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Analysis of Deep Space Telecommunication System Parameters, Design Control, Link Analysis and Space Communication Bands

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ABSTRACT: Communications are an absolute requirement for any space mission to be fruitful. From the moment of launch, the communications system is the only association that exists between a spacecraft and the Earth. Deep space telecommunication is thus a vital technology for observing and exploring the universe. Therefore, the need to understand and ameliorate the same is escalating as aerospace research is exponentially increasing at global scale. To make a system robust and proficient method of achieving both high bit rates and long distances in deep space, telecommunication system design and link analysis are performed. In the face of improving frequency bands, the conventional microwave communication technique has to be understood about nourishing the increased demand for the enormous volume of scientific data returning to this planet.

KEYWORDS: Deep space communication, Deep space observation, Telecommunication system design, Telecommunications,

I. INTRODUCTION

An essential, often extremely potent function in each and every space mission is that of communications. Every ambitious mission must have an end-to-end capability and expertise in communications system so as to receive commands and other information sent from Earth to the spacecraft, and to return data from the spacecraft to Earth. The challenge of communication in planetary exploration has been pivotal and largely atypical. As in generality greater number of deep space missions never return to Earth thus, from the moment of its launch, a spacecraft's tracking and communications systems is the only means with which to remain in direct relation with it. Extremely sensitive receiving systems are required for deep space communications. In addition, any concern with respect to the spacecraft can only be diagnosed, alleviated, or repaired via the communications system. Without a consistently effective and efficient communications system, a successful mission would be impossible.

The demands placed on deep space communications systems are incessantly increasing. For example, as of March 2016, the Mars Reconnaissance Orbiter (MRO) had sent back more than 298 terabits of data, which is indeed a magnificent accomplishment. However, NASA estimates that the deep space communications capability will need to burgeon and refurbish by nearly a factor of 10 each in the next three decades as our knowledge of the cosmos is increasing unequivocally and hitherto more detailed scientific questions are bound to arise. Hence, the ability to answer them requires pioneering and unprecedented advanced instruments and algorithmic systems that can help human kind to generate even more data (Borson, and Robinson, 2014). To understand the momentousness of communications in space technology one can look at Voyager 1. It is a space probe launched by NASA on September 5, 1977. Part of the Voyager program to study the outer Solar System, Voyager 1 has operated for 40 years, 8 months and 21 days as of May 26, 2018, the spacecraft still communicates with a powerful communication system via antennas. The radio

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signals from Voyager I's telemetry system travel at the speed of light and take a little more than 16 hours to reach Earth.

Substantial progress has been made in the subject in the last 25 years. The first satellite to orbit the Earth was Sputnik 1, launched by the Soviets in October 1957. It carried two radio beacons on frequencies of 20.005 and 40.01 MHz. The first satellite launched by the USA (Explorer 1 Carried beacons on 108.00 and 108.03 MHz. This lay just above the terrestrial FM broadcast band from 88 to 108 MHz) and just inside the civil aviation band which extends from 108 to 136 MHz. Communication capability measured in bits per second at a given range rose almost by a factor of 10^{18} in the 19 years from Explorer I of 1958 to Voyager of 1977. The data rate to the Mars Reconnaissance Orbiter is selected automatically and continuously during communications and can be as high as 2 million bits per second. The data rate to the Odyssey orbiter is a selectable 128,000 or 256,000 bits per second. Despite this space telecommunication is still inchoate and it is only pertinent that for proper exploration of our solar system and for exploration beyond this solar system we require advanced and revolutionary technology. There are numerous galaxies and billions of stars to investigate. Ambitious outer planet missions, with extremely tenuous communications links due to their great distance, and data-intensive orbiter or in situ missions incorporating high-bandwidth science instruments will demand improved telecommunications capabilities. Ultimately, our ability to create a virtual presence throughout this and other solar system will be directly linked to our overall deep space telecommunications capacity. Bigger and more daunting challenges await humankind; more exciting times are yet to come. These provocations to human race will undoubtedly call for more advanced telecommunications systems to transmit information to and from deep space. Telecommunications technology thus requires constant inventiveness, ingenuity and sophistication.

II. TELECOMMUNICATION SYSTEM DESIGN

Before delving deep into link analysis it is essential to understand the functions of of Telecommunication System. A typical deep space telecommunications system performs three basic functions as (1) Telemetry, (2) Command and (3) Tracking

Telemetry

Telemetry is derived from Greek roots: tele = remote and metron= measure. Telemetry function involves the transmission of information from a spacecraft to earth and has been used since World War II to record flight information of rockets and spacecraft. Telemetry data is made up of crucial science and engineering information transmitted to Earth via radio signals from spacecraft as they explore the far reaches of our solar system. This information usually consists of science data, engineering data, and imaging data. These can be measured in quality and quantity. Science data convey information gained from scientific investigation and trials onboard the spacecraft. These data are moderate in volume but are very valuable and thus have uncompromising quality and transmission accuracy requirements. Engineering data report the status of spacecraft equipments, instruments and systems. These data are low in volume and need to be of only moderate quality. Imaging data are of high volume and because of the redundancy present in planetary and/or astronomical scenes, imaging data need to be of only moderate quality. Telemetry parameter describing the status, configuration, and health of the spacecraft payload and subsystems are, in general, relayed to the earth to the Command and Data Acquisition (CDA) Station and sent to the Satellite Operations Control Center (SOCC). The telemetry units are "standby redundant," meaning only one unit is on and operating at a time. The operating telemetry unit collects the data, encodes, multiplexes, and formats it into two (normal and dwell) serial pulse code modulated (PCM) bit streams.

Command

The command function encompasses the transmission of information from the ground to the space craft. Space mission operations use the Command System to control the activities of spacecraft. Commands are sent to robotic probes as coded computer files that the craft execute as a series of actions. Commands are received on board the space craft for controlling mission operations and managing expendable resources. Command is needed to control spacecraft functions, to direct the spacecraft to take specified actions, with specified parameters, at a definite time-for example, to

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change flight path. The command link is characterized by a low data rate and a relatively low volume of data of extremely high quality to assure a minimum of errors in transmission to avoid misinterpretation of commands. Any Commanding Unit has three commanding modes:

- Store only
- Execute and store
- Store and execute

There are two modes of command execution: real-time and ground-command word-verify. In the real-time mode, verification of the uplinked command is performed within the command unit. If no errors are detected, the command is executed. If an error is detected, processing of the command is halted and a flag bit is telemeter to the ground station indicating that the command must be retransmitted. In the ground-command word-verify mode, the bits of the decoded command are telemeter back to the ground station for verification, and a subsequent execution message must be uplinked.

Tracking

It yields information on spacecraft position and velocity, the radio propagation medium, and the properties of the solar system, thus enabling trajectory monitoring and spacecraft navigation. In their passage through space, the signals transiting between spacecraft and ground station are altered by the medium through which they travel, by gravity, and by the relative velocity of the spacecraft and ground stations. The tracking data comprising Range, Doppler and Angle data is transferred to the control center for the purpose of orbit determination. Further, the signals are delayed substantially over these very long paths. By extremely accurate measurements of the radio signal characteristics, the position of the spacecraft, its velocity, and its acceleration can be determined. Simultaneously, important information is gained on the structure, composition, and temperature of the atmosphere of a body that may occult the signal, on the plasma state along the signal path, and on planetary and solar gravitational fields. Thus the process of transmitting radio signals to and from a cooperative spacecraft can allow us to navigate the spacecraft to its destination, measure properties of the gas and plasma in the signal path, and determine gravitational and relativistic effects. These tracking data are characterized by a very low rate, a need for long-term stability, extreme accuracy of measurement, and by the extent of data processing required to turn the signal into information. The effectuation and performance of these three functions: telemetry, command, and tracking depend on SNR or signal-to-noise ratio and efficiency. Therefore the aim is to design the telecommunication system that gives the highest signal power, lowest amount of noise, and most efficient use of signal-to-noise ratio, confined by constraints of spacecraft weight, size, and cost.

At this point it is important to note that interplanetary space is necessarily the same as free space as far as the propagation of microwave signals is solicited. In the absence of weather effects, the earth's atmosphere is almost completely transparent at 2.3 GHz (S-band) and 8.4 GHz (X-band), which are the frequencies being used for deep space telecommunications. Therefore, the calculation of received signal strength is a geometrical problem. If we assume that the transmitted power by spacecraft is P_T at distance r from the receiver on earth and the power were radiated isotropically, i.e. uniformly in all orientations; the power flux density (rate at which power is transferred by electromagnetic radiation through a real or virtual surface, per unit surface area and per unit wavelength), at the receiver would be the transmitted power divided by the area of a sphere of radius r . Pierce, and Posner, (2013) opined that the actual flux density is increased by a factor equal to the gain of the transmitting antenna, G_T . This implies that:

$$\rho = \frac{P_T G_T}{4\pi r^2}$$

$$P_R = \rho \mu A_r$$

i.e. The received signal level P_R is obtained by multiplying the flux density at the receiver by the area of the receiving antenna A_r times the receiving antenna efficiency it clear that the received power P_R can be increased by three actions. First, by increasing the transmitted power P_T but this has system repercussions. Even though the spacecraft-transmitted

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power is typically only 20 watts, the input power required to generate it represents a substantial fraction of the total power available on the spacecraft. Second, by improving the transmitting antenna gain G_T to concentrate the transmitted power more intensely on the receiving antenna. Better focusing requires a larger spacecraft antenna; this of course should be within limits of size and weight constraints and the ability to aim the resulting narrow beam. Third, increasing the receiving antenna area so as to collect as much of the incoming signal power as possible.

Before moving any further it is important to remember that on May 20, 1964, American radio astronomers Robert Wilson and Arno Penzias discovered the cosmic microwave background radiation (CMB), the ancient light that began saturating the universe 380,000 years after its creation. The CMB is the oldest light in the universe, dating from the first epoch in which photons could travel freely. Shortly after the Big Bang, the cosmos was a seething-hot, opaque fog of plasma and energy; things changed about 380,000 years later, when temperatures dropped enough for electrically neutral atoms to form, and the universe became transparent. The CMB is markedly uniform, lending support to the theory of cosmic inflation, which posits that the universe expanded much faster than the speed of light just a few tiny fractions of a second after the Big Bang. The cosmic microwave background radiation has a black-body spectrum with a temperature of 2.7 K (2.7 Kelvin, or about - 270.5 °C). A considerable amount of noise is introduced in the reception process which corrupts the receiving signal. Every object radiates energy at radio frequencies. The omnipresent 2.7 Kelvin thermal background of the universe produces a radio noise that is an important fraction of the signal power that is supplied to the ground receiving antenna. According to Stelzried, (1982) the noise spectral density is:

$$N_0 = kT$$

Where k is Boltzmann's constant = 1.38×10^{-20} mW/K Hz, and T is the system equivalent noise temperature = 28.5 K. (noise temperature is one way of expressing the level of available noise power introduced by a component or source.) Thus,

$$N_0 = 3.933 \times 10^{-22} \text{ W/Hz}$$

There are also other losses in the entire link such as circuit losses, antenna pointing losses, losses due to distance etc.. Therefore, the received signal-power-to-noise-spectral-density ratio, when this loss L is taken into account, is:

$$\frac{P_R L}{N_0}$$

How efficiently this signal-power-to-noise-spectral-density ratio is being used determines the ultimate telemetry capability. And it is the choice of modulation and coding methods that determines the efficiency with which this signal-to-noise ratio is used. Originally the signals were very simple but have become increasingly complex as the need and capacity for information has increased. Early space telemetry systems used Pulse Position Modulation (PPM) and Pulse Width Modulation (PWM) to transmit data. Modern telemetry uses Pulse Coded Modulation (PCM) to transmit data. Voyager, for example, uses Pulse code modulation (PCM) / Phase-shift keying (PSK)/Phase modulation (PM) modulation and convolution code, a type of error-correcting code that generates parity symbols via the sliding application of a Boolean polynomial function to a data stream, can convert any length message to a single 'codeword', with Viterbi decoding that uses the Viterbi algorithm for decoding a bit stream, which is a dynamic programming algorithm for finding the most likely sequence of hidden states – called the Viterbi path – that results in a sequence of observed events. This requires a received signal power-to-noise-spectral-density ratio of 2.05×10^5 Hz for a data rate of 115.2 kilobits per second.

Telecommunications Design Control

If all link parameters were constant and precisely known to a telecommunication engineer, a simple accounting of parameters could predict performance. In real life, however, the case is not quite so. Some parameters change with the effect of interplanetary plasma and spacecraft environment, some show variance because of earth's ground station environment and yet others with the communication channel conditions.

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In the past when space exploration was itself in its very early stages and engineers were novice in the field of designing telecommunication links and had little to no data, they used deterministic worst case scenario to stay within the link limits and ensure workings under safe link margins in times of uncertainties. The major disadvantage of this deterministic worst case scenario is that cost trade off and risk assessment cannot be done quantitatively.

Over the years, a statistical technique has evolved which has proved to be conducive in removing the disadvantages of deterministic approach while holding onto its advantages. It is important to remember that the overall telecommunication design system consists of various parameters multiplied with each other. In managing system design, the most convenient method is to use a DCT i.e., Design Control Table. To every parameter in a DCT favorable and adverse tolerances are assigned by the designers. These tolerances are not used as hidden safety margins. These are, instead, used as reflections of probable uncertainties, which include but are not limited to drift and aging of elements, parameter modeling errors manufacturing and measuring tolerances. It is easy to identify the parameter with the largest tolerances and thus easy to work out where more knowledge and improved hardware would prove to be most profitable.

Telecommunications Link Analysis

The performance of a telecommunications system depends on numerous link parameters. To have a robust link between the ground and the spacecraft, it is needed to accurately characterize the communications channel between the transmitter and the receiver. This is especially true for high capacity links that will be required in the future.

Received Power

The first step in link analysis is to calculate the received signal power. Pierce, and Posner, (2013) observed that received power P_R is computed by the following equation:

$$P_R = P_T L_T G_T L_{TP} L_S L_A L_P L_{RP} G_R L_R$$

here,

P_T : total transmitted power at antenna terminals

L_T : transmitting circuit loss between transmitting antenna terminals and radio case due to cabling

G_T : transmitting antenna gain

L_{TP} : pointing loss of the transmitting antenna

L_S : space loss (numerical ratio of received power to transmitted power between two antennas)

L_A : atmospheric attenuation

L_P : polarization loss between transmitting and receiving antennas due to mismatch in polarization patterns

L_{RP} : pointing loss of the receiving antenna

G_R : receiving antenna gain

L_R : receiving circuit loss between receiving antenna and receiver due to cabling.

The received power is referenced to some point in the receiving circuit and the choice of reference point affects L_R .

Noise Spectral Density

Noise spectral density is noise power per unit of bandwidth i.e. it is the power spectral density of the noise. The noise for any communication signal going from ground to a satellite or spacecraft is predominantly thermal. It is to note that thermal noise is caused by random motion of free electrons in a conductor excited by thermal agitation. For the communication signals going from a satellite to ground, thermal noise is assisted by random radiation picked up by the ground antenna. According to Yuen, (2013), this random radiation includes that from the atmosphere, the 2.7 K cosmic background, hot bodies in the field of view of the antenna and the portion of the ground seen by antenna side lobes.

We know that,

$$N_0 = kT$$

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The above relation though, is valid only for microwave frequency signals, which are currently being used for deep space telecommunications. For signals in other frequency regions, such as in optical frequencies, different expressions should be used (Pierce, and Po sner, 2013).

Carrier Performance Margin

Yuen, (2013) opined that carrier performance margin or simply carrier margin M_c on either uplink or downlink is defined as:

$$M_c = \frac{P_c}{2 B_{LO} N_0}$$

here,

P_c : portion of received power in the residual carrier

B_{LO} : one sided threshold loop noise bandwidth.

(P_c is calculated from P_R using the modulation indices of the link and depends on the type of modulation used)

The minimum useful carrier margin is about 10 dB.

Telemetry and Command Performance Margins

For both telemetry and command (Yuen, 2013)

$$ST/N_0 \text{ to receiver} = \frac{S}{R N_0}$$

here:

Portion of received power in the data modulation sidebands (P_R using the modulation indices of the link)

R: data bit rate

The parameter ST/N_0 to receiver is sometimes denoted by E_b/N_0 which is the signal energy per bit to noise spectral density ratio. And,

$$ST/N_0 \text{ output} = [ST/N_0 \text{ to receiver}] L_{system}$$

L_{system} : system losses

Ranging Performance Margin

Ranging is performed to determine the spacecraft orbital elements during transfer and geosynchronous orbits. The ranging signal-to-noise ratio at the spacecraft is (Yuen, 2013):

$$\text{ranging input SNR} = \frac{P_{R(u/l)}}{B_R N_{0(u/l)}}$$

$P_{R(u/l)}$: portion of received uplink power in the ranging modulation sideband (calculated from the uplink P_R using the modulation indices of the uplink)

$N_{0(u/l)}$: is the uplink (ie. one-sided noise spectral density of the spacecraft receiver)

B_R : is the one-sided noise bandwidth of the transponder ranging channel

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The ranging signal-to-noise-spectral-density ratio returned to the ground segment is (Yuen, 2013):

$$\text{received SNR} = \frac{P_{R(d/l)}}{N_{0(d/l)}}$$

$P_{R(d/l)}$: portion of received downlink power in the ranging modulation sidebands

$N_{0(d/l)}$: downlink one-sided noise spectral density.

$$\text{output SNR} = [\text{received SNR}] L_{\text{radio}}$$

L_{radio} : radio loss of ranging system

$$\text{ranging performance margin} = \text{output SNR} - \text{required SNR}$$

To properly understand and analyze the telecommunication link it is essential to look into the effects of the atmospheric, environmental, and extraterrestrial phenomenon and solar corona and solar wind effects telecommunications links

Atmospheric and Environmental Effects

The atmospheric attenuation and noise temperature resulting from oxygen, water vapor, clouds, and rain are the cardinal weather-related effects on telecommunications link performance. The two effects are in fact interconnected as higher noise contribution is produced by higher atmospheric attenuation. The Earth's atmosphere produces attenuation by absorbing or scattering the radio signals that pass through it, and system noise temperature increase at the receiving end of the link due to the presence of hot body.

Types of hot body noises are

Solar Noise- The increase in system noise when tracking a spacecraft angularly near the Sun depends on the intensity of solar radiation at the received frequency and on the position of the Sun relative to the antenna gain pattern.

Lunar Noise- It is the increase in system noise temperature for an antenna pointed near the Moon. The blackbody disk temperature of the Moon is about 240 K at X- and Ka-bands, somewhat lower at S-band (220 K), and its apparent diameter is almost exactly that of the Sun's (approximately 0.5 deg).

Planetary Noise- It is the increase in system noise temperature when tracking a spacecraft near a planet.

Galactic Noise-The center of the Milky Way galaxy is located near -30 degrees declination, 17 h 40 min right ascension. It is possible for a spacecraft with a declination of -30 deg to be in the vicinity of the galactic center, and an increase of system noise temperature would then be observed.

Also, generally atmospheric effects increase with increasing frequency. The noise power received by a receiving station antenna due to a hot body at a given frequency usually is expressed in terms of the body's brightness temperature, or noise temperature. The brightness temperature of a source (hot body) is a measure of the power radiated in a given frequency band by the source in the direction of the receiving antenna. This is equal to the physical temperature of a blackbody (perfect absorber) emitting the same power in that band (Stephen et al. 2018).

The brightness temperature, T_b background temperature observed by a ground antenna in a given direction through the atmosphere), in a fixed frequency band is given by radioactive transfer theory (Wu, et al., 2018):

$$T_b = \int_0^{\infty} T(l)\kappa(l)e^{-\tau(l)}dl + T_{\infty}e^{-\tau_{\infty}}$$

Where the optical depth is:

$$\tau(l) = \int_0^l \kappa(l')dl'$$

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here,

$\kappa(l)$: absorption coefficient (depends on atmospheric species, its abundance, temperature, pressure, height, and the frequency) T_∞ : cosmic background noise temperature from infinity (has an optical depth of τ_∞)

For a homogeneous, isothermal atmosphere, $K(l) = \kappa$ (mean absorption coefficient) and $T(l) = T_m$ (mean physical temperature). Thus, the optical depth through the total path is $\tau(l) = \kappa l$

The brightness temperature, T_b hence becomes

$$T_b = T_m \int_0^{l_0} e^{-\kappa l} \kappa dl + T_\infty e^{-\tau_\infty}$$

At the Super high frequency (SHF) band, the last term in the above equation reduces to 2.7 K, and the cosmic background component, in general, can be neglected. By integrating the above equation the brightness temperature can further be reduced to (Waters, 1976).

$$T_b = T_m(1 - e^{-\tau_0}) = T_m(1 - e^{-\kappa l_0}) = T_m(1 - 10^{-(A(\text{dB})/10)}) = T_m \left(1 - \frac{1}{L}\right) \text{ (K)}$$

here,

$\tau_0 = \kappa l_0$: total optical depth for the atmosphere

$L = e^{\tau_0} = e^{\kappa l_0} = e^{A/4.34} = 10^{A/10}$: linear loss factor due to the atmospheric absorption

when L becomes very large, $T_b = T_m$.

Atmospheric noise, temperature and attenuation statistics are provided in the form of cumulative distributions (CDs) for each effect. For example, a cumulative distribution of 0.90 (“90% weather”) means that 90% of the time a particular weather effect (noise temperature or attenuation) is less than or equal to a given value. Conversely, that particular effect is exceeded 10% of the time. Agreeing to Stephen et al., (2018) qualitatively, the weather conditions associated with selected cumulative distributions are described as follows:

CD = 0.00 (clear dry, lowest weather effect)

CD = 0.25 (average clear weather)

CD = 0.50 (clear humid, or very light clouds)

CD = 0.90 (very cloudy, no rain)

CD > 0.95 (very cloudy, with rain)

The mean effective radiating temperature, T_m , is thus modeled

as $T_m = 255 + 25 \times \text{CD}$ K

here

CD: cumulative distribution of weather effect ($0.0 \leq \text{CD} \leq 0.99$).

Note that the maximum value of T_m thus becomes nearly 280 K, or about 7 C.

Elevation angle modeling can be performed using either a flat-Earth or a round-Earth model. A flat-Earth model is used here, wherein the attenuation increases with decreasing elevation angle (Stephen, et al., 2018):

$$A(\theta) = A_{zen} \times AM = \frac{A_{zen}}{\sin(\theta)}, \text{ dB}$$

here,

θ : Elevation angle of antenna beam A_{zen} = zenith atmospheric attenuation (dB)

$$\left(\frac{1}{\sin(\theta)} = 1.0 \text{ at zenith} \right)$$

AM = number of air masses

For all DSN frequencies the cosmic background noise temperature before atmospheric attenuation is

$$T_{CMB} = 2.725 \text{ K}$$

With atmosphere attenuation, the effective cosmic background becomes

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$$T'_{CMB}(\theta) = \frac{T_{CMB}}{L(\theta)}, \text{ K}$$

It should be mentioned here that the basic database for the calculation of atmospheric effects is actually the attenuation statistics despite the fact that the noise temperature statistics are the best qualitative measures for comparison of various locations and various frequencies, especially when dealing with low-noise systems (where the atmospheric noise is a large part of the total system noise temperature).

Solar Corona and Solar Wind Effects

High density and strongly turbulent plasma being ejected from the Sun cause the solar corona and solar wind. The solar wind is a stream of charged particles released from the upper atmosphere of the Sun. This plasma consists of mostly electrons, protons and alpha particles with energies usually between 1.5 and 10 keV; embedded in the solar-wind plasma, at speeds of the order of 400 km/s, is the interplanetary magnetic field. The solar wind varies in density, temperature and speed over time and over solar longitude. The plasma is largely non homogeneous and turbulence and irregularities very great within 4 solar radii. Hence the radio frequency (RF) waves suffer severe degradation of their amplitude, frequency and phase if signal pass through these regions. As a plasma medium (Stephen et al. 2018), the homogeneous region of the solar wind has the following basic effects on radio wave signals: Group Delay- Group delay is the extra time delay due to the presence of an ionized medium in the propagation path. It is a function only of the slant total electron contents (STEC) along the path and the radio-wave frequency.

Dispersion- Because group velocity (The group velocity of a wave is the velocity with which the overall shape of the waves' amplitudes-modulation of the wave—propagates through space) is a function of the radio signal frequency, a dispersive phenomenon will occur when a broad band of frequency signals pass through the solar wind.

Faraday Rotation- An RF wave traversing the solar corona at an angle theta with respect to the Sun's magnetic field B (quasi-longitudinal) will rotate its polarization plane. The total rotation phi in radians is proportional to the product of the electron density and the magnetic field component along the path from the probe to the observer. A large Faraday rotation could result from either a high electron density or a large net longitudinal field component. Although no net Faraday rotation could be produced despite high electron densities and strong magnetic fields.

Absorption- The absorption effect of solar wind plasma in the microwave bands is very small. For a 2.3 GHz signal and a path length of 3×10^8 km, the total absorption will be only 0.01 dB which is practically negligible.

Due to the non homogeneous nature of plasma, strong turbulence and irregularities within specific perimeter of Sun there are various other effects as well like:

Intensity Scintillation- It refers to random fluctuations in the intensity of radio waves, on the timescale of a few seconds. The scintillation index can be calculated from a measurement time series of signal strength, as the ratio of the RMS of the received power fluctuations relative to the mean power, over the observation interval.

Spectral Broadening - Spectral broadening is the broadening of spectral lines due to the Doppler Effect caused by a distribution of velocities of atoms or molecules. Different velocities of the particles result in different Doppler shifts of the charged-particle refractive index (or density) irregularities as they are carried over the signal path by the solar wind, the cumulative effect of which is the line broadening. It is dependent on both electron density fluctuations and solar wind velocity, whereas the scintillation index only depends on the electron density fluctuations. It is not generally of concern in designing a telemetry link. However, it is of concern to a telecommunications engineer to determine an adequate value for the ground receiver carrier tracking loop bandwidth.

Space Communication Bands

Before understanding the telecommunication system it is essential to know some of the heavily used frequency bands for space communication

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VHF Band

Very high frequency (VHF) is the ITU designation for the range of radio frequency electromagnetic waves (radio waves) from 30 MHz to 300 MHz, with corresponding wavelengths of ten to one meters.

UHF Band

Ultra high frequency (UHF) is the ITU designation for radio frequencies in the range between 300 MHz and 3 GHz, also known as the decimeter band as the wavelengths range from one meter to one decimeter. This band includes navigation, positioning, time and frequency standard, mobile communication, and meteorological satellites.

L Band

The L band is the Institute of Electrical and Electronics Engineers designation for the range of frequencies in the radio spectrum from 1 to 2 gigahertz. This frequency range includes a very diverse range of satellites and encompasses many sub-allocations.

S Band

The S band is part of the microwave band of the electromagnetic spectrum. It is defined by an IEEE standard for radio waves with frequencies that range from 2 to 4 GHz, crossing the conventional boundary between UHF and SHF at 3.0 GHz. This encompasses the Unified S-band (USB) plan which is used by many spacecraft, and which was also used by the Apollo lunar missions. It also includes military space links including the US Defense Meteorological Satellite Program (DMSP).

C Band

C Band is the original frequency allocation for communications satellites. C-Band uses 3.7-4.2GHz for downlink and 5.925-6.425 GHz for uplink.

X band

Segment of super high-frequency radio spectrum that lies between 5.2 GHz and 10.9 GHz is used especially for radars and for spacecraft communication. This is used heavily for space research, deep space operations, environmental and military communication satellites. Many satellites/spacecraft carry complementary S and X band transmitters.

Ku band

The Ku band is the 12–18 GHz portion of the electromagnetic spectrum in the microwave range of frequencies. This symbol refers to "K-under" —in other words, the band directly below the K-band. In radar applications, it ranges from 12-18 GHz

Ka band

Ka band covers the frequencies of 26.5–40 GHz, i.e. wavelengths from slightly over one centimeter down to 7.5 millimeters. The Ka band is part of the K band of the microwave band of the electromagnetic spectrum. This symbol refers to "K-above": in other words, the band directly above the K-band. A region that will be used increasingly by a variety of fixed link, broadcast, environmental and space operations satellites in the future as more bandwidth is required than can be provided in the lower bands. The disadvantage of this band is the increased absorption due to water vapor and rain. It is not very useful for tropical regions of the Earth.

III. CONCLUSION

An analysis of a deep space telecommunication system has been performed. Only a sophisticated system can enable powerful science investigations that probe the nature of asteroids and the interiors of astronomical bodies. This paper summarizes the theoretical background for telecommunications link analysis and telecommunications design

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control. There is a dire need of an ever-evolving effective, efficient and unremitting telecommunication system. To understand and improve on the existing system we started with a look at the system design, perceived tracking, command and telemetry and looked into the need of each. We moved onto analyzing telecommunication links and delved slightly into the design control along with understanding the effects of the atmospheric, environmental, extraterrestrial phenomenon and solar wind and corona on the same. We also dabbled with different space communication bands used in telecommunication

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