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Frequencies for Mars Local Communications

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1. INTRODUCTION

There are many factors affecting the selection of frequency of Mars local communication links. They were discussed in an information paper, SF20-14D1 [1] and in [2]. This document revisits these issues and recommends candidate frequency plans to meet the near-term, mid-term and long-term needs.

2. FREQUENCY BANDS OF INTERESTS

The frequency bands of interests are UHF, S-, X-, and Ka-band. The specific UHF frequency of interest is approximately 420 +/- 30 MHz. S-band (with 10 MHz for transmit and 10 MHz for receive, centered at 2115 and 2295 MHz respectively) has been suggested as a possible alternative to UHF. X-band (two 50-MHz allocations, one in the 7.2-GHz band and the other in the 8.4-GHz band) is of interest because it is the frequency used by most existing and planned deep space missions for the links between spacecraft and the Earth. Ka-band (32 GHz) is attractive because it has ample spectrum to support multi-megabit links.

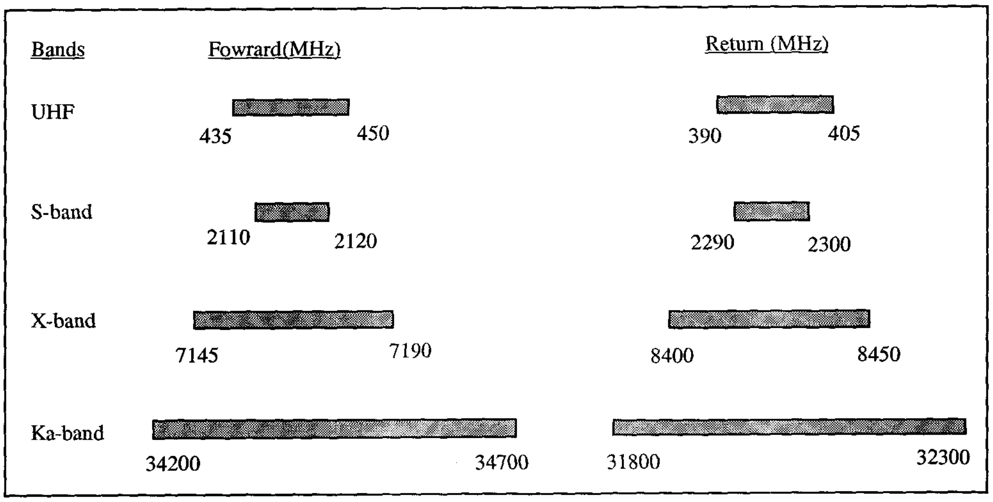

Figure 1. Frequency Bands of Interests

3. MISSION SCENARIOS

Mission scenarios play an important role in selecting the frequency for Mars local links. There are numerous mission scenarios for future Mars exploration, many of which include local links. Possible types of local links are surface links (lander to rover), surface (including aerobots) to low orbiters, surface to areostationary orbiters, orbiter to orbiter, and entry, descent and landing (EDL) links. Figures 1 and 2 depict two possible scenarios, their elements, and links. Figure 1 is a near-term scenario and Figure 2 is a longer-term scenario. These elements each have different mass, power, and volume constraints that can affect selection of frequency. This section will discuss some of the options and what they mean in terms of choosing a frequency band for the local links.

3.1 Surface Links

The Mars Pathfinder lander-to-rover link is an example of a surface link. Pathfinder used a 459.7-MHz modem for two-way communications at 9600 bps. Both elements used choked monopole antennas. The transmit power was 100 mW.

Typically, these links are line of sight and very short range (< 1 km). The missions are designed such that there is nearly continuous visibility. Data rates are typically sized around 8 kbps for the forward link and from 8 to 256 kbps for the return link. A problem for these links is blockage and multipath fading from the surface and rocks. The antennas are relatively close to the ground, which makes the fading problem worse.

Figure 2 – Longer-term Connectivity (courtesy of H. Vyas)

3.2 Surface to Low Orbiter Links

There are many types of surface elements. They can be large, capable landers or rovers, small short-lived probes, and aerobots – planes or balloons. Although the latter elements are not on the surface they exhibit similar characteristics in terms of in-situ communications. For these links, the desire is to have antenna beams (of the surface elements) that are pointed up (above a 15-degree elevation angle), as opposed to the surface links where the antenna beams should be along the surface.

One of the factors that can significantly affect the choice of frequency for these links is the type of antenna carried by the surface elements and the orbiter. Based on previous designs, it is very unlikely that surface elements will use a steerable antenna for these links. It is also expected that a relay orbiter will have a nadir-oriented, body-fixed low gain antenna (LGA), at least in the near-term. However, it is possible that an orbiter may carry a steerable spotbeam antenna in the future when it is operationally practical.

The following paragraphs describe briefly the characteristics of various surface elements and their constraints.

3.2.1 Large Lander or Rover—These elements typically are not as constrained as some others in terms of power, mass, and volume. They also tend to have higher data return requirements. They can support a higher transmit power because they will have solar arrays, which may limit them to daytime-only communications. Typical data rates for these elements are forward links of 8 kbps and return rates of 128 kbps.

A higher mass allocation will allow these elements to fly a larger, circularly polarized antenna, like a patch or helix, rather than a whip. The helix pattern could be shaped to provide slightly more gain off to the sides than at zenith to compensate somewhat for the slant range difference. This can be done on the orbiter as well. The larger vehicle allows for carrying the mass of a duplexer for full duplex communications.

3.2.1 Small Probes—The mass, volume, and power requirements for these elements are much more critical than for the large lander/rover. An example of this type of probe is the Deep Space 2 (DS2) microprobe that landed on Mars. Its mass allocation for telecom was about 50 g, including the antenna.

Power is generally from a battery or radioisotope heating unit (RHU). Transmission at night is probable because the Sun is not required for power. Typically, the output power is going to be less than 1 watt RF. DS2's output power was about 500 mW. The mass for the transceiver and antenna should be under 100 g. Generally for the small probes, the use of a UHF patch antenna is not feasible because there is not enough surface area for the ground plane and because the mass is too large. The whip is a low-mass, simple solution, albeit with limited performance. The whip has a null overhead; however, the satellite rarely gets that high in elevation. The links are typically half-duplex because the mass of a duplexer is too high. The transceivers may employ a transmit/receive switch for two-way communications. The typical return-data rate for these small probes is 8 kbps.

3.2.3 Aerobots—Balloons and airplanes, like small probes, are typically very power limited because of the absence of large solar arrays. The airplanes in previous proposals had a mass of about 10 kg and a wingspan of 1.8 m. The mission duration can be from minutes for an airplane to days or weeks for a balloon. Video data from a short-lived airplane will require very high data rates. If the plane is transmitting to an orbiter, it will be necessary to schedule the flight for an overpass by the satellite. Some airplane options would return data to a surface lander for relay to the Earth. Although there could be possible fading or blockage problems, the range would be much shorter than communicating with a satellite.

These elements are also very mass limited. Simple whip antennas are generally assumed. An airplane could use some type of conformal antenna (patch) if the structure is large enough. Again, the desired antenna beam direction is up, but with a very wide beamwidth to cover the orbiter's trajectory. The transceiver mass should be as small as possible (< 100 g), like the small probes. These elements are generally battery powered or with small solar panels to recharge the batteries so dc power for transmission is at a premium.

3.3 Surface to Areostationary Links

For these links, the range is much larger. The altitude of an areostationary orbiter is about 17000 km. The slant range does not change much as a function of elevation angle because of the high altitude. The desired antenna coverage is looking up—an elevation angle of 15 degrees to zenith with a 360-degree azimuth—but with the satellite stationary. This allows for using much higher gain antennas on the surface elements. The antennas have to be pointed, but only once up at the satellite as long

Using the in-situ communications equipment for EDL is problematic if the communication is back to Earth. If the relay-link frequency is UHF, there are limited large UHF receiving antennas on Earth (none at the DSN). Depending on the spacecraft design, the relay antennas may be covered by a backshell. If the spacecraft is carrying X-band or Ka-band DTE radio equipment, EDL communications to Earth at those frequencies, through the DSN, is the best option. This is because the DTE radio equipment will typically have a higher power transmitter, the X-band antennas will be physically smaller than similar gain UHF antennas (easier to accommodate on the spacecraft), and the higher frequencies are more immune to plasma effects caused by the spacecraft entry into the atmosphere.

3.5.2 Through a Relay Satellite

Using the relay communications equipment for EDL is necessary when the Earth is out of view of the spacecraft. Transmitting EDL information to a low orbiter overhead or to an areostationary satellite is feasible. There is also the option of trying to use the cruise stage for a relay; generally, the relative geometry between the cruise stage and entry vehicle's trajectories makes this very difficult. The biggest requirement is having an antenna that will be outside the shroud of the spacecraft and be in view of a satellite overhead. Getting visibility to a low orbiter could be a problem because of scheduling the overflight and the short duration of EDL.

Communicating to an areostationary satellite provides better visibility, but at a longer range. The EDL communications may use semaphores or a carrier signal instead of relatively high data rates (1 to 8 kbps). Of course, an areostationary satellite would have to be positioned over the EDL site. If the landing element has in-situ relay equipment on it, it could transmit through a switch to an external EDL antenna on the spacecraft backshell or other structure. The other option is to fly a separate EDL radio package that would be thrown away with the backshell. If this option were chosen, the package would include a battery for the short duration of EDL communications.

The antenna coverage for EDL will require a wide-beam, low-gain pattern. The spacecraft will not have any capability to point an antenna and the angles it has to communicate through will vary widely. The mass and power will have to be low, especially if the EDL radio equipment is an add-on to the regular spacecraft. Spacecraft power will be off of a battery, so it should be kept to a minimum. To support EDL communications, a low orbiter would need an antenna with a relatively wide beamwidth to cover the trajectory of the incoming spacecraft and an areostationary satellite would need an antenna to cover the disk of Mars.

4. TELECOM HARDWARE TECHNOLOGY

Previous Mars missions have used UHF band communications. Viking used an UHF relay system between the landers and the orbiters. Pathfinder used a space qualified Motorola UHF modem. Mars Global Surveyor carries the French Mars Balloon Relay (MBR) UHF radio. DS2 carried a UHF radio to talk to the MBR. The two Mars 98 missions (lander and orbiter) carried Cincinnati Electronics UHF radios to communicate with each other. The focus for near-term Mars missions has also been at UHF. However, S-band was considered for the original Mars 03 rover communications. That link was designed to use the French SOREP S-band transceiver for a surface link between the rover and the lander. The new Mars 03 rover mission will use UHF radios to talk to the Mars 01 orbiter. A non-Mars mission, Muses CN, designed a relay link at L-band. This design takes advantage of commercial parts designed for the Personal Communications Services (PCS) band.

Is UHF the right frequency for Mars local communications? Will technology and hardware considerations significantly affect the choice of frequency?

There is no major difference between UHF, S-band and X-band in terms of hardware availability and flight experience. All three frequencies have been flown and have space-qualified hardware. At the present, Ka-band is comparatively less favorable than UHF, S- and X-bands in terms of available space-qualified hardware. However, this can be changed in the future due to continuous development by interested space agencies and satellite industry.

4.1 Transceivers

The differences in transceivers at different frequency bands are really in the front-end electronics. The back-end processing, after intermediate frequency (IF) sampling is really the same for different frequency bands. Higher frequency bands require accommodation of a larger Doppler offset and Doppler rate. In the front end, the specification for the oscillators has to be tighter at higher frequencies to achieve similar phase noise characteristics.

5.1 Surface Links

For surface links, the range is so short that space loss is not as critical in determining link performance. Generally, with a small output power and a whip or other low gain antenna, the links have large margins. The margins are sufficient to offset multipath fading losses. Choice of frequency for these links is influenced by factors other than link performance, such as mass, volume, and equipment availability. Of the frequencies considered, UHF and S-band are more suitable than X- and Ka-band. If the surface elements are severely energy-limited or if the required power for these links is relatively high, then UHF would have an edge over S-band. Mars Pathfinder chose UHF because of an existing radio that it could use: a simplex UHF radio with a 100-mW transmitter. A recent Mars lander/rover study considered using S-band because the antenna mass was small and they could use an existing French S-band transceiver. The lower mass at S-band also allowed for adding an S-band duplexer for full duplex communications.

5.2 Links between Surface Elements and Low-altitude Orbiters

For links between surface elements and low orbiters, the choice of link frequency affects link performance greatly. The higher frequencies allow for smaller mass and volume; however, the power requirements increase considerably. This is true if neither the surface transmitter nor the orbiting receiver have steerable high gain antennas, but instead have fixed low gain antennas.

Table 1 shows a comparison between UHF, S-band and X-band for a return link at 16 kbps to an orbiter in a 400-km orbit. The same antenna gain was assumed for both the transmit and receive antennas at each frequency. Note the difference in power level required between the frequency bands to achieve a 3-dB margin. This is due to the difference in space loss. This is why UHF is so attractive for links where there are no steerable antennas.

For landed elements at Mars communicating to a low orbiter, UHF is the most viable option when non-steerable antennas are employed on both ends of the link. S- or X-band could be applicable when the link is from a much smaller body, like an asteroid (Muses CN) or a comet (ST4 Champollion), where the range is much less.

When steerable high-gain antennas are assumed for either the receiver or transmitter, the advantages of UHF disappear. If a steerable antenna is used in the link, most likely on the orbiter, then a move up in frequency to S- or X-band is desirable. Moving up to a higher frequency band would benefit the surface elements in several ways. First, it would alleviate the mass and volume constraints. The biggest change is the size and mass of the antenna on the surface element. Secondly, it would allow the surface elements to take advantage of the greater availability of commercial-off-the-shelf (COTS) hardware developed for terrestrial (S-band) wireless systems. The orbiter antenna would only need a gain of 16.5 dBi at S-band to match the performance at UHF, as shown in Table 1. This gain could be achieved using multiple patches or an array of helices.

Moving up to a frequency higher than UHF would also result in a smaller satellite footprint, which has both advantages and disadvantages. A smaller satellite footprint would reduce the potential for interference and increase frequency reuse capability. On the other hand, a smaller footprint would make it difficult for the satellite to provide simultaneous coverage to multiple surface elements scattered over a wide surface area, if and when it is needed.

5.3 Links between Surface Elements and an Areostationary Satellite

As previously mentioned, an areostationary satellite is likely to have both a HGA and a MGA (or LGA). The MGA will provide a large geographic coverage and can be used for low rate links while the HGA can support high rate links. For high rate links (or links through the HGA), use of frequencies higher than UHF makes the most sense. Studies of an areostationary satellite at Mars have generally assumed that the relay links will be X-band up and down. Both ends of the link would have steerable reflector antennas and return-link data rates up to 1 Mbps could be supported. The transmit power from the surface would only be about 2 W RF with a 0.3-m antenna (effective isotropic radiated power [EIRP] of 57 dBm). One problem with this scenario is potential interference with the X-band DTE links. This will be discussed later.

While a higher frequency is more suitable for high-rate links through the HGA, UHF and S-band can be used to support low rate links. If UHF is used, it allows the areostationary satellite to use a MGA to close the forward and return links (2 to 8 kbps) with surface elements and low-altitude orbiters equipped with a LGA. The UHF antenna will have a global beam, which will cover the entire Mars disk and low-altitude orbiters and will make operations simple.

Table 2 – Mars UHF and X-Band Links to an Areostationary Satellite

Mars Telemetry Link Budget - Areostationary Satellite

Mars Radius **3398** **km**
Orbit Altitude **17100** **km**

		UHF Forward	UHF Return	X-Band Forward	X-Band Return
Elevation angle	**deg**	**30.0**	**30.0**	**30.0**	**30.0**
TRANSMITTER PARAMETERS					
Transmitter Power,	dBm	40.0	40.0	37.0	34.8
Transmitter Circuit Losses	dB	-1.0	-1.0	-1.5	-1.5
Antenna Gain	dBi	10.0	0.0	15.0	26.0
Axial Ratio	dB	3.0	3.0	1.5	1.5
Modulation Index	deg	60.0	60.0	60.0	90.0
LINK PARAMETERS					
Range	km	18586.7	18586.7	18586.7	18586.7
Link Frequency	MHz	437.1	401.5	7171.0	8425.0
Atmospheric Attenuation	dB	0.0	0.0	0.0	0.0
Space Losses	dB	-170.6	-169.9	-194.9	-196.3
RECEIVER PARAMETERS					
Sky temperature	K	240.0	240.0	240.0	240.0
Pointing angle (Rel. to Nadir)	deg	8.3	8.3	8.3	8.3
Antenna Gain	dBi	0.0	10.0	24.6	36.4
Axial Ratio	dB	3.0	3.0	1.5	1.5
Polarization Losses	dB	-0.5	-0.5	-0.1	-0.1
Receiver Feeder Losses	dB	-1.0	-1.0	-1.5	-1.5
Receiver Noise Figure	dB	3.0	3.0	3.0	3.0
System Noise Temperature	K	550.9	550.9	556.1	556.1
Noise Spectral Density	dBm/Hz	-171.2	-171.2	-171.1	-171.1
TOTAL POWER SUMMARY					
Received Power	dBm	-123.1	-122.4	-121.4	-102.2
Received Pt/No	dB-Hz	48.1	48.8	49.7	68.9
SUPRESSED CARRIER - COSTAS LOOP					
Loop Bandwidth	Hz	400.0	400.0	400.0	400.0
Carrier Power/Total Power		-6.0	-6.0	-6.0	0.0
Received Carrier Power	dBm	-129.2	-128.4	-127.4	-102.3
Squaring Loss	dB	0.0	0.0	0.0	-3.0
Carrier SNR in the Loop	dB	16.0	16.7	17.7	39.8
Required Carrier Loop SNR	dB	10.0	10.0	10.0	17.0
Loop SNR Margin	dB	6.0	6.7	7.7	22.8
DATA CHANNEL PERFORMANCES					
Data Symbol Rate	sps	4000	16000	16000	2000000
Data Bit Rate (1)	bps	2000	8000	8000	1000000
Data Power/Total Power	dB	-1.2	-1.2	-1.2	0.0
Data Power to Receiver	dBm	-124.4	-123.6	-122.8	-102.2
Eb/No to receiver	dB	13.8	8.5	9.3	8.9
Systems Loss	dB	-1.5	-1.5	-1.5	-1.5
Eb/No Output	dB	12.3	7.0	7.8	7.4
Threshold Eb/No	dB	4.6	4.6	4.6	4.6
Performance Margin	**dB**	**7.7**	**2.4**	**3.2**	**2.8**

6.4 Martian Atmospheric Gaseous Attenuation

The atmospheric gaseous attenuation at Mars is worse at a higher frequency than at a lower frequency. However, the worst-case loss (at Ka-band) is still less than 1 dB. This is because the Martian atmosphere has very low concentrations of gaseous H_2O and O_2. Martian gaseous absorption is at least three orders of magnitude lower than that at Earth. An accurate water vapor altitude profile at Mars is not yet available. A conservative estimate for worst-case Martian atmospheric absorption is an increase by a factor of 1.5.

6.5 Martian Background Noise Temperature

Radio noise emissions at Mars are mainly from its atmospheric emission and surface noise. Mars has lower surface temperatures, lower atmospheric absorption, and radiation, but higher surface emissivity (due to the roughness of soil and rocks). The actual radio noise contributing to the antenna temperature is strongly dependent on the antenna orientation, elevation angle, and gain pattern. For a downward-looking antenna, the total noise temperature is about the same as the Earth's for all frequency bands of interest. For an upward looking antenna, the sky noise temperature is the highest at UHF (about 55 K) and lowest at X- and Ka-band (about 5 K). The sky noise temperature, however, is only a small part the total receiving-system noise temperature, which is dominated by receiver thermal noise.

6.6 Martian Dust Storm Effects

Dust storms in Mars can significantly affect a communication link. A large dust storm can cause at least 3-dB loss at Ka-band. Lower frequency bands (UHF, S, and X bands) suffer less dust storm attenuation, which has a linear relationship with frequency. Most large storms occur in the southern hemisphere during later spring and early summer.

6.7 Communication Blackout during the Martian Atmospheric Entry Phase

When a high-speed spacecraft enters the Martian atmosphere, a plasma sheath is formed in the front of the spacecraft due to the impacting ionization. This can cause a communication blackout, the extent of which depends on the communication frequency. A 30-second communication disruption was observed by Mars Pathfinder (X-band) [6]; a 1-minute blackout was experienced by both Viking Landers (UHF). If the frequency of a communications signal is higher than the critical frequency of the surrounding plasma, a radiowave can pass through the plasma sheath freely and there will be no communication disruption. It is believed that this is the case at Ka-band.

6.8 Assessment of Overall Propagation Effects

The overall signal attenuation of a radio wave propagating in the Martian environment is listed in Table 3 for various frequency bands. Because Mars has a thin atmosphere and few clouds, high frequency waves will not suffer losses as large as they experience on Earth for line of sight propagation. From a propagation point of view excluding free-space loss, there is no significant difference for the four frequency bands considered.

Table 3 – Radio Wave Attenuation in the Mars Region for Various Frequency Bands

	VHF (100 to 500 MHz)	S-Band (2 to 4 GHz)	X-Band (10 to 12 GHz)	Ka-Band (30 to 38 GHz)
Ionosphere (absorption & scintillation)	0.5 dB	0.15 dB	0.1 dB	0.05 dB
Troposphere (scattering)	0 dB	0 dB	0 dB	negligible
Gaseous	0 dB	0 dB	< 0.5 dB	< 1.0 dB
Cloud	0 dB	0 dB	0.05 dB	0.1 dB
Rain	0 dB	0 dB	0 dB	0 dB
Fog	0 dB	0 dB	0 dB	0.1 dB
Aerosol (Haze)	0 dB	0 dB	0 dB	0.1 dB
Dust*	0 dB	0.3 dB	1.0 dB	3.0 dB
Total Vertical Losses	0.5 dB	0.45 dB	1.15 dB	3.35 dB

* Worst case

operations, accompanied by a proper frequency scheme. Both the multiple access scheme and the frequency usage plan must be addressed in the design of a Mars communication architecture. However, a flexible spectrum allocation plan is needed so as not to encumber future architecture development.

8.2 Multiple Access

There are three commonly used multiple access schemes: Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). In a FDMA scheme, each user is assigned a distinct frequency or frequency channel such that all users can simultaneously transmit (access) to a host without interfering with each other. The frequency channels can be pre-assigned or dynamically assigned by the host. In a TDMA scheme, each user is given a time slot or slots of a shared frequency channel. Each user will use the assigned time slots to communicate with the host. Again, the time slots can be pre-assigned or dynamically assigned by the host. In a CDMA scheme, all users can simultaneously transmit to a host over the same frequency channel. There are different CDMA techniques. The most common one is a direct-sequence CDMA (DS-CDMA), where the signal from each user is coded or spread by a direct PN sequence. Multiple users can simultaneously communicate with a given host without interfering with each other.

Each of the three schemes has advantages and disadvantages and maybe applicable for different exploration eras. CDMA in general possesses certain desirable features that may be important in the long-term when there are many users in the Mars system having different characteristics and requiring multiple access to one or more assets. DS-CDMA is operational simple, it is inherently robust in a multipath environment, it can readily provide time of arrival information, and it may make it easier for future missions to conduct near-Earth testing. Tables 4 and 5 summarize the advantages and disadvantages of CDMA relative to FDMA and TDMA, respectively. To realize the potential benefits, there must be a significantly large spectrum available to support CDMA. The performance of a CDMA system is related to the progressing gain, which is the ratio of the available spectrum to the bandwidth of the signal at baseband. For a given data rate, the larger the available spectrum, the larger the processing gain and the better the performance in terms of interference rejection. In this regard, the higher frequency bands (X- and Ka-bands) would be more suitable to accommodate CDMA than the lower frequency bands (UHF and S-band).

Table 4. Relative Advantages of FDMA, TDMA, CDMA

Good Points	**FDMA**	**TDMA**	**CDMA**
Orthogonal signaling	X	X	
Constant bandwidth for changing data rate			X
Diversity against multi-path			X
One receiver at the orbiter		X	X
Graceful degradation of overloaded channels			X
Can be overlaid on other systems (co-existence)			X
Consistent with signaling for ranging			X

Table 5. Relative Disadvantages of FDMA, TDMA, CDMA

Bad Points	**FDMA**	**TDMA**	**CDMA**
Inter-modulation distortion at orbiter	X		
Hard hand-off with multiple satellites in view	X	X	
May require channel reassignment for multiple rates	X	X	
Guard band (frequency or time)	X	X	
High peak power		X	
Time synchronization		X	
Higher baseband receiver complexity			X

areostationary satellite. However, there is one factor that may favor Ku-band over the 37-38 GHz band. Using the 37-38 GHz band for local high rate link would create an interference situation where a local high-rate link would interfere with a DTE link, if also operating in the 37-38 GHz band. Ku-band would not have this problem, regardless of what the DTE frequency is (X, Ka or the 37-38 GHz). It is therefore better to use Ku-band for local high-rate links and reserve the 37-38 GHz band for high-rate space-to-Earth links.

9.4 Self-testing

Deep-space missions carrying an in-situ communications system such as an UHF relay system often need and want to conduct an in-flight testing when the spacecraft is still very close to Earth. UHF is one of the frequencies suggested for Mars local links. Near-Earth testing at UHF can create both technical and regulatory problems, as it was demonstrated by the recent near-Earth testing conducted for the Odyssey mission. This issue must be addressed in developing a frequency plan.

9.4.1 Objectives of Near-earth testing

The fundamental reason is to validate proper operations of the in-situ communication system (such as the transceiver and the RF front end), calibrate equipment performance (e.g., antenna gain pattern), and detect any anomalies and malfunctions prior to arrival at Mars. In some mission scenarios, an exiting mission would serve as communication relay to a subsequent mission. Knowing the status and the performance of the relay system onboard a Mars bound spacecraft is crucial to planning the subsequent mission. As such it is necessary to test the relay package as soon as after launch.

9.4.2 The problem

Normally, an earth station with UHF transmit and receive capabilities would be needed to perform the test. The earth station would send a UHF carrier modulated with data to the spacecraft being tested, and receive a UHF downlink modulated with data from the spacecraft. The problem is that the UHF frequencies (both the forward and return subbands) are allocated for other applications. Conducting this kind of testing en-route can interfere with other users of the spectrum. The recently completed near-Earth UHF testing by Odyssey is an example. The test had to be modified, curtailed, and carefully coordinated to avoid potentially harmful interference to the GOES satellites in the geostationary orbit. Of particular concern was the strong UHF uplink needed to conduct the test.

9.4.3 Possible solutions

Perhaps the best way to avoid interfering with users of the UHF spectrum in the Earth environment is for the spacecraft to implement a self-test capability. Depending on the mission scenario, launch configuration and telecom design, it is possible to implement certain self-testing capabilities. Figure 4 shows a candidate self-test scheme being considered by a NASA mission, Deep Impact. Deep Impact employs S-band for the link between the spacecraft and the impactor. The self-test plan is however applicable to Mars missions carrying a UHF relay package, providing that the two elements at both ends of the relay link are being launched together.

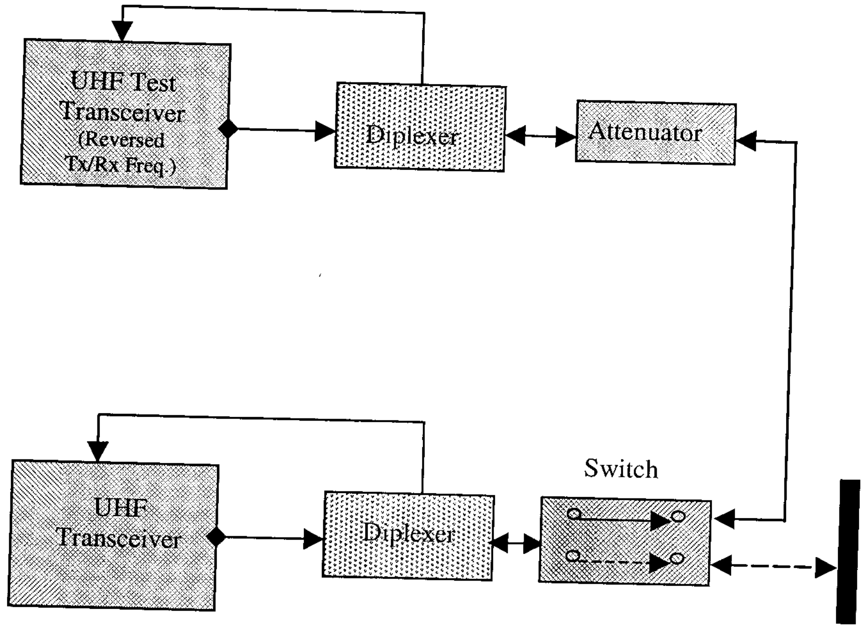

Figure 6. UHF In-Flight Test Block Diagram Flying a Single-String Telecom System (assuming that the spacecraft will carry a 2nd UHF transceiver for test only.)

While a self-test capability is desirable, it has limitations. One of the key objectives for an in-flight test is to calibrate the UHF antenna gain. This cannot be achieved by any of the onboard self-test schemes discussed. If such calibration is absolutely necessary, the self-tests can be augmented with an uplink test using an Earth station. The earth station in this case can transmit an unmodulated uplink carrier to the spacecraft at a pre-negotiated frequency that will minimize potential interference to other UHF users. The spacecraft must be frequency agile such that the best frequency (from interference point of view) can be used for this test. Another possibility is for the spacecraft to employ a spread spectrum signal such that the uplink signal can be spread over a wideband to minimize potential interference.

10. SUMMARY

The advantages of the frequency bands of interest have been analyzed in general terms for various types of telecommunication links or services. It is clear that no one single frequency is good for every type of link and meets all evaluation criteria. It is also clear that not all factors affecting the choice of frequency are equally important and that the relative importance of these factors could vary as a function of time. Multiple frequencies will be needed in the Mars region at different times and for different applications. It is necessary to adopt a flexible frequency allocation approach that will not be dependent on a specific exploration scenario, a specific architecture, or a specific multiple-access scheme. Toward this end, a frequency plan making use of the UHF frequencies augmented with S-band is proposed for Mars local links for the near-term and mid-term time frames. For the longer-term, the plan would continue to use UHF for Mars local links, mostly for low-rate links, and would employ Ku-band or the 37-38 GHz band for high rate links. Using X-band for local high-rate links is expected; but should be considered transitory.

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