ISTITUTO TECNICO INDUSTRIALE
"M. PANETTI"ANNO SCOLASTICO 2003-04
CLASSE VET.B

MISURA DELLA VELOCITA' CON ENCODER OTTICO

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GENERALITA'

Si vuole progettare un dispositivo in grado di fornire il numero di giri di un'asse rotante. Ad esempio la velocità di un motore in corrente continua.
In figura 1 è rappresentato lo schema a blocchi del sistema di misura.

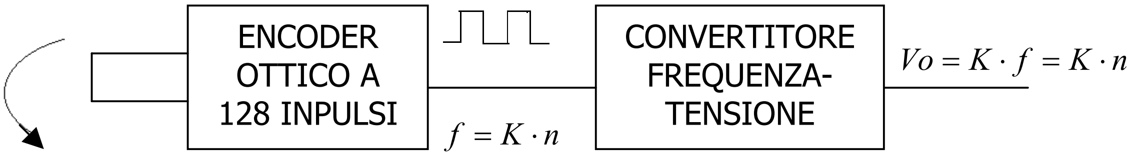


Figura 1. Schema a blocchi del sistema di misura

Il circuito consente di contare i giri del motore, collegando il perno dell'**Encoder Ottico** al perno del motorino di cui si vuole misurare il numero di giri.

Si riporta una breve descrizione del funzionamento.

L'Encoder genera un segnale costituito da 128 impulsi per ogni giro completo del suo asse.
La frequenza del segnale di uscita dell'Encoder vale:

$$f = \frac{Ke \cdot n}{60}$$

dove K_e è il numero di fessure interne dell'Encoder cioè:

$$f = \frac{128 \cdot n}{60}$$

Si è indicato con n il numero di giri/minuto.
Il convertitore frequenza/tensione trasforma la frequenza in una tensione con la legge lineare che risulta:

$$Vo = Kc \cdot f$$

dove Kc è la costante del convertitore frequenza/tensione.
Si ha:

$$Vo = Kc \cdot \frac{128 \cdot n}{60} = K \cdot n$$

dove $K = \frac{128 \cdot Kc}{60}$

è una costante.
In definitiva si ricava:

$$Vo = K \cdot n$$

e che la tensione di uscita è direttamente proporzionale al numero di giri del motore.
Si descrivono in dettaglio i componenti del sistema di misura.

ENCODER

Sono trasduttori di posizione di tipo digitale in grado di fornire un numero espresso in un particolare codice in funzione dello spostamento. Essi possono essere di tipo assoluto o incrementale, i quali a loro volta si suddividono in lineare o angolare come in figura 2 e 3.

Fig.2. Struttura interna dell'Encoder lineare

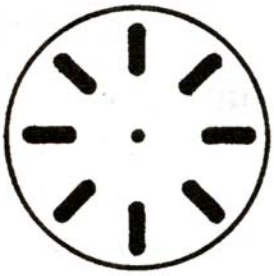


Fig.3. Struttura interna dell'Encoder angolare

Gli Encoder lineari sono costituiti da un nastro solidale all'organo in movimento, suddiviso in un certo numero di piste che, ad intervalli lineari di spazio, presentano zone umane e trasparenti corrispondenti a configurazioni numeriche differenti.
Il sistema di lettura, generalmente di tipo ottico è costituito da tante coppie di sorgenti e rilevatori di luce quante sono le piste ed è in grado di trasformare in numero binario le zone opache e trasparenti.
Questo trasduttore di posizione, a causa della discretizzazione costitutiva, può sembrare che abbia un valore risolutivo inferiore rispetto ai tradizionali trasduttori di posizione di tipo analogico.
In realtà il potere risolutivo vieni aumentato aumentando le piste dell'encoder.
La risoluzione dei sistemi analogici, invece, resta limitata dal rapporto segnale-rumore degli amplificatore elettronici utilizzati.
Un' inconveniente degli encoder a codice binario naturale si ha quando il trasduttore, passando da una posizione alla successiva determina la commutazione di almeno due bit.
Per ovviare a tale inconveniente si codifica il nastro o il disco con un codice binario che determina la commutazione di un solo bit.
Uno di questi codici, come è noto, è il Gray.
Gli encoder fin qui descritti vengono definitidi tipo assoluto in quanto la posizione sotto lettura è immediatamente codificata in un numero.
Gli encoder incrementali sono costituiti da fenditure trasparenti equidistanziate praticate sul nastro lineare o sul disco circolare.
Il sistema di lettura fornisce un impulso ogni qualvolta si presenta una fenditura sotto il suo campo d'azione.
Un dispositivo di conteggio digitale incrementa la configurazione numerica ad ogni impulso generato.

Nel progetto si è usato, l'Encoder Incrementale Angolare ENC1J della casa giapponese BOURNS rappresentato schematicamente in figura 4. Per ulteriori informazioni visitare il sito (www.bourns.com).

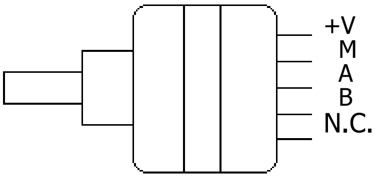


Figura 4. Encoder angolare incrementale

All'interno del perno rotante dell'Encoder è fissato un disco, segmentato con due serie di fenditure a 128 fessure trasversali sfalsate di ¼ di posizione.
In tal modo sulle uscite A e B si prelevano 128 impulsi a giro come indicato in figura 5.

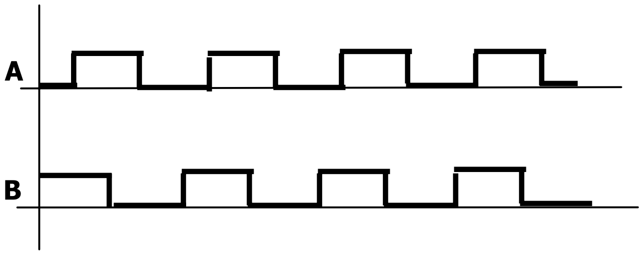


Figura 5. Segnali ottenuti dal sistema di lettura

Il segnale in frequenza si può prelevare sia dall'uscita A che B e convertire in tensione.
Se le uscite A e B sono collegate agli ingressi di un flip-flop di tipo D come in figura 6 l'uscita Q segnala il verso di rotazione orario o antiorario dell'asse rotante.

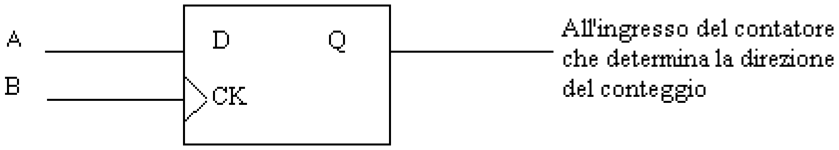


Figura 6. Circuito per discriminare il senso di rotazione dell'asse rotante

Più è elevato il numero di fessure più è precisa la lettura, perché ad ogni più piccolo movimento del perno si preleva sull'uscita dell'Encoder un numero maggiore di impulsi.
Da un lato del disco è applicato un <u>diodo emittente</u> e dal lato opposto due <u>fotodiodi riceventi</u>: fotodiodo A e fotodiodo B.
Alimentando l'Encoder, il diodo emittente emette verso il disco un fascio luminoso che, attraversa le fenditure ed eccita i fotodiodi.
L'encoder dispone di cinque piedini:

+Vcc...alimentazione positiva
Massa...potenziale di riferimento
Fase A...uscita A
Fase B...uscita B
N.C. ...non connesso

La tensione di alimentazione, deve essere compresa fra 4.75 e 5.25 Volt. Valore nominale Vcc=5V.
L’uscita A fornisce un’onda quadra la cui frequenza è proporzionale alla velocità di rotazione.
Analogamente sull’uscita B.

CONVERTITORE FREQUENZA-TENSIONE

Il convertitore frequenza-tensione, è un circuito in grado di fornire in uscita una tensione proporzionale alla frequenza del segnale di ingresso:

$$Vo = K \cdot f$$

In Figura 7 si mostra lo schema a blocchi di un possibile convertitore frequenza-tensione:

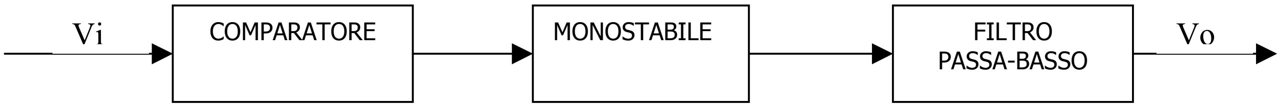


Figura 7. Schema a blocchi di un convertitore frequenza-tensione

Il comparatore ha il compito di squadrare il segnale analogico di ingresso se necessario. Il monostabile genera un impulso di durata T_m ogni T secondi. Ovviamente per un corretto funzionamentodovrà risultare:

$$Tm < T$$

Il filtro passa-basso fornisce il valore medio Vo della tensione del monostabile i cui livelli di uscita sono 0 e Vcc:

$$Vo = Vcc \cdot Tm \cdot f = K \cdot f$$

La costante K di tale convertitore vale:

$$K = Vcc \cdot Tm$$

Nel progetto si è usato il convertitore frequenza/tensione LM331 della National secondo lo schema suggerito dal costruttore e riportato in figura 8.

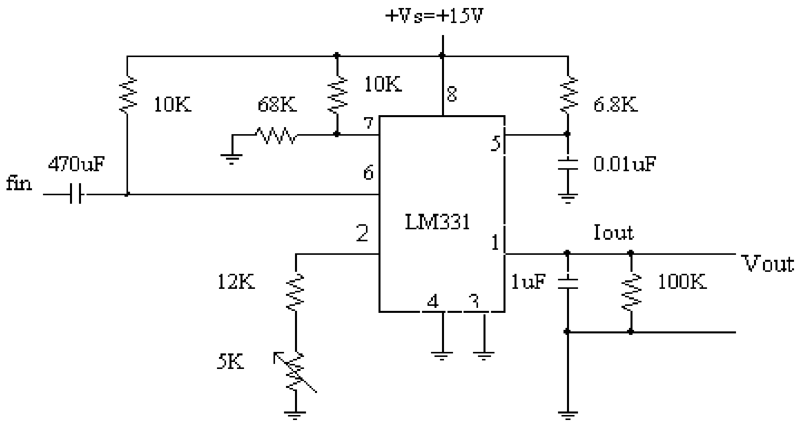


Figura 8. Convertitore frequenza-tensione con LM331

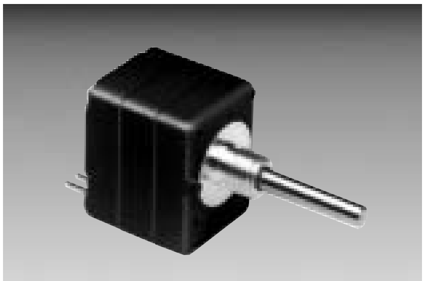
Il costruttore indica che l'integrato può operare con frequenza max $f = 10KHz$ dando in uscita una tensione max $Vo\max = f \cdot 2.09 \cdot \frac{R_L}{R_S} \cdot R_t \cdot C_t$

La frequenza di 10 KHz corrisponde ad un numero di giri:

$$n = \frac{60 \cdot f}{128} = \frac{60 \cdot 10 \cdot 10^3}{128} \cong 4687 \, {}^{giri}\!/_{\min}$$

Pertanto il sistema è in grado di misurare assi rotanti ad un numero di giri max 5000 giri/minuto.

Si riportano i data Sheet degli integrati utilizzati.



BOURNS®

Features

- Two channel quadrature output
- Bushing or servo mount
- Square wave signal
- Index channel available
- Small size
- Resolution to 256 PPR
- CMOS and TTL compatible
- Long life
- High operating speed

EN - Rotary Optical Encoder

Electrical Characteristics

Output	2-bit gray code, Channel A leads Channel B by 90 º (electrical) with clockwise rotation
Resolution	25 to 256 cycles per revolution
Insulation Resistance (500 VDC)	1,000 megohms
Electrical Travel	Continuous
Supply Voltage	5.0 VDC ±0.25 VDC*
Supply Current	26 mA maximum
Output Voltage	
Low Output	0.8 V maximum
High Output	4 V minimum
Output Current	
Low Output	25 mA minimum
Rise/Fall Time	200 ns (typical)
Shaft RPM (Ball Bearing)	3,000 rpm maximum
Power Consumption	136 mW maximum
Pulse Width (Electrical Degrees, Each Channel)	180 º ±45 º TYP.
Pulse Width (Index Channel)	360 º ±90 º
Phase (Electrical Degrees, Channel A to Channel B)	90 º ±45 º TYP.
Index Channel Centered on 1-1 State Combination of A and B Channels	0 º ±45 º

*Consult factory for other voltages up to 5 VDC.

Environmental Characteristics

Operating Temperature Range	-40 ºC to +75 ºC (-40 °F to +167 °F)
Storage Temperature Range	-40 °C to +85 °C (-40 °F to +185 °F)
Humidity	MIL-STD-202, Method 103B, Condition B
Vibration	5 G
Shock	50 G
Rotational Life	
A & C Bushings (300 rpm maximum)**	10,000,000 revolutions
W, S & T Bushings (3,000 rpm maximum)**	200,000,000 revolutions
IP Rating	IP 40

Mechanical Characteristics

Mechanical Angle	360 ° Continuous
Torque (Starting and Running)	
A & C Bushings (Spring Loaded for Optimum Feel)	1 N-cm (1.5 oz-in.) maximum
W, S & T Bushings (Ball Bearing Shaft Support)	0.07 N-cm (0.1 oz-in.) maximum
Mounting Torque	1.7 to 2.0 N-cm (15 to 18 lb.-in.) maximum
Shaft End Play	0.30 mm (0.012 ”) T.I.R. maximum
Shaft Radial Play	0.12 mm (0.005 ”) T.I.R. maximum
Weight	11 gms. (0.4 oz.)
Terminals	Axial or radial pc pins or ribbon cable
Soldering Condition	Recommended hand soldering using Sn95/Ag5 no clean solder, 0.025 ” wire diameter. Maximum temperature 399 °C (750 °F) for 3 seconds. No wash process to be used with no clean flux. Part can be wave soldered at 260 °C (500 °F) for 5 seconds, no wash process with no clean flux.
Marking	Manufacturer’s trademark, name, part number, and date code.
Hardware	One lockwasher and one mounting nut supplied with each encoder, except on servo mount versions.

**For resolutions ≤ 128 quadrature cycles per shaft revolution.

EN - Rotary Optical Encoder

BOURNS®

General Information

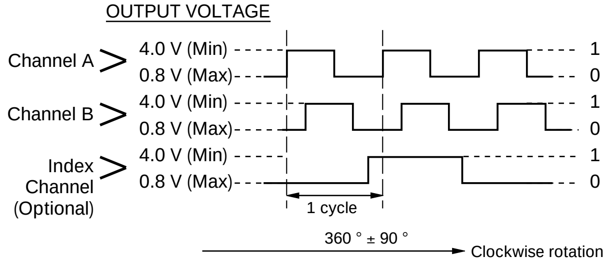
ROTARY OPTICAL
The Bourns® EN model is a self-contained rotary optical encoder. It produces a 2-bit quadrature signal which is suitable for digital systems where both magnitude and direction of adjustment must be provided. The EN encoder is ideal for use as a digital panel control or as a position sensing device in applications where long life, reliability, high resolution and precise linearity are critical.

The EN series encoder converts rotary input into electrical signals which can be used by microprocessors without A/D conversion. Bourns encoder output signals are square wave digital pulses which do not require debounce circuitry. Both features make it possible to significantly reduce the memory overhead, wiring and wiring interconnects required by other types of control devices.

EN optical encoders offer a useful rotational life of from 10 million to 200 million shaft revolutions, making them ideal for extended service applications. The Bourns encoder is also compact and well suited for situations where the available space is limited.

Quadrature Output Table

OUTPUT TABLE



STANDARD RESOLUTIONS AVAILABLE

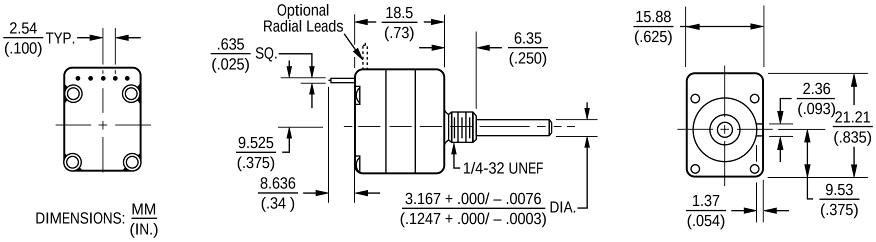
(Full quadrature output cycles
per shaft revolution)

25*	125
50*	128
64	200
100	256

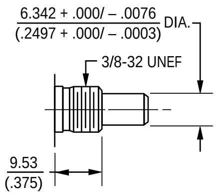
For Non-Standard Resolutions—
Consult Factory

* Channel B leads Channel A

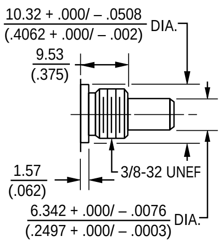
Dimensional Drawings



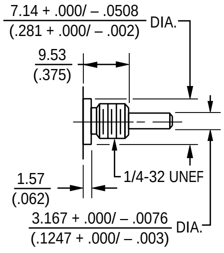
Bushing Style **C**



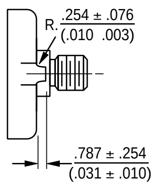
Bushing Style **A**



Bushing Style **S** (Ball Bearing)

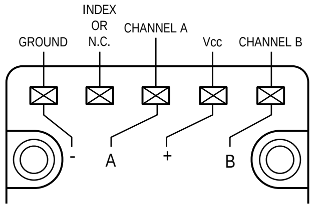


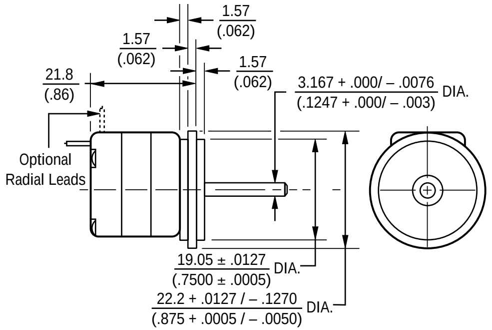
Bushing Style **T** (Ball Bearing)



Anti-rotation Lug View

TERMINATION DIAGRAM



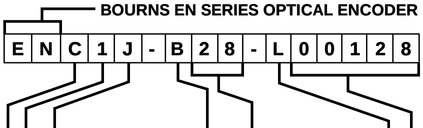


Servo Mount Style **W** (Ball Bearing)

Consult factory for options not shown, including:

- Wire lead or cable options
- Connectors
- Non-standard resolutions
- Special shaft/bushing sizes and features
- Special performance characteristics
- PCB mounting bracket

How To Order



ANTI-ROTATION LUG POSITION

Code	Description
D	None
J	9:00 Position
P	Rear Mounting Bracket

SHAFT LENGTH*

Code	Description
16	1/2 " Long
20	5/8 " Long
28	7/8 " Long

SWITCHING CONFIGURATION

Code	Description
1	Channel A Leads Channel B By 90 ° (Clockwise Rotation)**
2	Code 1 Switching With Index Channel

TERMINAL* CONFIGURATION**

Code	Description
L	Axial, Multi-Purpose Pin
R	Radial, Multi-Purpose Pin
M	Rear Ribbon Cable with Connector
N	Side Ribbon Cable with Connector
W	Rear Ribbon Cable - No Connector
Y	Side Ribbon Cable - No Connector

RESOLUTION

Code	Cycles Per Revolution
00025	25
00050	50
00064	64
00100	100
00125	125
00128	128
00200	200
00256	256

SHAFT STYLE

Code	Description	Use With Bushings (Code)
B	1/4 " Dia., Plain End	A, S
D	1/8 " Dia., Plain End	C, T, W
C	1/4 " Dia., Single Flatted	A, S

BUSHING CONFIGURATION

Code	Description
A	3/8 "D X 3/8 "L Threaded
C	1/4 "D X 1/4 "L Threaded
S	3/8 "D X 3/8 "L Threaded (Ball Bearing)
T	1/4 "D X 3/8 "L Threaded (Ball Bearing)
W	Servo Mount 7/8 "D (Ball Bearing)

* Shaft length measured from mounting surface.
** 25 and 50 ppr is reversed (Channel B leads Channel A)
*** Standard ribbon cable is 10 " long
Consult factory for other lengths.

REV. 04/03

National Semiconductor

June 1999

LM231A/LM231/LM331A/LM331 Precision Voltage-to-Frequency Converters

General Description

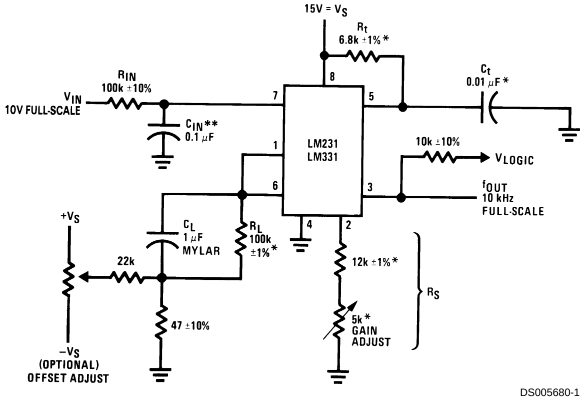
The LM231/LM331 family of voltage-to-frequency converters are ideally suited for use in simple low-cost circuits for analog-to-digital conversion, precision frequency-to-voltage conversion, long-term integration, linear frequency modulation or demodulation, and many other functions. The output when used as a voltage-to-frequency converter is a pulse train at a frequency precisely proportional to the applied input voltage. Thus, it provides all the inherent advantages of the voltage-to-frequency conversion techniques, and is easy to apply in all standard voltage-to-frequency converter applications. Further, the LM231A/LM331A attain a new high level of accuracy versus temperature which could only be attained with expensive voltage-to-frequency modules. Additionally the LM231/331 are ideally suited for use in digital systems at low power supply voltages and can provide low-cost analog-to-digital conversion in microprocessor-controlled systems. And, the frequency from a battery powered voltage-to-frequency converter can be easily channeled through a simple photoisolator to provide isolation against high common mode levels.

The LM231/LM331 utilize a new temperature-compensated band-gap reference circuit, to provide excellent accuracy over the full operating temperature range, at power supplies as low as 4.0V. The precision timer circuit has low bias currents without degrading the quick response necessary for 100 kHz voltage-to-frequency conversion. And the output are capable of driving 3 TTL loads, or a high voltage output up to 40V, yet is short-circuit-proof against V_{CC}.

Features

- Guaranteed linearity 0.01% max
- Improved performance in existing voltage-to-frequency conversion applications
- Split or single supply operation
- Operates on single 5V supply
- Pulse output compatible with all logic forms
- Excellent temperature stability, ±50 ppm/°C max
- Low power dissipation, 15 mW typical at 5V
- Wide dynamic range, 100 dB min at 10 kHz full scale frequency
- Wide range of full scale frequency, 1 Hz to 100 kHz
- Low cost

Typical Applications



$$f_{OUT} = \frac{V_{IN}}{2.09\ V} \bullet \frac{R_S}{R_L} \bullet \frac{1}{R_tC_t}$$

*Use stable components with low temperature coefficients. See Typical Applications section.

**0.1µF or 1µF, See “Principles of Operation.”

FIGURE 1. Simple Stand-Alone Voltage-to-Frequency Converter with ±0.03% Typical Linearity (f = 10 Hz to 11 kHz)

Absolute Maximum Ratings (Note 1)

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

	LM231A/LM231	**LM331A/LM331**
Supply Voltage	40V	40V
Output Short Circuit to Ground	Continuous	Continuous
Output Short Circuit to V_{CC}	Continuous	Continuous
Input Voltage	−0.2V to $+V_S$	−0.2V to $+V_S$
	$\mathbf{T_{MIN}}$ $\mathbf{T_{MAX}}$	$\mathbf{T_{MIN}}$ $\mathbf{T_{MAX}}$
Operating Ambient Temperature Range	−25˚C to +85˚C	0˚C to +70˚C
Power Dissipation (P_D at 25˚C)		
and Thermal Resistance (θ_{jA})		
(N Package) P_D	1.25W	1.25W
θ_{jA}	100˚C/W	100˚C/W
Lead Temperature (Soldering, 10 sec.)		
Dual-In-Line Package (Plastic)	260˚C	260˚C
ESD Susceptibility (Note 4)		
N Package	500V	500V

Electrical Characteristics

T_A=25˚C unless otherwise specified (Note 2)

Parameter	Conditions	Min	Typ	Max	Units
VFC Non-Linearity (Note 3)	4.5V ≤ V_S ≤ 20V		±0.003	±0.01	% Full-Scale
	T_{MIN} ≤ T_A ≤ T_{MAX}		±0.006	±0.02	% Full-Scale
VFC Non-Linearity In Circuit of *Figure 1*	V_S = 15V, f = 10 Hz to 11 kHz		±0.024	±0.14	%Full-Scale
Conversion Accuracy Scale Factor (Gain)	V_{IN} = −10V, R_S = 14 kΩ				
LM231, LM231A		0.95	1.00	1.05	kHz/V
LM331, LM331A		0.90	1.00	1.10	kHz/V
Temperature Stability of Gain	T_{MIN} ≤ T_A ≤ T_{MAX}, 4.5V ≤ V_S ≤ 20V				
LM231/LM331			±30	±150	ppm/˚C
LM231A/LM331A			±20	±50	ppm/˚C
Change of Gain with V_S	4.5V ≤ V_S ≤ 10V		0.01	0.1	%/V
	10V ≤ V_S ≤ 40V		0.006	0.06	%/V
Rated Full-Scale Frequency	V_{IN} = −10V	10.0			kHz
Gain Stability vs Time (1000 Hrs)	T_{MIN} ≤ T_A ≤ T_{MAX}		±0.02		% Full-Scale
Overrange (Beyond Full-Scale) Frequency	V_{IN} = −11V	10			%
INPUT COMPARATOR					
Offset Voltage			±3	±10	mV
LM231/LM331	T_{MIN} ≤ T_A ≤ T_{MAX}		±4	±14	mV
LM231A/LM331A	T_{MIN} ≤ T_A ≤ T_{MAX}		±3	±10	mV
Bias Current			−80	−300	nA
Offset Current			±8	±100	nA
Common-Mode Range	T_{MIN} ≤ T_A ≤ T_{MAX}	−0.2		V_{CC}−2.0	V
TIMER					
Timer Threshold Voltage, Pin 5		0.63	0.667	0.70	x V_S
Input Bias Current, Pin 5	V_S = 15V				
All Devices	0V ≤ $V_{PIN\ 5}$ ≤ 9.9V		±10	±100	nA
LM231/LM331	$V_{PIN\ 5}$ = 10V		200	1000	nA
LM231A/LM331A	$V_{PIN\ 5}$ = 10V		200	500	nA

Electrical Characteristics (Continued)

T_A=25˚C unless otherwise specified (Note 2)

Parameter	Conditions	Min	Typ	Max	Units
TIMER					
$V_{SAT\ PIN\ 5}$ (Reset)	I = 5 mA		0.22	0.5	V
CURRENT SOURCE (Pin 1)					
Output Current	R_S=14 kΩ, $V_{PIN\ 1}$=0				
LM231, LM231A		126	135	144	µA
LM331, LM331A		116	136	156	µA
Change with Voltage	0V ≤ $V_{PIN\ 1}$ ≤ 10V		0.2	1.0	µA
Current Source OFF Leakage					
LM231, LM231A, LM331, LM331A			0.02	10.0	nA
All Devices	T_A=T_{MAX}		2.0	50.0	nA
Operating Range of Current (Typical)			(10 to 500)		µA
REFERENCE VOLTAGE (Pin 2)					
LM231, LM231A		1.76	1.89	2.02	V_{DC}
LM331, LM331A		1.70	1.89	2.08	V_{DC}
Stability vs Temperature			±60		ppm/˚C
Stability vs Time, 1000 Hours			±0.1		%
LOGIC OUTPUT (Pin 3)					
V_{SAT}	I=5 mA		0.15	0.50	V
	I=3.2 mA (2 TTL Loads), $T_{MIN} \leq T_A \leq T_{MAX}$		0.10	0.40	V
OFF Leakage			±0.05	1.0	µA
SUPPLY CURRENT					
LM231, LM231A	V_S=5V	2.0	3.0	4.0	mA
LM331, LM331A	V_S=40V	2.5	4.0	6.0	mA
	V_S=5V	1.5	3.0	6.0	mA
	V_S=40V	2.0	4.0	8.0	mA

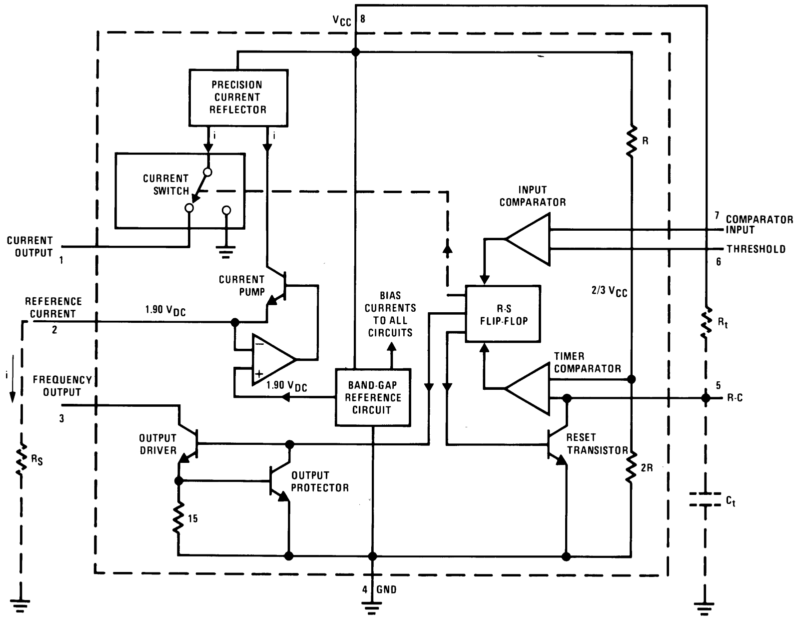
Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its specified operating conditions.

Note 2: All specifications apply in the circuit of *Figure 4*, with $4.0V \leq V_S \leq 40V$, unless otherwise noted.

Note 3: Nonlinearity is defined as the deviation of f_{OUT} from V_{IN} x (10 kHz/−10 V_{DC}) when the circuit has been trimmed for zero error at 10 Hz and at 10 kHz, over the frequency range 1 Hz to 11 kHz. For the timing capacitor, C_T, use NPO ceramic, Teflon®, or polystyrene.

Note 4: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Functional Block Diagram



DS005680-2

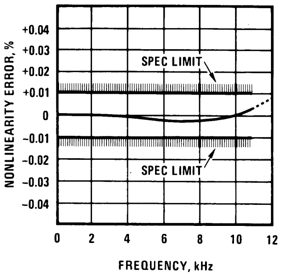
Pin numbers apply to 8-pin packages only.

FIGURE 2.

Typical Performance Characteristics

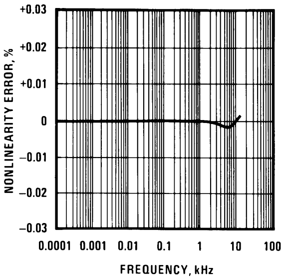
(All electrical characteristics apply for the circuit of *Figure 4*, unless otherwise noted.)

Nonlinearity Error as Precision V-to-F Converter (*Figure 4*)



DS005680-25

Nonlinearity Error



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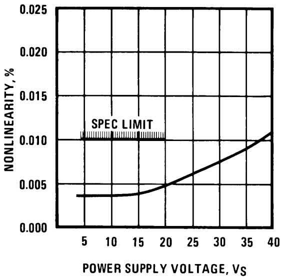
Nonlinearity Error vs Power Supply Voltage



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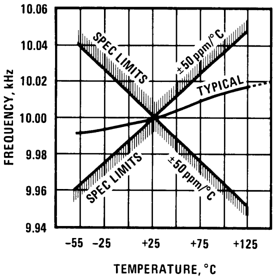
Frequency vs Temperature



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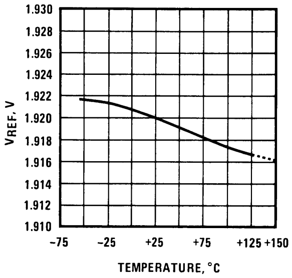
V_{REF} vs Temperature



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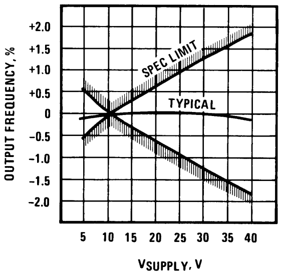
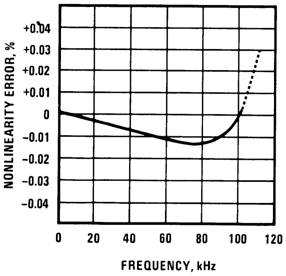
Output Frequency vs V_{SUPPLY}



DS005680-30

100 kHz Nonlinearity Error (*Figure 5*)



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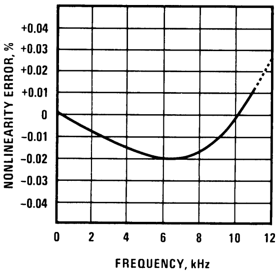
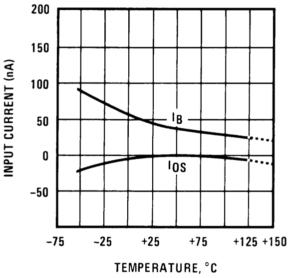
Nonlinearity Error (*Figure 1*)



DS005680-32

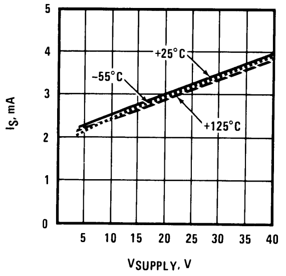
Input Current (Pins 6,7) vs Temperature



DS005680-33

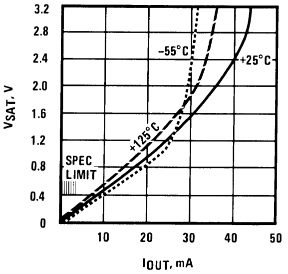
Typical Performance Characteristics (Continued)

Power Drain vs V_{SUPPLY}



DS005680-34

Output Saturation Voltage vs I_{OUT} (Pin 3)



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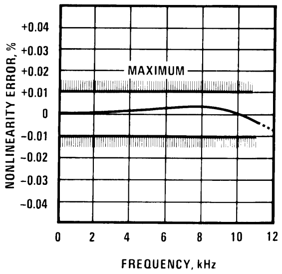
Nonlinearity Error, Precision F-to-V Converter (*Figure 7*)



DS005680-36

Typical Applications

PRINCIPLES OF OPERATION OF A SIMPLIFIED VOLTAGE-TO-FREQUENCY CONVERTER

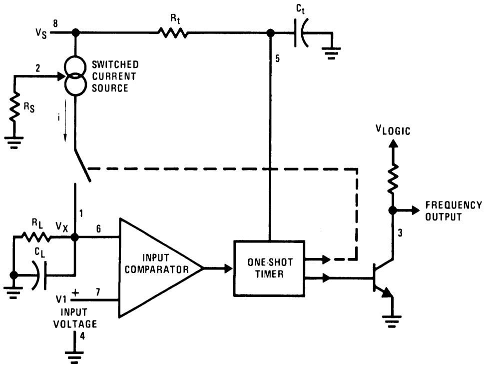
The LM231/331 are monolithic circuits designed for accuracy and versatile operation when applied as voltage-to-frequency (V-to-F) converters or as frequency-to-voltage (F-to-V) converters. A simplified block diagram of the LM231/331 is shown in *Figure 3* and consists of a switched current source, input comparator, and 1-shot timer.

The operation of these blocks is best understood by going through the operating cycle of the basic V-to-F converter, *Figure 3*, which consists of the simplified block diagram of the LM231/331 and the various resistors and capacitors connected to it.

The voltage comparator compares a positive input voltage, V1, at pin 7 to the voltage, V_x, at pin 6. If V1 is greater, the comparator will trigger the 1-shot timer. The output of the timer will turn ON both the frequency output transistor and the switched current source for a period t=1.1 R_tC_t. During this period, the current i will flow out of the switched current source and provide a fixed amount of charge, Q=i x t, into the capacitor, C_L. This will normally charge V_x up to a higher level than V1. At the end of the timing period, the current i will turn OFF, and the timer will reset itself.

Now there is no current flowing from pin 1, and the capacitor C_L will be gradually discharged by R_L until V_x falls to the level of V1. Then the comparator will trigger the timer and start another cycle.

The current flowing into C_L is exactly I_{AVE} = i x (1.1xR_tC_t) x f, and the current flowing out of C_L is exactly $V_x/R_L \cong V_{IN}/R_L$. If V_{IN} is doubled, the frequency will double to maintain this balance. Even a simple V-to-F converter can provide a frequency precisely proportional to its input voltage over a wide range of frequencies.



DS005680-4

FIGURE 3. Simplified Block Diagram of Stand-Alone Voltage-to-Frequency Converter and External Components

DETAIL OF OPERATION, FUNCTIONAL BLOCK DIAGRAM (*Figure 2*)

The block diagram shows a band gap reference which provides a stable 1.9 V_{DC} output. This 1.9 V_{DC} is well regulated over a V_S range of 3.9V to 40V. It also has a flat, low temperature coefficient, and typically changes less than ½% over a 100˚C temperature change.

The current pump circuit forces the voltage at pin 2 to be at 1.9V, and causes a current i=1.90V/R_S to flow. For R_s=14k, i=135 µA. The precision current reflector provides a current equal to i to the current switch. The current switch switches the current to pin 1 or to ground depending on the state of the R_S flip-flop.

The timing function consists of an R_S flip-flop, and a timer comparator connected to the external R_tC_t network. When the input comparator detects a voltage at pin 7 higher than pin 6, it sets the R_S flip-flop which turns ON the current switch and the output driver transistor. When the voltage at pin 5 rises to ⅔ V_{CC}, the timer comparator causes the R_S flip-flop to reset. The reset transistor is then turned ON and the current switch is turned OFF.

However, if the input comparator still detects pin 7 higher than pin 6 when pin 5 crosses ⅔ V_{CC}, the flip-flop will not be reset, and the current at pin 1 will continue to flow, in its attempt to make the voltage at pin 6 higher than pin 7. This

Typical Applications (Continued)

condition will usually apply under start-up conditions or in the case of an overload voltage at signal input. It should be noted that during this sort of overload, the output frequency will be 0; as soon as the signal is restored to the working range, the output frequency will be resumed.

The output driver transistor acts to saturate pin 3 with an ON resistance of about 50Ω. In case of overvoltage, the output current is actively limited to less than 50 mA.

The voltage at pin 2 is regulated at 1.90 V_{DC} for all values of i between 10 µA to 500 µA. It can be used as a voltage reference for other components, but care must be taken to ensure that current is not taken from it which could reduce the accuracy of the converter.

PRINCIPLES OF OPERATION OF BASIC VOLTAGE-TO-FREQUENCY CONVERTER (*Figure 1*)

The simple stand-alone V-to-F converter shown in *Figure 1* includes all the basic circuitry of *Figure 3* plus a few components for improved performance.

A resistor, R_{IN}=100 kΩ±10%, has been added in the path to pin 7, so that the bias current at pin 7 (−80 nA typical) will cancel the effect of the bias current at pin 6 and help provide minimum frequency offset.

The resistance R_S at pin 2 is made up of a 12 kΩ fixed resistor plus a 5 kΩ (cermet, preferably) gain adjust rheostat. The function of this adjustment is to trim out the gain tolerance of the LM231/331, and the tolerance of R_t, R_L and C_t.

For best results, all the components should be stable low-temperature-coefficient components, such as metal-film resistors. The capacitor should have low dielectric absorption; depending on the temperature characteristics desired, NPO ceramic, polystyrene, Teflon or polypropylene are best suited.

A capacitor C_{IN} is added from pin 7 to ground to act as a filter for V_{IN}. A value of 0.01 µF to 0.1 µF will be adequate in most cases; however, in cases where better filtering is required, a 1 µF capacitor can be used. When the RC time constants are matched at pin 6 and pin 7, a voltage step at V_{IN} will cause a step change in f_{OUT}. If C_{IN} is much less than C_L, a step at V_{IN} may cause f_{OUT} to stop momentarily.

A 47Ω resistor, in series with the 1 µF C_L, is added to give hysteresis effect which helps the input comparator provide the excellent linearity (0.03% typical).

DETAIL OF OPERATION OF PRECISION V-TO-F CONVERTER (*Figure 4*)

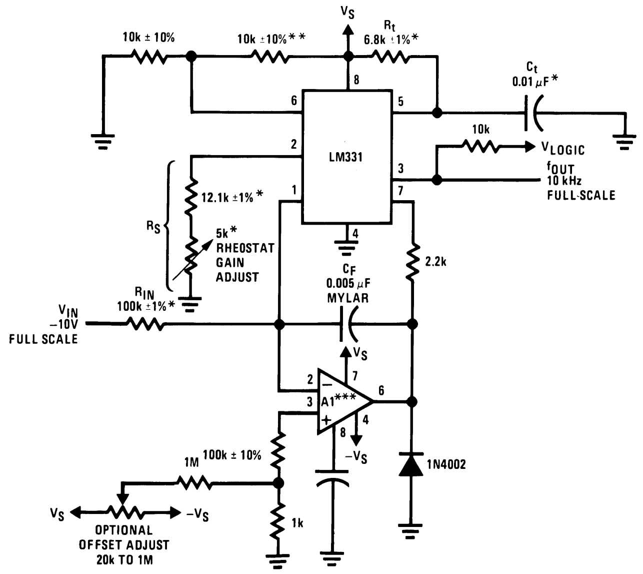
In this circuit, integration is performed by using a conventional operational amplifier and feedback capacitor, C_F. When the integrator's output crosses the nominal threshold level at pin 6 of the LM231/331, the timing cycle is initiated.

The average current fed into the op amp's summing point (pin 2) is i x (1.1 R_tC_t) x f which is perfectly balanced with $-V_{IN}/R_{IN}$. In this circuit, the voltage offset of the LM231/331 input comparator does not affect the offset or accuracy of the V-to-F converter as it does in the stand-alone V-to-F converter; nor does the LM231/331 bias current or offset current. Instead, the offset voltage and offset current of the operational amplifier are the only limits on how small the signal can be accurately converted. Since op amps with voltage offset well below 1 mV and offset currents well below 2 nA are available at low cost, this circuit is recommended for best accuracy for small signals. This circuit also responds immediately to any change of input signal (which a stand-alone circuit does not) so that the output frequency will be an accurate representation of V_{IN}, as quickly as 2 output pulses' spacing can be measured.

In the precision mode, excellent linearity is obtained because the current source (pin 1) is always at ground potential and that voltage does not vary with V_{IN} or f_{OUT}. (In the stand-alone V-to-F converter, a major cause of non-linearity is the output impedance at pin 1 which causes i to change as a function of V_{IN}).

The circuit of *Figure 5* operates in the same way as *Figure 4*, but with the necessary changes for high speed operation.

Typical Applications (Continued)



DS005680-5

$$f_{OUT} = \frac{-V_{IN}}{2.09\ V} \bullet \frac{R_S}{R_{IN}} \bullet \frac{1}{R_t C_t}$$

*Use stable components with low temperature coefficients. See Typical Applications section.

**This resistor can be 5 kΩ or 10 kΩ for V_S=8V to 22V, but must be 10 kΩ for V_S=4.5V to 8V.

***Use low offset voltage and low offset current op amps for A1: recommended type LF411A

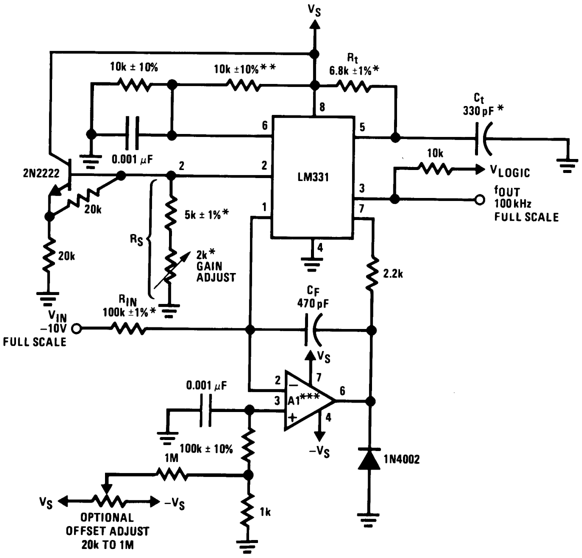
FIGURE 4. Standard Test Circuit and Applications Circuit, Precision Voltage-to-Frequency Converter

DETAILS OF OPERATION, FREQUENCY-TO-VOLTAGE CONVERTERS (*Figure 6* and *Figure 7*)

In these applications, a pulse input at f_{IN} is differentiated by a C-R network and the negative-going edge at pin 6 causes the input comparator to trigger the timer circuit. Just as with a V-to-F converter, the average current flowing out of pin 1 is $I_{AVERAGE} = i \times (1.1\ R_tC_t) \times f$.

In the simple circuit of *Figure 6*, this current is filtered in the network R_L = 100 kΩ and 1 µF. The ripple will be less than 10 mV peak, but the response will be slow, with a 0.1 second time constant, and settling of 0.7 second to 0.1% accuracy.

In the precision circuit, an operational amplifier provides a buffered output and also acts as a 2-pole filter. The ripple will be less than 5 mV peak for all frequencies above 1 kHz, and the response time will be much quicker than in *Figure 6*. However, for input frequencies below 200 Hz, this circuit will have worse ripple than *Figure 6*. The engineering of the filter time-constants to get adequate response and small enough ripple simply requires a study of the compromises to be made. Inherently, V-to-F converter response can be fast, but F-to-V response can not.



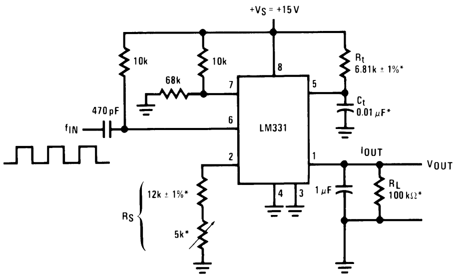
DS005680-6

*Use stable components with low temperature coefficients.
See Typical Applications section.

**This resistor can be 5 kΩ or 10 kΩ for V_S=8V to 22V, but must be 10 kΩ for V_S=4.5V to 8V.

***Use low offset voltage and low offset current op amps for A1: recommended types LF411A or LF356.

FIGURE 5. Precision Voltage-to-Frequency Converter, 100 kHz Full-Scale, ±0.03% Non-Linearity

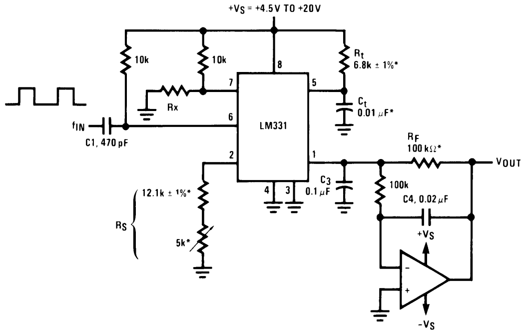


DS005680-7

$$V_{OUT} = f_{IN} \times 2.09V \times \frac{R_L}{R_S} \times (R_tC_t)$$

*Use stable components with low temperature coefficients.

FIGURE 6. Simple Frequency-to-Voltage Converter, 10 kHz Full-Scale, ±0.06% Non-Linearity



DS005680-8

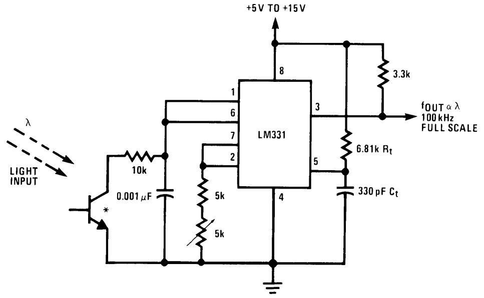
$$V_{OUT} = -f_{IN} \times 2.09V \times \frac{R_F}{R_S} \times (R_tC_t)$$

$$\text{SELECT } R_X = \frac{(V_S - 2V)}{0.2\ mA}$$

*Use stable components with low temperature coefficients.

FIGURE 7. Precision Frequency-to-Voltage Converter, 10 kHz Full-Scale with 2-Pole Filter, ±0.01% Non-Linearity Maximum

Light Intensity to Frequency Converter



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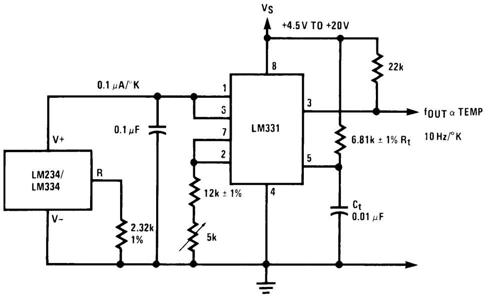
*L14F-1, L14G-1 or L14H-1, photo transistor (General Electric Co.) or similar

Temperature to Frequency Converter



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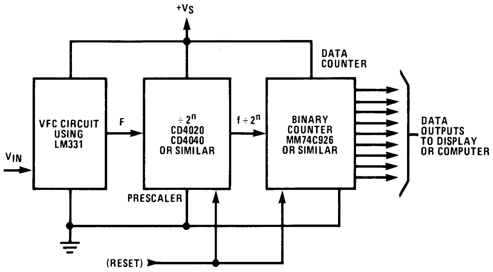
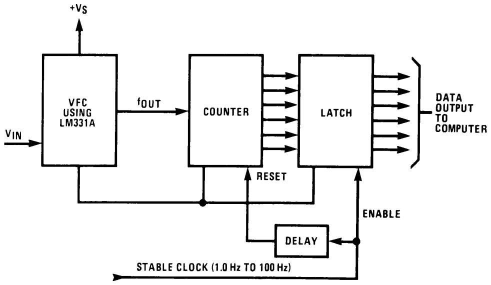
Typical Applications (Continued)

Long-Term Digital Integrator Using VFC



DS005680-11

Basic Analog-to-Digital Converter Using Voltage-to-Frequency Converter



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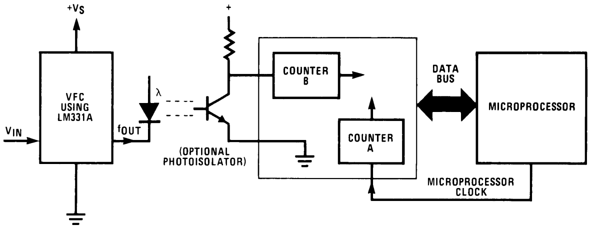
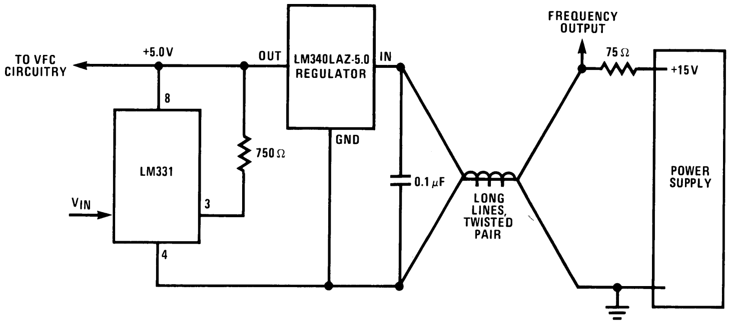
Analog-to-Digital Converter with Microprocessor



DS005680-13

Remote Voltage-to-Frequency Converter with 2-Wire Transmitter and Receiver



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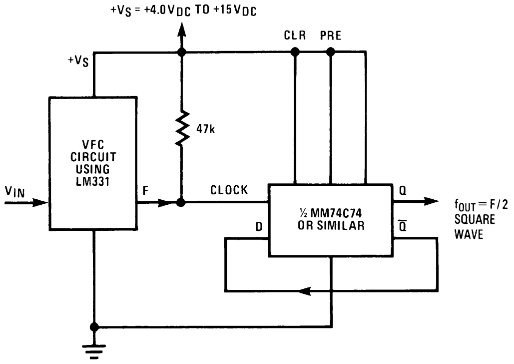
Typical Applications (Continued)

Voltage-to-Frequency Converter with Square-Wave Output Using ÷ 2 Flip-Flop



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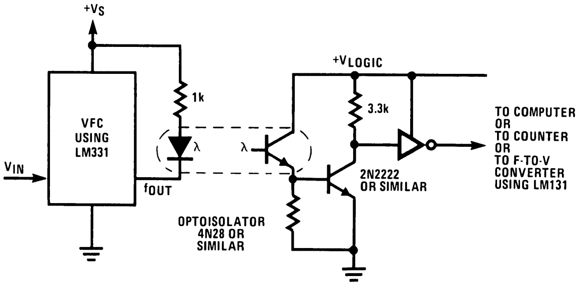
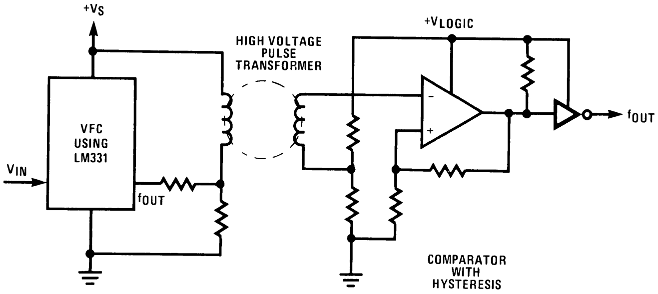
Voltage-to-Frequency Converter with Isolators



DS005680-16

Voltage-to-Frequency Converter with Isolators



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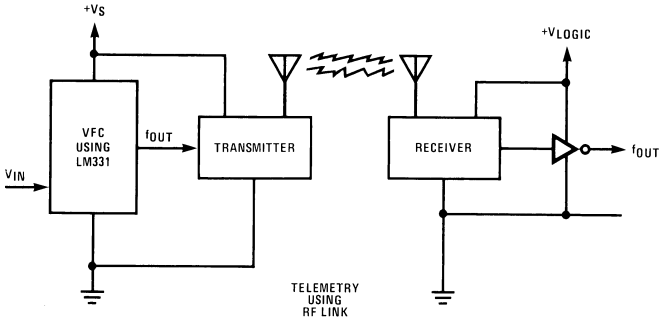
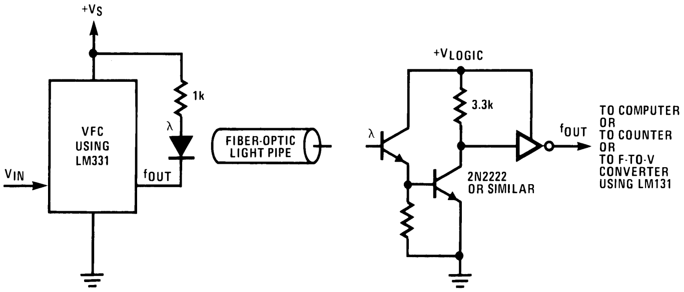
Typical Applications (Continued)

Voltage-to-Frequency Converter with Isolators



DS005680-18

Voltage-to-Frequency Converter with Isolators



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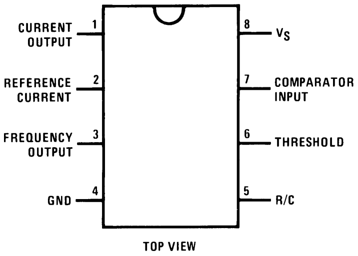
Connection Diagram

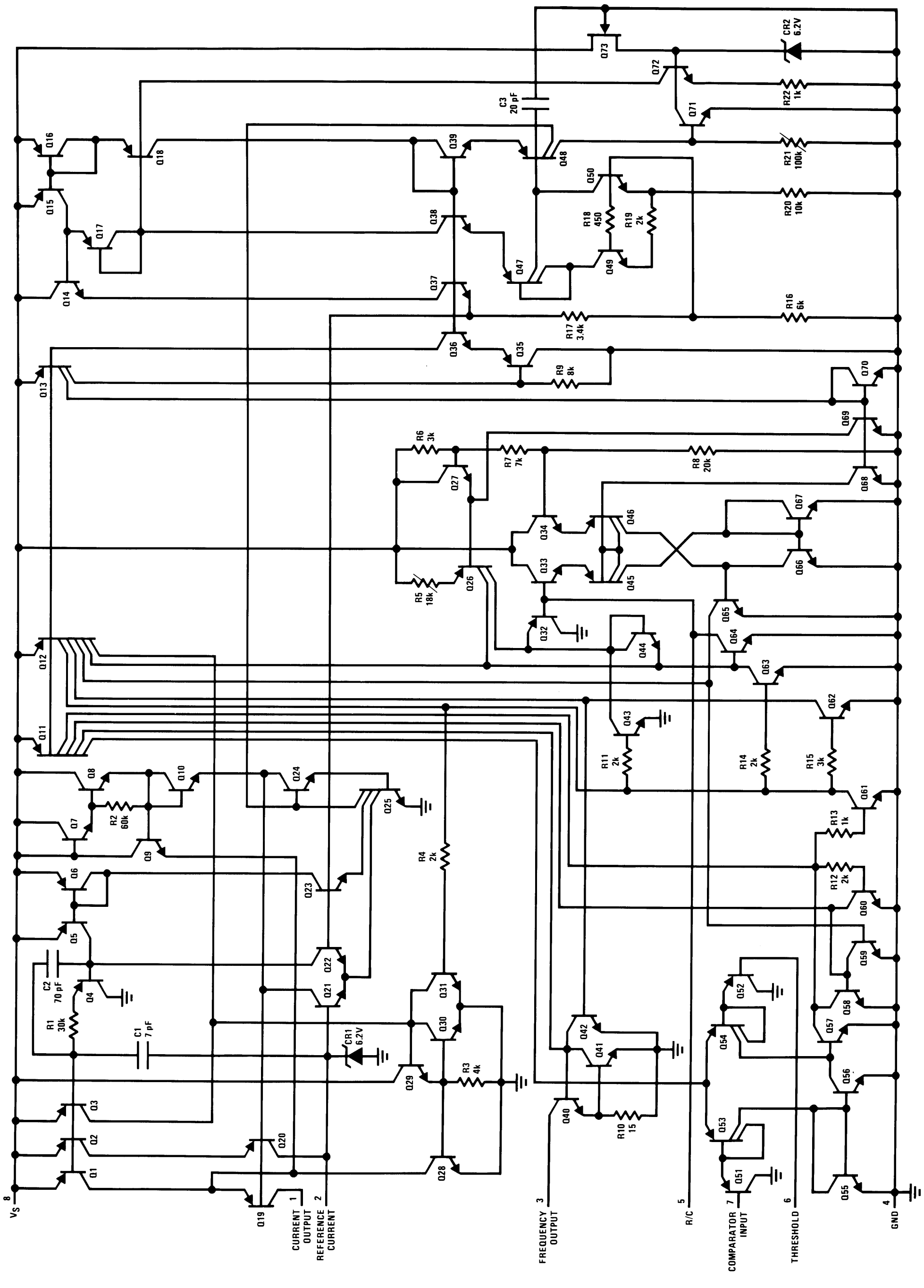
Dual-In-Line Package



DS005680-21

Order Number LM231AN, LM231N, LM331AN, or LM331N
See NS Package Number N08E

Schematic Diagram



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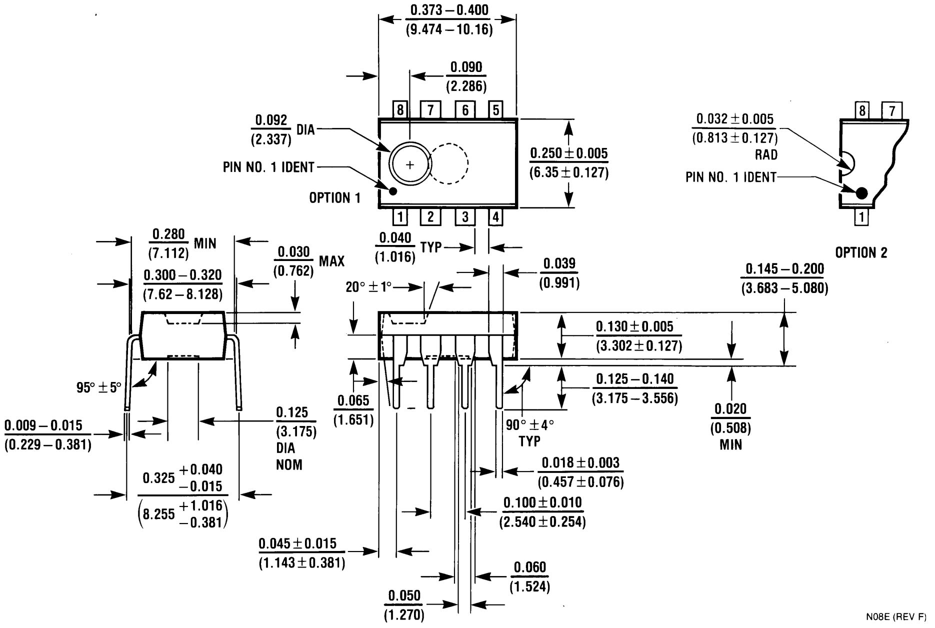
Physical Dimensions inches (millimeters) unless otherwise noted



Dual-In-Line Package (N)
Order Number LM231AN, LM231N, LM331AN, or LM331N
NS Package N08E

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