MINIMIZING THE POINTING DIRECTION ERRORS FOR TODAY'S HIGH-GAIN RF DIRECTIONAL ANTENNAS

INTRODUCTION

High-gain RF directional antennas transmit narrow beams of electromagnetic energy to and from adjacent or neighboring antennas scattered across the countryside. Because their beams are relatively narrow, pointing errors of only a few degrees can create sharp reductions in the strength of the signals being received. Compared with the full-strength radio waves at the center of the beam, those weaker off-axis signals are less robust and less reliable. They are also harder to demodulate. And they are more susceptible to intentional or unintentional interference. Current GPS alignment units will be compared based on their GPS subsystem specifications. The better the performance with respect to azimuth accuracy, the more the unit can assure extremely small pointing errors, and the more the difficulties discussed above can be minimized.

Most of the pointing errors that remain will be tightly clustered around the precise direction of the target antenna, but in practice, a small number of them will be slightly larger. Like many other statistically varying quantities, the pointing errors can be assumed to follow the familiar bell-shaped curve. Most will be close to the average; a few of them will be smaller or larger than the average, and fewer still will deviate far outside of the mean. Use these measurements to construct a graph of height versus frequency of occurrence and the familiar bell-shaped curve will quietly emerge.

POINTING ERRORS FOR CURRENT GPS ALIGNMENT UNIT

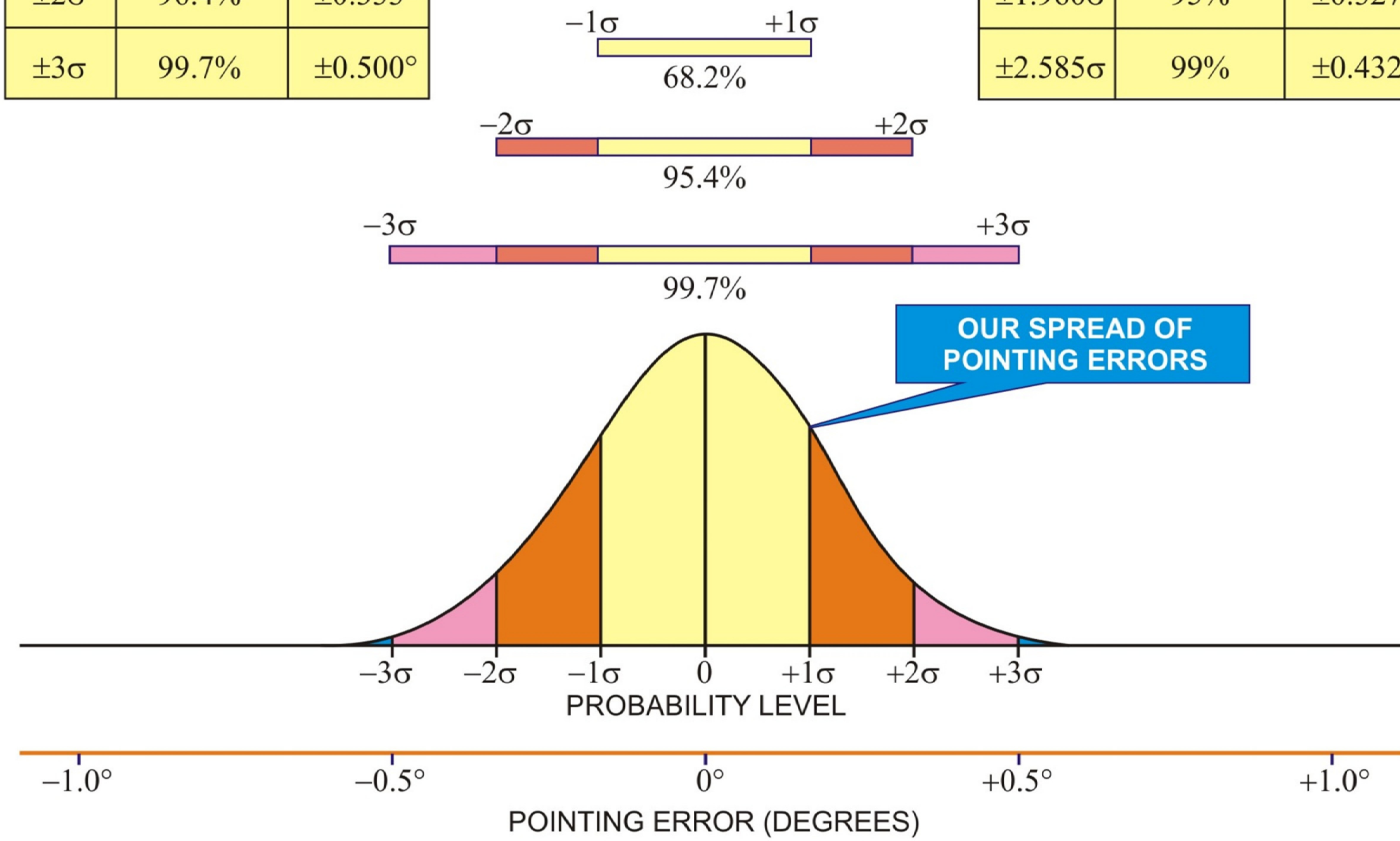
The well-portioned bell-shaped curve running across the bottom of Figure 1 highlights the error characteristics of the current GPS alignment unit designed by Sunsight. Notice that, in this case, the curve ranges over a rather narrow span of pointing errors with a variability of about +/- 0.5 degrees.

The precise shape of any bell-shaped curve can be completely characterized by a single number called σ (sigma) a quantity that is equal to the **root mean square (rms)** of a properly chosen set of random samples. Suppose, for example, the precise pointing direction of a particular RF directional antenna has been measured and recorded over several months and, as a result, these six randomly varying pointing-error measurements have been obtained:

FIGURE 1. THE PROBABLILITY OF VARIOUS POINTING ERRORS FOR QUALITY ALIGNMENT TOOL ACCURACY

SIGMA RANGE	PERCENT OF POINTING ERRORS	OUR POINTING ERROR
$\pm 1\sigma$	68.2%	±0.167°
$\pm 2\sigma$	96.4%	±0.333°
$\pm 3\sigma$	99.7%	±0.500°

SIGMA RANGE	PERCENT OF POINTING ERRORS	OUR POINTING ERROR
$\pm 1.655\sigma$	90%	±0.267°
$\pm 1.960\sigma$	95%	±0.327°
$\pm 2.585\sigma$	99%	±0.432°



$\Delta\Theta_1 = 0.08°$	$\Delta\Theta_4 = 0.11°$
$\Delta\Theta_2 = -0.01°$	$\Delta\Theta_5 = -0.07°$
$\Delta\Theta_3 = -0.05°$	$\Delta\Theta_6 = 0.04°$

All six of these pointing errors can be substituted into a well-known equation from statistics to compute an approximate σ (**root mean square-rms**) error as follows:

$$\sigma = \text{root mean square} = \sqrt{\frac{(0.08)^2+(-0.01)^2+(-0.05)^2+(0.11)^2+(-0.07)^2+(0.04)^2}{6}}$$

$$\boxed{\sigma = 0.166°}$$

This σ value (**rms**), together with various multiples of it, appears on the horizontal scale running across the bottom of Figure 1 together with the probability that any give sample will lie between:

-1σ and +1σ: (68.2%)
-2σ and +2σ: (95.4%)
-3σ and +3σ: (99.7%)

The expected errors associated with these three values -- and three others -- are summarized in the two boxes at the top of Figure 1.

The three σ values highlighted in the upper right-hand corner of the figure correspond to these three specific probability levels: 90%, 95% and 99% -- which statisticians sometimes refer to as R90, R95, and R99. For any Quality measurement tool, repeatable accuracy at the R99 (99.7%) or 3 sigma probability are the only levels that should be considered.

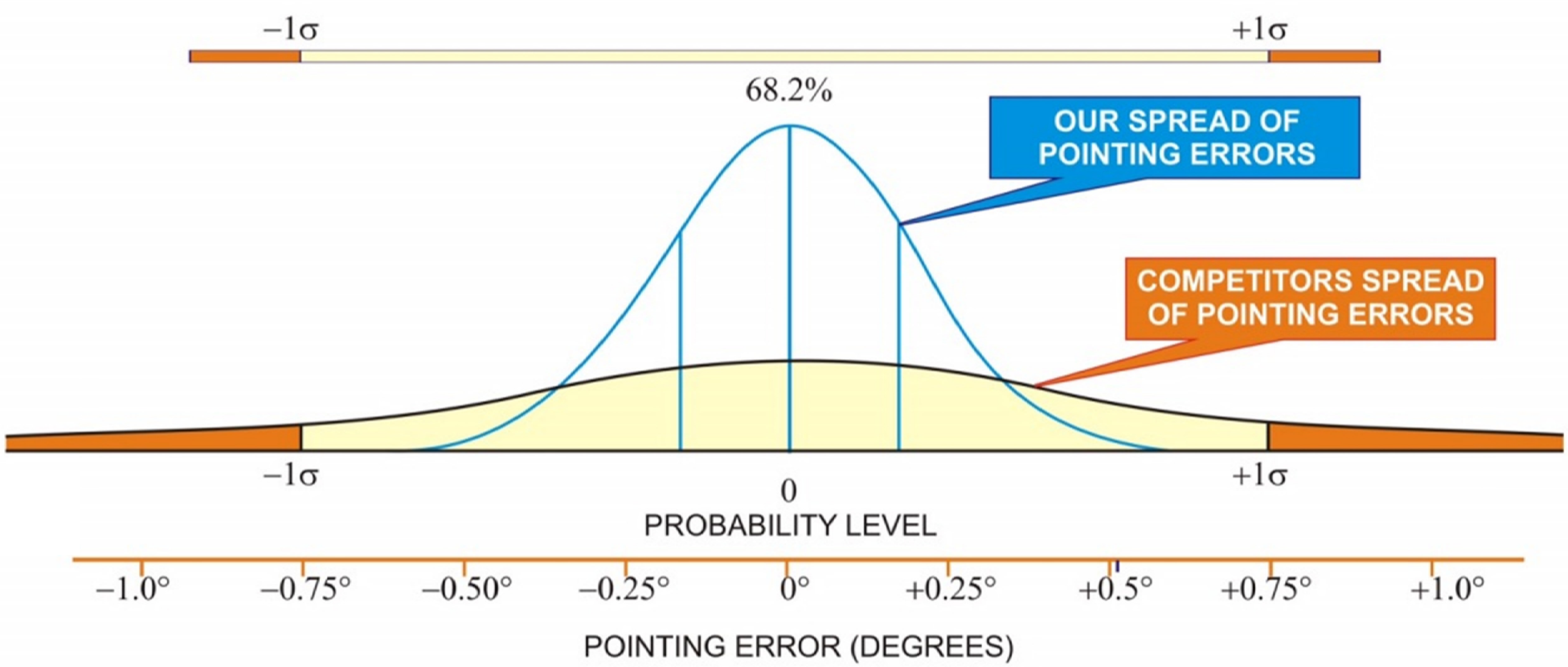
SIDE-BY-SIDE POINTING-ERROR COMPARISONS

Figure 2 was constructed by adding a second flat, squat curve to the graph in Figure 1. This extra curve highlights the pointing errors associated with some GPS alignment units. As this additional bell-shaped curve indicates, the pointing errors span +/-**2.25** degrees. Thus we see that these units have a pointing error **4.5 times** larger. These units have no

FIGURE 2. COMPARISON BETWEEN THE POINTING ERROR FOR SUNSIGHT ALIGNMENT UNIT AND MAIN COMPETITOR

SIGMA RANGE	PERCENT OF POINTING ERRORS	OUR POINTING ERROR	COMPETITOR'S POINTING ERRORS
$\pm 1\sigma$	68.2%	±0.167°	±0.750°
$\pm 2\sigma$	95.4%	±0.333°	±1.500°
$\pm 3\sigma$	99.6%	±0.500°	±2.250°

SIGMA RANGE	PERCENT OF POINTING ERRORS	OUR POINTING ERROR	COMPETITOR'S POINTING ERRORS
$\pm 1.655\sigma$	90%	±0.276°	±1.241°
$\pm 1.960\sigma$	95%	±0.327°	±1.470°
$\pm 2.585\sigma$	99%	±0.432°	±1.938°



room for error, a reading has to be exact, it will never be repeatable within 1 degree of accuracy, and if azimuth targets tighten to more than +/-3 degrees the unit will never be an acceptable option.

The two tables running across the top of Figure 2 provide convenient side-by-side comparisons between the statistical alignment errors associated with two competing devices. Basically, the values presented in these two tables indicate that, at any specific probability level, the second unit's errors are approximately **4.5 times** larger than the comparable errors associated with the first unit.

CONCLUDING REMARKS

High-gain directional antennas transmit narrow beams of electromagnetic energy to and from adjacent RF antennas scattered around the countryside. Consequently, small pointing errors can create sharp reductions in the strength of the signals being received. Those weaker signals are less reliable and robust, harder to demodulate, and more susceptible to intentional or unintentional interference. The Sunsight GPS alignment unit can minimize these difficulties by assuring extremely small pointing errors.

The bell-shaped curve characterizing the errors associated with the alignment unit being marketed by the second GPS alignment tool investigated is about **4.5 times** wider than the tall, skinny bell-shaped curve associated with the first unit in Figure 1. Those who operate, calibrate, and rely on properly modulated RF directional antennas would be wise to employ a unit that can deliver 1 σ (rms) accuracy of less than 0.3 or 3 σ (R99) of less than 1 degree. This will vastly minimize the errors in their pointing directions in demanding real-world situations.

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THE AUTHOR'S QUALIFICATIONS

Tom Logsdon (B.S. Math-Physics, M.S. Mathematics) has worked on the GPS radionavigation system for more than 40 years. He helped design the Transit Navigation System and the GPS and he acted as a consultant in the early design phases of the European Galileo Spaceborne Navigation System. His key assignments on the GPS have included hardware design and testing, constellation selection trades, geographical information systems, and a broad range of civilian and military applications.

Over the past 32 years, Logsdon has taught more than 300 short courses in two dozen different countries scattered across six continents. About 100 of them have centered around the unique capabilities of the GPS. He has written 20 technical papers and magazine articles dealing with the GPS, lectured at two dozen major universities, made guest appearances on 25 television shows, helped design an exhibit for the Smithsonian Institution, applied for a patent, and written and sold 1.8 million words, including 33 non fiction books. These have included ***Understanding the Navstar*** (Van Nostrand Reinhold), ***Orbital Mechanics*** (John Wiley and Sons), and ***The Navstar Global Positioning System*** (Chapman and Hall). He also writes articles for ***Encyclopaedia Britannica***, most of which deal with a variety of navigation-related topics.