ND DEPT OF TRANSPORTATION
SURVEYS & PHOTOGRAMMETRY

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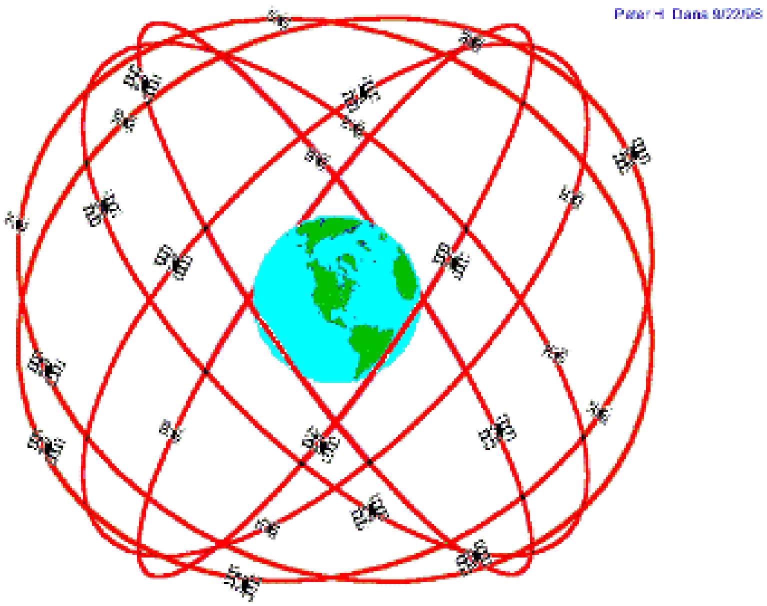
TRAINING MANUAL
FOR



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

GPS Operations

NOTE: This manual provides a written account of how certain activities are performed and is designed to guide and assist staff members in performing their functions.
When appropriate, there may be deviations from these written procedures due to changes in personnel, policies, interpretation, law, experimentation with different systems, or simply evolution of the process itself.

This manual may be changed at any time. Staff members are encouraged to review this manual periodically and suggest changes in the manual to keep the manual current and to minimize differences between the manual and actual practices.

INDEX

Chapter 1

How Does GPS Work?

How the Global Positioning System works is, conceptually, really very simple. All GPS is, is a distance (ranging) system. This means that the only thing that the user is trying to do is determine how far they are from any given satellite. There is no inherent vector information, which implies azimuth (compass direction) and elevation, in the GPS signal. All that the GPS satellite does is shoot out a signal in all directions, although there is a preferential orientation toward the Earth.

In essence, the GPS operates on the principle of trilateration. In trilateration, the position of an unknown point is determined by measuring the lengths of the sides of a triangle between the unknown point and two or more known points (i.e., the satellites). This is opposed to the more commonly understood triangulation, where a position is determined by taking angular bearings from two points a known distance apart and computing the unknown point's position from the resultant triangle.

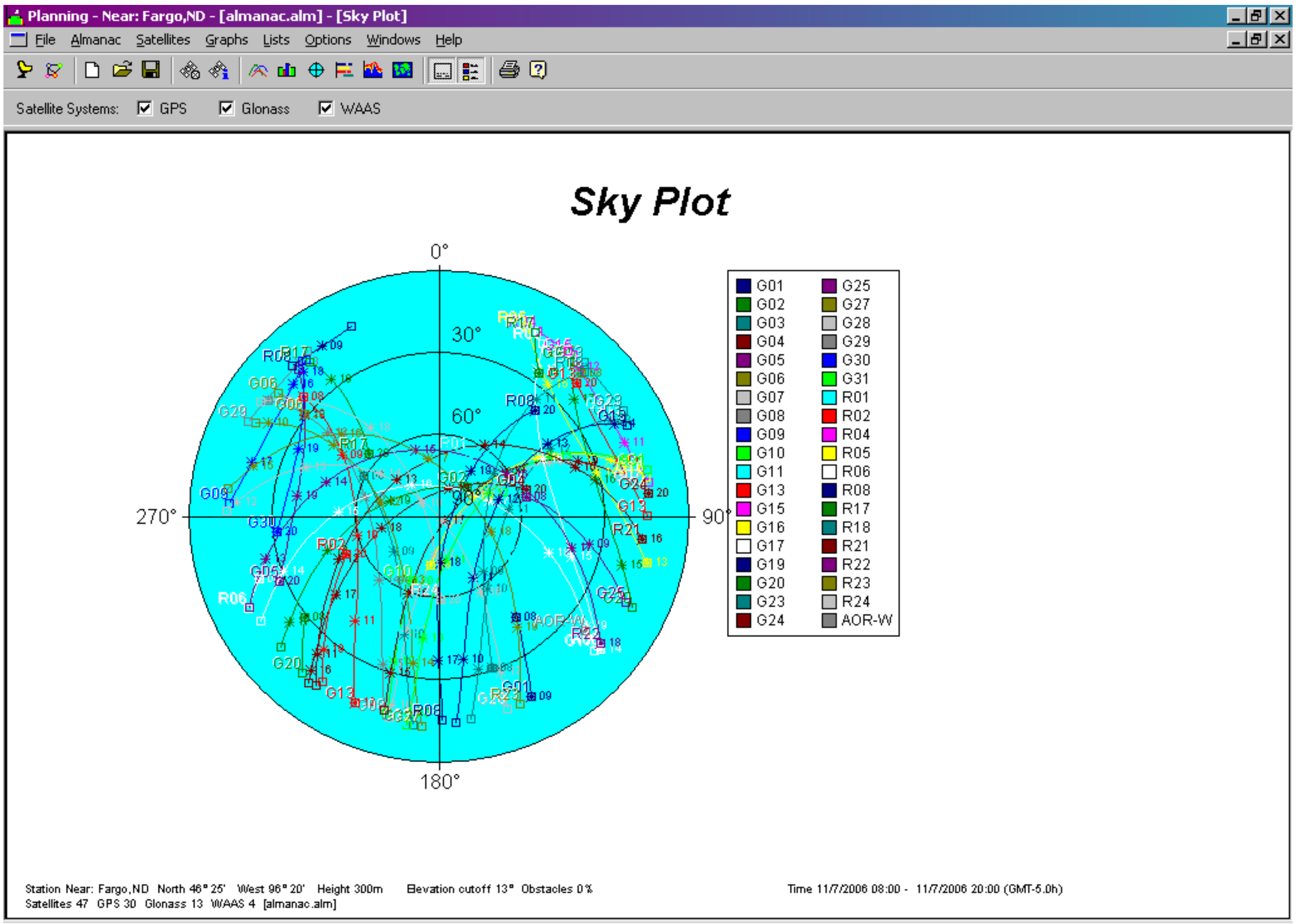
The satellites do this by transmitting a radio signal code that is unique to each satellite. Receivers on the ground passively receive each visible satellite's radio signal and measures the time that it takes for the signal to travel to the receiver. Distance is then a simple matter of computing D = V x T, or deriving distance (D) by multiplying the time in transit (T) of the signal by the velocity of transit (V). This is the old "if a car travels a 60 mph, how far will it travel in two hours?" Since radio waves travel at the speed of light, which is essentially fixed at 300,000 kilometers per second, the velocity is a given. Therefore, the only thing needed by the user to calculate distance from any given satellite is a measurement of the time it took for a radio signal to travel from the satellite to the receiver.

Where Are The Satellites?

It turns out that just knowing how far away you are from the requisite four satellites isn't enough. The ranges to the satellites only tell you where *you are relative to the satellites.* But where are the satellites? It is also necessary to know *where* each satellite is in space.

Fortunately, that's not too tough. In the first place, the military is very careful about where it sticks it very expensive space hardware. Once in place in space, the satellites' orbits tend to be very stable through time because they are far above virtually all of the atmosphere and the drag that it can induce. Variations in orbits that are due to gravitational forces are fairly easy to predict and compensate for. To compensate for the inevitable unpredictable perturbations in the satellites' orbits, they are constantly monitored from the ground. Corrections for any orbital variations that are identified are quickly uploaded from ground antennas to the satellites which then send the information back down to each receiver that's tuned in to them. This satellite position and orbital information is called the *"Ephemeris,"* or, as plural, *"Ephemerides."* (Orbital position is constantly changing, thus the term, based on the word "ephemeral," meaning lasting only a short time.)

The ephemeris is part of the Navigation/System data message (the *"NAV-msg")* that is also superimposed on the L1 and L2 carriers, in a sense acting as a modulation of the modulation that we've already talked about. Finally, in addition to the corrected satellite orbital and position data (the ephemeris data), the NAV-msg also carries a correction for any clock bias, or error in the atomic clocks, on board the satellites so that the receivers n the ground can compensate for these errors.



GPS Surveying

GPS *Surveying* has a special meaning. By implication, surveying means precision positioning' performed by highly trained professionals who are certified to produce legally defendable data. This can include both GPS and traditional surveying techniques. Examples of this kind of data collection might include property lines or construction surveying. The key here is that their positional data must be *legally defensible.*

Surveyors are, therefore, extremely concerned with reliability and accuracy. Consequently, surveyors "go the extra mile" when acquiring positional data by whatever method they choose to use, be it by traditional transit-and-rod (or, perhaps more accuately, theodolite and total station), or by GPS surveying.

Surveying, like mapping, is also undergoing a revolution because of GPS. GPS can survey points in minutes that conventional surveys might require hours or even days to perform. High-end GPS receivers can result in positions within millimeters of truth. But such accuracy comes at a price.

What's So Special About GPS Heights?

Heights, as measured by GPS, are of particular concern as they are not what we ordinarily think of when we think of elevation. GPS heights are defined with respect to the ellipsoid and not to the geoidal surface, or MSL (Mean Sea Level), which is what we use in ordinary day-to-day life. The height of the surface of the infinitely lumpy actual surface of the Earth above (or occasionally below) sea level is referred to as the **Orthometric Height,** or the height orthogonal ("square-to") to the geoidal surface, regardless of which way that surface happens to be "tilting." As we'll see in a moment, the two ways of measuring height are not always easily converted from one to another.

It is important to note that GPS heights tend not to be as accurate as the GPS horizontal positions. This is principally because the satellite geometry is essentially one-half the optimal configuration since the Earth itself blocks visibility to any satellites below (with the exception of pseudolites for aviation). Consequently, as a **rule of thumb, potential vertical error for any GPS position will be around two times greater than the horizontal error for that same position.**

FIGURES OF THE EARTH

Three Figures of the Earth. Before any type of measurement can take place, the surface on which we measure must be defined. Generally, we can assume the following three figures of the earth: **Topographic, mathematic (Ellipsoid), and Geoid.**

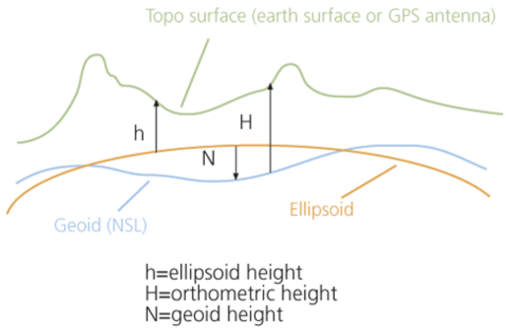
a. Topographic. The surface most apparent is the actual topographic surface of the earth. This includes the mountains, valleys, and other continental and oceanic forms. The surveyor makes the actual measurements on these surfaces, but because of the irregularities of the land, this figure is not suitable for mathematical computations. This surface generally concerns the topographer and the hydrographer but interests the geodesist only with regard to the effect of the terrain features on gravity.

b. Ellipsoid.. The shape of the earth is more precisely represented mathematically by an ellipsoid of revolution, which is made by rotating an ellipse around its minor axis. The radius of the equator usually designates the size of an ellipsoid. The radius is called the
Semi-major axis. The shape of the ellipsoid is given by a flattening, which indicates how
well an ellipsoid approaches the shape of a sphere

c. Geoid. In geodesy, precise computations are made by using an ellipsoid. Unfortunately, measurements made on the earth's surface are not made on a mathematical ellipsoid. The surface is called a geoid.

a. General. The geoid is the surface which the ocean waters of the earth would conform to if they were free to adjust to the forces acting on them. The ocean waters would conform to the surface under the continents if allowed to flow freely through sea-level canals. The forces acting on the oceans include the actual attraction of the earth's mass, attractions due to density differences in the earth's crust, and centrifugal force due to the earth's rotation. The component of centrifugal force opposing the attraction of gravity is greater at the equator than near the poles. Since terrain features such as mountains, valleys, and ocean islands exert gravity forces, they also affect the shape of the geoid. The geoid can also be defined as the actual shape of a surface at which the gravity potential is the same. While this surface is smoother than the topographic surface, the geoid still has bumps and hollows.
b. Characteristics. There are two very important characteristics of the geoid. First, the gravity potential in the geoid is the same everywhere, and the direction of gravity is perpendicular to the geoid. Second, whenever you use an optical instrument with level bubbles, **properly adjusted, the vertical axis of the instrument should coincide with the direction of gravity and is, therefore, perpendicular to the geoid**. The second factor is very important because the attraction of gravity is shown by the direction of the plumb lines.
c. Deflection of the Vertical. Since the ellipsoid is a regular surface and the geoid is irregular, the two surfaces do not coincide. However, they do intersect, forming an angle between the two surfaces. Geometry has taught us that the angle between the two surfaces is also the angle formed between the perpendicular to the ellipsoid and the geoid plumb line. This angle is called the *deflection of the vertical*. The word *normal* is sometimes used to describe the perpendicular to the ellipsoid and the

geoid since a normal is a line perpendicular to the tangent at a curve. In less precise language, this is known as perpendicular to a curve.
d. Separations. The separations between the geoid and the ellipsoid are called undulations of the geoid, geoid separations, or geoid heights. The geoid height reveals the extent to which an ellipsoid fits the geoid and thus helps to determine the best fitting ellipsoid.



GPS Operations

Almanacs

All of this discussion about planning begs two questions: “How does the planning software *know* what satellites will be where and when?” and “How do the receivers know *what* satellites to look for when they’re turned on in the field?” Both of these questions are answered through the use of *“Almanacs”* which are libraries of satellite orbit data such as rise and set times, angles of elevation, positions in space, etc.
Almanac data are periodically sent up to each of the satellites on an as-needed basis by the Control Segment and are good for 60 days. Almanacs can be downloaded directly from the satellites by the receiver. This is done automatically whenever the unit collects data for extended periods of time. It takes approximately 12.5 minutes of continuous and unbroken lock on a satellite to complete the transmission, although in actuality, it often takes somewhat more than that because it never seems to fail that a critical satellite moves out of view during the download process, necessitating a restart. These operations are all transparent to the user. Most receivers automatically update the internal almanac whenever they collect a new one, although a few require some form of initialization to let them know that a new almanac is available. Almanacs can also be downloaded to a PC from any number of sources such as the U.S. Coast Guard, the National Geodetic Survey, and numerous other private and public bulletin board servers. The PC project planning software will then use that information to make its predictions. The updated almanac can also be downloaded from the PC to the receiver so that, upon going into the field, the receiver can immediately know what satellites to begin looking for when it’s turned on. The opposite is also true. An almanac acquired by a receiver in the field can be downloaded to a PC for use in the mission planning software. Most programs will alert the user when a new almanac is required.

Ephemeris-A GPS ephemeris is the predictions of current satellite positions. Accurate GPS planning is only accomplished when a current ephemeris is used for the GPS planning.

Current ephemeris can be obtain by the following methods:

1. Downloading the ephemeris from the internet
2. Observing the satellites for a minimum of 15 minutes and downloading from the receiver.

Trimble:
http://www.trimble.com/gpsdataresources.html

The above link provides information and downloads to obtain a current ephemeris almanac.

Satellite Geometry

A minimum of four satellites are required to survey with GPS. A minimum of five satellites is recommended. The configuration of the visible satellites the receiver is able to track in relation to each other will make a significant difference in the data that is being collected. Satellite geometry is expressed as a numeric value known as Dilution of Precision (DOP). Good satellite geometry will have small DOP values while poor satellite geometry will have large DOP values. As a guideline DOP values of six or lower are required for NDDOT GPS surveys. The ideal satellite geometry is one which has the visible satellites distributed throughout the sky. Good satellite geometry will yield a higher precision.

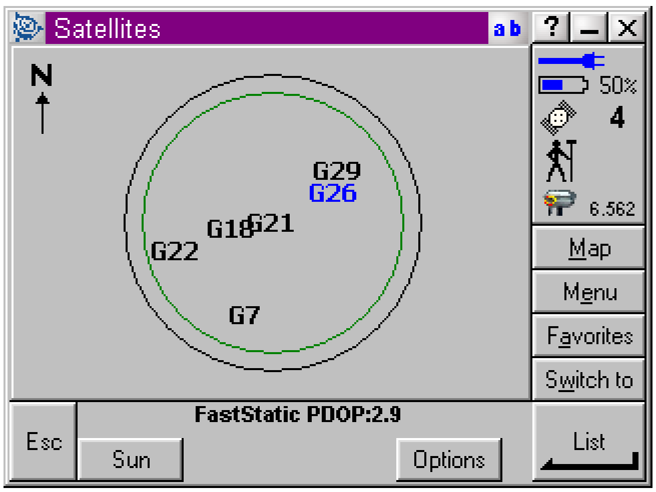
Satellite geometry factors that must be considered when planning a GPS survey are:

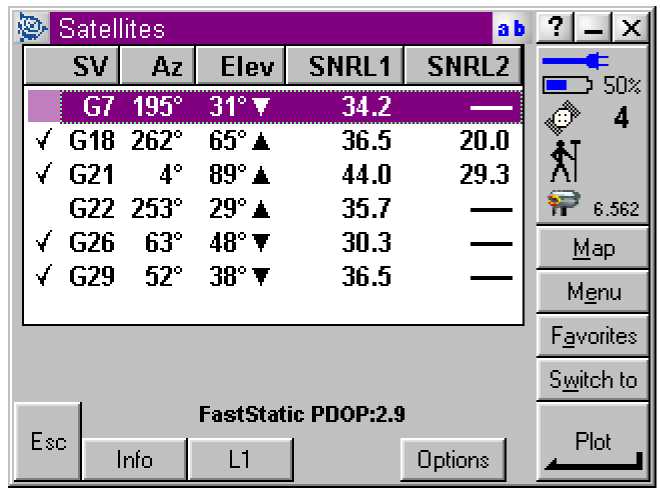
1. Number of satellites available
2. Minimum elevation angle above the horizon (elevation mask)
3. Obstructions limiting satellite visibility
4. Position Dilution of Precision (PDOP)
5. Vertical Dilution of Precision (VDOP)
6. Horizontal Dilution of Precision (HDOP)
7. Geometric Dilution of Precision (GDOP)

United States Coast Guard, Navigation Center:
http://www.navcen.uscg.gov
Or call for a 24 hour recorded message: 1-703-313-5907

The above link provides satellite information and important messages for all GPS users.

The Figures below, show the Satellite Geometry, and a listing of satellites and information about them.





Weather Conditions

Generally, weather conditions do not affect GPS surveying, however the following conditions must be considered when planning a GPS survey:

1. GPS Observations should never be conducted during an electrical storm.
2. Significant changes in weather or unusual weather conditions should be noted either in the field notes, data collector, or receiver.
3. Horizontal and vertical GPS observations can at times be affected by severe snow, hail and rain storms, high accurate GPS surveys should not be conducted during these periods.
4. Sunspots or magnetic storms can affect GPS observations, care needs to be taken to avoid GPS surveying during these periods.

Signal Strength

You'd think that with all of these radio waves raining down on us from dozens of satellites in space we'd all glow in the dark. Actually, the strength of the GPS signal is very small, equivalent to the tail light of a car seen from 2,500 kilometers away-halfway across the U.S.! Weaker, in fact, than the ordinary background radio noise that's all around us all of the time. How to isolate a coherent signal from a louder background noise can be solved by an interesting little concept discovered in information theory. Because the background noise is truly random, you can take random segments of that noise and repeatedly "lay" them on top of each other. Because they are random, they would eventually cancel, or zero themselves out. The pseudo-random code, while *seemingly* random, is not. So if you do the same thing with the code as you did with the random noise, you'll get a very different result. Remember, the receiver has an internal copy of the satellite's PRN (pseudo-random noise) code. The receiver can take its copy of that code and "lay it down" over the incoming noise (which contains the satellite code signal), and then "slew" its replica slightly back and forth. When the replica code and "hidden" satellite code align, they will reinforce each other resulting in a slightly stronger code signal. The receiver can then lay another copy of the code string and again slew it slightly back and forth until it lines up with the now slightly stronger satellite signal, and so on. Because the electronics are operating essentially at the speed of light, a lot of the "overlays" can be done in a very short time, quickly canceling out the noise (or most of it, anyway) and at the same time magnifying by many times the strength of the desired code.

GPS Velocity

Positioning isn't the only thing that can be accomplished with the Global Positioning System. Another important function is for Navigation, or the measurement of instantaneous position, *velocity,* and heading. Instantaneous position is measured just as we've described. However, while velocity could, by extrapolation, be calculated by simply differencing the positions between time I and time 2, it is more frequently accomplished in a slightly different manner. Because of the relative motion of the GPS satellites with respect to a receiver, the frequency of a signal broadcast by the satellites is always going to be "shifted," or slightly compressed or expanded, when received. This *Doppler shift* is proportional to the relative velocity between the satellite and receiver. The velocity of the satellites themselves as they move across the sky is known and is transmitted as part of the NAV-msg signal. Any *additional* Doppler shift that exists in the signal must, therefore, be due to motion of the receiver itself. From this, the receiver can deduce its own velocity from the measurement of any Doppler shift that is above and beyond that which is occurring as a result of the satellite's motions. This method of velocity calculation is virtually instantaneous and is extremely accurate. Typical velocity accuracy for a receiver with Selective Availability turned off (more about this later) is on the order of 0.5 kilometer per hour. Heading, or direction of travel, is calculated in a more straightforward manner. Simply projecting a line from one position to another results in a direction of travel. By looking at a sequence of positions, the receiver can average out any individual position variation and produce a direction of travel, or heading, that is accurate to within one or two seconds of arc. In this manner, any moving GPS receiver can also be used as an accurate compass.

Elevation Mask Angle

While dual-frequency receivers can virtually eliminate the ionospheric refraction problem, they're very expensive. However, the problem can be minimized with even the more commonly used single frequency receiver (likely receiving the Ll band alone). Nearly all GPS receivers, inexpensive or expensive, have a *"Mask Angle"* setting. This means that the receiver can be set to ignore any satellite signals that come from below a user-definable angle above the horizon, or "mask" them out. The most typical mask angle is usually somewhere between 10 and 15 degrees. The drawback here is that setting the mask angle too high might exclude satellites needed to acquire the necessary minimum of four. It's a trade-off. Are you so desperate for a position at that exact time that you're willing to accept a degraded signal? It does happen. In that case, the mask angle could be set to maybe 5 degrees, or even to zero if there's a clear view of the horizon, such as at sea, and simply accept a degraded signal and possibly (probably) a poorer accuracy as a result. In most cases it's better to keep the mask angle at that upper end of around 15 to (at most) 20 degrees and just wait for a sufficient number of satellites to become available above the mask. Now that the full GPS constellation is complete, there will rarely be times with too few satellites sufficiently high in the sky to get a good position. Another potential source of error is receiver noise, or electronic noise produced by the receiver itself that interferes with the very weak incoming signal. While this error is highly variable among receiver brands, most have some kind of internal filtering designed to minimize the problem some better than others.

Elevation mask also help to minimize the atmospheric noise in the data. Satellites that are high in the sky will have less atmospheric noise than satellites low in the sky and very close to the observer's horizon. By having an elevation mask set, the noise in the GPS satellite signals is kept to a minimum. **Most GPS processing software allows for the elevation mask to be raised while processing, but not lowered**.
Recommendation: ***As a guideline NDDOT requires an elevation mask setting of 15 degrees for all GPS surveys.***

Multi-Path Errors

Another potential, though relatively minor, source of signal error is *Multi-Path.* Multi-Path is simply the reception of a reflected satellite signal. With multi-path reception, the receiver collects both the direct signal from the satellite and a fractionally delayed signal that has bounced off of some nearby reflective surface then reached the receiver. This is the same kind of thing seen in television "ghosts." The problem is that the path of the signal that has reflected off some surface is longer than the direct line to the satellite. This can "confuse" some lower-end receivers resulting in an incorrect range measurement and, consequently, an incorrect position. There are several ways to deal with this problem. Most receivers have some way of "seeing" and comparing the correct and incorrect incoming signal. Since the reflected multi-path signal has traveled a longer path, it will arrive a fraction of a second later, *and* a fraction weaker than the direct signal. By recognizing that there are two signals one right after another, and that one is slightly weaker than the other, the receiver can reject the later, weaker signal, minimizing the problem. This ability is referred to as the receiver's multi-path rejection capability.

Mapping and survey quality receivers also use semi-directional, ground-plane antennas to reduce the amount of multi-path that the receiver will have to deal with. Semi-directional antennas are designed to reject any signal below a tangent to the surface of the Earth, meaning that they are preferentially directional upward. This is usually seen as a large (up to 20 to 30 centimeters across) flat metal plate (usually aluminum) with the actual, much smaller, receiver antenna attached on top. The metal plate interferes with any signals that may be reflected off of low reflective surfaces below them, such as bodies of water.

Dilution of Precision (DOP)

The cumulative UERE (User Equivalent Range Error) totals are multiplied by a factor of usually 1 to 6, which represents a value of the *Dilution of Precision*, or DOP. The DOP is, in turn, a measure of the geometry of the visible satellite constellation. The ideal orientation of four or more satellites would be to have them equally spaced all around the receiver, including one above and one below. Because we're taking our position from only one side of the Earth, that's really not possible since that part of space is blocked by the planet itself.

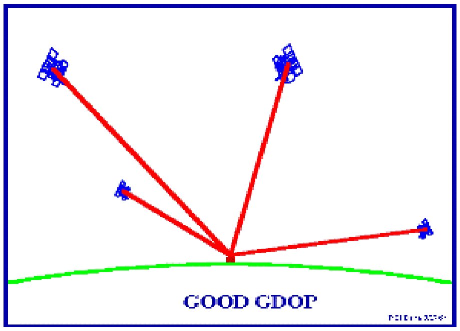
The next best orientation is, to have one satellite directly above and the other three evenly spaced around the receiver and elevated to about 25 to 30 degrees (to help minimize atmospheric refraction). This would result in a very good DOP value.

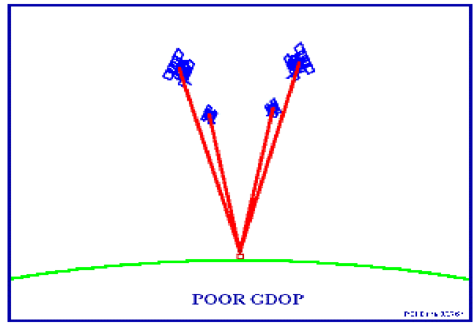
In this case, all of the satellites are clustered together. This would result in a poor DOP value. A low numeric Dilution of Precision value represents a good satellite configuration, whereas a higher value represents a poor satellite configuration.

The DOP at any given moment will change with time as the satellites move along their orbits.

Why can satellite geometry so adversely affect accuracy? Because of the sources of error already discussed, there is inherently a certain range of possible error in the distance calculation from any given satellite. That "range error" is variable but applies to all ranges derived from all satellites. When the satellites are widely spaced, the overlap area of the two zones of possible satellite range error is relatively small, called the *"area of positional ambiguity."*

The diagram at left illustrates a pair of widely spaced satellites which would result in a good, or low Dilution of Precision (DOP) value. In this case, the area of positional ambiguity is relatively small. The diagram at the right illustrates poor satellite geometry resulting in poor or high DOP .





Dilution of Precision Components (DOP)

There are a number of Dilution of Precision components. The overall ***GDOP,*** or *Geometric Dilution of Precision* includes: **PDOP,** or *Precision Dilution of Precision,* probably the most commonly used, which is the dilution of precision in three dimensions. Sometimes called the *Spherical DOP*. **HDOP,** or *Horizontal Dilution of Precision,* is the dilution of precision in two dimensions horizontally. This value is often lower (meaning "better") than the PDOP because it ignores the vertical dimension. **VDOP,** or *Vertical Dilution of Precision,* is the dilution of precision in one dimension, the vertical. **TDOP,** or *Time Dilution of Precision*, is the dilution of precision with respect to time.
A DOP value of less than 2 is considered excellent-about as good as it gets, but it doesn't happen often, usually requiring a clear view of the sky all the way to the horizon. DOP values of 2 to 3 are considered very good. DOP values of 4 or below are frequently specified when equipment accuracy capabilities are given. DOP values of 4 to 5 are considered fairly good and would normally be acceptable for all but the highest levels of survey precision requirements. A DOP value of 6 would be acceptable only in low precision conditions, such as in coarse positioning and navigation. Position data should not be recorded when the DOP value exceeds 6.

"Condo Canyons"

It's important to carefully consider where the data are to be collected. Is the area of interest on Main Street of a large city? If so, the receiver is likely to be surrounded by tall buildings that restrict satellite visibility resulting in poor DOPs since the only satellites that the receiver can see will be nearly straight up. That is, provided it's even possible to see enough satellites to get a position at all.

In addition, the glass-sided structures all around the receiver act as nearly perfect multi-path reflectors. It's possible that, because of the efficiency of the buildings to reflect the incoming satellite signal, the receiver's multi-path rejection capability may actually be overloaded. These are very difficult problems to overcome, particularly in dense urban areas with many tall buildings. And the problems aren't just in the cities. Even out in the country with wide open spaces there are conditions to be considered. Close proximity to high-power lines is a problem. The electromagnetic radiation surrounding the lines can interfere with the satellite signal, contributing an error that is nearly impossible to model or compensate for. Forests with dense canopy cover can obscure the sky and interfere with the incoming satellite signal. The problem is even worse if the vegetation is wet since the liquid water itself can also interfere with the signal. There are, however, some methods to get around these potential problems.

Human Error

The greatest contributor to error in GPS measurement is human error. Care must be taken while performing any GPS survey to keep human error to a minimum by proper procedures, redundant checks, repeat measurements and GPS observation log reports.
The following are some examples of human error:

1. Misreading antenna height measurements
2. Transposing numbers entered electronically and/or on the GPS observation log
3. Rushing observations
4. Poor centering and leveling over points
5. Observing the wrong survey point (for example, observing a reference mark instead of the actual mark itself)
6. Incorrect equipment configuration settings

GPS POSITIONING Techniques

Autonomous Positioning

Also referred to as Stand Alone, Point, You are Here, or Absolute Positioning. GPS method by which only one receiver is employed, position is determined from satellite observations only. Accuracy of about 10 meters. Recreational GPS receivers rely on this method.

Differential Positioning

Also referred to as relative positioning. GPS method by which two receivers are employed. One receiver is on a known station (base), one receiver is on an unknown station (rover). By observing common satellites simultaneously, GPS errors can be determined at the base station and applied to the roving station.

Carrier phase positioning

Also referred to as survey grade GPS. Method by which carrier phase GPS signals are used along with Differential positioning techniques to achieve survey grade <cm positions.

Real Time Differential Corrections

Method by which differential corrections are received and applied in real time.

Survey Planning

Proper planning and network design shall be used in GPS surveys for primary project control.
Satellite almanacs used for observation planning shall be no more than 30 days old.
Stations should be situated in locations that minimize obstructions. In general, a clear view of the sky above 20 degrees is desired.
Field reconnaissance and pre-mission observation planning will be accomplished for all surveys. Analysis should consider the number of available satellites and PDOP.
At least four healthy satellites shall be observed in common at all simultaneously occupied stations.
The PDOP shall not exceed 6 during any GPS survey observations.

<u>Field Observation</u>
GPS antennas should be set up over the points using fixed-height antenna tripods.
GPS observations will be collected at 1 second data epochs. The tracking elevation mask angle should be 15.
Vehicles should be parked away from or below the GPS antenna to minimize the chances of causing multipath signals.
Great care shall be taken in measuring and recording antenna heights. When using standard tripods, the antenna slope-height will be measured multiple times (per manufacturer's directions) and the average recorded.

NOTE: If bench marks are required on the project site, they shall be established from primary project control.

Secondary Control Monumentation Site Selection

It is critical that before setting any secondary control monumentation the project needs are identified. This is typically done through the initial scoping of the project to determine the projects limits, factors, and requirements. After the scoping has been completed the project surveyor shall identify areas to install secondary control monuments. The following considerations should be taken into account when choosing a site for installing secondary control monumentation:

1. Sites should be free of vertical obstructions blocking the horizon such as buildings, overhangs, terrain, trees, fences, utility poles, overhead lines, or any other visible obstructions, non-obstructed skies 15 degrees above the horizon is best.
2. Sites should not be located close to radio transmitters including cellular phone equipment because they may disrupt satellite signal reception.
3. Sites close to large flat surfaces such as signs, fences, glass, or utility boxes should be avoided.
4. Sites shall provide direct line of sight between adjacent control monuments.
5. Sites shall not exceed 0.2 mile (1000 feet) between adjacent intervisible secondary control monuments.
6. Establish a minimum of two primary control monuments for each project. (See Chapter 19 of Survey Manual for Primary Control procedure)

7. If feasible, sites should not be disturbed by future construction activities and should be outside the design construction limits and top of cuts for the project.
8. Sites shall be located within the existing highway Right-of-Way and near the Right-of-Way line.

NDDOT COORDINATE SYSTEMS AND DATUMS

In response to the needs of local surveyors for an accurate plane surveying coordinate system useful over relatively large areas, the U. S. Coast and Geodetic Survey (the predecessor of NGS) developed the State Plane Coordinate System in 1934.
The State Plane Coordinate System was established to provide a means for transferring the geodetic positions of monumented points to plane coordinates that would permit the use of these monuments in plane surveying over relatively large areas without introducing significant error.
A plane-rectangular coordinate system is by definition a flat surface. Geodetic positions on the curved surface of the earth must be "projected" to their corresponding plane coordinate positions. Projecting the curved surface onto a plane requires some form of deformation. Imagine the stretching and tearing necessary to flatten a piece of orange peel.
Survey data for use on NDDOT projects will be coordinated and regulated in NDDOT Chapter 19 Surveys and Photography Manual

COORDINATE SYSTEM

Because of the complexity of performing the calculations for geodetic surveying and the limited extent of most surveying projects, most surveyors generally use plane surveying techniques. For local projects of limited extent, plane surveying yields accurate results, but for large projects locally administered plane surveying systems may not be adequate. Not only can locally administered plane coordinate systems be inaccurate over large areas, but they cannot be easily related to other local systems.

HORIZONTAL DATUM

The horizontal control shall be tied to the North Dakota coordinate system of 1983, north or south zone (be sure to use the correct zone), based on the North American Datum of 1983; (1996 Adjustment), NAD83 (CORS96) until the readjustment of the National Spatial Reference System (NSRS) is available. The readjustment is scheduled for completion February, 2007. The control will then be based on NAD 83 (NSRS).

The DISTRICT or CONSULTANT shall set the PRIMARY CONTROL for the project by using a GPS survey to occupy pairs of monumented stations at both ends of the project and at intervals of every 2 to 3 miles throughout the project.

The Continuously Operating Reference Stations (CORS) will be used as the Master Control Network for all highway projects. The CORS stations used must surround (not all stations in a straight line or to one side) the project limits to prevent tilting of the coordinates and elevations.

The latest available adjustment of the NAD83 datum should be used. To assure the most current data is used, coordinates for these stations shall be obtained from the NGS database at: http://www.ngs.noaa.gov/cgi-bin/datasheet.prl

NOTE: The coordinates of the project control must be determined by using the NGS OPUS solutions.

VERTICAL DATUM

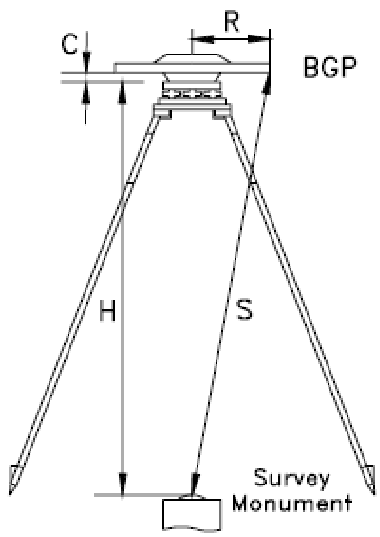
The vertical component of the survey shall be tied to the North American Vertical Datum of 1988 (NAVD 88).The OPUS solution will be used to determine the elevation component of each PRIMARY CONTROL point.

No levels will be run from existing Bench Marks to determine PRIMARY CONTROL elevations.

Antenna Height Measurement

Blunders in antenna height measurements are a common source of error in GPS surveys. All GPS surveys are three-dimensional whether the vertical component will be used or not and care needs to be taken during any GPS survey when measuring the antenna height. Antenna height measurements determine the height from the survey monument mark to the phase center of the GPS antenna.
There are three types of antenna height measurements done for CDOT GPS surveys:

1. tripod rods - To be used for Static, Fast Static, RTK, and PPK surveys. Preferred over adjustable height tripods for Static and Fast Static surveys.
2. Adjustable height tripods - To be used for Static, Fast Static, RTK, and PPK surveys.
3. Adjustable height rods - To be used only for RTK and PPK surveys.



H = True height of fixed height tripod rod

S = Slant height field measeurment

C = Distance for addition of ground plane

R = Radius from antenna phase center to edge of ground plane

BGP = Bottom of ground plane (or antenna)

UNITS OF LENGTH

Survey distance measurements will be collected and reported in **International Feet**. To convert metric dimensions to equivalent feet dimensions, they will be converted based on the International foot definition, by multiplying the metric dimension by 3.280839895 (1M=3.280839895ift).

COORDINATE CONVERSIONS

GPS works in an earth centered coordinate system. The projection to a state plane coordinate system is usually handled by GPS processing software. The GPS processing software will also calculate convergence angles, and combined factors. Combined factor = (grid scale factor x ellipsoidal reduction factor).
Though convergence angles will differ from point to point, if the procedures outlined in this manual for establishing project control are followed, the effect of the change in convergence angle will have a minimal effect on the accuracy of the survey.
Though combined factors will differ from point to point based on distance from reference meridian or elevation, a mean combined factor (NDDOT County Conversion Factors) should be used for each project. This policy will cause no appreciable loss in accuracy and will eliminate confusion caused by multiple combined factors.
NOTE: All surveys must use the current NDDOT County Conversion Factors. A current Conversion listing is found in the Appendix.

DISTANCE CONVERSIONS

When processing survey data from a total station traverse the combined factor must be applied to distances. The combined factor is the resulting product of the grid scale factor multiplied by the ellipsoidal reduction factor. Combined factor = (grid scale factor x ellipsoidal reduction factor).

DISTANCE EXAMPLE:
A project is located in Burleigh County. The Burleigh County conversion factor (cf) is 0.9998515. The 1/cf factor is 1.0001485221.

1 1. To determine the ground distance from the grid distance. Divide the grid distance by the Conversion Factor.

The distance on the grid is 5279.22 feet. What is the ground distance?

5279.22 / 0.9998515 = 5280 feet
The ground distance is 5280 feet.

1 2. To determine the grid distance from a ground distance. Multiply the ground distance by the conversion factor.

The distance on the ground is 5280 feet. What is the grid distance?

5280 * 0.9998515 = 5279.22 feet
The grid distance is 5279.22 feet

NOTE: One (1) divided by the conversion factor will provide a ground factor that when multiplied by the grid distances will determine the ground distances.
5279.22 * 1.0001485221 = 5280 feet

COORDINATE EXAMPLE:
A project is located in Burleigh County. It has the same conversion factors as the example above.

1. To determine the ground coordinates (DOT Burleigh County Coordinate System) from the grid coordinates. Multiple the grid coordinates by 1.0001485221.

Grid Coordinates * Burleigh County conversion factor (1/cf)=
Ground coordinate

421,173.7664 N * 1.0001485221= 421,236.3200 Y
1,889,225.8327 E * 1.0001485221 = 1,889,506.4245 X

2. To determine the grid coordinate (State Plane coordinate) from the ground coordinates. Multiple the ground coordinates by 0.9998515.

Ground coordinate * Burleigh County conversion factor (cf) = Grid coordinate (state plane-South Zone)

421,236.3200 Y * 0.9998515 = 421,173.7664 N
1,889,506.4245 X * 0.9998515 = 1,889,225.8328 E

DATA COLLECTION METHODS

When specifying standards and procedures for other types of surveys to be completed for NDDOT, consideration should be given to providing deliverable file formats that meet the needs of the customer in a format compatible with NDDOT systems. Consideration should also be given to other possible users of the data. Equipment and procedures should be specified that will ensure the standards for the survey are achieved. Many manufacturer specifications are achievable only under ideal conditions.

NOTE: No GPS data (targets, alignment, topography, utilities, etc.) shall be collected using the "CONTINUOUS TOPO" option.

PDOP shall be set no higher then 6 (we prefer 5).

No project GPS calibration is to be used.

Secondary Horizontal Project Control Procedures (RTK Control)

Equipment
Surveyors shall employ dual GPS receivers. Not less than two GPS receivers will be employed. Additional receivers can be employed to achieve better productivity.

Techniques
RTK GPS techniques may be employed.
1 second epochs shall be collected for RTK techniques
110 Measurements, and 2 minute shot for RTK Control. (7 Measurements, 10 seconds for topo shots)
Tracking elevation mask angle should be 15 deg.
Post-processing of simultaneous field observations shall be used.

Network Design
GPS surveys for Secondary Horizontal Project Control should be configured as networks of redundant vectors.
At least two primary horizontal project control stations shall be incorporated into the network design.

Planning
Proper planning and network design shall be used in GPS surveys for secondary project control.
Satellite almanacs used for observation planning shall be no more than 30 days old.
Field reconnaissance and pre-mission observation planning shall be accomplished for all surveys. Sky visibility diagrams shall be made for all stations. Diagrams will show magnetic azimuth and elevation angle to all obstructions above 15 to whole degrees. Obstruction data shall be entered into a GPS observation planning program and multi-receiver sessions shall be analyzed for acceptable observing times. Analysis should consider the number of available satellites and PDOP.

At least four healthy satellites shall be observed in common at all simultaneously occupied stations.
The PDOP should not exceed 6 during any GPS survey observations.

Field Observations
Fixed-height antenna tripods or survey tripods and optical plummet tribrachs shall be used for GPS antenna set-up over the points.
GPS observations will be collected at 1 second data epochs using NDDOT RTK techniques, The tracking elevation mask angle should be 15.
Vehicles should be parked away from or below the GPS antenna to minimize the chances of causing multipath signals.
Great care shall be taken in ***measuring and recording antenna heights***. When using standard tripods, the antenna slope-height will be measured multiple times (per manufacturer's directions) and the average recorded.

Differential Positioning

Differential GPS surveying is the determination of one location with respect to another location. A real-time dynamic DGPS positioning system includes a reference station, a communication link, and remote-user equipment. If results are not required in real time, the communication link can be eliminated and the positional information is post processed.
1. Reference Station. A reference station is placed on a known survey monument. It is an area with an unobstructed view of at least four satellites, at least 10° above the horizon. It consists of a GPS receiver, a GPS antenna, a processor, and a communication link (if real-time results are desired). The reference station measures the timing and ranging information broadcast by the satellites and computes and formats range corrections for broadcast to the user equipment. Using differential pseudo ranging, the position of a survey vessel is found relative to the reference station. The pseudo ranges are collected by the GPS receiver and transferred to the processor where PRCs are computed and formatted for data transmission. Many manufacturers have incorporated the processor within the GPS receiver, eliminating the need for an external processing device. The recommended data format is that proposed by the Radio Technical Commission for Maritime (RTCM) Services Special Committee (SC). The processor should be capable of computing and formatting PRCs every 1 to 3 seconds.
2. Communication Link. A communication link is used as a transfer media for differential corrections. The main requirement of the communication link is that the transmission be at a minimum rate of 300 bits per second. The type of communication system is dependent on the user's requirements.

Differential Global Positioning System Carrier Phase Horizontal-Positioning Techniques.

Differential GPS carrier phase surveying is used to obtain the highest precision from GPS and has direct application to most topographic and engineering surveys. Manufacturers' procedures should be followed for conducting a GPS field survey. The following four basic DGPS techniques are in use:

1. Static.
2. Fast static.
3. RTK.

4. PPK

Static GPS Surveys

Static survey methods shall be used for NDDOT project control surveys when the required Minimum Horizontal Accuracy Tolerance is for a Primary or Secondary survey. Static surveys allows for systematic errors to be resolved when high accuracy positions are required by collecting simultaneous data between stationary receivers for an extended period of time during which time the satellite geometry changes. Static survey methods require the creation of a GPS network and a schedule for the coordination of receivers, operators, observation times and the logistics of the project.
Receivers must be capable of recording data for post processing. Multi channel tracking dual frequency receivers are required. Receivers and post processing software must be specified by the manufacture to be suitable for high accuracy Static surveys. The Static Horizontal and Vertical Accuracy Tolerances specified by the manufacture shall meet or exceed the NDDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey.
Static equipment requirements:

1. Only extended leg tripods or fixed height tripods shall be used for any Static survey.
2. Antennas should have a ground plane in place for Static surveys.
3. Whenever feasible, all antennas for the survey should be of the same make and model.
4. As a guideline NDDOT recommends an epoch setting of 1 second and a sync time setting of 5 seconds for all Static surveys.

RTK GPS Surveys

RTK survey methods shall be used for any survey project requiring NDDOT Minimum Horizontal Accuracy Tolerances for a Primary survey.
RTK surveys are a “Radial” type survey that utilizes two or more receivers with at least one receiver remaining stationary over a known (reference or base station) project control monument. Other receivers (rovers) are moved from point to point collecting data in a short amount of time. Reference stations shall be of the same or higher accuracy as required for the RTK survey. RTK surveys measure the baselines from the reference station to the roving receivers point. A radio at the reference station broadcast the position of the reference point to the rovers and the system processes the baselines in “Real Time” allowing for project coordinate information to be gathered and analyzed during the actual field survey.
Receivers must be capable of being connected to a radio at the reference station for broadcasting and to a radio at the rover for receiving the reference station broadcast. Multi channel tracking dual frequency

receivers are required. Receivers must be specified by the manufacture to be suitable for RTK surveys. The RTK Horizontal and Vertical Accuracy Tolerances specified by the manufacture shall meet or exceed the NDDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey. Care needs to be taken in the field to ensure that the RTK calibration, base station, and project control points have been set up correctly to allow the RTK data being collected to meet or exceed the NDDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey. (See Existing NDDOT Primary Control Checks, and GPS Reports, for additional information).
Multipath at the reference station and at the rovers, re-initializations and loss of radio link must be kept to a minimum through project scheduling and organization of the “Best Use” survey method that should be used for the logistics of the survey project. **It should be kept in mind that RTK surveys are just another tool available to complete a survey project and should only be used only when the NDDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey can be met or exceeded.**

PPK GPS Surveys

PPK survey methods shall not be used for any survey project requiring NDDOT Minimum Horizontal Accuracy Tolerances for a NDDOT Class A - Primary survey.
PPK surveys are a “Radial” type survey similar to an RTK survey, however there is no radio at either the reference station or the rover to broadcast and the system does not process the baselines in real time. PPK utilizes two or more receivers with at least one receiver remaining stationary over a known (reference or base station) project control monument. Other receivers (rovers) are moved from point to point collecting data in a short amount of time. Reference stations shall be of the same or higher accuracy as required for the PPK survey. PPK surveys measures the baselines from the reference station to the roving receivers. Data is collected at both the reference station and at the rover receivers. The data is downloaded into a GPS processing software program to process the baselines.
Receivers must be capable of collecting data at the reference station and at the rover for downloading into a GPS processing program. Multi channel tracking dual frequency receivers are required. Receivers must be specified by the manufacture to be suitable for PPK surveys. The PPK Horizontal and Vertical Accuracy Tolerances specified by the manufacture shall meet or exceed the NDDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey.
Care needs to be taken in the field to ensure that the PPK calibration, base station, and project control points have been set up correctly to allow the PPK data being collected to meet or exceed the NDDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey. (See Existing NDDOT Primary Control Checks, and GPS Reports, for additional information).
Multipath at the reference station and at the rovers must be kept to a minimum through project scheduling and organization of the “Best Use” survey method that should be used for the logistics of the survey project. It should be kept in mind that PPK surveys are just another tool available to complete a survey project and should only be used only when the NDDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey can be met or exceeded.

As a guideline NDDOT recommends an epoch setting of 1 second and a sync time setting of 5 seconds for all PPK surveys.

GPS Equipment Maintenance and Calibration

General

Checking and calibration of all types of survey equipment is essential to obtain and maintain the tolerances required in this chapter. At the beginning of any survey all survey equipment needed to perform the survey shall be checked and calibrated by the professional land surveyor in responsible charge of the survey under his/her direct supervision and/or checking. All survey equipment shall be checked and calibrated once every six months thereafter and as needed during the course of the survey, whichever comes first.
Errors due to poorly maintained or malfunctioning equipment will not be accepted. If any equipment errors are found to exist they must be reported to Surveys and Photogrammetry devision prior to the start of the survey. These errors will need to be verified and eliminated prior to performing any survey. For surveys lasting longer than 6 months, the checking and calibration of equipment shall be repeated to show that the equipment is staying within acceptable tolerances as required.

Checking and Calibration

Following are the types of checking and calibration of equipment that are accepted by NDDOT:

1. Equipment Maintenance
2. Federal Published Calibration Baseline Check
3. Existing NDDOT Project Control Check
4. Zero Baseline Check

An authorized equipment vendor or manufacturers service department shall perform calibration of GPS survey equipment.

Equipment Maintenance

At the beginning of any survey and once every 6 months thereafter, all necessary survey equipment needed to perform the survey shall be checked and adjusted by the professional land surveyor in responsible charge of the survey under his/her direct supervision and/or checking. All equipment shall be checked once every six months and as needed during the course of the survey, whichever comes first.
Checks and adjustments shall include but are not limited to those outlined in Calibration and Checking and the following:

1. Tripods - nuts and bolts are tight, no loose or broken legs, tripod head is tight, flat, and not damaged.
2. Fixed Height Tripods - level bubbles are in adjustment, rod is not bent or damaged, height of rod is correct as reportedly measured, legs are secure.
3. Rods - level bubbles are in adjustment, rod is not bent or damaged, height of rod is correct as reportedly measured, and adjustable rod height clamps are secure.
4. Tribrachs - optical plummets are in adjustment, level bubble is in adjustment, no lose legs, no loose or missing screws, bottom head is flat and not damaged.
5. Collimators - level bubble is in adjustment, top and bottom heads are both flat with no damage.
6. Cables - no cuts, breaks, pinch marks or damage.
7. Receivers - no cracks or visible signs damage.
8. Receiver Antennas - if equipped with a ground plane it is not bent or warped, no cracks or visible signs of damage.
9. Ground planes should produce a plane that when leveled varies no more then +/- 0.003 meters when measured at three notches approximately 120 degrees apart. Ground planes that are warped more than +/- 0.003 meters shall not be used for any NDDOT GPS surveys.

Federal Published Calibrated Baseline Check

The National Geodetic Survey (NGS) conducts a cooperative program that provides surveyors with a means for calibrating and checking of errors in Electronic Distances Measuring Instruments (EDMI). Publications are available through NGS on the procedures for checking of EDMI against a Federal Calibrated Baseline. The same procedures used for checking of EDMI are adopted and used for checking of GPS equipment for Static, Fast Static, RTK, and PPK methods. The observed unadjusted baseline lengths shall meet or exceed the manufacturers ratings for the equipment used when checked against a calibrated baseline both horizontally and vertically.

NGS/NOAA

http://www.ngs.noaa.gov/CBLINES/calibration.html

The above link provides information and downloads of Federal Published Calibrated Baselines.

The basic procedures to perform a calibrated baseline check of GPS equipment in either Static or Fast Static mode is as follows:

1. A minimum of two receivers are setup on any two calibrated baseline marks.
2. Either a Static or Fast Static survey is performed with simultaneous observations collected at each mark with the same equipment configurations (i.e. elevation mask, epochs, sync time, maximum PDOP, satellite tracking, session duration, etc.) and methods that will be used for performing the survey.
3. After the first session is completed the receivers are moved and setup on each calibrated baseline mark so that each published baseline length is observed at least twice.
4. This procedure is repeated as many times as needed until all equipment that shall be used for the survey has collected simultaneous data observations at each calibrated baseline mark.

5. The data is downloaded and processed with the use of GPS processing software with the same procedures and settings that will be used for the survey.
6. The unadjusted baselines lengths and vertical differences are calculated and compared to the published calibrated baseline lengths and vertical differences.

7. For the equipment to be considered as being in adjustment the final unadjusted baselines lengths and vertical differences shall meet or exceed the manufacturers ratings for the equipment.

The basic procedures to perform a calibrated baseline check of GPS equipment in RTK mode is as follows:

1. A base receiver is setup on any one of the calibrated baseline marks.
2. A rover receiver collects data at each calibrated baseline mark with the same equipment configuration (i.e. elevation mask, epochs, sync time, maximum PDOP, satellite tracking, session duration, etc.) and methods that will be used for performing the survey.
3. After the rover has collected data at each calibrated baseline mark the base receiver is moved and setup on each calibrated baseline mark and the rover collects data at each calibrated mark.
4. This procedure is repeated as many times as needed until both a base and a rover receiver have occupied all calibrated baseline marks and data has been collected at all calibrated baseline marks.
5. The data is downloaded into the GPS processing software with the same procedures and settings that will be used for the survey.
6. The unadjusted baselines lengths and vertical differences are calculated and compared to the published calibrated baseline lengths and vertical differences.
7. For the equipment to be considered as being in adjustment the final unadjusted baselines lengths and vertical differences shall meet or exceed the manufacturers ratings for the equipment.

NDDOT Control Checks (Checkshot)

While collecting data in either RTK or PPK mode, the checking of existing NDDOT primary control monuments shall be completed to ensure the data being collected meets or exceeds the Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey. This check is intended to serve as a quality control check during the survey and is not to be used in place of a calibrated baseline check. A primary control check report shall be submitted for all existing primary control checks (See GPS Reports, for additional information). Primary control checks should be performed at the following times:

1. Immediately after each initialization (At the Start of the Survey)
2. During roving while initialized
3. Before ending the initialization session (At the End of the Survey)

Control monument checks shall be performed as follows:

1. The RTK rover shall be placed on a primary control monument mark and leveled.
2. RTK data shall be collected with the same equipment configuration (i.e. elevation mask, epochs, sync time, maximum PDOP, satellite tracking, session duration, etc.) and methods that will be used for performing the survey.
3. The horizontal and vertical difference between the record primary control data and the collected RTK data shall be verified by either inversing the two locations or by use of a RTK stakeout mode that calculates and reports the difference within the data collector.
4. The horizontal and vertical difference shall be stored for inclusion into the primary control check report.
5. The horizontal and vertical differences should meet or exceed the Minimum Horizontal and Vertical Accuracy Tolerances required for the survey or the RTK setup will be checked for errors and the process repeated.

Zero Baseline Check

The zero baseline check serves as an optional supplemental equipment check. This check is performed to check the antenna phase center of GPS antennas, and for noise carried through the GPS antennas and cables. All receivers, antennas, and cables that will be used while performing the survey should be checked. Publications available on the procedures for performing this type of check from various manufacturers such as Trimble.

The basic procedure for performing a zero baseline check of GPS equipment is as follows:

1. Multiple receivers are connected to a single receiver antenna through the use of a “Splitter Cable”.
2. Either a Static or Fast Static session is performed.
3. When the first session is completed each receiver, receiver antenna, and cable that will be used during the survey is rotated through the next session until all equipment has been used in conjunction with each other.
4. The data is downloaded and processed with the use of GPS processing software and the unadjusted baselines are calculated.
5. For the equipment to be considered as being in adjustment the final unadjusted baselines lengths should not exceed 0.002 meters.

APPENDEIX

NORTH ZONE

COUNTY	COUNTY COMBINATION FACTOR (cf)	1/cf
Benson	0.9998610	1.0001390194
Bottineau	0.9999275	1.0000725053
Burke	0.9999095	1.0000905082
Cavalier	0.9999340	1.0000660044
Divide	0.9999130	1.0000870076
Eddy	0.9998765	1.0001235153
Foster	0.9999205	1.0000795063
Grand Forks	0.9998805	1.0001195143
Griggs	0.9999295	1.0000705050
McHenry	0.9998830	1.0001170137
McKenzie	0.9998485	1.0001515230
McLean	0.9998925	1.0001075116
Mountrail	0.9998350	1.0001650272
Nelson	0.9998685	1.0001315173
Pembina	0.9999640	1.0000360013
Pierce	0.9998830	1.0001170137
Ramsey	0.9998685	1.0001315173
Renville	0.9999205	1.0000795063
Rolette	0.9999235	1.0000765059
Sheriden	0.9998895	1.0001105122
Steele	0.9999375	1.0000625039
Towner	0.9999160	1.0000840071
Traill	0.9999525	1.0000475023
Walsh	0.9998905	1.0001095120
Ward	0.9998530	1.0001470216
Wells	0.9998895	1.0001105122
Williams	0.9998445	1.0001555242

SOUTH ZONE

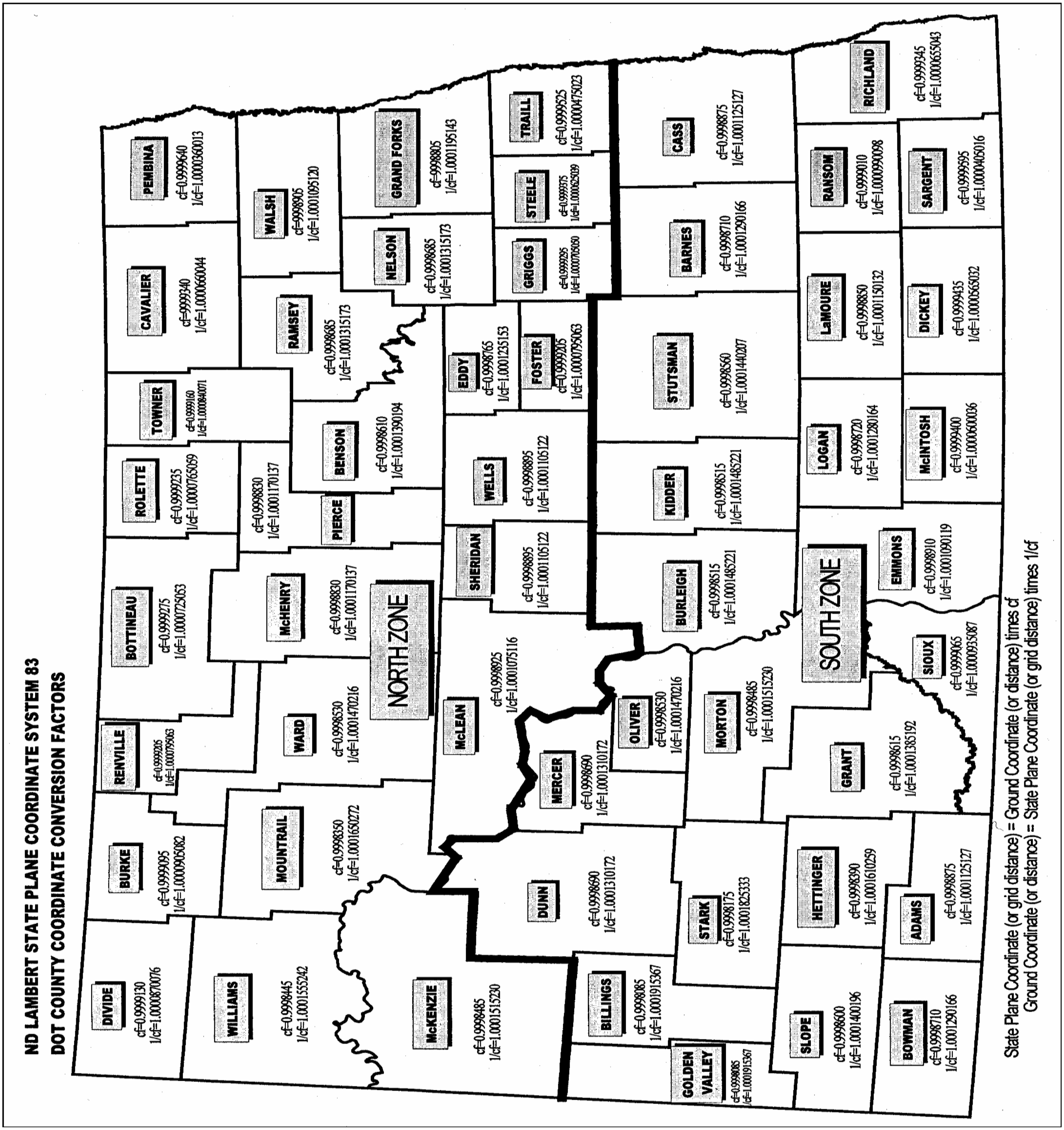
COUNTY	COUNTY COMBINATION FACTOR (cf)	1/cf
Adams	0.9998875	1.0001125127
Barnes	0.9998710	1.0001290166
Billings	0.9998085	1.0001915367
Bowman	0.9998710	1.0001290166
Burleigh	0.9998515	1.0001485221
Cass	0.9998875	1.0001125127
Dickey	0.9999435	1.0000565032
Dunn	0.9998690	1.0001310172
Emmons	0.9998910	1.0001090119
Golden Valley	0.9998085	1.0001915367
Grant	0.9998615	1.0001385192
Hettinger	0.9998390	1.0001610259
Kidder	0.9998515	1.0001485221
LaMoure	0.9998850	1.0001150132
Logan	0.9998720	1.0001280164
McIntosh	0.9999400	1.0000600036
Mercer	0.9998690	1.0001310172
Morton	0.9998485	1.0001515230
Oliver	0.9998530	1.0001470216
Ransom	0.9999010	1.0000990098
Richland	0.9999345	1.0000655043
Sargent	0.9999595	1.0000405016
Sioux	0.9999065	1.0000935087
Slope	0.9998600	1.0001400196
Stark	0.9998175	1.0001825333
Stutsman	0.9998560	1.0001440207

ND DEPT OF TRANSPORTATION

SURVEYS & PHOTOGRAMMETRY

DATE: JANUARY 2007

REVISED: MARCH 2008

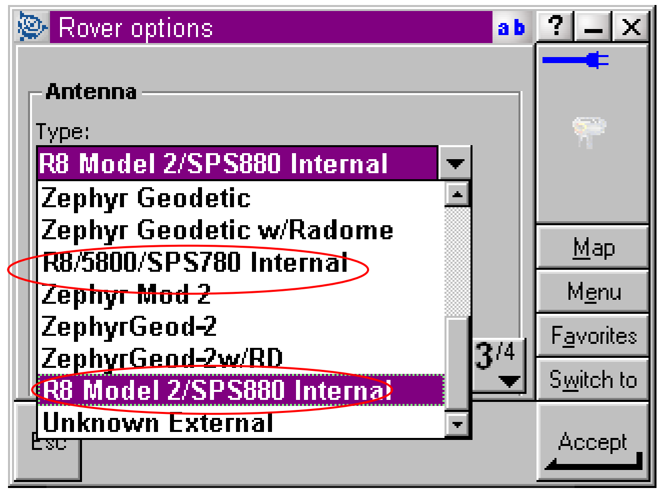


Survey Controller Ver. 11.32

Survey Styles: NDDOT RTK

Rover Options:

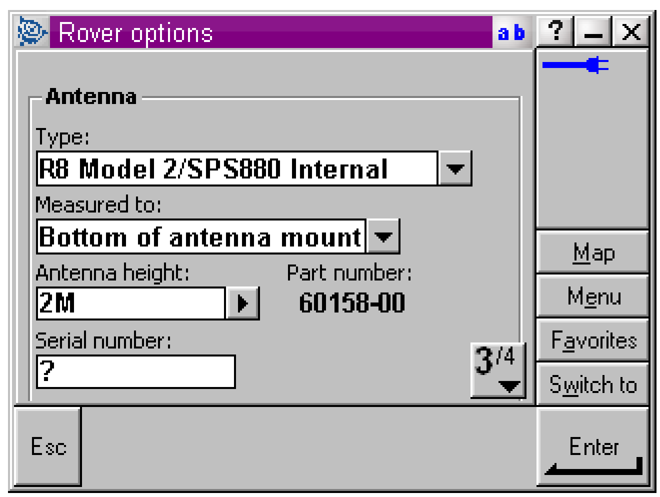
Survey Type: RTK
Broadcast Format: CMR+
Station Index: ANY
Prompt station Index: Check
Page 2
Satellite Differential: Off
Ignore Health: Unchecked
Elevation Mask: 15 Degrees
PDOP: 5 May be turned to 6 if having problems
Antenna Height: 6.562ift----2 meters
Page 4
Tracking Glonass & L2C: Unchecked



Please note the Model number on the bottom of the receiver!

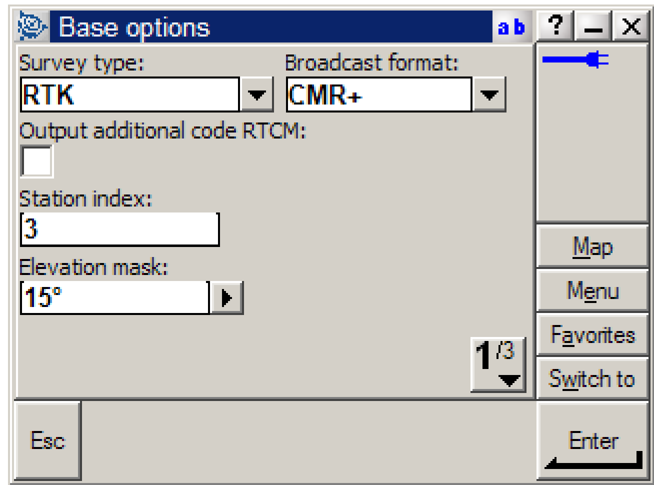
Rover Radio:

Type: Trimble Internal
Method: Trimble 450/900



Base Options:

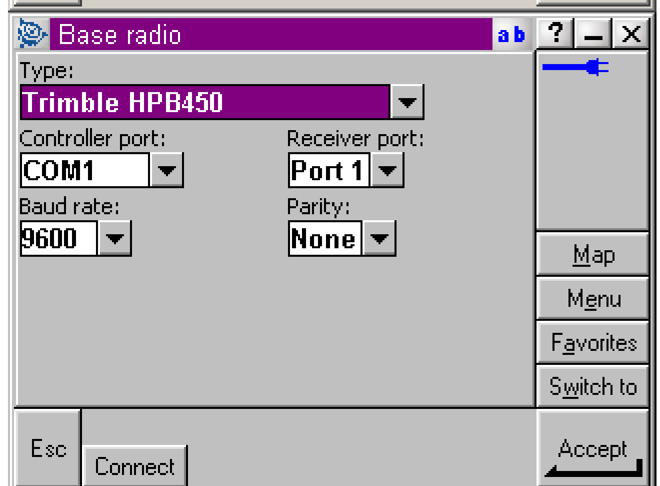
Survey Type: RTK
Broadcast Format: CMR+
Output additional code RTCM: Unchecked
Station Index: Any Number
Elevation Mask: 15 degrees
Page 2
Antenna Type: R8 Model 2/SPS880 Internal
Measure to: Center of Bumper
Antenna height: ?
Page 3
Tracking
Glonass and L2c: Unchecked
Use 4000 SSe: Unchecked



Base Radio:

Type: Trimble HPB450

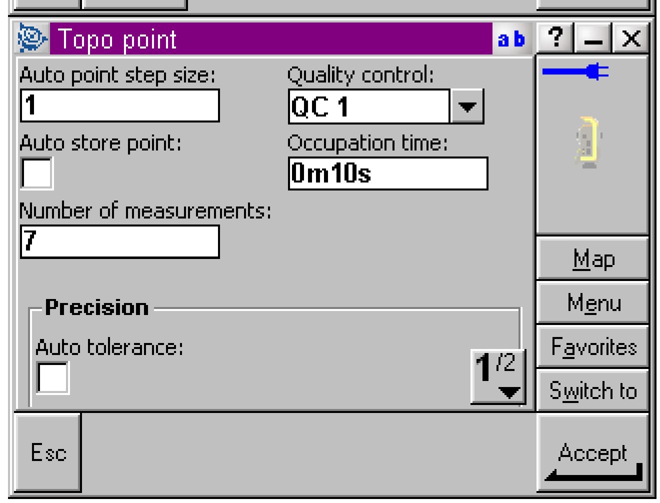
Controller Port: Com 1
Reciever Port: Port 1
Baud Rate: 9600
Parity: None



Topo Point

Auto Point Step: 1

Quality Control: QC1
Auto Store: Check
Occupation Time: 10 seconds
Number of Measurements: 7
Auto Tolerance: Unchecked
Page 2
Horizontal Tolerance: 0.049ift
Vertical Tolerance: 0.066ift

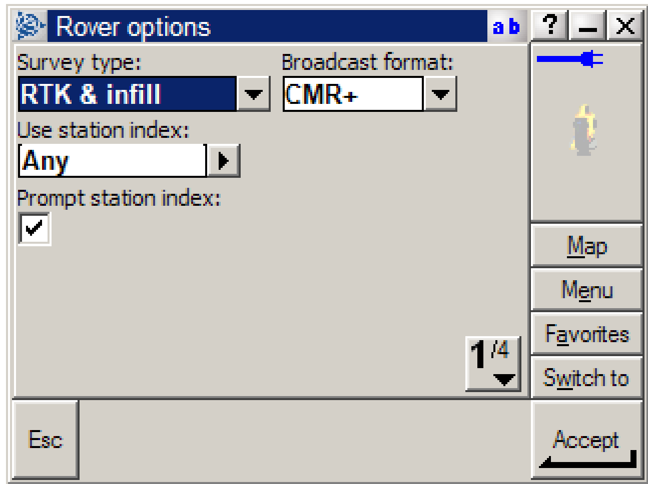


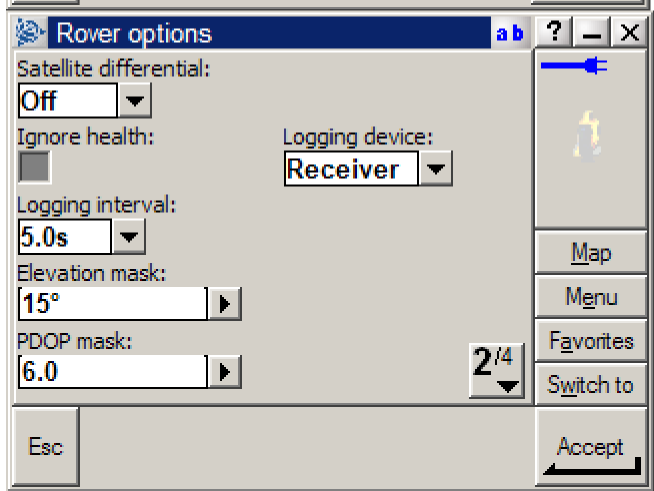
Survey Controller Ver. 11.32

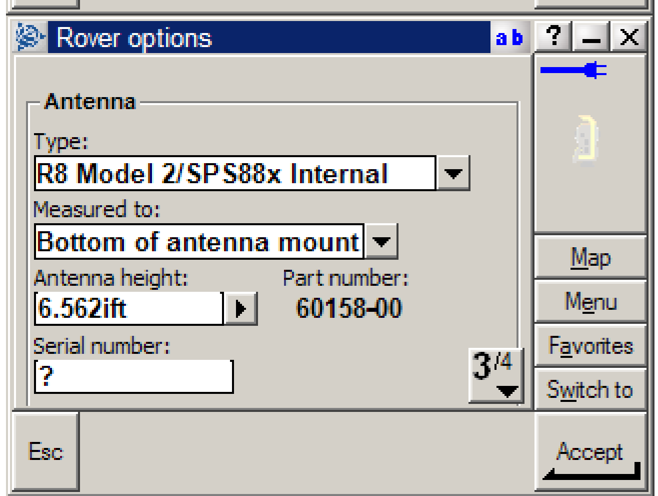
Survey Styles: NDDOT RTK & Infill

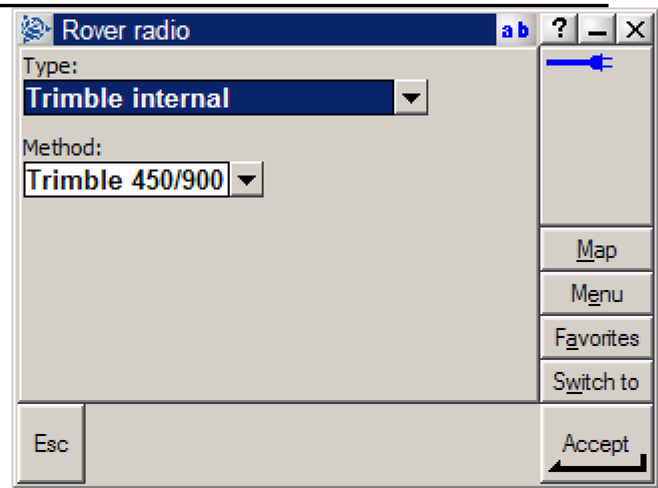
Rover Options:

Survey Type: RTK & Infill
Broadcast Format: CMR+
Station Index: ANY
Prompt station Index: Check
Page 2
Satellite Differential: Off
Ignore Health: Unchecked
Logging Device: Receiver
Logging Interval: 5.0S
Elevation Mask: 15 Degrees
PDOP: 5 May be turned to 6 if having problems
Page 3
Antenna Type: R8 Model2 or your current antenna
Measured to: Bottom of Antenna Mount
Antenna Height: 6.562ift----2 meters
Page 4
Tracking Glonass & L2C: Unchecked



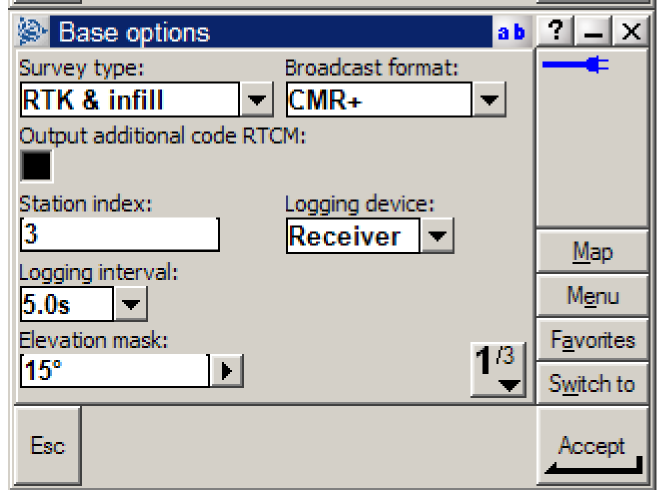






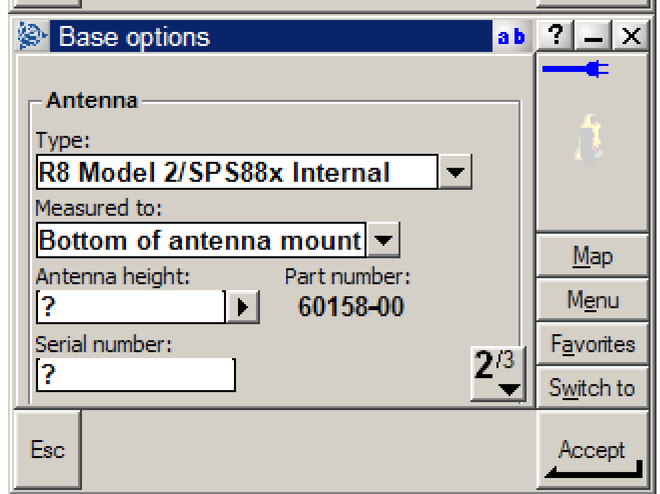
Rover Radio:

Type: Trimble Internal
Method: Trimble 450/900



Base Options:

Survey Type: RTK & Infill
Broadcast Format: CMR+
Output additional code RTCM: Unchecked
Logging Device: Receiver
Station Index: Any Number
Elevation Mask: 15 degrees
Page 2
Antenna Type: R8 Model 2/SPS880 Internal
Measure to: Bottom of Antenna Mount (Use 2M Pole, instead of Tribrachs)
Antenna height: ?
Page 3
Tracking
Glonass and L2c: Unchecked
Use 4000 SSe: Unchecked



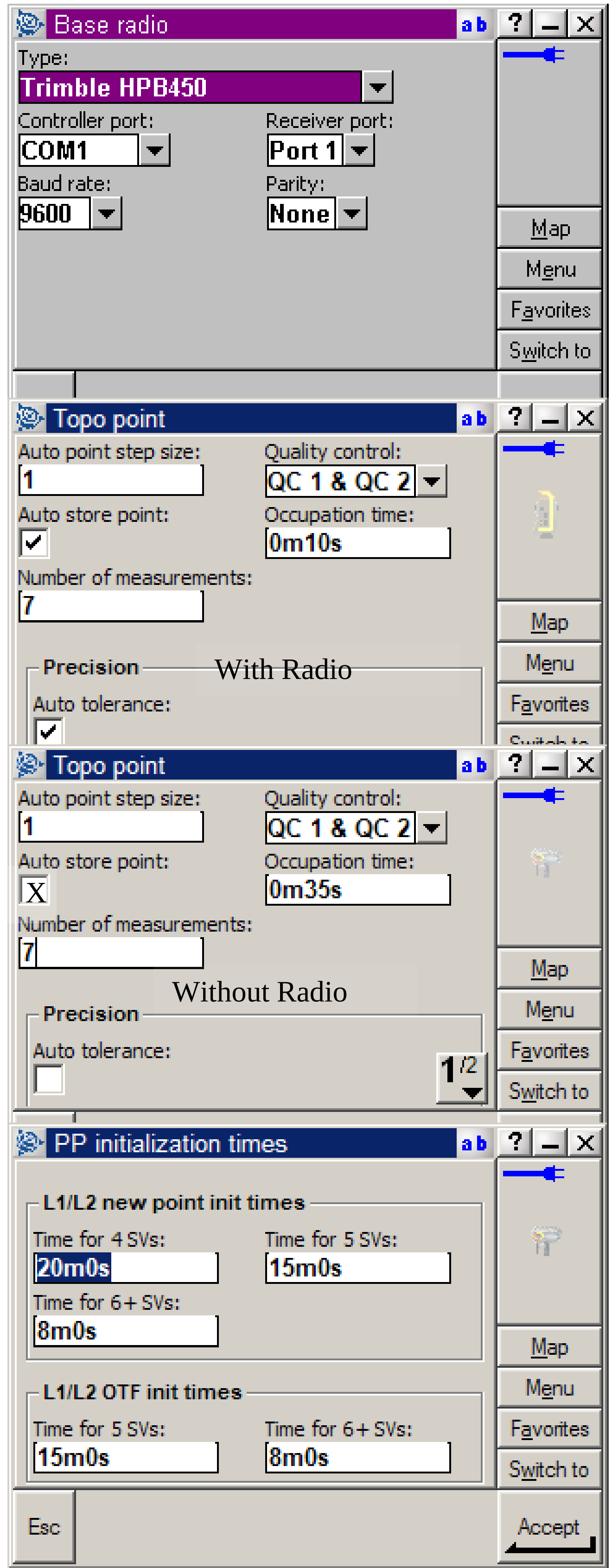
Base Radio:

Type: Trimble HPB450
Controller Port: Com 1
Reciever Port: Port 1
Baud Rate: 9600
Parity: None

Topo Point

Auto Point Step: 1
Quality Control: QC1 & QC2 (Without QC2 you will be unable to process infill data)
Auto Store: Check
Occupation Time: 10 seconds **NOTE:** (When you have no radio these need to be set to 35 seconds (5s Intervals' X 7 measurements=35 seconds))
Number of Measurements: 7
Auto Tolerance: Unchecked
Page 2
Horizontal Tolerance: 0.049ift
Vertical Tolerance: 0.066ift

(Note: Leaving your measurements at 7 and Occupation time set to 10- The measurements should override the time and take 7 measurements at 5s intervals for a 35s shot time. But insure that this is happening.



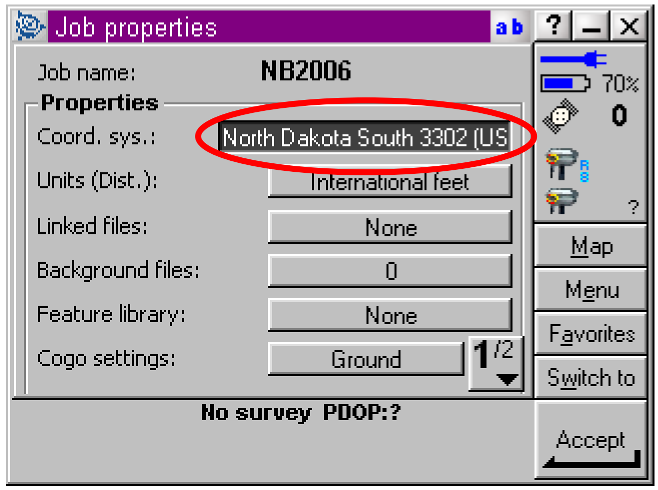
Job Properties

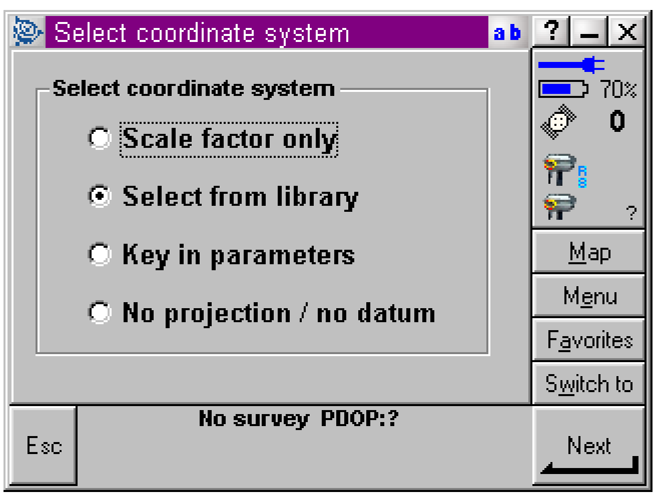
Job Properties:

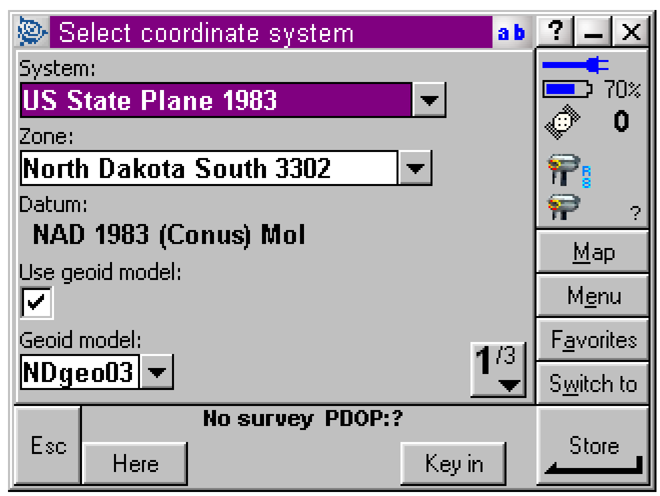
Coord Sys: North Dakota South, or North
Units: International Feet
System: US State Plane 1983
Zone: ND North/South
Datum: NAD 1983
Geoid: Checked
Geoid: NDgeo03.ggf
Project Height: Enter within 100ft

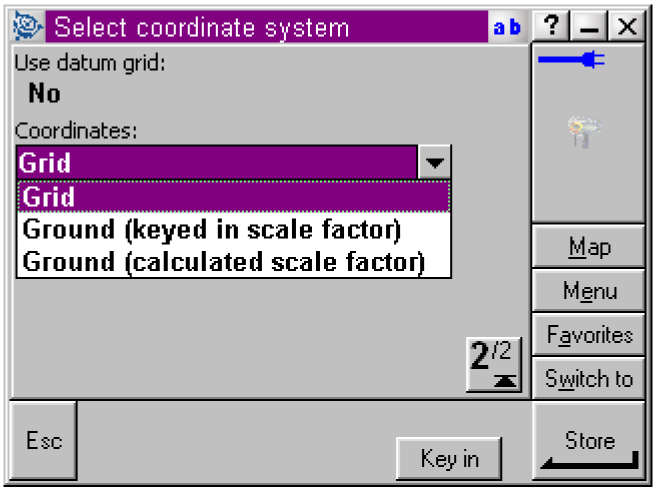
All Measurements must be:

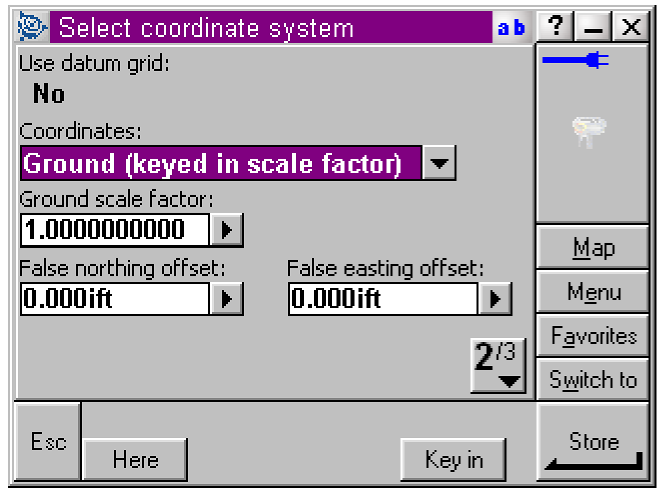
International Feet



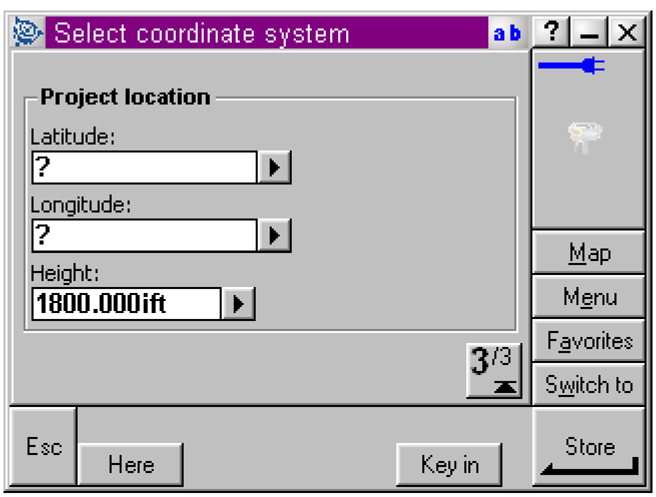








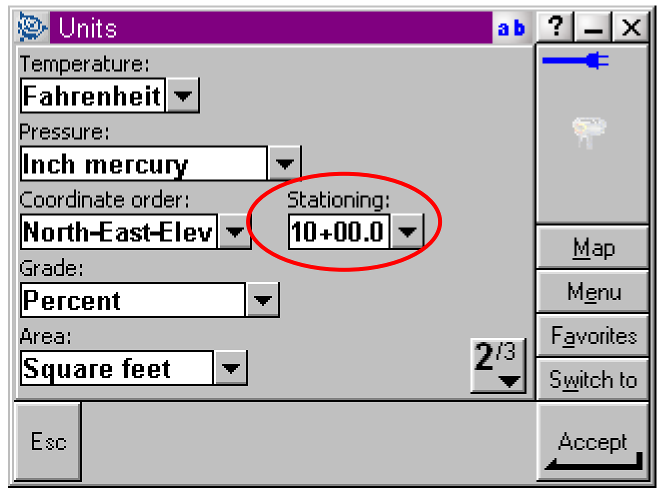
All Survey Data will be collected using Grid Coordinates. For final Ground Coordinate data submission, data will be converted to ground per "Design to Construction Automation" Manual beginning on page 19



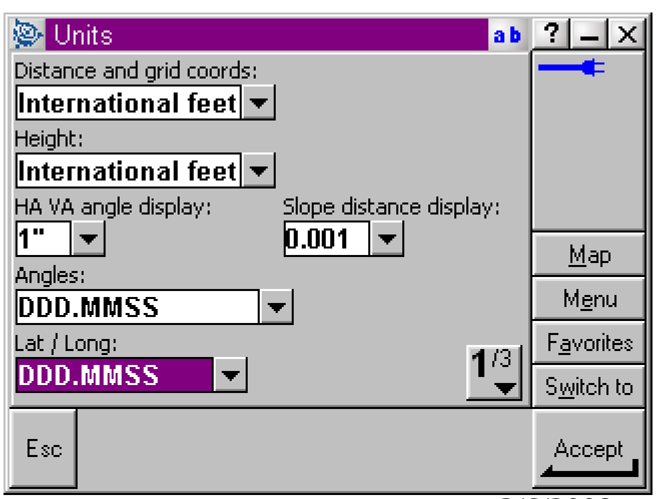
Project Height should be within 100ft of actual elevation.

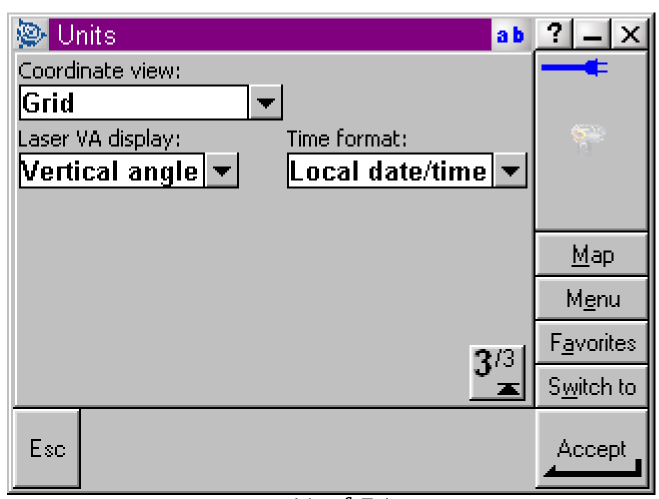
Job Properties
Units Attributes

Insure that the units are identified as **INTERNATIONAL FEET.**



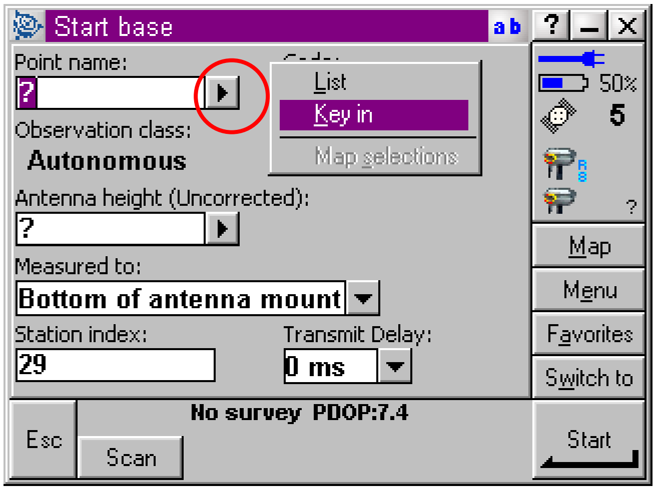
Set Stationing to 10+00, or your offsets will not match, when staking

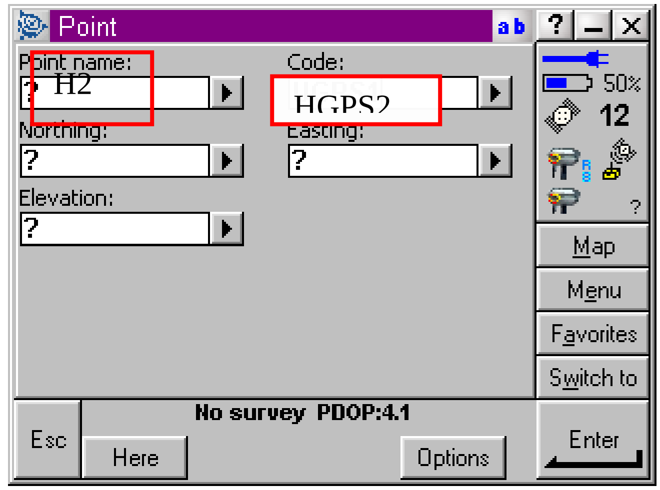




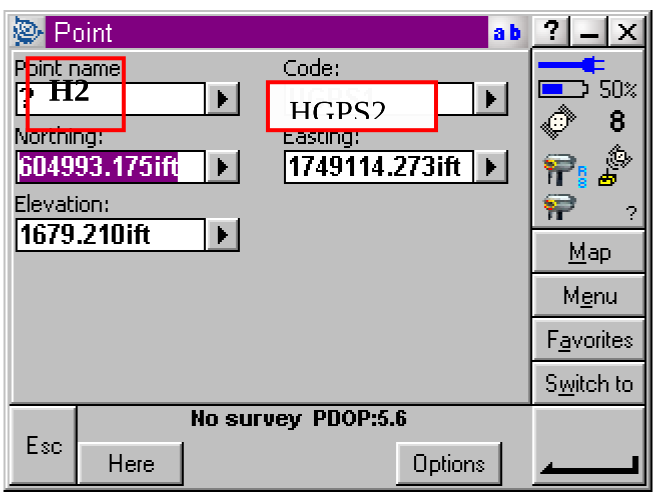
Starting a Base with "You Are Here"

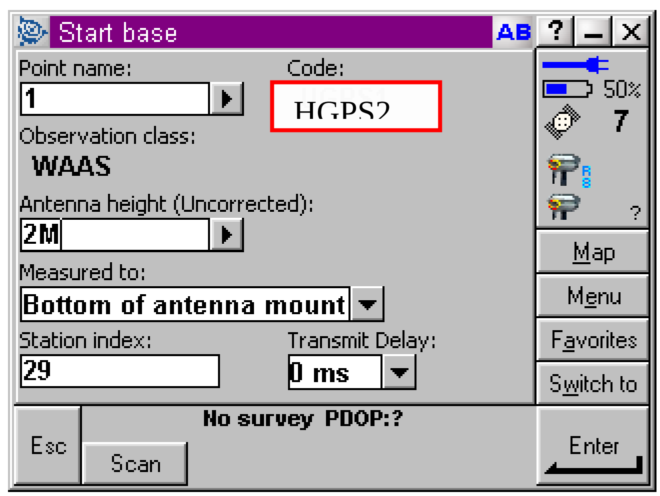
(No Control)



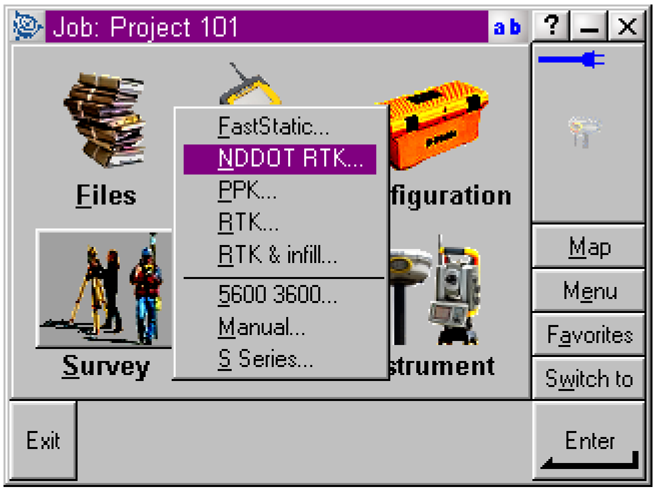


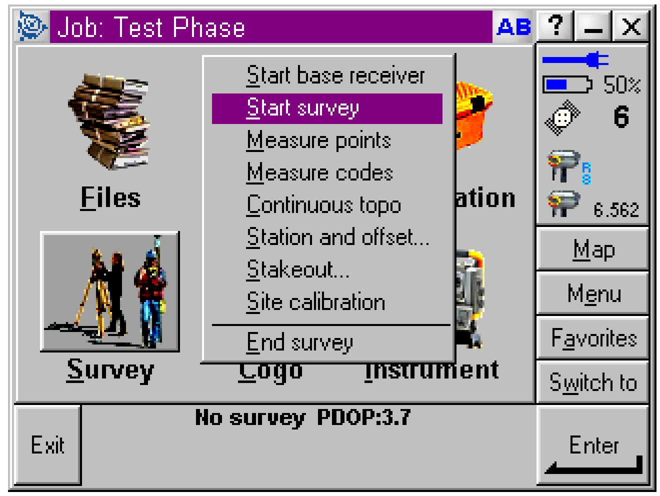
NOTE: When Using False Coordinates, Such as "You Are Here" **you must put an "H" in front of the point number, and code**. Ie. Point Name (H2), Code (HGPS2).

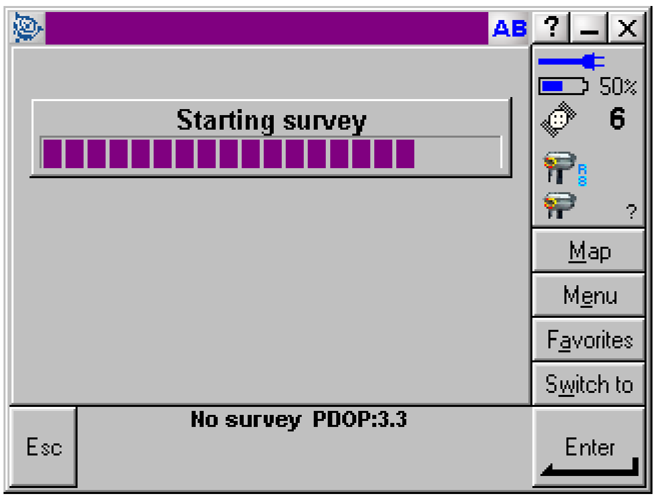


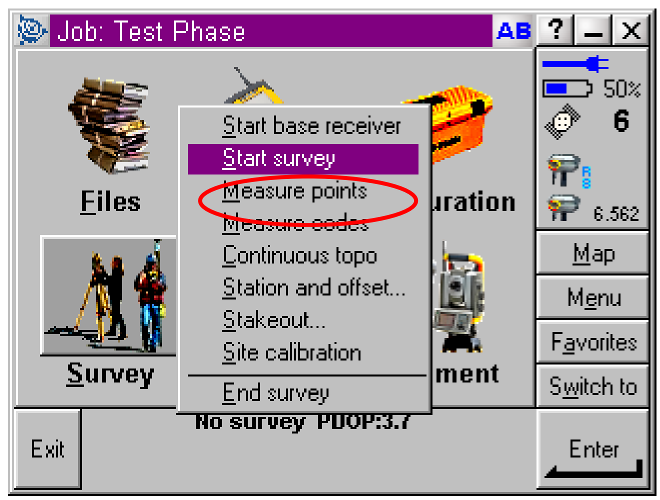


Measure Points





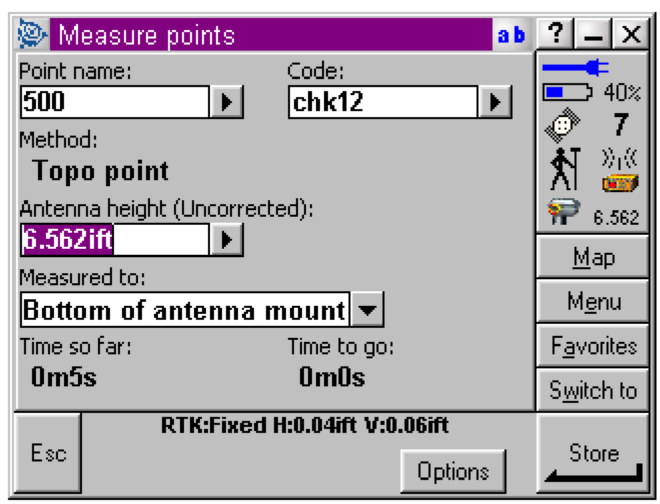




If your starting on an existing job, you need to insure that you have the correct Starting Point Number.
If your unsure you need to verify what ranges are open, or you could overwrite previously recorded data. After Starting Survey,

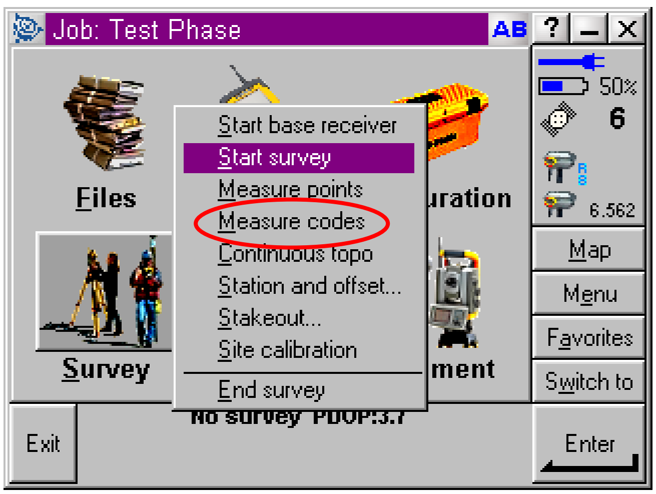
Remember, SURVEY DATA NEEDS TO BE LEAGALLY DEFENDABLE, CHECKSHOTS WILL HELP GREATLY.

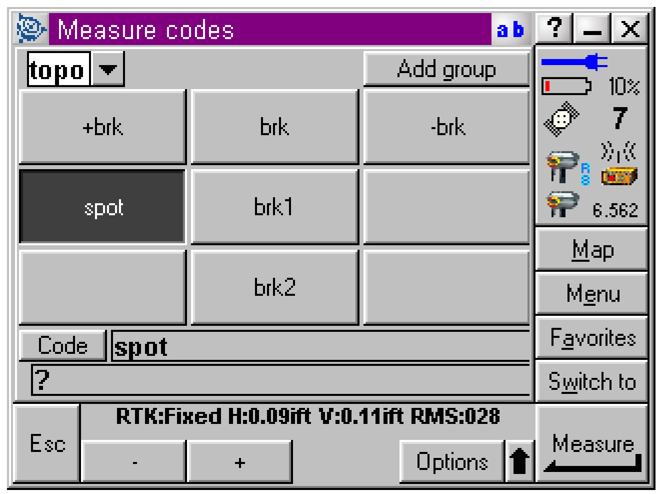
3/6/2008



Measure Codes

This is where most of the surveying will be done. Remember to check your files for the correct Point Name to collect data with. Note: If you have auto-store unchecked, you will have to manually store the point.

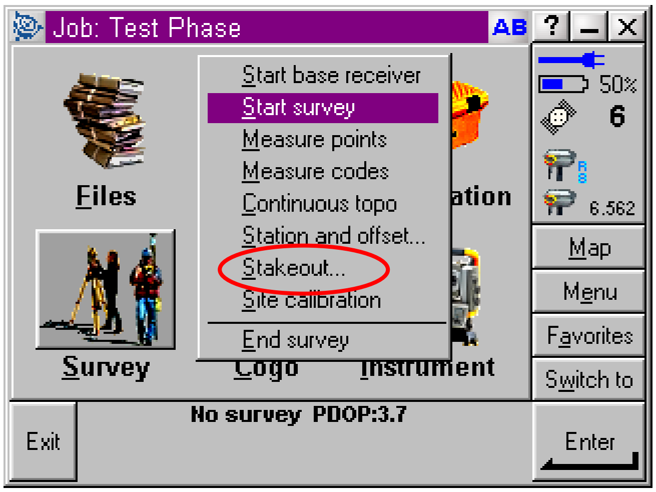


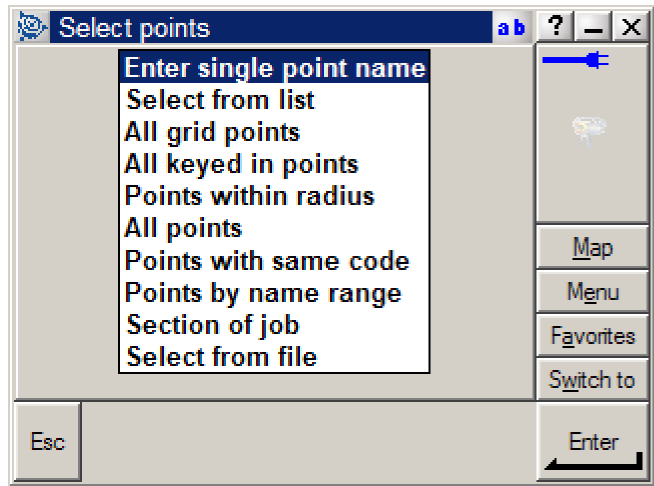


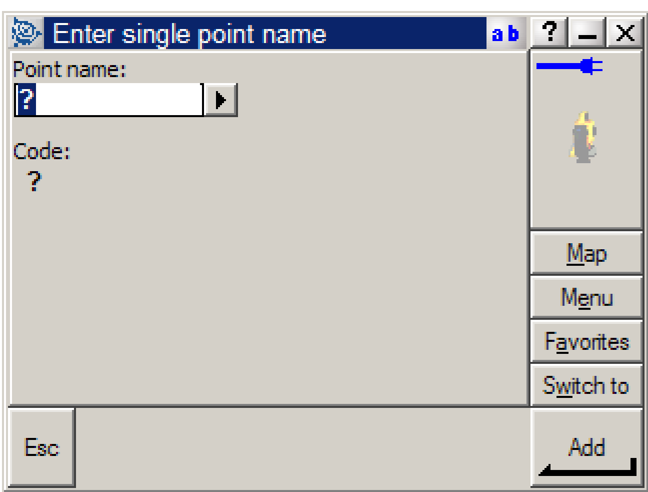
Measure Codes is useful when shooting repetitious items. Utilities, DTM's, ect. When ready to take a shot, simply touch the code, and it starts to take the shot.

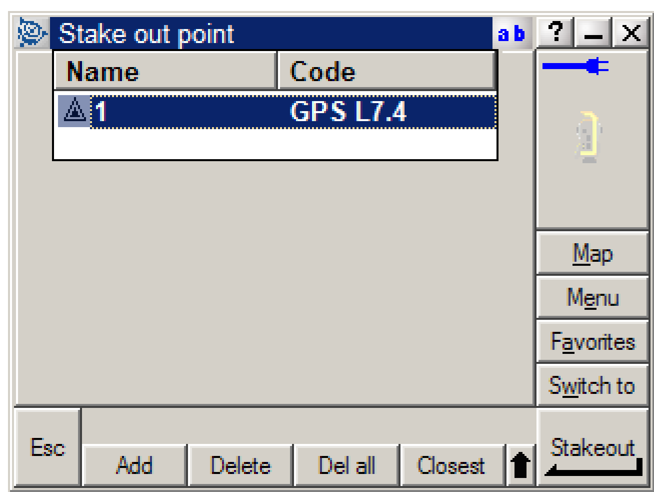
NOTE: Please Do not put the ENTIRE EFB Code list in, it will crash your TSC2. Place the codes your using in a couple of groups, and change according to needs.

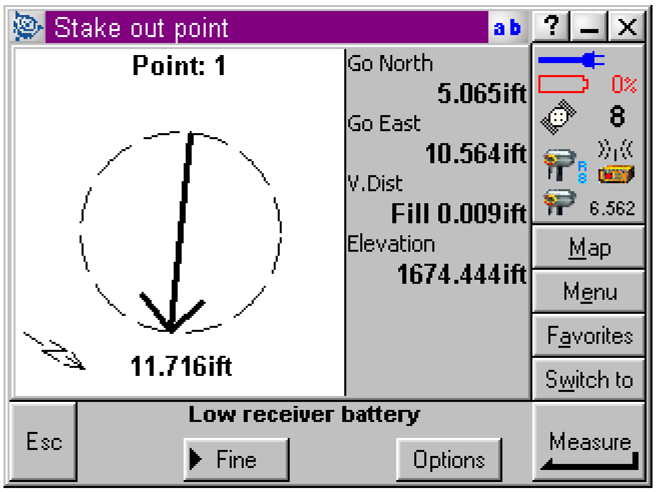
STAKEOUT POINTS
(With Base Station Set up)

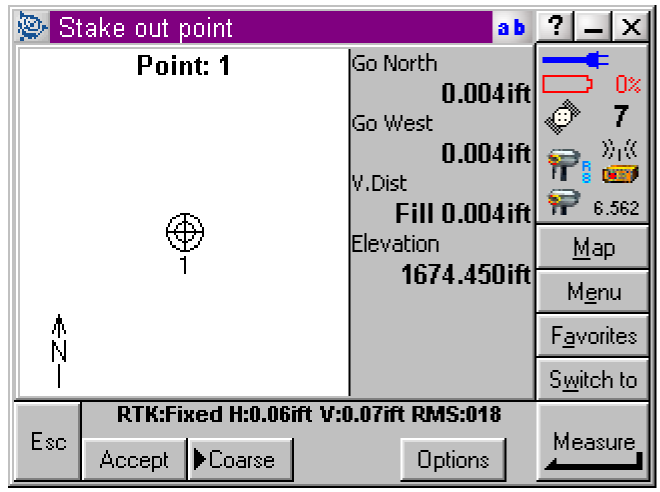




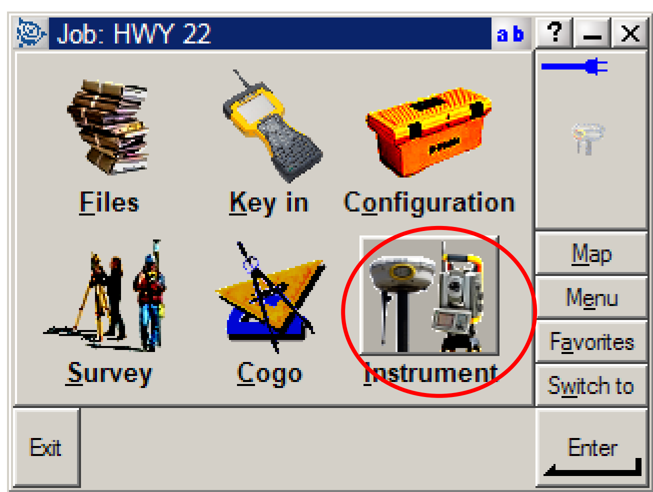








Note: Without a base station set-up, You can still navigate to a point, (ie. A control point that your not sure where it is). 1) Simply power on your Receiver, on the TSC2, 2) Select instrument, then 3) navigate to point. This should get you plus or minus 10M to the spot. (In this configuration, it acts just like a handheld GPS unit).



DESCRIPTION OF TERMS

Azimuth	The horizontal angle reckoned clockwise from the meridian -- from north in highway surveying.
Backsight	The reference point from which horizontal angles are measured.
Benchmark	The specific case of a vertical control point.
Consultant	A private surveying firm qualified under the laws of North Dakota to practice land surveying and acting, under agreement, as an agent of NDDOT.
Control	Any station for which position coordinates and/or elevation are already known, and from which the positions or elevations of unknown stations are determined.
Data Collector	Portable computer, usually sized to hold in one hand, which automatically records observations made with a total station.
Direct	The telescope of the total station is in its normal orientation relative to the supporting instrument trunions.
EDM	Electronic Distance Measuring.
Elevation	Orthometric height. The height of a station above the geoid, e.g., height above mean sea level. The commonly used height reference.
Ellipsoid	The height of a station above the Height ellipsoid surface defining the datum, in this case the NAD 83 datum.
Fast Static	GPS Observation technique achieving minimum point occupation times through coordinated relocation of some units.
FBN	Federal Base Network. That portion of the HARN in North Dakota established by NGS.
Foresight	The station or location to which a horizontal angle (relative to the backsight), zenith angle, and distance are measured.
GPS	Global Positioning System. A surveying technology using specialized radio receivers tuned to signals from military navigation satellites to position survey stations.

HARN	High Accuracy Reference Network. This is a single horizontal network of GPS and VLBI stations based on the new continental network established by NGS.
HI	Height of Instrument. The vertical distance from the station mark to the center of the trunion axis of the total station or level.
HT or HR	Height of Target (Reflector). The vertical distance from the station mark or the ground to the center of the object being sighted with the total station.
Kinematic	GPS Observation technique achieves shortest possible occupation time by continuously tracking satellites during movement between stations.
NAD 27	North American Datum of 1927. Horizontal reference datum.
NAD 83	North American Datum of 1983. Horizontal reference datum which superceded NAD 27.
NAVD 88	North American Vertical Datum of 1988. Vertical reference datum which superceded NGVD 1929.
NGS	National Geodetic Survey. The federal government activity responsible for national programs in geodesy and geodetic surveying. A Division under the National Ocean Service of the National Oceanic and Atmospheric Administration, within the Department of Commerce.
NGVD 29	National Geodetic Vertical Datum of 1929. Vertical reference datum.
PDOP	Position Dilution of Precision. A measure of GPS satellite geometry.
Post Processing	GPS observation data simultaneously collected by several receivers is returned to the office for differential correction processing and adjustment.
Photogrammetry	The science of obtaining reliable information about physical objects through recording, measuring, and interpreting photographic images.
Position	The coordinates, in a horizontal reference system, of station mark or feature. Latitude and longitude, and Northing and Easting are examples of position coordinates in systems used in surveying.
Real Time	GPS differential correction information is received and used to compute and display raw positions in the field as observations proceed.
Reverse	The telescope of the total station is "upside down" from its normal position relative to the supporting instrument trunions.
ROW	Right-of-Way. The strip or area of land around a state highway granted as easement or fee to the State and managed by NYSDOT.

Static GPS	Observation technique having all receivers stationary at points on a fixed, pre-determined schedule.
Total Station	Electronic surveying instrument that combines angle and distance-measuring capabilities in a single unit.
TPS	Total Station Positioning System
Zenith Angle	The angle, measured in the vertical plane, between straight up (zero) and the target of observation. Horizontal is, therefore, 90 degrees.

TSC2 Controller: Upgrading to the Trimble Survey Controller Software Version 11.32

This Support Note describes how to install the components required to upgrade a TSC2™ controller to the Trimble Survey Controller™ software version 11.32. Access the components from the *Downloads* section on the *Trimble Survey Controller for the TSC2* support page.

There are six main steps involved, but you may not need to complete them all.

Step 1: Trimble Data Transfer

This step updates the Trimble Data Transfer utility to the latest version. It includes installing the latest converters required by office applications to convert and process the new version of Trimble Survey Controller job files.

You must complete this step on any office computer that processes Trimble Survey Controller job files.

1. Click **Step 1: Trimble Data Transfer** (http://www.trimble.com/datatransfer.shtml).
2. Click *Trimble Data Transfer V1.27*.
3. Select the language from the drop-down list and then click **Download Now**.

__Note:__ Make sure that you upgrade the software in the same language as that of your previously installed software.

4. If prompted by an InstallShield Wizard Security Warning, select *I understand the security risk and wish to continue* and then click **Next**.
5. If a version of the Data Transfer utility is already installed on the computer, the InstallShield Wizard *Welcome* screen asks you to modify, repair, or remove the program. Select **Modify** and then click **Next**.
6. Select the *Land Survey Devices* checkbox and then click **Next**.
7. When the wizard has finished, click **Finish**.

__Note:__ If you have the Microsoft® Windows® 2000, XP, or Windows NT® operating system installed, you must be an administrator to install the Data Transfer utility.

Step 2: Operating system

Upgrade the Microsoft Windows Mobile™ 2003 Software for Pocket PCs operating system on a TSC2 controller to Microsoft Windows Mobile® version 5.0.3 software.

- If you are upgrading from the Trimble Survey Controller software version 11.10 or 11.20, you must obtain a Microsoft Windows Mobile 5.0 Companion CD, license sticker, and authorization key, before you can upgrade the operating system. Trimble will mail these out to TSC2 customers.
- If you are upgrading from the Trimble Survey Controller software version 11.21 or later, Microsoft Windows Mobile 5.0 is already installed on your controller, and you must follow the instructions below to upgrade to the latest version.

Finding out which version of the controller operating system you have

1. Tap *Start / Settings*.

2. Tap the *System* tab, and then tap the *System Information* icon.

   The Firmware version is displayed on the *System Information* screen.

Recording the Trimble Survey Controller authorization key

To find the authorization key:

1. Run the Trimble Survey Controller software on the controller.
2. From the main menu, tap *Configuration / About Trimble Survey Controller*.

   The authorization key appears on the screen. Record this 16-digit code.

Upgrading the operating system

1. Save any important files on the controller to the office computer. If you do not have any data to back up, you can leave out this step.

__Caution:__ The operating system installation for the TSC2 controller does not back up the files in the Trimble Data folder. This folder is deleted as part of the installation and the data is permanently lost.
Use ActiveSync to copy the files to the office computer and then to copy them back onto the controller after you upgrade it.

   a. Use the Microsoft ActiveSync® technology version 4.2 to connect the controller to the office computer.
   b. Use Explorer on the office computer, to browse to the */My Pocket PC/Built-in Storage /Trimble Data* folder on the controller.
   c. Click and drag a copy of the */Trimble Data* folder, and any other files you want to save to the office computer desktop.

2. Click **Step 2: Operating System** (http://www.trimble.com/tsc_ts.asp?Nav=Collection-44202).
3. Click **Save** to save the Operating System installer to the computer.
4. When the download is complete, do one of the following:
   - If the *Download complete* dialog appears, click **Run** to start the installation.
   - Double-click the file you just downloaded *(TrimbleTSC2UpdateV5_0_3WWE.exe)*.
5. Click **Setup** and then follow the instructions on the screen.

   To put the controller in USB mode, follow the instructions on the screen.

   When prompted, enter the Windows Mobile 5.0 software authorization key.
6. When the operating system upgrade is complete, tap the controller screen and then follow the instructions to complete the controller setup.
7. Copy the files you backed up earlier back onto the controller. If you did not back up any data, you can leave out this step.
   a. Use ActiveSync technology to connect the controller to the office computer.
   b. Use Explorer on the office computer, to browse to the */My Windows Mobile-Based Device* folder on the controller.
   c. Drag and drop the copy of the */Trimble Data* folder from the office computer to the controller. Put it at the same level as the */Windows* folder.

Note: *The ActiveSync technology is available as a download from www.microsoft.com.*
The Windows Mobile 5.0 software requires ActiveSync technology version 4.2 or later.

Step 3: Trimble Survey Controller Software

Upgrade to the Trimble Survey Controller software version 11.32.

Note: *If you use a Trimble R8 GNSS receiver with the Trimble Survey Controller software version 11.32, you must upgrade the receiver to firmware version 3.20 or later.*

Trimble GNSS receiver firmware is available from:
http://www.trimble.com/trimbler8gnss_ts.asp?Nav=Collection-21462

1. Click **Step 3: Trimble Survey Controller Software** (http://www.trimble.com/tsc_ts.asp?Nav=Collection-44202).
2. Click **Save** and then save the Software installer to the computer.
3. When the download is complete, do one of the following:
   - If the *Download complete* dialog appears, click **Run** to start the installation.
   - Double-click the file you just downloaded (*TSCv1132_Installation_TSC2.exe*).
4. Follow the instructions on the screen.

Caution: *If a /Trimble Data folder exists on the controller, the install wizard includes an option to download the files in Trimble data. If you clear the Download Trimble Data files checkbox, the contents of this folder are not downloaded. This folder is deleted as part of the install and the data is permanently lost.*

Step 4: Language packs

Installing the Trimble Survey Controller software version 11.32 Language Packs.

When you install a new language pack, the old language pack is deleted. This can take a few minutes.

1. Click **Step 4: Language packs** (http://www.trimble.com/tsc_ts.asp?Nav=Collection-44205).
2. Click the link for the language pack you want to install.
3. Click **Save** and then save the Language pack installer to the computer.
4. When the download is complete, do one of the following:
   - If the *Download complete* dialog appears, click **Run** to start the installation.
   - Double-click the file you just downloaded (*TSCv1132_LanguagePack_TSC2_<Language>.exe*).
5. Follow the instructions on the screen.

Step 5: Upgrade Trimble Data files

This step describes how to upgrade the Trimble Data files to the latest version and transfer them to the controller.

During an upgrade, if a */Trimble Data* folder exists on the controller you can choose to save all files in */Trimble Data* on the controller to the office computer.

Once you upgrade, you can transfer back onto the controller any files that are compatible with the new version of the Trimble Survey Controller software.

To determine compatibility, the software inspects the files before transferring them to the controller. Job and style files from the Trimble Survey Controller software version 10.70 and later can be converted and transferred. A variety of other files (for example, .fal from version 10.7 and 10.8, .dc, .csv, .txt, .dtm, .ttm, .ggf, .cdg, .pjg, .sgf, .pgf, .dxf, .shp, .rxl, .crd, .inp, .mos, .xml, .jxl, and .csd) can also be transferred back onto the controller.

A report of the transferred files is available at the end of this operation. The report details the files that were converted, the files that were transferred, and the files that were not transferred (for example, .xsl and .ixl files).

Note: *This step applies only if the contents of the Trimble Data folder were backed up during installation of the operating system or the software.*

1. Click **Step 5: Upgrade Trimble Data files** (http://www.trimble.com/tsc_ts.asp?Nav=Collection-44202).
2. Click **Save** to save the Transfer Trimble Data installer to the computer.
3. When the download is complete, do one of the following:
   - If the *Download complete* dialog appears, click **Run** to start the installation.
   - Double-click the file you just downloaded (*TSCv1132_TransferTrimbleData.exe*).
4. Follow the instructions on the screen.

Note: *The downloaded files are stored on the office computer in C:\Documents and Settings\[username]\Local Settings\Temp\[controller serial number]\Download.*

*You **cannot** copy old jobs onto the controller for the Trimble Survey Controller software to convert on−the−fly. If you have old job files to convert to the new version, and they were not downloaded during the upgrade process, copy them to the download folder and then use Step 5: Upgrade Trimble Data Files to convert the files and transfer them back onto the controller.*

Step 6: GPS receiver and GPS antenna files

This step updates the GPS receiver and GPS antenna files for the Trimble software on the office computer. If you have a new GPS receiver or a new GPS antenna, you may need to update some of the components in the office software to enable it to recognize the new equipment. If you do not have a new GPS receiver or a new GPS antenna you can leave out this step.

1. Click **Step 6: GPS receiver and GPS antenna files** (http://www.trimble.com/trimbleconfiguration_ts.asp).
2. Click **Download Trimble Office Configuration File Update Utility**.
3. Click **Save** to save the Trimble Office Configuration Files Update Utility installer to the computer.
4. When the download is complete, do one of the following:
   - If the *Download complete* dialog appears, click **Run** to start the installation.
   - Double-click the file you just downloaded (*CFGUpdate<date>.exe*).
5. Follow the instructions on the screen.

Trimble R8 GNSS Specs

TRIMBLE R8 GNSS SYSTEM

PERFORMANCE SPECIFICATIONS

Measurements

- Trimble R-Track technology
- Advanced Trimble Maxwell™ Custom Survey GNSS Chip
- High precision multiple correlator for GNSS pseudorange measurements
- Unfiltered, unsmoothed pseudorange measurements data for low noise, low multipath error, low time domain correlation and high dynamic response
- Very low noise GNSS carrier phase measurements with <1 mm precision in a 1 Hz bandwidth
- Signal-to-Noise ratios reported in dB-Hz
- Proven Trimble low elevation tracking technology
- 72 Channels:
  - GPS L1 C/A Code, L2C, L1/L2/L5 Full Cycle Carrier
  - GLONASS L1 C/A Code, L1 P Code, L2 P Code, L1/L2 Full Cycle Carrier
  - SBAS WAAS/EGNOS support[1]

Code differential GPS positioning[2]

Horizontal	±0.25 m + 1 ppm RMS
Vertical	±0.50 m + 1 ppm RMS
WAAS differential positioning accuracy[3]	typically <5 m 3DRMS

Static and FastStatic GPS surveying[2]

Horizontal	±5 mm + 0.5 ppm RMS
Vertical	±5 mm + 1 ppm RMS

Kinematic surveying[2]

Horizontal	±10 mm + 1 ppm RMS
Vertical	±20 mm + 1 ppm RMS
Initialization time	typically <10 seconds
Initialization reliability[4]	typically >99.9%

HARDWARE

Physical

Dimensions (W×H)	19 cm × 11.2 cm (7.5 in x 4.4 in), including connectors
Weight	1.35 kg (2.97 lb) with internal battery, internal radio, standard UHF antenna. 3.71 kg (8.18 lb) entire RTK rover including batteries, range pole, controller and bracket
Temperature[5]	
Operating	–40 °C to +65 °C (–40 °F to +149 °F)
Storage	–40 °C to +75 °C (–40 °F to +167 °F)
Humidity	100%, condensing
Water/dustproof	IP67 Dustproof, protected from temporary immersion to depth of 1 m (3.28 ft)
Shock and vibration	Tested and meets the following environmental standards:
Shock	Non-operating: Designed to survive a 2 m (6.6 ft) pole drop onto concrete. Operating: to 40 G, 10 msec, sawtooth
Vibration	MIL-STD-810F, FIG.514.5C-1

Electrical

- Power 11 to 28 V DC external power input with over-voltage protection on Port 1 (7-pin Lemo)
- Rechargeable, removable 7.4 V, 2.4 Ah Lithium-Ion battery in internal battery compartment. Power consumption is <3.1 W, in RTK mode with internal radio. Operating times on internal battery:
  - 450 MHz receive only option 5.3 hours, varies with temperature
  - 450 MHz receive/transmit option 3.5 hours, varies with temperature and wireless data rate
  - GSM/GPRS 3.8 hours, varies with temperature
- Certification Class B Part 15, 22, 24 FCC certification, 850/1900 MHz. Class 10 GSM/GPRS module. CE Mark approval, and C-tick approval

Communications and Data Storage

- 3-wire serial (7-pin Lemo) on Port 1. Full RS-232 serial on Port 2 (Dsub 9 pin)
- Fully Integrated, fully sealed internal 450 MHz receiver/transmitter option:
  - Transmit power: 0.5 W
  - Range[6]: 3–5 km typical / 10 km optimal
- Fully integrated, fully sealed internal GSM/GPRS option[7]
- Fully integrated, fully sealed 2.4 GHz communications port (Bluetooth®)[7]
- External cellphone support for GSM/GPRS/CDPD modems for RTK and VRS operations
- Data storage on 11 MB internal memory: 302 hours of raw observables based on recording data from 6 satellites at 15 second intervals
- 1 Hz, 2 Hz, 5 Hz, and 10 Hz positioning
- CMRII, CMR+, RTCM 2.1, RTCM 2.3, RTCM 3.0 Input and Output
- 16 NMEA outputs. GSOF and RT17 outputs. Supports BINEX and smoothed carrier

1 The availability of the L5 signal is dependent on the US Government.
2 Accuracy and reliability may be subject to anomalies such as multipath, obstructions, satellite geometry and atmospheric conditions. Always follow recommended survey practices.
3 Depends on WAAS/EGNOS system performance.
4 May be affected by atmospheric conditions, signal multipath, and satellite geometry. Initialization reliability is continuously monitored to ensure highest quality.
5 Receiver will operate normally to –40 °C. Bluetooth module and internal batteries are rated to –20 °C.
6 Varies with terrain and operating conditions.
7 Bluetooth and GSM type approvals are country specific. Contact your local Trimble Authorized Distribution Partner for more information.

Specifications subject to change without notice.