1. DESCRIPTION

The XLx31 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.

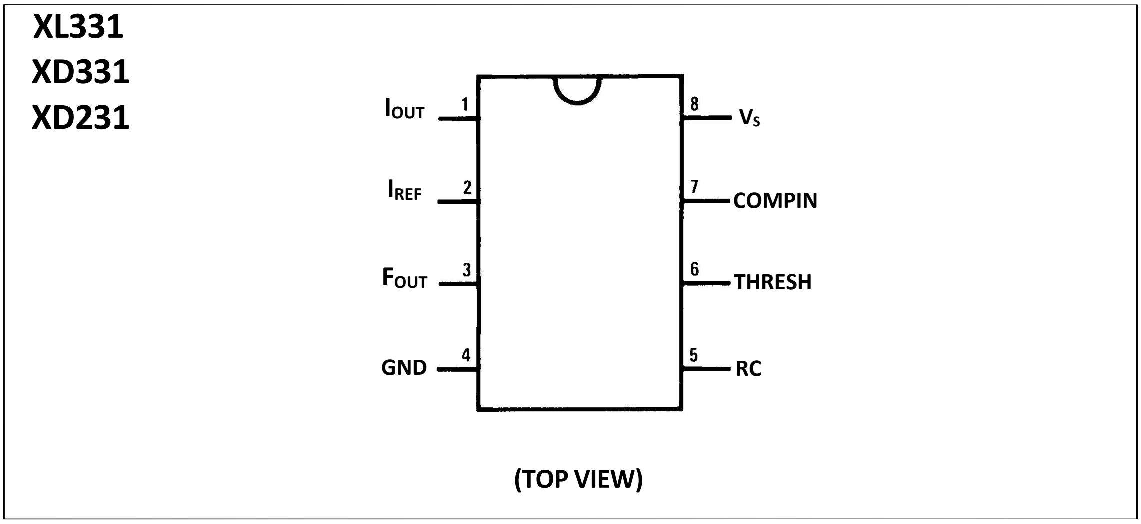
Further, the XL/XDx31 attain a new high level of accuracy versus temperature which could only be attained with expensive voltage-to-frequency modules. Additionally the XL/XDx31 are ideally suited for use in digital systems at low power supply voltages and can provide low-cost analog-to-digital conversion in microprocessor-controlled systems. And, the frequency from a battery-powered voltage-to-frequency converter can be easily channeled through a simple photo isolator to provide isolation against high common-mode levels.

The XL/XDx31 uses 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 V. 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 40 V, yet is short-circuit-proof against VCC.

2. FEATURES

- Ensured Linearity 0.03% Maximum
- Improved Performance in Existing Voltage-to-Frequency Conversion Applications
- Split or Single-Supply Operation
- Operates on Single 5-V Supply
- Pulse Output Compatible With All Logic Forms
- Low Power Consumption: 15 mW Typical at 5 V
- Wide Dynamic Range, 100 dB Minimum at 10-kHz
- Full Scale Frequency
- Wide Range of Full Scale Frequency:
- 1 Hz to 100 kHz
- Low-Cost

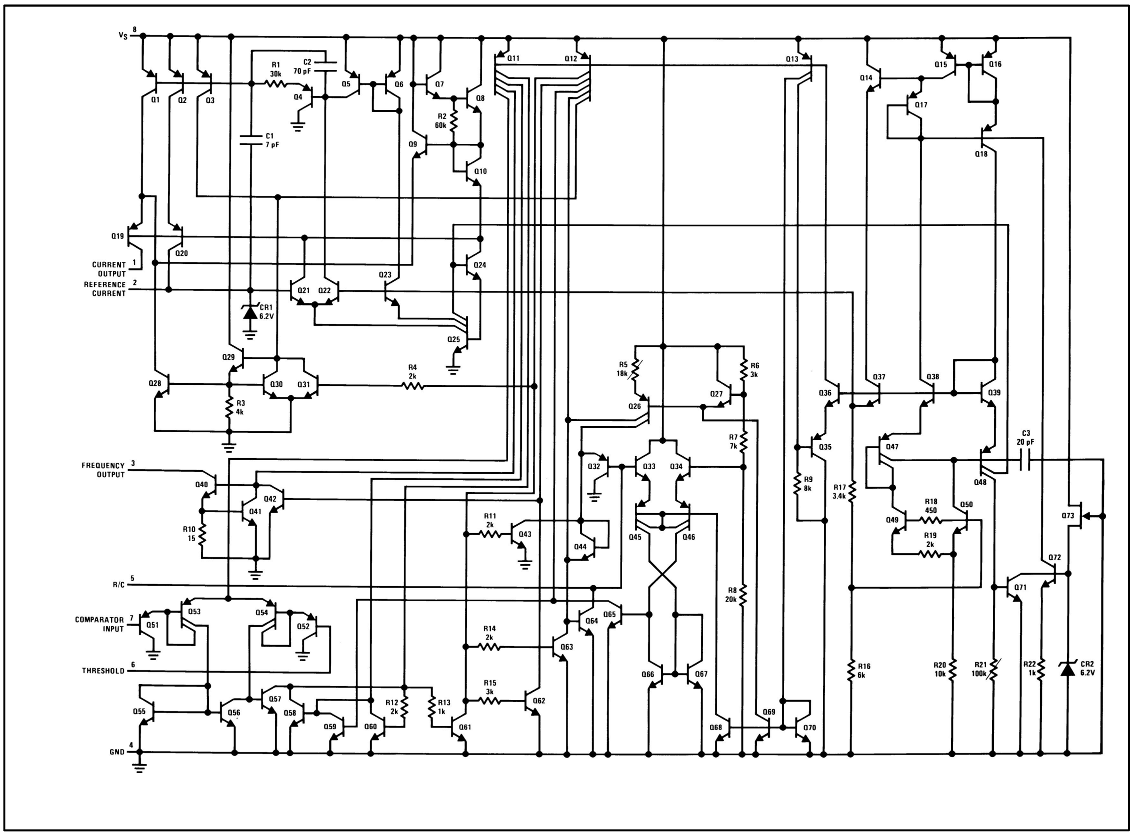
3. PIN CONFIGURATIONS AND FUNCTIONS



PIN FUNCTIONS

PIN		I/O	DESCRIPTION
NAME	NO.		
IOUT	1	O	Current Output
IREF	2	I	Reference Current
FOUT	3	O	Frequency Output. This output is an open-collector output and requires a pullup resistor.
GND	4	G	Ground
RC	5	I	R-C filter input
THRESH	6	I	Threshold input
COMPIN	7	I	Comparator Input
VS	8	P	Supply Voltage

4. SCHEMATIC DIAGRAM



5. FUNCTIONAL BLOCK DIAGRAM

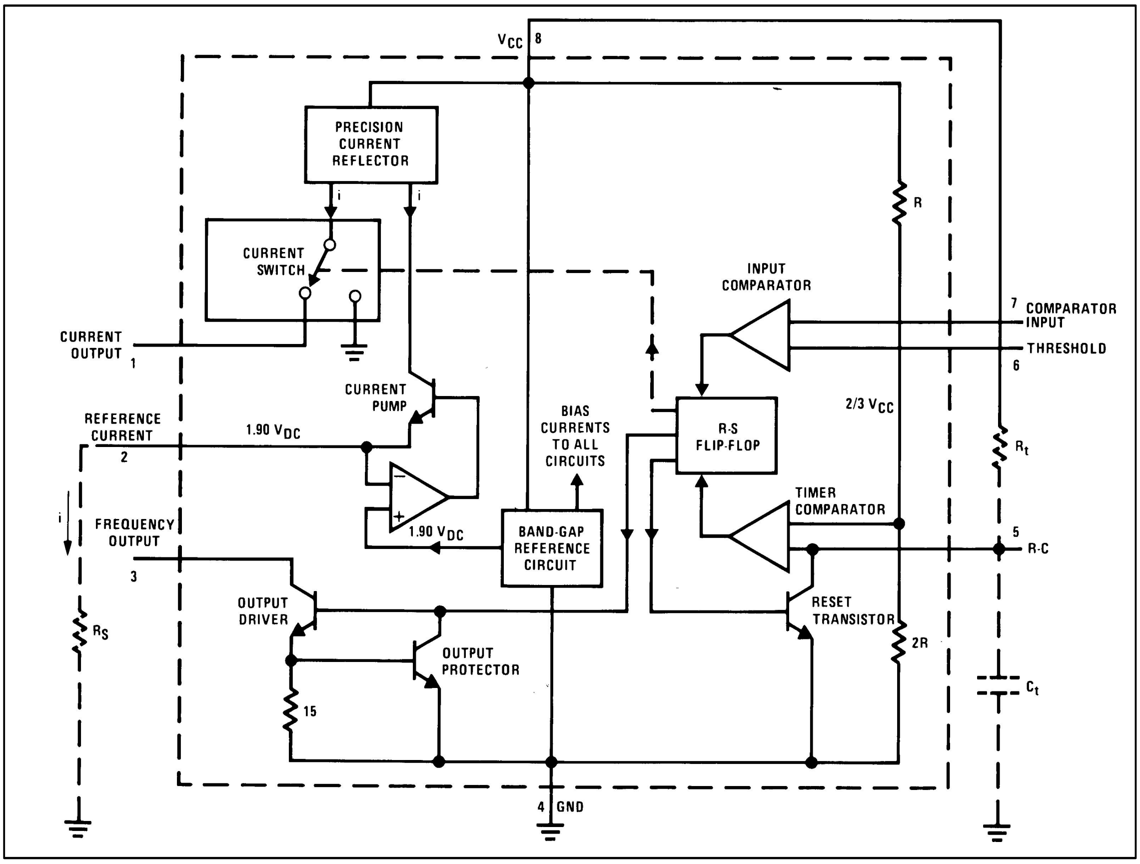
5.1. Overview

The Functional Block Diagram shows a band gap reference which provides a stable 1.9-VDC output. This 1.9 VDC is well regulated over a VS range of 4 V to 40 V. 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 1.9 V, and causes a current i = 1.90 V/RS to flow. For RS=14 k, 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 upon 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 RtCt 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 VCC, 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 the voltage on pin 7 as higher than pin 6 when pin 5 crosses ⅔ VCC, the flip-flop will not be reset, and the current at pin 1 will continue to flow, trying to make the voltage at pin 6 higher than pin 7. This condition will usually apply under start-up conditions or in the case of an overload voltage at signal input. 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.



6. SPECIFICATIONS

6.1. Absolute Maximum Ratings

		MIN	MAX	UNIT
Supply Voltage, V_S			40	V
Output Short Circuit to Ground		Continuous		
Output Short Circuit to V_{CC}		Continuous		
Input Voltage		−0.2	$+V_S$	V
Lead Temperature (Soldering, 10 sec.)	PDIP		260	°C

[1] Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

[2] All voltages are measured with respect to GND = 0 V, unless otherwise noted.

6.2. Thermal Information

THERMAL METRIC[1]		XD331, XD231	UNIT
		DIP	
		8 PINS	
$R_{θJA}$	Junction-to-ambient thermal resistance	100	°C/W

[1] For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report.

6.3. ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001[1][2]	±500	V

[1] JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

[2] Human body model, 100 pF discharged through a 1.5-kΩ resistor.

6.4. Recommended Operating Conditions

		MIN	MAX	UNIT
Operating Ambient Temperature	XD231	−25	85	°C
	XL331, XD331	0	70	°C
Supply Voltage, V_S		4	40	V

[1] All voltages are measured with respect to GND = 0 V, unless otherwise noted.

6.5. Electrical Characteristics

All specifications apply in the circuit of Figure 8-4, with 4.0 V ≤ VS ≤ 40 V, TA = 25°C, unless otherwise specified.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
VFC Non-Linearity	$4.5\text{ V} \le V_S \le 20\text{ V}$		±0.01	±0.03	% Full- Scale
	$T_{MIN} \le T_A \le T_{MAX}$		±0.02	±0.05	% Full- Scale
VFC Non-Linearity in Circuit of Figure 8-2	V_S = 15 V, f = 10 Hz to 11 kHz		±0.03	±0.22	%Full- Scale

Electrical Characteristics (continued)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
Conversion Accuracy Scale Factor (Gain)	XD231	V_{IN} = −10 V, R_S = 14 kΩ	0.95	1	1.05	kHz/V
	XL331, XD331		0.9	1	1.1	kHz/V
Temperature Stability of Gain	XL/XDx31	$T_{MIN} \le T_A \le T_{MAX}$ 4.5 V ≤ V_S ≤ 20 V		±50	±200	ppm/°C
Change of Gain with V_S		4.5 V ≤ V_S ≤ 10 V		0.02	0.25	%/V
		10 V ≤ V_S ≤ 40 V		0.01	0.18	%/V
Rated Full-Scale Frequency		V_{IN} = −10 V	10.0			kHz
Gain Stability vs. Time (1000 Hours)		$T_{MIN} \le T_A \le T_{MAX}$		±0.03		% Full-Scale
Over Range (Beyond Full-Scale) Frequency		V_{IN} = −11 V	10%			
INPUT COMPARATOR						
Offset Voltage				±5	±15	mV
XD231/XL331		$T_{MIN} \le T_A \le T_{MAX}$		±6	±20	mV
XD331		$T_{MIN} \le T_A \le T_{MAX}$		±5	±15	mV
Bias Current				−90	−350	nA
Offset Current				±10	±130	nA
Common-Mode Range		$T_{MIN} \le T_A \le T_{MAX}$	−0.2		V_{CC} − 2	V
TIMER						
Timer Threshold Voltage, Pin 5			0.63 × V_S	0.667 × V_S	0.7 × V_S	
Input Bias Current, Pin 5		V_S = 15 V				
All Devices		0V ≤ $V_{PIN\ 5}$ ≤ 9.9 V		±15	±150	nA
XD231/XL331		$V_{PIN\ 5}$ = 10 V		300	1200	nA
XD331		$V_{PIN\ 5}$ = 10 V		300	600	nA
$V_{SAT\ PIN\ 5}$ (Reset)		I = 5 mA		0.22	0.5	V
CURRENT SOURCE (PIN 1)						
Output Current	XD231	R_S = 14 kΩ, $V_{PIN\ 1}$ = 0	126	135	144	µA
	XL331, XD331		116	136	156	µA
Change with Voltage		0V ≤ $V_{PIN\ 1}$ ≤ 10 V		0.2	1	µA
Current Source OFF Leakage	XD231, XL331, XD331			0.02	10	nA
	All Devices	$T_A = T_{MAX}$		2	50	nA
Operating Range of Current (Typical)				(10 to 500)		µA
REFERENCE VOLTAGE (PIN 2)						
XD231			1.76	1.89	2.02	V_{DC}
XL331, XD331			1.7	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	0.5	V
		I = 3.2 mA (2 TTL Loads), $T_{MIN} \le T_A \le T_{MAX}$		0.1	0.4	V
OFF Leakage				±0.05	1	µA
SUPPLY CURRENT						
XD231		V_S = 5 V	2	4	8	mA
		V_S = 40 V	2.5	5	10	mA
XL331, XD331		V_S = 5 V	1.5	6	9	mA
		V_S = 40 V	2	5	12	mA

6.6. Dissipation Ratings

	VALUE	UNIT
Package Dissipation at 25°C(1)	1.25	W

The absolute maximum junction temperature (TJmax) for this device is 150°C. The maximum allowable power dissipation is dictated by TJmax, the junction-to-ambient thermal resistance (θJA), and the ambient temperature TA, and can be calculated using the formula PDmax = (TJmax - TA) / θJA. The values for maximum power dissipation will be reached only when the device is operated in a severe fault condition (e.g., when input or output pins are driven beyond the power supply voltages, or the power supply polarity is reversed). Obviously, such conditions should always be avoided.

Typical Characteristics(All electrical characteristics apply for the circuit of Figure 16, unless otherwise noted.)

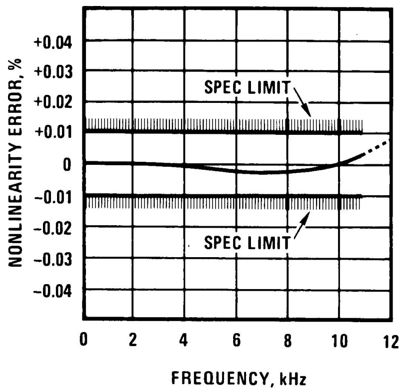


Figure 6-1. Non-Linearity Error as Precision V-to-F Converter (Figure 16)

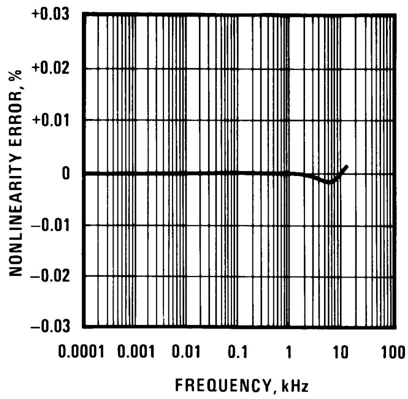


Figure 6-2. Non-Linearity Error

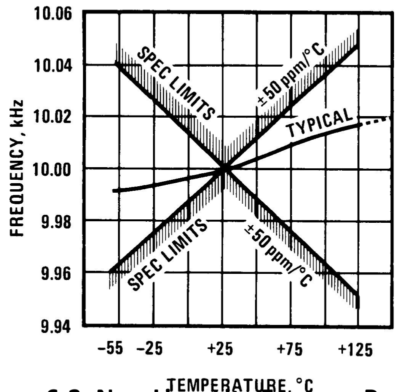


Figure 6-3. Non-Linearity Error vs. Power Supply Voltage

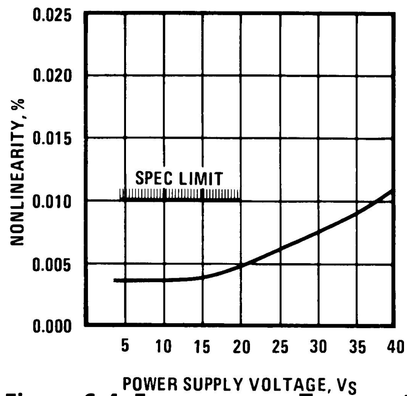


Figure 6-4. Frequency vs. Temperature

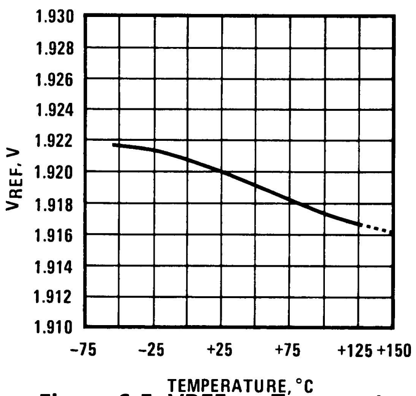


Figure 6-5. VREF vs. Temperature

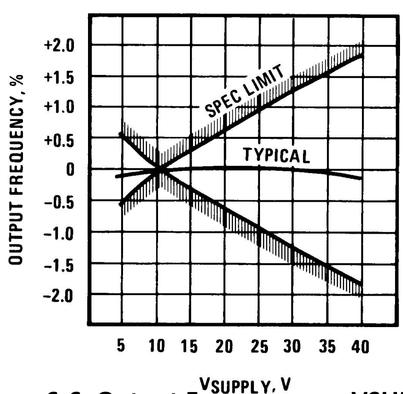


Figure 6-6. Output Frequency vs. VSUPPLY

Typical Characteristics (continued)

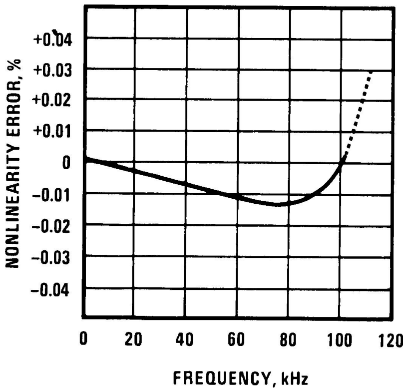


Figure 6-7. 100 kHz Non-Linearity Error (Figure 17)

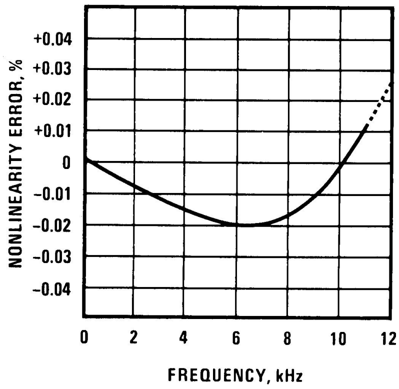


Figure 6-8. Non-Linearity Error (Figure 14)

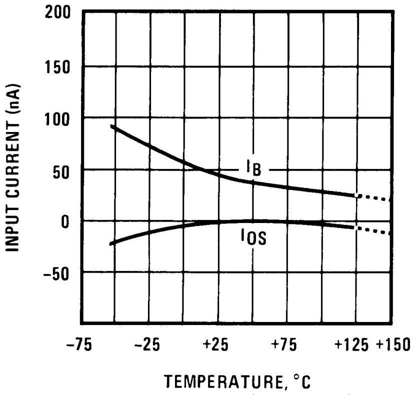


Figure 6-9. Input Current (Pins 6,7) vs. Temperature

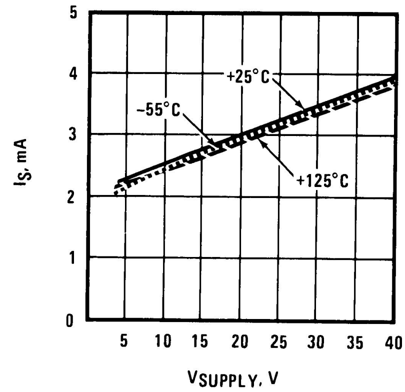


Figure 6-10. Power Drain vs. V_{SUPPLY}

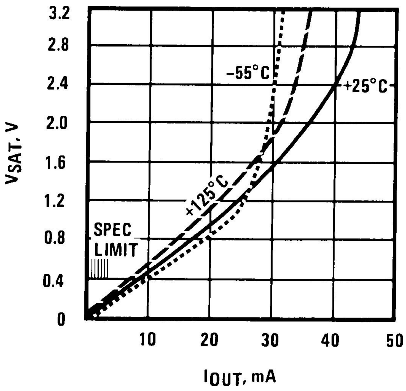


Figure 6-11. Output Saturation Voltage vs. I_{OUT} (Pin 3)

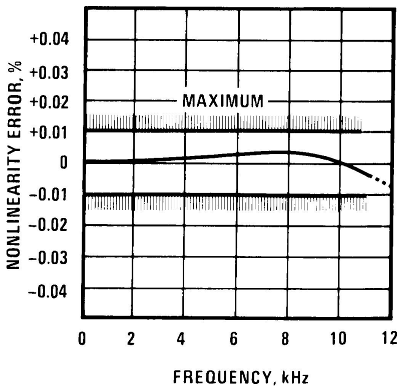


Figure 6-12. Non-Linearity Error, Precision F-to-V Converter (Figure 8-7)

7. DETAILED DESCRIPTION

7.1. Feature Description

The XL/XDx31 operate over a wide voltage range of 4 V to 40 V.

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

7.2. Device Functional Modes

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

If the voltage on pin 7 is higher than pin 6 when pin 5 crosses ⅔ VCC, the XL/XDx31 internal flip-flop will not be reset, and the current at pin 1 will continue to flow, trying to make the voltage at pin 6 higher than pin 7. This condition will usually apply under start-up conditions or in the case of an overload voltage at signal input. 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.

8. APPLICATION AND IMPLEMENTATION

8.1. Application Information

- Voltage to Frequency Conversions
- Frequency to Voltage Conversions
- Remote-Sensor Monitoring
- Tachometers

8.1.1. Simplified Voltage-to-Frequency Converter

The operation of these blocks is best understood by going through the operating cycle of the basic V-to-F converter, Figure 8-1, which consists of the simplified block diagram of the XL/XDx31 and the various resistors and capacitors connected to it.

The voltage comparator compares a positive input voltage, V1, at pin 7 to the voltage, Vx, 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 RtCt. During this period, the current i will flow out of the switched current source and provide a fixed amount of charge, Q = i × t, into the capacitor, CL. This will normally charge Vx 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 CL will be gradually discharged by RL until Vx falls to the level of V1. Then the comparator will trigger the timer and start another cycle.

The current flowing into CL is exactly IAVE = i × (1.1×RtCt) × f, and the current flowing out of CL is exactly Vx/RL ≃ VIN/RL. If VIN 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.

8.1.2. Principles of Operation

The XL/XDx31 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 XL/XDx31 is shown in Figure 8-1 and consists of a switched current source, input comparator, and 1-shot timer.

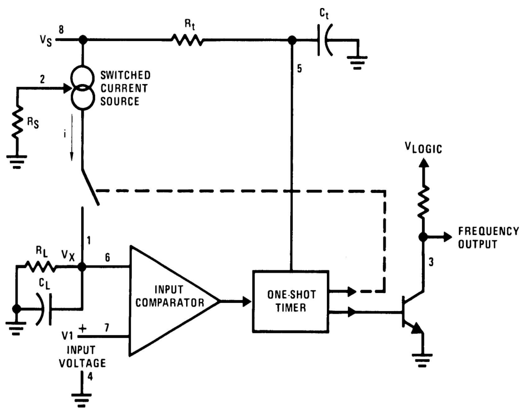


Figure 8-1. Simplified Block Diagram of Stand-Alone Voltage-to-Frequency Converter and External Components

8.2. Typical Applications

8.2.1. Basic Voltage-to-Frequency Converter

The simple stand-alone V-to-F converter shown in Figure 8-2 includes all the basic circuitry of Figure 8-1 plus a few components for improved performance.

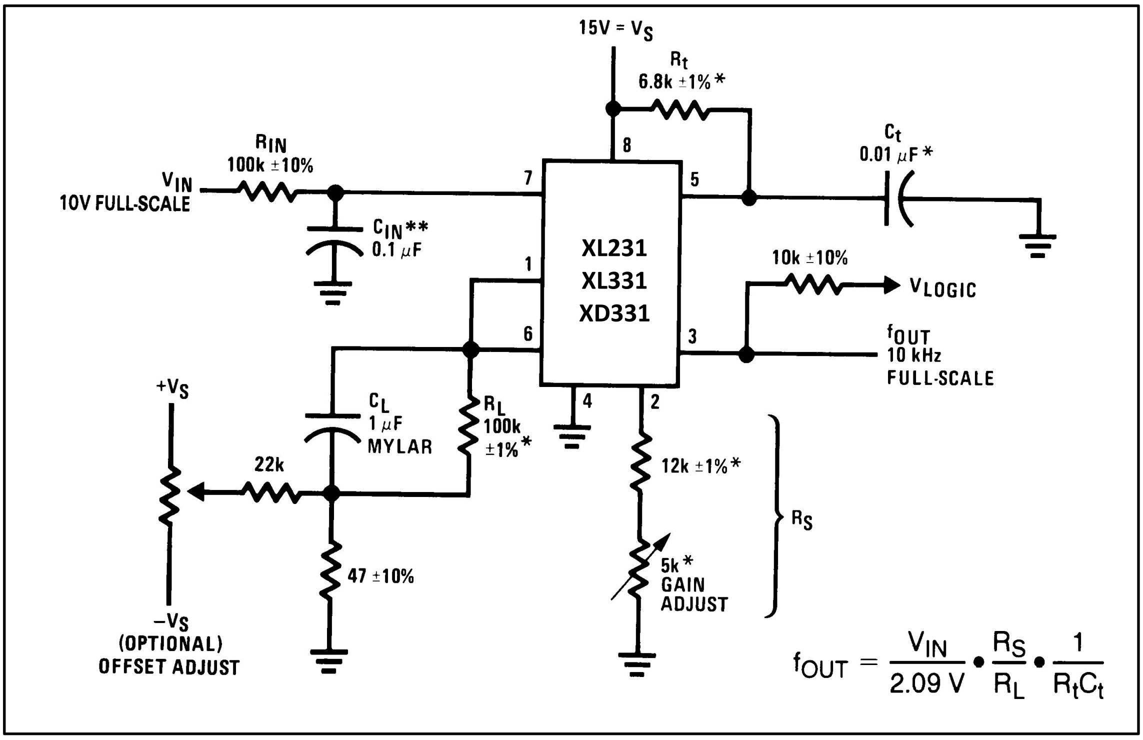


Figure 8-2. Simple Stand-Alone V-to-F Converter with ±0.03% Typical Linearity (f = 10 Hz to 11 kHz)

8.2.2. Design Requirements

For this example, the system requirements are 0.05% linearity over an output frequency range of 10 Hz to 4 kHz with an input voltage range of 25 mV to 12.5V.The available supply voltage is 15.0 V

8.2.3. Detailed Design Procedure

A capacitor CIN is added from pin 7 to ground to act as a filter for VIN, use of a 0.1 µF is appropriate for this application. 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 VIN will cause a step change in fOUT. If CIN is much less than CL, a step at VIN may cause fOUT to stop momentarily.

Next, we cancel the comparator bias current by setting RIN to 100 kΩ to match RL. This will help to minimize any frequency offset.

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.

The resistance RS 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 XL/XDx31, and the tolerance of Rt, RL and Ct.

A 47-Ω resistor in series with the 1-µF capacitor (CL) provides hysteresis, which helps the input comparator provide the excellent linearity.

This results in the transfer function of fOUT = (VIN / 2.09 V) × (RS / RL) × (1 / RtCt).

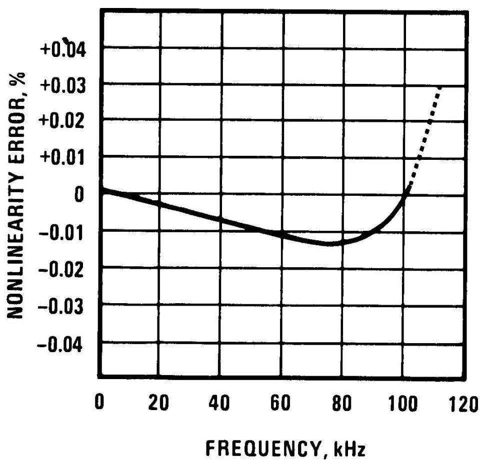


Figure 8-3. Output Non-Linearity Error vs. Frequency

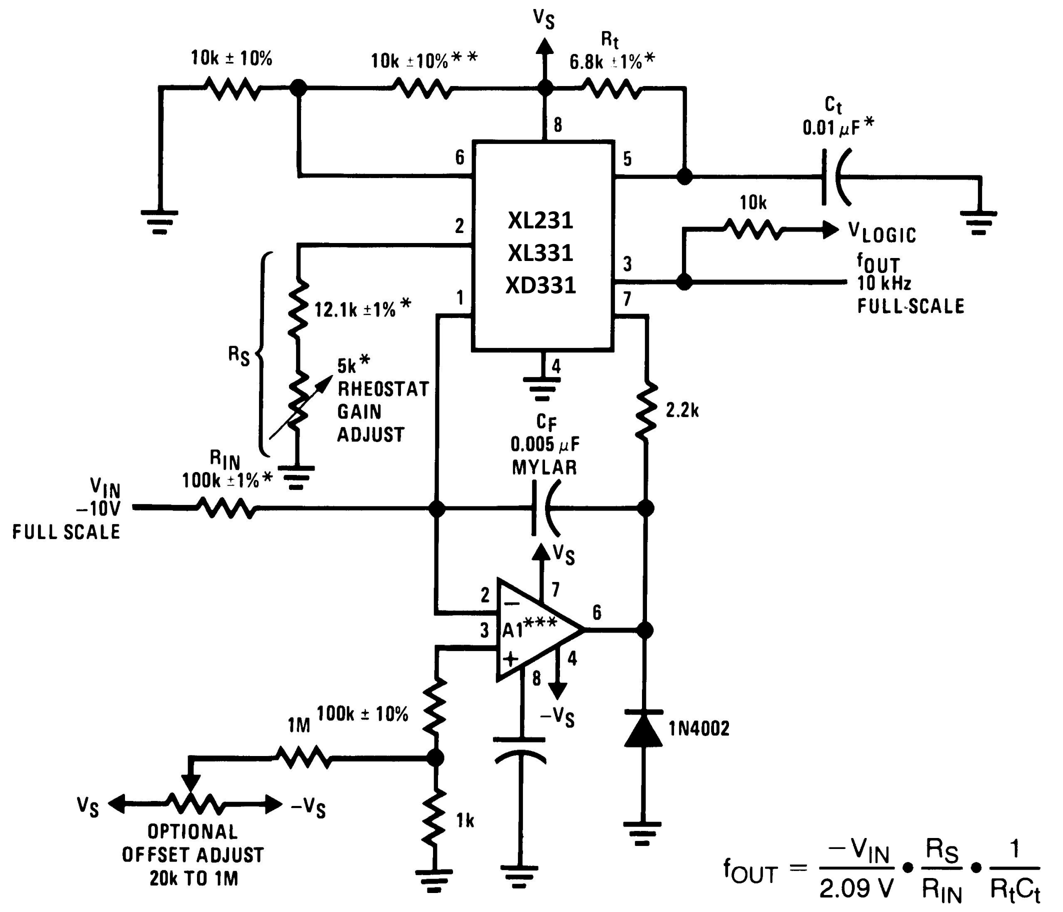
8.2.4. Precision V-To-F Converter

In this circuit, integration is performed by using a conventional operational amplifier and feedback capacitor, CF. When the integrator's output crosses the nominal threshold level at pin 6 of the XL/XDx31, the timing cycle is initiated.

The average current fed into the summing point of the op-amp (pin 2) is i × (1.1 RtCt) × f which is perfectly balanced with −VIN/RIN. In this circuit, the voltage offset of the XL/XDx31 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 XD231/331 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 VIN, as quickly as the spacing of the 2 output pulses 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 VIN or fOUT. (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 VIN).

The circuit of Figure 8-5 operates in the same way as Figure 8-4, but with the necessary changes for high-speed operation.



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

[1] Use stable components with low temperature coefficients.

[2] This resistor can be 5 kΩ or 10 kΩ for VS = 8 V to 22 V, but must be 10 kΩ for VS = 4.5 V to 8 V.

[3] Use low offset voltage and low offset current op-amps for A1: recommended type LF411A.

Figure 8-4. Standard Test Circuit and Applications Circuit, Precision Voltage-to-Frequency Converter

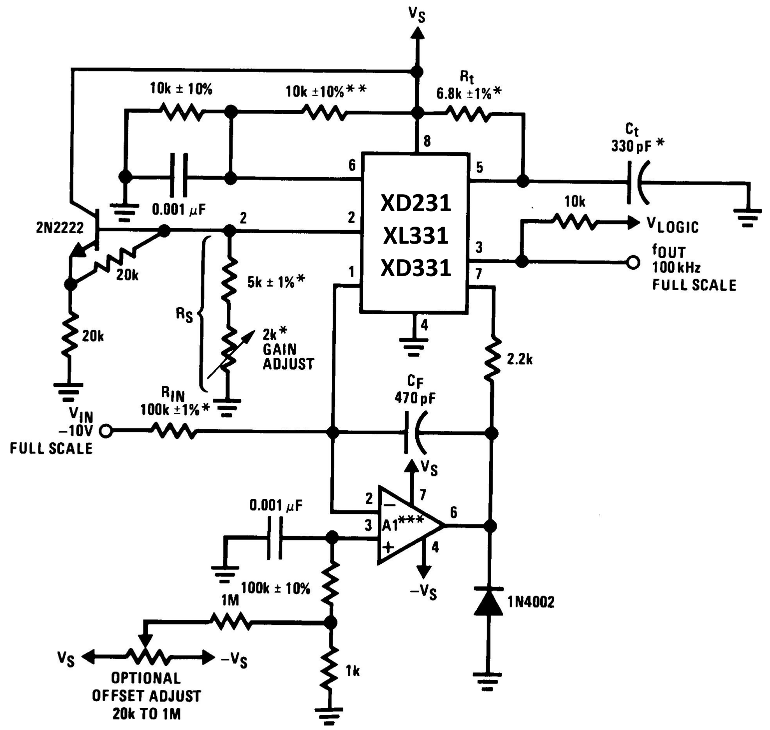
8.3. System Examples

8.3.1. F-to-V Converters

In these applications, a pulse input at fIN 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 IAVERAGE = i × (1.1 RtCt) × f.

In the simple circuit of Figure 8-6, this current is filtered in the network RL = 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 8-6. However, for input frequencies below 200 Hz, this circuit will have worse ripple than Figure 8-6. 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.



100 kHz Full-Scale, ±0.03% Non-Linearity

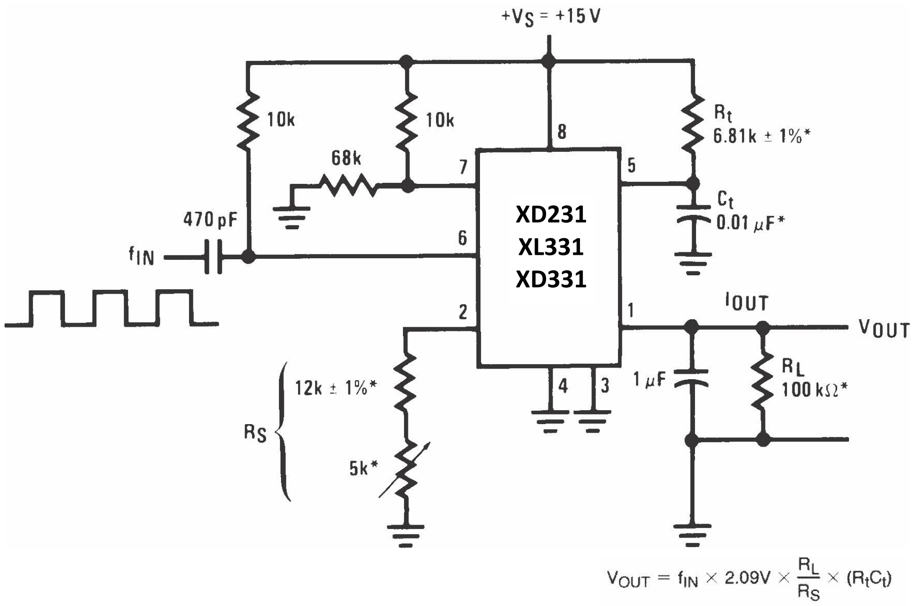
[1] Use stable components with low temperature coefficients.

[2] This resistor can be 5 kΩ or 10 kΩ for VS=8V to 22V, but must be 10 kΩ for VS=4.5V to 8V.

[3] Use low offset voltage and low offset current op-amps for A1:

recommended types LF411A or LF356.

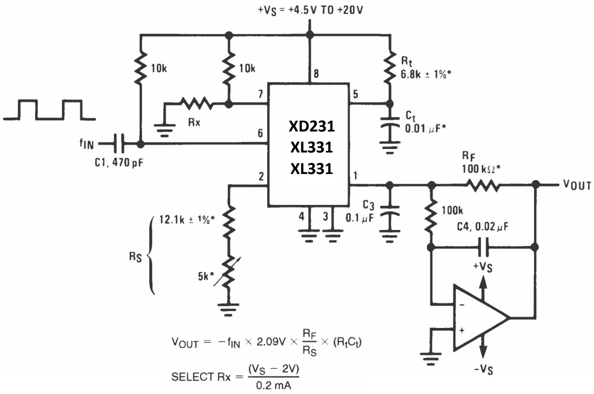
Figure 8-5. Precision Voltage-to-Frequency Converter Converter

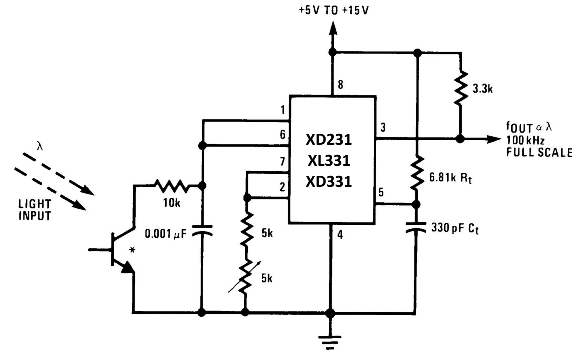


kHz Full-Scale, ±0.06% Non-Linearity

[1] Use stable components with low temperature coefficients.

Figure 8-6. Simple Frequency-to-Voltage





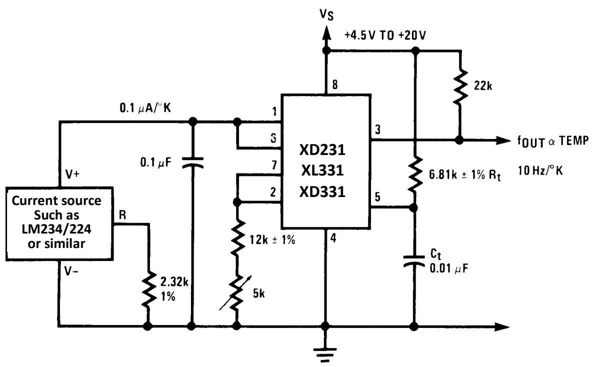
[1] 10 kHz Full-Scale With 2-Pole Filter, ±0.01% Non-Linearity Maximum

[2] Use stable components with low temperature coefficients.

[1] L14F-1, L14G-1 or L14H-1, photo transistor or similar

Figure 8-7. Precision Frequency-to-Voltage Converter

Figure 8-8. Light Intensity to Frequency



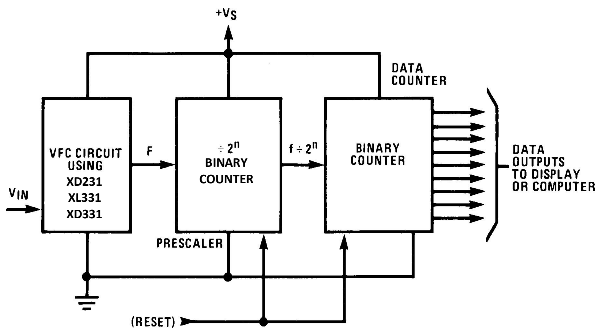
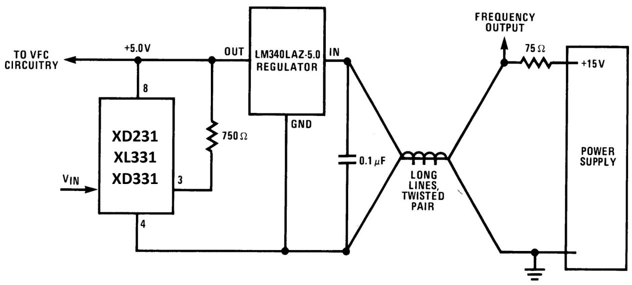


Figure 8-9. Temperature to Frequency Converter Using VFC

Figure 8-10. Long-Term Digital Integrator



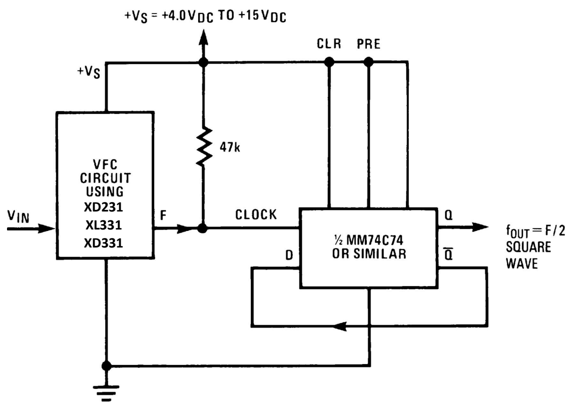


Figure 8-11. Remote Voltage-to-Frequency Converter With 2-Wire Transmitter and Receiver

Figure 8-12. Voltage-to-Frequency Converter With Square-Wave Output Using ÷ 2 Flip-Flop

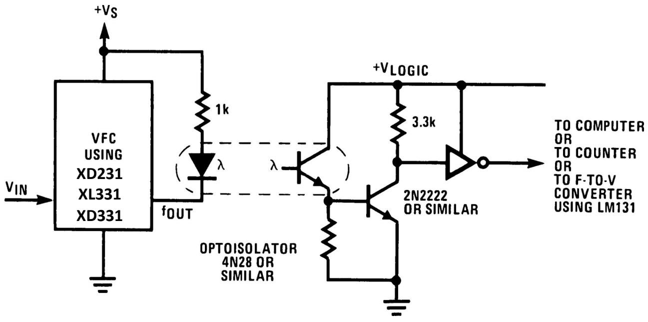


Figure 8-13. Voltage-to-Frequency Converter With Converter With Isolators

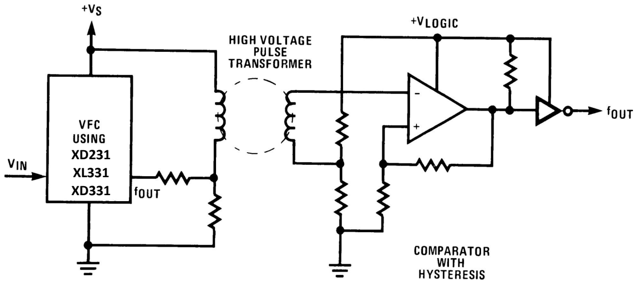


Figure 8-14. Voltage-to-Frequency Isolators

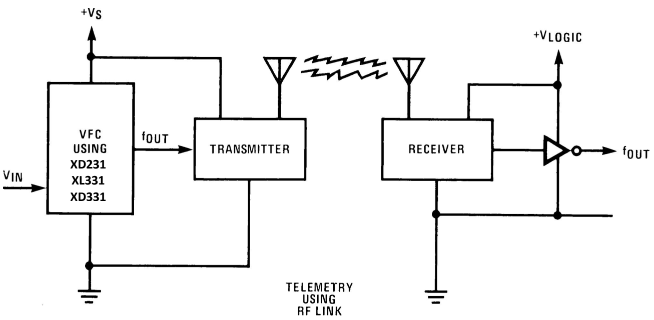


Figure 8-15. Voltage-to-Frequency Converter With Converter With Isolators

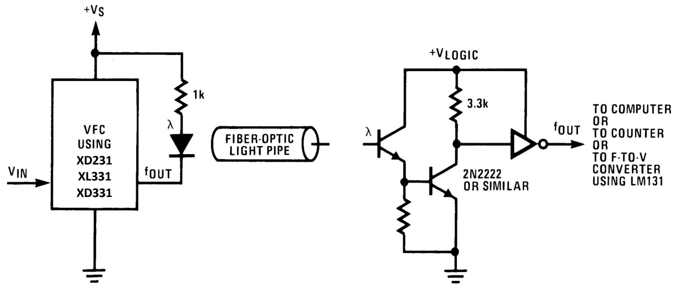


Figure 8-16. Voltage-to-Frequency Isolators

9. Power Supply Recommendations

The XL/XDx31 can operate over a wide supply voltage range of 4 V to 40 V. For proper operation, the supply pin should be bypassing to ground with a low-ESR, 1-µF capacitor. It is acceptable to use X7R capacitors for this. For systems using higher supply voltages, ensure that the voltage rating for the bypass caps is sufficient.

10. Layout

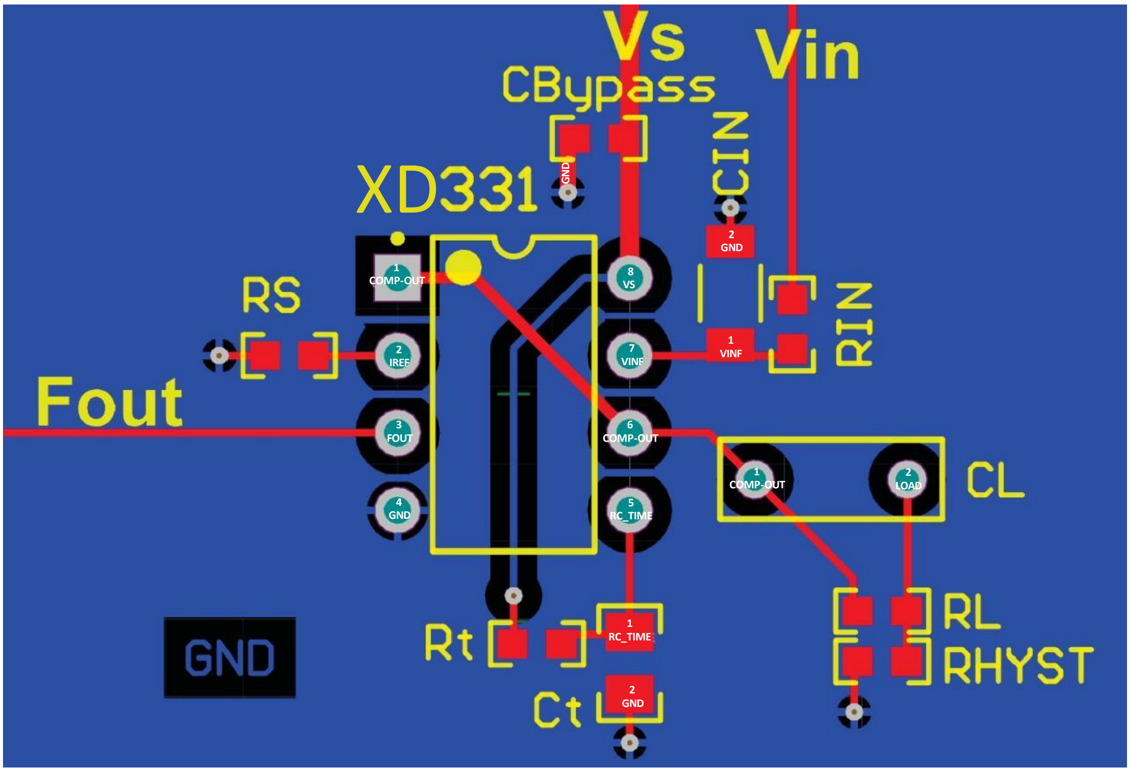
10.1. Layout Guidelines

Bypass capacitors must be placed as close as possible to the supply pin. As the XD331 is a through-hole device, it is acceptable to place the bypass capacitor on the bottom layer.

If an input capacitor to ground is used to clean the input signal, the capacitor should be placed close to the supply pin.

Use of a ground plane is recommended to provide a low-impedance ground across the circuit.

10.2. Layout Example



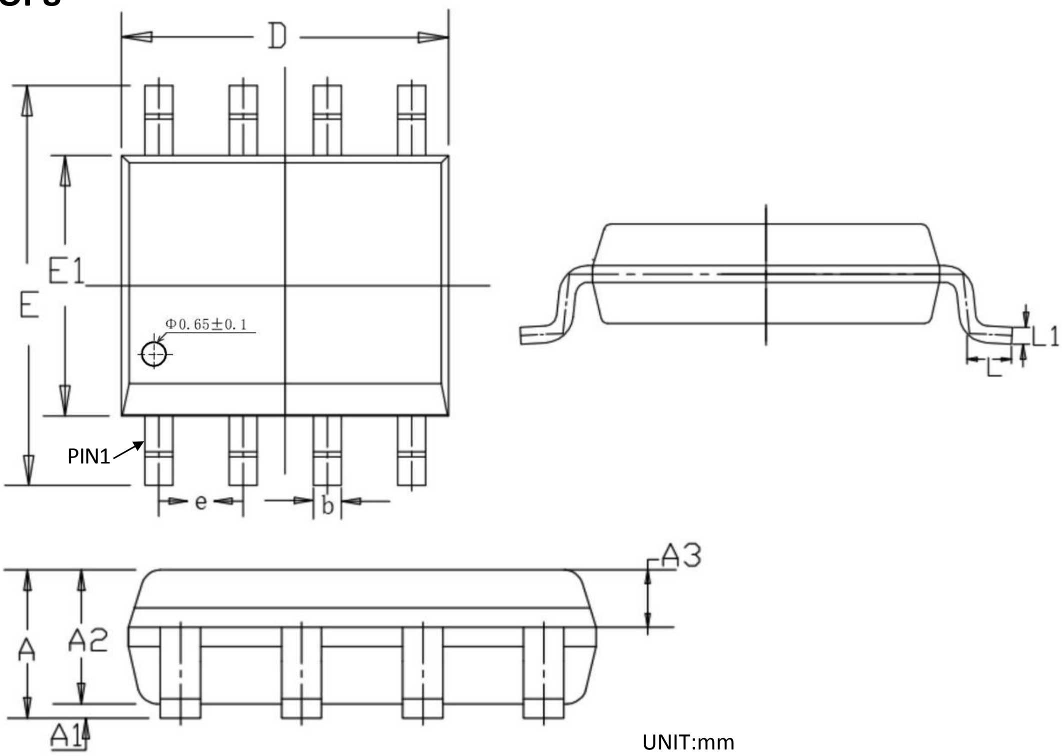
11. ORDERING INFORMATION

Ordering Information

Part Number	Device Marking	Package Type	Body size (mm)	Temperature (°C)	MSL	Transport Media	Package Quantity
XL331	XL331	SOP8	4.90 * 3.90	-0 to +70	MSL3	T&R	2500
XD331	XD331	DIP8	9.25 * 6.38	-0 to +70	MSL3	Tube 50	2000
XD231	XD231	DIP8	9.25 * 6.38	-25 to +85	MSL3	Tube 50	2000

12. DIMENSIONAL DRAWINGS

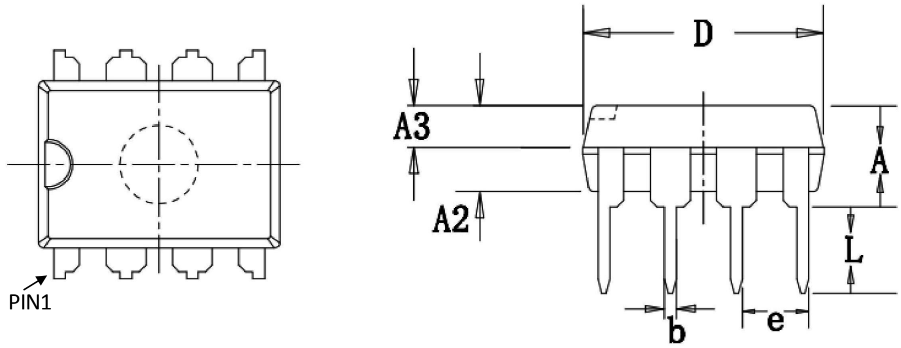
SOP8

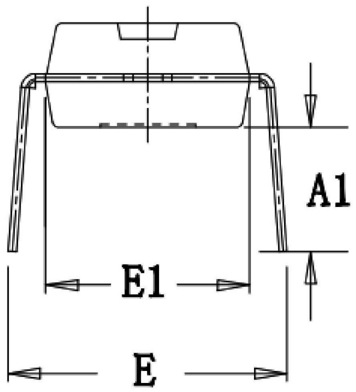


UNIT:mm

	MIN	NOM	MAX
A	1.450	1.550	1.650
A1	0.100	0.150	0.200
A2	1.300	1.400	1.500
A3	0.600	0.650	0.700
b	0.380	–	0.510
e	1.240	1.270	1.300
D	4.800	4.900	5.000
E	5.800	6.000	6.200
E1	3.800	3.900	4.000
L	0.450	0.600	0.750
L1	–	0.25BSC	–

DIP8





UNIT:mm

	MIN	NOM	MAX
A	3.600	3.800	4.000
A1	3.786	3.886	3.986
A2	3.200	3.300	3.400
A3	1.550	1.600	1.650
b	0.440	–	0.490
e	2.510	2.540	2.570
D	9.150	9.250	9.350
E	7.800	8.500	9.200
E1	6.280	6.380	6.480
L	3.000	–	–