisition control			<50		ps
		Internal CLK mode/internal acquisition control (Note 4)			10		ns

ELECTRICAL CHARACTERISTICS (continued)

(V_{DD} = 5V ±5%; unipolar/bipolar range; external reference mode, V_{REF} = 4.096V; 4.7µF at REF pin; external clock, f_{CLK} = 2.0MHz with 50% duty cycle; T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
ANALOG INPUT							
Track/Hold Acquisition Time		f_{CLK} = 2.0MHz				3	µs
Small-Signal Bandwidth		-3dB rolloff	±10V range		5		MHz
			±5V range		2.5		
			0V to 10V range		2.5		
			0V to 5V range		1.25		
Input Voltage Range (See Table 1)		Unipolar		0		10	V
				0		5	
		Bipolar		-10		10	
				-5		5	
Input Current		Unipolar	0V to 10V range			720	µA
			0V to 5V range			360	
		Bipolar	-10V to 10V range	-1200		720	
			-5V to 5V range	-600		360	
Input Dynamic Resistance		Unipolar			21		kΩ
		Bipolar			16		
Input Capacitance		(Note 5)				40	pF
INTERNAL REFERENCE							
REF Output Voltage	V_{REF}	T_A = +25°C		4.076	4.096	4.116	V
REF Output Tempco	TC V_{REF}				40		ppm/°C
Output Short-Circuit Current						30	mA
Load Regulation		0mA to 0.5mA output current (Note 6)				7.5	mV
Capacitive Bypass at REF				4.7			µF
REFADJ Output Voltage				2.465	2.500	2.535	V
REFADJ Adjustment Range		With recommended circuit (Figure 1)			±1.5		%
Buffer Voltage Gain					1.6384		V/V
REFERENCE INPUT (Buffer disabled, reference input applied to REF pin)							
Input Voltage Range				2.4		4.18	V
Input Current		V_{REF} = 4.18V	Normal or STANDBY power-down mode			400	µA
			FULL power-down mode			1	
Input Resistance		Normal or STANDBY power-down mode		10			kΩ
		FULL power-down mode		5			MΩ
REFADJ Threshold for Buffer Disable				V_{DD} - 50mV			V

Multi-Range (±10V, ±5V, +10V, +5V), Single +5V, 12-Bit DAS with 8+4 Bus Interface

ELECTRICAL CHARACTERISTICS (continued)

(V_{DD} = 5V ±5%; unipolar/bipolar range; external reference mode, V_{REF} = 4.096V; 4.7µF at REF pin; external clock, f_{CLK} = 2.0MHz with 50% duty cycle; T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
POWER REQUIREMENTS							
Supply Voltage	V_{DD}			4.75		5.25	V
Supply Current	I_{DD}	Normal mode, bipolar ranges				18	mA
		Normal mode, unipolar ranges			6	10	mA
		Standby power-down (STBYPD)			700	850	µA
		Full power-down mode (FULLPD) (Note 7)				120	µA
Power-Supply Rejection Ratio (Note 8)	PSRR	External reference = 4.096V				±1/2	LSB
		Internal reference			±1/2		LSB
TIMING							
Internal Clock Frequency	f_{CLK}	C_{CLK} = 100pF		1.25	1.56	2.00	MHz
External Clock Frequency Range	f_{CLK}			0.1		2.0	MHz
Acquisition Time	t_{ACQI}	Internal acquisition	External CLK	3.0			µs
			Internal CLK	3.0		5.0	µs
	t_{ACQE}	External acquisition (Note 9)		3.0			µs
		After FULLPD or STBYPD			5		µs
Conversion Time	t_{CONV}	External CLK		6.0			µs
		Internal CLK, C_{CLK} = 100pF		6.0	7.7	10.0	µs
Throughput Rate		External CLK				100	ksps
		Internal CLK, C_{CLK} = 100pF		62			ksps
Bandgap Reference Start-Up Time		Power-up (Note 10)			200		µs
Reference Buffer Settling		To 0.1mV REF bypass capacitor fully discharged	C_{REF} = 4.7µF		8		ms
			C_{REF} = 33µF		60		ms
DIGITAL INPUTS (D7–D0, CLK, $\overline{RD}$, $\overline{WR}$, $\overline{CS}$, HBEN, $\overline{SHDN}$) (Note 11)							
Input High Voltage	V_{INH}			2.4			V
Input Low Voltage	V_{INL}					0.8	V
Input Leakage Current	I_{IN}	V_{IN} = 0V or V_{DD}				±10	µA
Input Capacitance	C_{IN}	(Note 5)				15	pF
DIGITAL OUTPUTS (D7–D4, D3/D11, D2/D10, D1/D9, D0/D8, $\overline{INT}$)							
Output Low Voltage	V_{OL}	V_{DD} = 4.75V, I_{SINK} = 1.6mA				0.4	V
Output High Voltage	V_{OH}	V_{DD} = 4.75V, I_{SOURCE} = 1mA		V_{DD} - 1			V
Three-State Output Capacitance	C_{OUT}	(Note 5)				15	pF

TIMING CHARACTERISTICS

(V_{DD} = 5V ±5%; unipolar/bipolar range; external reference mode, V_{REF} = 4.096V; 4.7µF at REF pin; external clock, f_{CLK} = 2.0MHz with 50% duty cycle; T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
$\overline{CS}$ Pulse Width	t_{CS}		80			ns
$\overline{WR}$ Pulse Width	t_{WR}		80			ns
$\overline{CS}$ to $\overline{WR}$ Setup Time	t_{CSWS}		0			ns
$\overline{CS}$ to $\overline{WR}$ Hold Time	t_{CSWH}		0			ns
$\overline{CS}$ to $\overline{RD}$ Setup Time	t_{CSRS}		0			ns
$\overline{CS}$ to $\overline{RD}$ Hold Time	t_{CSRH}		0			ns
CLK to $\overline{WR}$ Setup Time	t_{CWS}				100	ns
CLK to $\overline{WR}$ Hold Time	t_{CWH}				50	ns
Data Valid to $\overline{WR}$ Setup	t_{DS}		60			ns
Data Valid to $\overline{WR}$ Hold	t_{DH}		0			ns
$\overline{RD}$ Low to Output Data Valid	t_{DO}	Figure 2, C_L = 100pF (Note 12)			120	ns
HBEN High or HBEN Low to Output Valid	t_{DO1}	Figure 2, C_L = 100pF (Note 12)			120	ns
$\overline{RD}$ High to Output Disable	t_{TR}	(Note 13)			70	ns
$\overline{RD}$ Low to $\overline{INT}$ High Delay	t_{INT1}				120	ns

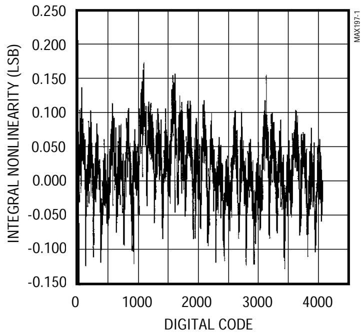
Note 1: Accuracy specifications tested at V_{DD} = 5.0V. Performance at power-supply tolerance limits guaranteed by Power-Supply Rejection test. Tested for the ±10V input range.
Note 2: External reference: V_{REF} = 4.096V, offset error nulled, ideal last code transition = FS - 3/2LSB.
Note 3: Ground "on" channel; sine wave applied to all "off" channels.
Note 4: Maximum full-power input frequency for 1LSB error with 10ns jitter = 3kHz.
Note 5: Guaranteed by design. Not tested.
Note 6: Use static loads only.
Note 7: Tested using internal reference.
Note 8: PSRR measured at full-scale.
Note 9: External acquisition timing: starts at data valid at ACQMOD = low control byte; ends at rising edge of $\overline{WR}$ with ACQMOD = high control byte.
Note 10: Not subject to production testing. Provided for design guidance only.
Note 11: All input control signals specified with t_R = t_F = 5ns from a voltage level of 0.8V to 2.4V.
Note 12: t_{DO} and t_{DO1} are measured with the load circuits of Figure 2 and defined as the time required for an output to cross 0.8V or 2.4V.
Note 13: t_{TR} is defined as the time required for the data lines to change by 0.5V.

Multi-Range (±10V, ±5V, +10V, +5V), Single +5V, 12-Bit DAS with 8+4 Bus Interface

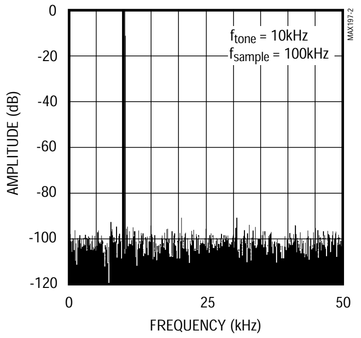
Typical Operating Characteristics

(T_A = +25°C, unless otherwise noted.)

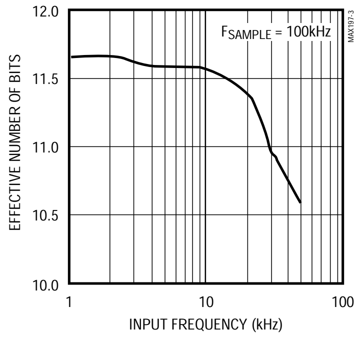
INTEGRAL NONLINEARITY vs. DIGITAL CODE



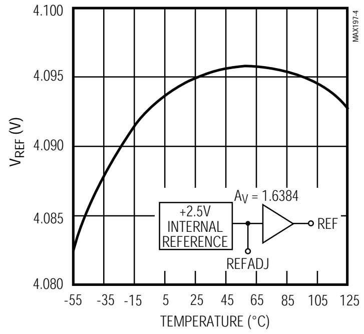
FFT PLOT



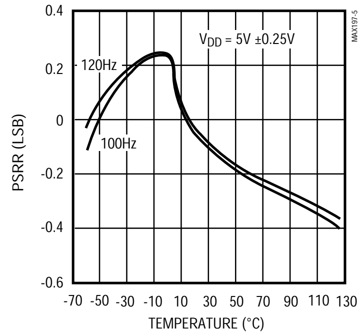
EFFECTIVE NUMBER OF BITS vs. INPUT FREQUENCY



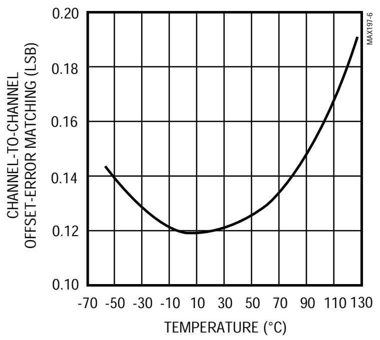
REFERENCE OUTPUT VOLTAGE (V_{REF}) vs. TEMPERATURE



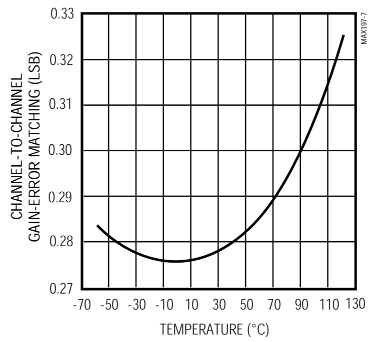
POWER-SUPPLY REJECTION RATIO vs. TEMPERATURE



CHANNEL-TO-CHANNEL OFFSET-ERROR MATCHING vs. TEMPERATURE



CHANNEL-TO-CHANNEL GAIN-ERROR MATCHING vs. TEMPERATURE



Pin Description

PIN	NAME	FUNCTION
1	CLK	Clock Input. In external clock mode, drive CLK with a TTL/CMOS compatible clock. In internal clock mode, place a capacitor from this pin to ground to set the internal clock frequency; f_{CLK} = 1.56MHz typical with C_{CLK} = 100pF.
2	$\overline{CS}$	Chip Select, active low.
3	$\overline{WR}$	When $\overline{CS}$ is low, in the internal acquisition mode, a rising edge on $\overline{WR}$ latches in configuration data and starts an acquisition plus a conversion cycle. When $\overline{CS}$ is low, in the external acquisition mode, the first rising edge on $\overline{WR}$ starts an acquisition and a second rising edge on $\overline{WR}$ ends acquisition and starts a conversion cycle.
4	$\overline{RD}$	If $\overline{CS}$ is low, a falling edge on $\overline{RD}$ will enable a read operation on the data bus.
5	HBEN	Used to multiplex the 12-bit conversion result. When high, the 4 MSBs are multiplexed on the data bus; when low, the 8 LSBs are available on the bus.
6	$\overline{SHDN}$	Shutdown. Puts the device into full power-down (FULLPD) mode when pulled low.
7–10	D7–D4	Three-State Digital I/O
11	D3/D11	Three-State Digital I/O. D3 output (HBEN = low), D11 output (HBEN = high).
12	D2/D10	Three-State Digital I/O. D2 output (HBEN = low), D10 output (HBEN = high).
13	D1/D9	Three-State Digital I/O. D1 output (HBEN = low), D9 output (HBEN = high).
14	D0/D8	Three-State Digital I/O. D0 output (HBEN = low), D8 output (HBEN = high). D0 = LSB.
15	AGND	Analog Ground
16–23	CH0–CH7	Analog Input Channels
24	$\overline{INT}$	$\overline{INT}$ goes low when conversion is complete and output data is ready.
25	REFADJ	Bandgap Voltage-Reference Output/External Adjust Pin. Bypass with a 0.01µF capacitor to AGND. Connect to V_{DD} when using an external reference at the REF pin.
26	REF	Reference Buffer Output/ADC Reference Input. In internal reference mode, the reference buffer provides a 4.096V nominal output, externally adjustable at REFADJ. In external reference mode, disable the internal buffer by pulling REFADJ to V_{DD}.
27	V_{DD}	+5V Supply. Bypass with 0.1µF capacitor to AGND.
28	DGND	Digital Ground

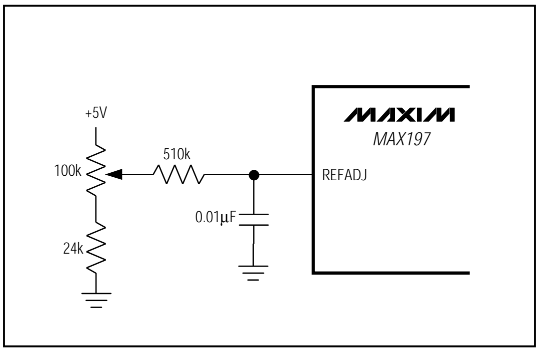


Figure 1. Reference-Adjust Circuit

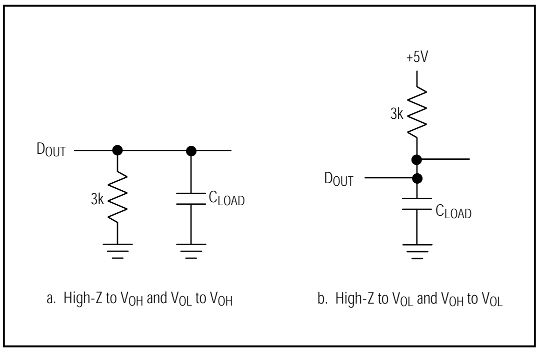


Figure 2. Load Circuits for Enable Time

Multi-Range (±10V, ±5V, +10V, +5V), Single +5V, 12-Bit DAS with 8+4 Bus Interface

Detailed Description

Converter Operation

The MAX197, a multi-range, fault-tolerant ADC, uses successive approximation and internal input track/hold (T/H) circuitry to convert an analog signal to a 12-bit digital output. The parallel-output format provides easy interface to microprocessors (µPs). Figure 3 shows the MAX197 in its simplest operational configuration.

Analog-Input Track/Hold

In the internal acquisition control mode (control bit D5 set to 0), the T/H enters its tracking mode on $\overline{WR}$'s rising edge, and enters its hold mode when the internally timed (6 clock cycles) acquisition interval ends. A low impedance input source, which settles in less than 1.5µs, is required to maintain conversion accuracy at the maximum conversion rate.

In the external acquisition control mode (D5 = 1), the T/H enters its tracking mode on the first $\overline{WR}$ rising edge and enters its hold mode when it detects the second $\overline{WR}$ rising edge with D5 = 0. See the *External Acquisition* section.

Input Bandwidth

The ADC's input tracking circuitry has a 5MHz small-signal bandwidth. When using the internal acquisition mode with an external clock frequency of 2MHz, a 100ksps throughput rate can be achieved. It is possible to digitize high-speed transient events and measure periodic signals with bandwidths exceeding the ADC's sampling rate by using undersampling techniques. To avoid high-frequency signals being aliased into the frequency band of interest, anti-alias filtering is recommended (MAX274/MAX275 continuous-time filters).

Input Range and Protection

Figure 4 shows the equivalent input circuit. With V_{REF} = 4.096V, the MAX197 can be programmed for input ranges of ±10V, ±5V, 0V to 10V, or 0V to 5V by setting the appropriate control bits (D3, D4) in the control byte (see Tables 2 and 3). The full-scale input voltage depends on the voltage at REF (Table 1). When an external reference is applied at REFADJ, the voltage at REF is given by $V_{REF} = 1.6384 \times V_{REFADJ}$ ($2.4V < V_{REF} < 4.18V$).

Table 1. Full Scale and Zero Scale

RANGE (V)	ZERO SCALE (V)	-FULL SCALE	+FULL SCALE
0 to 5	0	—	V_{REF} x 1.2207
0 to 10	0	—	V_{REF} x 2.4414
±5	—	-V_{REF} x 1.2207	V_{REF} x 1.2207
±10	—	-V_{REF} x 2.4414	V_{REF} x 2.4414

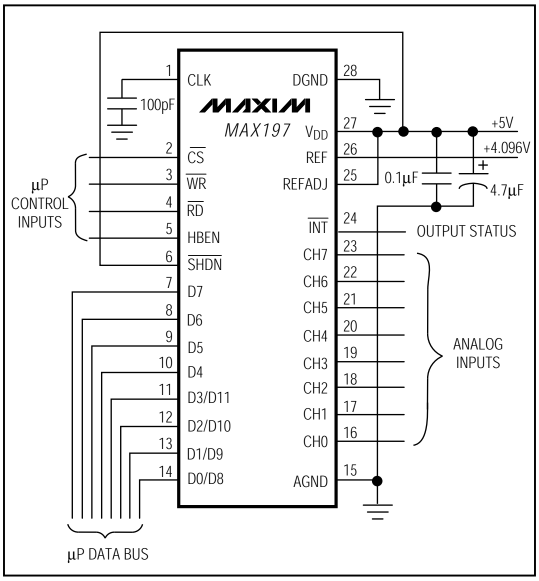


Figure 3. Operational Diagram

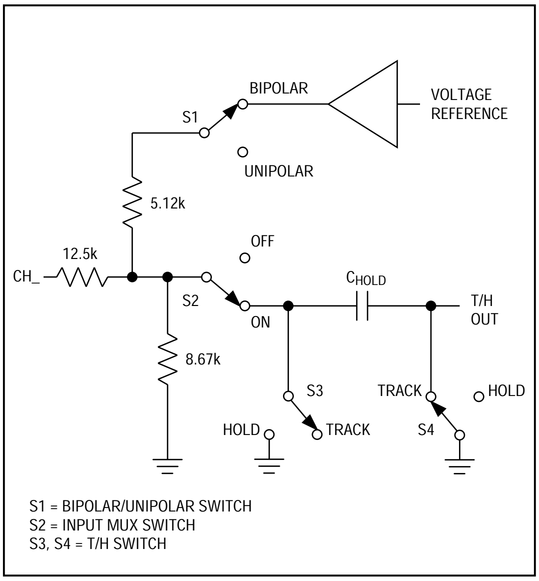


Figure 4. Equivalent Input Circuit

The input channels are overvoltage protected to ±16.5V. This protection is active even if the device is in power-down mode.

Even with V_{DD} = 0V, the input resistive network provides current-limiting that adequately protects the device.

Digital Interface

Input data (control byte) and output data are multiplexed on a three-state parallel interface. This parallel I/O can easily be interfaced with a µP. $\overline{CS}$, $\overline{WR}$, and $\overline{RD}$ control the write and read operations. $\overline{CS}$ is the standard chip-select signal, which enables a µP to address the MAX197 as an I/O port. When high, it disables the $\overline{WR}$ and $\overline{RD}$ inputs and forces the interface into a high-Z state.

Input Format

The control byte is latched into the device, on pins D7–D0, during a write cycle. Table 2 shows the control-byte format.

Output Data Format

The output data format is binary in unipolar mode and twos-complement binary in bipolar mode. When reading the output data, $\overline{CS}$, and $\overline{RD}$ must be low. When HBEN is low, the lower eight bits are read. When HBEN is high, the upper four MSBs are available and the output data bits D4–D7 are either set low (in unipolar mode) or set to the value of the MSB (in bipolar mode) (Table 6).

Table 2. Control-Byte Format

D7 (MSB)	D6	D5	D4	D3	D2	D1	D0 (LSB)
PD1	PD0	ACQMOD	RNG	BIP	A2	A1	A0

BIT	NAME	DESCRIPTION
7, 6	PD1, PD0	These two bits select the clock and power-down modes (Table 4).
5	ACQMOD	0 = internally controlled acquisition (6 clock cycles), 1 = externally controlled acquisition
4	RNG	Selects the full-scale voltage magnitude at the input (Table 3).
3	BIP	Selects unipolar or bipolar conversion mode (Table 3).
2, 1, 0	A2, A1, A0	These are address bits for the input mux to select the "on" channel (Table 5).

Table 3. Range and Polarity Selection

BIP	RNG	INPUT RANGE (V)
0	0	0 to 5
0	1	0 to 10
1	0	±5
1	1	±10

Table 4. Clock and Power-Down Selection

PD1	PD0	DEVICE MODE
0	0	Normal Operation / External Clock Mode
0	1	Normal Operation / Internal Clock Mode
1	0	Standby Power-Down (STBYPD); clock mode is unaffected
1	1	Full Power-Down (FULLPD); clock mode is unaffected

Table 5. Channel Selection

A2	A1	A0	CH0	CH1	CH2	CH3	CH4	CH5	CH6	CH7
0	0	0	*							
0	0	1		*						
0	1	0			*					
0	1	1				*				
1	0	0					*			
1	0	1						*		
1	1	0							*	
1	1	1								*

Table 6. Data-Bus Output

PIN	HBEN = LOW	HBEN = HIGH
D0	B0 (LSB)	B8
D1	B1	B9
D2	B2	B10
D3	B3	B11 (MSB)
D4	B4	B11 (BIP = 1) / 0 (BIP = 0)
D5	B5	B11 (BIP = 1) / 0 (BIP = 0)
D6	B6	B11 (BIP = 1) / 0 (BIP = 0)
D7	B7	B11 (BIP = 1) / 0 (BIP = 0)

How to Start a Conversion

Conversions are initiated with a write operation, which selects the mux channel and configures the MAX197 for either unipolar or bipolar input range. A write pulse ($\overline{WR}$ + $\overline{CS}$) can either start an acquisition interval or initiate a combined acquisition plus conversion. The sampling interval occurs at the end of the acquisition interval. The ACQMOD bit in the input control byte offers two options for acquiring the signal: internal or external. The conversion period lasts for 12 clock cycles in either internal or external clock or acquisition mode.

Writing a new control byte during conversion cycle will abort conversion and start a new acquisition interval.

Internal Acquisition

Select internal acquisition by writing the control byte with the ACQMOD bit cleared (ACQMOD = 0). This causes the write pulse to initiate an acquisition interval whose duration is internally timed. Conversion starts when this six-clock-cycle acquisition interval (3µs with f_{CLK} = 2MHz) ends. See Figure 5.

External Acquisition

Use the external acquisition timing mode for precise control of the sampling aperture and/or independent control of acquisition and conversion times. The user controls acquisition and start-of-conversion with two separate write pulses. The first pulse, written with ACQMOD = 1, starts an acquisition interval of indeterminate length. The second write pulse, written with ACQMOD = 0, terminates acquisition and starts conversion on $\overline{WR}$'s rising edge (Figure 6). However, if the second control byte contains ACQMOD = 1, an indefinite acquisition interval is restarted.

The address bits for the input mux must have the same values on the first and second write pulses. Power-down mode bits (PD0, PD1) can assume new values on the second write pulse (see *Power-Down Mode*).

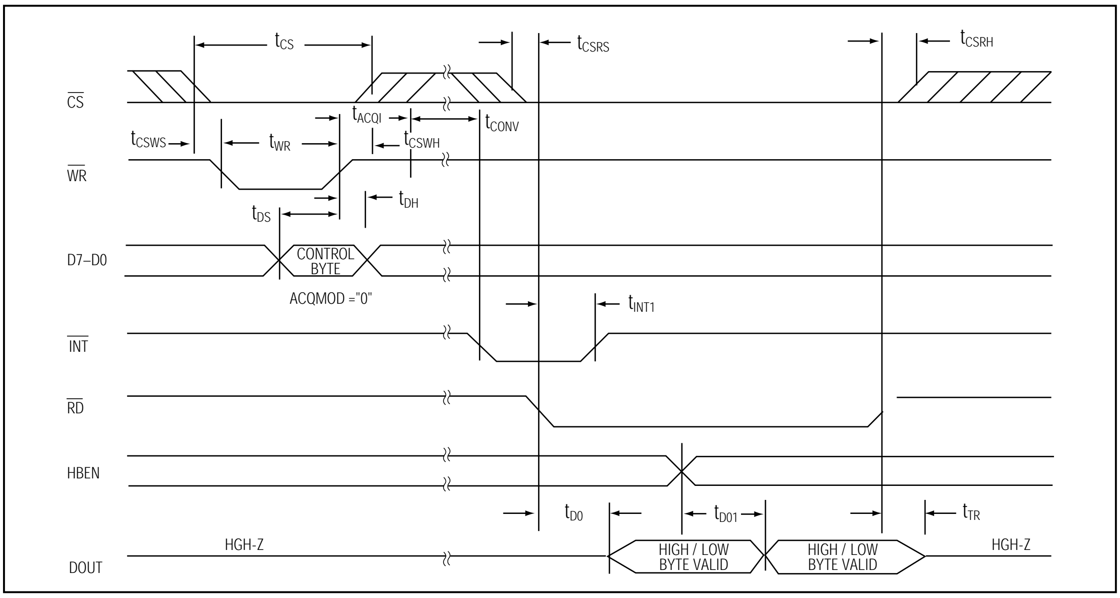


Figure 5. Conversion Timing Using Internal Acquisition Mode

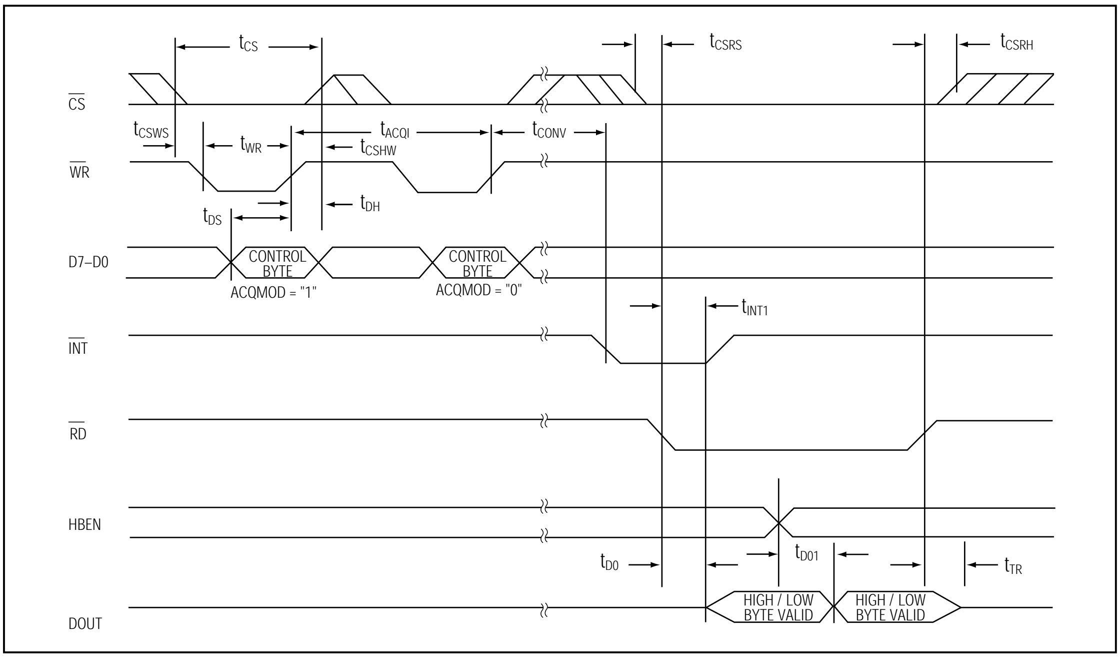


Figure 6. Conversion Timing Using External Acquisition Mode

How to Read a Conversion

A standard interrupt signal, $\overline{INT}$, is provided to allow the device to flag the µP when the conversion has ended and a valid result is available. $\overline{INT}$ goes low when conversion is complete and the output data is ready (Figures 5 and 6). It returns high on the first read cycle or if a new control byte is written.

Clock Modes

The MAX197 operates with either an internal or an external clock. Control bits (D6, D7) select either internal or external clock mode. Once the desired clock mode is selected, changing these bits to program power-down will not affect the clock mode. In each mode, internal or external acquisition can be used. At power-up, external clock mode is selected.

Internal Clock Mode

Select internal clock mode to free the µP from the burden of running the SAR conversion clock. To select this mode, write the control byte with D7 = 0 and D6 = 1. A 100pF capacitor between the CLK pin and ground sets this frequency to 1.56MHz nominal. Figure 7 shows a linear relationship between the internal clock period and the value of the external capacitor used.

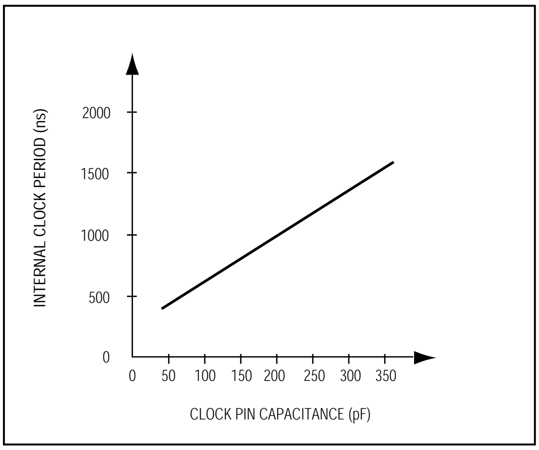


Figure 7. Internal Clock Period vs. Clock Pin Capacitance

External Clock Mode

Select external clock mode by writing the control byte with D7 = 0 and D6 = 0. Figure 8 shows CLK and $\overline{WR}$ timing relationships in internal and external acquisition modes, with an external clock. A 100kHz to 2.0MHz external clock with 45% to 55% duty cycle is required for proper operation. Operating at clock frequencies lower than 100kHz will cause a voltage droop across the hold capacitor, and subsequently degrade performance.

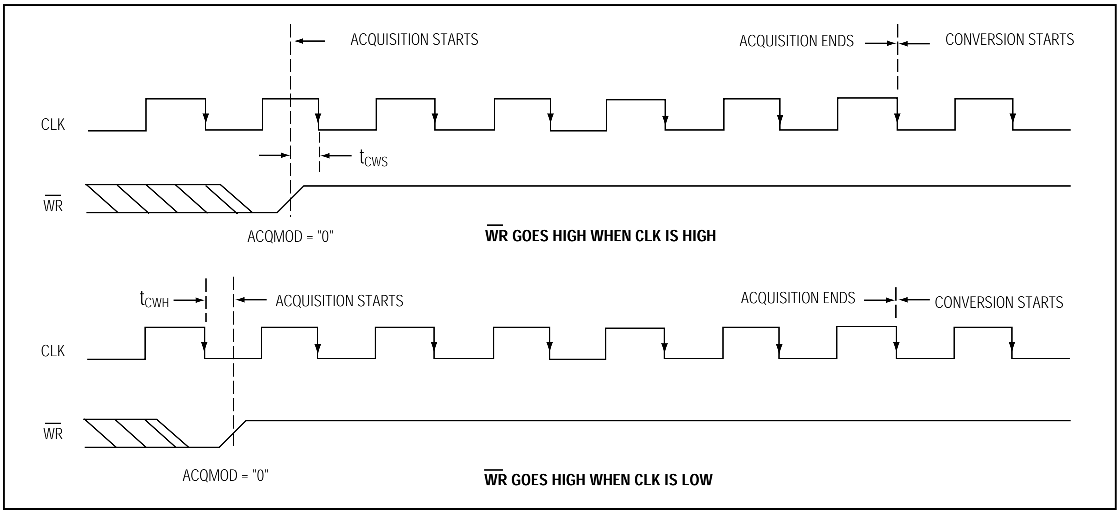


Figure 8a. External Clock and $\overline{WR}$ Timing (Internal Acquisition Mode)

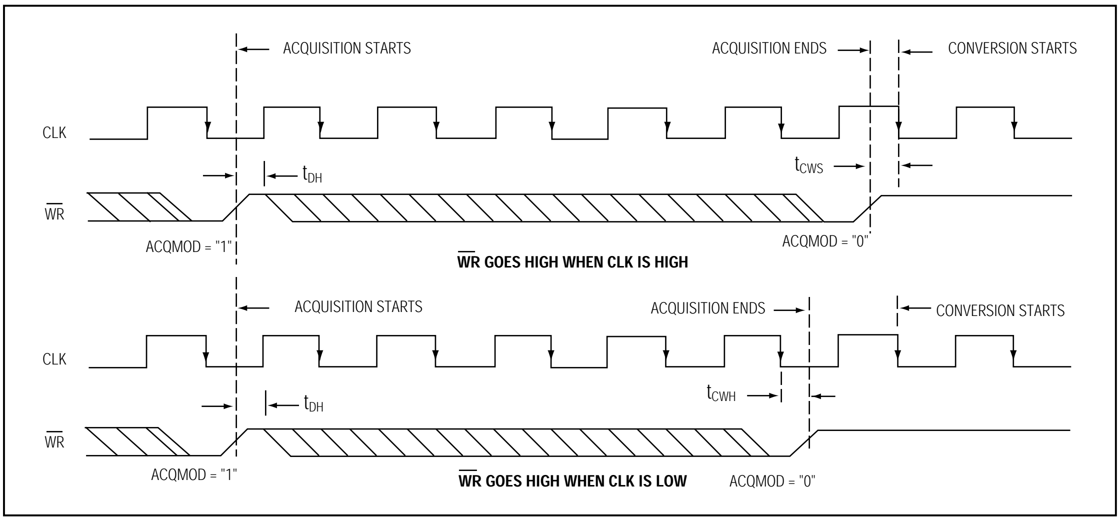


Figure 8b. External Clock and $\overline{WR}$ Timing (External Acquisition Mode)

Applications Information

Power-On Reset

At power-up, the internal power-supply circuitry sets $\overline{INT}$ high and puts the device in normal operation/external clock mode. This state is selected to keep the internal clock from loading the external clock driver when the part is used in external clock mode.

Internal or External Reference

The MAX197 can operate with either an internal or an external reference. An external reference can be connected to either the REF pin or to the REFADJ pin (Figure 9).

To use the REF input directly, disable the internal buffer by tying REFADJ to V_{DD}. Using the REFADJ input eliminates the need to buffer the reference externally. When the reference is applied at REFADJ, bypass REFADJ with a 0.01µF capacitor to AGND.

The REFADJ internal buffer gain is trimmed to 1.6384 to provide 4.096V at the REF pin from a 2.5V reference.

Internal Reference

The internally trimmed 2.50V reference is gained through the REFADJ buffer to provide 4.096V at REF. Bypass the REF pin with a 4.7µF capacitor to AGND and the REFADJ pin with a 0.01µF capacitor to AGND. The internal reference voltage is adjustable to ±1.5% (±65 LSBs) with the reference-adjust circuit of Figure 1.

External Reference

At REF and REFADJ, the input impedance is a minimum of 10kΩ for DC currents. During conversions, an external reference at REF must be able to deliver 400µA DC load currents, and must have an output impedance of 10Ω or less. If the reference has higher input impedance or is noisy, bypass it close to the REF pin with a 4.7µF capacitor to AGND.

With an external reference voltage of less than 4.096V at the REF pin or less than 2.5V at the REFADJ pin, the increase in the ratio of the RMS noise to the LSB value (FS / 4096) results in performance degradation (loss of effective bits).

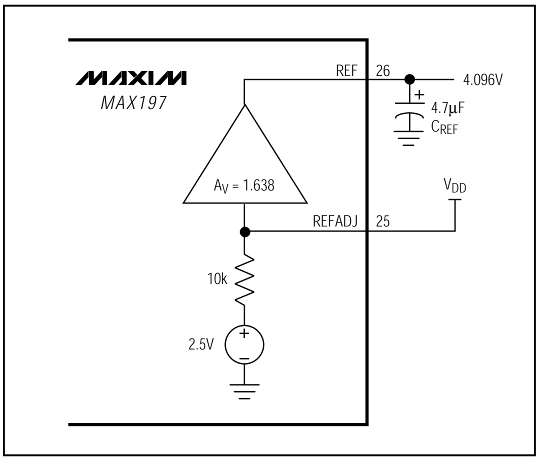


Figure 9b. External Reference, Reference at REF

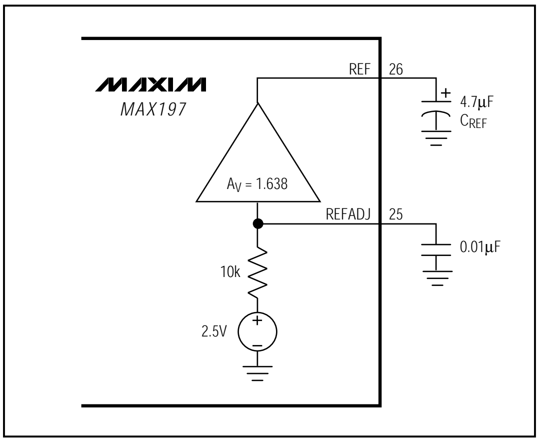


Figure 9a. Internal Reference

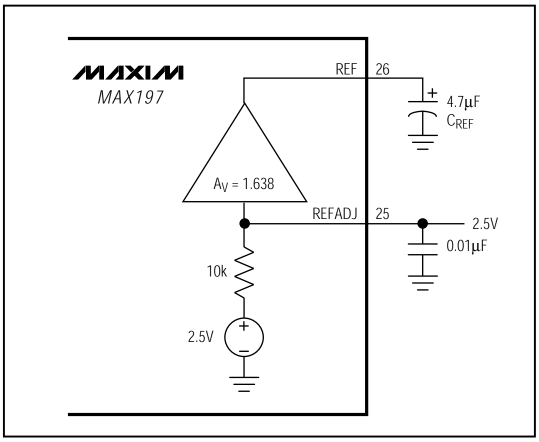


Figure 9c. External Reference, Reference at REFADJ

Power-Down Mode

To save power, you can put the converter into low-current shutdown mode between conversions. Two programmable power-down modes are available, in addition to a hardware shutdown. Select STBYPD or FULLPD by programming PD0 and PD1 in the input control byte. When software power-down is asserted, it becomes effective only after the end of conversion. In all power-down modes, the interface remains active and conversion results may be read. Input overvoltage protection is active in all power-down modes. The device returns to normal operation on the first $\overline{WR}$ falling edge during write operation.

For hardware-controlled (FULLPD) power-down, pull the $\overline{SHDN}$ pin low. When hardware shutdown is asserted, it becomes effective immediately and the conversion is aborted.

Choosing Power-Down Modes

The bandgap reference and reference buffer remain active in STBYPD mode, maintaining the voltage on the 4.7µF capacitor at the REF pin. This is a "DC" state that does not degrade after power-down of any duration. Therefore, you can use any sampling rate with this mode, without regard to start-up delays.

However, in FULLPD mode, only the bandgap reference is active. Connect a 33µF capacitor between REF and AGND to maintain the reference voltage between conversion and to reduce transients when the buffer is enabled and disabled. Throughput rates down to 1ksps can be achieved without allotting extra acquisition time for reference recovery prior to conversion. This allows conversion to begin immediately after power-down ends. If the discharge of the REF capacitor during FULLPD exceeds the desired limits for accuracy (less than a fraction of an LSB), run a STBYPD power-down cycle prior to starting conversions. Take into account that the reference buffer recharges the bypass capacitor at an 80mV/ms slew rate and add 50µs for settling time. Throughput rates of 10ksps offer typical supply currents of 470µA, using the recommended 33µF capacitor value.

Auto-Shutdown

Selecting STBYPD on every conversion automatically shuts the MAX197 down after each conversion without requiring any start-up time on the next conversion.

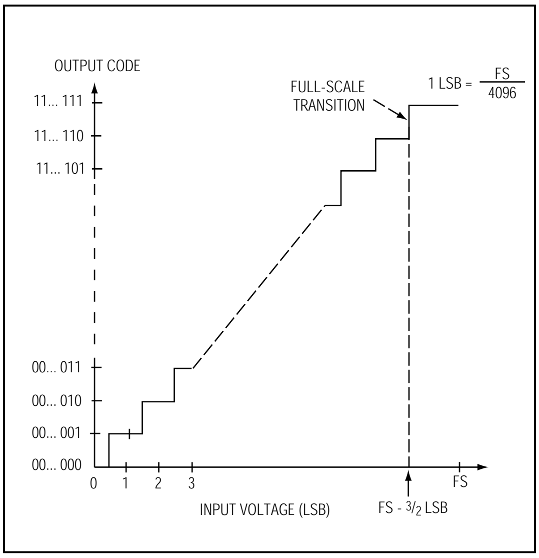


Figure 10. Unipolar Transfer Function

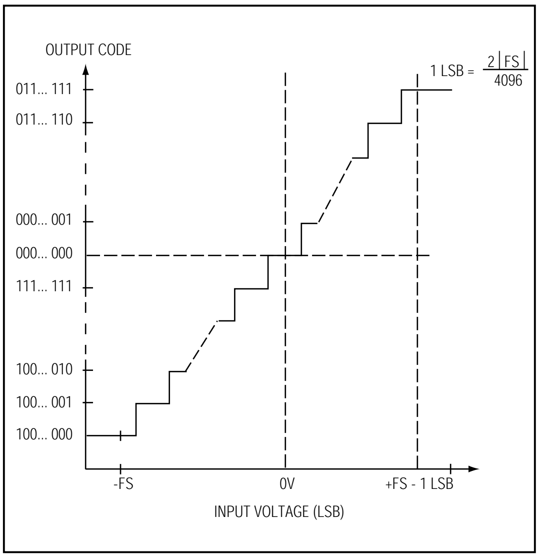


Figure 11. Bipolar Transfer Function

Transfer Function

Output data coding for the MAX197 is binary in unipolar mode with 1LSB = (FS / 4096) and twos-complement binary in bipolar mode with 1LSB = ((2 x $|FS|$) / 4096). Code transitions occur halfway between successive-integer LSB values. Figures 10 and 11 show the input/output (I/O) transfer functions for unipolar and bipolar operations, respectively. For full-scale (FS) values, refer to Table 1.

Layout, Grounding, and Bypassing

Careful printed circuit board layout is essential for best system performance. For best performance, use a ground plane. To reduce crosstalk and noise injection, keep analog and digital signals separate. Digital ground lines can run between digital signal lines to minimize interference. Connect analog grounds and DGND in a star configuration to AGND. For noise-free operation, ensure the ground return from AGND to the supply ground is low impedance and as short as possible. Connect the logic grounds directly to the supply ground. Bypass V_{DD} with 0.1µF and 4.7µF capacitors to AGND to minimize high- and low-frequency fluctuations. If the supply is excessively noisy, connect a 5Ω resistor between the supply and V_{DD}, as shown in Figure 12.

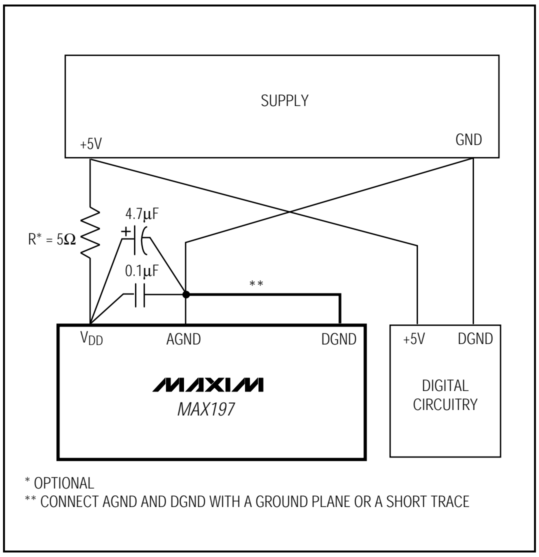


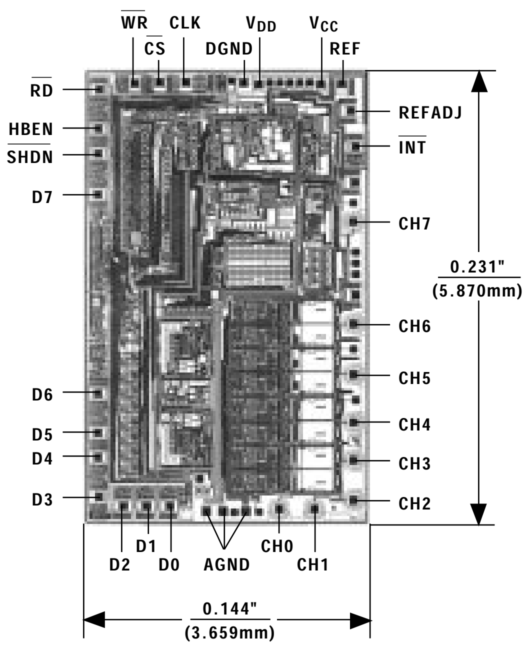
Figure 12. Power-Supply Grounding Connection

Ordering Information (continued)

PART	TEMP. RANGE	PIN-PACKAGE
MAX197AENI	-40°C to +85°C	28 Narrow Plastic DIP
MAX197BENI	-40°C to +85°C	28 Narrow Plastic DIP
MAX197AEWI	-40°C to +85°C	28 Wide SO
MAX197BEWI	-40°C to +85°C	28 Wide SO
MAX197AEAI	-40°C to +85°C	28 SSOP
MAX197BEAI	-40°C to +85°C	28 SSOP
MAX197AMYI	-55°C to +125°C	28 Narrow Ceramic SB**
MAX197BMYI	-55°C to +125°C	28 Narrow Ceramic SB**

*** Contact factory for availability and processing to MIL-STD-883.*

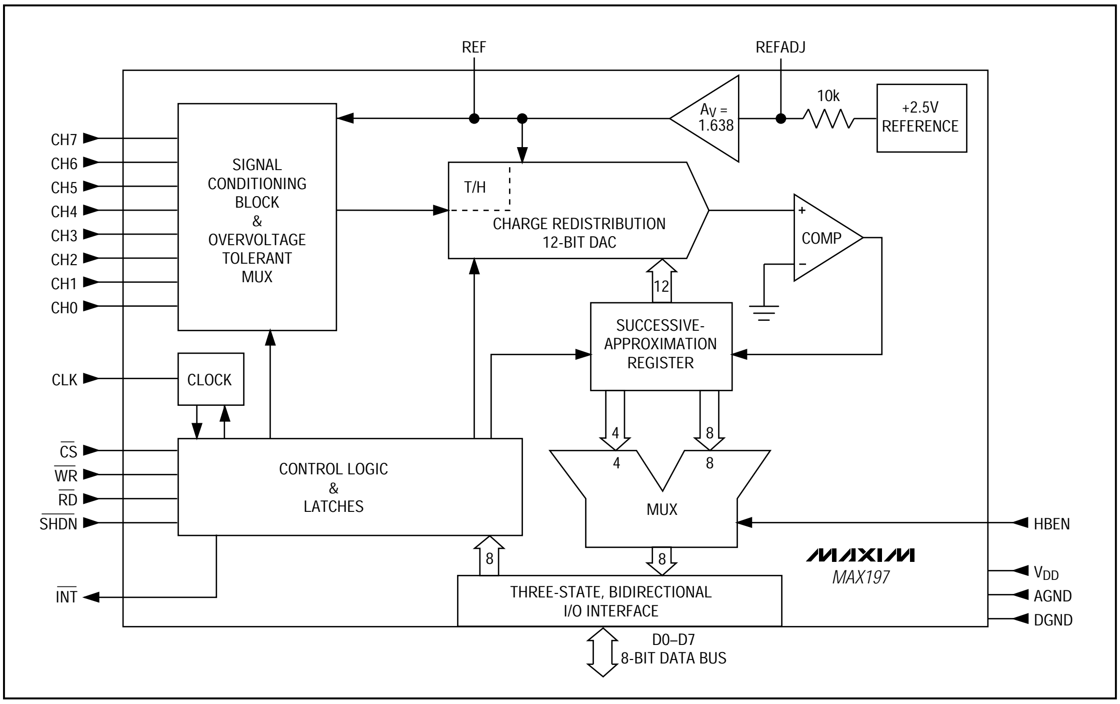
Chip Topography



TRANSISTOR COUNT: 2956
SUBSTRATE CONNECTED TO GND

Multi-Range (±10V, ±5V, +10V, +5V), Single +5V, 12-Bit DAS with 8+4 Bus Interface

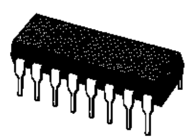
Functional Diagram



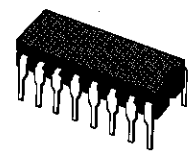
M54HC279
M74HC279

QUAD $\overline{S}$ - $\overline{R}$ LATCH

- HIGH SPEED
  t_{PD} = 12 ns (TYP.) AT V_{CC} = 5 V
- LOW POWER DISSIPATION
  I_{CC} = 2 μA (MAX.) AT T_A = 25 °C
- HIGH NOISE IMMUNITY
  V_{NIH} = V_{NIL} = 28 % V_{CC} (MIN.)
- OUTPUT DRIVE CAPABILITY
  10 LSTTL LOADS
- SYMMETRICAL OUTPUT IMPEDANCE
  $|I_{OH}|$ = I_{OL} = 4 mA (MIN.)
- BALANCED PROPAGATION DELAYS
  $t_{PLH} = t_{PHL}$
- WIDE OPERATING VOLTAGE RANGE
  V_{CC} (OPR) = 2 V TO 6 V
- PIN AND FUNCTION COMPATIBLE
  WITH 54/74LS279

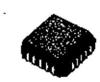


B1R
(Plastic Package)



F1R
(Ceramic Package)

M1R
(Micro Package)

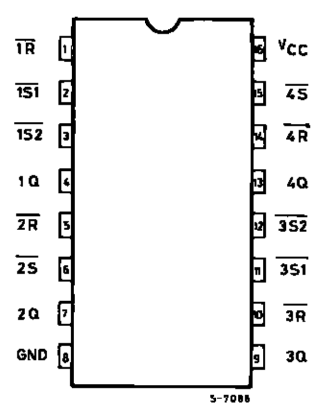


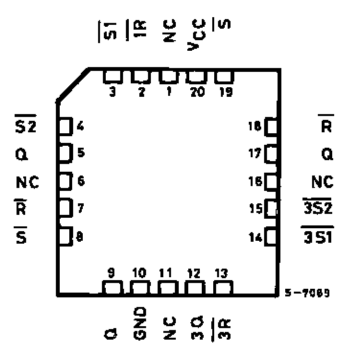
C1R
(Chip Carrier)

ORDER CODES :

M54HC279F1R	M74HC279M1R
M74HC279B1R	M74HC279C1R

PIN CONNECTIONS (top view)





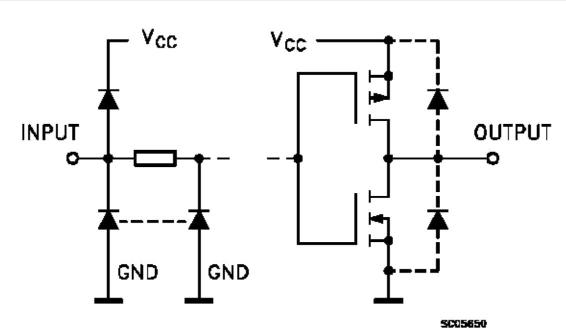
NC =
No Internal
Connection

DESCRIPTION

The M54/74HC279 is a high speed CMOS QUAD $\overline{S}$ - $\overline{R}$ LATCH fabricated in silicon gate C^2MOS technology. It has the same high speed performance of LSTTL combined with true CMOS low power consumption.

All inputs are equipped with protection circuits against static discharge and transient excess voltage.

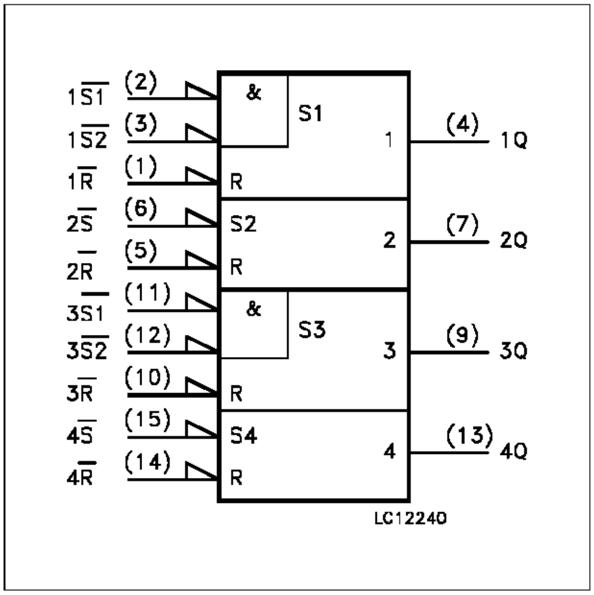
INPUT AND OUTPUT EQUIVALENT CIRCUIT



PIN DESCRIPTION

PIN No	SYMBOL	NAME AND FUNCTION
1, 5, 10. 14	$1\overline{R}$ to $4\overline{R}$	Reset Inputs (Active LOW)
2, 3, 6, 11, 12, 15	$\overline{1S1}$, $\overline{1S2}$, $\overline{2S}$, $\overline{3S1}$, $\overline{3S2}$, $\overline{4S}$	Set Inputs (Active LOW)
4, 7, 9, 13	1Q to 4Q	Outputs
8	GND	Ground (0V)
16	V_{CC}	Positive Supply Voltage

IEC LOGIC SYMBOL

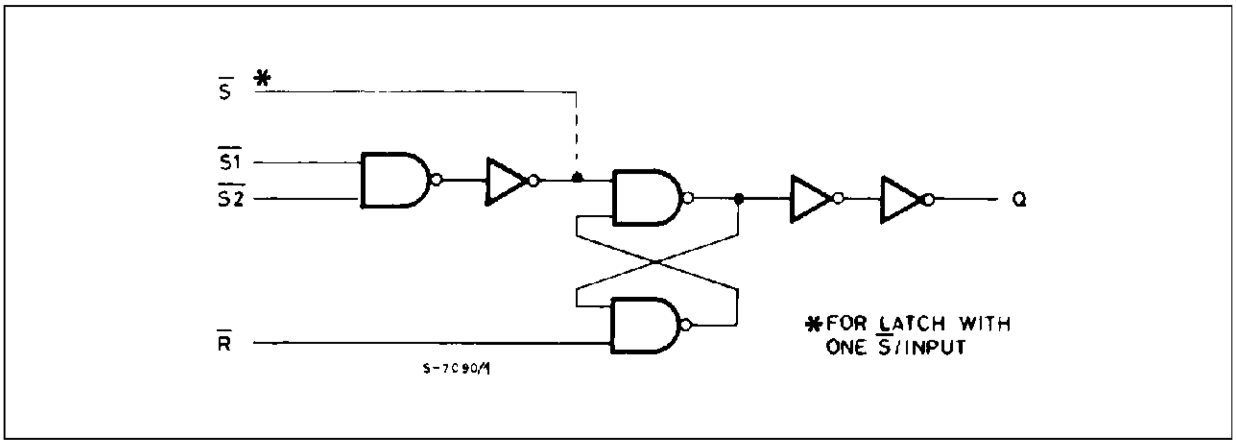


TRUTH TABLE

$\overline{S}$ #	$\overline{R}$	Q
H	H	Q0
L	H	H
H	L	L
L	L	H

NOTE: Q0 = THE LEVEL OF Q BEFORE THE INDICRTED INPUT CONDITION WAS ESTABLISHED.
\# FOR LATCHES WITH DOUBLE S INPUT:
H = BOTH S INPUTS HIGH
L = ONE OF BOTH INPUTS LOW

LOGIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_{CC}	Supply Voltage	-0.5 to +7	V
V_I	DC Input Voltage	-0.5 to V_{CC} + 0.5	V
V_O	DC Output Voltage	-0.5 to V_{CC} + 0.5	V
I_{IK}	DC Input Diode Current	± 20	mA
I_{OK}	DC Output Diode Current	± 20	mA
I_O	DC Output Source Sink Current Per Output Pin	± 25	mA
I_{CC} or I_{GND}	DC V_{CC} or Ground Current	± 50	mA
P_D	Power Dissipation	500 (*)	mW
T_{stg}	Storage Temperature	-65 to +150	^oC
T_L	Lead Temperature (10 sec)	300	^oC

Absolute Maximum Ratings are those values beyond which damage to the device may occur. Functional operation under these condition is not implied.
(*) 500 mW: ≅ 65 ^oC derate to 300 mW by 10mW/^oC: 65 ^oC to 85 ^oC

RECOMMENDED OPERATING CONDITIONS

Symbol	Parameter		Value	Unit
V_{CC}	Supply Voltage		2 to 6	V
V_I	Input Voltage		0 to V_{CC}	V
V_O	Output Voltage		0 to V_{CC}	V
T_{op}	Operating Temperature: **M54HC** Series **M74HC** Series		-55 to +125 -40 to +85	^oC ^oC
t_r, t_f	Input Rise and Fall Time	V_{CC} = 2 V	0 to 1000	ns
		V_{CC} = 4.5 V	0 to 500	
		V_{CC} = 6 V	0 to 400	

DC SPECIFICATIONS

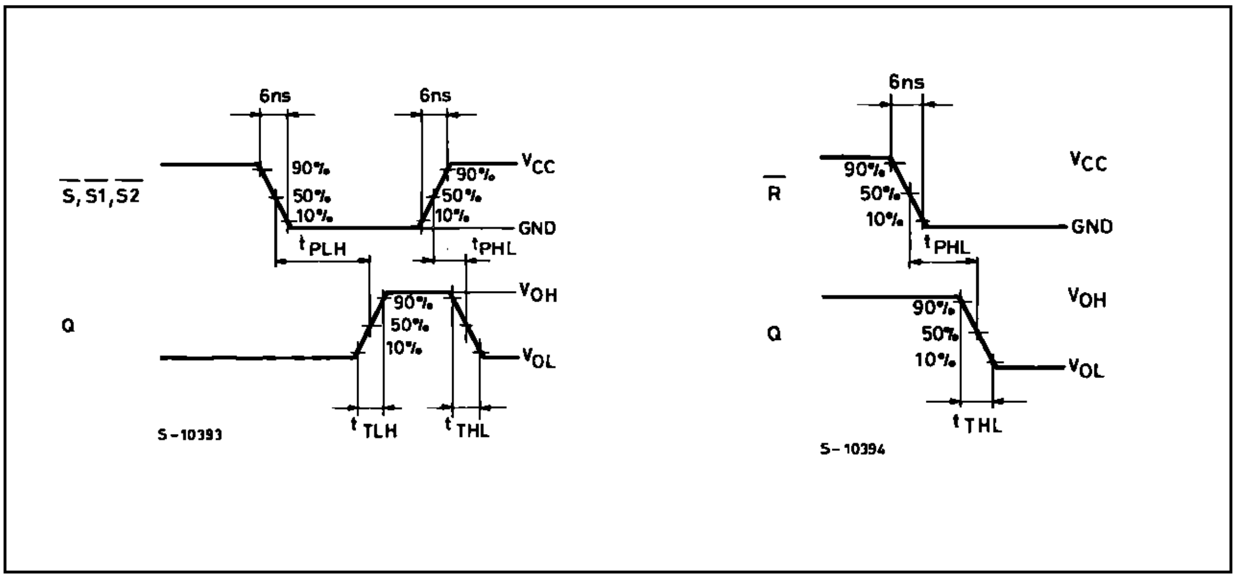
Symbol	Parameter	Test Conditions			Value							Unit
		V_{CC} (V)			T_A = 25 ^oC 54HC and 74HC			-40 to 85 ^oC 74HC		-55 to 125 ^oC 54HC		
					Min.	Typ.	Max.	Min.	Max.	Min.	Max.	
V_{IH}	High Level Input Voltage	2.0			1.5			1.5		1.5		V
		4.5			3.15			3.15		3.15		
		6.0			4.2			4.2		4.2		
V_{IL}	Low Level Input Voltage	2.0					0.5		0.5		0.5	V
		4.5					1.35		1.35		1.35	
		6.0					1.8		1.8		1.8	
V_{OH}	High Level Output Voltage	2.0	V_I = V_{IH} or V_{IL}	I_O=-20 μA	1.9	2.0		1.9		1.9		V
		4.5			4.4	4.5		4.4		4.4		
		6.0			5.9	6.0		5.9		5.9		
		4.5		I_O=-4.0 mA	4.18	4.31		4.13		4.10		
		6.0		I_O=-5.2 mA	5.68	5.8		5.63		5.60		
V_{OL}	Low Level Output Voltage	2.0	V_I = V_{IH} or V_{IL}	I_O= 20 μA		0.0	0.1		0.1		0.1	V
		4.5				0.0	0.1		0.1		0.1	
		6.0				0.0	0.1		0.1		0.1	
		4.5		I_O= 4.0 mA		0.17	0.26		0.33		0.40	
		6.0		I_O= 5.2 mA		0.18	0.26		0.33		0.40	
I_I	Input Leakage Current	6.0	V_I = V_{CC} or GND				±0.1		±1		±1	μA
I_{CC}	Quiescent Supply Current	6.0	V_I = V_{CC} or GND				2		20		40	μA

AC ELECTRICAL CHARACTERISTICS (C_L = 50 pF, Input t_r = t_f = 6 ns)

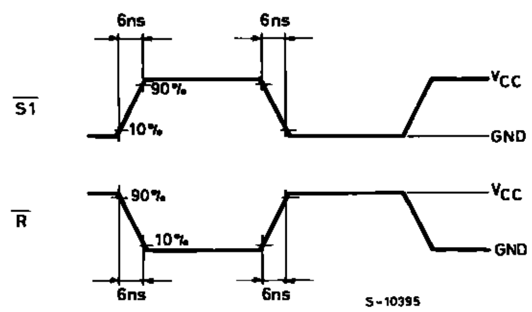
Symbol	Parameter	Test Conditions		Value							Unit
		V_{CC} (V)		T_A = 25 °C 54HC and 74HC			-40 to 85 °C 74HC		-55 to 125 °C 54HC		
				Min.	Typ.	Max.	Min.	Max.	Min.	Max.	
t_{TLH} t_{THL}	Output Transition Time	2.0			30	75		95		110	ns
		4.5			8	15		19		22	
		6.0			7	13		16		19	
t_{PLH} t_{PHL}	Propagation Delay Time (S1, S2 - Q)	2.0			45	130		165		195	ns
		4.5			15	26		33		39	
		6.0			13	22		28		33	
t_{PLH} t_{PHL}	Propagation Delay Time (S - Q)	2.0			38	100		125		150	ns
		4.5			12	20		25		30	
		6.0			10	17		21		26	
t_{PHL}	Propagation Delay Time ($\overline{R}$ - Q)	2.0			42	120		150		180	ns
		4.5			14	24		30		36	
		6.0			12	20		26		31	
C_{IN}	Input Capacitance				5	10		10		10	pF
C_{PD} (*)	Power Dissipation Capacitance				18						pF

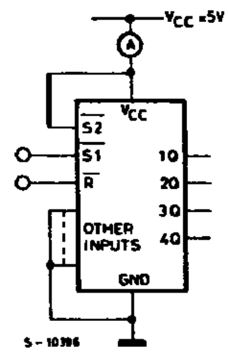
(*) C_{PD} is defined as the value of the IC's internal equivalent capacitance which is calculated from the operating current consumption without load. (Refer to Test Circuit). Average operting current can be obtained by the following equation. $I_{CC}(opr) = C_{PD} \bullet V_{CC} \bullet f_{IN} + I_{CC}$

SWITCHING CHARACTERISTICS TEST WAVEFORM



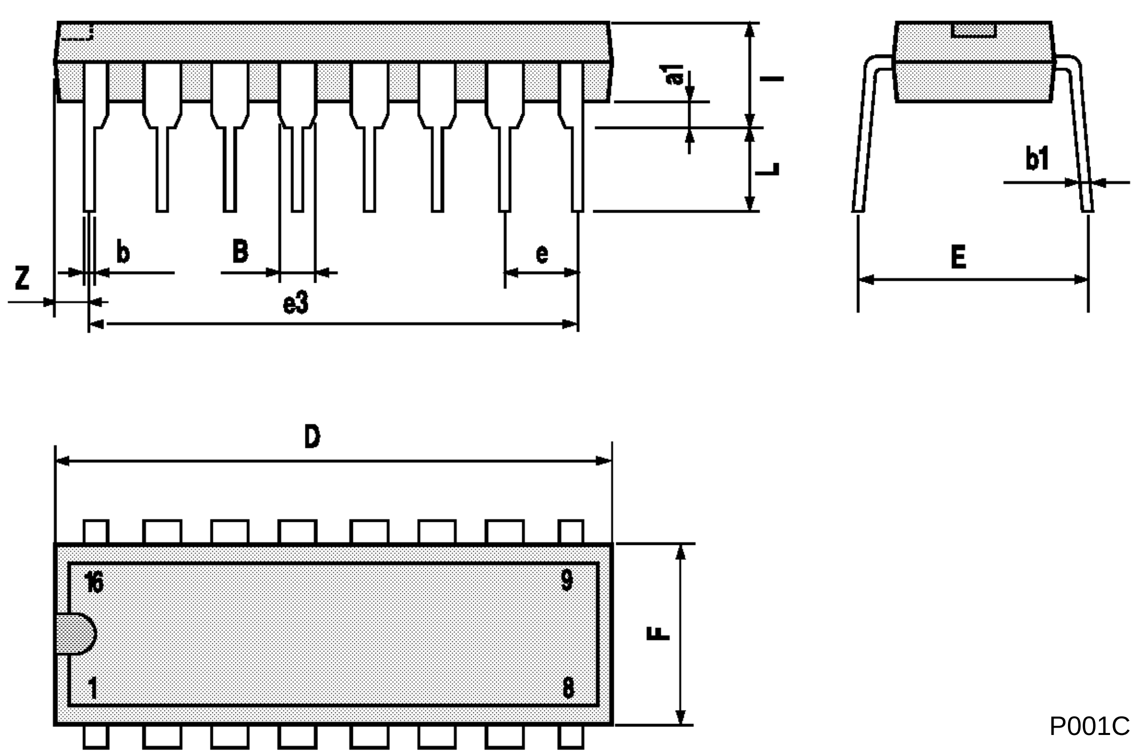
TEST CIRCUIT I_{CC} (Opr.)





Plastic DIP16 (0.25) MECHANICAL DATA

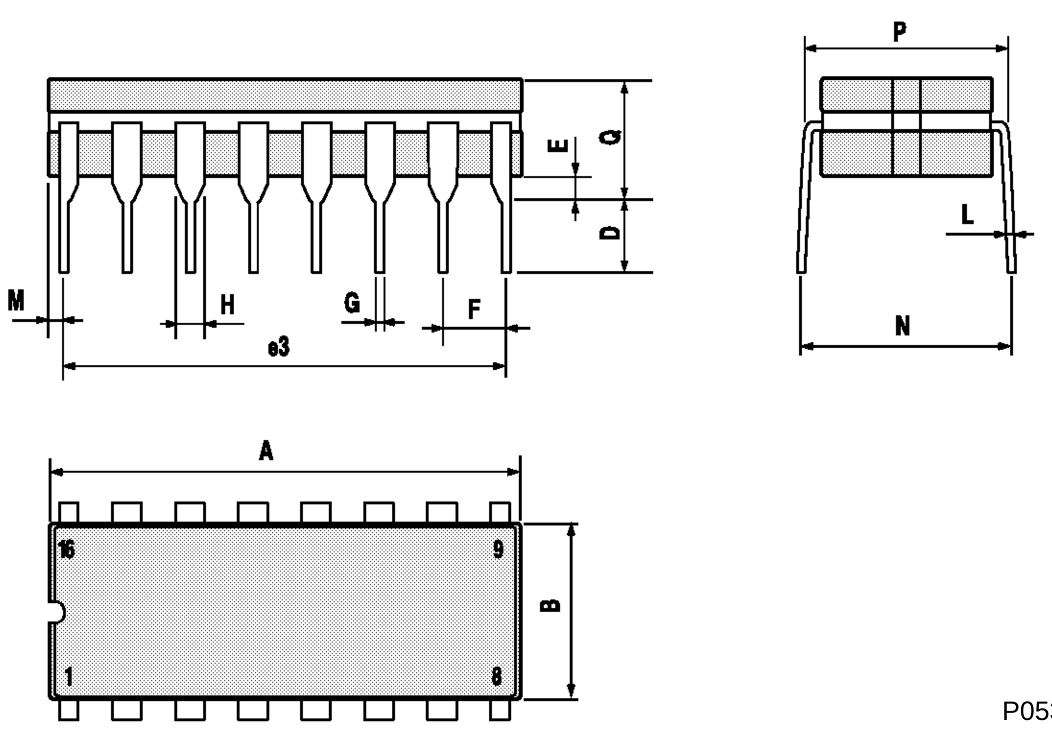
DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
a1	0.51			0.020		
B	0.77		1.65	0.030		0.065
b		0.5			0.020	
b1		0.25			0.010	
D			20			0.787
E		8.5			0.335	
e		2.54			0.100	
e3		17.78			0.700	
F			7.1			0.280
I			5.1			0.201
L		3.3			0.130	
Z			1.27			0.050



P001C

Ceramic DIP16/1 MECHANICAL DATA

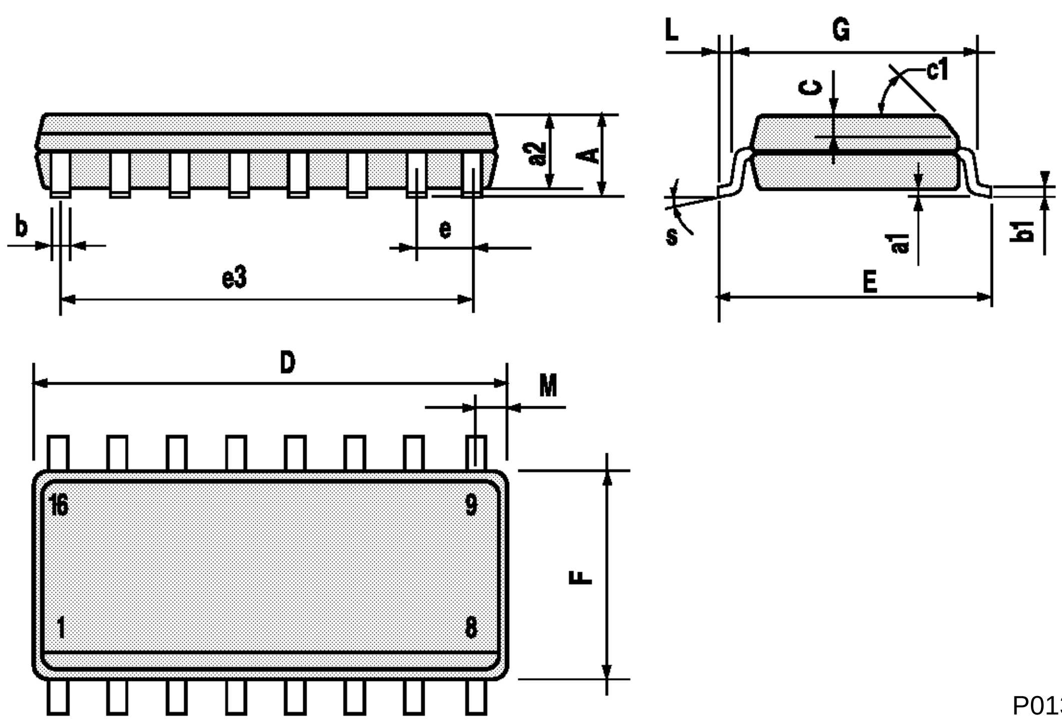
DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			20			0.787
B			7			0.276
D		3.3			0.130	
E	0.38			0.015		
e3		17.78			0.700	
F	2.29		2.79	0.090		0.110
G	0.4		0.55	0.016		0.022
H	1.17		1.52	0.046		0.060
L	0.22		0.31	0.009		0.012
M	0.51		1.27	0.020		0.050
N			10.3			0.406
P	7.8		8.05	0.307		0.317
Q			5.08			0.200



P053D

SO16 (Narrow) MECHANICAL DATA

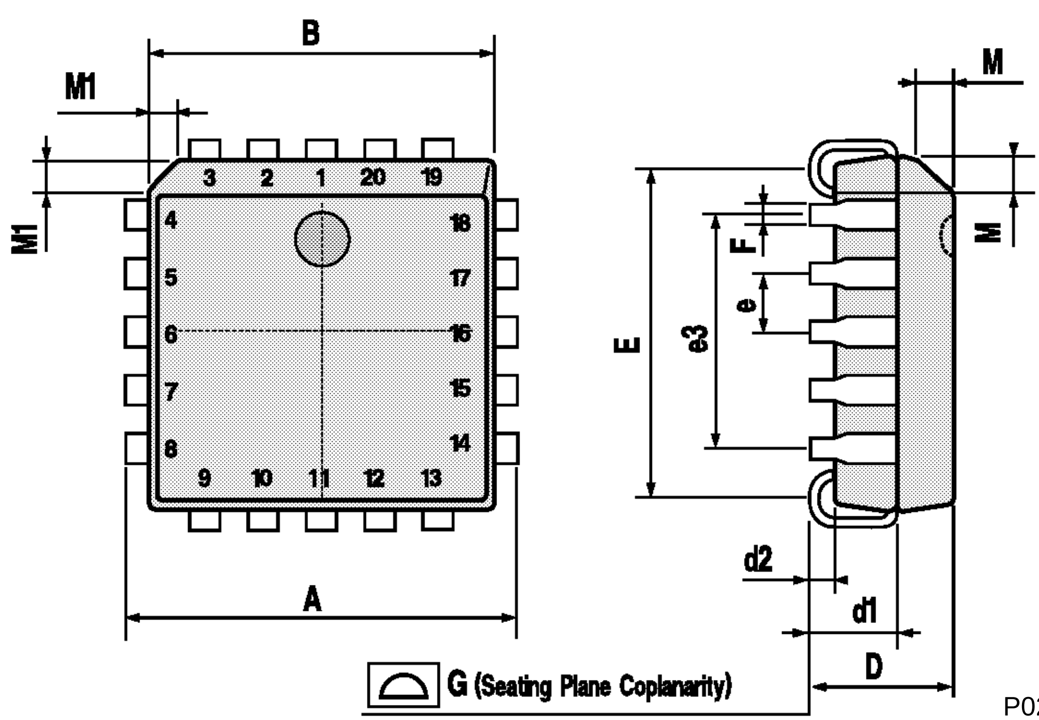
DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			1.75			0.068
a1	0.1		0.2	0.004		0.007
a2			1.65			0.064
b	0.35		0.46	0.013		0.018
b1	0.19		0.25	0.007		0.010
C		0.5			0.019	
c1	45° (typ.)					
D	9.8		10	0.385		0.393
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		8.89			0.350	
F	3.8		4.0	0.149		0.157
G	4.6		5.3	0.181		0.208
L	0.5		1.27	0.019		0.050
M			0.62			0.024
S	8° (max.)					



P013H

PLCC20 MECHANICAL DATA

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A	9.78		10.03	0.385		0.395
B	8.89		9.04	0.350		0.356
D	4.2		4.57	0.165		0.180
d1		2.54			0.100	
d2		0.56			0.022	
E	7.37		8.38	0.290		0.330
e		1.27			0.050	
e3		5.08			0.200	
F		0.38			0.015	
G			0.101			0.004
M		1.27			0.050	
M1		1.14			0.045	



P027A

FAIRCHILD
SEMICONDUCTOR™

September 1983
Revised December 1999

MM74HC08
Quad 2-Input AND Gate

General Description

The MM74HC08 AND gates utilize advanced silicon-gate CMOS technology to achieve operating speeds similar to LS-TTL gates with the low power consumption of standard CMOS integrated circuits. The HC08 has buffered outputs, providing high noise immunity and the ability to drive 10 LS-TTL loads. The 74HC logic family is functionally as well as pin-out compatible with the standard 74LS logic family. All inputs are protected from damage due to static discharge by internal diode clamps to V_{CC} and ground.

Features

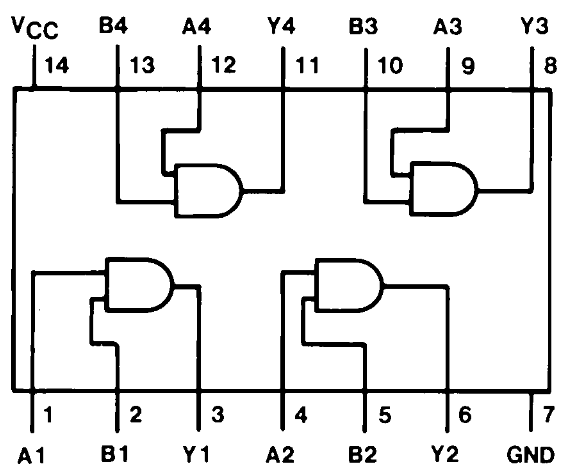
- Typical propagation delay: 7 ns (t_{PHL}), 12 ns (t_{PLH})
- Fanout of 10 LS-TTL loads
- Quiescent power consumption: 2 μA maximum at room temperature
- Low input current: 1 μA maximum

Ordering Code:

Order Number	Package Number	Package Description
MM74HC08M	M14A	14-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-120, 0.150" Wide
MM74HC08SJ	M14D	14-Lead Small Outline Package (SOP), EIAJ TYPE II, 5.3mm Wide
MM74HC08MTC	MTC14	14-Lead Thin Shrink Small Outline Package (TSSOP), JEDEC MO-153, 4.4mm Wide
MM74HC08N	N14A	14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300" Wide

Devices also available in Tape and Reel. Specify by appending the suffix letter "X" to the ordering code. (Tape and Reel not available in N14A)

Connection Diagram



Top View

Absolute Maximum Ratings (Note 1)

(Note 2)

Supply Voltage (V_{CC})	−0.5 to +7.0V
DC Input Voltage (V_{IN})	−1.5 to V_{CC} +1.5V
DC Output Voltage (V_{OUT})	−0.5 to V_{CC} +0.5V
Clamp Diode Current (I_{IK}, I_{OK})	±20 mA
DC Output Current, per pin (I_{OUT})	±25 mA
DC V_{CC} or GND Current, per pin (I_{CC})	±50 mA
Storage Temperature Range (T_{STG})	−65°C to +150°C
Power Dissipation (P_D)	
(Note 3)	600 mW
S.O. Package only	500 mW
Lead Temperature (T_L)	
(Soldering 10 seconds)	260°C

Recommended Operating Conditions

	Min	Max	Units
Supply Voltage (V_{CC})	2	6	V
DC Input or Output Voltage (V_{IN}, V_{OUT})	0	V_{CC}	V
Operating Temperature Range (T_A)	−40	+85	°C
Input Rise or Fall Times			
(t_r, t_f) V_{CC} = 2.0V		1000	ns
V_{CC} = 4.5V		500	ns
V_{CC} = 6.0V		400	ns

Note 1: Absolute Maximum Ratings are those values beyond which damage to the device may occur.

Note 2: Unless otherwise specified all voltages are referenced to ground.

Note 3: Power Dissipation temperature derating — plastic "N" package: −12 mW/°C from 65°C to 85°C.

DC Electrical Characteristics (Note 4)

Symbol	Parameter	Conditions	V_{CC}	T_A = 25°C		T_A = −40 to 85°C	T_A = −40 to 125°C	Units
				Typ	Guaranteed Limits			
V_{IH}	Minimum HIGH Level Input Voltage		2.0V		1.5	1.5	1.5	V
			4.5V		3.15	3.15	3.15	V
			6.0V		4.2	4.2	4.2	V
V_{IL}	Maximum LOW Level Input Voltage		2.0V		0.5	0.5	0.5	V
			4.5V		1.35	1.35	1.35	V
			6.0V		1.8	1.8	1.8	V
V_{OH}	Minimum HIGH Level Output Voltage	$V_{IN} = V_{IH}$ $\|I_{OUT}\| \leq 20\ \mu A$	2.0V	2.0	1.9	1.9	1.9	V
			4.5V	4.5	4.4	4.4	4.4	V
			6.0V	6.0	5.9	5.9	5.9	V
		$V_{IN} = V_{IH}$ $\|I_{OUT}\| \leq 4.0$ mA	4.5V	4.2	3.98	3.84	3.7	V
		$\|I_{OUT}\| \leq 5.2$ mA	6.0V	5.7	5.48	5.34	5.2	V
V_{OL}	Maximum LOW Level Output Voltage	$V_{IN} = V_{IH}$ or V_{IL} $\|I_{OUT}\| \leq 20\ \mu A$	2.0V	0	0.1	0.1	0.1	V
			4.5V	0	0.1	0.1	0.1	V
			6.0V	0	0.1	0.1	0.1	V
		$V_{IN} = V_{IH}$ or V_{IL} $\|I_{OUT}\| \leq 4.0$ mA	4.5V	0.2	0.26	0.33	0.4	V
		$\|I_{OUT}\| \leq 5.2$ mA	6.0V	0.2	0.26	0.33	0.4	V
I_{IN}	Maximum Input Current	$V_{IN} = V_{CC}$ or GND	6.0V		±0.1	±1.0	±1.0	μA
I_{CC}	Maximum Quiescent Supply Current	$V_{IN} = V_{CC}$ or GND $I_{OUT} = 0\ \mu A$	6.0V		2.0	20	40	μA

Note 4: For a power supply of 5V ±10% the worst case output voltages (V_{OH}, and V_{OL}) occur for HC at 4.5V. Thus the 4.5V values should be used when designing with this supply. Worst case V_{IH} and V_{IL} occur at V_{CC} = 5.5V and 4.5V respectively. (The V_{IH} value at 5.5V is 3.85V.) The worst case leakage current (I_{IN}, I_{CC}, and I_{OZ}) occur for CMOS at the higher voltage and so the 6.0V values should be used.

AC Electrical Characteristics

$V_{CC} = 5V$, $T_A = 25°C$, $C_L = 15$ pF, $t_r = t_f = 6$ ns

Symbol	Parameter	Conditions	Typ	Guaranteed Limit	Units
t_{PHL}	Maximum Propagation Delay, Output HIGH-to-LOW		12	20	ns
t_{PLH}	Maximum Propagation Delay, Output LOW-to-HIGH		7	15	ns

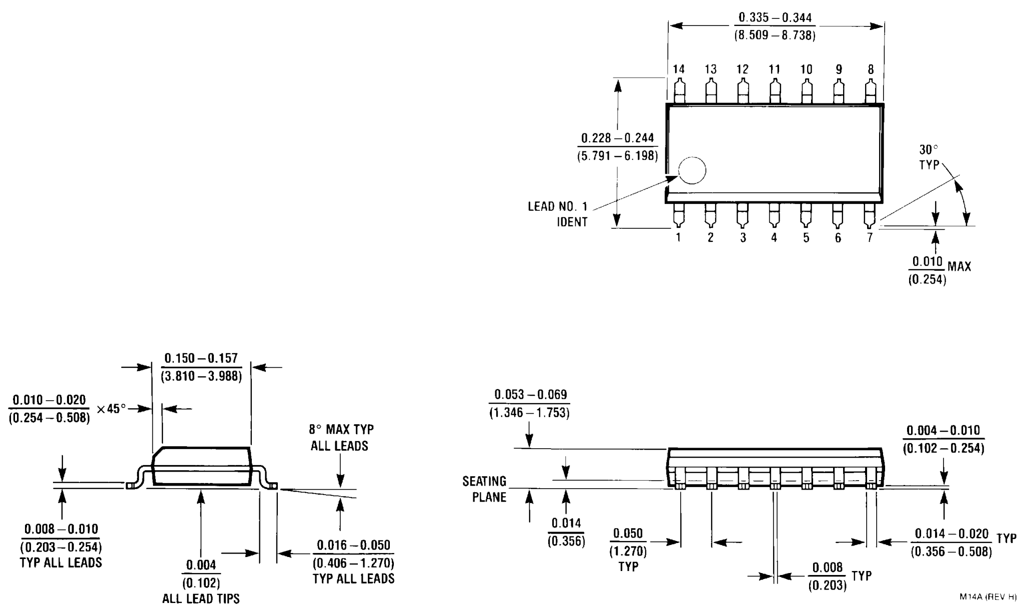
AC Electrical Characteristics

$V_{CC} = 2.0V$ to $6.0V$, $C_L = 50$ pF, $t_r = t_f = 6$ ns (unless otherwise specified)

Symbol	Parameter	Conditions	V_{CC}	$T_A = 25°C$		$T_A = -40$ to $125°C$	Units
				Typ	Guaranteed Limits		
t_{PHL}	Maximum Propagation Delay, Output HIGH-to-LOW		2.0V	77	121	175	ns
			4.5V	15	24	35	ns
			6.0V	13	20	30	ns
t_{PLH}	Maximum Propagation Delay, Output LOW-to-HIGH		2.0V	30	90	134	ns
			4.5V	10	18	27	ns
			6.0V	8	15	23	ns
t_{TLH}, t_{THL}	Maximum Output Rise and Fall Time		2.0V	30	75	110	ns
			4.5V	8	15	22	ns
			6.0V	7	13	19	ns
C_{PD}	Power Dissipation Capacitance (Note 5)	(per gate)		38			pF
C_{IN}	Maximum Input Capacitance			4	10	10	pF

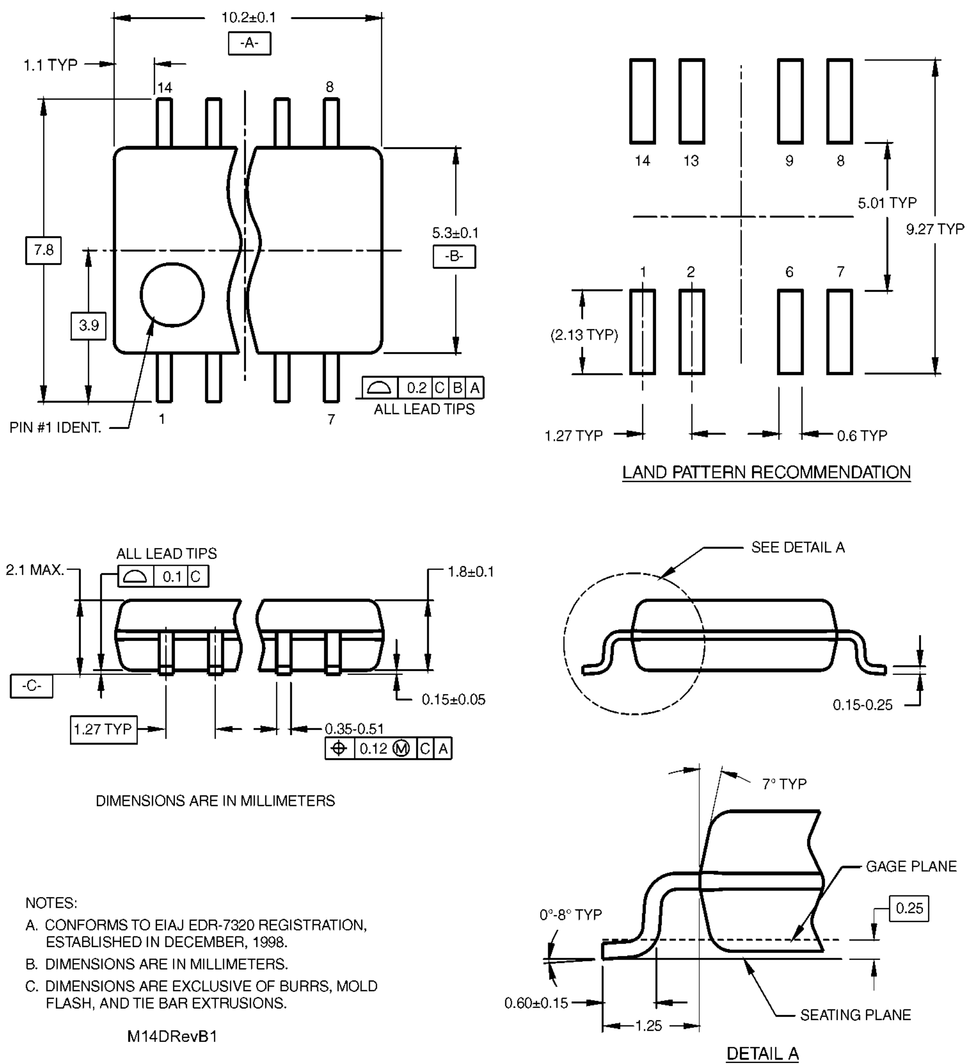
Note 5: C_{PD} determines the no load dynamic power consumption, $P_D = C_{PD} V_{CC}^2 f + I_{CC} V_{CC}$, and the no load dynamic current consumption, $I_S = C_{PD} V_{CC} f + I_{CC}$.

Physical Dimensions inches (millimeters) unless otherwise noted



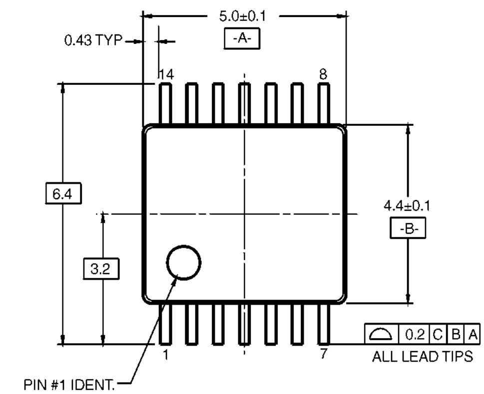
14-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-120, 0.150” Narrow Body
Package Number M14A

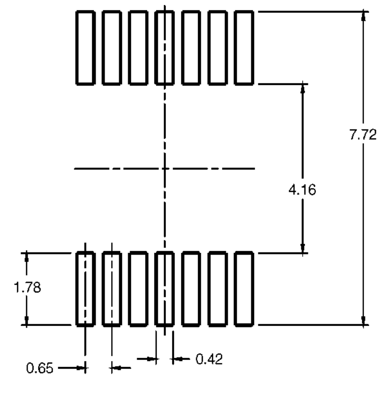
Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



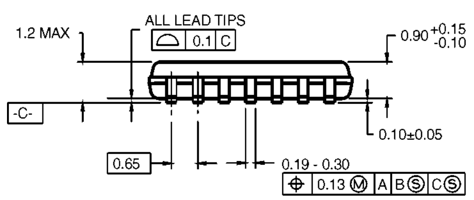
14-Lead Small Outline Package (SOP), EIAJ TYPE II, 5.3mm Wide
Package Number M14D

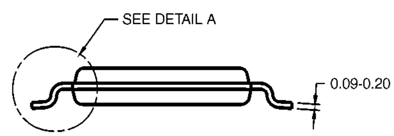
Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

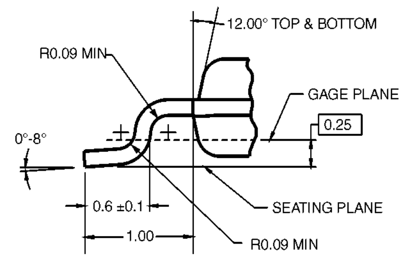




LAND PATTERN RECOMMENDATION







DETAIL A

NOTES:

A. CONFORMS TO JEDEC REGISTRATION MO-153, VARIATION AB, REF NOTE 6, DATE 7/93.

B. DIMENSIONS ARE IN MILLIMETERS.

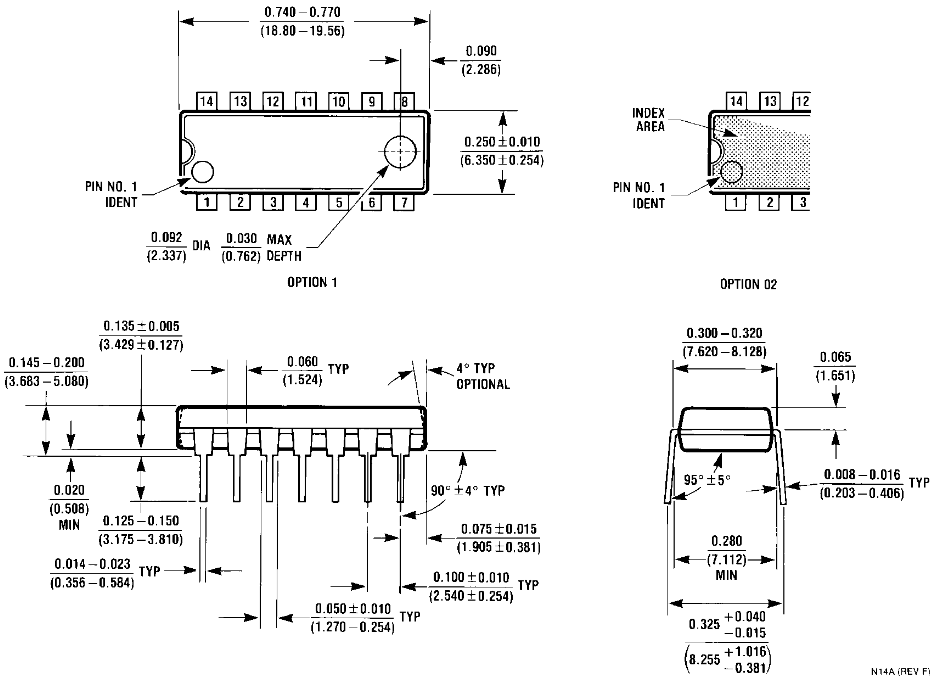
C. DIMENSIONS ARE EXCLUSIVE OF BURRS, MOLD FLASH, AND TIE BAR EXTRUSIONS.

D. DIMENSIONS AND TOLERANCES PER ANSI Y14.5M, 1982.

MTC14RevC3

14-Lead Thin Shrink Small Outline Package (TSSOP), JEDEC MO-153, 4.4mm Wide
Package Number MTC14

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300” Wide
Package Number N14A

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

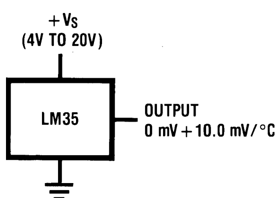
General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ˚ Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼˚C at room temperature and ±¾˚C over a full −55 to +150˚C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1˚C in still air. The LM35 is rated to operate over a −55˚ to +150˚C temperature range, while the LM35C is rated for a −40˚ to +110˚C range (−10˚ with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

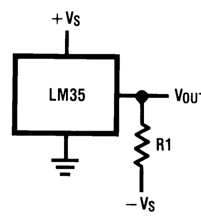
- Calibrated directly in ˚ Celsius (Centigrade)
- Linear + 10.0 mV/˚C scale factor
- 0.5˚C accuracy guaranteeable (at +25˚C)
- Rated for full −55˚ to +150˚C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08˚C in still air
- Nonlinearity only ±¼˚C typical
- Low impedance output, 0.1 Ω for 1 mA load

Typical Applications



DS005516-3

FIGURE 1. Basic Centigrade Temperature Sensor (+2˚C to +150˚C)



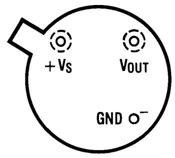
DS005516-4

Choose $R_1 = -V_S/50\ \mu A$
V_{OUT}=+1,500 mV at +150˚C
= +250 mV at +25˚C
= −550 mV at −55˚C

FIGURE 2. Full-Range Centigrade Temperature Sensor

Connection Diagrams

TO-46
Metal Can Package*

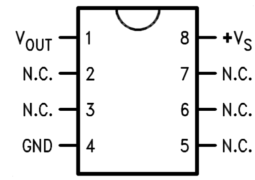


BOTTOM VIEW
DS005516-1

*Case is connected to negative pin (GND)

Order Number LM35H, LM35AH, LM35CH, LM35CAH or LM35DH
See NS Package Number H03H

SO-8
Small Outline Molded Package

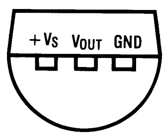


DS005516-21

N.C. = No Connection

Top View
Order Number LM35DM
See NS Package Number M08A

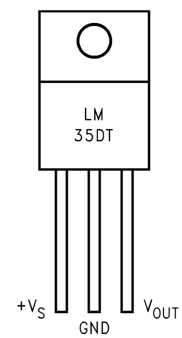
TO-92
Plastic Package



BOTTOM VIEW
DS005516-2

Order Number LM35CZ, LM35CAZ or LM35DZ
See NS Package Number Z03A

TO-220
Plastic Package*



DS005516-24

*Tab is connected to the negative pin (GND).
Note: The LM35DT pinout is different than the discontinued LM35DP.

Order Number LM35DT
See NS Package Number TA03F

Absolute Maximum Ratings (Note 10)

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

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp.;	
TO-46 Package,	−60˚C to +180˚C
TO-92 Package,	−60˚C to +150˚C
SO-8 Package,	−65˚C to +150˚C
TO-220 Package,	−65˚C to +150˚C
Lead Temp.:	
TO-46 Package, (Soldering, 10 seconds)	300˚C
TO-92 and TO-220 Package, (Soldering, 10 seconds)	260˚C
SO Package (Note 12)	
Vapor Phase (60 seconds)	215˚C
Infrared (15 seconds)	220˚C
ESD Susceptibility (Note 11)	2500V
Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)	
LM35, LM35A	−55˚C to +150˚C
LM35C, LM35CA	−40˚C to +110˚C
LM35D	0˚C to +100˚C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35A			LM35CA			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	T_A=+25˚C	±0.2	±0.5		±0.2	±0.5		˚C
	T_A=−10˚C	±0.3			±0.3		±1.0	˚C
	T_A=T_{MAX}	±0.4	±1.0		±0.4	±1.0		˚C
	T_A=T_{MIN}	±0.4	±1.0		±0.4		±1.5	˚C
Nonlinearity (Note 8)	T_{MIN}≤T_A≤T_{MAX}	**±0.18**		**±0.35**	**±0.15**		**±0.3**	˚C
Sensor Gain (Average Slope)	T_{MIN}≤T_A≤T_{MAX}	**+10.0**	**+9.9, +10.1**		**+10.0**		**+9.9, +10.1**	mV/˚C
Load Regulation (Note 3) 0≤I_L≤1 mA	T_A=+25˚C	±0.4	±1.0		±0.4	±1.0		mV/mA
	T_{MIN}≤T_A≤T_{MAX}	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
Line Regulation (Note 3)	T_A=+25˚C	±0.01	±0.05		±0.01	±0.05		mV/V
	4V≤V_S≤30V	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25˚C	56	67		56	67		µA
	V_S=+5V	**105**		**131**	**91**		**114**	µA
	V_S=+30V, +25˚C	56.2	68		56.2	68		µA
	V_S=+30V	**105.5**		**133**	**91.5**		**116**	µA
Change of Quiescent Current (Note 3)	4V≤V_S≤30V, +25˚C	0.2	1.0		0.2	1.0		µA
	4V≤V_S≤30V	**0.5**		**2.0**	**0.5**		**2.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.5**	**+0.39**		**+0.5**	µA/˚C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	˚C
Long Term Stability	T_J=T_{MAX}, for 1000 hours	±0.08			±0.08			˚C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35			LM35C, LM35D			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy, LM35, LM35C (Note 7)	T_A=+25˚C	±0.4	±1.0		±0.4	±1.0		˚C
	T_A=−10˚C	±0.5			±0.5		±1.5	˚C
	$T_A=T_{MAX}$	±0.8	±1.5		±0.8		±1.5	˚C
	$T_A=T_{MIN}$	±0.8		±1.5	±0.8		±2.0	˚C
Accuracy, LM35D (Note 7)	T_A=+25˚C				±0.6	±1.5		˚C
	$T_A=T_{MAX}$				±0.9		±2.0	˚C
	$T_A=T_{MIN}$				±0.9		±2.0	˚C
Nonlinearity (Note 8)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.3**		**±0.5**	**±0.2**		**±0.5**	˚C
Sensor Gain (Average Slope)	$T_{MIN} \le T_A \le T_{MAX}$	**+10.0**	**+9.8, +10.2**		**+10.0**		**+9.8, +10.2**	mV/˚C
Load Regulation (Note 3) $0 \le I_L \le 1$ mA	T_A=+25˚C	±0.4	±2.0		±0.4	±2.0		mV/mA
	$T_{MIN} \le T_A \le T_{MAX}$	**±0.5**		**±5.0**	**±0.5**		**±5.0**	mV/mA
Line Regulation (Note 3)	T_A=+25˚C	±0.01	±0.1		±0.01	±0.1		mV/V
	$4V \le V_S \le 30V$	**±0.02**		**±0.2**	**±0.02**		**±0.2**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25˚C	56	80		56	80		µA
	V_S=+5V	**105**		**158**	**91**		**138**	µA
	V_S=+30V, +25˚C	56.2	82		56.2	82		µA
	V_S=+30V	**105.5**		**161**	**91.5**		**141**	µA
Change of Quiescent Current (Note 3)	$4V \le V_S \le 30V$, +25˚C	0.2	2.0		0.2	2.0		µA
	$4V \le V_S \le 30V$	**0.5**		**3.0**	**0.5**		**3.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.7**	**+0.39**		**+0.7**	µA/˚C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	˚C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			˚C

Note 1: Unless otherwise noted, these specifications apply: −55˚C≤T_J≤+150˚C for the LM35 and LM35A; −40˚≤T_J≤+110˚C for the LM35C and LM35CA; and 0˚≤T_J≤+100˚C for the LM35D. V_S=+5Vdc and I_{LOAD}=50 µA, in the circuit of *Figure 2*. These specifications also apply from +2˚C to T_{MAX} in the circuit of *Figure 1*. Specifications in **boldface** apply over the full rated temperature range.

Note 2: Thermal resistance of the TO-46 package is 400˚C/W, junction to ambient, and 24˚C/W junction to case. Thermal resistance of the TO-92 package is 180˚C/W junction to ambient. Thermal resistance of the small outline molded package is 220˚C/W junction to ambient. Thermal resistance of the TO-220 package is 90˚C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested Limits are guaranteed and 100% tested in production.

Note 5: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specifications in **boldface** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10mv/˚C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in ˚C).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature range.

Note 9: Quiescent current is defined in the circuit of *Figure 1*.

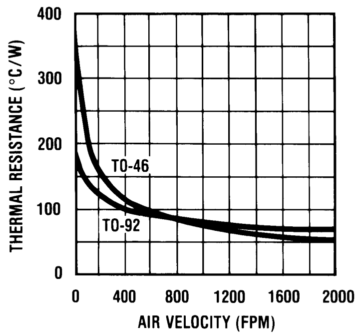
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

Note 11: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Typical Performance Characteristics

Thermal Resistance Junction to Air



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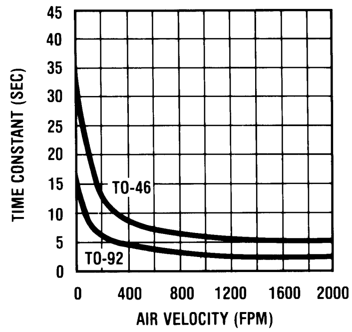
Thermal Time Constant



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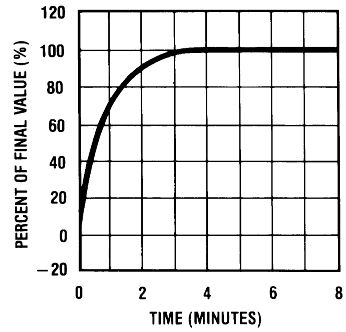
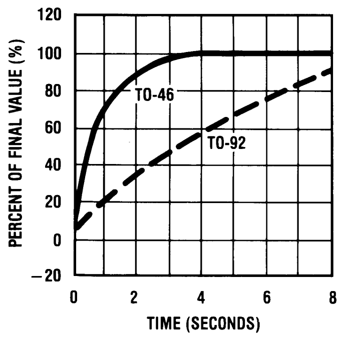
Thermal Response in Still Air



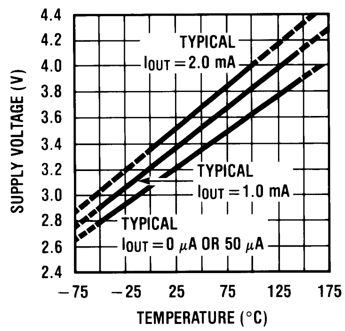
DS005516-27

Thermal Response in Stirred Oil Bath



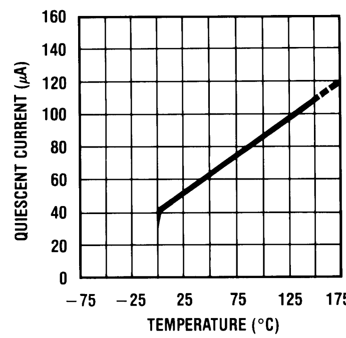
DS005516-28

Minimum Supply Voltage vs. Temperature



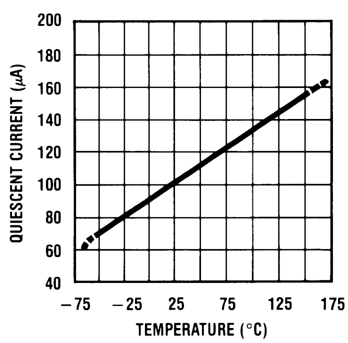
DS005516-29

Quiescent Current vs. Temperature (In Circuit of *Figure 1*.)



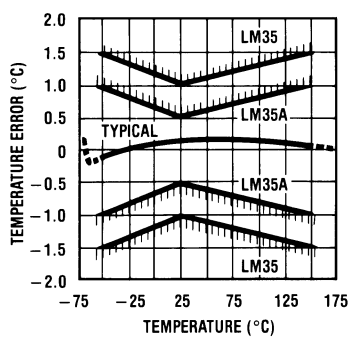
DS005516-30

Quiescent Current vs. Temperature (In Circuit of *Figure 2*.)



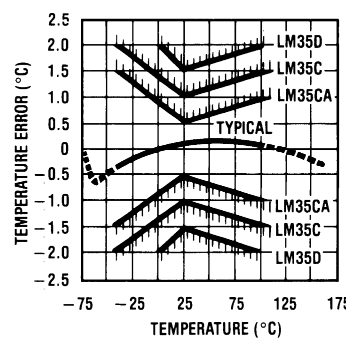
DS005516-31

Accuracy vs. Temperature (Guaranteed)



DS005516-32

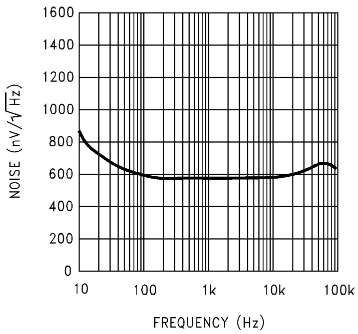
Accuracy vs. Temperature (Guaranteed)



DS005516-33

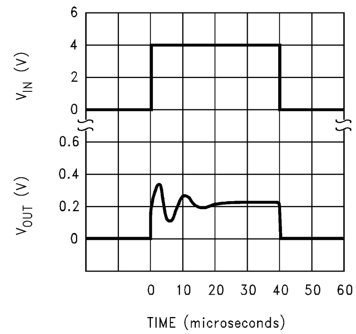
Typical Performance Characteristics (Continued)

Noise Voltage



DS005516-34

Start-Up Response



DS005516-35

Applications

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01˚C of the surface temperature.

This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature. This is expecially true for the TO-92 plastic package, where the copper leads are the principal thermal path to carry heat into the device, so its temperature might be closer to the air temperature than to the surface temperature.

To minimize this problem, be sure that the wiring to the LM35, as it leaves the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that the LM35 die's temperature will not be affected by the air temperature.

The TO-46 metal package can also be soldered to a metal surface or pipe without damage. Of course, in that case the V− terminal of the circuit will be grounded to that metal. Alternatively, the LM35 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM35 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to insure that moisture cannot corrode the LM35 or its connections.

These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

Temperature Rise of LM35 Due To Self-heating (Thermal Resistance, θ_{JA})

	TO-46, no heat sink	TO-46*, small heat fin	TO-92, no heat sink	TO-92**, small heat fin	SO-8 no heat sink	SO-8** small heat fin	TO-220 no heat sink
Still air	400˚C/W	100˚C/W	180˚C/W	140˚C/W	220˚C/W	110˚C/W	90˚C/W
Moving air	100˚C/W	40˚C/W	90˚C/W	70˚C/W	105˚C/W	90˚C/W	26˚C/W
Still oil	100˚C/W	40˚C/W	90˚C/W	70˚C/W			
Stirred oil	50˚C/W	30˚C/W	45˚C/W	40˚C/W			
(Clamped to metal, Infinite heat sink)	(24˚C/W)				(55˚C/W)		

*Wakefield type 201, or 1" disc of 0.020" sheet brass, soldered to case, or similar.
**TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

Typical Applications

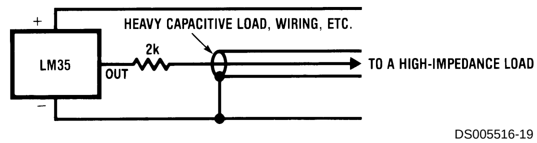


FIGURE 3. LM35 with Decoupling from Capacitive Load

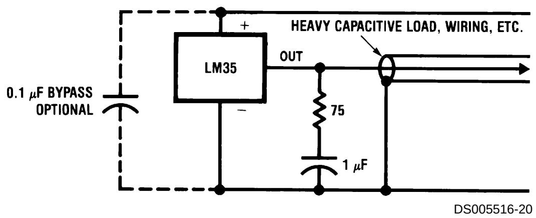


FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

Like most micropower circuits, the LM35 has a limited ability to drive heavy capacitive loads. The LM35 by itself is able to drive 50 pf without special precautions. If heavier loads are anticipated, it is easy to isolate or decouple the load with a resistor; see *Figure 3*. Or you can improve the tolerance of capacitance with a series R-C damper from output to ground; see *Figure 4*.

When the LM35 is applied with a 200Ω load resistor as shown in *Figure 5*, *Figure 6* or *Figure 8* it is relatively immune to wiring capacitance because the capacitance forms a bypass from ground to input, not on the output. However, as with any linear circuit connected to wires in a hostile environment, its performance can be affected adversely by intense electromagnetic sources such as relays, radio transmitters, motors with arcing brushes, SCR transients, etc, as its wiring can act as a receiving antenna and its internal junctions can act as rectifiers. For best results in such cases, a bypass capacitor from V_{IN} to ground and a series R-C damper such as 75Ω in series with 0.2 or 1 µF from output to ground are often useful. These are shown in *Figure 13*, *Figure 14*, and *Figure 16*.

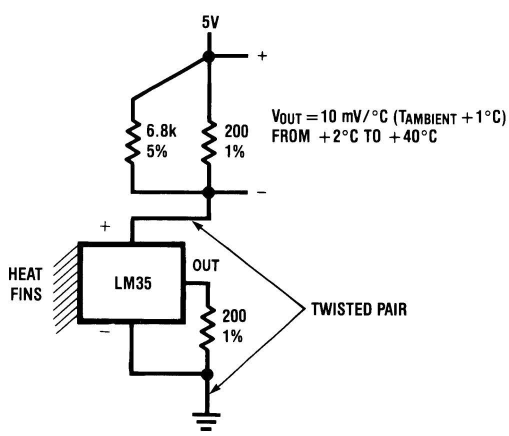


FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)

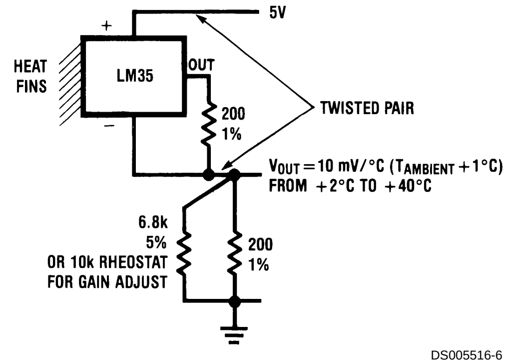


FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

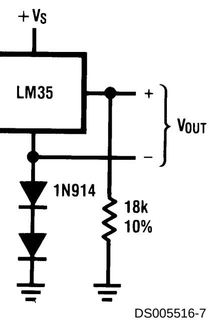


FIGURE 7. Temperature Sensor, Single Supply, −55˚ to +150˚C

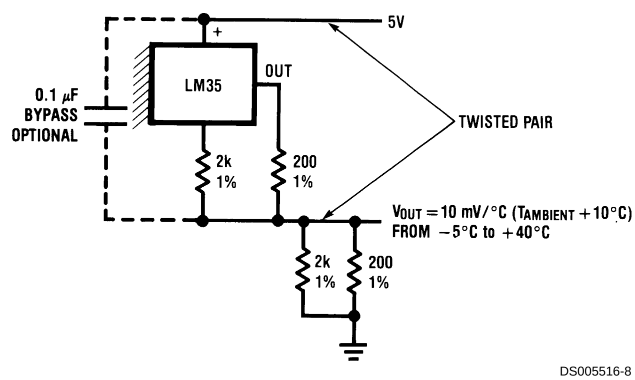


FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

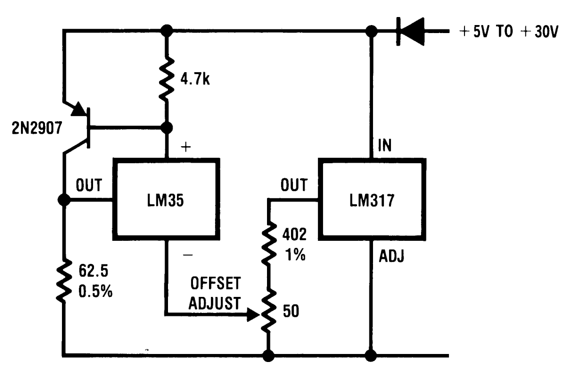


FIGURE 9. 4-To-20 mA Current Source (0˚C to +100˚C)

Typical Applications (Continued)

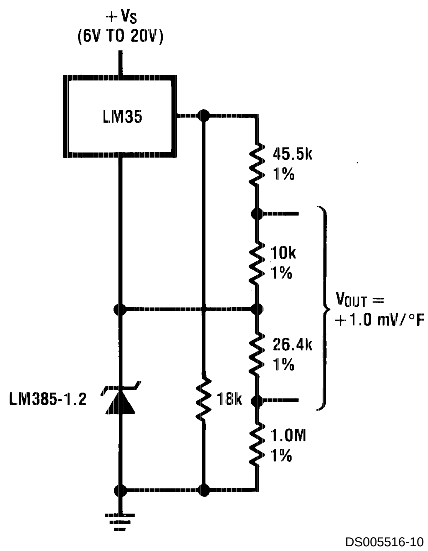


FIGURE 10. Fahrenheit Thermometer

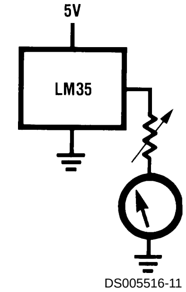


FIGURE 11. Centigrade Thermometer (Analog Meter)

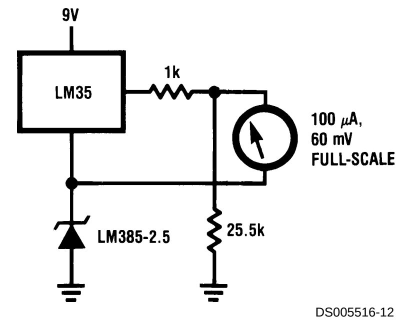


FIGURE 12. Fahrenheit ThermometerExpanded Scale Thermometer
(50° to 80° Fahrenheit, for Example Shown)

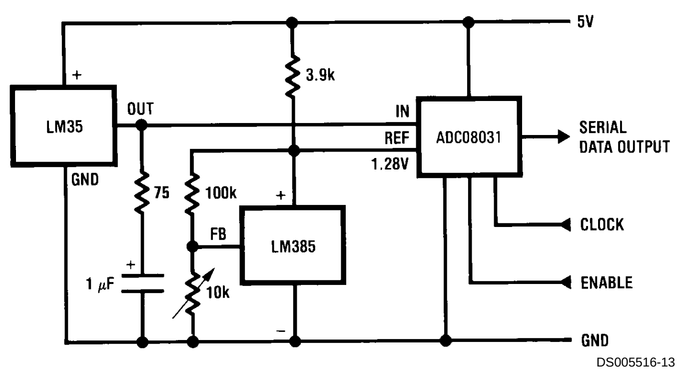


FIGURE 13. Temperature To Digital Converter (Serial Output) (+128°C Full Scale)

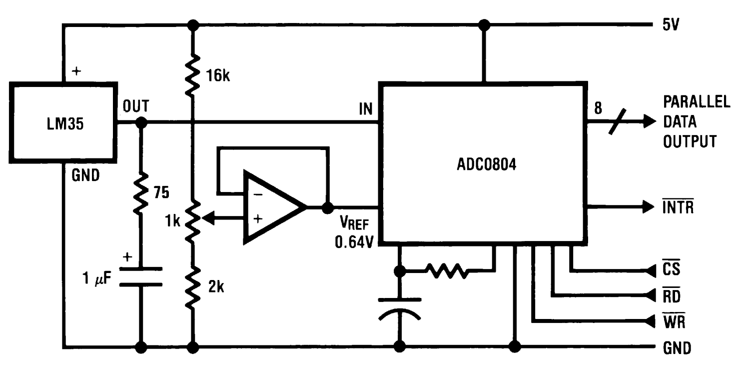
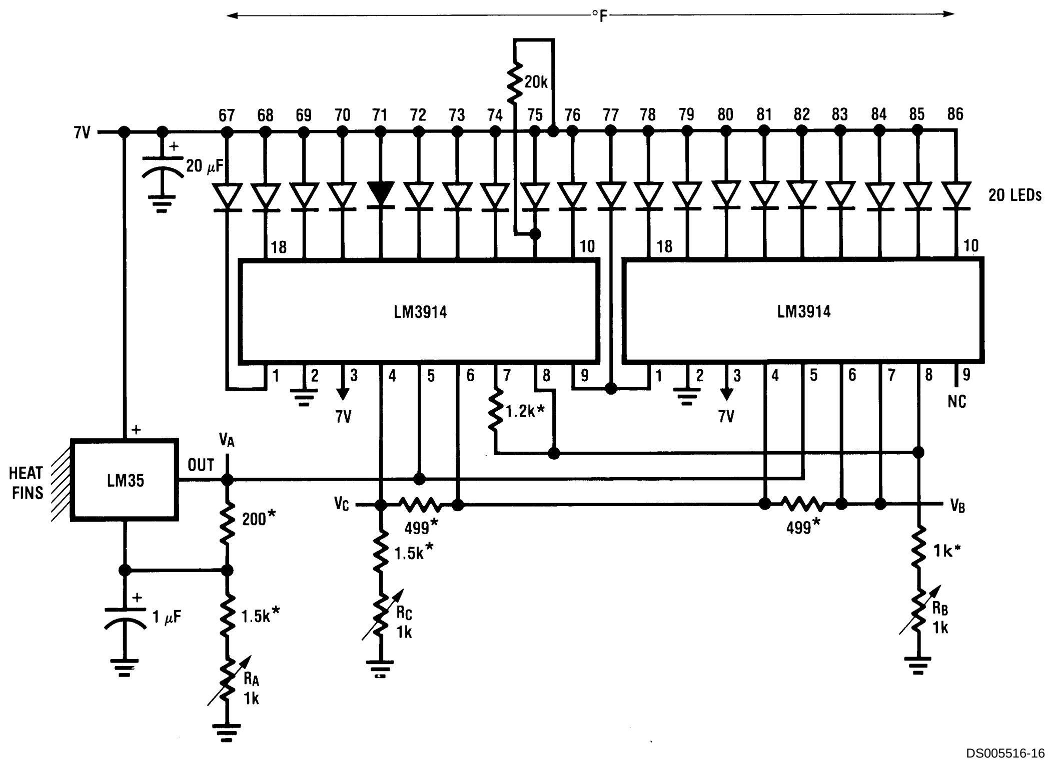


FIGURE 14. Temperature To Digital Converter (Parallel TRI-STATE™ Outputs for Standard Data Bus to μP Interface) (128°C Full Scale)

Typical Applications (Continued)



*=1% or 2% film resistor
Trim R_B for V_B=3.075V
Trim R_C for V_C=1.955V
Trim R_A for V_A=0.075V + 100mV/˚C x $T_{ambient}$
Example, V_A=2.275V at 22˚C

FIGURE 15. Bar-Graph Temperature Display (Dot Mode)

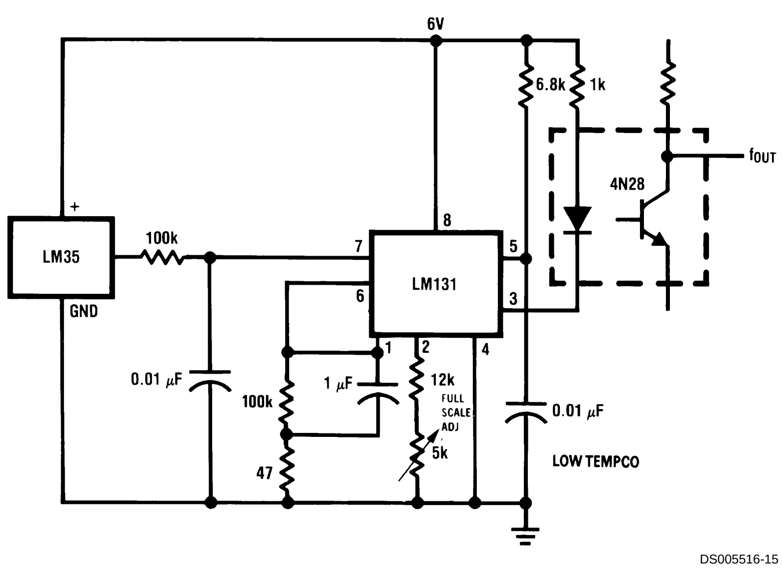
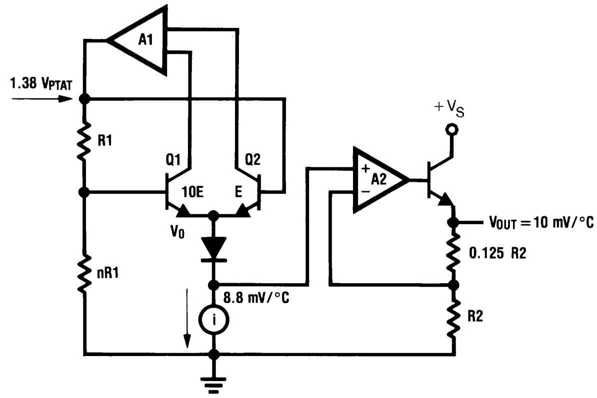


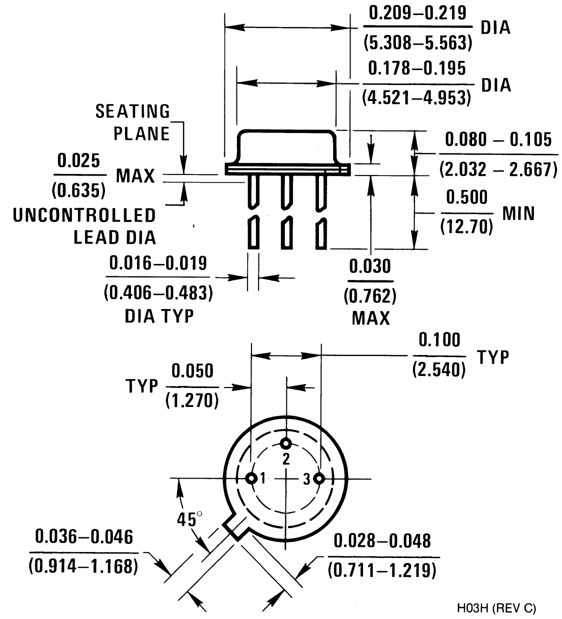
FIGURE 16. LM35 With Voltage-To-Frequency Converter And Isolated Output (2˚C to +150˚C; 20 Hz to 1500 Hz)

Block Diagram

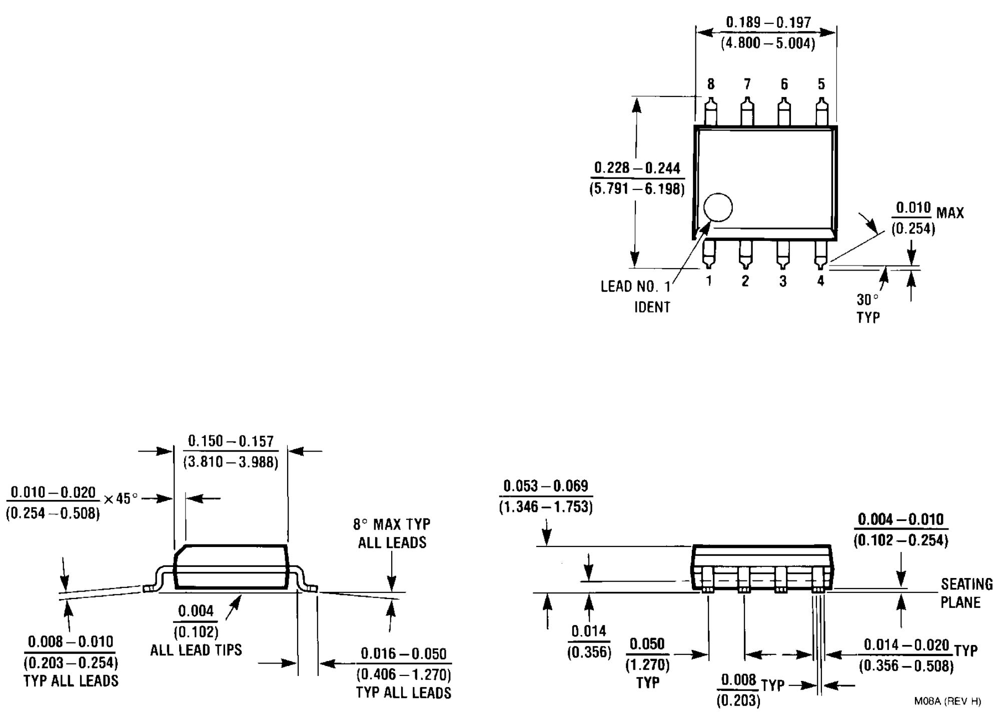


DS005516-23

Physical Dimensions inches (millimeters) unless otherwise noted

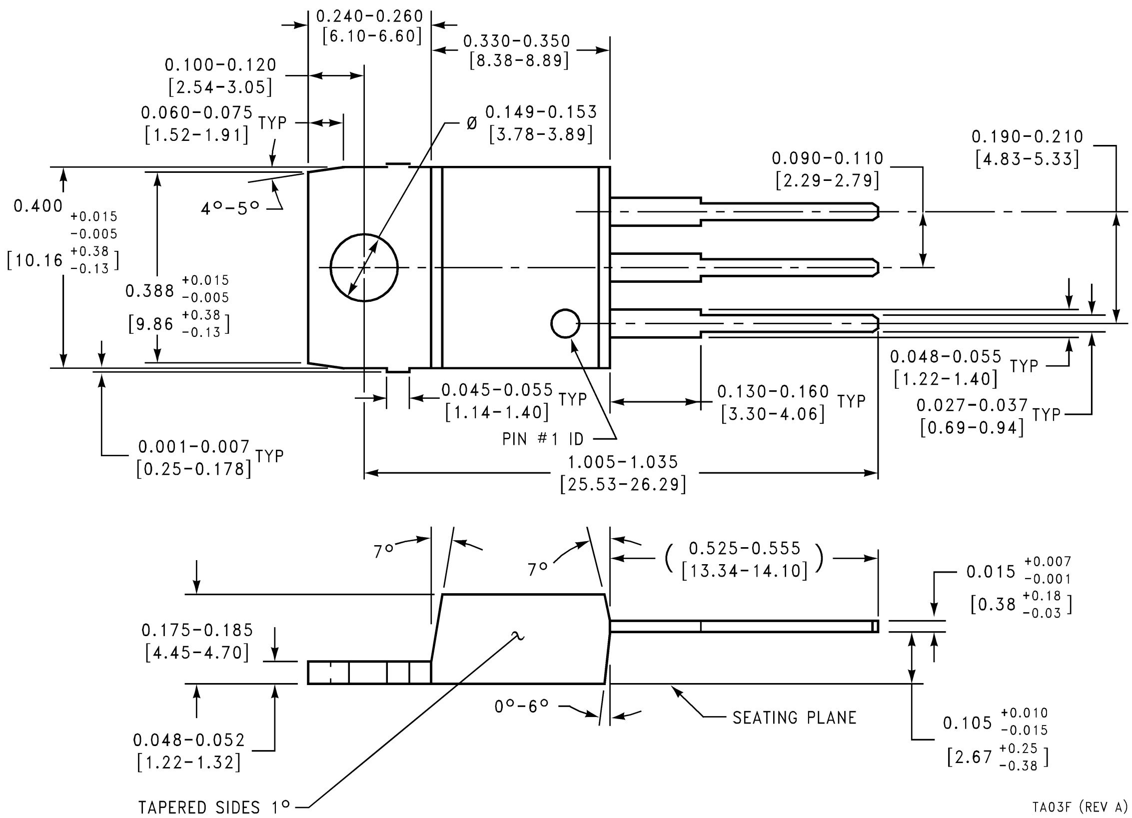


TO-46 Metal Can Package (H)
Order Number LM35H, LM35AH, LM35CH, LM35CAH, or LM35DH
NS Package Number H03H



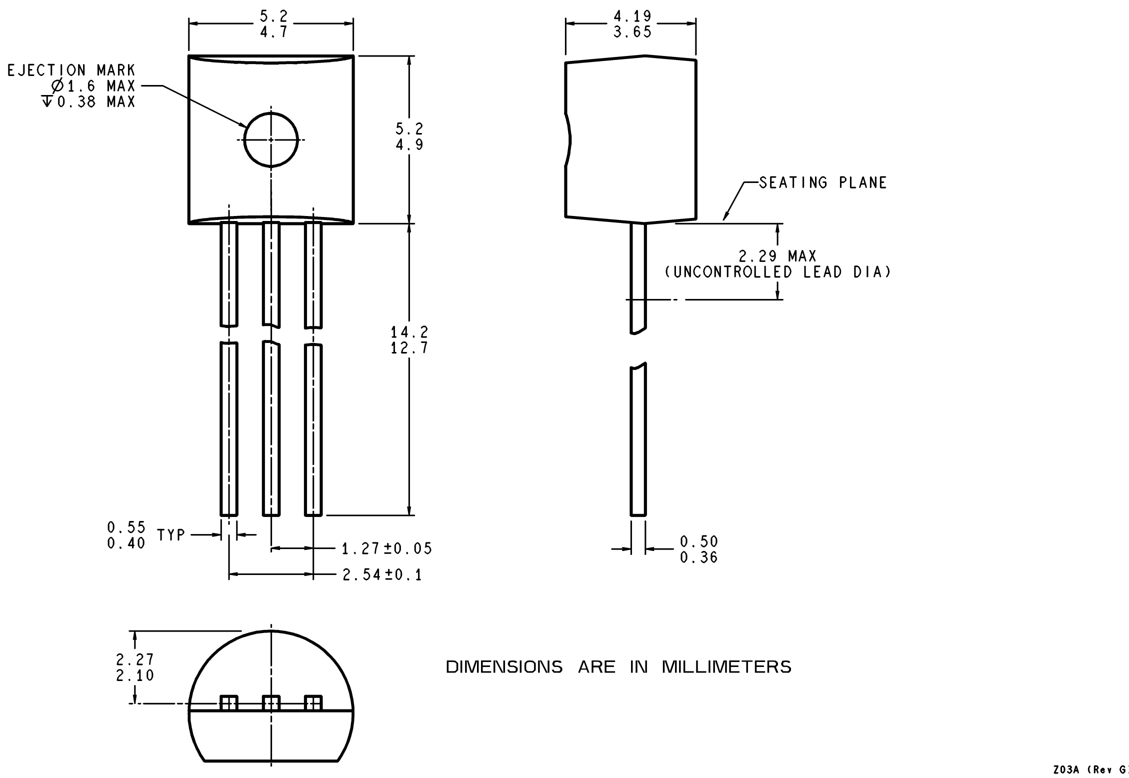
SO-8 Molded Small Outline Package (M)
Order Number LM35DM
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Power Package TO-220 (T)
Order Number LM35DT
NS Package Number TA03F

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



TO-92 Plastic Package (Z)
Order Number LM35CZ, LM35CAZ or LM35DZ
NS Package Number Z03A

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