International Journal of Electrical, Electronics and Computer Engineering **1**(2): 55-59(2012)

ISSN No. (Online) : 2277-2626

GPS Receiver Protection Requirement for Unmanned Ariel Vehicle

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(Received 30 October, 2012, Accepted 17, November, 2012)

ABSTRACT: In the area of military avionics, the most promising application areas of Global Positioning System (GPS) include missile guidance, Unmanned Ariel Vehicle (UAV) guidance and control and precision aircraft landings. Though spread spectrum technique is used for GPS anti-jamming requirements, but this alone fails to ensure protection of GPS receiver from jamming vulnerability. The existing guidance and control mechanism of aircrafts and UAVs is Inertial Navigation System (INS) and to some extent ground based support instrumentation. The GPS receiver integrated with INS is used for the guidance, control and maneuvering of missiles and UAVs. In this paper, the GPS signals interference caused due to various jammers are presented indicating the performance limitations of the GPS receivers for military applications. Applications of several GPS anti-jamming techniques that ensure its robustness are presented in this paper.

Keywords: Unmanned Ariel Vehicle, Pseudo Random Noise, Signal Design Concepts, Anti-Jamming Improvement, Interface signals, Robustness.

I. INTRODUCTION

Unmanned Aerial Vehicle (UAV) is a light-weight pilotless aircraft which can be guided, controlled and maneuvered while flying at low altitudes from remote ground Control Centre. Ever growing technologies in the control and guidance instrumentation for avionics have brought out several changes the avionic sensor designs. The GPS receiver is one such sensor presently being considered for UAV guidance application. GPS is a satellite based position determination system used for navigation worldwide. With GPS receiver, user can find his position easily, accurately, anywhere, at any time and in all weather conditions by getting signals from minimum four satellites. The 24 GPS satellites are equally placed in 6 elliptical orbital planes inclined to the equatorial plane at 55°. The satellites placed at a height of 20,850 Kms, rotate around the Earth with orbital period of 12 hours approximately, providing the user with minimum of five to eight GPS satellites visible from any point on the earth. The two GPS signals in L-band are at 1575.42 MHz (L1 carrier frequency) & 1227.60 MHz (L2 carrier frequency).

The received power of GPS signals on the Earth's surface is approximately -130dBm. This is due to the low power transmitter payloads on GPS satellites and high RF path loss. The GPS receiver operating at L1 frequency with C/A code has KTB noise power of –108.5dBm for a bandwidth of 2MHz. This results to negative SNR of 21.5 dB, which means that the GPS signal is submerged into the noise. Though, the spread spectrum technique allows extraction of the signal in the noise under interference-free condition to some extent, it can be jammed easily. One needs to generate enough jammer power with suitable modulation to deny the use of GPS in the potential threat area. The low power of GPS signal gives advantage to a jammer in producing strong interference signal closer to the GPS receiver. The civil interference environment is likely to increase in future for multiplicity of its transmission under various applications. However, the number and power of GPS signals may not increase significantly in future [1]. The interference may adversely affect the performance of receiver in applications such as missiles/UAV navigation, precision aircraft landings etc.

In the interference environment, the GPS receiver may not be able to operate correctly due to loss of GPS signal tracks, resulting in large navigation error which leads to catastrophe for avionics including aircrafts, missiles and UAV using GPS.

Since, GPS receiver is vulnerable to getting jammed by hostile forces on its growing use, it becomes essential to develop robust GPS receivers for their use in UAVs and missiles installations and in military as well as civilian applications.

In this paper, possible jamming environment of GPS receiver and its anti-jamming considerations are presented to finally aim at robustness in the modern GPS receivers.

II. SIGNAL DESIGN CONCEPTS

The modulation for the GPS carrier signals is Binary Phase Shift Keying (BPSK). This uses two codes namely C/A Code (Coarse Acquisition) and P-Code (Precise Code). The C/A Code (Coarse Acquisition) is Pseudo Random Noise (PRN) type. It modulates the L1 carrier over 1 MHz bandwidth and repeats every 1023 bits (one millisecond). There is different C/A code PRN for each satellite. P-Code modulates both the L1 and L2 carrier phases. The broadcast data message is then modulo-2 added to both the C/A code and the P code. The data transmission rate is 50 bits per second [3]. In BPSK modulation technique, these codes are directly multiplied with the carrier, which results in a 180° phase-shift of the carrier every time the state of the code changes. The L1 signal is modulated by both the C/A code and the P code, in such a way that the two codes do not interfere with each other. The signal modulated using BPSK resembles spread spectrum signals and provide inherent anti-jamming characteristics [2].

III. GPS IN UAV GUIDANCE TECHNOLOGY

Modern long-range missiles and UAVs are remotely guided using GPS. An UAV guidance and control System uses GPS to determine its current position and fly towards the GPS coordinates of a designated target direction, either directly or through a series of pre-programmed flight trajectory [4]. To ensure high accuracy and control on flight dynamics of a UAV, Kalman filtering technique is used in combination with the GPS. Kalman filtering is a form of optimal estimator characterized by recursive evaluation, and internal model of system dynamics being estimated. Inertial Navigation System (INS) uses Extended Kalman Filtering (EKF) technique in the precise determination of a vehicle's position, velocity and the course with respect to the fixed inertial space. This combination is called as GPS/INS integration. GPS and inertial navigation technologies are complementary to each other. Inertial technology provides true position and velocity information during a short time period. The short-term accuracy of INS is better but long-term accuracy gets worse, whereas, for a GPS, it is vice-versa. If the GPS signal is externally interrupted, the INS enables the navigation system to coarse the aircraft along until GPS signal is re-established [4]. The simplified block diagram of GPS/INS is shown in Fig.1.

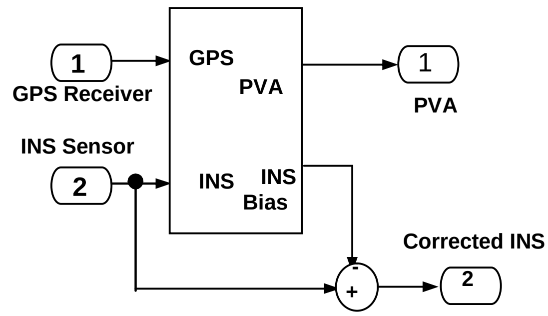


Fig. 1: Block diagram of a GPS/INS.

The nonlinear EKF technique can enable to estimate the vehicle dynamics (i.e. acceleration, angular rate, angle of attack, etc.) and with the GPS sensor outputs allows the navigation filter to produce Position, Velocity and Attitude (PVA) of the vehicle precisely along with filtered estimates of the inertial measurements for high-performance vehicle control applications. Coupling the GPS and INS sub-systems provides improved accuracy and stability, increased reliability, jamming immunity, and higher dynamic operation over the complete military operational environment.

IV. GPS JAMMERS TYPES AND THE GPS RECEIVER PERFORMANCE UNDER JAMMING

In GPS context, the jammers can be classified as communication and radar jammers in L band. Communication signals including TV transmitter broadcast in UHF band can interfere with low power GPS signal path, which may be unintentional. However, there could be intentional interference (i.e. jamming) in the wideband UHF channels that can degrade the performance of the GPS used in UAV. Radar Jammers in L-band can affectively deny the use of guided missile or UAVs intended operation. Due to noise jamming, military GPS receiver operation using typical P(Y) code loses its lock at J/S of 54 dB at the receiver input. A single 100W jammer can cause loss of lock at a range of 25 Km. The noise jammers with receiver like noise characteristic increases the noise threshold level in the receiver bandwidth of 2.0 MHz. A typical GPS C/A code receiver can tolerate a narrow band interference approximately 40 dB stronger than the GPS signal [4].

The key weakness with the C/A-code is its relatively short period. If a narrowband interferer jams a strong C/A-code line, additional degradation will result. Digital Radio frequency Memory (DRFM) is a coherent RF storage sub-system capable to store the GPS carrier signal and re-transmit with certain delay or carrier phase change, which can produce interference in the GPS/INS tracking, resulting to either break track in navigation/control loop of inertial guidance system of UAV or loss of navigation data giving false track positions.

V. EFFECTS OF GPS JAMMING ON UAV

If excessively high jamming levels are encountered (80 dB J/S at the receiver input for P(Y) code tracking), the GPS measurements may become so noisy those optimal weights given to the GPS measurements become negligible. In this case, the increase in Circular Earth Probable (CEP) (it is measure of median horizontal error magnitude over the total number of sample points) results from an increase in jammer power, and tracking quality of the deeply integrated system (i.e. tightly coupled GPS/INS) begins to degrade. In this case it is impossible to obtain correct tracking and provide any guidance to a UAV. In order to make the system robust a design is proposed. It offers several significant benefits at high J/S levels. The effects of measurement nonlinearities, which are significant at high J/S levels, are accounted for in efficient manner.

VI. ROBUSTNESS OF GPS/INS

In order to have robustness in the GPS/INS, design must be incorporated in code tracking loop functions so that the filter gains can continuously adapt to changes in the J/S environment, and the error covariance propagation is driven directly by measurements to enhance robustness under high jamming conditions [4].The estimator produces near-optimal state vector estimates, as well as estimates of the state error covariance matrix. The estimator operates in real time using recursive algorithms for both state vector and error covariance matrix estimation. The J/S levels are estimated adaptively in real time to facilitate easy transitions between course tracking and tight tracking. Extended-range correlation may be included optionally to increase the code tracking loss-of-lock threshold under high jamming and high dynamic scenarios.

A. Anti-Jamming Improvement in GPS/INS:

Adaptive spatial arrays are effective in especially broadband noise jamming. The first system developed to increase GPS anti-jam capability for users on the ground or in the air was the controlled reception pattern antenna. This device consists of an array of six antenna elements arranged in a hexagon around a central reference element. The elements are all connected to an electronics box that controls the phase and gain (or complex weights) of each element's output and combines the seven elements into a single output. This signal processing produces an adaptive gain pattern that can be manipulated to place a null in the direction of an undesired signal source. The underlying principle is fairly straightforward: Received GPS signals are rather weak and cannot be detected or measured without a signal-correlation process; therefore, the processing algorithm assumes that any measurable energy above the ambient noise must be a jamming signal, and so it computes the necessary weights to null the source.

However, as controlled reception pattern antenna arrays are physically quite large and it generally cannot be used for UAVs and smaller missiles that lack the necessary mounting space. In addition, a controlled reception pattern antenna can only counter a limited number of jammers, as it eventually runs out of "degrees of freedom" or anti-jamming options when the number of spatially distributed jammers becomes in large numbers.

Among the advanced techniques for reducing the effect of jammer power on GPS receiver, employs space-time adaptive processing technology. With this technique, the output of each antenna array element is delayed using a series of tapped delay lines, each stage of which outputs a version of the input signal slightly later than the previous stage. The output of each tap is available as a separate signal, and each can be processed with a unique complex weight and combined into a composite signal.

A very similar anti-jamming technique is a subset of space-time, space-frequency adaptive processing is known as adaptive narrowband filtering. Adaptive narrowband filters work with a single antenna element, so they are typically used in applications that lack sufficient space for a spatial antenna array. They are effective against structured interference signals, such as continuous (e.g., sine) waves or pulsed signals, but they are ineffective against broadband interference, which does not have an identifying signature that can be tracked and eliminated. Adaptive narrowband filters can operate in the frequency domain, time domain, or amplitude domain.

VII. ANTI-JAMMING (ECCM) FEATURES IN GPS RECEIVER

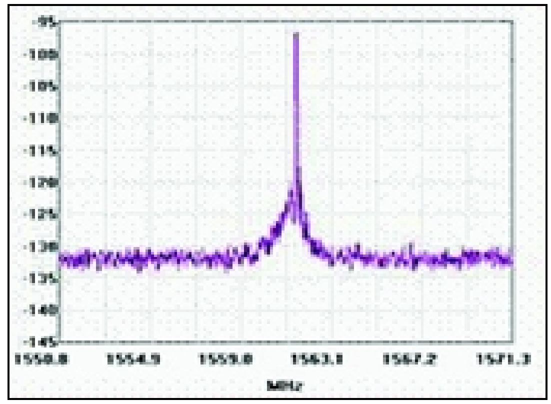
Currently, satellite navigation has been closely integrated with inertial navigation and mobile communication. In the future, integration with other systems will become a trend. Full use of auxiliary information of other systems or equipment will greatly improve the anti-jamming capability of satellite navigation receivers. At present, the method can be used in the following aspects [4]:

1. For static timing users, the receivers' interference tolerance can be enhanced by setting precise coordinates and using high-stability clock.
2. For vehicles, aircraft, and other dynamic users, GNSS/inertial navigation system integration can improve anti-jamming capability.
3. With messages and other necessary information broadcast by 2G or 3G mobile communication network, pilot positioning can be achieved directly and anti-jamming capability can be improved.

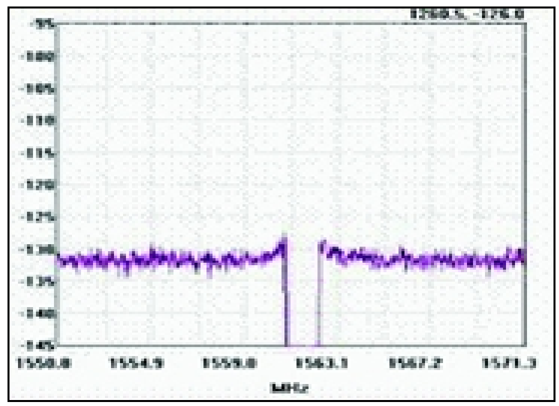
Adding active anti-jamming measures to receivers can upgrade the ability of the ECCM. At present, the methods that can be used in active ECCM include:

a) Time/frequency domain anti-jamming

Time and frequency domain processing can suppress narrowband interferences effectively. Anti-jamming capability can be improved by 35 to 65 dB based on the architecture of hardware and processing algorithms. The main advantages of the approach are that the instruments are low cost and easily integrated; however, its disadvantage is it is ineffective to wideband interference. Fig 2 (a), (b) presents the power spectrum comparison before and after anti-jam.



(a)



(b)

Fig. 2 (a) & (b): GPS Signal Power spectrum comparison before and after applying ECCM.

b) Spatial anti-jamming processing. Spatial processing is mainly using the antenna array disposal techniques from the direction of signal to distinguish the interference. Adaptive space-frequency and space-time filtering technology can effectively suppress various types of interference. According to the hardware scale and processing algorithms, we can get 35 to 55 dB or higher anti-jam improvement [4]. Spatial processing can suppress multiple wideband and narrowband interference at the same time. But it has the disadvantages of complex hardware, large scale, and high cost, and the number of anti-wideband interference is directly related to the scale of hardware and software. Fig. 3 presents the directional map of antenna array in spatial processing.

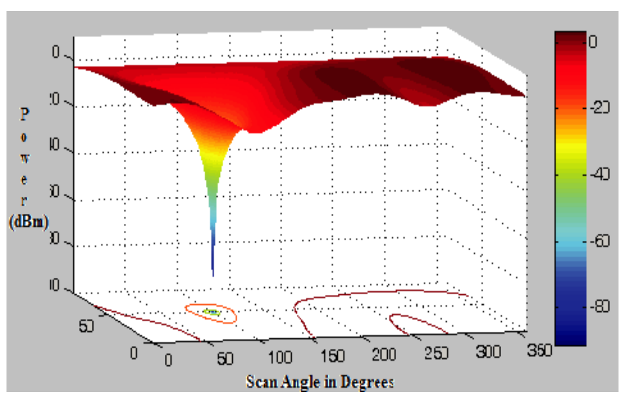


Fig. 3: Antenna Array Spatial Processing for Anti-Jamming.

Transversal filtering of CW signals (especially narrowband) can yield anti-jamming improvements of 20 to 25 dB. Amplitude domain processing can yield anti-jam improvements of 15 to 45 dB under a variety of narrow band jamming environments [5]. Adaptive spectral processing methods include digital excision filters and spectral amplitude domain processing. These methods offer improvements of 25 to 30 dB in a variety of narrowband jamming environments, including pulsed, swept, and multiple CW. Signal processing techniques that have anti-jamming features are bandwidth reduction and data wiping to increase beyond 20ms of coherent processing time [6]. Another proposed method employs I and Q correlator outputs as its inputs to a central processor that accounts for position and velocity error correlation among satellites [7].

One of the prominent technology that has recently emerged to address the need for GPS anti-jamming performance in avionics is called ultra-tight GPS/inertial coupling technology, is a method which jointly process the GPS and IMU data (GPS/Inertial Coupling). Navigation solutions are obtained using an extended Kalman filter. To meet the future challenge of GPS jamming, the efforts are being made in the design of GPS receiver for providing its further anti-jam performance by having large dynamic range receiver architecture and noise-thresholding for the frequency selection (L1, L2 and L5). Budding technology, the Micro-electro-mechanical (MEM) Inertial Measurement Unit, in future will have a significant impact on ruggedness of GPS Receivers in coming years.

Although space-time adaptive processing and space-frequency adaptive processing can also run out of degrees of freedom, they can counteract many more jammers of various types before reaching their limits. In general, greater anti-jam performance can be achieved by narrowing the bandwidth of these code and carrier tracking loops. These promising anti-jamming techniques optimally attack multiple GPS jammers with a coordinated use of spatial and temporal resources.

VIII. CONCLUSIONS

The effect of GPS receiver jamming and their potential applications for UAVs and aircrafts are explored. Various sources of GPS jammers, its anti-jamming techniques, and proposed receiver features for future design considerations of jam-resistant GPS receivers are deliberated. The requirement of robust anti-jamming GPS techniques for the control and guidance of UAVs are discussed in order to determine the appropriate GPS anti-jam technology for avionic applications.

ACKNOWLEDGEMENT

I express my deep gratitude to Sri S.P. Dash, Distinguished Scientist and Director, DLRL for giving me permission to carry out Project work at DLRL and giving me opportunity to present this paper. I also sincerely thank Prof. Habibullah Khan, Head of Dept., Electronics & Communication Engineering, K. L. University, Vijayawada for giving his valuable suggestions and encouragement to prepare the paper.

REFERENCES

[1] K.D. McDonald and S. B. Heppe, "Radio Frequency Interference to GNSS: Issues, Concerns and Status ", *Proc. ION 53rd Annual Meeting, Albuquerque, NM*, June 30-July 02, 1997, pp 619-634.

[2] R.G. Brown and P.Y.C. Hwang, "Introduction to Random Signals and Applied Kalman Filtering", John Wiley and Sons, New York, 1997.

[3] M.S. Braasch and A.J. Van Dierrenendonck, "GPS Receiver Architectures and Measurement", *Proc. of the IEEE*, Vol. **87**, No. 1, January '1999.

[4] R. Landry, "New Technique to Improve GPS Receiver Performances by Acquisition and Tracking Thresholds Reduction," *6th St. Petersburg International Conference on Integrated Navigation Systems*", St. Petersburg, Russia, May 1999.

[5] E. Gustafson, J.R. Dowdle, K.W. Flueckiger," A High Anti-jam GPS Based Navigator", ION, The Institute of Navigation National Technical Meeting, Anaheim, CA, Jan 26-28, 2000.

[6] Pizyjemski, E. Baloni, J. Dowdle and B. Holsapple, "GPS Anti-jam Techniques", *Proc. ION, 49th Annual Technical Meeting*, Cambridge, MA, June 1993.

[7] C. T. Bye, G.L. Hartmann and A. Killen, "Development of a FOG-Based GPS/INS", *Proc. IEEE PLANS, Palm Springs,* CA, April 1998.