# REPORT 1076

# CONSIDERATIONS AFFECTING THE ACCOMMODATION OF SPACECRAFT SERVICE FUNCTIONS (TTC) WITHIN THE BROADCASTING-SATELLITE AND FEEDER-LINK SERVICE BANDS

(Question 2/10 and 11, Study Programme 2L/10 and 11)

(1986)

## 1. Introduction

The Radio Regulations (No. 25) state that spacecraft service functions (TTC) will normally be provided within the service in which the space station is operating. The WARC-BS-77 provided no specific frequency slots for these functions except that it reserved guard bands at the edges of the 11.7 GHz to 12.5 GHz band for Region 1 and 11.7 GHz to 12.2 GHz for Region 3. A compatible frequency plan is assumed for the feeder links in the 17-18 GHz band as well. These guard bands could be used for the TTC space-to-Earth and Earth-to-space assignments.

It should be noted that some countries in Regions 1 and 3 may envisage the exploitation of the 14 GHz band for feeder links in the BSS. The use of guard bands in this frequency region may present difficulties because of sharing constraints with the FSS. Further studies are required.

As a matter of record, the RARC SAT-83 Final Acts specified that space services could be used in the assigned guard bands of 12 MHz at each end of the 12.2-12.7 GHz and 17.3-17.8 GHz bands for Region 2. The desired approach is to isolate TTC and broadcasting links to the extent that neither service is constrained by the other within the limits established by regulatory requirements.

The guard bands are limited when one considers the number of potential BSS satellites which may be located at a single orbital position. If many satellite systems are co-located at a single orbital position where each system may comprise several satellites each requiring TTC channels, excessive interference between the TTC and television broadcasting signals is a possibility. Thus, it appears necessary to develop technical guidelines for TTC frequency assignments. This Report attempts to define some of the important considerations associated with TTC assignment strategies and provides some technical data for estimating interference between TTC and broadcasting and feeder-link signals. The suggested sharing criteria have been derived for Regions 1 and 3 modulation characteristics with use being made of energy dispersal. Consequently, results may not be directly applicable for Region 2 satellites.

Although these guidelines are based on the application of traditional sub-carrier modulation techniques, it should be noted that alternative modulation systems are available. These are discussed in § 4 of this Report.

The alternative to using the guard bands would be to accommodate TTC assignments in either non-used or non-allocated broadcasting and feeder-link channels. Such possibilities will exist for practically any orbital position and frequencies will have to be agreed on a case-by-case basis rather than in a regular manner.

## TTC system requirements

### 2.1 *TTC functions* [CCIR, 1978-82a, b]

The TTC functions to be provided in the Earth-to-space direction are telecommand, ranging and spacecraft antenna tracking by means of radio-frequency sensing. In the space-to-Earth direction the functions are telemetry, ranging and earth station antenna tracking.

The telecommand signals are characterized as non-continuous low data rate transmissons, whereas telemetry signals are usually continuous low data rate transmissions. Ranging is usually accomplished with non-continuous tone or code ranging processors. Antenna tracking is performed with continuous RF sensing on CW or swept carrier signals using the residual carrier of the telecommand or telemetry signals as appropriate.

### 2.2 *Bandwidth requirements* [CCIR, 1982-86a]

The minimum bandwidth requirement for a TTC channel is determined by the tone ranging techniques and the stability of the on-board local oscillators. Applying temperature control techniques for this oscillator, a bandwidth assignment as low as 400 kHz may be sufficient for a stationary satellite. This value does not include the Doppler effect due to the satellite shift in relation to the Earth during the transfer phase. However, 400 kHz appears to be marginal when considering tone ranging and individual guard bands between TTC channels. One approach to conserving spectrum and providing flexibility is to assign 3 × 400 kHz, or 1200 kHz, to individual satellite broadcasting systems. Each system can internally coordinate their ranging operations with up to three satellites within this composite 1200 kHz band. Guard bands between the composite bands are required to differentiate between satellite systems. Figure 1 shows an example of this approach.

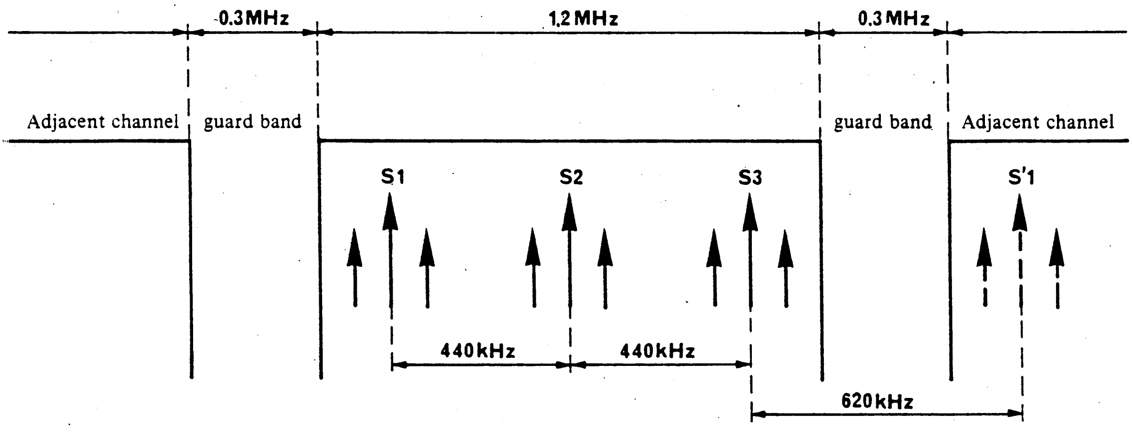

FIGURE 1 – *Signal spacing in space operation channels*

The number of TTC channels that can be accommodated in the guard bands (25 MHz for Regions 1 and 3 and 24 MHz for Region 2) does not appear to be a problem in terms of available bandwidth except for a few cases. The issue is rather how much separation in frequency is required between the closest TTC and television broadcasting channels, and how a sufficient decoupling of broadcasting and TTC signals can be achieved.

### 2.3 *Operational requirements* [CCIR, 1982-86a]

Distinctly different TTC requirements are needed during the launch, transfer orbit and geostationary orbit phases of a satellite. The latter phase includes nominal operations associated with a stabilized spacecraft, and non-nominal operations usually associated with loss of attitude control.

During nominal spacecraft operations all of the TTC functions need to be provided and some care will be needed to ensure proper signal qualities, the latter being particularly relevant for spacecraft antenna tracking. During satellite launch and transfer orbit and during non-nominal behaviour of the spacecraft in geostationary orbit, reduced requirements may suffice. In particular, spacecraft antenna tracking is not required. The major physical difference between these two modes of operation will be in the gain of the spacecraft antennas. In the latter case omnidirectional antennas will have to be employed and these, therefore, produce the limiting requirements for the e.i.r.p. levels of a general TTC system. Power could be reduced when using the primary service (broadcasting) transmission antennas.

The strategy for TTC frequency assignments discussed in § 4 should allow, in principle, the use of 12 and 17-18 GHz frequencies for TTC during any phase of the satellite life. However, certain limitations in e.i.r.p. levels will have to be respected in order to avoid an excessive interference environment with the BSS or other services. These points are discussed in § 3 and 4. Coordination between affected administrations, however, may resolve problems of a temporary nature on a case-by-case basis.

From the frequency management viewpoint the exclusive application of 12 and 17-18 GHz frequencies is believed to be beneficial in the long term and should actually form the baseline for any assignment strategy. Other constraints, in particular, the availability of TTC earth-station networks, may demand the use of lower frequencies during the transfer phase and during non-nominal in-orbit behaviour of the spacecraft.

The polarization of the 12-18 GHz TTC signals should be the same as for the primary service (broadcasting) signals. This enables the use of the same spacecraft antennas during the nominal spacecraft control periods. Opposite circular polarization between Earth-to-space and space-to-Earth links is preferable from the feeder-link operation viewpoint [Fromm and McEwan, 1981].

Using the same antennas for broadcasting and TTC functions also implies the need for sufficient frequency separation between the TTC and closest broadcasting signal on the same satellite. Preferably, this separation should amount to approximately 100 MHz or more to ease filtering requirements but lower separations of the order of only 30 to 40 MHz may be acceptable.

The links are to be provided for each spacecraft separately, during spacecraft launch and transfer orbit, with two or more earth stations around the Earth and subsequently with one principal earth station during nominal and non-nominal geostationary-orbit operations. Proper margins will have to be included for atmospheric effects. Spare satellites will be mandatory for most operational satellite broadcasting systems and individual TTC assignments will be necessary for each spacecraft. Replenishment studies suggest that up to three spacecraft in orbit may be required for any national satellite broadcasting system. This means that up to 48 TTC channels would have to be assigned in the event all available broadcasting channels are used at one satellite location. However, the typical requirement is expected to be less than 48 TTC channels.

### 2.4 *TTC earth stations*

The location of the principal TTC earth stations should be possible anywhere within the national territory of the country to be served or even outside. A location near the beam centre is preferable from the spacecraft antenna tracking viewpoint. It would be desirable moreover to use earth-station antennas having diameters which allow re-use of TTC frequencies for satellites which are at different nominal orbital positions.

### 2.5 *Implications of the Region 2 BSS Plan* [CCIR, 1982-86b]

Report 952 describes the feasibility of co-locating broadcasting satellites by slightly separating satellites which have adjacent cross-polarized broadcasting channels. The suggested nominal separation of 0.4° provides an additional 10 dB of isolation as compared to a co-located satellite for a 5 m earth-station antenna based on side-lobe characteristics recommended by the CCIR for this application. This level of isolation is applicable to TTC stations as well and can provide another element for reducing the interference environment between TTC and broadcasting and feeder-link signals.

### 2.6 *Alternative modulation techniques* [CCIR, 1982-86a]

Presently, most TTC services use traditional sub-carrier modulation techniques. However, considering the bandwidth limitations if many TTC channels are required, other modulation techniques may offer a solution to the potential interference problem, in particular when considering TTC operations during launch, transfer, and non-nominal spacecraft behaviour. A promising candidate is the use of spread-spectrum techniques in which all satellites at one location would use the same TTC RF signal frequencies, but would differentiate from each other by employing special codes.

## 3. Frequency sharing and service compatibility considerations

### 3.1 *Introduction*

Use of guard bands to transmit TTC signals raises questions about the mutual compatibility of the space operation service with any other services in the same or nearby frequency bands. Two types of compatibility should be considered:

- compatibility with the services using the bands adjacent to those allocated to the broadcasting satellite and feeder-link services: in the absence of information, this point is not dealt with in this section. Further studies are required;
- compatibility with the satellite-broadcasting and feeder-link services: TTC signals can interfere with broadcasting services in immediately adjacent channels and can receive interference from out-of-band emissions from the primary service (broadcasting). These mutual interferences suggest that protection ratios should be defined in order to ensure compatibility among services. Such compatibility will be subject to system characteristics and, in particular, of the modulation characteristics of the TTC signals, especially as the classical TTC sub-carrier concepts are expected to be more sensitive to unwanted emissions than spread-spectrum modulation techniques.

### 3.2 *Protection of adjacent broadcasting channels against TTC signals*

TTC signals should in no case impair broadcasting transmissions. Regarding the feeder links, tests carried out in France [CCIR, 1982-86c] showed that the protection ratio of the adjacent channels against the sum of interfering TTC carriers should equal 20 dB:

$$P_{TV}/(P_{TTC})_{total} \geqslant 20 \qquad \text{dB} \qquad (1)$$

where:

$P_{TV}$: carrier power of the adjacent channel signal at the payload receiver input;

$(P_{TTC})_{total}$: carrier power of the interfering TTC carriers at the payload receiver input.

However, due to the abrupt decrease in the effect of interference with increasing frequency separation between broadcasting and TTC signals, it has been demonstrated that the following ratio is sufficient:

$$P_{TV}/P_{TTC} \geqslant 26 \qquad \text{dB} \qquad (2)$$

where $P_{TTC}$ is the power of a single TTC interferer carrier at the payload receiver input. Further studies are required to confirm this value.

### 3.3 *Protection of TTC signals against broadcasting signals*

Taking into account the importance of TTC signals for proper functioning of the satellite, transmission of these signals should not be affected by out-of-band emissions of television signals. For the feeder link, the main source of interference is the signal on the adjacent channel (channels 1 or 40 in Regions 1 and 3). Tests on these risks of interference have been conducted in France [CCIR, 1982-86d]. With the television signals available in the laboratory, tests have shown that the following protection ratio is necessary for a TTC signal at the edge of the feeder-link channel (nominal frequency separation between TTC and feeder link signal equals 13.5 MHz):

$$P_{TTC}/P_{TV} \geqslant -27 \qquad \text{dB} \qquad (3)$$

where:

$P_{TTC}$: carrier power of the TTC signal at the input of the TTC satellite receiver input;

$P_{TV}$: carrier power of the feeder-link signal at the TTC satellite receiver input.

The test conditions and detailed results are provided in Annex I.

For the down link, the problem of interference is more complex because of intermodulation products in the satellite repeater and other interference sources. Further studies are required. Provisionally, the protection requirements derived for feeder-link interference may also be applied to the down link.

## 4. Considerations concerning TTC-frequency assignments

The objective for any TTC-frequency assignment must be to provide maximum flexibility for the design of TTC links while respecting all protection requirements. Maximum flexibility in the given environment is obtained when allowing TTC links to be operated in a given frequency slot with the largest possible range of signal variations. The upper limit in TTC signal level is constrained by the permissible interference into the adjacent broadcasting channel. The lower limit is set by the protection requirement of the TTC link itself. This level is critically dependent upon the TTC modulation parameters. Typical data valid for the Regions 1 and 3 interference environment is discussed in § 3 with complementary information in Annex I.

### 4.1 *Atmospheric attenuation and depolarization*

Atmospheric attenuation and depolarization will affect satellite broadcasting links, feeder links and TTC links. Proper link margins will have to be incorporated into any particular design. Relevant data can be found in Report 564. The applicable service availability requirement for TTC links may be influenced by specific requirements but for the sake of this study 5 dB and 10 dB rain margins are assumed for the 12 and 18 GHz bands, respectively. For TTC systems, it is desirable to provide an availability exceeded for 99.9% of the worst month. Where the rainfall rate and elevation angle are such that the attenuation exceeds the values assumed, then special means such as site diversity may need to be used.

Atmospheric depolarization is of major influence in determining the maximum permissible e.i.r.p. for TTC signals (sub-carrier techniques). Rain-induced depolarization, in the absence of power control, is normally of little practical concern because of the simultaneous attenuation of the depolarized component. In contrast, ice-depolarization may determine the critical interference situation. In the absence of detailed information, it is suggested that depolarization factors of $-20$ dB and $-15$ dB for 12 GHz and 18 GHz links, respectively, should be assumed.

### 4.2 *Sub-carrier modulation*

When applying the protection requirements derived in § 3 for mutual interference between TTC, broadcasting and feeder links, it becomes obvious that interfering links need to be isolated by means of orthogonal polarizations. This, together with the system requirements discussed in § 2.1 and 2.2 suggest the generalized frequency and polarization assignment concept as illustrated in Fig. 2a. The concept has been developed around the Regions 1 and 3 down-link Plan and assumes tacitly that the feeder-link Plan will be a transposition of the down-link Plan. It makes use of the regularity of the broadcast assignments. Feeder and broadcasting links and spacecraft service links to and from adjoining service areas have been assigned frequencies on orthogonal polarizations.

Certain orbital positions enjoy, for their first and last channels, frequency assignments in only one polarization. In such cases an alternative frequency arrangement for TTC channels can be considered as illustrated in Fig. 2b. This concept is fully compatible with that of Fig. 2a with no extra bandwidth requirement. The difference is that all TTC links are on opposite polarization with regard to the interfering and interfered-with broadcasting feeder-link channel.

As discussed in § 2, any individual satellite system shall be assigned 1200 kHz bandwidth. To allow for decoupling between satellite systems, a guard band of some 100 to 300 kHz should be inserted. This may lead in certain cases to conflicting requirements with the available bandwidth in the guard band, but in most practical cases all TTC signals can be accommodated. Specific concepts for detailed frequency assignments require further study.

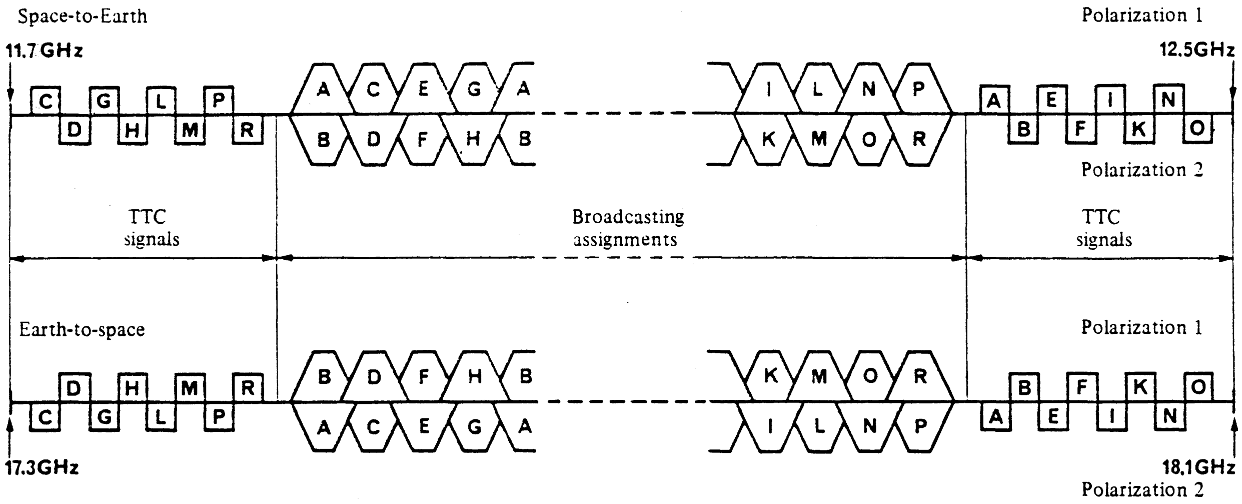

FIGURE 2a – *Proposal for TTC assignments for broadcasting satellites assuming sub-carrier modulation techniques for TTC signals: generalized concept for Region 1 assignments*

*Note 1.* – A to R denote service areas or countries.

*Note 2.* – The Region 3 concept can be derived by introducing applicable frequencies and number of channels.

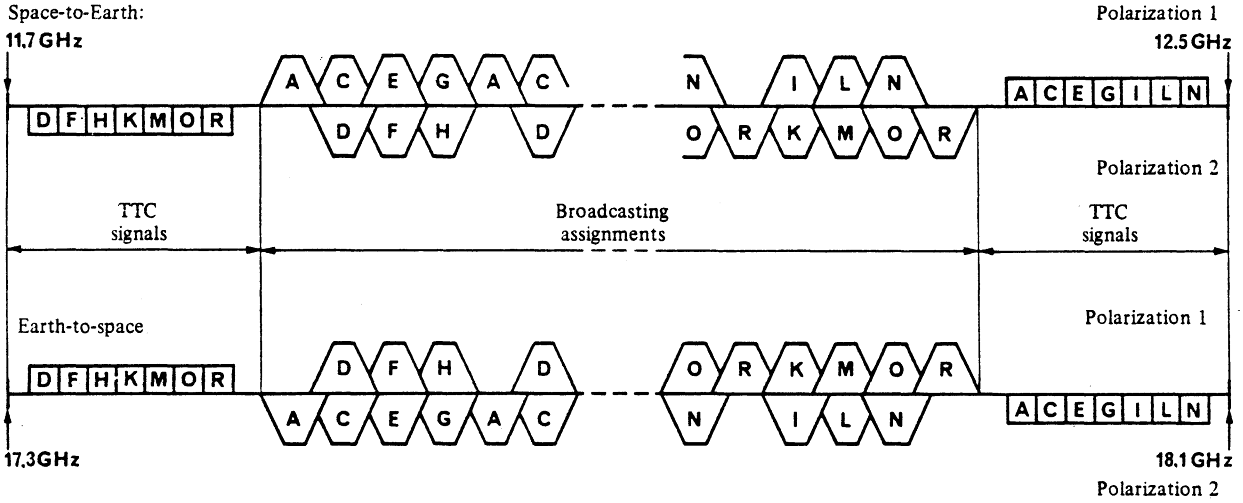

FIGURE 2b – *Proposal for TTC assignments for broadcasting satellites assuming sub-carrier modulation techniques for TTC signals: alternative concept (see text)*

*Note 1.* – A to R denote service areas or countries.

*Note 2.* – The Region 3 concept can be derived by introducing applicable frequencies and number of channels.

The protection of the first and last broadcasting or feeder-link channel requires the specification of a maximum permissible e.i.r.p. for sub-carrier TTC signals. From the interference viewpoint this will only be necessary for the TTC channels closest to the broadcasting or feeder-link channel but overall system homogeneity considerations suggest applying a maximum level generally. Margins for atmospheric attenuation and depolarization will also have to be taken into account. However, there appears to be no need to assume simultaneous attenuation on the feeder or broadcasting link and ice depolarization on the TTC link. For further detailed information, reference is made to a similar consideration relevant for feeder links [Fromm and McEwan, 1981]. With this assumption the maximum permissible e.i.r.p. for TTC links is calculated as follows (all values are in dB):

Earth-to-space direction:

$$e.i.r.p._{TTC} \leqslant e.i.r.p._{TV} - PR + 15 \quad \text{dB}$$

Space-to-Earth direction:

$$e.i.r.p._{TTC} \leqslant e.i.r.p._{TV} - PR + 20 \quad \text{dB}$$

where:

$e.i.r.p._{TTC}$: maximum permissible e.i.r.p. of TTC signals;

$e.i.r.p._{TV}$: nominal e.i.r.p. of the interfered-with broadcasting or feeder-link channel;

$PR$: protection ratio for TTC interfering into broadcasting feeder-link channels (see § 3).

The values "15 dB" and "20 dB" are taken from § 4.1 and represent the worst-case atmospheric depolarizations. Typical link budgets satisfying these requirements are given in Annex II.

The clear-sky overall cross-polarization isolation is about 25 dB because of imperfect antenna performance. This suggests that attenuation margins for broadcasting or feeder links in excess of 5 dB and 10 dB, respectively, would lead to a different specification for the maximum permissible e.i.r.p. of TTC links in both directions:

$$e.i.r.p._{TTC} \leqslant e.i.r.p._{TV} - PR - ATT + 25 \quad \text{dB} \tag{4}$$

where:

$ATT$: permissible (planned) attenuation on Earth-to-space feeder link (> 10 dB) or space-to-Earth broadcasting link (> 5 dB).

The proposed concepts for TTC frequency assignment avoid frequency re-use and are thus in principle compatible with omnidirectional or similar spacecraft TTC antennas with poor cross-polarization performance. Such antennas would be required if TTC links in the 12 and 18 GHz bands should also be operated during satellite launch, transfer or during non-nominal behaviour of the spacecraft in orbit. Obviously, such operations have to be carried out in compliance with the protection requirements. Otherwise, temporary deviations from these requirements will have to be coordinated among the administrations concerned. In particular, e.i.r.p. levels required for feeder-link TTC signals into omnidirectional spacecraft antennas can exceed the maximum value permitted. This could lead to critical interference situations and special coordination will be required for such cases. Applying the frequency concept with orthogonal polarization decoupling as introduced with Fig. 2b, is expected to facilitate such frequency coordination.

Example link budgets together with other observations are discussed in Annex II.

### 4.3 *Alternative TTC modulation techniques*

The frequency assignment concept suggested in § 4.2 implies that any alternative TTC modulation technique must be compatible with the bandwidth and e.i.r.p. assignments discussed in § 4.2. If it is a technique such as spread-spectrum modulation, it is not likely to cause any significant additional interference as compared to the sub-carrier signals. Additionally, alternative TTC modulation techniques must be able to coexist with sub-carrier signals. This appears to be possible with spread-spectrum techniques although further detailed studies are required. A preliminary concept, which may make easier the simultaneous operation of nominal TTC links and those required for satellite launch, transfer and non-nominal in-orbit behaviour, is reviewed in Annex III.

## REFERENCES

FROMM, H. H. and McEWAN, N. J. [May, 1981] Direct broadcast satellite feeder links: an example of possible implications of the Regions 1 and 3 Plan for feeder links to European broadcast satellite. ITU/Canada Seminar on RARC, 1983, Ottawa, Ontario, Canada.

*CCIR Documents*

[1978-82]: **a.** 10-11S/178 (ESA); **b.** 10-11S/153 (France).

[1982-86]: **a.** 10-11S/35 (ESA); **b.** 10-11S/26 (United States of America); **c.** 10-11S/8 (France); **d.** 10-11S/9 (France).

## ANNEX I

### TTC SIGNAL PROTECTION FROM THE ADJACENT TELEVISION CHANNEL IN THE FEEDER LINK

Tests carried out in France have studied the problems of feeder-link interference from the adjacent television channel to TTC signals (command and ranging). Tests were made using the equipment of a space operation service earth station and a model of the satellite command receiver. Conventional sub-carrier modulation techniques were used for the TTC signals. The television interferers were compatible with the technical characteristics of the RF channels specified in the Final Acts of the WARC-BS-77. Energy dispersal (600 kHz) was used. The TV carrier was modulated by the following video and sound signals:

- CCIR test lines (17, 18, 330, 331), white, grey and black lines or SECAM test card;
- two analogue sound sub-carriers.

Measurements were made on the carrier lock, the command bit error ratio and the ranging error. With the video and sound signals available in the laboratory, the worst case of interference was due to discrete lines from out-of-band TV spectrum emissions which were in the TTC band. The power of these discrete lines was equal to −30 dB (reference 0 dB being the total power of the adjacent TV channel). This −30 dB value corresponds to a −50 dB(W/Hz) power density in a 4 kHz band if energy dispersal is considered. This value is compatible with information given in Report 807 about the typical out-of-band envelope of the TV spectrum. In this case, tests have indicated a requirement for a −27 dB protection ratio for the TTC signal when the latter is at the edge of the adjacent television channel.

Because of the limited number of video signals used in the tests, other considerations on the maximum value of the discrete lines in the TTC band have been used to obtain the worst case of interference. In this case, measurements have given a −17 dB protection ratio corresponding to instantaneous discrete lines which could reach a −20 dB level (relative to the total power of the adjacent television channel). Further studies are required to confirm this probably pessimistic value of −20 dB.

## ANNEX II

### SUB-CARRIER TTC LINKS

### 1. **Example link budgets for sub-carrier TTC links** [CCIR, 1982-86a]

These link budgets are provided for illustration only. Assumptions are explained where essential. Budgets for specific satellite designs may differ.

### 1.1 *Earth-to-space links*

#### 1.1.1 *Nominal operations*

Table I presents a link budget that is valid for the nominal operation of the spacecraft in geostationary orbit. Distinction is made between the classical telecommand and ranging function and the specific requirements due to RF sensing which actually determine the link design.

#### 1.1.2 *Non-nominal operation*

Table II presents a link budget that refers to operations during satellite transfer and during non-nominal behaviour of the spacecraft in geostationary orbit.

TABLE 1 – *Example link budget for nominal operation, sub-carrier TTC links*

| | Link parameter | Telecommand ranging function | RF sensing function | Notes |
|---|---|---|---|---|
| 1 | $C/N_0$ (dBHz) | 60 | 60 | Required for RF sensing |
| 2 | Spacecraft receive antenna gain (dBi) | 40 | 26 (¹) | Lower RF sensing gain due to coupling loss |
| 3 | Receive thermal noise temperature (dBK) | 33 | 43 (¹) | Higher RF sensing noise temperature due to switching/redundancy |
| 4 | Receive noise power density (dB(W/4 kHz)) | – 160 | – 150 | At receive input |
| 5 | Receive interference power flux-density (dB(W/(m$^2$ · 4 kHz))) | – 148 | | Assumes:<br>$e.i.r.p._{TV}$ = 85 dBW,<br>20 dB cross polarization gain and spectrum at ± 15 MHz off centre (– 50 dB(W/4 kHz)) |
| 6 | Receive interference power density (dB(W/4 kHz)) | – 154 | – 168 | (5) + (2) – 46 dBm$^2$ |
| 7 | Total receive noise power density $N_0$ (dB(W/4 kHz)) | – 154 | – 150 | Sum of (4) and (6) |
| 8 | Required receive level at receiver input (dBW) | – 130 | – 126 | |
| 9 | Link margin (dB) | 10 | | Rain attenuation margin (see § 4.1) |
| 10 | Required earth-station e.i.r.p. (dBW) | 49 | 67 | Higher level may need to be used |
| 11 | Maximum permissible e.i.r.p. according to § 4 (dBW) | 69 | | $e.i.r.p._{TV,min}$ = 80 dBW is assumed |

(¹) Data refer to a particular satellite design and are not generally applicable.

TABLE 11 – *Example link budget for satellite transfer orbit and non-nominal operations, sub-carrier TTC links*

| | Link parameter | Telecommand ranging function | Notes |
|---|---|---|---|
| 1 | Required receive $C/N_0$ (dBHz) | 45 | (¹) |
| 2 | Spacecraft receive antenna gain (dBi) | −6 | Omni-type antenna |
| 3 | On-board losses (dB) | 2 | Switching, waveguide runs |
| 4 | Receive noise power density (dB(W/4 kHz)) | −160 | $T$ = 2000 K |
| 5 | Receive interference power flux-density (dB(W/(m$^2$ · 4 kHz))) | −128 | Assumes:<br>$e.i.r.p._{TV}$ = 85 dBW,<br>No cross-polarization gain,<br>spectrum at ± 15 MHz off-centre: (−50 dB(W/4 kHz)) (²) |
| 6 | Receive interference power density (dB(W/4 kHz)) | −182 | At receiver input |
| 7 | Total noise power density (dB(W/4 kHz)) | −160 | Sum of (4) and (6) (link is noise-dominated) |
| 8 | Required minimum receive carrier level | −151 | |
| 9 | Implementation margin (dB) | 10 | Rain attenuation margin (see § 4.1) |
| 10 | Maximum spreading loss (dB(m$^2$)) | 163 | |
| 11 | Required earth-station transmit e.i.r.p. (dBW) | 74 | Special coordination may be required (³) |

(¹) The common requirement for traditional spacecraft service functions operating in the 2 GHz band is 40 dB net. However, this may not be sufficient for this particular application considering the higher transmission frequency. It is for this reason that a higher value has been assumed here. Still, the actual requirement may exceed that estimated here and consequently further studies are needed before a reliable link budget can be constructed.

(²) The spacecraft receive antenna will have very limited cross-polar isolation, but this is not expected to influence the total noise power density significantly and has therefore been neglected.

(³) If TTC frequency assignments are employed according to Fig. 1a with the potential risk of insufficient decoupling between TTC and adjacent, co-polar feeder links, this decoupling must be achieved by means of the feeder link receive antenna on-board the interfered-with satellite. This decoupling is expected to be of the order of 20 to 30 dB which will normally be obtained with the co-polar radiation patterns of satellite receiving antennas.

## 1.2 *Space-to-Earth links*

### 1.2.1 *Nominal operation*

TABLE III – *Example link budget for nominal operation, sub-carrier TTC links*

| | Link parameter | Telemetry ranging function | Notes |
|---|---|---|---|
| 1 | Required receive $C/N_0$ (dBHz) | 55 | Sufficient for good quality ranging signal |
| 2 | Earth-station receiver antenna gain (dBi) | 53 | 5 m antenna |
| 3 | Earth-station receiver noise temperature (K) | 500 | Low noise receiver |
| 4 | Receive noise power density (dB(W/4 kHz)) | −165 | |
| 5 | Receive interference power flux-density (dB(W/(m$^2$ · 4 kHz))) | −170 | $PFD_{TV}$ = −100 dB(W/m$^2$),<br>20 dB cross-polarization advantage,<br>spectrum at ± 15 MHz<br>off-centre (−50 dB(W/4 kHz)) |
| 6 | Receive interference power density (dB(W/4 kHz)) | −160 | (5) + (2) − 43 dB(m$^2$) |
| 7 | Total noise power density (dB(W/4 kHz)) | −159 | (6) + (4) marginally interference dominated |
| 8 | Spreading loss (dB(m$^2$)) | 163 | Geostationary orbit |
| 9 | Link margin (dB) | 5 | Rain attenuation margin (see § 4.1) |
| 10 | Required minimum satellite e.i.r.p. (dBW) | 18 | Easily realisable with high transmit antenna gain |
| 11 | Maximum permissible e.i.r.p. (dBW) | 37 | Limit is set by permissible power flux-density limit |

PFD: power flux-density.

### 1.2.2 *Non-nominal operation*

TABLE IV – *Example link budget for satellite transfer orbit and non-nominal operations in-orbit, sub-carrier TTC links*

| | Link parameter | Telemetry ranging function | Notes |
|---|---|---|---|
| 1 | Required receiver $C/N_0$ (dBHz) | 33 | Net requirement, no margins included (¹) |
| 2 | Earth station receiver antenna gain (dBi) | 53 | 5 m antenna |
| 3 | Earth station receive noise temperature (K) | 500 | Typical performance |
| 4 | Receive noise power density (dB(W/4 kHz)) | −165 | |
| 5 | Receive interference power flux-density (dB(W/(m² · 4 kHz))) | −170 | $PFD_{TV}$ = −100 dB(W/m²),<br>20 dB cross-polarization advantage,<br>spectrum at ± 15 MHz<br>off-centre (−50 dB(W/4 kHz)) |
| 6 | Receive interference power density (dB(W/4 kHz)) | −160 | (5) + (2) − 43 dB(m²) |
| 7 | Total noise power density (dB(W/4 kHz)) | −159 | (6) + (4). Link is marginally interference dominated |
| 8 | Spreading loss (dB(m²)) | 163 | Geostationary orbit |
| 9 | Link margin | 10 dB | Rain attenuation margin (see § 4.1), and implementation losses |
| 10 | Required minimum satellite e.i.r.p. (dBW) | 1 | |
| 11 | Satellite transmit antenna gain (dBi) | −6 | Quasi omni-directional coverage |
| 12 | Losses (dB) | 2 | |
| 13 | Required transmitter power (dBW) | 9 | 8 W, requires TWT amplifier |

(¹) This net requirement is common for traditional spacecraft service functions operating in the 2 GHz band but may not be sufficient for this application when considering the significantly higher frequency band and Doppler shifts. Further studies are needed before a reliable link budget can be constructed.

## REFERENCES

*CCIR Documents*

[1982-86]: **a.** 10-11S/35 (ESA).

## ANNEX III

## SPREAD-SPECTRUM TTC LINKS

### 1. Example link budgets for spread-spectrum TTC links [CCIR, 1982-86a]

These link budgets are provided for illustration only. In the absence of a specific concept, calculations are based on the following formula and parameters:

$$(C/N)_{IF} = \frac{C \cdot D}{\frac{1}{2}\, C \cdot N \cdot P \cdot B + kTB + \dfrac{N \cdot B}{4\ \text{kHz}}} \qquad (5)$$

where:

$(C/N)_{IF}$: carrier-to-noise ratio in bandwidth $B$ (Hz);

$D$: implementation loss, 5 dB;

$P$: 1/chip rate, $(3.1 \times 10^6)^{-1}$;

$B$: IF bandwidth, 250 Hz;

$N_0$: TV out-of-band spectral power density, 60 dB below carrier in 4 kHz, proves to be non-critical for link design due to additional cross-polarization advantage (20 dB);

$k$: Boltzmann's constant $= -228.6$ dB(W(K$^{-1}$));

$T$: receiver noise temperature ($K$);

$N$: number of users, 25;

$(C/N_0)_{IF}$: carrier-to-noise density ratio, $(C/N)B$ (dBHz).

### 1.1 *Earth-to-space link*

#### 1.1.1 *RF sensing* (includes telecommand/ranging)

Assuming:

$C/N_0 = 45$ dBHz,

*Note.* – Much higher ratios are not feasible, this may require a special RF-sensing design. The influence of atmospheric fades remains to be assessed.

$T = 20\,000$ K, RF sensing,

and using formula (5) yields:

$$C = -133 \text{ dBW}$$

Employing the link data as for sub-carrier techniques, i.e.:

| | |
|---|---|
| Satellite receiving antenna gain : | 26 dBi |
| Spreading loss : | 163 dB(m$^2$) |
| Fade margin : | 10 dB |

leads to an e.i.r.p. of 60 dBW.

#### 1.1.2 *Telecommand/ranging function only during non-nominal orbit behaviour and transfer*

Assuming:

$C/N_0 = 34$ dBHz,

$T = 2000$ K, TC receiver,

and using formula (5) yields:

$$C = -157 \text{ dBW}$$

Employing the link data as for sub-carrier techniques, i.e.:

| | |
|---|---|
| Satellite receiving antenna gain : | –6 dBi |
| Spreading loss : | 163 dB(m$^2$) |
| Fade margin : | 15 dB |

leads to an e.i.r.p. of 73 dBW.

This latter e.i.r.p. is higher than that needed for nominal operation and needs therefore to be applied throughout all mission phases.

### 1.2 *Space-to-Earth links*

The determining link is that required during the satellite transfer and non-nominal in-orbit behaviour:

Assuming:

$C/N_0$ = 34 dBHz, sufficient for 125 bit/s,

Receive antenna = 53 dBi, 5 m earth-station antenna,

$e.i.r.p._{TV}$ = 63 dBW, reduced by 20 dB cross-polarization advantage

and using formula (5) yields:

$$C = -161 \text{ dBW}$$

Employing the link data as for sub-carrier techniques, i.e.:

| | |
|---|---|
| Spreading loss : | 163 dB(m$^2$) |
| Margin : | 10 dB |

leads to an e.i.r.p. of 2 dBW.

This e.i.r.p., employing an omnidirectional spacecraft transmitting antenna of −6 dBi and cabling losses of 2 dB, requires a transmit power of 10 dBW (10 W). This can be realized with a TWT amplifier.

## 2. Example frequency plan

An example frequency plan is illustrated in Fig. 3:

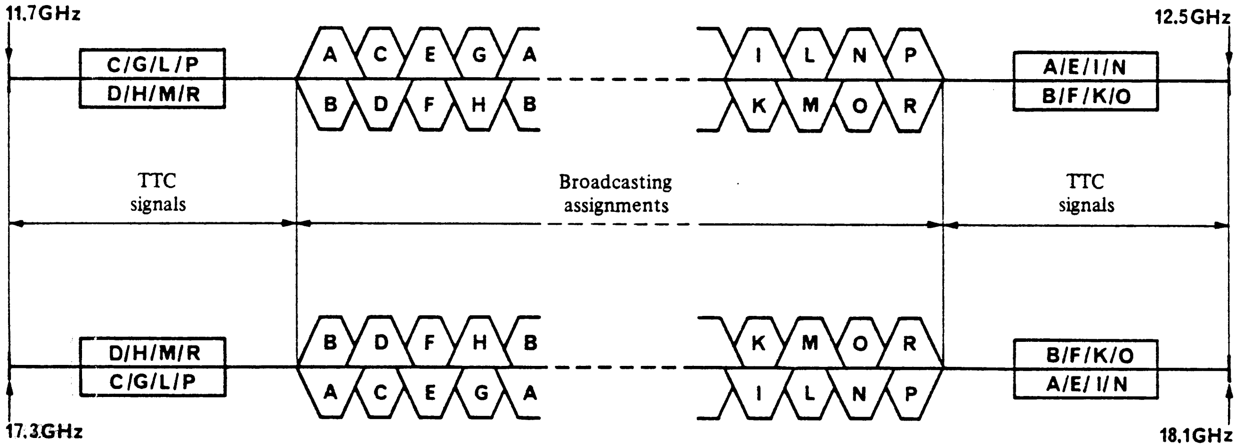

FIGURE 3 – *A proposal for TTC assignments for broadcasting satellites using spread-spectrum modulation techniques for TTC signals*

*Note 1.* – A to R denote service areas or countries.

*Note 2.* – These spread-spectrum assignments require a new approach in frequency coordination. Non-interference is achieved by code distinction rather than by frequency separation.

REFERENCES

*CCIR Documents*

[1982-86]: **a.** 10-11S/35 (ESA).