EUPOS®

European Position Determination System

Guidelines For Single Site Design

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1. Introduction

The quality of EUPOS services depends to a large extent on the appropriate GNSS reference station site selection and design. EUPOS member countries shall follow certain installation guidelines in order to guarantee the high quality of their national EUPOS networks. Observance of the guidelines will help network operators provide homogeneous services throughout the whole EUPOS coverage area, independent of the users' location.
Unlike the global International GNSS Service (IGS) network or the European EUREF Permanent Network (EPN), the EUPOS network is not designed primarily for scientific purposes, but it is recommended to involve some EUPOS reference stations per country into EPN. Accordingly, the EUPOS site design guidelines are not as strict as that of the IGS or EPN. However best practices provided in this document shall be carefully followed and precautions shall be taken in order to minimise performance problems during the operation phase.

This document does not provide guidelines for GNSS reference station equipment selection, data handling, etc; it only gives recommendations for site selection and site design.

2. Site selection

Selection of a suitable EUPOS station is dependent on the required location from an operational point of view, but is also governed by the availability of a suitable site with reliable telecommunication facilities.

2.1 Sky visibility

Of paramount importance is the suitability of the antenna location.

2.1.1 Sites are chosen for good all round satellite visibility. Obstruction shall be minimal above 5 degrees elevation, but satellite visibility down to the horizon is encouraged whenever possible.

2.1.2 Selected sites shall not have long-term significant changes to the surroundings (changes to buildings or trees; new construction, etc) foreseen or likely.

E.g.: The reference station at the Penc observatory in Hungary is a negative example in this aspect, trees around the observatory building have been growing above the antenna horizon during the last 10-15 years, see Figures 1-3 below. Some of the higher pine trees around the building should be chopped down.

Figure 1. Penc, observatory building in 1982
(image courtesy of FÖMI GNSSnet.hu)

Figure 2. Penc, observatory building with reference station pillar in 1997
(image courtesy of FÖMI GNSSnet.hu)

Figure 3. Penc, observatory building with reference station pillar in 2006
(image courtesy of FÖMI GNSSnet.hu)

2.2 Site stability

The position of the reference station antenna must be very stable, therefore it is highly important to erect antenna holding monuments or select suitable buildings in a stable environment.

2.2.1 Sites are preferred where no significant crustal instabilities have been recorded.

2.2.2 Sites shall not be located on soil that might slump, slide or significantly vary in elevation (e.g. because of subsurface liquid variations).

2.2.3 Locations with significant surface vibration due to heavy nearby traffic shall not be selected.

2.2.4 Reference stations shall not be installed on recently built or extended buildings that may still subside.

2.3 Multipath and interference

Multipath is caused by extraneous signal reflections from nearby metallic objects, ground or water surfaces reaching the GNSS antenna. This may cause signal interference between the direct and the reflected signal leading to noisier measurement, or it may confuse the tracking electronics of the hardware resulting in a biased measurement. In severe cases of multipath, loss of lock may even occur. At the reference stations, the antenna location should be selected very carefully to avoid a reflective environment.

2.3.1 The GNSS antenna shall not be installed in the vicinity of

- flat metal surfaces,
- walls,
- metal poles or other metal structures (e.g., high antenna towers, satellite dishes),
- wire fences (particularly chain link),
- large areas of glass (on building fronts),
- standing water, pools or lakes.

2.3.2 The GNSS antenna shall not be mounted less than 50 cm above a potentially reflecting horizontal surface.

In general the higher the antenna is mounted above a flat surface the smaller the risk of ground-bounced multipath errors is. However, to avoid antenna vibration the height of the antenna mount (e.g. iron pipe) above the surface elements and the applied monumentation should be carefully selected. If highly reflective surfaces cannot be avoided around the antenna it is recommended to cover such surfaces with microwave absorbing material (e.g. paint). This should be done every few years because of the aging.

Figure 4. Near-field ground bounced multipath environment
(image courtesy of FÖMI GNSSnet.hu)

There are near-field multipath effects caused by the antenna setup, e.g., pillar, tripod, tribrach, adaptor, etc. and the antenna environment on the GNSS site. The constant geometry of the antenna and its close surroundings cause a systematic change of the reception characteristics of the antenna. Near-field multipath effects will mainly bias the height component. These effects can cause more severe problems compared to multipath induced by reflectors, which are located further away from the antenna. Due to the short distance between the reflector and the antenna phase centre, the reflected signals tend to be much stronger than signals coming from more distant objects. Hence, the amplitude of near-field multipath errors is larger. Far-field multipath effects have a cyclic characteristic with periods in the order of minutes and tend to average out. This is not the case for near-field multipath where the periods can be in the order of many hours.

2.3.3 It shall be avoided to mount the GNSS antenna on top of (quadratic or round) pillars with large horizontal surfaces.

Figure 5. Bulky reference station pillar of station PENC
(image courtesy of FÖMI GNSSnet.hu)

The near-field multipath effect can be significantly mitigated by the calibration of the re-constructed near-field multipath environment along with the antenna PCV.
E.g.: The NETPOS RTK network of the Netherlands is equipped with small rover antennas without any means of multipath reduction (see Figure 6.). The use of such an antenna model and a special antenna adaptor is responsible for significant height errors in positioning caused by near-filed multipath effects. This effect could largely be reduced by the robot calibration of the antenna together with the reconstructed near-field multipath environment.

Figure 6. Antenna setup used in the NETPOS RTK network of the Netherlands causing strong near-filed multipath
(image courtesy of the Kadaster of the Netherlands)

2.3.4 If using pillars or special antenna adaptors it is recommended to carry out the individual robot calibration of the reconstructed near-filed multipath environment together with the antenna PCV.

2.3.5 It is recommended that the multipath environment is assessed at selected reference station antenna locations prior to permanent station installation.

2.3.6 Only GNSS antennas with choke ring multipath protection shall be used in the EUPOS network.

Radio frequency interference can cause serious GNSS tracking difficulties. GNSS signals detectable on Earth's surface are 10^{18} less powerful than a 100W light bulb! GNSS signals can therefore be easily disturbed either unintentionally or intentionally (GNSS jamming) by microwave radio sources that transmit signals in the protected frequency bands of the EM spectrum dedicated for satellite navigation.

Unintentional interference may originate from:

- Nearby high-power electric transmission lines,
- Nearby electric transformation stations,
- Nearby malfunctioning or non-standard radio or television broadcast stations,
- Nearby radar stations,
- Nearby non-standard wireless communication devices (e.g., Wi-Fi routers),
- Radio dispatch stations
    - Police, Fire & other emergency services,
    - Taxi services,
    - Pickup and delivery services.

2.3.7 Reference station antennas shall be installed at sites with low radio frequency interference potential.

2.3.8 Potential radio frequency interference sources should be detected prior to GNSS reference station installation by means of spectrum analysis.

2.3.9 The spectrum analysis should be repeated at the reference stations if tracking performance degradation is observed that is not caused by malfunctioning GNSS equipment.

It is the task of EUPOS National Service Centres to carry out spectrum analysis at the sites in question and alert the national communications authorities if interfering signals are detected. The authorities have to investigate the GNSS interference reports and take necessary steps to cease the disturbing signal.

E.g.: Figures 7-9. demonstrate a GPS L2 tracking disturbance observed at the KECS reference station of Kecskemét, Hungary, caused by interfering radio signals. The source of the disturbance was a CCTV camera transmitting its pictures via microwave radio. The frequency band of the device was non-standard, the spread spectrum signal weakened the GPS L2 reception at the reference station. The interference source was detected by the Hungarian GNSS Service Centre, and soon after localised and ceased by the authority.

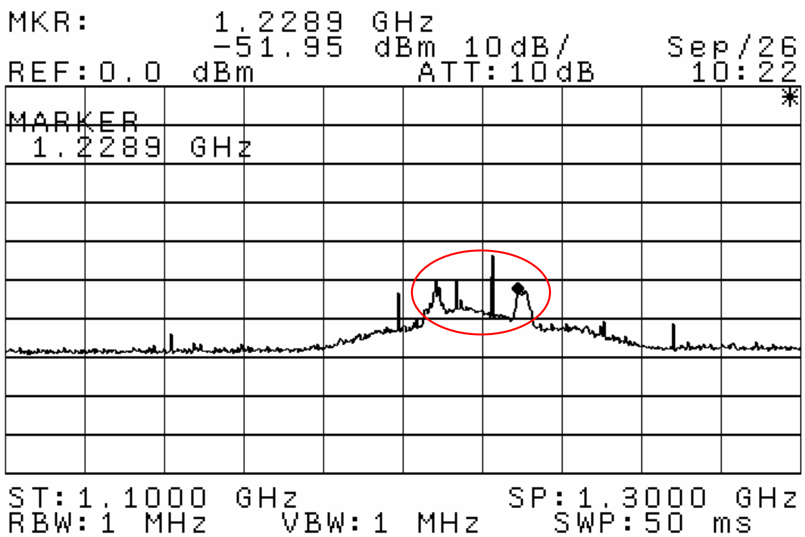

Figure 7. Radio frequency interference at GPS L2 frequency detected in Kecskemét, Hungary

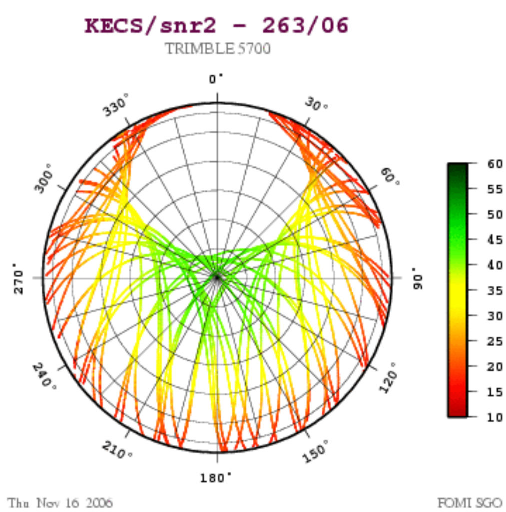

Figure 8. Normal GPS L2 tracking conditions at station KECS prior to the appearance of interfering signal (Signal to Noise ratio in dBHz)

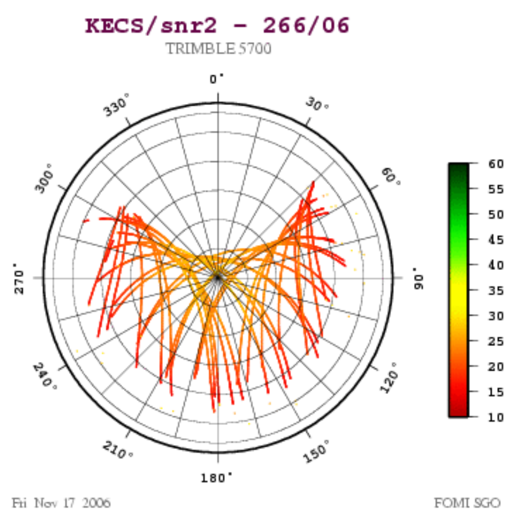

Figure 9. Tracking difficulties on GPS L2 frequency at station KECS caused by RF interference (Signal to Noise ratio in dBHz)

It is also possible to carry out continuous spectrum analysis and detect interfering signals or tracking performance degradation on the fly by special GNSS software receivers.

2.4 Communication link

EUPOS reference stations provide their GNSS observation data to networking centres in real time via some means of telecommunication. Sites with existing reliable telecommunication facilities (e.g. land registry offices) are therefore preferred when searching for suitable reference station locations.

2.4.1 EUPOS sites must have a reliable data communication connection (Internet or intranet) to the networking centre. The connection must have sufficient bandwidth and guaranteed high availability.

Probably the best solution is Internet or intranet (e.g. Virtual Private Network over the open Internet) connection on leased telephone lines. ADSL and ISDN connections can also be used, however Internet Service Providers normally do not guarantee high (>99%) network availability when using such networks and often the guaranteed reparation time upon connection breaks does not meet the strict EUPOS standard requirements. Microwave network or wireless Internet connection can be used as backups as the reliability of such systems is lower than that of land lines and they are exposed to signal interference.

2.4.2 The installation of backup communication lines is recommended to increase system availability.

2.5 Receiver installation

2.5.1 The GNSS receiver and communication devices should be kept in a heated / air conditioned building, preferably in a rack.

2.6 Access and protection

2.6.1 Reference stations should be located at secure sites, where their permanent preservation is ensured.

2.6.2 Reference stations should be accessible by maintenance engineers, even on weekends or public holidays.

2.6.2 Unauthorised people should not have access to the reference station equipment.

2.6.3 Selected sites should be protected against vandalism.

3. Station monumentation

GNSS reference station antenna motions propagate into the user position solution, adversely affecting the accuracy of field measurements. Therefore all necessary steps must be taken to guarantee the stability of the antenna mount.

The antenna can be mounted on a purposely built monument or fixed to a roof of a building. The monument can be in a form of a concrete pier, steel construction or rock outcrop. In the case of an antenna fixed to a roof of a building, the building is the monument and the pipe supporting the antenna is an extension of it. The reference marker is attached to the monument and serves as the geodetic reference point, it must be fixed permanently to the monument. The antenna height is measured to the reference mark.

There are various types of antenna mounts that can be used in the EUPOS network. The following examples are listed in the order of stability.

Drilled braced steel monuments are the most stable antenna mounts. The vertical steel pole is placed in a hole drilled into bedrock, filed with grout.

Figure 10. Short Drilled Braced Monument (image courtesy of UNAVCO)

Figure 11. Deep Drilled Braced Monument (image courtesy of UNAVCO)

Reinforced concrete pillars are stable monuments. The pillars are normally coupled to bedrock or founded on a larger mass of concrete set within a pit in soil.

The ‘Earlconic’ antenna monument applied at the Michigan Spatial Reference Network is an excellent example because of its stability and low multipath potential (see Figure 12.). The cylindrical poured concrete pillar has a diameter of 60 cm, it is descending 3.6 m in the ground and also extending 1.5 m above the ground surface. Internally, a re-inforced steel rebar cage extends from top to bottom supporting the concrete. The pillar is surmounted with a spun aluminium finned pole either 2.4 m in height or 4.8 m in height depending on the local obstructions.

Figure 12. Earlconic monument
of the station BIGR
Big Rapids, Michigan, USA
(image courtesy of the Michigan Department of Transportation)

An antenna mount fixed to the roof of a building is less stable than a pole drilled into bedrock or a pillar. The movements of the building and the roof structure due to thermal expansion (dilatation) have an adverse effect on the antenna stability. However, EUPOS is not an extremely high accuracy crustal movement monitoring network, where such movements are not acceptable. The benefit of having a readily available telecommunication link and a secure environment to shelter the reference station equipment can outweigh the lower stability. Nevertheless, the antenna installation on top of the roof must be as stable as possible.

A good example for stable roof-top monuments with the antenna mounted at a sufficient distance from reflecting surfaces is displayed on Figure 13. The antenna mount is welded atop a 2-m tall steel tripod on the roof of the building. (Please note that Figure 13 is a good example for antenna monumentation only. A site with nearby trees that can cause signal obstructions should not be selected by EUPOS network operators.)

Figure 13. Steel tripod monument on a rooftop
at station BRFT
Eusebio, Fortaleza, Brazil
(image courtesy of NOAA-NGS)

Unused chimneys, which are still in good condition, can be used as antenna monuments. An antenna holding metal structure can easily be attached to or placed on top of such chimneys.

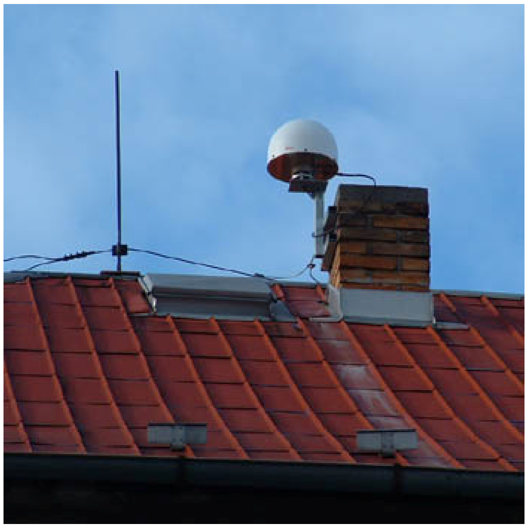

Figure 14. Antenna mounted on a steel plate fixed to an unused chimney at station CTAB Tábor, Czech Republic (image courtesy of ZÚ CZEPOS)

Figure 15. Antenna fixed to an unused chimney at station SZFV Székesfehérvár, Hungary (image courtesy of FÖMI GNSSnet.hu)

An antenna holding pole or pipe can also be built on top of a pitched roof. The lower part of the pipe must be rigidly fixed to a weight-carrying wall of the attic.

Figure 16. Antenna mounted on top of a pitched roof at station NYIR Nyírbátor, Hungary (image courtesy of FÖMI GNSSnet.hu)

Figure 17. Antenna mounted on top of a pitched roof at station TATA Tata, Hungary (image courtesy of FÖMI GNSSnet.hu)

It is relatively easy to build an antenna mount on top of a flat roof. A braced iron pipe based on a bulky concrete block is a suitable solution.

The antenna mounting pipe can also be fixed to the side of a penthouse building. The pipe must be rigidly attached to the wall. Figure 19 shows a monumentation example where the applied pipe length can result in harmful antenna vibrations in strong winds. Therefore it is recommended to reinforce the pipe like on the Figure 20.

Figure 18. Antenna installation on flat roof at station BALE
Baja, Hungary
(image courtesy of FÖMI GNSSnet.hu)

Figure 19. Wall-mounted antenna holding iron pipe at station MISC
Miskolc, Hungary
(image courtesy of FÖMI GNSSnet.hu)

Figure 20. Reinforced wall-mounted antenna mount at station CRAK
Rakovnik, Czech Republic
(image courtesy of ZÚ CZEPOS)

4. Antenna installation

4.1 It is recommended to have a uniform setup of all antennas in the network.

4.2 The reference station antenna shall be rigidly attached, such that there is not more than 0.1mm motion with respect to the antenna mounting point.

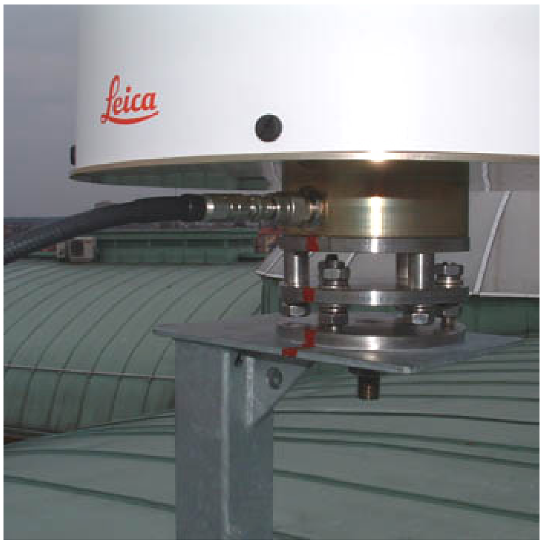

Figure 20. Antenna adaptor used in the CZEPOS network of the Czech Republic (image courtesy of ZÚ CZEPOS)

Figure 21. Antenna adaptor used in the GNSSnet.hu network of Hungary (image courtesy of FÖMI GNSSnet.hu)

4.3 The antenna reference point ideally will be mounted directly vertically above the marker (i.e., horizontal eccentricities ideally are zero).

4.4 The antenna must be levelled and oriented to True North using the North reference mark and/or antenna RF connector.

4.5 The marker to antenna reference point (ARP) eccentricities shall be determined (surveyed) to an accuracy of 1 mm.

4.6 The antenna coordinates shall be verified regularly, new coordinates shall be provided for stations located at sites influenced by known motion incidents such as earthquakes.

4.7 In the EUPOS network only antenna types with individual absolute PCV calibration results shall be used.

4.8 On the EUPOS network only high-quality coaxial GNSS antenna cables shall be used. The length of the antenna cable shall not exceed 50 m. In case a longer cable run has to be applied, an in-line, low-noise amplifier shall be used to compensate for the reduced signal strength. The use of extension antenna cables and cable connector adapters shall be avoided.

4.9 It is recommended to install lightning surge protection by applying inline surge arrestors.

4.10 If antenna radomes are used, models uniformly manufactured with less than 1 mm variability in thickness are preferred.

5. Station operation

5.1 Power supply

5.1.1 GNSS receivers and other station equipment such as computers and communication devices shall be protected against power fluctuations and failures by providing surge protection and backup power (Uninterruptible Power Supply).

5.2 Routine operation and maintenance

EUPOS reference stations are permanent stations that operate continuously 24 hours a day, 7 days a week.

5.2.1 The reference station observations (the equipment and its surroundings) should not be disturbed during normal operation, unless it is inevitable to temporarily stop the measurements (e.g., replacement of malfunctioning or obsolete equipment, firmware upgrades).

5.2.2 Reference station software maintenance (e.g., firmware upgrades) should be carried out remotely from the networking centre. The network centre operators should be able to reboot the GNSS receiver via remote control.

5.2.3 Whenever feasible it is advantageous to have contacts to a local call-out engineer or network administrator who can help the EUPOS networking centre operators in initial troubleshooting at the site upon station failure.

5.2.4 Every EUPOS site must be well documented, the station logs and descriptions must be always up-to-date.

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