TELEDYNE COMPONENTS

TC9400
TC9401
TC9402

3

VOLTAGE-TO-FREQUENCY/FREQUENCY-TO-VOLTAGE CONVERTERS

FEATURES

Voltage-to-Frequency

- Operation .... 1 Hz to 100 kHz
- Choice of Guaranteed Linearity:
  - TC9401 .... 0.01%
  - TC9400 .... 0.05%
  - TC9402 .... 0.25%
- Gain Temperature Stability .... ±25 ppm/°C Typ
- Open-Collector Output
- Output Can Interface With Any Form of Logic
- Pulse and Square-Wave Outputs
- Programmable Scale Factor
- Low Power Dissipation .... 27 mW Typ
- Single-Supply Operation .... +8V to +15V
- Dual-Supply Operation .... ±4V to ±7.5V
- Current or Voltage Input

Frequency-to-Voltage

- Operation .... DC to 100 kHz
- Choice of Guaranteed Linearity:
  - TC9401 .... 0.02%
  - TC9400 .... 0.05%
  - TC9402 .... 0.25%
- Op-Amp Output
- Programmable Scale Factor
- High Input Impedance .... >10 MΩ
- Accepts Any Voltage Waveshape

APPLICATIONS

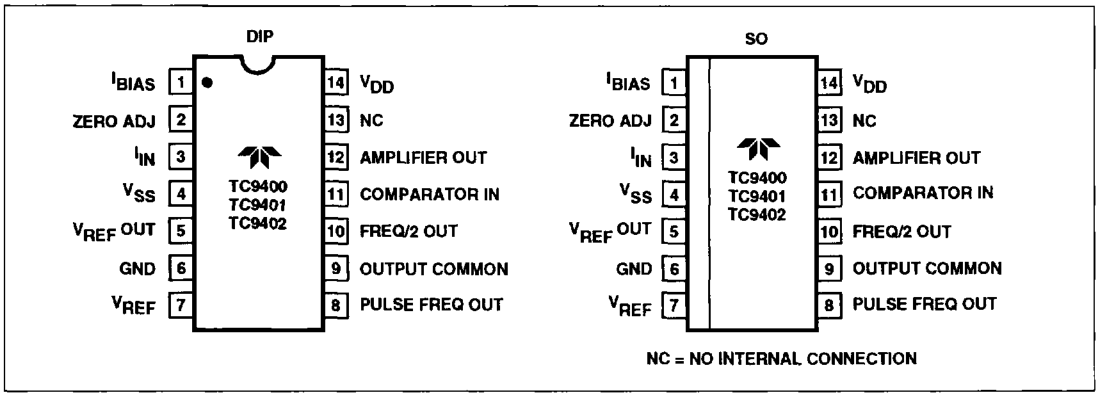
Voltage-to-Frequency

- Temperature Sensing and Control
- μP Data Acquisition
- Instrumentation
- 13-Bit Analog-to-Digital Converters
- Digital Panel Meters
- Analog Data Transmission and Recording
- Phase-Locked Loops
- Medical Isolation
- Transducer Encoding
- Alternate to 555 Astable Timer

Frequency-to-Voltage

- Frequency Meters/Tachometer
- Speedometers
- Analog Data Transmission and Recording
- Medical Isolation
- Motor Control
- RPM Indicator
- FM Demodulation
- Frequency Multiplier/Divider
- Flow Measurement and Control

PIN CONFIGURATIONS



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TC9400
TC9401
TC9402

GENERAL DESCRIPTION

The TC9400/TC9401/TC9402 are low-cost voltage-to-frequency (V/F) converters combining bipolar and CMOS technology on the same substrate. The converters accept a variable analog input signal and generate an output pulse train whose frequency is linearly proportional to the input voltage.

The devices can also be used as highly-accurate frequency-to-voltage (F/V) converters, accepting virtually any input frequency waveform and providing a linearly-proportional voltage output.

A complete V/F or F/V system requires the addition of two capacitors, three resistors, and reference voltage.

ORDERING INFORMATION

Part No.	Linearity (V/F)	Package	Temperature Range
TC9400CPD	0.05%	14-Pin Plastic DIP	0°C to +70°C
TC9400EJD	0.05%	14-Pin CerDIP	–40°C to +85°C
TC9400COD	0.05%	14-Pin SO	0°C to +70°C
TC9401CPD	0.01%	14-Pin Plastic DIP	0°C to +70°C
TC9401EJD	0.01%	14-Pin CerDIP	–40°C to +85°C
TC9402CJD	0.25%	14-Pin Plastic DIP	0°C to +70°C
TC9402EJD	0.25%	14-Pin CerDIP	–40°C to +85°C

ABSOLUTE MAXIMUM RATINGS

$V_{DD} - V_{SS}$ .... +18V
I_{IN} .... 10 mA
V_{OUT} Max $-V_{OUT}$ Common .... +25V
$V_{REF} - V_{SS}$ .... –1.5V
Storage Temperature Range .... –65°C to +150°C
Operating Temperature Range
C Device .... 0°C to +70°C
E Device .... –40°C to +85°C
Package Dissipation .... 500 mW
Lead Temperature (Soldering, 10 sec) .... +300°C

Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields. Stresses above 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 above 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, V_{SS} = –5V, V_{GND} = 0, V_{REF} = –5V, R_{BIAS} = 100 kΩ, Full Scale =10 kHz, unless otherwise specified. T_A = +25°C, unless temperature range is specified –40°C to +85°C for E device, 0°C to +70°C for C device.

VOLTAGE-TO-FREQUENCY		TC9401			TC9400			TC9402			
Parameter	**Definition**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Unit**
Accuracy											
Linearity 10 kHz	Output Deviation From Straight Line Between Normalized Zero and Full-Scale Input	—	0.004	0.01	—	0.01	0.05	—	0.05	0.25	% Full Scale
Linearity 100 kHz	Output Deviation From Straight Line Between Normalized Zero and Full-Scale Input	—	0.04	0.08	—	0.1	0.25	—	0.25	0.5	% Full Scale
Gain Temperature Drift (Note 1)	Variation in Gain A Due to Temperature Change	—	±25	±40	—	±25	±40	—	±50	±100	ppm/°C Full Scale
Gain Variance	Variation From Exact A Compensate by Trimming R_{IN}, V_{REF}, or C_{REF}	—	±10	—	—	±10	—	—	±10	—	% of Nominal
Zero Offset (Note 2)	Correction at Zero Adjust for Zero Output When Input is Zero	—	±10	±50	—	±10	±50	—	±20	±100	mV
Zero Temperature Drift (Note 1)	Variation in Zero Offset Due to Temperature Change	—	±25	±50	—	±25	±50	—	±50	±100	μV/°C
Analog Input											
I_{IN} Full Scale	Full-Scale Analog Input Current to Achieve Specified Accuracy	—	10	—	—	10	—	—	10	—	μA
I_{IN} Overrange	Overrange Current	—	—	50	—	—	50	—	—	50	μA
Response Time	Settling Time to 0.1% Full Scale	—	2	—	—	2	—	—	2	—	Cycle
Digital Output											
V_{SAT} @ I_{OL} = 10 μA (Note 3)	Logic "0" Output Voltage	—	—	0.4	—	—	0.4	—	—	0.4	V
V_{OUT} Max – V_{OUT} Common (Note 4)	Voltage Range Between Output and Common	—	—	18	—	—	18	—	—	18	V
Pulse Frequency Output Width		—	3	—	—	3	—	—	3	—	μs
Supply Current											
I_{DD} Quiescent	Current Required From Positive Supply During Operation										
E Device (Note 9)		—	2	4	—	2	4	—	—	—	mA
C Device		—	2	6	—	2	6	—	3	10	mA
I_{SS} Quiescent	Current Required From Negative Supply During Operation										
E Device (Note 10)		—	–1.5	–4	—	–1.5	–4	—	—	—	mA
C Device		—	–1.5	–6	—	–1.5	–6	—	–3	–10	mA
V_{DD} Supply	Operating Range of Positive Supply	4	—	7.5	4	—	7.5	4	—	7.5	V
V_{SS} Supply	Operating Range of Negative Supply	–4	—	–7.5	–4	—	–7.5	–4	—	–7.5	V
Reference Voltage											
V_{REF} –V_{SS}	Range of Voltage Reference Input	–1	—	—	–1	—	—	–1	—	—	V

NOTES:
1. Full temperature range.
2. I_{IN} = 0.
3. Full temperature range, I_{OUT} = 10 mA.
4. I_{OUT} = 10 μA.
5. 10 Hz to 100 kHz.
6. 5 μs minimum positive pulse width and 0.5 μs minimum negative pulse width.
7. t_R = t_F = 20 ns.
8. R_L ≥ 2 kΩ.
9. Full temperature range, V_{IN} = –0.1V.
10. V_{IN} ≈ –0.1V.
11. I_{IN} connects the summing junction of an operational amplifier. Voltage sources cannot be attached directly, but must be buffered by external resistors.

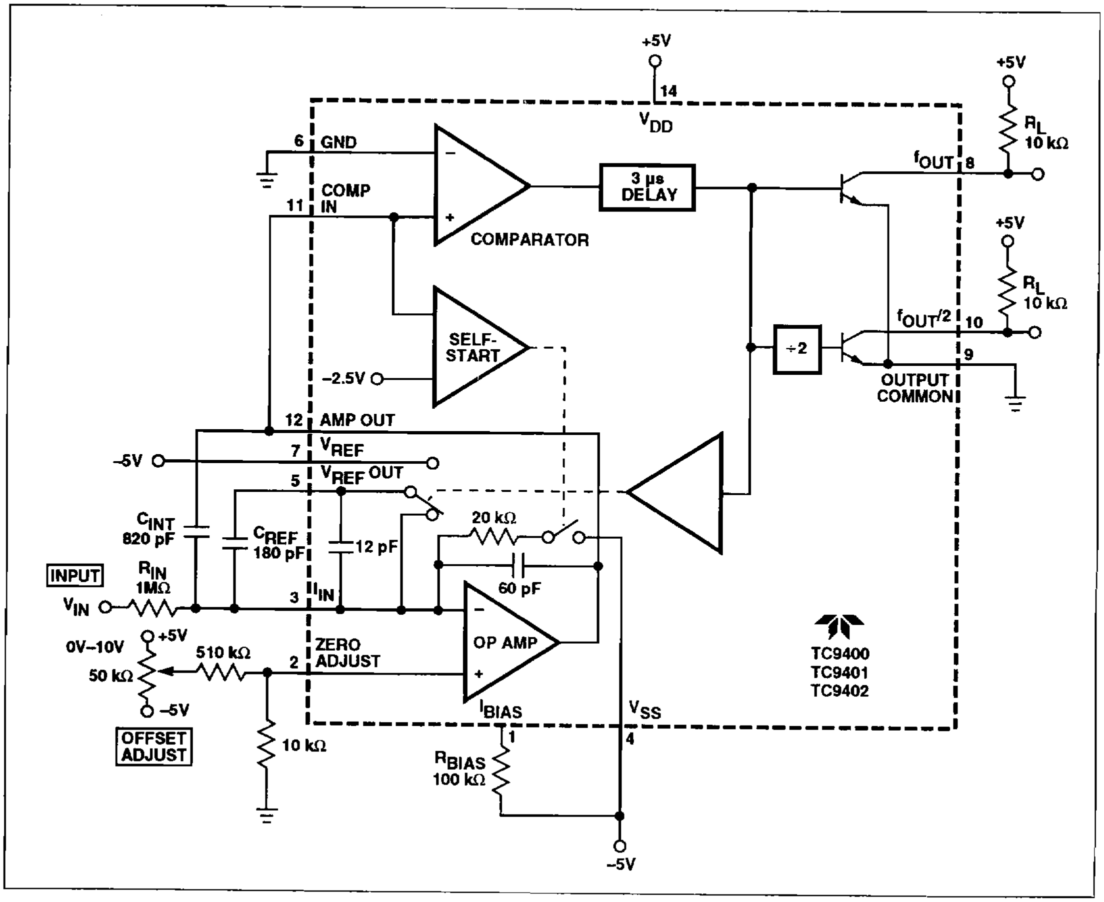
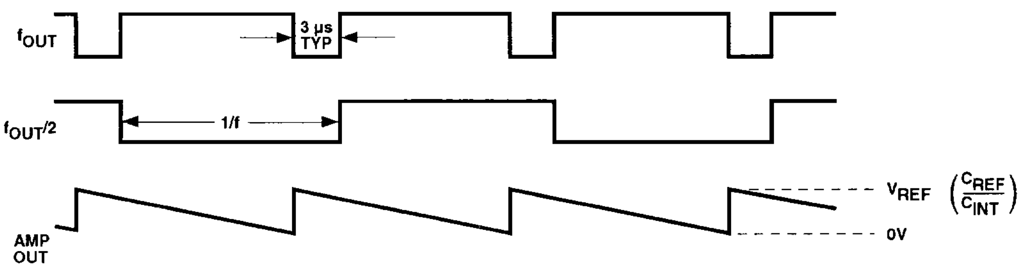


Figure 1 10 Hz to 10 kHz V/F Converter

VOLTAGE-TO-FREQUENCY (V/F) CIRCUIT DESCRIPTION

The TC9400 V/F converter operates on the principal of charge balancing. The input voltage (V_{IN}) is converted to a current (I_{IN}) by the input resistor. This current is then converted to a charge by the integrating capacitor and shows up as linearly decreasing voltage at the output of the op amp. The zero crossing of the output is sensed by the comparator causing the reference voltage to be applied to the reference capacitor for a time period long enough to virtually charge the capacitor to the reference voltage. This action reduces the charge on the integrating capacitor by a fixed amount ($q = C_{REF} \times V_{REF}$), causing the op-amp output to step up a finite amount.

At the end of the charging period, C_{REF} is shorted out, dissipating the stored reference charge, so when the output again crosses zero, the system is ready to recycle. In this manner, the continued discharging of the integrating capacitor by the input is balanced out by fixed charges from the reference voltage. As the input voltage is increased, the number of reference pulses required to maintain balance increases, causing the output frequency to also increase. Since each charge increment is fixed, the increase in frequency with voltage is near. In addition, the accuracy of the output pulses does not directly affect the linearity of the V/F. It must simply be long enough for full charge transfer to take place.



NOTES: 1. To adjust f_{MIN}, set V_{IN} = 10 mV and adjust the 50 kΩ offset for 10 Hz output.
2. To adjust f_{MAX}, set V_{IN} = 10V and adjust R_{IN} or V_{REF} for 10 kHz output.
3. To increase f_{OUT} MAX to 100 kHz, change C_{REF} to 27 pF and C_{INT} to 75 pF.
4. For high-performance applications, use high-stability components for R_{IN}, C_{REF}, V_{REF} (metal film resistors and glass capacitors). Also, separate output ground (pin 9) from input ground (pin 6).

Figure 2 Output Waveforms

The TC9400 contains a "self-start" circuit to ensure the V/F converter always operates properly when power is first applied. In the event during "power-on" the op-amp output is below comparator threshold, and C_{REF} is already charged, a positive voltage step will not occur. The op-amp output will continue to decrease until it crosses the –2.5V threshold of the "self-start" comparator. When this happens, a resistor is connected to the op-amp input, causing the output to quickly go positive until the TC9400 is once again in its normal operating mode.

The TC9400 utilizes both bipolar and MOS transistors on the same substrate, taking advantage of the best features of each. MOS transistors are used at the inputs to reduce offset and bias currents. Bipolar transistors are used in the op amp for high gain, and on all outputs for excellent current driving capabilities, CMOS logic is used throughout to minimize power consumption.

PIN FUNCTIONS

Comparator Input

In the V/F mode, this input is connected to the amplifier output (pin 12) and triggers the 3 µs pulse delay when the input voltage passes its threshold. In the F/V mode, the input frequency is applied to the comparator input.

Pulse Freq Out

This output is an open-collector bipolar transistor providing a pulse waveform whose frequency is proportional to the input voltage. This output requires a pull-up resistor and interfaces directly with MOS, CMOS and TTL logic.

Freq/2 Out

This output is an open-collector bipolar transistor providing a square wave one-half the frequency of the pulse frequency output. This output requires a pull-up resistor and interfaces directly with MOS, CMOS, and TTL logic.

Output Common

The emitters of both the freq/2 out and the pulse freq out are connected to this pin. An output level swing from the collector voltage to ground or to the V_{SS} supply may be obtained by connecting to the appropriate point.

R_{BIAS}

Specifications for the TC9400 are based on R_{BIAS} = 100 kΩ ±10%, unless otherwise noted. R_{BIAS} may be varied between the range of 82 kΩ ≤ R_{BIAS} ≤ 120 kΩ.

Amplifier Out

The output stage of the operational amplifier. A negative-going ramp signal is available at this pin in the V/F mode. In the F/V mode, a voltage proportional to the frequency input is generated.

Zero Adjust

The noninverting input of the operational amplifier. The low-frequency set point is determined by adjusting the voltage at this pin.

I_{IN}

The inverting input of the operational amplifier and the summing junction when connected in the V/F mode. An input current of 10 µA is specified for nominal full scale, but an overrange current up to 50 µA can be used without detrimental effect to the circuit operation.

V_{REF}

A reference voltage from either a precision source or the V_{SS} supply may be applied to this pin. Accuracy will be dependent on the voltage regulation and temperature characteristics of the circuitry.

V_{REF} Out

The charging current for C_{REF} is derived from the internal circuitry and switched by the break-before-make switch to this pin.

V/F CONVERTER DESIGN INFORMATION

Input/Output Relationships

The output frequency (f_{OUT}) is related to the analog input voltage (V_{IN}) by the transfer equation:

$$\text{Frequency out} = \frac{V_{IN}}{R_{IN}} \times \frac{1}{(V_{REF})\,(C_{REF})} = f_{OUT}.$$

External Component Selection

R_{IN}

The value of this component is chosen to give a full-scale input current of approximately 10 µA:

$$R_{IN} \cong \frac{V_{IN}\ \text{Full Scale}}{10\ \mu A}.$$

$$\text{Example:}\quad R_{IN} \cong \frac{10V}{10\ \mu A} = 1\ M\Omega.$$

Note that the value is an approximation and the exact relationship is defined by the transfer equation. In practice, the value of R_{IN} typically would be trimmed to obtain full-scale frequency at V_{IN} full scale (see "Adjustment Procedure"). Metal film resistors with 1% tolerance or better are recommended for high-accuracy applications because of their thermal stability and low-noise generation.

C_{INT}

The exact value is not critical but is related to C_{REF} by the relationship:

$$3C_{REF} \le C_{INT} \le 10\ C_{REF}.$$

Improved stability and linearity are obtained when $C_{INT} \le 4C_{REF}$. Low-leakage types are recommended, although mica and ceramic devices can be used in applications where their temperature limits are not exceeded. Locate as close as possible to pins 12 and 13.

C_{REF}

The exact value is not critical and may be used to trim the full-scale frequency (see "Input/Output Relationships"). Glass film or air trimmer capacitors are recommended because of their stability and low leakage. Locate as close as possible to pins 5 and 3.

V_{DD}, V_{SS}

Power supplies of ±5V are recommended. For high-accuracy requirements, 0.05% line and load regulation and 0.1 µF disc decoupling capacitors located near the pins are recommended.

Adjustment Procedure

Figure 1 shows a circuit for trimming the zero location. Full scale may be trimmed by adjusting R_{IN}, V_{REF}, or C_{REF}. Recommended procedure for a 10 kHz full-scale frequency is as follows:

(1) Set V_{IN} to 10 mV and trim the zero adjust circuit to obtain a 10 Hz output frequency.

(2) Set V_{IN} to 10V and trim either R_{IN}, V_{REF}, or C_{REF} to obtain a 10 kHz output frequency.

If adjustments ar performed in this order, there should be no interaction and they should not have to be repeated.

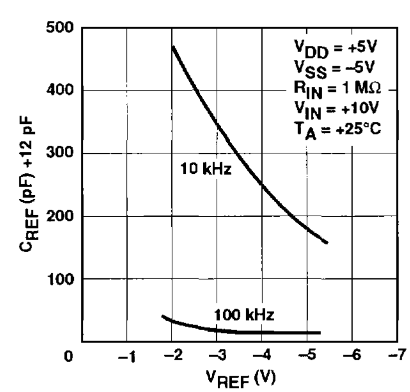
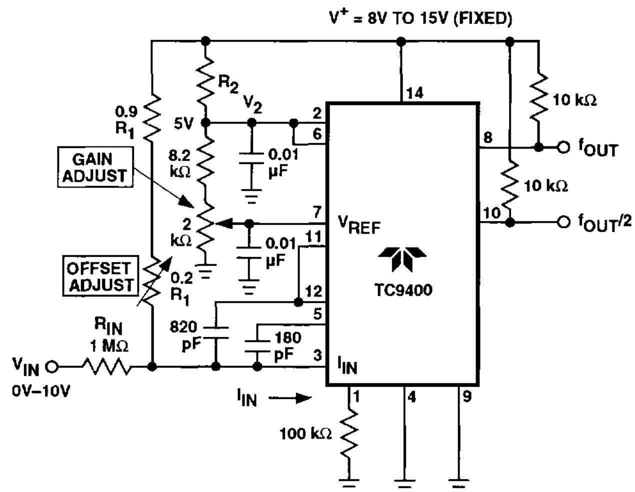


Figure 3 Recommended C_{REF} vs V_{REF}



V^+	R_1	R_2
10V	1 MΩ	10 kΩ
12V	14 MΩ	14 kΩ
15V	2 MΩ	20 kΩ

$$f_{OUT} = I_{IN} \times \frac{1}{(V_2 - V_7)\,(C_{REF})}$$

$$I_{IN} = \frac{(V_{IN} - V_2)}{R_{IN}} + \frac{(V^+ - V_2)}{(0.9\,R_1 + 0.2\,R_1)}$$

Figure 4 Fixed Voltage — Single Supply Operation

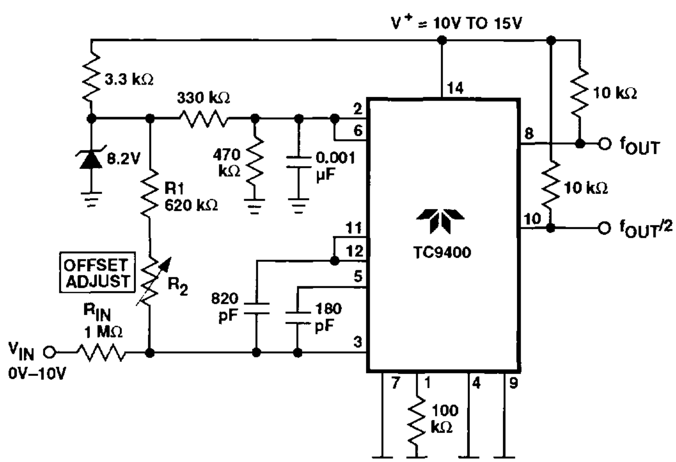


Figure 5 Variable Voltage — Single Supply Operation

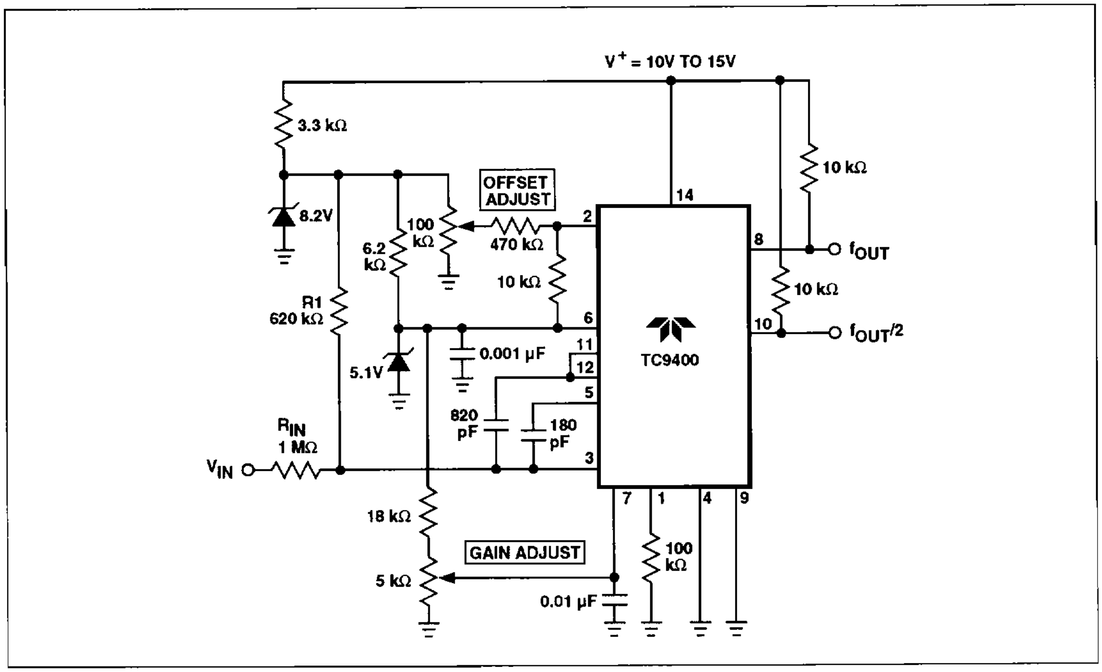


Figure 6 Single Variable Supply Voltage With Offset and Gain Adjust

ELECTRICAL CHARACTERISTICS:

V_{DD} = +5V, V_{SS} = –5V, V_{GND} = 0, V_{REF} = –5V, R_{BIAS} = 100 kΩ, Full Scale = 10 kHz, unless otherwise specified. T_A = +25°C, unless temperature range is specified –40°C to +85°C for E device, 0°C to +70°C for C device.

FREQUENCY-TO-VOLTAGE		TC9401			TC9400			TC9402			
Parameter	**Definition**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Unit**
Accuracy											
Nonlinearity (Note 5)	Deviation From Ideal Transfer Function as a Percentage Full-Scale Voltage		0.01	0.02		0.02	0.05		0.05	0.25	% Full Scale
Input Frequency Range (Note 6)	Frequency Range for Specified Nonlinearity	10		100k	10		100k	10		100k	Hz
Frequency Input											
Positive Excursion (Note 7)	Voltage Required to Turn Comparator On	0.4		V_{DD}	0.4		V_{DD}	0.4		V_{DD}	V
Negative Excursion (Note 7)	Voltage Required to Turn Comparator Off	–0.4		–2	–0.4		–2	–0.4		–2	V
Minimum Positive Pulse Width (Note 7)	Time Between Threshold Crossings		5			5			5		µs
Minimum Negative Pulse Width (Note 7)	Time Between Threshold Crossings		0.5			0.5			0.5		µs
Input Impedance		10			10			10			MW

ELECTRICAL CHARACTERISTICS (Cont.)

FREQUENCY-TO-VOLTAGE		TC9401			TC9400			TC9402			
Parameter	**Definition**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Unit**
Analog Outputs											
Output Voltage (Note 8)	Voltage Range of Op Amp Output for Specified Nonlinearity		$V_{DD}-1$			$V_{DD}-1$			$V_{DD}-1$		V
Output Loading	Resistive Loading at Output of Op Amp	2			2			2			kW
Supply Current											
I_{DD} Quiescent	Current Required From Positive Supply During Operation										
E Device (Note 9)			2	4		2	4				mA
C Device			2	6		2	6		3	10	mA
I_{SS} Quiescent	Current Required From Negative Supply During Operation										
E Device (Note 10)			–1.5	–4		–1.5	–4				mA
C Device			–1.5	–6		–1.5	–6		–3	–10	mA
V_{DD} Supply	Operating Range of Positive Supply	4		7.5	4		7.5	4		7.5	V
V_{SS} Supply	Operating Range of Negative Supply	–4		–7.5	–4		–7.5	–4		–7.5	V
Reference Voltage											
$V_{REF} - V_{SS}$	Range of Voltage Reference Input	–1			–1			–1			V

NOTES:
1. Full temperature range.
2. $I_{IN} = 0$.
3. Full temperature range, $I_{OUT} = 10$ mA.
4. $I_{OUT} = 10\ \mu A$.
5. 10 Hz to 100 kHz.
6. 5 µs minimum positive pulse width and 0.5 µs minimum negative pulse width.
7. $t_R = t_F = 20$ ns.
8. $R_L \geq 2\ k\Omega$.
9. Full temperature range, $V_{IN} = -0.1V$.
10. $V_{IN} = -0.1V$.
11. I_{IN} connects the summing junction of an operational amplifier. Voltage sources cannot be attached directly, but must be buffered by external resistors.

FREQUENCY-TO-VOLTAGE (F/V) CIRCUIT DESCRIPTION

When used as an F/V converter, the TC9400 generates an output voltage linearly proportional to the input frequency waveform.

Each zero crossing at the comparator's input causes a precise amount of charge ($q = C_{REF} \times V_{REF}$) to be dispensed into the op amp's summing junction. This charge in turn flows through the feedback resistor, generating voltage pulses at the output of the op amp. A capacitor (C_{INT}) across R_{INT} averages these pulses into a DC voltage which is linearly proportional to the input frequency.

F/V CONVERTER DESIGN INFORMATION

Input/Output Relationships

The output voltage is related to the input frequency (f_{IN}) by the transfer equation:

$$V_{OUT} = [V_{REF}\ C_{REF}\ R_{INT}]\ f_{IN}.$$

The response time to a change in f_{IN} is equal to (R_{INT} C_{INT}). The amount of ripple on V_{OUT} is inversely proportional to C_{INT} and the input frequency.

C_{INT} can be increased to lower the ripple. Values of 1 µF to 100 µF are perfectly acceptable for low frequencies.

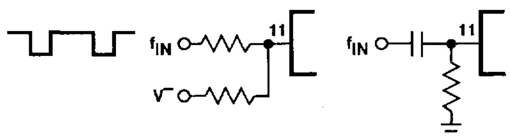
When the TC9400 is used in the single-supply mode, V_{REF} is defined as the voltage difference between pin 7 and pin 2.

Input Voltage Levels

The input signal must cross through zero in order to trip the comparator. To overcome the hysteresis, the amplitude must be greater than ±200 mV.

If only a unipolar input signal (f_{IN}) is available, it is recommended an offset circuit utilizing a resistor be used or the signal be coupled in via a capacitor.

For 100 kHz maximum input, R_{INT} should be decreased to 100 kΩ.



NOTE: C_{REF} should be increased for low f_{IN} max. Adjust C_{REF} so V_{OUT} is approximately 2.5V to 3V for maximum input frequency. When f_{IN} max is less than 1 kHz, the duty cycle should be greater than 20% to ensure C_{REF} is fully charged and discharged.

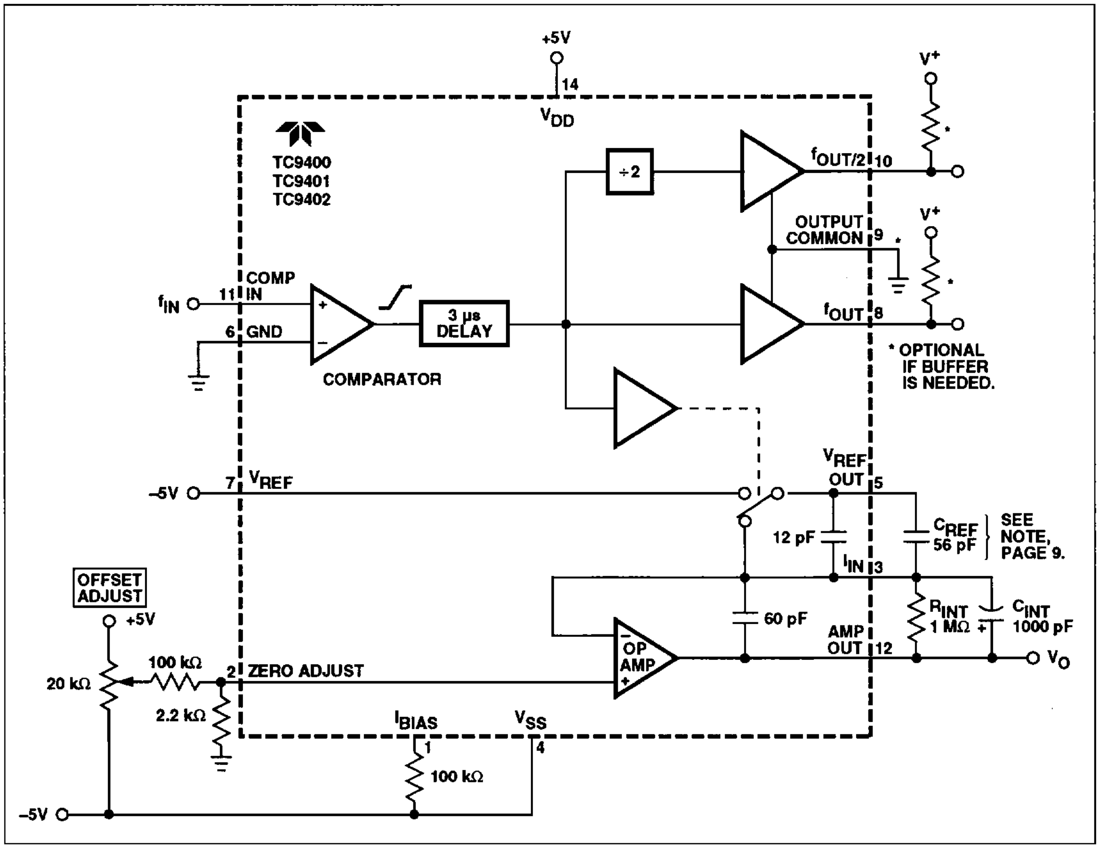


Figure 7 DC — 10 kHz F/V Converter

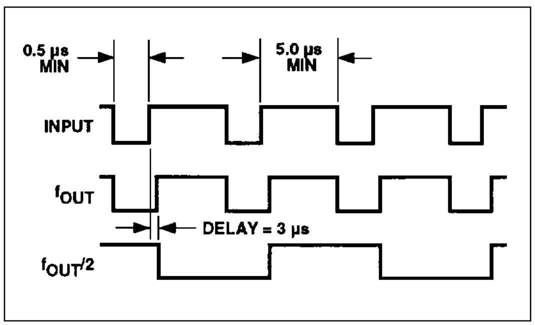
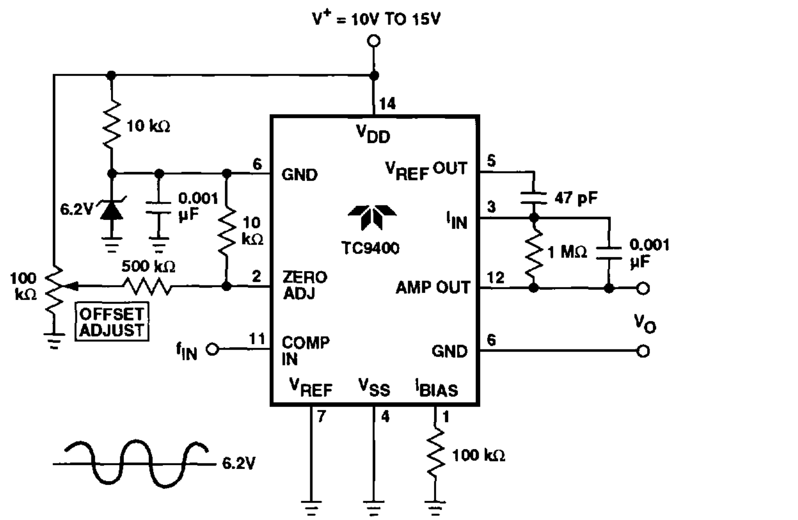


Figure 8 F/V Digital Outputs

Input Buffer

f_{OUT} and $f_{OUT}/2$ are not used in the F/V mode. However, these outputs may be useful for some applications, such as a buffer to feed additional circuitry. Then, f_{OUT} will follow the input frequency waveform, except that f_{OUT} will go high 3 µs after f_{IN} goes high; $f_{OUT}/2$ will be squarewave with a frequency of one-half f_{OUT}.

If these outputs are not used, pins 8, 9 and 10 may be left floating or connected to ground.



NOTES: 1. The input is now referenced to 6.2V (pin 6). The input signal must therefore be restricted to be greater than 4V (pin 6, 2V) and less than 10V to 15V (V_{DD}).

If the signal is AC coupled, a 100kΩ to 10 MΩ resistor must be placed between the input (pin 11) and ground (pin 6).

2. The output will now be referenced to pin 6 which is at 6.2V (V_Z). For frequency meter applications, a 1 mA meter with a series-scaling resistor can be placed across pins 6 and 12.

Figure 9 F/V Single Supply

The sawtooth ripple on the output of an F/V can be eliminated without affecting the F/V's response time by using the circuit in Figure 10. The circuit has a DC gain of +1. Any AC components (such as a ripple) are amplified positively via the lower path and negatively via the upper path. When both paths have the same gain, AC ripple is cancelled. The amount of cancellation is directly proportional to gain matching. If the two paths are matched within 10%, the ripple will be lowered by 1/10. For 1% matching, the ripple is lowered by 1/100. The 10 kΩ potentiometer is used to make the gain equal in both paths. This circuit is insensitive to frequency changes and signal waveshape.

F/V POWER-ON RESET

In F/V mode, the TC9400 output voltage will occasionally be at its maximum value when power is first applied. This condition remains until the first pulse is applied to f_{IN}. In most frequency-measurement applications this is not a problem, because proper operation begins as soon as the frequency input is applied.

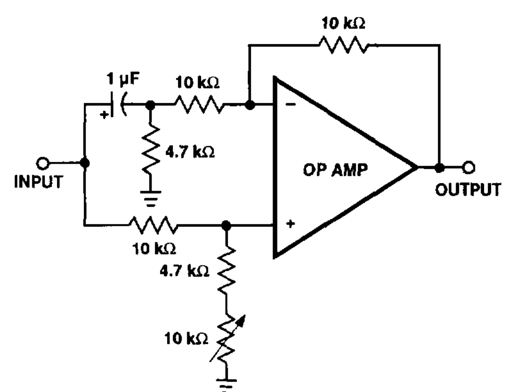


Figure 10 F/V Ripple Eliminator

In some cases, however, the TC9400 output must be zero at power-on without a frequency input. In such cases, a capacitor connected from pin 11 to V_{DD} will usually be sufficient to pulse the TC9400 and provide a power-on reset (see Figure 11A). Where predictable power-on operation is critical, a more complicated circuit, such as Figure 11B, may be required.

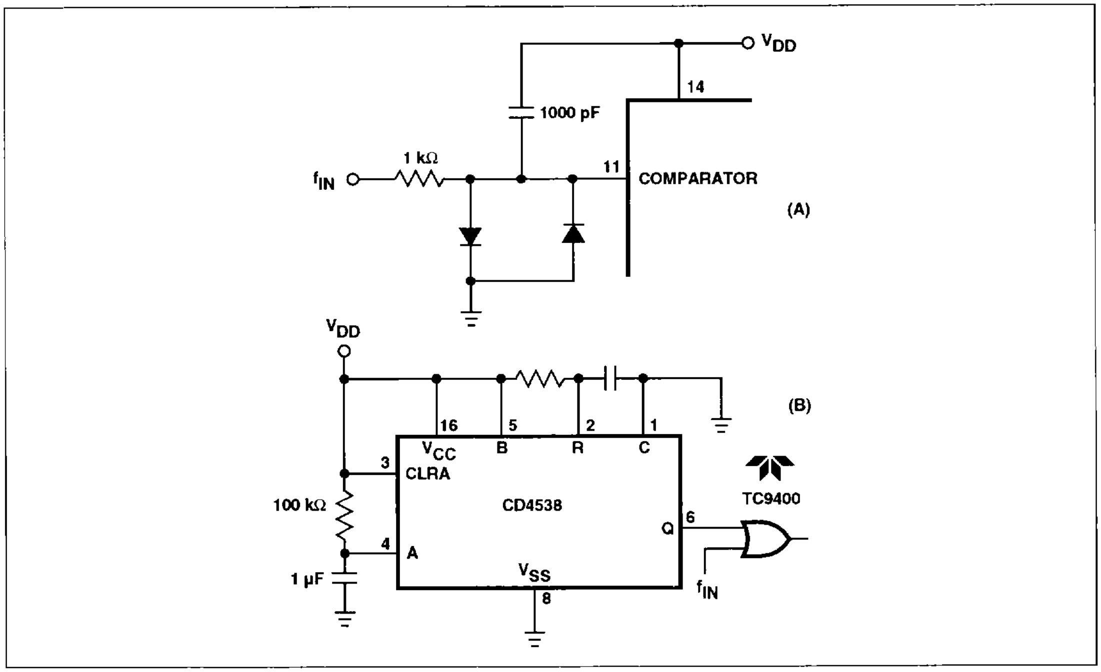


Figure 11 Power-On Operation/Reset