Journal of Al-Azhar University Engineering Sector

Vol. 18, No. 66, January 2023, 1 - 17

STUDYING THE EFFECT OF DIFFERENT TYPES AND DIMENSIONS OF MATERIALS FOR VERTICAL REFLECTIVE SURFACES ON MULTIPATH OF GPS SIGNAL

Mostafa H. A. Mohamed

Civil Engineering Department, Faculty of Engineering, Al-Azhar University, Cairo, Egypt
Correspondence: Mostafa.hassan@azhar.edu.eg

Received: 8 August 2022 **Accepted: 17 Oct. 2022**

Abstract

Multipath is one of major sources of error in GPS code and carrier phase measurements in the differential mode of operation. This paper includes four studies. The first one is the detection of the multipath errors from five tests carried out by setting up different material types of the vertical reflective surface (Aluminium Panel, Glass Panel, Ceramic Panel, Wood Board, and without reflective surface). The effects of different material types of reflective surface on the pseudo-range multipath are analysed using TEQC Software. The results obtained in this paper prove that different material types of vertical reflective do not give the same multipath error performance in Aluminium gave large Multipath Error, followed by glass, followed by Ceramic, then wood. In the second study is the detection of the multipath errors from three tests carried out by setting up at aluminium Panel dimensions difference (0.75X0.75 m, 1X1 m and1.25X1.25 m) as a vertical reflective surface and one test is without Multipath then analysed by using TEQC, the results obtained in this paper prove that the multipath error of GPS increases with the increase in aluminium Panel dimensions. Due to the occurrence of the largest multipath error in aluminium, in the third study, a multipath error was detected in four tests by positioning the 1.25 x 1.25 m aluminium panel at different distances (1 m, 2 m, 3 m, and without panel) from the antenna receiver, and it was found that the more the distance between the antenna and the aluminium receiver reduces the multipath error. In the fourth study, four tests were carried out by positioning the aluminium panel so that it inclines from the horizontal at different angles (10°, 20°, 30°, 40°) at a fixed distance of 1 m from the antenna, each test separately and found the multipath error decreases with the increase in the angle of inclination of the panel, as the statistical method for comparison and tests using the statistical T-test were presented in the previous studies.

Keywords: GPS observations, Multipath error, Vertical surface materials, TEQC.

دراسة تأثير الأنواع والأبعاد المختلفة للمواد للأسطح العاكسة العمودية لتعدد المسارات فى أشارات نظام تحديد المواقع العالمي

مصطفى حسن عبد الستار

قسم الهندسة المدنية، كلية الهندسة، جامعة الازهر، القاهرة.

بريد إلكتروني: Mostafa.hassan@azhar.edu.eg

الملخص

يعد خطأ تعدد المسارات مصدرًا رئيسيًا في ارصاد نظام تحديد الموقع العالمي، مما قد يمنع تحقيق أعلى مستويات الدقة. سيناقش هذا البحث اربع دراسات، الأولى يتم الكشف عن أخطاء تعدد المسارات من خمسة اختبارات تم إجراؤها عن طريق إعداد أنواع مختلفة من المواد للسطح العاكس الرأسي (الواح الألمنيوم، الزجاج، السيراميك، الخشب، بدون لوح). يتم تحليل تأثيرات أنواع مختلفة من المواد للسطح العاكس الرأسي على خطا تعدد المسارات بواسطة برنامج TEQC. النتائج التي تم الحصول عليها في هذا البحث تثبت أن الانواع المختلفة من المواد العاكسة الرأسية لا تعطي نفس أداء خطأ تعدد المسارات في جميع الاختبارات الخمسة ولكنها أعطت الألمنيوم ذو التأثير العالى على خطأ تعدد المسارات، يليه الزجاج، يليه السيراميك ثم الخشب. في الدراسة الثانية، تم الكشف عن أخطاء تعدد المسارات من ثلاثة اختبارات أجريت عن طريق إعداد الواح الألومنيوم مختلفة الابعاد (0.75 × 0.75 م، 1 × 1 م، 1.25 × 1.25 م) كسطح عاكس رأسي واختبار واحد بدون ثم حلل خطا تعدد المسارات بواسطة TEQC، وأثبتت النتائج التي تم الحصول عليها في هذا البحث أن خطأ تعدد المسارات يزداد مع زيادة أبعاد لوحة الألومنيوم. ونظرا لحدوث اكبر خطأ تعدد مسارات فى الالومنيوم حيث انه فى الدراسة الثالثة تم الكشف عن خطا تعدد المسارات باربع اختبارات بوضع لوح الالومنيوم 1.25 × 1.25 م علي مسافات مختلفة (1م، 2م، 3 م، بدون لوح) عن المستقبل الهوائى ووجد انه كلما زادت المسافة بين المستقبل الهوائي والومنيوم يقل خطا تعدد المسارات اما فى الدراسة الرابعة تمت باربع اختبارات بوضع لوح الومنيوم بحيث يميل عن الافقي بزاويا مختلفة (10°، 20°، 30°،40°) ويبعد مسافة ثابتة 1م من المستقبل الهوائي كل اختبار على حدة ووجد ان خطا تعدد المسارات يقل مع زيادة زاوية ميل اللوح كما تم عرض الطريقة الإحصائية للمقارنة والاختبارات باستخدام اختبار T الإحصائي في الدراسات السابقة.

الكلمات المفتاحية: قياسات نظام تحديد المواقع العالمى, خطأ تعدد المسارات, المواد الرئسية الأسطح, برنامج TEQC

1. INTRODUCTION

In difficult situations such as cities and indoors, an ever-increasing set of GNSS-based applications requires dependable and accurate navigation systems. Signal shadowing, obstruction, and multipath reduce accuracy and dependability in such situations. Position errors are enhanced as a result of these variables. Signal shadowing, in which the signal is there but attenuated, results in poor acquisition and tracking performance, full signal blockage results in higher precision dilution, and multipath results in poor measurement accuracy and fading, as an example. One of the most common types of errors is multipath, which is determined by the kind and number of reflectors in the receiver environment [9].

Nearby reflecting surfaces at the receiver position generate multipath error. Radio signals can be reflected by solid objects and surfaces in the same way that light reflects off a glossy surface. Buildings, dense tree canopies, vehicles, ships, and bridges are all examples of hard things that GPS signals cannot penetrate. Instead, these objects deflect the signals, resulting in multiple paths to the receiver. Signals received via a direct path will be affected by the reflected signals. Instead of going along a direct signal route, the reflected signal travels over a greater distance. As a result, the receiver position is erroneously computed, causing the position to change in the direction of the multipath source. The carrier phase measurements, as well as the C/A-code and P-code modulations, are affected by multipath [11].

Alberet al,2000 [1] Designed a multipath simulation model in which the multipath parameters may be changed, and their effects seen. The reflection coefficient, the antenna to reflector distance, the azimuth and elevation of the reflected signal, the possibility of multiple reflectors, and satellite dynamics are among the variables considered. The multipath's magnitude is determined by a few parameters [6]: the position of the reflected surface near the antenna, various types of reflected surfaces, GPS wave distance signals, and antenna height from the earth's surface.

Mohamed, 2019 [10] Mentioned that the data obtained in his improvements in existing that the best height for positioning the GPS antenna to decrease pseudo-range multipath is at the lowest level where the GPS antenna is placed on roofing. So, there are no obstacles or reflections over the antenna horizons.

Based on accurate knowledge of the geometry of the satellite-reflector-antenna and the properties of the reflector material and antenna, [8] proposed a ray-tracing technique to remove the multipath effect. It is valid when reflected by steel plates and brick walls, but it is unacceptable when reflected by water, according to the observations. In order to identify and eliminate multipath errors in urban areas. The impact of reflected surroundings on GPS signals should be widely investigated. Understanding the properties of multipath effects on GPS signals is also an important factor in reducing multipath impacts from a practical viewpoint. Many groups around the world have carried out experimental research on the multipath effects caused by reflecting environments [13].

Multipath Mitigation of Permanent GPS Stations Using Wavelet Decomposition was developed by [12]. To test the method's effectiveness, he placed a receiver beside the concrete wall and collected multipath signals. The results indicate that the suggested technique may considerably reduce the impacts of multipath at a permanent GPS station.

Dinesh et al, 2014 [2] Used GPS simulation to analyse the influence of commonly used materials on multipath propagation of GPS signals. Aluminium is shown to generate the first and most multipath, resulting in the greatest variety of possible errors. Glass, ceramics, PVC, and wood are the next materials on the list. Because the panels were 1×1 m, the multipath effect is determined by the dielectric constant, which determines the material's polarisation. Multipath is increased in materials with greater dielectric constants and vice versa. Experimental results showed that GPS was a workable technology for tracking the environment and resonant response when using a 0.9 m thin square aluminium plate as the reflecting surface. Attention should be given to the multipath issue for effective deployments in urban environments [7].

[15] Studied the influence of five widely used materials on multipath GPS signal propagation (aluminium, glass, wood, polyvinyl chloride (PVC), and ceramic). Field assessments involving current GPS signals were used to perform the research. However, such field evaluations are vulnerable to a variety of error factors that users have no control over.

2. ANALYSIS OF MULTIPATH ERROR BY TEQC SOFTWARE

To check the quality and integrity of the RINEX files, UNAVCO (University Navstar Consortium) scientists in Boulder, Colorado, created the TEQC software (Test of Quality Check of GPS raw data), which is available for public use at (http://www.unavco.org/facility/software/teqc/teqc.html) to verify the quality and integrity of the RINEX files (cycle slips, receiver multipath, and receiver clock drift).

To estimate multipath, it is not possible to simply compare the measured pseudo-range (P_1 and P_2) or carrier phase (ϕ_1 and ϕ_2) to the true geometric range since the error is a combination of several factors in addition to multipath. Therefore, multipath isolation or the formation of a multipath 'data combination' is essential. The following pseudo-range combination is obtained by carefully combining pseudo-range and carrier phase observations, taking advantage of the fact that noise and multipath effects on the carrier phase are minimal in comparison to those on the pseudo-range, although most other error sources are the same. So, $MP1$ and $MP2$ are the pseudo-range multipath effects on L1 and L2 can be given by equations 1 and 2 as follows [5].

$$MP_1 = P_1 - \frac{9529}{2329}.\phi_1 + \frac{7200}{2329}.\phi_2 + \frac{9529}{2329}(\lambda_1 N_1 + MP_{\phi 1}) - \frac{7200}{2329}(\lambda_2 N_2 + MP_{\phi 2}) \ldots\ldots \quad (1)$$

$$MP_2 = P_2 - \frac{11858}{2329}.\phi_1 + \frac{9529}{2329}.\phi_2 + \frac{11858}{2329}(\lambda_1 N_1 + MP_{\phi 1}) - \frac{9529}{2329}(\lambda_2 N_2 + MP_{\phi 2}) \ldots\ldots (2)$$

Where:

P1 and P2 are pseudo-range data on L1 and L2; $\phi 1$ and $\phi 2$ are carrier phase data on L1 and L2; and the terms in brackets are functions of the multipath carrier phase, $MP_{\phi 1}$, $MP_{\phi 2}$ and unknown integer ambiguities, N1, N2, where λ_1 and λ_2 are the wavelengths of the L1 and L2 carrier phases, respectively. When compared to the multipath pseudo-range, the impact of multipath on the carrier phase is minimal, and so may be ignored; those terms are biases that are considered constant if there is no cycle slip in carrier phase data, and thus can be discarded.

The measurements are metres in both cases. After the combination, the "pseudo-range multipath residual series" is referred to as the "pseudo-range multipath residual series." Every sidereal day, the pseudo-range multipath pattern repeats itself, but the geometry between the GPS satellite and the receiver (both in the same place) stays the same [4].

The pseudo range multipath pattern is replicated every sidereal day when the geometry between the GPS satellite and the receiver (both in the same region) remains unchanged [5]. On average, the difference in time Δt between two full satellite revolutions and one mean solar day is around 240 seconds [14].

3. DATA COLLECTION

3.1-In the first study, the data collection involved the comparison of the observation results from five tests that varied the material type of vertical reflective surface (aluminium panel, glass panel, ceramic panel, and wood board) at a distance of 1.50m from the receiver at an antenna Height of 1.10 m in four tests (15, 16, 17, and 18 February) respectively, and one test was without reflective vertical surface (No Multipath) on 19 February. The survey station is located on the roof of the Civil Engineering Department building, Al-Azhar University, Cairo, Egypt (N30°03'22" and E31°18'54"), as shown in Fig. 1 and Table 1.

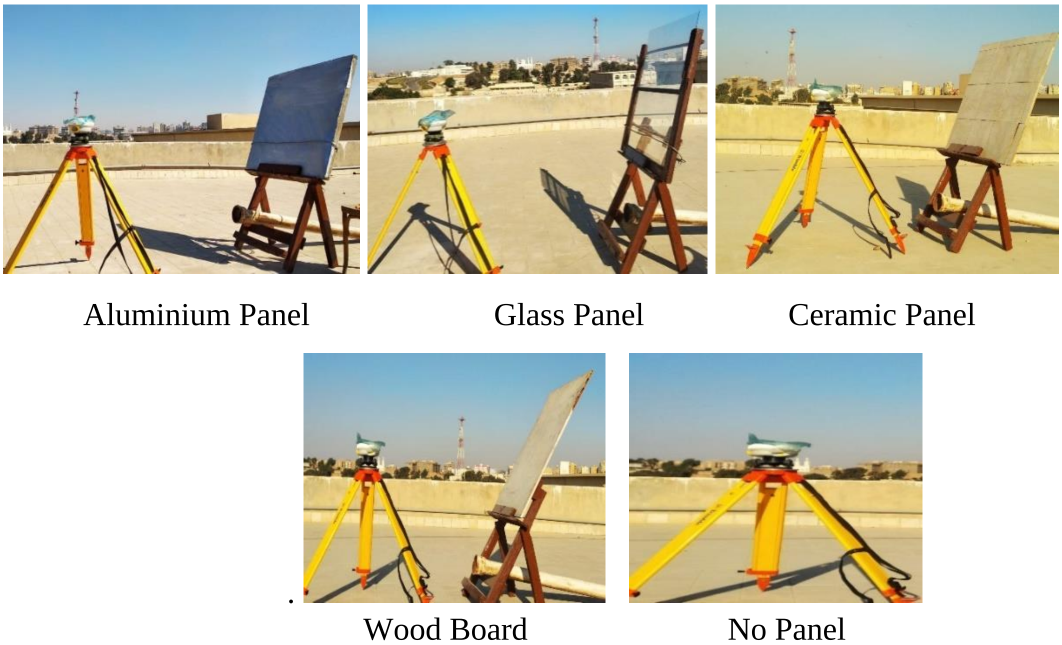

Fig. 1. GPS receiver set up on test sites with material types of the vertical reflective surface.

Table1. Days and Times of observation with different of Type of Surface Reflected in addition no panel.

Test	Day	Time GMT+2	Antenna Height (m)	Type of Surface Reflected
1	15-Feb	13:45:00 TO 15:25:00	1.1	Aluminium Panel
2	16-Feb	13:41:00 TO 15:21:00	1.1	Glass Panel
3	17-Feb	13:37:00 TO 15:17:00	1.1	Ceramic Panel
4	18-Feb	13:33:00 TO 15:13:00	1.1	Wood Board
5	19-Feb	13:29:00 TO 15:09:00	1.1	No Panel

3.2-The Second Study was done to compare the multipath effect using different size of aluminium panel. The panels were 1.5 m away from the receiver, antenna height is 1.10m, panels with 0.75 X 0.75 m, 1.0 X 1.0 m and 1.25 X 1.25 m were tested. The tests were performed on 20, 21, 22 February 2020 and another test was done with no panel on 23 February. The detail of the tests is given in table 2.

Table2. Details of tests with different of aluminium Panel Dimensions.

Test	Date	Time GMT+2	Antenna Height (m)	Aluminium Panel Dimensions
1	20-Feb	08:40:00 TO 10:20:00	1.1	0.75X0.75 m
2	21-Feb	08:36:00 TO 10:16:00	1.1	1 X1 m
3	22-Feb	08:32:00 TO 10:12:00	1.1	1.25 X1.25 m
4	23-Feb	08:28:00 TO 10:08:00	1.1	No Panel

3.3-In the Third Study, the data collection involved the comparison of the observation results from four tests that an aluminium panel (1.25 mX1.25 m) used in three tests as a reflective vertical surface, which were set up at three different distances (1 m, 2 m, and 3 m) from the receiver at an antenna Height of 1.10 m in three days (30, 31 January, and 01 February) respectively, and one test without a reflective vertical surface (No Multipath) on 02 Feb), as shown in table 3.

Table 3. Details of tests with different distances between receiver and aluminium Panel.

Test	Day	Time GMT+2	Antenna Height (m)	Distance between receiver and aluminium Panel
1	30-Jan	11:45:00 to 13:10:00	1.1	No Panel
2	31-Jan	11:41:00 to 13:06:00	1.1	1 m
3	01-Feb	11:37:00 to 13:02:00	1.1	2 m
4	02-Feb	11:33:00 to 12:58:00	1.1	3 m

3.4-In the Fourth Study, the data collection involved the comparison of the observation results from four tests. An aluminium panel (1.25 mX1.25 m) used in four tests as a reflective vertical surface, which was set up four aluminium inclination angle difference (10°, 20°, 30°, and 40°) from the receiver at an antenna Height of 1.1 m in four days (05, 06, 07, and 08 February), respectively. The aluminium panel is 1.0 m away from the receiver, as shown in table 4.

The observations were done at the same time to have the same satellite geometry. The data were collected using Trimble R4 GPS receiver, the PDOP (Position Dilution of Precision) value is less than 3.0.

Table.4. Details of tests with aluminium inclination angle difference.

Test	Day	Time GMT+2	Antenna Height(m)	Degree of Panel inclination (degree)
1	05-Feb	11:55:00 to 12:30:00	1.1	10°
2	06-Feb	11:51:00 to 12:26:00	1.1	20°
3	07-Feb	11:47:00 to 12:22:00	1.1	30°
4	08-Feb	11:43:00 to 12:18:00	1.1	40°

4. RESULTS AND DISCUSSION

4.1- In the first study: multipath values (MP1 &MP2) result from TEQC software because of material type of a vertical reflective surface on multipath error as shown in tables 5 to 7 and Fig 2. According to the mean of MP1 and MP2, it is shown that the effect of aluminium is the largest on the Multipath Error, followed by glass, followed by ceramic then wood as to seen in Fig.2.

Table 5. Multipath values MP1 result from TEQC software due to the effect of Variation of material type.

DATUME TIME	Values results from 5 testes for MP1(m).					
	Period (minutes)	No multipath	Aluminium Panel	Ceramic Panel	Wood Board	Glass Panel
1	0	0.25	0.25	0.25	0.25	0.26
2	5	0.26	0.25	0.27	0.26	0.26
3	10	0.25	0.24	0.25	0.26	0.26
4	15	0.28	0.28	0.27	0.28	0.30
5	20	0.29	0.30	0.29	0.30	0.31
6	25	0.28	0.32	0.28	0.29	0.28
7	30	0.26	0.30	0.30	0.29	0.29
8	35	0.24	0.28	0.24	0.24	0.24
9	40	0.25	0.29	0.25	0.24	0.25
10	45	0.26	0.29	0.26	0.26	0.26
11	50	0.26	0.34	0.27	0.26	0.26
12	55	0.25	0.30	0.27	0.27	0.26
13	60	0.26	0.34	0.28	0.26	0.26
14	65	0.26	0.30	0.28	0.26	0.28
15	70	0.25	0.30	0.26	0.27	0.29
16	75	0.26	0.32	0.26	0.26	0.29
17	80	0.28207	0.35	0.27	0.28	0.31
Mean of MP1 (m)		0.26	0.30	0.27	0.27	0.27
Standard Deviation (m)		0.01	0.031	0.01	0.01	0.02

To see if there are significant difference in multipath values using panels with different materials compared with the values when no panel is used, the T- statistical test was used [3]. From tables of T- test, the t- value is obtained for 16 degree of freedom and 95 % confidence level, it is equal to 1.74. From the values of MP1and MP2 as shown in tables 8 and 9, the following conclusion can be shown.

a- There are significant differences for aluminium material on Multipath Error for (MP1 and MP2).

b- There are no significant differences for wood material on Multipath Error for (MP1 and MP2).

c- There are no significant differences for ceramic material on Multipath Error for (MP1 and MP2).

d- There are no significant differences for glass material on Multipath Error for (MP2) and a significant difference on Multipath Error for (MP1).

Table 6. Multipath values MP2 result from TEQC software due to the effect of Variation of material type.

DATUME TIME	Values results from 5 testes for MP2(m).					
	Period (minutes)	No multipath	Aluminium Panel	Ceramic Panel	Wood Board	Glass Panel
1	0	0.27	0.28	0.29	0.28	0.25
2	5	0.24	0.24	0.24	0.24	0.24
3	10	0.24	0.25	0.26	0.26	0.26
4	15	0.27	0.29	0.28	0.32	0.30
5	20	0.28	0.30	0.27	0.29	0.29
6	25	0.25	0.27	0.26	0.27	0.26
7	30	0.24	0.25	0.27	0.26	0.25
8	35	0.23	0.26	0.24	0.24	0.24
9	40	0.22	0.25	0.22	0.23	0.22
10	45	0.22	0.26	0.23	0.23	0.22
11	50	0.22	0.26	0.22	0.21	0.23
12	55	0.22	0.25	0.23	0.23	0.23
13	60	0.22	0.27	0.23	0.22	0.23
14	65	0.22	0.25	0.23	0.25	0.24
15	70	0.22	0.24	0.23	0.25	0.25
16	75	0.22	0.25	0.23	0.23	0.24
17	80	0.23	0.28	0.23	0.24	0.24
Mean of MP2 (m)		0.24	0.26	0.25	0.25	0.25
Standard Deviation (m)		0.01	0.01	0.02	0.02	0.02

Table 7. Mean of (MP1 &MP2) result from TEQC software due to the effect of Variation of material type.

Material	No multipath	Aluminium	Ceramic	Wood	Glass
Mean of MP1 (m)	0.26	0.30	0.27	0.27	0.27
Mean of MP2 (m)	0.24	0.26	0.25	0.25	0.25

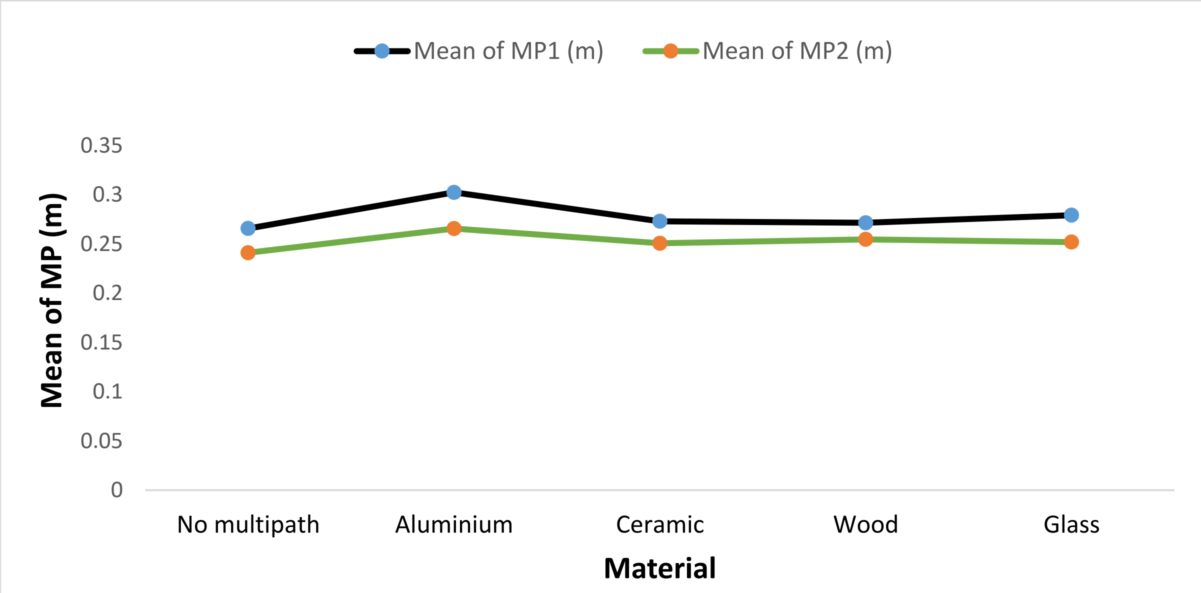

Fig 2. The effect of variation of vertical reflective surface on multipath errors (MP1 and MP2).

Table 8. T-calculated Statistical values for MP1results from 5 testes (different material).

T-calculated values result from 5 testes for MP1.					
Material	**No Multipath**	**Aluminium**	**Ceramic**	**Wood**	**Glass**
No Multipath	**0**	**4.43**	**1.44**	**1.16**	**2.21**
Aluminium	**4.43**	**0**	**3.44**	**3.65**	**2.52**
Ceramic	**1.44**	**3.44**	**0**	**0.28**	**0.95**
Wood	**1.16**	**3.65**	**0.28**	**0**	**1.21**
Glass	**2.21**	**2.52**	**0.95**	**1.21**	**0**

Table 9.T-calculated Statistical values for MP2 results from 5 testes (different material).

T-calculated values result from 5 testes for MP2.					
Material	**No Multipath**	**Aluminium**	**Ceramic**	**Wood**	**Glass**
No Multipath	**0**	**3.88**	**1.32**	**1.67**	**1.56**
Aluminium	**3.88**	**0**	**2.20**	**1.42**	**2.13**
Ceramic	**1.32**	**2.20**	**0**	**0.46**	**0.17**
Wood	**1.67**	**1.42**	**0.46**	**0**	**0.33**
Glass	**1.56**	**2.13**	**0.17**	**0.33**	**0**

4.2- In the Second study: multipath values (MP1 &MP2) results from TEQC software due to the effect of aluminium Panel dimensions on the multipath error as shown in tables 10 to 12 and fig 3. According to the mean of MP1 and MP2, it is shown that the multipath errors (MP1 and MP2) increase with the increase in aluminium panel dimension according to fig.3.

Table 10. Multipath values MP1 due to the chang of aluminium Panel dimensions.

DATUME TIME	Values result from 4 testes for MP1(m).				
	Period (min)	No Multipath	0.75 X0.75 m	1 X1 m	1.25 X1.25 m
1	0	0.26	0.26	0.26	0.28
2	5	0.27	0.27	0.27	0.30
3	10	0.29	0.31	0.30	0.32
4	15	0.27	0.27	0.27	0.27
5	20	0.29	0.28	0.36	0.32
6	25	0.31	0.29	0.30	0.31
7	30	0.33	0.32	0.33	0.32
8	35	0.29	0.30	0.30	0.32
9	40	0.30	0.31	0.30	0.32
10	45	0.30	0.32	0.31	0.35
11	50	0.28	0.29	0.28	0.30
12	55	0.28	0.29	0.27	0.31
13	60	0.28	0.30	0.29	0.31
14	65	0.27	0.30	0.27	0.30
15	70	0.26	0.28	0.26	0.28
16	75	0.25	0.27	0.27	0.28
17	80	0.26	0.28	0.26	0.28
Mean (m)		0.28	0.29	0.29	0.30
Standard Deviation (m)		0.02	0.01	0.02	0.02

Table 11. Multipath values MP2 due to the *chang* of aluminium Panel dimensions.

DATUME TIME	Values result from 4 testes for MP2(m).				
	Period (min)	No Multipath	0.75X0.75 m	1 X1m	1.25X1.25 m
1	0	0.26	0.26	0.26	0.25
2	5	0.26	0.26	0.28	0.30
3	10	0.26	0.27	0.27	0.26
4	15	0.28	0.28	0.28	0.27
5	20	0.28	0.31	0.37	0.27
6	25	0.28	0.28	0.27	0.28
7	30	0.28	0.31	0.29	0.31
8	35	0.28	0.30	0.28	0.30
9	40	0.27	0.27	0.27	0.26
10	45	0.28	0.28	0.26	0.29
11	50	0.25	0.25	0.25	0.27
12	55	0.26	0.26	0.28	0.29
13	60	0.26	0.26	0.26	0.29
14	65	0.24	0.24	0.24	0.24
15	70	0.24	0.27	0.25	0.26
16	75	0.22	0.24	0.24	0.25
17	80	0.26	0.28	0.28	0.27
Mean of MP2(m)		0.26	0.27	0.27	0.27
Standard Deviation (m)		0.01	0.02	0.02	0.01

Table 12. Mean of Multipath values (MP1 &MP2) due to the effect of aluminium Panel dimension.

Panel Dimensions	No Multipath	0.75X0.75 m	1 X1m	1.25X1.25 m
Mean of MP1(m)	0.28	0.29	0.29	0.30
Mean of MP2 (m)	0.26	0.27	0.27	0.27

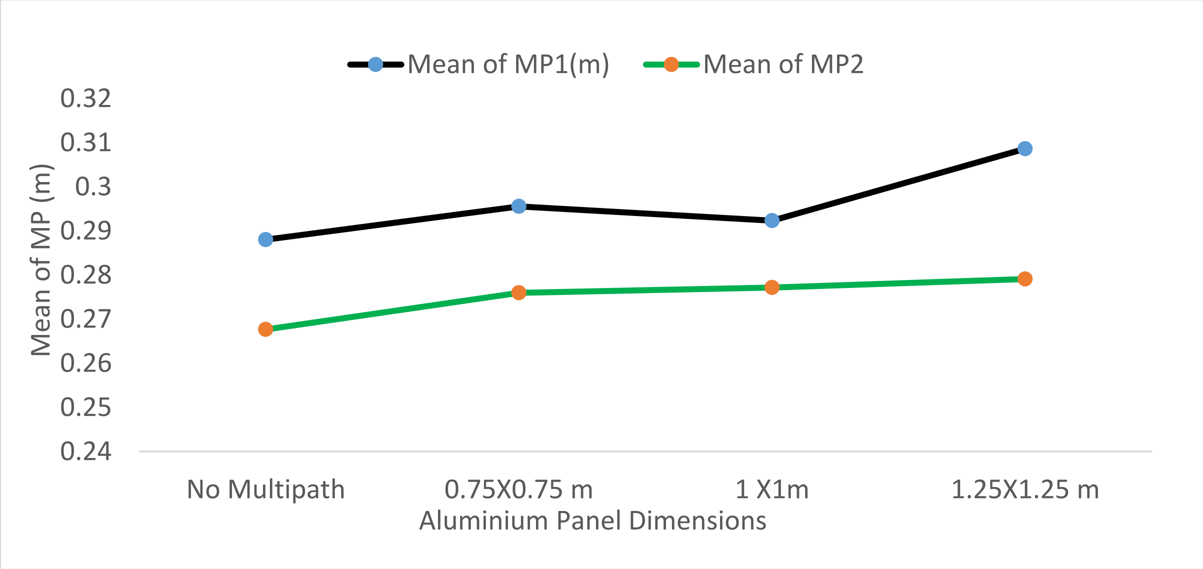

Fig 3. Effect Dimensions difference of aluminium Panel on Multipath Error MP1 and MP2.

By Applying T-statistical test on 4 tests

Using the T-calculated statistical values results from four testes for MP1 and MP2 as shown in table 13 and 14, degree of freedom is 16, Confidence level 95 % so T-table results from T-table is 1.33, there are no significant differences for aluminium Panel dimensions (0.75X0.75 m and 1.0X1.0m) on Multipath Error for (MP1 and MP2), in addition, there are significant differences for aluminium Panel dimensions (1.25X1.25m) on Multipath Error for (MP1 and MP2).

Table 13. T-calculated Statistical values for MP1results from 4 testes (different dimension).

T-calculated values results from 4 testes for MP1				
Panel Dimensions	**No Multipath**	**0.75X0.75 m**	**1X1m**	**1.25X1.25 m**
No Multipath	**0**	**1.16**	**0.51**	**2.89**
0.75X0.75 m	**1.16**	**0**	**0.40**	**2.01**
1X1m	**0.51**	**0.40**	**0**	**1.93**
1.25X1.25 m	**2.89**	**2.01**	**1.93**	**0**

Table 14. T-calculated Statistical values for MP2 results from 4 testes (different dimension).

T-calculated values results from 4 testes for MP2.				
Panel Dimensions	**No Multipath**	**0.75X0.75 m**	**1 X1m**	**1.25X1.25 m**
No Multipath	**0**	**1.27**	**1.16**	**1.81**
0.75X0.75 m	**1.27**	**0**	**0.13**	**0.45**
1X1m	**1.16**	**0.13**	**0**	**0.22**
1.25X1.25 m	**1.81**	**0.45**	**0.22**	**0**

4.3- In the third study: multipath values (MP1 & MP2) results from TEQC software due to the effect of changing the distance between the aluminium panel and the receiver on the multipath error are shown in tables 15 to 17 and fig 4. According to the mean of MP1 and MP2, it is shown that the multipath errors (MP1 and MP2) decrease with increasing the distance between the aluminium panel and the receiver according to fig.4.

Table 15. Mean of (MP1 &MP2) result from TEQC software due to the effect of changing the distance between the aluminium panel and the receiver on multipath.

Distance between the receiver and the aluminium panel (m)	**No Multipath**	**1 m**	**2 m**	**3 m**
Mean of MP1 (m)	**0.26**	**0.28**	**0.27**	**0.27**
Mean of MP2 (m)	**0.24**	**0.26**	**0.25**	**0.25**

Table16. Multipath values MP1 result from TEQC software due to the effect of changing the distance between the Aluminium panel and the receiver on multipath error.

DATUME TIME	**Values results from 4 testes for MP1(m).**				
	Period(min)	**No Multipath**	**1 m**	**2 m**	**3 m**
1	**0**	**0.27**	**0.28**	**0.34**	**0.27**
2	**5**	**0.27**	**0.28**	**0.29**	**0.28**
3	**10**	**0.28**	**0.28**	**0.27**	**0.28**
4	**15**	**0.27**	**0.33**	**0.27**	**0.31**
5	**20**	**0.26**	**0.32**	**0.25**	**0.28**
6	**25**	**0.28**	**0.30**	**0.31**	**0.27**
7	**30**	**0.26**	**0.30**	**0.30**	**0.27**
8	**35**	**0.25**	**0.31**	**0.31**	**0.27**
9	**40**	**0.25**	**0.28**	**0.26**	**0.30**
10	**45**	**0.25**	**0.25**	**0.25**	**0.26**
11	**50**	**0.25**	**0.24**	**0.26**	**0.25**
12	**55**	**0.24**	**0.25**	**0.26**	**0.24**
13	**60**	**0.25**	**0.25**	**0.27**	**0.25**
14	**65**	**0.25**	**0.26**	**0.25**	**0.25**
15	**70**	**0.27**	**0.28**	**0.28**	**0.28**
16	**75**	**0.27**	**0.27**	**0.27**	**0.27**
17	**80**	**0.25**	**0.24**	**0.24**	**0.25**
Mean of MP1 (m)		**0.26**	**0.28**	**0.27**	**0.27**
Standard Deviation (m)		**0.01**	**0.02**	**0.02**	**0.01**

Table17. Multipath values MP2 result from TEQC software due to the effect of changing the distance between the aluminium panel and the receiver on multipath error.

DATUME TIME	Values results from 4 testes for MP2(m)				
	Period	No Multipath	1 m	2 m	3 m
1	0	0.26	0.27	0.29	0.26
2	5	0.29	0.30	0.28	0.29
3	10	0.28	0.30	0.28	0.29
4	15	0.25	0.28	0.27	0.26
5	20	0.23	0.26	0.25	0.24
6	25	0.26	0.25	0.29	0.24
7	30	0.24	0.27	0.26	0.27
8	35	0.24	0.33	0.26	0.27
9	40	0.22	0.23	0.24	0.24
10	45	0.23	0.23	0.24	0.23
11	50	0.24	0.25	0.25	0.24
12	55	0.24	0.23	0.24	0.24
13	60	0.24	0.23	0.24	0.24
14	65	0.23	0.22	0.23	0.22
15	70	0.24	0.22	0.23	0.23
16	75	0.23	0.24	0.24	0.24
17	80	0.23	0.23	0.23	0.24
Mean of MP2 (m)		0.24	0.26	0.25	0.25
Standard Deviation (m)		0.01	0.03	0.02	0.02

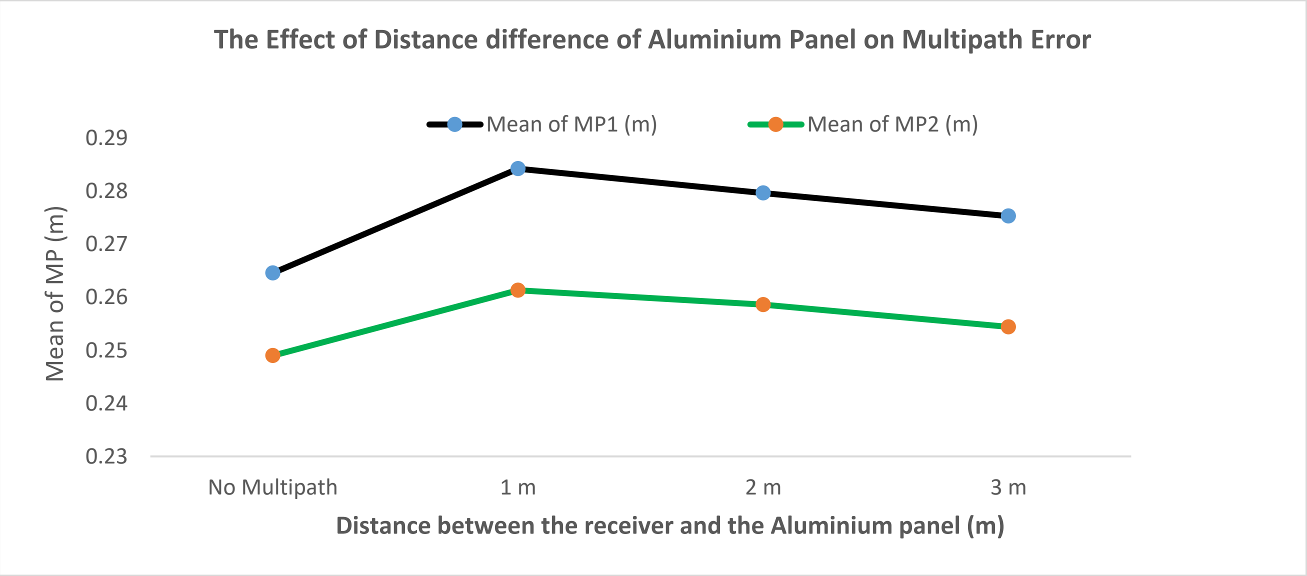

Fig 4. The effect of changing the distance between the aluminium panel and the receiver on multipath errors (MP1 and MP2).

By Applying T-statistical test on 4 tests

Using the T-calculated statistical values results from four tests for MP1 and MP2 as shown in tables 18 and 19. That degree of freedom is 16, Confidence level 95 % so T-table results from T-table is 1.33, there are no significant differences for the distance at 3.0 m between the aluminium panel and the receiver Multipath Error for MP2. In addition, there are significant differences for the distance at 1.0 m and 2.0 m between the aluminium panel and the receiver Multipath Error for MP2 and MP1.

Table 18. Using T-calculated Statistical values results from 4 testes for MP1.

T-calculated values results from 4 testes for MP1.				
Distance m	**No Multipath**	**1 m**	**2 m**	**3 m**
No Multipath	**0**	**2.70**	**2.18**	**2.09**
1m	**2.70**	**0**	**0.49**	**1.12**
2m	**2.18**	**0.49**	**0**	**0.56**
3 m	**2.09**	**1.12**	**0.56**	**0**

Table 19. Using T-calculated Statistical values results from 4 testes for MP2.

Table. . T-calculated values results from 4 testes for MP2.				
Distance m	**No Multipath**	**1 m**	**2 m**	**3 m**
No Multipath	**0**	**1.44**	**1.49**	**0.86**
1m	**1.44**	**0**	**0.29**	**0.76**
2m	**1.49**	**0.29**	**0**	**0.59**
3 m	**0.86**	**0.76**	**0.59**	**0**

4.4- In the fourth study: multipath values (MP1 &MP2) result from TEQC software due to the effect of different angles of inclination aluminium Panel on the multipath error, as shown in tables 20 to 22 and fig 5. According to the mean of MP1 and MP2, it is shown that the multipath errors (MP1 and MP2) reduce with an increase in the angle of inclination of the aluminium panel according to fig.5.

Table 20. Multipath values MP1 result from TEQC software due to the effect different angles of inclination aluminium Panel on multipath error.

DATUME TIME	**Values results from 4 testes for MP1(m).**				
	Period	**10°**	**20°**	**30°**	**40°**
1	**0**	**0.24**	**0.26**	**0.24**	**0.24**
2	**5**	**0.23**	**0.24**	**0.24**	**0.23**
3	**10**	**0.25**	**0.24**	**0.24**	**0.23**
4	**15**	**0.25**	**0.23**	**0.22**	**0.21**
5	**20**	**0.26**	**0.27**	**0.25**	**0.26**
6	**25**	**0.27**	**0.24**	**0.25**	**0.26**
7	**30**	**0.29**	**0.29**	**0.29**	**0.29**
Mean of MP1 (m)		**0.26**	**0.25**	**0.25**	**0.25**
Standard Deviation (m)		**0.02**	**0.02**	**0.02**	**0.02**

Table 21. Multipath values MP2 result from TEQC software due to the effect different angles of inclination aluminium Panel on multipath error

DATUME TIME	**Values results from 4 testes for MP2(m).**				
	Period	**10°**	**20°**	**30°**	**40°**
1	**0**	**0.24**	**0.27**	**0.26**	**0.25**
2	**5**	**0.24**	**0.24**	**0.23**	**0.23**
3	**10**	**0.23**	**0.21**	**0.21**	**0.22**
4	**15**	**0.22**	**0.21**	**0.22**	**0.21**
5	**20**	**0.27**	**0.27**	**0.28**	**0.27**
6	**25**	**0.28**	**0.28**	**0.27**	**0.27**
7	**30**	**0.29**	**0.30**	**0.27**	**0.28**
Mean of MP2 (m)		**0.25**	**0.25**	**0.25**	**0.25**
Standard Deviation (m)		**0.02**	**0.03**	**0.02**	**0.02**

Table 22. Mean of (MP1 &MP2) result from TEQC software due to the effect different angles of inclination aluminium Panel on multipath error.

Angle of inclination aluminium panel	10°	20°	30°	40°
Mean of MP1 (m)	**0.26**	**0.25**	**0.25**	**0.25**
Mean of MP2 (m)	**0.25**	**0.25**	**0.25**	**0.25**

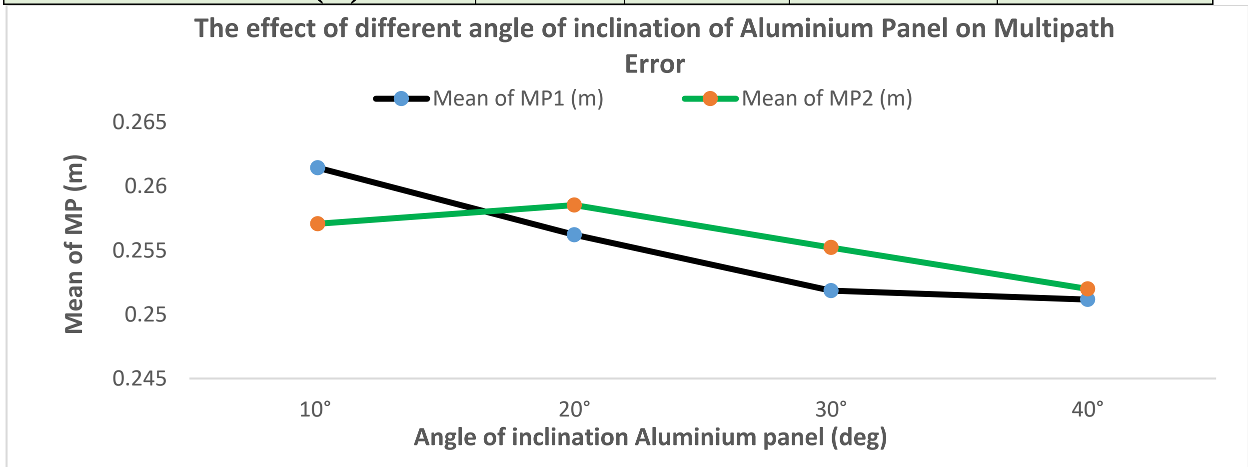

Fig5. The effect of different angles of inclination aluminium Panel on multipath errors (MP1 and MP2).

5. CONCLUSIONS

Based on the results of this paper, which computes multipath errors using different dimensions and types of material and then evaluates these errors by T- statistical test, so this paper can be divided into four studies:

In the first study, it is shown that there is an actual effect on the multipath error of GPS under different types of material (aluminium, Glass, Ceramic and Wood) for vertical reflective surfaces, and the results are shown as follows:

-The effect of aluminium is large on multipath Error, followed by glass, followed by ceramic then wood.

-There are significant differences for aluminium material and no significant differences for (wood material and ceramic material) on multipath Error for (MP1 and MP2) according to T- statistical test.

-There are no significant differences for glass material on the multipath error for (MP2) and significant difference on Multipath Error for (MP1) according to T- statistical test.

In the second study, it is shown that there is significant effect on the multipath error of GPS under the aluminium Panel dimensions difference for vertical reflective surfaces and the results are shown as follows:

-Multipath errors (MP1 and MP2) of GPS increases with the increase in aluminium panel dimensions.

- There are no significant differences for aluminium panel dimensions (0.75X0.75 m and 1.0X1.0m) and significant differences for aluminium panel dimensions (1.25X1.25m) on Multipath Error for (MP1 and MP2) according to T- statistical test.

In the third study, it is shown that

-Multipath errors (MP1 and MP2) of GPS reduce with increasing the distance between the aluminium panel and the receiver.

- There are no significant differences for the distance at 3.0 m between the aluminium panel and the receiver multipath Error for MP2. In addition, there are significant differences for the distance at 1.0 m and 2.0 m between the aluminium panel and the receiver multipath Error for MP2 and MP1.

In the fourth study, it is shown that multipath errors (MP1 and MP2) of GPS are reduced with an increase in the angle of inclination of the aluminium panel.

REFERENCES

[1] Alber, c., braun, j., rocken, c., ware, r., (2000)" obtaining single path phase delays from gps double differences. Am." Geophys. Union 27, 2661–266.

[2] Dinesh, s., wan mustafa, wh., mohd faudzi., m., kamarulzaman, m., hasniza, h., nor irza shakhira, b., siti robiah, a., shalini, s., jamilah, j., aliah, i., lim, bt., zainal fitry, ma., mohd rizal, ak., azlina, b. And mohd hasrol, hmy., (2014), "evaluation of the effect frequency interference (rfi) on global positioning system of radio (gps) accuracy." Defense s&t technical bulletin, vol. 3, no. 2, p. 100-118.

[3] Fawaz e., (2022), "lectures notes in engineering statistics," https://www.youtube.com/watch?v=0wl4tfx_yds&list=pl3mwtryjjhqwsvgrujlidapuyirray-0s&index=2, al-azhar university, cairo, egypt, 50 pages.

[4] Even-tzur, g., (2007), "comparison of pseudo-range multipath effects in a variety of gps antenna types." Survey review, 39(306):338-348.

[5] Ge, l., han, s. Rizos, c., (2002)." Gps multipath change detection in permanent gps statins." Survey review, 36(283): p.306-322.

[6] Kamarudin, m.n. and amin, z.m, (2004), "multipath error detection using different gps receiver's antenna." 3rd international federation of surveyors (fig) regional conference, jakarta, indonesia.

[7] Kijewski-correa.t, michael.k, (2007), "monitoring the wind-induced response of tall buildings: gps performance and the issue of multipath effects, journal of wind engineering and industrial aerodynamics" 95 (9–11) 1176–1198.

[8] Lau.l, paul.c, (2007), "development and testing of a new ray-tracing approach to gnss carrier-phase multipath modeling," journal of geodesy 81 (11) 713–732

[9] Misra,p and enge.p,(2006), "global positioning system: signals, measurements and performance," ganga jamuna press.

[10] Mostafa h. A. Mohamed., (2019), "studying the multipath effects of gps observations using different antenna," al-azhar university civil engineering research magazine (cerm) vol. (41) no. (1) january, p.379-384.

[11] Ogaja, clement, a., (2011), “applied gps for engineers and estimation and mitigation of gps multipath interference using adaptive filtering.” Department of ece, ace engineering college, ankushapur, ghatkesar mandal, ranga reddy district, india.

[12] Satirapod, c., rizos, c., (2005),” mitigation by wavelet analysis for gps base station applications.” Survey review, vol. 38, 2–10.

[13] Satirapod, c. Khoonphool, r. Rizos, (2003), “multipath mitigation of permanent gps stations using wavelets, in: proceedings of the international symposium on gps/gnss,” tokyo, japan.

[14] Wanninger, l. And may, m. 2000. “Carrier phase multipath calibration of gps reference stations.” Proceedings ion gps2000, salt lake city, ut, pp. 132-144.

[15] Yi, th., li, hn. And gu, m. (2012),”” effect of different construction materials on propagation of gps monitoring signals. Measurement, 2012, vol. 45, no. 5, p. 1126-1139.