REPORT 927-2*

GENERAL CONSIDERATIONS RELATIVE TO HARMFUL INTERFERENCE FROM THE VIEWPOINT OF THE AERONAUTICAL MOBILE SERVICES AND THE AERONAUTICAL RADIONAVIGATION SERVICE

(Questions 1/8 and 62/8 and Study Programme 21A/8)

(1982-1986-1990)

1. Background

The ITU definition of "harmful interference" is contained in Radio Regulation No. 163 as follows:

"Harmful Interference: interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with these Regulations."

The term "harmful interference" is not generally definable in a precise quantitative manner and therefore an assessment of harmful interference must be construed in the light of the nature of the operations and the safety environment. This leads directly to the conclusion that the determination of quantitative threshold levels of harmful interference for the various aeronautical mobile radiocommunication services requires the examination of the appropriate safety criteria.

2. Aviation safety criteria

A prime basis of aviation safety is the *statistical* assessment of performance criteria and failure rates. The following statistical "failure rates" may have been used as criteria by some civil aviation administrations in the international aeronautical community:

- the air traffic systems which ensure separation between aircraft flying *en route* are designed to reduce the chances of mid-air collisions to a level no greater than 2 in 10^8; and
- the certification of aircraft automatic landing equipment by many civil aviation administrations requires that the control system in each aircraft be demonstrated statistically to have a failure rate no greater than 1 in 10^7 landings.

In light of the above, it is evident that for aeronautical mobile radiocommunication services, the required interference protection ratios will be very much influenced by the statistical characteristics of the particular service. For instance, a radionavigation aid providing the sole guidance to an aircraft during automatic landing requires very high protection from harmful interference. Indeed, it would follow that the statistical probability of harmful interference in such cases needs to be more stringent than 1 in 10^7. In comparison it may be possible to identify other aeronautical systems which do not require this same degree of protection. § 5 of this Report examines this aspect further for the various aeronautical systems.

The above points lead directly to the thought that whilst it may be possible to quantify a signal level for unwanted harmful interference which would permit safe operation of a particular type of radio service, the promulgation of such a level without an associated description of its assumed nature and statistical variation could be of little value and could have serious implications. This would apply particularly to those environments where there are a multitude of potential interfering sources, possibly of more than one type, and where the aggregate harmful interferences at any particular point, therefore, could be expected to vary with time.

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* The Director, CCIR, is requested to bring this report to the attention of ICAO and IEC and Study Groups 1, 10 and 11.

3. Aeronautical and non-aeronautical sources of harmful interference

An important aspect of the study of harmful interference is the determination of whether or not the criteria for harmful interference from non-aeronautical sources has, or should have, any relationship with the technical planning criteria established in the aeronautical services for co-channel and adjacent channel assignments. Frequency assignment planning criteria adopted internationally within the aeronautical services are based on practical considerations which take into account the operational usage of the particular service. In addition, the planning criteria are based, reasonably enough, on the premise that mutual cooperation and internationally agreed aviation standards and procedures are used by everyone involved. It is a point of fact that the 146 Contracting States of ICAO are under certain obligations relative to the adoption of aeronautical standards, recommended practices, and procedures, as set forth in Article 38 of the Convention on International Civil Aviation (Chicago, 1944). Pursuant to these obligations, there is a highly developed international information and registration service which ensures that all aviation facilities and their "frequency protected" service volumes are formally promulgated and available on charts in accordance with Annex 15 to the Convention on International Civil Aviation; and appropriate information from this service becomes part of aircraft flight deck documentation. Thus, in respect of all technical protection criteria adopted in the international civil aviation community against "aeronautical-to-aeronautical" harmful interference, there is comprehensive and significant additional protection provided through the organizational structure of international civil aviation, with ICAO at its focal point.

The additional protection indicated in the above paragraph is largely non-existent for non-aeronautical sources of harmful interference to aviation, some of which are only partially regulated by the ITU. Consequently, there is not necessarily an inherent relationship between aeronautical protection criteria and those criteria which may be appropriate to safety services for application to non-aeronautical sources of harmful interference. Each potential non-aeronautical source of harmful interference requires individual consideration in this respect.

The following external sources of man-made emissions and radiations are known to have caused harmful interference to aeronautical services:

- broadcasting, LF/MF AM and VHF FM;
- cable distribution systems;
- power line distribution systems;
- power line carrier;
- industrial, medical and scientific equipment;
- local oscillator emission from domestic electronic equipment;
- information technology equipment.

It should be observed that some of the above are not under the direct purview of the ITU, and therefore, it will be necessary to effect coordination between ITU, ICAO, and other concerned organizations. However, this need not influence CCIR involvement in the investigation of adequate protection criteria.

4. Shared and exclusive allocations

Regardless of the original intentions of radio spectrum planners, there can be no doubt that the pressure on the radio spectrum for additional allocations to the various radiocommunication services can result in aeronautical protection criteria being effectively regarded as non-aeronautical sharing criteria. As a consequence, a safety service must take considerable precautions to ensure that any radio service sharing the same radio band is constrained sufficiently to leave an adequate margin under all likely circumstances so that the aggregate harmful interference never exceeds the required protection criteria.

The constraints of weight, size, and power consumption placed upon airborne equipment have resulted in relatively low powered transmitters and sensitive receivers, which is consistent with general ITU guidance for efficient and effective use of the radio spectrum. Nonetheless, the above set of conditions does cause difficulties for the aeronautical community when interference problems arise. For instance, the wanted signal at the edge of a VHF radiotelephony service volume must be no less than 70 μV/m to meet ICAO standards and recommended practices. For an aircraft flying at, say, 300 m above the ground, such a wanted field strength could be equalled by an unwanted signal source on the ground with an e.i.r.p. of only 16 μW. Many interfering sources can easily produce more than 16 μW. Article 8 of the Radio Regulations, the Table of Frequency allocations, contains examples of sharing arrangements between aeronautical and other radiocommunication services, some of which have resulted in harmful interference problems. In such cases, the need to maintain the necessary aeronautical protection criteria has led to a less efficient use of the radio spectrum for aeronautical purposes than could be achievable with separate exclusive allocations. Thus caution should be exercised before considering any sharing involving the aeronautical radiocommunication services.

Annex II details some of the items to be evaluated when considering the specific problem of sharing with the aeronautical flight test telemetry stations. In this regard Annex II responds to WARC-79 Resolution No. 505.

5. Aeronautical radiocommunication and radionavigation systems included in Annex 10 to the ICAO Convention

Precise details of aeronautical radiocommunication and radionavigation systems are contained in Annex 10 to the Convention on International Civil Aviation. Brief synopses are given below:

5.1 *HF and VHF digital data interchange and radiotelephony*

Air/ground digital data interchange or radiotelephony constitute a direct link between an aircraft in flight and aeronautical stations on the ground. The number of aircraft flying simultaneously in any given airspace and the multiplicity of air routes flown, result in a complex set of rules and procedures to ensure the safety of air operations. While it is true that interference to air/ground radiotelephony communications is relatively easier to detect, in as much as the pilot can hear it and is normally less likely to be misled, than in the case of interference to digital data interchange or to a radionavigation aid, such interference may nonetheless have serious consequences, particularly for aircraft contacting approach control of an airport while flying at positions where the ground clearance is of the order of a few hundred feet. Thus, regardless of adherence to precise phraseology and to other standard operational procedures, cases have arisen where even a slight interference to a single phrase has resulted in catastrophic consequences.

The conversion of the above factors into quantitative protection ratio criteria is a difficult task. On the one hand there is general acceptance of the view that some minimum interference to voice communications could normally be accepted, but on the other hand, it needs to be recognized that under difficult operational circumstances, errors that would normally be accepted can assume great significance, and under these circumstances an interference-free service can be vital. Therefore, a general protection ratio for HF and VHF radiotelephony should be developed such that the aggregate interference on any channel should not significantly add to the basic noise level of the safety service receivers used for air-ground communications. Following the same general idea, a protection ratio should be developed for HF and VHF digital data interchange.

Compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz is addressed in Report 929.

5.2 *VHF emergency frequencies*

The Radio Regulations and Annex 10 to the Chicago Convention on Civil Aviation contain special provisions for the use and protection of the aeronautical mobile emergency frequencies 121.5 MHz and 243 MHz. Subsequently, the ICAO has agreed on special procedures for monitoring these frequencies while, in addition, the COSPAS-SARSAT system provides for essential alerting capabilities. Also, EPIRBs, compulsory in some countries for carriage on board aircraft, operate on these frequencies. It is important that reception of distress and emergency transmissions will not be impaired. These frequencies are also used by other services for communications with the aeronautical services in the event of an emergency.

5.3 Landing guidance systems

5.3.1 Instrument landing system (ILS)-(VHF and UHF)

The ILS consists of a "localizer" (VHF) providing lateral guidance for aircraft to the airport runway, a "glide-path" (UHF) providing the line of descent in the vertical plane, and one, two, or three "marker beacons" providing the aircraft with height and distance checks at known points from the runway threshold. One or more "locators" or other supplementary approach aids such as VOR may be used in conjunction with the ILS to assist in guiding aircraft to the "on-course" radio beams. Each of the above components of the ILS performs a different function and hence it can be seen that these components do not provide any form of redundancy for each other.

In the approach and landing phase of flight, when the aircraft is manœuvring in close proximity to the ground, it is essential that harmful interference to any of the radio aids in use during this phase of flight be kept at an extremely low level of probability of occurrence. It is particularly relevant to note in this regard that the use of automatic landing systems which utilize ILS guidance signals, is the normal operating procedure for modern large aircraft, regardless of weather conditions. It should be noted that the very high level of protection against harmful interference required to support such operations is only needed within fairly constrained volumes of airspace around the ILS installations, e.g., around aerodromes. This factor may be helpful when considering the practical issues involved in protection against harmful interference.

Because of its critical nature considerable investigation of interference to ILS has occurred and Annex I gives more detailed information and derives protection ratios required under specified circumstances.

Compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz is addressed in Report 929.

5.3.2 Microwave landing system (MLS)

The MLS is intended for international application and will provide instrument landing guidance for all classes of airports and all types of aircraft, including air carriers, vertical and short take-off and landing aircraft, business and light aircraft of general aviation. MLS will support operations at the large commercial airports with categories of service which permit all weather landings, as well as curved or segmented paths. This can increase the number of aircraft landing in high traffic situations. Simplified equipment will permit inexpensive installation at small airports which serve the private aviation sector and the "commuter" airlines. For instance, the simplified version may provide a smaller coverage angle, limited or no curved approaches and no flare guidance.

The MLS consists of angle guidance equipment in the 5.0 - 5.25 GHz frequency band. Azimuth equipment provides lateral guidance to the extended airport runway centre line, elevation equipment provides the line of descent in the vertical plane, and precision distance measuring equipment (DME/P) in the 960 - 1 215 MHz frequency band provides distance from the airport runway to the aircraft. Each of these components performs a separate function, and when integrated provides the aircraft with a precise three-dimensional position fix, and guidance with respect to the selected approach path. Azimuth guidance for the "back course" (e.g. missed approach) is also available, employing a separate azimuth transmitter directing its beam into the back course sector. A ground-to-air data capability is also provided throughout the angle guidance coverage volume via stationary sector coverage beams. Among other things, this allows for ground antenna siting geometry to be transmitted to the aircraft for use in its position determination algorithm.

The azimuth and elevation signals are radiated from ground antennas and processed in an airborne MLS receiver. The angle information is developed by measuring the time difference between successive passes of highly directive narrow fan-shaped beams. The DME/P provides distance information in the aircraft by measuring total round-trip time between interrogations from an airborne transmitter and replies from a ground transponder. Whereas normal DME/N has a basic accuracy of about ±370 m (0.2 NM), the DME/P has an accuracy requirement curve of ±250 m (820 ft) at 37 km (20 NM), which narrows to ±30 m (100 ft) at runway threshold.

MLS transmission techniques and signal processing allow for a single accuracy standard - equivalent to the precision needed for full automatic landing procedures. It is essential that the accuracy of this system not be compromised by contamination of its signals with interference signals or multipath. Low thresholding (DME/P) together with narrow fan beams (angle scanning beam) effectively eliminates multipath effects. Proper channelization and control of unwanted signals are required to reduce interference below allowable levels.

Allowable MLS system errors are specified in terms of Path Following Error (PFE) and Control Motion Noise (CMN). PFE refers to low-frequency guidance errors which can cause the aircraft to deviate from its intended path. CMN refers to higher frequency error components which do not contribute to a path following error, yet can cause vibrations in the control surfaces or the pilot wheel and column during automatic landings. CMN can affect pilot confidence in the guidance system.

Annex 10 to the ICAO Convention gives detailed information relevant to system design and electromagnetic compatibility factors with other like-systems (e.g. minimum desired signal levels, channel plan, adjacent channel signal levels, D/U ratios, spurious emission limits, etc.) [ICAO]. The Radio Technical Commission for Aeronautics has defined minimum operational performance characteristics for both angle and distance measuring MLS avionics [RTCA, 1981, 1985 and 1988]. Additional studies are ongoing in the United States with regard to compatibility criteria from interference originating from out-of-band and other in-band systems.

5.4 *VHF omnidirectional radio range (VOR)*

The VOR system consists of a ground-based beacon radiating an omnidirectional signal providing directional guidance in the horizontal plane in such a manner that the airborne system provides an accurate indication of the compass bearing from the aircraft to the beacon. The system also provides identification signals and allows for voice transmission. The beacon transmits modulated CW signals continuously and can serve simultaneously any number of suitably fitted aircraft. The service volume of some *en route* facilities can extend beyond 300 km.

Most VOR installations provide *en route* service, often in association with DME equipment (see § 5.5). In addition, certain low-power VOR installations are used as holding or approach aids in the vicinity of aerodromes. With respect to the bearing function, interference to VOR can manifest itself as false bearing information to the aircrew and/or automatic flight control system, and this interference would directly impinge on the safety of the flight. The degree of the effect of the interference would depend on its type, strength and duration. In the low-powered VOR cases, even lower levels of interference could be critical to the operation of the aircraft, but fortunately, the service volumes concerned are relatively small.

Compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz is addressed in Report 929.

5.5 *Distance measuring equipment (DME) – (UHF)*

The DME system utilizes coded digital transmissions providing the aircraft with accurate slant-range distance measurements to ground-based beacon positions. The beacon transmits in response to an interrogation from an aircraft, and although the coded interrogation and reply offers a measure of interference protection, the system can become saturated when many aircraft are within range of a beacon. Under these circumstances, interference could be detrimental to safety.

DMEs are most often used in conjunction with VORs to provide international short-range navigational facilities. However, some DMEs are used in association with ILS, and consequently these circumstances may require special provisions to ensure adequate protection against harmful interference.

It is also important to recognize that DME frequency assignments are always "paired" by international agreement with either a VOR or ILS frequency. Consequently, frequency protection considerations need to be satisfied simultaneously on both of the paired frequencies.

5.6 *Radars*

Radar for aeronautical purposes can take many forms with widely varying characteristics and operational usages, e.g., long-range air traffic surveillance, radar altimeters, secondary surveillance radar, very short-range aerodrome surface surveillance, airborne weather detection and navigational assistance.

It is not possible to provide a universal interference assessment to cover these variations, and therefore, each case needs to be considered separately. However, it is worthy of note that regardless of the transmission characteristics employed, it is quite normal for the reception requirements of a radar system to be, necessarily, highly sensitive and thus capable of detecting low levels of unwanted signals.

Sophisticated processing techniques can sometimes be used to alleviate some types of interference, but these techniques are not practicable universally, and under some operational conditions are not acceptable.

Report 914 describes several techniques used on radars to reduce interference, many of which have been successfully adopted by aeronautical radar manufacturers.

5.7 *Non-directional beacons (NDB) – (LF/MF)*

Although at first sight NDBs may appear similar to VORs in concept, there are significant practical differences in their usage. NDBs are more widely implemented than VORs and are frequently used by smaller aircraft, which are, in some cases, not equipped to utilize VORs. NDBs are also frequently used to guide and establish aircraft on flight paths that enable them to acquire more accurate VHF aids (VOR, ILS, etc.) as part of the approach procedure. In addition, the airborne equipment used in association with NDBs is simpler in concept and is less able to cope with interference than more sophisticated airborne equipment. The basic simplicity of the system makes it less able to distinguish between true NDB signals and unwanted emissions near or within the channel passband. In particular, an "overhead beacon" indication on the aircraft flight deck can be falsely provided under certain conditions by interfering signals.

Interference to NDBs is an important issue in the aviation world, because many NDBs are in radio bands which are shared with other users in some parts of the world, and in addition, these bands are sometimes highly congested. Protection criteria against harmful interference must take these facts into consideration.

6. Other aeronautical radiocommunication and radionavigation systems in common use

In addition to the radiocommunication and radionavigation systems that are specifically detailed in Annex 10 to the Convention on International Civil Aviation (Chicago, 1944) there are a number of such systems that are in regular use by aviation operators which may also be seriously affected by harmful interference.

Some of these systems are briefly described in Annex III to this Report.

7. Conclusions

The design of an aeronautical radiocommunication system takes into consideration appropriate levels of integrity and reliability in order to achieve, in a statistical sense, the overall objectives of the total operational system. Criteria to protect aeronautical systems from non-aeronautical sources of interference must be adequate to meet these objectives (see also Recommendation 441).

REFERENCES

ICAO, Annex 10 to the Convention on International Civil Aviation, Volume I, Fourth Edition.

RTCA, Radio Technical Commission for Aeronautics, Document No. RTCA/DO-177 [July 1981] - Minimum Operational Performance Standards for Microwave Landing System (MLS) Airborne Receiving Equipment. Washington D.C.

RTCA, Radio Technical Commission for Aeronautics, Document No. RTCA/DO-189 [September 1985] - Minimum Operational Performance Standards for Airborne Distance Measuring Equipment (DME) Operation Within the Radio Frequency Range of 960 - 1 215 MHz. Washington D.C.

RTCA, Radio Technical Commission for Aeronautics, Document No. RTCA/DO-198 [18 March, 1988] - Minimum Operational Performance Standards for Airborne MLS Area Navigation Equipment. Washington D.C.

ANNEX I

SOME INTERFERENCE MECHANISMS RELATED TO THE INSTRUMENT LANDING SYSTEM

1. Introduction

Detailed examination of some of the interference mechanisms that could cause harmful interference to the ILS localizer signals has taken place in several aeronautical administrations, and this Annex summarizes some aspects of these examinations. The examinations have encompassed both theoretical studies and laboratory tests, and the degree of correlation has been extremely high.

2. Harmful interference threshold

The criteria establishing the threshold of harmful interference for ILS have been taken from Annex 10 of the Convention on International Civil Aviation (Chicago, 1944).

From the aircraft localizer receiver point of view, interference to a localizer signal will appear as an aberration of the localizer course line (in ICAO terminology, an aberration of the localizer course line is called a "bend"), and will contribute to the total allowable receiver output error. The allowable receiver output error ultimately is a function of the permissible lateral displacement of the aircraft from the localizer course line, and this displacement is dependent on the operational category of the ILS to be fulfilled and the approach speed of the aircraft. Annex 10 contains standards, recommended practices, and guidance material which are necessary for the attainment of the objectives of the instrument landing system, and this material indicates that in order to restrict aircraft deviations to less than 5 m lateral displacement from the localizer course line for Categories II and III, the aberration of the localizer course line must not be greater than 5 μA. Attention is drawn to the fact that there are other contributors to course aberrations which need to be considered in the attainment of the objectives of the instrument landing system, but these will not be discussed in this Annex. However, these other criteria must be taken into account in order to define satisfactorily protection ratio(s) for ILS. This matter also is addressed in § 4 of Report 929 in light of compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz.

For the purpose of this Annex, interference mechanisms producing an aberration of the localizer course line of 5 μA or greater have been defined to be harmful interference; however, in view of the factors mentioned above this value is subject to amendment.

3. Interference mechanisms

Several modes of interference were established by mathematical analysis and confirmed by laboratory tests using several airborne equipments conforming to ICAO standards.

3.1 *Interference from an unmodulated carrier signal*

Type I – If an unwanted signal is within the ILS localizer receiver RF passband and beats with the localizer carrier signal to produce a difference frequency within about 0.5 Hz of the 90 Hz or 150 Hz ILS sideband signals, the unwanted RF signal field strength must be as low as 46 dB below the localizer carrier level in order not to exceed the 5 μA limit.

Type II – If an unwanted signal is within the ILS localizer receiver RF passband and beats with the localizer carrier signal to produce a difference frequency within about 10 Hz of the 90 Hz and 150 Hz ILS sideband signals, but not within the Type I tolerance, above, the unwanted RF signal field strength must be as low as 26 dB below the localizer carrier level in order not to exceed the 5 μA limit.

Type III – If any unwanted signal is within the ILS localizer receiver RF passband with sufficient strength, there will be a progressive "capturing" of the receiver. In this case the unwanted RF signal field strength must be as low as 7 dB below the localizer carrier level in order not to exceed the 5 μA limit. Very strong signals, in the order of 10 mV or stronger, will cause receiver blocking and cross-modulation.

3.2 *Interference from a modulated carrier signal*

Type IV – If an unwanted signal contains a carrier with 20% amplitude modulation by a 90 Hz or 150 Hz component, the unwanted RF signal field strength must be as low as 13 dB below the localizer carrier level in order not to exceed the 5 μA limit. Such an unwanted signal, for example, can arise from the use of 3-phase rectification of a 50 Hz alternating current power supply.

4. Conversion to absolute signal-in-space field strength

Annex 10 to the Convention on International Civil Aviation specifies several signal conditions within the service volume of an ILS, and one of the relevant conditions near the runway threshold is that for facility performance category III localizers, the minimum field strength along the localizer course line shall not be less than 200 μV/m. Using this value of minimum field strength, the maximum absolute signal-in-space field strength of an unwanted signal near the runway threshold can be determined as shown in Table I:

TABLE I

Type of interference	Unwanted/wanted ratio (dB)	Field strength of unwanted signal near the runway threshold (μV/m)
I	−46	1
II	−26	10
III	− 7	90
IV	−13	45

5. Other factors

The preceding paragraphs have developed unwanted/wanted ratios with respect to harmful interference to the ILS localizer, but it is noted that certain operational and statistical factors could affect the practical application of these ratios. For instance, the effects caused by the Doppler shift of frequencies due to the speed of an aircraft, or the probability that an unwanted signal will meet the precise characteristics necessary to cause the particular interference mechanism, have not been taken into consideration, and attention is drawn to the fact that these, as well as other, factors need further study. However, it is relevant to note that the field strengths of unwanted signals shown in § 4, above, in the worst case could imply very severe emission limits on potential interfering sources near aerodrome aircraft approach paths. For example, an emission causing the Type I mechanism would need to be limited to a maximum e.i.r.p. of −95 dBW (3.3 μV/m, measured 30 m from the source), in order not to cause harmful interference to an aircraft flying at an altitude of 100 m above the source.

6. Summary and conclusion

The ILS localizer system is susceptible to certain types of interference. Further study is required to determine whether the practical effect of the described mechanisms are in any way alleviated by operational and probabilistic factors.

It is important to note that this Annex examines only those interference mechanisms where the unwanted signal appears within the RF passband of the ILS localizer receiver. There are other known mechanisms, such as intermodulation in ILS localizer receivers, which do not fall within this category. Studies relative to these mechanisms are continuing.

ANNEX II

CONSIDERATIONS FOR SHARING BETWEEN AERONAUTICAL FLIGHT TEST TELEMETRY STATIONS AND SPACE AND EARTH STATIONS IN THE FREQUENCY BANDS 1435 TO 1535 MHz AND 2310 TO 2390 MHz

1. Introduction

Frequencies for aeronautical flight test telemetry are considered in the mobile service.

Flight test telemetry is important to its users because:

- it frequently is necessary for the safety of the pilot and the aircraft;
- it provides the only good record of the nature of a failure that may have caused an accident, thus, it contributes to the safety of future flights;
- it is a daily tool in evaluating the progress of each flight and the performance of the vehicle being tested. The costs of each flight hour may be measured in tens of thousands of dollars. Telemetry significantly reduces the number of hours required to develop the aircraft, or a sub-system of the aircraft.

Because flight test telemetry is vital to its users, telemetry flights should operate without harmful interference. To achieve this end, all telemetry operations are scheduled. The formality of the scheduling varies from area to area of the country, based upon the number of licensees and the number of aircraft each licensee operates. Each geographical area has its own scheduling procedure. For example, in southern California where several telemetry systems share the band on a co-channel and adjacent-channel basis, the scheduling procedure is highly formalized and hour-by-hour schedules are developed to preclude interference. In other areas where a single licensee is isolated either geographically or by frequency separation, the scheduling becomes an informal procedure within the licensee's own organization. However, even under these ideal conditions there are more test vehicles than frequencies and the scheduling must be done.

Technically important aspects about a flight test telemetry station are:

- The bandwidth requirements of each flight and each aircraft installation often vary widely from one another. Emissions from 500KF9 to 3M00F9 are typical. Occasionally emissions of 10M0F9 are authorized.
- Typically, most aircraft or small missiles will have only one telemetry transmitter, however, some aircraft and many spacecraft will be equipped with two or more transmitters that typically have independent transmissions.
- Power output from each transmitter typically ranges between 1 and 65 W into antenna systems that are intended to be omnidirectional, but which in reality contain deep nulls.
- Communication paths frequently require that reliable signals from minimums in the aircraft antenna pattern be received at 150 to 200 km. Frequently, the antenna on aircraft and spacecraft will be well engineered to provide good null-free operation in the most optimum directions for normal flight profiles; however, installations in one-of-a-kind test programs may not be so engineered. In either case, abnormal attitudes encountered in roll, pitch, and yaw manœuvres may present the nulls in the antenna patterns of the aircraft or spacecraft to the ground antenna. In the event of aircraft or spacecraft failure, this abnormal condition may occur at the most important period of the flight for those engineers and technicians who must analyse the data from the test.

Thus, the signal strength analysis that is considered in this paper will necessarily be the worst-case situation. Interference from any other source during this worst-case situation could cause the data to be totally lost or useless.

Telemetry ground antenna installations vary widely. Simple installations in geographically isolated areas may use some stacked vertical omnidirectional arrays for reception of signals from aircraft flying near the receiver site. Usually they will employ some directive antenna arrays which may be simple horns with about 30° beam-widths, but more often become sophisticated parabolic or helical arrays with automatic tracking. A substantial portion of these sites employ two-axes tracking systems and parabolic reflectors from 2.5 to 10 m in diameter. Larger parabolas become excessively massive for the tracking systems to maintain the test aircraft in the beam under manœuvring conditions, and beam distortion because of the excessive gravitational forces on the dishes becomes a problem. The use of low-noise receivers is not uncommon. Frequently, the systems are located on mountain tops and track below the local horizon as well as above it, with capabilities of tracking through the zenith if necessary. Typically, such antennas are calibrated by using quiet space as a reference. The atmospheric noise floor of −204 dB (W/Hz) measured at 290 K, a 4 kHz bandwidth (commonly used as a CCIR reference bandwidth for such purposes), a zero dB signal-to-noise ratio in the receiver IF section, a receiver noise figure of 4 dB referred to the input, and a (9.144 m) (30 foot) diameter antenna (such an antenna has a measured gain of 38 dBi) and an effective aperture correction of 25 dB (corresponding to an approximate frequency of 1.5 GHz) combine to give an atmospheric noise flux level of −177 dB ($W/(m^2 \cdot 1$ kHz)). The system can be expected to operate with an FM capture ratio of 16 dB to 19 dB. Therefore, the system will be designed to operate at flux densities of −161 dB ($W/(m^2 \cdot 4$ kHz)). Extraneous co-channel signals, such as from a satellite must be at lower levels than −177 dB ($W/(m^2 \cdot 4$ kHz)) at the Earth's surface assuming the satellite can be in the field of view of the receiving telemetry ground station.

Telemetry standards commonly specify that spurious emissions from telemetry transmitters must be at levels lower in amplitude than −55 dB (W/3 kHz). These are conducted or equivalent radiated standards. Converting them to the basis of CCIR practice, this becomes approximately −54 dB ($W/(m^2 \cdot 4$ kHz)) if an isotropic radiator is assumed. Although this value exceeds the receiver noise floor for the receiving system, above, by 123 dB, usually the geographic separation of the transmitter from the receiver will be sufficient to guarantee that the receiver will not be adversely effected. The tracking antenna will provide about 33 dB of the required protection, and, since the interfering source can be expected to be on a flight ramp or runway that may be screened by a hill or removed from the runway by more than 5 km, the required protection will be supplied. This spurious emission standard cannot be used as a level of signal that would assure non-interference to the telemetry system.

Table II shows the range of parameters that can reasonably be used by a transmitter for flight test telemetry:

TABLE II

	Range of values to be expected in telemetry systems	
	Low values	High values
Gain, transmitting antenna (airborne) (dBi)	1.7	6
e.i.r.p. (dBW)	−3	18
Gain, receiving antenna (dBi)	2	41
Aircraft transmitter. Beamwidth (1)	360° × 30°	30° × 30°
Ground station. Beamwidth (2)	360° × 30°	1.4° × 1.4°

(1) The beamwidth for airborne antenna is referenced to the aircraft vertical axis.

(2) The beamwidth of the ground station is referenced to a tracking antenna (high gain) direction of maximum gain. It is usually a receiving antenna, but may be a transmitting antenna.

The current state of the development of aircraft and spacecraft continues to require frequencies for flight testing of both manned and unmanned vehicles. The altitudes of flights for such vehicles vary from a few metres to several hundred kilometres. The range varies from a few hundred metres to earth orbit. The primary distinction between the mobile service used for flight test and the other services where aeronautical or space telemetry equipment is used is the purpose of the transmission. The mobile service is used when the testing of the vehicle is the primary purpose of the flight. Other services are indicated when the primary purpose of the flight is research (atmospheric or space exploration, earth exploration) or operation of the vehicle. The equipment used for telemetering in the different services is often similar or even the same equipment. In cases where continuous data collection is required for an extended period of time, the use is generally not considered to be flight test and therefore, the frequency assignment is made in a band reserved for operational use and frequencies subject to daily or hourly scheduling are not authorized.

2. Interference from a satellite to telemetry ground stations

In Section 1 above, the flux density at the receiver site that will generate harmful interference has been considered. The figure, -177 dB (W/(m^2 · 1 kHz)), will cause the telemetry system to lose range and receiving margin required when the aircraft is at the edge of a test range, which may be at some great distance or some high altitude. The position of the tracking antenna, whether looking at satellite or looking away from it, could introduce a 33 dB or greater signal variation, based upon whether the main lobe or the minor lobes of the antenna encounter a satellite signal.

2.1 *Geostationary satellites:* Geostationary satellites may be out of view of any particular telemetry receiving site. However, depending upon their longitudinal position, the satellites can appear at local elevation angles up to 39° above the horizon at 48° latitude or up to 55° at 30° latitude. Such angles are clearly possible for telemetry currently in heavy use. It can be shown that even a 30° horn connected to a low noise receiver could suffer interference problems from satellites that have been proposed to operate in these bands. Thus, the -177 dB (W/(m^2 · 4 kHz)) can be assumed to be the level of co-channel receiver-site flux that could be allowed for non-interference of unscheduled satellite transmissions. Since this level is that of quiet space, it is not likely that it would be satisfactory to the satellite system designer.

2.2 *Satellites with near-earth orbits:* Satellites that are in non-geostationary orbit will progressively traverse the view of every telemetry ground receiving facility. The only way to achieve protection from co-channel operations for the telemetry ground station is by scheduling all transmissions from the aircraft and from the satellite. This requirement would make some data memory systems (for example, tape recorders and computer memories) and some control or command systems for the control of the transmitter on board the satellite necessary. Scheduling would have to be controlled through the same mechanisms/organizations that are used by the mobile service (aeronautical flight test telemetry), with the added complication that the satellite may be seen from several scheduling areas simultaneously. This added requirement could require significant and costly changes to the scheduling organizations and the equipment used for communication between the present areas. Earth exploration satellites authorized in current regulations in the 1525-1535 MHz band, if implemented, would present this kind of scheduling problem in Region 2, although both the mobile service and earth exploration services are secondary to space operations (telemetry) allocations.

2.3 *Satellites with near-earth equatorial orbits:* Such satellites would present the same problem as geostationary satellites, in that telemetry ground receiving sites would be likely to have their primary antenna lobe intercept the satellite position. This would occur several times a day. Their low altitude compared to the geostationary satellite may hide them from some high latitude receiving sites, but it would also provide less free-space attenuation of their signal. They would, therefore, interfere with telemetry at low latitudes and scheduling and a control system would also be required for co-channel sharing.

3. Interference to satellite receivers due to transmissions from airborne telemetry stations

Generally, the characteristics of satellite-borne receivers and the satellite orbits are not defined well enough to specify in this document the expected degradation in the presence of telemetry signals. Abnormal attitudes of aircraft during stalls, spin tests, or other specific manœuvres will require consideration at the receiving satellite of the primary beam of the aircraft antenna pattern. Therefore, the e.i.r.p. of the signal from the aircraft could be as great as 24 dBW. The signal could be concentrated at a discrete frequency for short periods of time, but would more usually be spread as an FM signal with modulation index between 1 and 5 and a bandwidth of between 650 kHz and 9 MHz. The altitude of the telemetry transmitter could be from the Earth's surface up to orbital altitudes. The combination of transmitter, antenna, and modulation scheme may be designed for one-time usage and depend heavily on equipment availability. It may not be the optimum design from a communications engineer's viewpoint. It can be seen that unless coordination and scheduling are accepted by all licensees of the band, interference is highly probable.

4. Interference to satellite receivers due to transmission from telemetry ground stations

Telemetry ground station antennas are usually considered to be for receiving purposes only. There is no regulation to this effect, and up link telemetry signals have limited use. The limited bandwidth of the available spectrum, in addition to causing crowding and the demand for more spectrum, is causing innovative systems to be placed upon the aircraft. These systems require data up links to control the data collection process or telemetry up links to combine data on the ground with data collected on-board the airborne vehicle. These systems provide significantly higher field strengths at the satellite than the airborne telemetry systems discussed above. There are not presently enough such systems to give typical power outputs, but the signal strength that is required will be larger for the aircraft receiving station than the ground receiving station. This is because the airborne receiver will not contain the cryogenic elements required for low-noise receivers, and temperature variation, vibration aboard the aircraft, etc., will rule out many techniques used to produce low-noise receivers.

5. Conclusions

In the 2.3 GHz band, the allocated terrestrial services can share by using the different frequency management techniques already discussed, i.e. scheduling, different frequency assignments, terrain shielding, etc. On the other hand, satellite operations in the same bands with the mobile service will encounter mutual interference with co-channel telemetry users unless all licensees accept a requirement for scheduling. The introduction of continuously transmitting satellites into this scheduling environment would place a severe hardship on telemetry licensees by enlarging the interference areas. The operating organization and communications systems required to establish a single scheduling organization would be costly to all licensees. Practical considerations suggest that such a scheduling procedure would be very difficult to achieve.

Co-channel frequency assignments for the satellite and mobile services are only practical when satellites do not transmit in the space viewed by telemetry receiving sites or when a single scheduling organization can be employed to prevent harmful simultaneous use of a frequency.

Consequential to the frequency allocations of the WARC-79, it is recognized that the maritime mobile-satellite service will require the band 1530-1535 MHz by 1990 and that the space operation service may require the band 1525-1530 MHz after January 1, 1982.

ANNEX III

SOME RADIONAVIGATION SYSTEMS NOT INCLUDED IN ANNEX 10 TO THE ICAO CONVENTION (CHICAGO, 1944)

1. Introduction

A number of commonly used radionavigation systems are employed throughout the world by operators of civil aviation aircraft.

Such systems, when used for navigation of the aircraft, could be subject to harmful interference. Therefore, for the sake of completeness, they are noted in this Annex.

2. Loran-C, Omega and Decca Navigator

Although Loran-C, Omega and Decca Navigator radionavigation systems have been used primarily by mariners, a large number of aircraft operators currently rely on these systems.

Loran-C can provide a position-fixing accuracy of better than 500 m with a repeatability of 18-90 m but its coverage area is geographically limited. A similar performance is provided by Decca Navigator.

Omega can provide reliable world-wide coverage with an accuracy of about 10 km due to its propagation characteristics and phase stability.

Such services require protection from harmful interference. Report 915 discusses the required protection criteria for Loran-C.

3. Satellite radionavigation systems

3.1 A number of satellite radionavigation systems are at the proposal stage or in the course of introduction and will be available to land, marine and aeronautical operators.

3.2 Currently available systems include TRANSIT and GPS (global positioning system) and they provide a position-fixing service. TRANSIT predictable accuracy is 500 m (single frequency) and GPS predictable accuracy will be 100 m or better. As the number of satellites increases in the GPS system the continuity of the service will increase. GPS will also provide ground speed information.

3.3 Signal processing techniques are employed in the satellite receivers to alleviate many types of interference; however, further studies of satellite radionavigation interference protection criteria are required.