# MAJOR RFI CONDITIONS EFFECTING TDRSS

James D. Lyttle

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James D. Lyttle

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# MAJOR RFI CONDITIONS EFFECTING TDRSS

## 1. INTRODUCTION.

The purpose of this interim report is to summarize in condensed form the major conclusions drawn from this project— to evaluate radio-frequency interference (RFI) conditions which would affect operating frequency band selections and data-communications equipment design approaches for the Tracking and Data Relay Satellite System (TDRSS).

The original objectives of the contract[1] were to update and expand existing RF environment models and from this data base to evaluate RFI densities likely to inhibit the use of tentative bands for TDRSS-relayed command and telemetry links, and to develop convenient geographic mapping of critical RFI evaluations. Most of the important conclusions drawn from this work have been published variously in three Interim Reports[2,3,4] and in many of the Monthly Progress Reports.

A Final Report for this project is also being published now. It contains a general chronological summary of the investigations performed under this contract, details of the significant RFI evaluations made (particularly in the 2 to 2.3 GHz band), and backup data supporting these results. To provide the latter, it is necessary to prepare and handle this document under appropriate Department of Defense (DOD) security classification controls.

1. -- Continued.

Consequently, a principle objective of this Interim Report is to provide, in an unclassified form, a brief summary of the likely RFI conditions and the essential conclusions reached relative to TDRSS implementations. Section 2 herein introduces general RFI conditions found in various radio-frequency bands. Section 3 deals more specifically with conditions in the nominally 2 to 2.3 GHz band, and Section 4 elaborates on related radar RFI impact areas. Section 5 presents overall conclusions and recommendations from the study.

# 2. GENERAL RFI CONDITIONS.

## 2.1 Scope of Investigation.

At the outset of this investigation, nominally ten radio-frequency (RF) bands were to be considered for TDRSS usage; these are listed in Table 2-1. First attention in the project was devoted to the 136 to 138 and the 400.5 to 401.5 megahertz (MHz) bands, on which the TDRSS design had previously been focused. Nevertheless, data was gathered from various immediately available sources on RF usages in all ten of the indicated bands. Subsequently, attention was shifted to the 2 to 2.3 and 13.4 to 15.25 gigahertz (GHz) bands. The RF utilization proposed then by the TDRSS Office is summarized in Table 2-2 and illustrated schematically in Figure 2-1.

Perhaps the most significant factor in any RFI analysis is geometric accessibility of potential RFI signals to the receivers of the system of interest. Obviously, receivers at the TDRSS ground terminal are much less accessible than those in a TDRS or user spacecraft. Although there are not likely (statistically) to be significant RFI sources accessible to the TDRSS ground terminal, it is assumed that this problem can be controlled through government regulation within the U.S. Obviously, survey of this local RFI environment and its explicit control cannot be undertaken until specific ground terminal site(s) have been selected; therefore, this investigation has not pointedly addressed RFI conditions that may impact on the return links at the TDRSS ground terminal.

Table 2-1. Communication Bands Considered for TDRSS Use

| Arbitrary Identification Number | Radio Frequency Band (MHz) | Link | From | To |
|---|---|---|---|---|
| 1 | 121.6-121.9 | Forward | TDRS | Users |
| 2 | 136-138 | Return | Users | TDRS |
| | | Return | TDRS | Earth |
| 3 | 148-149.9 | Forward | Earth | TDRS |
| | | Forward | TDRS | Users |
| 4 | 400.5-401.5 | Forward | TDRS | Users |
| 5 | 2025-2120 | Forward | TDRS | Users |
| | | Return | TDRS | Earth |
| 6 | 2200-2300 | Forward | Earth | TDRS |
| | | Return | Users | TDRS |
| 7 | 7700-7900 | Return | Users | TDRS |
| 8 | 8300-8500 | Forward | TDRS | Users |
| 9 | 13400-14000 | Forward | Earth | TDRS |
| | | Return | Users | TDRS |
| 10 | 14400-15350 | Forward | TDRS | Users |
| | | Return | TDRS | Earth |

Table 2-2. Proposed TDRSS Frequency Plan

Abbreviations:

| | | | | | |
|---|---|---|---|---|---|
| fwd | = | forward | SA | = | single access |
| rtn | = | return | MA | = | multiple access |
| users | = | user satellites | NB | = | narrowband |
| gnd | = | ground terminal | WB | = | wideband |
| TDRS | = | Tracking and Data Relay Satellite | | | |

| Line Item | RF Band (MHz) | Link | From | To | Functions |
|---|---|---|---|---|---|
| A1 | 2025-2120 | fwd | TDRS | users | Tunable SA |
| A2 | 2035.5-2036.5 | fwd | gnd | TDRS | TDRS command |
| A3 | 2090.1-2095.1 | fwd | TDRS | users | Alternate MA |
| A4 | 2103.9-2108.9 | fwd | TDRS | users | Prime MA |
| B1 | 2200-2300 | rtn | users | TDRS | 10-MHz SA, in 5 MHz steps |
| B2 | 2210.5-2211.5 | rtn | TDRS | gnd | TDRS telemetry |
| B3 | 2270-2275 | rtn | users | TDRS | Alternate MA |
| B4 | 2285-2290 | rtn | users | TDRS | Prime MA |
| C1 | 13400-13650 | rtn | TDRS | gnd | TDRS telemetry and turnaround tracking |
| C2 | 13700-13725 | rtn | TDRS | gnd | SA from users |
| C3 | 13750-13800 | fwd | TDRS | users | SA |
| C4 | 13825-14050 | rtn | TDRS | gnd | SA from users |
| D1 | 14600-14650 | fwd | gnd | TDRS | MA commands |
| D2 | 14685-14735 | fwd | gnd | TDRS | 2 NB SA |
| D3 | 14770-14870 | fwd | gnd | TDRS | WB commands |
| D4 | 14896-15121 | rtn | users | TDRS | SA |
| D5 | 15150-15250 | fwd | gnd | TDRS | WB commands |

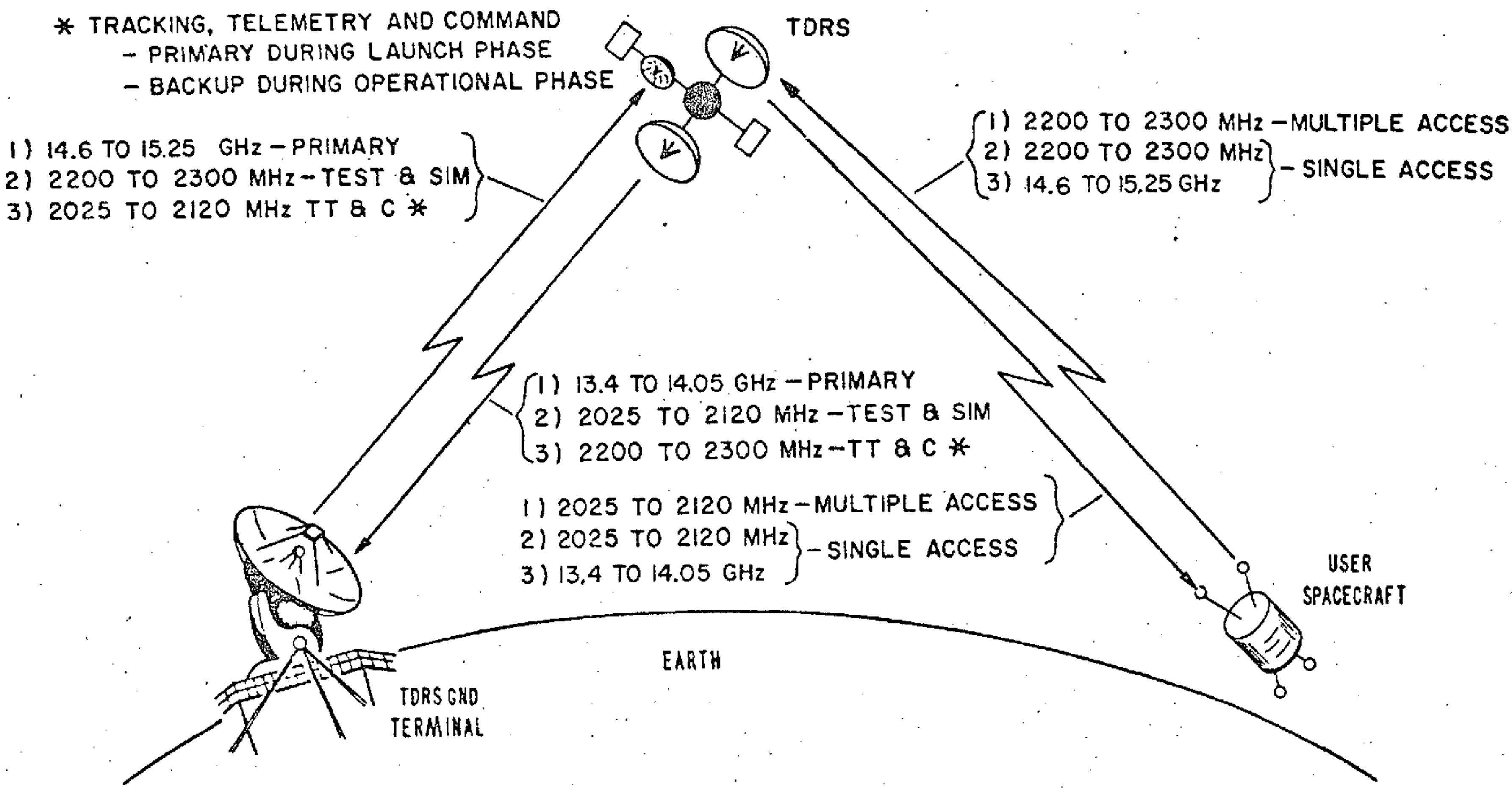


Figure 2-1. TDRSS Communication Links

## 2.1 -- Continued.

This study has focused on the spacecraft-borne receivers involved in the system, specifically:

| Link | From | To | RF Bands (GHz) | Table 2-2 Items |
|---|---|---|---|---|
| Forward | Ground | TDRSS | 14.6-14.87<br>15.15-15.25<br>2.036 | D1, D2 and D3<br>D5<br>A2 |
| Forward | TDRS | Users | 2.025-2.12<br>13.75-13.8 | A1, A3 and A4<br>C3 |
| Return | Users | TDRS | 2.2-2.3<br>14.896-15.121 | B1, B3 and B4<br>D4 |

## 2.2 Relative RFI in Bands of Interest.

Among the ten tentative RF bands for TDRSS usage, listed in Table 2-1, it is generally true that there is less RFI in each band that is relatively higher in frequency. There are certainly some localized exceptions to this, but as a general rule, it would be better to operate in the UHF band rather than the VHF band or in each successively higher microwave band than in a lower one.

2.2 -- Continued.

The nominally 2 to 2.3 and 13.4 to 15.3 GHz bands* clearly present lesser RFI problems than do the 136 to 138 and the 400.5 to 401.5 MHz bands.[2,3] Nevertheless, the 2 to 2.3 GHz band suffers from more high-power RFI now (and probably growing in the future) than the 7.7 to 7.9 and 8.3 to 8.5 GHz bands. Furthermore, there are RF bands other than the ten considered now that would present less RFI, on a world wide basis; however, it is recognized that:

a. obtaining authorization to use other favorable bands would be complex, and/or

b. other bands, such as high microwave and into millimeter-wave bands, would not be suitable for TDRSS hardware designs at this time.

In both the 2 to 2.3 and the 13.4 to 15.3 GHz bands, foreign radars represent the most significant source of likely RFI. Notably, the USSR (and other Communist countries that use Soviet electronic systems) have not reserved these bands for controlled space and radio-relay communications use as

---

*RF limits, in gigahertz (GHz), of relevant band designations originated and used by the U.S. Department of Defense:

| Current Form | Obsolete Form |
|---|---|
| E Band = 2-3 | S Band = 1.55-5.2<br>$S_c$ Band = 2-2.4 |
| J Band = 10-20 | K Band = 10.9-36<br>$K_e$ Band = 13.25-14.25<br>$K_c$ Band = 14.25-15.35<br>$K_u$ Band = 15.35-17.25 |

## 2.2 -- Continued.

have the U.S. and most of the rest of the world. The relatively slight RFI conditions in the appropriate parts of the 13.4 to 15.3 GHz band are briefly discussed in the following Section 2.3, while the more complex aspects of 2 to 2.3 GHz RFI conditions are summarized in Sections 3 and 4.

## 2.3 13.4 to 15.3 GHz Band RFI.

Referring to Table 2-2 and Figure 2-1, it can be seen that RFI impacts are of concern:

a. In TDRS receivers covering most of the 14.6 to 15.25 GHz band. (Line Items D1 through D5)

b. In user-satellite receivers covering only 13.75 to 13.8 GHz. (Line Item C3)

The only significant interference likely to be in these bands will be from foreign airborne radar/navigation systems; however, most of these equipments use relatively low power and the radiations from them are directed essentially downward from the aircraft. Thus, little energy should be radiated upward toward orbiting user spacecraft and much less to the distant TDRS.

Control of RFI into receivers at the TDRSS ground terminal can be accomplished by localized regulation in the U.S.

2.3 -- Continued.

Attention should be directed to restricting the use of airborne emitters in the 13.4 to 14.05 GHz band while flying in the vicinity of the ground terminal site(s), particular doppler navigators and radar altimeters like the AN/APN-(model numbers): 67, 113, 115, 122, 122(V), 129, 129(V), 130(V) and 130A(V).

# 3. 2 TO 2.3 GHz BAND RFI.

## 3.1 General Conditions.

With a few exceptions, three general types of emitters are operated in the nominally 2 to 2.3 GHz band, or more specifically related to TDRSS plans, the 2025 to 2120 and the 2200 to 2300 MHz bands:

a. Radars (primarily, Soviet Union air-defense types).

b. Radio-relay communications (fixed, ground-based, point-to-point, usually multi-channel multiplexed, direct-path propagation; not tropospheric-scatter propagation or satellite relay).

c. Spacecraft data links (primarily, U.S. Air Force and NASA earth-satellite control command systems and output telemetry).

In terms of RFI power, the radar systems represent the biggest competitor to further use of this band and are, therefore, the subject of most of the analysis in this RFI project and rest of this report. This RF band is not used for radio-relay communications in the same part of the world (Eastern Europe and Northern Asia) in which the radar systems are dominant, but such "microwave relay lines" are found throughout most of the rest of the world, particularly North America and Western Europe. Although spacecraft applications in the band are authorized internationally, these are almost all U.S. systems; however, the resulting impact of this use is essentially global.

3.1 -- Continued.

Within the 2 to 2.3 GHz band, some portions are relatively freer than others from RFI. Because of the nearly world wide nature of the TDRSS data-link system, it would be vary complex, perhaps impossible, to quantify these RFI levels in a multi-dimensional matrix of parameters, notable:

a. RF spectra
b. Geography and space
c. Power levels
d. Time usage densities.

Based primarily on the prevalence of radar-type RFI, Figure 3-1 provides a gross indication of the relatively better or worse subbands. In terms of signal power and of signal time density, the worst portions of the bands indicated have more than two orders of magnitude greater RFI than the best portions.

Radar RFI power and duty factor are discussed in the next section, and the slight RFI impact of radio-relay communications is summarized in Section 3.3. Frequency allocations for space use are reasonably well documented, but the space/power/time quantification of these applications is perhaps the most complex of all to predict from documentary data. Since the space uses are clearly dominated by the USAF and NASA, control of RFI problems from these sources should be handled by coordination and regulation, followed up by compliance control measurements if RFI problems arise.

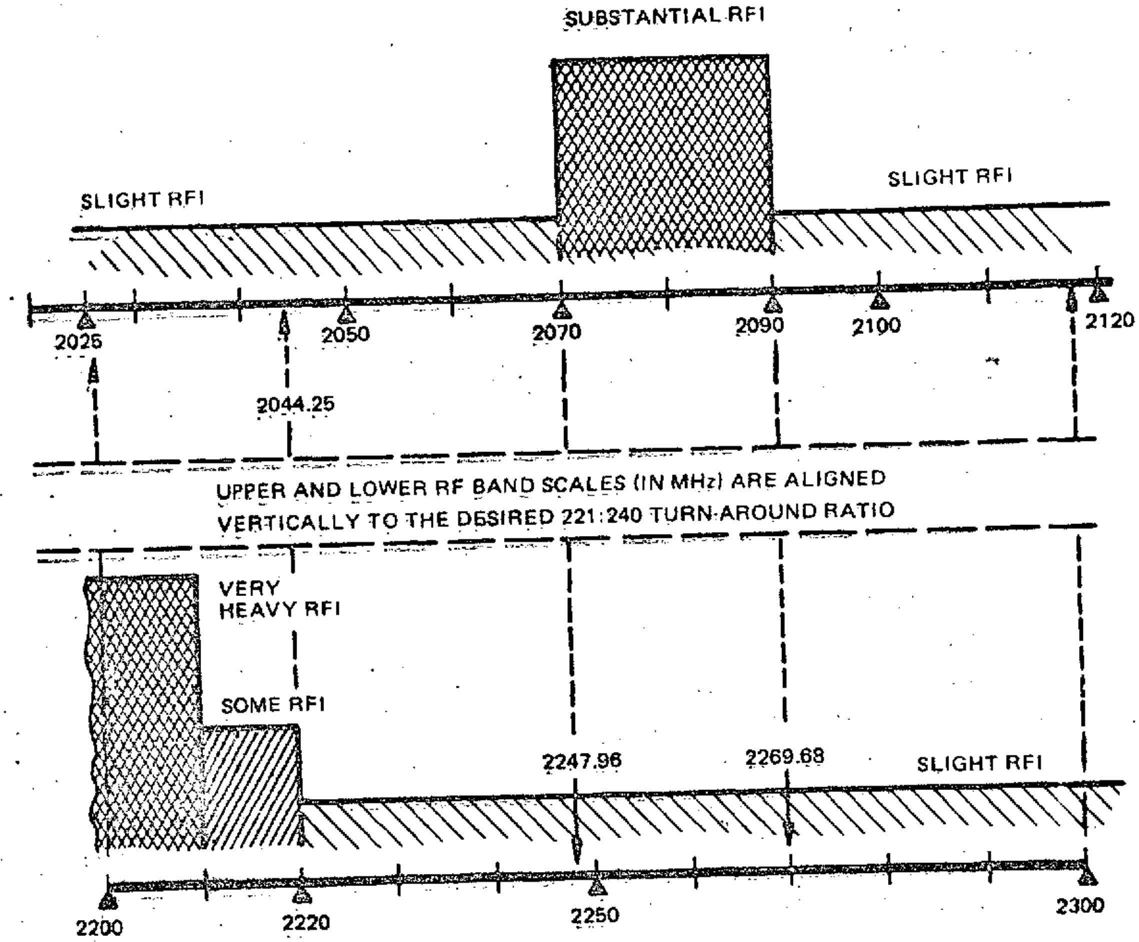


Figure 3-1. Relative RFI Densities Expected From Radars in the 2 to 2.3 GHz Band

## 3.2 Radar RFI Power and Duty Factor.

As a class, radars are the most powerful RF emitters in common use, certainly from the standpoint of peak power from pulsed radars. Although radar applications span the range of power outputs from fractions of a watt to megawatts (MW), the vast majority in numbers operate with hundreds of kilowatts (kW) or more of peak power, dominated by those used for air defense and other military long-range surveillance functions. Typical modern surveillance radars in E Band (2 to 3 GHz) have transmitter outputs between 1 and 10 MW (90 to 100 dBm). These high powers are further amplified through very directive antennas which concentrate this energy with peak gains of often 30 to 50 dB. Thus, the effective radiated power (ERP) in the radar antenna main beam can be 120 to 150 dBm. The foreign air-defense radars, which present the most significant RFI problem in the TDRSS band from about 2 to 2.3 GHz, are certainly of this power class.

Table 3-1 evaluates the approximate power required (in a 10-MHz bandwidth) for an emitter on the earth to be at the noise level of a TDRS receiver, without accounting for any antenna gain. This simplified example only illustrates that a radar of a megawatt or more of transmitter power will easily produce significant interference power in a TDRS receiver. The TDRS receiving antenna will probably not be pointed so as to yield its full gain from major RFI sources, such as these radars; nevertheless, any positive gain through this antenna will increase this RFI power.

Table 3-1. Ground-Based Emitter ERP Which Equals Noise Level in TDRS Single-Access Receivers

| | |
|---|---|
| Receiving antenna (external) noise temperature | ≦ 290° K |
| Receiver noise temperature | 250° K |
| Noise power density | -111.3 dBm/MHz |
| Noise power in 10-MHz channel | -101.3 dBm |
| Maximum* free-space loss at 2.2 GHz | -191.7 dB |
| Normalized** ERP at earth surface (to equal noise) | 90.4 dBm |

---

* Ground-based emitter located on the horizon as viewed from a TDRS --- nominally 41,680 km slant range (for a perfect geosynchronous orbit).

** Normalized to a 0-dBi gain level through the TDRS receiving antenna. (The ERP required to equal noise level in an SA receiving channel would decrease where it couples through positive gain in the receiving antenna, or a fixed ERP would appear in the receiver as increased SNR.)

3.2 -- Continued.

Only rarely would a radar main beam point directly at a TDRS, and if they did, they will typically be in motion so that the coupling time will be very brief. Despite this directivity, the radar transmitter powers are so high that there is sufficient energy radiated through the majority of side and back lobes to exceed noise level in a TDRS receiver. Radar power coupling into user-satellite receivers would be relatively greater than for the TDRS because these lower altitude orbits will be much closer to the RFI sources, although the user satellites may have less receiving antenna gain than TDRS in the direction of the earth.

The major conclusion to be drawn from this analysis is that, whenever the radio horizon of a TDRS or user satellite encompasses the locations of the major air-defense radars in TDRSS link frequency bands, *almost all of the pulses emitted by the radars will produce significant interference.* Calculation of the "excess" RFI power, well above receiver noise, is an essentially stochastic process which would have to be based on inexact input data on the radar transmitter powers and antenna patterns.

Since almost all pulses will be received as interference (i.e., but few statistically will be below TDRS receiver noise level), the most meaningful evaluations of this RFI problem are:

a. Block out the RF bands which are likely to be used most by competing RF emitters. (See Section 3.1)

3.2 -- Continued.

b. Plot the geographic areas (related to given orbits) where user satellites could receive commands, etc., while the RFI sources are beyond the radio horizon. (See Section 4)

c. Determine maximum pulse densities likely to be encountered at a TDRS if these receivers must be operated in radar RFI bands.

Because of the great variability in typical radar operations (when turned on, modes in use, antenna pointing, etc.), lack of explicit data on foreign radars, and different TDRS operating locations that may be used, only broad estimates can be provided for the pulse densities that could be encountered by TDRS receivers if they are tuned to portions of the band that are used by air defense radars. Obviously, it is best if these links (essentially the return links from user satellites to a TDRS) would be tuned to parts of the band suffering the least RFI (probably from about 2220 to 2300 MHz). If this is not practical, however, then the aggregate pulse densities in the radar bands would likely:

a. Produce pulse energy in a TDRS receiver less than 10 percent of the time.

b. Have a mean time between pulse arrivals of greater than 50 microseconds (μs).

c. Exhibit individual pulse durations between about 2 to 5 μs.

## 3.3 Radio-Relay Communications RFI.

After foreign military radar systems, microwave radio-relay communication lines represent the most prevalent type of RF emitters in the 2 to 2.3 GHz band, although they do not constitute very high-power sources. The general conclusion reached is that *They will not present a very serious source of RFI to the TDRSS*, although some interference should occur from them, more specifically:

a. The generally low transmitter power and the very deliberate design suppression of side and back lobe radiations from radio-relay sets (i.e., energy emitted from any direction except through their antenna main beam) will be at a sufficiently low level to cause but little interference effect on the TDRSS.

b. There is a possibility, although not great, that a TDRS vehicle will be initially positioned in the main beam of a radio-relay transmitter. Explicit prediction of this happening is complex[5] and the major effort involved to do so is not considered justified, because by far the most effective remedy will be to *move* the effected TDRS spacecraft somewhat, through a controlled drift in longitude, until it is out of the interferring main-beam coupling geometry. Furthermore, international control resolutions have been pressing for all

3.3 -- Continued.

new radio-relay systems be layed out specifically to avoid beam coupling within the "belt" around the earth in which all circular geo-synchronous satellite orbit positions lie.[6]

c. User satellites, in relatively low orbits, will occasionally intersect the main beams of radio-relay transmitters; however, the probabilistic length of time that such satellites will remain within (transit) such a main beam would be in the order of few tens of seconds and very rarely over a minute in duration.[3] If vital communications to a user satellite were interrupted (infrequently) by this form of interference, it will be a very short lived condition and retransmission of the "message" shortly thereafter would offset the problem.

## 3.4 RF Band Usage Recommendations.

*RFI conditions in any of the microwave bands considered should present very little problem if the TDRSS communications system design would offer considerable RF tuning flexibility within these bands.* Operational retuning would provide relief from RFI "hot spots" that will arise:

3.4 -- Continued.

a. As a function of time of day, day of week, season, etc. (Habitually time-varying RFI problems could even be predicted operationally and TDRSS frequencies shifted accordingly, much as an HF communications station methodically shifts frequency throughout the day according to ionispheric propagation predictions.)

b. As related to major geographic areas, which might effect one TDRS but not the other or effect user satellites in only part of their orbits, as presented in Section 4.3. (For example, Communist countries use the RF spectrum rather differently than the rest of the world, despite the fact that almost all significant RF users in the world, except China, are signators to International Telecommunications Union conventions. Also, some large areas of the world contain few RF emitters of any kind, such as:

1) The vast lower part of the southern hemisphere, approximately south of 40°S.

2) The Arctic, essentially north of about 65°N.

3) Major ocean areas, particularly the Southeast Pacific, South Atlantic, and Indian Oceans.)

3.4 -- Continued.

c. From growth in RFI, particularly radars, which is already apparent in the 2 to 2.3 GHz band and is likely to grow in the higher microwave bands, such as the 13.4 to 15.3 GHz band and others. (Even though international coordination and agreements are generally increasing, related to RF spectrum usage, the bases for sound prediction of RFI conditions are still very weak.)

Thus, the ability to reselect and retune TDRSS frequencies operationally would be one of the strongest techniques available to avoid or moderate the effects of RFI.

Generally, it should be preferable to *operate at frequencies below about 2070 MHz and above about 2220 MHz,* within the allocated bands from 2025 to 2120 and 2200 to 2300 MHz. With slightly more risk of RFI, frequencies between about 2090 and 2120 MHz can be considered.

To retain the desired RF turn-around ratio of 221:240*, the following corresponding bands would be appropriate:

| | | | |
|---|---|---|---|
| Lower Band: | 2044.25 to 2070 MHz | or | 2090 to 2117.92 MHz |
| | with | | with |
| Upper Band: | 2220 to 2247.96 MHz | | 2269.68 to 2300 MHz |

*Prime number ratio of $\frac{221}{240} = \frac{13\cdot 17}{2^4\cdot 3\cdot 5} = 0.9208333.....$

3.4 -- Continued.

It is still important to realize, however, that these perferable portions of the RF bands cannot be regarded as free of RFI from radars or other signal sources. They are relatively much less likely to include serious radar RFI than the portions between about 2070 and 2090 MHz and especially between 2200 and 2220 MHz. Probably the best combination of frequencies with the 221:240 ratio and 5 MHz of bandwidth would be centered about 2064.5 and 2242 MHz. *There would be substantially more frequencies available with little or no RFI if the specific 221:240 turn-around ratio were not required.*

Considering the proposed pairs of multiple-access (MA) frequencies, each with 5-MHz bandwidth:

| Frequencies (MHz) | Prime | Alternate |
|---|---|---|
| 2025 - 2120 range -- | | |
| MA band center | 2106.4 | 2092.6 |
| Lower band edge | 2103.9 | 2090.1 |
| Upper band edge | 2108.9 | 2095.1 |
| 2200 - 2300 range -- | | |
| MA band center | 2287.5 | 2272.5 |
| Lower band edge | 2285 | 2270 |
| Upper band edge | 2290 | 2275 |

The *"prime" MA frequencies should be relatively better choices than are the "alternates"* from the standpoint of lower RFI. Although it is quantitatively difficult to evaluate now, potential growth of radar RFI seems more likely to inhibit the use of

3.4 -- Continued.

frequencies between 2090 and 2120 MHz than would the frequencies below about 2070 MHz.

Geographic distribution and potential avoidance of this RFI is analysed in the next section of this report.

# 4. RADAR RFI IMPACT AREAS.

## 4.1 Distribution of Radars.

As described in preceeding sections, it has become clear that the most significant form of RFI to the TDRSS is likely to be from foreign radar sets, primarily those involved in air-defense functions. Types that can now be identified apparently have been designed and built in the USSR---most of which are in use within that country but some of them probably operated in the Eastern European countries closely allied with the USSR. (Currently, these are East Germany, Poland, Czechoslovakia, Hungary, Romania, and Bulgaria---essentially the Warsaw Pact group.) China received much military equipment from the USSR prior to about 1960, but since that time has become relatively self-sufficient with indiginous military hardware; however, no Chinese radars are known openly that operate in the 2 to 2.3 GHz band.

The main radar RFI impact zone, therefore, is the USSR with some extention into the Eastern European countries noted. There are logical reasons and ample evidence to show that any country's air-defense radar perimeter is essentially coincident with the country's physical and political boundaries.

From this deduction, limits can be defined for given satellite orbits, within which limits the satellite will be in line-of-sight of the country borders (air-defense perimeter) defined to contain the RFI-source radars. When a satellite (such as TDRS or user satellite) is anywhere within these limits, determined for its orbit altitude, a significant level of

4.1 -- Continued.

radar-pulse interference will be received. The pulse densities of this RFI will increase the more that the total horizon limits of the satellite encompass the radar deployment area. Many variables of radar operations and of satellite orbit orientation will affect these densities; therefore, explicit evaluation of the RFI densities is not reasonably justified, even if the actual number and location of these radars were known.

4.2 TDRS Locations.

For link receivers on the TDRS vehicles to avoid this radar RFI, these geo-synchronous spacecraft must be located between nominally 59° and 101° west longitude, assuming negligible eccentricity and inclination movement. If this type of radar RFI also originates from Eastern European countries, the TDRS location limits would be reduced to 67° to 101°W---using the western edge of East Germany as the furthest extremity. The limits would have to be reduced also for significant amounts of eccentricity and/or inclination in a TDRS orbit.

Since none of these limits for TDRS location are satisfactory, compared to the desired 41° and 171°W (±10°), it must be assumed that the TDRS receiver links require a design to ameliorate the affect of radar RFI, as suggested in conclusions (Section 5) of this report.

## 4.3 User Satellite Orbits.

User satellites in lower altitude orbits will cyclically pass in and out of this radar RFI zone. The pattern and time duration of the portions of these orbits which will encounter interference will vary greatly depending upon the orbit parameters, principally altitude and inclination.

The most straightforward way of coping with this high power interference problem is to *schedule communications* (essentially forward-link commands) *to these user satellites when they are not in this interference zone,* since its outer limits can be predicted rather well.

Again, the deducation is followed that the air-defense radar perimeter of a country, like the USSR and its military allies, is essentially coincident with the physical/political borders. Assuming that most user satellites will be in essentially circular orbits, their paths will lie on essentially spherical "shells" around the earth at these given altitudes. A geometric projection can be made of the loci on these shells, where the satellite will be just at the horizon from the specified countries' borders---i.e., the radar RFI zone.

Such a map has been constructed and is presented in Figure 4-1. User satellite circular orbits were evaluated at 500, 1000, 1500, 3000 and 5000 kilometer (km) altitudes to produce the loci plotted. The hatch-shaded area above the 500-km line indicates the potential radar RFI zone for that

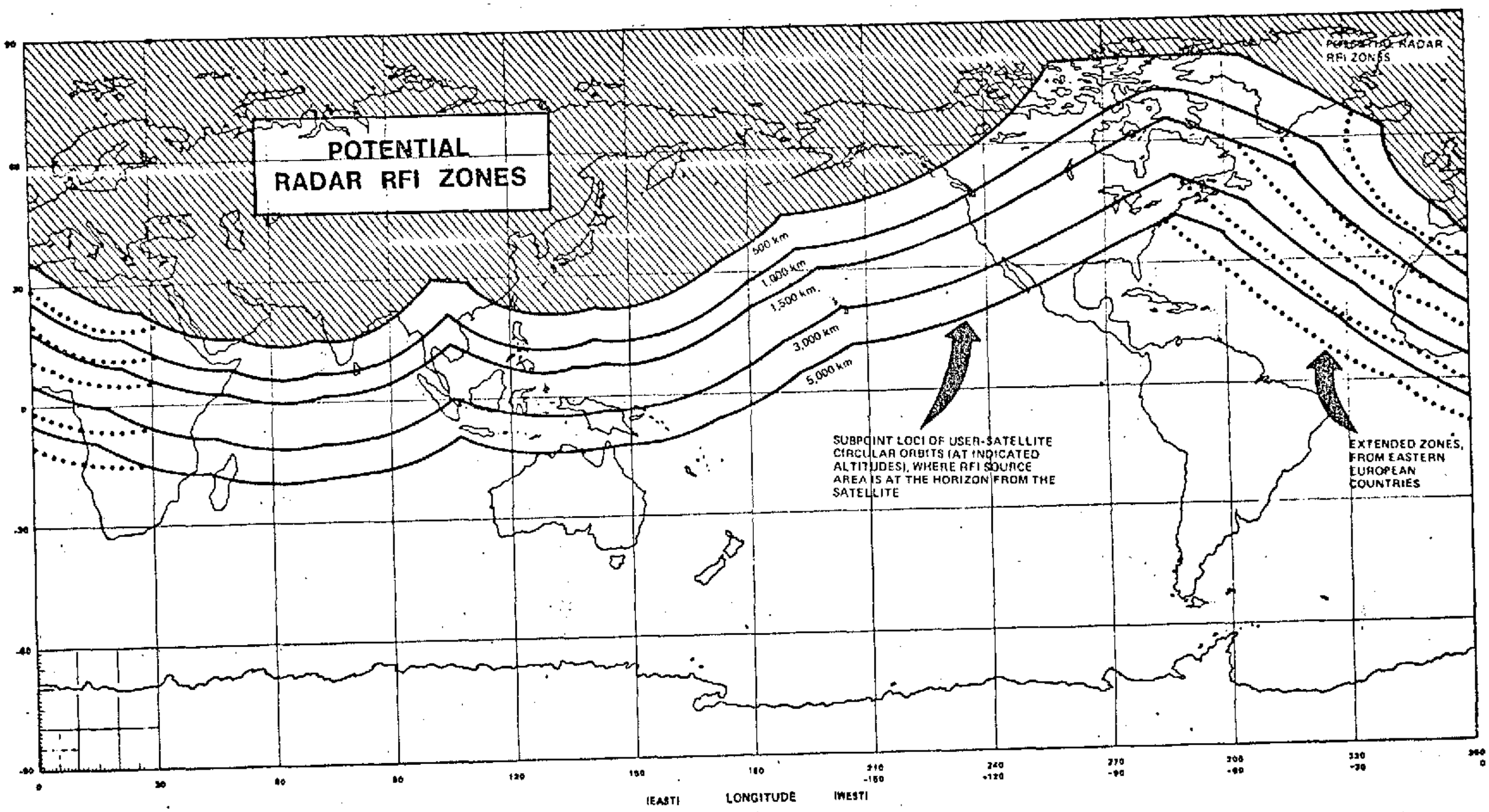


Figure 4-1. Zone Limits of Likely Radar RFI in the 2 to 2.3 GHz Band Related to Five Circular Orbit Altitudes

4.3 -- Continued.

altitude; that is, if the subpoint latitude and longitude of a user satellite were in this zone, it would be accessible to this RFI source.

Successively larger zones are indicated by the loci lines plotted for the higher altitude orbits. The solid lines indicate the RFI zone limits related to the USSR proper, considered to be the principal source of this interference. The dotted lines indicate the extention of these zones for the noted Eastern European allies of the USSR.

Figure 4-1 uses a rectilinear map projection with equal divisions for both latitude and longitude. As in any flat map projection of the entire earth, distortion is introduced; in this one, the area around the poles is spread out and enlarged. Ones first impression in looking at this map suggests that the potential radar RFI zones are very extensive. Figure 4-2 provides a more accurate evaluation of the "areas" which are within or over the horizon from these RFI sources.

Area, in this case, means that portion of the whole sphere or shell, on which a given circular orbit lies. Because the velocity of satellites in essentially circular orbits are nearly constant, this "area" is directly proportional to time that the satellite would be within or over the horizon from the defined radar RFI zones.

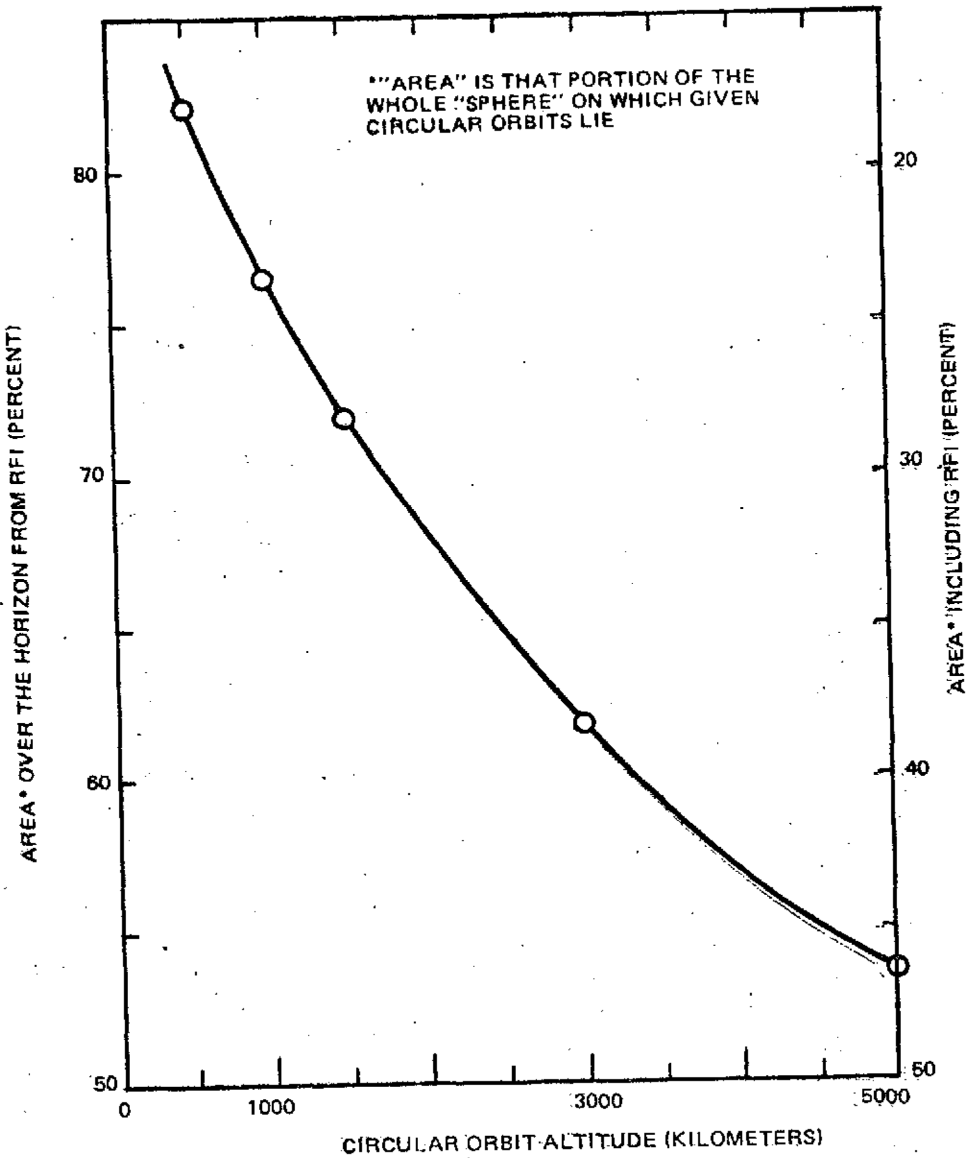


Figure 4-2. Proportion of User Satellites Circular-Polar Orbits Which are Within or Over the Horizon from Defined Radar RFI Zones

4.3 -- Continued.

The values in Figure 4-2 would be directly applicable for user satellites in circular polar orbits (essentially 90° inclination). For lesser inclination orbits, the RFI areas would be reduced, particularly for the lower altitude orbits---because the potential radar sources are located generally at high latitudes in the northern hemisphere. As an example, Figure 4-3 presents the area proportions for circular orbits with 30° inclination. It can be seen that a low 500-km altitude orbit would be in this RFI zone only about 5% of the time.

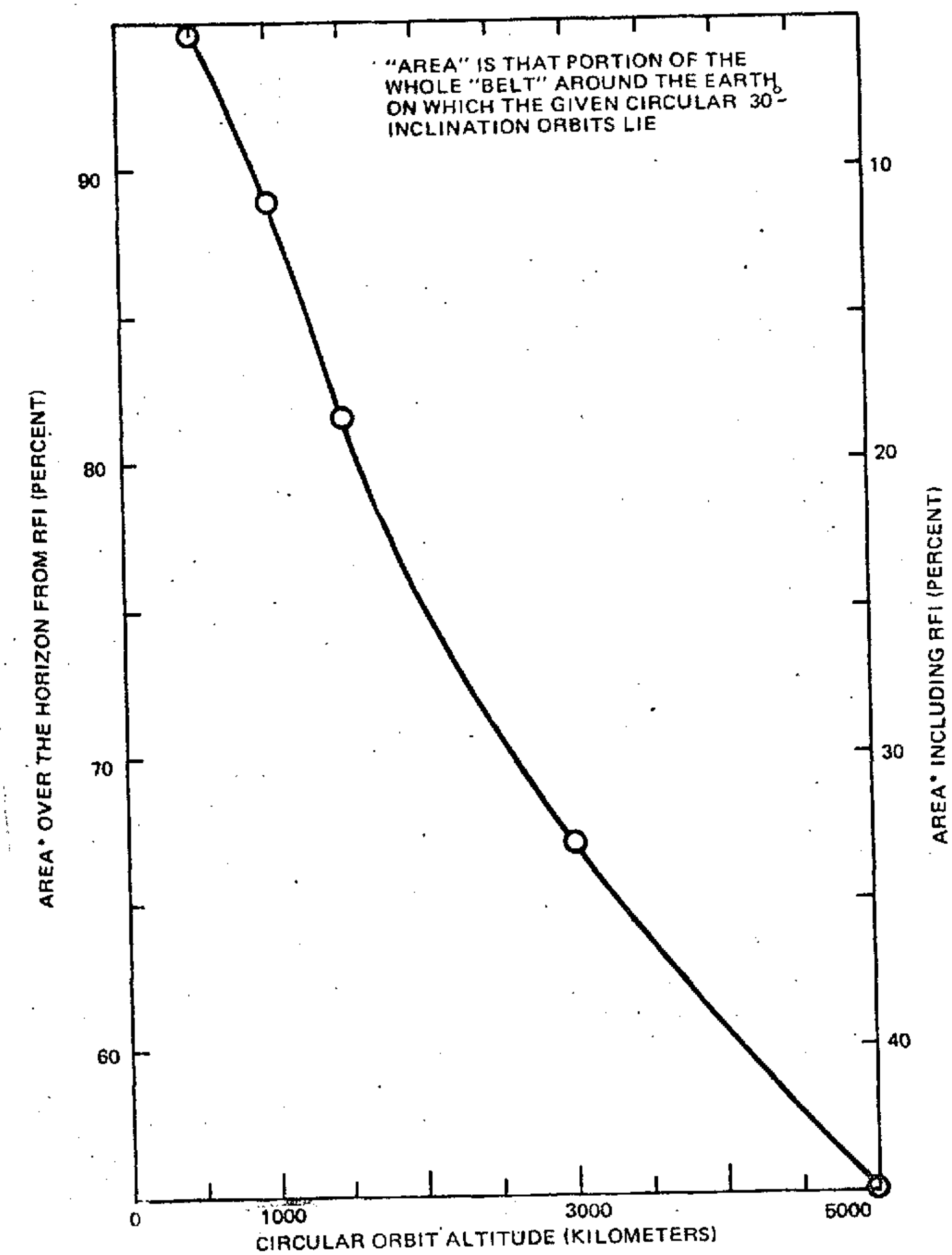


Figure 4-3. Proportion of User Satellite Circular 30°-Inclination Orbits Which are Within or Over the Horizon From Defined Radar RFI Zones

## 5. CONCLUSIONS AND RECOMMENDATIONS.

Broad conclusions and recommendations drawn from this investigation can be summarized briefly:

a. The nominally 2 to 2.3 GHz band, in general, is not the best choice for TDRSS operations from the standpoint of low radio-frequency interference (RFI). Relatively however, it is better than almost any part of the VHF band and much of the lower UHF band.

b. The nominally 13.4 to 15.3 GHz band now presents much less RFI, as do many other high microwave frequency bands, and international regulation should be able to maintain this compatibility for space usage.

c. RFI conditions in any of the microwave bands considered should present very little problem if the TDRSS communication system design would offer considerable RF tuning flexibility within these bands. Operational retuning would provide relief from RFI "hot spots" that will arise as a function of time, as related to geographic areas, and from growth in RFI (particularly radars).

5. -- Continued.

d. Within the desired 2025 to 2120 and 2200 to 2300 MHz bands, it should be preferable to operate at frequencies below about 2070 MHz and above about 2220 MHz. With somewhat greater risk from RFI growth, the band from about 2090 to 2120 MHz could be used.

e. Redundant burst, communication coding or other modulation techniques should be employed which are relatively tolerant to pulse RFI (typical of radar signals) because that is likely to be the dominant form of RFI.

f. TDRS vehicles could not reasonably be positioned to avoid geographically the major RFI sources in the 2 to 2.3 GHz band and maintain their wide area coverage applied to low orbiting user satellites; therefore, RF tuning flexibility and communication modulation techniques should be stressed in the design of links to be received at TDRS vehicles.

g. If RF tuning flexibility, etc., do not satisfactorily avoid RFI in links received at user satellite, then time scheduling of communications to them to avoid known geographic RFI zones should be implemented, similar to the mapping approach provided in Section 4.3 herein.

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