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Mars solar conjunction prediction modeling

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ABSTRACT

During the Mars solar conjunction, telecommunication and tracking between the spacecraft and the Earth degrades significantly. The radio signal degradation depends on the angular separation between the Sun, Earth and probe (SEP), the signal frequency band and the solar activity. All radiometric tracking data types display increased noise and signatures for smaller SEP angles. Due to scintillation, telemetry frame errors increase significantly when solar elongation becomes small enough. This degradation in telemetry data return starts at solar elongation angles of around 5° at S-band, around 2° at X-band and about 1° at Ka-band. This paper presents a mathematical model for predicting Mars superior solar conjunction for any Mars orbiting spacecraft. The described model is simulated for the Mars Orbiter Mission which experienced Mars solar conjunction during May–July 2015. Such a model may be useful to flight projects and design engineers in the planning of Mars solar conjunction operational scenarios.

1. Introduction

Mars superior solar conjunction (i.e., Mars blackout) occurs when the Earth, Sun and Mars become aligned (refer Fig. 1). During the Mars blackout, telecommunication and tracking between the spacecraft and the Earth significantly degrades. The radio signal degradation is dependent on the angular separation between the Sun and spacecraft, the signal frequency band and the solar activity. The solar corona and solar wind are the result of high density and strongly turbulent ionized gases (plasma) being ejected from the Sun. These ionized particles stream from the Sun at speeds on the order of 400 km/s and form the solar wind. The solar wind is not uniform and is accompanied by significant fluctuations in the solar magnetic field. Solar wind plasma density decreases with radial distance and becomes largely homogeneous when the distance from the Sun exceeds 4 solar radii. Within 4 solar radii, turbulence and irregularities are much greater and plasma becomes inhomogeneous. When radio frequency waves pass through these regions, the spacecraft signals suffer severe degradation of their amplitude, frequency and phase. Estimation of solar effects is complicated by the solar cycle that places an overlay of solar event frequency on top of the normal solar activity. Such events include coronal mass ejections, and an increase in the number of streamers. During the low periods of the solar cycle, events are less frequent and generally confined to the Sun equatorial region. During periods of high solar activity, events are much more frequent and may occur at any place on the Sun surface [1-3].

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Nomenclature

$R_{\oplus}$	Equatorial radius of the Earth
$R_{\odot}$	Radius of photosphere of the Sun
$\vec{a}^{m}$	Spacecraft position vector from the aero-center
$\vec{r}_{\oplus}^{m}$	Earth vector from the aero-center
$\vec{r}_{\odot}^{m}$	Sun vector from the aero-center
$\vec{a}^{s}$	Spacecraft position vector from the Sun center
$\vec{r}_{\oplus}^{s}$	Earth vector from the Sun center
(x, y, z)	Coordinates of the Sun surface
(a_1^s, a_2^s, a_3^s)	Components of the spacecraft position vector $\vec{a}^{s}$
$\vec{b}$	Vector joining the Earth-edge 1 to the spacecraft
$\vec{c}$	Vector joining the Earth-edge 2 to the spacecraft
(b_1, b_2, b_3)	Components of the vector $\vec{b}$
(c_1, c_2, c_3)	Components of the vector $\vec{c}$
$\vec{r}_{e1}^{s}$	Vector representing the line from the Sun-center to Earth-edge 1
$\vec{r}_{e2}^{s}$	Vector representing the line from the Sun-center to Earth-edge 2
$\hat{S}_p^s$	Unit vector orthogonal to $\vec{r}_{\oplus}^{s}$ in the spacecraft, Sun and Earth centers plane
$\vec{r}_{i}^{s}$	Vector normal to the plane
$(A_{Line1}^s, B_{Line1}^s, C_{Line1}^s)$	Coefficients of the intersection between Line 1 and the Sun surface
$(A_{Line2}^s, B_{Line2}^s, C_{Line2}^s)$	Coefficients of the intersection between Line 2 and the Sun surface

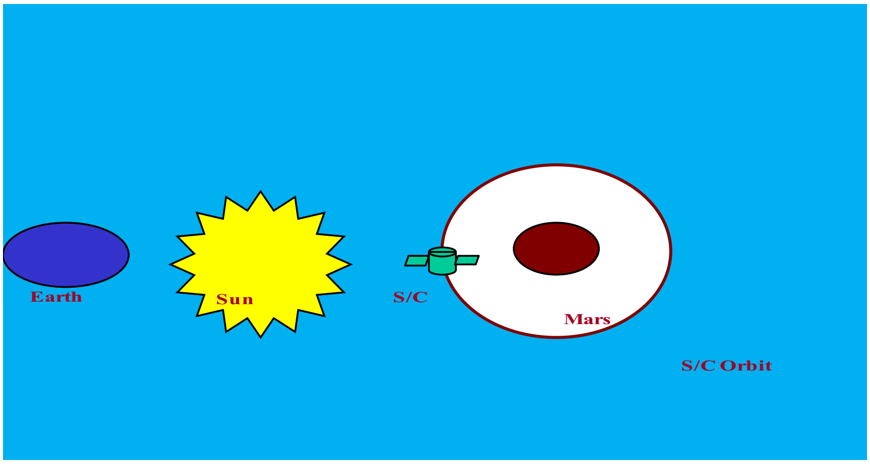

Fig. 1. Mars solar superior conjunction geometry: the Earth, Sun and spacecraft are aligned.

Signal-strength fluctuations on a spacecraft-to-Earth link can degrade the received telemetry performance. The degree of amplitude scintillation induced on an emitted signal by the intervening charged particles of the solar corona during a spacecraft-to-Earth superior conjunction depends on a variety of factors. One important factor is the minimum distance from the Sun of the signal ray path, usually measured in number of solar radii. If the signal path is close enough to the Sun, the solar elongation angle (1 solar radii=0.26°) or Sun–Earth–Probe (SEP) angle is sometimes used to express ray-path distance. As the electron-density fluctuations increase as the SEP angle decreases, the degree of amplitude (or intensity) scintillation increases until an SEP angle is reached in which the fluctuations saturate.

The phase of the solar cycle is another factor that can affect the degree of scintillation. Scintillation is expected to be worse during solar maximum conditions than during solar minimum conditions. During periods of solar maximum, there is a higher incidence of solar events and a higher likelihood that the signal path will be affected by the coronal density fluctuations. Such events include coronal mass ejections and the appearance of streamers. The sub-solar latitude of the signal path is another factor that can affect the degree of scintillation. There may be less activity in the polar (high) latitudes due to less-dense, less turbulent media such as coronal holes. During solar maximum periods, transient coronal solar activity may occur in any sub-solar latitude of the signal path, while during solar minimum conditions coronal activity is more or less confined in the equatorial regions. Disentangling solar-latitude dependence and solar-activity dependence in each conjunction data set is difficult. In addition, many times the ingress and egress scintillation profile curves are asymmetric and could take on a different character depending on solar conditions. The degree of scatter in the amplitude measurements (scintillation) about a representative profile also can vary depending upon the conditions.

The scintillation index is a measure of the degree of fluctuation that a signal's amplitude experiences due to passage through the small-scale plasma irregularities in the corona. It can be calculated from a measurement time series of signal strength as the ratio of the root mean square of the received power fluctuations relative to the mean power over the observation interval. The scintillation index, m, thus is defined as the root mean square of the received