TECHNICAL Talk
ROTASYN

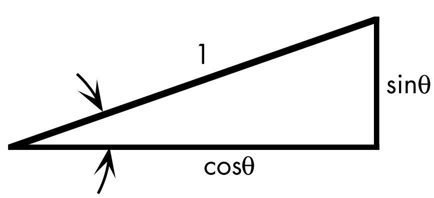
An introduction to resolvers and resolver-to-digital converters. How resolvers work, resolver signal format, and how to use resolvers with commercially available resolver-to-digital converters.

Understanding Resolvers and Resolver-to-Digital Conversion

What is a resolver?

A *resolver* is a position sensor or transducer which measures the instantaneous angular position of the rotating shaft to which it is attached. Resolvers and their close cousins, synchros, have been in use since before World War II in military applications such as measuring and controlling the angle of gun turrets on tanks and warships. Resolvers are typically built like small motors with a rotor (attached to the shaft whose position is to be measured), and a stator (stationary part) which produces the output signals.

The word resolver is a generic term for such devices derived from the fact that at their most basic level they operate by resolving the mechanical angle of their rotor into its orthogonal or Cartesian (X and Y) components. From a geometric perspective, the relationship between the rotor angle (θ) and its X and Y components is that of a right triangle:



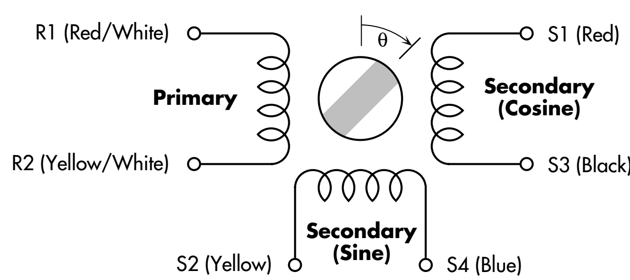
Resolving an Angle into its Components

Fundamentally, then, all resolvers produce signals proportional to the sine and cosine of their rotor angle. Since every angle has a unique combination of sine and cosine values, a resolver provides *absolute* position information within one revolution (360°) of its rotor. This absolute (as opposed to incremental) position capability is one of the resolver's main advantages over incremental encoders.

Electrical Characteristics

Electrically, the Rotasyn, like a traditional resolver, is a transformer in which the coupling between the primary and the secondaries varies as the sine and cosine of the rotor angle. Whereas a traditional resolver has its primary on the rotor and its secondaries in the stator (necessitating brushes and slip rings or a rotating transformer to couple signals into the primary), the Rotasyn contains both primary and secondary windings in the stator and uses a unique solid rotor to directly vary the coupling between the primary and the secondaries.

Like all transformers, the Rotasyn (as well as a traditional resolver) requires an AC *carrier* or *reference* signal (sometimes also called the *excitation*) to be applied to its primary. The amplitude of this reference signal is then modulated by the sine and cosine of the rotor angle to produce the output signals on the two secondaries.



Rotasyn Schematic

By convention, the primary and secondary leads of all resolvers are identified with the nomenclature and wire colors shown above. For best performance, the reference signal should be a sine wave.

In any transformer, there is a value which relates the output voltage produced by the secondary to that fed into

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the primary. For resolvers, this quantity is called the *transformation ratio* or TR and is specified at the point of maximum coupling between primary and secondary. For industrial resolvers, the de-facto standard transformation ratio is 0.5, which means that the maximum voltage produced by either secondary is half the amplitude of the reference signal.

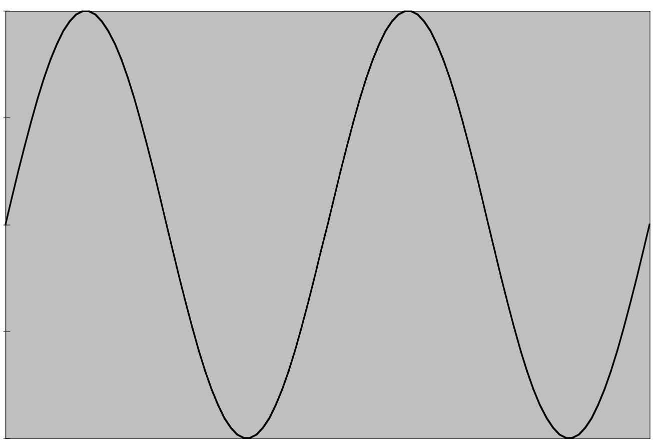
If we define the reference voltage $V_{(R1-R2)}$ as V_R, then the voltages on the secondaries are given by the following equations

$$\text{Sine Secondary:}\quad V_{(S2-S4)} \equiv V_S = V_R\ \text{TR}\ \sin\theta$$
$$\text{Cosine Secondary:}\quad V_{(S1-S3)} \equiv V_C = V_R\ \text{TR}\ \cos\theta$$

where θ is the mechanical angle of the rotor as shown previously in the Rotasyn schematic.

Resolver Signal Format

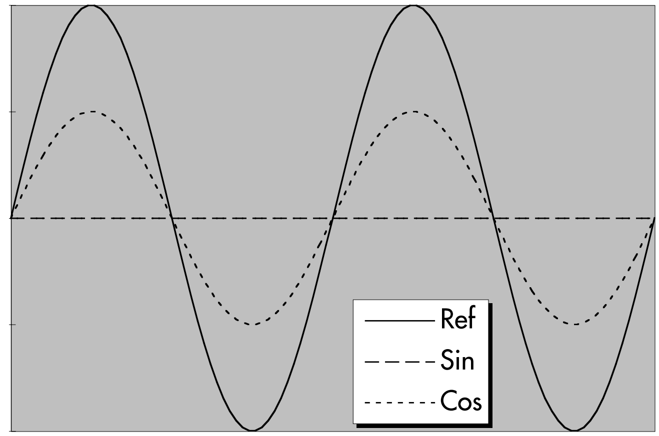
If we excite the Rotasyn primary (V_R) with the recommended sinusoidal reference signal as shown below, the



Sinusoidal Reference Applied to Rotasyn Primary

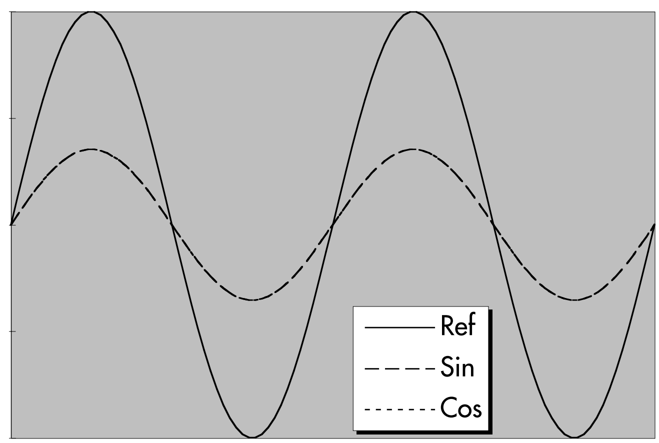
secondary voltages are also sinusoidal at the same frequency and nominally in phase with the reference. Their amplitude is proportional to the amplitude of the reference, the transformation ratio of the Rotasyn, and the sine or cosine of the mechanical angle of the rotor. Using the industry-standard 0.5 TR, we can look at the secondary voltages for different rotor angles as they would appear on an oscilloscope.

For instance, with the rotor at 0° (called *Electrical Zero* or EZ and marked on the Rotasyn PC board), the amplitude of the sine secondary is 0 (since sin0° = 0) and the amplitude of the cosine secondary will be at its maximum of half the reference amplitude (since cos0° = 1):



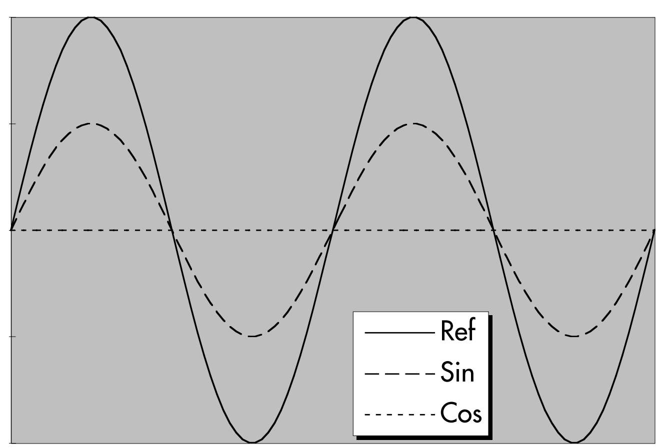
Resolver Signals with Rotor at 0° (EZ)

With the rotor at 45°, the secondary voltages are the same but only 70.7% of their maximum since sin45° = cos45° = 0.707:



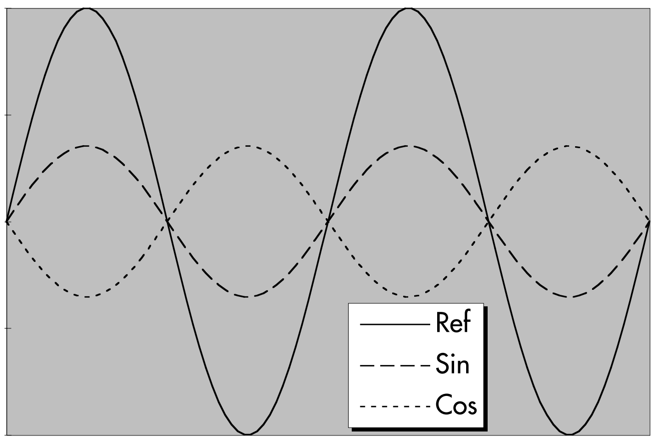
Resolver Signals with Rotor at 45°

With the rotor at 90°, the sin voltage is at maximum and the cosine voltage is zero:



Resolver Signals with Rotor at 90°

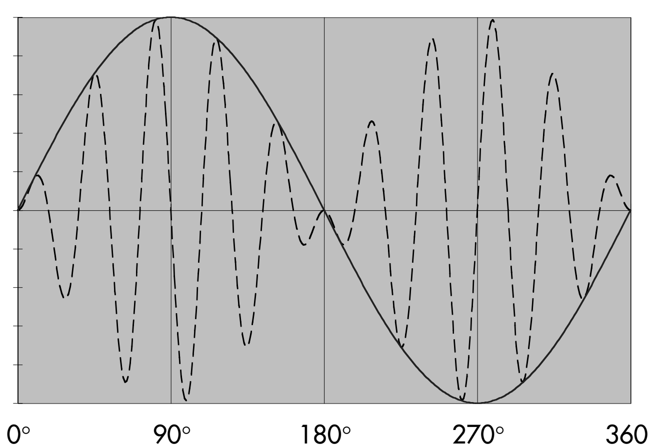
With the rotor at 135°, the amplitudes of the secondary voltages are the same as at 45°, but the phase of the cosine voltage reverses since cos135° is –0.707:



Resolver Signals with Rotor at 135°

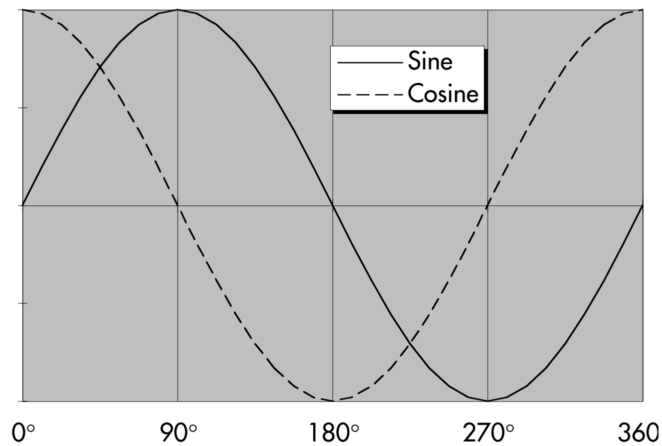
Other rotor angles may be shown similarly.

While it is helpful to know how the resolver signals appear as functions of time since that is what one sees when one looks at them with an oscilloscope, it is often more convenient to work with the *envelope* (amplitude at the reference frequency) of the signals with respect to rotor position. If the rotor of the resolver is turned at a rate such that it makes one complete revolution in the time of 10 cycles of the excitation frequency (speeds this high are very difficult and cause other problems in practice, but are useful for understanding), the envelope of the secondary signals can be clearly seen. Shown below is the envelope of the sine secondary signal with respect to rotor position:



Modulation Envelope of Sine Secondary Signal

The process of removing the carrier signal—leaving just the envelope—is called *demodulation* and is performed by the Resolver-to-Digital (R/D) converter. The demodulated sine and cosine resolver signals are shown below:



Demodulated Resolver Secondary Signals

Resolver-to-Digital Conversion

The resolver-to-digital converter performs two basic functions: demodulation of the resolver format signals to remove the carrier, and angle determination to provide a digital representation of the rotor angle. The most popular method of performing these functions is called *ratiometric tracking conversion*. Since the resolver secondary signals represent the sine and cosine of the rotor angle, the ratio of the signal amplitudes is the tangent of the rotor angle. Thus the rotor angle, θ, is the arc tangent of the sine signal divided by the cosine signal:

$$\theta \equiv \arctan\frac{\sin\theta}{\cos\theta} = \arctan\frac{Vs}{Vc}$$

The ratiometric tracking converter performs an implicit arc tangent calculation on the ratio of the resolver signals by forcing a counter to track the position of the resolver. This implicit arc tangent calculation is based on the trigonometric identity

$$\sin(\theta - \delta) \equiv \sin\theta\cos\delta - \cos\theta\sin\delta$$

This equation says that the sine of the difference between two angles can be calculated by cross multiplying the sine and cosine of the two angles and subtracting the results. Further, as long as the difference between the two angles is relatively small ($\delta = \theta \pm 30°$), the approximation

$$\sin(\theta - \delta) \cong \theta - \delta$$

may also be used, further simplifying the equation. Thus, if the two angles are within 30° of each other, the difference between the angles can be calculated using the cross multiplication shown above.

In the R/D converter, this equation is implemented using multiplying D/A converters to multiply the resolver signals (proportional to $\sin\theta$ and $\cos\theta$) by the cosine and sine of the digital angle, δ, which is the output of the converter, as shown below.

The results are subtracted, demodulated by multiplying by the reference signal, and filtered to give a DC signal proportional to the difference or error between the resolver angle, θ, and the digital angle, δ. The digital angle, δ, stored in the counter, is then incremented or decremented using a voltage controlled oscillator until this error is zero, at which point $\delta = \theta$ (the digital angle output of the converter is equal to the resolver angle). This incrementing and decrementing of the digital angle, δ, causes it to track the resolver angle, θ, hence the name of this type of converter.

A more detailed description of tracking converter operation is available from the converter manufacturers. See the 2S80 and 2S90 series product data sheets and application notes from Analog Devices, the 19200 series data sheets from ILC Data Devices Corp. (DDC), or the 168 and 268 series data sheets from Control Sciences Inc. Contact information for these companies is given below.

Analog Devices
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Phone: +1 516.567.5600
Fax: +1 516.567.7358
Internet: www.ilcddc.com

Control Sciences Inc.
Phone: +1 818.709.5510
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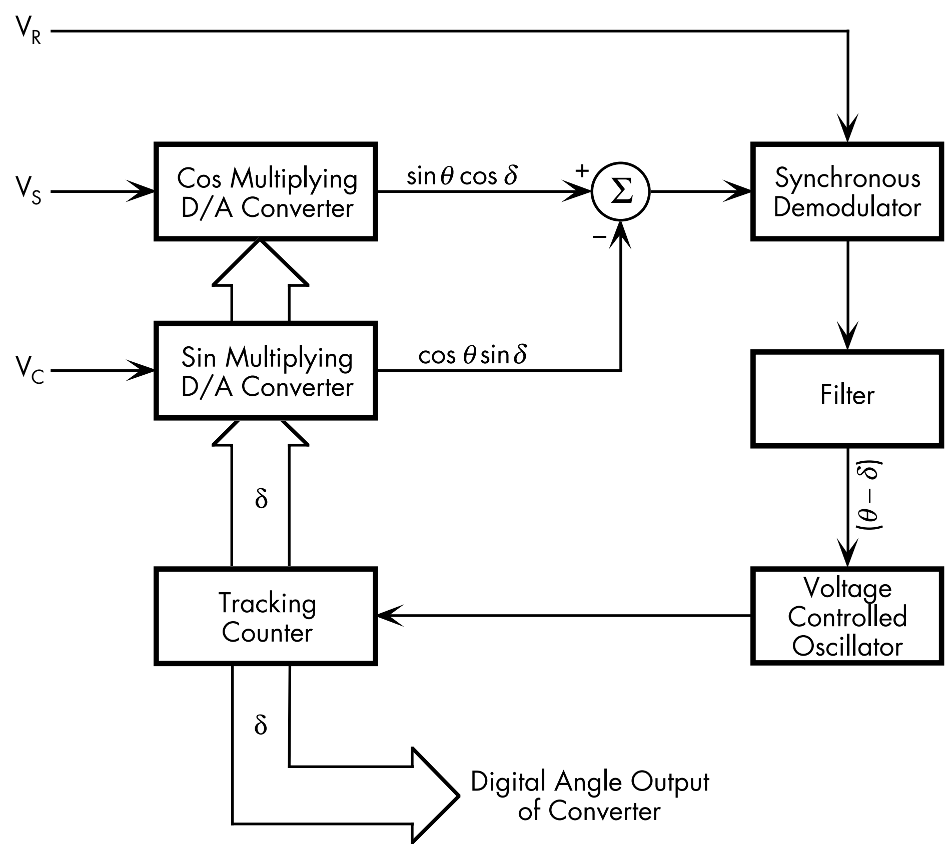
www.controlsciences.com



Typical Tracking Resolver-to-Digital Converter

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