

XD331 DIP-8 / XL331 SOP8 / XD231 DIP-8

1 Features

- Ensured Linearity 0.01% 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
- Excellent Temperature Stability: ± 50 ppm/ $^{\circ}\text{C}$ Maximum
- 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

2 Applications

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

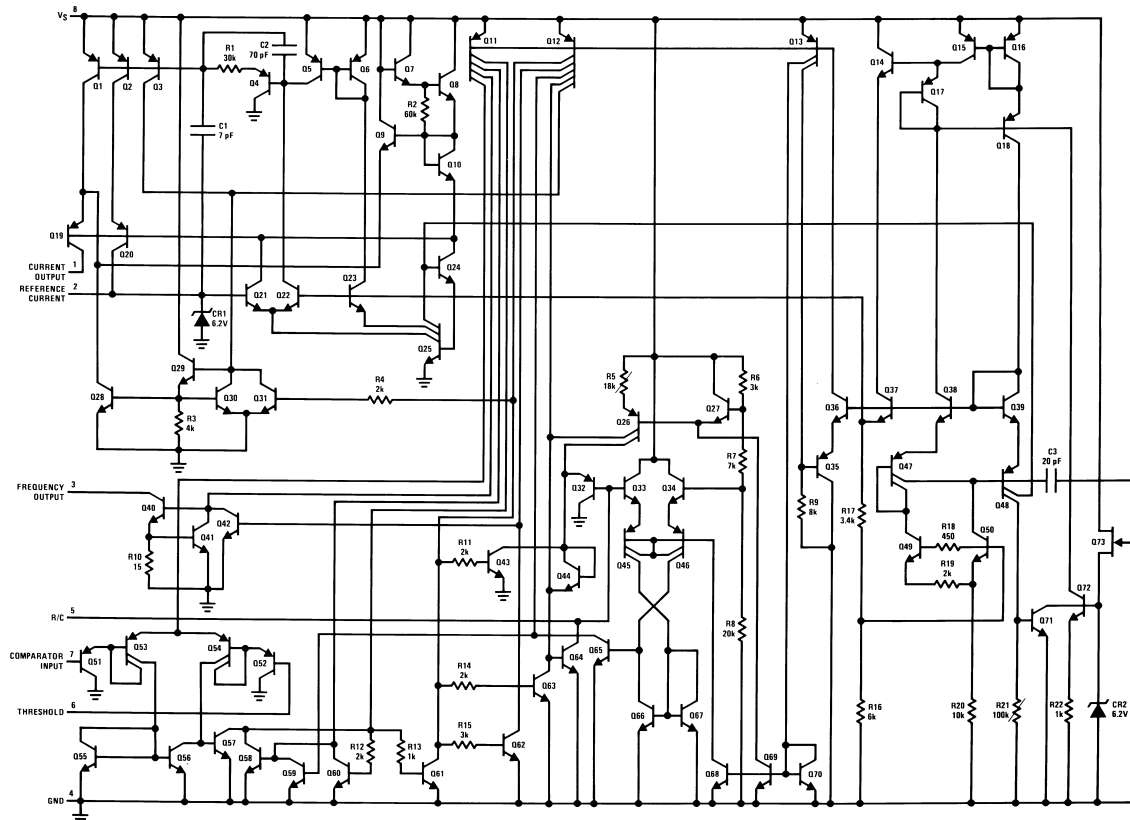
3 Description

The XDx31 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.

4 Device Information⁽¹⁾

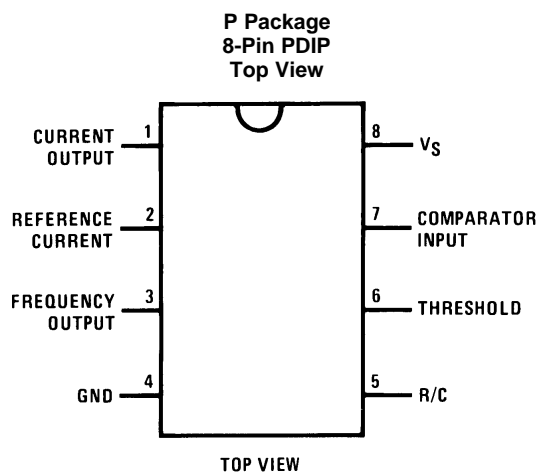
| PART NUMBER | PACKAGE |
|-------------|---------|
| XD331-231 | DIP8 |
| XL331 | SOP8 |

Schematic Diagram



XD331 DIP-8 / XL331 SOP8 / XD231 DIP-8

5 Pin Configuration 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 |

6 Specifications

6.1 Absolute Maximum Ratings⁽¹⁾⁽²⁾⁽³⁾

| | | 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 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.

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6.3 Recommended Operating Conditions

| | | MIN | MAX | UNIT |
|--------------------------------------|-------------|-----|-----|------|
| Operating Ambient Temperature | XD231 | -25 | 85 | °C |
| | XD331 XL331 | 0 | 70 | °C |
| Supply Voltage, V_S ⁽¹⁾ | | 4 | 40 | V |

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

6.4 Thermal Information

| THERMAL METRIC ⁽¹⁾ | | XD331 XL331 | UNIT |
|-------------------------------|--|-------------|------|
| | | P (PDIP) | |
| | | 8 PINS | |
| $R_{\theta JA}$ | 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, SPRA953.

6.5 Electrical Characteristics

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|--------------|---|-------------------|--------------------|------------------|--------------|
| VFC Non-Linearity ⁽¹⁾ | | $4.5\text{ V} \leq V_S \leq 20\text{ V}$ | | ±0.003 | ±0.01 | % Full-Scale |
| | | $T_{MIN} \leq T_A \leq T_{MAX}$ | | ±0.006 | ±0.02 | % Full-Scale |
| VFC Non-Linearity in Circuit of Figure 14 | | $V_S = 15\text{ V}$, $f = 10\text{ Hz to } 11\text{ kHz}$ | | ±0.024 | ±0.14 | % Full-Scale |
| Conversion Accuracy Scale Factor (Gain) | XD231 | $V_{IN} = -10\text{ V}$, $R_S = 14\text{ k}\Omega$ | 0.95 | 1 | 1.05 | kHz/V |
| | XD331, XL331 | | 0.9 | 1 | 1.1 | kHz/V |
| Temperature Stability of Gain | XDx31 | $T_{MIN} \leq T_A \leq T_{MAX}$ $4.5\text{ V} \leq V_S \leq 20\text{ V}$ | | ±30 | ±150 | ppm/°C |
| | XDx31 | | | ±20 | ±50 | ppm/°C |
| Change of Gain with V_S | | $4.5\text{ V} \leq V_S \leq 10\text{ V}$ | | 0.01 | 0.1 | %/V |
| | | $10\text{ V} \leq V_S \leq 40\text{ V}$ | | 0.006 | 0.06 | %/V |
| Rated Full-Scale Frequency | | $V_{IN} = -10\text{ V}$ | 10.0 | | | kHz |
| Gain Stability vs. Time (1000 Hours) | | $T_{MIN} \leq T_A \leq T_{MAX}$ | | ±0.02 | | % Full-Scale |
| Over Range (Beyond Full-Scale) Frequency | | $V_{IN} = -11\text{ V}$ | 10% | | | |
| INPUT COMPARATOR | | | | | | |
| Offset Voltage | | | | ±3 | ±10 | mV |
| | XD231 | $T_{MIN} \leq T_A \leq T_{MAX}$ | | ±4 | ±14 | mV |
| | XD331/XL331 | $T_{MIN} \leq T_A \leq T_{MAX}$ | | ±3 | ±10 | mV |
| Bias Current | | | | -80 | -300 | nA |
| Offset Current | | | | ±8 | ±100 | nA |
| Common-Mode Range | | $T_{MIN} \leq T_A \leq T_{MAX}$ | -0.2 | | $V_{CC} - 2$ | V |
| TIMER | | | | | | |
| Timer Threshold Voltage, Pin 5 | | | $0.63 \times V_S$ | $0.667 \times V_S$ | $0.7 \times V_S$ | |
| Input Bias Current, Pin 5 | | $V_S = 15\text{ V}$ | | | | |
| | All Devices | $0\text{ V} \leq V_{PIN 5} \leq 9.9\text{ V}$ | | ±10 | ±100 | nA |
| | XD231 | $V_{PIN 5} = 10\text{ V}$ | | 200 | 1000 | nA |
| | XD331/XL331 | $V_{PIN 5} = 10\text{ V}$ | | 200 | 500 | nA |
| $V_{SAT PIN 5}$ (Reset) | | $I = 5\text{ mA}$ | | 0.22 | 0.5 | V |

(1) Non-linearity is defined as the deviation of f_{OUT} from $V_{IN} \times (10\text{ kHz}/-10\text{ V}_{DC})$ 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.

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Electrical Characteristics (continued)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|--------------------------------------|---|---|-------------|-------------|------|-------------------------|
| CURRENT SOURCE (PIN 1) | | | | | | |
| Output Current | XD231 | $R_S = 14\text{ k}\Omega, V_{\text{PIN } 1} = 0$ | 126 | 135 | 144 | μA |
| | XD331, XL331 | | 116 | 136 | 156 | μA |
| Change with Voltage | | $0\text{V} \leq V_{\text{PIN } 1} \leq 10\text{ V}$ | | 0.2 | 1 | μA |
| Current Source OFF Leakage | XD231 XD331 XL331 | | | 0.02 | 10 | nA |
| | All Devices | $T_A = T_{\text{MAX}}$ | | 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} |
| XD331, XL331 | | | 1.7 | 1.89 | 2.08 | V_{DC} |
| Stability vs. Temperature | | | | ± 60 | | ppm/ $^{\circ}\text{C}$ |
| Stability vs. Time, 1000 Hours | | | | $\pm 0.1\%$ | | |
| LOGIC OUTPUT (PIN 3) | | | | | | |
| V_{SAT} | $I = 5\text{ mA}$ | | | 0.15 | 0.5 | V |
| | $I = 3.2\text{ mA}$ (2 TTL Loads), $T_{\text{MIN}} \leq T_A \leq T_{\text{MAX}}$ | | | 0.1 | 0.4 | V |
| OFF Leakage | | | | ± 0.05 | 1 | μA |
| SUPPLY CURRENT | | | | | | |
| XD231 | $V_S = 5\text{ V}$ | | 2 | 3 | 4 | mA |
| | $V_S = 40\text{ V}$ | | 2.5 | 4 | 6 | mA |
| XD331, XL331 | $V_S = 5\text{ V}$ | | 1.5 | 3 | 6 | mA |
| | $V_S = 40\text{ V}$ | | 2 | 4 | 8 | mA |

6.6 Dissipation Ratings

| | VALUE | UNIT |
|---|-------|------|
| Package Dissipation at 25 $^{\circ}\text{C}$ ⁽¹⁾ | 1.25 | W |

- (1) The absolute maximum junction temperature (T_{Jmax}) for this device is 150 $^{\circ}\text{C}$. The maximum allowable power dissipation is dictated by T_{Jmax} , the junction-to-ambient thermal resistance (θ_{JA}), and the ambient temperature T_A , and can be calculated using the formula $P_{\text{Dmax}} = (T_{\text{Jmax}} - T_A) / \theta_{\text{JA}}$. 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.

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6.7 Typical Characteristics

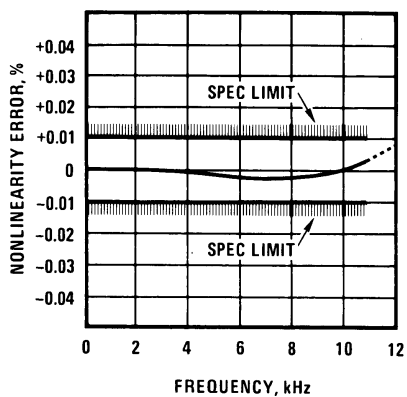


Figure 1. Non-Linearity Error as Precision V-to-F Converter

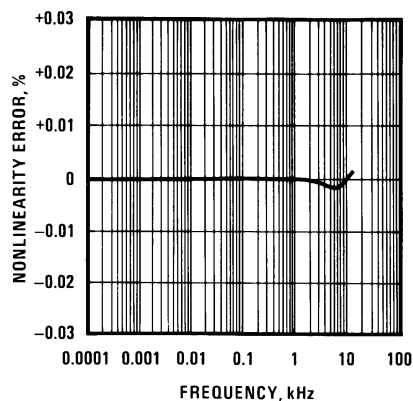


Figure 2. Non-Linearity Error

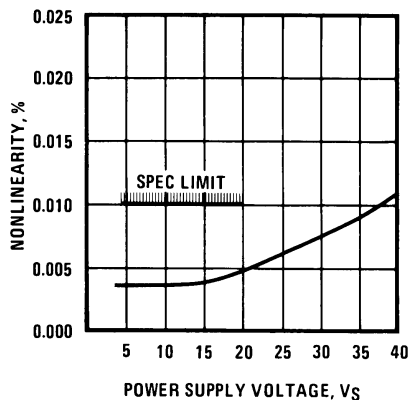


Figure 3. Non-Linearity Error vs. Power Supply Voltage

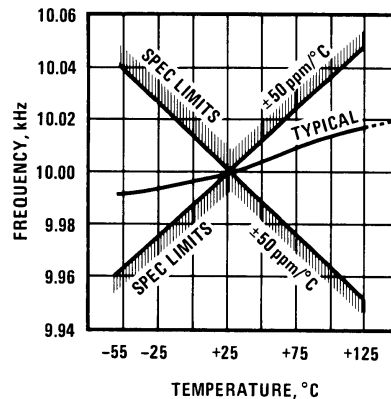


Figure 4. Frequency vs. Temperature

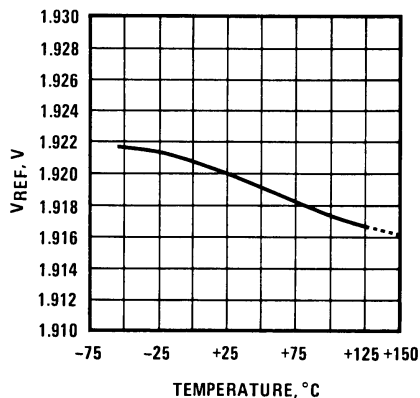


Figure 5. V_{REF} vs. Temperature

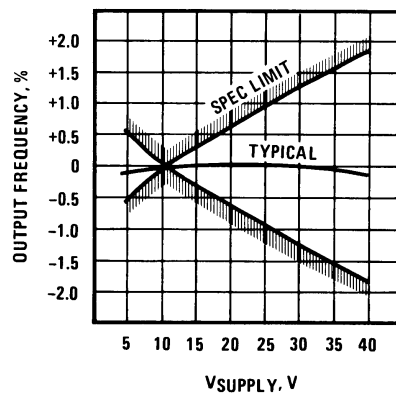


Figure 6. Output Frequency vs. V_{SUPPLY}

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Typical Characteristics (continued)

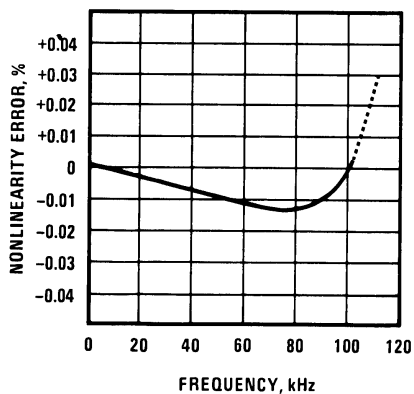


Figure 7. 100 kHz Non-Linearity Error

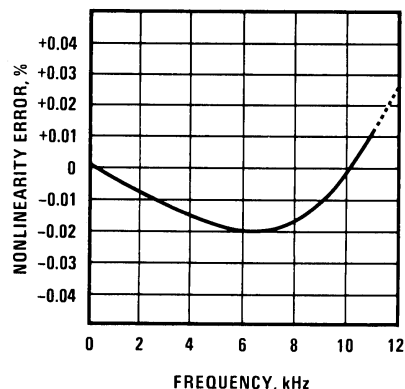


Figure 8. Non-Linearity Error (Figure 14)

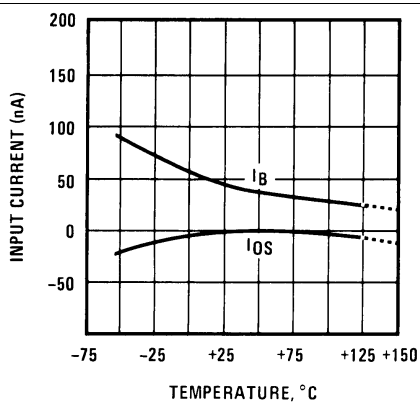


Figure 9. Input Current (Pins 6,7) vs. Temperature

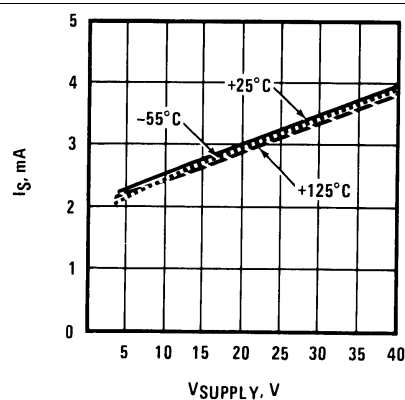


Figure 10. Power Drain vs. V_{SUPPLY}

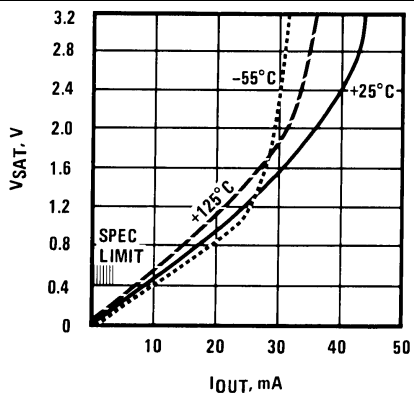


Figure 11. Output Saturation Voltage vs. I_{OUT} (Pin 3)

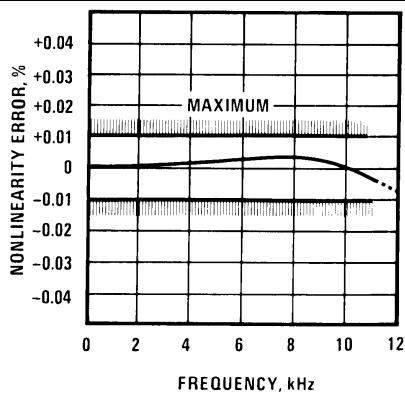


Figure 12. Non-Linearity Error, Precision F-to-V Converter

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7 Detailed Description

7.1 Overview

7.1.1 Detail of Operation, Functional Block Diagram

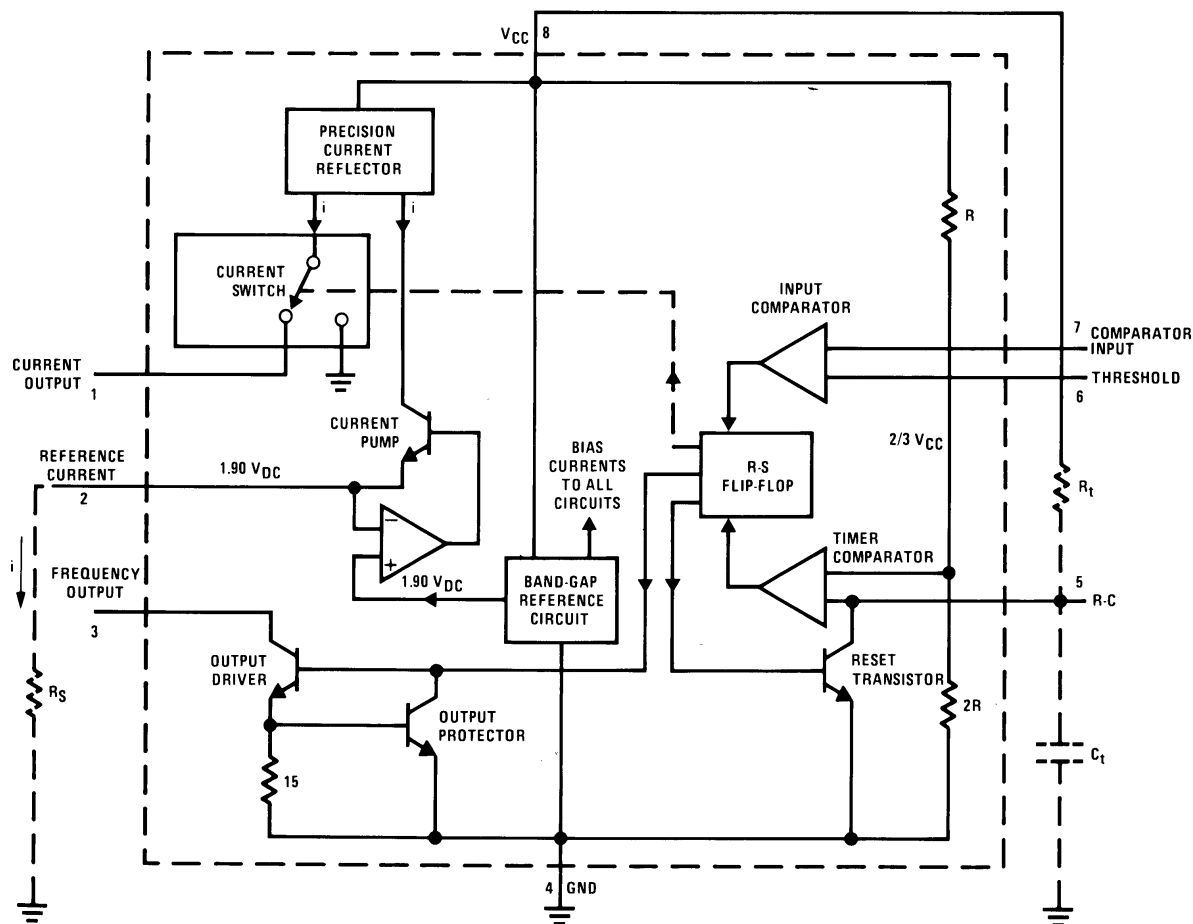
The *Functional Block Diagram* shows a band gap reference which provides a stable 1.9-V_{DC} output. This 1.9 V_{DC} is well regulated over a V_S range of 3.9 V to 40 V. It also has a flat, low temperature coefficient, and typically changes less than ½% over a 100°C temperature change.

The current pump circuit forces the voltage at pin 2 to be at 1.9 V, and causes a current $i = 1.90 \text{ V}/R_S$ to flow. For $R_S=14 \text{ k}$, $i=135 \mu\text{A}$. 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 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 the voltage on pin 7 as 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, 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.

7.2 Functional Block Diagram



8 Application and Implementation

8.1 Application Information

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 13, which consists of the simplified block diagram of the XDx31 and the various resistors and capacitors connected to it.

The voltage comparator compares a positive input voltage, V_1 , at pin 7 to the voltage, V_x , at pin 6. If V_1 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 $t = 1.1 R_t C_t$. During this period, the current i will flow out of the switched current source and provide a fixed amount of charge, $Q = i \times t$, into the capacitor, C_L . This will normally charge V_x up to a higher level than V_1 . 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 V_1 . Then the comparator will trigger the timer and start another cycle.

The current flowing into C_L is exactly $I_{AVE} = i \times (1.1 \times R_t C_t) \times f$, and the current flowing out of C_L is exactly $V_x / R_L \approx V_{IN} / R_L$. 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.

9.1.2 Principles of Operation

The 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 XDx31 is shown in Figure 13 and consists of a switched current source, input comparator, and 1-shot timer.

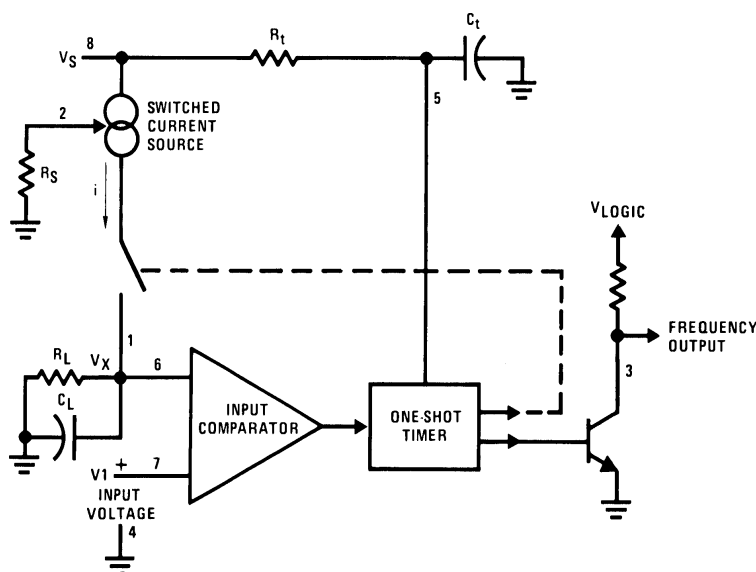
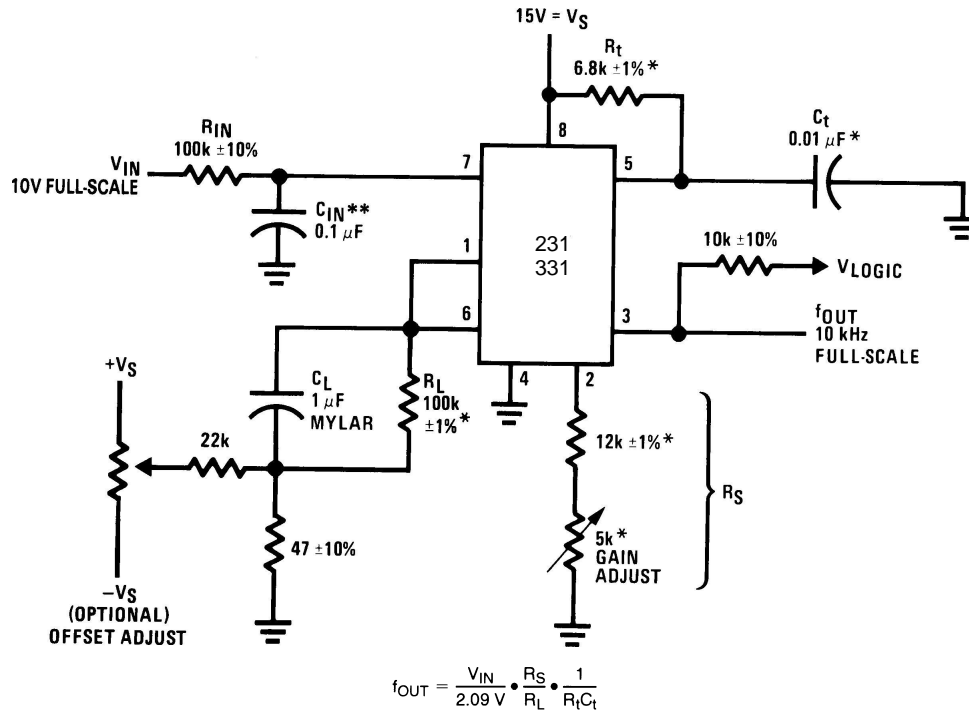


Figure 13. Simplified Block Diagram of Stand-Alone Voltage-to-Frequency Converter and External Components

8.2 Typical Applications

8.2.1 Basic Voltage-to-Frequency Converter

The simple stand-alone V-to-F converter shown in Figure 14 includes all the basic circuitry of Figure 13 plus a few components for improved performance.



*Use stable components with low temperature coefficients. See *Application Information*.

**0.1 μ F or 1 μ F, See *Typical Applications*.

Figure 14. Simple Stand-Alone V-to-F Converter with $\pm 0.03\%$ Typical Linearity ($f = 10$ Hz to 11 kHz)

8.2.1.1 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 12.5 V. The available supply voltage is 15.0 V.

8.2.1.2 Detailed Design Procedure

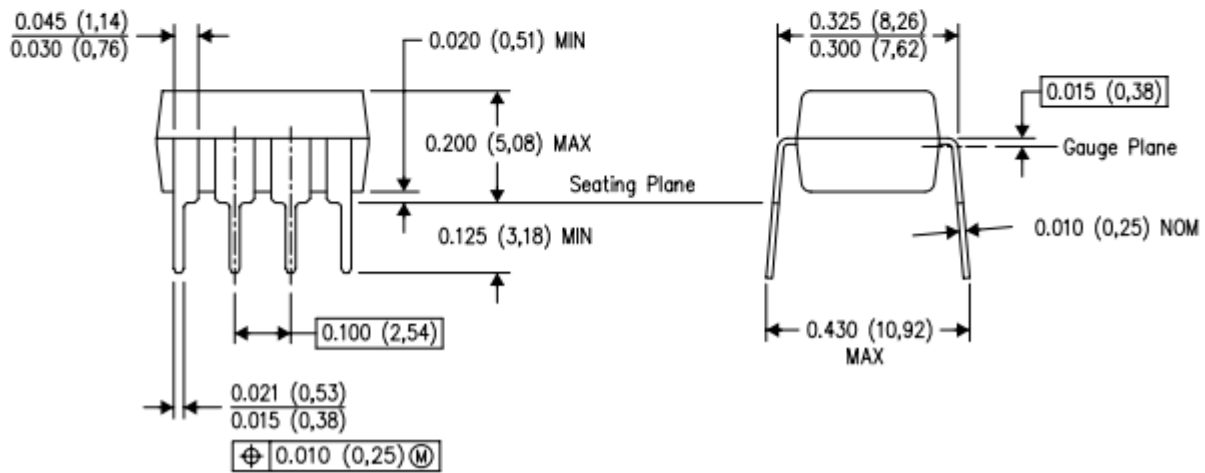
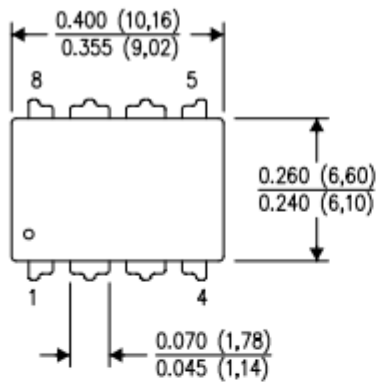
A capacitor C_{IN} is added from pin 7 to ground to act as a filter for V_{IN} , use of a 0.1 μ F is appropriate for this application. A value of 0.01 μ F to 0.1 μ F will be adequate in most cases; however, in cases where better filtering is required, a 1- μ F capacitor can be used. When the RC time 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.

Next, we cancel the comparator bias current by setting R_{IN} to 100 k Ω to match R_L . This will help to minimize any frequency offset.

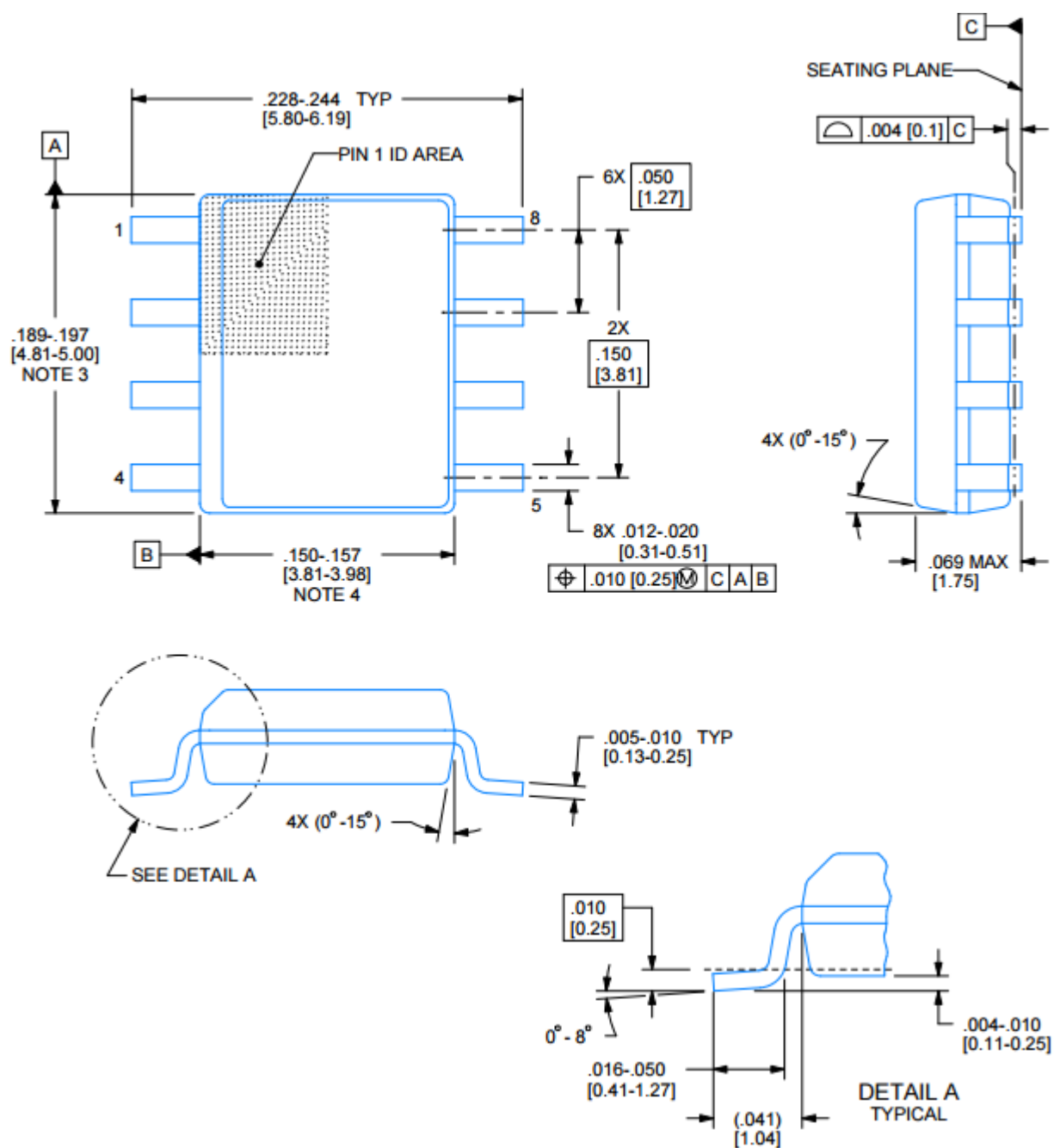
For best results, all the components should be stable low-temperature-coefficient components, such as metal-film resistors. The capacitor should have low dielectric absorption; depending on the temperature characteristics desired, NPO ceramic, polystyrene, Teflon or polypropylene are best suited.

The resistance R_S at pin 2 is made up of a 12-k Ω fixed resistor plus a 5-k Ω (cermet, preferably) gain adjust rheostat. The function of this adjustment is to trim out the gain tolerance of the XDx31, and the tolerance of R_t , R_L and C_t .

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[LTC2414CGNPBF](#) [TC7109ACKW](#) [TC7109CLW](#)