

# Programmable seven-channel RC encoder

NE5044

## DESCRIPTION

The NE5044 is a programmable parallel input, serial output pulse width encoder. A multiplexed dual linear ramp technique is used to allow up to 7 inputs to be converted to a serial pulse width modulated signal with excellent linearity and minimal crosstalk. Fixed or variable frame rates can be used, externally controlled, for ease of demodulation. An on-board 5V regulator eliminates power supply sensitivities and provides up to 20mA current capability for driving external loads.

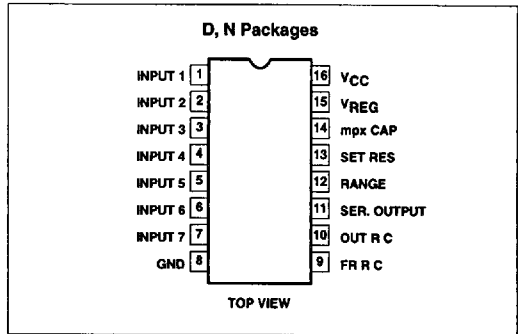
## FEATURES

- 3 to 7 channels, externally selectable
- Constant-current dual linear ramp for linearity better than 0.3%
- Internal voltage regulator for low drift
- Wide supply range 4.5-12V
- Fixed or variable frame rate set by external RC
- External control for channel gain or range
- Versatile applications: exponential rates, mixing, dual rate, reversing, etc.
- Compatible with all transmission mediums

## APPLICATIONS

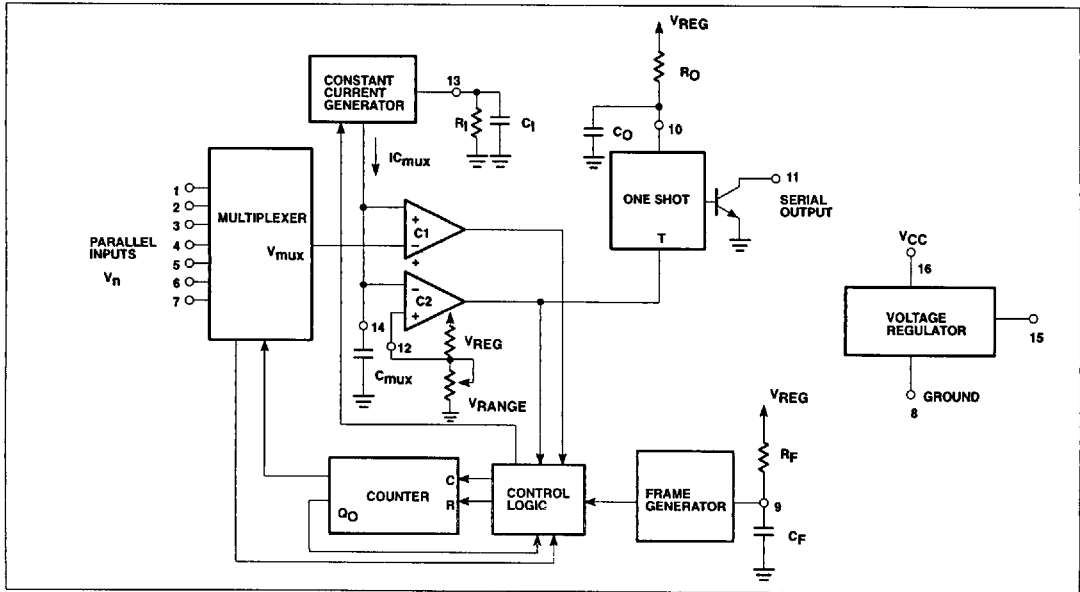
- Radio-controlled aircraft, cars, boats, trains

## PIN CONFIGURATION



- Industrial controllers
- Remote-controlled entertainment systems
- Security systems
- Instrumentation recorders/controls
- Remote analog/digital data transmission
- Automotive sensor systems
- Robotics
- Telemetry

## BLOCK DIAGRAM



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## ORDERING INFORMATION

DESCRIPTION	TEMPERATURE RANGE	ORDER CODE	DWG #
16-Pin Plastic Small Outline (SO) Package	0 to +70°C	NE5044D	0005D
16-Pin Plastic Dual In-Line Package (DIP)	0 to +70°C	NE5044N	0406C

## ABSOLUTE MAXIMUM RATINGS<sup>1</sup>

SYMBOL	PARAMETER	RATING	UNIT
V <sub>CC</sub>	Supply voltage	13	V
I <sub>OUT</sub>	Regulator output current	-25	mA
	Serial output peak current	30	mA
	Constant-current generator	-1	mA
	Parallel inputs, range input	0-V <sub>REG</sub>	V
	One-shot input, frame generator input	0-V <sub>REG</sub>	V
T <sub>A</sub>	Operating temperature range	0 to +70	°C
T <sub>STG</sub>	Storage temperature range	-65 to +150	°C

**NOTE:**

1. T<sub>A</sub>=25°C, unless otherwise stated.

## DC ELECTRICAL CHARACTERISTICS

Test Conditions T<sub>A</sub> = 25°C V<sub>CC</sub>=10V using Test Circuit, unless otherwise stated.

SYMBOL	PARAMETER	TEST CONDITIONS	LIMITS			UNIT
			Min	Typ	Max	
<b>Power supply requirements</b>						
V <sub>CC</sub>	Power supply voltage range		4.5		12	V
I <sub>CC</sub>	Power supply current	Excluding control pots and serial output currents		11	15	mA
<b>Voltage regulator</b>						
V <sub>REG</sub>	Output voltage		4.5	5.0	5.5	V
I <sub>OUT</sub>	Output current	V <sub>R</sub> ≥4.5V			-20	mA
	Line regulation	7≤V <sub>CC</sub> ≤12		0.005	0.02	V/V
<b>Multiplexer</b>						
I <sub>IN</sub>	Input current	V <sub>n</sub> =2.5V		±30	±200	nA
V <sub>IN</sub>	Input voltage range	V <sub>n</sub> -V <sub>Range</sub> ≥0.75V	1.5		5	V
	Crosstalk			±1	±5	µs

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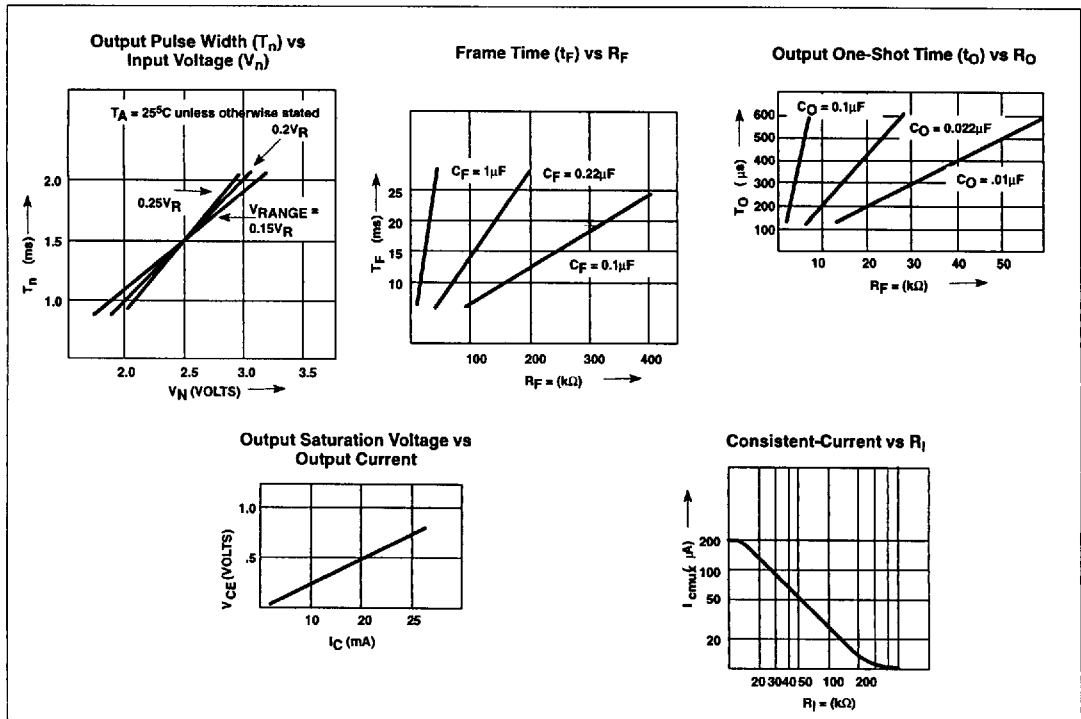
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## AC ELECTRICAL CHARACTERISTICS

Test conditions  $T_A=25^{\circ}\text{C}$ ,  $V_{CC}=10\text{V}$  using Test Circuit, unless otherwise stated.

SYMBOL	PARAMETER	TEST CONDITIONS	LIMITS			UNIT
			Min	Typ	Max	
<b>Output pulse</b>						
$t_n$	Position	$R_I \cdot C_{MUX}=1.25\text{ms}$ $V_n=0.5V_{REG}$ ; $V_{RANGE}=0.2V_{REG}$	1350	1500	1650	$\mu\text{s}$
	Position linearity error			5		$\mu\text{s}$
	Position tempco	$0^{\circ}\text{C} \leq T_A \leq 70^{\circ}\text{C}$		0.15		$\mu\text{s}/^{\circ}\text{C}$
	Position PSR	$6\text{V} \leq V_{CC} \leq 12\text{V}$		0.5	1	$\mu\text{s}/\text{V}$
$t_O$	Width	$R_O C_O=300\mu\text{s}$	240	285	330	$\mu\text{s}$
	Saturation voltage	$I_O=25\text{mA}$		0.6	1	V
$I_{11}$	Leakage current			0.05	50	$\mu\text{A}$
$R_I$	Range input voltage	$R_I=50\text{k}\Omega$ $R_I=25\text{k}\Omega$	0.75 1.00			V
	Frame time (fixed)	$R_F C_F=30\text{ms}$	17	20	23	ms
	Inhibit threshold				0.4	V

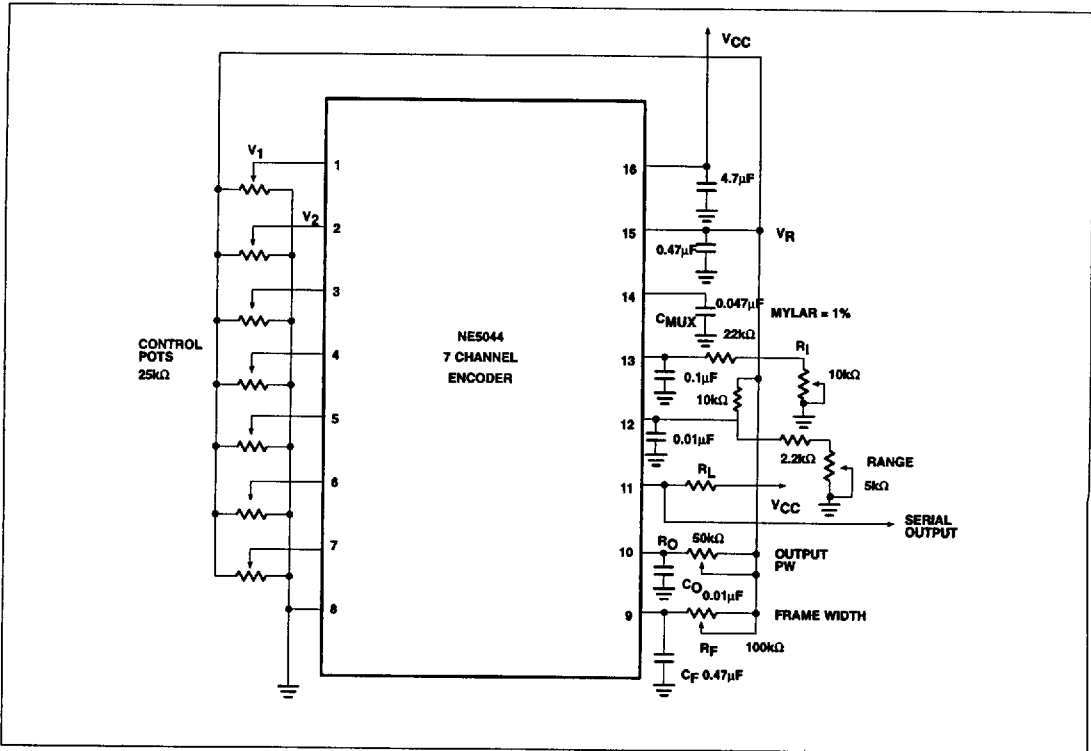
## TYPICAL PERFORMANCE CHARACTERISTICS



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## TEST CIRCUIT



### CIRCUIT OPERATION

The NE5044 is a programmable parallel input, serial output encoder containing all the active circuitry necessary to generate a precise pulse width modulated signal with 3 to 7 channels. The number of channels is externally programmable by grounding unused control inputs. A multiplexed dual linear ramp technique is used to provide excellent linearity, minimal crosstalk and low temperature drift. An on-board 5V regulator eliminates power supply sensitivities and has up to 20mA current capability for driving external loads. The encoder can be used in the fixed-frame mode or, with the addition of one external NPN transistor, as a variable-frame encoder.

The multiplexer functions as a strobed voltage-follower so that each input, when active, appears as a high-impedance input (>1MΩ) and transfers the input voltage to the output. Only one of the seven inputs is active at any time and when a given input is inactive, it appears as an open circuit. The high-impedance multiplexer inputs eliminate loading on control inputs and simplify mixing circuits where several controls may be mixed onto one input.

Channel 4, 5, 6 and 7 inputs may also be used to select the desired number of output pulses by grounding one or more of these pins. That is, by grounding Pin 4 (Channel 4 input) only the first three inputs of the encoder will be used and a 3-channel encoder results. Grounding Pin 5 results in a 4-channel encoder, and so on. Thus, any number of channels between 3 and 7 may be selected. Internal voltage clamping prevents encoder malfunction if any input is shorted to supply, ground or open-circuited. The remaining channels will continue to be encoded except as noted above. This feature

eliminates catastrophic failures due to control pot open- or short-circuits.

The constant-current generator is a bidirectional current source whose current is set by an external resistor  $R_1$ , where:

$$I_C = \pm \frac{V_R}{2R_1}$$

The current generator alternately charges and discharges the capacitor  $C_{MUX}$ . An internal feedback loop maintains a constant current and very high output impedance. This yields a typical linearity error of voltage input to pulse width output for the encoder of less than 0.1%. An external capacitor,  $C_1$ , is required to insure stability of the feedback loop.

Two high gain comparators, C1 and C2, compare the voltage across  $C_{MUX}$  with the multiplexer output voltage and the range input voltage. The input bias currents and offset voltages of these comparators are sufficiently low so as to not influence the overall accuracy of the encoder. The comparators feed the counter control logic which in turn controls the counter and current generator. The operation of this loop is as follows: When  $I_C$  is positive (sourced from the current generator into  $C_{MUX}$ ) the capacitor linearly charges up until it reaches a voltage equal to the multiplexer output voltage; assume this to be the voltage at Pin 1,  $V_1$ . At this time the output of C1 goes high, which reverses the direction of  $I_C$  (sinking into current generator from  $C_{MUX}$ ).  $C_{MUX}$  now linearly discharges until it reaches the voltage set on Pin 12,  $V_{RANGE}$ . At this time the output of C2 goes high, which again reverses the polarity of  $I_C$ , clocks the

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counter, and triggers the output one-shot.  $C_{MUX}$  again charges up but now  $C_1$  goes high when  $C_{MUX}$  reaches  $V_2$ , the voltage on Pin 2. The resulting voltage waveform on  $C_{MUX}$  is a triangle wave whose positive peaks correspond to the voltages on Pins 1 through 7 for the first through seventh peaks and whose negative peaks are constant and equal to  $V_{RANGE}$ . This waveform is shown in the first portion of Figure 1.

Independent control of  $I_C$  and  $V_{RANGE}$  allows the encoder to be tailored to virtually any combination of input voltage changes and output pulse width changes. The functional relationships between these variables will be defined in the next section.

The frame generator controls the encoder frame time. It can operate as an astable or monostable multivibrator whose period is  $0.66 \times R_F \times C_F$ . The encoder will generate a synchronizing pulse at the end of each frame. When  $C_{MUX}$  reaches the seventh positive peak it reverses and discharges to  $V_{RANGE}$ . The counter is clocked to the state where  $Q_0$  is high when  $V_{CMUX} = V_{RANGE}$ .  $C_{MUX}$  again charges up, but now the output of  $C_1$  is ignored, due to  $Q_0$  being high, and charges up to  $V_{CLAMP}$  and remains there. The encoder will remain in this state until a pulse from the frame generator is received. If  $R_F$  and  $C_F$  are connected as shown in the Block Diagram, then the frame generator operates in the astable mode, producing a narrow pulse output. This pulse allows  $C_{MUX}$  to start discharging again. When  $C_{MUX}$  reaches  $V_{RANGE}$ , the counter is clocked to the state where  $Q_1$  is high (channel 1) and the entire process starts over. The frame period in this mode is  $0.66 \times R_F \times C_F$  and is referred to as the fixed-frame mode. The variable-frame mode will be discussed in the application section.

The output one-shot generates a positive pulse whose width is equal to  $R_0 C_0$ . The output is an open-collector, NPN transistor capable of sinking 25mA. This configuration allows the encoder to drive a wide variety of RF stages as well as providing current pulses in 2-wire communications applications.

## ENCODER DESIGN EQUATIONS

The triangular waveform on  $C_{MUX}$  has a fixed slope (constant current) and variable positive peak voltages. The time between the negative peaks of  $C_{MUX}$ , which is equal to the output period for that channel, is given by:

$$t_n = \frac{2 (V_n - V_{RANGE}) C_{MUX}}{I_C}$$

$I_C$  is given by:

$$I_C = \frac{V_R}{2R_1}$$

where  $V_R$  = Reference Voltage.

Additionally,  $V_n$ , the voltage on Pin n, which is the control voltage for Channel n, is typically the wiper voltage on a pot connected between  $V_R$  and ground. Thus  $V_n = X_n V_R$ .

$V_{RANGE}$  is also derived from  $V_R$  so that  $V_{RANGE} = Y V_R$ . The resulting channel time period is:

$$t_n = \frac{2 (X_n - Y) V_R \cdot C_{MUX}}{(V_R / 2R_1)}$$

$$t_n = 4R_1 C_{MUX} (X_n - Y)$$

Thus, each channel pulse width,  $t_n$ , is independent of supply voltage and depends only on external passive components.

The conversion rate, CR, for each channel is the change in output period,  $\Delta t_n$ , divided by the change in input voltage for that channel,  $\Delta V_n$ .

$$CR = \frac{\Delta t_n}{\Delta V_n} = \frac{\Delta t_n}{\Delta X_n} = 4 R_1 C_{MUX}$$

In most applications, the input variable  $X_n$  will have some neutral or center value about which it will vary, thus  $X_n = X_0 + X_n$ ,

and

$$CR = \frac{\Delta t_n}{\Delta X_n} = 4R_1 C_{MUX}$$

Where  $X_0$  is the neutral value for X and is assumed to be the same for all n. Now

$$t_n = 4R_1 C_{MUX} (X_0 + Y + X_n)$$

If we let  $t_{NEUTRAL} = 4R_1 C_{MUX} (X_0 + Y)$  be the neutral value for  $t_n$ , then

$$t_n = t_{NEUTRAL} + 4R_1 C_{MUX} (X_n)$$

Consider the following example to see how these design equations are used.

Assume:

$$t_{NEUTRAL} = 1.5ms$$

$$X_0 = 0.5 \text{---Control pot in center at}$$

$$t_n = t_{NEUTRAL}$$

$\Delta X_n = \pm 0.1$ ---Control pot resistance varies  $\pm 10\%$  (of total resistance) around neutral. This should include mechanical trim if used.

$$\Delta t_n = \pm 0.5ms$$

For this example, the conversion rate is

$$CR = \frac{\Delta t_n}{\Delta X_n} = \frac{0.5ms}{0.1} = 5ms$$

so

$$4R_1 C_{MUX} = 5ms.$$

If we let  $C_{MUX} = 0.047\mu F$  then

$$R_1 = \frac{5ms}{4 \times 0.047\mu F} = 26.5k\Omega = 27k\Omega$$

and

$$t_{NEUTRAL} = 1.5ms = 4R_1 C_{MUX} (X_0 + Y)$$

$$Y = 0.5 - \frac{1.5ms}{5ms} = 0.2$$

The output pulse width is given by

$$t_0 = R_0 C_0$$

so if  $t_0 = 330\mu s$  and  $C_0 = 0.01\mu F$  then

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$$R_O = \frac{330\mu s}{0.01\mu F} = 33k\Omega$$

The frame time constant,  $t_F$  is given by

$$t_F = 0.66 R_F C_F$$

If  $t_F = 20ms$  and  $C_F = 0.47\mu F$

$$R_F = \frac{20ms}{0.66 \times 0.47\mu F} = 62k$$

Figure 2 shows the external connections for this example.

It should be noted that the temperature stability of all the encoded times depend on the temperature coefficients of the respective external  $R_C$  time constants. No internal temperature compensation is used on the chip. The typical temperature sensitivity of  $t_n$  using wirewound resistors and polycarbonate capacitors is less than 100ppm/°C in the -20°C to +70°C temperature range. For the above example, this corresponds to a change in  $t_n$  of  $\pm 7.5\mu s$  for a change in temperature of  $\pm 50^\circ C$ .

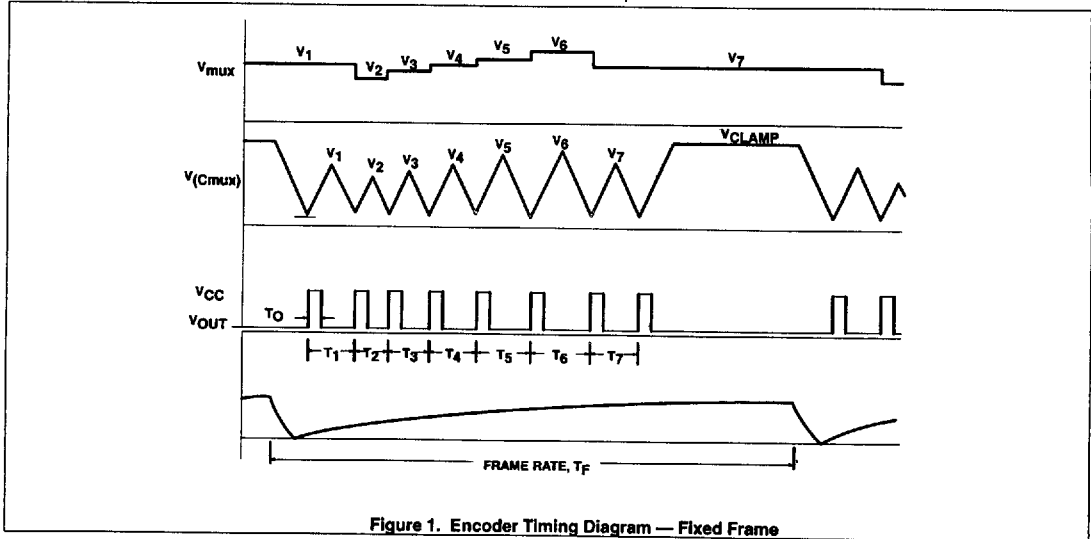


Figure 1. Encoder Timing Diagram — Fixed Frame

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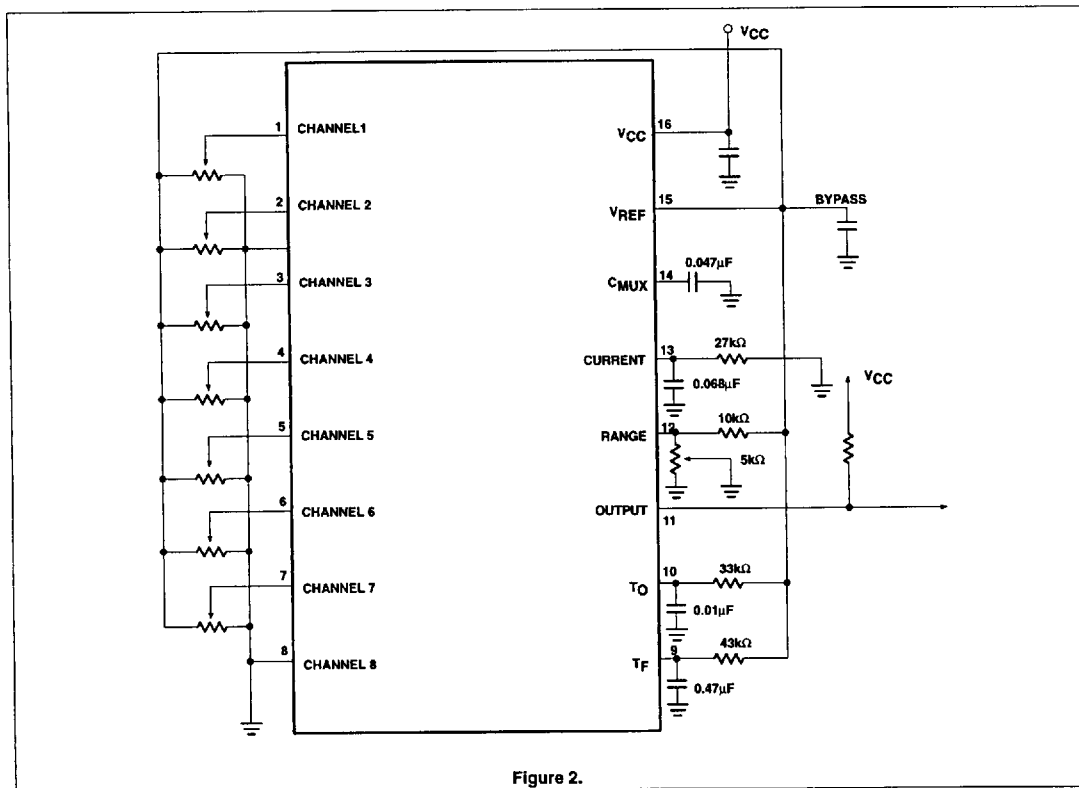


Figure 2.