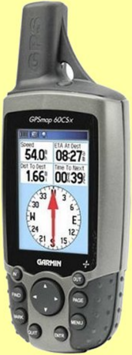
# Introduction to GPS

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# 1. Why GPS?

Trying to figure out where you are and where you're going is probably one of man's oldest requirement / pastimes. Navigation and positioning are crucial to so many activities and yet the process has always been quite cumbersome. Over the years all kinds of technologies have tried to simplify the task but every one has had some disadvantage. Finally, the U.S. Department of Defense decided that the military had to have a super precise form of worldwide positioning. And fortunately they had the kind of money ($12 billion!) it took to build something really good.


Figure 1: Blue Tooth GPS

## 2. What is GPS?

The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. In fact, with advanced forms of GPS you can make measurements to better than a centimeter.

GPS receivers have been miniaturised to just a few integrated circuits and so are becoming very economical. And that makes the technology accessible to virtually everyone. These days GPS is finding its way into cars, boats, planes, construction equipment, movie making gear, farm machinery, even laptop computers.


Figure 2: Hand Held GPS

# 3. How GPS works?

Here's how GPS works in five logical steps:

1. The basis of GPS is "triangulation" from satellites. We're using the word "triangulation" very loosely here because it's a word most people can understand, but purists would not call what GPS does "triangulation" because no angles are involved. It's really "trilateration". Trilateration is a method of determining the relative positions of objects using the geometry of triangles.

2. To "triangulate", a GPS receiver measures distance using the travel time of radio signals.

3. To measure travel time, GPS needs very accurate timing.
4. Along with distance, you need to know exactly where the satellites are in space.
5. Finally you must correct for any delays the signal experiences as it travels through the atmosphere.

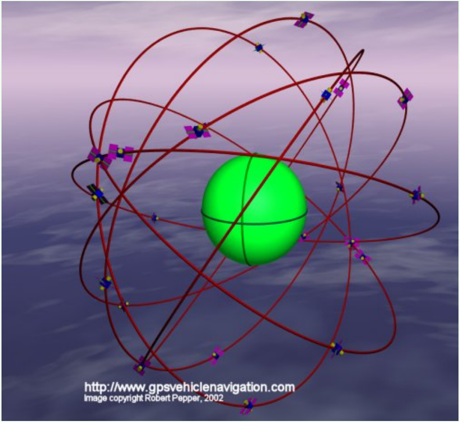


Figure 3: GPS Satellite Orbit

## 3.1. Triangulating from Satellites

The whole idea behind GPS is to use satellites in space as reference points for locations here on earth. By very accurately measuring our distance from three satellites we can "triangulate" our position anywhere on earth.

The distance measurements from three satellites can pinpoint you in space, as explained below.

- Suppose we measure our distance from a satellite and find it to be 18,000 km. Knowing that we're 18,000 km from a particular satellite narrows down all the possible locations we could be in the whole universe to the surface of a sphere that is centered on this satellite and has a radius of 18,000 km.

- Next, say we measure our distance to a second satellite and find out that it's 20,000 km away. That tells us that we're not only on the first sphere but we're also on a sphere that's 20,000 km from the second satellite. Or in other words, we're somewhere on the circle where these two spheres intersect.

- If we then make a measurement from a third satellite and find that we're 21,000 km from that one, that narrows our position down even further, to the two points where the 21,000 km sphere cuts through the circle that's the intersection of the first two spheres.

So by ranging from three satellites we can narrow our position to just two points in space. To decide which one is our true location we could make a fourth measurement. But usually one of the two points is a ridiculous answer (either too far from Earth or moving at an impossible velocity) and can be rejected without a measurement.

## 3.2. Measuring distance from satellite

We can find distance, if velocity and time are known to us. In the case of GPS we're measuring a radio signal so the velocity is going to be the speed of light.

The times are going to be awfully short. If a satellite is right overhead the travel time would be something like 0.06 seconds. So we have to use very precise clocks.

How do we measure travel time? To explain it let's use following analogy:

Suppose there was a way to get both the satellite and the receiver to start playing "Twinkle twinkle little star" at precisely 12 noon. If sound could reach us from space then standing at the receiver we'd hear two versions of the "Twinkle twinkle little star", one from our receiver and one from the satellite. These two versions would be out of sync. The version coming from the satellite would be a little delayed because it had to travel more than 18,000 km. If we wanted to see just how delayed the satellite's version was, we could start delaying the receiver's version until they fell into perfect sync. The amount we have to shift back the receiver's version is equal to the travel time of the satellite's version. So we just multiply that time times the speed of light. to get the distance.

That's basically how GPS works. Only instead of the "Twinkle twinkle little star" the satellites and receivers use something called a "Pseudo Random Code".

## 3.3. Getting perfect timing

Measuring the travel time of a radio signal is the key to GPS. An error of just one thousandth of a second in time, will result an error of 300 km in distance. On the satellite side, timing is almost perfect because they have incredibly precise atomic clocks on board. But not on receivers on the ground.

## 3.4. Extra Measurement Cures Timing Offset

If our receiver's clocks were perfect, then all our satellite ranges would intersect at a single point (which is our position). But with imperfect clocks, a fourth measurement, done as a cross-check, will NOT intersect with the first three. So the receiver's computer says "there is a discrepancy in my measurements. I must not be perfectly synced with universal time". Since any offset from universal time will affect all of our measurements, the receiver looks for a single correction factor that it can subtract from all its timing measurements that would cause them all to intersect at a single point. That correction brings the receiver's clock back into sync with universal time, and bingo! - you've got atomic accuracy time right in the palm of your hand.

Once it has that correction it applies to all the rest of its measurements and now we've got precise positioning. One consequence of this principle is that any decent GPS receiver will need to have at least four channels so that it can make the four measurements simultaneously. With the pseudo-random code as a rock solid timing sync pulse, and this extra measurement trick to get us perfectly synced to universal time, we have got everything we need to measure our distance to a satellite in space. But for the triangulation to work we not only need to know distance, we also need to know exactly where the satellites are.

## 3.5. Satellite Positions

How do we know exactly where they are? After all they're floating around 18,000 km up in space. That 18,000 km altitude is actually a benefit in this case, because something that high is well clear of the atmosphere. And that means it will orbit according to very simple mathematics.

On the ground all GPS receivers have programme into their computers that tells them where in the sky each satellite is, moment by moment. The basic orbits are quite exact but just to make things perfect the GPS satellites are constantly monitored by the Department of Defense. They use very precise radar to check each satellite's exact altitude, position and speed. The errors they're checking for are called "ephemeris errors" because they affect the satellite's orbit or "ephemeris". These errors are caused by gravitational pulls from the moon and sun and by the pressure of solar radiation on the satellites. The errors are usually very slight but if you want great accuracy they must be taken into account. Once the DoD has measured a satellite's exact position, they relay that information back up to the satellite itself. The satellite then includes this new corrected position information in the timing signals it's broadcasting.

So a GPS signal is more than just pseudo-random code for timing purposes. It also contains a navigation message with ephemeris information as well. With perfect timing and the satellite's exact position, can we make perfect position calculations? No, as we are not living in vacuum.

## 3.6. Error Correction

Up to now we've been treating the calculations that go into GPS very abstractly, as if the whole thing were happening in a vacuum. But in the real world there are lots of things that can happen to a GPS signal that will make its life less than mathematically perfect. To get the most out of the system, a good GPS receiver needs to take a wide variety of possible errors into account.

First, one of the basic assumptions we've been using, i.e. "distance is calculated by multiplying a signal's travel time by the speed of light" is not exactly true.

But the speed of light is only constant in a vacuum. As a GPS signal passes through the charged particles of the ionosphere and then through the water vapor in the troposphere it gets slowed down a bit, and this creates the same kind of error as bad clocks.

Trouble for the GPS signal doesn't end when it gets down to the ground. The signal may bounce off various local obstructions before it gets to our receiver. This is called multipath error and is similar to the ghosting you might see on a TV. Good receivers use sophisticated signal rejection techniques to minimize this problem.

### 3.6.1. Problems at the satellite

Even though the satellites are very sophisticated they do account for some tiny errors in the system. The atomic clocks they use are very, very precise but they're not perfect. Minute discrepancies can occur, and these translate into travel time measurement errors. And even though the satellites positions are constantly monitored, they can't be watched every second. So slight position or "ephemeris" errors can sneak in between monitoring times.

### 3.6.2. Intentional Errors

As hard as it may be to believe, the same government that spent $12 billion to develop the most accurate navigation system in the world intentionally degraded its accuracy. The policy was called “Selective Availability” or “SA” and the idea behind it was to make sure that no hostile force or terrorist group can use GPS to make accurate weapons. Basically the DoD introduced some “noise” into the satellite’s clock data which, in turn, added noise (or inaccuracy) into position calculations. The DoD may have also been sending slightly erroneous orbital data to the satellites which they transmitted back to receivers on the ground as part of a status message. Together these factors made SA the biggest single source of inaccuracy in the system. Military receivers used a decryption key to remove the SA errors and so they’re much more accurate.

### 3.6.3. Turning Off Selective Availability

On May 1, 2000 the White House announced a decision to discontinue the intentional degradation of the GPS signals to the public beginning at midnight. Civilian users of GPS are now able to pinpoint locations up to ten times more accurately. As part of the 1996 Presidential Decision Directive goals for GPS, President Clinton committed to discontinuing the use of SA by 2006. The announcement came six years ahead of schedule. The decision to discontinue SA was the latest measure in an on-going effort to make GPS more responsive to civil and commercial users worldwide.

## 3.7. Differential GPS

### 3.7.1. Need of Differential GPS

Basic GPS is the most accurate radio-based navigation system ever developed. And for many applications it's plenty accurate. But it's human nature to want MORE! So some crafty engineers came up with "Differential GPS" a way to correct the various inaccuracies in the GPS system, pushing its accuracy even farther.


Figure 4: Reference Station

Differential GPS or “DGPS” can yield measurements good to a couple of meters in moving applications and even better in stationary situations. That improved accuracy has a profound effect on the importance of GPS as a resource. With it, GPS becomes more than just a system for navigating boats and planes around the world. It becomes a universal measurement system capable of positioning things on a very precise scale.

### 3.7.2. Working of Differential GPS

Differential GPS involves the cooperation of two receivers, one that’s stationary and another that’s roving around making position measurements. GPS receivers use timing signals from at least four satellites to establish a position. Each of those timing signals is going to have some error or delay depending on what sort of perils have befallen it on its trip down to us.

Since each of the timing signals that go into a position calculation has some error, that calculation is going to be a compounding of those errors. Luckily the sheer scale of the GPS system comes to our rescue. The satellites are so far out in space that the little distances we travel here on earth are insignificant. So if two receivers are fairly close to each other, say within a few hundred kilometers, the signals that reach both of them will have traveled through virtually the same slice of atmosphere, and so will have virtually the same errors. That's the idea behind differential GPS: We have one receiver measure the timing errors and then provide correction information to the other receivers that are roving around. That way virtually all errors can be eliminated from the system, even the pesky Selective Availability error that the DoD puts in on purpose. The idea is simple. Put the reference receiver on a point that's been very accurately surveyed and keep it there.

This reference station receives the same GPS signals as the roving receiver but instead of working like a normal GPS receiver it attacks the equations backwards. Instead of using timing signals to calculate its position, it uses its known position to calculate timing. It figures out what the travel time of the GPS signals should be, and compares it with what they actually are. The difference is an "error correction" factor. The receiver then transmits this error information to the roving receiver so it can use it to correct its measurements. Since the reference receiver has no way of knowing which of the many available satellites a roving receiver might be using to calculate its position, the reference receiver quickly runs through all the visible satellites and computes each of their errors. Then it encodes this information into a standard format and transmits it to the roving receivers. GPS receivers don't actually transmit corrections by themselves. They are linked to separate radio transmitters. The roving receivers get the complete list of errors and apply the corrections for the particular satellites they're using.

Error transmissions not only include the timing error for each satellite, they also include the rate of change of that error as well. That way the roving receiver can interpolate its position between updates.

### 3.7.3. Where to get Differential Corrections?

In the early days of GPS, reference stations were established by private companies who had big projects demanding high accuracy - groups like surveyors or oil drilling operations. And that is still a very common approach. You buy a reference receiver and set up a communication link with your roving receivers. But now there are enough public agencies transmitting corrections that you might be able to get them for free!

The United States Coast Guard and other international agencies are establishing reference stations all over the place, especially around popular harbors and waterways. These stations often transmit on the radio beacons that are already in place for radio direction finding (usually in the 300kHz range).

Anyone in the area can receive these corrections and radically improve the accuracy of their GPS measurements. Most ships already have radios capable of tuning the direction finding beacons, so adding DGPS will be quite easy. Many new GPS receivers are being designed to accept corrections, and some are even equipped with built-in radio receivers.

### 3.7.4. Other ways to work with Differential GPS

Post Processing DGPS: Not all DGPS applications are created equal. Some don't need the radio link because they don't need precise positioning immediately. It's one thing if you're trying to position a drill bit over a particular spot on the ocean floor from a pitching boat, but quite another if you just want to record the track of a new road for inclusion on a map. For applications like the later, the roving receiver just needs to record all of its measured positions and the exact time it made each measurement.

Then later, this data can be merged with corrections recorded at a reference receiver for a final clean-up of the data. So you don't need the radio link that you have to have in real-time systems.

If you don't have a reference receiver there may be alternative source for corrections in your area. Some academic institutions are experimenting with the Internet as a way of distributing corrections. There's another permutation of DGPS, called "inverted DGPS," that can save money in certain tracking applications.

Let's say you've got a fleet of buses and you'd like to pinpoint them on street maps with very high accuracy (maybe so you can see which side of an intersection they're parked on or whatever). Anyway, you'd like this accuracy but you don't want to buy expensive "differential-ready" receivers for every bus. With an inverted DGPS system the buses would be equipped with standard GPS receivers and a transmitter and would transmit their standard GPS positions back to the tracking office. Then at the tracking office the corrections would be applied to the received positions.

It requires a computer to do the calculations, a transmitter to transmit the data but it gives you a fleet of very accurate positions for the cost of one reference station, a computer and a lot of standard GPS receivers.

### 3.7.5. Advanced Concepts

If you want to know where DGPS might be headed, take a look at your hand, because soon DGPS may be able to resolve positions that are no farther apart than the width of your little finger.

Imagine the possibilities. Automatic construction equipment could translate CAD drawings into finished roads without any manual measurements. Self-guided cars could take you across town while you quietly read in the back seat.

### 3.7.6. Augmented GPS

FAA realised the great benefits GPS could bring to aviation, but they wanted more. They wanted the accuracy of Differential GPS and they wanted it across the whole continent. Maybe the whole world.

Their plan is called the "Wide Area Augmentation System" or "WAAS," and it's basically a continental DGPS system. The idea grew out of some very specific requirements that basic GPS just couldn't handle by itself. It began with "system integrity". GPS is very reliable but every once in a while a GPS satellite malfunctions and gives inaccurate data. The GPS monitoring stations detect this sort of thing and transmit a system status message that tells receivers to disregard the broken satellite until further notice. Unfortunately this process can take many minutes which could be too late for an airplane in the middle of a landing.

So the FAA got the idea that they could set up their own monitoring system that would respond much quicker. In fact, they figured they could park a geosynchronous satellite somewhere over the U.S. that would instantly alert aircraft when there was a problem. Then they reasoned that they could transmit this information right on a GPS channel so aircraft could receive it on their GPS receivers and wouldn't need any additional radios.

But wait a second! If we've got the geosynchronous satellite already transmitting on the GPS frequency, why not use it for positioning purposes too? Adding another satellite helps with positioning accuracy and it ensures that plenty of satellites are always visible around the country. But wait another second! Why not use that satellite to relay differential corrections too?

The FAA figured that with about 24 reference receivers scattered across the U.S. they could gather pretty good correction data for most of the country. That data would make GPS accurate enough for “Category 1” landings (i.e. very close to the runway but not zero visibility)

### 3.7.7. Local Area Augmention

To complete the system the FAA wants to eventually establish “Local Area Augmentation Systems” near runways. These would work like the WAAS but on a smaller scale. The reference receivers would be near the runways and so would be able to give much more accurate correction data to the incoming planes. With a LAAS aircraft would be able to use GPS to make Category 3 landings (zero visibility).

# 4. Putting GPS to work

GPS technology has matured into a resource that goes far beyond its original design goals. These days engineers, scientists, sportsmen, farmers, soldiers, pilots, surveyors, hikers, delivery drivers, sailors, dispatchers, fire-fighters, and people from many other walks of life are using GPS in ways that make their work more productive, safer, and sometimes even easier.

In this section you will see a few examples of real-world applications of GPS. These applications fall into five broad categories.

- Location - determining a basic position
- Navigation - getting from one location to another

- Tracking - monitoring the movement of people and things
- Mapping - creating maps of the world
- Timing - bringing precise timing to the world

## 4.1. Location

"Where am I?"

The first and most obvious application of GPS is the simple determination of a "position" or location. GPS is the first positioning system to offer highly precise location data for any point on the planet, in any weather. That alone would be enough to qualify it as a major utility, but the accuracy of GPS and the creativity of its users is pushing it into some surprising realms. Knowing the precise location of something, or someone, is especially critical when the consequences of inaccurate data are measured in human terms.

## 4.2. Tracking

If navigation is the process of getting something from one location to another, then tracking is the process of monitoring it as it moves along. Commerce relies on fleets of vehicles to deliver goods and services either across a crowded city or through nationwide corridors. So, effective fleet management has direct bottom-line implications, such as telling a customer when a package will arrive, spacing buses for the best scheduled service, directing the nearest ambulance to an accident, or helping tankers avoid hazards.

GPS used in conjunction with communication links and computers can provide the backbone for systems tailored to applications in agriculture, mass transit, urban delivery, public safety, and vessel and vehicle tracking. So it's no surprise that police, ambulance, and fire departments are adopting GPS based system to pinpoint both the location of the emergency and the location of the nearest response vehicle on a computer map. With this kind of clear visual picture of the situation, dispatchers can react immediately and confidently.

## 4.3. Mapping

"Where is everything else?" It's a big world out there, and using GPS to survey and map it precisely saves time and money in this most stringent of all applications. Today, GPS makes it possible for a single surveyor to accomplish in a day what used to take weeks with an entire team. And they can do their work with a higher level of accuracy than ever before. Mapping is the art and science of using GPS to locate items, then create maps and models of everything in the world. And we do mean everything. Mountains, rivers, forests and other landforms. Roads, routes, and city streets. Endangered animals, precious minerals and all sorts of resources. Damage and disasters, trash and archeological treasures. GPS is mapping the world.

### 4.3.1. Timing

"When will it all happen?" Although GPS is well-known for navigation, tracking, and mapping, it's also used to disseminate precise time, time intervals, and frequency. Time is a powerful commodity, and exact time is more powerful still. Knowing that a group of timed events is perfectly synchronised is often very important. GPS makes the job of "synchronising our watches" easy and reliable. There are three fundamental ways we use time. As a universal marker, time tells us when things happened or when they will. As a way to synchronise people, events, even other types of signals, time helps keep the world on schedule. And as a way to tell how long things last, time provides and accurate, unambiguous sense of duration.

GPS satellites carry highly accurate atomic clocks. And in order for the system to work, our GPS receivers here on the ground synchronise themselves to these clocks. That means that every GPS receiver is, in essence, an atomic accuracy clock. Astronomers, power companies, computer networks, communications systems, banks, and radio and television stations can benefit from this precise timing.

# 5. Demonstartion

Let us move to outside to see how GPS trace you movement and how to record Point of Interest. Arky and Sajjad will be with us to demonstrate and to answer queries.

# SUGGESTED READING


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# Thank you

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