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POWER BUDGET ANALYSIS OF REFLECTED GPS L1 AND L5 FREQUENCY SIGNALS FOR PASSIVE MICROWAVE IMAGING

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The GPS signals are commonly used for navigation purposes. Another utilization of reflected GPS signals is for remote sensing. This paper focuses on the power budget analysis of bi-static radar using GPS satellite as a “transmitter of opportunity”. In this application the direct and reflected GPS signals are acquired using customized hardware, where the receiver can be mounted on an airborne platform or remain static. GPS satellites currently transmit L1 frequency signals with C/A codes used as a ranging signal, but plans for transmitting additional L5 frequency signals as part of GPS modernization efforts are underway. Here we present the simulated results for power budget analysis of both GPS L1 and L5 frequency signals. The Signal to Noise Ratio (SNR) for different ranges is calculated and results have been plotted. It can be deduced that SNR of GPS L5 reflected signal is higher as compared to GPS L1 signal for similar target ranges and therefore, these signals are more suitable for remote sensing applications as compared to GPS L1 signals. Simulation is carried out in MATLAB®.

Keywords: Power budget analysis, Bi-static Radar, GPS L5 signal

1. Introduction

Global Positioning System (GPS) is a worldwide radio navigation system designed and commissioned by U.S Department of Defense (DoD), it comprises of 24 satellites revolving around the earth in 6 orbits with 4 satellites in each orbit. Initially, it was only used for position and velocity measurement but reflected GPS signals can also be utilized for remote sensing applications. Therefore, secondary applications of GPS signals are attracting lot of attention due to various applications which will be elaborated later on. GPS satellite can be used as transmitter of opportunity in bi-static radar configuration for target detection purposes [1].

A GPS transmitter and a modified receiver form a GPS based bi-static radar system which can also be used for remote sensing application [2]. In bi-static radar both transmitter and receiver are separated by a distance called base line and making angle called bi-static angle. A GPS based bi-static radar scenario is depicted in Figure 1.

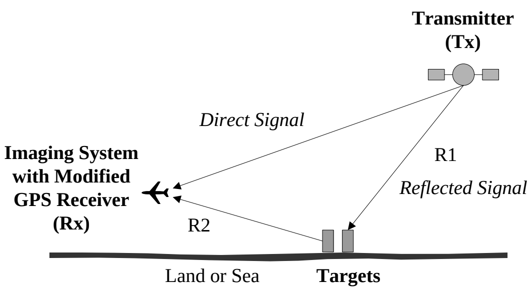

Figure 1. GPS based bi-static radar scenario

GPS signals are used as transmitter of opportunity to illuminate the target and a modified GPS receiver is used to process these received signals. This type of radar using transmitter of opportunity is called passive bi-static radar.

The advantage of using passive bi-static radar is that no dedicated transmitter is required. GPS based bi-static radar has low power consumption as compared to bulky dedicated transmitters and also has the ability to detect stealthy targets as bi-static radar cross section is different from mono static radar.

As mentioned earlier direct GPS signals are used for position and velocity measurement, however some GPS signals are scattered or reflected from moving or stationary objects as they strike the reflecting object. These reflected signals have very low power and SNR because of low GPS signal power and after reflecting from surface their power is further reduced, which renders them difficult to detect. However after applying some signal processing techniques these reflected signals can also be utilized in various remote sensing applications [3]. Reflected signals have valuable information about reflecting surface and can also be used to generate an image of target in a region of concern. The reflected GPS signals have various applications which include measuring soil moisture contents, wind speed measurement, passive microwave imaging and oceanic remote sensing [4,5,6].

The need for a dedicated transmitter is eliminated for GPS based target detection and imaging. GPS navigation infrastructure already being used can also be used for target detection and imaging. Using such an

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expensive infrastructure that is already designed, installed and maintained proves to be a big advantage for the user. Another major advantage of the GPS is that it has a wide coverage area taking in account the complete surface of earth. Also GPS is available all day long. GPS has more real-time imaging opportunities one for each GPS satellite in sight. The direct and reflected GPS signals can be received by selecting a suitable GPS satellite. The selected GPS satellite must have optimum geometry in terms of signal power and visibility [3].

GPS is a multi-billion US Dollars project of US Government and the signals are freely available for public use. Thus GPS based remote sensing system becomes very attractive for further research. Owing to the challenges involved, work done in this field is very limited and there are ample opportunities for further research.

The transmitted GPS signals are right hand circularly polarized (RHCP) and after reflecting from earth surface their polarization changes and these signals may become Left hand circularly polarized (LHCP). These direct signals received from a specific satellite are locked and used as a reference for acquiring and detecting reflected signals. Commercially available GPS receivers cannot be used to receive reflected GPS signals because they have only one RHCP antenna which can only receive direct signals. The GPS data is acquired in digital format which is then saved for off line processing later on in order to perform remote sensing or image the area of concern. A directional antenna with high gain is used for reception of GPS data in the form of reflected signals. The data acquiring circuit has a suitable intermediate frequency (IF) and sampling frequency. The major problem of a Global Navigation Satellite System based system is the reception of weak reflected GPS signals owing to their appalling SNR and constant data rate (minimum of 20 M Samples/s) of acquiring GPS IF data. By appropriate means this received data is transferred to processing system [7].

An image of the area of concern can be generated if the direct and reflected GPS signals are manipulated. The (Synthetic Aperture Radar) SAR principle is used in which the receiver or bi-static radar is required to maintain its movement in spatial sphere of influence [8]. In a realistic scenario the reflected GPS frequency signals from objects on the earth surface will be acquired by suitable hardware, as mentioned above, which can be placed on a moving object (an arial platform or UAV) to create the effect of a synthetic aperture and provide the requisite change in geometry as shown in Figure 1. To reconstruct an image from reflected GPS signals based on bi-static radar configuration, range resolution is very important parameter. It is the ability of radar system to detect two or more targets at different ranges but on same bearing. The range resolution is given by

$$\boldsymbol{\delta_r} = \frac{\boldsymbol{c}}{\boldsymbol{2Bcos}\left(\frac{\boldsymbol{\beta}}{\boldsymbol{2}}\right)} \tag{1}$$

Where B is the bandwidth of transmitted signal and β is the bi-static angle. Range resolution depends on the bandwidth of the signal and bi-static angle. Increasing the bandwidth will improve the resolution. In our case we cannot change the bandwidth because we have no control over GPS transmitter. The parameter which can be modified is bi-static angle. At zero angle, bi- static radar becomes a mono-static radar and we have maximum range resolution. However, GPS L5 signals will be transmitted at higher bandwidths thus significantly improving the image range resolution.

GPS signals are presently being transmitted at L1 frequency using coarse acquisition code. This coarse acquisition (C/A) is unique for each satellite. Coarse acquisition (C/A) code is available for all civilian users while P(Y) code is only available for military purposes. As an attempt to upgrade GPS system, new third civil GPS L5 signal is expected to be included in the GPS signal. This new civil signal will in turn be more accurate and backward compatible with existing GPS equipment.

In order to access and confirm their suitability for remote sensing application power budget analysis of these signals is required. The power budget analysis and effects of clutters for passive target detection and imaging has been described by (Mojarrabi 2002). Similarly detection of air target using GPS based static radar has been described by (V. Behar 2011).

The civil L1 signal is transmitted by satellites at center frequency of 1572.42 MHz and contains the coarse acquisition (C/A) code. The BPSK modulated C/A code has a chip rate of 1.023 MHz and period of one millisecond i.e. it is repeated every millisecond. The L1 frequency signal bandwidth is 2.046 MHz. As the GPS L1 signal has low bandwidth and inferior GPS signal power, after reflection this signal power is further reduced which makes detection almost impossible using conventional signal acquisition methods [9].

The new GPS L5 signal is also designed for civilian purposes. The signal is transmitted at 1176.45MHz with chip rate of 10.23 MHz, period of 1milli second and 24MHz bandwidth. The In phase (I) and Quadrature phase (Q) components are modulated with 10 bit and 20 bit Neumann Hoffman codes respectively, whereas I component is a data channel and Q component is a data less channel also called pilot signal. This new GPS L5 signal has 10 times longer C/A code as compared to GPS L1 signal and more importantly have better signal to noise ratio due to 10 times more bandwidth and spatial resolution than L1 frequency signal [10]. Improvement in signal structure will in turn improve position accuracy and availability of services.

In fact due to large distance covered by GPS signal (distance is about 20,200km) the C/A code has low power spectral density than power spectral density of noise. An effective and enhanced processing gain can be obtained by correlating this received signal with locally generated code sequence longer than in case of conventional GPS receiver. The correlation can be performed either in coherent or in non-coherent summation format.

The reflected signal is significantly weaker than the direct signal due to the scattering process and larger distance covered. Even after coherent correlation, the output may still lie below the noise floor. In order to further increase the processing gain a series of waveforms can be accumulated and non coherent summation can be performed. However, in this scenario some method of Doppler or phase compensation or Doppler ambiguity removal will be required. Otherwise the correlations peaks tend to enlarge and become relatively flat, possibly due to drift in phase and Doppler on account of temporal and spectral variations [9].

In this paper we performed the power budget analysis for the scenario depicted in Figure 1. Simulations are carried out for both GPS L1 and L5 signals and results are compared.

2. Power Budget Analysis of GPS L1 Signal

The power Budget analysis for bi-static radar is performed initially for reflected GPS L1 signal followed by GPS L5 signal.

Consider that the power transmitted is P_t and gain of transmitter is G_t. σ be the cross section of target , R_1 be the Range from GPS transmitter to target(22000km), than R_2 the range from target to receiver (also called slant Range) is given by [1]

$$R_2 = \sqrt{\frac{PtGtGr\lambda^2\sigma}{(4\pi)^3 R1^2 P_r}}\,km \tag{2}$$

The power received at receiving antenna is given by [1]

$$P_r = \frac{PtGt}{4\pi R1^2 4\pi R2^2} * \sigma A_{ef} \tag{3}$$

Where A_{ef} is the effective area of receiving antenna [1]

$$A_{ef} = \frac{\lambda^2 * Gr}{4} \tag{4}$$

The reflected signal power also depends on gain of receiving antenna and Radar Cross section (RCS). Having larger value of RCS indicates that an target can easily be detected. RCS depends on the target size, material and shape.

The Signal to Noise ratio at the receiver for bi-static radar is given by [1]

$$SNR = \frac{PtGtGr\lambda^2\sigma}{(4\pi)^3 R1^2 R2^2 KTB_n} \tag{5}$$

Where Gr is the gain of receiving antenna, Pr is power received at the receiver, Nr = KTB_n is the receiver noise and λ is GPS L1 wavelength. It is apprized that SNR is minimum when $R_1 = R_2$, however, since the GPS satellite is transmitting at a height of about 20,200 km and GPS based SAR is more suitable for limited range applications, R_2 has been limited to 1000 m in the graphs. SNR plot for GPS L1 frequency with target cross section of $10m^2$ is shown in Figure 2. From Figure 2 it is evident that the SNR is very poor even at short distances, which is the main restriction for this type of passive microwave imaging radar. The processing gain obtained by correlating the signal for longer periods of time significantly improves the SNR and thus makes it possible to generate an image of target within the area of concern. The correlation can be performed in coherent or non coherent summation manner, since noise in uncorrelated therefore the SNR is improved.

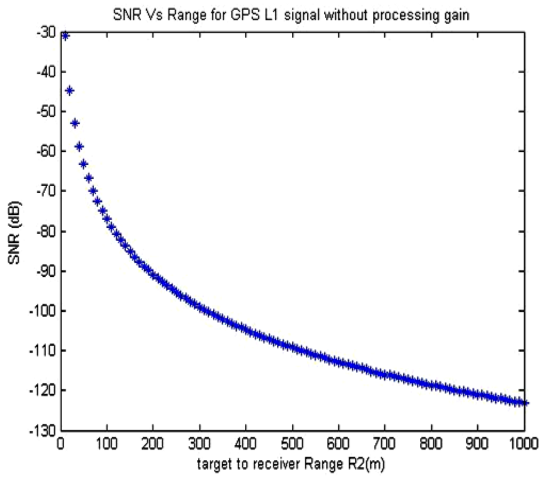

Figure 2. SNR versus Range plot without processing gain.

The simulation results of SNR versus range for reflected GPS L1 signal as shown in figure (2) was carried out for 0 to 1000 m range and SNR for different ranges is calculated. At a range of 100m the GPS L1 signal has SNR of -75 dB, which is very low and detection is almost impossible. The SNR obtained after correlating for longer period of time the SNR is given [10].

$$SNR = \frac{PtGtGr\lambda^2\sigma}{(4\pi)^3 R1^2 R2^2 KTB_n} G_{sp} N^{0.8} \quad (6)$$

Where G_{sp} is processing gain and N is maximal number of non coherent samples. Non coherent summation is used as it takes larger values of N to achieve desired gain than coherent summation. In non coherent summation longer summation time is used to recover the signal from noise and increases processed SNR.

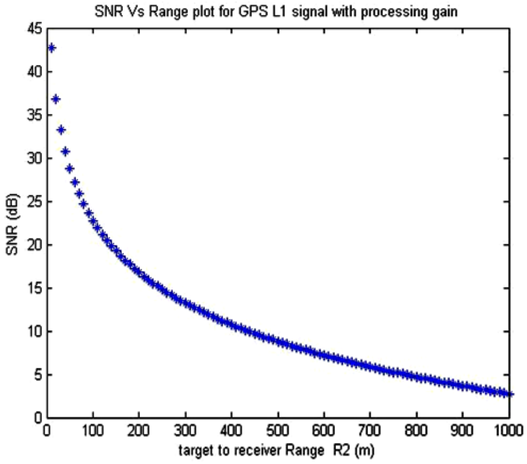

Figure 3. SNR Vs Range plot with processing gain.

The simulation results of SNR Vs Range for a GPS L1 reflected signal with processing gain of 43dB is shown in Figure 3. Correlating for longer period of time with non coherent summation has improved SNR and at a range of 100 m , the SNR is 22dB and therefore detection is possible and further utilization of the reflected signal for remote sensing applications can be carried out.

The parameters values used for the power budget analysis of GPS L1 signal are summarized in Table 1.

Table 1. Parameters values for analysis

No.	Parameter	Value	Unit
1	Transmitted power (Pt)	40	watt
2	Transmitter antenna gain (Gt)	13	dB
3	Receiver antenna gain (Gr)	30	dB
4	Bandwidth	2.046	MHz
5	Receiver noise level (Nr)	-131	dB
6	Processing interval (T_Q)	0.1	Second

3. Power Budget Analysis of GPS L5 Signal

Because of the limitations of the GPS L1 signal the new GPS L5 signal can also be used for remote sensing applications. The power budget analysis for the same scenario shown in Figure 1 is also performed for reflected GPS L5 signals and the parameters used for the power budget analysis of GPS L5 signal are summarized in Table 2.

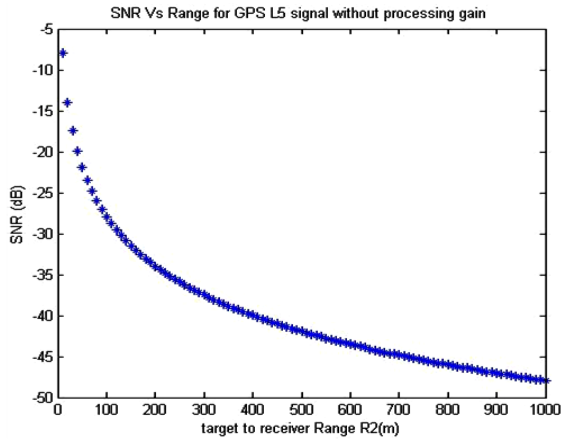

Figure 4. SNR Vs Range plot without processing gain.

Table 2. Parameters values for analysis.

No.	Parameter	Value	Unit
1	Transmitted power (Pt)	50	Watt
2	Transmitter antenna gain (Gt)	15	dB
3	Receiver antenna gain (Gr)	30	dB
4	Bandwidth	24	MHz
5	Receiver noise level (Nr)	-131	dB
6	Processing interval (T_Q)	0.1	second

The SNR versus Range plot for GPS L5 signal for target cross section of $10m^2$ is shown in Figure 4 while other parameters remain the same. The simulation for the 0 to 1000m target ranges is carried out and SNR for these ranges is plotted. The SNR of received signal reflected from a target at a range of 100m is -27dB which is 48dB higher compared to GPS L1 signal. Received signal has SNR level above reference noise level of -131dB. It is worth mentioning that minimum signal power received from GPS L5 signal is -157.9 dBW which is 0.6dB higher as compared to L1 Signal [10].

The SNR can be further improved by adding processing gain obtained by correlating signal for longer duration and is shown in Figure 5. The processing gain is given by $G_{sp} = BT_Q$, where B is the bandwidth and T_Q is the processing interval.

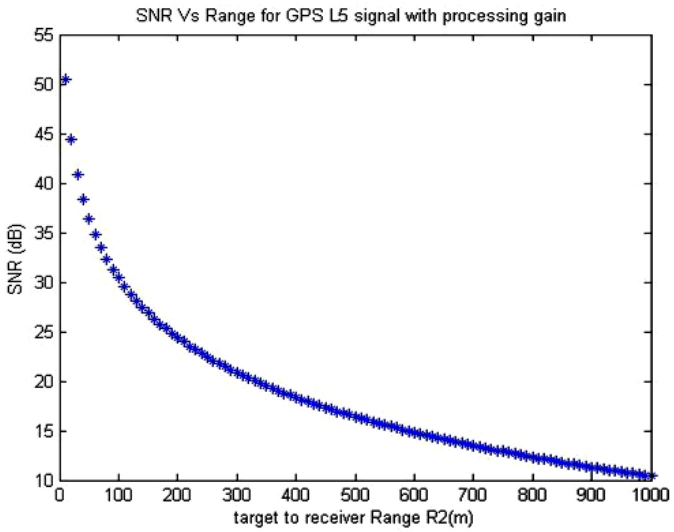

Figure 5. SNR Vs Range plot with processing gain.

Table 3. SNR of GPS L1 and L5 reflected signals for different transmitter to receiver ranges.

No.	Target to receiver range R2(m)	Without processing gain		With processing gain	
		L1 SNR (dB)	L5 SNR (dB)	L1 SNR (dB)	L5 SNR (dB)
1	10	-30	-7	42	50
2	50	-63	-21	28	36
3	100	-75	-27	22	30
4	200	-90	-33	16	24
5	500	-109	-41	8	16
6	800	-118	-46	4	12
7	1000	-123	-47	2	10

As shown in Figure 5 the SNR for the same target range is calculated and plotted for L5 signal. At a target range of 100m the SNR of L5 signal with processing gain is 30dB which was 22dB in case of GPS L1 signal. Correlating reflected signal for longer period of time has improved SNR by more than 8dB as compared to SNR of L1 signal.

Table 3 summarizes the SNR of reflected GPS L1 and L5 frequency signals for different target to receiver ranges .It is evident that the SNR is very poor even at short distances, which is the main restriction for this type of passive microwave imaging radar. The processing gain obtained by correlating the signal for longer periods of time during reconstruction significantly improves the SNR and thus makes it is possible to utilize the reflected GPS signal for remote sensing applications or generate an image for the area of concern using suitable hardware and reconstruction algorithms.

4. Conclusions and Recommendations

In this paper power budget analysis for GPS L1 and L5 signals have been performed and results have been plotted for different target to receiver ranges. From the results obtained it is concluded that for the GPS based bi-static radar system the received signal power and signal to noise ratio (SNR) of the reflected GPS L5 signal is higher than GPS L1 signal for same target to receiver ranges due to its 10 times more bandwidth and longer chip rate, which in turn improves processing gain. Therefore it can be deduced that the GPS L5 signal has higher received SNR and bandwidth. Thus it is possible to generate an image of target within an area of interest with better spatial resolution with GPS L5 as compared to GPS L1 signal.

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