

Effect of Radio Frequency Interference (RFI) on the Precision of GPS Relative Positioning

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Abstract. The successful of GPS observations are dependent on several factors between satellite vehicles and GPS receivers, where low GPS power levels have led to the threat of radio frequency interference (RFI) on the GPS signals. This study was conducted to evaluate the effect of RFI on the precision of positions of single and dual frequency receivers through relative positioning technique by taking into consideration the radius of GPS receiver from interference source, length of baseline and response of rejection. Several tests were conducted in real environment by simulating the interference signal towards GPS receivers in the nominated GPS L1 and L2 bands. Calculations were made to identify the distance and interference signal power between interference source and GPS receiver in order to investigate the level of effect. To be able to study this effect on the precision of GPS positions, the 3D residual positions and geometric dilution of precision (GDOP) have been used. The findings of this study have demonstrated that a sufficient time for the GPS receiver to respond in particular interference signal power level and the radius from the interference source were made as compared to previous work. It was also indicated that the residual positions and GDOPs were affected proportionally when nearly to interference source but not similar for both days due to GPS coverage and other probable errors. Therefore, a good investigation on RFI towards GPS signals should be conducted in secured environment which can control the various GPS error parameters in order to obtain a reliable result on this effect.

Introduction

To date, Global Positioning System (GPS) has been utilized in most applications based on positioning, navigation, and timing (PNT) elements. Theoretically, GPS uses the radio magnetic waves to transmit signals from their satellite antenna to various types of receivers which can accept these signals. This signal reception is referring to specific frequency bands allocated by United State (U.S) government organizations. Generally, there are two carrier frequencies used by most of the GPS users, denoted as L1 and L2. In L1 carrier, it contains two spreading codes known as coarse/acquisition (C/A)-code and precision P(Y)-code. Meanwhile, L2 carrier contains only the P(Y)-code. Both carriers are modulated by the spread spectrum codes together with a unique pseudorandom noise (PRN) associated with each space vehicle (SV). This spread spectrum signals can reduce the effect of intentional and unintentional interferences as what most equipments in hydrographic positioning ranging systems and wireless Local Area Network (LAN) systems utilized [1]. However, this is not a promise for GPS receivers, especially for civilian users to not being affected by RFI since the proliferation of telecommunications and other wireless data transmission systems which create the intermodulation products and other out-of-band transmissions in the vicinity of GPS bands [2].

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Theoretically, all GPS users can receive the GPS signals for any PNT applications as long as no probable errors are subjected to affect the signal receptions [3]. As for a part of the radio magnetic waves it is clear that, overall, the GPS signals were mind for signal interferences. For instance, most of the communications today used radio waves between transmitter and receiver with different network providers. Even in the Global Navigation Satellite System (GNSS), where both GPS and GALILEO signals have similar frequency with each other which known as intersystem interference [4].

Worryingly, the effect of RFI on the GPS signals is recently becoming more prevalent for both civil and military users throughout the world. Both of them have resulted in degradation of performance in GPS observations although carried out in a good environment. There are two general types of RFI which known as unintentional and intentional RFI. GPS signals that reach the Earth are vulnerable to various probable errors, including RFI, due to their weak power levels. For understanding, the received signal levels for the C/A code and P(Y) code components on the L1 and L2 carriers are not exceed -153 dBW and -155.5 dBW respectively [4]. These low power levels can cause GPS signals to be swamped by relatively low powered interference signals, even though they are well below the noise floor [5].

This study is a continuation of the previous work [3], whereby its findings have shown that the effect of RFI was different between single and dual frequency GPS receivers in terms of response time, relative and absolute positioning, and length of baseline. However, it was not adequate for GPS static operations for applying 1 minute- response for certain interference signal power levels since the minimum observation for the fastest rapid static GPS techniques are around 5-20 minutes. The relative positioning has been adopted as a mechanism to detect any differences in the position of the rover station with respect to the reference station in kinematic mode of data processing [6]. On the other hand, this study was done to simulate the performance of GPS receiver as it moves towards interference sources. The findings of this study highlight the importance of monitoring the effect of RFI when conducting GPS static surveys from the interference sources. Two types of GPS receivers were used to differentiate their limitations to RFI effects. Both receivers are single-frequency (Promark-3) and dual-frequency (Topcon Hiper-Ga).

Data Collections

1.1. Field Observations

The tests were conducted in an open field environment, where the standard procedures for GPS static observations had applied. In this study, four stations have been chosen as reference and rover stations, where two reference stations were located in Kuala Klawang (KLAW) and Universiti Putra Malaysia (UPMS) while two rover stations were located in Science & Technology Research Institute for Defence (STRIDE), Kajang, Malaysia (i.e., STN1 and STN2). Figure 1 shows the project plan for this study. Based on this plan, two types of baselines were established regarding to their distances from reference stations (e.g., KLAW and UPMS). At this point, any rovers referred to KLAW station was classified as a long baseline (more than 30 km), while a short baseline for any rovers referred to UPMS station (less than 10 km). This were based on the recommended field practices for GPS cadastral control surveying which set that the GPS cadastral control survey baselines must be less than 30 kilometres in length, but not less than 50 meters [7]. A signal generator was used to transmit interference signal via directional antenna. Monitoring process on the satellite signals was conducted using the Topcon PC-CDU software (i.e., installed with toughbook PC), used to control the operation of the receiver and data collection.

First, static surveys were carried out for two epochs (i.e., two separate days) at two stations; Station 1 (STN1) and Station 2 (STN2) which refer to dual and single frequency receivers respectively. These surveys were conducted to determine their “true” positions. These “true” positions have been used to define the residual positions which are calculated by differencing them with the “affected” positions in RFI tests. The dates were setup at 16 May 2012 and 14 September 2012 for STN1 and STN2 respectively.

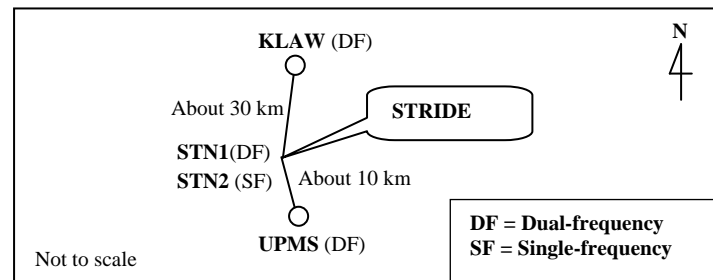


Figure 1 The layout of the two reference stations in relation to rover stations

Next, RFI tests were conducted on 18 and 19 June 2012 by incrementally increasing the interference signal power levels based on distances between GPS receiver and interference source starting from -140 dBm until the GPS receivers were totally jammed. The calculation on distances were made based on 1m, 3m, 5m, 10m, 30m, 100m, 300m, and 1 km. All measurements of interference signal power levels with their respective distances were made as suggested by [8]:

- P_T : Transmitted power from directional antenna
 P_R : Received power at GPS receiver
 L : Free-space path loss
 L_O : Cable loss of directional antenna (standard from manufacturer)
 R : Distance (km)
 f : Frequency (MHz)
 d : FM signal peak deviation
 $EIRP$: Equivalent isotropically radiated power

$$L = 32.44 + 20 \log R + 20 \log f \quad (1)$$

$$EIRP = P_R + L \quad (2)$$

$$P_R = EIRP - L \quad (3)$$

With L_E and f being constant;

For $L_O = -50$ dBm

For GPS frequency, f :

L1, $f_{L1} = 1575.42$ MHz; L2, $f_{L2} = 1227.60$ MHz

Hence,

$$P_T = P_R + L_O \quad (4)$$

Findings

1.2. Day 1 (18 June 2012)

Table 1 and 2 show the results obtained for Day 1 observations for single and dual frequency receivers. Here, it was clearly shown that position residuals from single frequency receiver are a lot worse than dual frequency receiver. Although high GDOPs recorded at short baseline for dual frequency receiver, fortunately their position residuals are better than a short baseline for single frequency receiver. This scenario was occurred due to some inconsistencies on satellite availability along the observation period at baseline UPMS-STN1 which leads to the poor GDOPs. Moreover, this situation has proved the statement in [6], where a measure of GDOP alone is insufficient to quantify the quality of GPS positioning data. On the other hand, the significant biases of position residuals for single frequency receiver were recorded at -100 dBm for both baselines, while -93.98 dBm for dual frequency receiver. On this day 1 operations, it was shown that dual frequency receiver can give reliable 3D positions rather than single frequency receiver at the highest interference signal power levels. For the effect on distance, it was shown that both stations could only tracked satellites at the maximum of 3m from the interference source with a power level at -89.54 dBm. However, single frequency receiver tends to be affected early than dual frequency receiver at 5 m radius from the interference source, compared to 3 m for dual frequency receiver.

1.3. Day 2 (19 June 2012)

For Day 2, dual frequency receiver was rejected earlier than single frequency receiver at noise level of -80 dBm as shown in Table 3 and 4. No GPS signals recorded at this phase due to a complete absence of GPS satellites which cannot resist the interference signal at this level. However, the readings from dual frequency receiver are more precise than single frequency receiver, where the range of position residuals from single frequency receiver is set large than dual frequency receiver. However, the significant biases of position residuals were counted at -119.54 dBm for both receiver types at both baselines. Single frequency recorded to give inconsistent positions at earlier time rather than dual frequency receiver. Meanwhile, the affected distance towards RFI can be seen on single frequency receiver which records at 3m radius. Although the dual frequency receiver cannot track any signals at 1m radius unlike single frequency receiver, but this can help in giving an early alert to GPS surveyors. As abovementioned, it was indicated that dual frequency receiver is outperformed the single frequency receiver where it can resist the effect of RFI better.

Table 1. Results obtained from RFI test at STN2 (single-frequency) on Day 1.

Types of Baselines	Power Level (dBm)	Distance (m)	Residual Positions (m)			GDOP
			dN	dE	dU	
Long Baseline	0	0	0.4953	0.0043	-0.3334	2.32
	-140	1000	0.1677	0.1335	-0.8510	2.57
	-129.54	300	-0.1295	0.1523	-0.7303	2.71
	-120	100	-0.2200	0.0383	-0.2014	2.89
	-119.54	30	-0.0813	0.2264	-1.4145	3.12
	-100	10	-0.3257	0.1523	-0.6893	3.37
	-93.98	5	0.7597	-0.3429	2.2387	5.62
	-89.54	3	-1.9625	-0.5363	2.4081	8.10
Short Baseline	0	0	0.4751	0.0222	-0.3981	2.32
	-140	1000	0.1882	0.1500	-0.9077	2.57
	-129.54	300	-0.0823	0.1346	-0.5789	2.71
	-120	100	-0.1800	0.0313	-0.0894	2.89
	-119.54	30	-0.1073	0.2109	-1.2668	3.12
	-100	10	-0.3094	0.1794	-0.7391	3.37
	-93.98	5	0.7389	-0.3250	2.2407	5.62
	-89.54	3	-1.9730	-0.5003	2.2797	8.10

Table 2. Results obtained from RFI test at STN1 (dual-frequency) on Day 1.

Types of Baselines	Power Level (dBm)	Distance (m)	Residual Positions (m)			GDOP
			dN	dE	dU	
Long Baseline	0	0	-0.1349	-0.0386	0.4024	1.98
	-140	1000	-0.4293	0.1343	-0.3195	2.24
	-129.54	300	-0.5300	0.0890	-0.1676	2.36
	-120	100	-0.5900	0.0823	-0.1775	2.52
	-119.54	30	-0.4589	0.0291	0.1073	2.71
	-100	10	-0.4893	-0.0823	0.5719	2.91
	-93.98	5	-0.7593	-0.3294	1.8914	2.90
	-89.54	3	0.7250	-0.5163	3.3610	7.34
Short Baseline	0	0	-0.0046	0.0193	-0.0623	2.00
	-140	1000	-0.0479	0.0245	-0.1004	10.04
	-129.54	300	-0.0374	0.0127	-0.0282	8.50
	-120	100	-0.0300	0.0299	-0.1271	8.12
	-119.54	30	-0.0453	0.0172	-0.0726	3.12
	-100	10	-0.0341	0.0168	-0.0774	3.37
	-93.98	5	-0.5271	-0.1170	0.5464	2.90
	-89.54	3	-0.0994	0.1741	-0.7936	7.40

Table 3. Results obtained from RFI test at STN2 (single-frequency) on Day 2.

Types of Baselines	Power Level (dBm)	Distance (m)	Residual Positions (m)			GDOP
			dN	dE	dU	
Long Baseline	0	0	0.0939	0.0792	-0.5025	2.30
	-140	1000	0.0860	-0.0176	0.0976	2.56
	-129.54	300	0.1381	-0.0216	0.2054	2.69
	-120	100	-0.0900	0.1262	-0.7020	2.87
	-119.54	30	-0.0975	0.0266	0.0564	3.16
	-100	10	0.1350	-0.0130	-0.2301	3.34
	-93.98	5	0.2131	0.0447	-0.8704	3.63
	-89.54	3	-0.7253	0.2308	-1.8982	6.97
Short Baseline	-80	1	1.3292	1.2801	-8.2294	6.28
	0	0	0.0478	0.0799	-0.3699	2.30
	-140	1000	-0.0095	0.1045	-0.5374	2.56
	-129.54	300	-0.0021	0.1038	-0.5408	2.69
	-120	100	0.0000	0.1027	-0.5294	2.87
	-119.54	30	-0.1799	0.0183	0.1229	3.16
	-100	10	0.1273	0.0359	-0.4677	3.34
	-93.98	5	0.1532	0.0872	-1.0217	3.63
	-89.54	3	-1.0290	0.1111	-1.0041	7.03
	-80	1	1.2166	1.2477	-7.8550	6.28

Table 4. Results obtained from RFI test at STN1 (dual-frequency) on Day 2.

Types of Baselines	Power Level (dBm)	Distance (m)	Residual Positions (m)			GDOP
			dN	dE	dU	
Long Baseline	0	0	-0.0142	-0.0219	0.4699	2.05
	-140	1000	-0.0139	0.0173	-0.0890	2.56
	-129.54	300	-0.0100	0.0188	-0.1039	2.69
	-120	100	-0.0100	0.0160	-0.0845	2.87
	-119.54	30	0.0036	1.0045	0.0348	2.34
	-100	10	-0.3810	-0.1720	0.9234	2.89
	-93.98	5	-0.2319	-0.2466	1.5692	2.30
	-89.54	3	-0.2506	-0.3199	2.0286	4.51
Short Baseline	-80	1	~Loss of tracking signals~			
	0	0	-0.0273	-0.0919	0.4896	2.05
	-140	1000	-0.0136	0.0083	-0.0282	2.56
	-129.54	300	-0.0067	0.0073	-0.0285	2.69
	-120	100	-0.0100	0.0053	-0.0142	2.87
	-119.54	30	0.0400	-0.3446	0.0338	2.38
	-100	10	-0.0255	-0.0212	0.1099	2.89
	-93.98	5	0.0251	0.0404	0.0385	2.30
	-89.54	3	1.3082	1.0884	-6.4331	6.47
	-80	1	~Loss of tracking signals~			

Conclusion

The findings of this study have demonstrated the effects of RFI on the precision of positions in a sufficient time for the GPS receiver to response to any particular interference signals, as opposed to [3]. Using the GPS relative positioning technique can reduce the effect of RFI on the GPS signals due to the corrections made at base station for accurate and precise rover station coordination. This was done through combination of code and carrier phase measurement on both frequencies [1]. Next is a situation when at a constant power level, after the position fix has been stabilised, the effect of RFI on the precision of GPS positions would be approximately the same, with some differences due to varying GPS coverage and high risk of probable errors in an open field test for both different dates. Because of these limitations, similar tests should be reiterated in a controllable environment by utilizing a GPS simulator in a secured laboratory to obtain a reliable investigation of this effect, as demonstrated by [9].

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