Photo courtesy Garmin

Gee, How Does GPS Do It?

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The Global Positioning System made its way from a U.S. Navy application of the 1970s into today's cars and boats. Commonly referred to as GPS, this tool works by using signals transmitted from satellites circling the earth to ground stations. But there's so much more to this fascinating and useful technology.

Photo courtesy Si-Tex

How Does GPS Actually Work?

The easiest and most reliable measurement we can make with current technology is time itself. Everyone has heard of "atomic clocks" which can measure time to within billionths of a second by counting the vibrations of the atoms themselves. If we put enough atomic clocks in orbit and measure the time it takes, at the speed of light, for the signal of three of those clocks/satellites to reach the $300.00 GPS units in the cockpits of our boats, we must know where we are (it is coastal piloting to the *n*th degree). Akin to using a handheld compass to find the angle from your boat to three landmarks and drawing the lines back to the boat to find the boat's location relative to those objects, the GPS uses time differences to do the same thing; a handheld GPS can tell your elevation while hiking or biking.

There are a couple of wrinkles in this simple model which demonstrate the genius of the designers. Forgetting about the "Doppler effect" (why a car's horn sounds differently as it approaches and then moves away from you), which is easily compensated for, the first wrinkle was thrown in by the findings of Albert Einstein (in fact, without Einstein's work in 1905, there would be no GPS). Under his Theory of Relativity, objects traveling at high speeds actually distort time itself. So, with the satellite traveling around the Earth at a distance of 11,000 nautical miles twice a day, the "relativistic effects" have to be accounted for.

The second GPS wrinkle was the cost. To make the system work, every clock must be accurate to within billionths of a second of the other. Such clocks cost about $100,000.00 each, and while an expense like that hardly stops the government side of the project, what about the accuracy of your GPS? It needs to be equally precise, yet the clock in your GPS is no more accurate (or expensive) than a quartz wristwatch. How can that be?

When my children confront me with some fantastic fact, I answer with this bit of logic: "If that were true, what else would have to be true to make it so?" This usually shortens the debate about Martians populating early Earth, and the designers of the GPS system used essentially this same logic to replace a $100,000 atomic clock with a cheap quartz wristwatch by using the signal from a fourth satellite. If our GPS clock was as accurate as the ones in the satellites, the redundant signal from the fourth satellite should give the same position as was calculated by the other three. Once the GPS knows the difference in the calculated positions, it knows the error factor built in by the cheap quartz watch and it then compensates for it – giving you atomic clock accuracy on your boat!

How Accurate is it?

As it developed, GPS accuracy was good to within the length of a football field. Nowadays it is accurate to within 10 meters, or just under 33 feet. But with such fantastic technology, why can't it be more accurate? The answer is time again.

The speed of light is about one billion feet per second, or one foot in one-billionth of a second. While that is almost incomprehensibly fast, think of it this way: if you dropped a magazine and then circled the world 10 times, you'd be back just before it hit the floor. So every clock in the system has to be accurately attuned to the others by that same one-billionth of a second or needs a margin of error built in. The Department of Defense is working to get all clocks synchronized within a few billionths of a second as they pass overhead each day, but until then, we'll have to be happy with knowing where we are on Earth within 33 feet! ⚓

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