European Radiocommunications Committee (ERC)
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SHARING BETWEEN TERRESTRIAL FLIGHT TELEPHONE SYSTEM (TFTS) AND RADIO ASTRONOMY IN THE 1.6 GHz BAND

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1 INTRODUCTION

During the preparation for the WARC-92, the ERC tried to find a suitable frequency band for terrestrial aeronautical public correspondence, since the band allocated at MOB-87 was only 2 x I MHz and the new requirements were 2 X 5 MHz. The first band suggested for the uplink was 1700-1705 MHz, sharing was however difficult due to the small earth stations tracking low earth orbit (LEO) satellites in the METSAT service. The frequency band 1670-1675 MHz was then suggested, since it is difficult for the METSAT to use this band as a downlink, without causing interference to the radio astronomy service in the lower adjacent frequency band. Since the TFTS only includes a limited number of ground stations, the possibility for an allocation in this band should be investigated. This report includes the summary of the compatibility study between TFTS and Radio Astronomy Service.

2 TECHNICAL PARAMETERS FOR THE TERRESTRIAL FLIGHT TELEPHONE SYSTEM

The technical parameters used in the calculations have been received from ETSI RES-5, which is working with the standard for the TFTS-system. The parameters are preliminary since the ETS has not yet been approved. The maximum power used in the calculation was 44 dBm and the attenuation of the spurious emission was 65 dB.

Each ground station will be designated as either high, medium or low power. The high power ground stations, called en-route stations, are for en-route coverage. Medium ground stations are for use mainly during the climb and descent phases of flight and low power ground stations, called airport ground stations, are only for use when aircraft are on the ground. The en route stations are spaced 380 + 20 km apart.

3 HARMFUL INTERFERENCE LEVEL FOR RADIO ASTRONOMY SERVICE

In the frequency band 1660-1670 MHz, both spectral line and continuum observations are taking place. The interference criteria that has been used is taken from CCIR Report 224.

The requirements are that the PFD shall not exceed the levels for more than 10% of time, but since it's considered probable that reflections from overflying aircraft will account for a large proportion of the 10%, the interference level has been calculated for l%.

4 SHARING

4.1 Cases of interference

The TFTS-system can cause interference in three ways.

1) Since the radio astronomy is very sensitive to interference, even spurious at low levels can cause interference at large distance.

2) The TFTS-carriers can cause interference outside the RAS band due to the large bandwidth used for continuum measurements, which influence the radio astronomy receiver selectivity.

3) Receiver intermodulation.

4.2 Calculations

Two cases have been studied:

- An airport 16 km from the radio astronomy site. For separation distances less than 100 km, the domination propagation mechanism is diffraction rather than tropospheric scatter. The propagation estimates are, taken from CCIR Recommendation 370-5.

- A radio astronomy site close to the sea. The maximum distance from a TFTS ground station is assumed to be 200 km, the propagation model used was troposcatter and ducting.

In both cases a negative margin is obtained, but sharing is possible if proper site shielding is achieved together with the methods below. For continuum observation it may be necessary to avoid the lower frequencies.

Measures to achieve greater attenuation:

a) Out-of-band emission
Recognising that most of the wide band emissions are caused by the power amplifier and that the current specification (65 dB below the carrier) can be met by the aircraft transmitters, then a better performance can be expected from the ground station transmitters which are not subject to rigorous aviation requirements. So it should be possible to improve the out-of-band emission by 10-20 dB.

b) e.i.r.p.
The calculations were made on the assumption that transmitters would operate at full power, it should be possible to arrange the system plan such that a 10 dB lower e.i.r.p. sufficient near the critical RAS sites.

c) Filters
It is unlikely that more than 6 dB attenuation will be available even if TFTS transmission are restricted to above 1673 MHz. There will inevitably be some loss in e.i.r.p. at the transmitted frequency, this will be made worse as more filter sections are added to increase the attenuation. This approach also has an undesirable effect on frequency planning. Note that measurements on a PA may show that sideband power rolls off with increasing separation from the carrier, in which case some advantage could be gained by using the higher frequencies at critical sites even if filtering is not used.

d) Polar Diagram Control
A radiated pattern which incorporates a notch in the direction of the RAS site could be produced by the TFTS antenna. A reduction of 10 to 20 dB should be possible. This would involve the use of an additional element, either parasitic or driven, associated with each transmitting antenna at the TFTS ground station. This approach could with advantage be kept as a fallback move should interference levels be found over a period of time to be greater than predicted. The loss of coverage would need to be taken into account. If two spaced TFTS ground stations were involved coverage could be completed from one or the other except at the protected site.

For further information about the calculations, see **Annex**.

5 CONCLUSION

The conclusion is that sharing is possible between RAS and TFTS, if proper site shielding is achieved through careful choice of TFTS antenna site, together with other measures. Proper site shielding should be possible to achieve, since the number of stations is limited. For continuum observation it may be necessary to avoid the lower frequencies. It should be noted that there are radio astronomy sites a few meters from the sea, so there exist large coordination distances.

ANNEX

1 HARMFUL INTERFERENCE LEVELS FOR RADIOASTRONOMY

	Assumed Bandwith (MHz)	Input Power (dBW)	Power flux-density (dB(W/m²))	Spectral Power Flux-density (dBW/(m²Hz))
Spectral line observations	0.02	-220	-194	-237*)
Continuum observations	10	-205	-181	-251**)

Integration time, 2000s.

The requirements are that the PFD at the sites shall not exceed the levels stated above for more than 10% of time.

According to CCIR Report 696, an antenna gain of 0 dB can be used, when calculating the interference power into the receiver input.

2 INTERFERENCE DUE TO SPURIOUS

2.1 Distance less than I00 km

For separation distances less than 100 km, the dominating propagation mechanism is diffraction rather than tropospheric scatter. It is considered probable that reflections from overflying aircraft will account for a large proportion of the 10% so the interference level has been calculated for 1% of the time.

Propagation estimates are taken from CCIR Recommendation 370-5, **Figure 11**. For various transmit antenna heights this plots against distance the field strength available for 1% of time at 50% of location, using a receiving antenna at a height of 10 m with the assumption that the ΔH between the terminals is 50 m.

For the present purpose the plot for a transmit antenna height of 37.5 is chosen. This is typical for a RAS antenna, whilst the 10 m figure for the receive antenna is typical of TFTS antenna. We should thus obtain the correct fieldstrength from the reciprocal path and also have the assurance that it is the 10 m high terminal which has a variable position as the figures assume.

The plots of **Figure 11** claim to be suitable for use over the band 450-1000 MHz but in the 25 km region in which the example occur, the values given are less than those in **Figure 4a**, the equivalent plots for 30-250 MHz, by only 2 dB, so there should be a small additional margin at 1670 MHz.

Table I is for spectral measurements, for continuum measurement the margin is 14 dB less.

d (km)	Fieldstrenght (dB(μV/m))	PFD (dBW/(m²Hz))	Margin (dB)
16	56	-202	-35
30	42	-216	-21

Table 1

Commentary
In order to achieve greater attenuation the following methods could be considered:

a) Out-of-band emission
Recognising that most of the wide band emissions are caused by the power amplifier and that the current specification (65 dB below the carrier), can be met by the aircraft transmitters, then a better performance can be expected from the ground station transmitters which are not subject to rigorous aviation requirements. So it should be possible to improve the out-of-band emission by 10-20 dB.

*) Some RAS sites can accept -225, which gives in the following calculations an extra margin of 12 dB
**) It can be acceptable with -240

b) e.i.r p.
The calculations were made on the assumption that transmitters would operate at full power, it should be possible to arrange the system plan such that a 10 dB lower e.i.r.p. is sufficient near the critical RAS sites.

c) Filters
It is unlikely that more than 6 dB attenuation will be available even if TFTS transmission are restricted to above 1673 MHz. There will inevitably be some loss in e.i.r.p. at the transmitted frequency, this will be made worse as more filter sections are added to increase the attenuation. This approach also has an undesirable effect on frequency planning. Note that measurements on a PA may show that sideband power rolls off with increasing separation from the carrier, in which case some advantage could be gained by using the higher frequencies at critical sites even if filtering is not used.

d) Siting
There is much scope for improvement by choice of transmitter location. The calculations are for an average location at the distance chosen. Recommendation 370, **Figure 12** indicates the variations, which may be found at various locations. For ΔH equal to 50, 1% of locations provide a further 20 dB attenuation. A ground survey is the only answer to a more accurate result.

e) Antenna height
Recommendation 370-5, **Figure 17** suggests that a 6 dB reduction in interference may be obtained by lowering the TFTS antenna from 10 m to 3 m. This will have little or no effect on the signal strength at the altitude providing the path is unobstructed.

f) Polar Diagram Control
A radiated pattern which incorporates a notch in the direction of the RAS site could be produced by the TFTS antenna. A reduction of 10 to 20 dB should be possible. This would involve the use of an additional element, either parasitic or driven, associated with each transmitting antenna at the TFTS ground station. This approach could with advantage be kept as a fallback move should interference levels be found over a period of time to be greater than predicted. The loss of coverage would need to be taken into account. If two spaced TFTS ground stations were involved coverage could be completed from one or the other except at the protected site.
A suitable combination of these methods should allow sufficient attenuation.

2.2 Distance greater than 100 km
The en-route stations are spaced 380 ± 20 km apart and the maximum distance from a RAS station must therefore be about 200 km.
The interference level can be calculated by equation (1)

P_r = - 54 dBm/Hz - 30 + G_r - L_b(1%) (dBW) (1)

Where $G_{r\,=}$ 0 dBi
The tables in the examples are for spectral line measurement, for continuum measurement the margin is 14 dB less.

2.2.1 Troposcatter
According to CCIR Report 569, the transmission loss due to tropospheric forward scatter may be estimated using the methods of § 3.1 of Report 238, but using, instead of the term Y(q), the term -Y(q). The transmission loss can be calculated as follows:

L_b(1%) = 30log f $_{MHz}$-201og d_{km} + F(θd)-V(d_e)-Y(1%) (2)

The value of the factor k is assumed to be 1.33 (median atmospheric conditions). The following parameters are obtained:

f:	1665 MHz	1665 MHz
d:	200 km	150 km
θ:	0,023	0,0l76
N_s:	320	320
d_e:	250	200
F(θd)	155	150

Zone 7a: maritime temperate, over land.
Zone 7b: maritime temperate, over sea.

The antenna height for RAS is assumed to be 40 and 10-50 for the TFTS. The value of V(d_e) and Y(1%) is taken from CCIR Report 238-5, **Figure 2** and **Figures 6-9**.

Zone	d (km)	PFD (dBW/m^2 Hz)	Margin (dB)
7a	200	-242	5
7b	200	-232	-5

Table II

Zone	d (km)	PFD (dBW/m^2 Hz)	Margin (dB)
7a	150	-240	3
7b	150	-230	-7

Table III

2.2.2 Ducting

According to CCIR Report 569, the transmission loss can be calculated as follows:

$L_b(l\%) = 92,5 + 20\log f_{GHz} + 10\log d_{km} + yd + A_c + A_h$ (3)

Where:

f = 1,665 GHz $A_h = 0$

Table IV: 100% coast land.

Table V: 100% sea.

	ΔH = 50		ΔH = 75		ΔH = 100	
d	PFD	Margin	PFD	Margin	PFD	Margin
200	-215	-22	-221	-16	-225	-12
150	-207	-30	-212	-25	-215	-22

Table IV

d	PFD	Margin
200	-205	-32
150	-200	-37

Table V

The calculations are made for A_h= 0, an additional attenuation of up to 30 dB can be achieved by site shielding.

3 REQUIRED RADIO ASTRONOMY RECEIVER SELECTIVITY

3. 1 Spectral lines

The interference power in any 20 kHz band must not exceed - 220 dBW for spectral line observations. Within the TFTS band the emitted power in a 20 kHz wide band will be 14 dBW. The interfering power can be calculated using the following equation:

$I = 14dBW - L_b - FDR$, (4)

where FDR is the frequency dependant rejection of the radio astronomy receiver.

The maximum separation distance is 200 km. The transmission loss can be calculated from equation (3):

Zone	L_b (duct)
Coast land	158 dB
Sea	167 dB
Land	148 dB

Table VI

With site shielding, the above values can be increased by up to 30 dB With ΔH >50 the attenuation can be even greater.

The propagation loss due to tropospheric scatter is 189 dB. This means that tropospheric scatter will be the dominating mode of propagation in the cases where the sum of L_b (duct) and the site shielding exceeds 189 dB.

Equation (3) gives the required FDR without site shielding summarized in **Table VII**.

Zone	FDR
Coast land	77 dB
Land	68 dB
Sea	87 dB

Table VII

According to CCIR Report 697-2, section 3.3, "The attainable performance of practical receivers", the 3 dB bandwidth of a receiver should be 60% of the 100 dB bandwidth. For spectral line observations the 3 dB bandwidth is 20 kHz (Report 696, **Table 1**); thus the 100 dB bandwidth should be 33.3 kHz. Assuming that an observation is being made right at the edge of the band with a 3 dB bandwidth between 1669.98 and 1670.00 MHz, the receiver will still have an FDR of 100 dB at 1670.033 MHz, so no problems should be encountered with spectral line observations. Many receivers can only achieve about 70 dB attenuation. In these cases sufficient site shielding must be provided.

3.2 Continuum

Assuming that the 3 dB bandwidth for continuum observations is 10 MHz (CCIR Report 696, **Table 1**), the 100 dB bandwidth should be 16.67 MHz. With the 3 dB point at 1670 MHz. the -100 dB point will occur at 1673.33 MHz, and the filter attenuation will be 2.9 dB/100 kHz. Taking this attenuation into account, the transmitted interfering power from 10 channels, spaced by 100 kHz, will be:

$$I = 10*1og*(10^{1.4} \sum_{i=0}^{9} 10^{-0.3-0.29n-0.29i)} \qquad (5)$$

where n is the number of 100 kHz spaces not used in the TFTS transmitter. counting from the lower edge of the band. The maximum interference power in 10 MHz for continuum observations is -205 dBW. Thus

$$I = - 205 + L_b \qquad (6)$$

Inserting the values of L_b from section 3.1 ($\Delta H = 50$), and solving for n, gives the following result:

Zone	n
Coast land	21
Sea	18
Land	25

Table VIII

These values are valid when no site shielding is afforded. In the worst case, as can be seen in **Table VIII**, half the TFTS bandwidth must be kept free. If site shielding of 30 dB is present, the values are improved, see **Table IX**.

Zone	n
Coast land	11
Land	11*
Sea	14

Table IX

The 70 dB attenuation point will be at 1672.3 MHz, so even if the filter only achieves 70 dB attenuation, the above values essentially apply.

* In this case L_b is 189 dB, because of tropospheric scatter.

4 NON-LINEAR EFFECTS WITHIN THE RECEIVER (RAS)

Typical values for the intermodulation intercept point range from -55 dBW for a parametric amplifier to about -40 dBW for a transistor amplifier, both values being referred to the amplifier input.

From Report CCIR 697-3, the following formula can be used to calculate the signal level which might cause interference by intermodulation.
$S_{IM} = (21P + \Delta P_H)/3$ dBW

Where:
ΔP_H is the input power that can cause harmful interference (dBW).
IP is the input level to which the intercept point corresponds (dBW).
With $\Delta P_H = -220$ dBW and IP = -55 dBW, we get $S_{IM} = -110$ dBW.

The required attenuation from the TFTS is then:
L_{bIM} =44 dBm -30+110 = 124 dB.

Compare this with the necessary attenuation due to out-of-band emission:
L_b =44 dBm -30-65 + 10 + 220 = 179 dB.

Since we have come to the conclusion that it is possible to achieve an attenuation of 179 dB, the necessary attenuation to avoid intermodulation could also be achieved.