Radio Occultation Experiment for Deriving Planetary Atmospheric Profiles

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Abstract

The radio occultation experiment employs the spacecraft and ground station radio systems to conduct radio occultation of the atmosphere and ionosphere to obtain vertical profiles of temperature, pressure, neutral density, and electron density. Radio signals that are transmitted from spacecraft are received using antennas on Earth. This radio signal bends in the planet's atmosphere as it is propagating through a dispersive medium and because of the Classical Doppler effect which in turn modulates the frequency, phase, amplitude, and polarization of signal. The measured frequency shift is used to derive the atmospheric parameters of the planet. The signal transmission can be made either from spacecraft, in which case there is a transmitter system on board, or it can be transmitted from Earth and received on spacecraft, where the instrument on board is a receiver. In this work, the design and testing results of transmitter and receiver onboard instrument design configurations for measuring frequency shift will be discussed.

1. Introduction

Radio occultation is one of the major applications of radio science in space missions and played a central role in determining the vertical structures of planetary atmospheres from the early stage of planetary exploration in the 1960s (e.g. Eshleman et.al.,1987; Tyler et al.,1987). Radio-science technique provides considerable knowledge of the atmosphere and gravity of the planets. In radio occultation experiment conducts with an orbiter, the spacecraft transmits radio waves toward a tracking station on the earth and sequentially goes behind the planetary ionosphere, neutral atmosphere, and solid planet as seen from tracking station First, and re-emerges in reverse sequence. when the spacecraft's trajectory takes it behind the planet seen from Earth, there is occultation by the planet's atmosphere. During an occultation event, the refractive index of the gases in the ionosphere and atmosphere alters the characteristics of the propagating radio wave. In conducting such observations, the geometry and other experimental conditions must be controlled so that the only significant unknown factors are the properties of the medium along the radio path. Radio occultation experiment relies on the extreme frequency stability of both the onboard radio wave source and the recording system at the ground.

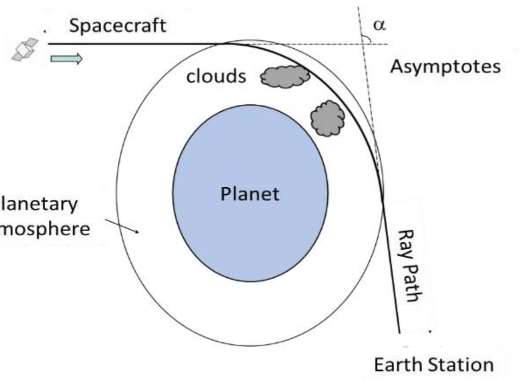

Figure 1: Schematic of RO Experiment

2. Instrument Design Options:

To perform radio occultation experiment, four instrument design configurations are there as given below

- Single band transmitter on board
- Dual band transmitter on board
- Single band receiver on board
- Dual band receiver on board

The design verification model of a dual-band transmitter (X Band (8.4 GHz) & S Band (2.3 GHz)) on board, single X Band (8.4 GHz) transmitter, and Single X Band (7.14 GHz) Receiver on board is being designed, and discussed in detail as per the sections given below.

2.1 Dual Band Transmitter on-board

In this design configuration, a crystal oscillator (TCXO) is to generate the stabilized (stability is in order of 10-8) reference frequency i.e. 10 MHz, With the help of a Phased Locked Loop (PLL) based frequency synthesizer, X Band (8.4 GHz) & S Band (2.3 GHz) frequency are being generated. To transmit two bands at the same time, a power combiner is used and further, to provide sufficient amplification of both signals, a power amplifier is used. For transmission of X and S band signals to Earth, the high gain antenna is used at the end stage of the transmitter.

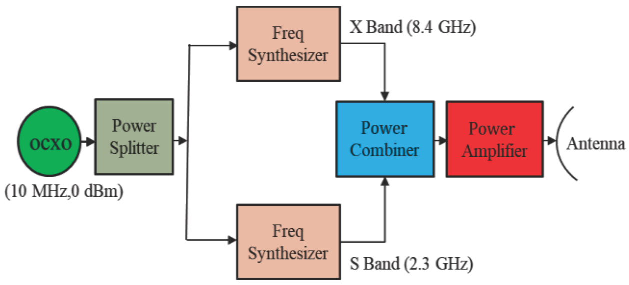

Figure 2: Dual Band Transmitter design diagram

2.2 Single X Band Transmitter on-board

In single band (X Band) transmitter on board, an ultra-high stable crystal oscillator (USO) having stability in order of 10-15will provide reference frequency and, with the help of a multiplier chain like four Doubler stage and two Tripler stages will generate X Band (8.4 GHz). A power amplifier and high gain antenna stage are utilized at the end of the stage to transmit the X-band signal to the ground.

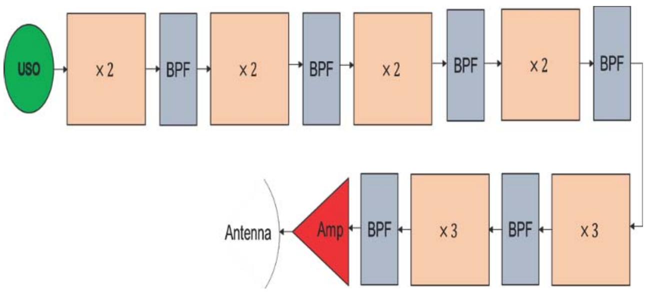

Figure 3: Single Band Transmitter design diagram

2.3 Single X Band Receiver on-board

On-board receiver power was calculated using the link budget, i.e., -82 dBm. Using the double-down conversion technique, a 148 MHz baseband signal with both in-phase and quadrature-phase components is derived from X band frequency, i.e., 7.14 GHz.

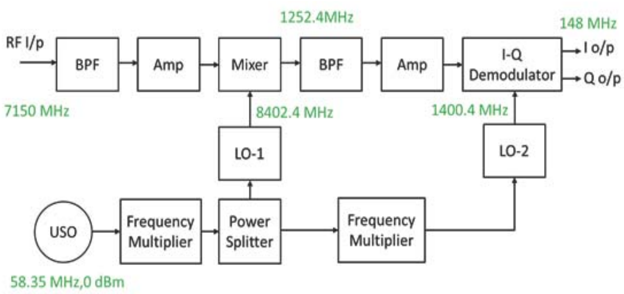

Figure 4: Single Band Receiver design diagram

3. Testing set-up and Results

These different instrument configurations were tested in laboratory using spectrum analyzer to check the power level at each stage of transmitter and receiver on board instrument. The figures shown below represents the testing set-up in laboratory and results.

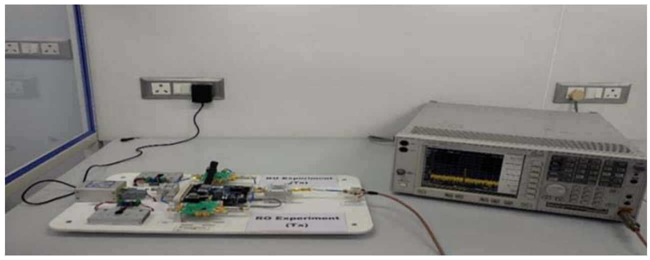

Figure 5: Testing set-up for Dual Band Transmitter

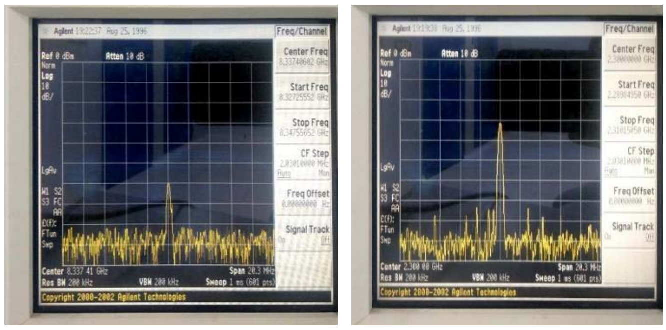

Figure 6: Testing results for X Band and S Band

Figure 5 shows the testing setup of the dual-band transmitter onboard instrument. With the help of a spectrum analyzer, checked the power level of the last stage power amplifier. Figure 6 represents the power level of the X and S Bands, respectively. Similarly, Figure 7 shows the testing set-up for both single X band transmitter and receiver onboard instrument. For testing of the receiver onboard instrument, the frequency from the X Band transmitter was tuned at 7.14 GHz at a power level of -82 dBm for testing.

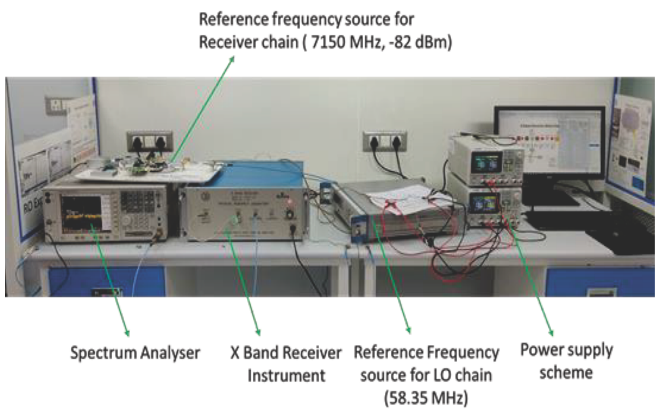

Figure 7: Testing set-up for Single X Band Receiver

To test the output of local oscillator chains 1 and 2, a frequency generator was used to generate reference frequency, i.e., 58.35 MHz with 0 dBm power level.

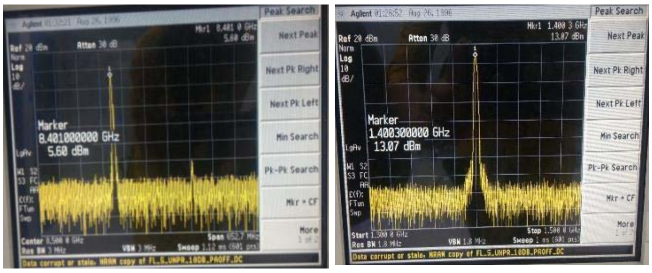

Figure 8: Testing results of Local oscillator chain 1 and 2

Figure 8 shown above represents the output power level of local oscillator chain 1, i.e., ~ 6 dBm and ~13 dBm for 8.4 GHz and 1.40 GHz centre frequency, respectively. This output of local oscillator chain 1 has a frequency of 8.4 GHz, and this power level is used as a single X-band transmitter chain. In a single-band transmitter onboard instrument, the Doppler and dispersive media effects must be cancelled from the received frequency shift component.

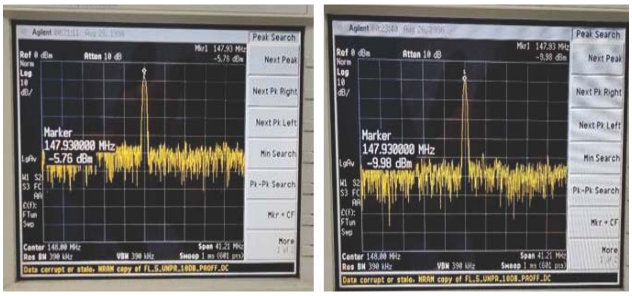

Figure 9: Testing results for In phase and Quadrature phase components in Single X Band Receiver

Figure 9 shows the output power level of the In phase and Quadrature phase components of the baseband signal, i.e., 148 MHz.

4. Summary

We have designed and tested different design configurations in laboratory for performing radio occultation experiment. For comparison between different instrument design options several parameters are considered. From resource requirement, design complexity and on board processing point of view transmitter on board configuration is more advantageous. Moreover, the transmitter and receiver on board can be either single band or dual band, where the advantage in the case of dual band transmitter is that can separate the frequency shift due to classical Doppler and dispersive media effect. Using the measured frequency shift from this dual Band transmitter on board configuration, one can derive the profile of atmospheric parameters. Further work is ongoing.

5. References

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