The Development of Performance, Interference, Sharing and Coordination Criteria

July 1986

Prepared for:

NASA Headquarters
Office of Space Science Applications
Code EC, John Kiebler
Washington, D.C. 20546

Contract No. NASW - 3973

Prepared by Tom Tillotson

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The Development of Performance, Interference, Sharing and Coordination Criteria

The criteria for sharing and coordination between the Earth Exploration Satellite service and other radio services has not been fully developed at this time. This purpose of this paper is to develop a plan showing how the necessary criteria might be developed.

Some criteria does exist in the form of general restrictions, protection criteria and coordination procedures for space and terrestrial services sharing the same bands. These criteria are as follows:

1) Power Flux Density Limits as outlined in Article 28 of the Radio Regulations. This Article does not pertain directly to the protection of EES services, but, does impose limitations on the power that a transmitting spacecraft can employ and will therefore have an effect on link performance and receiving system parameters. Limiting spacecraft transmit power will require more sensitive receiving systems that may in turn be more susceptible to interference.

2) Equivalent Isotropically Radiated Power Limits and antenna pointing limits as outlined in Article 27, RR. This Article was intended to protect systems operating in the GSO from fixed and mobile services but has a further effect on low orbit satellites in that a maximum e.i.r.p. of +55 dBW is specified for stations pointing in any direction. This level is still sufficiently high to cause interference to low orbit sensors or telecommunication links under a variety of conditions, but, provides some regulation.

3) Coordination areas determined per Appendix 28, RR, for coordination between Earth stations and terrestrial services. Coordination contours are an effective means of establishing the need for coordination. At present the only EES entry in Appendix 28 is in the 8025-8400 MHz. This band and the 65-66 GHz band are the only primary allocations for EES telemetry. Entries in Appendix 28 for EES bands having Secondary status may be valuable for coordination between services of equal status and for consideration by primary services.

4) Appendix 29, RR, delta T/T calculations for coordination between satellite networks utilizing the geoststionary orbit. Generally earth exploration satellites will be low orbit satellites and will not be subject to the criteria set forth in Appendix 29. Also, low orbit satellites are secondary to satellite systems utilizing the GSO. EES are, however,

utilizing the GSO for data relay (Earth Resource Budget Satellite now operational). In this case the actual service will be intersatellite or fixed-satellite supporting earth exploration and will have the same status as other data relay services utilizing the GSO. In general this Appendix will not apply to the EES service.

5) CCIR Recommendation 514 which specifies maximum received power densities from shared services. This recommendation is a broad statement of the performance and protection criteria required for earth exploration. It does not address specific EES telemetry bands in terms of sharing criteria, or adjustments to the protection criteria set forth. It sets forth baseline requirements which can be studied in more detail for specific telemetry bands.

Indicated in tables 1,2, and 3 are frequency bands allocated for EES telecommunications, EES passive sensing and EES active sensing. Shown in the tables is the allocation status, shared services and in some cases applicable criteria.

Criteria that actually specifies maximum permissible interference power at system inputs, such as numbers 3, 4, and 5 above, has been developed using system noise power as a reference. Number 4 above, delta T/T calculations, actually references interference to the equivalent noise temperature. Number 5, CCIR Recommendation 514, has a permissible interference level based on a 1 dB degradation in signal to noise which corresponds to an order of magnitude increase in the bit error rate. Knowing the system noise level and bandwidth, permissible interference can be specified as an absolute power or power/bandwidth. The level of permissible interference specified in Rec. 514 is used in Appendix 28 to determine coordination distances.

Determining suitable criteria for EES bands depends on the use of the band and the shared services. For example the criteria developed for an EES passive sensing band will be developed in a manner different than for a telemetry band. In either case the resultant criteria will be related to, and can be referenced from the system noise power or equivalent system noise temperature.

A general procedure can be followed to quantize the required protection criteria. This is as follows:

1) *Determine system characteristics.* This includes system noise temperature, desired BER, S/N or C/N, antenna gain, desired signal PFD, processing gains, reference bandwidth,

etc.

2) *Determine the degradation in C/N or S/N that can be tolerated.* This is usually based on the highest BER that can be tolerated, or, on signal aquistion thresholds.

3) *Calculate the interference power that results in the specified S/N degradation.* This is the power at the input of the receiving system from the output of the receiving antenna.

4) *Determine protection criteria based on the interference power.* This can be the actual level of interference power that causes the S/N degradation, or can be expressed as a percentage of noise power or noise temperature.

5) *Determine sharing criteria based on protection criteria.* This usually requires a knowledge of interferer populations or number of interference entries. Sharing criteria is then the maximum allowable interference from an individual interferer such that the cummulative interference does not exceed the protection criteria.

Developing Criteria for Telecommunication Bands

In telecommunication bands, interference and sharing criteria are needed to maintain data integrity whether the data is telemetry, telecommand, playback of stored scientific data, or real time scientific data. In an effort to gather information on EES telecommunication requirements we have looked at another service, the Space Research Satellite (SRS) service which has virtually identical telecommunication requirements. Some standards are presently being proposed for the Space Research Service (SRS) in CCIR SG2 document 2/1029-E, Protection Criteria Relating to Near-Earth Space Research Systems (see attachment). The very same approach outlined in this document can be applied to the EES.

The basis for developing protection criteria for receiving Earth stations in the referenced report is that a 1 dB degradation in the link threshold performance will result in harmful interference, and that this corresponds to an interference to noise (I/N) of -6 dB. Synonymous with link threshold performance in the last statement is signal to noise ratio. According to CCIR Report 544 where empirical data was taken on a narrowband phase-locked loop, a 1 dB degradation of S/N in the loop occurred when the I/N was approximately -3 dB. The actual I/N at threshold depends on the criteria selected for determining the threshold, i.e. loss of lock or rate of skipped cycles. Report

544 goes on to state that 1 dB degradation in the loop S/N for a typical operating level of 6 dB was enough to cause loss of lock.

A second justification for using a 1 dB degradation in S/N as the protection criteria is that at the typical BER rates used for space telecommunications, one error in 10^5 to 10^6 bits prior to error correction, this amount of degradation results in an order of magnitude reduction in the BER.

As put forth in CCIR Recommendation 514, a typical Earth station receiver may have a noise temperature of 100 K (-148 dBW/MHz), and utilizing a 1 dB degradation in S/N as the protection criteria, the total interference power in any 1 MHz band should not exceed -154 dBW/MHz, and given that cosmic noise will increase the system operating noise temperature 20 dB per decreasing frequency decade so shall the total permissible interference power increase.

For a receiving space station operating at approximately 600 K (-171 dBW/KHz) a 1 dB S/N degradation would occur at I/N levels of -177 dBW/KHz. CCIR Recommendation 514 specifies that techniques are available for protection against interference 10 dB above the noise level. This is usually done by increasing ES transmitter power and means that interference as high as -161 dBW/KHz can be tolerated. A more conservative approach, especially for use during orbit transfer or on manned missions would be to utilize a maximum interference level of -177 dBW/KHz as the protection criteria used in coordination procedures.

Developing Criteria for EES Passive Sensing Bands

Protection criteria has been established for passive sensing bands in CCIR Report 694 as 20% of the minimum discernable power. CCIR Report 693 establishes the minimum discernable power change to provide useful passive sensing. The criteria established from these two reports appears in Table 2. The first CCIR documents on passive sensing published in the early 1970's set forth the 20% of minimum discernable interference power criteria, a choice that is not fully explained in available literature.

Extensive analysis has been performed on all passive sensing bands to determine levels of interference that can be expected when operating over an industrialized area such as the U.S. The analysis can be found in two reports: Interference to Remote Passive Microwave Sensors from Adjacent and Subharmonic Bands, April 1985, NASA Contract NASW - 3973, and Analysis of Interference to Remote Passive Microwave Sensors, July 1986, NASA Contract NASW - 3973.

Sharing criteria in sensing bands where interference exists can be determined from the interference margin in those bands. For example utilizing present interferer statistics interference to sensors operating in the 10.6-10.7 GHz sensing band will be below threshold. However, within this band and in the lower adjacent band there are plans for Digital Termination Systems.

According to present estimates there are expected to be 10,000 nodal stations and 400,000 subscriber stations. An analysis was made to determine how many interferers of this station class could be in operation before a low orbit sensor received interference above threshold. It was determined that at a point where 3,500 nodal and 10,000 subscriber stations were in service, interference to the passive sensor would be above threshold (see NASW - 3973, July 1986, report referenced above, section 5.3).

Considering the estimates for future use of this service, an average reduction in total eirp towards the sensor of 4.6 dB for nodal and 16.0 dB for subscriber stations would be required for interference free sharing. This reduction can be realized through increased mainlobe gain and decreased transmitter power, decreased sidelobe levels, and decreased numbers of transmitters. The threshold for interference in this band is -156 dBW total power, therefore sharing criteria between the DTS station class and passive sensors should be established as -156 -4.6 = -160.6 dBW interference from individual nodal stations and -156 -16 = -172 dBW interference from individual subscriber stations.

Developing Criteria for EES Active Sensing Bands

An analysis of sharing between spaceborn active microwave sensors and terrestrial radar has been performed in CCIR Report 695-1. The report studied state of the art spaceborn synthetic aperture radar and terrestrial pulsed type radiolocation radar. Conclusions drawn from the report are: that in low gain modes no interference is expected from terrestrial stations, in high gain modes perceptible interference may occur and would be similar to that encountered by currently operating airborne mapping radars, and interference free SAR operation could be achieved through the use of limited receive power levels in the SAR at the cost of reduced dynamic range.

Based on the processing gain of the desired signal and that of the noise it was determined in Report 695-1 that the maximum undesired signal is -94 dBW. An analysis of the sidelobe to sidelobe coupling from terrestrial to spaceborn radars indicates that the received power from

systems outlined in Report 695-1 will be on the order of -112 dBW. This leaves an interference margin of 18 dB. For interference to occur during sidelobe to sidelobe coupling at least 63 interfering stations would have to be coherently transmitting; not a likely scenario. There will however be interference when the radar is on the horizon or overhead of the interfering stations and the terrestrial station sweeps past the satellite. Interference in such cases cannot be reasonably avoided because of the nature of the systems and are analyzed in the Report 695-1. The argument for interference free operation in this case is that the terrestrial station will not likely sweep past the satellite on every pass, therefore subsequent passes will result in uncontaminated images.

According to recent FCC and Government frequency lists there are some 4400 terrestrial radiolocation / radiodetermination systems presently operating near 1.2 GHz, only a fraction of which will be operating in the sensors passband. To establish sharing criteria would require a statistical analysis to determine how often a sufficient number of emitters would be coherently transmitting towards the radar during any given pass and the maximum number of passes to obtain an error free image would have to be determined.

Table 1. Frequency Allocations for the Earth Exploration Satellite Service

Frequency [GHz]	Link	Status	Comments and Sharing*	Applicable Criteria**
.401- .403	E-S	Secondary	Shared with: METEOROLOGICAL AIDS; SPACE OPERATION; Meteorological Satellite; Fixed & Mobile.	Appendix 29
.460- .470	S-E	Secondary	Subject to not causing harmful interference (671). Shared with: FIXED & MOBILE; Meteorological Satellite (S-E); Maritime Mobile (equipment to conform with app. 20).	Recommendation 514 Appendix 29
1.525- 1.535		Secondary	Shared with: SPACE OPERATION (S-E); FIXED & MOBILE; MARITIME MOBILE (S-E) (effective from Jan. 1990).	Article 27 (2502) Article 28 (2557) Appendix 29
1.69- 1.71	S-E	Secondary	Subject to not causing harmful interference (671). Shared with: METEOROLOGICAL AIDS; METEOROLOGICAL SATELLITE (S-E); FIXED & MOBILE.	Recommendation 514 Article 27 (2502) Article 28 (2553, 2557) Appendix 29
2.025- 2.11	E-S S-S	Secondary	Subject to interference agreement (747). Shared with: FIXED & MOBILE; (E-S)/(S-S) links of the Space Research and Space Operation Service (747).	Article 27 (2502) Appendix 29
2.2- 2.29	S-E S-S	Secondary	Subject to interference agreement (750). Shared with: FIXED & MOBILE; (S-E)/(S-S) links of the Space Research and Space Operation Service (750).	Recommendation 514 Article 27 (2502) Appendix 29
8.025- 8.175	S-E	Secondary Primary	in Regions 1 & 3. in Region 2. Shared with: FIXED & MOBILE; FIXED SATELLITE (E-S).	Recommendation 514 Article 27 (2502, 2505, 2507) Article 28 (2570) Appendix 28 Appendix 29
8.175- 8.215	S-E	Secondary Primary	in Regions 1 & 3. in Region 2. Shared with: FIXED & MOBILE; METEOROLOGICAL SATELLITE (E-S); FIXED SATELLITE.	Recommendation 514 Article 27 (2502, 2505, 2507) Article 28 (2570) Appendix 28 Appendix 29
8.215- 8.4	S-E	Secondary Primary	in Regions 1 & 3. in Region 2. Shared with: FIXED & MOBILE; FIXED SATELLITE (E-S).	Recommendation 514 Article 27 (2502, 2505, 2507) Article 28 (2570) Appendix 28

				Appendix 29
# 22.55- 23.		Primary	Inter-satellite link. Shared with: FIXED & MOBILE; BROADCASTING SATELLITE.	Appendix 29
# 23.0- 23.55		Primary	Inter-satellite link. Shared with: FIXED & MOBILE.	
25.25- 27.5	S-S	Secondary	Shared with: FIXED & MOBILE; Standard Frequency and Time Signal Satellite (E-S); FIXED SATELLITE in the 27-27.5 range.	Article 27 (2505, 2508) Appendix 29
29.95- 30.	S-S	Secondary	for telemetry, tracking and control purposes (882). Shared with: FIXED SATELLITE (E-S); Mobile Satellite (E-S); Fixed & Mobile.	Appendix 29
65.- 66.		Primary	No direction given. Shared with: SPACE RESEARCH; Fixed & Mobile.	Appendix 29

* Primary services are in CAPITALS, secondary services are in regular print. Footnotes are parenthesized.

** Parenthesized numbers indicated paragraph number of specified article.

The Earth Exploration Satellite Service is not allocated in these bands, but the Inter-Satellite Service may imply links with EES systems provided water vapor sensing is not carried out on the spacecraft near these bands.

Table 2. Allocations for Passive Sensors

Frequency [GHz]	Status	Comments and Sharing*	Interference Threshold [dBW]
1.400-1.427	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive).	-171.0
4.200-4.400	Secondary	Footnote allocation. Shared with: AERONAUTICAL RADIONAVIGATION.	-158.0
6.425-7.075	Secondary	Footnote allocation. Shared with: FIXED, MOBILE FIXED-SATELLITE (Earth to space)	-158.0
10.600-10.700	Primary	Shared with: FIXED, MOBILE, RADIO ASTRONOMY, SPACE RESEARCH, Radiolocation.	-156.0
15.200-15.400	Secondary Primary	15.2-12.35 GHz Shared with: FIXED, MOBILE, Space Research 15.35-15.4 GHz. Shared with: SPACE RESEARCH (passive), RADIO ASTRONOMY.	-160.0
18.600-18.800	Secondary	Regions 1 & 3 Shared with: FIXED, MOBILE,	-152.0

		FIXED-SATELLITE (space to Earth), Space Research (passive).	
	Primary	Region 2 Shared with: FIXED, MOBILE, FIXED-SATELLITE (space to Earth), SPACE RESEARCH (passive).	
21.200-21.400	Primary	Shared with: FIXED, MOBILE, SPACE RESEARCH (passive).	-160.0
22.210-22.500	Primary	Shared with: FIXED, MOBILE, RADIO ASTRONOMY, SPACE RESEARCH (passive).	-155.0
23.600-24.000	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive).	-157.0
31.300-31.800	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive) 31.5-31.8 GHz in Regions 1 & 3- Fixed, Mobile.	-156.0
36.000-37.000	Primary	Shared with: FIXED, MOBILE, SPACE RESEARCH (passive).	-146.0
50.200-50.400	Primary	Shared with: FIXED, MOBILE, SPACE RESEARCH (passive).	-157.0
51.400-59.000	Primary	Shared with: SPACE RESEARCH (passive) 54.25-58.2- GHz FIXED, MOBILE, INTER-SATELLITE.	-157.0
64.000-65.000	Primary	Shared with: SPACE RESEARCH (passive).	-157.0
86.000-92.000	Primary	Shared with: SPACE RESEARCH (passive), RADIO ASTRONOMY.	-138.0
100.000-102.000	Primary	Shared with: FIXED, MOBILE, SPACE RESEARCH (passive).	-150.0
105.000-126.000	Primary	Shared with: 105-116 GHz- RADIO ASTRONOMY, SPACE RESEARCH (passive), 116-126 GHz- FIXED, MOBILE, INTER-SATELLITE, SPACE RESEARCH (passive).	-150.0
150.000-151.000	Primary	Shared with: FIXED, MOBILE, INTER-SATELLITE, SPACE RESEARCH (passive), FIXED-SATELLITE (space to Earth).	-150.0
164.000-168.000	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive).	-150.0
182.000-185.000	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive).	-150.0

217.000-231.000	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive).	-150.0
275.000-277.00		Not allocated.	-150.0

Table 3. Allocations for Active Microwave Sensors

Frequency [GHz]	Status	Comments and Sharing*
1.215 - 1.3	Secondary	RADIOLOCATION, RADIONAVIGATION-SATELLITE Amateur
3.1 - 3.3	Secondary	RADIOLOCATION
5.25 - 5.35	Secondary	RADIOLOCATION, Space Research
8.55 - 8.65	Secondary	RADIOLOCATION
9.5 - 9.8	Secondary	RADIOLOCATION, RADIONAVIGATION
13.4 - 14.0	Secondary	RADIOLOCATION, Standard Frequency and Time Signal Satellite (E-S), Space Research
17.2 - 17.3	Secondary	RADIOLOCATION, Space Research (active)
24.05 - 24.25	Secondary	RADIOLOCATION, Amateur
33.5 - 35.6	Primary	RADIOLOCATION, Space Research
78. - 79.	Primary	RADIOLOCATION, Amateur, Amateur Satellite

Appendix A

Summary of Criteria Applying to EES and METSAT Services

RECOMMENDATION 514 CCIR study group II - Criteria for EES systems:

For earth receiving sites: total power is not to exceed -154 dB (W/MHz) for more than 1% of the time, for frequencies between 1 and 10 GHz.
For near-earth spacecraft receivers: total power is not to exceed -161 dB (W/MHz) for more than 1% of the time, for frequencies between 300 MHz and 10 GHz.

APPENDIX 28 Radio Regulations - Determining earth station coordination distances based on permissible interference power:

For EES Services: -154 dBW/MHz is the permissible interference power for a receiving earth station between 8025 and 8400 MHz.
For METSAT Services: -131 dBW/4KHz is the permissible interference power for a transmitting earth station between 7900 and 8400 MHz.

ARTICLE 27 Radio Regulations - EIRP restrictions on terrestrial services:

(2502) If the EIRP of fixed & mobile services between 1 and 10 GHz exceeds +35 dBW, the antenna should be directed at least 2° away from the geostationary-satellite orbit.
(2503) If the EIRP of fixed & mobile services between 10 and 15 GHz exceeds +45 dBW, the antenna should be directed at least 1.5° away from the geostationary-satellite orbit. [2] NOT APPLICABLE
(2504) For fixed & mobile services above 15 GHz, there are no pointing restrictions. NOT APPLICABLE
(2505) The maximum EIRP of a fixed or mobile service shall not exceed +55 dBW. [1,3]
(2507) The power delivered by a transmitter to the antenna of a station in the fixed or mobile service in bands 1-10 GHz shall not exceed +13 dBW. [1]
(2508) The power delivered by a transmitter to the antenna of a station in the fixed or mobile service in bands above 10 GHz shall not exceed +10 dBW. [2,3]

[1] Apply to the following frequencies:	1626.5	- 1645.5	MHz	(for countries mentioned in footnote 730)
	1646.5	- 1660	MHz	(for countries mentioned in footnote 730)
	2655	- 2690	MHz	(for Regions 2 & 3)
	5725	- 5750	MHz	(for countries in Region 1 mentioned in footnotes 803 and 805)
	5755	- 5850	MHz	(for countries in Region 1 mentioned in footnotes 803, 805 and 807)
	5850	- 7075	MHz	
	7900	- 8400	MHz	
[2] Apply to the following frequencies:	10.7	- 11.7	GHz	(for Region 1)
	12.5	- 12.75	GHz	(for countries in footnotes 848 & 850)
	12.7	- 12.75	GHz	(for Region 2)
	12.75	- 13.25	GHz	
	14.0	- 14.25	GHz	(for countries in footnote 857)
	14.25	- 14.3	GHz	(for countries in footnotes 857, 860 & 861)
	14.3	- 14.4	GHz	(for Regions 1 and 3)
	14.4	- 14.5	GHz	
	14.5	- 14.8	GHz	

[3] Apply to the following frequencies: 17.7 - 18.1 GHz
27.0 - 27.5 GHz (for Regions 2 & 3)
27.5 - 29.5 GHz

ARTICLE 28 Radio Regulations - Power flux-density limits for transmitting space services:

The power flux-density at the Earth's surface produced by emissions from a space station, including emissions from a reflecting satellite, for all conditions and for all methods of modulation, shall not exceed the following values:

Frequency	PFD Limits
(2553) 1670 - 1700 MHz:	-133 dB(W/m^2) in any 1.5 MHz band.
(2557) 1525 - 2500 MHz:	-154 dB(W/m^2) in any 4 KHz band for angles of arrival between 0° and 5° above the horizontal plane. -154 + 0.5 (∂-5) dB(W/m^2) in any 4 KHz band for angles of arrival ∂ (in degrees) between 5° and 25° above the horizontal plane. -144 dB(W/m^2) in any 4 KHz band for angles of arrival between 25° and 90° above the horizontal plane.
Apply to the following frequencies:	1525 - 1530 MHz (for Regions 1 & 3) 1530 - 1535 MHz (for Regions 1 & 3, up to January 1990) 1670 - 1690 MHz 1690 - 1700 MHz (for countries in footnotes 740 & 741) 1700 - 1710 MHz 2290 - 2300 MHz
(2562) 2500 - 2690 MHz	NOT APPLICABLE
(2566) 3400 - 7750 MHz	-152 dB(W/m^2) in any 4 KHz band for angles of arrival between 0° and 5° above the horizontal plane. -152 + 0.5 (∂-5) dB(W/m^2) in any 4 KHz band for angles of arrival ∂ (in degrees) between 5° and 25° above the horizontal plane. -142 dB(W/m^2) in any 4 KHz band for angles of arrival between 25° and 90° above the horizontal plane.
Apply to the following frequencies:	3400 - 4200 MHz 4500 - 4800 MHz 5670 - 5725 MHz (for countries in footnotes 803 & 805) 7250 - 7750 MHz
(2570) 8.025 - 11.7 GHz	-150 dB(W/m^2) in any 4 KHz band for angles of arrival between 0° and 5° above the horizontal plane. -150 + 0.5 (∂-5) dB(W/m^2) in any 4 KHz band for angles of arrival ∂ (in degrees) between 5° and 25° above the horizontal plane. -140 dB(W/m^2) in any 4 KHz band for angles of arrival between 25° and 90° above the horizontal plane.
Apply to the following frequencies:	8025 - 8500 MHz 10.7 - 11.7 GHz
(2574) 12.2 - 12.75 GHz	NOT APPLICABLE
(2578) 17.7 - 19.7 GHz	-115 dB(W/m^2) in any 1 MHz band for angles of arrival between 0° and 5° above the horizontal plane. -115 + 0.5 (∂-5) dB(W/m^2) in any 1 MHz band for angles of arrival ∂ (in degrees)

between 5° and 25° above the horizontal plane.
-105 dB(W/m^2) in any 1 MHz band for angles of arrival between 25° and 90° above the horizontal plane.

(2582) 31.0 - 40.5 GHz NOT APPLICABLE

APPENDIX 29 Radio Regulations - Threshold for coordination between satellite services utilizing the geostationary orbit:

If the calculated value of the increase in system noise temperature as compared to the equivalent system noise temperature, $\Delta T/T$, expressed as a percentage, is greater than the threshold value of 4%, coordination is required.

ATTACHMENT

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REPORT [AK/2] *

PROTECTION CRITERIA RELATING TO

NEAR-EARTH SPACE RESEARCH SYSTEMS

(Question 1-1/2, Study Programmes 1C/2 and 1D/2)

1. Introduction

Much of the spectrum suitable for space research is also allocated to one or more other services and thus frequency sharing between the services is required. This report discusses factors which affect the susceptibility of systems in the space research service to interference, and specifies appropriate protection criteria for the service in the frequency bands up to about 30 GHz. The protection criteria are for use in coordination and interference analyses when actual system data are unavailable.

2. General considerations

Four types of space research communications functions are telecommand, maintenance telemetering, stored scientific data and real-time scientific data. Interference affects each of these somewhat differently (see Report 548).

In telecommand, a fundamental principle of design of most research spacecraft is that no false command should result in a completely aborted mission and no unalterable state may be reached via any command. As there is usually an unavoidable severe dependence on the spacecraft telecommand system during critical mission phases such as during launch and injection sequences or during emergency situation, interference during these critical periods could severely compromise the mission.

Maintenance telemetering can be stored or sampled and transmitted in real-time. Except during critical periods, such as launch and injection sequences, emergency situations, or during bio-medical data transfer of human occupants, a maintenance telemetry system is fairly tolerant of interruptions and interference. During critical periods, read-outs must of course be highly reliable. The diagnostic use of these data makes it clear that at critical times in a mission there may be long periods (several hours) in which the maintenance telemetry must be protected from harmful interference. For other periods of a mission, however, this class of function can accommodate limited interruption without serious effect.

Stored scientific data can usually be played back more than once for error detection. This is probably the class of data most tolerant of interference of limited duration.

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* This Report should be brought to the attention of Study Groups 4 and

Real-time non-stored data are the most susceptible to interference, in that the transmission occurs only once and is unrepeatable. Much of the value of an expensive spacecraft may be represented by such data, so it is imperative that this class be well protected against interruption or degradation. Usually, the time of reception of interesting non-stored data is known in advance to within several hours.

Many space research systems employ PCM/PSK/PM modulating techniques and phase locked loop circuitry for the demodulation of system carriers and sub-carriers. High data rate transmissions are usually based upon BPSK or QPSK modulation. Phase locked loop circuitry is also used during search, acquisition and tracking sequences, and is employed in both ground and spaceborne receivers. Discussion of an experimental investigation into the interference effects in phase locked loops is presented in Report 544, Geneva 1982. In Report 545, Geneva 1982, the effects of interference on research spacecraft telemetering (especially binary bit detectors) are discussed.

3. Protection Criteria

In a communication link, the permissible ratio of interference to system noise may be determined by the portion of design margin allocated to external interference. In space-to-space and space-to-Earth links, the incentive is to minimize link margins, to save weight and power, to comply with emission limits, and in the interest of economy. Typical link design margins to allow for the effects of non-ideal conditions are generally in the range of 3 to 6 dB for spacecraft operating at frequencies below about 10 GHz. For spacecraft operating at frequencies above about 10 GHz, larger link margins are usually required to off-set the effect of weather conditions.

Considering these low link margins, interference can be harmful to typical space research systems if the link threshold performance is decreased by more than 1 dB. This corresponds to a required ratio of system noise spectral density to interference spectral density (N/I) of about 6 dB.

Where it was initially anticipated that channel coding techniques would allow operation with N/I ratios of -10 dB, it has been found through experience that a value of +6 dB is required.

3.1 Reference Bandwidth

The reference bandwidth in which a protection level must be specified depends upon the smallest bandwidth likely to be employed. For earth station receivers, phase locked loops may employ bandwidths of a few Hertz. The detection bandwidth on the space station is usually greater (1 kHz or more) due to the need for rapid, automatic acquisition of signals from the Earth.

Thus, recommended values for the reference bandwidths for space research receivers are:

Earth station receivers: 1 Hz
Space station receivers: 1 kHz

3.2 Reference Percentage of Time

In considering interference into space research earth stations, it is necessary to note that sporadic interference from man-made sources can be expected due to trans-horizon propagation, fluctuating weather conditions, and the changing gain in the link between the interfering station and the receiving station due to the relative motions of the antennas, etc. Therefore, any established criterion of interference must be stringent enough to minimize the possibility of this type of interference.

Further, as propagation data are usually presented in the form of a percentage of time that certain conditions are exceeded, it is necessary to relate outage time with propagation data. For manned space missions, a loss of more than five minutes of communication during critical periods would seriously affect the mission. However, propagation conditions are such that the least transmission loss between two stations will persist for much longer periods than five minutes. Therefore to provide protection which will prevent interference for longer than five minutes per day, it is necessary not only to consider the worst hour in the year, but also the worst five minutes within that hour. This is approximately 0.001% of the time. For unmanned missions, where safety of life is not a factor, the reference percentage of time is 0.1%.

3.3 Required Protection Levels

3.3.1 Earth Station Receivers

In the 1-20 GHz region, the total noise temperature of receiving earth stations is typically about 70K or greater depending on the antenna contribution. This contribution is a function of frequency, antenna elevation angle, existing meteorological conditions and ground and thermal radiation into the antenna side and back lobes. Below about 1 GHz, cosmic noise increases the operating noise-temperature of the system at the rate of about 20 dB per decade of decreasing frequency. Therefore based on the required N/I ratio of 6 dB established in Section 3.0, and a receive noise temperature of 70K, the following criterion is the most directly appropriate for the protection of earth stations:

In the frequency range 1-20 GHz, harmful interference can occur if the total time during which the power density of noise like interference or the total power of CW-type interference in any single band and all sets of bands 1 Hz wide, is greater than -216 dB(W/Hz) at the input terminals of the receivers for a period exceeding 0.001% of the time for manned missions, and 0.1% of the time for all other near Earth space research missions. For frequencies below about 1 GHz, permissible interference may be increased at the rate of 20 dB per decreasing frequency decade. This interference criteria applies to all three of the down-link communication functions discussed in section 2.

3.3.2 Space Station Receivers

The total noise temperatures of typical space station receivers is generally 600K or more. These levels are derived, in part, by the necessity of the spacecraft antenna to point at the Earth (290 K). Equivalently, then, based on the required N/I of 6 dB, the following criterion is most directly appropriate for the protection of space stations:

In the frequency range 100 MHz - 30 GHz, harmful interference can occur if, the power density of noise like interference or the total power of CW-type interference in any single band and all sets of bands 1 kHz wide, is greater than -177 dB(W/kHz) at the input terminals of the receiver.

Due to the motion of low orbit spacecraft, which are susceptible to this level of interference, the amount of time of exposure to the interference is limited to 0.1% of the time for both manned and unmanned missions.