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On the Sharing of Portions of the Band 25.25-27.5 GHz Between the Proximity Links in the Inter-Satellite Service and Local Multipoint Communications Systems in the Fixed Service

1.0 Introduction

This document addresses the potential for the sharing of spectrum in portions of the frequency band 25.25-27.5 GHz between proximity links operating in conjunction with the international space station and local multipoint communications systems (LMCS). In **Section 2** of this report the background on spectrum policy and spectrum utilization by this and neighbouring bands by these classes of system are described. In **Section 3** the characteristics of the proximity links and of LMCS systems are summarized; a more detailed description of these systems can be found in **Annexes B and C** of the report. In **Section 4** of the report the possibilities for sharing between the two services is discussed, based on more detailed quantitative sharing analyses in **Annexes D and E.** These findings are summarized and discussed in **Section 5.**

2.0 Background

This "background" over the period 1991 to the present is reviewed to the extent necessary to understand how the scenario of LMCS fixed systems sharing spectrum in the 26 GHz band with proximity links has evolved.

2.1 ITU Activities at WARC-92

The use of the 25.25 GHz band was addressed by WARC-92, primarily because of a foreseen need by space agencies, including the Canadian Space Agency, for use of this band for inter-satellite links to transmit wide-band data from low-orbiting spacecraft and space stations to the ground via a geostationary data-relay satellite such as TDRSS or its successors. The Canadian proposals to WARC-92 included the definition of a new radiocommunication service, the Space Communications Service, to provide precisely the spectrum required by those stated inter-satellite communications requirements, and also included the allocation of this new service on a primary basis throughout the band 25.25-27.5 GHz band.

WARC-92 did not accept the Canadian service definition proposal as such. However, it did allocate the band on a primary basis to the Inter-Satellite service over the complete band, and also included the footnote 881 A, as follows:

881A **(WARC-92)**Use of the 25.25-27.5 GHz band by the inter-satellite service is limited to space research and Earth exploration-satellite applications, and also transmissions of data originating from industrial and medical activities in space.

This footnote met the basic objectives of the Canadian WARC-92 proposals, to have the inter-satellite links in the band 25.25-27.5 GHz used only for scientific satellite and related applications.

2.2 The Evolution of Inter-Satellite Requirements Since 1992

In 1992 it was envisaged by space agencies that the Inter-Satellite allocation in the 22.55-23.55 GHz band would be used for communication from the ground via data-relay satellites in GSO, such as the TDRSS follow-on satellite series of satellites, to low-Earth orbit (LEO) satellites such as the space station, Radarsat or its follow-on, etc. The band 25.25-27.5 GHz would be used as the higher-capacity return link from the LEO satellites via the GSO data-relay satellites to the ground. The wider band was envisaged to be used as the return link because more traffic was anticipated in the return link than in the forward link.

Since 1992 a need has arisen for wide-band communication links between the space station and remote terminals. These "remote terminals" may be either astronauts or robotics, or both. These links would be used both near the space station for maintenance activities, and for scientific activities near the space station. The operational range of these links is 50 km. It should be noted that Canada is a significant contributor to the building and operation of the space station. A major part of Canada's activity related to the space station is the adaption of the Canadarm, developed first for the Shuttle, to maintenance, operations, and repair near the space station. This task has evolved to longer range activities. Thus the proximity links are an integral part of Canada's contribution to the successful implementation and operation of the station. Canada's activities of this nature cost in the order of $ 3 Billion, approximately 10 % of the cost of the currently envisaged space station.

Reconsideration of the use of the 25.25-27.5 GHz band to accommodate these proximity link requirements resulted in two bands becoming available, a "go" band and a "return" band. One of these is the 300 MHz wide band 25.25 - 25.55 GHz," the 25.4 GHz" band; the other is the 400 MHz wide band 27.1-27.5 GHz, the "27.3 GHz" band. These two bands are also referred to elsewhere in the report respectively as the Low Band and the High Band. Canada has suggested to the space station project office that these bands be divided into 60 MHz wide RF channels, with three such channels in each direction being used primarily for M & O activities at and near the space station. More detailed engineering work has considered a number of channelling plans, with channel bandwidth varying from 15 MHz to 45 MHz [3].

2.3 Development of Local Multipoint Communication Systems (LMCS)

Local Multipoint Communication Systems (LMCS) were developed first in the United States in the mid-1980's by the company "Suite 12 Group" in Freehold, New Jersey. These LMCS systems are also known in the USA as Local Multipoint Distribution Service (LMDS) systems. These systems are basically short-haul simplex or full-duplex systems in a short-range star network configuration. An extensive metropolitan area is served by a large number of local star networks. The traffic on

these networks is primarily point-to-multipoint television programming distribution, but may also include full-duplex information-highway type traffic. The characteristics of these systems are described below in Section 3.2, and in more detail in Annex C of the report. This section considers only the spectrum requirements of the system, and what action has been taken to acquire that spectrum.

The Suite 12 Group petitioned the FCC in December 1991 to re-designate the fixed service in the band 27.5-29.5 GHz from point-to-point microwave common carrier service to a local multipoint distribution service. In a Notice of Proposed Rulemaking [7] the FCC stated on December 10, 1992 that it intended to redesignate the fixed service in the band to accommodate multipoint technology. It invited comments from US industry by March 16, 1993. On July 13, 1995 the FCC released its ruling [8] that included a number of decisions on the use of the band 27.5-30.0 GHz in the USA. That ruling specified that LMDS systems in the USA could use for LMCS the bands 27.5 - 28.35 GHz and 29.1 - 29.25 GHz on a primary basis. The lower 850 MHz is shared with FSS on a secondary basis, and the upper 150 MHz is shared with feeder links to non-GSO MSS systems on a co-primary basis.

In a similar action, Western International Communications Ltd. (WIC) petitioned Industry Canada in September 1993 [2] to designate the fixed service in the band 27.5-29.5 GHz to LMCS systems. This petition was in response to Industry Canada's Gazette Notices DGTP-004-93 and DGTP-005-93, documents which were intended primarily to re-allocate the Canadian Table of Frequency Allocations following WARC-92. In part in response to this initiative on the part of WIC, Industry Canada issued a proposed spectrum policy document DGTP-013-94 [10] on December 15, 1994, which asked the Canadian public for comments on the designation of spectrum above 20 GHz for LMCS systems and for advanced communications satellite systems such as that being planned at CRC.

3.0 System Characteristics from a Spectrum-Sharing Perspective

In this section the characteristics of proximity link systems (in the Inter-Satellite service) and LMCS systems (in the Fixed service), also known as LMDS systems, are described. These descriptions are summaries of more detailed descriptions of proximity link systems in **Annex B** and LMCS systems in **Annex C**. These descriptions are not intended as a general description of the systems, but only of those characteristics used in the analysis of inter-service sharing.

3.1 Characteristics of Proximity-Link Systems

The proximity links considered in this study are to be used for wide-band video and multimedia communication between the space station and either astronauts or robotics at distances of up to 50 to 70 km. from the space station. The information used in the study was based on that obtained from Jack Miller, a NASA consultant [4] suggested as an information source by the Scientific Authority, and from a July 1994 publication of Steven M. Bolen, NASA Johnson Space Centre [3] provided by

Jack Miller.

The space station is assumed to be at altitudes ranging from 350 km to 430 km above the earth. The remote communication terminals may be as much as 70 km above or below the station, ie. may be anywhere in an altitude range from 280 km to 500 km above the earth.

A baseline design of the proximity links is a digital channel carrying 22 Mbps of information, not including additional bits for channel-encoding purposes. The modulation used will be either 4-phase PSK or 8-phase PSK, with or without channel encoding. The encoding in general reduces the required pre-detection link C / N ratio, but increases the required channel bandwidth. The complete system includes several such 22 Mbps channels in both the forward (base to remote) and return (remote to base) directions. The minimum bandwidth, that of an 8-phase PSK 22 Mbps system without channel encoding, is 14.7 MHz. The maximum bandwidth required, that of a half-rate 4-phase PSK system with the same information rate, is 44 MHz. Wider bandwidth higher data-rate channels may also be required; for example, channels with 88 Mbps to 110 Mbps are being considered, with correspondingly wider bandwidths.

A number of interference criteria were considered to determine the seriousness of interference into a proximity-link receiver. These include $\Delta T / T$, I / N over the signal bandwidth, and C / I over the signal bandwidth. $\Delta T / T$ or the ratio between worst-case interference-power-density and receiver noise temperature, requires the least information about the systems involved but is the least accurate in terms of the actual burden of the interference. I / N measured over the bandwidth of the desired signal is a more accurate measure of the actual burden of the interference, but requires knowledge of the bandwidth of the desired signal. C / I is the most accurate measure, but requires much more information about both systems, information which may not be available or which may change considerably before the design of the links is frozen. On that basis the measure used to evaluate the burden of the interference experienced was I / N integrated over the signal bandwidth. The full RF bandwidth is considered primarily because the signals are wide-band digital ones, rather than FDMA multiplexed narrow-band signals.

From that point, the only information required about the proximity links necessary to determine the burden of interference from LMCS systems is :

1. the overall noise figure or noise temperature of the proximity-link receiver, 773 ° K or 28.9 dB (° K)

2.1 the bandwidth of the received signal, 14.7 MHz to a much wider bandwidth. (As shown below, the minimum bandwidth is the most pessimistic assumption),

3. the antenna gain characteristics of the proximity-link receiving antenna, 32.55 dBi in the 27.3 GHz high band and 31.93 dBi in the 25.4 GHz low band, and

4. the location of the proximity-link receiver with respect to the interfering LMCS systems.

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3. the antenna gain characteristics of the proximity-link receiving antenna, 32.55 dBi in the 27.3 GHz high band and 31.93 dBi in the 25.4 GHz low band, and

4. the location of the proximity-link receiver with respect to the interfering LMCS systems.

As said above, the proximity link receiver may be anywhere between 280 km and 500 km, but at the minimum altitude it will be looking upward. It must be assumed to be pointing in the most pessimistic direction from an interference-reception perspective, consistent with it pointing towards the space station.

The other interference event that needs to be taken into account is that from the proximity-link transmitter into the terrestrial fixed receiver. The limit on the EIRP of the proximity-link receiver is controlled by the limits on the pfd on the Earth's surface from space station transmissions. It was decided at WARC-92 that this limit should be RR 2578. To determine whether the proximity link is in accordance with this constraint it is necessary to know only the link's maximum transmitted EIRP in any 1 MHz bandwidth, and the location and direction of transmission of the link.

The EIRP of the proximity link is 25.55 dBW at 27.3 GHz, and 24.93 dBW at 25.4 GHz. The maximum power-flux-density (pfd) on the Earth's surface from a proximity-link transmitter would occur when the link was pointed towards the Earth from the minimum altitude of the space station, 350 km. (Remote units may be at a lower altitude, but would be pointed upward when at those altitudes.) The minimum proximity-link bandwidth would be 14.7 MHz, if the modulation used was 8-phase PSK without channel encoding, as indicated in Table B.1 of Annex B. Based on this information and Equation A.8 of Annex A, the maximum pfd on the Earth's surface from such a transmission would be - 105.1 dBW per 1 MHz per m^2.

3.2 Characteristics of Local Multipoint Communication Systems

Local Multipoint Communication Systems (LMCS) are described in Annex C. In this section the information in that annex is summarized, concentrating on the information required for the inter-service interference analysis.

LMCS systems are short-range systems intended for use by individuals or perhaps offices. An LMCS local network would be in a Star configuration, with a central hub and user terminals on the periphery. The main traffic on the systems is analog FM television from the central hub to the remote receiving user terminals, but the system is also set up to handle full-duplex multi-media traffic between remote site and hub. There would be many such local star networks in a large metropolitan area.

Two models of LMCS system are described in References [1] and [2], denoted here as Systems LMCS-A and LMCS-B . Only the transmission characteristics of these systems are required, as the protection of the LMCS systems from harmful interference from satellite systems is specified by RR 2578. The transmission characteristics of these systems are provided in Table 1.

Table 1

Characteristics of LMCS Systems

LMCS System Type	LMCS-A	LMCS-B
Maximum Power, dBW/MHz	- 17.60	-12.30
Channel Bandwidth, MHz	18	18
Maximum APC, dB	0.0	20.0
Hub Antenna Gain, dBi	12.0	12.0
Max. Hub EIRP, dBW	6.95	2.25
Subscriber Antenna Gain, dBi	31.0	34.0

The cell size in rain zone N would be 4 km. Additional star-network cells with complete frequency re-use would be located every 4 km to provide complete service to a metropolitan area. The system LMCS-A is considered further, even though it has a lower maximum EIRP, because that 6.95 dBW EIRP is transmitted continuously even in clear-sky conditions. The EIRP of system B outside of the atmosphere is considerably less than that of system A, because the power of that system's hub transmitter is backed off as much as 20 dB during clear-sky conditions.

For the purposes of this interference analysis it is assumed that every cell in the beam of the proximity-link receiving antenna beam is carrying television traffic from the hub to the remote terminals, a reasonable assumption in the early days of the network's implementation. Further, it is assumed that all of the energy of the 18 MHz wide transmitted TV signal is in the narrow 14.7 MHz bandwidth of the proximity-link receiver. This is a reasonable assumption, given the spectral nature of an analog television signal. This assumption results in a "Bandwidth Factor" of +0.8 dB in the estimate of interference into the proximity link system that would not be present if a wider-bandwidth proximity-link signal format were assumed.

The other LMCS system characteristics necessary to determine the interference from those systems into proximity link systems are:

* the Hub elevation-angle antenna-discrimination characteristics, taking into account secondary ground reflections;

* clear air atmospheric attenuation as a function of elevation angle;

* rain zone of the LMCS system; and

* the affective area of a metropolitan area served intensively by LMCS systems.

Hub Antenna Effective Discrimination : The antenna is assumed to have the normal $\{ \theta/\theta_o \}^2$ main-lobe characteristics. However, the maximum discrimination is assumed to be 11 dB, due to the need to account for secondary re-transmission or reflections from the terrain [1].

Clear-Air Attenuation: This attenuation is significant at low angles, but drops off to about 2.5 dB at elevations of 8° or more. The complete clear-air attenuation function used is described in Table C-3 of Annex C. Clear-air conditions are assumed, as they are the norm, and interference from system LMCS-A is much greater during clear-air conditions.

Rain Zone: Rain Zone N is assumed, even though there is no rain zone N in Canada. The rain zone enters the interference analysis only through the effective radius of the LMCS cell. The reason for assuming the worst-case Rain-Zone N is that the proximity link would be subject to interference from any location on the globe, and if Canada exported LMCS equipment in such an area it would be implemented with the 4 km cells appropriate for Rain Zone N.

Metropolitan Area: Reference [1] suggests a "weighting" of 0.333 of the actual area seen by the proximity link's antenna beam. A modification to this is made in that it is assumed that the beam covers one large metropolitan area with 100 % coverage, plus 33.3 % coverage in other parts of the beam. That area is assumed to be 9,750 km^2, 50 % greater than that of the greater metropolitan Toronto area, essentially the area covered by the GO -Train system in metropolitan Toronto.

4.0 Interference Environment that Might Be Experienced in Sharing Spectrum Between Proximity-Link and LMCS Systems

In this section the interference environment is described at both the LMCS receiver and the proximity-link receiver. The power-flux-density (pfd) of the interference at the LMCS receiver fro a proximity-link transmitter is discussed in Section 4.1. The interference at the proximity-link receiver from all LMCS networks in the proximity-link's antenna beam is discussed in Section 4.2 in terms of the I / N ratio in the proximity-link receiver.

4.1 Interference into LMCS Systems from Proximity Links

As indicated above, the interference into LMCS systems from proximity links is discussed in detail in Annex E. It was decided at WARC-92 that the maximum pfd from space stations in the band 25.25 - 27.5 GHz would be specified by Radio Regulation 2578. That limit in RR 2578 is

- 115 dB(W/m^2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;

- 115 + 0.5(δ - 5) dB(W/m^2) in any 1 MHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and

- 105 dB(W/m^2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

As indicated in Section 3.1 above, the pfd from a proximity-link transmitter at the minimum space-station altitude of 350 km, pointing towards a remote receiver directly below it, would be - 105.1 dBW per 1 MHz per m^2 in the 27.3 GHz High band. At a 25° elevation angle the distance to the Earth would increase to 750 km, so the pfd would decrease to -111.7 dBW per 1 MHz per m^2. At a 5° elevation angle the distance would be 1660 km, so the pfd would be - 118.6 dBW per 1 MHz per m^2. At all angles the pfd is within the constraints of RR 2578, so there is no reason to believe that proximity links would cause harmful interference into LMCS systems.

4.2 Interference into Proximity Links from LMCS Systems

The interference into proximity links from LMCS systems is discussed in Annex D, using the relations developed in Annex A and the system characteristics described in Annexes B and C, and summarized in Section 3 above.

Tables D.2 and D.3 of Annex D indicate the aggregate interference to thermal noise ratio I_{agg} / N due to interference from LMCS systems in the proximity link's antenna beam, when the proximity link is at 350 km and 500 km respectively. Note that the proximity link would not suffer appreciable interference at a lower altitude because its antenna would be pointing away from the Earth. There is slightly more interference at the lower altitude, an increase of about 0.6 dB. As well, there is a mild variation in the magnitude of the interference when the proximity-link antenna is pointing towards the Earth at different elevation angles, the greatest I_{agg} / N is at elevation angles in the 20° to 40° range. The greatest (worst) I_{agg} / N is about -5.1 dB at an altitude of 350 km, and about -5.7 dB at an altitude of 500 km. It should be noted that the overall I_{agg} / N may be higher than these values, because other sources of interference such as fixed and mobile systems and other applications in the Inter-Satellite service have not been taken into account. (This evaluation was not requested.)

Table 2 provides a detailed description of the worst-case interference budget at the proximity-link receiver when the receiver is at a 30° elevation angle as seen from the ground at the centre of the proximity-link's antenna beam. As indicated, the interference can be considered as equivalent to thermal noise in the proximity-link receiver with a noise temperature in the 178° K to 238° K range.

Table 2

Interference Budgets and I / N Ratios

Link Parameter	Low Band, 25.4 GHz		High Band, 27.3 GHz	
	At 350 km	At 500 km	At 350 km	At 500 km
LMCS EIRP, dBW	**+ 6.95**	**+ 6.95**	**+ 6.95**	**+ 6.95**
Elevation Angle	30 °	30 °	30 °	30 °
LMCS Hub Disc., dB	**- 11.0**	**- 11.0**	**- 11.0**	**- 11.0.**
Clear-Air Atten., dB	**- 0.75**	**- 0.75**	**- 0.75**	**- 0.75**
Path Length, km	652	909	652	909
Free-Space Loss, dB	**- 176.87**	**- 179.76**	**- 177.50**	**- 180.39**
Antenna Gain, dBi	**+ 31.93**	**+ 31.93**	**+ 32.55**	**+ 32.55**
Spreading Loss, dB	**- 1.2**	**- 1.2**	**- 1.2**	**- 1.2**
Polarization Loss, dB	**- 3.0**	**- 3.0**	**- 3.0**	**- 3.0**
Carriers in Band, N_f, dB	0	0	0	0
Cell Area, km^2	78.5	78.5	78.5	78.5
Antenna Beam Width, Deg.	5.90	5.90	5.49	5.49
Actual Beam Area, km^2	6,017	10,892	5,599	9,431
Effective Beam Area, km^2	6,017	7,964	5,209	7,477
10 Log (No. Transmitters)	**+ 20.78**	**+ 23.04**	**+ 20.16**	**+ 22.42**
Rcvd. Interference, dBW	***- 133.16***	***- 133.79***	***- 133.79***	***- 134.42***
Link Bandwidth, dB (Hz)	+ 71.67	+ 71.67	+ 71.67	+ 71.67
Thermal Noise Temp dB(°K)	+ 28.88	+ 28.88	+ 28.88	+ 28.88
Thermal Noise Power, dBW	**- 128.05**	**- 128.05**	**- 128.05**	**- 128.05**
I / N, dB	***- 5.11***	***- 5.74***	***- 5.74***	***- 6.37***
Effective Interference Temp.	**238 ° K**	**206 ° K**	**206 ° K**	**178 ° K**

5.0 Summary

The spectrum-sharing analysis in this report has considered the potential interference between proximity links associated with the international space station and LMCS systems of the type considered for development in Canada. Interference from LMCS systems into a proximity link, and from a proximity link into an LMCS system, are both analyzed.

The systems considered in the analysis are LMCS systems as described by WIC to Industry Canada in 1994 [2], and as modelled in a Canadian contribution to ITU-R [1], and the proximity link system as modelled by NASA [3,4]. The frequency bands assumed to be used for proximity-link use in accordance with both decisions of WARC-92 and the current (1994) Canadian Allocation Table are 25.25 - 25.55 GHz and 27.1 - 27.5 GHz. In those bands the results of the sharing study are:

1. The maximum power-flux-density from the proximity link system on the Earth's surface varies with the altitude and inclination of the proximity-link transmitter, but may be as great as only 0.1 dB below the limit imposed by Radio Regulation 2578. Thus the power level of the link cannot be increased to lessen the burden of interference from the LMCS systems.

2. The worst - case aggregate I / N ratio in the proximity-link receiver from LMCS transmissions is in the order of - 5.1 dB. This value is quite high, given that other sources of interference from both other terrestrial fixed and mobile networks and other satellite networks have not been included in the interference budget. The noise is equivalent to wide-band (white) Gaussian noise at the proximity-link receiver with a noise temperature of up to 238 ° K . This is the case independent of the stochastic characteristics of an individual LMCS signal, since the aggregate interference would be due to many LMCS transmissions.

It should be noted that these results apply only to the LMCS systems proposed by WIC to Industry Canada. There are indications based on data available to NASA that there may be LMDS systems implemented in the USA with considerably higher power levels. Such systems may eventually find application in Canada if there are not constraints placed on the power levels of such systems by either national of ITU-R actions. The aggregate I / N in the proximity-link receiver would increase on a dB-for-dB basis with an increase in LMCS (or LMDS) transmitter power level, ie. a 10 dB increase in LMCS power levels would result in a + 4.9 dB I / N ratio, or a noise temperature of about 2,38 K .

A way of avoiding this potential problem without putting tight constraints on the future development of LMCS systems would be to avoid the proximity link frequency bands. This could be done in the 26 GHz frequency range by designating LMCS spectrum to be between 25.55 GHz and 27.1 GHz. There would still be the potential of harmful interference to data-relay links from LEO to GSO satellites, but at least that designation would avoid the potential problem of interference to proximity links, in which astronauts may be involved.

6.0 References

1. Canadian contribution WP 7B/9D/CAN 1 to the July 1995 meeting of Joint Working Group 7B/9D, "Considerations for Bandsharing Between the Inter-Satellite Service and the Fixed Service Employing Local Multipoint Communications Systems", 14 July, 1995

2. Submission of Western International Communications Ltd. (WIC) in response to Industry Canada Gazette Notices DGTP-004-93 and DGTP-006-93, Sept. 30, 1993.

3. Steven M. Bolen, "Proximity Operations Communications System (POCS) Design Overview", Final Report to NASA Johnson Space Centre, July 1, 1994.

4. private communication with Jack Miller, a consultant to NASA

5. Canadian First Draft Proposals in preparation for the ITU World Radiocommunication Conference WRC-95, March 9, 1995.

6. Canadian Proposals in preparation for the ITU World Radiocommunication Conference WRC-95, 18 August, 1995

7. FCC Notice of Proposed Rulemaking, December 10, 1992, to Redesignate the 27.5-29.5 GHz Frequency Band, and Policies for Local Multipoint Distribution Service.

8. Proposed 28 GHz Band Plan of the FCC, 13 July, 1995.

9. ITU-R Recommendation 837 (1992) : Characteristics of Precipitation for Propagation Modelling.

10. Canada Gazette Notice No. DGTP-013-94, Proposed Spectrum Policy to Accommodate Microwave Radio Systems, Including Local Wideband Distribution and Advanced Communication Satellites in Certain Bands Above 20 GHz, dated December 15, 1994.

Annex A

Basic Relations Used to Evaluate The Noise and Interference Environment at the Proximity Link Receiver

A.1 Introduction

In this annex the basic relations are developed to evaluate the magnitude and the severity of the interference from terrestrial LMCS transmissions at the receiver of a proximity link operating at or near the Space Station that is being developed in a international co-operative program by a number of Space Agencies, including CSE.

In **Section A.2** the criteria to be used to evaluate the severity of the interference from LMCS transmissions is chosen and developed. Interference into proximity link receivers that would result from sharing the band with terrestrial fixed LMCS systems is considered in **Section A.3.** In **Section A.3.1** the hypothetical interference environment at the proximity-link receiver is discussed qualitatively. That information is used in **Section A.3.2** in the development of detailed quantitative relations to be used to evaluate the magnitude of the resulting interference. The relations to be used to determine the magnitude of the other possible interference condition, that from the proximity links into the LMCS receivers, is considered in **Section A.4.**

A.2 Interference Criteria

A.2.1 Criteria to Evaluate Interference from LMCS Systems into Proximity-Links

Before it can be determined whether interference from LMCS systems is harmful, it is necessary to specify the measure with which that interference is to be measured. The options available for such a measure are:

1. a post-detection measure involving both the signal and the interference, such as the proximity-link signal-to-interference ratio if the desired signal is an analog one, or bit-error-ratio if it is a digital one; or

2. a pre-detection measure involving both the signal and the interference, usually the carrier-to-interference ratio, possibly compared to the pre-detection carrier-to-thermal-noise ratio; or

3. a comparison of the maximum pre-detection interference-spectral-density over a standard bandwidth, usually either 4 kHz or 1 MHz, sometimes expressed as a ΔT increase in the proximity-link system noise temperature T; or

4. a comparison of the total pre-detection interference-to-noise ratio over the bandwidth of the desired signal.

These four criteria are compared with the knowledge that the bandwidth of the desired proximity-link signal has been estimated at 60 MHz, but beyond that the details of the desired signal are unknown. Because a detailed design of the proximity link is not yet available, it would be difficult and rather speculative to use either of the first two criteria; they are more properly used in a detailed coordination activity, if such an activity were to be carried out at some later time.

The third criteria is very similar to the fourth, except that it would tend to concentrate on the maximum values of the spectral density of the interfering signal. This may lead to an incorrect conclusion, both because the desired signal is expected to be a single wide-band one, with the result that local peaks in the spectral density of the interference have very little effect on the intelligibility of the desired signal, and because the total interference is expected to be a combination of many incoherent small interfering signals, resulting in an interference environment similar to white thermal noise.

For these reasons, the fourth criteria is used, ie. the ratio of the total interference over the signal bandwidth to the total internal thermal noise of the proximity link over the same bandwidth.

The second decision to make in evaluating the severity of the interference is whether that evaluation should be the interference-to-noise ratio (I/N) of a single interfering signal, or the same ratio where I is the aggregate power of all LMCS signals interfering with that proximity link. The nature of the interference in this case is that there may be hundreds or thousands of interfering signals in the proximity-link system, no one of which is serious by itself but when combined with many other similar signals may be serious. Determination that a single-entry I/N ratio was very small would be of very little value unless the total number of interferers was known and the result of their combination in the proximity-link receiver were evaluated. For these reasons, the criterion used to evaluate the seriousness of LMCS interference is

the proximity-link system's I/N ratio, where I is the combined power of all the interfering LMCS signals at the proximity-link receiver, over the signal bandwidth, and N is the total internal thermal noise over that same bandwidth.

Thus relations are required and are developed in Section A.3 to determine the magnitude of the aggregate interference from all LMCS transmitters in the antenna beam of the proximity-link system. This aggregate interference level is then compared,, at different space-station locations, with the magnitude of the Gaussian thermal noise in the proximity-link system.

A.2.2 Criteria to Evaluate Interference from Proximity-Links into LMCS Systems

As indicated in Reference [1], the maximum pfd from a space station on the surface of the Earth in the 25.25 - 27.5 GHz band is indicated in Radio Regulation 2578 to be

- 115 dB(W/m^2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;

- 115 + 0.5(δ - 5) dB(W/m^2) in any 1 MHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and

- 105 dB(W/m^2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

This criteria was used in the Canadian contribution WP 7B/9D/CAN 1 to the ITU-R WP 7B/9D meeting in July 1995 [1], and will be used in a similar way this study. Thus relations are required and are developed in **Section A.4** to determine the pfd over a 1 MHz band on the surface of the Earth at different elevation angles.

A.3 Relations Describing the Aggregate Interference from LMCS Systems into a Proximity-Link Receiver

The interference into the proximity-link receiver is considered first in general terms in Section A.3.1, in enough detail that explicit relations can be developed in Section A.3.2 to determine the aggregate interference level I to compare with the thermal noise level in the proximity-link receiver.

A.3.1 General (Qualitative) Consideration of the Interference into the Proximity-Link Receiver

As described in **Annex B**, the proximity-link channels may be up to 60 MHz in width. The aggregate interference is the total interference power at the proximity-link receiver input from the composite of all LMCS transmissions over that 60 MHz bandwidth, over the area of the Earth's surface as seen by the proximity-link's receiving antenna. The expected frequency plan of the LMCS system is an RF channel every 20 MHz (see **Annex C**), so there are up to three statistically-independent RF carriers from each LMCS site. These carriers are likely to be analog FM television carriers, but they may alternatively be digital signals carrying either voice of data. An LMCS "cell" is considerably smaller in area than the area covered by the proximity-link's antenna beam, and the frequency is re-used in each LMCS "cell". As a result, the total interference into the proximity-link receiver is the addition of a number (in the range from 10 to 50) statistically-independent signals. The combination of a number of statistically independent signals is a Gaussian-like signal, the power

of that signal being the weighted sum of the powers of the individual signals, independent of the detailed characteristics of those signals. Because the composite is a Gaussian-like signal, its power can be added to that of the thermal noise in the proximity-link receiver to determine the power of the composite (I + N) signal. As stated above, the criterion of acceptability of that composite interference is the ratio I / N. Further detail of this interference is discussed in **Annex D**, taking into account the detailed characteristics of the proximity links as described in **Annex B** and the LMCS systems as described in **Annex C**.

A.3.2 Quantitative Consideration of that Interference

Based on Section A.3.1 above, the composite interfering signal is very close to Gaussian, independent of the characteristics of the individual LMCS signals, and so can be described simply by its power level over the 60 MHz of the proximity-link signal.

The power of the interference from a **single** LMCS transmitter at the proximity-link receiver is

$$I_{SE} = EIRP_{LMCS} - A_{Clear\ Air}(\theta) - D_{LMCS,PROX}(\theta) - FSL_{LMCS,PROX} + G_{PROX}(0) - D_{Polarization} \quad \text{A.1,}$$

where

$EIRP_{LMCS}$ is the EIRP of a single LMCS transmission;

$A_{Clear\ Air}(\theta)$ is the clear-air attenuation between the LMCS transmitter and the proximity-link receiver, at an elevation angle of θ degrees;

θ is the elevation angle of the proximity-link receiver as seen from the LMCS transmitter;

$D_{LMCS,PROX}(\theta)$ is the discrimination of the LMCS transmitting antenna in the direction of the proximity-link receiver, at an elevation angle of θ degrees;

$FSL_{LMCS,PROX}$ is the free-space loss between the LMCS transmitter and the proximity-link receiver;

$G_{PROX}(0)$ is the boresite (worst case) gain of the proximity-link receiving antenna; and

$D_{Polarization}$ is the reduction in the received interference power due to different signal polarization being used by the LMCS and proximity-link systems.

No account is taken of rain attenuation in the above equation, because the worst interference into

space systems is during clear weather [1], a situation a high percentage of the time. If the LMCS system has power control to apply during heavy rain, the value of $EIRP_{LMCS}$ that is used in determination of interference is the clear-air value.

The free-space loss $FSL_{LMCS,PROX}$ is given by the relation

$$FSL_{LMCS,PROX} = 92.5 + 20 \text{ Log}(f) + 20 \text{ Log}(d_1) \quad \text{A.2,}$$

where

f is the carrier frequency in GHz, and

d_1 is the separation between LMCS transmitter and the proximity-link receiver in km.

Thus the single-entry interference I_{SE} is

$$I_{SE} = EIRP_{LMCS} - A_{Clear\ Air}(\theta) - D_{LMCS,PROX}(\theta) - 92.5 - 20 \text{ Log}(f)$$
$$- 20 \text{ Log}(d_1) + G_{PROX}(0) - D_{Polarization} \quad \text{A.3.}$$

The aggregate interference at the proximity-link receiver is

$$I_{agg} = \sum_A \sum_F I_{SE}(d, \theta, f) \quad \text{A.4,}$$

where the addition is both $\sum_F$ over the frequency band of the proximity-link signal, and $\sum_A$ over the area of the proximity-link's receiving antenna beam.

In general, the different components $I_{SE}(d, \theta, f)$ in the double summation of Equation A.4 have different distances d_1 and elevation angles θ. However, because the receiving antenna of the proximity-link system is a high gain one, in the order of 32 dBi with a beam-width of about 4 °, all of the interfering LMCS systems are assumed to be at the same distance from the space station and at the same elevation angle.

With this approximation, Equation A.4 can be written in the form

$$I_{agg}(\theta, f) = EIRP_{LMCS} - A_{Clear\ Air}(\theta) - D_{LMCS,PROX}(\theta) - 92.5 - 20 \text{ Log}(f) - 20 \text{ Log}(d_1)$$
$$+ G_{PROX}(0) - D_{Polarization} + 10 \text{ Log}(N_f) + 10 \text{ Log}(A_P / A_L) \quad \text{A.5,}$$

where

N_f is the number of LMCS carriers in the bandwidth of the proximity-link system,

A_P is the effective area "illuminated" by the proximity-link receiving antenna, and

A_L is the area of an LMCS cell.

This aggregate interference I_{agg} may have different values at the lower and upper edges of the 25.25 to 27.5 GHz band, and may have very different values when the proximity link antenna points to areas on the Earth's surface with different elevation angles θ. Further simplification of Equation A.5 must await substitution of numerical values of the parameters in the equation; these parameter values are discussed in **Annexes B and C** .

A.4 Relations Describing the Interference from a Proximity-Link Transmitter into an LMCS Receiver

As discussed above in Section A.2.2, it is assumed, as in Reference [1], that the LMCS system is so-designed that it can accommodate interference from a space station up to the levels specified in Radio Regulation 2578. The magnitude of the interference power-flux-density on the surface of the Earth is

$$PFD = EIRP_{PROX} - FSL_{PROX,LMCS} + G_{1\,Meter} - 10\,Log(B_{PROX}) \quad \text{A.6a,}$$

$$= EIRP_{PROX} - 92.5 - 20\,Log(f) - 20\,Log(d_2)$$

$$+ G_{1\,Meter} - 10\,Log(B_{PROX}) \quad \text{A.6b,}$$

where

$EIRP_{PROX}$ is the EIRP of the proximity-link transmitter over its total signal bandwidth;

f is the carrier frequency in GHz;

d_2 is the distance from the proximity-link transmitter to the point on the Earth of interest in km;

$G_{1\,Meter}$ is the gain of an ideal 1 square meter antenna; and

B_{PROX} is the effective noise bandwidth of the proximity-link signal.

No account is taken of rain attenuation in this equation, because the worst interference is during clear-air conditions. Further, no account is taken of clear-air attenuation, because Radio Regulation states explicitly

> "These limits relate to the power flux-density that would be obtained under assumed free-space propagation conditions."

This condition is somewhat artificial, especially at very low elevation angles, but presumably WARC-92 would have set lower limits in Article 28 for the 25.25-27.5 GHz band if it were intended to take into account clear-air attenuation in determining the pfd on the Earth's surface.

Equation A.6b can be simplified by substituting an explicit function for the gain of a 1 square meter antenna, ie.

$$G_{1\,Meter} \equiv 21.44 + 20\,Log(f)\ dBi \quad \text{A.7.}$$

Substituting this expression in Equation A.6b, the result is

$$PFD = EIRP_{PROX} - 71.1 - 20\,Log(d_2) - 10\,Log(B_{PROX}) \quad \text{A.8.}$$

Further simplification and use of this equation is made in **Annex E**, based on the characteristics of the systems in **Annexes B and C**.

Annex B

Relevant Characteristics of Proximity Links

B.1 Introduction

This annex is not intended to be a general description of proximity links used in space activities. Such a description is available in Reference [3], the basis for much of the data in this annex. It was indicated to the author [4] by John E. Miller of Stanford Telecom of Seabrook Maryland, USA, that Reference [3] is a description of the current design of proximity links to be used on and near the space station being implemented by NASA, CSA, and other space agencies.

Rather, this annex is intended to simply provide all the information necessary to determine the proximity-link parameters of Equations A.5 and A.8 of **Annex A**. References [3] and [4] are used in the determination of those parameters.

B.2 Geometrical or Orbital Considerations

In this section the orbital characteristics of the space station are described. This information is used with other information to determine parameters θ, d_1, and A_P of Equation A.5, and the parameter d_2 of Equation A.8.

The planned orbit of the space station os a pseudo-circular orbit with an altitude in the range 350 km to 430 km, and an inclination of 51.6° with respect to the Earth's equatorial plane. The remote terminal of the proximity link may be as much as 70 km from the space station, at altitudes ranging from 280 km to 500 km.

B.3 Frequency Band and Channelization Considerations

There are two proposed frequency bands for space station proximity links in the band 25.25-27.5 GHz that was allocated to the Inter-Satellite service at WARC-92. It is proposed that there be a "lower" 300 MHz wide band from 25.25 GHz to 25.55 GHz, and a 400 MHz wide "upper" band from 27.1 GHz to 27.5 GHz. It is proposed that these bands be channelized into sub-bands up to 60 MHz wide, carrying multi-media digital traffic. This traffic will include:

* digital video traffic at an 88 Mbps to 110 Mbps rate, possibly requiring a complete 60 MHz wide channel,

* edited high-rate digital video traffic, at a 17 Mbps to 22 Mbps rate,
* edited low-rate digital video traffic, at a 3 Mpbs to 4 Mpbs rate,
* digital voice at a 19.2 kbps to 64 kbps rate, and
* telemetry and telecommand data at rates between 9.6 kbps and 56 kbps.

B.4 Link Characteristics Options

A baseline design of the proximity link system considered in Reference [3] is that an RF channel carry 22 Mbps of multi-media data. Four-phase and eight-phase PSK systems, both with and without channel encoding schemes, are considered for this application. The four of many possible schemes considered in detail in Reference [3] are:

* 4 φ- PSK without channel encoding,
* 4 φ- PSK with a 1/2 rate code,
* 4 φ- PSK with a 3/4 rate code,
* 4 φ- PSK with a 7/8 rate code,
* 8 φ- PSK without channel encoding,
* 8 φ- PSK with a 1/2 rate code,
* 8 φ- PSK with a 3/4 rate code, and
* 8 φ- PSK with a 7/8 rate code.

B.5 System Characteristics

The systems are designed to operate with a bit error rate not greater than $1.0 * 10^{-5}$. Characteristics of the various components of such systems are:

Maximum Transmitter Power:		1 watt, 0 dBW
TWTA Output power backoff:		7 dB
Maximum antenna gain:	**High band:**	**32.55 dBi, with a 5.49 ° beamwidth**
	Low Band:	**31.93 dBi, with a 5.90 ° beamwidth**
EIRP	**High Band:**	**25.55 dBW**
	Low Band:	**24.93 dBW**
Maximum Range:		50 km. (other data suggests up to 70 km may be required for some applications)