Single-Supply Acceleration-to-Frequency Circuits

A single-chip accelerometer and a V-to-F circuit ease digitizing and transmission of remote signals

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Introduction

A monolithic accelerometer's output can be connected to a voltage-to-frequency converter (VFC), a circuit whose output is a variable frequency, to generate a frequency proportional to acceleration simply and at low cost. The information in the resulting high-level ac signal can be sent through noisy environments having attenuation and nonlinear response—yet can be recovered reliably. For acceleration-to-digital conversion, a microprocessor can be easily programmed to read the frequency and directly compute the applied acceleration.

We will suggest here two circuits using single-supply voltage. One employs a precision high-linearity VFC, the AD654; the other uses a popular low-cost 555 timer chip.

High-performance acceleration-to-frequency circuit:

Figure 1 shows a circuit, using a VFC, whose output frequency varies directly with applied acceleration. The circuit operates from a single +5-volt power supply.

The ADXL05 is housed in a TO-100 hermetically sealed can. Acceleration (positive or negative) sensed in the direction of the package tab is directly converted to an analog voltage. The acceleration may be associated with motion, or it may involve static measurements involving *g*, the acceleration of Earth gravity. For example, if the ADXL05 is mounted so that the tab's orientation is tilted with respect to the vertical, the output will depend on the in-line component of *g*, thus providing a measure of the tilt angle.

An on-chip buffer amplifier is available to provide scaling and offset; the accelerometer's output voltage, as the input to the AD654 VFC, controls the frequency of the output pulse train appearing at pin 1 of the AD654. Table 1 illustrates a set of scaling options for controlling the sensitivity of frequency to acceleration—and the frequency representing zero acceleration—for various nominal values of external resistance and capacitance.

Table 1. Nominal Circuit Component Values for Various Zero-g Frequencies and Scale Factors

Zero-*g* Frequency Hz	Scale Factor Hz/*g*	Ct (Rt=2.49kΩ) microfarads	R3 kilohms	R2 kilohms	R1 kilohms
			Standard Values		
10	10	10	182	464	14.70
100	10	1	49.90	127	40.20
100	100	1	182	464	14.70
1,000	10	0.10	16.50	42.20	133
1,000	100	0.10	49.90	127	40.20
1,000	1,000	0.10	182	464	14.70
10,000	10	0.01	16.90	43.20	1,370
10,000	100	0.01	16.90	43.20	137
10,000	1,000	0.01	49.90	127	40.20
100,000	10	0.001	0.169	0.43	137
100,000	100	0.001	1.69	4.32	137
100,000	1,000	0.001	16.90	43.20	137

The nominal sensitivity of the ADXL05 (voltage output at pin 8) is ±200 mV/*g*, with 1.8 volts representing 0 *g*. The on-chip buffer amplifier (output at pin 9) increases the output offset to +2.5 V (to provide for the maximum symmetrical output voltage swing, using a +5-V supply), and also amplifies and buffers the signal. C5 and R3 provide low-pass filtering to improve low-level resolution (but limit frequency response). Gain and offset calculations are based on *nominal* values of accelerometer and VFC parameters; the actual performance is affected by device tolerances, which may be substantial. For increased accuracy of zero-*g* offset and scale-factor, trim potentiometer circuits can be used to predict resistance values for 1% tolerance fixed resistors.

Nominal design equations: The output of the AD654 is a pulse train whose frequency is related to the input voltage by:

$$f_{out} = 0.1\,V_{IN}\left(\frac{1}{R_tC_t}\right)$$

Thus, for a 0-*g* output of 2.5 V from the ADXL05, the frequency corresponding to a zero acceleration is

$$f_{0g} = \frac{0.25}{R_tC_t}$$

The scale factor, or slope of the relationship, expressed in Hz/*g*, is the product of the sensitivity of the accelerometer (200 mV/*g*), the gain of the buffer amplifier, and the VFC relationship, or

$$SF = \Delta f/g = 0.2\frac{R_3}{R_1}\left[\frac{0.1}{R_tC_t}\right]$$

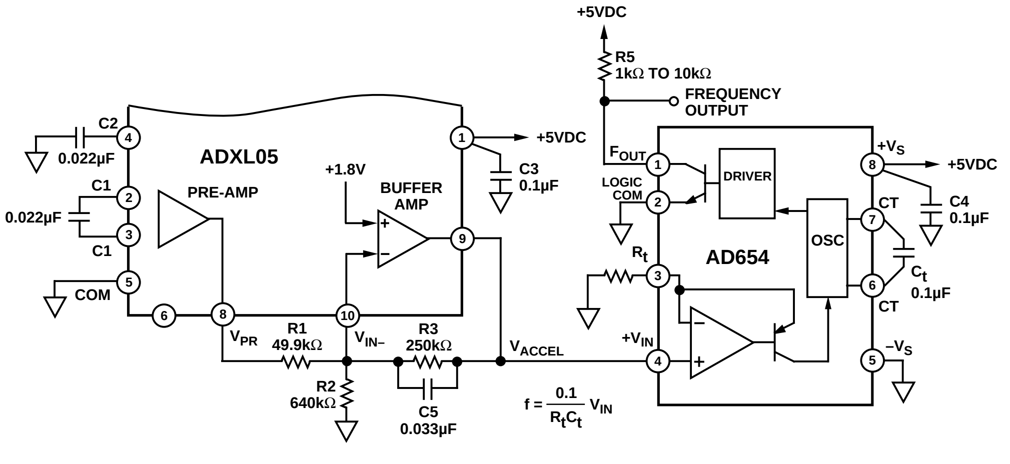

Figure 1. High-performance acceleration-to-frequency circuit using the high-linearity AD654 VFC.

Figure 2 is a plot of the nominal relationship between frequency and acceleration for a 1-kHz zero acceleration frequency and a 100-Hz/g scale factor.

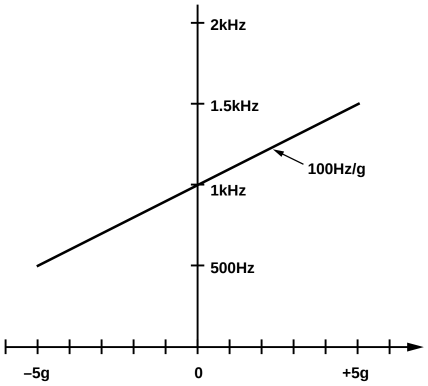

Figure 2. Relationship between VFC output frequency and acceleration of the ADXL05 chip.

The accelerometer may be self-calibrated, using the Earth's gravity. With the accelerometer's tab horizontal, the accelerometer will measure 0 *g*, allowing the 0-*g* offset to be adjusted. With the accelerometer's tab pointing straight down, the output voltage at pin 9 will correspond to +1 *g*. If the accelerometer is rotated so that the tab points straight up, its output will measure –1 *g*. The difference in the readings, 2 *g*, can then be used to set the acceleration-to-frequency overall scale factor, using an adjustable Rt, i.e., replacing it by a fixed 1% resistor in series with an empirically established trim value.

The 0-*g* frequency may be adjusted with a 50-kΩ trimming pot, connected between the ADXL05's pin 6 (a +3.4-V reference) and ground. The pot's wiper connects to the buffer amplifier's summing junction, pin 10, via R2 (changed to 100 kΩ). The 0-*g* & full-scale frequency adjustments should be iterated, if necessary, to get the most-accurate setting. The adjustable voltage divider may be replaced by fixed resistors for dynamic measurements that might affect pot settings.

Acceleration to frequency at very low cost using a 555 timer: Figure 3 shows how an ADXL05 accelerometer can be connected to a low-cost CMOS 555 timer to provide a frequency output. The component values indicated were selected for a ±1-*g* tiltmeter application.

The nominal 200-mV/*g* output of the accelerometer appears at pin 8 and is amplified by a factor of 2 to a 400-mV/*g* level by the on-board buffer amplifier. The 0-*g* bias level at pin 9 is approximately 1.8 V. Capacitor C4 and resistor R3 form a 16-Hz low-pass filter to lower noise and improve the measurement resolution.

The CMOS 555 operates as a voltage controlled oscillator, where R5, R6, and C5 set the nominal operating frequency. Resistors R5 & R6 were chosen to give an approximate 50% duty cycle with a +1.8-V (0-*g*) input signal applied to pin 5 of the 555. To minimize any change in frequency due to supply variations, the 555 operates ratiometrically from the accelerometer's +3.4-V reference rather than directly off the +5-V supply.

The output frequency of this circuit is determined by the charge and discharge times set by R5, R6, and C5.

Using the circuit and component values shown in Figure 3, the nominal output scale factor at pin 9 of the accelerometer will be ±400 mV/*g*, so the voltage output will be +1.8 V ± 0.4 V. The output scale factor at pin 3 of the 555 will be approximately 16,500 Hz ± 2,600 Hz per *g*.

Frequency stability of this circuit was found to be quite good. Using the circuit of Figure 3 with a 15.5-kHz 0-*g* frequency, the measured 0-*g* frequency drift over the 0 to +70°C commercial temperature range was 5 Hz/°C, which is 0.03%/°C. The change in frequency vs. supply voltage is less than 10 Hz with a +5.0 to +9.0-volt supply range. ▶

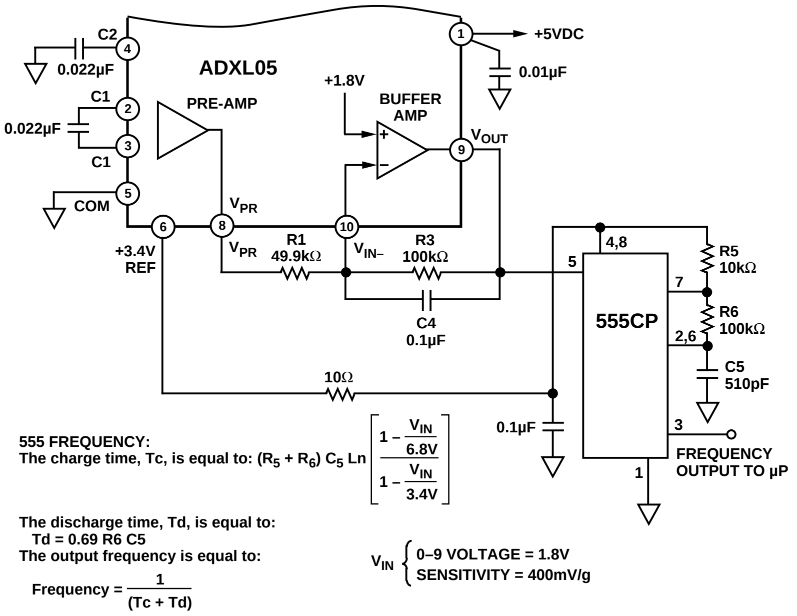

Figure 3. Low-cost acceleration-to-frequency circuit, using a popular and widely available 555 timer.