C-2023

# Time-transfer and clock-synchronization technique for microsatellites in the lunar region

## Paper ID

77319


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## Year

2023



## Abstract

The growing number of scientific and commercial missions to the Moon surface poses the need for a dedicated communication and navigation infrastructure. A precise Positioning, Navigation and Timing (PNT) service is a key technology to allow lunar assets to determine their position and velocity, to plan and execute maneuvers and to maintain time. Argotec is working on ANDROMEDA, an end-to-end Communication and Navigation service for users on the Moon surface and in Low Lunar Orbit, based on a constellation of 24 microsatellites operating in high-elliptical frozen orbits around the Moon. To support missions with Communication and Navigation capabilities, an accurate on-board frequency reference and a time-transfer technique are crucial technologies. This paper presents a trade-off analysis of different time-transfer techniques, including existing GNSS, Two-Way Pseudo-Noise ranging, Network Time Protocol, Two Way Satellite Time and Frequency Transfer and Optical links. Furthermore, an additional investigation on crucial constraints on microsatellites' design is performed with the goal of choosing the most suitable time-transfer technique and frequency reference for a microsatellite platform. A Two-Way coherent time transfer technique compatible with Consultive Committee for Space Data System (CCSDS) standards is studied and proposed. Special attention is given to synchronization

accuracy, which is one of the most critical requirements for the navigation service. The choice of the technique has been supported by a trade-off analysis on the frequency reference to be adopted on board. Parameters such as Size, Weight and Power consumption (SWAP) have been taken into account in this phase, as well as costs and ground effort, paying particular attention to low-SWAP solutions. Finally, an error budget assessment is carried out considering free space propagation losses, relativistic effects, ephemeris errors, synchronization errors, and Earth's atmosphere contribution such as ionospheric and tropospheric delay.