# Effect of different construction materials on the propagation of Locata's 2.4GHz signal

**Author:**
Tambuwala, N.; Jamaluddin, M.; Politi, A; Dempster, A.G

**Publication details:**
IGNSS2007 Symp. on GPS/GNSS
pp. paper 160

**Event details:**
IGNSS2007
Sydney, Australia

**Publication Date:**
2007

**DOI:**
https://doi.org/10.26190/unsworks/713

# Effect of different construction materials on the propagation of Locata's 2.4 GHz signal

***Nilofer Tambuwala, Mohsin Jamaluddin***
Department of Geomatic Engineering
University of Melbourne, VIC 3000, Australia
Tel: +61425819930 Email: n.tambuwala@ugrad.unimelb.edu.au

***Arnon Politi***
School of Surveying and Spatial Information Systems
University of New South Wales, Sydney, NSW 2052, Australia
Tel: +61293854526 Email: nonie@unsw.edu.au

***Andrew G. Dempster***
School of Surveying and Spatial Information Systems
University of New South Wales, Sydney, NSW 2052, Australia
Tel: +61293856890 Email: a.dempster@unsw.edu.au

## ABSTRACT

*Locata* technology is the future of indoor positioning. It solves the problems faced by traditional positioning systems, by implementing a network of terrestrially based transceivers that transmit their own GPS-like signals, at the licence-free frequency of 2.4 GHz. However, electromagnetic signals are attenuated when passing through walls and other obstructions. This paper outlines the research carried out to test the effects of some commonly used construction materials on the pseudorange of Locata's signals. Reasons for these effects have been explored based on the properties of the tested materials. The effects of signal attenuation on the accuracy of the positioning solution have been further explored, by introducing a combination of construction materials at different locations within a network of *LocataLites*. This is aimed at enhancing the performance of Locata technology for indoor applications.

**KEYWORDS**: Locata, Pseudolite, Indoor positioning, Signal attenuation,

accuracy, precision

## 1. INTRODUCTION

GPS is today considered all over the world, as the most popular and widely used three-dimensional positioning technology. Current Location Based Services utilize mainly GPS for their positioning solutions, with single-receivers typically providing 3-15 m positioning solutions (D'Roza and Bilchev, 2003).

However GPS has a number of drawbacks, its major limiting factor being the requirement of line-of-sight between receiver antenna and the satellites. This results in GPS receivers being unable to obtain a position fix inside buildings, under the cover of trees or in between tall buildings or cliffs which restrict the view of the sky.

Locata Corporation has invented a new positioning technology called *Locata*, which is designed to overcome the limitations of other currently available positioning systems. It consists of time-synchronised, terrestrial-based pseudolite transceivers called *LocataLites*. A network of LocataLites forms a *LocataNet*, which transmits GPS-like signals (C/A and carrier signal). Details of the current system design are outlined in Barnes *et al.* (2005). Tests show that the system is capable of positioning to sub-cm accuracies with a precision comparable to RTK-GPS (Barnes *et al*, 2006b)

In the current system design the LocataLites transmit their own proprietary signal structure in the license free 2.4GHz ISM band. This allows not only easy integration with current GPS systems, but also vast flexibility due to complete control over both the signal transmitter and the receiver. (Barnes *et al*, 2003a)

A major innovative aspect of this technology is its capability to provide precise indoor positioning based on a patented *TimeLoc* system (Barnes *et al*, 2003a). This allows for standalone navigation and precise time transfer.

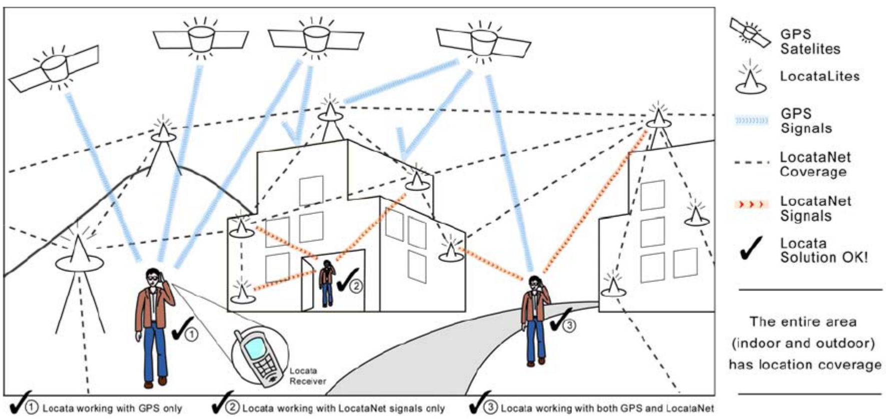


**Figure 1:** The *Locata* technology positioning concept (Barnes *et al*, 2003b)

However indoor positioning is highly dependent on the placement of walls and partitions within a building, as these affect the way transmitted electromagnetic signals propagate, and how fast they attenuate. As such, the indoor use of wireless technology poses one of the biggest design challenges. Theoretically, electromagnetic waves, such as those emitted by

Locata's transceivers, can be imagined to emanate from a point source, travelling in all directions in a straight line, filling the entire spherical volume of space; while varying in strength with a $1/\text{Range}^2$ rule (Rappaport, 1996). However, in reality, propagation rarely follows this basic model. In the real world, radio signals are distorted by reflection, diffraction, scattering and attenuation that give rise to signal fades and other signal propagation losses.

In an outdoor environment radio signals experience fluctuations in strength due to multipath effects, i.e. the signal transmitted can follow a number of propagation paths to the receiver. The signal that finally reaches the receiver will generally be weaker than the direct 'line-of-sight' signal due to power lost during multiple reflections (Rappaport, 1996). The indoor environment is even more complex. Multipath still plays a major role as the signal can be reflected, diffracted around sharp corners or scattered from walls, ceilings or floor surfaces. In a study conducted in 2004, Barnes *et al* tested the accuracy of the Locata positioning technology for machine guidance in an indoor industrial environment where multipath effects were high. The study found Locata to be ten times more accurate than the current positioning system in operation in the same environment.

The above mentioned study proves the viability of Locata for indoor positioning. However, the study was conducted within one large warehouse with unobstructed line-of-sight between transceivers. As such, there was no requirement for the signals to penetrate walls and other obstructions. This study, tests the comparatively large scale effects caused by signal attenuation. In an indoor environment, optimal network geometry with direct line-of-sight between all transceivers is not realistically possible. It is more than likely that in order to achieve a large scale positioning solution, the direct line-of-sight from the transmitters and the reflected signals, will both be required to pass through the walls of a building or the obstacles within it.

In comparison to GPS signals, LocataLite signals are more powerful. Because of this, signals from a Locata transceiver can provide significant building penetration (Barnes *et al*, 2003b). However the signal will be attenuated as it travels through different materials within a building. In this study, firstly, 7 different kinds of construction materials were tested to look at how these affect the pseudorange of Locata's signal. The study tested Locata's C/A code pseudorange, which are generated digitally, with continuous transmission (over all slots). The system uses commercially available GPS patch antennas for the transceivers, in addition to a custom built ¼ wave antenna for one of the *LocataLite* transceivers (Barnes *et al*, 2005).

Secondly, a network of LocataLites was set up to test the effect of the different construction materials on positioning accuracy. Fairly large errors were found in the pseudorange when the signal was obstructed with standard thicknesses of the tested construction materials, and these pseudorange errors were seen to propagate into the network positioning solution. However, with post processing, the errors computed in this paper can be applied as corrections to get higher positioning accuracies within a LocataNet.

## METHODOLOGY

### 2.1 Tests on pseudorange

In this test, the question of how different construction materials affect the pseudorange of

Locata's transmitted signal was considered. The following construction materials were tested: timber, aluminium, iron, Plexiglas, cork, plasterboard and glass. Three different thickness of plasterboard and two different thicknesses of timber and glass were tested, as these are the most commonly used construction materials for walls and partitions within a building. The details of the materials tested are shown below:

| Material | Comments |
|---|---|
| Plasterboard | Standard core encased in a heavy-duty paper line. By far the most popular interior lining product used in domestic and commercial construction today. 10, 20 and 30 mm tested. 10mm boards were stacked together to incrementally increase the width. |
| Wood | Particleboard used commonly for building panels and in furniture. 12 and 24 mm tested. 12mm boards were stacked together. |
| Glass | Standard window panes. 3 mm and 6 mm tested. 3mm glass panes were stacked together. |
| Aluminum | 3 mm tile tested. Aluminium is commonly used for window frames and other glazed structures. |
| Iron | Untreated iron tile. Multiple uses within the construction industry. 2 mm tested. |
| Plexiglas | Used for casting and moulding, and often used instead of glass. 7 mm tested. |
| Cork | Low density fiberboard, commonly used to provide acoustic insulation.17 mm tested |

**Table 1.** Materials tested

For this experiment the power output of the LocataLites was set to 10 mW.

One LocataLite was set up on a pre-surveyed point, on the roof of the School of Surveying building of UNSW in Sydney. A rover antenna was set up on another point of known coordinates, about 15 metres away, within direct line-of-sight of the LocataLite antennae. For each tracked PRN code coming from the LocataLite, the receiver outputs its calculated pseudorange. The raw pseudoranges themselves were recorded. Initial recordings were taken with the transmitting antenna completely blocked, to ensure that the receiver was not recording signals from any other source. Once this was established, each construction material was placed in front of the transmitting antenna, at a distance of about 15cm, and raw pseudoranges were recorded at 10Hz, for 3 minutes periods. Between the recordings for each material, a 2 minute recording with the transmitting antenna completely unobstructed was taken. Additionally, data was also logged for the transition period between no material and insertion of a material in front of the antenna, in order to confirm that the rover did not lose lock on the LocataLite during this process.

The instrument set up is illustrated as follows:

**Figure 2.** Left: A double clasp on a tripod, used to hold up materials in front of the transmitting antenna of the LocataLite. Right: The rover antenna connected to a laptop to record Locata signals at 2.4 GHz

### 2.2 Network Tests

A network of 5 LocataLites, equally spread around a rover receiver, was set up in an open field, ensuring line-of-sight to all LocataLites. The positions of the LocataLites and the rover were surveyed in. The following figure shows the network setup:

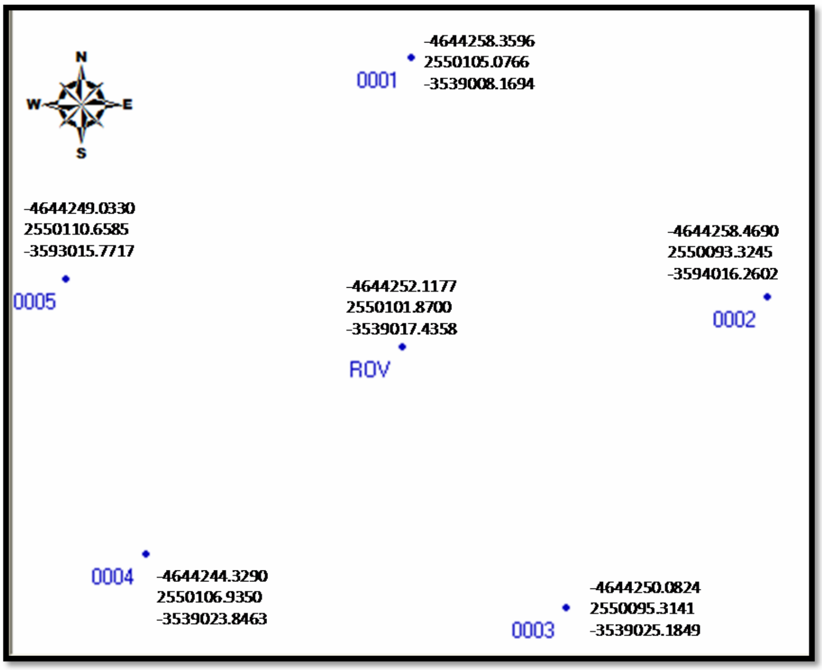


**Figure 3.** Network setup showing XYZ coordinates on WGS84. 1-5 indicates the mean position of the 2 transmitting antennae of each of the 5 LocataLites, to ±0.05m. ROV indicates the approximate position of the rover antenna, from initial survey.

The obtained XYZ coordinates were programmed into the FME chip of each LocataLite. Following this, the most essential process was to eliminate the error associated with the clock drift at the receiver. This is the largest contributor of errors to the pseudorange. In a LocataNet, this error can be eliminated using the same method used in GPS (and internally in the Locata receiver during the navigation algorithm) by solving for time using measurements from the different synchronized LocataLites.

Once the network was synchronized, raw pseudoranges and the positioning solution obtained for the rover were recorded. Sheets of material were inserted in front of transmitting antenna 2 and/or 5, and the data was logged at 10Hz, for a period of 5 minutes each time. The measurements recorded were as follows:

| Test | Plasterboard (PB) (10mm) | Wood (WD) (12mm) | Glass (GL) (3mm) | Aluminium (AL) (3mm) | Iron (IR) (2mm) | Plexiglas (PP) (17mm) |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | 2 | |
| 3 | 2 | | | | | |
| 4 | 2 and 5 | | | | | |
| 5 | 2 | | | | | 5 |
| 6 | | | | 5 | | 2 |
| 7 | | 2 | | 5 | | |
| 8 | 5 | 2 | | | | |
| 9 | | 2 | | | | 5 |

**Table 2.** Network tests carried out. Numbers in the table indicate the antenna which was obstructed.

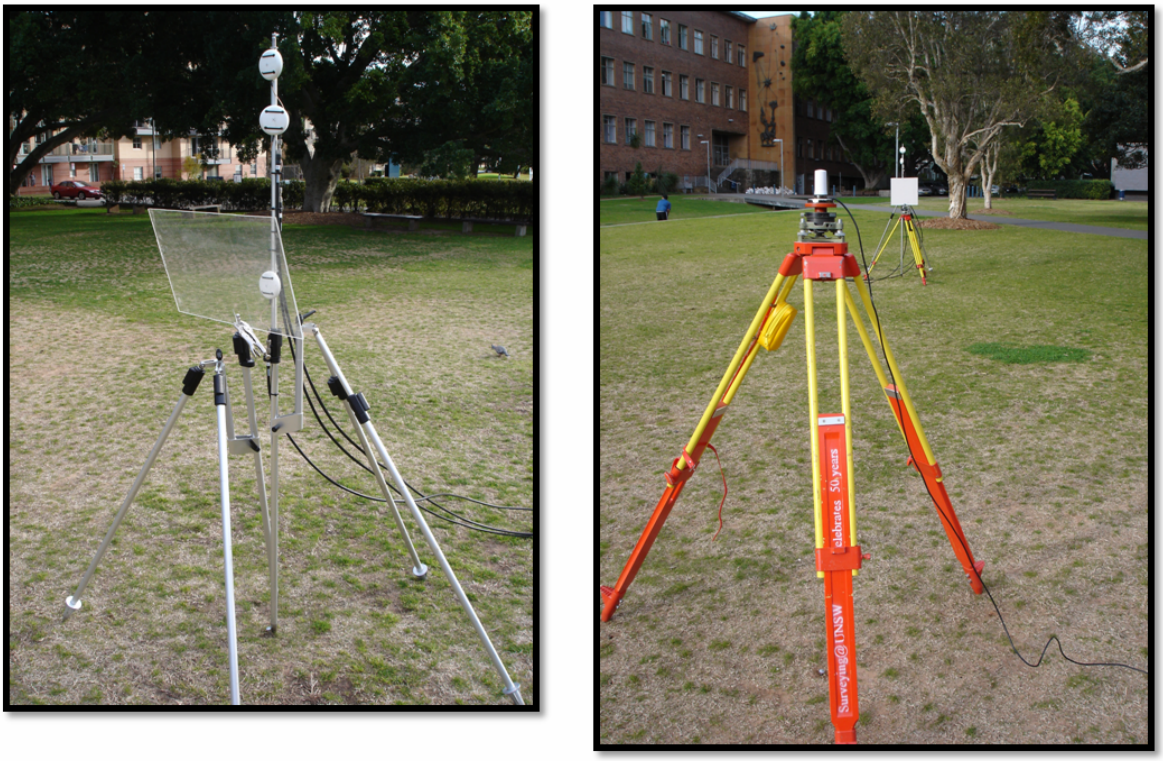

**Figure 4.** Left: 17mm Plexiglas obstructing antenna 5. Right: Rover antenna tracking LocataLite, with antenna 2 obstructed by 10mm plasterboard in the background.

## 3. RESULTS AND ANALYSIS

### 3.1 Errors in pseudorange

For each thickness of each material tested, the recorded signal was first analysed to ensure that the rover had not lost lock on the LocataLite during the observation period. Any observations, where lock on the LocataLite had been lost, were removed from the output. The remaining raw pseudorange observations were averaged, with outliers (observations less than or greater than 1.5 times the standard deviation) removed. For plasterboard, wood and glass, the pseudorange value obtained by averaging out the observations for each thickness, were further averaged, to obtain one value for an average of the tested thicknesses.

The pseudorange recorded when the antenna was unobstructed, was taken as the control. Any deviation from this value, found in the remaining tests, was computed as an error in the pseudorange. This error can only be attributed to the presence of a material obstructing the transmitting antenna of the LocataLite, since all other variables were kept constant. The computed errors in the pseudorange for each tested material are shown below:

| | Error in pseudorange (m) | Thickness (mm) |
|---|---|---|
| No material | 0.0000 | 0.0 |
| Wood | -0.0793 | 18.0 |
| Glass | -0.1709 | 4.5 |
| Cork | -0.1795 | 17.0 |
| Plexiglas | -0.4247 | 7.0 |
| Plasterboard | -0.5502 | 20.0 |
| Aluminum | -0.5652 | 3.0 |
| Iron | -2.4870 | 2.0 |

**Table 3.** Errors in pseudoranges for materials tested

The negative values indicate that the recorded pseudorange for each obstructing material was longer than the control pseudorange, implying that each of the construction materials worked to slow down the Locata signal.

These errors in the pseudorange range from 7 cm for wood, to as high as 56 cm for aluminium. The 2mm sheet of iron completely blocked out the signal, and hence it shows the largest error in the recorded pseudorange. On the other side of the scale, the 18mm wood board had the smallest effect on the pseudorange. The standard thickness of glass and cork cause similar errors in pseudorange, as do plasterboard and aluminium.

The pseudorange errors that resulted from obstructing the direct line-of-sight of the Locata signal are significantly large, considering the rover was only located at a distance of 15 m from the LocataLite antennae. In order to standardise the data, and allow for appropriate corrections to be applied in future positioning with this technology, the above information was used to compute the pseudorange error that would result for 1mm thickness of each material that allows passage of the Locata signal. This is shown as follows:

| | Error in pseudorange for 1mm thickness (m) |
|---|---|
| Wood | -0.0044 |
| Cork | -0.0106 |
| Plasterboard | -0.0275 |
| Glass | -0.0380 |
| Plexiglas | -0.0607 |
| Aluminum | -0.1884 |

**Table 5.** Error in pseudorange/1mm thickness of materials

In the next section, these errors in pseudorange are quantified in terms of their effect of the actual positioning solution outputted by the rover when tracking 4 or more LocataLites.

### 3.2 Errors in position

The first test carried out was with the rover tracking 5 unobstructed LocataLites antennae. This was taken as the control test with the mean of the temporal solutions used as the 'true' position of the rover.

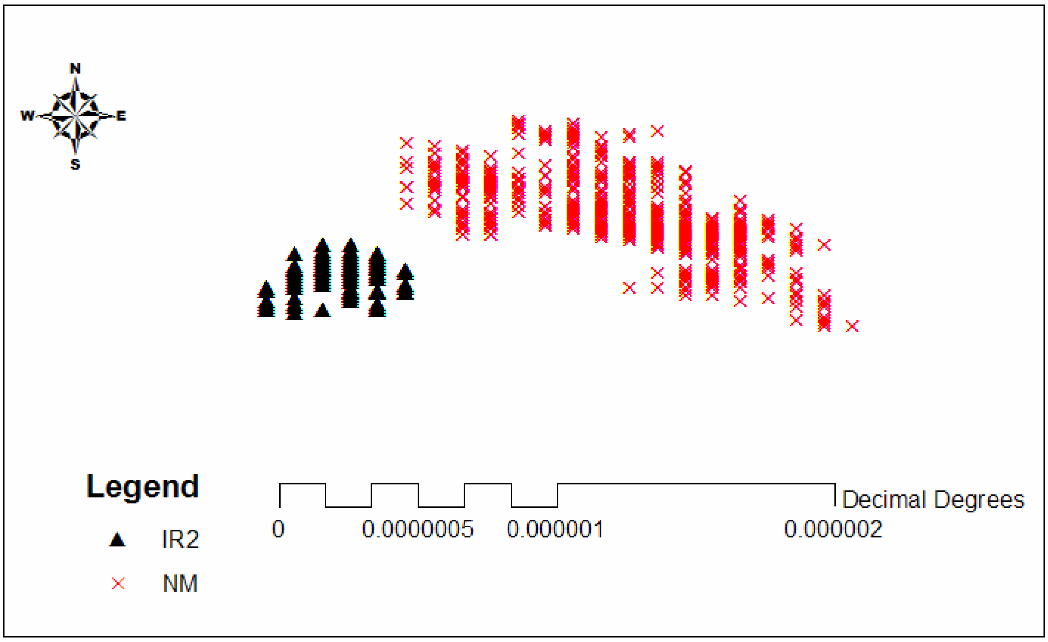


**Figure 5.** Test 2 (IR obstructing 2) compared to the control test

As Figure 5 shows the error in position was quite significant with a LocataLite antenna being blocked by iron. As was seen with the pseudorange tests, iron completely blocked out the signal, and the same was the case here. Consequently, the rover lost lock on LocataLite 2, effectively reducing the network to 4 LocataLites. This is reflected by the bias in the positioning solution towards the west.

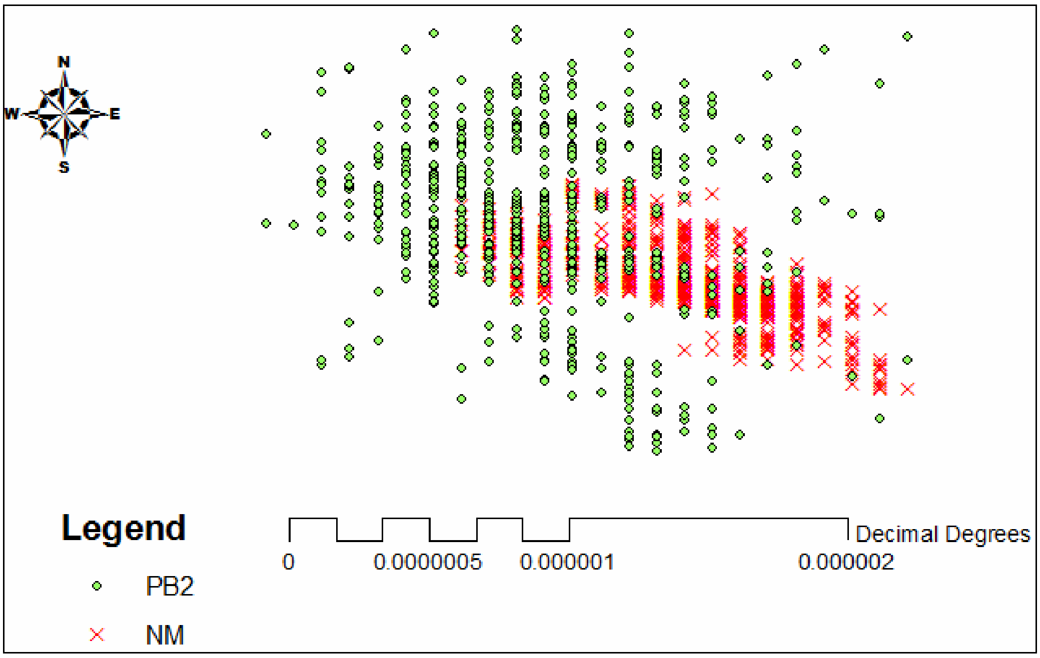


**Figure 6.** Test 3 (PB obstructing 2) compared to the control test

In Test 3, plasterboard was placed in front of the same LocataLite antenna that was obstructed by iron in the previous test. The results show a wide dispersion with a north-westerly bias. The large variations in the temporal positioning solutions are most likely due to the large errors in pseudorange, that result when the Locata signal is obstructed by standard thicknesses of plasterboard.

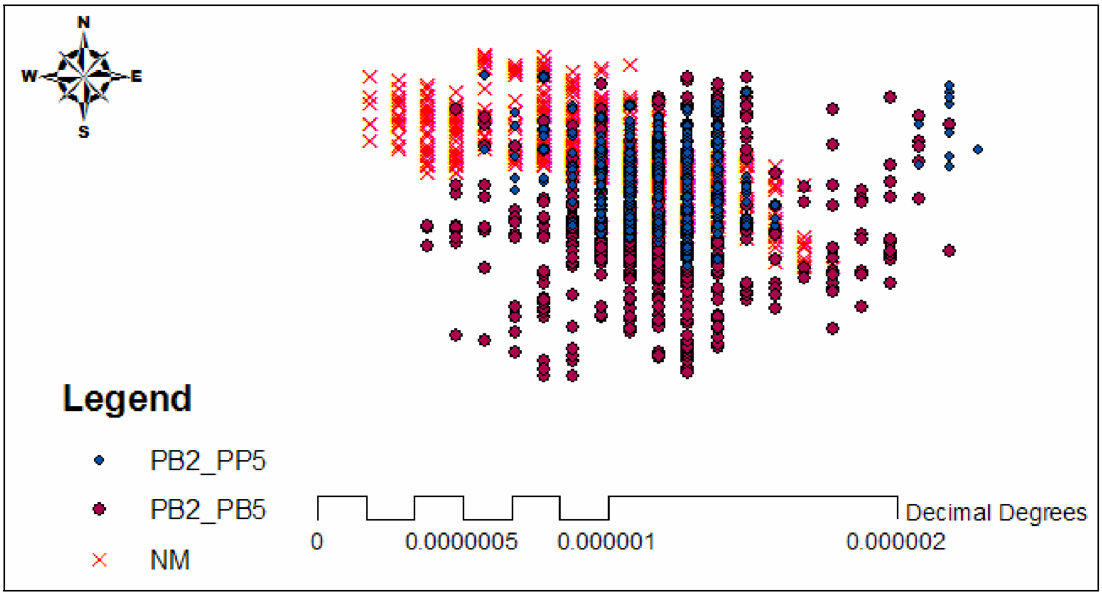


**Figure 7.** Test 4 (PB obstructing 2 and 5) and Test 5 (PB obstructing 2 and PP obstructing 5) compared to the control test

In Test 4, an additional 10mm plasterboard was introduced at LocataLite 5, and then replaced by Plexiglas in Test 5. In comparison to the previous test, the temporal positioning solutions obtained here show less north-south and east-west variation from the 'true' position. In fact, the north-south distribution for both tests in quite close to the distribution of the control test. This can be attributed to the geometry of the set-up with the antennas to the north-east and north-west of the network being obstructed. The similarity in the results of the two tests can be attributed to the similarity in the errors in pseudorange that result from standard thicknesses of the two materials. The higher precision of Test 5 is most likely due to the slightly smaller errors in pseudorange caused by Plexiglas than by plasterboard.

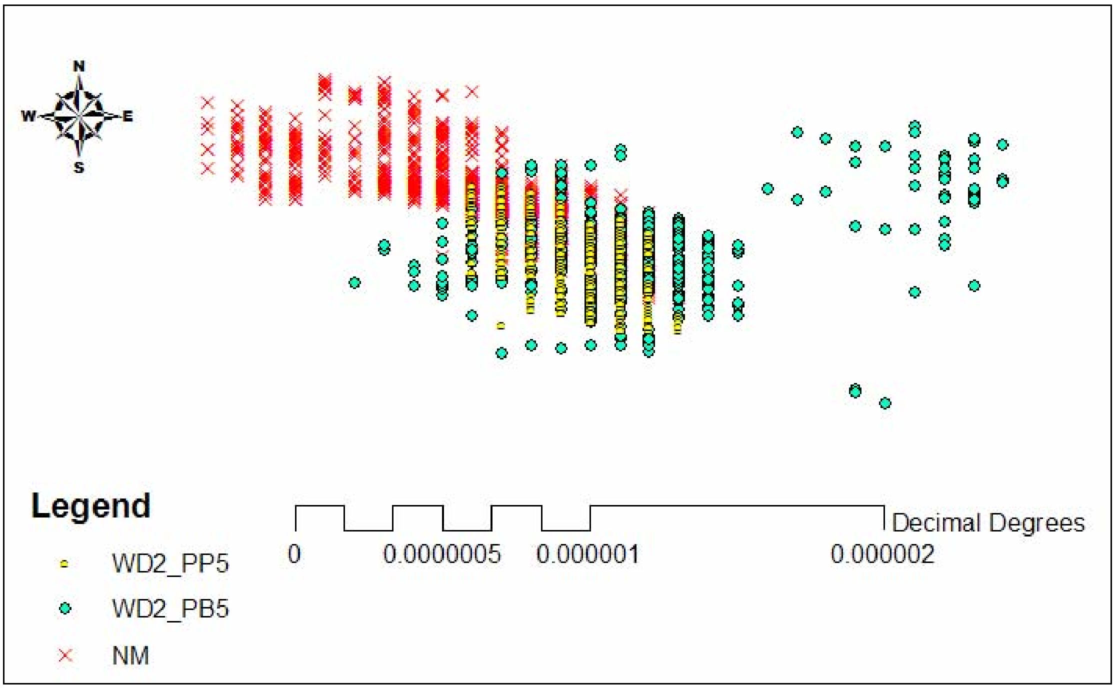


**Figure 8.** Test 6 (WD obstructing 2 and PB obstructing 5) and Test 7 (WD obstructing 2 and PP obstructing 5) compared to the control test

Wood was the primary material tested in Test 6 and 7. However since wood has the smallest effect on pseudorange, the distribution shown in Figure 8 is similar to Figure 7, and relays mainly the previously seen characteristics of plasterboard and Plexiglas. The random group of positioning solutions to the east for Test 6 appears to be a characteristic of plasterboard. The higher precision of the results obtained in Test 7 can again be attributed to the lack of plasterboard in this test, and the slightly lower error in pseudorange caused by a standard thickness of Plexiglas than by plasterboard.

In general, the majority of the data for both tests indicate a positioning solution closer to the control, with a slight south-eastern bias. The pseudorange error caused by plasterboard and Plexiglas is nearly seven and five times that of the wood respectively, and therefore the observed bias away from LocataLite 5 in the south-easterly direction.

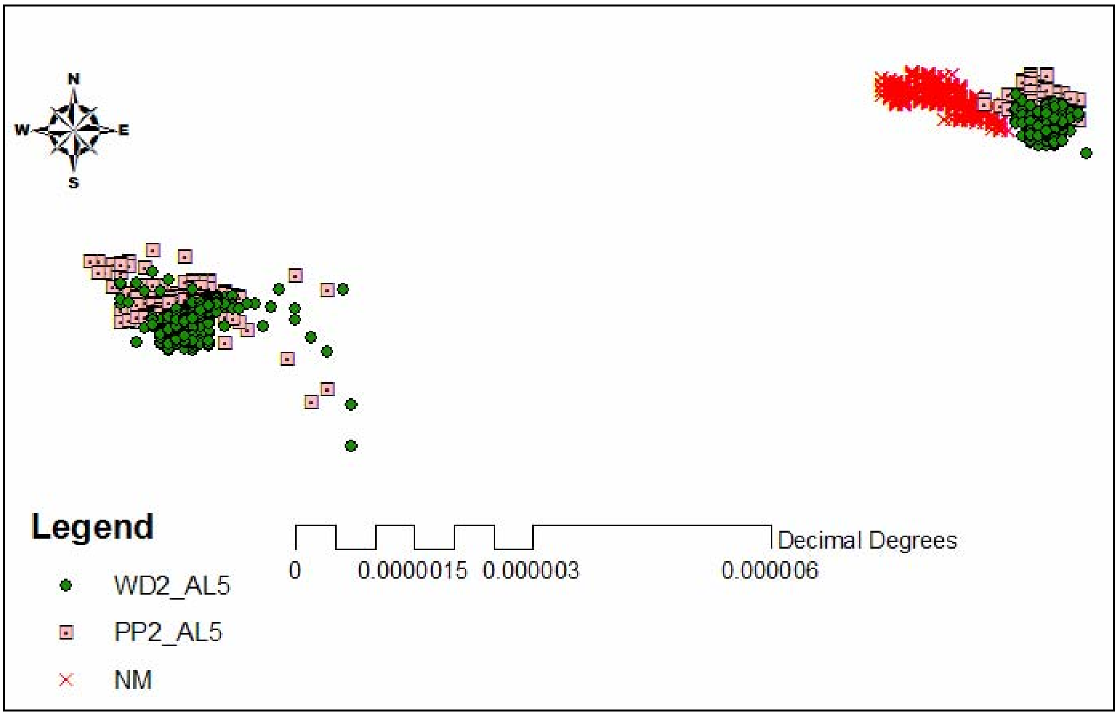


**Figure 9.** Test 8 (PP obstructing 2 and AL obstructing 5) and Test 9 (WD obstructing 2 and AL obstructing 5) compared to the control test

For Test 8 and Test 9 aluminium was used to obstruct the antenna of LocataLite 5. The effect of aluminium can be seen in both the tests as the temporal positioning solutions are split into two distinct groups, one closer to LocataLite 5 while the other biased in the direction of LocataLite 2. The error in pseudorange for aluminium is more than twice that of Plexiglass and seven times that of wood. The combined effect has resulted in varied positioning solution mainly owing to signal fluctuations caused by aluminium. It appears that for the group of solutions to the north, in both tests, the rover had lost lock on LocataLite 5, showing a precise yet inaccurate solution similar to that seen in Test 2. For the remaining group of positioning solutions to the south-west, it can be speculated that the rover was tracking reflected or highly attenuated signals from LocataLite 5, resulting in false positioning. The distinctive positioning pattern generated by aluminium can enable easy filtering of the results to minimise the error in the final positioning solution.

The following figure together with Table 6 and 7, summarise the results of the 9 network tests, and contrast the mean of their temporal positioning solution against the “true” position of the rover.

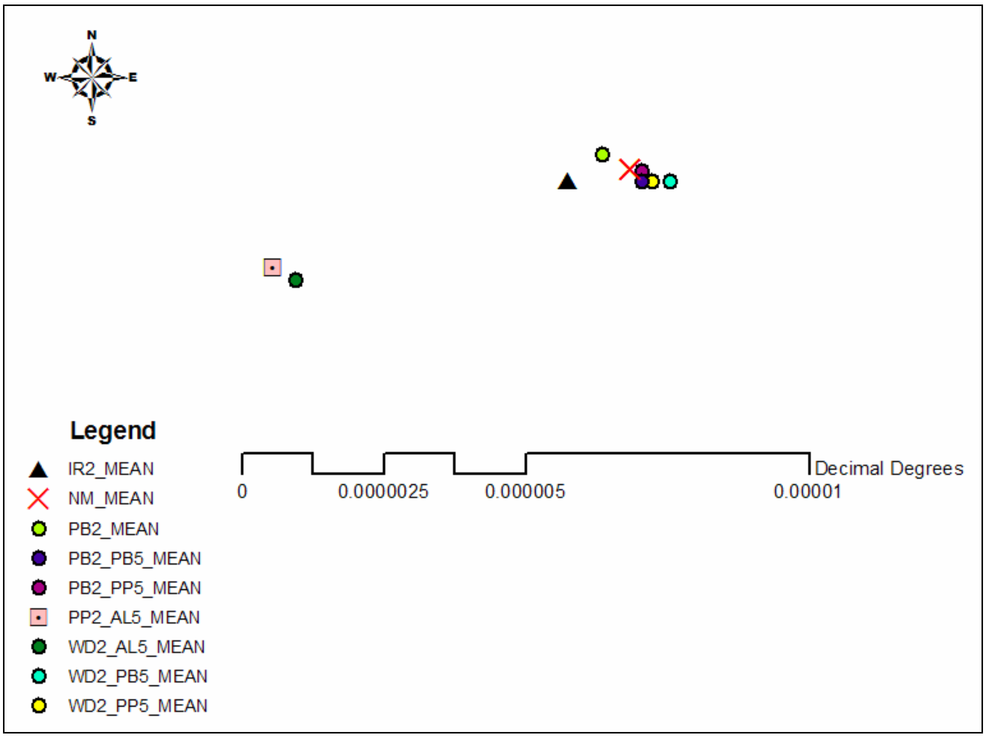


**Figure 10.** Mean Rover positions for all tests

| TEST | | LAT (mean) | LONG (mean) | E (mean) | N (mean) |
|---|---|---|---|---|---|
| 1 | NM ("true" position) | 33.55235045 | 151.1369261 | 336829.5043 | 6244782.137 |
| 2 | IR2 | 33.55235025 | 151.136925 | 336829.2208 | 6244782.194 |
| 3 | PB2 | 33.55235069 | 151.1369256 | 336829.3772 | 6244782.061 |
| 4 | PB2_PB5 | 33.55235022 | 151.1369263 | 336829.5545 | 6244782.208 |
| 5 | PB2_PP5 | 33.55235039 | 151.1369263 | 336829.5554 | 6244782.156 |
| 6 | PP2_AL5 | 33.55234871 | 151.1369198 | 336827.8773 | 6244782.645 |
| 7 | WD2_AL5 | 33.55234848 | 151.1369202 | 336827.9788 | 6244782.718 |
| 8 | WD2_PB5 | 33.55235023 | 151.1369268 | 336829.6829 | 6244782.208 |
| 9 | WD2_PP5 | 33.55235021 | 151.1369265 | 336829.6058 | 6244782.212 |

**Table 6.** Mean position of the rover obtained from each test

| TEST | | STDEV (decimal degrees) | | STDEV (m) | |
|---|---|---|---|---|---|
| 1 | | LAT | LONG | E | N |
| 2 | IR2 | -0.00020000 | -0.0011000 | -0.283 | 0.057 |
| 3 | PB2 | 0.00024000 | -0.0005000 | -0.127 | -0.076 |
| 4 | PB2_PB5 | -0.00023000 | 0.0002000 | 0.050 | 0.072 |
| 5 | PB2_PP5 | -0.00000006 | 0.0002000 | 0.051 | 0.019 |
| 6 | PP2_AL5 | -0.00174000 | -0.0000063 | -1.627 | 0.508 |
| 7 | WD2_AL5 | -0.00197000 | -0.0059000 | -1.525 | 0.581 |
| 8 | WD2_PB5 | -0.00022000 | 0.0000007 | 0.179 | 0.071 |
| 9 | WD2_PP5 | -0.00024000 | 0.0004000 | 0.102 | 0.076 |

**Table 7.** Deviation of the mean position of the rover, for each test, from the "true" position

As is clear from Figure 10, the tests involving aluminium show the largest error in position. This is due to the constant position fluctuations as seen in Tests 8 and 9. One way to minimise this error, in future applications of Locata technology, would be to define a maximum standard deviation value (or an error ellipse) and eliminate output positions that are outside this value.

Table 7 indicates that the error in positioning is significantly greater in the Easting than in the Northing. This can be attributed to the geometry of network setup, with only the north-east and north-west LocataLites being obstructed.

## 4. CONCLUSIONS

The study of how different construction materials affect the propagation of Locata's 2.4 GHz signal was presented in this paper. Of the materials tested wood caused the smallest error to the pseudorange, followed by cork, plasterboard, glass, Plexiglas and aluminium. Iron completely blocked out the Locata signal even though only a 2mm thick sheet was used. Standardised errors for 1mm thickness of each material that allow propagation of the Locata signal, was computed. In future indoor application of Locata technology, these computed errors can be applied as corrections to improve the accuracy of positioning.

The errors in pseudorange were seen to propagate into the 2D positioning solution obtained from a LocataNet, with plasterboard having the largest effect on precision. Aluminium, when introduced in the network, caused large signal fluctuations, severely affecting the accuracy of the positioning solution. Iron, once again, completely blocked out the signal from the LocataLite it was obstructing, resulting in a precise yet inaccurate solution.

## REFERENCES


Barnes, J., Rizos, C. and Wang, J. (2003a) Locata: the positioning technology of the future?, *6th Int. Symp. on Satellite Navigation Tech. including Mobile Positioning and Location Services,* Melbourne, Australia, July, CD-ROM, proc. Paper 49

Barnes, J., Rizos, C., Wang, J., Small, D., Voigt, G. and Gambale, N. (2003b) High precision indoor and outdoor positioning using LocataNet, *Journal of Global Positioning Systems* 2(2): 73-82

Barnes, J., Rizos, C., Kanli, M., Small, D., Voigt, G., Gambale, N., Lamance, J., Nunan, T. and Reid, C. (2004) Indoor industrial machine guidance using Locata: a pilot study at BlueScope Steel, *60th Annual Meeting of the U.S. Inst. of Navigation*, Dayton, Ohio, June

Barnes, J., Rizos, C., Kanli, M., Pahwa, D., Small, D., Voigt, G., Gambale, N. and Lamance, J. (2005) High accuracy positioning using Locata's next generation technology, *18th Int. Tech. Meeting of the Satellite Division of the U.S. Institute of Navigation,* Long Beach, California, September

Barnes, J., Rizos, C., Kanli, M. and Pahnwa, A. (2006) A solution to tough GNSS land applications using terrestrial-based transceivers (LocataLites), *Proceedings of the 19th Int. Tech. Meeting of the Satellite Division of the U.S. Inst. of Navigation,* Fort Worth, Texas, September, 1487-1493

D'Roza, T. and Bilchev, G. (2003) An overview of location based services, *BT Technology Journal* 21(1): 20-27

Rappaport, T.S. (1996), Wireless Communications - Principles & Practice, *IEEE Press* 71: 130-131