**PLESSEY Semiconductors**

T-51-09-08

# ZN559

## LOW COST 8-BIT LATCHED INPUT MONOLITHIC D-A CONVERTER

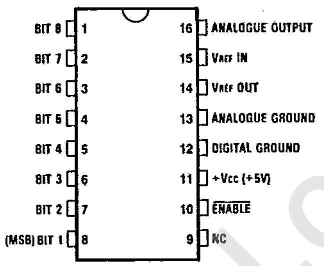
The ZN559 is a low cost 8-bit D-A converter with input latches to facilitate updating from a data bus. The latch is transparent when enable is LOW and the data is held when enable is taken HIGH. The device has a precision 2.5V voltage reference, the use of which is pin optional to retain flexibility. An external fixed or varying reference may therefore be substituted.

### FEATURES

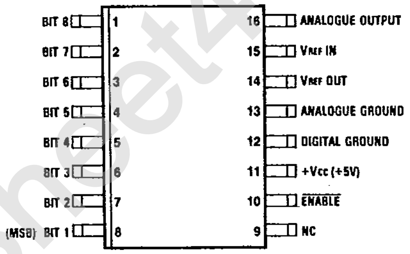
- Low Cost DAC with Data Latch and On-Chip Reference
- Guaranteed Monotonic over the Full Operating Temperature Range
- Complementary to the ZN449 ADC
- 800ns Settling Time
- Single +5V Supply
- Microprocessor, TTL and 5V CMOS Compatible
- Commerical and Military Temperature Ranges

### ORDERING INFORMATION

| Device type | Operating temperature | Package |
|---|---|---|
| ZN559D | 0°C to +70°C | MP16 |
| ZN559E-8 | 0°C to +70°C | DP16 |
| ZN559J-8 | -55°C to +125°C | DC16 |



ZN559J (DC16)
ZN559E (DP16)



ZN559D (MP/W16)

*Not to scale*

**Pin connections - top view**

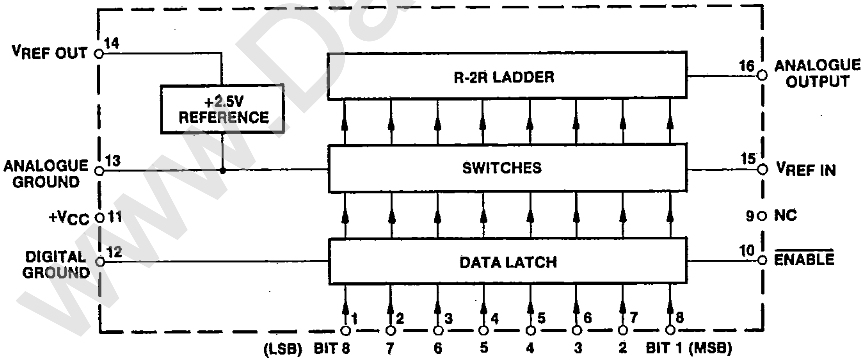


Fig.1 System diagram

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## ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| Supply voltage $V_{CC}$ | $+7.0V$ |
| Max. voltage, logic and $V_{REF}$ input | $+V_{CC}$ |
| Operating temperature range | 0 to +70°C (ZN559E & ZN559D)<br>−55 to +125°C (ZN559J) |
| Storage temperature range | −55 to +125°C |
| Analogue ground to digital ground | ±200mV |

**ELECTRICAL CHARACTERISTICS** ($V_{CC} = +5V$, $T_{amb} = 25°C$ unless otherwise specified).

| Parameter | Min. | Typ. | Max. | Units | Conditions |
|---|---|---|---|---|---|
| **Internal voltage reference** | | | | | |
| Output voltage | 2.475 | 2.550 | 2.625 | V | $R_{REF} = 390\Omega$<br>$C_{REF} = 1\mu F$ |
| Slope resistance | | 0.5 | 2 | Ω | |
| $V_{REF\ OUT}$ T.C. | | 50 | | ppm/°C | |
| Reference current | 4 | | 15 | mA | Note 1 |
| **D-A converter** | | | | | |
| Linearity error | | | ±1.0 | LSB | $2.0V \leqslant V_{REF\ IN} \leqslant 3.0V$ |
| Differential non-linearity | | ±0.5 | ±0.75 | LSB | |
| Linearity error T.C. | | ±3 | | ppm/°C | |
| Differential non-linearity T.C. | | ±6 | | ppm/°C | |
| Offset voltage ZN559E | | 3 | 6 | mV | All bits OFF |
| ZN559D | | 3 | 6 | mV | All bits OFF |
| ZN559J | | 3 | 6 | mV | All bits OFF |
| Offset voltage T.C. | | ±6 | | µV/°C | |
| Full scale output | 2.540 | 2.550 | 2.560 | V | External reference<br>$V_{REF\ IN} = 2.560V$,<br>all bits ON |
| Full scale output T.C. | | 2 | | ppm/°C | |
| Analogue output resistance | | 4 | | kΩ | |
| External reference voltage | 0 | | 3.0 | V | |
| Settling time to 0.5 LSB | | 800 | | ns | 1 LSB major transition (note 2) |
| | | 1.25 | | µs | All bits ON to OFF or OFF to ON (note 2) |
| Operating temperature range: | | | | | |
| ZN559E & ZN559D | 0 | | 70 | C | |
| ZN559J | −55 | | 125 | C | |
| Supply voltage ($V_{CC}$) | 4.5 | 5.0 | 5.5 | V | |

Note 1 See REFERENCE

Note 2 $R_L = 10M\Omega$, $C_L = 10pF$.

## ELECTRICAL CHARACTERISTICS (Cont.)

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| Parameter | Min. | Typ. | Max. | Units | Conditions |
|---|---|---|---|---|---|
| Supply current | | 20 | 30 | mA | Note 3 |
| Power consumption | | 100 | | mW | |
| **Logic**<br>(over specified operating temperature range) | | | | | |
| High level input voltage $V_{IH}$ | 2.0 | | | V | |
| Low level input voltage $V_{IL}$ | | | 0.8 | V | |
| High level input current $I_{IH}$ | | | 60<br>20 | μA<br>μA | $V_{IN} = 5.5V$, $V_{CC} = Max.$<br>$V_{IN} = 2.4V$, $V_{CC} = Max.$ |
| Low level input current $I_{IL}$ | | | −5 | μA | $V_{IN} = 0.4V$, $V_{CC} = Max.$ |
| Input clamp diode voltage | | −1.5 | | V | $I_{IN} = -8mA$ |
| Enable pulse width | 100 | | | ns | |
| Data set-up time | 150 | | | ns | Note 4 |
| Data hold time | 10 | | | ns | Note 5 |

Note 3 All inputs HIGH ($V_{IH} = 3.5V$).
Note 4 Set up time before $\overline{\text{enable}}$ goes high.
Note 5 Hold time after $\overline{\text{enable}}$ goes high.

## D-A CONVERTER

The converter is of the voltage switching type and uses an R-2R ladder network as shown in Fig. 2. Each 2R element is connected to 0V or $V_{REF\ IN}$ by transistor voltage switches specially designed for low offset voltage (<1mV). A binary weighted voltage is produced at the output of the R-2R ladder.

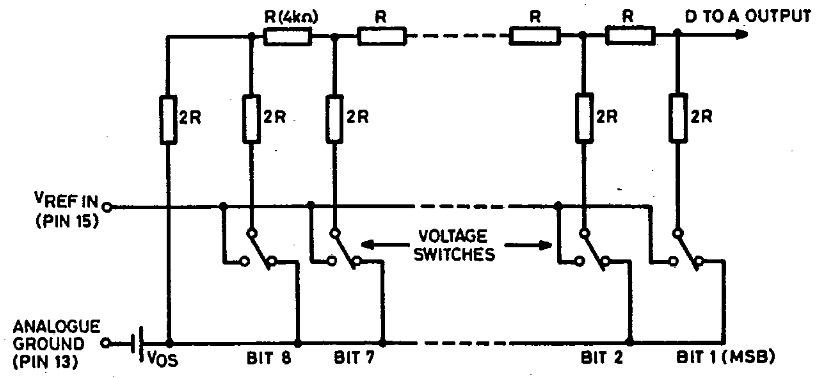

Fig. 2 The R-2R ladder network

Analogue output $= \frac{n}{256}(V_{REF\ IN} - V_{OS}) + V_{OS}$

where n is the digital input to the D-A from the data latch.

$V_{OS}$ is a small offset voltage produced by the D-A switch currents flowing through the package lead resistance. The value of $V_{OS}$ is typically 1mV. This offset will normally be removed by the setting up procedure (see APPLICATIONS section) and because the offset temperature coefficient is low ($\pm 6\mu V/°C$) the effect on accuracy is negligible.

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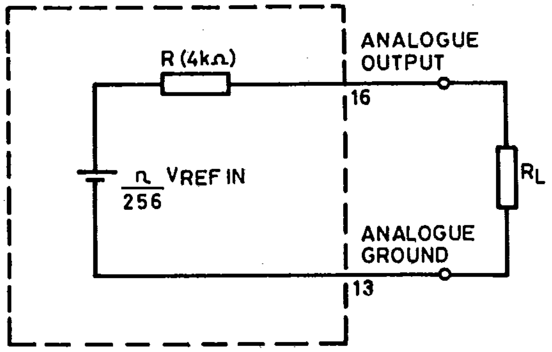

**Fig. 3 Analogue output equivalent circuit**

Fig. 3 shows an equivalent circuit of the output (ignoring $V_{OS}$). The output resistance R has a temperature coefficient of +0.2% per °C.

The gain drift due to this is $\frac{0.2R}{R + R_L}$ % per °C

$R_L$ should be chosen to be as large as possible to make the gain drift small. As an example if $R_L = 400k\Omega$ then the gain drift due to the T.C. of R for a 100°C change in ambient temperature will be less than 0.2%. Alternatively the ZN559 can be buffered by an amplifier (see APPLICATIONS section).

## REFERENCE

### (a) Internal reference

The internal reference is an active band gap circuit which is equivalent to a 2.5V Zener diode with a very low slope impedance (Fig. 4). A resistor ($R_{REF}$), should be connected between $+V_{CC}$ (pin 11) and pin 14. The recommended value of 390Ω will supply a nominal reference current of (5.0-2.5)/0.39 = 6.4mA. A stabilising/decoupling capacitor $C_{REF} = 1\mu F$ is required between pins 14 and 13 for internal reference option, $V_{REF\ OUT}$ (pin 14) being connected to $V_{REF\ IN}$ (pin 15).

Up to five ZN559's may be driven from one internal reference (there is no need to reduce $R_{REF}$). This useful feature saves power and gives excellent gain tracking between the converters.

### (b) External reference

If required an external reference voltage may be connected to $V_{REF\ IN}$. The slope resistance of such a reference source should be less than $\frac{2.5\Omega}{n}$, where n is the number of converters supplied.

$V_{REF\ IN}$ can be varied from 0 to +3V for ratiometric operation. The ZN559 is guaranteed monotonic for $V_{REF\ IN}$ above 2V.

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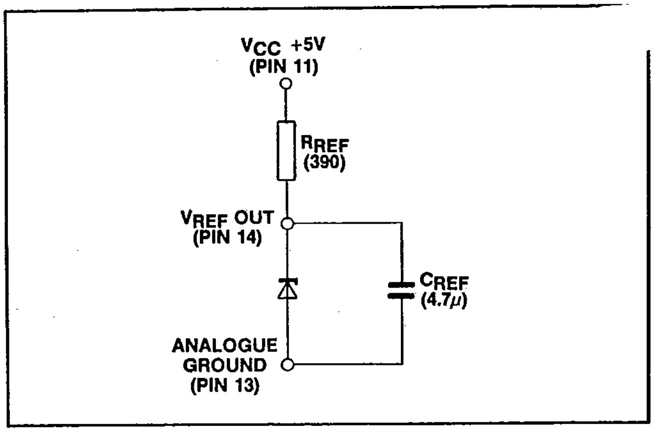

Fig. 4 Internal voltage reference

## LOGIC

Input coding is binary for unipolar operation and offset binary for bipolar operation. When the enable input is low the data inputs drive the D-A directly. When enable goes high the input data word is held in the data latch.

The equivalent circuit for the data and clock inputs is shown in Fig.5.

The ZN559 is provided with seperate analogue and digital ground connections. The circuit will operate correctly with as much as ±200mV between the two grounds.

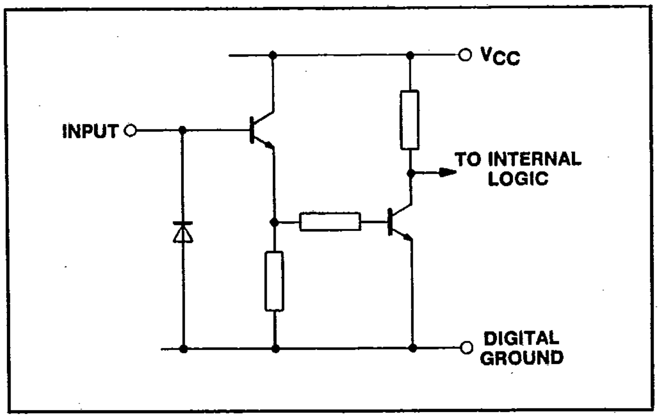

Fig. 5 Equivalent circuit of all inputs

## APPLICATIONS

In some applications the standard 0 to $V_{REF\ IN}$ output voltage range and drive capability are not suitable, and other output ranges, both unipolar and bipolar are required.

To maintain flexibility two types of operational amplifier are illustrated; the industry standard 741 and a low cost pin-compatible alternative with a JFET input, the LF351. The LF351 features a high slew rate of 13V/μs, which gives a faster potential settling time than the 741. To keep drift to a minimum when using the 741, the external range setting resistors are calculated to match them to the 4KΩ ladder output impedance. This is not a consideration with the LF351, as the input offset current change with temperature is negligible for the impedances concerned. The resistor values for the LF351 were chosen to keep the output ringing to a minimum; a problem sometimes encountered with high slew rate op-amps. It is only the relative and not the absolute values of these resistors which set the range, and therefore can be changed as long as their ratios remain the same.

### 1) Unipolar operation

The general scheme for unipolar operation is shown in Fig. 6 and is suitable for amplifiers with input bias currents less than 1.5μA.

The resulting full scale range is given by

$$V_{OUT}\,FS = \left(1 + \frac{R1}{R2}\right)(V_{REF\ IN} - 1LSB)$$
$$= G\,(V_{REF\ IN} - 1LSB)$$

The impedance at the inverting input is R1//R2 and for low drift with temperature (741 only), this parallel combination should be equal to the ladder resistance (4kΩ).

The required nominal values of R1 and R2 are therefore given by R1 = 4GkΩ and $R_2 = 4G/(G-1)$kΩ.

Using these relationships a table of nominal resistance values for $R_1$ and $R_2$ can be constructed for $V_{REF\ IN} = 2.5$V.

| Output range | G | $R_1$ | $R_2$ |
|---|---|---|---|
| +5V | 2 | 8kΩ | 8kΩ |
| +10V | 4 | 16kΩ | 5.33kΩ |

For gain setting $R_1$ is adjusted about its nominal value. Practical circuit realisations for +5 and +10V output ranges are given in Figs. 7 & 8

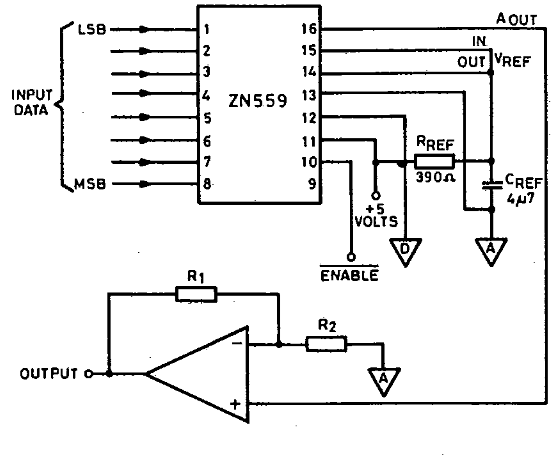

Fig. 6 Unipolar operation - basic circuit

RESISTORS ± 2%
POTENTIOMETERS ± 20%

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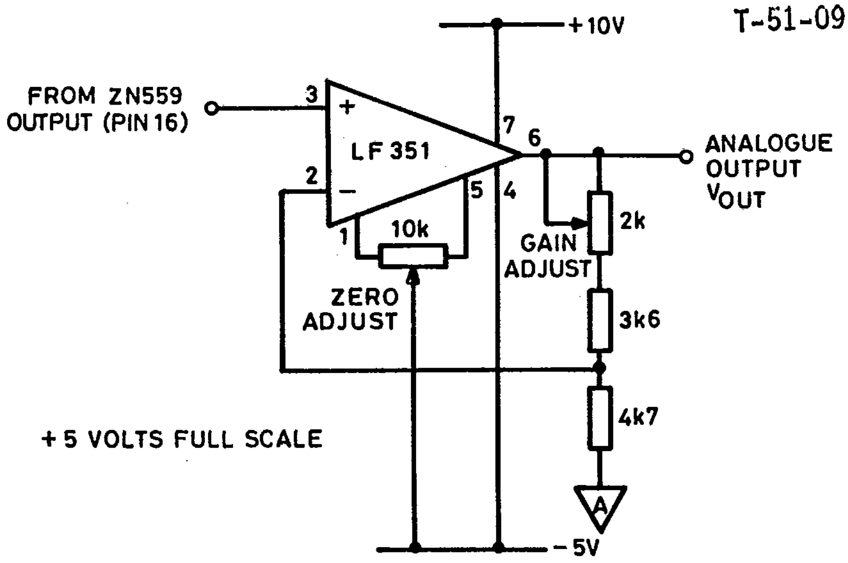
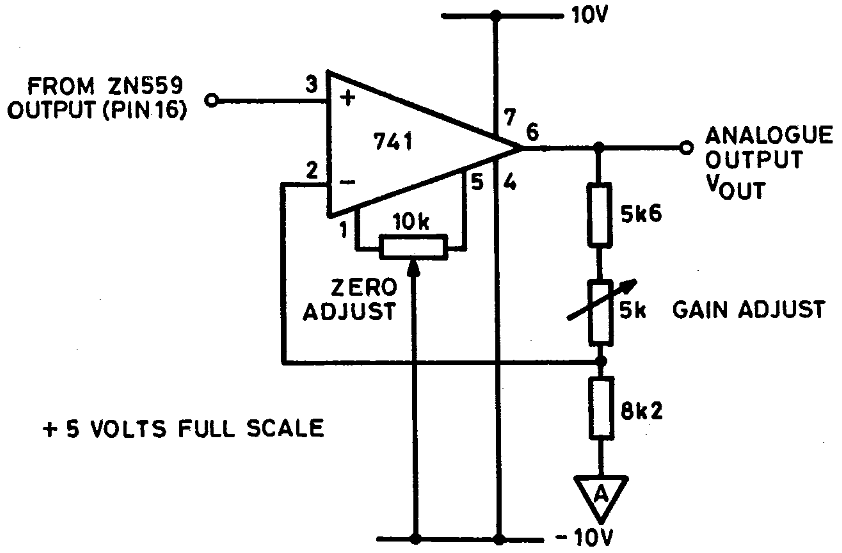


a) Using an LF351



b) Using a 741

Fig. 7 +5V full scale unipolar operation - component values

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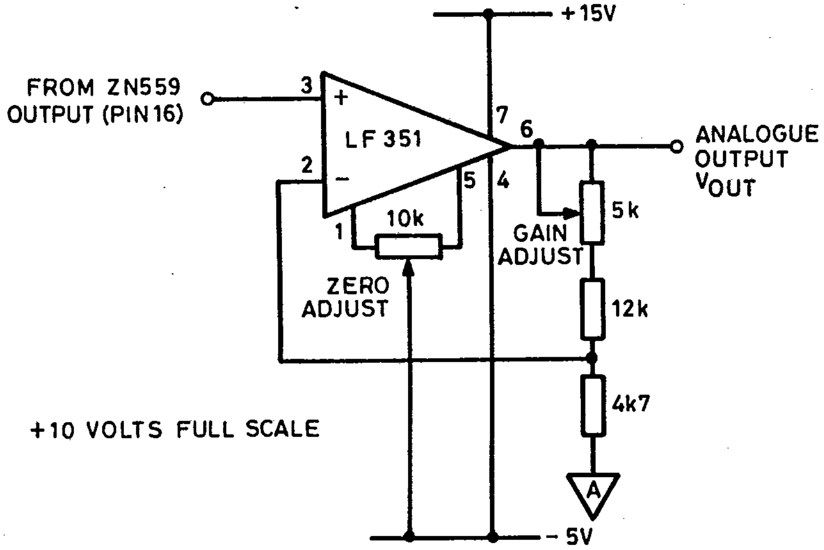
RESISTORS ± 2%
POTENTIOMETERS ± 20%



a) Using an LF351

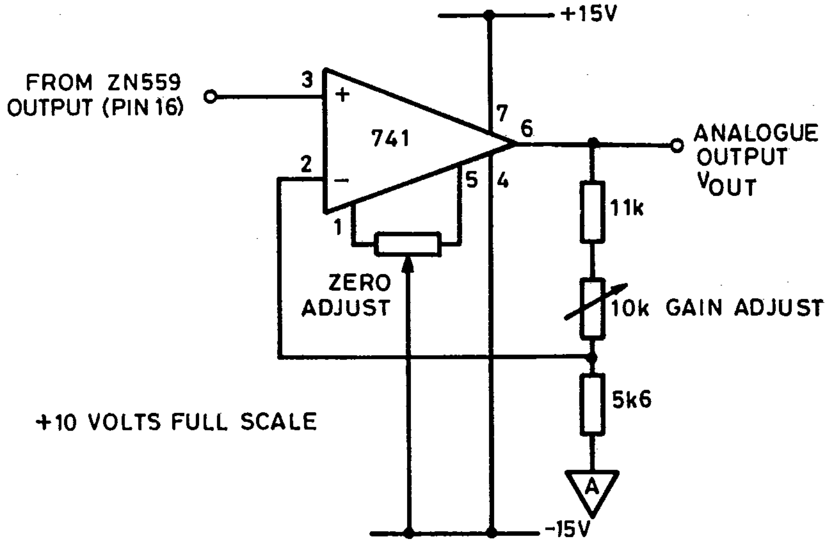


Fig. 8 + 10V full scale unipolar operation - component values

## UNIPOLAR ADJUSTMENT PROCEDURE

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(i) Set all bits to OFF (low) with $\overline{\text{enable}}$ low and adjust zero until $V_{OUT} = 0.0000V$.

(ii) Set all bits ON (high) and adjust gain until $V_{OUT} = FS - 1LSB$.

### UNIPOLAR SETTING UP POINTS

| Output range, +FS | LSB | FS - 1LSB |
|---|---|---|
| +5V | 19.5mV | 4.9805V |
| +10V | 39.1mV | 9.9609V |

$$1LSB = \frac{FS}{256}$$

### UNIPOLAR LOGIC CODING

| Input code (Binary) | Analogue output (Nominal value) |
|---|---|
| 11111111 | FS - 1LSB |
| 11111110 | FS - 2LSB |
| 11000000 | ¾ FS |
| 10000001 | ½FS + 1LSB |
| 10000000 | ½FS |
| 01111111 | ½FS - 1LSB |
| 01000000 | ¼FS |
| 00000001 | 1LSB |
| 00000000 | 0 |

### (2) Bipolar operation

For bipolar operation the output from the ZN559 is offset by half full scale by connecting a resistor $R_3$ between $V_{REF\ IN}$ and the inverting input of the buffer amplifier (Fig. 9).

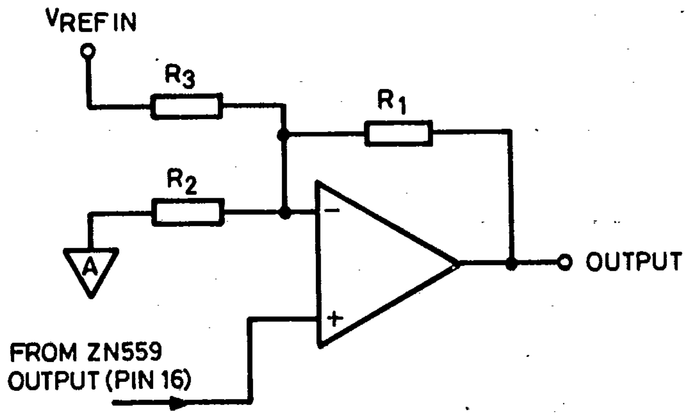

**Fig. 9 Bipolar operation - basic circuit**

When the digital input to the ZN559 is zero the analogue output is zero and the amplifier output should be − full scale. An input of all ones to the D-A will give a ZN559 output of $V_{REF\ IN}$ − 1LSB and an amplifier output of + full scale. When using the 741, the parallel combintion of $R_1$, $R_2$, and $R_3$ should match the 4kΩ ladder resistance.

The nominal values of $R_1$, $R_2$ and $R_3$ which meet these conditions are given by

$R_1 = 8G\text{k}\Omega$, $R_2 = 8G/(G\text{-}1)\text{k}\Omega$ and $R_3 = 8\text{k}\Omega$

where the resultant output range is $\pm G\ V_{REF\ IN}$.

A bipolar output range of $\pm V_{REF\ IN}$ (which corresponds to the basic unipolar range 0 to $V_{REF\ IN}$) is obtained if $R_1 = R_3 = 8\text{k}\Omega$ and $R_2 = \infty$.

Assuming that $V_{REF\ IN} = 2.5\text{V}$ the nominal values of resistors for ±5 and ±10V output ranges are given in the following table:

| Output range | G | $R_1$ | $R_2$ | $R_3$ |
|---|---|---|---|---|
| ±5V | 2 | 16kΩ | 16kΩ | 8kΩ |
| ±10V | 4 | 32kΩ | 10.66kΩ | 8kΩ |

Minus full scale (offset) is set by adjusting $R_1$ about its nominal value relative to $R_3$. Plus full scale (gain) is set by adjusting $R_2$ relative to $R_1$.

Practical circuit realisations are given in Figs. 10 & 11.

Note that in the ±5V case (741 only), $R_3$ has been chosen as 7.5kΩ (instead of 8.2kΩ) to give a more symmetrical range of adjustment using standard potentiometers.

RESISTORS ± 2%
POTENTIOMETERS ± 20%

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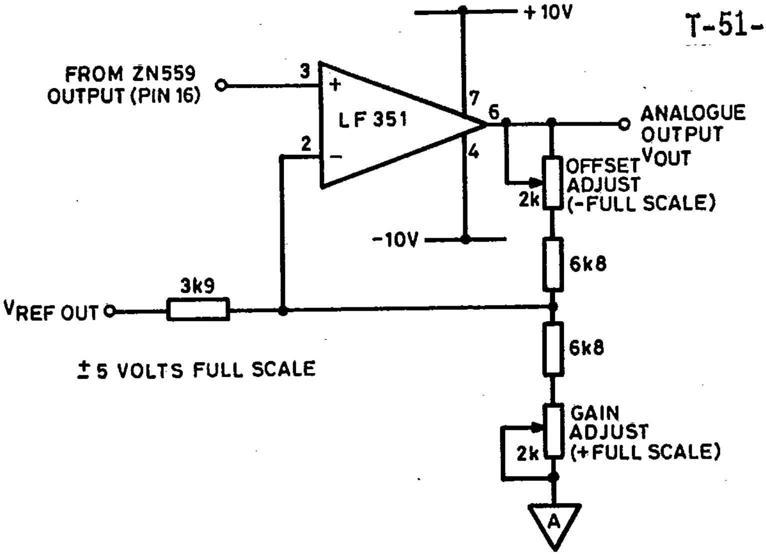
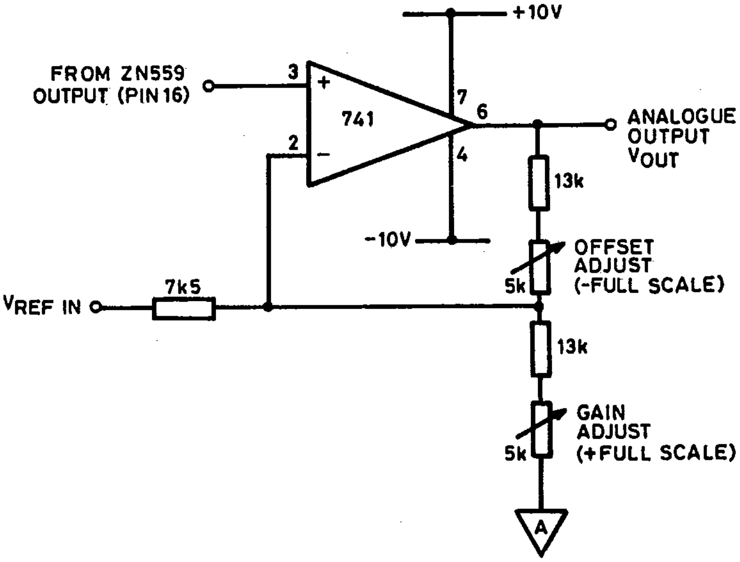


a) Using an LF351



b) Using a 741

Fig. 10 ± 5V full scale bipolar operation - component values

RESISTORS ± 2%
POTENTIOMETERS ± 20%

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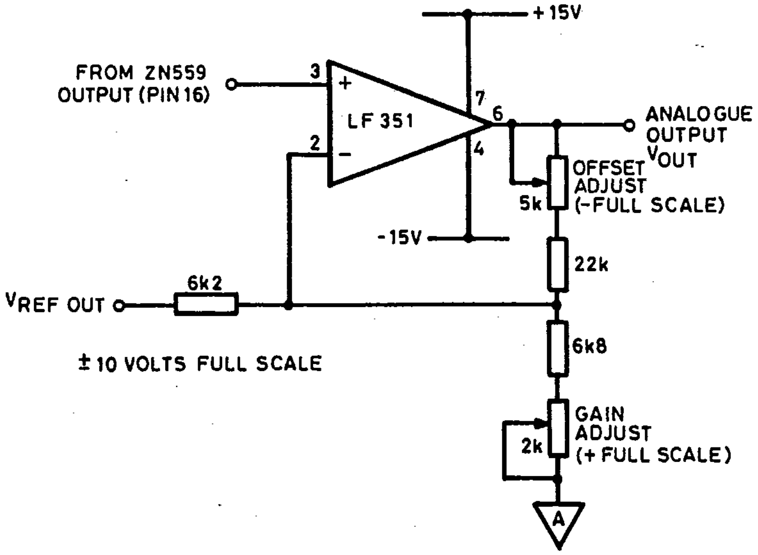
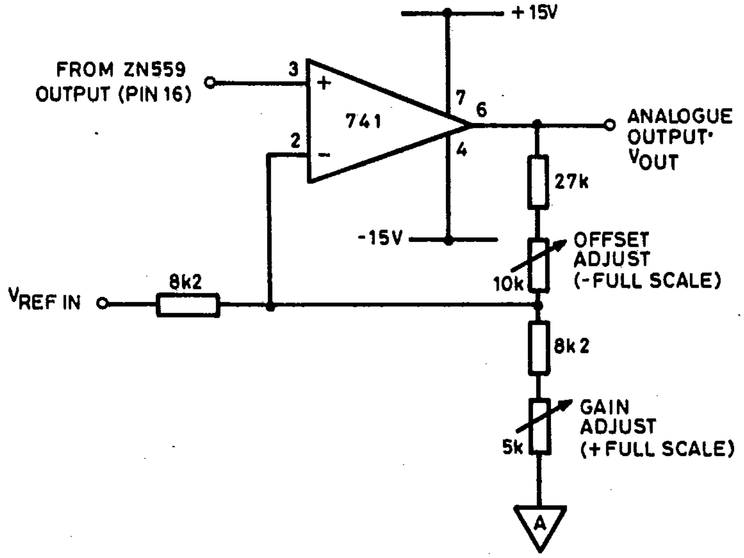


a) Using an LF351



b) Using a 741

Fig. 11 ± 10V full scale bipolar operation - component values

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**Bipolar Adjustment Procedure**

(i) Set all bits to OFF (low) with $\overline{\text{enable}}$ low and adjust offset until the amplifier output reads −full scale.

(ii) Set all bits ON (high) and adjust gain until the amplifier output reads +(full scale - 1LSB).

### BIPOLAR SETTING UP POINTS

| Input range, ±FS | LSB | −FS | +(FS - 1LSB) |
|---|---|---|---|
| ±5V | 39.1mV | −5.0000V | +4.9609V |
| ±10V | 78.1mV | −10.0000V | +9.9219V |

$1\text{LSB} = \frac{2\text{FS}}{256}$

### BIPOLAR LOGIC CODING

| Input code (Offset binary) | Analogue output (Nominal value) |
|---|---|
| 11111111 | +(FS - 1LSB) |
| 11111110 | +(FS - 2LSB) |
| 11000000 | +½FS |
| 10000001 | +1LSB |
| 10000000 | 0 |
| 01111111 | −1LSB |
| 01000000 | −½FS |
| 00000001 | −(FS - 1LSB) |
| 00000000 | −FS |