SATELLITE COMMUNICATIONS AND GPS

MODULE 5

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Satellite Signal Acquisition, Tracking: GPS Receiver Code and Carrier Tracking, Measurement Errors and Tracking Thresholds, Signal Acquisition, Sequence of Initial Receiver Operations. Use of Digital Processing, Considerations for Indoor Applications.
GPS Applications: Civil Navigation Applications of GNSS, GIS, Government and Military Applications. (Text Book 2)

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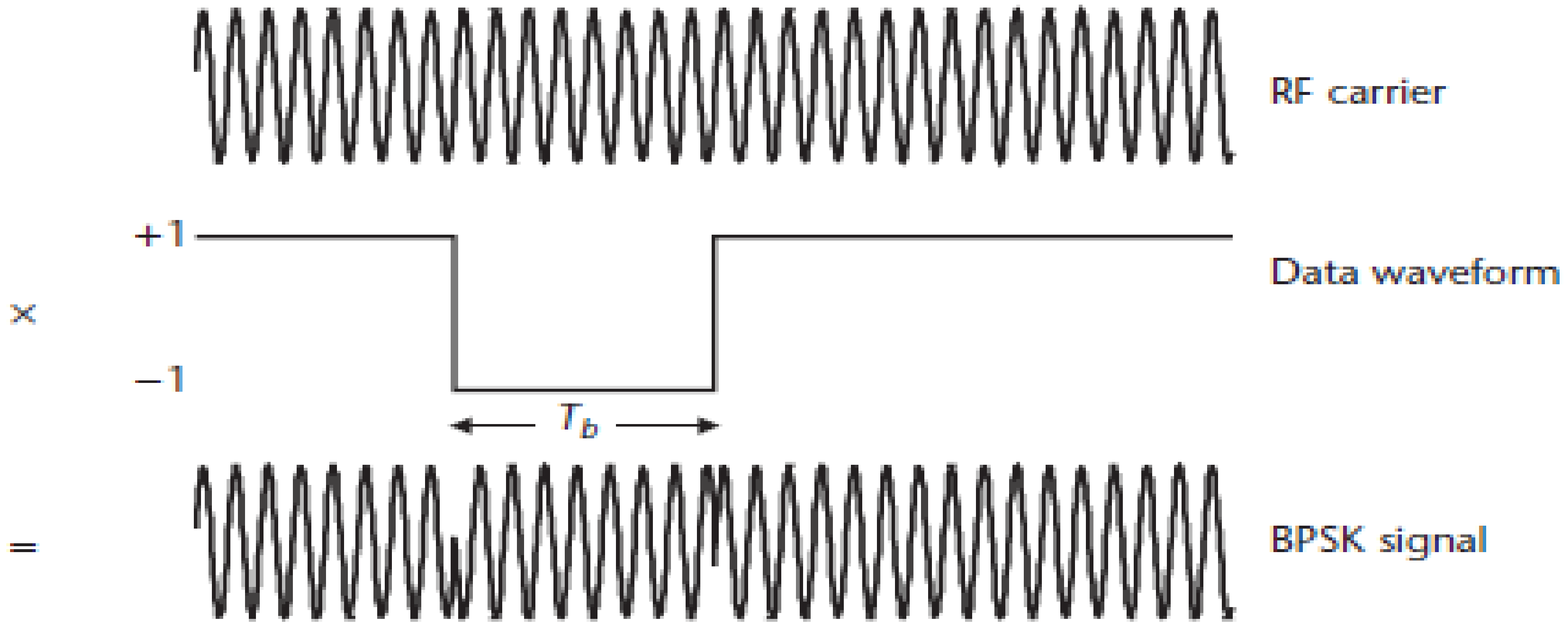

BPSK modulation.

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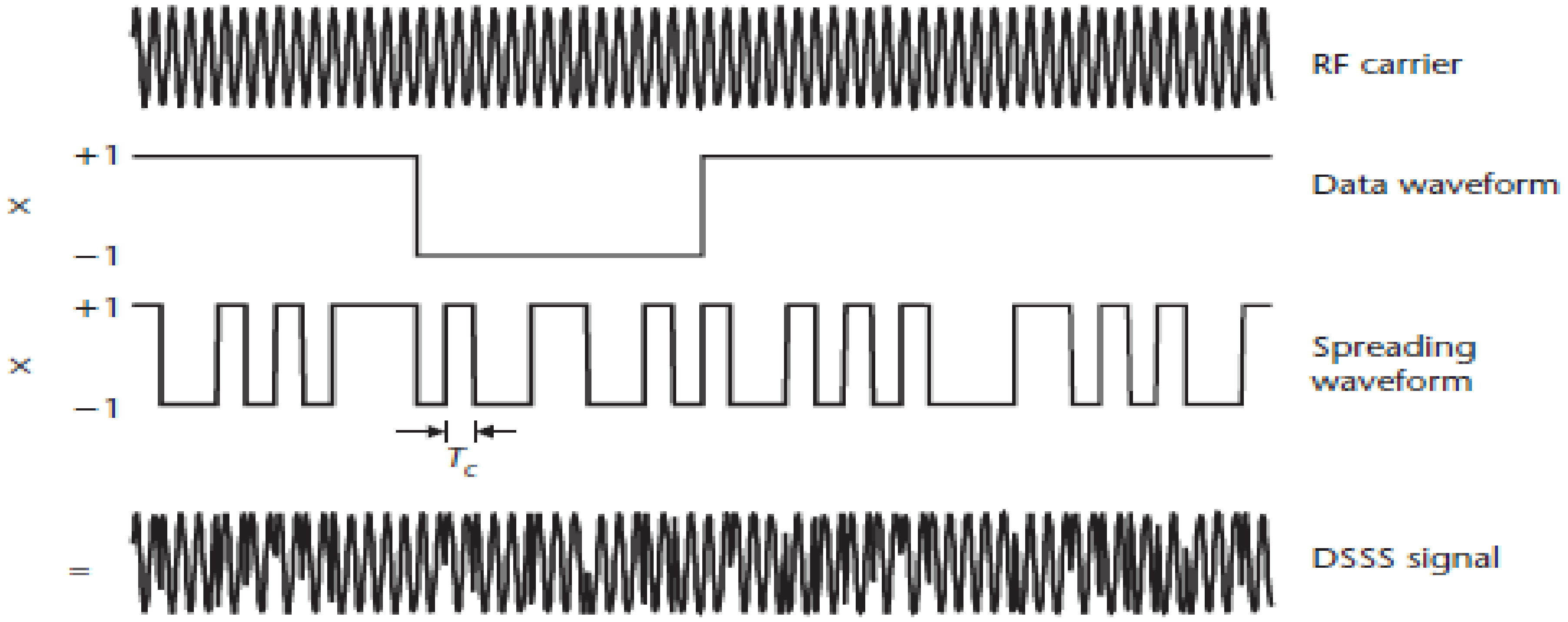

Figure 4.2 DSSS modulation.

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A GPS signal is nothing but the GPS data spread by a spreading PRN code and then modulated using the carrier signal using Binary phase shift keying (BPSK) ->known as Direct sequence spread spectrum (DSSS) .

The data and PRN are represented by bi phase representation(i.e using either the mapping [0, 1]-> [-1, +1] or [0, 1]->[+1, -1]).

For example legacy GPS C/A signal is 50bps data spread by 1024 bit ling 10.23 MHz PRN code(20msec code) and then BPSK modulated by L1 carrier as shown in fig above.

PVT (position, velocity and time) are important.

- It is important to understand that the GPS signal undergoes the Doppler frequency shift induced on the SV(satellite) PRN code due to LOS relative dynamics(movement) between the antenna phase centers of the receiver and the SV (space vehicle).

* The objective of GPS receiver- to keep the prompt phase of its replica code generator at the highest correlation with the desired SV code phase.

* Three correlators used (typ) for tracking – one at the prompt or on time correlation position for carrier tracking, other two placed symmetrically early and late wrt prompt code phase for code tracking.

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Problems in receiver are – if the receiver has not simultaneously tuned its replica carrier matching with the desired SV carrier frequency, signal correlation process in range dimension is greatly attenuated as the GPS receiver has a frequency roll off characteristic.

As a result the receiver does not acquire SV.

If the signal was successfully acquired due to SV code and frequency was successfully replicated during search process, but the receiver loses track of SV frequency it also loses code track.

Hence, in the Doppler frequency dimension GPS receiver achieves carrier matching process by first searching for carrier Doppler frequency of desired SV and then tracks SV carrier Doppler state.

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* Achieved by adjusting nominal carrier frequency of its replica carrier generator to compensate for Doppler induced effect on SV carrier signal due to LOS relative dynamics between receiver and SV.

* Additionally an additional Doppler error effect on carrier loop caused by frequency offset in the receiver's reference oscillator with respect to its specified frequency, which is common to all satellites tracked by receiver, as determined by navigation filter – time bias rate in units of seconds/s.

This error is important in search process.

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- Also it is important to understand that the GPS receiver must detect the SV in the carrier phase dimension by replicating the carrier frequency plus Doppler .
- The GPS signal acquisition and tracking are the two processes that are done at the receiver to identify from which satellite the signal is received and what is the frequency shift in order to track and decode the information in the GPS signal.
- An acquisition method is used to detect the presence of the signal.

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- Once the signal is detected, the necessary parameters must be obtained and passed to a tracking program which adjusts the phase and frequency values of the locally generated signal to received signal frequency and phase.
- In the code or range dimension, the GPS receiver accomplishes the cross-correlation process by first searching for the phase of the desired SV and then tracking the SV code state.
- Thus the GPS signal acquisition and tracking process is a two-dimensional (code and carrier) signal replication process.
- This is done by adjusting the nominal spreading code chip rate of its replica code generator to compensate for the Doppler-induced effect on the SV PRN code due to LOS relative dynamics between the antenna phase centers of the receiver and the SV.

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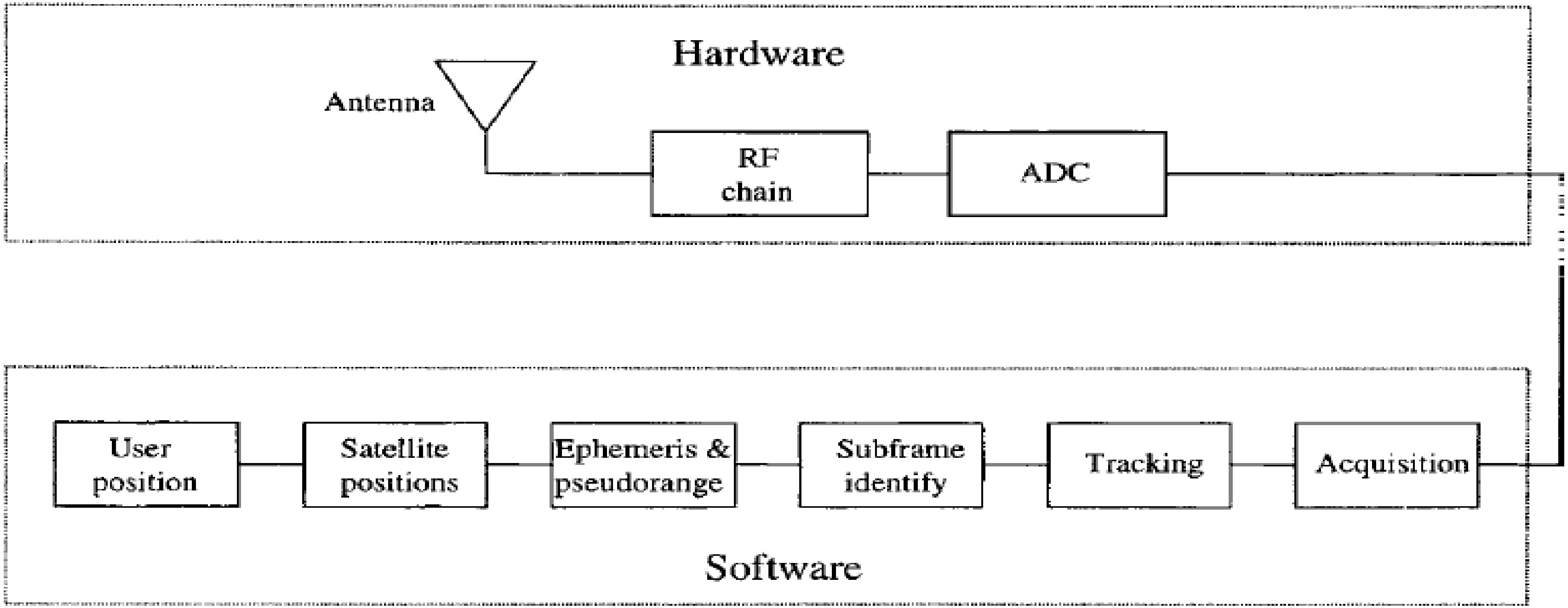

FIGURE 1.1 A fundamental GPS receiver.

Signal Acquisition

GPS signal acquisition is process of identifying(searching) for the presence of the signal from a particular satellite.

This is search is accomplished by generating the replica of the transmitted signal (both carrier and code)at the receiver and comparing with the received signal to acquire the signal.

As the received signal must match in both carrier frequency and code phase , the signal match for success is two dimensional.

The range dimension is associated with the replica code.

The Doppler dimension is associated with the replica carrier.

The initial search process is always a C/A code search for C/A code receivers and usually begins with a C/A code search for P(Y) code receivers also.

The initial C/A code search usually involves replicating all 1,023 C/A code phase states in the range dimension.

If the uncertainty is large in either or both dimensions, the search pattern is correspondingly large, and the expected search time increases.

Some criteria must be established to determine when to terminate the search process for a given SV and select another candidate SV.

Range dimension for C/A code search is bounded by the ambiguity of C/A code to only 1,023 chips total range uncertainty.

For a C/A code search is performed on all 1,023 C/A code phases.

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The code phase is typically searched in increments of 1/2 chip. Each code phase search increment is a code bin.

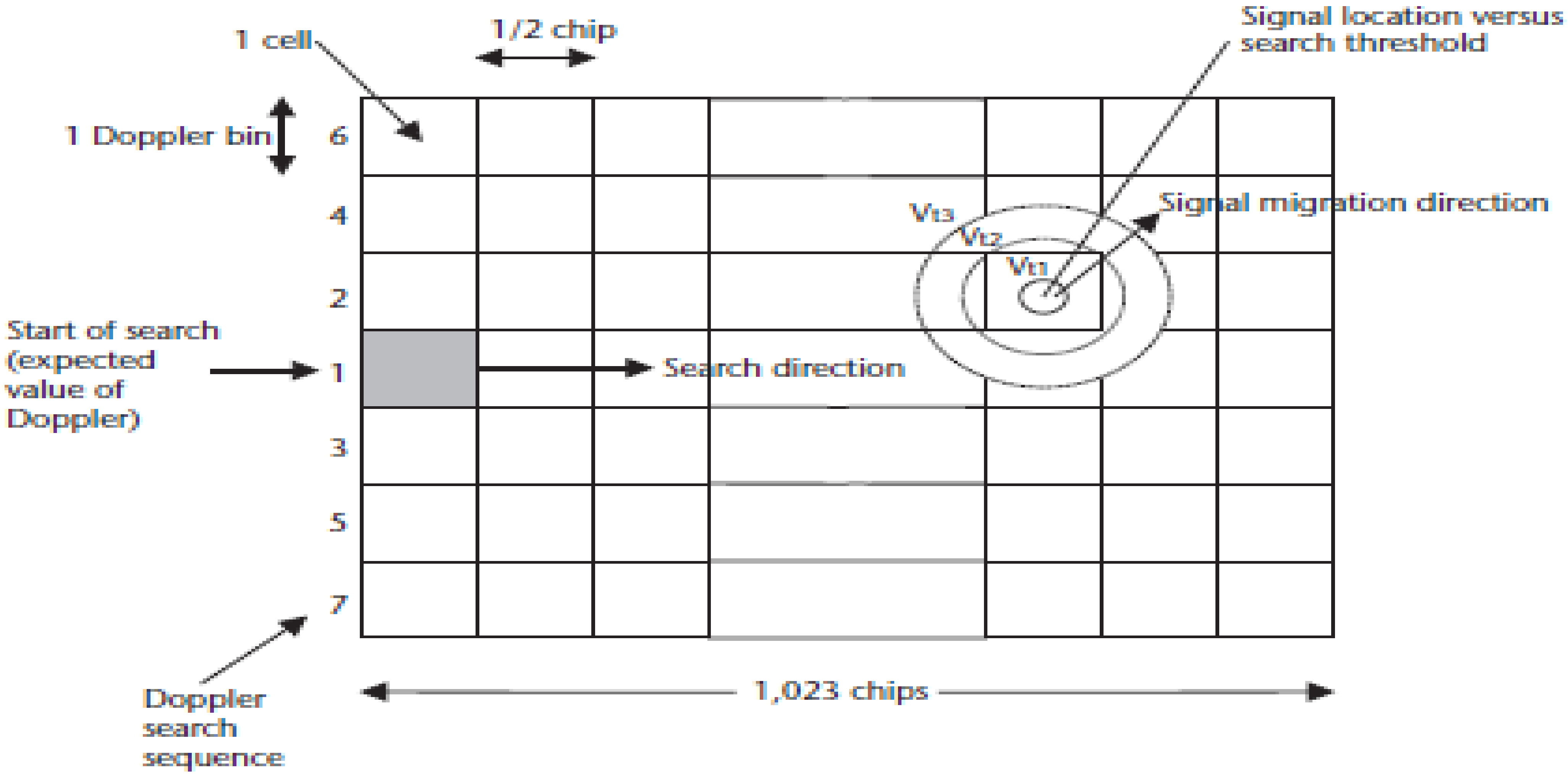
Each Doppler bin is roughly 2/(3*T*) Hz, where *T* is the search dwell time (the longer the dwell time, the smaller the Doppler bin).

The combination of one code bin and one Doppler bin is a cell.

Figure illustrates the two-dimensional search process.

If the Doppler uncertainty is unknown and the SV Doppler cannot be computed from a knowledge of the user position and time plus the SV orbit data, then the maximum user velocity plus just less than 800 m/s maximum SV Doppler (for worst case) for a stationary user must be searched in both directions about zero Doppler.

Figure illustrates the two-dimensional search process.



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The C/No ratio is poor (<20db in indoor)

~~The indoor measurements do not have to be accurate as is expected.~~

In indoor applications, it is often acceptable for the position determination to only be sufficiently accurate to identify the building location.

In indoor GPS applications receivers operate on multipath signals since there is little or no direct GPS signal energy inside most buildings.

User position is estimated by extensive averaging of the code correlations with several weak GPS SV (multipath)signals until there is enough signal processing gain to obtain a set of transmit time measurements from them.

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One common practice for GPS receivers in cellular handsets is -they never close any tracking loops, but rather to dwell on the GPS signals in a controlled (network-aided) search mode long enough to extract enough crude range measurements to provide a snapshot position.

They utilize a reference receiver with a clear view of the sky within the cellular network to provide the information needed to replicate their code phase and to synthesize their Doppler estimate during an extended search dwell.

Applications of GPS -Civil Navigation Applications of GNSS

GNSS- Global Navigation Satellite System

Transit Satellite Navigational System fielded by US navy in earlier 1960s was used to locate nuclear submarines in open ocean. A satellite came into view only every 90 mins (approx.), not useful for aircraft.

The first satellites were launched in late 70s for commercial use to find one's time very accurately knowing its location whenever satellite was visible .

Two dimensional positioning and velocity determination were possible by 3 satellites in view and with four satellites this increase to 3 dimensions. With more satellites daily periods of good navigation (low GDOP) grew and by 1990s full 24 hour coverage was achieved.

DOP- dilution of precision, PDOP factor- position DOP accounts for dilution of position in GPS.

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Widespread use of GPS was possible because of advancements in large scale ICs, and monolithic microwave integrated circuits, dense memory chips and microprocessors.

GPS was first used to derive a ship’s position by the U.S. Navy in the early 1960s and used by nuclear submarines to fix their positions in the open ocean, large commercial vessels also use GPS to find their position and transmit it via a radio link to a control station on the shore. The ship’s position can then be monitored by the Coast Guard or other agency, and dangerous situations can be alarmed and rectified.

The first companies to offer commercial GPS products were Magnavox, Rockwell Collins, Trimble, NovAtel.

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For chipsets main companies were SiRF, Analog Devices, Motorola, Philips, QUALCOMM, Sony, STMicroelectronics, Texas Instruments and Trimble

For modules, the main competitors were Furuno, JRC, Motorola, Sony, GARMIN, THALES and Trimble.

For licensed intellectual property (IP) cores, competitors include QUALCOMM and Trimble.

Marine Navigation

Marine navigation was the first to embrace satellite navigation. Along with radios and radar, a GPS receiver is a piece of standard equipment on any boat operating far from shore

Marine Navigation Contd.

There are about 50 million boats worldwide, 1 million Commercial coastal and inland vessels , more than 90,000 registered merchant vessels worldwide that use GPS service.

The U.S. Coast Guard's system of differential correction broadcasts has been widely accepted. These systems provide accuracy in the 1-3 m range within about 150 miles of a correction beacon which can be a benefit to commercial fishermen in providing the ability to monitor small changes in speed caused by a dragged net's snagging, allowing rapid response to prevent serious damage.

GPS is used in sailboat and yacht racing. For this kind of speed accuracy the combination of SOG(Speed on Ground) with wind speed and speed through the water gives information about set and drift and apparent wind speed and direction which helps the yachting tactician in finding the fastest route to the mark.

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Ferries and cruise lines are also prime candidates for accurate navigation systems. On any major cruise ship one can see a plethora of GPS navigators, electronic chart displays, and other equally impressive electronics

Figure shows a marine navigator with database management capability and graphical display of position and speed information.

ADS/GPS (Automatic Dependent Surveillance) capabilities to all oil carriers and ships derive a carrier or ship's position from GPS and transmit it via a radio link to a control station on the shore.

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Typical GPS marine navigator. (Courtesy of GARMIN.)

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The ship's position can then be monitored by the Coast Guard or other agency, and dangerous situations can be alarmed and rect

Fisheries management uses GPS for accurate position determination and recording to prove or disprove a boundary against false accusations.(i.e Fisherman should not enter in to un authorized places beyond their own boundary, in which case they are treated as intruders and legal action can be taken by the owner country)

GPS can aid in the berthing and docking of large vessels, by means of position, attitude, and heading reference systems. These installations use multiple antennas aboard the vessel to determine an accurate representation of the ship's orientation.

Combined with appropriate reference cartography, this can be an immense aid in the handling of large vessels in close quarters.

GPS is used for accurate positioning in seismic survey and oil exploration activities, as well as in dredging, buoy laying, and maintenance as Dredge operators are paid based on the amount of material they remove from a harbour or shipping channel, so that the accurate measurement of position can optimize the operation, reducing cost and wasted effort. Most of the world’s 6000 oil tankers are now fitted with GPS/ADS equipment.

The availability of GPS and accurate DGPS has proven a boon to the development of precise seismic maps and location of drill sites with respect to identified geologic structure, especially in the offshore case, where exploration teams have to pay significant revenue per day for accurate satellite positioning services. This information is being used in a navigational aid known as an Electronic Chart Display and Information System (ECDIS). A typical ECDIS can cost nearly $100,000 per installation.

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GPS plays an important role in securing the of large container ships as they ply the seas by providing ability to track them continuously and hence protecting against terrorism.

Air Navigation

Most transoceanic airliners rely on INS and GPS.

INS(inertial navigation system) -is a navigation device that uses computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculates the position, the orientation, and the velocity (direction and speed of movement) of a moving object without the need for external references.

Air Navigation Contd.

GPS provides airborne systems with sufficient integrity to perform NPA.

NPA **(non-precision approach**)- is the most common type of instrument approach performed by pilots for the orderly transfer of an aircraft under instrument flight conditions to the beginning of the initial approach to a landing. NPA uses specially certified GPS navigator in place of a VOR(**Very high frequency omni-directional range**) or NDB (A **non-directional (radio) beacon)** receiver.

Figure 12.3 Typical general aviation GPS navigator. (Courtesy of GARMIN.)

Land Navigation

Land navigation opportunities for GPS are enormous. The most promising navigation market for GNSS in terms of sheer size is for land navigation products.

Initial use of GPS technology for land navigation was for fleet tracking applications, and later on it was used for individual vehicle navigation is also which reduced the national annual traffic death rate.

AVLS(Automatic Vehicle Location System) installed in emergency vehicle, and scheduled service fleet dispatch and control are GPS equipped and are used to schedule maintenance and safety enhancement.

In the United States, municipal transport facilities use GPS to announce and display location information to passengers with sight and hearing disabilities. Both audible and visual presentations be provided.

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The incorporation of moving maps and databases into private passenger vehicles will generate more demand for GPS products than all other vehicle markets combined.

Fleet operators can gain significant benefits from more efficient tracking and dispatch operations with integrated navigation and communications facilities.

One such concept is called *geofencing,* where a vehicle's GPS is programmed with a fixed geographical area and alerts the fleet operator whenever the vehicle violates the prescribed "fence".

In 2004 over 4 million vehicles were equipped with GPS receivers communicating via cell phones providing voice or map guidance.

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Use of GPS in ITS(Intelligent Transportation Systems)

These systems are meant to modify traffic flow according to demand and other factors. One way to do this involves the monitoring of the progress of vehicles that are transmitting their position to a central location. Traffic signals or rerouting signs can then be used to respond to situations where a particular *probe* vehicle is not progressing as it should under optimum conditions.

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Another aspect of ITS involves the automatic collection of highway and other tolls and tariffs. This eliminates the need for vehicles to stop at state lines or at toll booths on toll roads and bridges.

- One way to do this is if the position is being reported and appropriate accounting arrangements are made between the tariff-collecting authority and the vehicle's operator. This is most appropriate for commercial operations, but it is not inconceivable that private automobiles could be subject to the same kind of system. It would be possible in early implementation to provide a through lane at toll booths for appropriately equipped vehicles.
- In a potential tariff systems where total road usage could be tracked and taxed rather than just on given roadways.

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- The GPS equipment can be used to find the initial and final locations of the vehicle and accurate distance can be found out to calculate the tax amount.

GNSS in Surveying, Mapping, and Geographical Information System(GIS)

The production of maps and charts and the geo-referencing of data using GPS are natural outgrowths of the accurate and reliable techniques developed for the land-survey market.

Surveying

The huge economic advantage of using GPS in surveying applications drove the development of very sophisticated GPS equipment and tools to predict GPS coverage and derive position with centimeter accuracy.

The value of the GPS technology in the surveying business stems from the availability of absolute positions with respect to a universal coordinate system (WGS-84) and from the fact that they can be determined with a much smaller survey crew.

GNSS in Surveying, Mapping, and Geographical Information System(GIS)

With the aid of GPS device a single surveyor can collect data in the field, where it would take a two- or three-person crew to achieve the same results using some conventional methods.

Collected data can be processed to the required accuracy using inexpensive computing facilities, and the GPS equipment in the field can be used by the surveyor for rough surveys or the location of benchmarks or other features.

Surveying

Huge time and resource advantage led to developments of GPS surveying. Extreme accuracy is possible. A single surveyor can collect data in field instead of 2-3 persons with conventional methods.

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Collected data can be processed to desired accuracy using inexpensive computing facilities. GPS equipment in the field can be used for rough surveying or location of bench marks and other features. A great deal of sophistication has been added to this area. This leads to sophistication of receivers.

Mapping

Extreme accuracy is possible by applying information on satellite positions from data obtained . Aircraft or spacecraft are used to photograph large areas of earth’s surface. Index marks available from ground, provide reference locations on these photographs- used to determine scale and orientation.

GPS can be used to survey these references. By knowing the position of the camera, use of these references can be eliminated.

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Using GPS, this technology augmenting accurate INS has been developed.

Inertial systems have excellent short term stability, can drift over time, needing recalibration. GPS has its inherent absolute referencing capabilities, can provide excellent augmentation to INS. The two can be used together.

The generation of road maps, or any other kind of feature map, is achieved simply by recording a series of positions as a receiver is moved over the area to be mapped. Any degree of post processing necessary to achieve desired accuracy is available.

Specific locations recorded may be annotated with location-specific information, such as street address, elevation, or vegetation type. This type of data collection is particularly useful for the building of data for GIS.

GIS (geographical information systems)

While the market for simple surveying by GPS may well be saturated, the use of GPS as an aid for position-based data collection for geographical information systems (GIS) continues to fuel growth in the market for sophisticated receivers.

Management of natural resources is growing faster. Environmental studies involve the collection of large amounts of position related data, necessitating GIS usage.

GIS applications (or GIS apps) are computer-based tools that allow the user to create interactive queries (user-created searches), store and edit spatial and non-spatial data, analyze spatial information output, and visually share the results of these operations by presenting them as maps.

GIS can be used to manage a distributed inventory such as a utility, municipality or steelyard to locate and identify this inventory quickly and accurately.

- In GIS it is possible to capture position-referenced data in the field using GPS, with a simple handheld computer.
- **Few example of the GIS with GPS are**

➢ **Management of a municipality's streetlights**.

There may be a mix of fluorescent, sodium, mercury, and incandescent lights, with several varieties of each.

The maintenance engineer capable of recognizing the types can be dispatched with a GPS-based data collector to log the location of each type of installation. This information can be loaded into a central database, so that when maintenance is necessary, the appropriate replacements can be ordered, stocked, and dispatched.

➢ In Steel mills

Steel mills store large quantities of product in huge yards, stacked in such a way as to prevent warping. The stacks must be rotated periodically, on a set schedule. Further, there are different types of products that are indistinguishable from one another, except for the record of where each was put. The layout of these yards does not lend itself to physical marking, so accurate GPS can be used to locate each stack and reference its contents to a central database.

Differential Applications and Services

A **Differential Global Positioning System** (**DGPS**) is an enhancement to the Global Positioning System (GPS) which provides improved location accuracy, in the range of operations of each system, from the 15-meter nominal GPS accuracy to about 1–3 cm[in case of the best implementations.

Each DGPS uses a network of fixed ground-based reference stations to broadcast the difference between the positions indicated by the GPS satellite system and known fixed positions. These stations broadcast the difference between the measured satellite and actual (internally computed) pseudoranges pseudoranges(known as differential corrections), to specific locations using one of the means of communications, such as Internet, cellular, VLF-HF-microwave radios, satellite links, and receiver stations may correct their pseudoranges by the same amount.

The digital correction signal is typically broadcast locally over ground-based transmitters of shorter range.

FAA's(Federal Aviation Administration) WAAS(Wide Area Augmentation System) is ground based stations that send differential corrections.

NDGPS-Nationwide GPS of the U.S. Coast Guard provides correction signals In addition to the freely provided satellite transmitted corrections, broadcast over an existing network of non directional beacon transmitters around the coast of the United States and in the Great Lakes. This NDGPS system is being expanded to cover all of the U.S. landmass so it can be used by vessels in all inland waterways and by railroads for positive train control. These broadcasts are provided free of charge, but require the purchase of specialized receivers and demodulators to decode the correction signals, sent at 283–325 kHz.

Attitude Determination Systems:

Used for attitude determination of host vehicles. Ex: pointing long artillery gun barrel, finding an aircraft’s attitude, outputting ship’s heading and roll, and particularly determining spacecraft attitude.

All these units use multiple antennas for 3-D solutions or at least a linear array to determine a pointing vector.

Today integrations between GPS receivers and inertial sensors are with software is in great demand.

A typical space application of GPS attitude determination aboard NASA’s Thermosphere, Ionosphere, Mesosphere energetics and dynamics aircraft (TIMED). TIMED mission studied the influences of sun and humans on the least explored and understood portions of

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earth’s atmosphere, the mesosphere and lower thermosphere / ionosphere.

Precision Approach Aircraft Landing Systems

Most instrument approaches carried out by commercial air carriers are precision approaches. Unlike NPA(non precision approaches). These procedures give glideslope guidance to the aircraft on approach. The lack of signal integrity precludes the use of unaided GPS for demanding aviation applications. These applications require the use of either code differential or kinematic carrier-phase tracking techniques which give higher accyracy. Precision landing systems require not only better integrity (warnings of system failure or inaccuracy within 6 seconds or less) but also better accuracy than is provided by the basic GPS service.

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The FAA's WAAS provides this warning, and sufficient accuracy to perform close to category I precision landing requirements.

This allows about 90% of the airline approaches currently performed to use a GPS approach augmented in this way.

Category II and III approaches, involving lower weather minima, also require improved accuracy and integrity warnings, which will be provided by airport-based differential stations broadcasting GPS corrections directly to the aircraft on approach (i.e., LAAS).