Ionospheric Scintillation Observation via FPGA-based Miniature Software-Defined Radio on CubeSat: Mission Concept

ITIT - 24

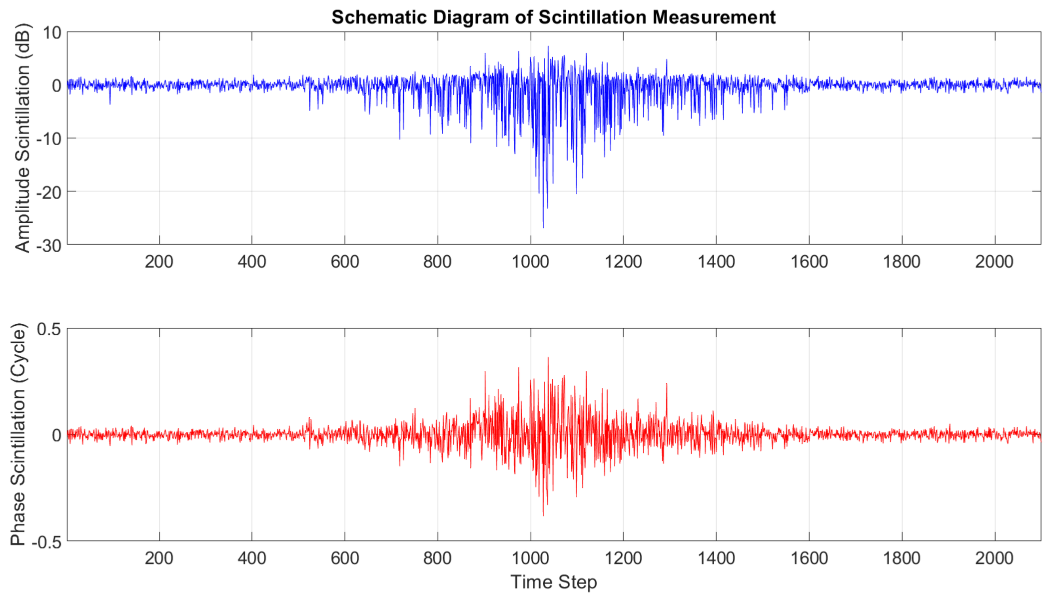
Tung-Jun Lin[1], and Cissi Y. Lin[1,2]

Email: tungjun0716@gmail.com

1. Department of Space Science and Engineering, National Central University, Taiwan; 2. Center for Astronautical Physics and Engineering, National Central University, Taiwan

Introduction

Ionospheric scintillation is a phenomenon that occurs when a signal passes through small-scale irregularities in the ionosphere, causing fluctuations in both the power and phase of the signal[3]. In this study, we propose a demonstration of using the S-band transceiver with a GMSK modulation scheme to measure the ionospheric scintillation disturbance. We will employ DSSS (Direct-Sequence Spread-Spectrum) to enhance the processing gain of the GMSK signal, thereby reducing the risk of signal loss due to ionospheric scintillation.



$$S_4 = \sqrt{\frac{\langle I^2\rangle - \langle I\rangle^2}{\langle I\rangle^2}}$$

$$\sigma_\phi = \sqrt{\langle \phi^2\rangle - \langle \phi\rangle^2}$$

Fig 1. Simulation of scintillation measurement

Motivation

- Base on SAISI project
  - Satellite Automatic Identification System Instrument project
  - Build a Miniature Software-Defined Radios (MSDR) that can be integrated into CubeSats as a communication payload
  - Implement a Satellite Automatic Identification System (S-AIS)
  - Monitor open-water vessels
  - Collect meteorological data on the ocean
- Scintillation Measurement
  - Use built MSDR GMSK transceiver
  - Measure the ionospheric scintillation disturbance by S_4 index
  - Employ DSSS to reduce the risk of signal loss
  - Set as the second scientific mission of SAISI project

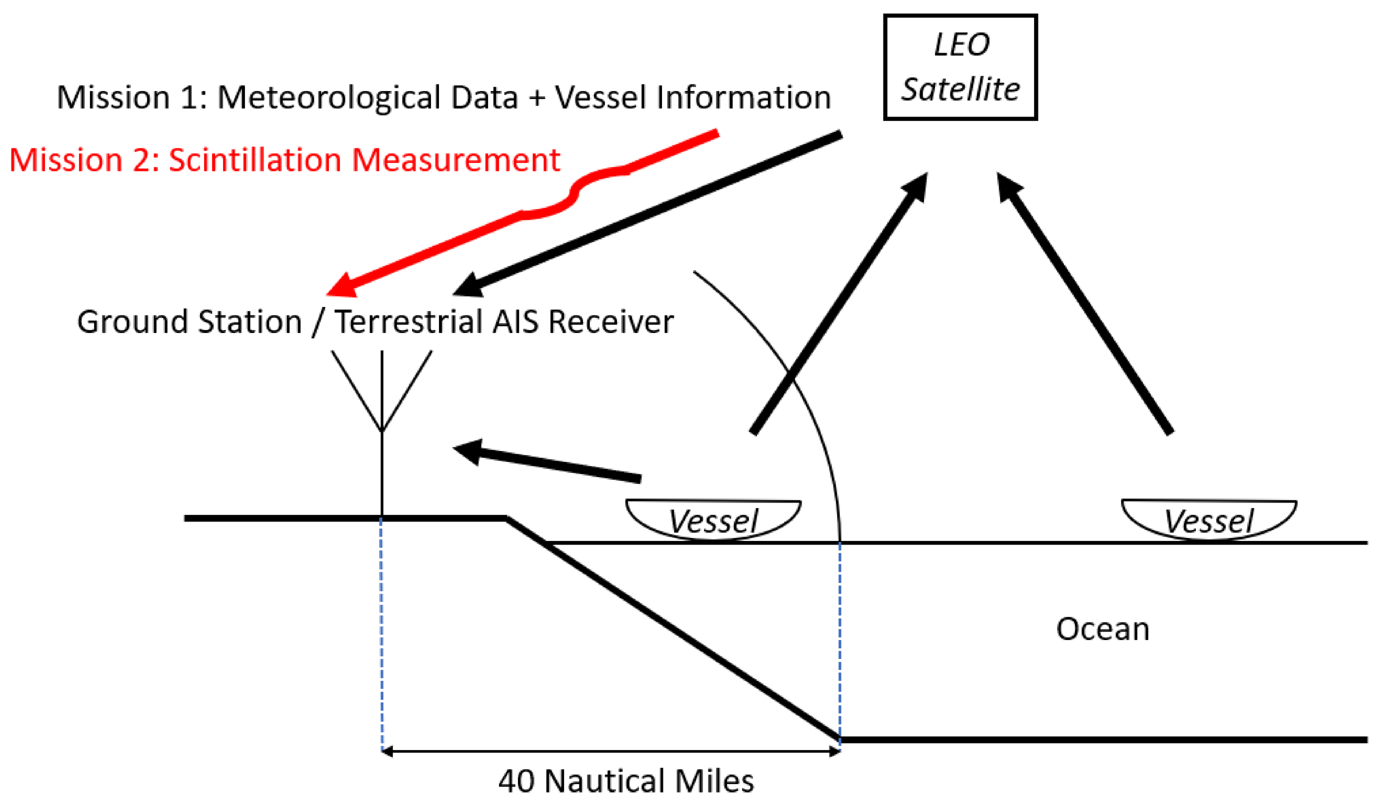


Fig 2. Schematic diagram of SAISI project

DSSS with GMSK

- DSSS (Direct-Sequence Spread-Spectrum)
  - Provide resistance to jamming by another transmitter
  - Mask signal in the background noise and prevent eavesdropping
  - Provide a means for multiple users to use the same channel
  - Processing gain can decrease the effect of the interference component
  - Inherently wide bandwidth may interfere to adjacent frequency-bands

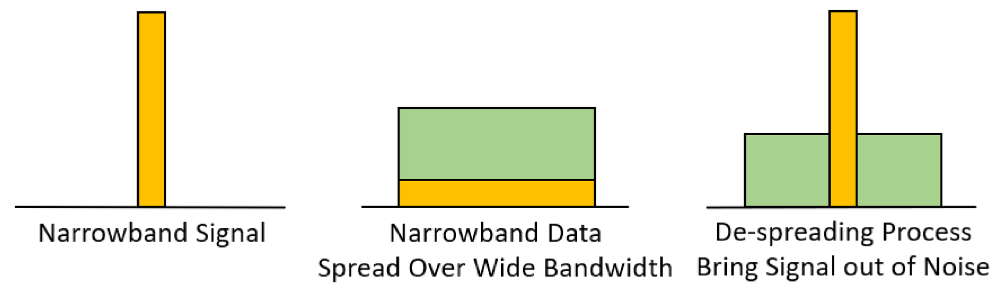


Fig 4. Schematic diagram of DSSS

- GMSK (Gaussian Minimum-Shift Keying)
  - Gaussian filter helps to obtain the better sidelobe suppression
  - Small BT (Bandwidth-Time product) value of Gaussian filter limit the bandwidth with the increase Inter-Symbol Interference (ISI)

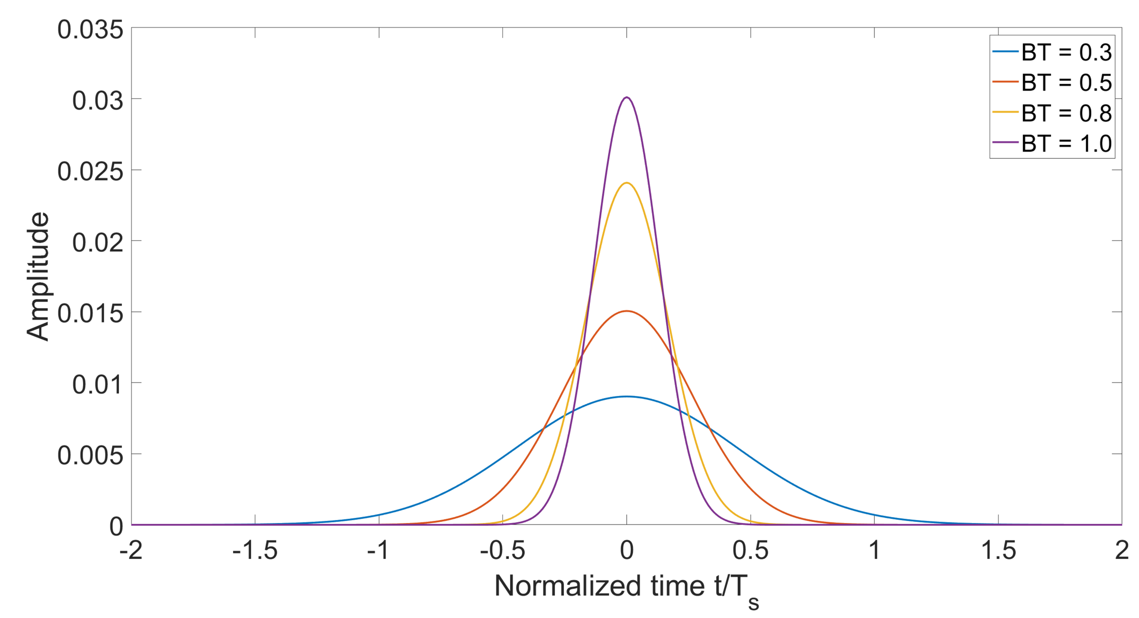


Fig 3. Impulse response of Gaussian filter with different BT value

- Combine high processing gain DSSS with low BT value GMSK[1,2]
  - Compensation of ISI effect with high spectrum efficiency
  - Use Gold sequence as the chips of DSSS and GMSK with BT = 0.3

Miniature Software-Defined Radios

Zedboard with SoC (Zynq-7000) and RF Agile Transceiver (AD9361) are used as the development platform for the MSDR transceiver.

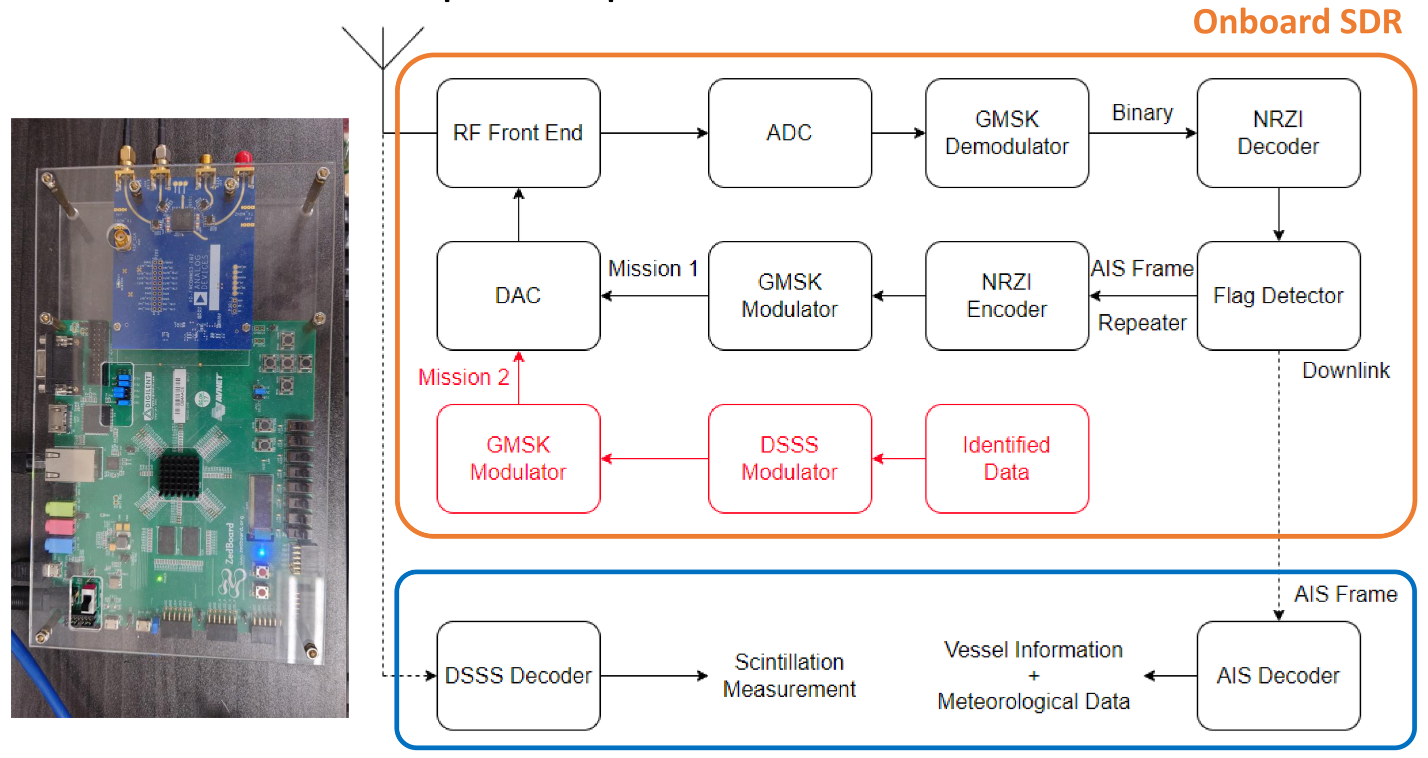


Fig 4. Zynq-7000 and AD9361 with MSDR Structure

MSDR DSSS GMSK Transmitter

DSSS with GMSK Modulation block diagram

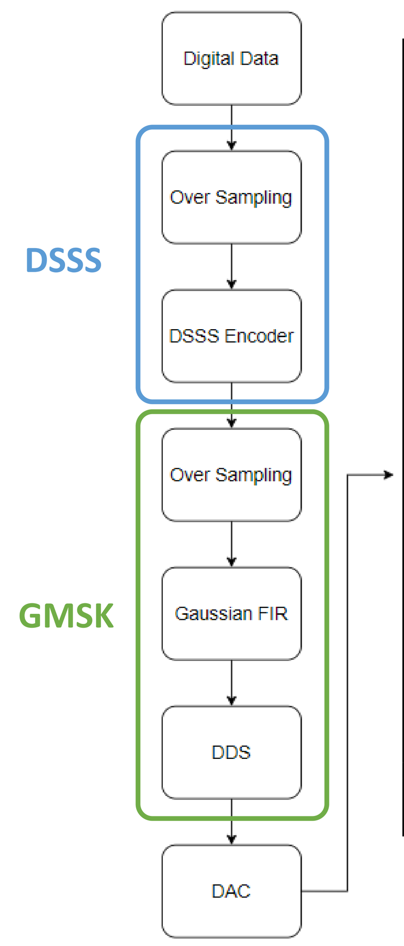


Fig 5. Spectrum of DSSS GMSK Signal in S-band

Summary and Future Works

We have built an MSDR transceiver with DSSS GMSK transmitter utilizing development platform. The successful verification of the transmission capability of DSSS GMSK signals has been accomplished, and we are currently anticipating the establishment of the DSSS GMSK receiver at the ground station. Our specific interest lies in measuring the S_4 index around Taiwan. Looking ahead, our vision for the second scientific mission of SAISI project is to provide real-time scintillation measurement data in the vicinity of Taiwan.

Furthermore, we propose to develop a CubeSat constellation for SAISI project to achieve seamless communication between LEO satellites and ground stations in Taiwan. By considering communication links with an elevation angle greater than 30 degrees, simulations have shown that a constellation comprising 112 CubeSats distributed across 7 orbits is necessary in order to achieve 24-hour near real-time monitoring around Taiwan.

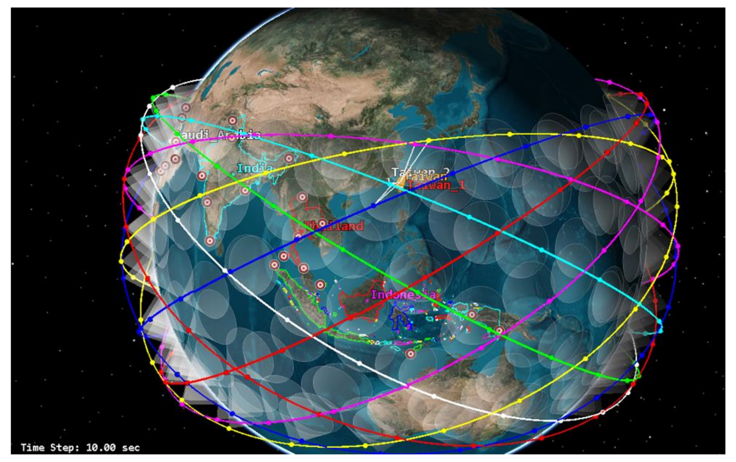


Fig 6. Constellation simulation

Reference

[1] Akira OGAWA, Masaaki KATAYAMA, Takaya YAMAZATO, and Tsuneo MAEBARA (1994). PERFORMANCE OF CDMA WITH DS/SS/GMSK. *IEEE*. doi: 10.1109/ISSSTA.1994.379524

[2] Aldis J. P., and Barton S. K. (1994). THE PERFORMANCE OF GMSK AS A MODULATION SCHEME FOR DIRECT SEQUENCE CDMA. *IEEE*. doi: 10.1109/ISSSTA.1994.379522

[3] Shih-Ping Chen (2017). An Empirical Model of L-band Scintillation S4-index Constructed by Using FORMOSAT-3/COSMIC Data. Doctoral dissertation, National Central University, Taiwan.