AN INTRODUCTION

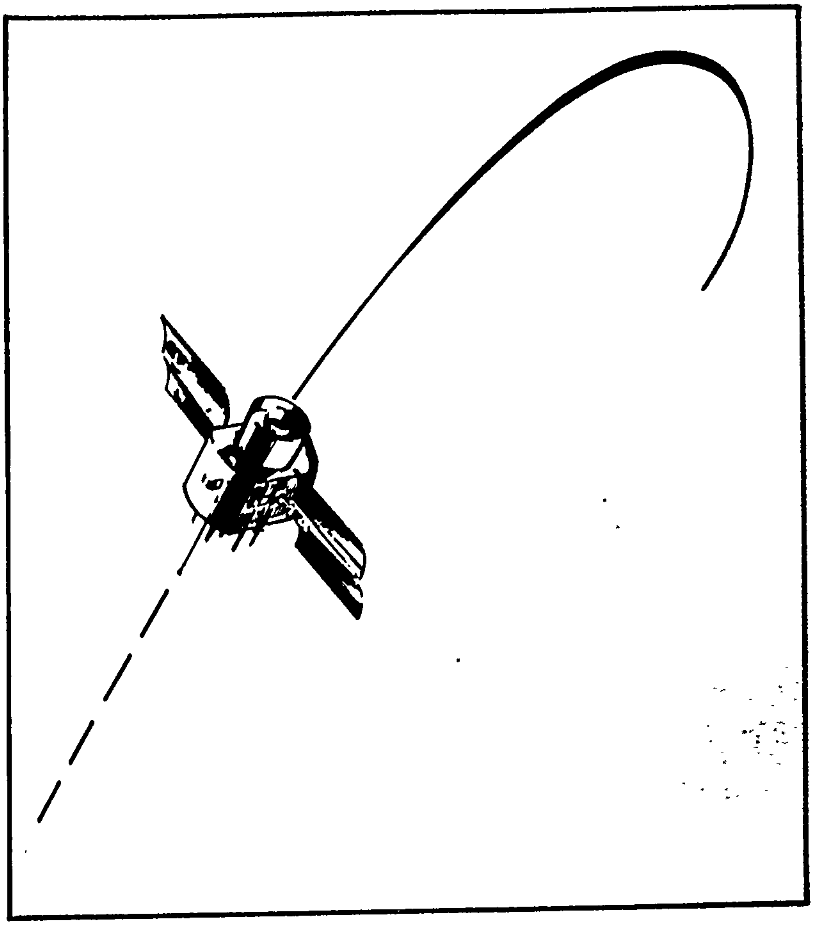
TO

G P S

The
Global Positioning System

(Everyman's Guide to Satellite Navigation)

by
Steven D. Thompson
Illustrations by Peggie Glenn
ARINC Research Corporation



PREFACE

This booklet is designed to acquaint upper and middle level managers with the principles involved in using GPS for navigation. It should provide a sufficient understanding of the concepts of satellite navigation and the details of the GPS system to permit participation in executive level program and policy decision making.

Others with an interest in air navigation will find it helpful even if they have only a limited technical background.

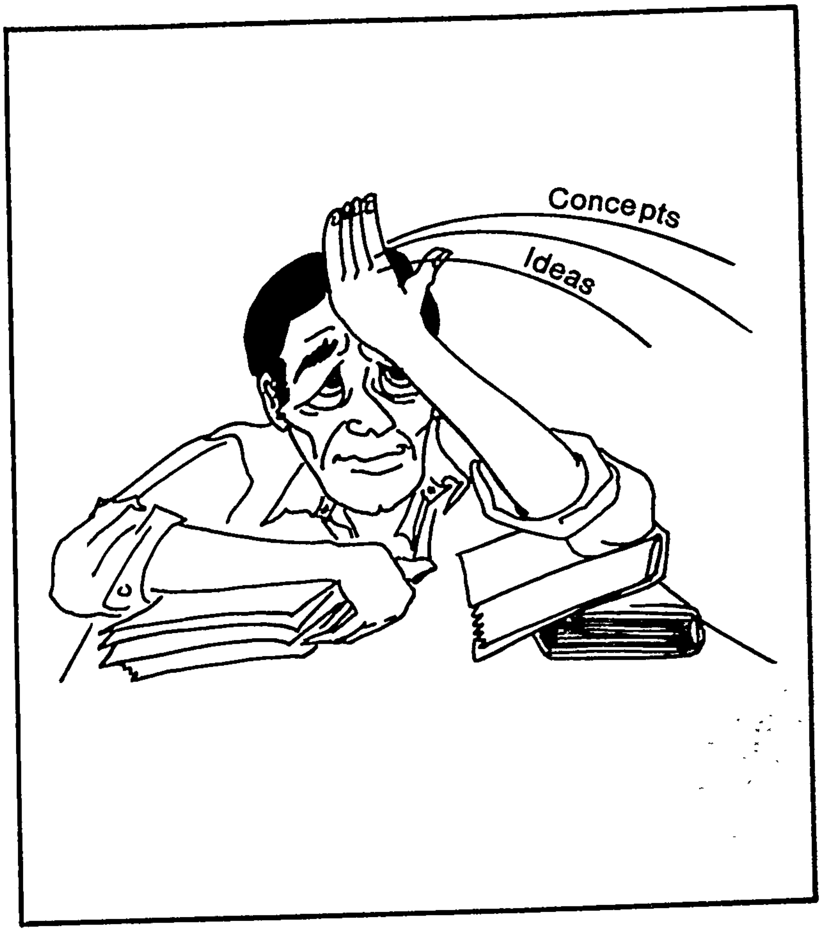
CONTENTS

Preface iii

Part I Concepts 1

Part II Details, details, details 29

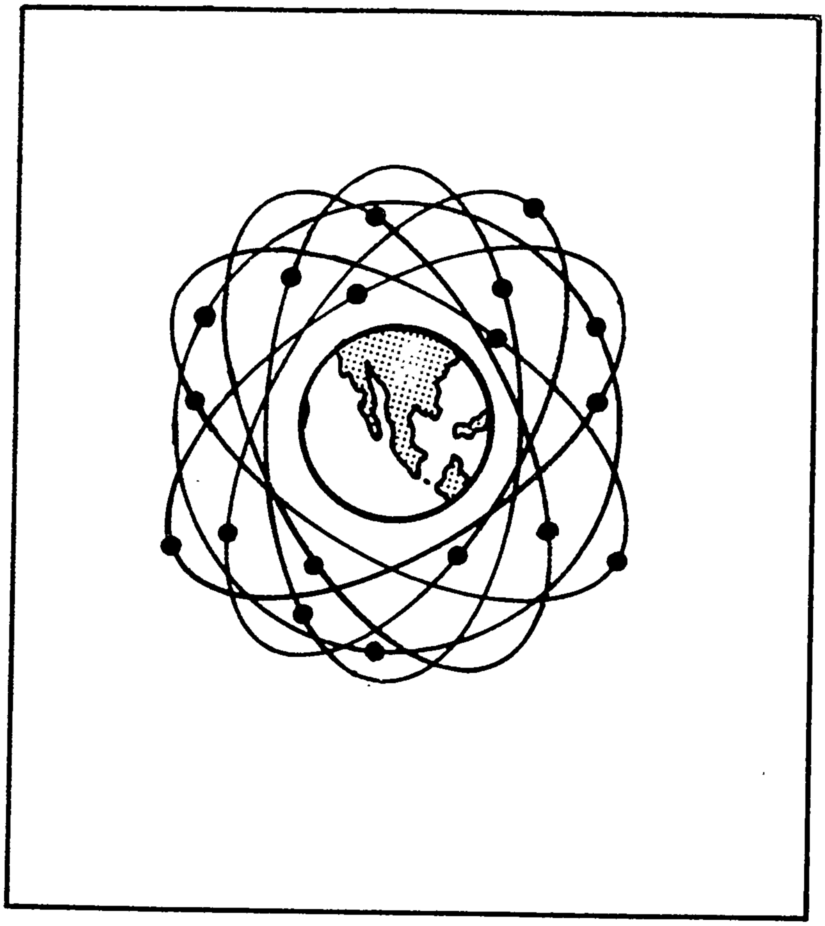
Part III The System 55



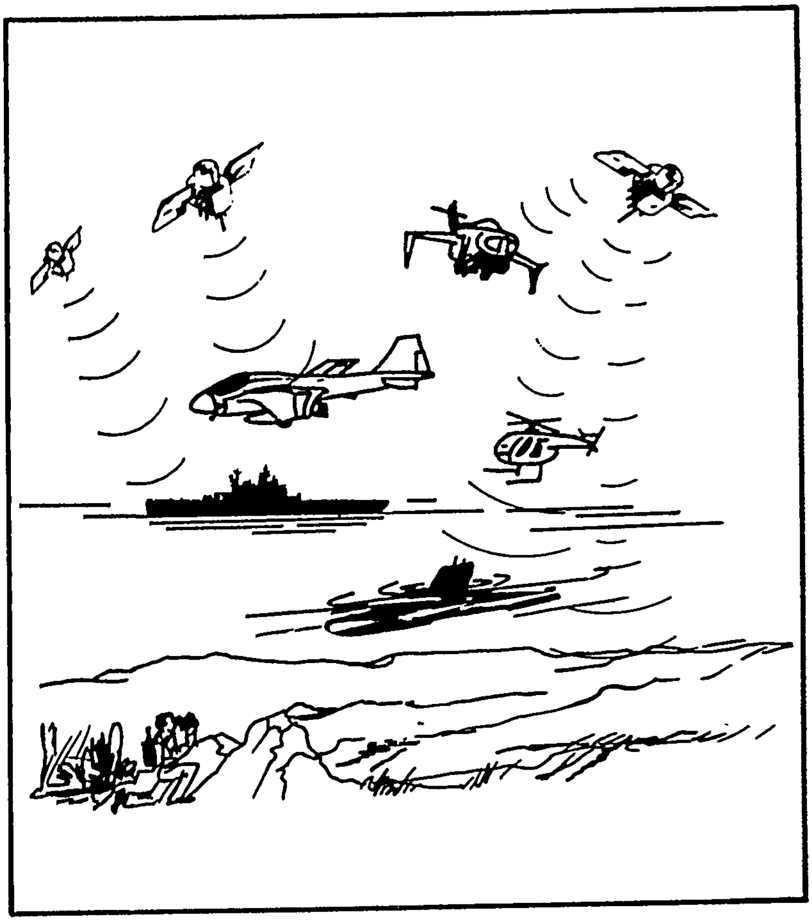
PART I

CONCEPTS

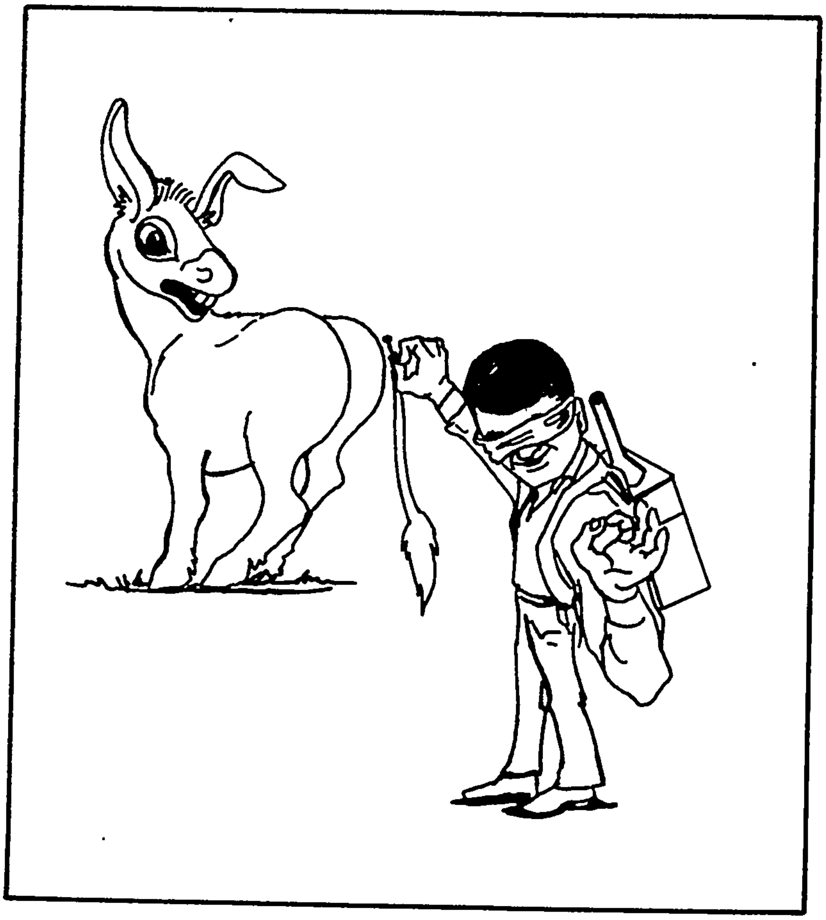
... principles, ideas, and stuff like that



GPS is a satellite navigation system. It is designed to provide continuous, accurate coverage all over the world.

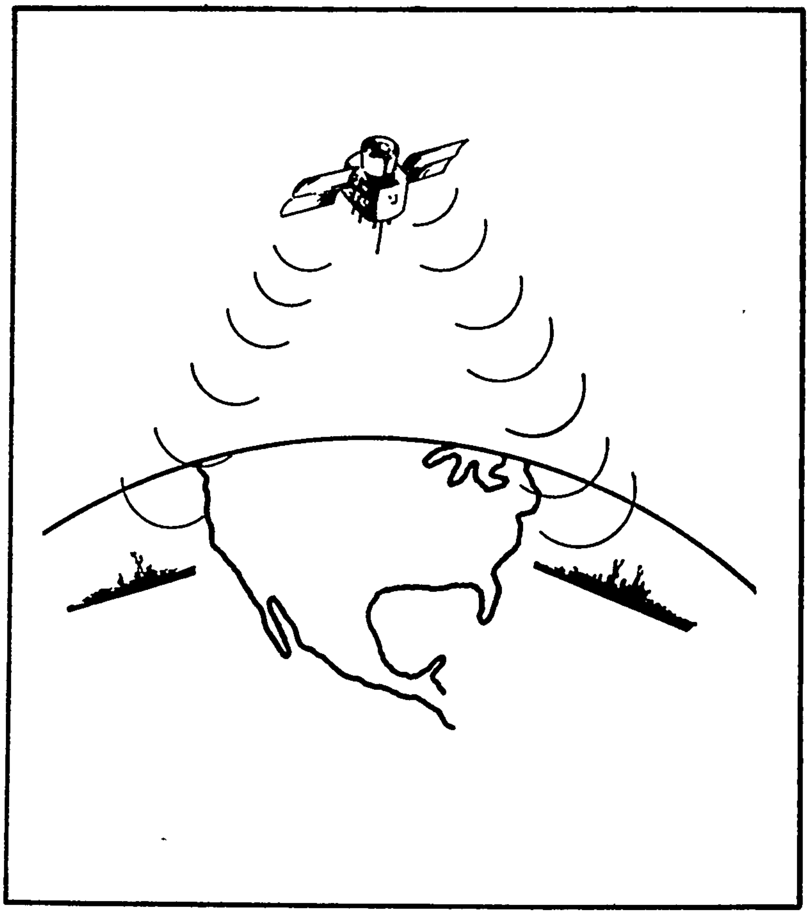


GPS applications include navigation at sea, in the air, and on the ground.

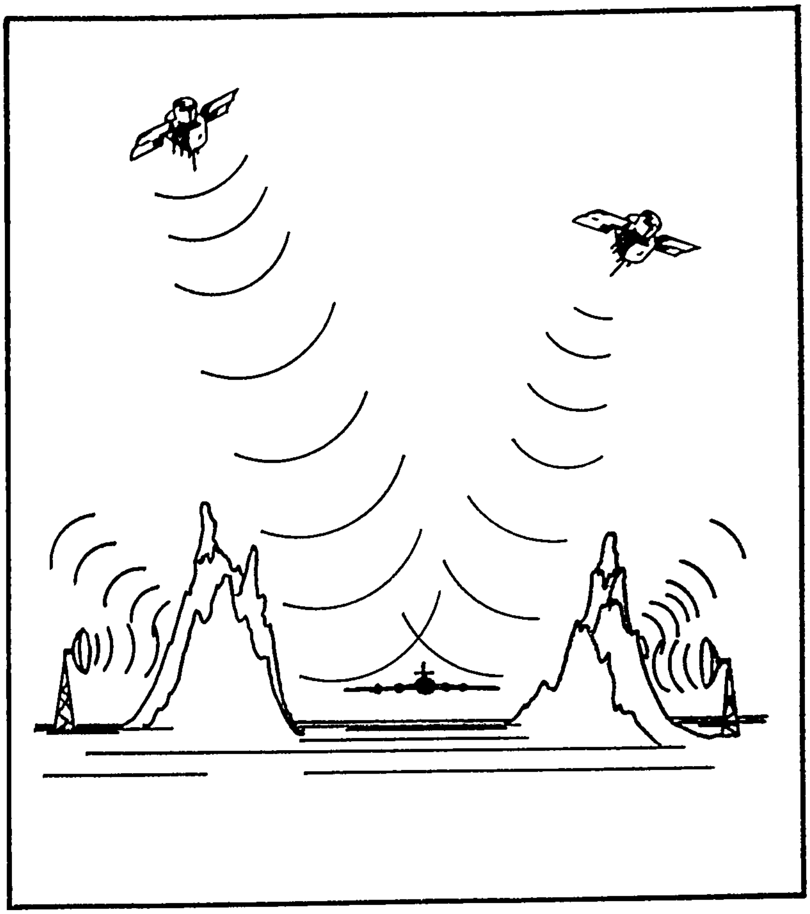


Receivers can even be carried by individuals, and the system's accuracy is amazing.

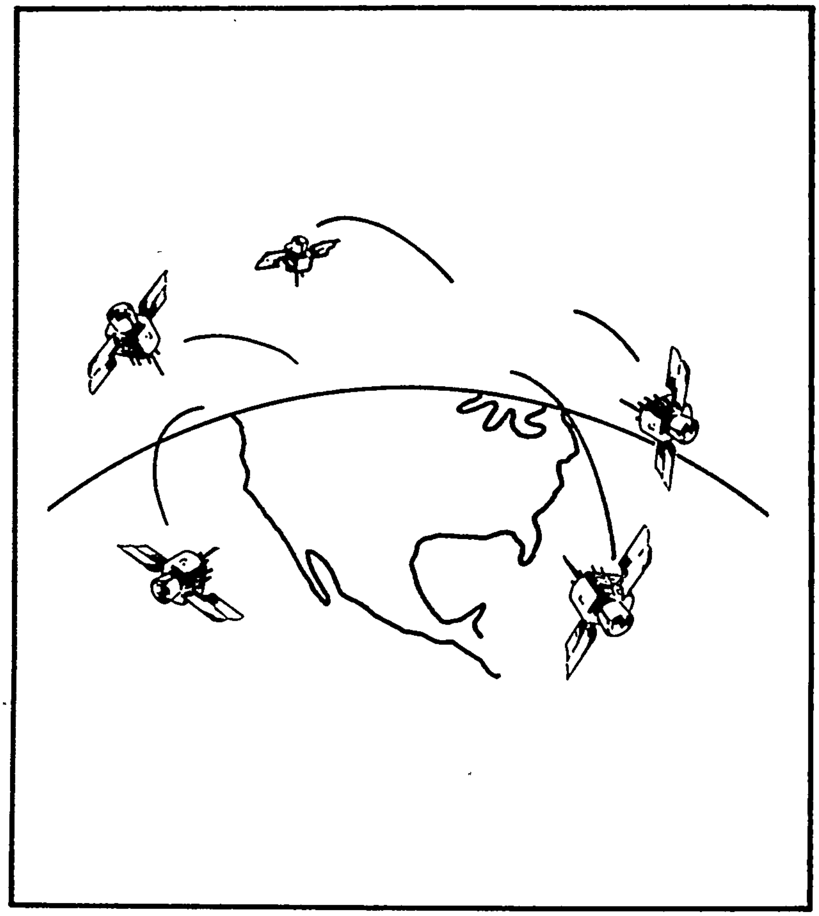
Why use satellites?



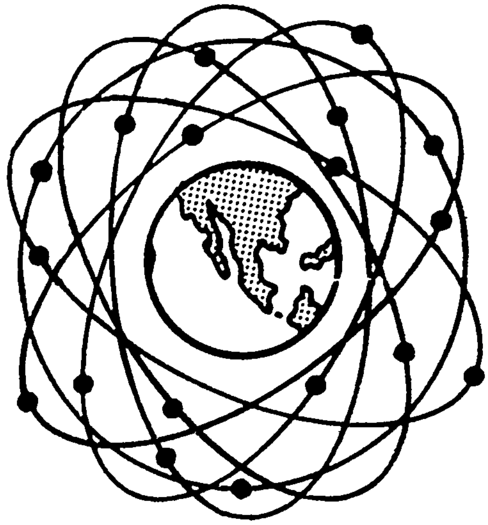
Because they are up high which means they can "see" a large area and...



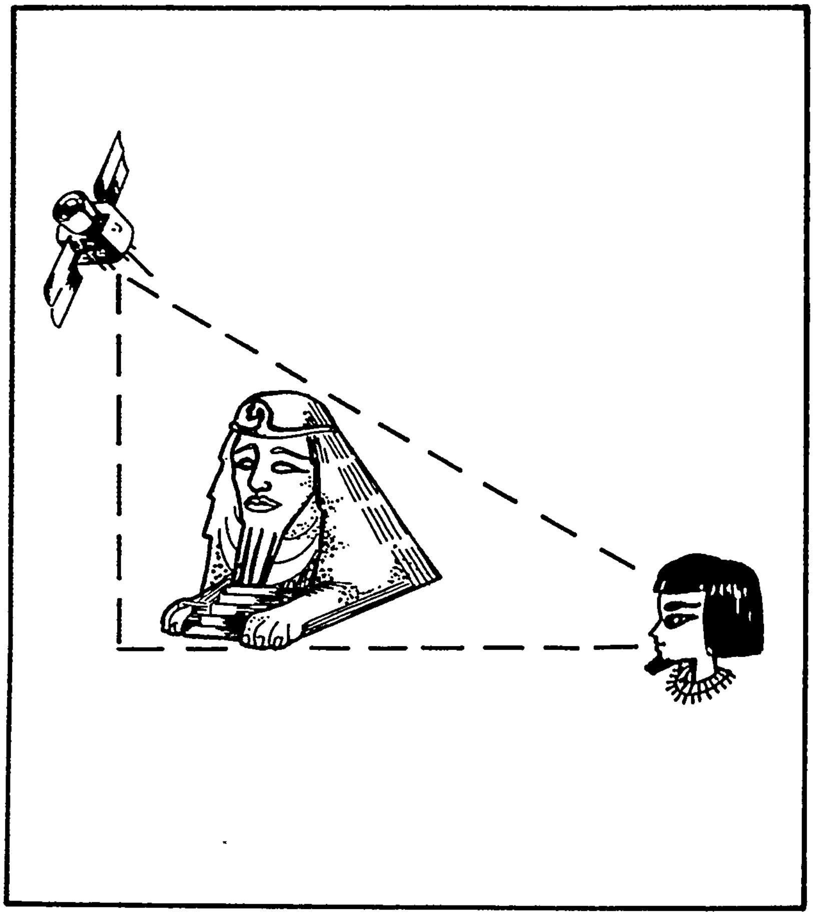
...reception of the satellites' signals close to the ground is not interfered with by terrain or geography that may limit the coverage of ground-based radionavigation facilities.



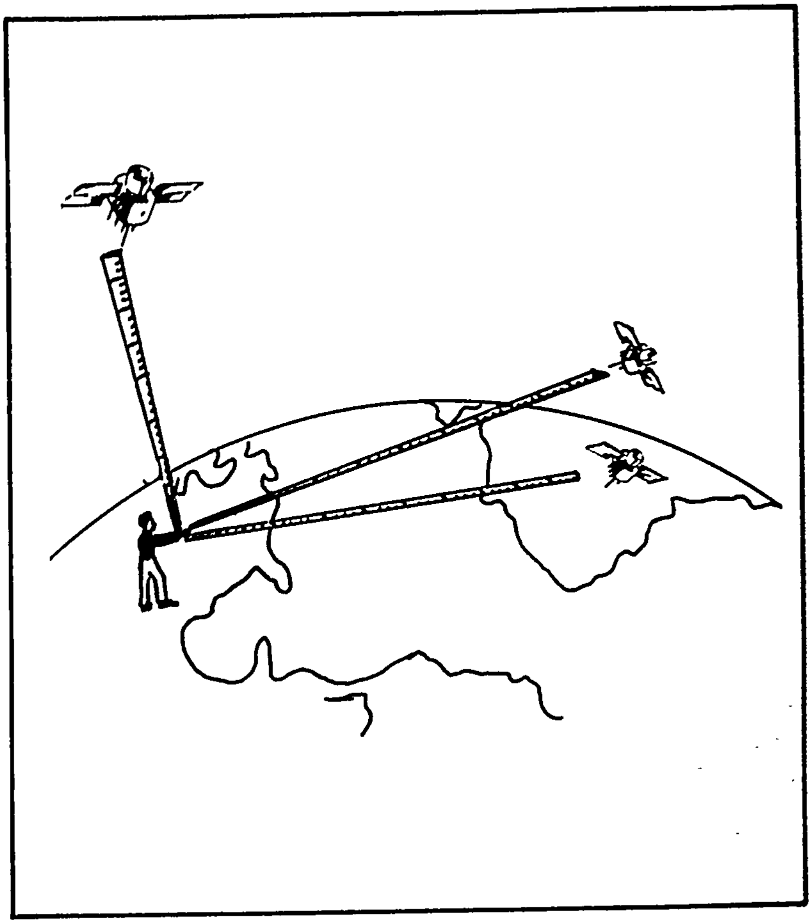
GPS uses a "constellation" of satellites orbiting approximately 10,900 nautical miles above the earth's surface. Each satellite will complete an orbit approximately once every 12 hours.



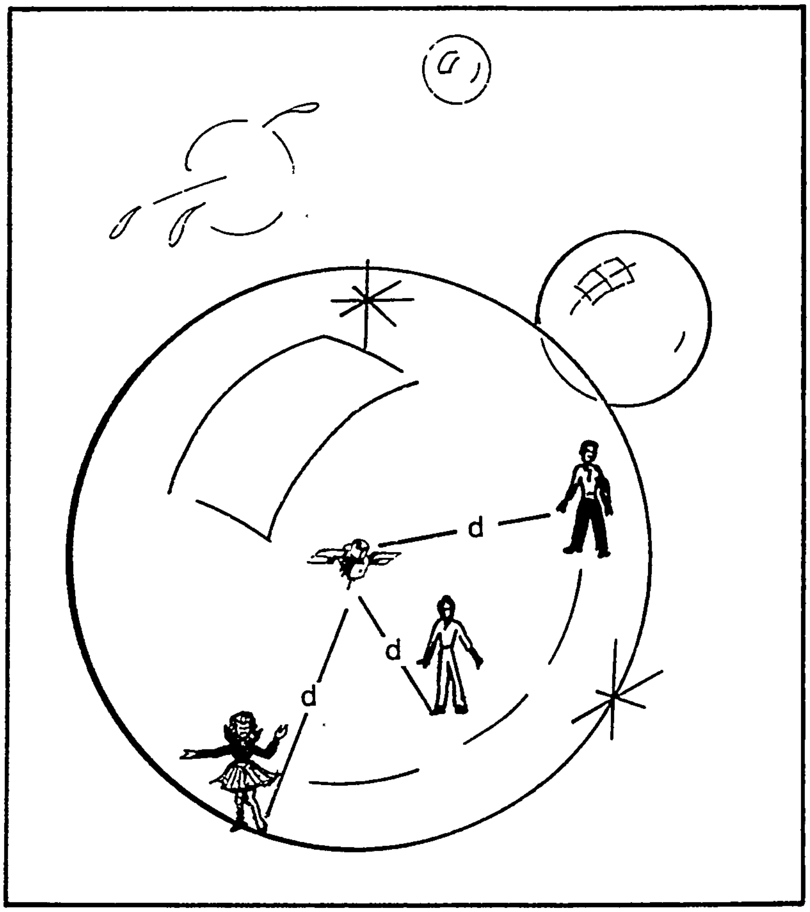
The satellites will not randomly orbit the earth. Current plans call for 18 satellites, three equally spaced around each of six different orbits to give world-wide coverage. There will also be three operating spare satellites in orbit.



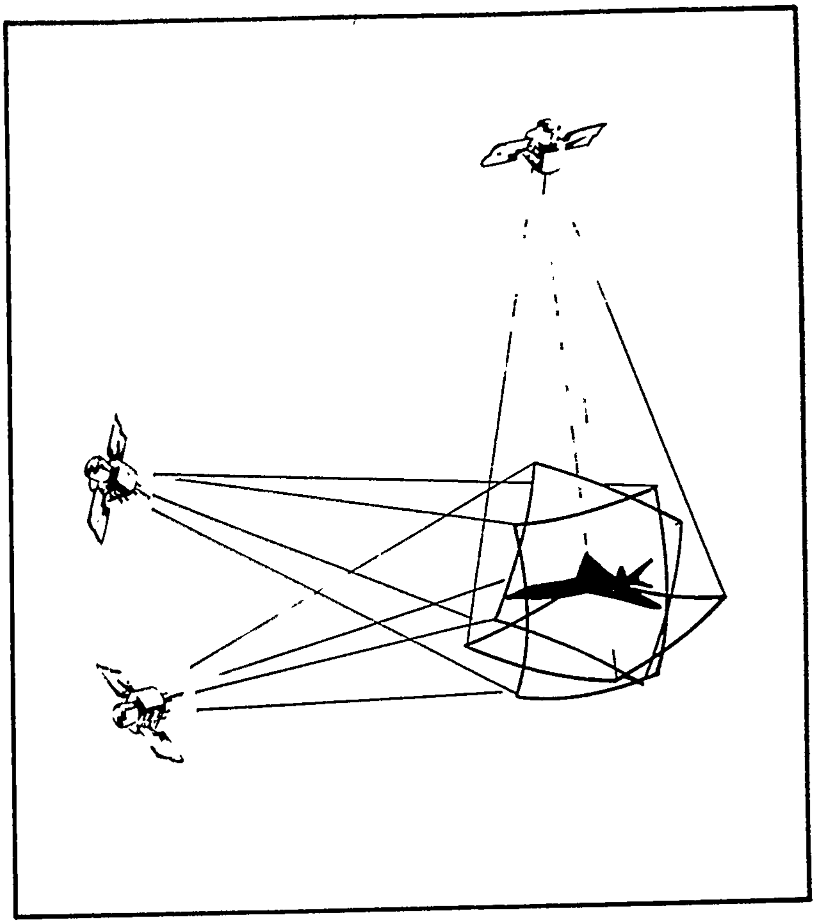
Now, how can we find out where we are by using a constellation of 18 satellites 10,900 miles overhead? It isn't practical to use measuring devices and then triangulate as the ancient Egyptians did.



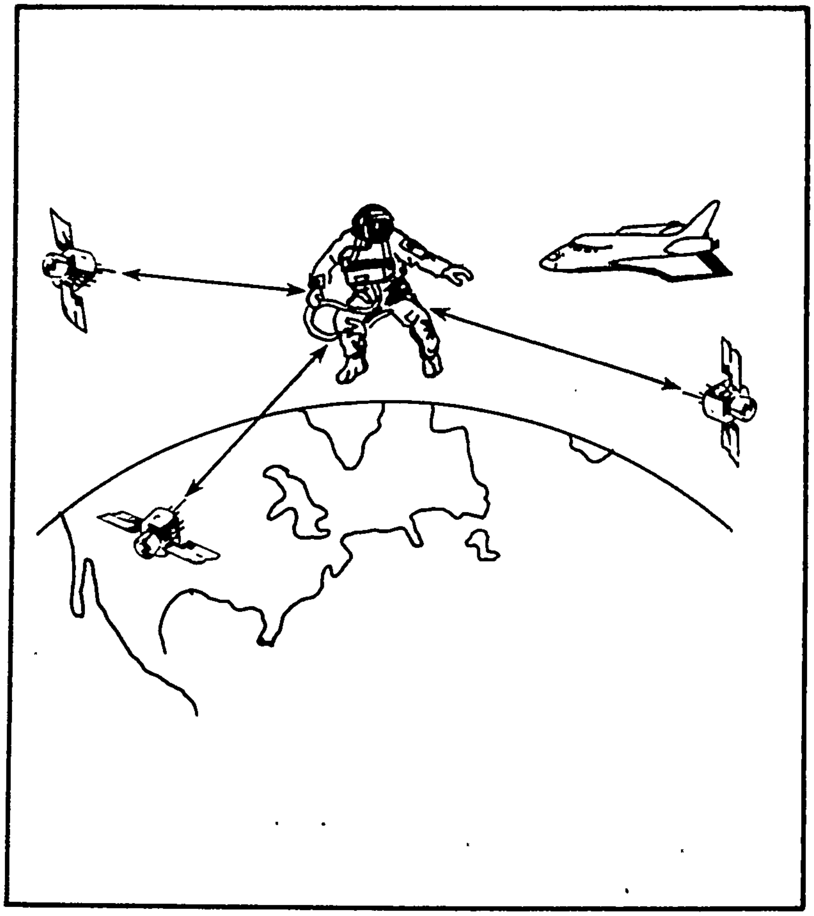
Instead, we use the principle of "ranging." All we have to do is measure the distance from our position on earth to the positions of several satellites.



If we know the location of one satellite and the distance to it, all we can calculate from that is that we are located somewhere on the theoretical surface of a theoretical sphere with its center at the location of the satellite.

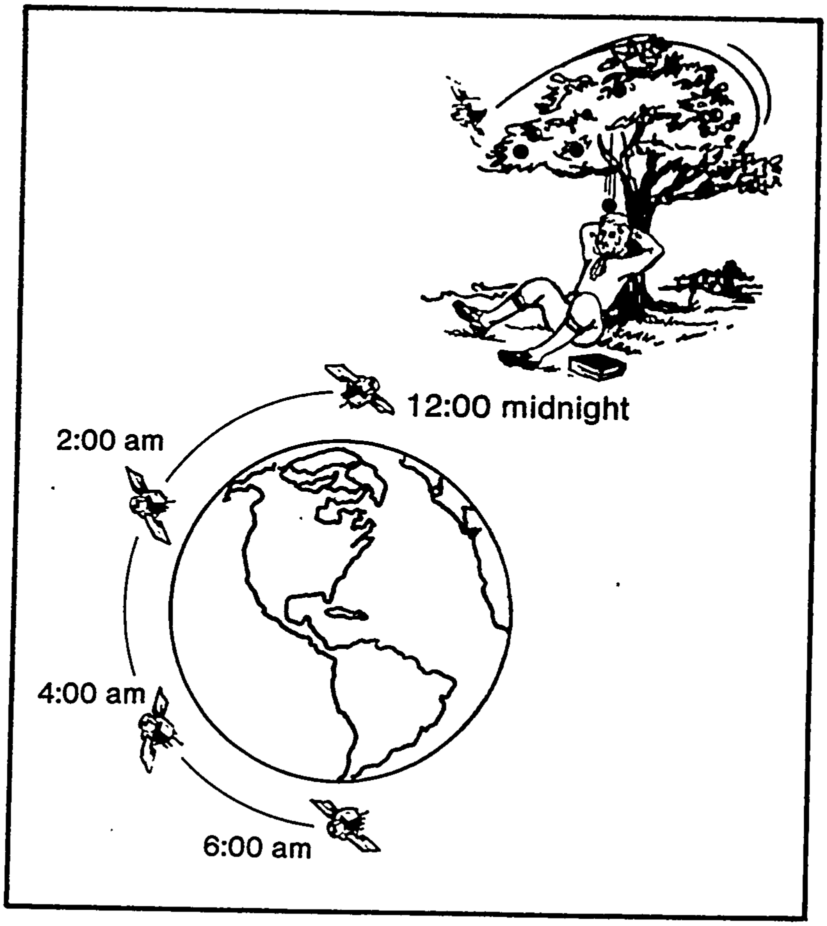


To learn exactly where we are requires that we know the distance to three satellites whose positions we know.

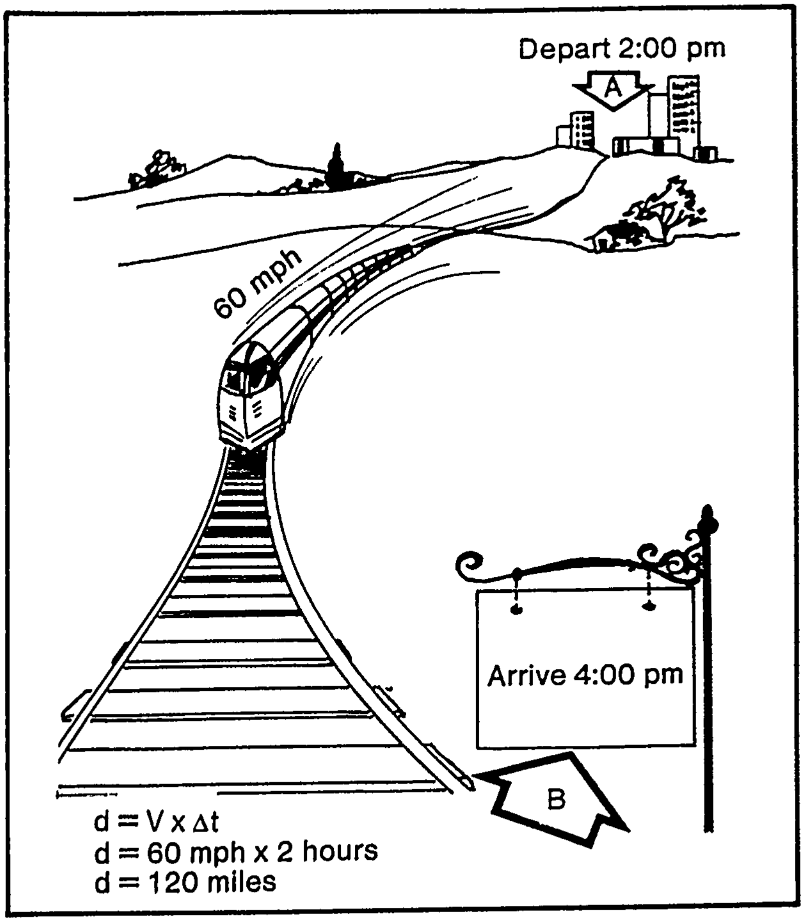


Let's summarize what we know. We can find our position in free space by knowing the position of three satellites and simultaneously measuring the distances from our location to the location of the satellites. We solve for the three unknowns (our position, e.g.; x, y, z) with three range equations.

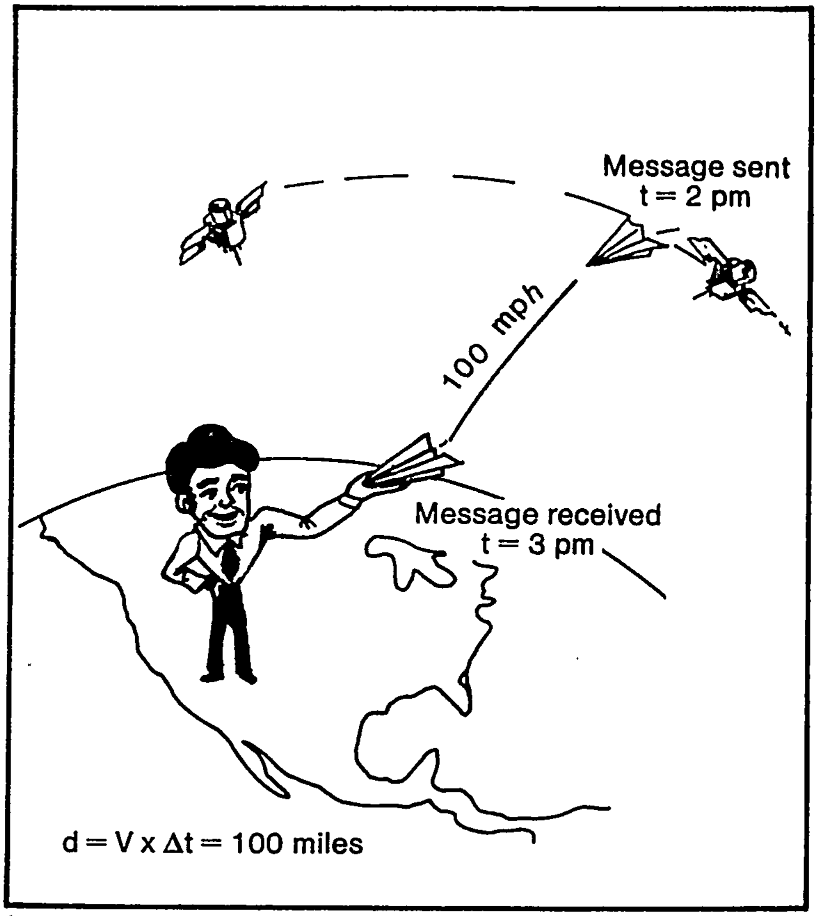
But how can we find the distance to three satellites? And how do we know where they are when we find our range?



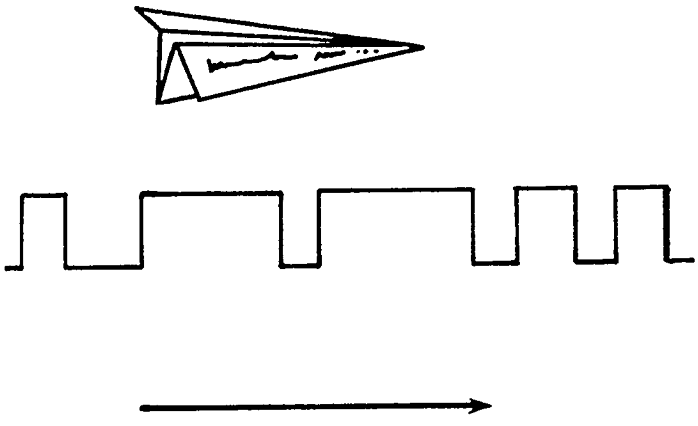
Well, first off, it turns out that it isn't very hard to predict where a satellite will be. Remember Newton? And his law?...a body in motion will continue in motion..., etc. There isn't very much in space to alter the orbits of the satellites once they get going so we can predict quite accurately what their location will be at any given time.



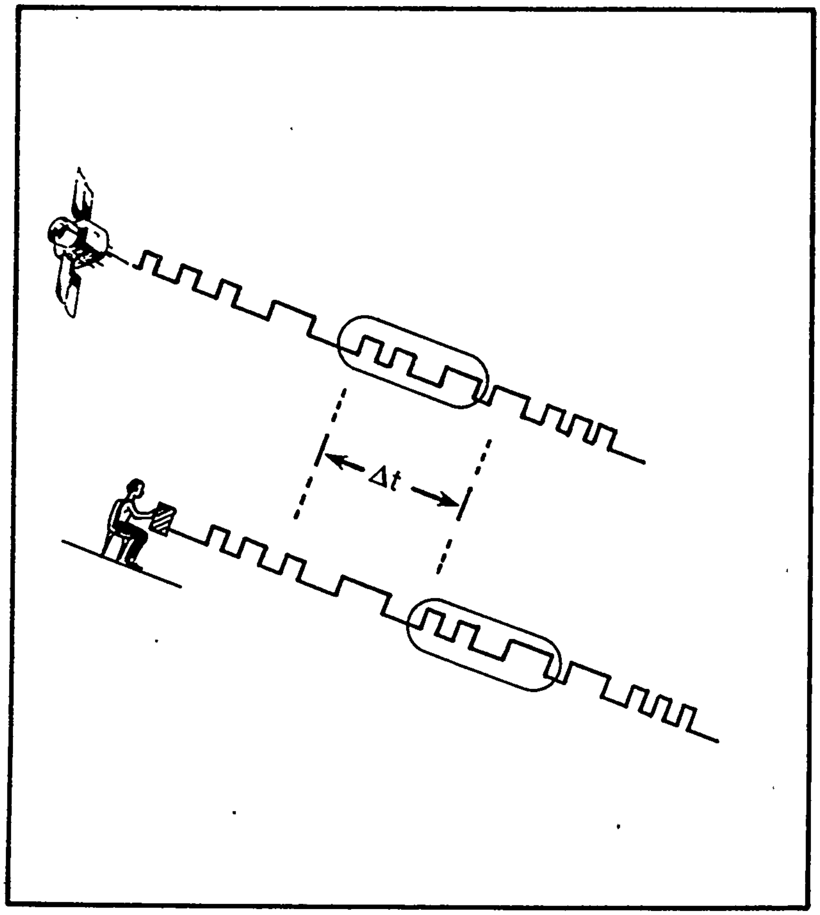
Now the tricky part – how to find the distance to a satellite. We take advantage of the relationship among distance, velocity, and time. If we can send something with a known velocity from point A to point B and measure how long the trip takes, we can figure out the distance.



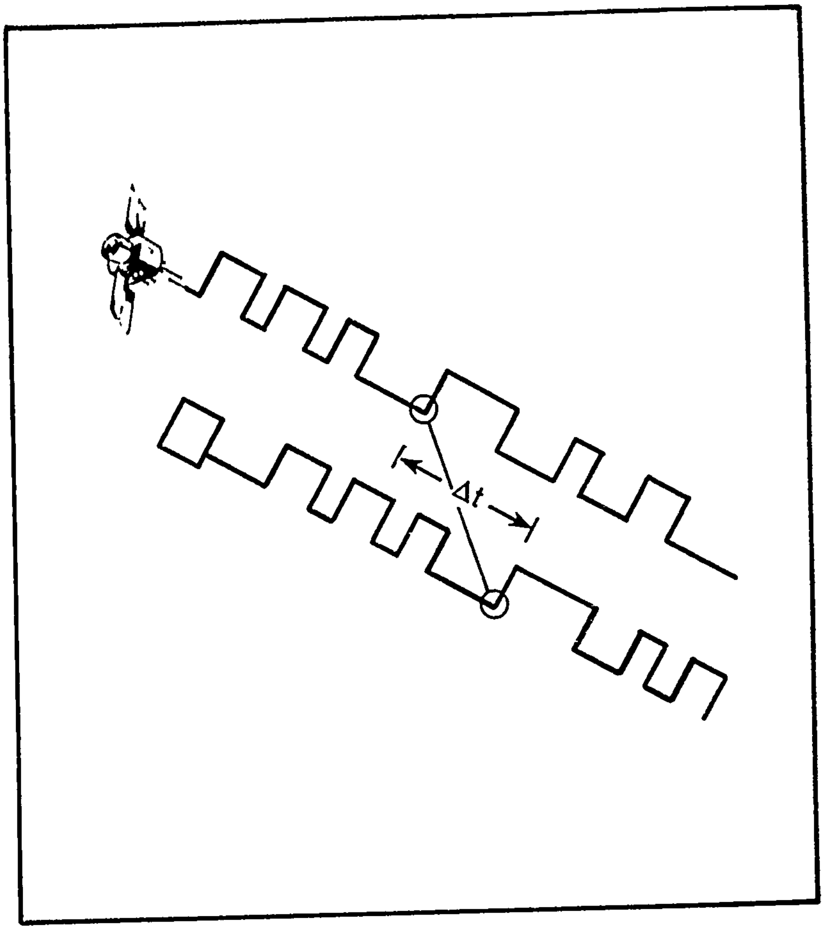
If we could send a message from the satellite to the ground that recorded the time that the message was sent, then, by noting the time the message was received, we could determine how long it took to travel to us...and if we knew the velocity of that message between the satellite and us...we'd be able to calculate the distance! We would have ranged!



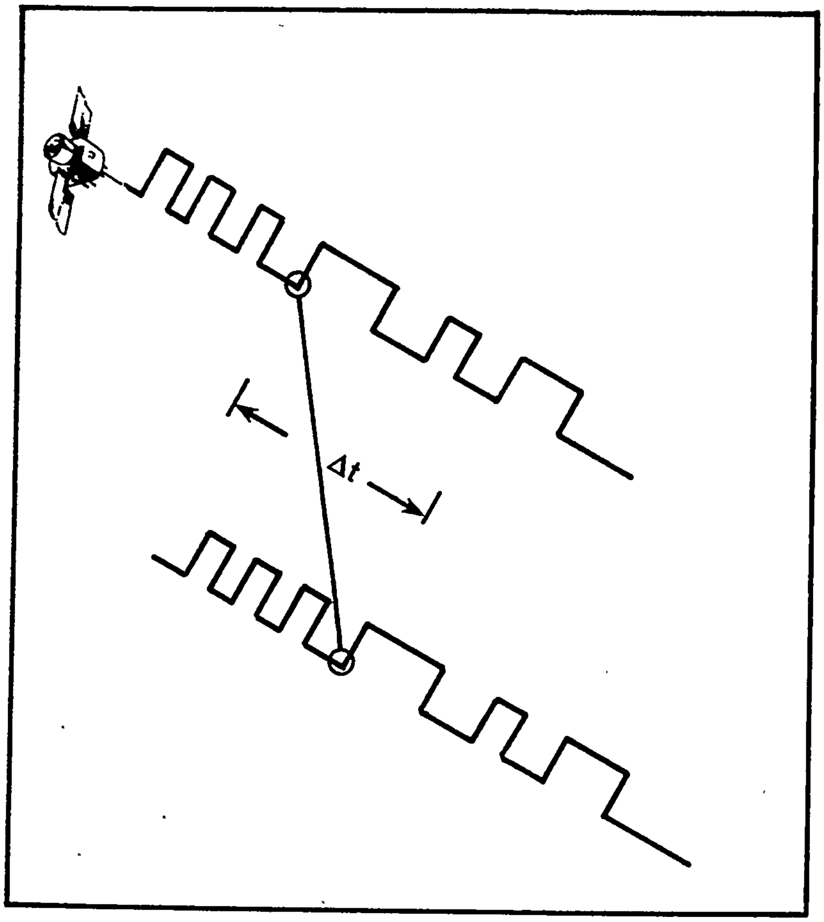
There are ways to learn when a message was sent without its having been specifically stated. The message in GPS is sent by radio waves at a known velocity, the speed of light, which is about 186,000 miles per second, give or take a couple of miles.



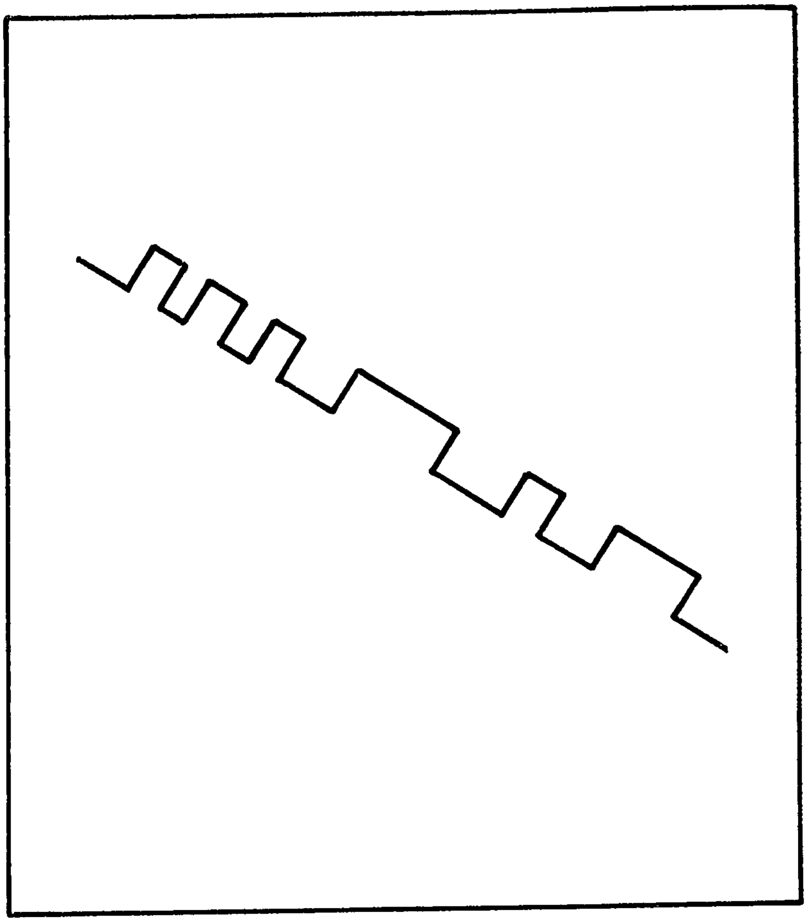
We use a clever technique to learn how long it takes the satellite's signal to reach any receiver. It depends on all satellites and all receivers simultaneously generating an identical series of codes. When a message arrives at our receiver, we match the code accompanying it with the code we have been generating, and we can see how long ago it was sent. A message arriving at our position with the same code we generated half a second ago has taken half a second to reach us.



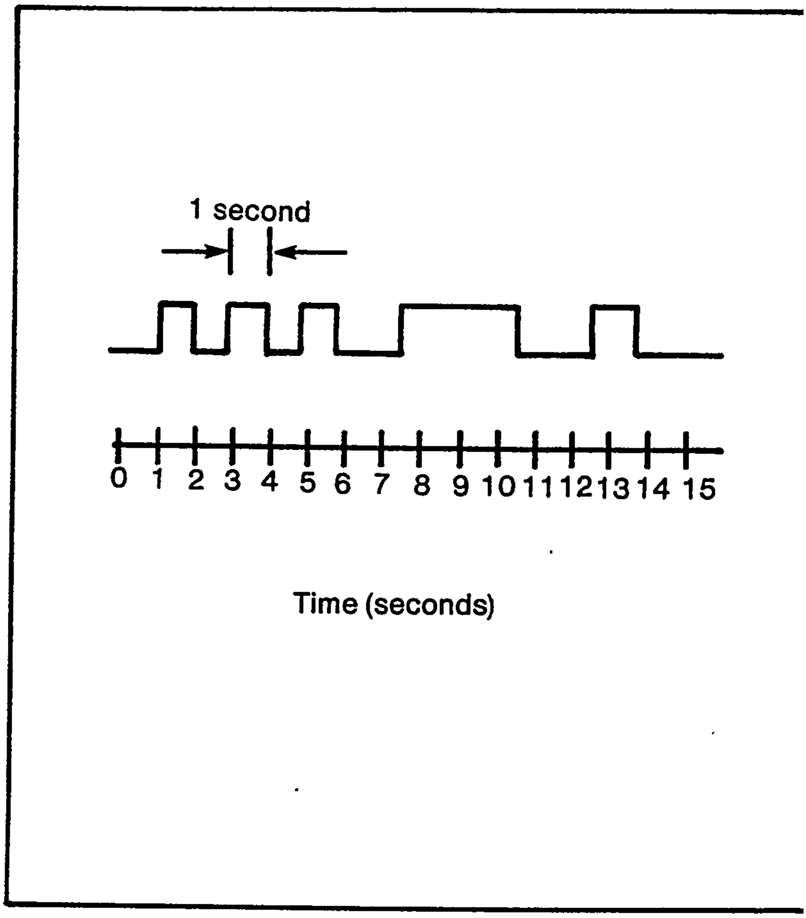
If the satellite and receiver are close together, the time difference will be short.



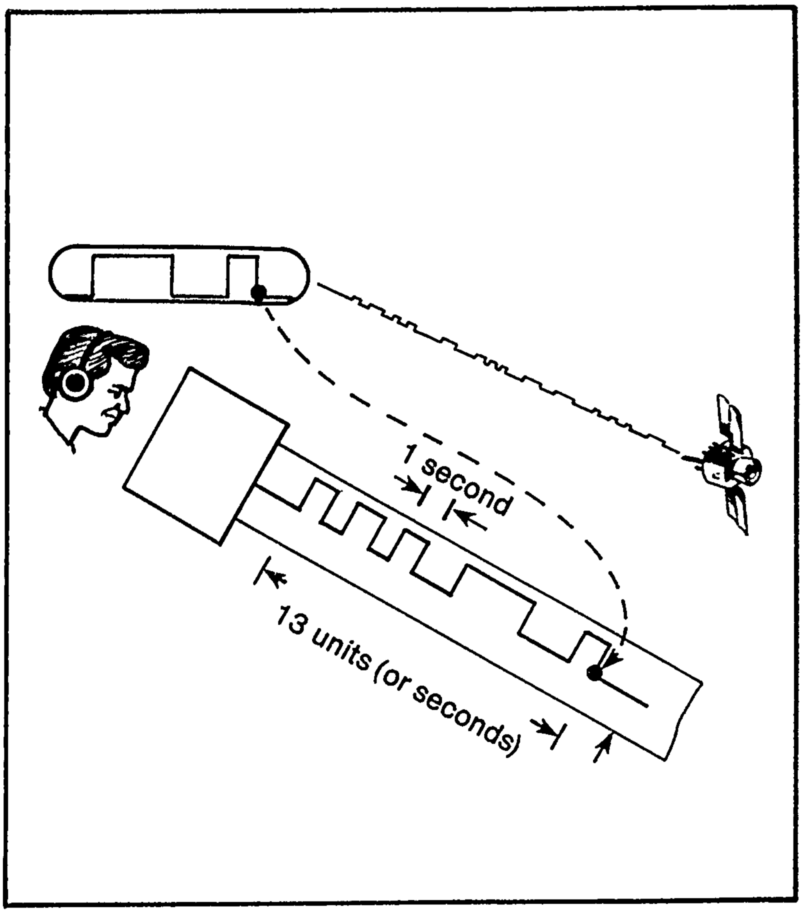
If the satellite and receiver are far apart. the Δt will be longer.



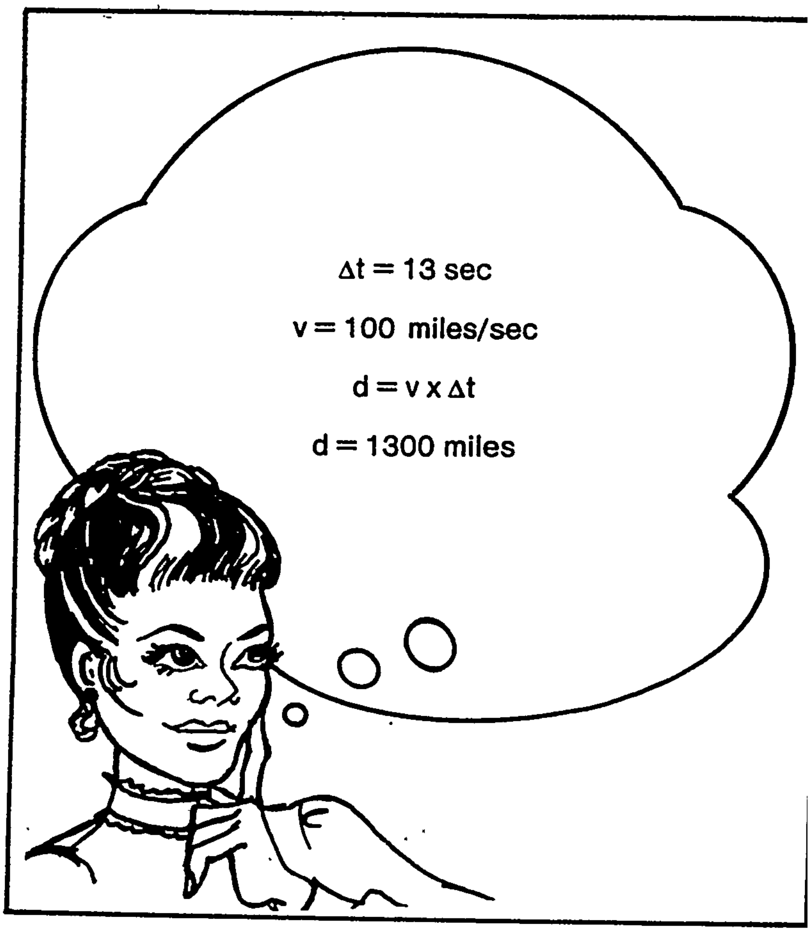
The satellite and receiver must generate the exact same radio signal at exactly the same time. The signals must be in a coded form to facilitate comparing the signals. The signal appears random but in fact is generated according to a complicated set of instructions and repeats itself every seven days. Because of this, the signal is often referred to as "pseudo random."



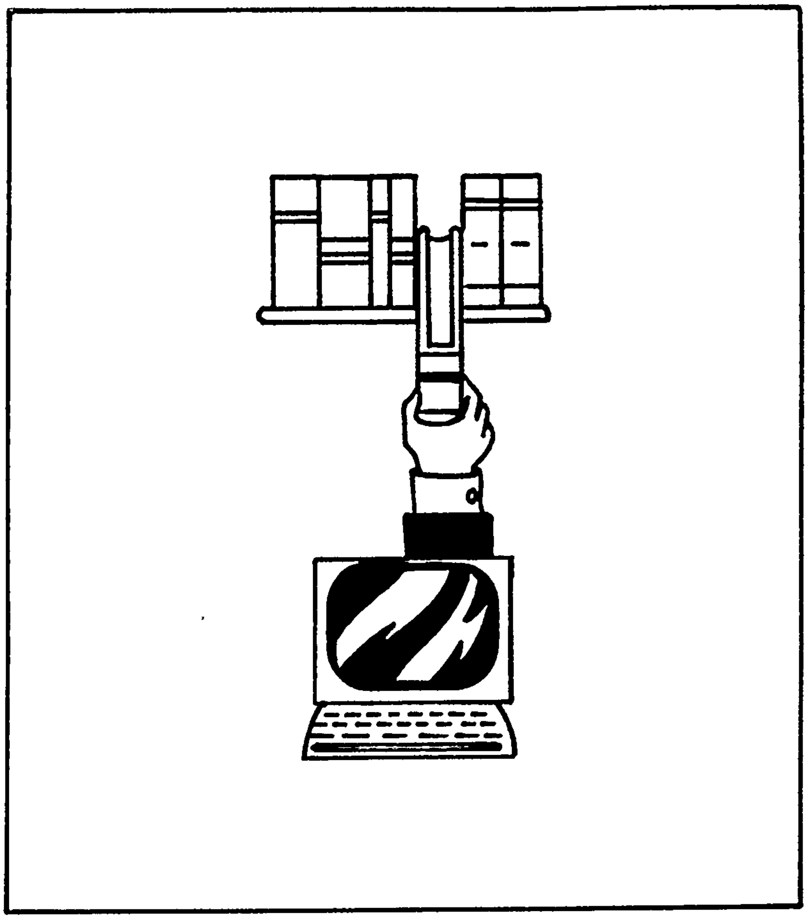
Let's try an example. To keep the numbers simple, we'll assume the speed of the radio signal is "only" 100 miles per second. Our coded signal will consist of on/off (up/down) signals sent in increments (or multiples) of one second.



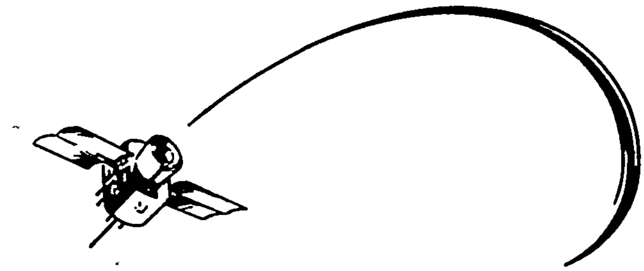
Now, suppose we have a chart recorder plotting out the "pseudo random" code that is simultaneously being generated by the satellite. We listen for the satellite's signal and simply note how long it has been since our chart recorded that same signal. In this example, it took 13 seconds for the signal to travel from the satellite to our receiver.



By knowing that it took 13 seconds for the signal to reach us, we know our distance from the satellite. And if we noted that the time we received the signal was, say 3 hr: 24 min: 17 sec, we can conclude that the signal was sent 13 seconds earlier, or at 3:24:04.



And, because the orbit of the satellite is known, we can look up in a book (or data base) where the satellite was at 3:24:04. Now, just do this with three satellites at once and you know where you are...but that's what we have computers for.



Let's Review

1. We can determine our location in space if we know the location of three satellites and their distances from us.

2. We measure our range (distance) to the satellites by noting how long it takes a radio signal to reach us.

3. We know how long the radio signal takes because we are simultaneously generating the same pseudo random code as the satellite. As we listen to the satellite's signal, we note how long ago we generated the same signal.

4. If we know the time it takes for the signal to reach us, we know the distance because the signal is traveling at the speed of light and $d = v \times \Delta t$.

5. We know the satellite's position when it sent the signal because the satellite follows a known orbit.