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# Indoor Carrier Phase Measurements Through GNSS Transmitters Theory and First Experimental Results

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## BIOGRAPHY

**Alexandre Vervisch-Picois and Nel Samama** are members of the Navigation Group of the Department of Electronics and Physics at the Institut Telecom, Telecom and management SudParis (IT/TMSP). They have been working for many years in the GPS field on projects such as the development of new communication schemes and indoor location techniques. Their current interest is in finding a simple approach for a standard GNSS receiver to enable indoor positioning.

## ABSTRACT

The repeater indoor positioning system is based on the use of GNSS repeaters in order to provide GNSS availability indoors through the way of an amplification of the signals received on an outdoor (typically on the roof) antenna. The complete system, already described in previous conferences, uses four repeaters in order to provide a full 3D 1 to 2 meter accuracy indoor positioning. The measurements, at the receiver end, are the pseudo-ranges at the instant of transition from one repeater to the next, the transmission being achieved through a sequential scheme (only one repeater transmitting at any given time). This approach implements a sort of "time differential" approach that provides such a good positioning accuracy. Unfortunately, it is not possible to improve this accuracy since the sequential scheme does not allow for carrier phase measurements. The pseudolite system allows such measurements but has the problems of synchronisation (not present in the case of repeaters since we are using the GNSS constellation time) and near-far.

Repealites (a shortcut between repeater and pseudolite) is a recent concept under consideration. We still use an identical signal transmitted from all the so-called repealites but which is slightly delayed for each transmitter. The correlation function, at the receiver end, now shows  $N$  primary peaks in the case of  $N$  transmitting repealites. Interference problems and near-far effects have been addressed in previous papers and we are now interested in the positioning accuracy resulting from carrier phase measurements. The multipath problem, very

acute indoors, is dealt with through the use of the SMICL (Short Multipath Insensitive Code Loop) design. Ambiguity resolution and resulting accuracies are presented through both the theoretical and experimental aspects.

## INTRODUCTION

The advent of the GNSS era has put positioning at the centre of the preoccupations of the industrial and scientific communities and "on board" GPS devices have popularized it. Now, the next step concerns indoor positioning. Indeed, for public and commercial uses, positioning indoors is a major issue. Positioning of pedestrians, vehicles or goods in an environment where they spend most of their time, that is to say indoors, is the logical consequence of the GNSS success. But a relatively cheap solution with performances comparable to GNSS outdoor does not exist indoors, yet. Thus this is a major technical challenge. It is even more than that, in reality, as accuracy required for navigation indoors is higher than that outdoors because of the smallness of the spaces considered: where 5 to 10 meters accuracy is sufficient outdoors, 1 to 2 meters are just enough indoors. Indoor positioning is a situation where high precision (inferior to 1 m) is often a necessity.

This paper presents a method, among several others, for high precision positioning. Its principle is based on the use of a local constellation of transmitters. This choice has been made because of the limitation of the GNSS high sensitivity methods. Indeed it appears that, because of attenuation, satellite signals indoors are too weak to provide the required accuracy, when they are detected.

Such a method was already used with pseudo-satellite beacons, the so-called pseudolites (C. Kee 2001). Accurate positions (a few cm) were obtained.

However, the pseudolites method has three limitations: First, the synchronization of the transmitters (to carry out a GNSS-like positioning). Secondly the Near-Far problem which corresponds to interferences of pseudolites between them caused by too large differences between the distances Receiver-Transmitters. Third, the indirect paths, which are not proper to pseudolite systems, but that are very present indoors and largely contribute to the degradation of performances.

Synchronization can be ensured by different methods (C.Rizos 2003) but the requirement of independent beacons (without any cable link) means that whatever the method, synchronization remains the costliest and the most complex part of the technique. The Near-Far problem is usually solved by using a pulsing scheme which consists of pulsing the transmission of each pseudolite in such a way that the pseudolites do not broadcast together at the same time. In general the time of emission corresponds to 10 % of the GPS code duration. The third limitation, the multipath problem, is solved by carrying out carrier phase measurements which are noiseless and less sensitive to multipath. The problem of the carrier phase ambiguity remains and this is generally solved by a triple difference differential method after an initialization step (C.Rizos 2003).

The method presented here is a high precision method for indoor positioning using the principle of the pseudolites but with two new techniques that will allow the three issues to be solved in another way. The first part of the paper presents the Repealite constellation which allows Near-Far mitigation and is also a costless way of synchronization. The second part of the paper is about the multipath mitigation technique named SMICL developed by the Navigation group at Telecom SudParis. The third part presents a method that could be used with both repealite and SMICL in order to obtain high precision positioning with the carrier phase measurements.

Finally the fourth and the fifth parts present experimentations and simulations illustrating the techniques presented in the previous part.

## I. THE REPEALITE POSITIONING METHOD

The concept of Repealite is to retransmit continuously the repeated signal onto all antennas of an indoor constellation but at each antenna the signal is so delayed that the code (which is the same code but delayed) transmitted on each repeater do not interfere once they arrive at the receiver antenna. Note that the transmitted codes are the same for all antennas, as it is for the repeater approach. Figure.1 illustrates the concept.

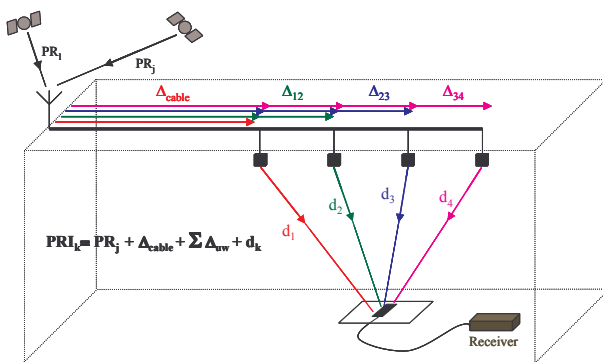


Figure 1: The repealite positioning principle

The configuration is almost the same as that for the pseudolite positioning system. The only difference is that one satellite signal is enough for all transmitters, and it has been shown that for Near-Far mitigation purposes, it is more interesting to use a single satellite signal generator instead of an outdoor antenna (A. Vervisch-Picois ITM 2009).

With 4 delayed tracking channels the receiver is able to measure 4 indoor pseudoranges. These measurements can be mathematically expressed as follows (with the notation of figure 1).

$$\begin{aligned} PRI_1 &= d_1 + \Delta_{cable} + PR_j \\ PRI_2 &= d_2 + \Delta_{cable} + \Delta_{12} + PR_j \\ PRI_3 &= d_3 + \Delta_{cable} + \Delta_{12} + \Delta_{23} + PR_j \\ PRI_4 &= d_4 + \Delta_{cable} + \Delta_{12} + \Delta_{23} + \Delta_{34} + PR_j \end{aligned} \quad (1)$$

In (1),  $PRI_k$  is the indoor pseudorange measured by the receiver,  $PR_i$  is the outdoor pseudorange including error and clock bias between GPS time and the clock of the receiver,  $\Delta_{cable}$  is the common part of the delay in the cable between the outdoor antenna and the first (undelayed) repealite,  $\Delta_{uw}$  is the delay between repeater  $R_u$  and  $R_w$  and  $d_k$  is the indoor geometric distance between repealite  $R_k$  and the indoor receiver.

If the positions of the Repealites are known, the indoor position can then be computed in a local referential with the classical GPS algorithms, as for example the least square algorithm. The velocity can also be calculated in the local referential, just like GPS outdoors, since the contribution of satellite  $S_j$  to the Doppler is common to the 4 repealites and that the only contribution of the signal (Varying from one  $PRI_i$  to another.) to Doppler is the relative velocity between the antenna of the indoor receiver and the antenna of the repealite  $R_i$ .

Although it is possible, repealites are not pulsed. The way to avoid the Near-Far problem is to adapt the  $D_{ij}$  to mitigate the interference due to the secondary peaks of the autocorrelation function (A. Vervisch-Picois IEE J-STSP 2009). Thus, pulsing the repealites is not an absolute necessity, except to avoid interference on an outdoor signal. But this is another subject, not dealt with the present paper.

## II. SHORT MULTIPATH INSENSITIVE LOOP

The demodulation of the GPS signal is carried out by two locked loops: the Phase Locked Loop (PLL) which demodulates the carrier and the Delay Locked Loop (DLL) which demodulates the code. The goal of these loops is to keep a local replica of the signal in phase with the incoming signal in typical tracking architecture. This is called the tracking.

To do this, the DLL uses the correlations of the local replica and its Early and Late versions with the incoming

signal. The delay between Early and prompt replica is constant and defined by the receiver designer.

The standard Early-Late discriminator, corresponding to Standard DLL (SDLL), corrects the phase of the local replica in order to maintain equality between the correlation result Early and the correlation result Late. With no indirect path, the incoming signal and the local replica are then perfectly in phase.

However, indirect paths have a strong influence on the shape of the autocorrelation function, and therefore the point where Early correlation is equal to Late correlation does not correspond any more to the perfect alignment of the local code replica and the incoming signal.

Multipath mitigation is a major issue of the GNSS. Most of the multipath mitigation methods, like Narrow correlator or Strobe correlator, are efficient in mitigating multipaths. Their efficiency depends on the parameter settings, but whatever these settings are, it always remains a limit below which the shortest multipaths (which corresponds to a few meters) are not mitigated. Thus even if they are mitigated, the multipath influence is not fully eliminated from the code measurements. An error of several meters remains.

For outdoor positioning, it is acceptable but in the perspective of high precision indoor positioning, it is not since the short multipaths are too numerous and too strong (A. Fluerau ENC-GNSS), .

Thus, the Navigation Group in France has developed a very specific discriminator function which allows the full mitigation of the short multipath. The standard DLL of a GPS receiver becomes the Short Multipath Insensitive Loop.

This loop was fully presented in (N. Jardack IEEE-TAES 2010), we recall here the main aspects.

The discriminator formula:

$$D = (IE^2 + QE^2) - ((IP')^2 + (QP')^2) = 0 \quad (2)$$

Where

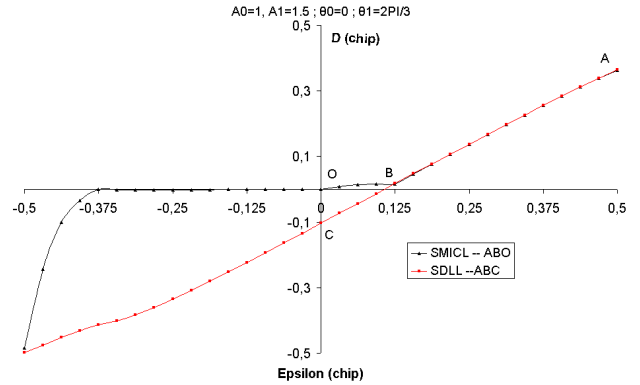
$$\begin{cases} IP' = IP - \frac{\Delta}{2} \frac{IE + IL}{2 - \Delta} \\ QP' = QP - \frac{\Delta}{2} \frac{QE + QL}{2 - \Delta} \end{cases} \quad (3)$$

IE, IP, IL respectively design the in-phase correlation results for Early, Prompt, Late correlator.

QE, QP, QL respectively design the in-quadrature phase correlation results for Early, Prompt, Late correlator.

Thus, the SMICL discriminator is using classical GPS loop correlators.

Let's see the new discriminator general aspect compared to SDLL in presence of short multipath for GPS code C/A:



**Figure 2: SMICL versus SDLL discriminator output**

The true zero without error is at the centre of the figure 2. We can check that the SMICL discriminator reaches this zero while the SDLL discriminator make a significant error of about 0.1 chip.

The originality of the asymmetric shape of the SMICL discriminator has a consequence on its performance in terms of noise. Indeed the SMICL must be used with C/N0 above 40 dBHz, which is why it is absolutely indicated for indoor positioning using a local constellation, like the Repealite system, since the power of the signal can be controlled.

The SMICL has been validated experimentally and all the results are detailed in (A. Vervisch-Picois and N. Jardack ITM 2009).

In the perspective of high precision positioning, the major interest of the SMICL resides in its capacity to mitigate the short multipath. The pseudorange measurements can then be effectively used in complement to a carrier phase measurement.

### III. PHASE MEASUREMENTS WITH REPEALITE AND SMICL

Now, the near-far problem is mitigated by the use of a good configuration of Repealites, and the short multipaths are mitigated enough to achieve a good accuracy in the pseudorange measurements. In order to carry out high precision positioning, the question of carrier phase measurements remains.

The carrier phase measurements present two advantages: Firstly, as mentioned before, they are less sensitive to multipath than code measurements. Secondly, they are really much less noisy.

However, they present a disadvantage. The carrier phase ambiguity must be solved before any calculation.

Equation (4) gives the expression of a typical GPS signal of one satellite:

$$S(t) = A \cdot \sin(2\pi \cdot f_{L1} \cdot t + \phi_1(t)) \cdot c(t + \phi_c(t)) \quad (4)$$

With:

A the amplitude of the signal

$f_L$  the frequency of the carrier

$c(t)$  the PRN code of the satellite

$\phi_c(t)$  the code phase which is measured by the receiver.

$\phi_1(t)$  the carrier phase which is measured by the receiver.

We can rewrite  $\phi_1(t)$ :

$$\phi_1(t) = 2\pi \int_0^t f_1(\tau) d\tau \quad (5)$$

$f_1(t)$  is measured by the carrier loop of the receiver, its dependency on  $t$  corresponds to the variation in Doppler shift of the signal. The carrier phase measurements concern the evolution of the phase  $\phi_1(t)$ .

The pseudorange measured by the carrier phase can be expressed as follows:

$$PR_{cp}(t) = \frac{\lambda}{2\pi} \phi_1(0) + \lambda \int_0^t f_1(\tau) d\tau \quad (6)$$

$\phi_1(0)$  corresponds to the initial phase between the incoming signal and its local replica. This value can not be measured properly because of the periodicity of the carrier phase. It can thus be expressed:

$$\phi_1(0) = 2\pi.n + \Phi_1 \quad (7)$$

In equation (7),  $n$  is the phase ambiguity and  $\Phi_1$  is the fraction of phase remaining at  $t = 0$ .

So the full pseudorange can be rewritten:

$$PR_{cp}(t) = n.\lambda + \frac{\lambda}{2\pi} \Phi_1 + \lambda \int_0^t f_1(\tau) d\tau \quad (8)$$

For L1 signal,  $\lambda = 19$  cm, so it is clear in (8) that the phase ambiguity  $n$  will take values from a few tens to a few hundreds for a typical indoor environment. This ambiguity  $n$  must be resolved every time we want to measure pseudorange.

To solve the carrier phase ambiguity in (8), we would like to avoid the use of differential methods. Thanks to the use of the SMICL, the code measurements can be trusted since even if the short multipaths are strong and numerous indoors, the SMICL fully mitigates them in most cases.

We propose a method of resolving the phase ambiguity.

## Phase ambiguity resolution using code

If the SMICL allows code measurements with significant multipath mitigation, we could imagine that code measurements would be enough to carry out carrier phase ambiguity resolution. However, this is not the case for a real time application because the code measurements are significantly noisier than carrier measurements. Thus, if the code measurements are used without any pre-processing, there is a risk of substantial ambiguity error because of the noise. It is preferable to smooth the code measurements before using them to determine phase ambiguity. A two steps method is proposed. The first step consists of smoothing the code measurements using the phase measurements and the second consists of determining the carrier phase ambiguity using the smoothed version of the code.

## Kalman Code Smoothing

Carrier-code smoothing is an operation which consists of using the noiseless carrier measurements to smooth the code measurements and which functions well against thermal noise but whose efficiency is limited against multipath.

With SDLL, the Kalman smoothing method is limited by the presence of multipath.

However, as with the SMICL, the noise is, theoretically, the only source of error on indoor pseudorange (Indeed, indoors, a lot of uncertainties, which are present with satellites, disappear: No crossing of ionosphere and troposphere and the knowledge of the fixed repeater antenna positions is excellent).

The idea of the method is then to carry out Kalman filtering on each measured code pseudorange in order to centre the ambiguous carrier-phase pseudorange. The ambiguity is thus resolved by the combination of the two measurements sets.

The filter equations are as follows:

Predicted Pseudorange Smoothed Code

$$PR_{s_n}^- = PR_{s_{n-1}}^+ + (PR_{cp_n} - PR_{cp_{n-1}}) \quad (9)$$

Predicted Error Covariance

$$p_n^- = p_{n-1}^+ + q \quad (10)$$

Kalman gain calculation

$$k_n = p_n^-(p_n^- + r)^{-1} \quad (11)$$

Updating PRcode estimate

$$PR_{s_n}^+ = PR_{s_n}^- + k_n (PR_{cp_n} - PR_{s_n}^-) \quad (12)$$

Updating estimation error variance

$$p_n^+ = (1 - k_n)p_n^- \quad (13)$$

$n$  corresponds to the current time epoch. The first step (9) uses the carrier measurement  $PR_{cp}$  and the estimate of the Pseudorange Smoothed Code  $PR^-$  of the previous epoch  $n - 1$  to build the estimate which will be filtered in the epoch  $n$   $PR^+$ . This is the key step, since it is the one where code and carrier measurements are combined. The others are classic Kalman filtering steps.

In (10) the error covariance  $p$  is predicted from the previous state and variation of the carrier-phase measurements  $q$ , which are parameters of the filter. The Kalman gain is then calculated considering the variance of error measurements on code  $r$ .

Finally, in step (12) the estimation  $PR^+$  is updated by the difference between the predicted smoothed Pseudorange  $PR^-$  and the measured pseudorange  $PR_c$  weighted by the Kalman gain. Step (13) is the updating of the variance prediction.

This method is actually the same as the Pseudorange Code Smoothing fully described in (E.D Kaplan, 2005) which is, in this case, proper to differential code Double Difference carrier smoothing.

If this method, usually used with differential GPS, can be used in our case, this is because there is no integer ambiguity for the code indoors (when the repeaters of pseudolites are used). Indeed we notice that for an indoor constellation, the size of the environment (a few tens metres) is largely inferior to code duration (300 km), so there is no integer ambiguity.

### Carrier phase ambiguity determination

Once the previous Kalman filtering gives the smoothed code, it can be directly used to calculate the position, this is the direct method. However, because of the high sensitivity of the SMICL to noise, and because of Kalman filter settings, this direct method brings improvements but does not have the accuracy of carrier pseudorange. The Smoothed Code inaccuracy can largely exceed the value of the wavelength  $\lambda$  (19 cm for GPS L1).

This is why it is interesting to use the smoothed pseudorange, not for the calculation of the position but for the determination of the carrier phase ambiguity, accepting the idea that the ambiguity determination can err by of 1 or 2 cycles. This is this method that we have chosen to present in this paper.

The advantage of the chosen method is that it uses the redundancy of the code and phase measurements. This is an advantage since it increases the protection of the measurements against the phenomenon of carrier cycle slips, which very often occur in the presence of

multipaths (H. Niwa, IEEE 2008). Even if we tolerate an error of 1 or 2 cycles on the carrier phase determination, we are sure of keeping sub metrical positioning.

We also have to remember that the more powerful the signal is, the less noisy it is, and so the more the error on ambiguity is mitigated.

Differential methods, like triple differences, generally prefer to use the carrier measurement without the code since the code is too noisy and too degraded by indoor multipaths.

In order to illustrate the functioning of the method, experimental results are presented in part IV and simulation results are presented in part V.

## IV. EXPERIMENTAL RESULTS

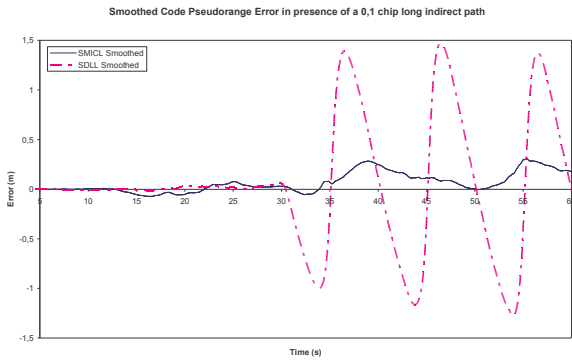
To check the validity of the method experimentally, we do not need a complete repeater system. Actually, a one-satellite generator with specific multipath scenarios is enough to check the validity of the carrier phase ambiguity determination. We have a softly implemented version of the SMICL on a NordNav R30 receiver. We also had access to specific equipment from CNES (the French Space Agency) with a sufficient bandwidth and a sampling frequency of 31.25 MHz with the Data conversion software. A Spirent generator is also used in order to "play" the scenarios.

The considered signal is as follows: each scenario lasts 60 seconds. During the first 30 seconds, no multipaths are generated. After 30 seconds, a single multipath is added, with a relative power 3dB lower than the direct path. The delays considered here for the reflected path ranges are 0.1 chip, 0.25 chip and 0.425 chip. In addition, we decided to add a 0.1 Hz Doppler shift to the reflected path in order to have a variable phase for the multipath: in this case, within 30 seconds, the complete range of phases is scanned three times.

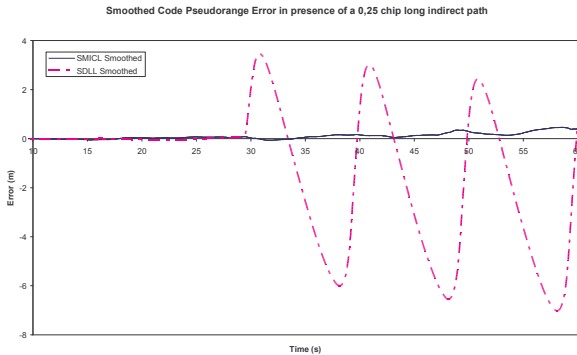
The first half of the scenario is used to calibrate the pseudorange measurement. Indeed, during this step there is no multipath on the signal: the measurement is not affected by any error except noise.

Then, the three scenarios are fully played carrying out the classical SDLL and are played once again carrying out the SMICL.

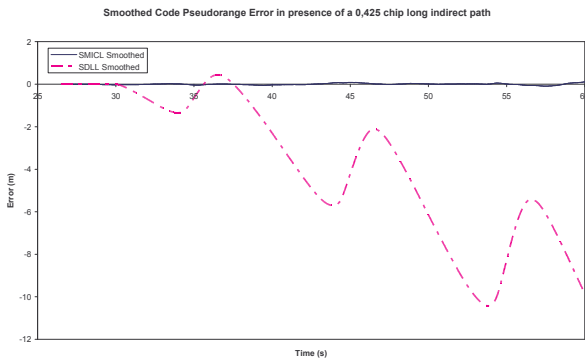
Once we have the carrier phase and code measurements, we apply the code smoothing method. This gives the following results, visible in figures 3, 4 and 5:



**Figure 3: Error on smoothed code pseudorange for SDLL and SMICL with a 0.1 chip long multipath**



**Figure 4: Error on smoothed code pseudorange for SDLL and SMICL with a 0.25 chip long multipath**



**Figure 5: Error on smoothed code pseudorange for SDLL and SMICL with a 0.425 chip long multipath**

If we compare the three figures 3-5, we observe that the accuracy of the method increases with the length of the indirect path. This phenomenon is linked to the sensitivity of the SMICL to noise. Indeed, in these experiments the indirect path is short and powerful. Thus when the indirect path signal has a phase which is opposite those of the direct path signal, the destructive effect of the indirect path is so significant that the Signal-to-Noise-Ratio (SNR) decreases of 15 dB. In such

conditions, the SMICL suffers from noise. This effect is more significant for the shorter indirect path and this is why the oscillations that can be observed on the smoothed pseudorange error are bigger in figure 3 than in figure 5.

We can use the result of the smoothing method in order to evaluate the carrier phase ambiguity. This gives the percentage results presented in table 1 and 2:

**Table 1: Error on ambiguity determination for SDLL**

Indirect path	%	%	%	%
	No error	Error = 1	Error = 2	Error > 2
<b>0.1 chip</b>	12.3	10.8	10.7	66.2
<b>0.25 chip</b>	2.9	3.3	3.1	90.7
<b>0.425 chip</b>	5.6	5.5	5	83.9

**Table 2: Error on ambiguity determination for SMICL**

Indirect path	%	%	%	%
	No error	Error = 1	Error = 2	Error > 2
<b>0.1 chip</b>	71.5	28.5	0	0
<b>0.25 chip</b>	69.3	19.6	11.1	0
<b>0.425 chip</b>	100	0	0	0

Table 1 and 2 indicate, for each, path the proportion of code smoothed measurements that induces error on the carrier phase ambiguity determination for the Standard Delay Locked Loop and the Short Multipath Insensitive Code Loop.

The results for SDLL are, as expected, very inaccurate, even if the multipaths are smoothed by filtering. However, the SMICL demonstrates its efficiency since the worst error encountered is of 2 cycles and represents 11 %.

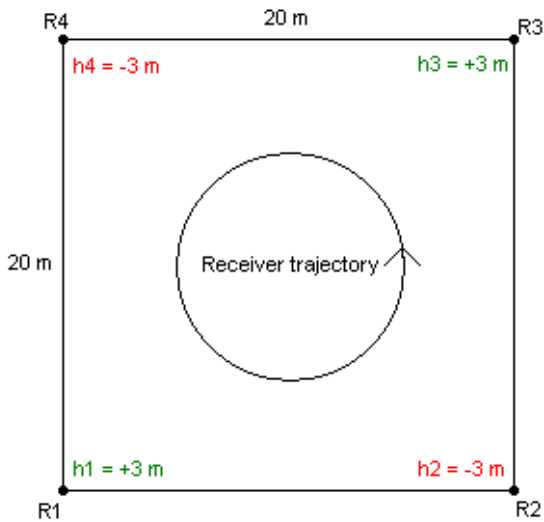
This means that the technique of the SMICL can be used with success to evaluate the carrier phase ambiguity.

## V. SIMULATION RESULTS

In order to have an idea of the performance that can be expected, we present simulation results using the smoothing method to determine ambiguity.

We consider a circular movement in a 20m by 20m square area. The radius of the circle is 5 m and the repeaters are positioned at each corner of the square. The receiver's altitude is 0m. The altitude of repeaters number 1, 2, 3 and 4 are respectively: 3m, -3m, 3m and -3m.

These geometrical considerations are summarized in figure 6:



**Figure 6: Receiver simulated movement**

The movement duration is 32 seconds, which corresponds to a speed of 1 m/s.

We simulate this trajectory with Matlab-Simulink. We also have a modelling of the SMICL and SDLL loop and we are able to simulate the effect of the movement (in terms of Doppler and phase evolution) on these loops. Thus, we can calculate the code pseudorange and the carrier pseudorange measured on the Numerically Commanded Oscillators of the loops. In order to evaluate the carrier ambiguity determination method, we add an indirect path on each trajectory. These indirect paths have a signal amplitude of 0.5 (compared to the signal of the direct path whose amplitude is 1) and the lengths of the paths are oscillating between 20 and 50 metres depending on the repealite.

The sampling frequency chosen is 10 MHz and the intermediate frequency is 4 MHz. We do not apply any filtering in the RF samples. The integration duration of the loops is of 5 ms.

The Carrier-to-Noise ratio on every signal is 55 dBHz, which is excellent, rarely encountered in outdoor GPS. However, we want to minimise the effect of noise and we use a local constellation for that reason. We can thus consider that the power of emission can be quite high. For the entire movement, we establish the statistics, as with the experimental results. This is done for each Repealite. The results for SDLL are presented in table 3:

**Table 3: Error on ambiguity determination for SDLL**

Repealite	% No error	% Error = 1	% Error = 2	% Error > 2
R1	5.1	7.7	8.8	78.4
R2	4.6	4.6	4.8	86
R3	3.9	4.0	4.3	87.8
R4	9.2	9.3	10.1	71.4

The indirect paths cause large error with the SDLL, even when the pseudorange is smoothed. Indeed, for each repealite the pseudorange code smoothed measurements makes an error of more than 2 cycles (40 cm) for more than 70 % of the measurements. The worst cases are R2 and R3 with more than 85 %. It is clear that the smoothing method is not adapted to carrier phase determination with SDLL because of multipaths influence.

It is different for SMICL, whose results are presented in table 4:

**Table 4: Error on ambiguity determination for SMICL**

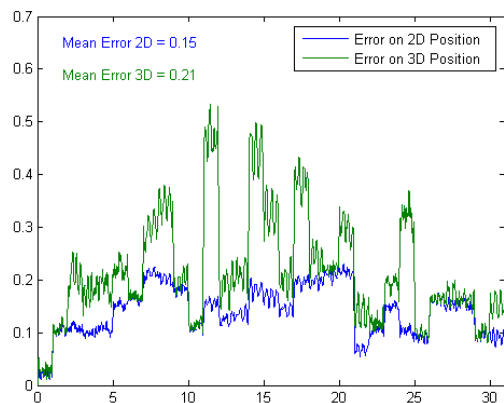
Repealite	% No error	% Error = 1	% Error = 2	% Error > 2
R1	38.3	59.3	2.4	0
R2	14.1	82.3	3.6	0
R3	100	0	0	0
R4	98.5	1.5	0	0

The SMICL results are coherent with what was expected: there is no error superior to 2 cycles for every smoothed pseudoranges. We notice that for pseudorange of repealites 1 and 2, the 1 cycle error is predominant. This is a residual effect of noise which, because of the asymmetric form of the discriminator, tends to decentre the mean error. This effect can be observed in figures 3 and 4, when the curve of error of the pseudorange measured by the SMICL remains over the zero axis. This is why, it is better to have a signal as noiseless as possible.

However, the measurements of Table 4 allow us to apply the ambiguity determination method with success, for sub metric positioning.

To conclude this simulation illustration, we present two figures representing the movement calculation. They represent the movement calculated with the carrier phase measurements whose ambiguity is re-evaluated with the smoothing method every second.

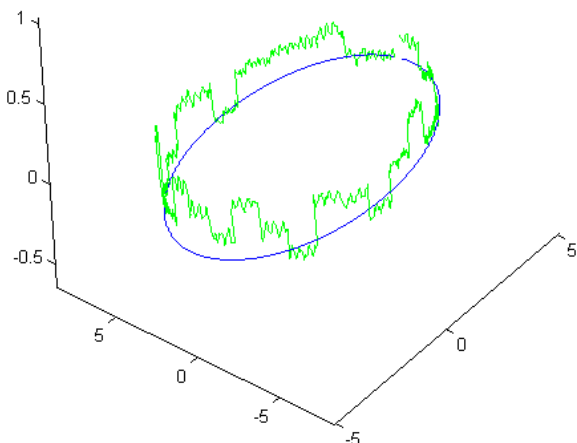
The first figure (figure 7) represents the 2 and 3 dimensions positioning error during the movement:





**Figure 7: Calculated position in 2D view (scale in m)**

The second (figure 8) represents the movement in 3 dimensions.



**Figure 8: Calculated position in 3D view (scale in m)**

As indicated in figure 7, the mean error is about 15 cm on 2D horizontal positioning and 20 cm on 3D positioning.

In both figure 7 and 8, we can see that the calculated trajectory jumps sometimes. These jumps correspond to the re-evaluation of the carrier-phase ambiguity. It must be noticed that their amplitude does not exceed 40 cm, which corresponds to 2 cycles.

## CONCLUSION

Sub-metric indoor positioning with a local constellation is hard to obtain without differential methods. Techniques like repeaters give at best 1 or 2 meters error. The Repealite method is interesting, since the carrier phase measurements are possible. In order to solve the ambiguity problem with maximum accuracy but without carrying out a full differential system, it is possible to use the Short Multipath Insensitive Code Loop previously used in the repeater case.

As the pseudorange code measurements are noisy, we have proposed here a method inspired by Double Difference code smoothing using Kalman filtering to mitigate the noise.

Thus, the receiver is able to evaluate the code ambiguity with a reasonable accuracy of 1 or 2 cycles, on condition that the signal is not too noisy. This allows positioning accurate to a few decimeters.

This method could be largely improved with better knowledge of the SMICL behavior and limitation. This could help to mitigate the ultimate cycle errors. We could also imagine a better way to re-evaluate the ambiguity, for example we could use the SMICL only when the

Carrier-to-noise ratio is high enough, instead of recalculating it every second. Such improvements could lead to improved accuracy.

All this, and carrying out experiments of real positioning with repealites, is what we are working on.

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