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Interference and Regulatory Aspects of GNSS Pseudolites

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Abstract. Galileo, the European Satellite Navigation System, is currently under development. Even before first satellites of the constellation are launched, Galileo signals will be provided through ground based Navigation Signal Generators for the investigation of signal performance and characteristics. These low power devices, called Pseudolites (Pseudo-Satellites), will transmit signals equivalent to those which are transmitted by the in-orbit satellites. However, from the regulatory point of view they are not providing Radionavigation Satellite Service (RNSS) as defined in International Tele communication Union (ITU) Radio Regulations but "something else". This has to be investigated, because it is expected that Pseudolites (PLs) will, beyond their roles to evaluate signal performances in the early phase of the program, significantly extend the navigation service availability into areas where the critical RF propagation of direct line of sight to satellites is blocked. Sound experience over many years has already been gained worldwide through the research with GPS Pseudolites. Galileo will introduce sophisticated and ambitious new signal schemes initiating new designs for innovative Pseudolite solutions. Old and new signals will coexist for many years to come. Currently there are various projects ongoing to develop Pseudolites for Galileo. A practicable regulatory framework, taking specific operational conditions of Pseudolites into account, has to be developed by the regulatory authorities to encourage the implementation of Pseudolite-networks on one side. But, at the same time, it is important to set strict rules for the implementation to avoid harmful interferences created by Pseudolites to RNSS and other radio receivers operated in the vicinity of a Pseudolite-network. The creation of a clear regulatory framework has eventually to provide the planning security for Pseudolite-network operators and RNSS-provider considering service guarantees. Pseudolites, as well as other means to achieve a nearly seamless service availability have been an essential element of the Galileo system architecture from its early system studies. In the Galileo architecture, PLs are defined as a sub-group of the so-called Local Elements. Technically speaking, Pseudolites are low power transmitters that either transmit or repeat (Synchrolites) RNSS-equivalent signals on the same frequency bands allocated to RNSS as defined in the ITU-R Radio Regulations. The creation of a regulatory framework for the operation of Pseudolites, which is yet undefined, has recently received a growing attention in the spectrum engineering working groups and frequency management groups of the European Conference of Postal and Telecommunications Administrations (CEPT). So far, PLs are operated under experimental license only. In order to prepare inputs to this process, the performance requirements in typical application scenarios have been investigated. This paper presents initial considerations and preliminary results of investigations performed on the interference properties of general GNSS Pseudolites. It proposes a concept for typical scenarios that can serve as generic Pseudolite network architectures to be considered in the on-going process to determine a regulatory framework for future operational networks.

Keywords: GPS, Galileo, GNSS, Pseudolites, Interference.

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1 Introduction

Over the past two decades, Pseudolites have been developed and investigated for a wide variety of applications. At the beginning they were used to test GPS signals and the GPS user equipments when no in-orbit satellites were available. Then their usage has evolved to augmentation of GPS and even for pseudolite-only indoor navigation systems (Wang, 2002).

Currently there are GPS pseudolites available which can broadcast L1- or L2-signals. From the regulatory point of view all tests and investigations have been performed with special temporary experimental licenses. Interference issues were investigated when particularly necessary but in general licensing process has been defined so far to authorize the operational use of GPS Pseudolites. This is because a Pseudolite that is not consciously adjusted and carefully maintained can very quickly turn into a jammer interferer), inhibiting any navigation service in a large area around the beacon.

In the course of development of the Galileo satellite navigation systems, Pseudolites were defined as part of the Galileo architecture namely as "Local Elements". The future operator of Galileo system (Concessionaire) considers offering service guarantees. Thus it is of growing importance to investigate the frame conditions for controlled implementation and operation of GNSS Pseudolites.

The approach presented here proposes the following steps:

- Definition of generic Pseudolite application scenarios for all RNSS systems to provide the technical background and basis for regulation;
- Definition of corresponding architecture parameters and specifications describing these scenarios;
- Investigations of their regulatory constraints and possible categories for regulations (service definition):
    - Develop methodologies to investigate interference scenarios of Pseudolites with RNSS;
    - Dito develop methodologies to analyse their interference scenario with other services;
- Consideration by the relevant regulatory working groups at regional and international level (ITU-R);
- Invite Administrations to consider new allocations for Pseudolites.

The objective of the entire efforts should be to define a well balanced process that encourages on one side the implementation of Pseudolites keeping on the other side the operators of RNSS networks and national administrations in the loop. The cost and complexity of administrative efforts are also to be kept in mind.

2 Scenario Definitions

In order to assess the various environments where pseudolites can be used, a classification has to be made. Over the past twenty years, numerous scenarios for pseudolites have been described in literature as

- Aeronautical applications
- Indoor applications
- Urban and Local GNSS augmentation
- Harbor entrance and docking
- Open pit mining
- …

Each scenario has its specific environmental and propagation conditions which require a thorough treatment of the use of pseudolites.

For the subsequent investigations, two basic scenarios are proposed, which are considered representative for a wide range of applications:

Scenario 1: "areas where RNSS satellite signals are partially available", such as in urban canyons, but also in aeronautical applications

Scenario 2: "Indoor", where signals from RNSS satellites are blocked.

The above classification is important in view of the definition of regulatory constraints and interference issues between Pseudolites and Radio Navigation Satellite Services (RNSS) and Pseudolites and other services as explained later on.

The main system parameters defining a Pseudolite network are:

- Carrier frequencies
- Effective Isotropic Radiated Power (EIRP)
- Antenna characteristics
- Pulse shaping
- Applied duty cycle
- Number of Pseudolite transmitters
- Locations

The scenarios are defined as follows:

Scenario 1 - Urban and Local Scenario

The purpose of using pseudolites in an urban or local environment is augmentation of GNSS by extending its service availability into the areas where satellite signals are not available with a sufficient RF power level for reliable tracking.

In addition the impaired geometrical distribution of the visible satellites leads to a degraded positioning performance.

In terms of propagation characteristics it is difficult to define a generic urban or local scenario because multipath effects, shadowing and reflections vary significantly in the different environments such as narrow streets with multi-storey buildings or wide open places with surrounding buildings. Also the service areas that are targeted for navigation service augmentation (e.g. to provide location based services) vary with highly specific scenarios ranging from a few hundreds square meters to a few tens of square kilometers. With regard to the regulatory frame conditions, aeronautical applications with pseudolites are also part of this category. It is also important if a Pseudolite network is dedicated for permanent or short-term operations, e.g. during an event with mass attractions (sports, commerce, fairs, and others).

The most critical case so far is the implementation of a mobile Pseudolite network, particularly in densely populated areas.

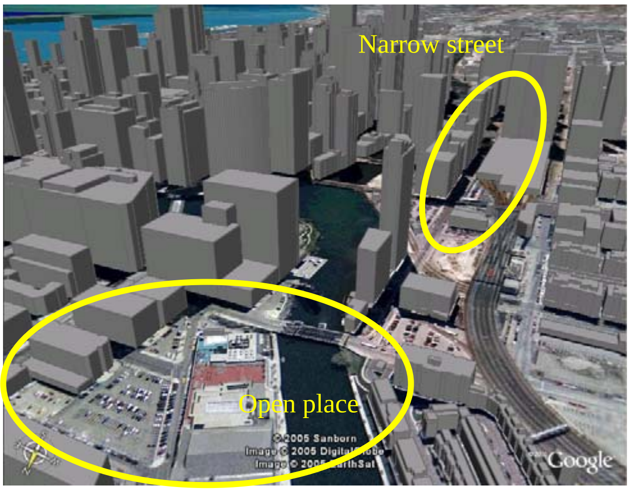

Fig. 1 Different urban and local environments

Altmayer (1998) has investigated the impact of a dual pseudolite system in a medium sized street environment. The tests were conducted with a continuous-wave pseudolite, i.e. without pulsing. For the positioning tests, the experiments with various antenna diagrams were performed to achieve a balanced power flux density over the entire service area. It turned out that shaping the antenna diagram can reduce the degrading impacts of the near-far or hot spot problem. Significant improvements mitigating multipath impacts in various environments through the use of optimised antenna diagrams has been investigated by several studies (Kee et al., 2000; Martin, 1999).

Thus special attention must be paid to the proper radio frequency planning in the urban scenarios to avoid performance degradations or loss of services caused by the near far problem and the impact of multipath propagations.

A very critical area is the transition zone from outdoor to indoor as shown in Fig. 2 because the navigation performance is affected by the potential interference from Pseudolites and direct satellite signals. The figure gives a typical scenario where the user is approaching a building via an open square with perfect satellite coverage followed by a canopy with degraded satellite visibility and then entering the building with almost no satellites available. The goal for pseudolite usage under these conditions is to provide uninterrupted signal sources for position calculation.

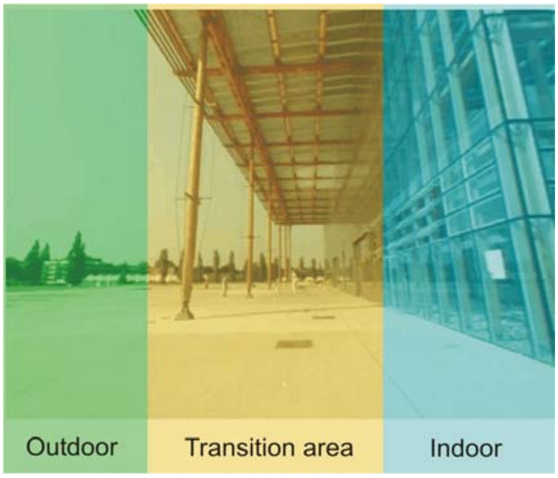

Fig. 2 Typical transition area from in-door to outdoor positioning

A typical Urban and Local scenario can be characterized by:

Carrier frequencies

In the past Pseudolites were mostly developed to complement with the GPS L1-signal. Only a few dual frequency pseudolites have been developed. It can be assumed that future Pseudolites will be applied to operate in all the allocated RNSS frequency bands. In particular Pseudolites that support the Galileo signals will become available to improve the service availabilities in all the three main user communities targeted by the system. Exact carrier frequencies correspond to the carrier frequencies transmitted by the satellites. The Galileo carrier frequencies for each band are provided in Fig. 10.

Transmitter power

The effectively transmitted RF power is defined at the antenna input. In the case of a pulsed transmitter, the RF power is reduced by an adjustable duty cycle. The optimum duty cycle has to be determined by careful adjustments. The finally transmitter average RF power of a pulsed GNSS pseudolite is reduced by

$$P_{loss} = 20 \log PDC \qquad (1)$$

where PDC is the pulsed duty cycle. The impact of a duty cycle on the overall performance has been investigated in (Stansell, 1986; SC-159 RTCA, 2000)

Focusing on Galileo in particular it is assumed that the received signal at the maximum distance from the Pseudolite has to be in the same order as the receive power contribution of a single Galileo satellite, i.e. -128 dBm. Then the received peak power at the user's antenna at maximum distance is

$$P_{PSL,rec,\max\_dist} = -128 - 20 \log PDC \quad [dBm] \qquad (2)$$

The maximum transmit power of a pseudolite can be calculated with

$$EIRP_{PSL} = P_{PSL,rec,\max\_dist} - 20\log\left[\frac{\lambda}{4\pi \cdot dist}\right] \qquad (3)$$

with λ = 0.19m e.g. for the Galileo L1-signal.

Fig. 3 depicts the required transmitter power for up to a maximum distance of 500m with a duty cycle of 2%.

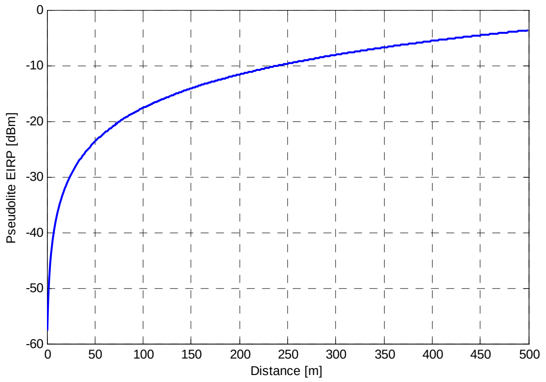

Fig. 3 Pseudolite EIRP for an urban scenario

Pulse patterns and duty cycles

Most of the pseudolites that have been used for indoor applications so far are operated with duty cycles. In this case Pseudolites contribute to the navigation solution in the receiver only for a fraction of the period while the rest of the period is left for satellite reception if available. Different pulsing schemes and pulse duty cycles were used. There are currently two pulsing schemes recommended by the maritime and the aeronautical standards RTCM (Stansell, 1986) and RTCA (SC-159 RTCA, 2000), respectively.

In general the pulse duty cycles vary from (1/11) 2% to 20% (Kee et al., 2000).

Antennas

Basically there are two antenna types which can be used to transmit Pseudolite signals: Patch antennas and helical antennas. Both can provide right-hand circular polarization using the same polarisation as the satellite transmissions. The main differentiator between both is the gain and pattern. Patch antennas have a hemispherical shaped antenna diagram with an almost uniform gain whereas helical antennas have a directional diagram and higher gain.

Considerations for optimising Pseudolite antennas can be found in (Kee et al., 2000) and (Martin, 1999).

Number of Pseudolites

The number of Pseudolites actually implemented at a site depends on the purpose to be achieved and the overall propagation characteristic of the desired service area. Pseudolites in Scenario 1 are assumed to augment the associated GNSS system. In this case, it is not necessary to ensure visibility of at least four Pseudolites for a full positioning capability. The number of implemented equipments should be driven to avoid hot spots. In other words, a distributed network of low power devices would be better than the implementation of a few high power transmitters.

Aeronautical Environment (special case of scenario 1

Applications of Pseudolites in the aeronautical environment can be seen as a special case of pseudolite usage. The operations area extends wider than in an urban scenario and several parameters which influence the regulatory treatment differ from an urban usage.

In an aeronautical environment pseudolites are used for precision approach and landing purposes (CAT II/III). Until a short time ago they have been part of the LAAS concept (RTCA DO246/C, 2005). Pseudolites have been removed from the latest version of the RTCA DO246/C because of missing regulations w.r.t. the airborne receivers and the unsolved concerns about jamming caused by pseudolites.

The main benefit of using pseudolites is an increased availability for precision approaches. For robust navigation performance, GPS Wideband signals have been chosen. Pulsing of the signals was foreseen. Investigations have been done e.g. by several researchers (e.g., van Dierendonck et al., 1997; Lee et al., 2004; Bartone, 1999).

Coverage Area

When pseudolites are used for precision approach, landing and rollout on runway, a horizontal coverage area of 100m to 20NM (37km) is necessary. Most of the airport approaches are conducted with a glide path angle of 3°. Therefore the vertical coverage is set to 5°, taking into account a safety margin for signal acquisition and steep approaches.

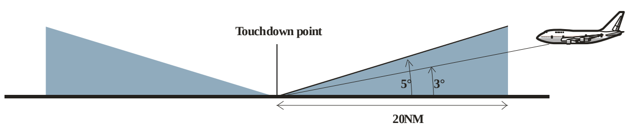

Fig. 4 Airport pseudolite coverage for precision approach

Besides a wide area coverage pseudolite reception while on the runway and during taxi is necessary. Thus the antenna pattern has to be shaped to fulfill this requirement.

Antenna characteristic of widely used dB Systems Inc. Multipath Limiting Antenna (MLA) dBs 200A.

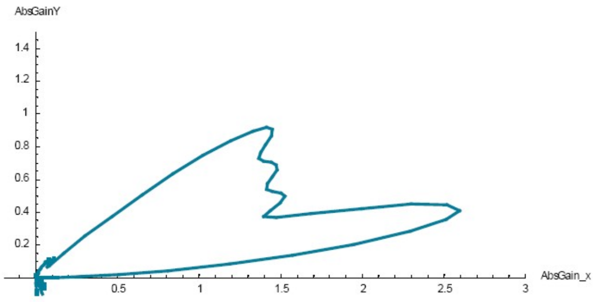

Fig. 5 Vertical antenna diagram of dBs 200A MLA (RIPA-2)

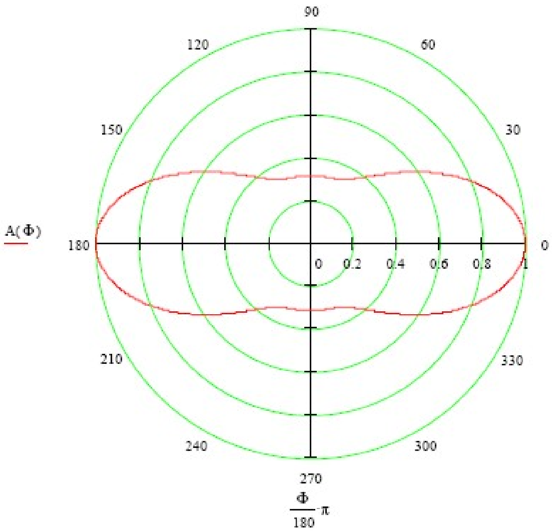

Fig. 6 Top view of antenna pattern (RIPA-2)

Transmitter power

The same formula used in the previous section can be applied. A typical scenario for aviation comprises an airport and its associated airspace and corridors for approach and landing. To improve the navigation conditions Pseudolite signals should have coverage up to 20NM. At the periphery of the services area the received signal level must be in the order of the regular GPS wideband signals, i.e. about -133 dBm.

The Pseudolite signal is pulsed with a 2% duty cycle. That leads to a peak $EIRP_{APL}$ of 38.75 dBm (7.5 watts) and an average EIRP of 21.75 dBm (150 mW) (van Dierendonck et al., 1997).

If the computation is performed with Galileo L1 minimum receiver power of -128 dBm this gives Fig. 7.

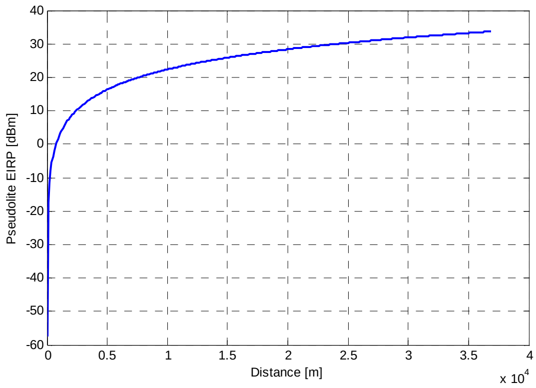

Fig. 7 Peak EIRP for aeronautical PSL usage

Siting

The location of Pseudolites, particularly in the radio environment of an airport requires careful interference analysis and site planning to ensure a good cooperative performance of the space and round component. Bartone et al. (2002) showed that placing a pseudolite with a lateral and advanced offset to the runway gives best results in terms of coverage and the received power.

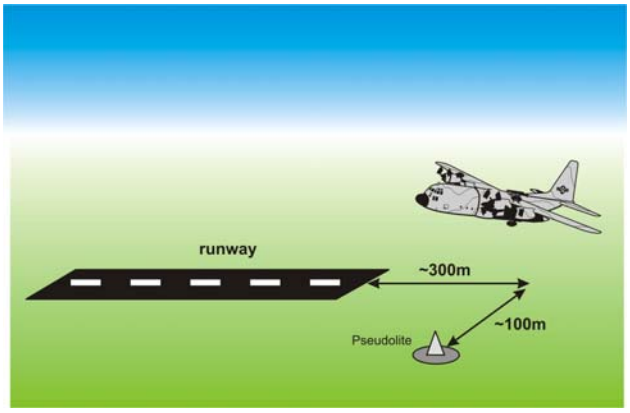

Fig. 8 Pseudolite location for landing application

Scenario 2 - Indoor scenario

Several studies have been conducted to investigate indoor positioning with GPS pseudolites (Kee et al., 2000; Barnes et al., 2004).

A typical scenario comprises four or more Pseudolites in a room or hall where they are used to determine the position and track one or more mobile receivers. Usually these systems operate in a stand alone mode without additional GNSS satellite signals. These systems can be synchronized or asynchronous.

The main differentiator to the urban and local scenario with respect to regulatory issues is that the indoor Pseudolite systems are assumed not to interfere with outdoor GNSS systems. Thus from the regulatory point of view they could be treated differently from the outdoor pseudolite systems. The main criterion in this respect would be that the aggregate power flux density created by the internal Pseudolites outside the building is "insignificant", and thus, does not create harmful interference to the receivers used in the neighbourhood of the building.

Admittedly, the protection threshold for "insignificance" remains yet to be determined. Its determination must take typical receiver performance parameters into account that the receivers will have in the different market segments, ranging from consumer products to high-end equipment for geodesy, safety of life or governmental usages.

Typical parameters for which appropriate values are to be determined to precisely describe the conditions for an indoor scenario are:

Carrier frequencies

Again it is assumed that all the GNSS frequency bands will be used in order to cover all the existing and upcoming GNSS services. This also includes GPS L5, Galileo PRS and Galileo CS.

Transmitter power (EIRP)

The transmitter power was chosen to cover the specific area and taking into account the pulsing scheme. Usually power levels are computed according to the scheme given in the following section. Unfortunately most of the more complex calculation methods are only valid for distances above 200m (e.g. models of Okumura, Hata or Walfisch-Ikegami).

A rough assumption gives an EIRP of -60dBm to -30dBm for a pulsed signal with 2% duty cycle and a coverage distance of up to 40m.

Pulse patterns and duty cycles

In general the same parameters as given in Scenario 1 hold also for this scenario.

Antennas

Most researchers had used helical antennas in the past to overcome extensive indoor multipath problems. In contrast to the patch antennas, helical antennas can be easily shaped to have a more directional diagram and thus avoid multipath due to lateral reflectors. In a typical indoor scenario, pseudolite antennas are mounted under the ceiling or around the corners of a room. These are quite unfavorable places concerning signal propagation and reflections. Patch antennas radiate in a hemispherical diagram thus emitting into nearby reflectors like walls or ceiling creating multipath. A custom made helical antenna with a well shaped beam pattern reduces these influences and prevents multipath.

Number of Transmitters

Depending on the area size and the operating area at least 4 pseudolites have to be installed. Usually in order to overcome signal blockage more than 4 (up to 6 or 7) are used for a certain area.

Summary of scenario characteristics

The following table summarizes the above mentioned parameters for both scenarios.

Table 1: Summary of both scenarios

	Local/Urban	Indoor
Carrier freq.	GPS + Galileo	GPS + Galileo
EIRP	up to +39dBm	-60dBm to - 30dBm
Pulse duty cycle	variable 1/11, 2%-20%	variable 1/11, 2%-20%
Antenna	omni directional	directional
# of Pseudolites	< 4	4 or more

Both scenarios probably could be dealt with by considering different regulatory constraints. While the outdoor situation would have to consider a more specific case by case analysis on the power flux density distribution created by (pulsed) Pseudolites, respectively, while the indoor case might be regulated with a simplified procedure. Standardised low power devices (type approved) could be used as long as their sole indoor applications would be legally enforced.

3 Interference issues

Since the very first use of Pseudolites the users have to deal with an effect caused by the CDMA (wideband) nature of the GNSS signals. Spread spectrum signals like GPS and Galileo signals are vulnerable to interference caused by spread spectrum in-band transmissions (or intentional jamming in a hostile scenario) due to the limited signal dynamic range of the correlation properties (receiver RF front-end and correlators). This effect, where the receive power level varies significantly with the distance to a Pseudolite, is also known as "Near-Far" problem, while satellite signals show an almost constant power level due to their "nearly equal" distance to a receiver. Most of the navigation receivers are designed for maximum sensitivity but not for large dynamic ranges. This holds for participating receivers (Pseudolites receivers) as well as for non-participating receivers since it is of great importance to ensure that the same receivers can be used - outside and inside the areas augmented by Pseudolites.

Many ideas have been studied to mitigate the interference problems caused by pseudolites, which include, such as carrier frequency offset (Parkinson et al., 1996), use of better adapted spreading codes (Ndili, 1994), pulsing of the Pseudolites signal (Cobb, 1997) and pulse blanking of a participating receiver. Although many of these ideas provide a good potential for successful interference mitigation they unfortunately require major modifications to GNSS receivers.

So far, it can be concluded that only pulsing of the signal provides a certain level of interference mitigation without the need to modify the receiver and it will also prevent a non-Pseudolites receiver from being unduly interfered.

Based on the studies carried out on this topic so far, basically two pulse patterns have been found for GPS signals (Stansell, 1986, SC-159 RTCA, 2000).

For the Galileo system these GPS pulse patterns appear less applicable due to largely different signal structures of the Galileo signal. Therefore, dedicated studies were performed for Galileo to determine optimized Pseudolite pulsing schemes. On of these is reported in Abt et al. (2007).

4 Regulatory Issues

Local, global or regional regulation?

Pseudolites have been explained as terrestrial devices that make extended or augmented navigation services available over some limited local areas differing in terms of "indoor" or "wider" area coverage.

Authorizations to operate these devices are usually granted under national legislation by the national regulatory authorities. This describes the present status quo.

However, looking into the future perspectives of these devices to enable a wide variety of innovative applications in commercial, scientific, military and other application segments certainly raises the need to search for a common international approach in defining equal or at least similar regulatory conditions to operate these devices. Transparent regulatory frame conditions would provide valuable planning security for all the parties involved: pseudolite manufacturers, system implementers as well as the operators of the RNSS-systems.

Due to the fact that these devices have a potential to be applied in large quantities, worldwide, it is of utmost importance to agree on appropriate rules for their implementation before their implementations get out of control. Particularly when RNSS providers, for instance the future Concessionaire of the European RNSS system Galileo, might intend to offer their service guarantees, they must rely on the legal conditions that ensure service availabilities which are not potentially restricted by the harmful interferences caused by pseudolites.

On the other hand it is apparently in the interest of the entire global GNSS-provider community to extend their (inter-operable) highly accurate navigation and timing services into urban canyons and indoor environments. One important element of a seamless provision of navigation and timing services is the fact that ideally the same user receivers could be used from outdoor to indoor. Therefore, from the regulatory point of view, only the co-frequency pseudolites are of prime concern.

In summary, the regulation of Pseudolites is a local (national) affair; however, it has an international impact. Appropriate regulations that are eventually shared worldwide would enable common high standards and allow attractive navigation and timing services to the advantages for both the navigation providers and the users.

Regulatory Rules and Players

All of the about 200 sovereign countries in the world develop, and agree mutually with in a formal administrative process, the use of any Hertz of the technically useful frequency spectrum. Frequencies are natural resources and their use is an element of sovereignty in each country. Frequency bands are allocated to generic services such as e.g. to the Radionavigation Satellite Service (RNSS), independent of any particular systems, technologies, manufacturers or brands. Decisions are taken one by one at the highest level in World Radiocommunication Conferences (WRC) every three to four years.

All the frequency allocations and the criteria for use of the spectrum are agreed, actually word by word, and published in the new editions 18 month after the end of a WRC as the Radio Regulations by the Radiocommunication Sector (ITU-R) of the International Telecommunication Union (ITU) in Geneva. The last conference was convened in Geneva, Switzerland, from 22 Oct. to 19 November 2007.

The rules published with the Radio Regulations are periodically transferred into national legislations in each of the ITU Member States. Immediately after a WRC a Conference Preparatory Meeting (CPM) defines the new agenda items for the following Conference. The agreement on still open or new issues, as agreed by a CPM leads to the detailed investigations in the Task Groups, the Working Parties, and other entities with relevant competences covering all the aspects of radio communications. In a number of cases where positions on allocations or use of spectrum differ, they are reflected by splitting the world into three Regions as shown in Fig. 9.

Also shown in Fig. 9 are the regional groups of Member State Administrations that advocate regional interests and organize study group structures (Working Groups, Project Teams) that meet in time coherently to working sessions at the ITU-R identifying their particular interests on agenda items and subjects.

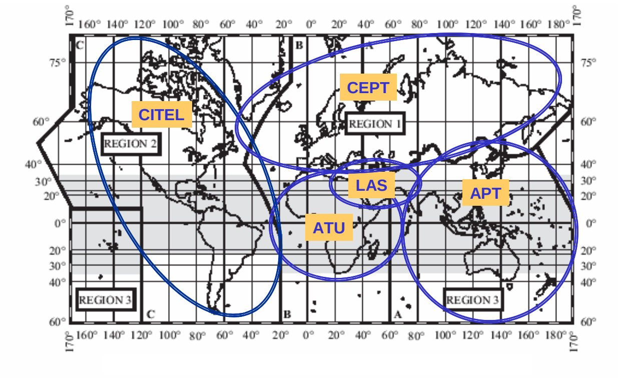

Fig. 9 Regional Groups of administrations considering regulatory frames

The conferences of regional Administrations comprise CITEL (Inter-American Telecommunication Commission, Washington, DC), CEPT (European Conference of Postal and Telecommunications Administrations), ATU (African Telecommunication Union), LAS (League of Arab States), and APT (Asian-Pacific Telecommunication Group).

Additional allocations of frequency bands to the Radio Navigation Satellite Service (RNSS) were made at WRC2000 in Istanbul, Turkey. All RNSS-allocations as published in the latest edition of the Radio Regulations are shown in Fig. 10. The WRC2003 decided on rules for use of the allocated spectrum. These rules ensure the sharing among RNSS-systems and between RNSS and other services allocated to the bands.

In the lower two of the four bands shown in Fig. 10, the allocation of RNSS is co-primary with other radio services (ARNS, RLS, RNS, a. o.). Pseudolite-network planners have to keep this constraint in mind. Also shown in Fig. 10 is the fractional use of the allocated RNSS spectrum by the Galileo system as well as GPS and Glonass.

With the variety of multiplexed signals transmitted by Galileo in the bands as shown in Fig. 11, three main user groups are primarily addressed with the signals offered that are optimized to their needs, respectively identified. Target user groups are in (1) the private and commercial market segments, (2) the safety-of-life segments comprising aeronautical, railway, and maritime applications, as well as (3) the governmental public regulated services.

It is assumed that Pseudolites would be attractive in each of these segments. It is therefore essential that the rules are developed for each of the allocated bands, because each band introduces different sharing conditions. The two main groups to share with are the terrestrial radio navigation systems DME/TACAN in the aeronautical radio navigation service (ARNS) and the complex group of civil and military radars in radio location/navigation services (RLS, RNS).

Regarding the regulation to protect the systems in the ARNS from the signals in the RNSS, two dedicated ITU-R Recommendations (M.1639 and M.1642) were developed and eventually endorsed by the ITU-R (prior to WRC03). While one document explains the detailed derivation of the protection limit for ARNS, the other provides the second procedure and algorithms to determine the actually aggregate power flux density from all navigation satellites. Similar recommendations for other service compatibilities are presently under consideration in the ITU-R Working Party 8D.

As mentioned before, the signals provided by Galileo in the different bands are shown in Fig. 11. GPS, Glonass and a number of other potential RNSS providers have published further systems that intend to utilize the bands in a similar way, most of them have co-frequency with the corresponding Galileo signals.

Sharing the frequencies in this manner fosters the use of common, particularly mass-market, low cost receivers since they all could operate with a unique RF-front-end.

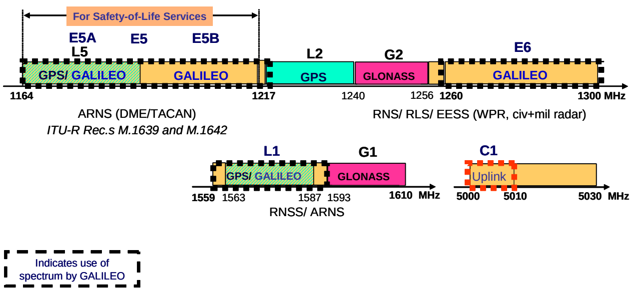

Fig. 10 Frequency bands allocated to RNSS

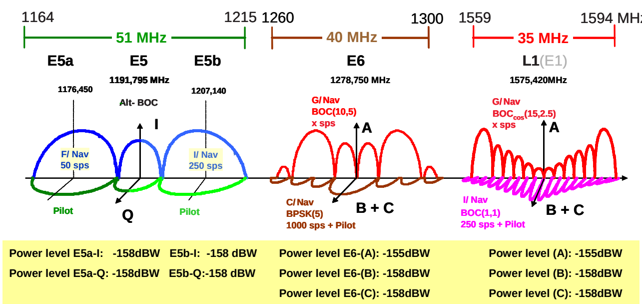

Fig. 11 Use of bands by Galileo

Developing the rules for the Pseudolite operations

Each of the published or operational RNSS systems provides signals targeting at specific user groups: consumer, professional, military, aviation, just to mention a few. Thus, a wide variety of pseudolites will be developed. Important will be how much efforts are dedicated to the careful system design, performance monitoring and maintenance of the devices in operation.

The Galileo system intends to provide the services that are tailored to three distinct user groups. Each group is expected to show their interests in the implementation of Pseudolites and to optimize their signal provision in a given local area. Particularly the pseudolite segment supporting consumer market installations in exhibition plazas, train stations, shopping malls, and alike, will presumably be the largest group of users showing great uncertainties in the implementation and maintenance of these pseudolite devices.

In other cases, neighboring pseudolite implementers may not consult each other to investigate the overall compatibility. Or pseudolite implementations for different user groups (governmental, commercial) may not have sufficient information about the other's planning because of classified or proprietary restrictions. All this supports the need for a formalistic procedure before any transmission should occur.

This exposes the fundamental dilemma of the situation: On one hand, it is in the interest of (at least) the Galileo system operator to encourage as many pseudolite networks as possible to achieve a good overall user perception of the Galileo services. On the other hand, without a (costly) transparent administrative control instrument, the situation would be quickly out of control.

But, without a cadastre or an otherwise realistic control instrument of the implemented installations it would soon be difficult to guarantee any service qualities by the satellite navigation service operators.

It can be expected, that particularly from low cost sites (due to equipment quality, maintenance period, etc.), sooner or later interfering signals could turn an advantage into its opposite. Granted service guarantees in particular in those areas could turn into a major cost (service agreement contracts) and/or nuisance factors.

From the regulatory point of view pseudolites are terrestrial devices. They are not operating in the RNSS even if their transmission schemes and protocols are very similar to those transmitted by the RNSS satellites. The allocations in the Radio Regulations provide in the lower and upper band the opportunity to operate pseudolites in the aeronautical service (ARNS) but not for other purposes.

Besides formalistic reasons, there is a significant difference between the RNSS and what pseudolites provide in technical terms. Different to navigation satellites, pseudolites could create large differences in the effectively radiated RF power flux density when a receiver moves from a location close to the pseudolite transmitter towards the edge of the coverage. This move leads to an unbalance of the receive power from space and from the pseudolite.

Moving with a receiver towards the Pseudolites service area results in great changes of local signal strength' while the satellite signal strength remains almost constant and equal within a defined range. The dynamic range of an RNSS receiver is normally fairly low because the receivers are optimized for highest sensitivities to provide best possible service availability. In the presence of strong and weak signals the receiver creates intermodulation products that raise the noise floor which in turn can lead to a degradation of positioning performance.

In other words, the assumptions for a maximum pfd that form the basis for an additional and co-primary RNSS allocation differ from what pseudolites now would actually create.

From the regulatory point of view the following questions need to be answered: (1) What is the radio navigation service provided by a Pseudolite? (2) What are the reasonable constraints to protect the RNSS and other services in the bands to ensure radio compatibility for all the users? (3) How to regulate (license, monitor, arbitrate, etc.) their implementation?

Studies are presently underway to investigate some typical technical scenarios that are representative for a particular group of applications. Two basic scenarios were determined so far that provide a clear distinction: (1) indoor with no (i.e. below threshold) power flux densities to the world outside and (2) outdoor where navigation receivers at least can receive marginally some of the satellite signals.

For the case of indoor, a simplified procedure might be applied. This could be ensured e.g. by a commercial-off-the-shelf Pseudolites approved as a low power device and authorized for indoor uses only.

The next steps on the journey

CEPT has taken the initiative to investigate the regulatory frame conditions in more detail. Working Group Spectrum Engineering in its project team 39 has started to investigate the technical conditions for the operation of Pseudolites and has invited WG Frequency Management (WG FM) and WG Regulatory Affairs (WG RA) to investigate corresponding administrative and legal aspects.

Studies in the band 1164-1215MHz comprise compatibility analysis with RNSS and ARNS, in the band 1215-1300MHz sharing with RNSS, RNS, RLS, Space Research, Earth Exploration Satellite Service, and the Amateur Radio and Amateur Radio Satellite Service. In the band 1559-1610MHz sharing with RNSS and ARNS is required while the Fixed Service allocation is terminated and is of less significance in the long run.

The main reason for this article is to invite interested parties to collaborate and contribute to this analysis. The Global Navigation Satellite Service as the entirety of all RNSS systems eventually will be provided as a joint effort of all the RNSS providers to the advantage of global user communities. Pseudolites can and should play a significant role in the seamless provision of positioning and timing services extended into the areas where the physical propagation conditions would otherwise not guarantee reliable signal reception.

Final remark

The work reported here is the result of several discussions with many colleagues in companies and administrations as well as in the Galileo program. The issues raised here are quite difficult in terms of finding a solution which equally is acceptable to regulators, system operators, Pseudolites-providers and the user communities.

Interested study groups are encouraged to complement the on-going investigations in support of the regulatory process.

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