

## AN-011 Cosine Error Adjustment

When measuring the speed of an object with radar, an adjustment needs to be made based on the angle the object in motion is traveling relative to the radar. This is known as the Cosine Error and is straight forward to correct for the true speed of the object if the angle is known.

Figure 1 provides an easy way to understand the cosine error. If the line of sight that the RADAR makes with the object in motion is an angle  $\theta$ , then the measured speed is different from the actual speed by a factor  $\cos \theta$ . Knowing this angle, the actual speed can be easily calculated.

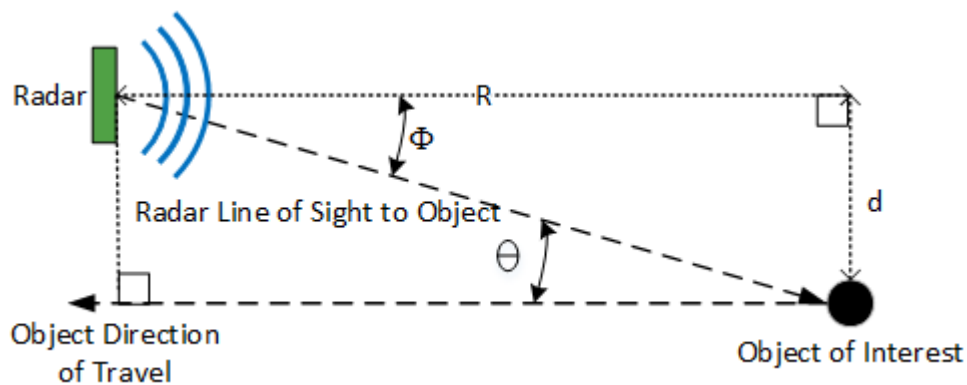


Figure 1. Cosine Error

The math for the correction is:

$$v_M = v_A \cos \theta \quad \text{Equation 1}$$

If  $v_M$  is the measured speed, the actual speed,  $v_A$ , is a higher value that has been reduced by the cosine of the angle  $\theta$ . For all the angles of  $\theta$  from  $0$  to  $90^\circ$ , the cosine provides numbers from  $1$  to  $0$ . Therefore, the actual speed  $v_A$  will be a number larger than the measured speed,  $v_M$ . The larger the angle  $\theta$ , the higher the actual speed  $v_A$  will be.

Alternatively, rearranging to solve for  $v_A$ , you get:

$$v_A = \frac{v_M}{\cos \theta} \quad \text{Equation 2}$$

Here it's easier to see that  $v_A$  will be greater than  $v_M$  with the adjustment by the inverse of  $\cos \theta$ . Since  $\cos \theta$  is always a number between  $1$  and  $0$ , it will be a multiplier over  $v_M$ .

As an example, let's say you're measuring the speed of a car and you read the measured speed  $v_M$  to be  $25$  mph. The car is at an angle of  $30^\circ$ . Using Equation 2 gives the actual speed  $v_A$  to be  $28.9$  mph.

A test that may be tried is to use a vehicle moving at a constant, known speed, to determine what cosine error is being seen by the sensor. In this case, the equation uses the inverse cosine as shown in Equation 3.

$$\theta = \cos^{-1}\left(\frac{v_M}{v_A}\right) \quad \text{Equation 3}$$

For example, a vehicle moving at 30 mph constant speed is reported with a speed of 24.5 mph. Using Equation 3, this results in a cosine angle of 35.2°.

If the angle to the object is not known but the range R and distance d are, the correction can still be calculated. The range to the object is not the line of sight distance but the range of the object if it were slid across and directly in front of the radar module as shown in Figure 1. Likewise, the distance d is the separation distance between the path of the object and the line 90° from the radar module. Knowing these two values, the adjustment to speed is:

$$v_A = v_M \frac{R}{\sqrt{R^2 + d^2}} \quad \text{Equation 4}$$

The angle  $\theta$  is related to the range and distance by:

$$\Phi = \tan^{-1} \frac{d}{R} \quad \text{Equation 5}$$

where the angles  $\theta$  and  $\Phi$  are equivalent.

A simple lookup table is provided below for various speed and angle combinations.

*Table 1. Actual Speed Look Up Table*

Angle	Measured Speed (mph)						
	10	20	30	40	50	60	70
0°	10.0	20.0	30.0	40.0	50.0	60.0	70.0
10°	10.2	20.3	30.5	40.6	50.8	60.9	71.1
15°	10.4	20.7	31.1	41.4	51.8	62.1	72.5
20°	10.6	21.3	31.9	42.6	53.2	63.9	74.5
30°	11.5	23.1	34.6	46.2	57.7	69.3	80.8
40°	13.1	26.1	39.2	52.2	65.3	78.3	91.4
45°	14.1	28.3	42.4	56.6	70.7	84.9	99.0
50°	15.6	31.1	46.7	62.2	77.8	93.3	108.9
60°	20.0	40.0	60.0	80.0	100.0	120.0	140.0

If the angle the objects make with the sensor is known, there are API commands available to correct for the cosine error. There are two different API commands for an object moving towards and away from the sensor based on the fact that vehicles typically are in different lanes which are spatially apart.

The two API commands are listed in Table 1. All speed reports will be adjusted by the set angle and utilize the equivalent of Equation 2 to correct the speed.

Table 2. Cosine Error Correction API

Command	Name	R/W	Value
^/+n.n	Inbound Cosine Error Correction	Write	Set n.n to the angle the sensor makes with inbound objects.
^-/n.n	Outbound Cosine Error Correction	Write	Set n.n to the angle the sensor makes with inbound objects.

**Revision History**

Version	Date	Description
A	Apr. 20, 2017	Initial release.
B	March 14, 2023	Corrected formatting. Added text for calculating cosine angle based on speed measurements. Added text about cosine angle correction API commands.