

# Chapter 16

## Computer Modelling of Autonomous Satellite Navigation Characteristics on Geostationary Orbit

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### EXECUTIVE SUMMARY

*Satellite systems are a fast-developing and broad field of study. The use of global navigation satellite systems for relatively autonomous spacecraft navigation holds a lot of interest for researchers. It is extremely expensive to research space applications as live experiments. Therefore, computer modelling comes in handy when there is a need to analyze important factors in space environment. The chapter describes the radionavigation field model that uses the off-nadir satellites. This model allows estimation of the availability and accuracy characteristics of autonomous satellite navigation in space up to the geostationary orbit in order to provide the necessary research data.*

### INTRODUCTION

Global navigation satellite system (GNSS) is an infrastructure of different satellite constellations and augmentations that is used to provide accurate position and time information worldwide. This is a simplest and cheapest global method of navigation available to a wide range of users. There are currently only two fully deployed satellite constellations. They are Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) that have the capability to provide the service worldwide. They have found many different uses in the modern world.

DOI: 10.4018/978-1-7998-5357-2.ch016



The market of GNSS is a constantly increasing sphere that encompasses a variety of different applications. According to the GNSS market report (European GNSS Agency[GSA], 2017), GNSS is widely used in smartphones and other small devices intended for personal use; calculation the location of vehicles, including unmanned, on the ground, in the sea or in the air; such accurate fields as agriculture, surveying and timing. In 2017 there were 5.8 bln GNSS devices in use, expecting to increase this number to 8 bln before 2020. Even though this market is mostly dominated by smartphones, billions of people in the professional market segments still benefit from it. This broad market requires many specialists in the sphere and it is necessary to attract the attention of workers, students, and researchers to it.

There still appear new possible uses for GNSS as the market is in the phase of development. One of such uses was somewhat unexpected for most of the researchers and deals with the satellite navigation in space. The wide use of unmanned spacecraft requires a cheap and reliable way of navigation as the radio link communication with the ground is somewhat lacking. The chapter proposes a model to study the autonomous satellite navigation in space and geostationary orbit specifically using computer modeling.

## **BACKGROUND**

The idea to extend the range of satellite navigation from the surface up to the near-Earth space has appeared somewhere in mid-20<sup>th</sup>. This mostly were attempts to formalize the service volume in space and to produce a viable solution for the lack of satellite signals in space above Earth. The researchers produced different ideas like the use of back-lobe signals of the navigation satellites' antennas radiation patterns, signals passing through main-lobes and side-lobes of the antennas radiation patterns of the off-nadir satellites and surface-based "pseudo"-satellites. After the 1997 and AMSAT-OSCAR-40 (Moreau et al., 2002) launch, the opinions shifted towards the signals that are transmitted through main-lobes and side-lobes of the navigation satellites' antennas from behind Earth, as it was proven that a sensitive receiver can receive the weak GPS signals.

According to (US Department of Defense [DOD], 2008a, 2008b, 2008c), the near-Earth space is divided into terrestrial service volume (TSV) and space service volume (SSV). The TSV covers the near-Earth space from the surface and up to 3000 km for GPS, while the SSV covers the volume from TSV up to geosynchronous orbit altitude that is approximately 36000 km. For visual information see Figure 1.

The SSV is divided into medium and High Earth orbit altitudes including the geosynchronous orbits. The navigation satellites are orbiting at about 20000 km, so how can they be available at 36000 km? The traditional navigation is still partially possible in the medium altitudes, but, with the increase of altitude, it becomes evident that the number of available satellites is not enough to find the user's location. Therefore, the need for a new source of signal arises. The signals from the off-nadir satellites have become such a source, they are shown in Figure 2.

Figure 2 shows the antenna radiation pattern of an off-nadir satellite. The Earth is plotted in the center of the picture as a circle, the satellite is plotted on the left. The satellite's antenna radiation pattern is divided into the main and side lobes. Even though side-lobe signals are usually harmful, they have become a way to increase the number of available satellite signals in space. Signals passing through the main petals are partially shaded by the Earth, but some of the signals passing through the part of the main-lobe diagram can still be received. The signals that are passing through the side-lobes are much weaker than the signals passing through the main lobe of the radiation pattern, but they can still be received in the geostationary orbit by utilizing a sensitive receiver. Moreover, the spacecraft(SC) requires



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