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Optimal configuration of dual-spacecraft radio occultation observation for future lunar ionosphere exploration

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The lunar ionosphere is one of the remaining mysteries of the Moon. The lunar ionosphere was found by stellar radio occultation observations (Elsmore, 1957) and radio occultation observations of spacecraft, such as Luna 19, Luna 20, and SELENE (Vasilyev et al., 1974; Vyshlov et al., 1976; Imamura et al., 2012). However, the existence of the lunar ionosphere is still debated. The estimated electron densities of several hundreds to 1000 cm-3 are much larger than a theoretical estimate (Daily et al., 1977).

Three different theories have been proposed to explain the existence of the lunar ionosphere. One is increase in the density of the neutral particle near the terminator, which is supply source of electrons (Daily et al., 1977). Second is existence of remnant magnetic fields which prevent the solar wind from stripping electrons of the lunar ionosphere (Savich 1976). Third is updraft of charged dust grains which are accompanied by electrons (Stubbs et al., 2011).

The cause of the lunar ionosphere remains an open question because the quality and quantity of the present data are inadequate. Principal factor is the terrestrial ionosphere. The amplitude of fluctuation of total electron content (TEC) of the terrestrial ionosphere is similar to or larger than the expected TEC of the lunar ionosphere. The cause of the lunar ionosphere cannot be elucidated without removal of the terrestrial ionosphere.

A dual-spacecraft radio occultation technique is one of the effective methods to remove the effect of the terrestrial ionosphere. By observing a target and a reference spacecraft simultaneously, the fluctuation of the terrestrial ionosphere which is common in two propagation paths can be canceled out. The dual-spacecraft technique has been used in the radio occultation experiment on SELENE mission (Ando et al., 2012). Although the enhancement of the electric density caused by the lunar ionosphere was detected, the number of successful observations was severely restricted. Observations were carried out only when the elongation of the two spacecraft was smaller than the beam width of the ground antenna that is 0.03 degrees. Furthermore, the accuracy of the measurement was limited because two S-band signals with a relatively small frequency interval of 69 MHz were used instead of S-band and X-band signals. Therefore, the total number of observations was 19 among which the lunar ionosphere was detected only twice.

In this paper, optimal configuration of the dual-spacecraft radio occultation observation is considered for a future exploration. Here, the dual-spacecraft consists of an orbiter and a lander. Appropriate orbital element and landing site are discussed to collect sufficient amount of data. We focus on a solar zenith angle dependency of observation that is a key parameter to study the mechanism of the lunar ionosphere generation. The effect of the terrestrial ionosphere for the dual-spacecraft radio occultation observation is also estimated by using GPS-derived TEC data. This effect was calculated from the differences of the TEC between two near-by GPS satellites whose elongation angles are between one to five degrees.