

## Dynamic Characteristics of Tracking Converters

by Mark Thomas

It is easy to get confused by the terms used to describe the dynamic performance of tracking resolver-to-digital converters:

"What is the *bandwidth* of this converter?"

"*Acceleration constant*! – what does that tell me about the performance?"

"I want to increase the *resolution*, how will that affect the *tracking rate*?"

The aim of this application note is to give a simple explanation of the meaning of the dynamic characteristic specifications, and to explain their particular relevance in the case of synchro- and resolver-to-digital converters.

All synchro/resolver-to-digital converters manufactured by Analog Devices utilize a Type 2 tracking loop in order to convert the analog input signal into a digital output signal.

Examination of the block diagram of a typical converter will reveal that it essentially consists of six circuit elements connected in a loop; these being the Control Transformer (Sine/Cosine Multipliers), Error Amp, Phase Sensitive Detector, Integrator, Voltage Controlled Oscillator and Up/Down Counter. The purpose of the converter is to produce a digital representation of the input (analog) signal. It is a closed-loop control system.

All closed-loop control systems can be classified according to the nature of their steady-state errors (i.e., the state

where all transient signals have decayed), and in the particular case of the Type 2 system, the steady-state error is zero for both a stationary input signal and a constantly varying (constant velocity) input signal. The only time when the error signal is present is during periods of acceleration or deceleration.

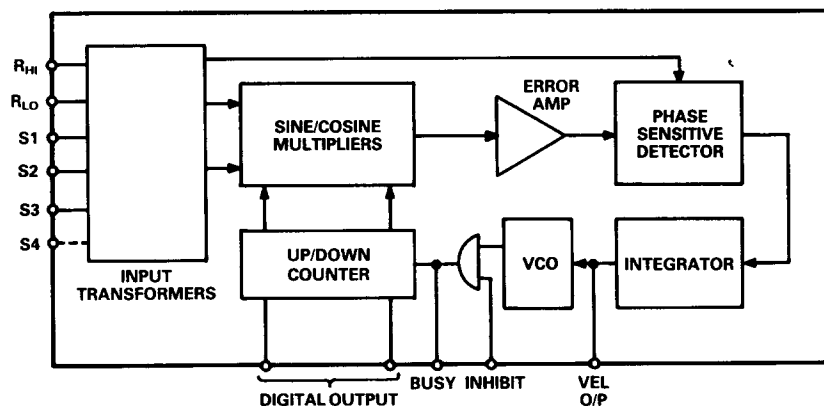
The advantage of using a Type 2 loop is that the digital output will always represent the analog input (within the device accuracy specification) under the conditions of a stationary input and also a constantly varying (constant velocity) input, i.e., there is not velocity lag.

When considering the dynamic performance of the converter, the key specifications which will be of interest to the system designer will usually be found under the heading "Dynamic Characteristics"; the specifications being Bandwidth, Acceleration Constant, Reference Frequency, Tracking Rate, Velocity Scaling, Settling Time and Resolution. Let us look at each of these in turn.

### Bandwidth

Being a Type 2 tracking loop, the converter is essentially a second order low pass filter. It has a predictable dynamic response, the critical frequency and damping characteristics being set by the values of the components which make up the loop.

Until very recently, the bandwidth of the converters has been set by the designer and could not be varied



by the user. This meant that the user could not optimize the performance of the device in order to suit the system requirements. However, with the release by Analog Devices of the monolithic converter, the user can, for the first time, optimize the bandwidth and other dynamic characteristics.

The bandwidth of the converter indicates the small signal response of the loop, and is shown diagrammatically on the data sheets as a plot of gain and phase against frequency.

The plots show how the converter will respond if a small signal, sinusoidally varying about a fixed point, is applied to the input of the device. It is important to stress that the gain and phase plots only indicate the response of the device to small changes in the input signal; the sinusoidally varying signal must not cause saturation in any component part of the loop, and will in general have a maximum amplitude of about 5 degrees. The output from the converter will also be a small signal, sinusoidally varying about a fixed point; the gain and phase relationship between the input and output signals are shown on the plots. The frequency axis refers to the frequency of the sinusoidally varying input signal, and not, it should be stressed, to the frequency of the reference carrier. The bandwidth figure quoted for the converter is defined as the frequency of the sinusoidally varying input signal, at the point where the device has a gain of  $-3\text{dB}$ . For example, in the case of the 1S74 hybrid converter, the bandwidth quoted on the data sheet is 230Hz. If we apply a sinusoidally varying input signal with a maximum amplitude of 1 degree, oscillating at 230Hz about a fixed point, we should observe a sinusoidally varying output signal, with a maximum amplitude of about 0.7 degrees ( $1/\sqrt{2} \times 1 \text{ deg}$ ) and lagging by almost 90 degrees.

Both the bandwidth and the transfer function from which it is derived, are calculated specifications based on the individual transfer functions of the component parts of the converter loop. They allow the system designer to evaluate the frequency response of the converter and, in combination with the other components of the system, the frequency response of the overall system. The effect of increasing the bandwidth is to allow the converter to respond to faster (higher frequency) small changes in the input signal; hence, the response time is shorter. How-

ever, an increasing bandwidth also leads to an increase in the susceptibility to noise, as the higher frequency noise signals come into the range of frequencies "seen" by the converter (remember that the converter is effectively a low pass filter). One of the major detrimental effects of this increase in the susceptibility to noise, is the appearance of the noise on the analog velocity output signal.

#### Acceleration Constant ( $K_a$ )

This parameter specifies the ability of the converter to withstand and track input accelerations. It is specified in the data sheet with the dimension of  $"/\text{sec}^2$  and is defined as:

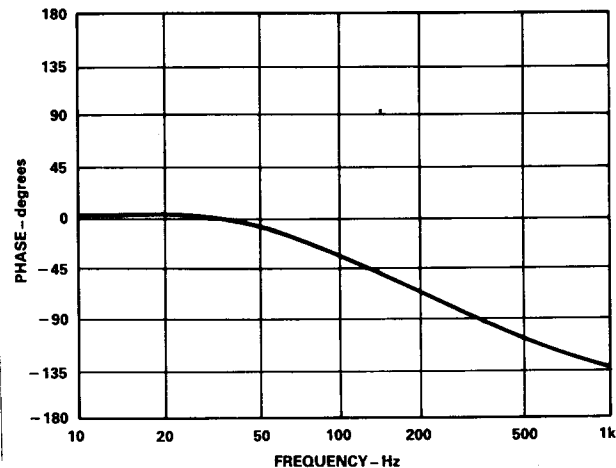
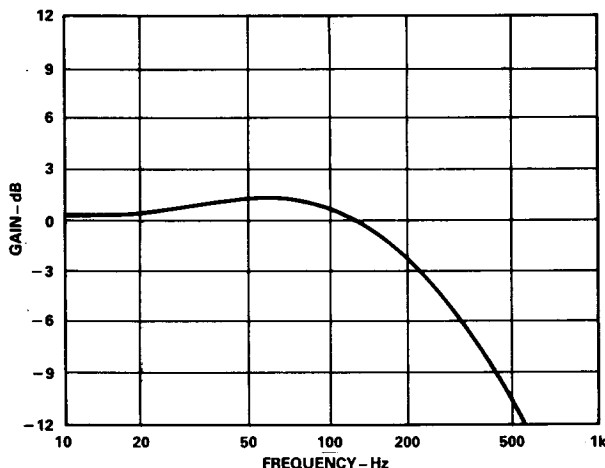
$$K_a = \frac{\text{Input Acceleration}}{\text{Error in Output Angle}}$$

Once the  $K_a$  is known, the acceleration is defined in any units, e.g., with a  $K_a$  equal to  $227,555 / \text{sec}^2$ , we can immediately see that there will be 1 arc minute of additional error for an input acceleration of  $227,555 \text{ arc min/sec}^2$ , or 1 degree of additional error for an acceleration of  $227,555 \text{ degrees/sec}^2$ .

However, the acceleration figure quoted in the specification is not the maximum acceleration which the converter can withstand. This maximum figure is governed by the maximum allowable output swing of the internal error amplifier. If this maximum acceleration is exceeded, then the digital output will irrecoverably lose track with the input. In general, the maximum acceleration will be reached when the error between the input and digital output is approximately 5 degrees. Therefore, a converter can withstand an acceleration in  $\text{deg/sec}^2$  of about five times  $K_a$  value.

#### Reference Frequency

In general, the higher the bandwidth of the converter, the higher is the required reference frequency, which will also result in a faster possible tracking rate and shorter settling time. The only limitations on the maximum frequency the reference can have are the limits set by the components used in the converter loop. All converters have options available which will function with a 2.6kHz reference frequency, and many hybrids can operate up to 10kHz reference. The new monolithic converters will function with a reference frequency to 20kHz. In order for the demod-



ulator to reject higher order multiples of the reference frequency, the reference frequency of the converter should be at least 2.5 times the closed-loop bandwidth; hence, possible bandwidth is limited by reference frequency used.

### Tracking Rate

This is defined as the maximum angular speed for which the converter output will be able to keep track with the converter input. It should be noted that the tracking rate figure quoted in the data sheet actually indicates the guaranteed minimum limit to a range of tracking rates acceptable to the converter. This converter will, therefore, keep track in both directions with inputs varying from stationary up to the tracking rate figure quoted in the data sheet. However, due to component tolerances within the converter loop, the maximum limit of this tracking rate range may well exceed the figure quoted, and can vary from device to device. The higher the reference frequency at which the converter is intended to operate, then the higher will be the maximum possible tracking rate. However, the actual limit for the maximum tracking rate is set by the integrator and Voltage Controlled Oscillator (VCO).

The maximum recommended rate for the VCO sets the maximum possible tracking rate for the converter, e.g., if the maximum recommended VCO rate is 1MHz, then with a 12-bit converter the maximum possible tracking rate will be set a  $1,000,000/4096$  revs/sec.

The input to the VCO is obtained from the output of the integrator, and so the maximum voltage swing available at the integrator output will also limit the maximum tracking rate. In general, if the power supply rails are lowered, the maximum voltage swing available from the integrator will be lowered and the maximum possible tracking rate will also decrease. (N.B. this does not happen in all converters.) Signal voltage levels which are outside the specified limits for the converter will also degrade the dynamic performance, and the overall accuracy of the device.

### Velocity Scaling

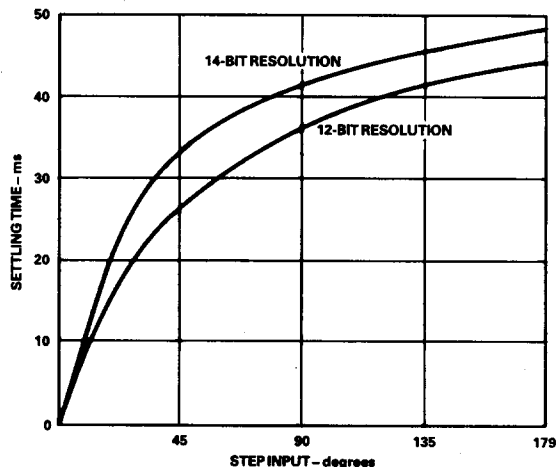
Closely linked to tracking rate is the scaling of the analog velocity signal output. The VCO rate is fixed for a given input current by the VCO scaling factor which relates the VCO output frequency to the input current. The input current is scaled by the velocity scaling resistor which is set by the manufacturer for the majority of converters.

However, in the case of the monolithic converters, the value of this velocity scaling resistor may be selected by the user, allowing the velocity output to be scaled down to suit the user's requirements.

### Settling Time

If a step input is applied to the converter, a finite time will be required for the internal loop to null and produce the required digital output. In all the data sheets, the settling time is given as the time required for the converter to settle within 1LSB of the quoted accuracy in response to a step input of 179 degrees (i.e., the worst possible case). Therefore, this specification gives an indication of the large signal response of the converter.

A typical settling time curve for steps of less than 179 degrees is shown below.



It can be seen that for step inputs within approximately 5-10 degrees, the response is linear, and can be derived from the small signal response of the converter (i.e., see bandwidth). Beyond this region, the internal error voltage will exceed the linear range of the converter.

### Resolution

The VCO output clocks the up/down counter; therefore, for a given VCO output rate, increasing resolution will lead to a lengthening of the settling time of the output bits. The converters available have either a 10-, 12-, 14- or 16-bit output resolution, or in particular cases, the resolution may be varied to have any of these four output resolutions. Increasing the resolution from  $N$  to  $N + 2$  bits will lead to a factor of 4 decrease in the tracking rate and an increase in the settling time.