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On the Measurement Accuracies between Tracking Radars and Modern Satellite Based Navigation Systems for Test Range Applications - A Comparison

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Abstract

Tracking Radars have played a vital role in the test and evaluation of cruise and ballistic missiles throughout the world since World War -II till date. Most of the test ranges in the world commonly use dual axis tracking radars either in the S or C band for external trajectory information of the missile under test. The modern day GNSS with their satellite based augmentation systems like WAAS have given scope to get internal telemetered trajectory data from the missile under test with GNSS receiver as a passenger within comparable accuracies and better. A comparison of the accuracies has been made in this paper between the data of various tracking radars with that of the augmented GNSS data. This paper thus instigates the Tracking Radar manufacturers worldwide to relook into their design to enhance the tracking accuracies to compete with the results of the present day satellite navigation systems and their augmentation systems at least for test range applications.

1 Introduction

The development of missiles dates back to World War -II. During those days short range rockets were developed with wired telemetry. With better established technology of wireless and parallel development of Radars turned out to be vital for missile development. The basic concept of radio-frequency auto track principles like Conical Scanning and 3-Channel Mono-pulse dates back to the research of World War-II time. Such tracking radars have been in use in the missile test ranges for more than fifty years. However, with the gradual development of the technologies in antenna fabrication, servo-systems, RF feed and LNA designs have enhanced both the reliability and accuracy of such tracking radars. Today, sophisticated tracking radars are available in S and C bands which can track ballistic missiles with transponder fitted onboard with an accuracy of 15-30 meters within the minimum detectable signal limits.

However development of such radars demands high budget requirements. Moreover with the maturity of the control algorithms and the sub-systems being used in the development of guided missiles, the requirements of external monitoring of the missile under test through tracking Radars is diminishing as most of the vital parameters are telemetered out in real time. At the same time, ever since the implementation of GPS, the technological developments that have gone through in the Satellite navigation and positioning, the reliability and accuracy of the GNSS data has increased manifolds. This has opened up the possibilities of using the low cost light weight GNSS receivers as passengers in the developmental missiles and gets the trajectory data with decimeter accuracy as can be telemetered out. In the subsequent sections, we discuss the details of the tracking Radars followed by the development of augmented navigations systems and principles and finally a comparison is done on the error values of both the data for missile trajectory information.

2 Tracking Radars – A Brief Review

Tracking radars as deployed in test ranges basically operate in two frequency bands S and C. In most of the S band radars the auto-track principle is based on conical scanning or sequential lobing as it is difficult to design mono-pulse feed in S-band Radar applications due to aperture blockage problems. However in conical scan feed we compromise on the angle accuracy compared to mono-pulse feed. Most of the C-band tracking radars have 3 Channel mono-pulse feed designs which relatively provide better angle accuracy than conical scan feed design. Also the beam width is relatively more in S-band tracking Radars compared to C band tracking radars. These tracking radars can track the targets in skin and transponder modes. Skin mode is the normal mode of operation where the received signal is the reflected signal from the body of the missile. Normally, the range of tracking is limited within 100 km for most of the missiles in skin mode of tracking. To extend the range in case of ballistic missiles, the transponder mode of tracking is used which can continue track for thousands of kilometers. The various kinds of errors which affect the radar measurements can be broadly classified as RCS fluctuations error like Glint and Scintillations which affect the angle measurements in skin mode. Transponder delay fluctuations affect the range measurements in transponder mode of tracking. The atmospheric errors like ionosphere error and troposphere errors affect both the angle and range measurements for tracking radars. Finally thermal noise error of the radar receiver is also contributing in the range and angle measurements of the tracking radar. The detailed modeling of these error sources is beyond the scope of this article. However, the following table compares the order of typical tracking errors of the S and C band tracking radars deployed in test ranges in totality.

Table 1: Accuracies of typical tracking radars employed in test ranges (Source: System manuals of various Radar Systems)

Radar Type	Precession	Mode of tracking		Beam width
		Skin	Transponder	
S Band Conical Scan	Range	8 meters	16 meters	3 degrees
	Angle	≈ 5 min (RMS)	≈ 5 min (RMS)	
C Band Mono-pulse	Range	2 meters	2 meters	1 degrees
	Angle	≈ 100 m rad (RMS)	≈ 100 m rad (RMS)	

3 GNSS and Satellite based Augmentation Systems

Present day GNSS systems use multi-constellation systems to improve the satellite availability and reliability of signals. Moreover various satellite based Wide Area Augmentation Systems (WAAS) of different countries which transmit the GNSS errors from geostationary satellites to the user segment have opened up a platform to have improved positional accuracy over large areas of the globe from sub-decimeter to centimeter accuracies even under moving conditions by nullifying most of the errors present in the stand alone GNSS systems. Under these situations the GNSS receivers with augmented signal if installed in the ballistic or cruise missiles as passengers and the data can be telemetered out, can act as an alternate source of positional information with improved precision compared to the results of tracking radars presented in table I. Table II presents the precession values of the various satellite based WAAS of different countries in static conditions. However in dynamic conditions the accuracies may degrade slightly depending on the response time of the GNSS receiver used.

Table 2: Accuracies of different SBAS of different countries

Name of SBAS	Country	Accuracy achieved		Remarks
		Horizontal	Vertical	
WAAS	USA	1-2 meters	2-3 meters	These accuracies in position determination may degrade slightly in case of moving platforms like missiles
EGNOS	EU	10-20 centimeters	20-30 centimeters	
SDCM	Russia	< meter	< meter	
GAGAN	India	≈ decimeter	≈ decimeter	
MSAS	Japan	10-20 centimeters	20-30 centimeters	
SNAS	China	10-20 centimeters	20-30 centimeters	
Commercial SBAS (Omni star provider)				
VBS	USA	< meter	< meter	
XP	USA	≈ decimeter	≈ decimeter	
HP	USA	< decimeter	< decimeter	

Source: Official internet website of corresponding SBAS

4 Conclusions

A comparison between Table 1 and Table 2 clearly indicates increased accuracy can be achieved in all the SBAS systems in both horizontal and vertical directions than the corresponding counterpart of tracking Radar that are employed in test ranges. Although the tracking radars cannot be replaced completely for the new designs of developmental trials of cruise and ballistic missiles, however for routine flights of missiles, GNSS receivers with SBAS features as passengers can definitely give improved positional information of such missiles under test. This concept can be further extended to calculate the miss-distance between various aerial targets and the interceptor missiles and such complex missions which usually happens in test ranges throughout the globe.

5 References

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