REPORT 1050-1*

TECHNICAL AND OPERATIONAL CONSIDERATIONS FOR A RADIODETERMINATION SATELLITE SERVICE IN BANDS 9 AND 10

(Question 91/8)

(1986-1990)

1. Introduction

Satellite systems operating in the radiodetermination satellite service (RDSS) could provide radionavigation and radiolocation functions to aeronautical, maritime and land based mobile users.

WARC MOB-87 allocated the bands 1 610 - 1 626.5 MHz (Earth-to-space) and 2 483.5 - 2 500 MHz (space-to-Earth) to the radiodetermination-satellite service. Those allocations are on a primary or a secondary basis depending on the Region and, within each Region, depending on the country. In some countries of Region 3 an allocation is made in the band 2 500 - 2 516.5 MHz (space-to-Earth).

This report presents a general system concept for RDSS. Annex I provides a description of one of the several systems authorized for implementation in the United States. Frequency sharing considerations in the bands allocated to RDSS are discussed in Annex II.

2. Requirements to be met

2.1 Definition

Radiodetermination is defined in the Radio Regulations as the determination of the position, velocity and/or other characteristics of an object, or the obtaining of information relating to these parameters, by means of the propagation properties of radio waves (No. 10 of Article 1).

The same Regulations also define the radiodetermination-satellite service as a radiocommunication service for the purpose of radiodetermination involving the use of one or more space stations (No. 39 of Article 1).

2.2 Types of requirement

Several studies of users requirements carried out in the United States and France have shown that there is a sizeable demand for a radiodetermination-satellite service for simultaneously meeting the following requirements:

- instantaneous and accurate location of mobile stations at their home base through a central earth station;

---

[*] This Report should be brought to the attention of Study Groups 2, 4, 7 and 9.

- navigation aid to mobile stations by transmission of their position at any given moment;
- two-way transmission of auxiliary information concerning purposes of radiodetermination between home bases and mobile stations.

This service can be applied to land, maritime and aeronautical uses.

2.3 Present systems

The present satellite systems fall into two categories:

- radiolocation-satellite systems,
- radionavigation-satellite systems.

In both cases, the principle used to locate the mobile station is generally based on the use of a one-way link with users as described below.

In radiolocation-satellite systems, the mobile station's coordinates are calculated on the ground at a central station based on transmission from the mobile station. The coordinates thus calculated are available to each user home base; the individual user can know his position only if a special return link is established for providing him with the appropriate information. The COSPAS-SARSAT location system is an example of a fully global radiolocation-satellite system; however, it uses low-altitude satellites, does not provide instantaneous location, and is reserved for search and rescue applications (see Report 761).

Conversely, radionavigation-satellite systems enable users to establish their location independently, without requiring the active intervention of another agency. Calculations are made by the user equipment, which comprises a receiver listening out for locating signals and information relating to satellite ephemerides. As in the case described above, satellite radionavigation does not enable a users home base* to know the position of the mobile station unless a return link is provided to carry the appropriate information. The GPS-NAVSTAR and GLONASS systems are examples of radionavigation-satellite systems (see Report 766).

2.4 New systems

The requirements expressed in section 2.2 cannot all be met by any one of the present systems described in section 2.3. New radiodetermination-satellite systems in the planning, development or implementation stages will use two-way links between mobile stations and central earth stations through geostationary satellites simultaneously affording:

- accurate position-finding (by bi- or tri-lateration);
- virtually immediate access;
- position information available to both the mobile user and his home base through a central earth station;
- access by mobile station equipment based on the use of proven technologies;

---

* Home base refers to the operational headquarters for a fleet of mobile stations which is usually located at some distance from the central earth station.

- capacity to serve a large number of mobile units.

A detailed description of the system being developed in the United States is given in Annex I.

3. Preferred characteristics of radiodetermination-satellite systems

3.1 General design

The general system concept addressed in this report requires forward and return satellite links. It is based on a fully "closed loop" principle whereby the propagation delay, in relation to the reference signal transmitted by the master central earth station, relayed through the geostationary satellites, is determined at the master central earth station. The position of the user may then be computed at the master central earth station and the position information is transmitted in a digital message back to the user.

In the case of land mobile links, the transmission of messages could be momentarily interrupted by natural obstacles such as vegetation and terrain or by man-made obstacles such as urban agglomerations and other constructions. The transmission systems and information exchange protocols should be designed to allow for such interruptions.

Provision should be made for repeating messages that have not been acknowledged by either the mobile station or the central earth station.

Possible interference from other services using the same frequency bands may be regarded as one of the causes of momentary interruptions.

3.2 Choice of the satellite orbit

Several types of orbit can be used for radiodetermination-satellite systems; three types are at present being used for systems which are either operating, planned or in the implementation phase, i.e. low-altitude inclined circular orbits, high-altitude inclined orbits and the geostationary-satellite orbit.

3.2.1 Low-altitude orbits

Generally speaking, these are circular orbits with an inclination of about 90°, an altitude of 600 - 1,200 km and an orbital period of the order of 100 minutes. With a single satellite it is possible to cover the entire Earth, including the poles, but with a fairly low passage frequency (passing roughly the same point on the equator three times a day). This can be improved only by using several satellites, and a nearly continuous service could be provided through a multiple satellite system.

A satellite's instantaneous coverage area is limited (roughly 5,000 km in diameter), as is its duration of visibility from a point on the ground (on average, ten minutes per passage or 30 minutes a day at the Equator). This gives rise to interruptions in coverage which seriously limit the possibilities of access to the radiodetermination service by a user on the ground.

3.2.2 High-altitude orbits

These are orbits of medium inclination (e.g. 63.4° in the case of eccentric orbits) and periods of about 12 or 24 hours. Four satellites would be necessary to cover a limited region such as Europe or the United States.

3.2.3 Geostationary-satellite orbit

Geostationary-satellite systems offer the following advantages:

- instantaneous access over a wide service area compared with low-altitude satellite systems;
- a smaller number of satellites for a limited service area compared with high-altitude satellite systems.

A geostationary satellite system, however, is not fully global and does not cover the polar regions as the low altitude polar orbiting satellite systems do.

Only two satellites are required to provide radiodetermination in a limited region like Europe or the United States.

3.3 Preferred frequencies for satellite-to mobile station links

Because of the requirement for low user transmit powers, and the fact that most applications will require near omnidirectional low-gain user antennas, the preferred frequency bands for this service are in the 0.3-6 GHz range in order to avoid excessive atmospheric transmission losses. This is especially true on the user-to-satellite and satellite-to-user links.

3.3.1 Down-link

The satellite-to-mobile station link budget may be initially approximated as follows:

$$P_t \, G_t \times G_r/T_r = k \times E_b/N_0 \times R_b \times (4 \, \pi d/\lambda)^2 \qquad (1)$$

where $P_t \, G_t$ represents the satellite emission

G_r/T_r represents reception by the mobile station

k is the Boltzmann constant

E_b/N_0 represents link quality (related to bit error ratio)

R_b is the bit rate of the link

$(4 \, \pi d/\lambda)^2$ is the free-space attenuation between the satellite and mobile earth station assuming isotropic antennas.

The right-hand side of equation (1) is determined by the given requirements, both qualitative and quantitative, and by the selected orbit; the only free parameter is the wavelength λ. Consequently, (1) may be written:

$$P_t\ G_t \times G_r/T_r = \alpha f^2 \qquad (2)$$

Let us consider this equation when f varies from 0.3 to 6 GHz.

- G_r must be between 1 and 3 dBi to maintain the link regardless of the mobile station's movement (position and course), without using a self-pointing antenna, which would be both costly and cumbersome.

- T_r is imposed chiefly by the state of the art; it remains virtually constant and of the order of 600 K between 1 and 10 GHz. It increases below 1 GHz owing to noises picked up by the antenna.

- G_t is fixed, in the first analysis, by the extent of the coverage area, when the use of a single beam is considered. For an aperture of $\sigma = 4°$, which permits coverage of an area like that of the United States or Europe, $G_t = 34$ dBi.

1) Maximum frequency:

When G_r, T_r and G_t are fixed, equation (2) becomes:

$$P_t = ßf^2 \qquad (3)$$

Equation (3) shows that the power emitted by the satellite increase as the square of the frequency. The maximum frequency for a quality- and quantity-specified service can be calculated for maximum power of $P_t = +20$ dBW.

For instance, if $E_b/N_o = +4$ dB and $R_b = 64$ kbit/s (which can service 230,000 mobile stations each receiving on average one message of 1000 bits/h) and assuming an additional attenuation of 6 dB to cover fixed losses and fading margins, equation (1) gives us:

$f_{max} \sim 5$ GHz.

2) Minimum frequency:

For a fixed satellite antenna gain G_t, the antenna diameter D_t varies with the wavelength, so that:

$$D_t = \gamma/f \qquad (4)$$

For an antenna gain of 34 dBi and a maximum diameter of 3 m which, with a small margin, is compatible with the volume available under satellite launcher shrouds, the minimum frequency is about 1.6 GHz, for lower frequencies, unfurlable antennas which are more costly to develop will be needed.

In addition, if traffic requirements increase, it may become necessary to divide the coverage area into several sub-areas and use a multibeam satellite antenna. In that case, the gain G_t and therefore the diameter D_t must be increased. For example, if the area is covered by eight beams, D_t must be multiplied by $\sqrt{8} = 2.7$, so that in the above case $D_t = 8$ m. For $f = 1$ GHz, D_t would be equal to 13 m.

3) To sum up, the most appropriate frequencies for the down-link are between about 1 and 5 GHz.

3.3.2 Up-link

The mobile station-to-satellite link budget can again be represented by equation (1) by inverting the assignment of the left-hand factors.

P_t G_t now represents the e.i.r.p. of the mobile station emission.

The ratio G_r/T_r is now reception by the satellite.

The earlier considerations regarding G_r and G_t are inverted, although this in no way affects their consequences, since equation (1) reflects the antenna gain product. The considerations regarding T_r remain more or less the same for reception on board the satellite and on board the mobile station. The remainder of the reasoning may therefore be modelled on the case of the down-link.

1) Maximum frequency:

Once again, $P_t = ßf^2$ (3)

The imperative of having mobile equipment at minimum cost and the current state of the art in transistor technology results in a maximum power of 16 dBW.

Equation (1) can be used to calculate the corresponding maximum frequency with the same assumptions for E_b/N_o, R_b and the additional attenuation:

$f_{max} \sim 3$ GHz.

2) Minimum frequency:

The considerations advanced in the case of the up-link are once again fully applicable, this time considering the gain G_r of the satellite receiving antenna.

3) In short, the best frequencies for the up-link are between about 1 and 3 GHz.

3.4 Bandwidths needed for satellite-mobile station links

3.4.1 Down-link

The down-link to the user transceiver is provided by the satellite having the best viewing angle of the service area. The function of this link is to provide timing references to the user which can be used in initiating position determination requests and to transmit control commands, data messages, and calculated user position information to the user.

Transmissions may be made sequentially over a single channel per beam.

According to section 3.3.1, a typical satellite e.i.r.p. value is 54 dBW, which corresponds to a power spectrum density of -109 dB(W/m^2).

However, the Radio Regulations establish limits for the power spectrum density in bands shared with terrestrial services. For instance, between 1 525 and 2 500 MHz the limit is set at -144 dB(W/m^2 . 4 kHz) for angles of arrival in excess of 25°. A spectrum spreading method is needed in order to respect that limit.

A uniform spread would give a total bandwidth B such that:

$$10 \log (B/4000) \geq 144-109$$

so that $B \geq 12$ MHz, which broadly implies that the code rate should be:

$$R_c \geq 6 \text{ MHz}.$$

3.4.2 Up-link

The function of the user up-link is to transmit position requests and messages to the central earth station from the user transceiver. User transmissions can occur only in response to the synchronization timing marks in the down-link signal to the user. The user up-link is received by each of the RDSS satellites.

Sequential multiplexing cannot be used for this link owing to the different received signal time-lags resulting from the geographical position of each mobile station. A code-distribution multiplexing technique could be used. In this case, the least costly solution is for the terminal to retransmit at the same rate R_c as the down-link. The choice of a high rate also ensures a spreading factor which can be used for frequency sharing with other users.

3.4.3 Distance measurements

The precision required for two-dimensional positioning, assuming a known altitude, is 5-10 m. This objective implies that the error due to noise and interference in a simple measurement should not exceed 1.5 m, i.e. 5 ns in a two-way path time measurement. In view of the signal-to-noise ratio at the reconstituted code rate and of the small amount of time available for taking each measurement (16 ms per mobile station if the outward link has a bit rate R_b = 64 kbit/s), measurement precision may be estimated at 4% of the period of code $T_c = 1/R_c$. By deduction, $R_c \geq 8$ MHz, hence the bandwidth required is greater than 16 MHz.

3.4.4 Synthesis

In the light of the above, it is estimated that a minimum bandwidth of about 16 MHz is needed for observing the power spectrum density limit and ensuring the accuracy required for positioning purposes. Moreover, the resulting spread factor facilitates frequency sharing with other spectrum users.

3.5 Feeder links between the central earth station and the satellite

3.5.1 Up-link

The up-link provides communications between the central earth station and the single satellite with the best viewing angle for the RDSS service area. The function of this link is to provide timing synchronization, control messages, and calculated user positions for the entire system. The up-link transmission consists of individual data streams for each user reception area.

All fluxes are at the same code rate R_c to ensure the same positioning accuracy in all areas. The fluxes can be time-division multiplexed by adopting a bit rate of $R'_b = nR_b$ if there are n beams.

The spread factor over the up-link equals $(R_c/R_b)/n$. The bandwidth required for this link is again at least 16 MHz.

3.5.2 Down-links

Each of the satellites within the system transmits a down-link signal to the central earth station. This transmission consists of the signals received by the satellite from each of its user-to-satellite beams. These individual signals are frequency multiplexed onto a single transmission from each satellite.

In this case the bandwidth required over the down-link equals 16 x n MHz if there are n beams. The spread factor remains R_c/R_b. Time-division multiplexing cannot be used on this link owing to the travel time differences of individual messages.

3.6 System Capacity Considerations

3.6.1 Up-Link

A radiodetermination satellite system may allow transmissions to be made from the mobile users at random times whenever a position fix is needed. Typically, this requires the transmission of a short data packet consisting of the user's identification code and other data bits. This data packet has to be precisely synchronized to a system time reference mark to insure accurate ranging measurements.

Code division multiplex is typically used on the mobile user-to-central earth station link to separate transmissions from different mobile units that overlap in time. The same pseudorandom noise code may be employed by all mobile units in the system if the code selected has good auto-correlation properties. Correlators currently in use can separately acquire and lock onto two different but overlapping transmissions when the acquisition sequence of one burst begins two chips earlier or later than the other burst. At a chip rate of 8 megachips per second, two chips occupy 250 nanoseconds. Theoretically, this characteristic could allow up to 4 million transmissions using the same pseudorandom code to be processed at the central earth station each second.

However, the capacity of an RDSS system is also limited by the combination of user terminal e.i.r.p. and satellite G/T and by the code noise between overlapping transmissions. The following formula has been used to determine the number of simultaneous transmissions (K) that can be supported over a single transponder, and is one basis for estimating the capacity of an up-link RDSS transponder:

$$[E_b/N_o]^{-1}_{req} = [E_b/N_o]^{-1}_{single} + (K-1)\ [E_b/N_o]^{-1}_{code\ noise}$$

and, assuming the the effects of code noise are about 2/3 the effects of thermal noise,

$$[E_b/N_o]_{code\ noise} = 1.5 * R_s$$

where:

$[E_b/N_o]_{req}$ = E_b/N_o required to achieve desired BER;

$[E_b/N_o]_{single}$ = predicted link E_b/N_o in absence of code noise;

R_s = spread ratio, i.e. ratio of chip rate to data rate.

This formula is plotted in Figure 1 for a typical range of required E_b/N_o and predicted E_b/N_o values. As noted in Section 4.4 below, the actual capacity of an RDSS transponder is likely to be lower because of the effects of interference.

3.6.2 Down-Link

The downlink from the space station to the mobile users is typically a continuous transmission which provides time reference marks for the radiodetermination satellite system, together with the calculated position data.

The capacity of this link can therefore be modelled as a standard digital transmission link as follows:

$$10 \log R = e.i.r.p. - P_{loss} + G/T - 10 \log k - 10 \log [Eb/No]_{req}$$

where:

R = information transmission rate;

e.i.r.p. = space station e.i.r.p.

Ploss = total path losses between space station and user terminal;

G/T = ratio between RDSS user terminal antenna gain and receiving system noise temperature;

k = Boltzmann's constant;

$[Eb/No]_{req}$ = Eb/No required for desired BER including operating margins.

Figure 2 illustrates a hypothetical example of this relationship between down link capacity and satellite e.i.r.p. for an RDSS user terminal G/T of -26.8 dB(K^{-1}) and a total path loss of 192.5 dB.

Since the G/T of an omnidirectional user terminal is generally fixed by current technology, the capacity of a radiodetermination satellite down link can be related directly to space station e.i.r.p., or equivalently, power flux density. The current power flux-density limits specified in the Radio Regulations for the 2 483.5 - 2 500 MHz band restrict space station e.i.r.p.s and thus are a limiting factor on the capacity of the radiodetermination satellite service.

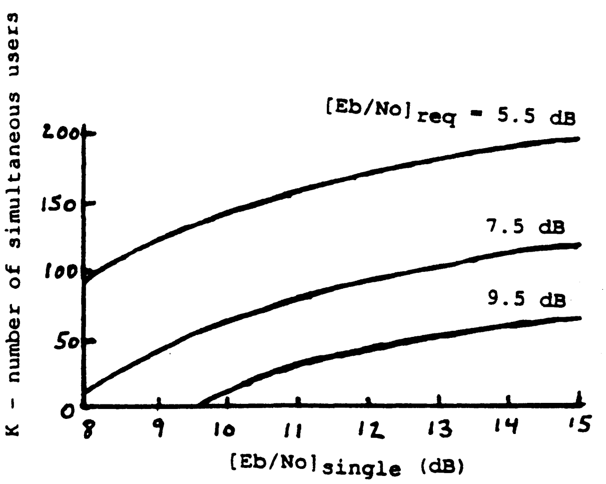

Figure 1. Capacity of RDSS Up-Link for [Eb/No]code noise = 28.85 dB

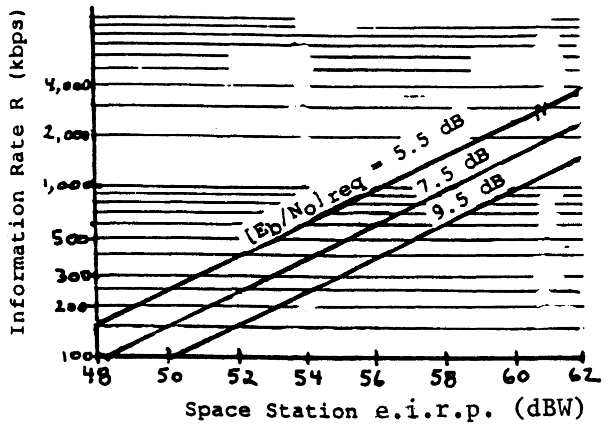

Figure 2. Capacity of RDSS Down-Link

3.6.3 Operational Considerations

The total number of mobile users that can be supported by a radiodetermination satellite system will depend on the frequency of position fixes and the length of the data packets exchanged between the user and central earth station.

The following formula provides an estimate of the average number of users that can be supported by a single beam RDSS system:

$$N_{users} = [R_{bit/s} * T_{sec}] / L_{bits}$$

where

N_{users} = number of users;

L_{bits} = length of user transmission;

$R_{bit/s}$ = system transmission rate;

T_{sec} = interval between user transmissions.

Figure 3 illustrates this relationship. The up-link capacity of a typical beam in an RDSS system is plotted as a tradeoff between a high position update rate application, such as aeronautical navigation, and a low position update rate application, such as routine truck fleet monitoring. For multiple beam satellites, the approximate capacity obtained from this approach for the single beam case would be multiplied by the number of beams on the satellite.

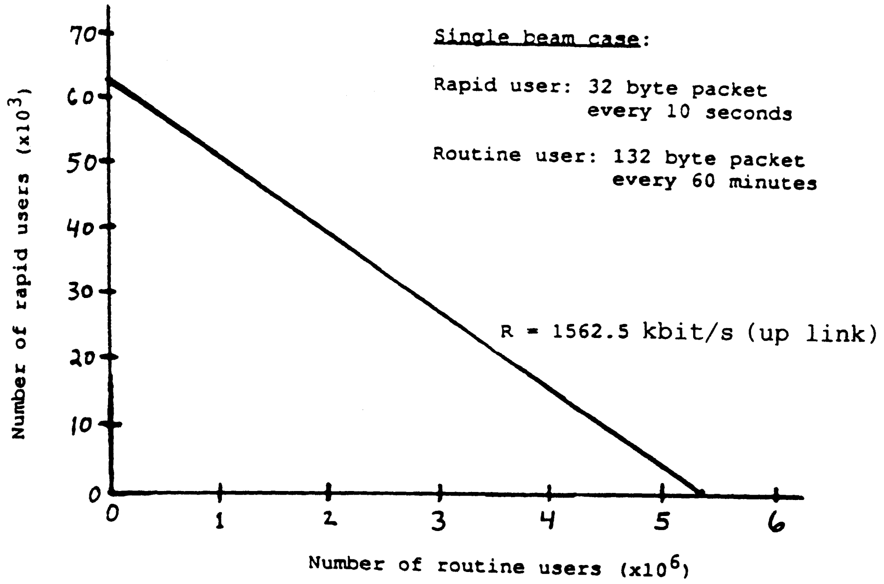

Figure 3. Average RDSS Capacity

4. Frequency sharing

The frequency bands allocated to RDSS involve various sharing considerations. The 1987 Mobile WARC specified sharing conditions in Articles 11 and 28 that were established or adapted for the purpose of allowing implementation of RDSS service. Annex II discusses the frequency sharing conditions in these bands. Further studies are needed to determine more precise results concerning the sharing conditions that should be applied to both RDSS and existing services operating in these bands.

4.1 Sharing with other services

The frequency bands deemed best for an RDSS application should be selected to minimize potential interference to other radiocommunications services. On one hand the characteristics of this type of service, i.e. mobile, low average power user transmitter, near omnidirectional user antenna, etc. do not make it an easy service with which to share frequencies. On the other hand, however, the shortness of individual emissions by mobile users and the generalized use of spectrum spreading techniques are factors which favour sharing.

4.2 Sharing within the RDSS

The use of spectrum spreading techniques also facilitates frequency sharing between systems within the RDSS.

Between systems of the same type, sharing may make use of the cross-correlation properties of pseudo-random codes. Theoretical evaluations show that up to 12 separate RDSS systems could serve the same area.

4.3 Feeder-link sharing

These feeder links would be expected to share bands available for other links in the fixed satellite service and would thus be subject to appropriate coordination requirements. For RDSS feeder links provided in the band 5 150 - 5 216 MHz, further study is necessary on sharing conditions.

4.4 Assessment of Interference Into an RDSS System

For interference sources characterized by a relatively constant level of emissions, the effects of interference into an RDSS system can be quantified in terms of the effects of the interference on the bit error rate of the digital transmission.

As is typical with other services, the sources of degradation to system performance can be divided into those sources within the system which are under the control of the system designer, and those sources external to the system which are characterized as interference. In the case of RDSS, external interference has to be allocated between that caused by other satellite systems and that caused by terrestrial sources of interference.

Internal sources of performance degradation include thermal noise, code noise from other overlapping transmissions within the same space station antenna beam, and transmissions within other antenna beams on the same space station.

External interference from other satellite systems includes both interference from other RDSS systems, as well as interference from satellite systems in other space services operating in the same bands.

In other space services, such as the fixed satellite service, it is typical to allocate 25% of the total noise budget to interference from other space systems and 10% to terrestrial sources of interference, and to leave the remaining 65% of the noise budget under the control of the space system designer. Such an allocation of interference does not appear appropriate for an RDSS system.

With no antenna discrimination on the mobile antenna, the situation of sharing between different RDSS satellite systems is very different from the situation in the fixed satellite service. For RDSS systems, it is primarily the characteristics of the pseudorandom noise codes that provide the discrimination needed between different transmissions, whether within the same RDSS satellite system or between two different RDSS systems.

Section 3.6.1 indicates that the effective inbound capacity of an RDSS system is determined by the code noise occurring within the system. This code noise has to be allocated both among the users of the system, which is under the control of the system designer, as well as to other RDSS systems operating in the same band with overlapping space station coverages, which is not under the control of the system designer. For the outbound link, code noise interference can occur between different beams on the same satellite, between different satellites in the same RDSS system, and between different RDSS systems. In addition, interference may also be caused by other space services not using spread spectrum techniques, which is a likely occurrence in the bands used for the feeder links of an RDSS system.

Therefore, it is appropriate that the total interference to an RDSS system due to other space systems be apportioned between code noise from other RDSS systems and interference from space systems in other services. In the latter case, it is appropriate that no more than 10% of the total noise budget be allocated to satellite systems in other space services sharing the same bands. A 10% allocation of the total link noise to terrestrial sources of interference appears appropriate for RDSS. Further study of this question is necessary.

5. Conclusion

This Report presents initial information describing link requirements, and frequency sharing information, concerning the concept of a radiodetermination satellite system whose design objective is to provide low-cost position information to aeronautical, maritime and land mobile users.

Further study is necessary on sharing considerations including electromagnetic compatibility of RDSS with other services, as well as studies on the effects of multipath and on probabilistic system performance.

ANNEX I

CHARACTERISTICS OF A RADIODETERMINATION-SATELLITE SERVICE SYSTEM BEING DEVELOPED IN THE UNITED STATES

1. *General system concept*

A radiodetermination satellite service (RDSS) system is being developed in the United States of America to provide position and navigation information and a limited digital message capability to users with small, low cost transceivers (see Note). The system is intended to be used for maritime, aeronautical and land mobile applications. It will use code and time division techniques to achieve electromagnetic compatibility with other RDSS systems.

Note. – The United States of America has provided advanced publication information on this system to the IFRB under the name USRDSS.

This proposed RDSS system is designed to operate in two different accuracy modes. Higher accuracy would be obtained by determining the location of the user (i.e. an aircraft, ship or land-based vehicle) by first determining the distance of the user from two geostationary satellites. This bi-lateration information would then be used in conjunction with a digitized terrain map of the surface of the Earth (or, in the case of an aircraft, with data from the aircraft's altimeter) to calculate the location of the system user. In the event that accurate terrain data or altimeter data is not available, a second method would be employed which utilizes the data from a third satellite to provide tri-lateration information. The third satellite data could also be used to verify the bi-lateration calculations. In the first mode of operation, the accuracy over the United States of America is expected to be of the order of 5-10 m. The second, or tri-lateration, mode is expected to yield position accuracies of 50-100 m over the United States of America. Because of geometric considerations, the system accuracy is latitude dependent, being more accurate at higher latitudes with the United States of America than near the equator.

The communications links and equipment of the proposed RDSS system could also be used simultaneously for relaying short digital messages between the system users via the satellites and the central earth station. A general description of overall system operation is contained in [O'Neill, 1985].

2. *Link description*

The planned RDSS will use 8 spot beams for coverage of the continental United States of America for its user links and a single broader beam antenna for its feeder links. Four frequency bands have been allocated for the operation of the system as follows:

- user-to-satellite: 1610.0-1626.5 MHz;
- satellite-to-user: 2483.5-2500.0 MHz;
- central earth station-to-satellite: 6525.0-6541.5 MHz;
- satellite-to-central earth station: 5117.0-5183.0 MHz.

Because of the potential use of the system for safety of human life applications, low power constraints and limited antenna gains of the user transceiver, the frequency bands proposed for both the satellite-to-user and user-to-satellite links were selected to avoid major losses due to atmospheric attenuation. System performance is further enhanced by automatic re-transmission of signals that are not acknowledged.

The proposed RDSS uses a spread-spectrum modulation with a chip rate of 8.192 Mbit/s. Such a modulation would, unless filtered, have relatively high levels of out-of-band emissions. The interference effects of the users will be mitigated by filtering the RDSS user transmissions. The degree of filtering required is undergoing further study. The baseband data rate will be about 16 kbit/s for the user-to-satellite link, and 64 to 128 kbit/s per beam for the satellite-to-user link.

2.1 *Forward link*

The forward link originates in the central earth station in the form of an 8.192 MHz clock signal and eight data streams, one for each of the eight satellite-to-user antenna beams. Each data stream has a data information rate of 64 kbit/s, which results in a 128 kbit/s transmission bit rate by the use of ½ rate forward error-correction convolutional encoding. Each data stream consists of user addresses, beam number information, framing information and messages directed towards the user. These data streams are multiplexed into a single 8.192 Mbit data stream. This signal is transmitted to the satellite in the frequency band 6525.0-6541.5 MHz using a 7.5 m parabolic dish antenna. Link characteristics for the forward link are provided in Table I.

After being received in the satellite, the signal is applied to a baseband demodulator which recovers the timing pulses and data streams in the original signal. The baseband information is passed to a beam demultiplexer which routes each data stream to the appropriate beam. Pseudo-random (PN) code modulators impose unique PN codes on each of the data streams, synchronizing the code to the clock signal. This signal is then up-converted, filtered and supplied to the power amplifier serving the appropriate down-link antenna beam for transmission to the user in the 2483.5-2500.0 MHz frequency band. The transmission is received by the RDSS user through a near-omnidirectional antenna.

The satellite transmission has a frame structure. Each frame is numbered and consists of 98 560 chips at a rate of 8.192 × 10^6 chips/s. This results in a frame duration of approximately 12 ms (1540 transmission bits, 770 data information bits). Each frame is identified so that it can serve as a time epoch for replies from the user transceivers. Data transmission is organized in frames, with each frame containing a short synchronization segment for rapid acquisition. These data frames are addressed to a particular user and consists of data packets.

A link budget giving the performance of the link for a 10^{-5} bit error ratio (BER) after coding is summarized in Table II. As shown in the table, the major noise sources include thermal noise, noise generated by system users located in other antenna beams of the system coupling into the antenna beam being considered, and noise generated by users of other systems of the same general type operating in the same service area.

2.2 *Return link*

The return link originates in the user transceiver. User transceivers are locked on to the continuous outbound data stream from the central station. Based on the need of the user to obtain a position determination, the user will initiate a request at a precisely defined time mark relative to receipt of a frame reference.

Data origiating with the user consists of position determination requests and messages. These are transmitted from the user through its near-omnidirectional antenna to the geostationary RDSS satellites in the 1610.0-1626.5 MHz frequency band. The signals received by each beam are then applied to a linear transponder which produces two times four contiguous 16.5 MHz channels occupying the 66 MHz wideband 5117.0-5183.0 MHz. Each of these two groups is transmitted to the central earth station in a frequency re-use mode using two orthogonal linear polarization. Characteristics for the return links are provided in Table III.

TABLE I – *Forward link characteristics*

Central earth station transmit	
Frequency band (MHz)	6525.0-6541.5
Input power to antenna (dBW)	21.5
Antenna gain (dBi)	51.5
Polarization	Linear
Off-axis pattern	32 – 25 log θ (Recommendation 465)
Satellite receive	
G/T (dB(K^{-1}))	1.0
Antenna:	
Gain (edge of coverage) (dBi)	29.0
Beamwidth (half-power) (degrees)	5.6
Polarization	Linear
Satellite transmit (per beam) (¹)	
Frequency band (MHz)	2483.5-2500.0
Input power to antenna (dBW)	19.8
Antenna:	
Gain (edge of coverage) (dBi)	33.8
Beamwidth (half-power) (degrees)	2.2
Polarization	RHC
User receive	
G/T (nominal towards satellite) (dB(K^{-1}))	–26.8
Antenna:	
Gain (²) (nominal towards satellite) (dBi)	1.0
Beamwidth (half-power) (degrees)	70
Polarization	RHC

(¹) Eight separate beams on each satellite cover the service area.

(²) User antenna gain will vary between 1 and 3 dBi.

TABLE II – *Link budgets for forward link*

Central earth station-to-satellite (6533.25 MHz)	
e.i.r.p. (dBW)	73.0
Free space path loss (dB)	200.2
Atmospheric loss (dB)	1.4
Satellite G/T (minimum) (dB(K^{-1}))	– 1.5
C/N_0 (up link) (dBHz)	98.5
Satellite-to-user (2491.75 MHz)	
e.i.r.p. (minimum) (dBW)	53.6
Free space loss (dB)	191.8
Atmospheric loss (dB)	0.7
User G/T(1) (dB(K^{-1}))	–26.8
C/N_0 (thermal) (dBHz)	62.9
C/I_0 (adjacent beams) (dBHz)	71.1
C/I_0 (three other systems) (2) (dBHz)	63.8
$C/(N_0 + I_0)$ (down link) (dBHz)	60.0
$C/(N_0 + I_0)$ (total link) (dBHz)	60.0
Information data rate (64 kbit/s) (dB(bit/s))	48.1
E_b/N_0 received (dB)	11.9
E_b/N_0 required (3) (dB)	9.8
Margin (dB)	2.1

(1) Assumes 1 dBi user antenna gain towards satellite and an elevation angle of 20°.

(2) Assumes three other systems of the same type operating in the same service area.

(3) Includes 4.6 dB needed to achieve a BER of 10^{-5}, with coding, 2 dB of modem implementation loss and 3.2 dB of system margin.

TABLE III – *Return link characteristics*

User transmit	
Frequency band (MHz)	1610.0-1626.5
Input power to antenna (dBW)	16
Antenna:	
Gain (nominal towards satellite) (dBi)	1
Polarization	LHC
Satellite receive	
G/T (edge of coverage) (dB(K^{-1}))	1.0
Antenna:	
Gain (edge of coverage) (dBi)	29.0
Polarization	LHC
Satellite transmit	
Frequency band (MHz)	5117.0-5183.0
Input power to antenna (¹) (dBW)	17.1
Antenna:	
Gain (minimum) (dBi)	25.2
Beamwidth (degrees)	5.8
Polarization	Linear
Central earth-station receive	
G/T (minimum) (dB(K^{-1}))	29.4
Antenna:	
Gain (dBi)	49.4
Beamwidth (half-power) (degrees)	0.6
Polarization	Linear

(¹) Per four channels transmitted using a single polarization. Each channel originates in a single up-link beam.

The earth-station receiver demodulates user data bursts. The wideband spread spectrum characteristics of the user bursts enable the receiving system to make time of arrival measurements accurate to a few nanoseconds, by delay locked discriminator techniques. The user data is also demodulated and then routed to the central computer. There are 8 channels per satellite, and 3 active receiving satellites; therefore the receiving system will have 24 similar receivers. Each receiver will have several (at least 20) demodulation modules to allow reception of many overlapping user bursts.

When the reply signals from a user are received at the central earth station, it must know exactly at what time the user transmission originated in order to make the appropriate range calculations. This is done by including in the transmission the forward frame number corresponding to the time at which the user initiated the transmission.

The link budget summarizing performance for the return link is presented in Table IV. As shown in the table, the major noise sources include: thermal noise; noise generated by four other system users operating in the same satellite antenna beam coverage area; noise generated by system users located in other antenna beam coverage areas coupling into the antenna beam being considered; and noise generated by users of other systems of the same general type operating in the same service area.

TABLE IV – *Link budgets for return link*

User-to-satellite link (1618.25 MHz)	
e.i.r.p. (1) (dBW)	17.0
Free space loss (dB)	189.0
Atmospheric loss (dB)	0.7
Satellite G/T (nominal) (dB(K^{-1}))	1.0
C/N_0 (thermal) (dBHz)	56.9
C/I_0 (other users, in-beam) (dBHz)	65.1
C/I_0 (adjacent beam users) (dBHz)	70.3
C/I_0 (three other systems in same service area) (dBHz)	58.4
$C/(N_0 + I_0)$ (up link) (dBHz)	54.1
Satellite-to-central earth station (5150.0 MHz)	
e.i.r.p. (2) (dBW)	42.3
e.i.r.p. per user signal (dBW)	18.3
Free space loss (dB)	198.1
Atmospheric loss (dB)	1.4
Earth station G/T (dB(K^{-1}))	29.4
C/N_0 (down link) (dBHz)	76.8
C/N_0 (total link) (dBHz)	54.1
Information data rate (16) (dBHz)	42.0
E_b/N_0 received (dB)	12.1
E_b/N_0 required (3) (dB)	10.0
Margin (dB)	2.1

(1) Assumes 1 dBi user gain at an elevation angle of 20°.

(2) This e.i.r.p. is used to transmit four channels of a single polarization, each channel consisting of the signal from a single up-link beam.

(3) Includes 4.6 dB needed to achieve a BER of 10^{-5}, 2 dB implementation loss and 3.4 dB system margin.

2.3 *Probabilistic performance measures*

It is difficult to represent link performance as a single set of equations due to the number of variables present at any particular time, such as the number of users transmitting, their location etc. Therefore, parameters can only be chosen to model the system at a specific point in time. To analyze the performance of the system over time, a computer program can be used to simulate system operation and determine the probability of achieving certain levels of performance for individual users and for the system as a whole. Further study is being performed in this area.

2.4 *Positioning accuracy*

Positioning accuracy is determined by the magnitude of the ranging error, the error in determining the user's altitude above mean sea level and the geometrical relationship between the satellites and the users. Variations in propagation delay will be largely compensated for by using data from a network of 300 transceivers at fixed, known locations.

Ranging accuracy of the system is a function of the signal-to-noise (S/N) ratio in the synchronizing circuit. The minimum uncoded S/N ratio for operation of the communications channel is 4.6 dB. The synchronizer has 6 dB more processing gain than the communications channel, so that the minimum S/N in the synchronizer is 10.6 dB. This produces an r.m.s. ranging error of approximately 5 ns, applying the equation of Report 509. Since the ranging error occurs both in the user and central earth-station receivers, the resultant r.m.s. range error is 7 ns for the round trip, or approximately 1 m r.m.s. error in distance between the satellite and the user.

Altitude above sea level can be computed from the terrain map stored in the computer or, in the case of aircraft, from the aircraft altimeter. Either of these methods introduces further errors into the position calculations. The positioning accuracy is approximately twice the total ranging plus data-base error due to the geometrical relationship between the satellites and the surface of the Earth. For example, a 1 m ranging error and 5 m terrain map error would result in a positioning error of 12 m. Within the United States of America, this position error is expected to be approximately 5 to 10 m.

In the lower accuracy mode, triangulation is performed using three geostationary satellites rather than two satellites and a model of the Earth's surface. This eliminates one source of error but, because of this different geometrical relationship, positioning accuracy is much worse, 30 to 50 times the total ranging error. A 1 m error in ranging results in positioning accuracy of 30 to 50 m.

2.5 *Multipath effects*

An estimate for required fade margin of 2 dB was developed, based on the user antenna radiation pattern and an elevation angle to the satellite of 20°. This, however, does not consider the possible effect on multipath performance due to mounting a basically two-dimensional near-omnidirectional antenna on a flat surface such as the top of a vehicle. It also does not address the possibility of a reduced need for multipath fade margin in a system utilizing very short messages that are automatically re-transmitted if not acknowledged. More study is required in this area.

3. *System capacity*

3.1 *User-to-satellite link*

The use of spread-spectrum modulation in conjunction with the "Aloha" (see Report 741) type random access method on the user-to-satellite link yields a system which acts quite differently than a non-spread Aloha system. In a non-spread Aloha system, two messages being received simultaneously (a "collision"), usually results in the loss of one or both messages. In a spread Aloha system, such as planned for the RDSS, a number of messages may be received simultaneously, but still be received correctly, if they are transmitted using different pseudo-random-noise modulation codes with good cross-correlation characteristics. If two signals using the same PN code collide in the receiver, it may still be possible to decode both messages, provided that there are two decoders available for that PN code and the two signals are slightly offset in time. The RDSS signal processing ground station is to be designed to operate with an average collision rate in the user-to-satellite link of approximately 10 signals within each of the 8 beams. All signals will still be received with good signal-to-noise ratios with up to 32 simultaneous user transmissions per beam from all RDSS systems operating in the coverage area.

3.2 *Satellite-to-user link*

On the satellite-to-user link, messages would be addressed to specific users (or groups of users) and transmitted sequentially at an approximate rate of 350 position fixes per second in each antenna beam, assuming a message packet length of 128 bits.

4. Signal Format

4.1 Up-link Format

The up-link transmission from a mobile user consists of a transmission burst, approximately 20 to 80 milliseconds in duration, transmitted at a chip rate of 8 million chips per second (8 Mcps). As illustrated in Figure 1, the transmission burst is divided into an acquisition sequence to allow the central earth station to lock onto to the incoming packet, a length field to indicate the length of the data portion of the packet, a routing address for preprocessing control and routing of incoming packets, the user identification code (physical address), format and protocol control fields, a variable length data field, a cyclic redundancy check (CRC) for error detection, and forward error correction (FEC) flush bits. The data field contains an internal diad required for position determination and an application packet of other data as required.

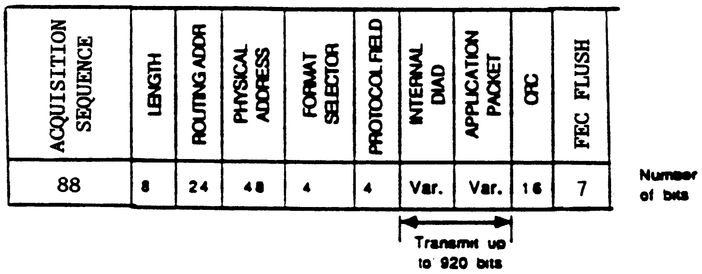

Figure 1. Structure of up-link RDSS Signal.

4.2 Down-link Format

The signal consists of a continuous transmission of fixed length frames, with the beginning of each frame constituting a time reference mark for the RDSS system. As illustrated in Figure 2, each frame consists of an acquisition aid, the frame number, a beam number, and standard down-link packets addressed to a particular user or group of users. Each down-link packet is delimited by HDLC flags, and contains an address (individual or group user identification code), format and protocol control fields, an application packet containing the calculated user position and other data, and a frame check sequence (FCS) for error detection.

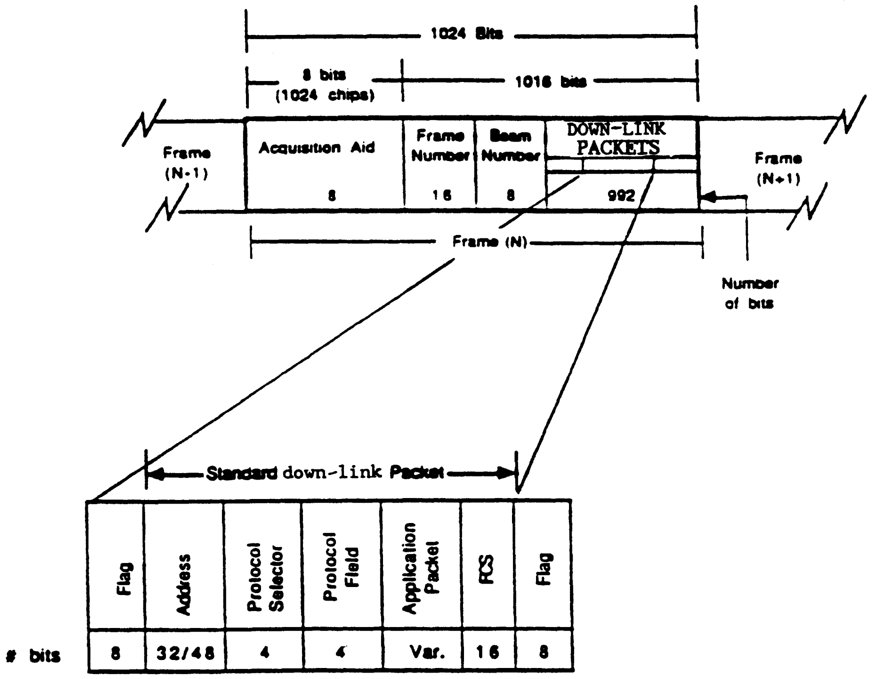

Figure 2. Structure of down-link RDSS Signal

REFERENCES

O'NEILL, G. K. [March, 1985] GEOSTAR: a multi-purpose satellite system to serve civil aviation needs. *ICAO Bull.*, Vol. 40, 3, 12-17. International Civil Aviation Organization, Montreal, Canada.

ANNEX II

FREQUENCY SHARING ANALYSIS FOR THE RADIODETERMINATION-SATELLITE SERVICE

This annex discusses the conditions for sharing in the bands allocated to the radiodetermination-satellite service (RDSS) listed below. Sections [1-4] describe sharing with other services (inter-service sharing) while section [5] discusses sharing between RDSS systems (intra-service sharing).

1. *User-to-satellite link (1610-1626.5 MHz)*

Allocations in this band include aeronautical radionavigation (primary), fixed (primary footnote in several Region 1 countries), fixed (secondary footnote in several Region 3 countries) and radioastronomy (secondary, Radio Regulation No. 734). In addition, the sub-band 1 625.5 - 1 626.5 is also allocated by WARC-MOB-87 to the aeronautical mobile service for transmissions from aircraft stations for public correspondence purposes.

The 1987 Mobile WARC specified that the equivalent isotropically radiated power (e.i.r.p.) transmitted in any direction by an RDSS earth station in the band 1 610 - 1 626.5 MHz shall not exceed -3 dBW in any 4 kHz band. In addition, uniform coordination distances of 100 and 400 kilometres were specified for ground based RDSS transmitters and airborne RDSS transmitters, respectively.

1.1 *Aeronautical radionavigation service*

Considering that users of this band are typically mobile and individual users presumably have extremely low duty cycles, it is expected that interference between users will be transient and could be handled using operational techniques commonly used in mobile services, such as re-transmitting an interfered-with signal. Additional information and study is required. Information and study are also needed on the possibility of interference that might be caused by out-of-band emission from RDSS transmitters to the radionavigation satellite service in the adjacent frequency band.

1.2 *Radioastronomy service*

The radioastronomy service uses the band 1610.6-1613.9 MHz for observations of a hydroxyl line (Radio Regulation No. 734). Due to the extreme sensitivities required by radioastronomy receivers, it would not be possible to perform observations of this line when a transmitting RDSS user is within the line-of-sight of an observatory. In order to protect these valuable observations, a plan for coordinating RDSS and radioastronomy usage of this frequency band has been developed in conjunction with radioastronomers in the United States of America. The plan calls for RDSS users to restrict their transmission to the first 200 ms following the one second time markers of coordinated universal time (UTC) whenever the transmitter is located in a specific area surrounding a radioastronomy observatory.

The effect of these restrictions is to increase the response time to user transmissions slightly since the transmissions can occur only within certain periods of time, and to increase the integration time for radioastronomy observations of the hydroxyl line. These restrictions, however, permit two apparently incompatible services to utilize the same frequency band with acceptable operational complexities.

The influence of the proposed sharing plan on the radio astronomy service needs further study. Report 1182 provides additional information on this matter.

1.3 *Fixed service (Radio Regulation No. 730)*

Radio Regulation No. 730 provides for an additional allocation to the fixed service in several countries, primarily in Region 1. Frequency sharing between RDSS and fixed service systems in this up-link band depends upon the relative locations of the receiving satellite, the service area in question and the fixed service systems.

1.3.1 *Interference to fixed service systems*

RDSS users may cause sporadic interference in a fixed service system when operating in the vicinity of a fixed service system receiver. The interference would consist of short bursts of noise, approximately 20 ms long. A single user would generate such a burst of interference at intervals ranging from once per minute for certain aircraft to several times a day for some land-based users and so would have an extremely low duty cycle.

The area within which a fixed service receiver could receive interference from an RDSS user will vary depending on the location, receiver noise and antenna gain of the receiving system but, in general, would extend to the horizon.

1.3.2 *Interference to RDSS satellites*

Two potential interference situations exist for interference from fixed service systems to an RDSS satellite, depending upon whether or not the fixed service system is in the service area of the satellite. For fixed service systems located within the RDSS service area, interference effects are reduced by antenna discrimination of the fixed service system. For fixed service systems located outside of the RDSS service area, interference is reduced by antenna discrimination of both the fixed service system and RDSS satellite antennas.

In the absence of any antenna discrimination between the systems, the interference power level received by an RDSS satellite from a typical 2 W fixed service system transmitting through a 32 dBi antenna would be about 16 dB above the carrier power level of the desired RDSS user signals. The carrier to total interference ratio necessary to protect the RDSS satellite from interference is approximately 0 dB which makes the interference equivalent in power level to the emissions of a single RDSS user. A level 4 dB lower than this appears to be appropriate as a single-entry interference criteria. This level is achieved by a single interferer if 21 dB of discrimination is provided by the two antennas.

For fixed systems located outside of the RDSS service area, the RDSS satellite antenna will have significant levels of discrimination towards the fixed station transmitter. The entire 21 dB of discrimination is achieved in the RDSS satellite antenna if it is pointed more than 7.6° away from the fixed station location. Additional discrimination is provided if the fixed station antenna is not pointed directly towards the RDSS satellite.

For fixed service systems located within an RDSS service area, all discrimination between the two systems must be obtained from the fixed service system antenna discrimination. A typical 32 dBi fixed service system antenna would provide 21 dB of discrimination at an off-axis angle of 12°. Considering, however, that a fixed service system is generally pointed relatively close to the horizon and that an RDSS satellite would be visible considerably above the horizon within its service area, fixed service transmitters located within an RDSS service area should not represent an interference problem.

1.4 Aeronautical mobile service

Transmissions from aircraft stations in the aeronautical mobile service may cause interference into RDSS space station receivers. Such interference may occur when the aircraft is within the coverage area of the RDSS space station, as well as when the RDSS space station appears near the horizon as seen from the aircraft. Transmissions from RDSS user terminals may also cause interference to reception in the aeronautical mobile service at the aeronautical ground station. Additional information and study is required.

1.4.1 Interference to RDSS

RDSS systems in the 1.6 GHz band will typically use random access, time division multiple access techniques, with pseudo-random codes to distinguish between simultaneous, or overlapping, transmissions from different RDSS users. A significant characteristic of such RDSS systems is the number of simultaneous users, i.e. overlapping transmission bursts, that can be processed by the central earth station in the RDSS system.

For this analysis, the effect of the Aeronautical Public Correspondence (APC) interference is assumed to add to the noise level in the satellite receiver. Under this assumption, the RDSS decorrelator will not distinguish between the noise caused by other simultaneous spread spectrum transmission bursts from RDSS users and longer term transmissions being characterized here as APC interference. Thus, an estimate of the degradation caused to RDSS system performance by APC interference can be expressed by relating the noise level produced by interfering APC transmitters to an equivalent number of simultaneous RDSS users. The calculation of this value indicates the number of simultaneous RDSS users that would have to be displaced to maintain the desired RDSS bit error rate of the remaining RDSS users at the same level that would occur in the absence of APC interference.

The following formula expresses this effect by calculating the equivalent number of simultaneous RDSS users that would be displaced by the aggregate noise produced by all of the terrestrial APC aircraft transmitters in the RDSS bandwidth:

$$10\log_{10}[N_{rdss}] = e.i.r.p._{apc} + 10\log_{10}[N_{apc}] - e.i.r.p._{rdss} - F_{shield} - DG_{sat} + BW_{apc} \qquad (5)$$

where:

N_{rdss} - equivalent number of simultaneous RDSS users suppressed by the aggregate APC interference

$e.i.r.p._{apc}$ - e.i.r.p. of an APC voice channel (dBW)

N_{apc} - number of APC voice channels within the RDSS satellite receiver bandwidth

$e.i.r.p._{rdss}$ - e.i.r.p. of a typical RDSS transmitter (dBW)

F_{shield} - effective reduction in e.i.r.p. of an APC transmitter towards the RDSS satellite receiver caused by the shielding of the aircraft superstructure (dB)

DG_{sat} - RDSS space station antenna discrimination towards the APC service area (dB)

BW_{apc} = effective attenuation of apc signal by RDSS demodulation (dB)

where BW_{apc} is given by the following formula:

$$BW_{apc} = 10 \log_{10} \left[\frac{1}{K} \sum_{n=0}^{K-1} \left\{ \frac{\sin\left(\pi \frac{7.25 + n/K}{8}\right)}{\left(\pi \frac{7.25 + n/K}{8}\right)} \right\}^2 \right] \qquad (6)$$

where K is the total number of APC channels in the 1 625.5 - 1 626.5 MHz band.

Typical RDSS stations in the 1 610 - 1 626.5 MHz band will be mobile transmitters (e.g. 17 dBW e.i.r.p) which employ a bandwidth of 16.5 MHz to transmit to the satellite.

Transmission parameters have not yet been defined for APC systems in this band, although APC systems are being experimentally developed in nearby bands around 900 MHz. Such systems could typically employ mobile transmitters with an output of 10 watts and CSSB modulation with an assigned bandwidth of 5 kHz per voice channel.

In the case where the APC service area of an aeronautical station in the mobile service is assumed to lie within the coverage area of the RDSS space station, a value of 10 dB is assumed for F_{shield} while 0 dB is assumed for DG_{sat}.

In the case where the APC service area lies outside the RDSS space station service area, no shielding is assumed to be provided by the aircraft superstructure while DG_{sat} is assumed to be 20 dB.

The effective attenuation of the APC spreading by RDSS demodulation (BW_{apc}) is -25.7 dB, calculated by use of formula (6), taking into account K=40 channels. Therefore, using equation (5) and the worst-case situation of co-coverage, it may be calculated that simultaneous transmission bursts from 4,600 APC users would be equivalent to a single RDSS user. For $e.i.r.p._{apc}$ = 16 dBW.

The limited bandwidth of 1 MHz available for APC is such that 4,600 far exceeds the total number of simultaneous calls possible. Therefore it appears that APC systems operating in the 1 625.5 - 1 626.5 MHz band would not have a significant impact on RDSS operating in this band with respect to the RDSS demodulator characteristics and performances.

However, the service area of a single terrestrial APC system is likely to be smaller than the RDSS coverage area, allowing the 1 MHz allocation to be reused with the RDSS coverage area. Thus, several APC systems may be operated within the RDSS coverage area.

In addition, several APC systems outside the RDSS coverage area are likely to be located within the visibility of an RDSS space station, and the aggregate effect of such interference should be taken into account.

Moreover, other APC interference effects can have a greater impact on RDSS. For example, the loading of an RDSS transponder by the aggregate of APC users within the RDSS service area may shift the operating point of the RDSS transponder by a significant amount. Further study of these potential sources of interference is required.

1.4.2 Interference from RDSS

Two scenarios are considered for interference to APC ground receivers, since the parameters describing APC are not yet decided. The results should therefore be treated with caution since the final APC parameters may differ from those assumed for either of these cases.

APC Characteristics

	Scenario I	Scenario II
Modulation	GMSK	ACSSB
Bit Rate	38 kbit/s	
Channel Bandwidth	25 kHz	6 kHz
Transmitted power	14 dBW	11 dBW
Aircraft antenna gain	0 dBi	0 dBi
Protection ratio	10 dB	22 dB
Maximum distance between transmitter and receiver	390 km	390 km
Minimum pfd at ground antenna	-108.8 dBW/m^2	-111.8 dBW/m^2
Maximum interfering field strength at ground receiver	27.2 dBμV/m	12.2 dBμV/m

RDSS characteristics

Maximum e.i.r.p.: -3 dBW in any 4 kHz band

e.i.r.p.: -14.8 dBW in 25 kHz
-21 dBW in 6 kHz

Signal distribution: $\sin^2 x/x^2$

Signal duration: 12 - 20 ms

Maximum signal repetition: 1 per minute (airborne)
1 per hour (ground-based)

Interference assessment

(i) RDSS Land Based Transmitter

Scenario I

The APC allocation is at the top of the RDSS band. Therefore, taking into account the $\sin^2 x/x^2$ distribution, the effective interference EIRP in 25 kHz is -14.8 dBW. Therefore for a maximum interfering field strength of 27.2 dBμV/m (Rec 370, Land, 10% time, 1% locations) a separation of 14 km is required.

Scenario II

The effective interference EIRP in 6 kHz is -21 dBW. Therefore, for a maximum interfering field strength of 12.2 dBμV/m (Rec 370, Land, 10% time, 1% locations) a separation of 26 km is required.

(ii) RDSS Airborne Transmitter

The pfd at the ground antenna may be evaluated using the equation:

$$\text{Rx Pfd} = \text{Tx Power} - \text{Path Loss} + \text{Tx Antenna Gain} - \text{Shielding} - \log_{10} \frac{4\pi}{\lambda^2}$$

For the maximum permissible interfering signal

Rx pfd = Minimum wanted signal pfd - protection ratio

Using the data from the table above, and assuming an aircraft shielding of 4dB, the minimum permissible path loss L for each scenario can be evaluated.

Scenario I

$$-108.8 - 10 = -14.8 - L - 5 - 4 + 26$$

$$\therefore L = 121$$

Therefore, the necessary path loss is thus 121 dB which requires (Recommendation 525-1) 16 km separation.

Scenario II

$$-111.8 - 22 = -21 - L - 5 - 4 + 26$$

$$\therefore L = 129.8$$

Therefore, the necessary path loss is thus 129.8 dB which requires (Recommendation 525) 45 km separation.

Potential for interference

In the cases considered, the above analyses show that separations varying from 14 km to 45 km are required to ensure that RDSS does not cause unacceptable interference to APC, with the given protection ratios. In these analyses, however, the RDSS transmission is assumed to be continuous. As indicated above, this is not the case and the typical signal duration is 12 - 20 ms at a repetition rate of 1 per minute for airborne and 1 per hour for ground-based RDSS terminals. With this situation, it is questionable whether the interference experienced will be unacceptable.

The nature of RDSS means that the transmitters considered here are generally mobile therefore it is not practicable to impose minimum separation restrictions between RDSS users and APC ground stations to the requirements determined above.

Summary

RDSS transmissions in the band 1 610 - 1 626.5 MHz may cause interference to APC ground stations located within up to 45 km depending on APC characteristics and RDSS transmitter position (land or air). The extent of this interference will be dependent on the susceptibility of APC to the pulsed transmissions of RDSS.

2. *Satellite-to-user link (2483.5-2500.0 MHz)*

The 2483.5-2500.0 MHz band is part of the 2400-2500 MHz band designated for industrial, scientific and medical (ISM) applications by Radio Regulation No. 752. Radio services operating within this band must accept harmful interference which may be caused by these applications.

Also, the band is allocated to radiolocation, fixed and mobile service users. The 1987 Mobile WARC limited RDSS space station transmissions in this band to the maximum power flux-density limits specified in No. 2557 of the Radio Regulations, and maximum coordination distances of 100 and 400 kilometres are specified for ground-based and airborne RDSS receivers, respectively.

Consideration should also be given to the second harmonic frequency of the satellite-to-user links which could interfere with radio astronomy observations in the band 4 990 - 5 000 MHz. See Report 1182.

2.1 *Sharing with ISM operations*

Due to the large number of microwave ovens in use today, this section concerns potential interference to RDSS user receivers from microwave oven emissions in the 2400-2500 MHz band. Previous studies have indicated that interference to the RDSS system from microwave ovens should not pose a serious operational problem. The effect of possible interference from microwave ovens operating in close proximity to an RDSS user would be to cause a modest increase in a user's re-transmit rate.

2.2 *Sharing with fixed and mobile service system*

2.2.1 *Interference to RDSS*

Due to the omnidirectional characteristic of the user receive antenna, the RDSS users are susceptible to interference from nearby fixed and mobile service transmissions. In fact, the potential for interference is quite high if fixed or mobile service transmitters are within line-of-sight of the user receivers.

There appear to be few fixed and mobile service assignments in the 2484-2500 MHz band. As a means, therefore, of expanding the use of the spectrum to include RDSS operations, it may be necessary to re-assign fixed and mobile service users to slightly different frequencies within the allocated frequency band. In countries where extensive use of this band for fixed and mobile service use is not made, re-assignment such as this may be desirable in order to utilize RDSS type services.

2.2.2 Interference to fixed and mobile service systems

The power flux-density produced by RDSS space stations operating in the band 2 483.5 - 2 500 MHz is currently limited by No. 2557 of the Radio Regulations. Higher power flux-densities would allow the capacity of RDSS systems operating in this band to be limited by interference from other RDSS users, rather than the thermal noise performance of the RDSS receiver at the specified power flux-density limit. The result would be higher RDSS system capacity. However, the increase of power flux-density requires careful study to resolve the problem of sharing conditions between RDSS and the fixed and mobile services.

2.3 *Sharing with the radiolocation service*

Because of the great diversity of terrestrial radiolocation stations, it is difficult to make a definitive statement as to the feasibility of sharing between the radiodetermination satellite service and the radiolocation service. Inter-system interference will be a function of system power and sensitivity, antenna gains, relative system locations, pulse length, pulse repetition frequencies and types of received signal processing, among other factors. In general, the radiolocation systems that would be most likely to produce or receive interference would be those systems which have a high antenna gain towards the RDSS satellites and which are located near the service area of an RDSS system, and therefore are near the main beam of the RDSS satellite. This occurs when a low elevation angle RDSS service area contains radiolocation stations or is adjacent to an area containing radiolocation stations. The satellite emissions would appear to the terrestrial radiolocation system from a single point in the sky. Depending upon the signal processing used in the radiolocation receiver it may be possible to process out a recognizable signal of the type emitted by the RDSS.

The high power terrestrial radiolocation service transmitters will cause interference in RDSS users operating in the vicinity of the radiolocation site. It may be possible, however, for RDSS users to operate in this area if the radiolocation transmitter antenna scans the horizon so that emissions in the direction of the RDSS user are periodically low. In the case of the RDSS users, only a relatively short period of interference-free transmissions is necessary to establish a link to the satellite. By utilizing these interference-free periods, it may be possible to achieve effective communications in these areas.

3. *Satellite-to-central earth station* (5 150 - 5 216 MHz)

The 5 150 - 5 216 MHz band is allocated under Footnote 797 to the fixed-satellite service and the inter-satellite service, for use as feeder links serving the aeronautical radionavigation and/or aeronautical mobile (R) service, subject to agreement obtained under the procedure set forth in Article 14. This band is also allocated on a world-wide basis to the aeronautical radionavigation service with use by the international microwave landing system (MLS) (Radio Regulation No. 796) taking precedence. MLS equipment, however, is being developed and distributed only in the 5030-5090 MHz portion of the spectrum.

The band 5 150 - 5 216 MHz is also allocated under the provisions of RR No. 797A to RDSS (space-to-Earth), for feeder links in conjunction with RDSS systems operating in the 1 610 - 1 626.5 MHz and 2 483.5 - 2 500 MHz bands, subject to the condition that the total power flux-density at the Earth's surface shall in no case exceed -159 dB(W/m2) in any 4 kHz band for all angles of arrival.

In certain countries, the band 5 150 - 5 250 MHz is also allocated to the mobile service on a primary basis subject to agreement obtained under the procedures of Article 14.

3.1 *interference to MLS receivers*

The portion of the MLS that could operate in this band is a mobile receive-only station used on board aircraft for final approach and landing at major airports. Indications are that the system would have a noise temperature near 2600 K and a receive antenna gain of about 3 dBi.

Using these hypothetical characteristics and a maximum RDSS satellite power flux-density of -159 dB(W/m^2) in a 4 kHz band, a noise-to-interference ratio in excess of 30 dB is obtained. This value would be sufficient to protect the MLS receivers and thus there should be no sharing difficulties encountered in this band.

3.2 *Interference to RDSS central earth station*

Any potential interference to the central earth station from MLS transmitters would be controlled via proper earth-station site selection and coordination so as to avoid airport facilities utilizing MLS systems.

3.3 Sharing with the mobile service

The -159 dB(W/m2) power flux-density limit on RDSS transmissions specified in No. 797A of the Radio Regulations to protect MLS receivers in the aeronautical radionavigation service is more than sufficient to also protect receivers in the mobile service.

Normal coordination procedures employed between earth stations and terrestrial stations (see Appendix 28 to the Radio Regulations) should be sufficient to protect the RDSS receiving earth stations from interference caused by ground based transmitters in the mobile service. However, these procedures may not be applicable to airborne transmitters in the mobile service. Because of the low levels of the signals being received from the RDSS space station in these bands, airborne transmitters in the mobile service in certain countries may cause unacceptable levels of interference at large distances from the receiving earth station. Additional information and study is required.

4. *Control earth station-to-satellite (6525-6541.5 MHz)*

This link, operating as a feeder link in a fixed satellite service band, would be the subject of normal coordination with other satellite systems (see Appendix 29 to Radio Regulations) and terrestrial stations (see Appendix 28 to Radio Regulations).

5. *Sharing within the RDSS service*

The use of pseudo-random-noise codes by the RDSS system to produce the spread-spectrum modulation of the user-to-satellite signals enables a large number of users to access the satellite simultaneously. The same process is also effective for extracting signals from interference generated by other RDSS systems in the same service area, provided the signals are modulated by pseudo-random-noise codes that have good cross-correlation characteristics. Gold codes, for example, are a class of codes that have these characteristics and can be readily generated in large numbers. This method of coordination through the use of Gold codes permits an RDSS system to operate with other RDSS systems in the same area. For systems serving different areas, sharing is further enhanced by the antenna discrimination provided by the high gain RDSS satellite antenna.