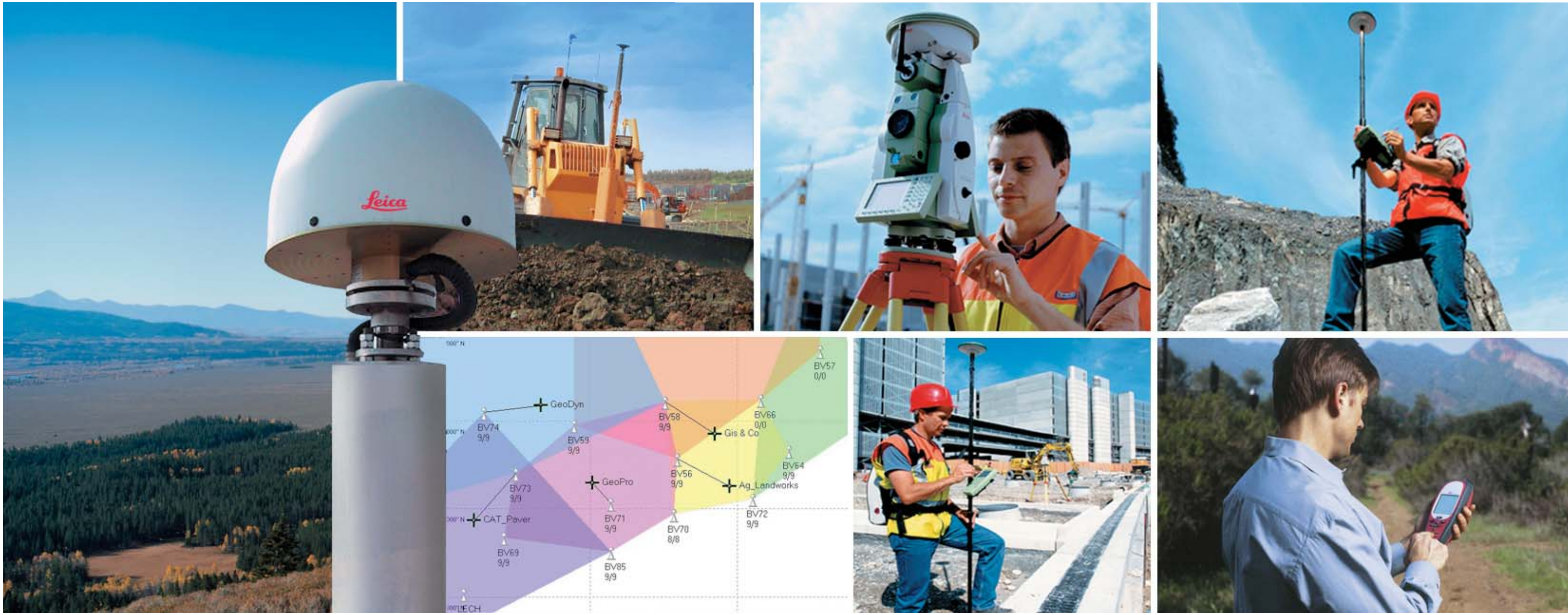
GPS Reference Stations and Networks
An introductory guide



- when it has to be **right**

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Geosystems

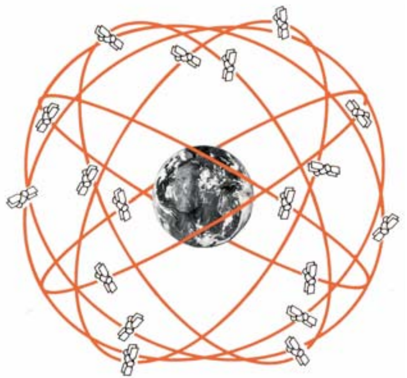
Contents

1. Introduction: aim of this book

Although the benefits of Continuously Operating GPS Reference Stations - often referred to by the acronym CORS - are generally well recognized today, there is still considerable uncertainty within many organizations and amongst many would-be users as to the best way to establish reference stations and provide appropriate levels of services for the GPS user community.

This book offers practical advice on how to set up and run both individual GPS reference stations and networks of stations and to provide the services that are required.

As budgets are sometimes limited, and as reference stations and networks can vary considerably in complexity and, therefore, the investment needed, emphasis is placed on efficient, cost-effective solutions.



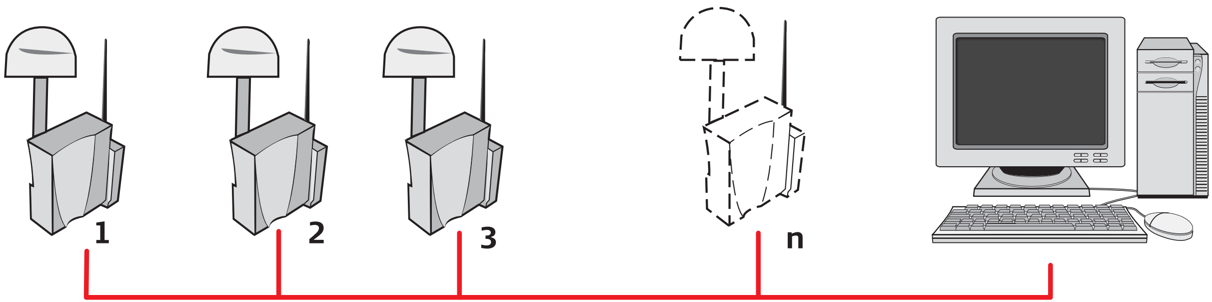
For general background information on GPS, please see the book "GPS Basics" 713282 by Leica Geosystems.

2. What is a Continuously Operating Reference Station (CORS)? What is a network?

A continuously operating GPS reference station - or permanent reference station as it is often called - comprises a GPS receiver and antenna set up in a stable manner at a safe location with a reliable power supply. The receiver operates continuously, logging raw data, perhaps also streaming (continuously outputting) raw data, and often outputting RTK and DGPS data for transmission to RTK, GIS and GPS navigation devices. The receiver is usually controlled by a computer that can be located remotely if necessary. The PC will usually download data files at regular intervals and pass them to an FTP server for access by the GPS user community.

One or more single reference stations supplying GPS services to users in the immediate surrounding areas may be all that is required by some organizations. Other authorities, however, may need to establish networks of reference stations - perhaps 5, 10, 20, 50, or even more stations - to provide complete GPS services over entire regions and even countries. A single server (computer) running a GPS reference station software and communicating by telephone, LAN, WAN or Internet can control all the stations in the network (PCs are not required at the receivers).

This brief introduction illustrates that reference stations and networks can vary considerably in extent and complexity. Organizations that are studying the establishment of reference stations should consider carefully what the stations will be used for, what services they will have to provide, and what will be the appropriate levels of sophistication and cost.



3. What are GPS reference stations used for?

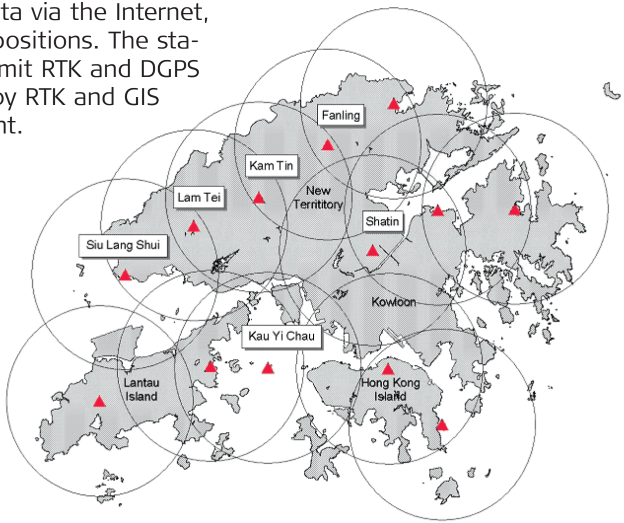
The first reference stations, in the days when GPS was in its infancy, were set up along coastlines to transmit DGPS corrections to improve the accuracy of ship navigation.

Today, with the widespread acceptance of high-precision GPS measurement techniques, GPS reference stations are being established all over the world in ever increasing numbers. They are used to monitor the Earth's crust, to provide geodetic control, to support surveying, engineering, GIS data collection, machine control and precise positioning, as well as to monitor natural and man-made structures. GPS reference stations provide the control needed for a wide variety of applications.

3.1 Geodetic control for surveying, engineering, mapping, cadastre etc.

A network of continuously operating GPS reference stations is more efficient than a traditional triangulation and traverse network. The stations can be set up at convenient locations in areas where they are needed (rather than on remote hilltops). Network geometry is not as critical as with traditional networks, and the accuracy is higher and more consistent. Users set up their field receivers in the areas in which they are working, download reference station data via the Internet, and compute their positions. The stations can also transmit RTK and DGPS data for direct use by RTK and GIS field rover equipment.

Such a network can be of almost any size. Whilst one or two stand-alone reference stations may be all that is required for a local area, town, municipality, opencast mine or engineering site, a multi-station network will usually be needed to provide full GPS service coverage for a large county, region or entire country.



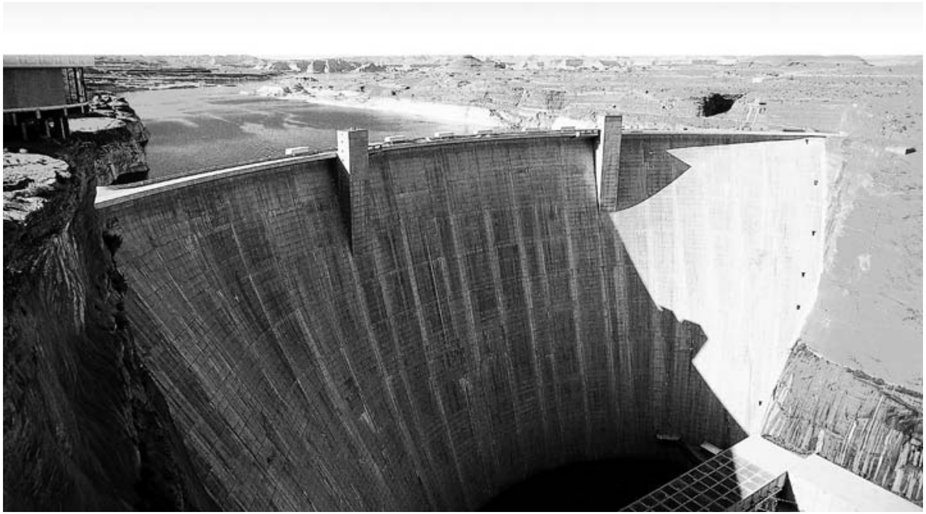
3. What are GPS reference stations used for? (continued)

3.2 Monitoring the Earth's crust, natural and man-made structures

In regions where earthquakes are likely to occur, along major fault lines, and in areas of volcanic activity, networks of suitably positioned GPS reference stations are often used to monitor movements of the Earth's crust.

A central computer with a reference station software controls the receivers, downloads data, and computes the network to determine the positions of the antennas. Movements can be analyzed.

Similar networks, though usually on a smaller scale, are used to monitor the positions and movements of natural and man-made structures such as glaciers, landslides, dams, bridges, buildings, towers, offshore oilrigs etc.



3. What are GPS reference stations used for? (continued)

3.3 Machine guidance

On large construction sites and in opencast mines, work can be carried out faster, with higher accuracy and using less material when machines are equipped with automatic guidance and height-control systems. Bulldozers, graders, scrapers, drilling machines etc. can be positioned and steered to centimeter-accuracy with RTK. The height of the blade can be controlled automatically.

When fields are large, agricultural machines for sowing seed, distributing fertilizer, harvesting, spreading insecticide etc. operate more efficiently and cost effectively when guided by RTK or DGPS.

GPS reference stations provide the control and support needed for machine guidance.

3.4 GIS data collection

Water, electricity, gas and telephone authorities, cadastral offices, municipalities and other similar organizations often operate Geographical Information Systems. The GIS database shows the location of property boundaries, infrastructure, and assets such as water pipes, hydrants, power lines, gas pipes, telephone lines etc.

RTK and DGPS measurement techniques are widely used for updating the database, surveying new features, and re-surveying existing features to improve the accuracy of the data.

GPS reference stations provide the control and support needed by RTK and GIS rover equipment.

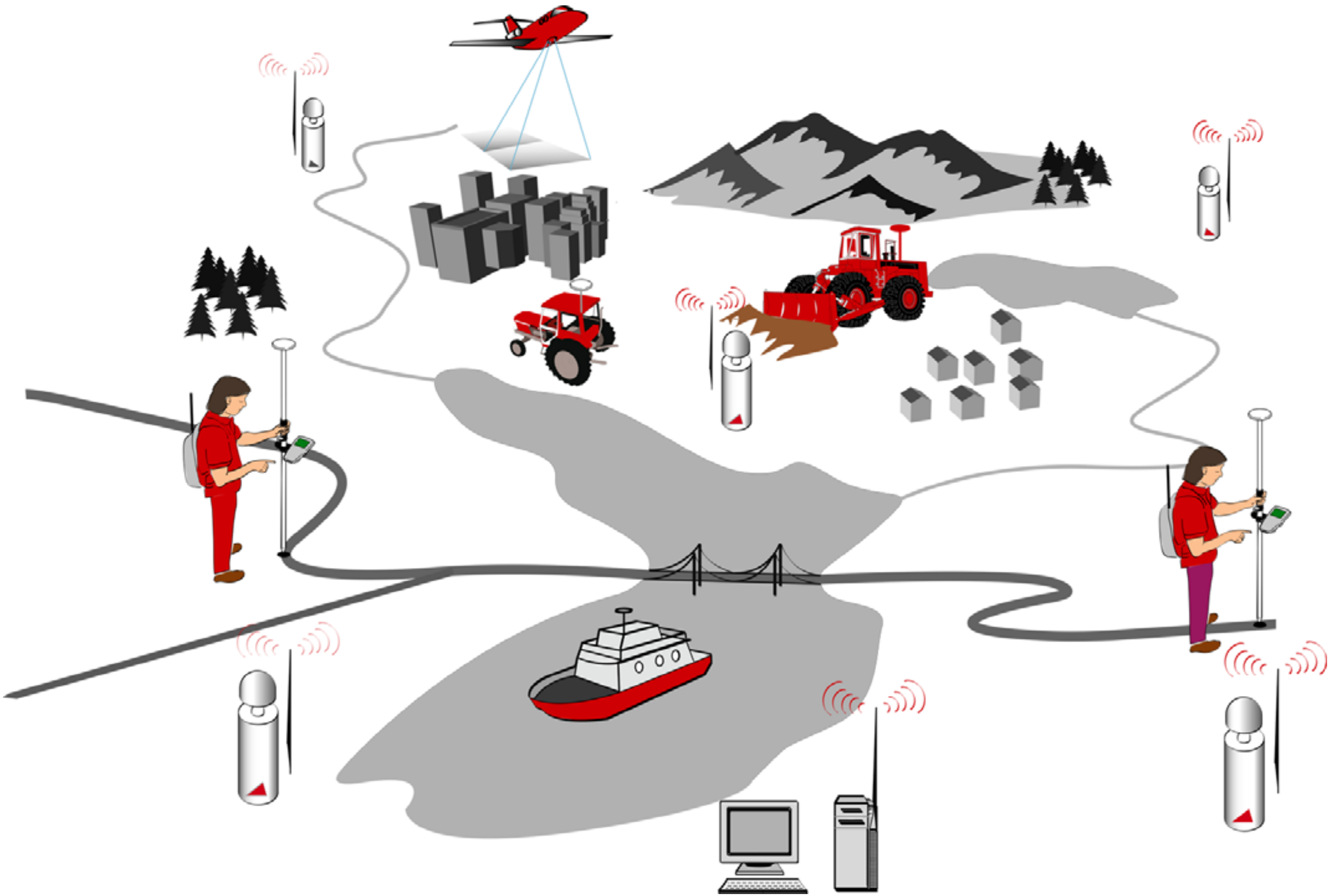
3.5 Endless possibilities

GPS reference stations and networks can be used in many ways for many applications.

Stations and networks can be set up and configured for just one particular application and one user group. Or they can be designed to be multi-functional to support a wide range of applications and a multitude of users.

A single reference station may be perfectly sufficient for a small locality. A multi-station, multi-purpose network will often be preferred for an entire region. The permutations are endless.

One or more permanent reference stations will be needed whenever GPS surveying or monitoring has to be carried out repeatedly over the same area for a long period of time.



GPS reference stations and networks support all types of users and applications

4. What does a GPS reference station or a network of stations have to do?

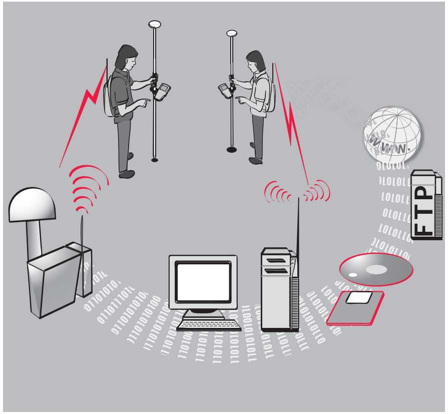
The GPS receivers at reference stations run continuously. The raw code and phase measurement data are usually logged internally in files of specified length. Depending on the application, the file length can be set to any required value from a few minutes to several hours or even to a full day.

Reference station software running on a computer - let us call it a server - controls the receivers and downloads the data files at regular intervals. If required, the raw data can also be streamed continuously, second by second, from the receivers to the server. The reference station software running on the server converts the data to RINEX (Receiver INdependent EXchange format) and produces compressed RINEX files. The RINEX files are pushed to an FTP server for easy Web access by the GPS user community and are also archived for safekeeping.

A server running reference station software can control a single receiver at a stand-alone reference station or an entire network comprised of many receivers. In case of a single stand-alone station, the computer will often be connected directly to the receiver. In case of a multi-station network, the server will usually be at a control center and connected to the receivers by telephone, LAN, WAN or Internet (PCs are not required at the receivers).

Once set up and configured, the stations and network will run fully automatically. However, system supervisors can log in, inspect the receivers and the network and make any changes that are necessary.

A main requirement today is to provide the data needed by real-time survey and GIS rover equipment. The receivers at the reference stations can output data in standard RTCM formats and in other proprietary formats (Leica, CMR, CMR+) for transmission to and use by RTK and GIS field rover receivers. Transmission can be directly from the stations or via other suitable locations. Communication for transmission of RTK and DGPS data will usually be by radio, high-speed wireless (GSM, GPRS, CDMA etc) or even by the Internet.



4. (continued)

If it is required to monitor any movements within a network, it is also possible to arrange for the positions of the antennas to be computed automatically at regular intervals.

The functionality and complexity of an individual station or a network of stations will depend on a number of factors, including:

- The applications for which the station or network is to be used for
- The services that have to be provided
- The number and type of users that have to be supported
- The most suitable methods of communication
- The available infrastructure
- The costs of running the station or the network
- The possibility to charge for services and data
- The available budget

5. Selecting suitable sites

When selecting sites for continuously operating GPS reference stations careful consideration must be given to the following:

- The need for an open view of the sky
- No objects in the vicinity that could cause multipath
- No transmitters in the area that could cause interference
- What the stations will be used for
- How to provide a stable mount for the antenna?
- How to provide reliable power and communication?
- How to house and protect the equipment?
- How to ensure security against vandals and passers-by?
- Accessibility for inspection and service
- Cost

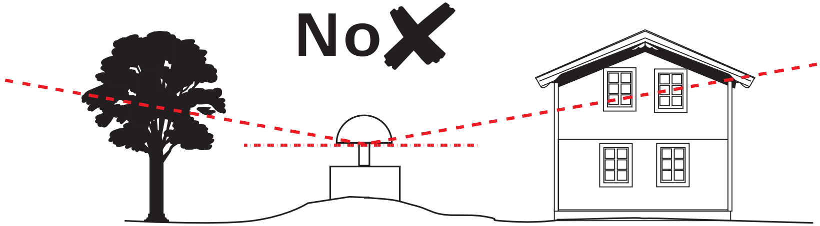
6. Open view of the sky

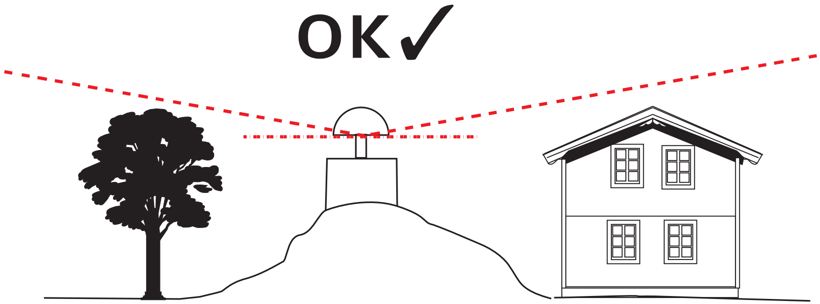
Receivers at reference stations will usually be set to track satellites down to 10° above the horizon (10° cut-off angle). For some applications it may even be required to track satellites down to the horizon, i.e. to 0° elevation.

Obstructions can lead to loss of satellite signals and may also cause multipath (reflected signals). Multipath can have a negative influence on the quality of the data and, therefore, accuracy.

For these reasons sites should be selected where there will be no obstructions above 10° above the horizon of the antenna. This is particularly important for reference stations that will form part of a high accuracy geodetic network. The best, of course, is if there will be no obstructions at all above the antenna horizon.

One way to make fully certain that a site is absolutely perfect for a geodetic reference station is to set up a receiver and antenna, log data for several days, and then analyze the data using the TEQC tool from UNAVCO (see 30. Useful links).





7. Setting up a reference station on a pillar

Well-constructed pillars with solid foundations, ideally bedrock, will usually be preferred for stations that are to be used for monitoring movements of the earth.

Pillars are also sometimes used at stations that form part of a geodetic control network (set ups on buildings are often more practical however).

If pillars are to be used the following should be considered carefully:

- How to provide reliable power and communication?
- Where to place the receiver, power supply and communication device?
- Security

Pillars can be of concrete or metal. Note that, in hot climates, very tall pillars could be liable to slight diurnal deformations caused by the heat of the Sun.

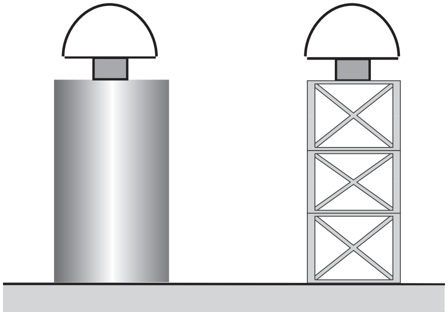
If the pillar is suitably designed, it may be possible to place the GPS receiver, power supply and communication device inside the pillar. Otherwise these items will have to be located in a suitable container, shed or nearby building. Depending on the climate, ventilation or even air conditioning may be necessary.

If the equipment can be placed in a nearby building, the required power and telephone connections will often be available. If the equipment has to be placed in the pillar or in a container, special power and telephone lines may have to be arranged, which can increase costs significantly.

At remote sites in sunny climates, it is possible to arrange a bank of batteries with a solar panel charging system to power the GPS receiver and a communication device, such as a satellite phone or mobile phone.

Unless the reference station can be set up within a secure area, a high fence may be needed to protect the equipment from vandals and passers-by.

Reference stations using pillars need careful planning especially as the required infrastructure can lead to high costs. Examples of pillars can be found on the UNAVCO web site (see 30. Useful links).



8. Setting up a reference station on a building

There are significant advantages in setting up reference stations on buildings, as power and telephone connections are usually available and the equipment should be relatively safe.

Buildings are usually suitable for reference stations that form part of a geodetic control network, that support surveying and engineering applications, and that transmit RTK and DGPS data to RTK and GIS rover units.

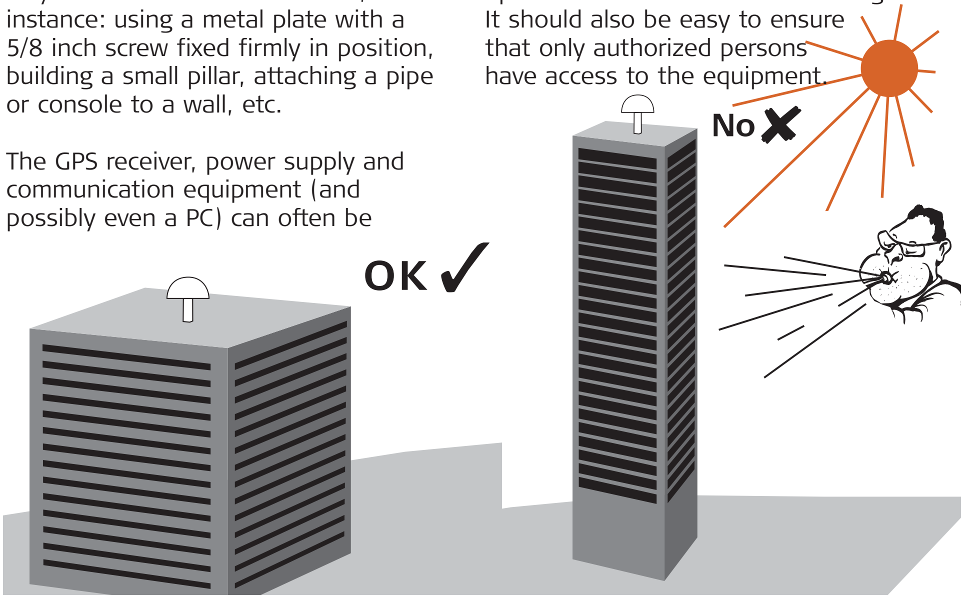
Although it is usually advantageous to place the GPS antenna as high as possible, towers and thin, tall, skyscraper-type buildings are often not suitable as they may sway in strong winds. In hot climates, very tall structures may also deform (bend) slightly due to expansion caused by the Sun.

Flat-roofed buildings of medium height with a relatively large base will normally be very stable and suitable for reference stations.

It is usually easy to arrange a stable mount for the GPS antenna on the roof of a building. There are various ways in which this can be done, for instance: using a metal plate with a 5/8 inch screw fixed firmly in position, building a small pillar, attaching a pipe or console to a wall, etc.

The GPS receiver, power supply and communication equipment (and possibly even a PC) can often be located in a room below the roof where power and telephone connections are available.

In most cases infrastructure costs can be kept reasonably low when setting up a reference station on a building. It should also be easy to ensure that only authorized persons have access to the equipment.



9. Setting up a reference station on a man-made-structure

Networks of GPS reference stations can be used very effectively for monitoring deformations and movements of man-made structures such as dams, bridges, buildings, offshore oilrigs etc.

If the need is to identify slow, long-term movements, data can be logged in the receivers, downloaded at regular intervals to a central control computer, and then processed automatically to obtain the positions of the antennas.

In order to monitor rapid, short-term movements and even vibrations, the raw data have to be streamed continuously at a high rate from the receivers to the control computer. Software running on the computer processes the baselines between the stations continuously.

Movements and deformations can be identified.

The type of structure and the movements to be monitored will determine where and how the GPS antennas have to be set up. The availability of power and telephone connections has to be considered when positioning the GPS receivers, power supply and communication devices.

10. GPS receivers, GPS antennas, cables

10.1 GPS receivers

Modern, universal, dual-frequency receivers, such as those of the Leica System 1200 and System 500 series, are by far the most suitable for reference stations as they produce all types of measurement data (L1, L2, code, phase), generate all required outputs (RTK, DGPS, NMEA) and support every kind of application.

In order to be able to provide the required services to different users at the same time in an optimum manner, it is best if the receiver can log data at high rates, continuously stream raw data, and also output RTK and DGPS data in all commonly used formats (RTCM, Leica, CMR, CMR+).

Simultaneous data logging at two different rates to two different files can also be required for some applications.

The receivers used at reference stations should have sufficient ports for:

- Connecting to a control computer running the reference station software
- Streaming raw data to a control computer if this is a requirement
- Attaching communication devices for transmitting RTK and DGPS data
- Connecting primary and backup power supplies
- Connecting peripheral devices such as meteorological and tilt sensors

Single-frequency receivers are limited in performance and not suitable for use at the multi-purpose reference stations that are often required today. They can be used, however, at stations that simply transmit DGPS data to GIS rovers and navigation receivers. Although it is possible to use single-frequency receivers within small, short-baseline networks that are used for monitoring movements, dual-frequency receivers will usually be preferred.

10. GPS receivers, GPS antennas, cables (continued)

10.2 GPS antennas

If reference stations form part of a national, first-order, geodetic-control network, IGS type choke-ring antennas fitted with Dorne & Margolin elements will often be mandatory. Any reference station that forms part of the global International GPS Service (IGS) network will also usually require a choke-ring antenna. This type of antenna has very high phase-center stability, suppresses multipath to negligible levels, and helps to ensure that measurement data will be of the highest possible quality.

For single, stand-alone reference stations and for reference stations in networks that are used mainly to support surveying and engineering and to provide data to RTK and GIS rovers, standard, compact geodetic antennas are often suitable.

Compact geodetic antennas provide good quality data that are sufficient for most users and applications, and they are significantly less expensive than choke-ring antennas.

10.3 Antenna cables

A standard 10m cable will often be sufficient to connect the antenna to the receiver. If the receiver has to be located further away from the antenna, a longer cable will be needed.

Antenna cables up to 100m or more are obtainable, but the longer the cable the thicker it has to be to minimize loss of signal and the heavier and more unwieldy it becomes. Extra-long cables also cost much more than standard cables.

The best is to use cables that are as short as possible. Cables longer than 30m should rarely be needed.

Choke-ring antenna

Compact geodetic antenna

11. Power supply

11.1 Power supply at the receivers

A GPS reference station needs a reliable, continuous power supply. An AC to DC converter connected to the mains (line) will normally be used for powering the receiver and any other ancillary equipment such as communication devices.

A UPS (Uninterruptible Power Supply) unit will provide backup power for a limited time should the mains (line) supply fail. UPS units are available in various types and sizes (capacity). The larger the capacity, the longer the UPS will power the equipment.

A UPS of appropriate size will almost certainly be needed at a reference station where the mains (line) power is unreliable. However, if the power supply at the mains is very reliable and unlikely to fail, it may be decided that a UPS is not necessary.

When studying whether a UPS is required, it is worth considering whether the reference station is part of a network of stations or whether it is a stand-alone station.

If one station in a network of stations should stop operating very occasionally for a short period of time due to power failure, users of field receivers, RTK and GIS rovers may be able to obtain the data and services that they require from other nearby stations and continue to work; thus the occasional short power failure at one station may not be too critical.

If the station is a single, stand-alone station (not part of a network) - i.e. the only station supplying GPS services to the surrounding area - a power failure will result in all users of field equipment having to stop work.

When evaluating whether to install UPS units and what capacity would be needed, it is also important to consider the level of reliability that is demanded. Users that have to pay for data and services are unlikely to tolerate failures; in this case UPS units will usually be required.

If stations form part of a monitoring network and if failure could lead to danger or even loss of life, UPS units of appropriate size will probably be obligatory.

Note that modern GPS receivers used for reference stations will restart automatically when power is restored.

It may sometimes be necessary to establish a reference station in an area where there is no power. At remote sites in sunny climates, it is possible to arrange a bank of batteries with a solar panel charging system to power the GPS receiver and a communication device such as a satellite phone or mobile phone.

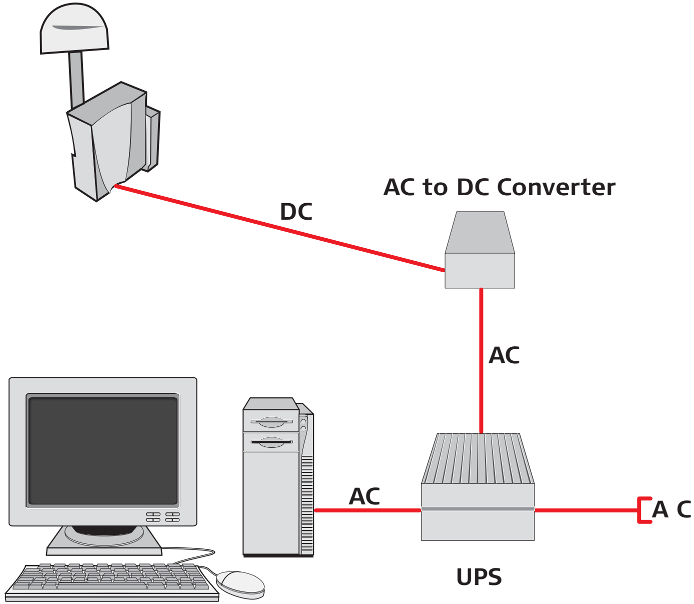
11. Power supply (continued)

11.2 Power supply for the computer running the reference station software

It is advisable to consider installing a UPS (Uninterruptible Power Supply) unit to provide backup power for the computer running the reference station software. The UPS will bridge short power cuts and will also enable the software to shut down safely before power fails completely.

A UPS of appropriate size may well be mandatory if the computer controls an entire network of receivers. At a stand-alone reference station, a UPS (if required) should be able to provide backup power for both the receiver and the computer.

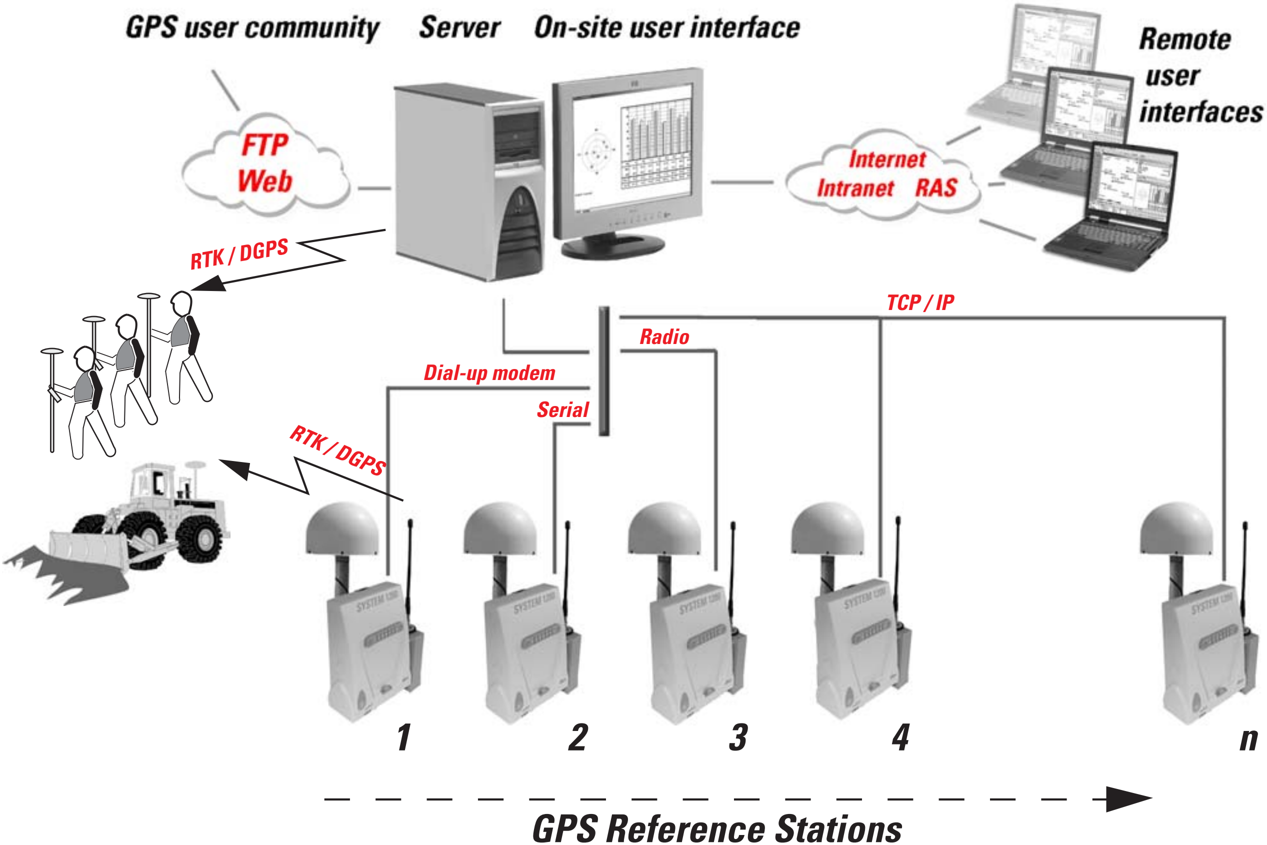
If power fails at the computer but not at the reference stations, the receivers will continue to operate normally, log data, and transmit RTK and DGPS data. As soon as power is restored, the computer will reboot and the software should restart automatically and download the data files from the receivers. Thus power failure may lead to a delay in down-loading data but may not result in a loss of data.



12. GPS reference station software and control computer (server)

Although it is possible to run a single, stand-alone reference station - perhaps to support a mine, construction site or community - without a computer running reference station software, such a reference station will have severe disadvantages and is unlikely to be more than a temporary solution. Such a station may be sufficient if the only requirement is to transmit RTK and DGPS data to RTK and GIS rovers. However, if raw data has to be archived and made available for users, the receiver tracking will have to be stopped - perhaps every evening - and the logged data downloaded manually.

Even for a single, stand-alone reference station, it is always advantageous if the receiver can run continuously, the data can be downloaded fully automatically at regular intervals, and the entire operation can be controlled and inspected as required by a supervisor.


GPS user community
Server
On-site user interface
Remote user interfaces
FTP
Web
Internet
Intranet
RAS
RTK / DGPS
TCP / IP
Radio
Dial-up modem
Serial
RTK / DGPS
1
2
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GPS Reference Stations

12. GPS reference station software and control computer (server) (continued)

12.1 Reference station software and control computer (server)

Reference station software running on a computer - let us call it a server - can control a single receiver at a stand-alone station or all the receivers at all stations in a network. In case of a single stand-alone station, the receiver will often be connected directly to the computer. In case of a multi-station network, the server will usually be at a control center and connected to the receivers by telephone, LAN, WAN or Internet (PCs are not required at the receivers).

GPS receivers at reference stations run continuously. The raw measurement data are usually logged internally in the receivers in files of the required length. Reference station software running on the server controls the receivers and downloads the data files automatically at regular intervals. Receivers can also stream raw data continuously to the server instead of logging data or even stream raw data at the same time as they are logging data.

Reference station software running on the server checks the raw data for completeness, compresses the raw data, converts it to RINEX, compacts RINEX, archives raw data and RINEX files, and pushes raw data and RINEX files to an FTP server for easy access by the GPS user community. The software also monitors the operation of the receivers, the quality of the data, the communication links, the functioning of the entire network, and generates messages and reports as necessary.

System supervisors have full control over the receivers at the stations and the entire network. They can log in to the server, perhaps even from remote locations, inspect the operation of the receivers and the network, start and stop the various operations, change configurations, parameters and operating modes, upload new firmware to the receivers etc.

Once configured and started, a reference station or a network of stations controlled by software running on a server will operate fully automatically. Well-designed reference stations and networks are extremely powerful yet, once set up, they are very easy to use.

12.2 Reference station software: calculation of RTK/DGPS data

Although the receivers can output RTK and DGPS data directly in standard RTCM formats and in proprietary formats (Leica, CMR, CMR+) for immediate transmission from the stations to RTK and GIS field rovers, some organizations prefer to have the distribution of RTK and DGPS data controlled from one central location.

If permanently open communication links are available, raw data can be streamed continuously from the receivers to the server. A software component running on the server computes the required RTK/DGPS data continuously in the required format - standard RTCM format or proprietary (Leica, CMR, CMR+) format - and outputs it immediately for distribution to RTK and GIS rovers.

12.3 Reference station software: continuous network analysis and calculation of correction parameters for enhanced RTK

The maximum range from a reference station at which a standard RTK rover can operate successfully (i.e. resolve ambiguities) is usually quoted as about 30km. This assumes favourable atmospheric conditions and that the rover is receiving standard RTK data from the station. The limitation in range is due to the effects of distant dependent errors relating to satellite orbits, ionospheric delays and tropospheric delays.

Using a network of several reference stations, it is possible to model these distance dependent errors and to correct for them.

The raw data have to be streamed continuously from the receivers to the server. Network analysis software running on the server continuously analyzes the “state” of the network data and models the distance dependent errors. Correction parameters are computed continuously.

If the RTK rover receivers are equipped with the appropriate algorithms, these correction parameters can be transmitted to the rovers and the rovers apply them. Alternatively, the correction parameters can be applied at the server and corrected RTK data can be transmitted to the rovers. In both cases, improved RTK at longer ranges can be achieved. See 20 for full information.

12.4 Reference station software: calculation of the positions of the antennas

Networks of GPS reference stations are often used for monitoring movements of the Earth's crust, particularly along fault lines and in areas of volcanic activity. Small networks can be used to monitor the positions and movements of natural and man-made structures such as dams, bridges, buildings, oilrigs, landslides, glaciers etc.

A software component running on the server can compute the baselines of the network continuously or at regular intervals to determine the positions (coordinates) of the antennas.

Depending on the applications and the requirements, slow, long-term movements, rapid, short-term movements, and even vibrations can be investigated.

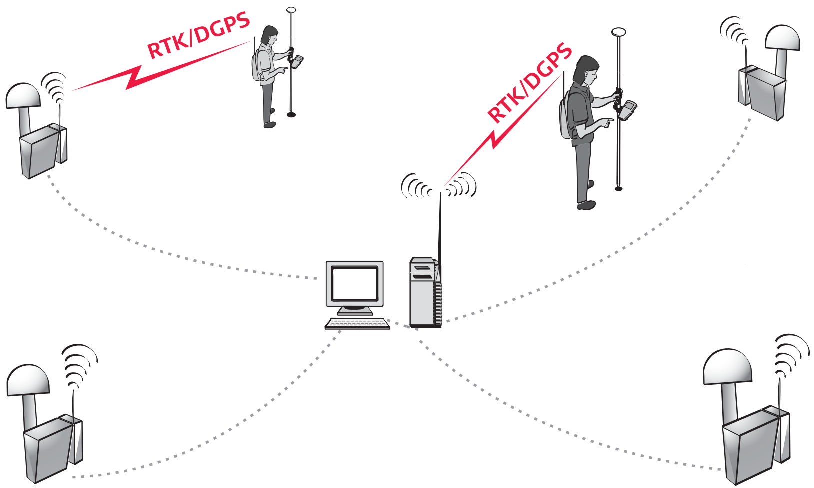
13. RTK and DGPS data

13.1 RTK and DGPS data: output from the receivers

The receivers at reference stations can be configured to output RTK and/or DGPS data continuously in standard RTCM V2.1/2.2/2.3/3.0 formats and/or in Leica, CMR and CMR+ proprietary formats.

The data can be transmitted from one or more ports in one or more formats.

Radios and phones can be used to transmit RTK and DGPS data directly from the receivers; see 16.1. The Internet can also be used as explained in 18.2.



13.2 RTK and DGPS data: computed and output at the server

Some organizations prefer to have the distribution of RTK and DGPS data managed from one central location, rather than transmitting directly from the receivers. This allows better control over user access and facilitates charging for data if this is a requirement.

Using permanently open communication links, raw data can be streamed continuously from the receivers to the server. Software running on the server computes the required RTK/DGPS data continuously in standard RTCM V2.1/2.2/2.3/3.0 formats and/or in Leica, CMR and CMR+ proprietary formats. The data are output in the required format(s) and transmitted to RTK and GIS rovers.

Radios, phones and even the Internet can be used to transmit the RTK/DGPS data. For more details see 16.2 and 18.3.

14. The need for reliable communication

Reliable communication is vital for the efficient operation of GPS reference stations and networks of stations.

- The reference station software running on the server has to control the receivers and download the data.
- RTK and DGPS data have to be transmitted for use by RTK and GIS rover receivers.

Communication technology and information technology are evolving very quickly. The availability of the various techniques - or at least the feasibility of using them - can also vary considerably from country to country.

When selecting the most suitable method for communication between the server and the receivers, various factors should be considered carefully, including:

- What the station or network of stations is to be used for.
- The communication technologies that are available locally and for which reliable support is available.
- The cost of the communication equipment and the installation costs.
- The running costs.
- The service and support costs.

When making a decision on the most suitable means for transmitting RTK and DGPS data to RTK and GIS rovers, the following should also be taken into account:

- The number of RTK and/or GIS rovers that the station or network has to support.
- The range at which RTK rovers have to operate.
- The communication equipment that will be needed by RTK and GIS rovers.
- The cost of this equipment and the running costs.

From the above it will be obvious that there is no standard solution. What is best for a station or network in one country may not be appropriate for a station or network in another country.

The following chapters outline the various communication methods that may be considered. The final decisions as to which methods are the most suitable should only be taken after consulting carefully with communication and information companies and specialists that understand the requirements and that are thoroughly familiar with the local market.

15. Communication between the server and the receivers

The reference station software running on the server (computer) has to control the receivers and download the internally logged data files.

For some applications it may be necessary to stream the raw data continuously (second by second) from the receivers to the server instead of downloading the logged data files. Some organizations may even prefer to have both streamed data and downloaded files.

For controlling the receivers and downloading logged data files, the communication links can be either dial-up (i.e. opened when required) or permanently open (i.e. continuously on). Dial-up links will usually be preferred, however, as the costs are generally lower than for permanently open links.

If the raw data have to be streamed continuously, permanently open communication links are essential.

Note that the costs of permanently open links - in particular the running costs - are usually higher than those of dial-up links.

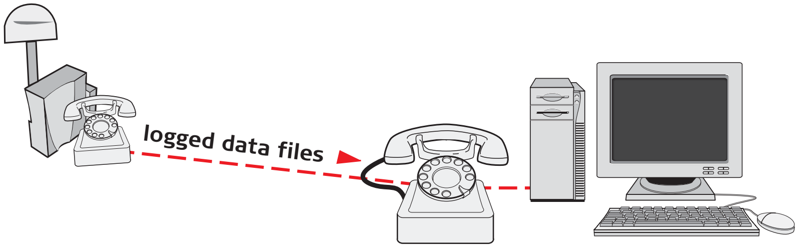
15.1 Dial-up links (open when required)

If standard telephones are available at the reference station sites, standard landlines and telephone modems can be used to connect the receivers to the server. The reference station software running on the server will dial the receivers and download the logged files automatically at preset times.

For a small network, one telephone modem at the server should be sufficient. Such a network should be relatively easy to set up and should not be too expensive.

Mobile phone modems (GSM, CDMA, TDMA, GPRS etc) can be used if standard telephones are not available at the reference station sites. The phones have to be powered and permanently switched on. Running costs (call charges) will often be higher than with standard landline.

Another solution could be to use the Internet. See 17 for more details.



Dial when required

15. Communication between the server and the receivers (continued)

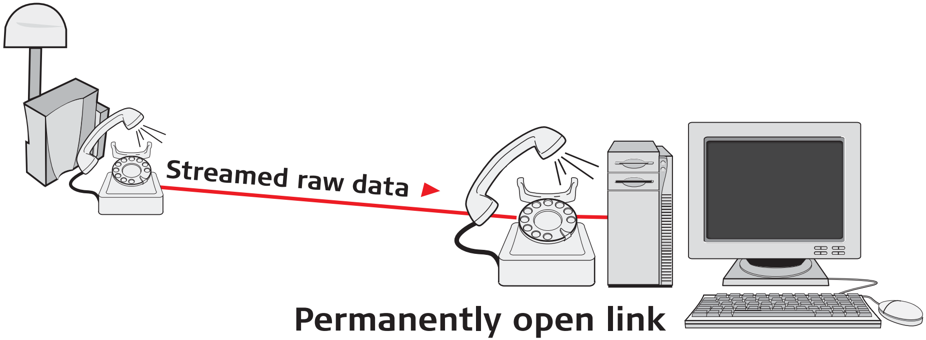
15.2 Permanently open links (continuously on)

If the raw data have to be streamed continuously from the receivers to the server, the communication links between the receivers and the server have to be permanently open.

Standard landline telephone modems and mobile phone modems can be used, however the running costs (call charges) will often tend to be high. It is also worth investigating the possibility of using leased lines, as these will usually provide very high reliability.

Note that a port and telephone modem will be needed at the server for each reference station from which data is to be streamed. Thus a 10-station network will require 10 permanently open lines, a modem at each of the 10 receivers, and 10 modems at the server. Another possibility is to use a telephone access router at the server. Note that the costs of this hardware can add up!

The trend today is to try to make use of the Internet to achieve permanently open links for streamed data between the receivers and the server. Running costs with the Internet should be significantly lower than with telephone connections.
See 17 for more details.



16. Communication: transmission of RTK and DGPS data

The GPS receivers used at reference stations can output RTK and DGPS data from one or more ports in standard RTCM formats and/or in proprietary formats. See 13.1. The data can be transmitted directly from the receivers.

If raw data are streamed continuously from the receivers to the server through permanently open links, software running on the server can compute and output RTK and DGPS data in standard RTCM formats and/or in proprietary formats. See 13.2.

16.1 Transmission directly from the receivers

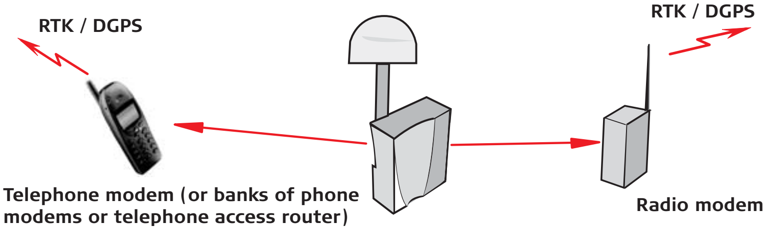
One way to transmit RTK and DGPS data directly from the receivers is to use radio modems. If two radio modems are attached to a receiver, they have to transmit at different frequencies (use different channels). RTK and GIS rover receivers have to be equipped with compatible radio modems. The advantages are that any number of RTK and GIS rover receivers can receive the data and that the users of rover receivers do not incur telephone charges.

Another common solution is to attach a telephone modem - landline or even a mobile - to the reference station receiver. RTK and GIS rover receivers with suitable mobile telephone modems dial in to obtain the required RTK and DGPS data. A telephone connection usually permits longer RTK and DGPS range than a radio modem, but the rovers incur telephone charges and only one rover at a time can dial in to one telephone at a reference station.

If a suitable telephone access router or a bank of telephone modems is attached to the reference station receiver, several rovers (perhaps 5 or 10 or even more) can dial in to the station at the same time. The more rovers the router or bank of modems has to support, the more it is likely to cost.

Transmission by both radio and telephone is possible if a radio modem is attached to one port of the receiver and a telephone modem (or bank of modems or router) is attached to another port.

Another solution could be to use the Internet. See 18 for more details.



16. Communication: transmission of RTK and DGPS data (continued)

16.2 Distribution (transmission) from a control center

Some organizations prefer to distribute the RTK/DGPS data from one central location rather than transmitting directly from the receivers.

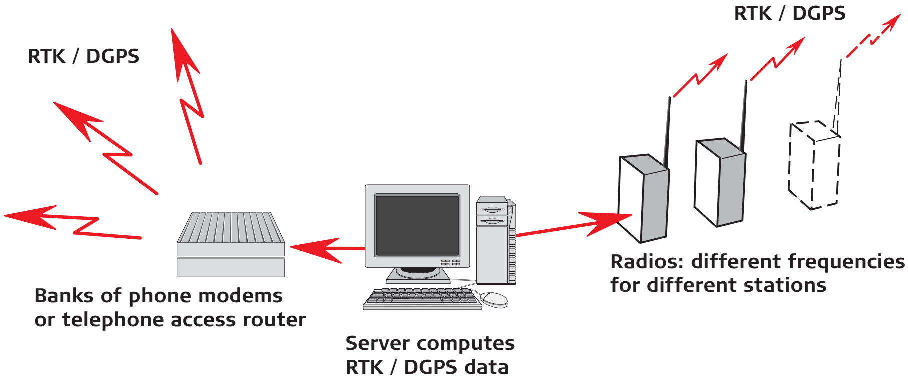
The raw data have to be streamed continuously from the receivers to the server thorough permanently open communication links as outlined in 15.2. Software running on the server computes the required RTK/DGPS data in standard RTCM formats and/or in proprietary formats for each reference station.

The RTK/DGPS data for a specific reference station will be output via a dedicated port, thus the number of RTK/DGPS output ports at the server should equal the number of reference stations. Radios, phones or even the Internet can then be used to distribute the RTK/DGPS data.

If radios are used, the RTK/DGPS data for different reference stations have to be transmitted on different frequencies (use different channels) in order to prevent interference. As the range of radio modem transmission is usually limited, radio transmission stations or repeaters may be needed to provide full coverage for a network area.

If phones are used, a unique phone number will be needed for each reference station for which RTK/DGPS data is available. Telephone access routers or banks of modems will be needed in order to ensure that several rovers can access the RTK/DGPS data from the same station at the same time.

It is possible to have a single telephone number for all reference stations if the rover receivers that are equipped with mobile phones can send their positions to the server.



16. Communication: transmission of RTK and DGPS data (continued)

The rover phones the control center and sends its position coordinates in NMEA format. A software component running on the server decides which reference station is closest to the rover. A telephone access router transmits the RTK/DGPS data for this station to the rover. The router has to be of sufficient size to allow simultaneous multi-user access to the RTK/DGPS data from all stations.

It is also possible to distribute the RTK/DGPS data from the control center using the Internet. See 18 for more information.

16.3 Radio versus phone: advantages and disadvantages

Radio modems
The advantages of using radio modems are that any number of RTK and GIS rovers can benefit from the service and that there are no charges.

The disadvantage is that the range at which RTK and GIS rovers can operate is usually less than if phones are used.

- The higher the output power of the transmitting radio, the greater will be the range at which rovers can operate. Output power is restricted in many countries, however.
- The higher the radio antenna can be set up at the transmitting station, the greater will be the range at which rovers can operate.
- Use of high quality antennas at the transmitting radios and at the rover receivers will also improve the range.
- Transmission from UHF radio modems is "semi" line-of-sight. Obstructions, particularly at longer ranges, can cause loss of reception at the rover.
- Interference on adjacent frequencies may also sometimes lead to poor reception at the rover.

Phones
The advantage of using phones is that the range at which rovers can operate is usually not limited by the communication means. The connection is also very reliable with no interference and little loss of reception due to obstructions. A disadvantage is that the rovers incur call charges.

A telephone access router or a bank of telephone modems will be required if several rovers have to access the RTK/DGPS data from the same reference station at the same time. Depending on the number of users it has to support, this equipment can be quite costly.

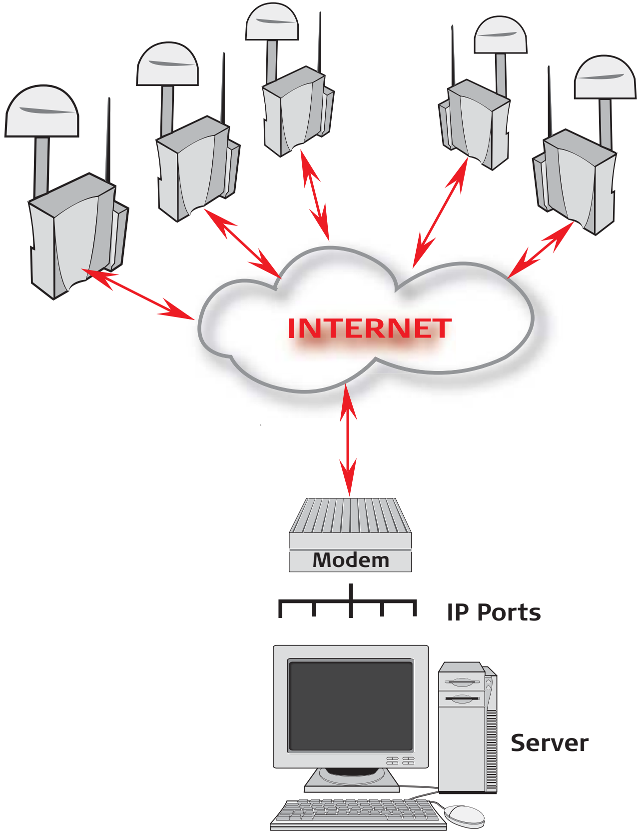
Radio and phone
Note that it is possible to transmit RTK/DGPS data directly from the receivers or from a control center by both radio and phone. Users of rover units can then use the service that they prefer.

17. Using the Internet, or other IP-based methods, for communication between the server and the receivers

There is a rapidly growing interest today in using IP-based methods for communication between the receivers and the server running the reference station software, and also for distribution of RTK and DGPS data. IP-based communication can be LAN, WAN, WLAN, Internet, Intranet, and Radio IP etc.

For simplicity, this document refers to the Internet to represent all IP-based methods.

The main attraction of using the Internet for communication between the server and the receivers is that it is usually possible to reduce running costs (charges). If raw data have to be streamed continuously from the receivers to the server as outlined in 15.2, the running costs with the Internet will usually be much lower than with telephone connections.



17. Using the Internet, or other IP-based methods, for communication between the server and the receivers (continued)

A possible disadvantage of using the Internet could be that the reliability and quality of standard Internet connections may not be quite as high as with standard telephone connections.

Internet connections of very high reliability can normally be guaranteed if dedicated (leased) lines or MPLS (MultiProtocol Label Switching) are used between the server and the receivers. However, the cost is likely to be higher than the cost of standard Internet connections.

The costs and reliability of the various options can usually be clarified by discussing carefully with the local Telecom Company and Internet Service Provider.

In order to access the Internet, the receiver at a reference station will require a modem, a Com Server or Ethernet port, and a static IP address. The modem could be a telephone, cable, or broadband/ADSL modem.

The server will require a suitable modem and one IP port for each reference station from which data will be streamed (i.e. 10 IP ports are needed if data is to be streamed from 10 stations).

The modem could be a telephone, cable, or broadband/ADSL modem. However, if the server has to receive continuously streamed raw data simultaneously from several reference stations - which will often be the case - the best would be a broadband/ADSL or cable modem with a suitably large bandwidth.

The reference station software running on the server operates in exactly the same way with Internet connections as with standard telephone connections.

18. Using the Internet to distribute and access RTK and DGPS data

18.1 Equipment needed by RTK and GIS rovers

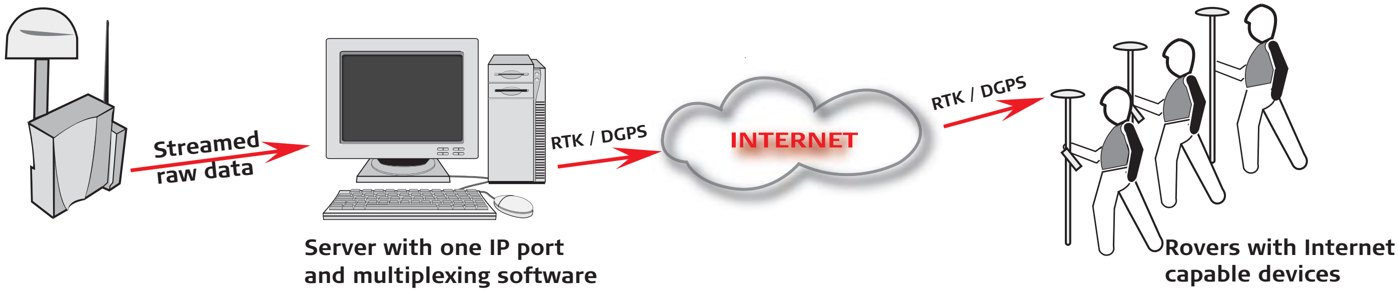
RTK/DGPS data can also be distributed using the Internet.
In order to access the Internet and obtain the required data, RTK and GIS rover receivers have to be equipped with Internet capable devices such as GPRS or CDMA phone modems.

18.2 Distribution from a single stand-alone reference station

At a stand-alone reference station, the receiver will often be connected directly to the server (computer) running the reference station software. Raw data has to be streamed continuously from the receiver to the server.

Software running on the server computes the required RTK/DGPS data in the required format (standard RTCM formats or proprietary formats; see 12.2). The server needs one IP port for output of the RTK/DGPS data to the Internet.

RTK and GIS rovers, equipped with Internet capable devices, access the IP port and obtain the required RTK/DGPS data. Multiplexing software running on the server allows several rovers to access the IP port and the RTK/DGPS data at the same time.



18. Using the Internet to distribute and access RTK and DGPS data (continued)

18.3 Distribution from a network control center

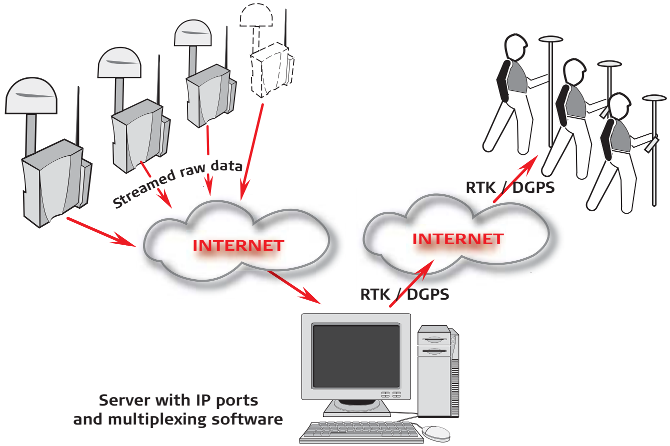
In case of a multi-station network, the server will be at a control center. Raw data have to be streamed continuously from the receivers to the server. The connection between the server and the receivers can be via the Internet as explained in 17. Software running on the server computes the required RTK/DGPS data in the required format (standard RTCM formats or proprietary formats; see 12.2) for each reference station.

The computed RTK/DGPS data can be output via the Internet. The server needs one IP port for each reference station for which RTK/DGPS data are to be output (i.e. if RTK/DGPS data are to be output for 10 stations, 10 IP ports are needed).

RTK and GIS rovers, equipped with Internet capable devices, access the IP ports and obtain the RTK/DGPS data for the stations. Multiplexing software running on the server allows several rovers to access the RTK/DGPS data from the same the IP port at the same time.

It is possible to have a single IP port for all reference stations if the rover receivers that are equipped with Internet capable devices can send their positions to the server.

The rover accesses the server via the IP port and sends its position coordinates in NMEA format.
A software component running on the server decides which reference station is closest to the rover. The RTK/DGPS data for this station are then transmitted to the rover.
Multiplexing software running on the server allows several rovers to access the server via the same IP port at the same time.



18. Using the Internet to distribute and access RTK and DGPS data (continued)

18.4 Summary of the various ways by which RTK/DGPS data can be distributed

Using radio modems (see 16)

Any number of rovers can access the data and the rovers do not incur running costs (charges). Limited range, obstructions and interference can be drawbacks.

Using phones (see 16)

The connections are reliable and there are few restrictions to range. However, rovers incur calling charges. Routers or banks of modems are needed in order that several rovers can access the data from the same station at the same time.

Using the Internet

The running costs (call charges) for rovers should be less than with mobile phones, but the reliability of the connections may not always be quite as high. There are few restrictions to range at which connections are possible and multi-user access can be arranged.

In order to compare the use of the Internet with the use of mobile phones, the best is to clarify all cost and reliability issues very carefully with the local Telecom Company and Internet Service Provider.

19. NTRIP - Networked Transport of RTCM via Internet Protocol

NTRIP is a new protocol, developed by the Federal Agency for Cartography and Geodesy of Germany, for streaming Global Navigation Satellite System (GNSS) data over the Internet. NTRIP has become an RTCM standard.

NTRIP provides certain advantages for a reference station software server when distributing RTK/DGPS data to RTK and GIS rovers. NTRIP can be used for distributing data in any format, for example in standard RTCM V2.1/2.2/2.3/3.0 formats and/or in Leica, CMR and CMR+ proprietary formats.

With NTRIP, all communication and data passes through a single IP port at the server. RTK and DGPS rovers can only obtain data if they are authorized, thus the network operator has full control over access to the data. This facilitates billing (charging for data) if this is a requirement.

An RTK or DGPS rover that accesses the server IP port can request data from a so-called mount point or request a list of the available mount points.

For example the mount points could be the sources for the RTK and/or DGPS data from the various reference stations, the source for the network data in RTCM V3.0 format and network correction parameters (see 20.3), the source for network corrected RTK data (see 20.4), etc.

If the requested mount point is available, the data from this source are transmitted to the rover. If the requested mount point is not available, the rover has to select another mount point (source of data) from the list.

20. Continuous network analysis and calculation of network correction parameters for enhanced RTK

20.1 Accuracy and range of RTK: the influence of distance dependent errors

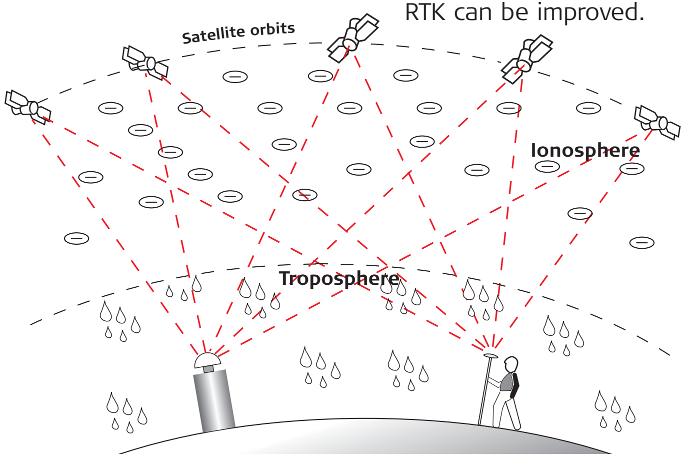
When receiving standard RTK data from a reference station, an RTK rover can usually operate successfully (i.e. resolve ambiguities) at ranges up to about 30km in reasonably favourable conditions. In some regions of the World, where conditions for RTK are often exceptionally good, ranges of about 40km or more may be achieved at times. In other areas, especially during the afternoon and in periods of high ionospheric activity, the maximum range for RTK may be reduced significantly.

The accuracy of RTK is normally quoted as about 10mm + 1ppm root mean square. Thus the positional accuracies that can be expected are approximately as follows:

- At 1km: 10mm +1mm = 11mm rms
- At 10km: 10mm +10mm = 20mm rms
- At 30km: 10mm + 30mm = 40mm rms

If RTK measurements could be carried out in an absolutely perfect environment, there would be no ppm accuracy component and no restriction to range. Unfortunately, however, the environment is never perfect and it also changes continuously.

Various influences, particularly those relating to ionospheric delays, tropospheric delays and satellite orbits, lead to distance dependent errors and restrict the range at which the rover can resolve the ambiguities. It follows that if the distant dependent errors within the network can be modelled with a reasonable degree of success and appropriate corrections can be computed and applied, the accuracy and range of RTK can be improved.



20. Continuous network analysis and calculation of network correction parameters for enhanced RTK (continued)

20.2 Network analysis and computation of network correction parameters

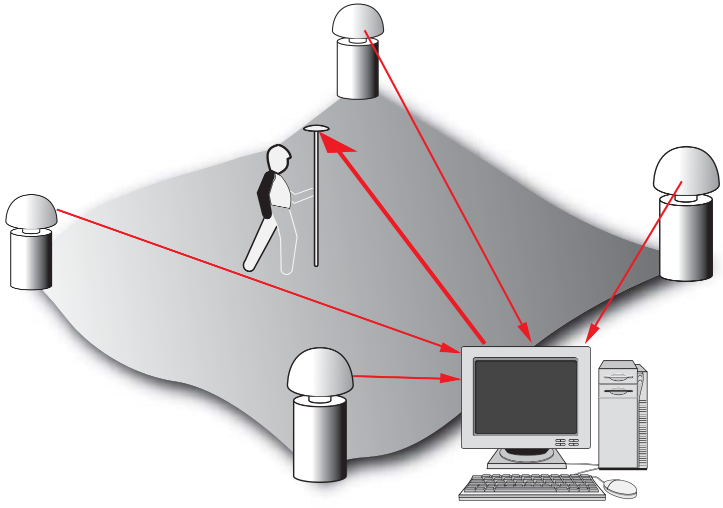
The raw data have to be streamed continuously from the receivers at the network reference stations to the server through permanently open communication links. Use of the Internet will generally be preferred, as the running costs should be much lower than with telephone connections (see 17 and 15.2).

A network analysis component of the reference station software processes the incoming data continuously in order to analyze the state of the environment within the network. It models the distance dependent errors and computes network correction parameters. The entire process runs continuously and automatically.

There are two ways in which the network analysis and network corrections parameters can be used to improve the performance of RTK:

- The network data in RTCM V3.0 format and the network correction parameters can be transmitted to the rover and the rover applies them.
- The network correction parameters can be applied at the server and the server transmits "corrected" RTK data to the rover.

Note that if a network has a very large number of stations, it will be split into cells (subsets of the network).



20. Continuous network analysis and calculation of network correction parameters for enhanced RTK (continued)

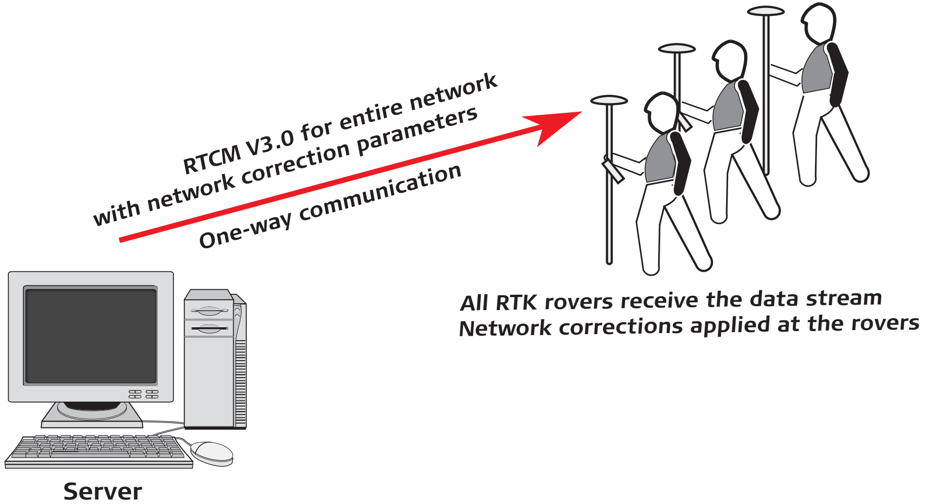
20.3 Network data in RTCM V3.0 format and network correction parameters are transmitted to the rover and the rover applies them.

The network analysis software running on the server produces the required RTCM V3.0 data for the network. This RTCM V3.0 data includes the network correction parameters.

In order to be able to use the data, RTK rover receivers have to be RTCM V3.0 compatible. They have to understand the RTCM V3.0 format and they have to be able to apply the network correction parameters.

The RTK rovers operating in the network area receive the RTCM V3.0 network data with the network correction parameters. This data contains all of the required information for the entire network, i.e. for all stations in the network.

Depending on how RTK processing is implemented in a particular rover receiver, the rover can now process the baseline from one reference station (probably from the closest station), or perhaps even the baselines from several stations, resolve the ambiguities and derive position coordinates. The results are largely free of the distance dependent errors described in 20.1.



20. Continuous network analysis and calculation of network correction parameters for enhanced RTK (continued)

The accuracy and range are superior to those of standard RTK.

As the RTCM V3.0 data contains the information for the entire network (i.e. for all stations), all RTK rovers operating within the network can receive exactly the same information. Thus only a single RTCM V3.0 data stream has to be output by the server.

If a network has a very large number of stations, it will be split into cells (subsets of the network).

Radios, phones or the Internet can be used to distribute the RTCM V3.0 data to RTK rovers. The communication needs to be one-way only, i.e. server to rover. The rover does not send information to the server.

If radios are used, the RTCM V3.0 network data stream will probably have to be redistributed via repeater stations or transmission stations in order to ensure full coverage over the network area.

If phones are used, all rovers should be able to dial a single number for the RTCM V3.0 network data stream. A suitable router will be needed to ensure simultaneous multiple user access.

If the Internet is used, all rovers should be able to access the same IP address for the RTCM V3.0 network data stream. Multiplexing software running on the server will allow simultaneous multiple user access.

20.4 Network correction parameters are applied at the server and the server transmits "corrected" RTK data to the rover.

The network analysis software running on the server analyzes the network and computes the network correction parameters for the network as explained in 20.2. With this method, however, the network correction parameters are applied at the server and not at the rover.

In order to obtain the required data, the RTK rover has to transmit its position in an NMEA message to the server. Using this position information, the network analysis software identifies which reference station is closest to the rover.

The software then applies the network correction parameters to the measurements from this reference station in such a way that a baseline computation between the reference station and the rover should be free of the distance dependent errors described in 20.1.

20. Continuous network analysis and calculation of network correction parameters for enhanced RTK (continued)

"Corrected" RTK data in the formats RTCM V2.3/3.0 and Leica, can then be output for transmission to the rover. The RTK rover receives the data and processes the baseline from the reference station, resolves the ambiguities, and derives position coordinates.

As the RTK data received by the rover are already "corrected", the accuracy and range are superior to those of standard RTK.

Note that as the "corrected" RTK data can be transmitted in RTCM V2.3 and Leica formats, rover receivers do not have to be RTCM V3.0 compatible.

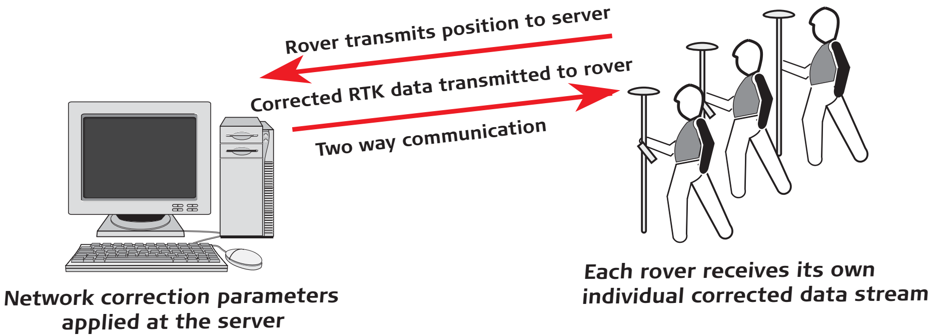
As the RTK rover has first to send its position to the server, two-way communication is needed. Thus phones and the Internet can be used but not radios.

As the "corrected" RTK data transmitted to the rover depends on the position of the rover, all roving receivers operating within the network area will receive different individual data steams.

If phones are used, all rovers will dial a single number in order to obtain "corrected" RTK data. The software ensures that each rover receives the RTK data stream that it requires.

A suitable telephone access router will be needed to ensure simultaneous multiple user access.

If the Internet is used, all rovers will access the same IP address in order to obtain "corrected" RTK data. The software ensures that each rover receives the RTK data stream that it requires. Multiplexing software running on the server permits simultaneous multiple user access.



20. Continuous network analysis and calculation of network correction parameters for enhanced RTK (continued)

20.5 Comparison of the two methods

With the first method described in 20.3, the rover receivers have to be RTCM V3.0 compatible in order to be able to use the transmitted data. Radios as well as phones and the Internet can be used. The software needed at the server will be somewhat less complex than for the second method described in 20.4.

With the second method described in 20.4, the RTK data can be output in any required format. Rover receivers do not need to be RTCM V3.0 compatible. Phones and the Internet can be used but not radios. The software needed at the server will be slightly more complex than for the first method described in 20.3.

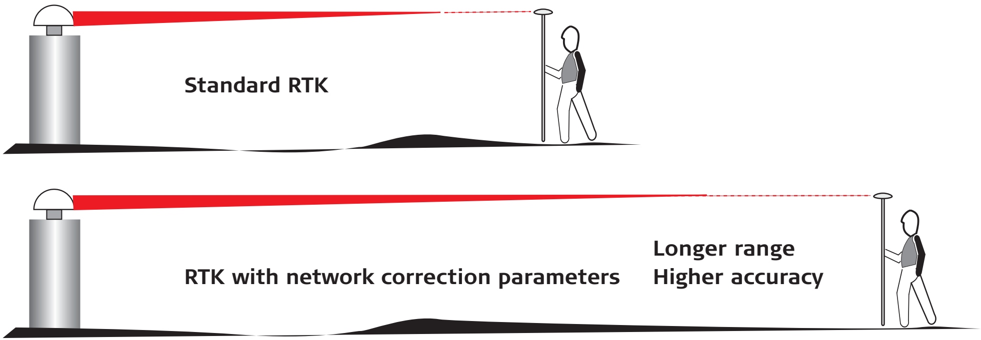
20.6 Improved RTK performance

Both of the methods described above will improve the accuracy, reliability and range of RTK.

- Accuracy will be improved, as the ppm accuracy component - i.e. the distance dependent component - will be reduced significantly.
- Thus RTK accuracy will be much more uniform at different distances.
- The reliability of RTK position fixes (ambiguity resolution) will be improved, particularly under difficult ionospheric conditions and at longer ranges.
- The time needed for RTK position fixes will be reduced when operating at long ranges and under difficult ionospheric conditions.
- The maximum range will be improved.

As the range of RTK is increased, reference stations can be further apart. Thus fewer stations are needed to provide RTK coverage for a given area.

Note that the reference stations should be reasonably evenly distributed throughout the area in order that the software can effectively analyze the state of the environment within the network and compute the appropriate network correction parameters.



21. Using an FTP server to distribute RINEX data

RINEX (Receiver INdependent EXhange) is a standard data format that is universally accepted by the GPS surveying community and that can be used by all commercially available post processing software.

The reference station software running on the server downloads the raw data files logged in the receivers, converts the data to RINEX, and produces RINEX files of the required length (e.g. 1 hour, 2 hours, 3 hours etc.). The software can also create RINEX files from the raw data that are streamed continuously from the receivers to the server.

Using RINEX files of reference station data, users of GPS field equipment can post process baselines from reference stations and determine positions to very high accuracy. Post processing is often used to determine high order geodetic control points.

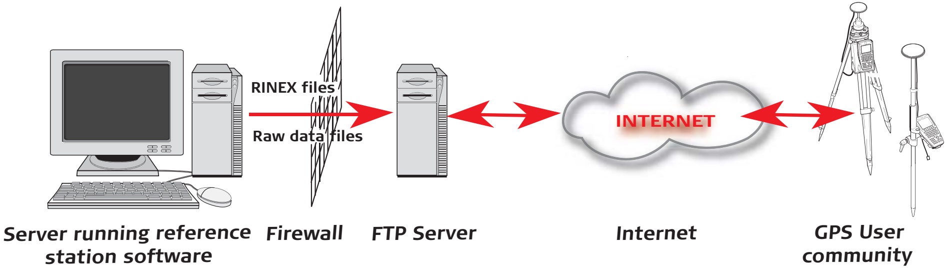
There is also almost no practical range limit to post processing. With sufficient data, very long baselines can be processed successfully.

In order to make RINEX data readily available for the GPS user community, the reference station software can transfer the RINEX files automatically to an FTP server. FTP stands for File Transfer Protocol and is used to facilitate the distribution of files via the Internet.

There is a range of FTP server software available and your IT support personnel will certainly be able to suggest a suitable product.

FTP server software can usually be configured for public and/or restricted access. It can be arranged that anyone can obtain data or - which will often be preferable - that users have to be registered and enter passwords in order to access the RINEX files.

Although the reference station server software and the FTP server software could run on the same computer, the need for a firewall to protect the reference station server will usually mean that it is preferable to use separate computers.



22. Processing baselines between stations to check antenna positions and monitor movements of natural and man-made structures

22.1 Processing the baselines between the stations of a network

Baselines between the reference stations of a network can be computed in real time or by post processing.

For **real time processing**, raw data have to be streamed continuously from the receivers to the server running the reference station software. A software component computes the baselines between the reference stations continuously in real time as the data are received. The computation process resolves the ambiguities continuously and is similar to the real time processing in an RTK receiver. The accuracy that can be expected and the length of baselines that can be processed are also essentially the same as for RTK receivers.

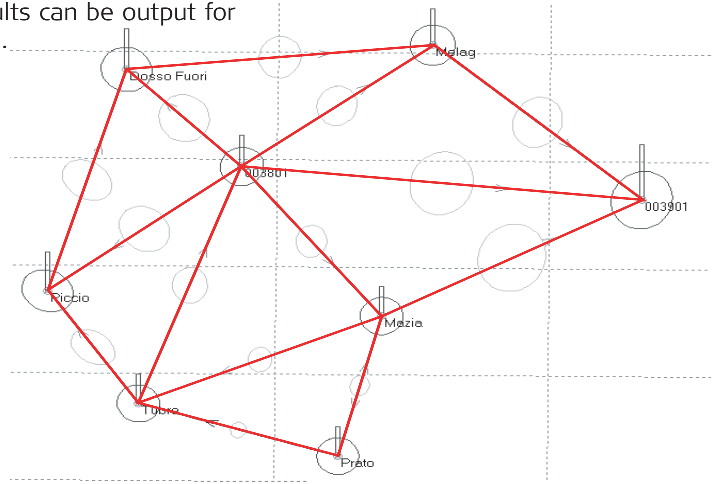
For **post processing**, data files logged in the receivers and downloaded at regular intervals are normally used.

The reference station software passes the files to a post processing software that can be configured to process the baselines automatically as the files are received. With sufficient data - i.e. from sufficiently long observation periods - post processing can successfully compute baselines of almost any length and achieve higher accuracy than real-time processing.

Coordinate results can be output for further analysis.

22.2 Checking the positions of the antennas

Although antennas that are set up in a stable manner at safe locations should not move, some organizations that are responsible for reference stations still prefer to be assured at regular intervals that the antennas have not been disturbed.



22. Processing baselines between stations to check antenna positions and monitor movements of natural and man-made structures (continued)

The positions (coordinates) of the antennas can be determined by real time processing or by post processing as explained in 22.1.

As the requirement is usually one of periodic quality control, it is often sufficient to post process the baselines between stations once a day, or once a week, or perhaps even once a month. Depending on the software, processing can often be organized to run automatically at the required time intervals.

22.3 Monitoring movements of the Earth's crust, and of natural and man-made structures

Networks of GPS reference stations provide the most effective method for measuring movements between tectonic plates, in earthquake zones, along major fault lines, and in areas of high volcanic activity.

Small networks with short baselines are often very suitable for monitoring the positions and movements of man-made structures such as dams, bridges, buildings, oilrigs etc.

If rapid, short-term movements, and even vibrations, have to be detected and monitored, real time processing as described in 22.1 will usually be needed. Real time processing produces a continuous stream of independent position fixes (coordinates). Movements can be identified and analyzed.

- Real time processing uses raw data that are streamed continuously through permanently open communication links. Running costs for permanently open links can be high.

- Post processing can use data files that are logged internally in the receivers and communication links that need to be opened only when files have to be downloaded. Thus running costs may be lower than with permanently open links.

If the movements that have to be monitored are known to be slow and to occur over a relatively long period of time, it may be more economical and more suitable to use post processing.

Using data files of appropriate lengths, baselines between reference stations can be processed at required time intervals, perhaps every 12 hours, 24 hours or even 7 days. If required, the results could be passed to an adjustment package for automatic least squares network adjustments.

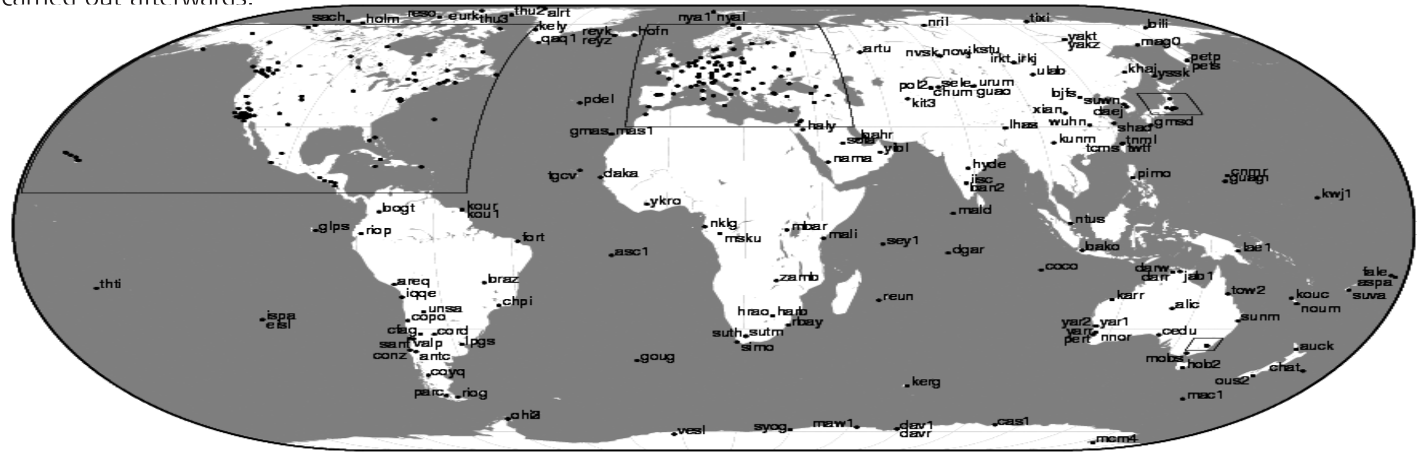
Post processing will certainly be preferred if the baselines between stations are very long. Networks with stations that are far apart and that cover very large areas are often used for monitoring the movements of tectonic plates.

23. Determining the WGS84 coordinates of the reference stations

GPS baseline processing - whether in post processing or in real time mode - solves a baseline between a known reference and an unknown rover position. The baseline computation is always carried out in the WGS84 coordinate system. Thus WGS84 coordinates of the rover are determined relative to the WGS84 coordinates of the reference. Any transformation to local coordinates is carried out afterwards.

For successful baseline processing, the WGS84 coordinates of the reference should be known accurately, to at least about + or - 10m. As the purpose of reference stations is to serve as the basis for determining the positions of rover receivers, it follows that accurate WGS84 coordinates are needed for the reference stations.

There is a global network of over 300 IGS (International GPS Service) stations. The coordinates of these stations are given in an International Terrestrial Reference Frame (ITRF). For simplicity one can say that the ITRF coordinates of the IGS stations are just about the most accurate WGS84 coordinates available.



23. Determining the WGS84 coordinates of the reference stations (continued)

Many countries already have a national network of GPS reference stations. Such a network will usually have been connected to the IGS network and the stations will have accurate WGS84 coordinates.

When establishing a new stand-alone reference station or a new network of stations, it will usually be preferable to connect the new station or the new network to the national network. Contact the national survey organization for information on the national network and how to obtain data from the national stations.

If there is no suitable national network, the best is to connect the new station or the new network of stations to the IGS network.

- For general information on the IGS network go to the IGS web site (see 30. Useful links).
- For information on IGS stations and how to obtain RINEX data files consult the SOPAC web site (see 30. Useful links).
- Note that post processing software may provide links to the closest IGS stations and facilitate the download of RINEX data files.

To determine the WGS84 coordinates of a new stand-alone station or the "master" station of a new network, proceed as follows:

- Select one station of the new network as the "master".
- At the master log data (1 minute rate is sufficient) for at least 24 hours, and possibly for up to 7 days.
- Download RINEX data from the closest IGS station or from the closest national station.
- Process the baseline from the IGS station, or from the national station, to the master using 24 hours of data. If data have been logged for several days, process the baseline for different 24-hour periods and take the mean.
- Perhaps process the baselines to the master from an additional one or two IGS, or national, stations. Take the mean.
- This will provide very accurate WGS84 coordinates for the master and link the master to the IGS, or national, network.

The WGS84 coordinates of the stations of the new network have to be fiducially accurate, i.e. the network has to have a very high degree of relative accuracy between the stations. The easiest is to proceed as follows:

- At all stations log data (1 minute rate is sufficient) for at least 24 hours, and possibly for several days.
- Using the WGS84 coordinates of the master as the starting point, process all the baselines of the network using 24 hours of data. Possibly repeat for another one or two 24-hour periods. Adjust the network if adjustment software is available.
- This will provide WGS84 coordinates for all stations. The coordinates will have a high degree of relative accuracy.

24. Where should the stations be positioned? What should be the distances between the stations?

If the prime purpose of a network is to monitor a natural or man-made structure - e.g. a fault line, volcano, dam, bridge etc. - the positions of the stations will be determined largely by the structure that has to be monitored and the movements that are expected.

If a network is to be a geodetic control network that has to supply services to the GPS surveying community, careful thought should be given to the positioning of the stations and the separation distances between the stations. Consider the following:

- The extent of the area to be covered.
- The areas of high development and high population.
- The areas of low development and low population.
- The services that have to be provided:
  Perhaps only RINEX data for post processing.
  Perhaps also RTK data.
  Perhaps also DGPS data.
- The number of GPS rover receivers operating in the area and that will use the services.
- The available budget.

GPS reference stations should be set up where they are needed most and where they can provide services to the largest number of users. This will usually mean establishing more stations in highly developed areas and less stations in under developed areas.

For relatively small highly developed areas, such as in the regions of major conurbations where many RTK rovers are operating, GPS reference stations will usually have to transmit RTK data. The range limit at which an RTK rover can operate successfully (i.e. resolve ambiguities in real time) will have to be taken into account when determining the separation distance between stations.

Depending on the requirement, the range of RTK that is typically achieved in the area, whether standard RTK data is transmitted, or whether the reference station software provides network correction parameters for enhanced RTK (see 20), one could imagine that the separation distance between the reference stations could be between about 30km and 70km.

In very large countries, with immense open spaces of undeveloped land and where few RTK rovers are operating, it will usually be pointless and uneconomical to try to achieve RTK coverage. A suitable approach could be to set up reference stations only at the major population centers and those areas where there are major development projects. If sufficient RTK rovers are being used, these stations could transmit RTK data to provide RTK coverage within about a 20km to 30km radius.

24. (continued)

A surveyor carrying out a project at a long distance from the reference stations would have to set up a temporary field reference, log data for a sufficient period of time, download the RINEX files from the reference stations, and post process to obtain an accurate position.

The temporary reference station would then transmit RTK data and provide coverage for the project area.

Using several hours of data, post processing will provide good results (5mm + 0.5ppm or better) with baselines of 100km, 200km, 300km and even longer. Thus, if necessary, for very large undeveloped areas, the distances between GPS reference stations could even be up to several hundred kilometres.

25. Charging for products such as RINEX and RTK/DGPS data

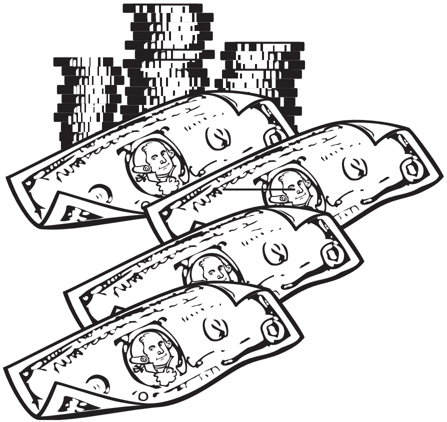
Reference stations and networks require significant investments. Running costs, particularly for networks, have also to be considered.

Some organizations establish stand-alone reference stations or networks purely for their own use.

Other organizations provide products and services for the GPS user community: they allow access to RINEX files and possibly raw data files on an FTP server, they distribute RTK and DGPS data, and they may even provide transformation parameters in order that RTK and GIS rovers can easily transform WGS84 values into the local coordinate system.

If users of GPS rover receivers are able to obtain the required data easily and reliably from permanent reference stations, they derive benefits from the services and do not need to invest in additional receivers for use as temporary field references.

Many organizations that operate reference stations and networks are interested in recovering at least part of their investment and covering their running costs. They would like to charge for the data and the services that they provide.



25. Charging for products such as RINEX and RTK/DGPS data (continued)

If users have to be registered and enter passwords to access an FTP server and obtain RINEX files and possibly raw data files, it should be relatively easy to generate a log of who has logged in and obtained data. Charges could then be made for downloaded data. It may also be possible to ask for a registration fee.

If RTK/DGPS data are distributed by radio, it is almost impossible to arrange a charging system. A solution could be that the authority running the reference stations sells or rents the required radio modems to users of RTK and GIS equipment.

It is easier to create a charging system if users of RTK and GIS rovers obtain the required data by telephone or Internet.

If RTK and GIS rovers use mobile telephone modems to obtain RTK/DGPS data, it may be possible to arrange with the telephone company that part of the charges are credited to the authority operating the reference stations.

Another possibility would be that RTK and GIS rovers, with mobile telephone modems or Internet IP addresses, would have to register their telephone numbers or IP addresses with the authority operating the reference stations. Only telephone and Internet connections from registered devices would be able to obtain data. Software at the control server could create a log showing the duration during which each registered device (i.e. user) had obtained data. Charging could then be arranged.

Another possibility would be that users of RTK and GIS rovers, with mobile telephone or Internet connections, would have to enter passwords. Only those rovers able to authenticate themselves (i.e. make connections with registered passwords) would be able to obtain data. Software at the control server could create a log showing the duration during which each password (i.e. user) had obtained data. Charging could then be arranged.

26. Some examples of stand-alone reference stations and networks

From the preceding chapters it will be obvious that reference stations and networks can be set up and configu-red in many different ways, for many different applications, and with many different levels of complexity. The solutions will vary according to the requirements, the areas to be covered, the services to be provided, and the available budgets.

The following examples are intended only as general guides and provide suggestions for possible solutions. They should not be taken as complete recommendations.

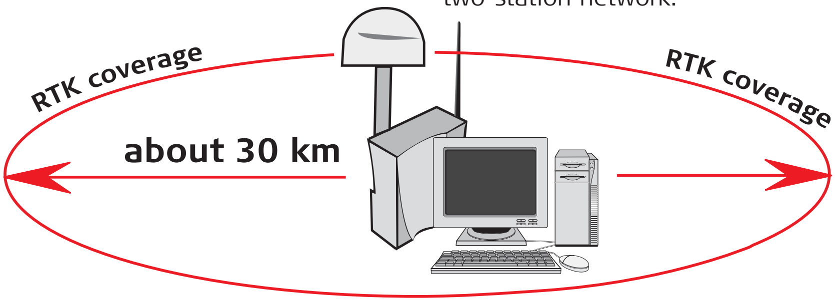
26.1 Stand-alone reference station for a small area such as an opencast mine, construction site, or local community

GPS survey work on construction sites and in opencast mines is usually carried out with RTK. Thus a single stand-alone reference station transmitting RTK data by radio directly from the receiver may be all that is required. In most cases it will be preferable to have reference station software running on a PC to control the receiver, and to download and archive logged data.

A single stand-alone reference station may also be perfectly sufficient for a small community. Radio and/or phone could be used to transmit RTK/DGPS data. A router or bank of phone modems would be needed in order that several users could phone in at the same time.

Reference station software running on a PC will control the receiver, download and archive data. With a PC connected, it is also possible to distribute RTK/DGPS data to a number of users at the same time via the Internet.

For civil engineering and construction sites where very high accuracy is required, for example for a bridge, it may be desirable to set up a second independent reference station in order that RTK rovers can obtain two independent position fixes at critical points. A single PC (server) running the reference station software could control the two reference station receivers; this would then become a two-station network.



26.2 A simple network of a few stations providing complete RTK coverage for a relatively small well developed area.

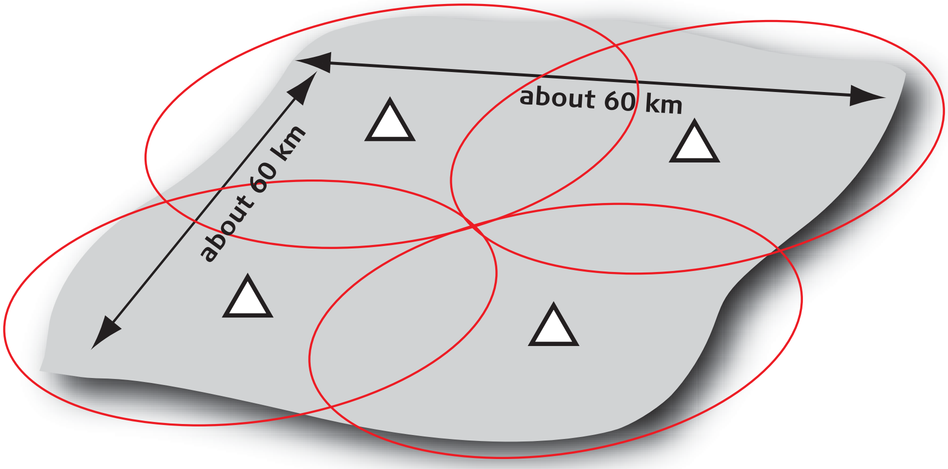
In developed areas with high populations, such as around metropolitan areas, most GPS survey work will be carried out with RTK. Thus the main requirement will be to provide complete RTK coverage.

Purely as an example, imagine that RTK/DGPS services have to be provided throughout an area of about 60km x 60km. A relatively simple solution would be to have 4 or 5 reference stations spaced about 30km apart. This would provide good RTK coverage throughout the area.

Dial-up lines could connect the stations to a central server running the reference station software. The software would control the receivers, download logged data files, and push RINEX files to an FTP server.

RTK/DGPS data could be transmitted directly from the receivers by radio and/or phone. The radios at the stations would have to be set to different channels (frequencies). A router or bank of phone modems would be needed at each station in order that several users could dial in at the same time.

Such a network would be relatively simple and easy to set up and, as there would be no permanently open lines, the running costs should be low.



26.3 A more complex network providing complete RTK coverage for a relatively large highly developed area.

If the area for which RTK coverage is required is relatively large, there are two possibilities:
i) As outlined in 26.2 but with more stations. However, this will mean increased costs for equipment and infrastructure.
ii) Place the stations further apart and use software for continuous network analysis and calculation of network correction parameters. This will allow RTK at longer ranges (see 20.).

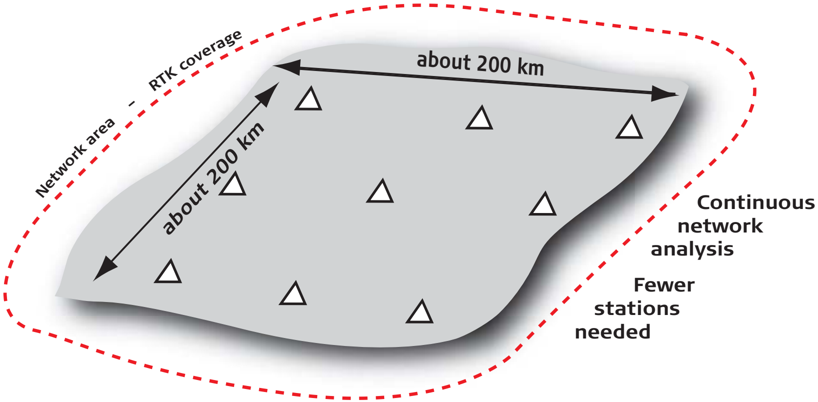
The following example is based on possibility ii), i.e. using software for continuous network analysis and calculation of network correction parameters.

Imagine that RTK/DGPS services have to be provided throughout an area of about 200km x 200km. With about 9 reference stations and a separation distance between stations of about 70km, RTK rovers will usually be within about 35km of a station and the maximum distance from a station should not be more than about 50 km.

For continuous network analysis and calculation of network correction parameters, raw data have to be streamed continuously from the receivers to a central server running the reference station software.

Permanently open communication links between the receivers and the server are required. The best is to use the Internet, as running costs (charges) will be lower than with permanently open telephone lines.

The software running on the server would control the receivers, download logged data files, and push RINEX files to an FTP server.



26. Some examples of stand-alone reference stations and networks (continued)

In order to increase the range at which RTK rovers can operate successfully, the software would also:

- Transmit the network data in RTCM V3.0 format and the network correction parameters to RTK rover receivers. Transmission could be by radio, phone or Internet.
- And/or
- Apply the network correction parameters at the server and transmit "corrected" RTK data to the rover receivers. Transmission could be by phone or Internet.

See section 20 for full details.

As the distribution of RTK/DGPS data and logged data is all controlled from a central server, it should also be possible to set up a system for charging for data if this is a requirement.

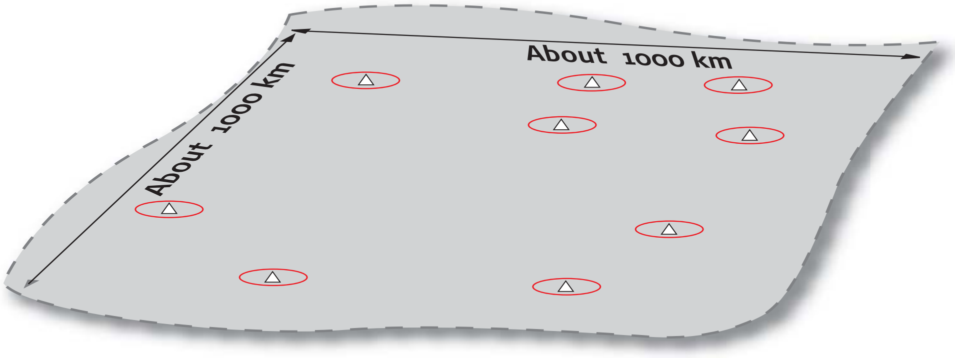
Such a network would be more complex than that outlined in 26.2 but it would require fewer stations for the area to be covered.

26.4 A network of a few stations providing RINEX data and limited RTK/DGPS for a very large undeveloped area

Some parts of the world have low populations and/or are undeveloped. As in such regions there will be few RTK and DGPS rovers operating, it will usually be uneconomical to attempt to achieve RTK coverage. A few reference stations that are widely separated may be quite sufficient.

As an example, imagine that a geodetic control network is needed for a region of about 1000km x 1000km where there are only a few small centers of population.

The most economical solution would be to set up a reference station at each of the important population centers. If there is sufficient demand, these stations could transmit RTK/DGPS data by radio and/or phone to provide local RTK coverage (e.g. within a radius of about 30km).



With large distances (perhaps up to several hundred kilometres) separating the reference stations, most of the region would have no RTK coverage at all.

Although, if necessary, the reference stations could be single stand-alone stations, the best would be to connect the receivers by dial-up lines to a central server running the reference station software. The software would control the receivers, download logged data files, and push RINEX files to an FTP server.

A survey crew operating in a remote area would have to set up a temporary field reference station, log data for a sufficient period (perhaps several hours), download the RINEX files from one or more reference stations, and post process the baselines from these stations. This would provide position coordinates with an accuracy of a few centimetres that could then be used as the starting point for the new survey.

26.5 A combined approach: networks of stations providing RTK/DGPS coverage for highly developed areas, widely spaced stations providing RINEX data throughout undeveloped areas.

Some countries or regions have one or more large, highly developed conurbations, in which millions of people live and work, separated by vast areas of thinly populated land.

Whereas RTK/DGPS services will be essential for the developed zones it will often not be economical to provide RTK coverage for the thinly populated areas.

A network of widely spaced reference stations supplying RINEX data as outlined in 26.4 will usually be sufficient for the less developed areas with low population.

Networks of more closely spaced stations providing full RTK coverage will be needed for the highly developed zones surrounding the major cities.

Depending on the areas to be covered, such networks could be as described in 26.2 (without continuous network analysis and calculation of network correction parameters) or as described in 26.3 (with continuous network analysis and calculation of network correction parameters).

A single server could handle the combined network.

In some cases, however, it may be preferable to have separate servers for each of the smaller “RTK” networks and for the larger “RINEX” network. The smaller “RTK” networks will of course be linked to and form part of the larger “RINEX” network.

27. Meteorological and tilt sensors

27.1 Meteorological sensors

The delay in the GPS signals as they pass through the atmosphere provides valuable information for meteorologists. Some organizations that operate GPS reference stations supply data to meteorological authorities. The data is used to assist weather forecasting and studying climatic change.

For such applications it is usually required to connect a meteorological sensor to the GPS receiver at the reference station. The meteorological sensor delivers temperature, humidity and pressure data, which are recorded together with the GPS data.

The reference station software running on the server downloads the data and provides the meteorology and GPS data in RINEX format.

27.2 Tilt sensors

If the GPS antenna at a reference station is set up on a high column or pillar, some organizations prefer to attach a tilt sensor to the column or pillar. The tilt sensor is connected to the GPS receiver.

A twin-axis tilt sensor will measure tilt in two directions. The data are recorded in the receiver together with the GPS data. The reference station software running on the server downloads the data and provides the tilt data in RINEX format. The tilt data can then be analyzed in order to monitor any inclination of the column or pillar.

Met sensor

Tilt sensor

When studying whether to install a tilt sensor, it is worth considering the following:

- The higher the pillar or column, the more likely it is to tilt.
- High metal pillars or columns may undergo daily deformation due to heating by the Sun.
- A low well-constructed pillar with a good foundation is unlikely to tilt.
- If any tilt occurs it will often be slow and over a long period of time.
- Movement of the antenna can be determined to a high degree of accuracy by post processing the baselines between the stations as outlined in 22.2.
- Checking the positions of the antennas by post processing will often be all that is required by many organisations.

28. Protection against lightning

If a reference station is in an exposed area and in a region where thunderstorms are likely to occur, it is advisable to protect the equipment against lightning. Protection can be provided by a lightning conductor and/or by a lightning surge arrestor.

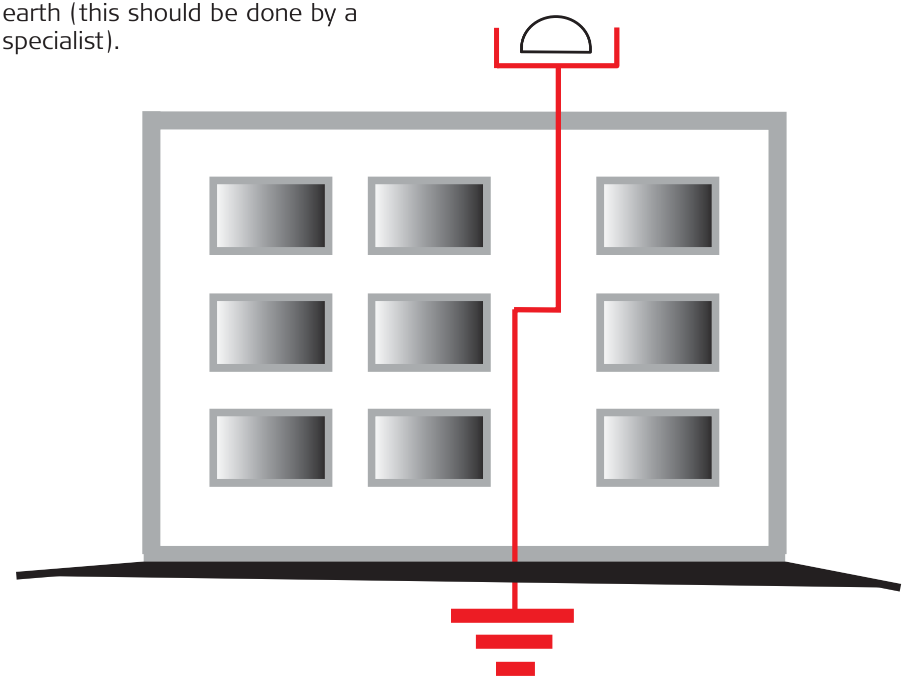
28.1 Lightning conductor

A tall building will usually have a lightning conductor. This usually comprises one or more metal rods connected by a thick copper strip, the lower end of which is firmly embedded in the ground below. Specialized firms install lightning conductors for buildings.

A lightning conductor can be placed close to or around the GPS antenna. In order not to obstruct the satellite signals, the rod or rods should not be too high. One solution is to have four small rods placed around the antenna in such a way that they do not rise above 10° above the horizon of the antenna.

If the antenna is on a building, the lightning protector should be connected to the lightning protection system of the building and thus to the earth (this should be done by a specialist).

If the antenna is on a pillar, the lightning protector will need a copper strip that is correctly earthed. Always employ or consult a specialist.



28. Protection against lightning (continued)

28.2 Lightning surge arrestor

A surge arrestor is a small device that has to be placed within the antenna cable between the GPS antenna and the receiver. It has also to be correctly earthed.

If the antenna is on a building, the surge arrestor should be connected to the lightning protection system of the building and thus to the earth (this should be done by a specialist). If the antenna is on a pillar, the lightning surge arrestor has to be connected to a copper strip that is correctly earthed. Always employ or consult a specialist.

The surge arrestor protects the receiver and any equipment connected to the receiver (e.g. a computer) from electrical surges caused by lightning strikes. But the GPS antenna is NOT protected.

There are several products on the market and they are not expensive.

The manufacturers will advise which products are the most suitable.

Employ or consult a specialist to ensure that the connection to earth is carried out correctly.

Many organizations consider that it is sufficient to install only a lightning surge arrestor and not a lightning conductor.

29. Points to take into account when deciding what type of stations and/or networks are needed

- What is required?
- What applications have to be supported?
- What will the stations and/or network be used for?
- What is needed today?
- What will be needed in future?
- The area to be covered
- Where to establish the stations?
- What can be the separation distance between stations?
- The need for suitable sites with an open view of the sky
- Power, communication, security
- The infrastructure that is readily available and can be used
- The new infrastructure that has to be added
- The type of users that have to be supported
- The number of users that have to be supported
- Is it sufficient simply to log data and provide RINEX files?
- Is it also required to transmit RTK/DGPS data?
- The most suitable methods of communication between the receivers and the server
- The most suitable methods for distributing RTK/DGPS data
- The most suitable communication for distributing RTK/DGPS data
- The cost of establishing the stations and/or network
- The cost of running the stations and/or network
- The running costs for RTK and GIS rovers
- Computing the baselines between stations to check the positions of the antennas
- The budget that is available today
- The budget that will be available in future
- Charging for services and data

GPS reference stations and networks are readily scalable. They can be easily enhanced and upgraded as requirements change and the number of users increases. Thus, initially, it will often be quite sufficient to establish only the stations and services that are really needed. Afterwards, as the requirements increase, the number of users grows and additional funds are available, new stations and features can be added and the services that are provided can be improved and enlarged.

The initial investment is never lost.

30. Useful links

Leica Geosystems AG
http://www.leica-geosystems.com
For further information on GPS reference stations and networks

UNAVCO
http://www.unavco.org/facility/software/preprocessing/preprocessing.html
For TEQC tool.

IGS
(International GPS Service)
http://igscb.jpl.nasa.gov/
For general information on the IGS network

EUREF (RINEX data)
http://www.epncb.oma.be/_dataproducts/datacentres/index.html
For information on the UREF network.

SOPAC
http://sopac.ucsd.edu/cgi-bin/dbShowArraySitesMap.cgi
For information on IGS stations and how to obtain RINEX data files

NGS
http://www.ngs.noaa.gov/CORS/instructions2/
For information on RINEX.

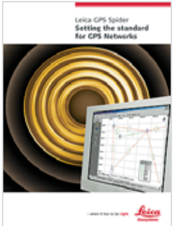
RINEX
Receiver Independent Exchange Format
http://igscb.jpl.nasa.gov/igscb/data/format/rinex210.txt

RTCM
http://www.rtcm.org
For information on RTCM formats.

ITRF
International Terrestrial Reference Frame
http://lareg.ensg.ign.fr/ITRF/

NTRIP
http://igs.ifag.de/NTRIP.htm

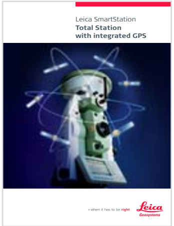
NMEA
National Marine Electronics Association
http://www.nmea.org



Leica GPS Spider
Product brochure

Leica GRX1200
Product brochure

Leica GPS1200
Product brochure



Leica SmartStation
Product brochure

Whether providing corrections from just a single reference station, or an extensive range of services from a nationwide RTK network – innovative reference station solutions from Leica Geosystems offer tailor-made yet scalable systems, designed for minimum operator interaction whilst providing maximum user benefit. In full compliance with international standards, Leica's proven and reliable solutions are based on the latest technology.

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