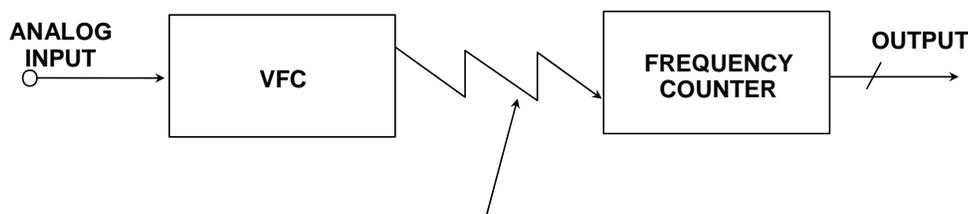


Voltage-to-Frequency Converters

by Walt Kester and James Bryant

INTRODUCTION

A voltage-to-frequency converter (VFC) is an oscillator whose frequency is linearly proportional to a control voltage. The VFC/counter ADC is monotonic and free of missing codes, integrates noise, and can consume very little power. It is also very useful for telemetry applications, since the VFC, which is small, cheap and low-powered can be mounted on the experimental subject (patient, wild animal, artillery shell, etc.) and communicate with the counter by a telemetry link as shown in Figure 1.



- ◆ CONNECTION NEED NOT BE DIRECT
- ◆ CIRCUIT IS IDEAL FOR TELEMETRY

Figure 1: Voltage-to-Frequency Converter (VFC) and Frequency Counter Make a Low-Cost, Versatile, High-Resolution ADC

There are two common VFC architectures: the *current-steering multivibrator VFC* and the *charge-balance VFC* (Reference 1). The charge-balanced VFC may be made in *asynchronous* or *synchronous* (clocked) forms. There are many more VFO (variable frequency oscillator) architectures, including the ubiquitous 555 timer, but the key feature of VFCs is linearity—few VFOs are very linear.

The current-steering multivibrator VFC is actually a current-to-frequency converter rather than a VFC, but, as shown in Figure 2, practical circuits invariably contain a voltage-to-current converter at the input. The principle of operation is evident: the current discharges the capacitor until a threshold is reached, and when the capacitor terminals are reversed, the half-cycle repeats itself. The waveform across the capacitor is a linear triangular wave, but the waveform on either terminal with respect to ground is the more complex waveform shown.

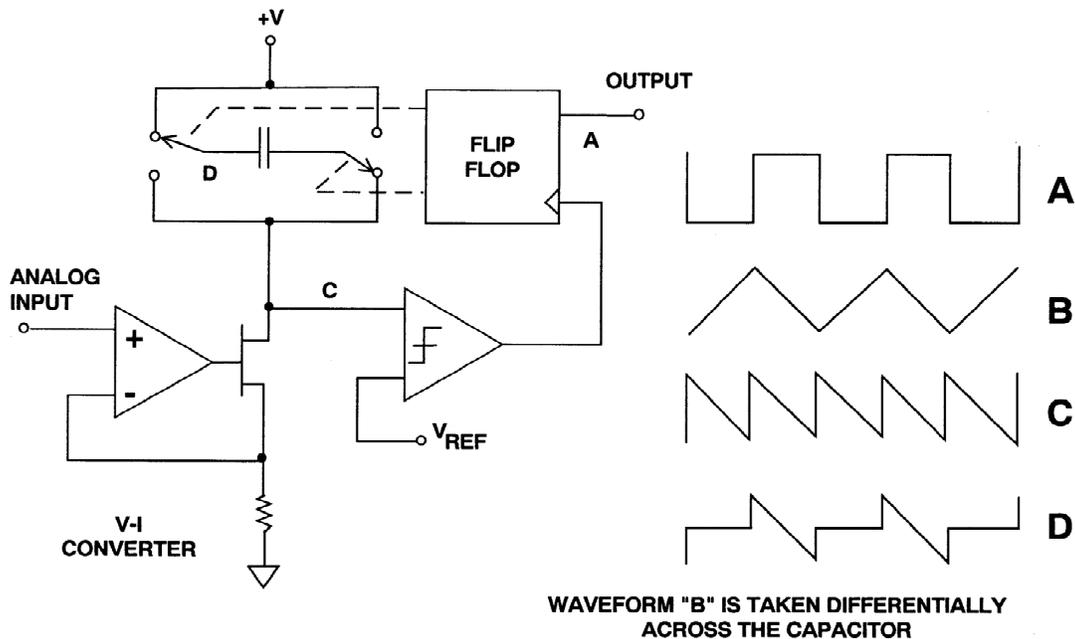


Figure 2: A Current-Steering VFC

Practical VFCs of this type have linearities around 14-bits, and comparable stability, although they may be used in ADCs with higher resolutions without missing codes. The performance limits are set by comparator threshold noise, threshold temperature coefficient, and the stability and dielectric absorption (DA) of the capacitor, which is generally a discrete component. The comparator/voltage reference structure shown in the diagram is more of a representation of the function performed than the actual circuit used, which is much more integrated with the switching, and correspondingly harder to analyze.

This type of VFC is simple, inexpensive, and low-powered, and most run from a wide range of supply voltages. They are ideally suited for low cost medium accuracy ADC and data telemetry applications.

The charge balance VFC shown in Figure 3 is more complex, more demanding in its supply voltage and current requirements, and more accurate. It is capable of 16-18 bit linearity.

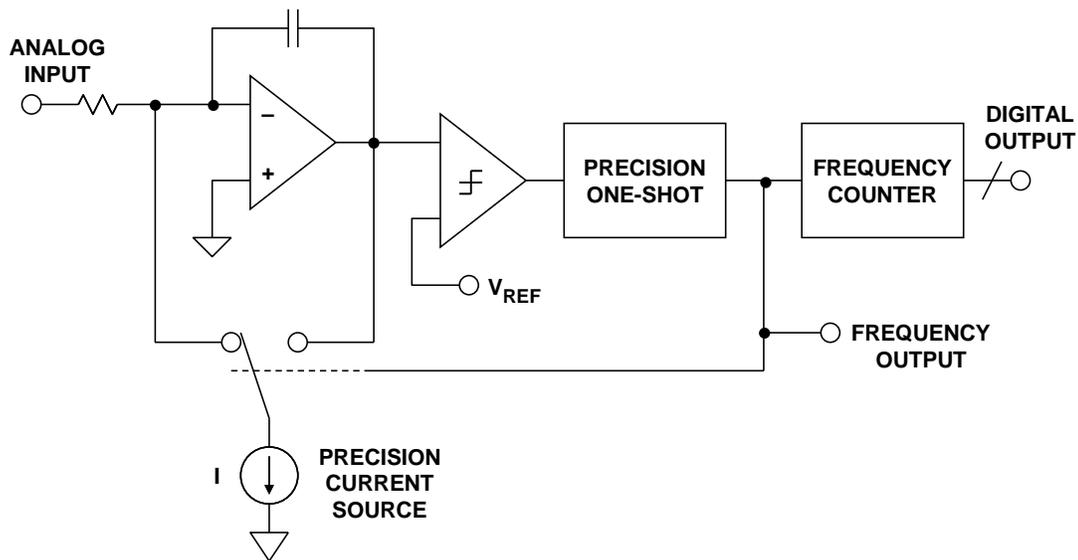


Figure 3: Charge Balance Voltage-to-Frequency Converter (VFC)

The integrator capacitor is charged by the signal as shown in Figure 3. When it passes the comparator threshold, a fixed charge is removed from the capacitor, but the input current continues to flow during the discharge, so no input charge is lost. The fixed charge is defined by the precision current source and the pulse width of the precision monostable. The output pulse rate is thus accurately proportional to the rate at which the integrator charges from the input.

At low frequencies, the limits on the performance of this VFC are set by the stability of the current source and the monostable timing (which depends on the monostable capacitor, among other things). The absolute value and temperature stability of the integration capacitor do not affect the accuracy, although its leakage and dielectric absorption (DA) do. At high frequencies, second-order effects, such as switching transients in the integrator and the precision of the monostable when it is retriggered very soon after the end of a pulse, take their toll on accuracy and linearity.

The changeover switch in the current source addresses the integrator transient problem. By using a changeover switch instead of the on/off switch more common on older VFC designs: (a) there are no on/off transients in the precision current source and (b) the output stage of the integrator sees a constant load—most of the time the current from the source flows directly in the output stage; during charge balance, it still flows in the output stage, but through the integration capacitor.

The stability and transient behavior of the precision monostable present more problems, but the issue may be avoided by replacing the monostable with a clocked bistable multivibrator. This arrangement is known as a *synchronous* VFC or SVFC and is shown in Figure 4.

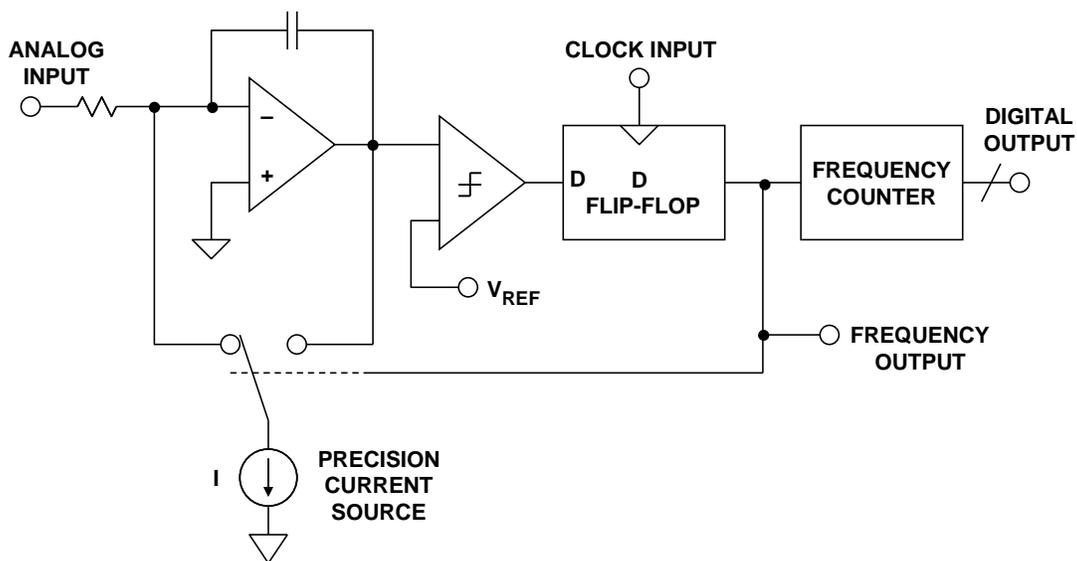


Figure 4: Synchronous VFC (SVFC)

The difference from the previous circuit is quite small, but the charge balance pulse length is now defined by two successive edges of the external clock. If this clock has low jitter, the charge will be very accurately defined. The output pulse will also be synchronous with the clock. SVFCs of this type are capable of up to 18-bit linearity and excellent temperature stability.

This synchronous behavior is convenient in many applications, since synchronous data transfer is often easier to handle than asynchronous. It does mean, however, that the output of an SVFC is not a pure tone (plus harmonics, of course) like a conventional VFC, but contains components harmonically related to the clock frequency.

The display of an SVFC output on an oscilloscope is especially misleading and is a common cause of confusion—a change of input to a VFC produces a smooth change in the output frequency, but a change to an SVFC produces a change in probability density of output pulses N and $N + 1$ clock cycles after the previous output pulse, which is often misinterpreted as severe jitter and a sign of a faulty device (see Figure 5).

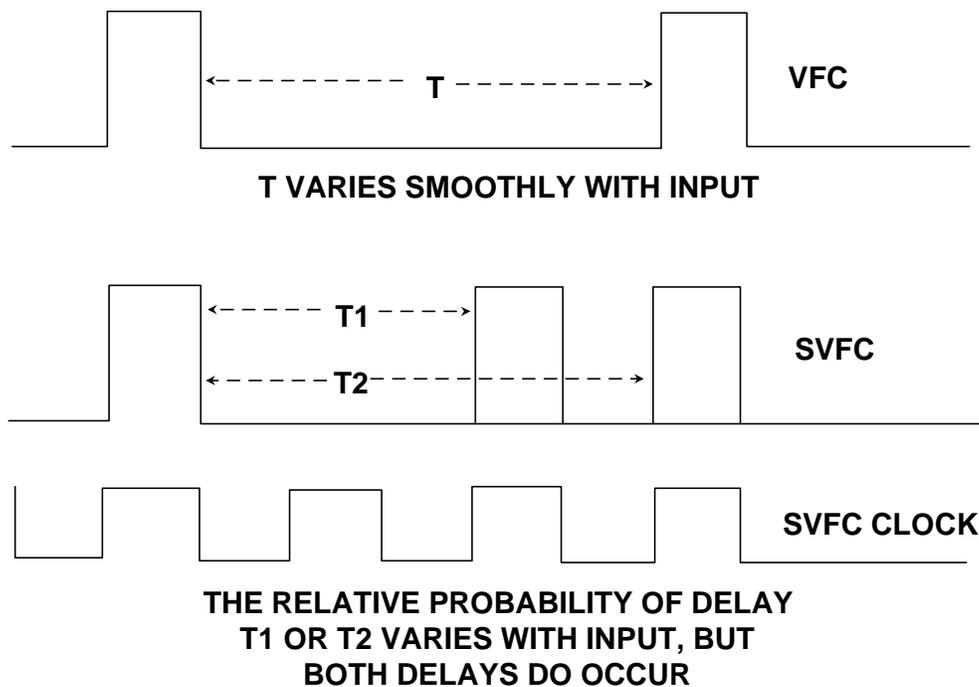


Figure 5: VFC and SVFC Waveforms

Another problem with SVFCs is nonlinearity at output frequencies related to the clock frequency. If we study the transfer characteristic of an SVFC, we find nonlinearities close to sub-harmonics of the clock frequency F_C as shown in Figure 6. They can be found at $F_C/3$, $F_C/4$, and $F_C/6$. This is due to stray capacitance on the chip (and in the circuit layout!) and the coupling of the clock signal into the SVFC comparator which causes the device to behave as an injection-locked phase-locked loop (PLL). This problem is intrinsic to SVFCs, but is not often serious: if the circuit card is well laid out, and clock amplitude and rate of change kept as low as practical, the effect is a discontinuity in the transfer characteristic of less than 8 LSBs (at 18-bit resolution) at $F_C/3$ and $F_C/4$, and less at other sub-harmonics. This is frequently tolerable, since the frequencies where it occurs are known. Of course, if the circuit layout or decoupling is poor, the effect may be much larger, but this is the fault of poor design and not the SVFC itself.

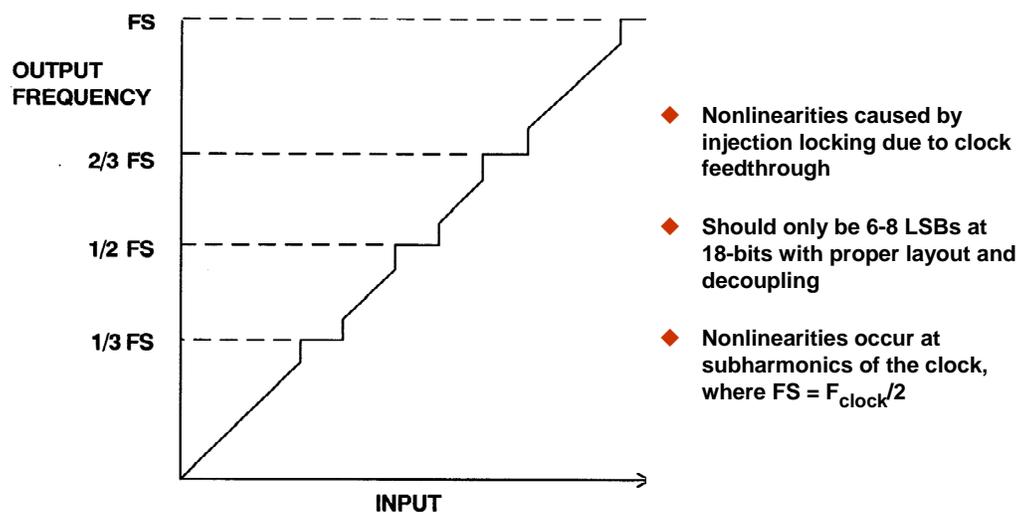


Figure 6: SVFC Nonlinearity

It is evident that the SVFC is quantized, while the basic VFC is not. It does NOT follow from this that the counter/VFC ADC has higher resolution (neglecting nonlinearities) than the counter/SVFC ADC, because the clock in the counter also sets a limit to the resolution.

When a VFC has a large input, it runs quickly and (counting for a short time) gives good resolution, but it is hard to get good resolution in a reasonable sample time with a slow-running VFC. In such a case, it may be more practical to measure the period of the VFC output (this does not work for an SVFC), but of course the resolution of this system deteriorates as the input (and the frequency) increases. However, if the counter/timer arrangement is made "smart," it is possible to measure the approximate VFC frequency and the exact period of not one, but N cycles (where the value of N is determined by the approximate frequency), and maintain high resolution over a wide range of inputs. The [AD1170](#) modular ADC released in 1986 is an example of this architecture.

VFCs have more applications than as a component in ADCs. Since their output is a pulse stream, it may easily be sent over a wide range of transmission media (PSN, radio, optical, IR, ultrasonic, etc.). It need not be received by a counter, but by another VFC configured as a frequency-to-voltage converter (FVC). This gives an analog output, and a VFC-FVC combination is a very useful way of sending a precision analog signal across an isolation barrier. There are a number of issues to be considered in building FVCs from VFCs, and these are considered in References 2-5.

SUMMARY

Analog Devices has a wide range of voltage to frequency converters (VFCs) for the instrumentation, industrial and automation markets (see [Voltage-to-Frequency Converter Selection Table](#)), including the [AD537](#), [AD650](#), [AD652](#), [AD654](#), and [ADVFC32](#). They are ideally suited for use in analog-to-digital conversion (ADC), long term integration, linear frequency modulation and demodulation, and frequency-to-voltage conversion. Analog Devices' latest family of VFCs, the [AD7740](#), [AD7741](#), and [AD7742](#), are synchronous VFCs based on sigma-delta technology and provide high linearity in tiny packages at low cost.

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