XVII A.P.
DÜSSELDORF
21.5-1.6 1990
CCIR

XVIIth PLENARY ASSEMBLY
DÜSSELDORF, 1990

INTERNATIONAL TELECOMMUNICATION UNION

COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND OF ABOUT 87-108 MHz AND THE AERONAUTICAL SERVICES IN THE BAND 108-137 MHz

RECOMMENDATION 591 (SG 8)
REPORT 929 (SG 8)
REPORT 1198 (SG 10)
DECISION 71 (SG 8 AND 10)

CCIR INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

Geneva, 1990

CCIR

1. The International Radio Consultative Committee (CCIR) is the permanent organ of the International Telecommunication Union responsible under the International Telecommunication Convention "... to study technical and operating questions relating specifically to radiocommunications without limit of frequency range, and to issue recommendations on them..." (International Telecommunication Convention, Nairobi 1982, First Part, Chapter I, Art. 11, No. 83).*

2. The objectives of the CCIR are in particular:

a) to provide the technical bases for use by administrative radio conferences and radiocommunication services for efficient utilization of the radio-frequency spectrum and the geostationary-satellite orbit, bearing in mind the needs of the various radio services;

b) to recommend performance standards for radio systems and technical arrangements which assure their effective and compatible interworking in international telecommunications;

c) to collect, exchange, analyze and disseminate technical information resulting from studies by the CCIR, and other information available, for the development, planning and operation of radio systems, including any necessary special measures required to facilitate the use of such information in developing countries.

* *See also the Constitution of the ITU, Nice, 1989, Chapter 1, Art. 11, No. 84.*

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COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND OF ABOUT 87-108 MHz AND THE AERONAUTICAL SERVICES IN THE BAND 108-137 MHZ

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RECOMMENDATION 591-1*

COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND OF ABOUT 87-108 MHz AND THE AERONAUTICAL SERVICES IN THE BAND 108-136 MHz**

(Question 61/8)

(1982-1986)

The CCIR,

CONSIDERING

(a) that high-powered FM broadcasting service operations in close geographic proximity to aerodrome facilities are at times incompatible with airborne ILS, VOR and VHF communications equipment utilizing those facilities, and that this is a widely recognized problem among many users of aviation facilities in the Northern Hemisphere of ITU Region 2 and parts of Region 1;

(b) that in accordance with RR No. 44, the aeronautical radionavigation service is "A radionavigation service intended for the benefit and for the safe operation of aircraft";

(c) that FM broadcasting transmitters employ power levels which are relatively much higher than aeronautical services transmitters;

(d) that aeronautical radionavigation and communication receivers have varying degrees of signal sensitivity and susceptibility to interference;

(e) that high power broadcasting transmissions may cause interference to airborne receivers, depending upon relative distance between the transmitter and receiver;

(f) Recommendation No. 704 of the World Administrative Radio Conference (Geneva, 1979) (WARC-79) which addresses potential interference problems between the FM broadcasting service and the aeronautical radionavigation service;

UNANIMOUSLY RECOMMENDS

1. that administrations be invited to advise the broadcasting and aviation communities of the potential FM broadcasting and aeronautical systems incompatibility problem;

2. that administrations develop or, where applicable, strengthen coordination procedures between the aviation and broadcasting communities to minimize future problems;

3. that Report 929 be used as the best available guidance to date on the above matters.

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* The Director, CCIR, is requested to bring this Recommendation to the attention of the International Civil Aviation Organization (ICAO) and Study Groups 1 and 10.

** This band will be expanded to 137 MHz by 1 January, 1990.

REPORT 929-2 *

COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND OF ABOUT 87-108 MHz AND THE AERONAUTICAL SERVICES IN THE BAND 108-137 MHz

(Question 61/8)

(1982-1986-1990)

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* The Director, CCIR, is requested to bring this Report to the attention of Study Group 10 and to the International Civil Aviation Organization (ICAO).

** The abreviation "COM" is used in this Report to denominate communications in the aeronautical services.

1. Background and introduction

1.1 Frequency modulation (FM) broadcasting service interference to instrument landing systems (ILS) localizer, VHF omnidirectional radio range (VOR) and VHF communications equipment (see Note) is a widely recognized problem among users of aviation facilities. In Region 2, the FM broadcasting service operates in the 88-108 MHz band and has caused interference problems in the adjacent VHF aeronautical services band 108-136 MHz. In Region 1 the FM broadcasting band has been expanded up to 108 MHz, and therefore administrations in that Region may experience interference problems.

Note. – For a description of the ILS, VOR and VHF communications systems, attention is drawn to Report 927.

1.2 In air/ground communication receivers, this interference problem ranges from nuisance background FM broadcasting audio to distorted and garbled reception. In airborne ILS localizer and VOR receivers, the interference problem ranges from nuisance background FM broadcasting audio to errors in course deviation and flag operation. The interference to these navigation receivers is thought to be the more serious problem, as an error in course deviation, especially during the critical approach and landing phase, is not as readily evident to the pilot as the disruption of communications.

1.3 The level of interference to aircraft receivers is usually most severe at airports having major FM broadcasting facilities nearby, and the interference varies with the type of aircraft and associated navigation and communication (NAV/COM) equipment. The problems experienced are the result of factors such as:

- FM broadcasting stations operate with high-power levels of up to 250 kW e.r.p., whereas aeronautical facilities such as air/ground communication transmitters and ILS localizers operate at low-power levels, in the order of 0.02 kW to 6 kW e.r.p.
- Spurious emissions from FM broadcasting stations.
- The susceptibility of existing airborne receivers to this form of interference. ICAO has addressed the problem of high-powered, adjacent-band FM broadcasting interference and has produced new interference immunity standards for airborne receivers in Annex 10 to the Convention on International Civil Aviation (ICAO Annex 10) applicable as of 1998.
- Lack of a guard-band between the highest assignable frequency for FM broadcasting and the lowest assignable radionavigation frequency.

There is an increasing probability of harmful interference due to the growing need for additional aeronautical frequency assignments and the growing number of FM broadcasting applications for new frequencies, power increases and relocation.

1.4 The decision of the World Administrative Radio Conference (Geneva, 1979) to generally extend the VHF/FM broadcasting band to 108 MHz, puts broadcasting and aeronautical radionavigation services in adjacent frequency bands. That this might lead to problems of interference, was recognized in the agenda of the Regional Administrative Conference for FM Sound Broadcasting in the VHF Band (Region 1 and certain countries concerned in Region 3), (Geneva, 1982) to determine the technical constraints to be used in planning the new band for the broadcasting service.

1.5 To further study the compatibility situation, Joint Interim Working Party 8-10/1 met in May, 1984, in March 1987 and in August 1988 and prepared reports which outlined the possibilities and techniques for improving suppression of intermodulation products at broadcasting transmitting stations (see also Report 1198), dealt with aspects of the necessary protection ratios for the aeronautical radionavigation receivers, and presented future improvements of the immunity of airborne radionavigation equipment to interference from FM broadcasting stations. It also described procedures and compared assessment techniques that may be used to better predict interference situations in general or in special circumstances.

1.6 With technical criteria provided by the JIWP 8-10/1 and submission of contributions from administrations to the Regional Administrative Conference for FM sound broadcasting in the VHF band (Region 1 and certain countries concerned in Region 3), Geneva 1984, compatibility criteria and assessment criteria were agreed (see Final Acts of the Conference, named "Geneva Agreement, 1984"). Compatibility between the FM broadcasting frequency plan and the existing frequency plan for the aeronautical radionavigation service was not fully studied. Also, no compatibility tests with the aeronautical mobile (R) service were performed. Incompatibilities identified with the aeronautical services were not taken into account in all cases when selecting FM broadcasting frequencies.

2. Types of interference mechanisms

2.1 *Type A interference*

2.1.1 *Introduction*

2.1.1.1 In the normal operation of broadcast transmitters, type A interference may arise in two ways. First, a single transmitter may generate spurious emissions or several broadcast transmitters may intermodulate to produce components in the aeronautical frequency bands; this is termed type A1. Second, the side bands of a broadcasting transmitter may include non-negligible components in the aeronautical bands; this mechanism, which is designated type A2, will in practice arise only from transmitters having frequencies near to 108 MHz.

2.1.1.2 From the viewpoint of the aviation receiver, the spectral characteristics of the unwanted signal are of particular significance. To a first approximation, the effects of modulated FM broadcasting signals are likely to be "noise-like" in the receivers, with a consequential reduction in the wanted operational performance of aviation receivers.

2.1.1.3 In addition, adverse effects in the ILS/VOR audio (identification) channel can occur.

2.1.1.4 However, if an unmodulated broadcast transmission were to produce stable frequency components close to the ILS modulation signal frequencies (e.g. within ± 15 Hz of the modulation frequencies 90 Hz and 150 Hz) then highly significant interference could occur even at very low levels of unwanted signals (see Report 927).

2.1.2 *Type A1 interference*

Variously described as "in-band" or "on-channel", caused by spurious emissions (including intermodulation products) from the broadcast transmitter station. This is generally a low-level effect and can be regarded as harmful interference, as defined in the Radio Regulations, in cases where the level is sufficient to affect the performance of avionics receivers. No rejection can be provided at the airborne receiver. Attenuation at source, the choice of broadcast assignment, and/or distance separation are the only practical solutions.

2.1.3 *Type A2 interference*

Interference to ILS channels near to the 108 MHz band edge due to out-of-band emissions from broadcasting stations operating on carrier frequencies in the upper end of the broadcasting band.

2.2 *Type B interference*

2.2.1 *Introduction*

2.2.1.1 Mechanisms producing this type of interference can occur due to radiations from broadcast transmitters outside the aeronautical band. Their incidence depends on a number of factors which include:

- the very large power differentials between the two services;
- the wide variability of the geometry between the aircraft, the aviation ground transmitters and the FM broadcasting transmitters;
- the susceptibility of the aviation receivers (which varies from receiver to receiver and which also depends on the frequency separation between wanted and unwanted signals);

- the aviation ground system installation differences (particularly antenna radiation pattern);
- the airborne system differences (particularly antenna frequency response and feeders);
- the FM broadcasting station antenna radiation pattern.

2.2.1.2 The airborne receiver, designed to work in a low-power environment and needing to detect small wanted input signals, cannot easily cope in the presence of an unwanted signal close in frequency and at a very much greater power level (perhaps higher by 80 dB or more).

2.2.1.3 The two main interference mechanisms involved are receiver-generated intermodulation (B1) and receiver desensitization (B2). It is important to note that these are separate mechanisms with separate characteristics.

2.2.2 *Type B1 interference*

Intermodulation generated in an airborne receiver as a result of the receiver being driven into non-linearity by a high-powered broadcasting signal outside the aeronautical band. In order for this type of interference to occur, normally at least two broadcasting signals need to be present and they must have a frequency relationship which, in non-linear combination, can produce an intermodulation product within the wanted RF channel in use by the airborne receiver. One of the broadcasting signals must be powerful enough to drive the receiver into regions of non-linearity but interference may then be produced even though the other signal(s) may be significantly less powerful. Under certain conditions, type B1 interference can occur with a combination of only one broadcasting signal and an aeronautical ground signal.

Perhaps the most serious practical aspect of this mechanism from the frequency planning viewpoint is that an acceptable existing situation involving FM broadcasting signals at non-critical levels can be transformed into a practical problem by, for example, the addition of a new broadcasting station or an increase in power at an existing broadcasting station or implementation of new aeronautical stations.

2.2.3 *Type B2 interference*

Desensitization occurring when the RF section of an airborne receiver is subjected to overload by one or more broadcasting transmissions. This arises because the relatively wide-band RF selectivity of such receivers makes it difficult to provide significant RF attenuation immediately below 108 MHz. Such desensitization is most likely to occur in the first active stage which could be an RF amplifier, a mixer, or a combination of both in series, depending on the receiver design.

3. Aeronautical services protection requirements

3.1 Protection criteria for ILS and VOR

ICAO Annex 10 contains specifications and characteristics relevant to the protection of both ILS and VOR.

3.1.1 Service Volume

The ILS localizer service volume is defined in ICAO Annex 10 and is illustrated in Figure 1. The service volume of VOR varies widely and details can be obtained from the Aeronautical Information Publication (AIP) of the Administration operating the installation.

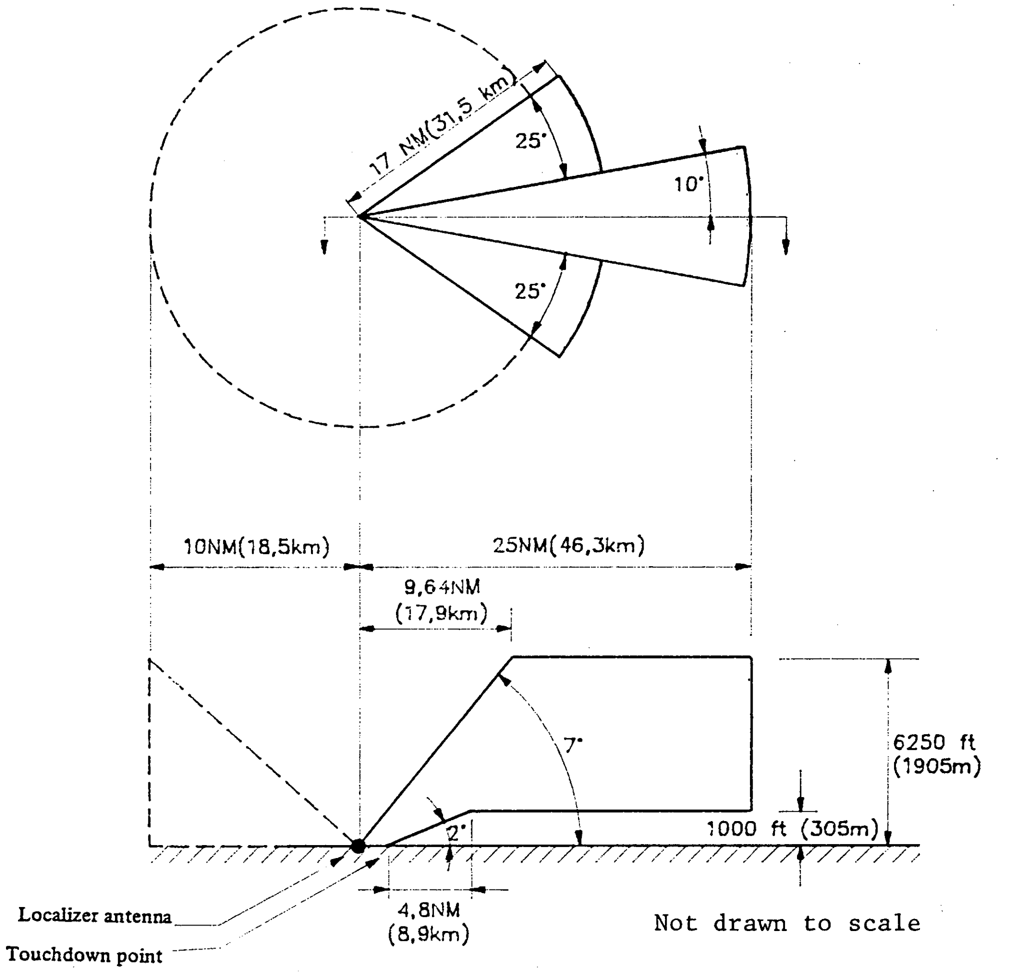

FIGURE 1 - ILS localizer protection volume

— — —: Limits of the ILS back-beam protection volume

3.1.2 Wanted Signal

Subject to the considerations given below, the field strength to be protected throughout the service volume is:

- ILS: 40 μV/m (32 dB (μV/m)),
- VOR: 90 μV/m (39 dB (μV/m)).

If a service is provided in the localizer back-beam volume, the field strength to be protected is 40 μV/m.

However, flight measurement of ILS or VOR field strength may, in some areas of the coverage volume, reveal values higher than the minimum required by ICAO. Some administrations consider that these higher values may be taken into account in resolving particularly difficult frequency assignment cases for both FM broadcasting and expansion of aeronautical facilities. In doing so, due account must be taken of the required integrity of the radionavigation service and variations with time, monitor limits, measurement errors, etc. For example, in certain areas of the ILS coverage Volume, ICAO Annex 10 requires a higher field strength to be provided in order to increase the received signal-to-noise ratio thereby increasing system integrity. This is the case for ILS facilities within the localizer course sector (± 10 degrees) from a range of 18.5 km up to runway touchdown point where signals of 90 - 200 μV/m are required by ICAO, depending upon the Facility Performance Category (I, II, III) of the ILS involved. (See ICAO Annex 10, Volume I, paragraph 3.1.3.3).

3.1.3 Test Points

Test points may be chosen to establish the compatibility condition at significant parts of an ILS or VOR service volume. The position of such points may vary between aeronautical installations depending on the location of the broadcasting stations. Examples of test point selection are given in Annex II.

3.2 Protection Criteria for COM Services

It should be noted that Annex 10 to the ICAO Convention does not specify a *minimum* field strength strength for COM ———— – rather it states that 75 μV/m shall be exceeded for a "large percentage of occasions". In practice there are many occasions when VHF COM ———— need to take place below the 75 μV/m level and hence a lower figure is considered appropriate, for quantitative assessment purposes. It is considered that a value of 40 μV/m is appropriate for the general case.

In areas where extended range COMs operate, the value should be further reduced to 30 μV/m. ICAO Annex 10 also requires COM receivers in ground installations to operate with signals having a field strength of 20 μV/m.

The choice of a representative level for COM services for compatibility assessment is particularly difficult. There are many occasions and circumstances where safety messages are required to be passed using a wanted signal below 10 μV /m. In addition, the assessment of voice quality is largely subjective and hence difficult to quantify. Note - See 4.1.3 for S+N/N, section 10 for future work required and Part 7 of Annex I.

4. AERONAUTICAL RECEIVER MEASUREMENTS AND PROTECTION REQUIREMENTS

4.1 *Standard interference thresholds for bench measurements*

It is stressed that the following thresholds are for the purpose of standardizing bench measurements and whilst they are chosen to be reasonable representations of typical operational situations there will be some circumstances where they do not provide adequate protection to the aviation service in practice.

4.1.1 *ILS*

The changes to course guidance current due to the interference effects from FM broadcasting signals should not be permitted to add appreciably to the course structure perturbations permissible in Annex 10 to the ICAO Convention due to other causes. With the wanted signal at the required level (§ 3.1) and the signal adjusted for a difference in depth of modulation (DDM) of 0.093, the change in course guidance current should not exceed 7.5 µA. In the case of changes to flag operation, there is less assurance in defining common criteria to cover all designs of flag systems. Therefore until further refinement can be made, the following tentative limits may be employed:

- in the case of an unwanted signal forcing a flag to appear for more than 1 s (auto-pilot performance may be affected by a shorter time period);
- in the case of the unwanted signal forcing a flag to disappear when there is no desired signal present, the value which just puts the flag out of sight for more than 1 s. (The absence of an ILS signal does not represent a typical operational situation. However, when that situation does occur, the absence of the flag could be dangerous.)

The above values should be used for both type A and B interference modes.

Note. – The above does not consider centering error. The centering error due to FM broadcasting interference, when statistically combined with other specified environmental conditions, should not be permitted to exceed the levels prescribed by the ICAO.

4.1.2 *VOR*

The wanted signal at the required level (§ 3.1) shall be modulated with a standard VOR test signal as described in the Radio Technical Commission for Aeronautics (RTCA) Document DO-153A, Minimum performance standards for VOR. The interference threshold should then be:

- a change of the bearing indication by 0.5° corresponding to 7.5 µA deflection current; or
- a change in the audio voltage level by 3 dB; or
- the appearance of the flag for more than 1 s.

4.1.3 COM

The interference threshold criteria for airborne COM receivers are as follows:

- With a signal at the required level (see § 3.2) the interference criterion should be a reduction in the audio signal plus noise-to-noise ratio, $(S + N)/N$, to 6 dB.
- With no wanted signal present, the interference shall not cause more than 5 dB (equivalent RF) increase in AGC voltage or an audio interference plus noise-to-noise ratio, $(I + N)/N$, of greater than 6 dB.
- The criteria for ground receivers may differ from those stated for airborne receivers. Further work is required to determine the criteria for ground receivers. (See Section 10 of this Report).

4.2 *Unwanted (broadcast) signal characteristics*

4.2.1 In many instances the worst case ILS/VOR interference problem is generated by utilizing actual programme material as the modulation of the unwanted signals taking into account Region 1 and Region 2 FM transmission characteristics, including supplementary channels where applicable.

4.2.2 To facilitate consistency of test methods and results, receiver immunity measurements should be performed using an unwanted signal which is modulated with colored noise in accordance with Rec. 559 with a set-up audio injection level (quasi-peak) before 50µs pre-emphasis corresponding to ±32 kHz deviation in accordance with Rec. 641. However, in order to simulate stereophonic transmission the noise modulation source is applied to the left and right channel with a 6 dB difference in level between channels.

Administrations in their testing procedures may also use other modulation conditions that represent the actual broadcast practices in their countries.

Note 1. - Particular attention may need to be made on the bench to reduce unintentional noise modulation effects.

Note 2. - If using a single signal source to simulate third-order transmitter intermodulation products, increased deviations may be required.

Note 3. - Some previously reported receiver immunity data were obtained under test conditions employing a different FM modulation procedure than described above. In comparing or combining such data, testing one or more common receivers using each procedure would first be required to determine if a correction factor must be applied.

4.3 Protection requirements for VOR/ILS receivers

Considerable study of the immunity characteristics of ILS and VOR receivers to FM broadcast interference have been made and reported to Geneva 1984 Conference and to the CCIR. Some new results are given in Annex I to this report, and further studies should continue on the specific aspects detailed in section 10.

The values which appear below have been used in planning within Region 1. They may however be subject to modification or qualification in the future as new information becomes available.

4.3.1 Type A1 Interference

4.3.1.1 A protection ratio of 17 dB was used, including a small safety margin in order to take account of multiple interference entries resulting from different broadcast transmitters.

4.3.1.2 Where the actual frequency of the spurious emission is known, Table I gives the values of protection ratio used for frequency differences up to 200 kHz from radionavigation transmitters. Type A1 interference need not be considered for frequency differences greater than 200 kHz.

TABLE I

Frequency difference between spurious emission and wanted signal (kHz)	Protection ratio (dB)
0	17
50	10
100	− 4
150	−19
200	−38

4.3.2 *Type A2 interference*

The protection ratio values used are given in Table II.

TABLE II

Frequency difference between wanted signal and broadcasting signal (kHz)	Protection ratio (dB)
150	−41
200	−50
250	−59
300	−68

A frequency difference less than 150 kHz cannot occur. For frequency differences greater than 300 kHz, this type of interference need not be considered.

Note - FM sound broadcasting stations may in some regions employ compression techniques and/or provide services on subcarrier frequencies up to 99 kHz. Bench tests have shown that combinations of these practices, especially when associated with a deviation larger than ±75 kHz, may result in 0 to 10 dB increase in susceptibility of an ILS receiver operating at a frequency of 108.1 MHz to A2 type interference from a broadcasting station operating at a frequency of 107.9 MHz. Special consideration should be afforded to these conditions where these broadcasting operating practices exist. (See also Parts 3 and 6 of Annex I.)

4.3.3 *Type B1 interference*

Third-order intermodulation products of the form:

$f_{intermod} = 2 f_1 - f_2$ (two-signal case) or

$f_{intermod} = f_1 + f_2 - f_3$ (three-signal case)

with $f_1 > f_2 > f_3$,

generated in the airborne ILS or VOR receiver could cause an unacceptable degradation of receiver performance, if $f_{intermod}$ coincides with, or is close to, the frequency of the wanted signal and the inequalities given below are fulfilled taking account of § 5.6.

Intermodulation of the second order is irrelevant and intermodulation of a higher order than three has not been considered.

N_1, N_2 and N_3 in the inequalities below have the following meaning:

N_1: level (dBm) of the broadcasting signal of frequency f_1 (MHz) at the input of the aeronautical radionavigation receiver;

N_2: level (dBm) of the broadcasting signal of frequency f_2 (MHz) at the input of the aeronautical radionavigation receiver;

N_3: level (dBm) of the broadcasting signal of frequency f_3 (MHz) at the input of the aeronautical radionavigation receiver.

max {0.4; 108.1 − *f*} in the inequalities below has the following meaning: either 0.4 or 108.1 − *f*, whichever is greater.

4.3.3.1 *Two-signal case*

$$2\left(N_1 - 20 \log \frac{max\{0.4;\ 108.1 - f_1\}}{0.4}\right) + N_2 - 20 \log \frac{max\{0.4;\ 108.1 - f_2\}}{0.4} + 120 > 0$$

4.3.3.2 *Three-signal case*

$$N_1 - 20 \log \frac{max\ \{0.4;\ 108.1 - f_1\}}{0.4} +$$

$$+ N_2 - 20 \log \frac{max\ \{0.4;\ 108.1 - f_2\}}{0.4} +$$

$$+ N_3 - 20 \log \frac{max\ \{0.4;\ 108.1 - f_3\}}{0.4} + 126 > 0$$

4.3.3.3 *Frequency offset conditions*

Before applying the formulae given in § 4.3.3.1 or 4.3.3.2 a correction is applied to each signal level which is a function of the frequency difference between the wanted signal and the intermodulation product; this correction is given in Table III.

$$N_{1,2,3}\ \text{(corrected)} = N_{1,2,3} - \text{correction term}$$

TABLE III

Frequency difference between wanted signal and intermodulation product (kHz)	Correction term (dB)
0	0
± 50	2
± 100	8
± 150	16
± 200	26

For frequency differences beyond ± 200 kHz, type B1 interference need not be considered.

4.3.4 *Type B2 interference*

Table IV contains maximum permitted levels of broadcasting signals at the input to the airborne ILS or VOR receiver.

TABLE IV

Frequency of broadcasting signal (MHz)	Level (dBm)
107,9	−20
106	− 5
102	5
≤ 100	10

For intermediate values, the maximum permitted level was determined by linear interpolation.

5. COMPATIBILITY ASSESSMENTS

Practical assessments on the compatibility of broadcast and aeronautical services may be made using the criteria in sections 3 and 4. It has not been possible to identify a single method for the assessment of compatibility which is applicable in all of the situations encountered in practice. A number of administrations have developed particular assessment methods and procedures for application within their own country (see Annex II). These assessment methods are in many cases based on some or all of the assumptions which are described below. Applicable values are quoted for important parameters, however it is stressed that these are primarily quoted as guidance since no overall agreement covering all aspects presently exists.

5.1 Separation distance from a test point of an aeronautical radionavigation station

Broadcasting stations which are:

- more than 500 km from a VOR test point
- more than 255 km from an ILS test point

or

- beyond the radio line-of-sight from a VOR or ILS test point

are considered as being unlikely to affect the service of that aeronautical radionavigation station.

These separation distances are based upon a test point height of

- 2450 m for an ILS test point
- 12200 m for a VOR test point.

5.2 *Separation distances* from a broadcasting station

5.2.1 Table V gives separation distances between a broadcasting station with a given e.r.p. and frequency and a test point of an aeronautical radionavigation station beyond which it is considered unlikely that the service of the aeronautical station could be affected. The more critical requirements are those for A1 and B1; the higher of the two separation distances is shown in each case.

TABLE V – *Distance (km) between a test point of a radionavigation station and a sound broadcasting station* beyond which the aeronautical service is unlikely to be affected

Effective radiated power of Broadcasting station.		Broadcasting station frequency (MHz)						
		≤ 100	102	104	105	106	107	107.9
dBW	kW	distance (km)						
55	300	125	210	400	500	500	500	500
50	100	75	120	230	340	500	500	500
45	30	40	65	125	190	310	500	500
40	10	25	40	70	105	180	380	500
35	3	20	20	40	60	95	210	500
30	1	20	20	25	35	55	120	370
25	0.300	20	20	20	20	30	65	200
20	0.100	20	20	20	20	20	40	115
≤ 15	≤ 0.030	20	20	20	20	20	20	65

5.2.2 The A1 distances assume the protection ratio for frequency coincidence, and that the level of the broadcasting transmitter spurious emissions conform to the level given in § 5.5. The B1 distances ensure that the signal level is below the cut-off value as given in § 5.7 with free-space propagation, but are subject to an upper limit of 500 km due to the practical considerations of the line-of-sight limit, in conformity with § 5.1.

5.2.3 Where two or more assignments are used at a common site, the highest e.r.p. must be taken.

5.2.4 Linear interpolation shall be used for e.r.p. (dBW) and frequency values not appearing in Table V.

5.2.5 Preliminary analyses based on these distances assume, in the case of A1 and B1 types of interference, that there is frequency coincidence between a spurious emission or intermodulation product and the frequency of the radionavigation station. When the frequencies of the radionavigation station and of all broadcasting transmitters that may be involved are known, detailed calculations can be made for all types of interference using the data for protection of the aeronautical radionavigation service given in § 4.3 and 3.1. However, in the case of A1 type interference it will be necessary to check that the transmitter does not generate significant spurious components apart from third-order intermodulation products.

5.2.6 Any case-by-case study may take into account other relevant factors such as details of the propagation path between the broadcasting station and the aeronautical test point, and the radiation pattern of the broadcasting antenna in both the vertical and horizontal planes.

5.3 Compatibility assessment calculations

In determining compatibility in accordance with the criteria specified in 4.3, the following factors should be considered for each test point within the service volume. Sufficient test points should be used to ensure compatibility within the operational service volume as modified by any physical constraints.

- the field strengths of the desired signal as given in 3.1 and 3.2
- the field strength of every FM broadcasting station in the band 87.5 - 108 MHz inside the relevant distance from an aeronautical station test point (see Table V) and within line of sight based on smooth earth. The field strength should be determined considering:
  - effective radiated power and polarization of the transmission
  - horizontal and vertical radiation characteristics of the transmitting antenna using the most accurate information available
  - height of the transmitting antenna center of radiation
  - the 50 % time propagation curves of Rec. 528. Up to the radio horizon, a free-space calculation may be considered as an acceptably close approximation.

Note: Practical examples of calculation methods are shown in Annex II.

5.4 Polarization

No account is taken of polarization differences between the broadcasting and the aeronautical radionavigation signals except in special cases (e.g. circular polarization of the broadcasting signal).

The interfering signals are assumed to have the same polarization (vertical or horizontal) as the navigation system. If, instead, the broadcasting station has a different polarization, there is in theory some reduction of received interfering signal levels, but it was agreed in this case, not to make any allowance. When power in another plane of polarization needs to be added at the transmitting antenna, a 1 dB allowance should be added to the higher plane power when the total power is increased by 50% or more. However, no allowance needs to be taken for true circular polarization.

5.5 Spurious Emission Levels (Analysis of Type A1 Interference)

A detailed consideration of the mechanisms of generation of spurious emissions, particularly those in the form of intermodulation products, is contained in Report 1198. In that Report, attenuation of spurious emission levels are indicated which are substantially more stringent than those contained in Appendix 8 of the Radio Regulations, except in the case of very low transmitter powers.

The attenuation of spurious emission levels indicated in Report 1198 are:

- for transmitter powers ≤ 0.25 W; 40 dB
- for transmitter powers ≥ 7.9 kW; 85 dB
- between the above limits, the spurious emission at the transmitter output is assumed to be 25 μW.

To calculate interfering field strengths from these values it is necessary to know the gain of the transmitting antennas. Antenna gains relative to a dipole are likely to vary from 0-10 dB according to transmitter power with high gains associated with high powers.

In the Geneva Agreement, 1984, an antenna gain of 10 dB was assumed for all transmitter powers.

Note:

1) In the case of several transmitters contributing to one spurious component (category (a) in 4.3.1.2) the most powerful transmitter is taken as the reference.

2) Attenuation of spurious emission levels of better than 85 dB are known to have been achieved in practice in seeking solutions to specific cases of difficulty.

5.6 Receiver Input Voltage

The field strength, E, should be converted to signal power, N, at the receiver input according to the following formula:

$$E\,(\text{dB}(\mu\text{V/m})) = N\,(\text{dBm}) + 118 + L_s + L(f)$$

where:

L_s: system fixed loss of 3.5 dB;

$L(f)$: system frequency-dependent loss at frequency, f, of 1 dB per MHz from 108-100 MHz and then 0.5 dB per MHz below 100 MHz.

Measurements on installed antenna systems are contained in Part 8 of Annex I.

Note.- See Section 3.3.1 of Annex I.

5.7 Trigger and cut-off values (Analysis of Type B1 Interference)

5.7.1 Trigger value is the minimum value of an FM broadcasting signal which, when applied to the input of an aeronautical VHF (ILS, VOR or COM) receiver, is capable of initiating the generation of a third order intermodulation product (IP) of sufficient power to represent potential interference. Thus every third order IP generated in the aeronautical receiver must have at least one component with a power level that is not less than the trigger value if that IP is a potential source of interference. The trigger value suitable for use when assessing compatibility between FM broadcasting and the ILS and VOR can be derived from the following formula (see Part 9 of Annex I).

$$N = -42 + 20 \log \frac{\max\{0.4;\ 108.1 - f\}}{0.4}$$

where: f = broadcasting frequency, in MHz

N = trigger value, in dBm

5.7.2 The sum of the signal levels in dBm ($2N_1 + N_2$ or $N_1 + N_2 + N_3$ in paragraph 4.3.3 above, where N is the power level of the broadcasting signal at the input to the aeronautical receiver) just forming a B1 IP is a constant. Thus as N_1 increases in power the necessary power for N_2 or N_3 decreases. When N_1 reaches the appropriate B2 power level (para 4.3.4) the interference mode changes from B1 to B2 type. The value of N_2 and/or N_3 associated with that level of N_1 is termed the cut-off value.

An analysis of the possible limiting cases (Part 9 of Annex I) gives a minimum cut-off value of 44 dB below the trigger value. However, practical considerations indicate that a value of 24 dB below the trigger value would be appropriate giving

$$N = -66 + 20 \log \frac{\max\{0.4;\ 108.1 - f\}}{0.4}$$

where N = cut-off value, in dBm

6. *Airborne equipment*

6.1 *Current international standardization principles*

Airborne equipment is subject to a very high degree of national and international standardization. However this has always been directed towards those aspects which ensure:

- an adequate performance under ICAO-specified conditions of wanted signal-in-space;
- interchangeability of equipment from different manufacturers;
- safety when carried onboard aircraft (e.g. fire risk, etc.); and
- specified minimum performance over a specified range of temperature, pressure, etc.

As far as electromagnetic compatibility is concerned the international standardization has also had to ensure that adequate adjacent channel rejection characteristics are specified – and in turn this becomes a key factor in the extensive national and international coordination of frequency assignment activity within the aviation community. In addition very stringent conditions are laid down to ensure that airborne equipment does not adversely affect, and is not adversely affected by, other airborne equipment installed in close proximity on the aircraft.

The scope of the standardization of airborne equipment has, however, necessarily had to take cognizance of the vital fact that the airborne system is not capable of standardization on those aspects which are affected by differences between airframe types. The antenna and feeder characteristics are the main areas of difficulty here, because the airframe exerts considerable influence over the antenna and feeder characteristics and very wide variations exist. In consequence, ICAO specifies —— "signal-in-space" characteristics to ensure minimum acceptable performances. Airborne equipment design has sought to ensure that the "black boxes" will be adequate to process these wanted signals under adverse antenna/feeder circumstances.

6.2 *Current equipment and expected improvements*

Tests so far carried out on airborne receivers, including those described in Annex I of this Report, have shown wide variations in those characteristics and susceptibilities relevant to the rejection of very high-level unwanted signals. ICAO has addressed the problem of high-powered adjacent band FM broadcast interference and has produced new interference immunity standards for airborne receivers in ICAO Annex 10 applicable as of 1998.

Laboratory tests have been performed that characterize the response of a selected sample of aircraft receivers for which an experimental band pass filter has been added to the antenna input (see Part 5 of Annex I). The use of external filters has not been considered feasible as a general solution for technical and airworthiness reasons, nor acceptable as a factor to modify theoretical criteria used to establish electromagnetic compatibility. However, unique singular cases may occur which are suitable for employing an external filter. Within this context the installation and use of an external fiiter is subject to the appropriate rules, regulations and procedures exercised by the concerned aviation authorities.

However, at least one administration will be conducting a series of control tests to fully evaluate the use of add-on filters.

It is, however, very important to note that there are practical limits to the technical improvements that can be realized in both the short- and long-terms, and therefore airborne equipment improvements cannot reasonably be expected to resolve all compatibility problems with the FM broadcasting service. Accordingly, close coordination between aeronautical and broadcasting authorities will continue to be required in the long term.

7. **Summary of study**

The study of potential interference between the FM broadcasting service and the aeronautical radionavigation services in the band 108-118 MHz, has received considerable attention in a number of administrations as reported above. These studies take on a special importance in regions where the band up to 108 MHz has recently become available to FM broadcasting and where, therefore, broadcast implementation is imminent.

It is evident that no simple technical solutions to the compatibility problem are immediately available. The interference potential from FM broadcasting stations (singly or otherwise) to ILS, VOR and/or VHF COM will depend on many factors. Apart from airborne equipment performance itself, the most important factors as shown in Annex I will involve combinations of:

- broadcasting transmitter power (e.r.p.) and antenna characteristics (height, directivity, etc.);
- separation distances;
- frequency separation;
- frequency relationships;
- geographical and topographical aspects.

In this Report, § 2 explains how all the interference mechanisms can be divided into two main categories, type A and type B.

Some examples of each type of interference to VHF-ILS/VOR and COM receivers are shown in detail in the annexes and some conclusions arrived at in terms of theoretical geographical areas where interference is likely to appear, taking into account the different combinations and values of the above parameters.

Taking this framework into account, it will be possible for the administrations to consider throughout the process of planning, case by case, all the potential conflicts e.g. along the guidelines presented in this Report.

It will be necessary for the relevant broadcasting and civil aviation authorities to consider, in close cooperation, possible solutions to eliminate any potential interference problems between the two services.

8. Conclusions

8.1 The problem is complex and not capable of complete quantification by adoption of a single set of protection criteria. The complication is introduced mainly by the wide variability of aircraft equipment characteristics which need to be accommodated.

8.2 The interference potential from type A and type B mechanisms both need to be addressed in practice. ILS and VOR in the sub-band 108-118 MHz are more critically affected by interference.

8.3 The volume of airspace to be protected in ILS cases is relatively small, but in the VOR and VHF COM cases it may be very large.

8.4 New interference immunity criteria for airborne equipment have been established by ICAO. These improvements, which will be incorporated by 1998, will not solve the problems completely.

8.5 The calculations given in this Report show that the current requirements of the Radio Regulations (in respect of spurious emission limits for FM sound broadcasting transmitters above one kW) would possibly require large distance separations in order to avoid type A interference problems. Suppression levels of better than 85 dB are known to have been achieved in practice in seeking solutions to specific cases of difficulty (see also § 5.5).

8.6 This report strongly indicates that the coordination of frequency assignments, siting and suppression will be needed to supplement any general criteria in order to reduce the interference potential.

8.7 For at least the type A mechanisms, it is evident that adequate reduction of the levels of unwanted signals at the aviation receiver will involve consideration of the broadcasting power, the separation distance and the frequency separation.

8.8 Both the aeronautical and broadcasting services need to cooperate closely in order to minimise restrictions on their freedom to deploy their respective facilities. For example, avoiding the use of high power at the broadcasting channels closest to 108 MHz will assist in achieving compatibility. Selection of frequencies for new aeronautical facilities should be made after analysis of existing FM facilities or those coordinated between Administrations to ensure continued compatibility.

9. General recommendations

9.1 Close and continuing assignment coordination between aeronautical and broadcasting authorities appears to be the only practical way to reduce the probability of interference to the aeronautical services to generally acceptable levels.

9.2 Further study is required in order to develop/refine standard interference criteria for the assessment of airborne ILS, VOR, and VHF COM system compatibility with broadcasting signals.

10. Future tests and investigations

10.1 Compatibility between the aeronautical radionavigation service and the sound broadcasting stations in the bands concerned should be studied and in particular:

10.1.1 protection ratio values for future airborne receivers against A1 type of interference from sound broadcasting stations in cases where the frequency of the spurious emissions does not coincide with the aeronautical frequency;

10.1.2 protection ratio values for future aeronautical receivers against A2 type of interference from sound broadcasting stations including measurements of FM broadcast spectra;

Receiver manufacturers should be consulted in regard to meeting a protection ratio goal for type A2 interference of -60 to -70 dB for 150 kHz frequency difference, -70 to -76 dB for 200 kHz difference, in future receivers.

10.1.3 criteria for prediction of third-order intermodulation (referred to as B1 type of interference) generated in airborne receivers by three unwanted signals, for receivers meeting the ICAO standard for two-signal intermodulation for future receivers;

10.1.4 the effect of sinusoidal modulation of the sound broadcasting transmitters during test and line-up and any precautions or procedures to be adopted at broadcasting stations in order to maintain the agreed protection of the aeronautical radionavigation service;

10.2 Compatibility between the aeronautical mobile (R) service (including digital communications) in the 118-137 MHz band and the FM sound broadcasting service.

10.3 compatibility criteria that can be used to predict potential interference in an assignment decision context including the determination of the correlation of bench tests with in-service operational performance of aeronautical receivers;

10.3.1 cumulative effect of multiple FM broadcast signals;

10.3.2 the applicability of cut-off values in the assessment process;

10.3.3 FM broadcast antenna pattern characterization;

10.3.4 statistical analysis of data;

10.3.5 description of, and experience with, assessment techniques in correlation with flight test and operational experience;

10.3.6 effect of FM broadcast signals on auto-pilot system performance;

10.3.7 effect on assessment criteria of special techniques used in FM broadcasting (e.g. subsidiary communication carriers, increases in deviation) (see Part 4 of Annex I).

10.4 Effect of broadcasting signals on the performance of aeronautical ground equipment (ILS/VOR monitors and VHF COM);

10.5 Effect of FM broadcasting on ILS receivers when there is no desired signal present at the receiver (see §§ 3.6.7 and 4.1.1 and Tables XI and XII of Annex I);

10.6 Effect of aeronautical signal interaction with broadcasting transmission: (e.g. an IM product caused by a broadcasting and an aeronautical navigation signal);

10.7 Characterization of ILS and VOR signal levels in their service areas, including appropriate margins (e.g. to account for signal variability);

10.8 Aircraft antenna systems with a view to improving FM signal rejection characteristics;

10.9 Applicability of the aircraft ILS/VOR antenna system characteristic, as defined in Geneva Agreement, 1984;

10.10 Applicability of type B1 and B2 existing immunity formulas of the Geneva Agreement, 1984, for ILS/VOR receivers.

ANNEX I

RECEIVER TEST RESULTS

Part 1 of Annex I

1. *France*

1.1 *Introduction*

1.1.1 The tests were conducted in the summer of 1984 on the following ILS localizer/VOR receivers:

- Becker NR2030
- Collins 51RV 1A
- King KX-175B
- Narco NAV 121

The tests were conducted in a Faraday cage. The desired signal levels were −86 dBm for localizer and −79 dBm for VOR. The undesired signals were generated by actual broadcast transmitters using modulation as per Recommendation 559.

1.2 *Distinction between types A2 and B2 interference effects*

1.2.1 The method consists in measuring the protection ratios when the broadcast signal is first modulated by noise coloured in accordance with CCIR standards and then unmodulated. The interference from the CW signal must be of the B2 type since it has no side bands. If the protection ratios are the same, then any side-band energy received in the passband of the receiver is not the determining factor.

Note. – The measurements were made under the following conditions: if Δf is the difference between the radionavigation frequency (ILS/VOR) and the broadcasting frequency, the measurement for $\Delta f = 0$ and $\Delta f = 50$ kHz (reference values) could only be made with a broadcasting frequency of 108.0 MHz in VOR and 108.1 MHz in ILS.

1.2.2 If the broadcasting frequency is then kept at 107.9 or 108.0 MHz and the frequency of the radionavigation signal is shifted within its band by Δf, the radionavigation receivers will always have the same desensitization characteristic since the latter depends only on the broadcasting frequency.

Note. – For $\Delta f = 0$, in the case of the unmodulated signal, the value given is an indicative one.

1.2.3 The first set of measurements (see Table VI) was made with an output filter of a stereophonic FM transmitter (3 cavities). Its bandwidth was 530 kHz at −3 dB and 800 kHz at −10 dB. The filter served to attenuate the transmitter's residual noise (already low to start with) outside its wanted band, thus making it possible to measure very low protection ratio values (below −80 dB). The filter did not in any way affect the quality of the wanted signal from the broadcasting transmitter. The other measurements were made without the filter; the results are given in Table VII . It can be seen that for values of Δf of about 200 to 300 kHz, the filter makes very little difference to the results when the signal is modulated.

1.3 *Applicability of cut-off values to assessment criteria*

1.3.1 *Demonstration of the non-existence of a cut-off level*

1.3.1.1 The tests made on a sample of radionavigation receivers show that the concept of the cut-off phenomenon does not exist in reality. In fact, the figures here below show what really happens.

TABLE VI – *Broadcasting transmitter equipped with a band-pass filter*

Δf	Receiver A				Receiver B				Receiver C	
	ILS		VOR		ILS		VOR		VOR	
	M	N	M	N	M	N	M	N	M	N
0	11.5	13.0	10.5	26.0	10.0	11.0	10.0	26.0		
50	−14.0	−61.0	−12.5	−49.0	−12.0	−60.0	−17.0	−63.0	− 1.0	−49.0
100	−48.0	−74.0	−50.0	−74.0	−41.5	−69.0	−47.0	−72.0	−44.0	−54.0
150	−76.0	−77.0	−75.0	−70.0	−70.0	−71.0	−76.0	−76.0	−53.0	−53.0
200	−79.5	−80.0	−79.0	−74.0	−72.0	−72.0	−78.0	−79.0	−52.5	−52.5
300	−80.5	−83.0	−76.0	−74.5	−74.5	−75.0	−92.0	−90.0		
400	−85.0	−86.0	−87.0	−88.0	−76.0	−76.0	−91.0	−93.0		
500	−79.0	−86.0	−74.0	−75.0	−76.5	−76.5	−92.0	−92.5		
800	−86.0	−86.0	−86.0	−88.0	−77.0	−77.0	−91.0	−91.0		
1000	−86.0	−86.0			−74.0	−77.0				

M: broadcasting signal modulated by coloured noise.

N: broadcasting signal not modulated.

TABLE VII – *Broadcasting transmitter without band-pass filter*

Δf	Receiver A				Receiver B	
	ILS		VOR		VOR	
	M	N	M	N	M	N
0	8.0	10.0	10.0	10.0	3.0	8.0
50	−11.0	−22.5	−12.0	−24.0	−15.5	−32.0
100	−46.0	−57.0	−47.0	−57.5	−49.0	−68.5
150	−72.5	−73.0	−72.0	−73.0	−70.0	−70.0
200	−76.0	−76.5	−76.0	−75.0	−78.0	−77.0
300	−78.0	−77.5	−77.0	−75.5	−81.5	−82.0
400	−80.5	−80.0	−81.5	−82.0	−86.5	−86.5
500	−79.0	−83.0	−74.5	−75.0	−92.0	−93.0
800	−79.0	−85.0	−82.0	−84.0	−90.0	−92.0
1000	−81.0	−85.5	−79.0	−79.0	−89.0	−90.0

M: broadcasting signal modulated by coloured noise.

N: broadcasting signal not modulated.

1.3.1.2 The intermodulation criterion is a linear law in N_1, N_2, N_3 of the form $N_1 + N_2 + N_3 + K = 0$. If we take the position N_3 = constant, the relation between N_1 and N_2 can be plotted (see Figure 2):

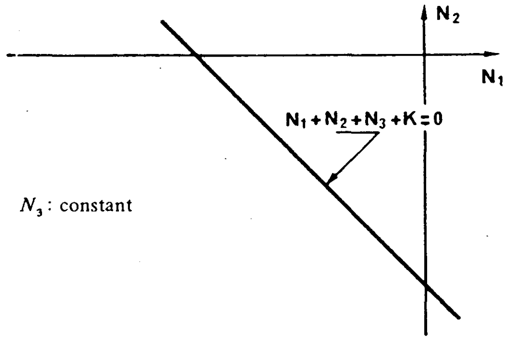

FIGURE 2

1.3.1.3 The existence of a cut-off threshold on N_1 is expressed by the fact that for $N_1 \leqslant N_1$ cut-off, there is no longer any intermodulation. The same is true for $N_2 \leqslant N_2$ cut-off.

1.3.1.4 If such a cut-off value really existed, the above theoretical curve would in practice be distorted (see Figure 3):

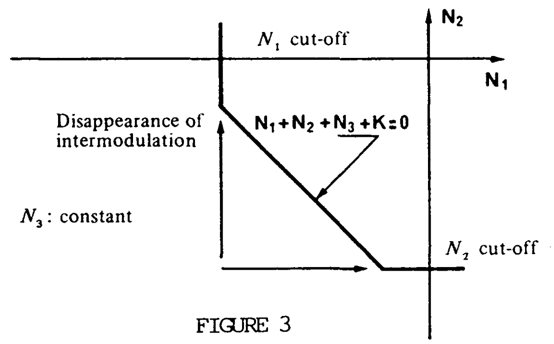

FIGURE 3

1.3.1.5 The tests made on radionavigation receivers have made it possible to draw Figs. 7 to 12.

1.3.1.6 The distortion described above is never found in these curves. We may however note that they have the shape shown in Figure 4:

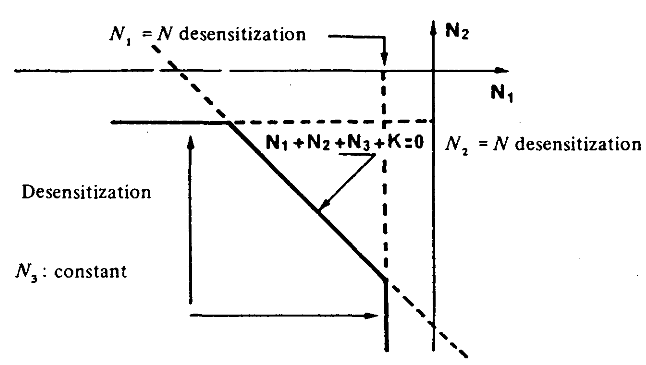

FIGURE 4

1.3.1.7 This is explained by the occurrence of a desensitization phenomenon, which, beyond a certain threshold, conceals the intermodulation phenomenon.

1.3.2 *Conditions at the limits when type B2 interference outweighs type B1 interference*

1.3.2.1 *Assumptions*

A disturbance by three broadcasting stations is expressed by:

- the combination of frequencies:

$$f_1 + f_2 - f_3 = f_{aeronautical}$$

- the equation for the levels:

$$N(f_1) + N(f_2) + N(f_3) + K(f_1, f_2, f_3, f_{aero}) = 0$$

We denote $x(f)$ by the expression:

$$20 \log \frac{max \{108.1 - f; 0.4\}}{0.4}$$

in which $max \{a; b\}$ represents the greater of two values a and b.

Thus for $f \geq 107.7$ MHz, $x(f) = 0$.

We can also write:

$K = 126 - x(f_1) - x(f_2) - x(f_3)$

1.3.2.2 *Theoretical attempt to find the transition point between the two types of interference*

We shall attempt to find the minimum level $N_l(f)$ corresponding to the transition from type B1 interference to type B2.

For a signal of frequency f_1, this value is obtained by a simultaneous desensitization caused by signals f_2 and f_3, or:

$$N_l(f_1) + N_d(f_2) + N_d(f_3) + 126 - x(f_1) - x(f_2) - x(f_3) = 0 \quad (1)$$

The desensitization level at frequency f is denoted by $N_d(f)$ (see § 4.2.2 of JIWP 8-10/1 report May 1984).

Permutating the signals, we also get:

$$N_l(f_2) + N_d(f_1) + N_d(f_3) + 126 - x(f_1) - x(f_2) - x(f_3) = 0 \quad (2)$$

$$N_l(f_3) + N_d(f_1) + N_d(f_2) + 126 - x(f_1) - x(f_2) - x(f_3) = 0 \quad (3)$$

It is logical to make the assumption that $N_l(f)$ has the form:

$$N_l(f) = x_0 + x(f) \quad (4)$$

where x_0 is a constant to be determined. Measurements have always yielded frequency dependences of the form $x(f)$.

If we introduce equation (4) into equations (1), (2) and (3), we get:

$$x_0 + x(f_1) = -126 + x(f_1) + x(f_2) + x(f_3) - N_d(f_2) - N_d(f_3)$$

$$x_0 + x(f_2) = -126 + x(f_1) + x(f_2) + x(f_3) - N_d(f_3) - N_d(f_1)$$

$$x_0 + x(f_3) = -126 + x(f_1) + x(f_2) + x(f_3) - N_d(f_1) - N_d(f_2)$$

Resolving this equation, we get:

$$x_0 + 126 = 2[x(f_1) - N_d(f_1)] = 2[x(f_2) - N_d(f_2)] = 2[x(f_3) - N_d(f_3)]$$

We can thus write for any frequency, f, involved in an intermodulation product:

$$N_d(f) = -1/2(x_0 + 126) + x(f)$$

$N_d(f)$ is thus defined in two ways:

- firstly, by three straight lines (see Fig. 2, § 4.2.2 of the Joint Interim Working Party 8-10/1 Report May 1984).

  It should be noted that such a law is obviously the linear approximation of a law without discontinuity;

- secondly, by the function $x(f)$, which, allowing for a vertical shift, is represented by the constant:

$$1/2(x_0 + 126)$$

Comparing these two laws graphically (see Fig. 5), we find that the three sections of curve constitute a good approximation of the law $x(f)$ for $1/2(x_0 + 126) = 20$. This gives $x_0 = -86$.

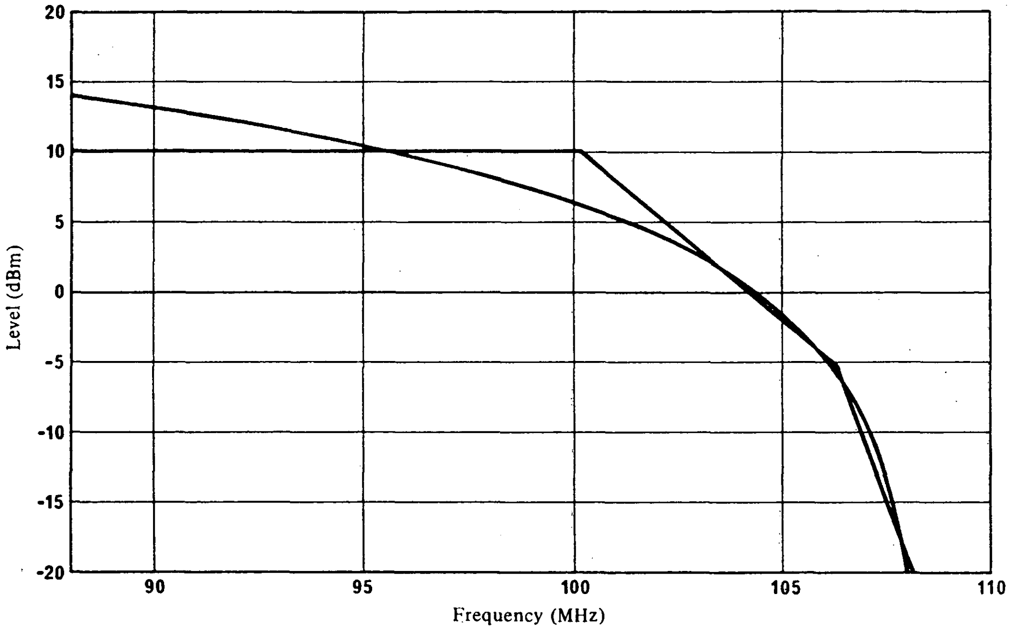

FIGURE 5

1.3.3 *Conclusion*

Although the hypothesis of cut-off thresholds was disproved by the experimental measurements, it was shown that it was pointless in practice to deal with type B1 interference appearing below a certain threshold. The effects of such interference are then completely obscured, because the preponderant disturbance is type B2. On the basis of the above calculations the following formulae should be used, defining the limiting values:

- Current ILS and VOR receivers:

$$N(f) \geqslant -86 + 20 \log \frac{108.1 - f}{0.4} \quad \text{dBm} \quad \text{for } f \leqslant 107.7$$

$$N(f) = -86 \quad \text{dBm} \quad \text{for } f \geqslant 107.7$$

- Future ILS and VOR receivers:

$$N(f) \geqslant -58 + 20 \log \frac{108.1 - f}{0.4} \quad \text{dBm} \quad \text{for } f \leqslant 107.7$$

$$N(f) = -58 \quad \text{dBm} \quad \text{for } f \geqslant 107.7$$

These values are plotted on the curves of Fig. 6.

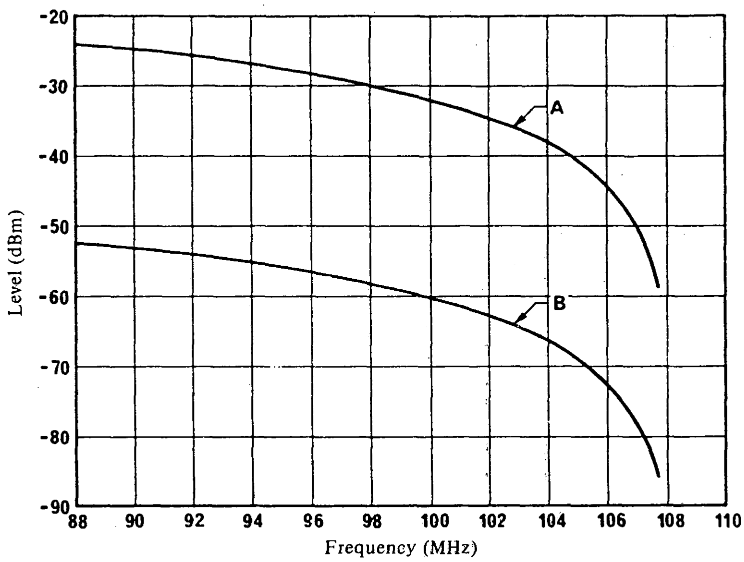

FIGURE 6

Curves A: future receivers
B: current receivers

1.4 French test data on 3-signal type B1 interference.

Interpretation of the curves

The laws sought are of the form:

$$N_1 + N_2 + N_3 + K = 0$$

where N_1, N_2, N_3 are the respective levels in dBm of the three broadcasting transmitters at frequencies f_1, f_2, f_3.

To make them easier to use, the curves have been plotted , Figures 7 to 12, for three values of N_3; each of these curves in (N_1, N_2) must have a slope of -1:

$$N_1 + N_2 + (N_3 + K) = 0$$

The modification in the slope is brought about by the desensitization of the receiver.

On each of the curves, levels (N_1, N_2, N_3) are found which are lower than the cut-off level proposed in Annex IX of Joint Interim Working Party 8-10/1 report, May 1984 and for which type B1 interference was measured. Some of these points are marked by squares.

The cut-off levels are represented by broken lines. They depend on the frequency and the type of receiver used: ILS or VOR.

Under each of the curves is given the equation of the intermodulation law in its conventional form, when the slope is -1.

On the curves of Fig. 7, the desensitization of the receiver can be seen:

- when N_1 = −20 dBM for f_1 = 107.9 MHz, the same disturbance is found with N_2 = −50, −60 or −70 dBm;
- similarly, when N_2 = −8 dBm for f_2 = 107.5 MHz, the same disturbance is found with N_1 = −40, −50, −60 or −70 dBm.

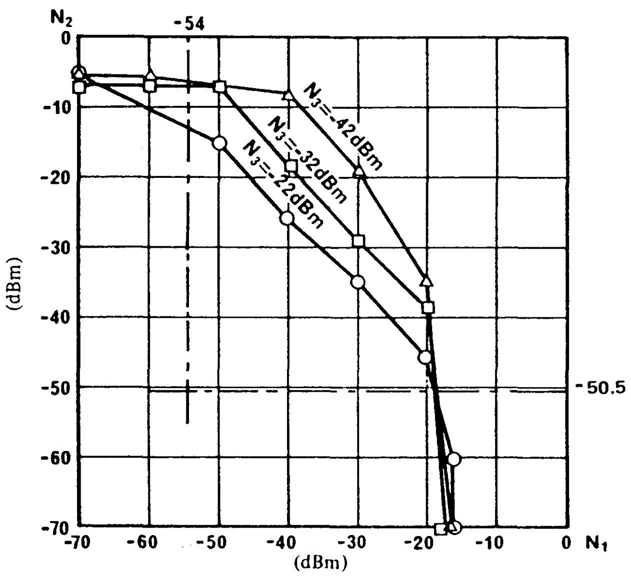

FIGURE 7 – *Type B1 interference test*

Equation obtained: $N_1 + N_2 + N_3 + 87 = 0$

Receiver type: receiver A
Signal type: ILS localizer
Receiver frequency: 108.5 MHz
Wanted signal: −86 dBm (50 Ω)

f_1 = 107.9 MHz
f_2 = 107.5 MHz
f_3 = 106.9 MHz

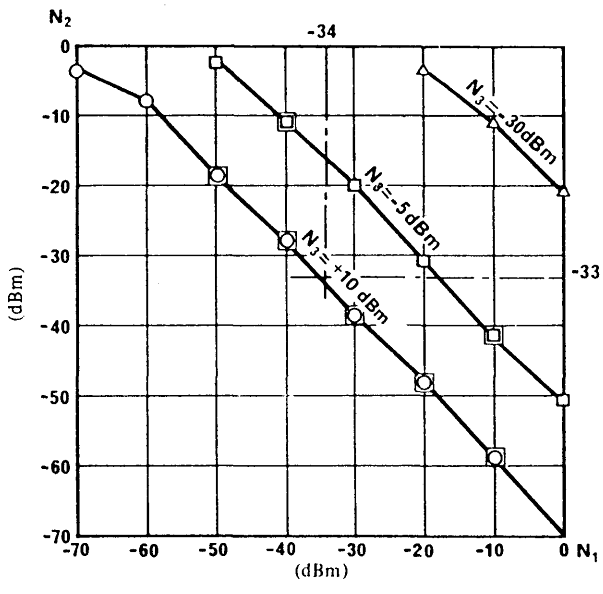

FIGURE 8 – *Type B1 interference test*

Equation obtained: $N_1 + N_2 + N_3 + 60 = 0$

Receiver type: receiver A
Signal type: ILS localizer
Receiver frequency: 108.1 MHz
Wanted signal: −86 dBm (50 Ω)

f_1 = 104.1 MHz
f_2 = 103.7 MHz
f_3 = 099.7 MHz

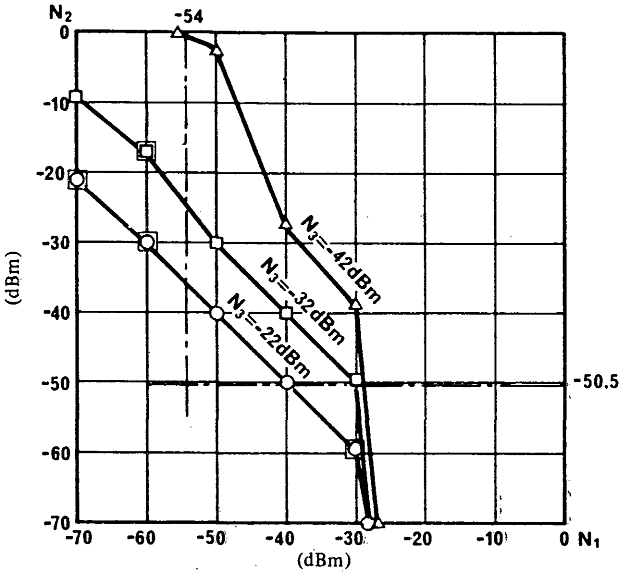

FIGURE 9 – *Type B1 interference test*

Equation obtained: $N_1 + N_2 + N_3 + 112 = 0$

Receiver type: receiver C
Signal type: ILS localizer
Receiver frequency: 108.5 MHz
Wanted signal: −86 dBm (50 Ω)

f_1 = 107.9 MHz
f_2 = 107.5 MHz
f_3 = 106.9 MHz

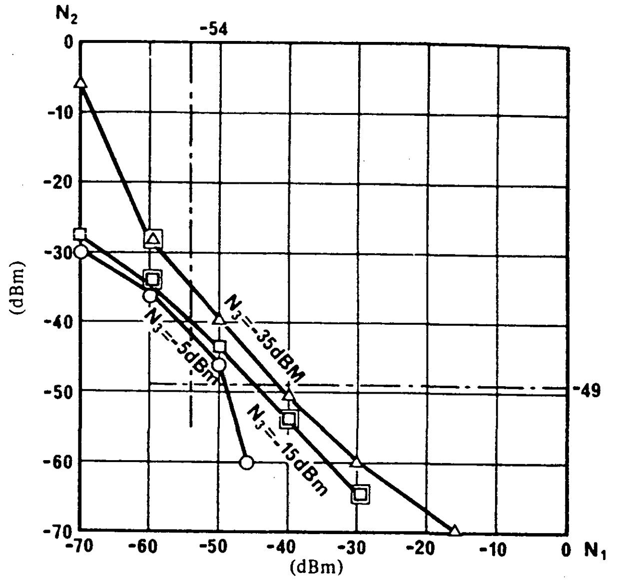

FIGURE 10 – *Type B1 interference test*

Equation obtained: $N_1 + N_2 + N_3 + 126 = 0$

Receiver type: receiver B
Signal type: ILS localizer
Receiver frequency: 108.1 MHz
Wanted signal: −86 dBm (50 Ω)

f_1 = 107.9 MHz
f_2 = 107.4 MHz
f_3 = 107.2 MHz

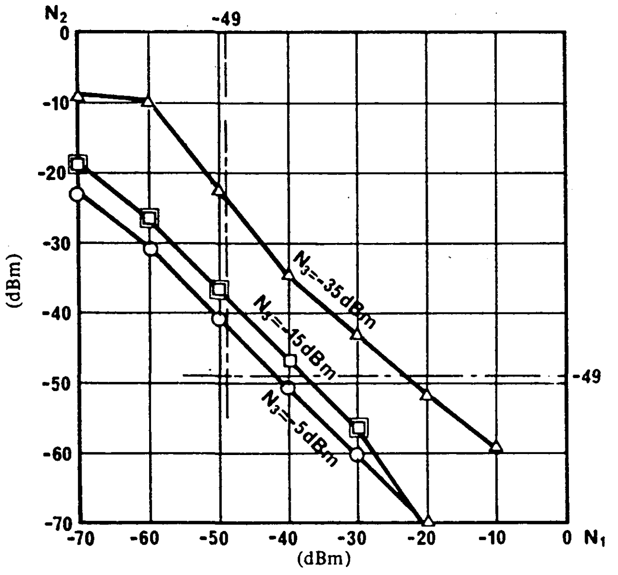

FIGURE 11 – *Type B1 interference test*

Equation obtained: $N_1 + N_2 + N_3 + 108 = 0$

Receiver type: receiver B
Signal type: VOR
Receiver frequency: 108.2 MHz
Wanted signal: −79 dBm (50 Ω)

f_1 = 107.9 MHz
f_2 = 107.4 MHz
f_3 = 107.1 MHz

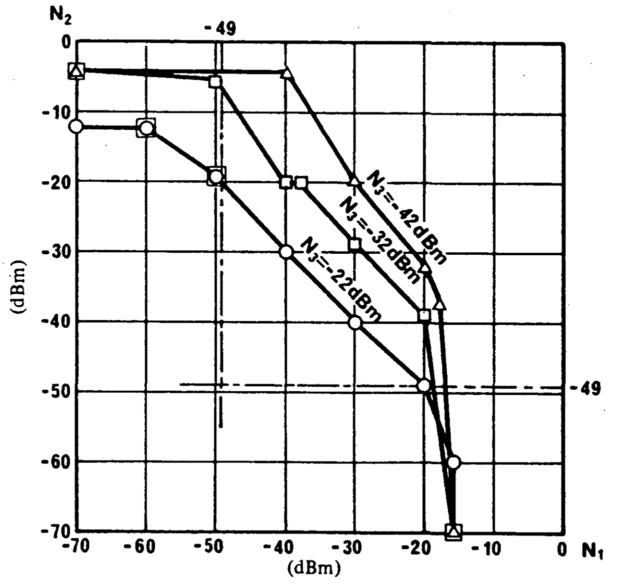

FIGURE 12 – *Type B1 interference test*

Equation obtained: $N_1 + N_2 + N_3 + 90 = 0$

Receiver type: receiver C
Signal type: VOR
Receiver frequency: 108.4 MHz
Wanted signal: −79 dBm (50 Ω)

f_1 = 107.9 MHz
f_2 = 107.5 MHz
f_3 = 107 MHz

Part 2 of Annex I

2. *Finland*

2.1 *Introduction*

2.1.1 Studies and laboratory tests on type B1 interference in ILS-localizer receivers have been performed in Finland. The construction of about 40 receivers was studied and three of those were actually measured. The receivers measured were Collins 51RV 2, Collins 51RV 4B and King KX-175B.

The interference criterion chosen was ± 7.5 μA change in course guidance current of 90 μA. Combinations of unwanted signals (f_1 and f_2) were selected to produce an intermodulation product of third order both in the lower end and the upper end of the ILS band. Wanted signal levels were −86 dBm, −76 dBm and −66 dBm.

2.1.2 Studies showed that all 40 receivers had front-ends tunable according to the selected ILS frequency.

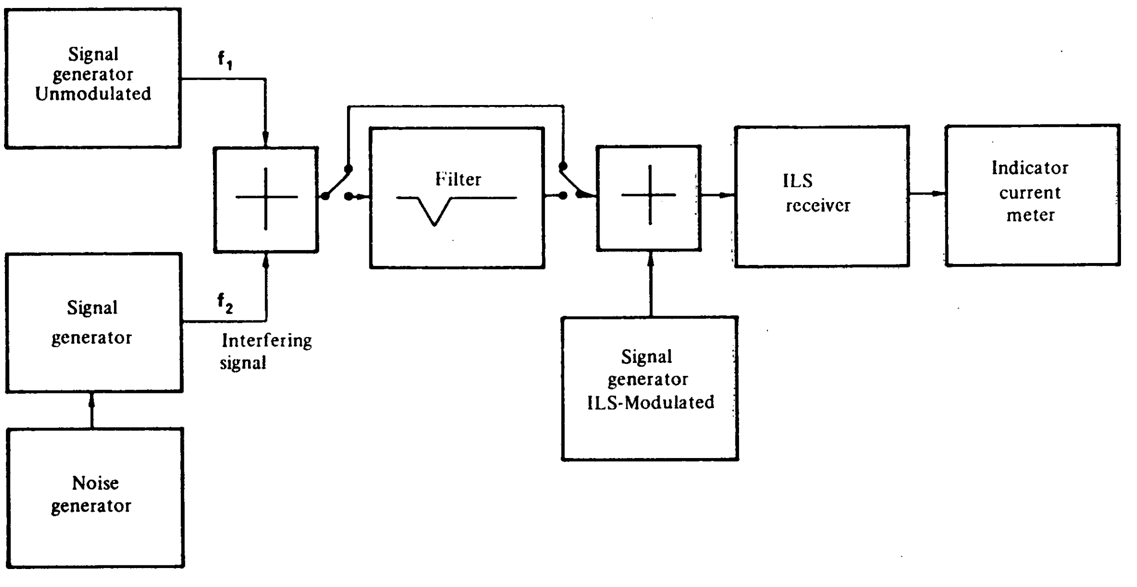

FIGURE 13- *Intermodulation measurement test set-up (interference type B1)*

Interfering signal at f_2 has noise modulation with weighting according to Recommendation 559 and 32 kHz r.m.s. deviation.
Filter at wanted signal frequency (f_a).
Wanted signal level −86 dBm, −76 dBm or −66 dBm.
Indicator criterion ±7.5 μA change from 90 μA.

2.2 *Test results*

2.2.1 In the frequency range below 107.7 MHz the measurement results seemed to follow the formula:

$$2N_1 + N_2 + 3\left(A - B\log\frac{\Delta f}{0.4}\right) \geq 0$$

where:

$\Delta f = f_a - f_1$ (MHz)

f_a: ILS channel tuned frequency (MHz),

f_1 and f_2: broadcasting frequencies ($f_1 > f_2$),

N_1: signal level at f_1 (dBm),

N_2: signal level at f_2 (dBm).

$f_a = 2f_1 - f_2$

TABLE VIII – *Interference threshold, interference type B1*

A. Broadcasting frequencies in the range 107.7-108 MHz	
Receiver	Condition for interference
No. 1	$2N_1 + N_2 + 81 \geqslant 0$
No. 2	$2N_1 + N_2 + 96 \geqslant 0$
No. 3	$2N_1 + N_2 + 129 \geqslant 0$
B. Broadcasting frequencies in the range below 107.7 MHz	
Receiver	Condition for interference
No. 1	$2N_1 + N_2 + 3\left(27 - 10 \log \frac{\Delta f}{0.4}\right) \geqslant 0$
No. 2	$2N_1 + N_2 + 3\left(32 - 5 \log \frac{\Delta f}{0.4}\right) \geqslant 0$
No. 3	$2N_1 + N_2 + 3\left(43 - 20 \log \frac{\Delta f}{0.4}\right) \geqslant 0$

Note 1. – Frequencies selected (MHz) (Table IX) and the linear models given in this Table were fitted to the results.

Note 2. – Interfering signal with Recommendation 559 weighting (coloured noise, 32 kHz r.m.s. deviation)
– Wanted ILS signal level −86 dBm
– Criterion for interference is a ± 7.5 μA change in the set course guidance current 90 μA.

TABLE IX

f_1 f_2	107.9 107.7	107.1 106.1	103.1 98.1	107.9 103.9
f_a	108.1	108.1	108.1	111.9

2.2.2 Coefficient *A* varied from 27 to 43 and coefficient *B* from 5 to 20. As the coefficients depend considerably on the receiver selected more different receiver designs should be measured.

2.2.3 The measurements showed also that with higher levels of the wanted signal (+10 dB, +20 dB) the intermodulation immunity to unwanted signals improves with some of these receivers, almost in relation to the increase in the wanted signal level.

2.2.4 For the case with three interfering signals the interference threshold formula should have the following general form:

$$N_1 + N_2 + N_3 + 3A + 6\,\text{dB} - C \log \frac{\Delta f_1 \times \Delta f_2 \times \Delta f_3}{(0.4)^3} \geqslant 0$$

where:

$\Delta f_i = f_a - f_i$(MHz) and

C: determined by the slope of the filter before the component where intermodulation arises ($C \neq B$).

For a single tuned circuit $C = 20$.

2.2.5 The additional +6 dB term comes from the theoretical difference between type $2N_1 + N_2$ and type $N_1 + N_2 + N_3$ terms.

Part 3 of Annex I

3. *Canada and the United States of America*

3.1 A measurement programme on interference to avionics receivers from signals from FM broadcast services was undertaken by the United States Federal Aviation Administration and Transport Canada. The tests were conducted both at ARINC laboratories in Annapolis, Maryland, United States of America and at Transport Canada laboratories in Ottawa, Canada. This part of Annex I presents results of these tests.

3.2 Subsequent flight tests conducted in Canada indicated that there was good correlation between Type B1 receiver bench test data and flight test results (i.e. the measured FM signal levels that caused interference in receivers during the flight tests were approximately the same levels that caused interference in the bench tests, at corresponding localizer signal level).

3.3 *Common reference point for airborne equipment measurements and future specifications*

3.3.1 Voltage is referenced to the receiver input calculated on the basis of the generator output across 50 Ω (see Fig. 14). It is stressed that this does not affect the final results in terms of permissible field strengths at the receiver antenna but is solely a highly desirable means of reducing confusion in the future. Figure 14 also shows an example of the resulting RF generator level setting procedures.

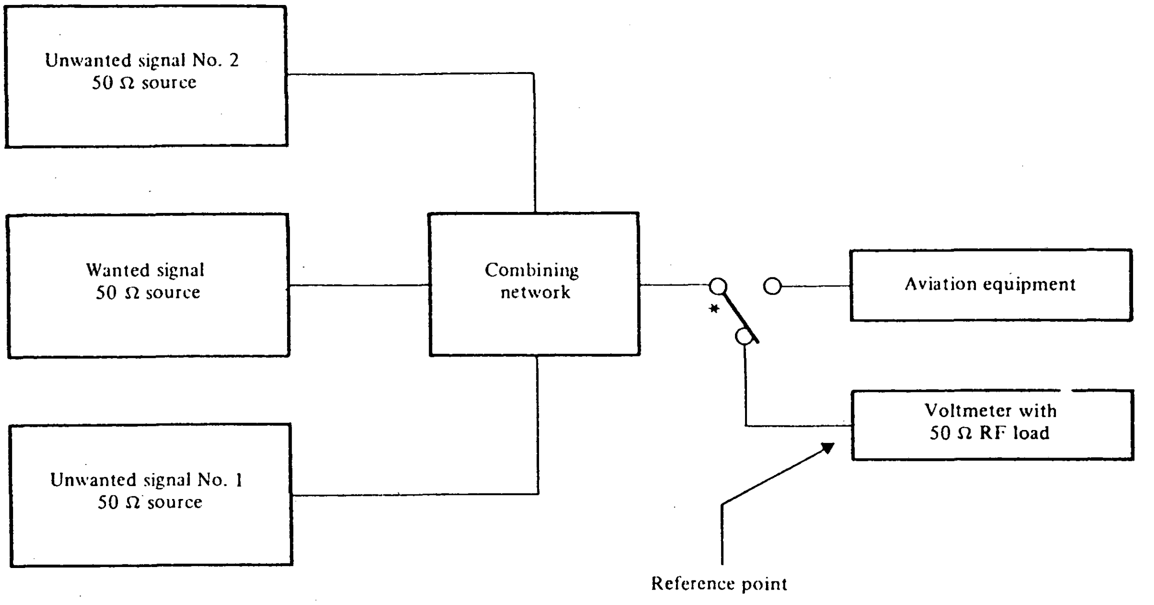

FIGURE 14 – *Definition of standard reference point for specification and measurement of airborne receiver immunity*

* Substitute voltmeter with 50 Ω load for aviation equipment to set RF levels.

3.4 Results of a joint Canadian/United States test programme

3.4.1 *Description of tests*

3.4.2 *Type A2 interference*

3.4.2.1Tests were conducted to determine the extent of interference caused by sideband energy from FM broadcast signals on ILS localizer and, to a lesser extent, VOR receiver performance.

3.4.2.2Earlier results of a limited test effort were submitted to the JIWP 8-10/1, May 1984.They became the basis for type A1/A2 interference criteria in the JIWP 8-10/1 report, were subsequently accepted by the Geneva Agreement 1984 ——————
and used as a basis for the A1/A2 protection criteria in Appendix 1 paragraphs III and IV of its Final Acts. The results reported herein extend that data base to fifteen receivers (nine general aviation and six air-carrier types).

3.4.2.3Each ILS localizer receiver was subjected to four different FM modulations used to simulate FM broadcast signals; CCIR coloured noise, pink noise, pre-recorded voice, and rock music. While a minimum desired signal level was used for most of the tests, several higher desired signal levels were used for some tests to determine if the receivers were operating in their linear range. Cross-pointer and flag data were recorded for both on-centre line and off-centre line simulated aircraft approaches. AGC data was recorded for mechanism analysis.

3.4.3 *Type B2 interference*

3.4.3.1ILS localizer receiver overload thresholds caused by FM broadcast signals were examined.

3.4.3.2Pure carrier (CW) signals were employed for the interferer to determine type B2 desensitization thresholds.

3.4.4 *Type B1 interference*

3.4.4.1Receiver intermodulation interference tests were conducted on thirteen ILS localizer receivers; both airline quality and general aviation type.

3.4.4.2The tests first examined the sensitivity of the receivers to different types of modulation used to simulate FM broadcast signals. Tests were run with and without a desired signal present.

3.4.4.3A comprehensive set of equi-signal level data was taken for both 2- and 3-signal, third-order receiver intermodulation products on localizer frequencies 108.1, 109.1 and 110.1 MHz. The results were compared against those calculated from existing and future immunity formulae presented in the Geneva Agreement, 1984 All three forums, ICAO, JIWP and Geneva Agreement, 1984, adopted the same future immunity formulae. These formulae are contained in Annex III.

3.4.4.4Several receivers were tested to examine the effect of various desired localizer signal levels on the interference threshold, and the effect of unequal interfering signal levels.

3.5 Type A2/B2 tests

3.5.1 *Introduction*

3.5.2 A total of 20 receivers were tested for type A2/B2 interference effects at ARINC laboratories, Annapolis, Maryland, United States of America, during August-September, 1984 (see Table X for a list of receivers tested).

TABLE X

Unit under test (UUTs)
King KX-175B KNS-80 KN-53 KNS-81 KNR-615
Collins VIR 351 TSO 51RV 1 51RV 1A 51RV 2B ILS 70
Cessna ARC RT 385A
Narco NAV 121 NAV 825
Bendix RNA 26C RNA 34A

3.6 *Test procedures*

3.6.1 Figure 15 is the set-up used for all the tests.

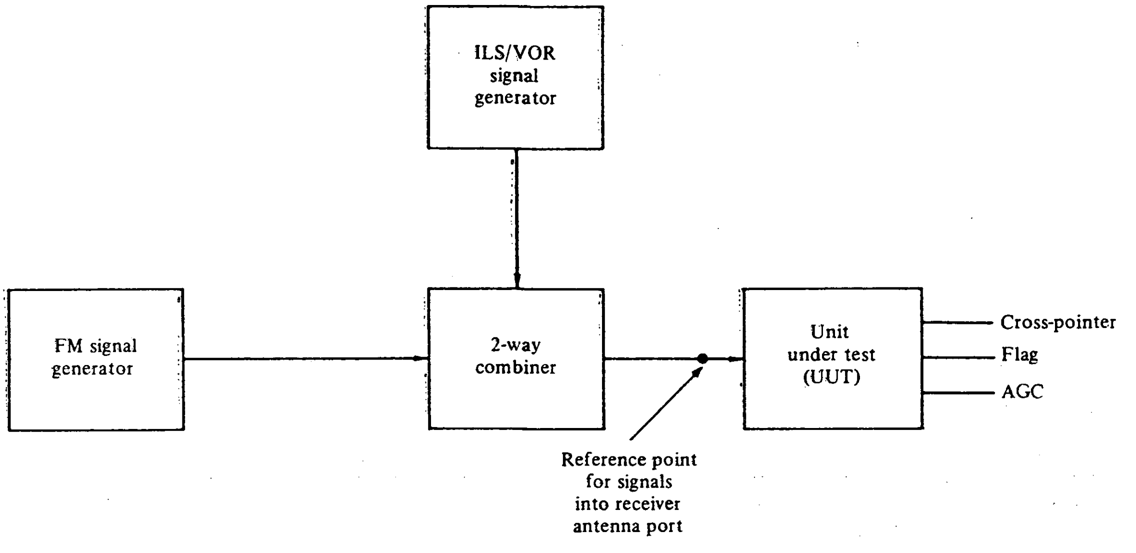

FIGURE 15 – *Block diagram of test set-up for type A2/B2 tests*

3.6.2 For the A2/B2 tests, the amplitude modulated wanted signal (W) simulated a ground localizer signal with a carrier frequency of 108.1 MHz. Differences in the depth of modulation (DDM) of 0.0 and 0.093 were used. A DDM of 0 corresponds to a centre-line approach. A DDM of 0.093 corresponds to the standard deflection of 90 μA and is a manufacturer specified receiver calibration point. Linearity of the ILS receiver performance was investigated by varying the wanted signal level from −76 dBm to −106 dBm where possible and measuring the W/U ratio at each level.

3.6.3 Various unwanted signals, U, were fed into the antenna port of the UUT along with a wanted signal, W. For each data point, the unwanted signal was introduced at an undetectable level and increased until the interference threshold for cross-pointer and flag were exceeded, as monitored by a multimeter, strip chart recorder and visual observation of flag action.

3.6.4 The actual FM broadcasts used were:

– part of a routine which included speech, laughing, applause and periods of silence; and

– music recorded from an on-air FM broadcast station which included both loud and soft passages.

CCIR coloured noise was generated by passing white noise through a filter whose characteristics are described in Recommendation 559, Fig. 2, curve B. Pink noise was generated by a suitable source.

3.6.5 Peak deviation was set to 75 kHz (broadcast standard). The FM modulated signal was adjusted until the peak deviation due to the audio input exceeded the 75 kHz limit no more than 10 times per minute (broadcast standard).

3.6.6 For A2 and B2 tests, a single simulated FM signal was generated. The interference threshold (see §3.4.7) was approached from below. If the cross-pointer threshold was reached first, the FM signal was further increased until the flag threshold was also reached.

3.6.7 *Interference criteria*

3.6.7.1 *Cross-pointer*

Change in cross-pointer current greater or equal to ± 9 μA which lasts for a period of time greater or equal to approximately 0.2 s. A fluctuation which lasts less than about 200 ms is not considered significant because it has a negligible effect on cross-pointer activity.

3.6.7.2 *Flag* (with wanted signal)

Appearance of the flag for a period of time greater or equal to approximately 1 to 2 s. The appearance of the flag indicates an unusable wanted signal.

3.6.7.3 *Flag* (no wanted signal)

Disappearance of the flag for a period of time greater or equal to approximately 1 to 2 s. The disappearance of the flag is an indication that a usable wanted signal is present.

3.7 *Test results*

3.7.1 *General test observations*

3.7.1.1 Both air carrier and general aviation type receivers were included in the tests. Test results transcended type; e.g. no general statements could be made as to which group included the worst and best performers. A large range of responses was seen from model to model. Results were found to be surprisingly consistent from unit to unit of the same model.

3.7.2 *A2 VS B2 interference*

3.7.2.1 One of the objectives of the tests was to determine if the interference detected was of the A2 type (sidebands of the unwanted signal received within the passband of the receiver) or B2 (desensitization due to strong off-tuned signal). To determine this, the protection ratio for CW was compared to that for the FM modulated signal (all other parameters remaining equal). The interference from the CW must be of the B2 variety since it has no sidebands. If the protection ratio with modulation was the same as that without, it was assumed that both were of the B2 variety. Put another way, if the protection ratios are the same, then any side-band energy received in the passband of the receiver is not the determining factor. If the protection ratio with modulation is higher (requiring a smaller U to exceed the same threshold) then it was assumed to be of the A2 type.

3.7.2.2 A2/B2 test results are shown in Fig. 16 in the aggregate. Both the existing and future B2 immunity criteria curves from Fig. 23 are reproduced in part on Fig. 16. The current receivers as a whole exceed the existing immunity criteria, i.e. the data points fall below the upper curve. The future immunity curve represents an improvement of 10 dB. More than half of the receivers will require increased immunity to meet the future criteria for all Δf.

3.7.2.3 The test results show that the exact form of FM modulation used for bench testing did not seem to make much difference for A2/B2 protection ratios. In general, A2 and B2 effects data for $\Delta f > 200$ kHz do not differ by more than 2 dB.

However, for a few of the receiver types tested, the CW-only interferer (type B2) did require a higher signal level than an FM modulated interferer for isolated cases out to $\Delta f = 800$ kHz. This was unexpected.

3.7.2.4 For some specific receiver/frequency combinations, the protection ratio for CW was actually higher than that for FM modulation. This may be due to the fact that the unwanted signal frequency fell on a spurious response frequency of the unit under test (UUT). The FM signal with its broad spectrum would deposit only a small amount of its energy on that frequency. The CW signal would deposit all or most of its energy at that frequency, requiring a smaller CW signal to have the same effect as the modulated signal.

3.7.2.5 In most of the tests, the cross-pointer and flag interference thresholds were exceeded before significant audio interference was heard in the identification channel.

3.7.2.6 IF AGC data, while being inconclusive, seems to indicate that in many cases the UUT was desensitized by the RF AGC and no signals reached the IF amplifier. Both IF and RF AGC data were recorded for one receiver, and the results were consistent with this hypothesis.

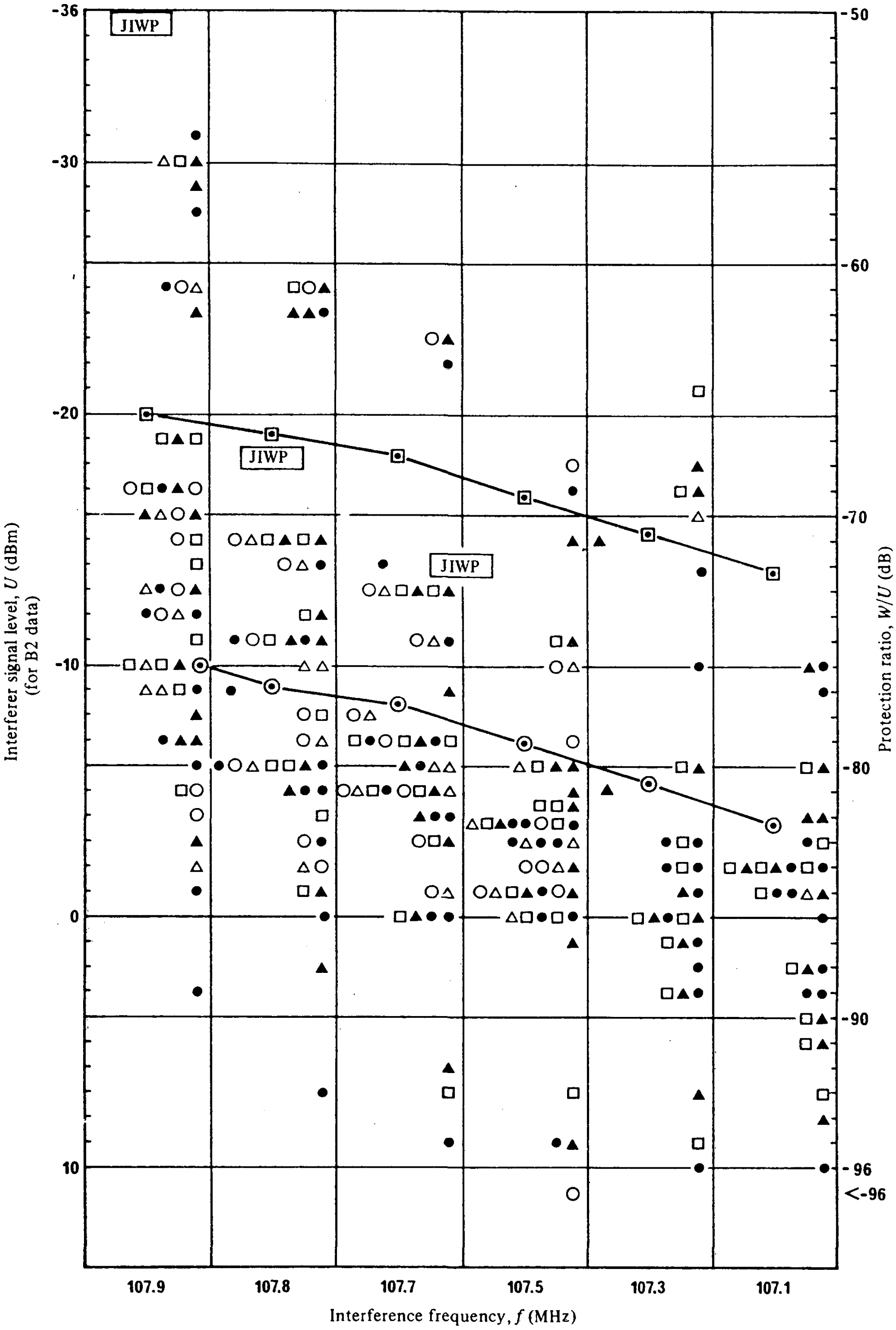

FIGURE 16 – *Protection ratios for ILS localizer receiver*

Type A2/B2 interference

ILS frequency: 108.1 MHz

- ● CW
- ▲ CCIR noise
- □ Pink noise
- △ Voice
- ○ Rock music

ΔI = 9 μamp

W = −86 dBm

DDM = ±0.093

JIWP : Type A2 immunity

Type B2 immunity thresholds:

- ⊙ Future
- ⊡ Current

3.7.2.7 A1/A2 data was taken at wanted signal levels of −76, −86, −96 and −106 dBm where possible to determine if the receivers were operating linearly at −86 dBm. The results indicate that in some cases the receivers were bordering on overload for a desired signal level of −76 dBm. However, others exhibited linear relationships, that is, the same *W/U* ratio was achieved for the range of *W* from −76 dBm to −96 dBm.

3.7.2.8 Most of the receivers reached the cross-pointer threshold before reaching the flag threshold. Some receivers desensitized the cross-pointer as soon as the flag showed, others did not. Some receivers tested, exhibited large cross-pointer errors before the flag showed, and in some UUTs the flag never showed for interference levels up to the maximum tested, +10 dBm.

3.7.2.9 The effects of interference on cross-pointer were the greatest off centre-line, e.g. with a wanted signal DDM of 0.093. When on centre-line, 0 DDM, the flag was displayed before the cross-pointer threshold was exceeded. Often the cross-pointer threshold was never exceeded for interference levels up to +10 dBm.

- An explanation is that the interference affects both the 90 and 150 Hz filters equally, tending to move the cross-pointer to the centre and creating the illusion of being closer to the centre-line than is actually the case (i.e. widening of the approach path). This was observed for the vast majority of tests with a 0.093 DDM;
- when the receiver is receiving a centre-line ILS signal, this effect is masked. The predominant on-centre line interference effect is to desensitize the receiver to the wanted signal causing the flag to be displayed even when a good signal is present.

3.7.2.10 Large cross-pointer errors were found to occur in some of the tested receivers as a result of the reception of a strong FM signal. This type of interference could be construed as a valid course since it occurred with the flag still hidden. In a few receivers this error took the form of a strong "fly left" indication.

3.8 Type B1 tests

3.8.1 *Introduction*

A total of 13 receivers were tested for type B1 interference effects at Transport Canada laboratories in Ottawa, Canada, during May 1984.

3.8.2 *Test procedure*

3.8.2.1 The airline-quality and general aviation-type ILS localizer receivers tested for 2-signal and 3-signal, third-order receiver intermodulation (type B1) interference effects were:
- Bendix RNA 26C
- Bendix RNA 34A
- Cessna RT 385A
- Collins 51RV 1
- Collins 51RV 1A
- Collins ILS 70
- Collins VIR 351
- King KNR-615 (two units)
- King KNS-80
- King KX-175B
- Narco NAV 121
- Narco NAV 825

3.8.2.2 Tests were first conducted to determine the sensitivity of these receivers to different types of modulation on the broadcasting signals causing intermodulation interference. Modulations used were CCIR coloured noise (as per Recommendation 559), pink noise and taped music programme material. The broadcasting frequencies for the 2-signal and 3-signal intermodulation products were selected to correspond to broadcasting signals in the Ottawa area. Actual on-air broadcast signals received via an antenna system were fed into the localizer receivers to provide a basis for comparison with the other types of modulation.

3.8.2.3 Using an appropriate modulation based on the preceding modulation sensitivity tests, testing was carried out on all the receivers for 2-signal and 3-signal intermodulation effects on localizer frequencies 108.1, 109.1 and 110.1 MHz.

3.8.2.4 On a few receivers, additional tests were conducted to investigate the effect of increasing the desired localizer signal level and the effect of unequal interfering signal levels.

3.8.2.5 The block diagram for the 3-signal tests set-up is shown in Fig. 17. Maximum deviation for modulation on the broadcasting (stereo mode) signals was the North American standard of 75 kHz peak. The maximum equi-signal level generated by the test set-up was −5 dBm. When the on-air broadcasting signals were used, they were fed directly into the receivers from an antenna located outside the test laboratory and attenuated as necessary from a maximum equi-signal level of −15 dBm.

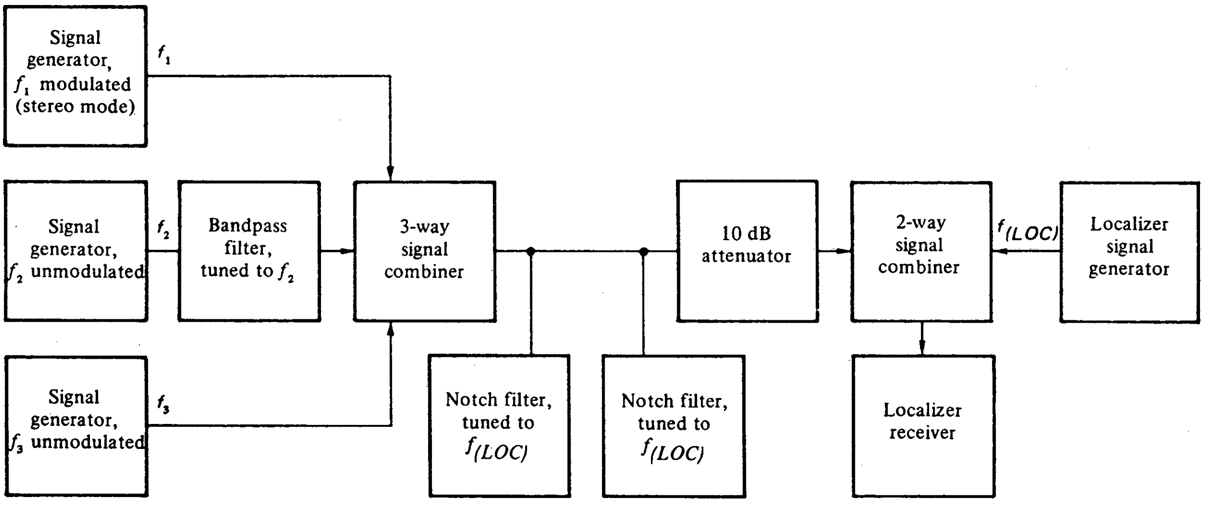

FIGURE 17 – *Block diagram of test set-up for 3-signal type B1 tests*

f_1, f_2, f_3: broadcasting frequencies, $f_1 > f_2 > f_3$

$f_{(LOC)}$: localizer frequency

3.8.2.6 The interference criteria used were the appearance of the flag or a change of 7.5 μA in cross-pointer current for a localizer signal with a difference in depth of modulation (DDM) of 0.093 (90 Hz > 150 Hz). Conversion of the minimum localizer field strength of 32 μV/m through an isotropic loss-less antenna/feeder system results in a received signal level of −86 dBm; for test purposes, a desired signal level of −89 dBm was used as it accounted for the signal splitter loss in a typical aircraft localizer receiver installation. In tests where there was no desired signal present, the interference criterion was the flag being pulled down for a period of time exceeding 1 s. The equi-signal levels of the interfering signals were tabulated whenever an interference criterion was exceeded.

3.8.3 *Test results*

3.8.3.1 *Modulation sensitivity tests*

3.8.3.1.1 The results of the modulation sensitivity are contained in Table XI for the 2-signal case 2(106.9) − 105.3 = 108.5 MHz and in Table XII for the 3-signal case 106.1 + 105.3 − 103.3 = 108.1 MHz.

TABLE XI – *Effect of modulation on equi-signal levels for the 2-signal intermodulation product: 2(106.9) – 105.3 = 108.5 MHz*

Localizer signal status	Modulation		Measured equi-signal levels (dBm)													
	f_1 (MHz) 106.9	f_2 (MHz) 105.3	RX A	RX B	RX C	RX D	RX E	RX F	RX G	RX H	RX I	RX J	RX K	RX L 108.50	RX L 108.55	RX M
On	On-air	On-air	–27	–24	–20	–21	–23	–20	–27	–34	–29	–33	–39	–37	–34	–39
On	CCIR	CW	–26	–24	–20	–21	–23	–19	–27	–33	–28	–34	–38	–36	–34	–38
On	CW	CCIR	–27	–25	–21	–22	–24	–19	–28	–34	–28	–34	–39	–36	–32	–39
On	Pink	CW	–26	–24	–20	–21	–23	–19	–27	–33	–28	–33	–38	–36	–34	–38
On	CW	Pink	–27	–25	–21	–	–24	–19	–28	–34	–29	–34	–39	–36	–32	–39
On	Tape	CW	–28	–25	–21	–23	–23	–19	–28	–35	–29	–35	–40	–38	–34	–40
Off	On-air	On-air	–30	–34	Nil	–26	Nil	Nil	Nil	–30	Nil	–37	Nil	Nil	–39	Nil
Off	CCIR	CW	Nil	–28	Nil	–24	Nil	Nil	Nil	Nil	Nil	–22	Nil	Nil	–39	Nil
Off	CW	CCIR	Nil	–10	Nil	Nil	Nil	Nil	Nil	–	–	Nil	Nil	Nil	–36	Nil
Off	Pink	CW	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Off	CW	Pink	Nil	Nil	Nil	–	Nil	Nil	Nil	–	–	Nil	Nil	–	Nil	–
Off	Tape	CW	–27	–33	Nil	–27	Nil	Nil	Nil	Nil	Nil	–33	Nil	Nil	–38	Nil

RX: Receiver

3.8.3.1.2 In tests where there was a desired localizer signal present, the different type of modulation resulted in only a 1-2 dB change in equi-signal levels and agreed closely with those obtained when the on-air broadcast signals were used.

3.8.3.1.3 In the tests where there was no wanted signal present, the on-air signals were able to cause interference in about one-half of the receivers tested in the 2-signal case and about one-third of the receivers in the 3-signal case. It was noted that when the flag indicator dropped from view (falsely indicating the presence of a valid localizer signal), the equi-signal level was a few dB to 10 dB less than that required to cause type B1 interference when a localizer signal was present. The CCIR coloured noise modulation was not able to cause interference in the 3-signal case; however, in the 2-signal case, coloured noise modulation of f_1 (the highest FM broadcast frequency in the intermodulation product) was able to cause interference in some of the receivers, whereas similar modulation of f_2 (the other broadcasting frequency) was unable to cause interference. The pink noise modulation was unable to cause interference in tests where there was no localizer signal present.

3.8.3.1.4 As an additional test in the 2-signal case, receiver L was tuned to 108.55 MHz while the intermodulation product remained at 108.50 MHz (see Table XI). It was found that this receiver was more susceptible to interference when there was a frequency difference of 50 kHz between the intermodulation product and the tuned localizer frequency.

3.8.3.1.5 Based on these tests, CCIR coloured noise was used to modulate broadcasting frequency f_1 in the receiver intermodulation tests.

TABLE XII – *Effect of modulation on equi-signal levels for the 3-signal intermodulation product: 106.1 + 105.3 – 103.3 = 108.1 MHz*

Localizer signal status	Modulation			Measured equi-signal levels (dBm)												
	f_1 (MHz) 106.1	f_2 (MHz) 105.1	f_3 (MHz) 103.3	RX A	RX B	RX C	RX D	RX E	RX F	RX G	RX H	RX I	RX J	RX K	RX L	RX M
On	On-air	On-air	On-air	–20	–20	Nil	–20	–22	Nil	–23	–32	–23	–30	–34	–29	–36
On	CCIR	CW	CW	–20	–21	–17	–20	–22	–16	–24	–34	–25	–30	–36	–30	–36
On	CW	CCIR	CW	–20	–	–17	–20	–22	–17	–24	–32	–24	–30	–36	–30	–35
On	Pink	CW	CW	–20	–21	Nil	–20	–22	–16	–24	–32	–24	–30	–36	–30	–36
On	CW	Pink	CW	–	–	–	–20	–22	–16	–24	–32	–25	–31	–	–30	–36
On	Tape	CW	CW	–21	–21	–18	–22	–23	–17	–25	–33	–28	–32	–37	–32	–38
Off	On-air	On-air	On-air	–25	–28	Nil	–24	Nil	Nil	Nil	–	Nil	–31	Nil	Nil	Nil
Off	CCIR	CW	CW	–	Nil	Nil	Nil	Nil	Nil	Nil	–	Nil	Nil	Nil	Nil	Nil
Off	CW	CCIR	CW	Nil	–	–	Nil	Nil	Nil	Nil	–	Nil	Nil	Nil	Nil	Nil
Off	Pink	CW	CW	Nil	Nil	Nil	Nil	Nil	Nil	Nil	–	Nil	Nil	Nil	Nil	Nil
Off	CW	Pink	CW	–	–	–	Nil	Nil	Nil	Nil	–	Nil	Nil	–	–	–
Off	Tape	CW	CW	–16	–6	Nil	Nil	Nil	Nil	Nil	–	Nil	Nil	Nil	Nil	Nil

RX: Receiver

3.8.3.2 *Receiver intermodulation tests*

3.8.3.2.1 The results of the 2-signal tests are contained in Table XII and plotted in Figs. 18, 19 and 20 for localizer frequencies 108.1, 109.1 and 110.1 MHz respectively. Similarly, the results of the 3-signal tests are contained in Table XIII and plotted in Figs. 21, 22 and 23. In addition to the equi-signal level test data, theoretical levels were also calculated using the following different formulae (detailed in Annex III).

– the existing immunity formulae in the Geneva Agreement, 1984, referred to as Geneva Agreement 1984, existing immunity in Tables XIII and XIV;

– the future immunity formulae in the Geneva Agreement, 1984, referred to as Geneva Agreement, 1984-future immunity and ICAO future immunity in Tables XIII and XIV. Note that the 3-signal formula was derived in § 4;

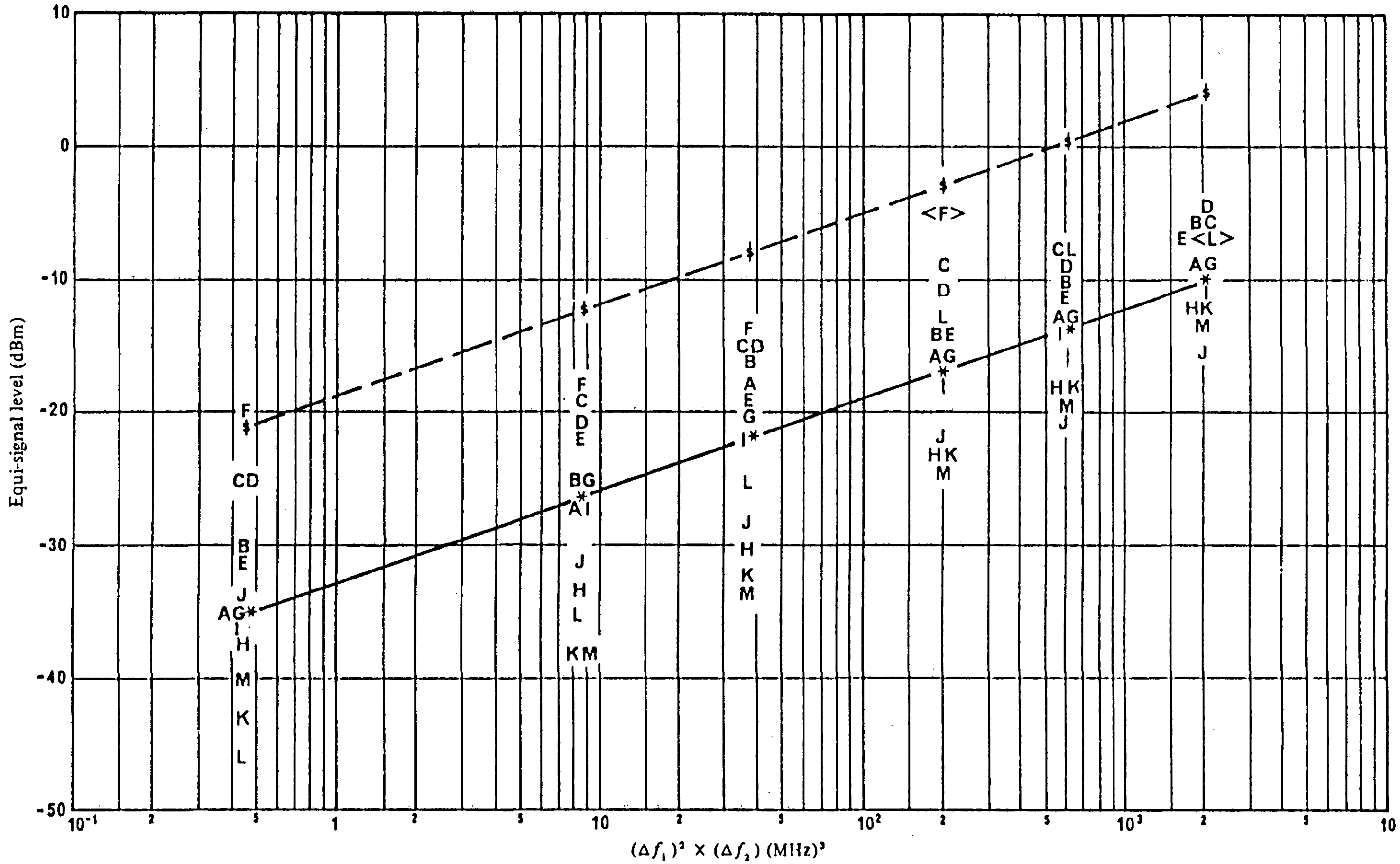

FIGURE 18 – *2-signal intermodulation on 108.1 MHz*

——— * Geneva Agreement 1984, existing immunity

— — $ } Geneva Agreement 1984, future immunity; ICAO future immunity

A-M: data points for receivers A to inclusive from Table XIII

<>: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$\Delta f_i = f_{(LOC)} - f_i$

$f_{(LOC)}$: localizer frequency (MHz)

f_i: broadcast frequency (MHz)

$f_1 > f_2$

i: 1

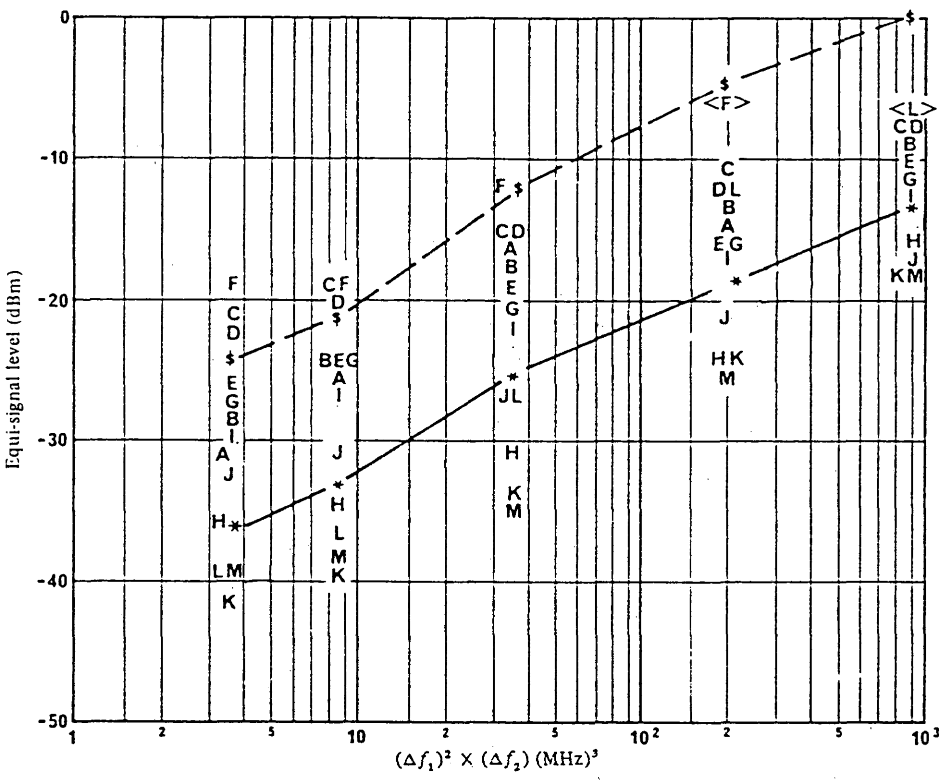

FIGURE 19 – *2-signal intermodulation on 109.1 MHz*

——— * Geneva Agreement 1984, existing immunity

— — $ Geneva Agreement 1984, future immunity; ICAO future immunity

A-M: data points for receivers A to M inclusive from Table XIII

< >: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$\Delta f_i = f_{(LOC)} - f_i$

$f_{(LOC)}$: localizer frequency (MHz)

f_i: broadcast frequency (MHz)

$f_1 > f_2$

i: 1

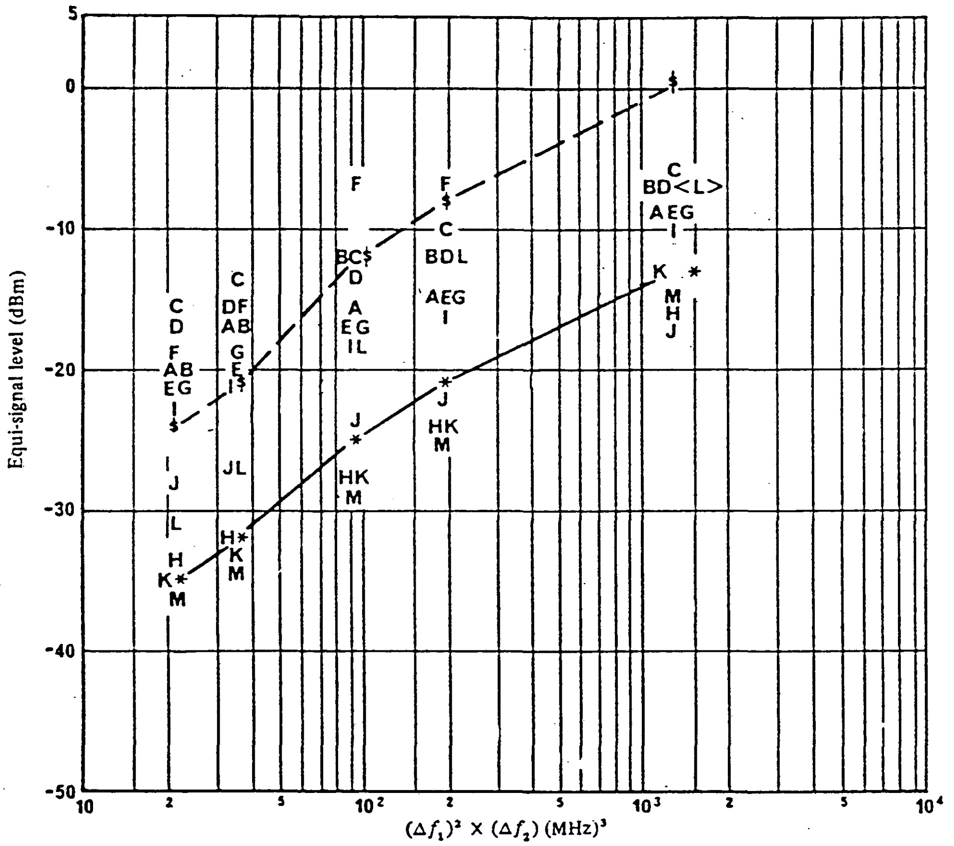

FIGURE 20 – *2-signal intermodulation on 110.1 MHz*

——— * Geneva Agreement 1984, existing immunity

— — $ Geneva Agreement 1984, future immunity; ICAO future immunity

A-M data points for receivers A to M inclusive from Table XIII

< >: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$\Delta f_i = f_{(LOC)} - f_i$

$f_{(LOC)}$: localizer frequency (MHz)

f_i: broadcast frequency (MHz)

$f_1 > f_2$

i: 1

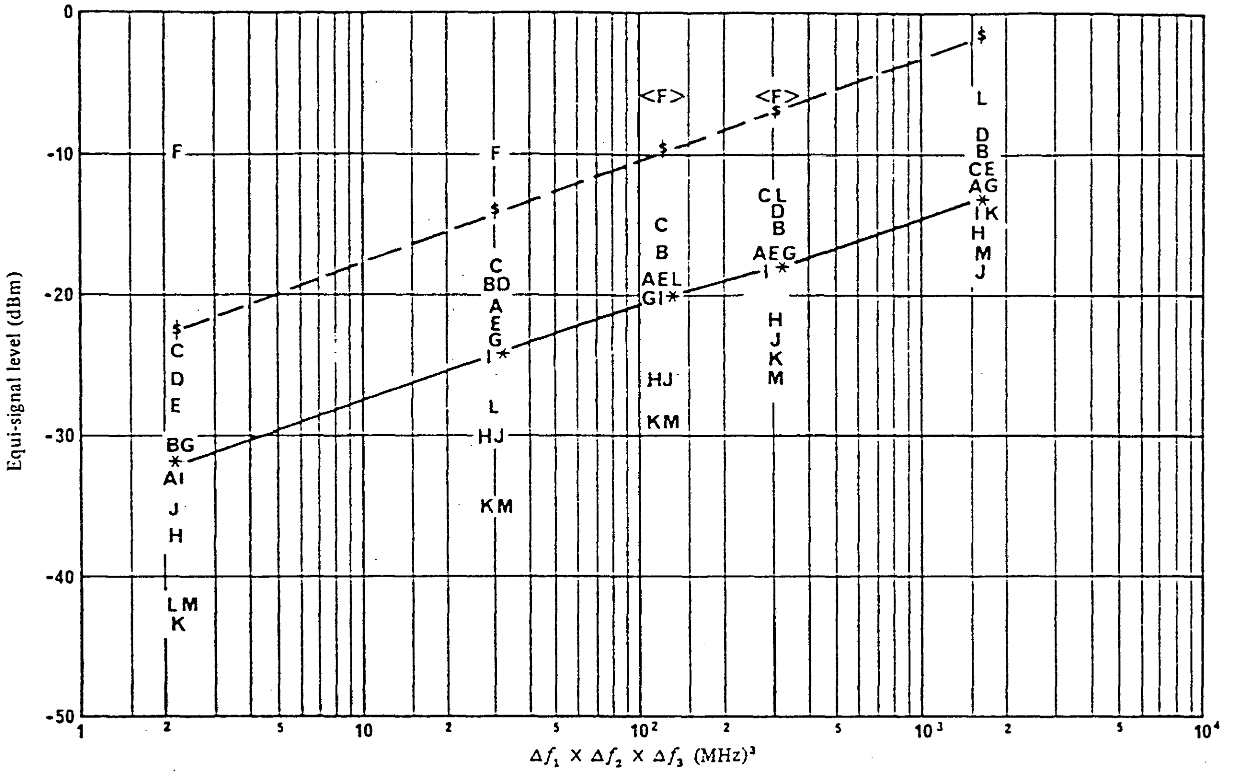

FIGURE 21 – *3-signal intermodulation on 108.1 MHz*

——— * Geneva Agreement 1984, existing immunity

— — $ Geneva Agreement 1984, future immunity; ICAO future immunity

A-M: data points for receivers A to M inclusive from Table XIV

< >: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$\Delta f_i = f_{(LOC)} - f_i$

$f_{(LOC)}$: localizer frequency (MHz)

f_i: broadcast frequency (MHz)

$f_1 > f_2 > f_3$

i: 1, 2, 3

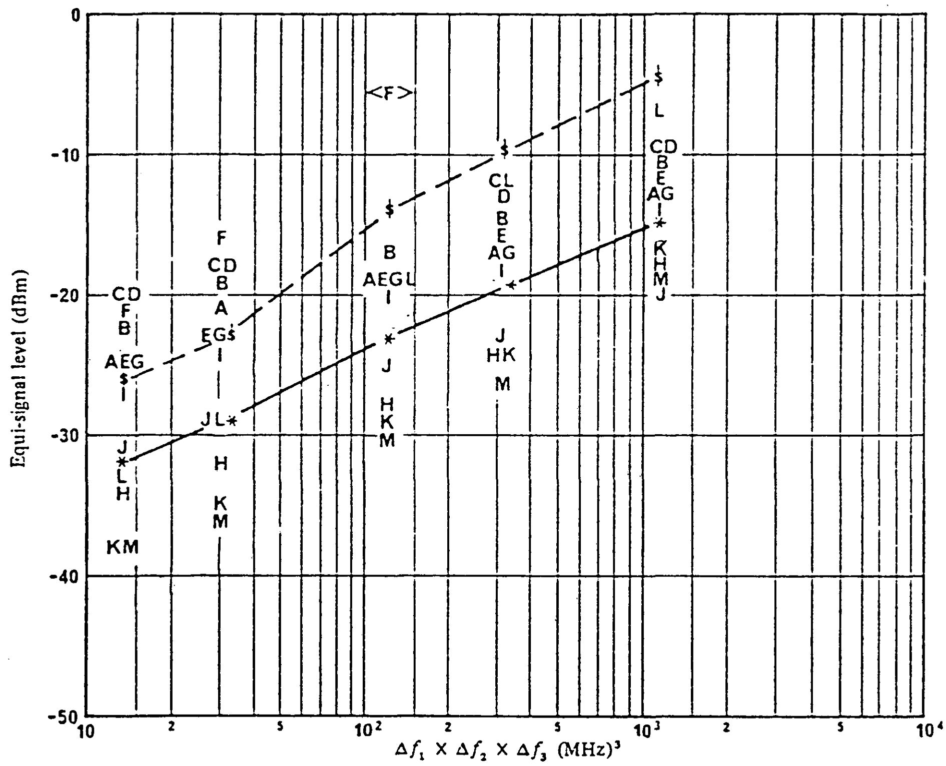

FIGURE 22 – *3-signal intermodulation on 109.1 MHz*

——— * Geneva Agreement 1984, existing immunity

— — $ Geneva Agreement 1984, future immunity; ICAO future immunity

A-M data points for receivers A to M inclusive from Table XIV

<>: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$\Delta f_i = f_{(LOC)} - f_i$

$f_{(LOC)}$: localizer frequency (MHz)

f_i: broadcast frequency (MHz)

$f_1 > f_2 > f_3$

i: 1, 2, 3

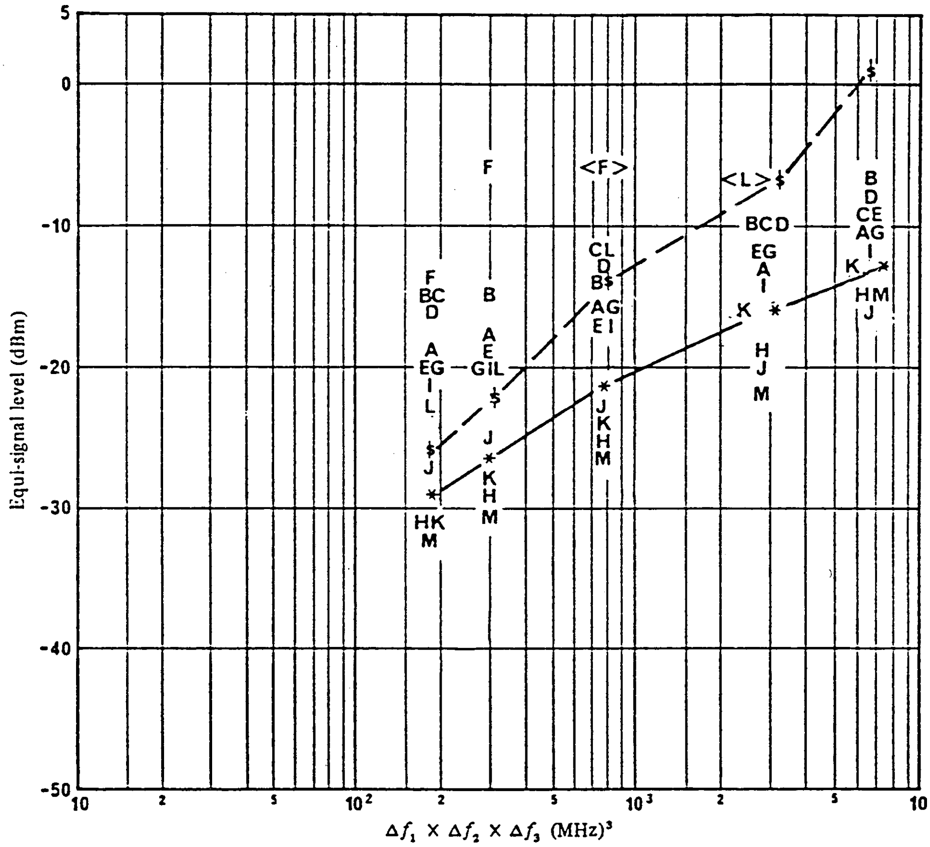

FIGURE 23– *3-signal intermodulation on 110.1 MHz*

——— * Geneva Agreement 1984, existing immunity

— — $ } Geneva Agreement 1984, future immunity; ICAO future immunity

A-M: data points for receivers A to M inclusive from Table XIV

<>: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$\Delta f_i = f_{(LOC)} - f_i$

$f_{(LOC)}$: localizer frequency (MHz)

f_i: broadcast frequency (MHz)

$f_1 > f_2 > f_3$

i: 1, 2, 3

TABLE XIII – *Measured and calculated equi-signal levels for 2-signal, third-order receiver intermodulation (type B1) interference*

Frequencies (MHz)			Measured equi-signal levels (dBm)													Calculated equi-signal (dBm)	
f_1	f_2	$f_{(LOC)}$	RX A	RX B	RX C	RX D	RX E	RX F	RX G	RX H	RX I	RX J	RX K	RX L	RX M	G.A.* existing	G.A.** ICAO future
107.5	106.9	108.1	−35	−30	−25	−25	−31	−20	−35	−37	−36	−34	−43	−46	−40	−34.5	−20.5
106.5	104.9	108.1	−27	−25	−19	−21	−22	−18	−25	−33	−27	−31	−38	−35	−38	−26.0	−12.0
105.5	102.9	108.1	−18	−16	−15	−15	−19	−14	−20	−30	−22	−28	−32	−25	−33	−21.7	−7.7
103.5	98.9	108.1	−16	−14	−9	−11	−14	> −5	−16	−23	−18	−22	−23	−13	−24	−16.8	−2.8
101.5	94.9	108.1	−13	−10	−8	−9	−11	–	−13	−18	−14	−20	−18	−8	−19	−13.6	+0.3
98.1	88.1	108.1	−9	−6	−6	−5	−7	–	−9	−12	−11	−15	−12	> −7	−13	−10.0	+4.0
107.9	106.7	109.1	−30	−28	−21	−22	−26	−19	−27	−36	−29	−32	−41	−39	−39	−36.4	−24.0
107.5	105.9	109.1	−25	−24	−19	−20	−24	−19	−24	−34	−26	−30	−39	−36	−38	−32.7	−20.5
106.5	103.9	109.1	−16	−17	−15	−15	−19	−12	−20	−30	−21	−26	−33	−26	−34	−25.2	−12.0
104.5	99.9	109.1	−14	−13	−10	−12	−15	> −6	−15	−24	−16	−21	−24	−12	−25	−18.5	−4.9
101.5	93.9	109.1	–	−9	−8	−8	−10	–	−11	−16	−12	−17	−18	> −7	−18	−13.4	+0.3
107.9	105.7	110.1	−20	−20	−16	−17	−21	−19	−21	−34	−23	−28	−35	−31	−36	−34.8	−24.0
107.5	104.9	110.1	−17	−17	−14	−16	−20	−16	−19	−32	−21	−27	−33	−27	−34	−31.6	−20.5
106.5	102.9	110.1	−16	−12	−12	−13	−17	−7	−17	−28	−18	−24	−28	−18	−29	−24.5	−12.0
105.5	100.9	110.1	−15	−12	−10	−12	−15	−7	−15	−24	−16	−22	−24	−12	−25	−20.8	−7.7
101.5	92.9	110.1	−9	−7	−6	−7	−9	–	−9	−16	−10	−17	−13	> −7	−15	−13.2	+0.3

RX: Receiver

* Geneva Agreement 1984, existing immunity

** Geneva Agreement 1984, future immunity; ICAO future immunity

TABLE XIV – *Measured and calculated equi-signal levels for 3-signal, third-order receiver intermodulation (type B1) interference*

Frequencies (MHz)				Measured equi-signal levels (dBm)													Calculated equi-signal (dBm)	
f_1	f_2	f_3	$f_{(LOC)}$	RX A	RX B	RX C	RX D	RX E	RX F	RX G	RX H	RX I	RX J	RX K	RX L	RX M	G.A.* existing	G.A.** ICAO future
107.5	106.5	105.9	108.1	−33	−31	−24	−26	−28	−10	−31	−37	−33	−35	−43	−42	−42	−31.9	−22.5
106.5	104.5	102.9	108.1	−21	−19	−18	−19	−22	−10	−23	−30	−24	−30	−35	−28	−35	−24.2	−14.0
105.5	102.5	99.9	108.1	−19	−17	−15	–	−19	> −6	−20	−26	−20	−26	−29	−19	−29	−20.2	−9.7
104.5	100.5	96.9	108.1	−17	−15	−13	−14	−17	> −6	−17	−22	−18	−23	−24	−13	−25	−17.5	−6.9
101.5	95.3	88.7	108.1	−12	−10	−11	−9	−11	–	−12	−15	−14	−18	−14	−6	−17	−12.6	−1.7
107.9	106.3	105.1	109.1	−25	−22	−20	−20	−25	−21	−25	−34	−27	−31	−38	−33	−38	−31.8	−26.0
107.5	105.5	103.9	109.1	−21	−19	−18	−18	−23	−16	−23	−32	−24	−29	−35	−29	−36	−28.6	−22.5
106.5	103.5	100.9	109.1	−19	−17	–	–	−19	> −6	−19	−28	−20	−25	−29	−19	−30	−22.5	−14.0
105.5	101.5	97.9	109.1	−17	−15	−12	−13	−16	–	−17	−24	−18	−23	−24	−12	−26	−19.1	−9.7
103.5	97.5	91.9	109.1	−13	−11	−10	−10	−12	–	−13	−18	−14	−20	−17	−7	−19	−14.7	−4.6
107.9	105.3	103.1	110.1	−19	−15	−15	−16	−20	−14	−20	−31	−21	−27	−31	−23	−32	−29.1	−26.0
107.5	104.5	101.9	110.1	−18	−15	–	–	−19	−6	−20	−29	−20	−25	−28	−20	−30	−26.5	−22.5
106.5	102.5	98.9	110.1	−16	−14	−12	−13	−17	> −6	−16	−25	−17	−23	−24	−12	−26	−21.3	−14.0
104.5	98.5	92.9	110.1	−13	−10	−10	−10	−12	–	−12	−19	−14	−20	−16	> −7	−22	−15.9	−6.9
99.5	98.7	88.1	110.1	−10	−7	−9	−8	−9	–	−10	−15	−12	−16	−13	–	−15	−12.7	+0.6

RX: Receiver

---

* Geneva Agreement 1984, existing immunity

** Geneva Agreement 1984, future immunity;
ICAO future immunity

In Figs. 18 to 23 inclusive, the parameters plotted on the horizontal axis are meaningful because the intermodulation mechanism depends on the product of frequency differences.

3.8.3.2.2 Figures 18 to 23 inclusive indicate that, based only on bench tests results, approximately one-third of the receivers tested were not protected by the Geneva Agreement 1984, existing immunity formulae.

3.8.3.2.3 None of the receivers tested met the Geneva Agreement 1984, and ICAO future immunity specification for all 2-signal intermodulation combinations at 108.1, 109.1 and 110.1 MHz; one receiver did, however, exceed the specification at 109.1 and 110.1 MHz. Some receivers exceeded the future immunity specification at 109.1 and 110.1 MHz for small differences between the localizer frequency and highest broadcasting frequency.

3.8.3.2.4 Only one receiver exceeded the possible future immunity specification for all 3-signal intermodulation combinations at 108.1, 109.1 and 110.1 MHz; some receivers exceeded the specification at 109.1 and 110.1 MHz for small differences between the localizer frequency and highest broadcast frequency.

3.8.3.3 *Effect of increased localizer signal levels*

3.8.3.3.1 Table XV shows the effect of varying the level of the localizer signal on the interfering equi-signal levels. For a 30 dB increase in localizer signal (i.e. from −90 dBm to −60 dBm), the corresponding increase in equi-signal levels was non-linear and ranged from a low of 4 dB for receiver A to a high of 23 dB for receiver M.

TABLE XV – *Effect of varying localizer signal level on interfering equi-signal levels*

Frequencies (MHz)			Measured equi-signal levels (dBm)																			
			Receiver A				Receiver I				Receiver J				Receiver L				Receiver M			
f_1	f_2	f_{LOC}	LOC signal (dBm)				LOC signal (dBm)				LOC signal (dBm)				LOC signal (dBm)				LOC signal (dBm)			
			−90	−80	−70	−60	−90	−80	−70	−60	−90	−80	−70	−60	−90	−80	−70	−60	−90	−80	−70	−60
107.5	106.9	108.1	−36	−32	−26	−23	−38	−33	−27	−18	−36	−30	−24	−17	−47	−44	−39	−32	−39	−34	−25	−16
106.5	104.9	108.1	−27	−25	−21	−19	−27	−23	−18	−13	−32	−26	−22	−16	−36	−32	−24	−19	−37	−31	−21	−14
105.5	102.9	108.1	−18	−16	−13	−14	−21	−18	−14	−10	−27	−23	−19	−14	−25	−21	−17	−14	−31	−27	−18	−11
103.5	98.9	108.1	−16	−12	−9	−6	−16	−13	−9	−6	−22	−18	−16	−12	−12	−9	−7	–	−22	−20	−12	−7
101.5	94.9	108.1	−13	−9	−6	–	−13	−10	−7	–	−20	−15	−14	−10	−8	> −6	–	–	−17	−15	−8	–
107.9	105.7	110.1	−23	−19	−15	−10													−36	−30	−21	−14
107.5	104.9	110.1	−21	−18	−13	−9													−34	−28	−19	−12
106.5	102.9	110.1	−18	−15	−11	−7													−28	−24	−15	−10
105.5	100.9	110.1	−15	−12	−9	> −7													−24	−21	−12	−8

3.8.3.4 *Effect of unequal interfering signal levels*

3.8.3.4.1 Three receivers were tested to determine if equations of the form $2N_1 - N_2 = K$ (2-signal type B1) hold for unwanted signal levels N_1 and N_2 which differ from each other. Referring to Tables XVI and XVII, it is seen that the range of signal levels for which the equation is valid varies from +7 dBm to −80 dBm. The difference between signal levels for a given intermodulation product was as great as 62 dB for the 2-signal case and 87 dB for the 3-signal case. The limiting condition is the generation of type B2 desensitization when one of the signals is too large.

TABLE XVI – *2-signal type B1 effects with unequal signal levels*
(Illustrating the wide range of signal levels for which the type B1 equation holds)

2-signal $2[f_{(1)}] - f_{(2)} = f_{(ILS)}$ $f_{(ILS)}$ = 108.7 MHz		
Interfering signal level (dBm)		$2(N_1) + N_2$ (dBm)
N_1 (f_1)	N_2 (f_2)	
−50 −20	− 7 −68	−107 −108
−10 −40	−71 − 9	−91 −89
−30 0	+ 1 −62	−59 −62
−20 0 10	+ 5 −38 −60	−35 −38 −40
−10 0 +10	+ 2 −17 −38	−18 −17 −18

Note. – Five different frequency combinations for $f_{(1)}$ and $f_{(2)}$ were used yielding five different summations.

TABLE XVII – *3-signal type B1 effects with unequal signal levels*
(Illustrating the wide range of signal levels for which the type B1 equation holds)

3-signal $f_{(1)} + f_{(2)} - f_{(3)} = f_{(ILS)}$ $f_{(ILS)}$ = 109.3 MHz			
Interfering signal level (dBm)			$N_1 + N_2 + N_3$ (dBm)
N_1 (f_1)	N_2 (f_2)	N_3 (f_3)	
+ 1 −40	−40 + 1	+1 +1	−38 −38
−70 −80 −60	+2 +7 −1	+2 +7 −1	−66 −66 −62

Note. – Two different sets of frequencies $f_{(1)}$, $f_{(2)}$ and $f_{(3)}$ are represented.

Part 4 of Annex I,

United States

THE EFFECT OF FM STEREO PLUS SUBCARRIER MODULATING SIGNALS ON PROTECTION CRITERIA

Type A2 Interference
Type B2 Interference

4.1 Introduction

In North America the baseband of the modulating signal can extend to 99 kHz and include sub-carrier signals that are added to the regular stereo multiplex signal; in addition, the audio processing equipment normally used at FM broadcasting stations alters significantly the stereo multiplex signal in a manner that renders the CCIR coloured noise modulating signal no longer representative.

4.2 Test Method

Protection ratio measurements were taken for the ILS section of receivers when the interfering FM broadcast signal was:

- unmodulated
- modulated by the CCIR coloured noise signal
- modulated by a synthetic program noise signal
- modulated by the CCIR coloured noise and subcarrier signals.
- modulated by the synthetic program noise and subcarrier signals.

The CCIR noise modulation was generated and set up in accordance with the procedures of Recommendation 559 and Report 796.

The synthetic program noise signal (SPN) was developed by the National Public Radio for subcarrier tests in FM broadcasting(1). Pink noise is filtered by a 50 Hz high pass and a 15 kHz low pass filters and limited by a special clipper circuit. The noise clipping simulates the peak-to-average or density characteristics of typical audio processors. The resulting signal has a spectrum typical of processed FM program signals in North America.

The subcarrier signals were single unmodulated subcarriers, pairs of unmodulated subcarriers and data modulated subcarriers. The tests were conducted on 3 ILS frequencies near the lower limit of the frequency band using the following receivers:

CESSNA	RT385A
COLLINS	51RV-1A
COLLINS	VIR351
KING	KX175B
NARCO	NAV121

The level of the desired signal was set to -89 dBm at the input port of the ILS section of the NAVCOM receiver. The interference criteria was a change of 7.5 microamp in cross-pointer current for a localizer signal with a difference in depth of modulation (DDM) of 0.093. The three upper channel frequencies of the FM band were used for the undesired FM broadcast signal. The level of the FM signal was set at a minimum and then increased until interference was produced in the receiver under test. The CCIR coloured noise modulating signal set up in accordance with CCIR standards results in, after pre-emphasis, a peak FM carrier deviation of 100% (75 kHz). When subcarriers were added to the modulating signal, the total carrier peak deviation was obtained by adding the subcarrier deviation to the adjusted deviation from the stereo signal.

4.3 Results and Analysis

4.3.1 Type A2 Interference

The test results given in Table XVIII are for a carrier separation of 200 kHz where the FM frequency is 107.9 MHz

With the SPN plus sub-carriers as the modulating signal, additional protection of an average of 5dB for four of the receivers tested and of 10dB for the remaining receiver, is required. Data for CCIR coloured noise plus sub-carriers indicates that the protection ratios did not exceed the existing criteria (i.e., the SPN plus sub-carrier signals yielded the most stringent protection criteria).

From the tests, for frequency differences between the wanted signal and the broadcast signal of more than 300 kHz, the B2 type immunity criteria becomes the dominating interference mechanism.

4.3.2 Type B2 Interference

Existing Type B2 immunity criteria are contained in Table 7.4. of the Geneva Agreement, 1984. The measurements were taken with carrier separations of 400 kHz or greater and with the ILS frequencies 108.1, 108.3 and 108.5 MHz paired with the FM frequencies 107.9, 107.7 and 107.5 MHz. The different modulating signals described for the Type A2 tests were also used. The test results are given in Table XIX.

These results indicate that for carrier separations of 400 kHz or greater and with the FM broadcast station operating on frequencies of 107.7 MHz or below, the addition of the subcarrier signal to the modulating signal has no effect on the existing B2 immunity criteria. Two types of receivers did not follow this general trend for separations of 800 kHz and this may be an indication of a spurious response in the receivers. This needs further study.

The results also indicate that for carrier séparations of 400 kHz or greater and with an FM broadcast modulated carrier at 107.9 MHz, one receiver out of five overloaded at an undesired signal level lower than the existing criterion while the other four overloaded at higher levels.

References

(1) National Association of Broadcasters, Westinghouse Broadcasting Cable Inc., National Public Radio, (August 30, 1983) Increased FM Deviation, Additional Subcarriers and FM Broadcasting.

	MODULATING SIGNAL																	
	CCIR	SPN	CCIR + 67 kHz	SPN + 67 kHz	CCIR + 83 kHz	SPN + 83 kHz	CCIR + 92 kHz	SPN + 92 kHz	CCIR + Data SC	SPN + Data SC	CCIR + 67/83 kHz	SPN + 67/83 kHz	CCIR + 67/92 kHz	SPN + 67/92 kHz	CCIR + 67/83 kHz	SPN + 67/83 kHz	CCIR + 67/92 kHz	SPN + 67/92 kHz
Total Dev. %	100		105		105		105		105		105		105		110		110	
Receivers																		
Rx 1	-64	-49	-56	-45	-51	-43	-49	-40	-57	-46	-58	-45	-55	-43	-50	-42	-48	-41
Rx 2	-71	-57	-64	-51	-57	-48	-54	-46	-64	-53	-64	-53	-61	-51	-56	-44	-53	-44
Rx 3	-72	-55	-63	-50	-56	-49	-52	-47	-64	-54	-62	-52	-60	-50	-55	-45	-52	-45
Rx 4	-56	-53	-56	-49	-53	-49	-50	-47	-56	-51	-56	-51	-55	-50	-52	-45	-50	-44
Rx 5	-70	-57	-63	-52	-56	-51	-53	-48	-63	-55	-62	-53	-61	-52	-56	-46	-52	-45
Desired signal: -89 dBm at 108.1 MHz Undesired signal at 107.9 MHz																		
Geneva Agreement 1984 A2 Protection criteria for Δf ≥ 200 kHz is -50 dB																		

Table XVIII – Effect of FM Subcarrier Systems on Protection Ratios for Type A2 Interference

Carrier Separation	Modulating Signal	Total Deviation %	Maximum Level (dBm) at receiver input					
			1	2	3	4	5	Geneva Agreement 1984
400 kHz (108.3-107.9)MHz	None	0	-5	-10	-6.5	-7.5	-11	-20
	CCIR	100	-25	-10	-5	-8	-11	
	CCIR + SC 10%	105	-25	-10	-5	-9	-11	
	CCIR + SC 20%	110	-25	-10	-6	-9	-11	
	SPN	100	-28	-15	-8	-9	-11	
	SPN + SC 10%	105	-28	-15	-8	-9	-11	
	SPN + Sc 20%	110	-29	-14	-8	-9	-11	
400 kHz (108.1-107.7)MHz	None	0	-4	-15	-7	-8	-11	-18.4
	CCIR	100	-13	-13	-9	-8	-13	
	CCIR + SC 10%	105	-13	-13	-9	-8	-13	
	CCIR + SC 20%	110	-13	-13	-9	-8	-13	
	SPN	100	-16	-10	-8	-9	-10	
	SPN + SC 10%	105	-16	-10	-8	-9	-10	
	SPN + SC 20%	110	-16	-10	-8	-9	-10	
600 kHz (108.5-107.9)MHz	None	0	-12	-7	-4	-6	-8	-20
	CCIR	100	-30	-6	-4	-8	-8	
	CCIR + SC 10%	105	-30	-6	-4	-8	-8	
	CCIR + SC 20%	110	-30	-6	-4	-9	-8	
	SPN	100	-31	-8	-6	-9	-12	
	SPN + SC 10%	105	-31	-8	-6	-9	-12	
	SPN + SC 20%	110	-31	-8	-6	-9	-13	
600 kHz (108.3-107.7)MHz	None	0	-0.5	-7	-3.5	-6.5	-7.5	-18.4
	CCIR	100	0	-6	-6	-10	-9	
	CCIR + SC 10%	105	0	-6	-6	-10	-9	
	CCIR + SC 20%	110	0	-6	-6	-10	-9	
	SPN	100	-3	-8	-4	-8	-14	
	SPN + SC 10%	105	-3	-8	-4	-8	-14	
	SPN + SC 20%	110	-3	-8	-4	-8	-14	
600 kHz (108.1-107.5)MHz	None	0	-8.5	-6	-2.5	-6.5	-8.5	-16.8
	CCIR	0	0	-6	-6	-8	-13	
	CCIR + SC 10%	105	0	-6	-5	-8	-13	
	CCIR + SC 20%	110	0	-6	-5	-8	-13	
	SPN	100	-6	-6	-7	-8	-16	
	SPN + SC 10%	105	-6	-6	-7	-8	-16	
	SPN + Sc 20%	110	-6	-6	-7	-8	-16	
800 kHz (108.5-107.7)MHz	None	0	-15.5	-6	-1	-6	-4.5	-18.4
	CCIR	100	-16	-5	-13	-22	-9	
	CCIR + SC 10%	105	-16	-5	-13	-22	-9	
	CCIR + SC 20%	110	-16	-5	-14	-23	-12	
	SPN	100	-15	-7	-13	-22	-21	
	SPN + SC 10%	105	-15	-7	-13	-22	-21	
	SPN + SC 20%	110	-15	-7	-13	-22	-21	
800 kHz (108.3-107.5)MHz	None	0	+2.5	-5	-2.5	-26	-4	-16.8
	CCIR	100	+3	-4	-17	-24	-19	
	CCIR + SC 10%	105	+3	-4	-17	-24	-19	
	CCIR + SC 20%	110	+3	-4	-17	-24	-19	
	SPN	100	+1	-6	-17	-23	-21	
	SPN + SC 10%	105	+1	-6	-17	-23	-21	
	SPN + SC 20%	110	+1	-6	-17	-23	-21	
1000 kHz (108.5-107.5)MHz	None	0	+3.5	-3	-0.5	-5	-3	-16.8
	CCIR	100	+4	-3	-3	-8	-7	
	CCIR + SC 10%	105	+4	-3	-3	-8	-7	
	CCIR + SC 20%	110	+4	-3	-3	-8	-7	
	SPN	100	+3	-3	-2	-6	-4	
	SPN + SC 10%	105	+3	-3	-1	-6	-4	
	SPN + SC 20%	110	+3	-3	-1	-6	-4	

Desired Signal: -89 dBm

Table XIX-Effect of FM Subcarrier Signals on Type B2 Interference Immunity

Part 5 of Annex I

United States

TEST DATA EXHIBITING THE EFFECT OF AN EXPERIMENTAL FILTER*

5.1 This filter weighs 2.2 kg, is 2.9 cm in diameter, and is 30 cm long. Electrically it is chebishev (equal ripple) with maximum ripple of 0.3 dB in the 2 dB bandwidth when the 50 ohm input and output are matched. The 2 dB bandwidth is 108.1 MHz to 132.3 MHz with a centre frequency insertion loss of 0.8 dB. The filter characteristics are shown in Figures 24 and 25 and the measured data are presented in Tables XX to XXV.

Frequencies (MHz) Undesired		Desired	Bare Receiver, Equal Undesired Signal Levels (dBm) A	B	C	D	E	F	G	H	J	K
107.5	106.9	108.1	-39	-37	-30	-32	-35	-39	-39	-41	-39	-34
106.5	104.9	108.1	-31	-37	-28	-27	-32	-32	-27	-36	-33	-27
105.5	102.9	108.1	-23	-30	-24	-21	-29	-24	-18	-28	-25	-17
103.5	98.9	108.1	-13	-22	-13	-15	-21	-17	-10	-16	-20	-15
101.5	94.9	108.1	-10	-16	-10	-12	-16	-13	-8	-13	-20	-12
107.9	106.7	109.1	-35	-37	-31	-29	-34	-36	-33	-36	-36	-31
107.5	105.9	109.1	-34	-35	-29	-26	-35	-32	-28	-36	-33	-26
106.5	103.9	109.1	-24	-26	-24	-22	-32	-24	-18	-29	-23	-17
104.5	99.9	109.1	-15	-21	-13	-15	-22	-18	-10	-16	-19	-15
101.5	93.9	109.1	-10	-13	-8	-10	-16	-12	-6	-11	-18	-11
107.9	105.7	110.1	-26	-28	-27	-23	-34	-28	-23	-33	-28	-20
107.5	104.9	110.1	-24	-24	-25	-21	-32	-25	-20	-30	-23	-18
106.5	102.9	110.1	-19	-23	-19	-17	-28	-20	-13	-24	-22	-16
105.5	100.9	110.1	-15	-22	-15	-15	-23	-17	-9	-17	-19	-15
101.5	92.9	110.1	-9	-10	-6	-9	-13	-10	-6	-10	-18	-10

TABLE XX – Undesired equal signal levels necessary to produce a 7.5 uA deviation from a standard ILS localizer deflection of 90 uA. This table is for the bare receiver and two signal intermodulation interference.

Frequencies (MHz) Undesired			Desired	Bare Receiver, Equal Undesired Signal Levels (dBm) A	B	C	D	E	F	G	H	J	K
107.5	106.5	105.9	108.1	-37	-41	-32	-33	-36	-38	-34	-41	-39	-34
106.5	104.5	102.9	108.1	-25	-32	-26	-24	-31	-27	-20	-30	-26	-21
105.5	102.5	99.9	108.1	-20	-25	-12	-19	-26	-22	-14	-21	-26	-19
104.5	100.5	96.9	108.1	-17	-21	-15	-17	-22	-19	-12	-17	-23	-17
101.5	95.3	88.7	108.1	-10	-15	-11	-11	-12	-13	-8	-10	-15	-12
107.9	106.3	105.1	109.1	-29	-34	-30	-27	-35	-31	-25	-35	-30	-25
107.5	105.5	103.9	109.1	-27	-29	-27	-24	-34	-26	-21	-31	-25	-21
106.5	103.5	100.9	109.1	-21	-23	-19	-19	-28	-22	-13	-21	-24	-19
105.5	101.5	97.9	109.1	-17	-21	-14	-16	-23	-18	-12	-17	-21	-17
103.5	97.5	91.9	109.1	-12	-16	-12	-12	-17	-14	-9	-12	-18	-13
107.9	105.3	103.1	110.1	-22	-24	-23	-20	-30	-23	-16	-26	-25	-20
107.5	104.5	101.9	110.1	-21	-23	-20	-19	-28	-21	-14	-22	-23	-19
106.5	102.5	98.9	110.1	-18	-20	-12	-15	-23	-18	-10	-17	-22	-17
104.5	98.5	92.9	110.1	-12	-15	-11	-12	-17	-14	-8	-11	-20	-13
99.5	98.7	88.1	110.1	-9	-11	-9	-10	-14	-11	-6	-15	-16	-11

TABLE XXI – Undesired equal signal levels necessary to produce a 7.5 uA deviation from a standard ILS localizer deflection of 90 uA. This table is for the bare receiver and three signal intermodulation interference.

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* (See § 6.2 of report)

Frequencies (MHz)			Receiver with Filter, Equal Undesired Signal Levels (dBm)									
Undesired		Desired	A	B	C	D	E	F	G	H	J	K
107.5	106.9	108.1	-35	-31	-22	-28	-31	-34	-34	-37	-38	-31
106.5	104.9	108.1	-20	-23	-14	-15	-22	-20	-12	-23	-25	-15
105.5	102.9	108.1	-3	-6	-2	-2	-11	-5	>0	-6	-8	>0
103.5	98.9	108.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
101.5	94.9	108.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
107.9	106.7	109.1	-31	-32	-25	-24	-30	-31	-28	-33	-34	-27
107.5	105.9	109.1	-27	-28	-20	-19	-27	-24	-20	-29	-28	-20
106.5	103.9	109.1	-9	-8	-12	-9	-20	-11	-2	-11	-16	0
104.5	99.9	109.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
101.5	93.9	109.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
107.9	105.7	110.1	-20	-20	-20	-17	-28	-21	-16	-29	-21	-15
107.5	104.9	110.1	-15	-11	-16	-13	-25	-16	-9	-20	-16	-9
106.5	102.9	110.1	-1	-4	-1	>0	-11	-4	>0	>0	-14	>0
105.5	100.9	110.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
101.5	92.9	110.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0

TABLE XXII– Equal undesired signal levels necessary to produce a 7.5 uA deviation from a standard ILS localizer deflection of 90 uA. This table is for the receiver with an aviation bandpass filter (108 to 132 MHz BP) and two signal intermodulation interference.

Frequencies (MHz)				Receiver with Filter, Equal Undesired Signal Levels (dBm)									
Undesired			Desired	A	B	C	D	E	F	G	H	J	K
107.5	106.5	105.9	108.1	-29	-30	-22	-23	-28	-30	-24	-31	-36	-25
106.5	104.5	102.9	108.1	-6	-11	-5	-7	-15	-11	0	-6	-11	-4
105.5	102.5	99.9	108.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
104.5	100.5	96.9	108.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
101.5	95.3	88.7	108.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
107.9	106.3	105.1	109.1	-20	-23	-17	-18	-25	-24	-14	-25	-19	-14
107.5	105.5	103.9	109.1	-14	-17	-13	-13	-23	-13	-9	-15	-15	-7
106.5	103.5	100.9	109.1	>0	0	>0	>0	-1	>0	>0	>0	>0	>0
105.5	101.5	97.9	109.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
103.5	97.5	91.9	109.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
107.9	105.3	103.1	110.1	-7	-10	-5	-7	-15	-9	-9	-15	-11	-4
107.5	104.5	101.9	110.1	0	-4	0	-2	-8	-3	-1	>0	-3	-1
106.5	102.5	98.9	110.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
104.5	98.5	92.9	110.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
99.5	98.7	88.1	110.1	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0

TABLE XXIII–Equal undesired signal levels necessary to produce a 7.5 uA deviation from a standard ILS localizer deflection of 90 uA. This table is for the receiver with an aviation bandpass filter (108 to 132 MHz BP) and three signal intermodulation interference.

Frequencies (MHz) Undesired		Desired	Receiver Input Conditions Bare	Filter	Diff.
107.5	106.9	108.1	-36.5	-32.1	4.4
106.5	104.9	108.1	-31.0	-18.9	12.1
105.5	102.9	108.1	-23.9	-5.4	18.5
103.5	98.9	108.1	-16.2	>0.0	>16.2
101.5	94.9	108.1	-13.0	>0.0	>13.0
107.9	106.7	109.1	-33.8	-29.5	4.3
107.5	105.9	109.1	-31.4	-24.2	7.2
106.5	103.9	109.1	-23.9	-10.9	13.0
104.5	99.9	109.1	-16.4	>0.0	>16.4
101.5	93.9	109.1	-11.5	>0.0	>11.5
107.9	105.7	110.1	-27.0	-20.7	6.3
107.5	104.9	110.1	-24.2	-15.0	9.2
106.5	102.9	110.1	-20.1	-6.8	13.3
105.5	100.9	110.1	-16.7	>0.0	>16.7
101.5	92.9	110.1	-10.1	>0.0	>10.1

TABLE XXIV – Average level of the undesired equal signals necessary to produce a 7.5 uA deviation from a standard ILS localizer 90 uA deflection. This table is for the two signal intermodulation cases and shows the results for different receiver input conditions. Column four is for the bare receiver, column five is for a bandpass filter (108 to 132 MHz BP) in series with the receiver and column six is the difference between the filtered receiver and the bare receiver.

Frequencies (MHz) Undesired			Desired	Receiver Input Conditions Bare	Filter	Diff.
107.5	106.5	105.9	108.1	-36.5	-27.8	8.7
106.5	104.5	102.9	108.1	-26.2	-8.4	17.8
105.5	102.5	99.9	108.1	-20.4	>0.0	>20.4
104.5	100.5	96.9	108.1	-18.0	>0.0	>18.0
101.5	95.3	88.7	108.1	-11.7	>0.0	>11.7
107.9	106.3	105.1	109.1	-30.1	-19.9	10.2
107.5	105.5	103.9	109.1	-26.5	-13.9	12.6
106.5	103.5	100.9	109.1	-20.9	>0.0	>20.9
105.5	101.5	97.9	109.1	-17.6	>0.0	>17.6
103.5	97.5	91.9	109.1	-13.5	>0.0	>13.5
107.9	105.3	103.1	110.1	-22.9	-9.2	13.7
107.5	104.5	101.9	110.1	-21.0	-3.1	17.9
106.5	102.5	98.9	110.1	-17.2	>0.0	>17.2
104.5	98.5	92.9	110.1	-13.3	>0.0	>13.3
99.5	98.7	88.1	110.1	-11.2	>0.0	>11.2

TABLE XXV – Average level of the undesired equal signals necessary to produce a 7.5 uA deviation from a standard ILS localizer 90 uA deflection. This table is for the three signal intermodulation cases and shows the results for different receiver input conditions. Column five is for the bare receiver, column six is for a bandpass filter (108 to 132 MHz BP) in series with the receiver and column seven is the difference between the filtered receiver and the bare receiver.

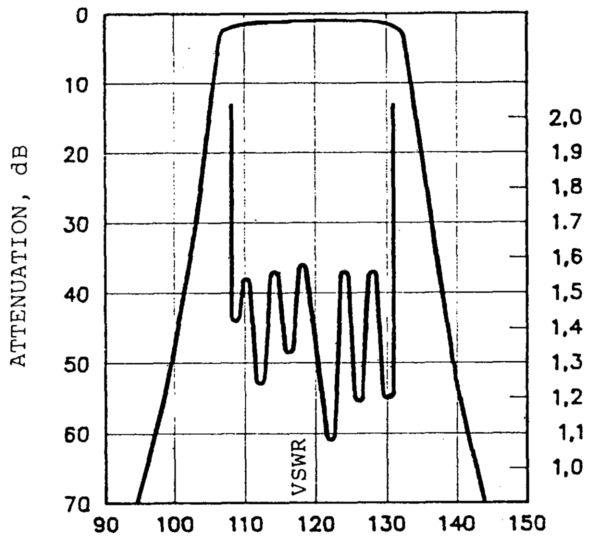


FIGURE 24- Smoothed frequency response and VSWR curve of a custom designed tubular filter

5.2 Experimental data taken to measure frequency response characteristics of a typical, fixed tuned, tubular bandpass filter as a function of temperature variation, is presented in Figure 25.

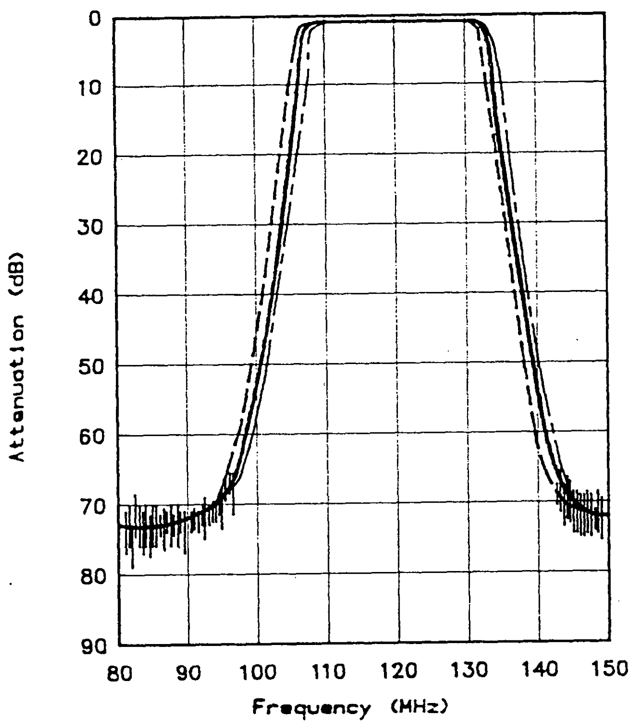


Figure 25– Unsmoothed frequency responses showing temperature variation

- - - - 20 degrees Celsius characteristic
——— + 24 degrees Celsius characteristic
— — — + 50 degrees Celsius characteristic

5.3 Modified ILS/VOR/COM receiver

A solid state ILS/VOR/COM receiver was modified in design by the company which produced them, to help eliminate FM broadcast interference. The modification, initiated several years ago, consisted of adding a series-tuned L-C circuit notch filter inside the VHF communications section of the receiver chassis, at the point of the coaxial connection from the antenna.

The filter circuit is comprised of a single inductor (L = 0.1 uH) connected in series with a single capacitor (C = 22 pF) which is in turn, grounded. The resonant frequency of this combination is 107.302 MHz with L and C values specified (see Figure 26). Usual production tolerance of capacitors (5%) and inductors (10%) could result in a worst case resonant frequency somewhere between 100 and 116 MHz. However, the components are carefully chosen to avoid significantly impacting receiver sensitivity in the VHF communications band. A circuit quality factor of Q = 40 (a reasonably well manufactured inductor) as used by the manufacturer, gives a 3 dB bandwidth of the filter circuit of slightly more than 2.6 MHz.

SERIES L-C NOTCH FILTER FREQUENCY RESPONSE AT THE ANTENNA INPUT TO THE VHF COMMUNICATIONS SECTION OF THE ILS/VOR/COM RECEIVER (SEE NOTE)

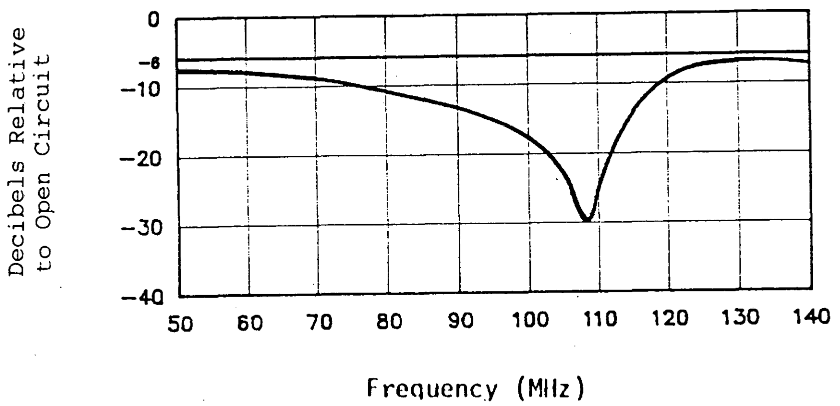


Figure 26

Note: With the filter installed and matched, the insertion (sensitivity) loss is relative to the -6 dB level (net reactance absorbed). For example, filter insertion loss at 126 MHz is about 1 dB.

Part 6 of Annex I

United States

THE OVERLOAD CHARACTERISTICS OF AERONAUTICAL ILS NAVIGATION RECEIVERS

6.1 Ten aeronautical localizer receivers were tested to determine their susceptibility to overload (desensitization) caused by strong signals in the FM broadcast band. The tests were conducted to show the effects of both modulated and CW signals on each receiver's performance.

6.2 The data collected for this project are presented in Tables XXVI and XXVII. The values shown for each receiver are the absolute levels in dBm necessary to produce a 7.5 uA deviation from a standard ILS localizer deflection of 90 uA. The localizer frequency was 108.1 MHz and its level was -89 dBm for all tests. Receiver A was not tested under conditions indicated by *** because it was returned to the manufacturer before the test plan was finalized. A value of >0 indicates that the interference criteria of 7.5 uA could not be met for a particular receiver when the undesired signal was equal to 0 dBm, the limit of the test setup.

Undesired Frequency (MHz)	Undesired CW Signal Levels (dBm)									
	Receivers Tested									
	A	B	C	D	E	F	G	H	J	L
108.099	-94	-99	-100	-100	-99	-98	-99	-99	-98	-98
108.097	-97	-97	-97	-99	-99	-98	-98	-100	-96	-97
108.094	-96	-97	-97	-99	-100	-98	-98	-101	-97	-97
108.090	-97	-96	-98	-100	-100	-98	-98	-101	-97	-97
108.085	-96	-97	-98	-100	-97	-98	-97	-100	-97	-98
108.080	-96	-96	-97	-95	-88	-84	-88	-85	-95	-97
108.070	-54	-72	-67	-78	-56	-45	-46	-45	-48	-71
108.060	-33	-49	-43	-59	-36	-31	-28	-28	-25	-49
108.050	-35	-31	-28	-43	-34	-30	-23	-28	-28	-38
108.040	-19	-22	-25	-31	-31	-24	-18	-25	-20	-31
108.030	-15	-20	-19	-22	-21	-20	-18	-18	-23	-28
108.020	-16	-19	-18	-16	-16	-18	-18	-15	-25	-25
108.010	-13	-21	-16	-14	-15	-19	-16	-15	-26	-23
108.000	-19	-26	-16	-15	-13	-19	-15	-15	-26	-24
107.950	-6	-15	-11	-10	-11	-18	-10	-11	-24	-18
107.900	-5	-13	-9	-9	-9	-16	-10	-21	-18	-15
107.850	***	-14	-11	-7	-7	-15	-10	-8	-22	-13
107.800	***	-13	-11	-5	-7	-12	-9	-7	-22	-11
107.700	-5	-13	-9	-7	-4	-9	-9	-4	-16	-13
107.600	***	-13	-14	-3	-4	-11	-9	-7	-18	-9
107.500	-5	-13	-12	-9	-3	-4	-8	-7	-18	-8
107.300	***	-14	-8	-1	>0	-5	-9	-12	-10	-6
107.100	-7	-14	-5	-1	-1	-3	-8	-6	-4	-7
106.100	-6	-16	-3	>0	>0	-8	-10	-3	-2	-2
104.100	>0	-5	>0	>0	>0	>0	>0	>0	>0	>0
102.100	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
98.100	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0

TABLE XXVI - Undesired CW signal level, at the receiver antenna terminal, necessary to produce a 7.5 uA deviation from a standard ILS localizer deflection of 90 uA. The localizer frequency was 108.1 MHz.

*** Not Tested

Undesired Frequency (MHz)	Undesired Modulated Signal Levels (dBm)									
	Receivers Tested									
	A	B	C	D	E	F	G	H	J	L
108.000	***	-51	-53	-52	-48	-49	-51	-52	-52	-53
107.950	***	-20	-21	-19	-18	-20	-21	-21	-22	-23
107.900	***	-15	-11	-9	-8	-16	-11	-22	-17	-14
107.850	***	-14	-10	-8	-6	-16	-10	-28	-23	-12
107.800	***	-14	-11	-6	-6	-20	-12	-6	-23	-11
107.700	***	-14	-11	-7	-6	-15	-10	-4	-17	-10
107.600	***	-15	-15	-4	-4	-8	-9	-6	-17	-11
107.300	***	-14	-9	-4	-4	-6	-9	-17	-20	-6

TABLE XXVII-Undesired modulated signal level, at the receiver antenna terminal, necessary to produce a 7.5 uA deviation from a standard ILS localizer deflection of 90 uA. The localizer frequency was 108.1 MHz.

*** Not Tested

Part 7 of Annex I

France

COMPATIBILITY BETWEEN THE AERONAUTICAL MOBILE (R) SERVICE (118 - 137 MHz) AND THE FM BROADCASTING SERVICE

7.1 Introduction

The criteria for compatibility between the aeronautical mobile (R) service and the FM broadcasting service used up to now have not been validated by laboratory tests and were more or less derived from navigation receiver test results.

The first tests conducted by one country show some interesting results in the response of COM receivers to A1 and B1 type interference.

7.2 Immunity characteristics of two COM aircraft receivers to A1 type interference

Using the two interference criteria in §§ 3.2 and 4.1.3 of this report. the different threshold listed in Table XXVIII below were found.

TABLE XXVIII

	RECEIVER 1			RECEIVER 2		
ΔF	N1	N2	R1	N1	N2	R1
0	-96	-115	10	- 97	- 115	11
50	-91	-110	5	- 91	- 108	5
100	-79	-100	- 7	- 70	- 93	- 16
.150	-56	- 83	- 30	- 53	- 78	- 33
200	-50	- 77	- 36	- 47	- 71	- 39
250	-44	- 71	- 42	- 43	- 69	- 43
300	-40	- 71	- 46	- 36	- 65	- 50
350	-37	- 73	- 49		- 64	
400	-35	- 71	- 51	- 29	- 59	- 57
500	-29	- 57	- 57	- 25	- 52	- 61
600				- 29	- 45	- 57
700				- 21	- 43	- 65
1000		- 45		- 19	- 37	- 67

The first criterion relates to tests carried out with the wanted signal of -86dBm.

The second criterion relates to tests carried out without a wanted signal.

For the interference in the presence of the wanted signal on 118.25 MHz of -86dBm it has been possible to give the protection ratio in dB which is defined by:

Protection ratio = Wanted Signal level in dBm - interfering signal level in dBm

N1 : level of interfering signal in dBm to meet the first criterion.
N2 : level of interfering signal in dBm to meet the 2nd criterion.
R1 : protection ratio (-86 dBm - N1) in dB.

The tests have been conducted with two receivers:
EAS type ER 4 - 671 - and Dittel FSG 70

7.3 Immunity characteristics for B1 type of interference

The tests were conducted with a unmodulated wanted signal of -86 dBm and one interfering signal which was frequency modulated by pink noise.

The intermodulation product considered was:
2 x 107.9 - 94.75 = 121.05 MHz

Table XXIX shows the level in dBm corresponding to the first interference threshold. To ascertain the nature of the interference law, a calculation was also made of (2 N1 + N2)/3 which gives the average level; the results shows that the interference law is of the type 2 N1 + N2 = constant.

N1 and N2 were the levels of the unwanted signals.

TABLE XXIX

RECEIVER 1			RECEIVER 2		
N1	N2	(2 N1+N2)/3	N1	N2	(2N1+N2)/3
7	-39	-8	5	-49	-13
5	-35	-8	0	-37	-12
0	-25	-8	- 5	-27	-12
-5	-17	-9	-10	-15	-12
-10	- 6	-9	-12	-10	-11
-15	3	-9	-15	- 5	-12
-17	8	-9	-17	0	-11
			-19	3	-12
			-20	4	-12

7.4 Conclusions

It is possible to propose, as for the radio-navigation receivers case, a law of the type 2N1 + N2 = constant. This constant will be fairly low, and therefore high signal levels will be needed to cause interference.

However, the final value of this constant cannot be derived from tests conducted with only two receivers and in consequence Administrations should be encouraged to conduct additional tests to achieve a more precise law for two-signal interference.

It can be assumed that due to the separation between the two bands of 10 MHz, the interference law will not be very frequency dependent.

These characteristics of the COM receiver have also to be checked by other measurements.

Part 8 of Annex I

CANADA

AIRCRAFT ANTENNA TEST RESULTS

8.1 Measurements were made in Canada on ILS/VOR antennas as installed on 10 general aviation, corporate and commercial transport aircraft. Data were taken in the horizontal plane at four aircraft orientations (forward, aft, port and starboard). The composite of all the aircraft antenna gain curves is shown in Figure 27. The antenna system loss characteristics defined by the Geneva Agreement, 1984, (i.e. Ls +L(f) from section 5.8) is shown in Figure 27. This curve describes a curve which basically represents the maximum of the composite gain data.

8.2 Figure 27 shows that there is a 15-20 dB variation in system gain in the 88-118 MHz band. The test data also indicates that almost all of the aircraft/antenna system combinations exhibited less gain in the band 108 to 118 MHz than that defined by the Geneva Agreement, 1984, curve. As a consequence, an actual received ILS signal level may be significantly less than the -89.5 dBm calculated using the curve of the Geneva Agreement, 1984, and assuming the minimum ILS field strength of 40 μV/m (32 dBμV/m).

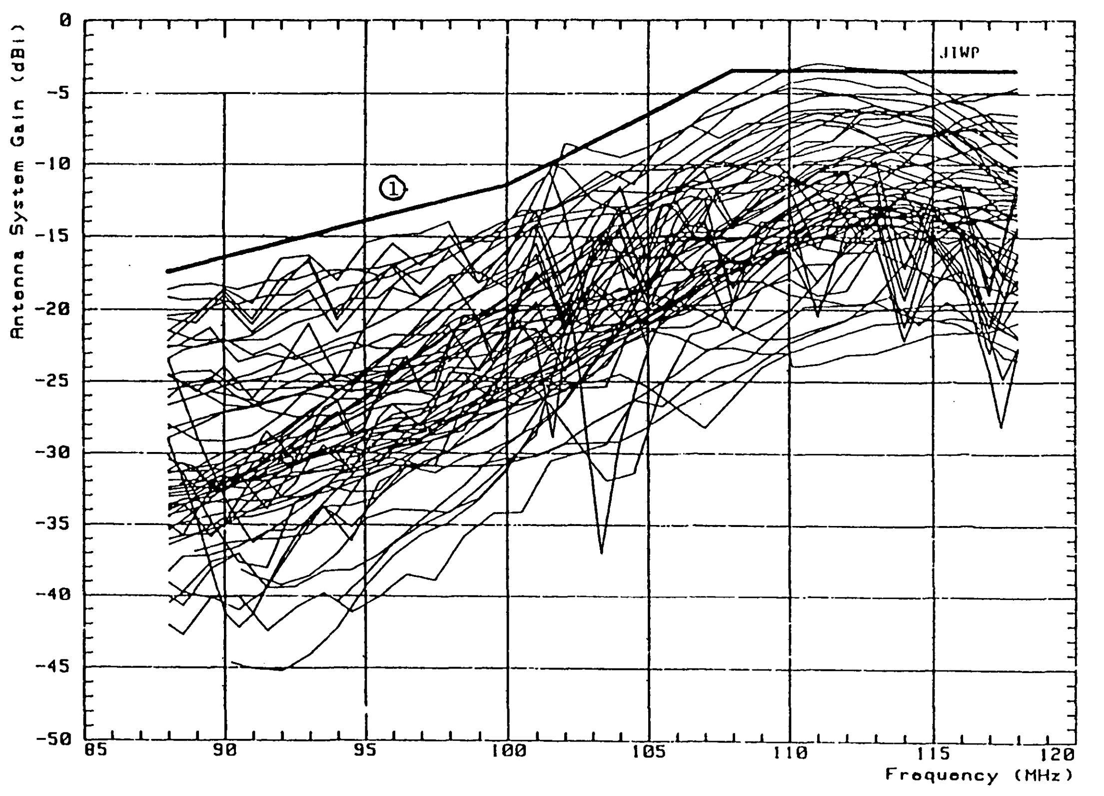


Fig. 27 : Composite Aircraft Antenna Gain Data

① - curve = Geneva Agreement, 1984.

Part 9 of Annex I - United Kingdom

TRIGGER AND CUT-OFF VALUES

9.1 INTRODUCTION

Theoretically every FM broadcasting signal present at an aeronautical test point should be taken into account when assessing the B1 type interference potential. However, unless the level of these signals exceed certain values they cannot be a factor in producing B1 interference. Taking account of such signals would lead to the waste of costly personnel and computer time. To combat this the concepts of 'Trigger' value and 'Cut-off' value have been used.

9.2 'TRIGGER' VALUE

9.2.1 Definition

Trigger value is the minimum value of an FM broadcasting signal which, when applied to the input of an aeronautical VHF (ILS, VOR or COM) receiver, is capable of initiating the generation of a third order intermodulation of sufficient power to represent potential interference.

9.2.2 Derivation

9.2.2.1 For the two signal case Para 4.3.3.1 of Report 929 states that B1 interference can occur if:

$$2\left(N_1 - 20 \log \frac{\max\{0.4;\ 108.1 - f_1\}}{0.4}\right) + N_2 - 20 \log \frac{\max\{0.4;\ 108.1 - f_2\}}{0.4} > -120 \text{ dBm} \quad (1)$$

If

$$N_1 - 20 \log \frac{\max\{0.4;\ 108.1 - f_1\}}{0.4} = N_2 - 20 \log \frac{\max\{0.4;\ 108.1 - f_2\}}{0.4} = NT - 20 \log \frac{\max\{0.4;\ 108.1 - f\}}{0.4} \quad (2)$$

$$\text{Then } 3\left(NT - 20\log\frac{\max\{0.4;\ 108.1 - f\}}{0.4}\right) > -120 \text{ dBm} \tag{3}$$

$$\text{and } NT > -40 + 20\log\frac{\max\{0.4;\ 108.1 - f\}}{0.4} \text{ dBm} \tag{4}$$

NT is then the trigger value for the frequency f.

9.2.2.2 For the three frequency case Para 4.3.3.2 gives

$$N_1 - 20\log\frac{\max\{0.4;\ 108.1 - f_1\}}{0.4}$$

$$+ N_2 - 20\log\frac{\max\{0.4;\ 108.1 - f_2\}}{0.4}$$

$$+ N_3 - 20\log\frac{\max\{0.4;\ 108.1 - f_3\}}{0.4} > -126 \tag{5}$$

This leads to a trigger value of

$$NT > -42 + 20\log\frac{\max\{0.4;\ 108.1 - f\}}{0.4} \tag{6}$$

9.2.2.3 Since, when this check is applied, it is now known whether a 2 or a 3 signal case is likely the inequality in (6) is used to define the trigger value as:

$$NT = -42 + 20\log\frac{\max\{0.4;\ 108.1 - f\}}{0.4} \text{ dBm} \tag{7}$$

This is the value in Annex 2 Para 7.6.5.4 of the Geneva Agreement.

9.3 'CUT-OFF' VALUE

9.3.1 Definition

'Cut-off' value is the minimum value of FM broadcasting signal which, when applied to the input of an aeronautical VHF (ILS, VOR or COM) receiver is capable of producing a third order IP of sufficient power to represent potential interference when combined with 1 or 2 other broadcasting signals at a level just equal to the type B2 power limit.

9.3.2 Derivation

9.3.2.1 From consideration of the interference criteria it can be seen that the 'cut-off' value is influenced by the actual value of the triggering signal. The triggering signal has the trigger value as its lower limit and the B2 transition level as its upper limit. Para 7.6.6 of Annex 2 of the Geneva Agreement gives the value of the B2 threshold level which varies from - 20 dBm at 107.9 MHz to 10 dBm at, and below, 100 MHz. Between 107.9 and 100 MHz, to a first approximation, the B2 limit has the same law as the B1 frequency term. Thus for this purpose the upper B1 limit can be taken as:

$$N_1 = -20 + 20 \log \frac{\max\left\{0.4;\ 108.1 - f_1\right\}}{0.4} \qquad (8)$$

9.3.2.2 Two Frequency Case

With the N_1 limit given in (8), N_2 would have to exceed a value given by (9) for interference.

$$N_2 > -80 + 20 \log \frac{\max\left\{0.4;\ 108.1 - f_2\right\}}{0.4} \qquad (9)$$

Between the two extremes, the N_2 interference threshold value would vary with N_1 as follows:

$$N_2 > -120 - 2\left(N_1 - 20 \log \frac{\max\left\{0.4;\ 108.1 - f_1\right\}}{0.4}\right)$$

$$+ 20 \log \frac{\max\left\{0.4;\ 108.1 - f_2\right\}}{0.4} \qquad (10)$$

9.3.2.3 Three Frequency Case

The general case becomes:

$$N_2 > -126 - N_1 + 20 \log \frac{\max\{0.4;\ 108.1 - f_1\}}{0.4} - N_3$$

$$+ 20 \log \frac{\max\{0.4;\ 108.1 - f_3\}}{0.4}$$

$$+ 20 \log \frac{\max\{0.4;\ 108.1 - f_2\}}{0.4} \qquad (11)$$

When N_1 and N_3 at their B2 limit this would give

$$N_2 > -86 + 20 \log \frac{\max\{0.4;\ 108.1 - f_2\}}{0.4} \qquad (12)$$

9.3.2.4 To cover all cases the equation (12) would be applicable. However, experience in Europe has shown that frequency combinations repeat when the lower signal levels are taken into account. Also trigger values are often well below the type B2 limit. A group of European Administrations have produced a common assessment method which adopts the following cut-off value

$$N > -66 + 20 \log \frac{\max\{0.4;\ 108.1 - f\}}{0.4} \qquad (13)$$

Comparison of computer test runs with criteria (12) and (13) has shown that no interference cases were missed by the use of (13).

Part 10 of Annex I - Canada

COMPARISON OF MEASURED AND CALCULATED CUT-OFF VALUES FOR TYPE B1 INTERFERENCE

10.1 During the Type B1 test program which produced data contained in Section 3.8, Annex I, some data were also taken to determine the cut-off levels where Type B2 effects supercede Type B1 effects. In Table 1, these data are compared with the cut-off values calculated using the formula of the Geneva Agreement, 1984 (see para 5.7) and with the formulae developed by the United Kingdom analysis for current immunity of ILS localizer receivers (see equations (8), (9) and (12) of Part 9, Annex I).

10.2 Although the limited test data in Table 1 show cut-off levels as low as - 70 and - 85 dBm, the cut-off formula of the Geneva Agreement, 1984 will not give a cut-off level below - 54 dBm. The United Kingdom formula gives a better correlation with the test data.

Intermodulation Product	Receiver 1 (dBm)				Receiver 2 (dBm)				Receiver 3 (dBm)				N(Geneva Agreement 1984) (dBm)			N(UK) (dBm)		
	N1	N2	N3	K	N1	N2	N3	K	N1	N2	N3	K	N1	N2	N3	N1	N2	N3
2(107.5) - 106.9 = 108.1	-35	-35	-	-105*	-30	-30	-	-70*	-25	-25	-	-75*						
	-10	(-85)	-	-105	-11	(-30)	-	-92	(-33)	-10	-	-76	-50	-44	-	-16	-70	-
	(-50)	-3	-	-102	(-42)	-10	-	-94	-19	(-40)	-	-78						
2(106.5) - 104.9 = 108.1	-27	-27	-	-81*	-25	-25	-	-75*	-19	-19	-	-57*						
	-10	(-64)	-	-84	-19	(-40)	-	-78					-42	-36	-	-8	-62	-
	(-30)	-20	-	-80	(-34)	-10	-	-78	-9	(-40)	-	-58						
2(107.9) - 106.7 = 109.1	-30	-30	-	-90*									-54	-43	-	-20	-69	-
	-6	(-76)	-	-88														
2(107.5) - 105.9 = 109.1	-25	-25	-	-75*														
	-6	(-67)	-	-79									-50	-39	-	-16	-65	-
	(-33)	-10	-	-76														
2(106.5) - 103.9 = 109.1	-16	-16	-	-48*									-42	-34	-	-8	-60	-
	-6	(-40)	-	-52														
107.5 - 106.5 - 105.9 = 108.1	-33	-33	-33	-99*	-31	-31	-31	-73*	-24	-24	-24	-72*						
	(-70)	-15	-15	-100	(-60)	-17	-17	-74	(-60)	-7	-7	-74	-50	-42	-39	-16	-74	-5
	-15	(-70)	-15	-100	-17	(-60)	-17	-74	-17	(-40)	-17	-74						
	-15	-15	(-70)	-100	-18	-18	(-60)	-76	-17	-17	(-40)	-74						
107.9 - 106.3 - 105.1 = 109.1	-25	-25	-25	-75*														
	(-60)	-8	-8	-76									-54	-41	-36	-20	-73	-3
	-18	-18	(-40)	-76														
	-9	(-60)	-9	-78														
107.5 - 105.5 - 103.9 = 109.1	-21	-21	-21	-63*														
	(-50)	-7	-7	-64									-50	-38	-34	-16	-70	0

TABLE XXXI – Comparison of Measured and calculated Cut-Off Values for Type B1 Interference.

Notes:

1) Cut-off levels in the data are circled. e.g. (-60)

2) Cut-off levels indicate where Type B2 interference effects started or became dominant.

3) * indicates equi-signal reference.

4) For 2-signal case: $2N1 - N2 - K = 0$

for 3-signal case: $N1 - N2 \quad N3 - K = 0$

where N1, N2, N3 = signal levels for FM stations f1, f2, f3 respectively, and $f1 > f2 > f3$.

5) $N(\text{Geneva Agreement 1984}) = -54 - 20 \log \left[\frac{\max (0.6;\ 108.1 - f)}{0.4}\right]$

6) $N2(UK) = -80 + 20 \log 2.5 (\max (0.4;\ 108.1 - f2))$
for 2-signal case, and
$-86 + 20 \log 2.5 (\max (0.4;\ 108.1 - f2))$
for 3-signal case

7) B2 limits: $N1(UK) = -20 + 20 \log 2.5 (\max (0.4;\ 108.1 - f1))$ and
$N3(UK) = -20 + 20 \log 2.5 (\max (0.4;\ 108.1 - f3))$.

ANNEX II

PART 1 Compatibility Assessment Methods

1.1 Introduction

Several methods have been developed which permit the theoretical assessment of compatibility. Such methods are of most use before new broadcasting or aeronautical facilities are introduced.

Details of the methods currently in use may be found parts 2 to 5. A comparison of the computation philosophy adopted may be found in Table XXXII.

It should be noted that the enhanced method described in Appendix 1 is the only one which has been field-tested in order to prove that if known parameter values are used for a specific situation then its predictions correlate with reality. All four methods can be used, with generalized parameters and worst-case combinations of wanted and unwanted signal levels to provide conservative general analysis. More operational experience is required to assess the generalized approaches in this regard.

	CANADA GENERAL	CANADA ENHANCED (NOTE 2)	USA (ILS only)	LEGBAC (Unified Assessment Method)	POLAND
FM ANTENNA PATTERN	OMNI HRP NO VRP MAX e.r.p.	Measured HRP theoretical or measured VRP	Manufacturer's specifications where available. HRP omni-directional VRP -14 dB beyond $\pm$ 5^{o} (V)	HRP - as given in GE 84 -plan VRP - no correction below the horizontal Generalized model with limiting value	VRP - similar to theoretical model in Report 1198
FM PROPAGATION	Free-space	IF-77	Free-space to radio horizon	Free-space with 100 % attenuation beyond the radio horizon	Free-space with an attenuation of 20 dB beyond the radio horizon
AIRCRAFT ANTENNA FREQUENCY RESPONSE	Geneva Agreement 1984	Measured for specific aircraft	Geneva Agreement 1984	JIWP 8-10/1	Geneva Agreement 1984
AIRCRAFT ANTENNA RECEPTION PATTERN	Omni-directional	Measured for specific aircraft	Omni-directional	Omni-directional	Omni-directional
AERONAUTICAL SIGNAL	Geneva Agreement 1984 levels	Measured or derived from idealized or measured ILS pattern	40 µV/m	The minimum ICAO values for ILS and VOR throughout the volume	Predicted values
AVIONIC RECEIVER SUSCEPTIBILITY	Geneva Agreement 1984 criteria	Specific receiver characteristic at various ILS signal levels	Unique calculated values	Geneva Agreement 1984 criteria	A1 - predicted B1 - modified by the difference between the predicted and wanted levels
TEST POINTS	Interference area	Interference area or test points along flight path	1000 x 1000 foot horizontal grid 100 foot vertical increments, 100 x 100 foot horizontal grid near FM station (NOTE 1)	Broadcast station related with additional fixed test points for ILS	Similar to Geneva Agreement 1984 with additional fixed test points on air routes and in ILS volume

TABLE XXXII

Test methods currently in use

NOTES: 1. Initial cull at 8000 x 8000 ft. to reduce computer time with + 12 dB added to FM e.r.p.

2. One or more of the parameters of the enhanced model may be substituted by their equivalent in the general model

1.2 Relevant Parameters in Correlation Studies

Table XXXIII lists the identified parameters that need to be considered when correlating measured interference to calculated or predicted interference, for each of the mechanisms - Types A1, A2, B1 and B2. Explanatory notes follow where applicable. The parameters listed apply to ILS localizer, VOR, and VHF communications systems.

RELEVANT PARAMETERS IN CORRELATION STUDIES

			INTERFERENCE MECHANISM			
		PARAMETERS	A1	A2	B1	B2
1.	S	FM ANTENNA FUNDAMENTAL FREQUENCY, HORIZONTALLY RADIATED SIGNAL PATTERN		X	X	X
2.	L	FM SPURIOUS EMISSION, HORIZONTALLY RADIATED SIGNAL PATTERN	X			
3.	S	FM ANTENNA FUNDAMENTAL FREQUENCY, VERTICALLY RADIATED SIGNAL PATTERN		X	X	X
4.	L	FM SPURIOUS EMISSION, VERTICALLY RADIATED SIGNAL PATTERN	X			
5.	L	POLARIZATION OF FM SIGNAL		X	X	X
6.	S	FM SIGNAL PROPAGATION	X	X	X	X
7.	S	AIRCRAFT ANTENNA RECEPTION PATTERN	X	X	X	X
8.	S	AIRCRAFT ANTENNA AND FEEDER SYSTEM FREQUENCY RESPONSE	X	X	X	X
9.	S	AERONAUTICAL SYSTEM, ACTUALLY RADIATED SIGNAL	X	X	X	
10.	S	AVIONIC RECEIVER INTERFERENCE IMMUNITY AND SELECTIVITY CHARACTERISTICS	X	X	X	X
11.	U	MULTIPLE FM SIGNAL CONTRIBUTIONS	X		X	X
12.	U	AIRCRAFT ANTENNA CROSS-POLARIZATION DISCRIMINATION	X	X	X	X
13.	U	OTHER ELECTROMAGNETIC SIGNALS IN THE ENVIRONMENT (E.G, ISM, CATV, NEARBY AERONAUTICAL NAVAIDS SUCH AS TVOR, ETC.)	X	X	X	X

S = SIGNIFICANT FACTOR
L = LESSER IMPORTANT FACTOR
U = UNKNOWN FACTOR (NO PRACTICAL EXPERIENCE)

TABLE XXXIII

E X P L A N A T I O N

PARAMETERS 1, 2, 3 and 4	By measurement of field strength of the radiated signal or by calculation, the radiation pattern is established in the direction of measurement. Measurements at different azimuths and elevations may be combined to fully characterize the radiation pattern. Beam tilt, if any, should be taken into account.
PARAMETER 6	Site and antenna elevation need to be taken into account. Propagation is free space up to radio horizon with diffraction losses beyond (see Recommendation 528). Variability due to season/weather effects should be considered.
PARAMETER 7	Both broadcasting and aeronautical bands.
PARAMETER 9	Terrain effects need to be taken into account. Variability due to season/weather effects should be considered.
PARAMETER 10	The A1 mechanism is affected by avionic receiver characteristics only to the extent that the receiver selectivity admits the spurious emission. Modulation characteristics will affect result.
PARAMETER 13	Energy other than from FM broadcasting transmitters could contaminate signal measurements in any of the four mechanisms.

1.3 **Result of correlation experiments**

1.3.1 Introduction

In Canada, correlation between the predictions of the enhanced analysis model and flight results under test conditions was examined for the Type B1 interference mechanism. For these tests, the ILS transmitter of an ILS test facility near Ottawa was re-tuned and operated at 108.5 MHz, to coincide with the receiver intermodulation product: 2(106.9) - 105.3 = 108.5 MHz.

1.3.2 Analysis model

The analysis technique considered the following factors:

- measured FM antenna horizontal radiation patterns;
- measured localizer transmitter antenna radiation pattern;
- measured aircraft antenna radiation pattern and gain;
- measured receiver interference immunity in the presence of various localizer signal levels;
- aircraft position and heading;
- aircraft inside mainbeams of FM transmitters.

1.3.3 Flight test results

Figure 28 presents an example of the results of the two versions of the enhanced technique (i.e. an interference area and a test point analysis along a flight path).

The "predicted area of no interference" was plotted assuming worst case aircraft antenna orientation, that being maximum gain towards the FM transmitter sites and minimum gain towards the ILS transmitter site. This plot therefore presents a limiting case: any interference found during a flight test should be outside the "predicted area of no interference".

The correlation between the flight test results and the detailed prediction technique using test points along flight paths can be seen in flight path segments RUN R47 and RUN R48. In RUN R47, the lobe structure of the ILS antenna radiation pattern can be seen creating short segments of no interference on either side of the front course sector, in both the predicted and flight test results. These flight tests confirmed the prediction that there would be no interference in the front course sector. In RUN R48, again no interference was predicted or found in the front course sector.

1.3.4 Conclusion

It is known that for each factor used in the analysis model, there exists a variation between actual parameters and characteristics of the Geneva Agreement, 1984. Submitted data quotes variations of -10 to +4 dB for FM antenna patterns, -10 to +30 dB for ILS actual signal levels as compared to the -89 dBm minimum level and finally 7 dB between actual and predicted FM levels (due to ground reflections). Considering that predicted results matched flight results very closely, the correlation obtained can only be explained by the use of measured characteristics for all factors considered.

B1 EMI CONTOUR: 2*106.9-105.3-108.5 CARP 1000 feet

ID	FREQ	LATITUDE	LONGITUDE	ERP(W)	DIST(NM)	BEAR(°)	G (dBi)
CARP 180	108.5	4519 6	076 154	--	--	--	-16.0
CKOI OTT	106.9	453011	07551 2	100000	13.5	34.5	-12.0
CKBY OTT	105.3	453011	07551 2	84000	13.5	34.5	-11.0

Variables considered in this analysis:

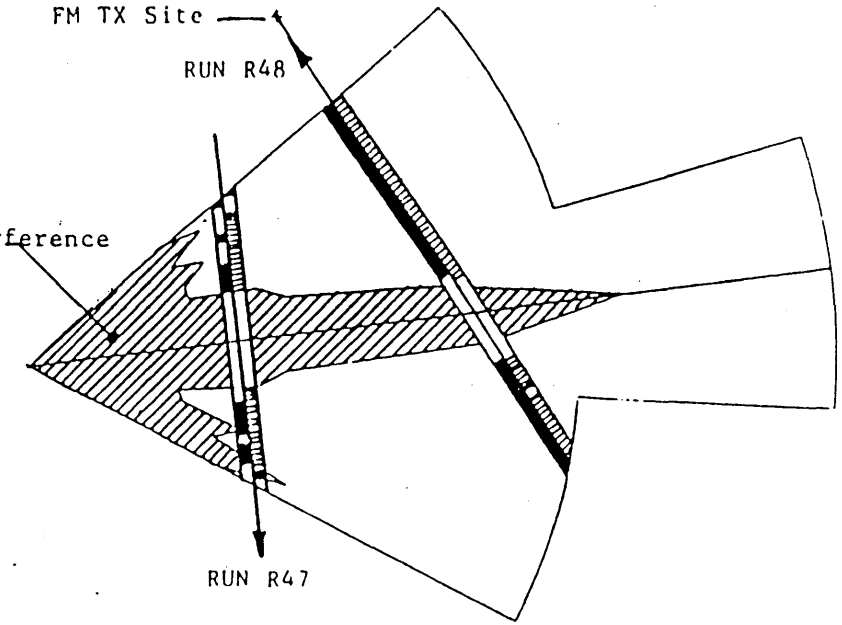
LOCALIZER antenna type:...YES
LOCALIZER signal level: ..YES
FM1 antenna directivity:..YES
FM2 antenna directivity: .YES

Details

LOC. AZIMUTH : 83 °
LOC. TX ANT. :a2CARP7NM
Aircraft RX : K
Aircraft ANT gain:User Defined
RX DELTA f cubed = 8.192

Measured LOC. signal CARP 1000 feet 108.50	
LOC. ANT. DIST (NM)	FIELD E (dBuV/m)
1.0	82.0
2.0	81.0
4.0	75.0
6.0	71.0
8.0	65.0
10.0	61.0
12.0	58.0
14.0	56.0
16.0	52.0
18.0	51.0
20.0	49.0
22.0	46.0
24.0	43.0
25.0	43.0
Flight alt.	1000 FT ASL

COMMENTS:
WORST CASE AIRCRAFT ANTENNA ORIENTATION for RX K.
FM gain = MAX.
LOC gain = MIN.



Flight Path Segment where Interference was Predicted Using Test Point Analysis.

Flight Path Segment where Interference was Detected in Flight Tests.

FIGURE 28

1.4 Expected validity of generalized methods

Some of the generalized methods described in this Annex have been used to predict the theoretical compatibility of well established operational situations. These methods are conservative and it is not uncommon for negative compatibility margins, sometimes very large, to be predicted for well established operational situations where no complaints of incompatibility have apparently been received. This raises doubts about the degree of validity of the methods and/or at least some of the compatibility criteria which they apply. Conclusions drawn from using any general method applied to well established operational situations, some of which have been in use for many years, should be viewed with some caution. In North America, aeronautical and broadcasting systems were engineered one by one based on case-by-case evaluations, for example, taking account of conditions at specific locations. There is some doubt about the validity of applying a generalized method to a situation such as that in Region 2.

It is desirable to attempt to quantify the magnitude of the discrepancies which could be introduced by known approximations or assumptions.

The sources of discrepancy and the estimated magnitude are:

- Horizontal radiation pattern of broadcasting station. Differences of + or - 2 dB can exist between predicted and measured value on any bearing. Differences of + 5 to - 10 dB have been found to exist in Canada for side mounted antennas between nominal theoretical e.r.p. and assumed omni-directionality and measured values on any bearing.

- Wanted radionavigation signal level. Differences of -10 to +30 dB can exist between the minimum value of aeronautical signal level (-89 dBm) and the actual value at a test point.

- Aircraft antenna system performance. Differences of 0 to -20 dB can occur between the antenna system frequency dependency model quoted in the Geneva Agreement, 1984 Annex 2, Part 7.6.2 and the measured values. This difference also takes into account any effects due to antenna directivity.

- Aeronautical receiver immunity. Differences in the range -10 to +30 dB could occur when account is taken of the deviation of the characteristics for a particular model of receiver compared with the characteristics specified in the Geneva Agreement, 1984 and also the expected variation of receiver performance as the level of the wanted signal is varied.

It should be noted that some of these expected discrepancies are inter dependent. For example, if the receiver performance is level dependent, this can be affected both by the variation of the level of the wanted signal and also by the aircraft antenna performance.

It should also be noted that one significant source of potential discrepancy which can be considerably reduced is the replacement of a free-space propagation prediction model by one using ITS IF 77 [Gierhard and Johnson, 1983], or the 50% time propagation curve from Rec. 528. This will have the effect of reducing discrepancies by up to 30 dB for paths which extend to near or beyond the radio horizon estimated on the basis of a smooth 4/3 earth approximation. On shorter paths, however, the effect can be expected to be negligible.

A further possible source of discrepancy has been identified which can not yet be quantified. This applies only to the case of radiated intermodulation products (A1) where it is considered important to consider the VRP of the broadcasting antenna at the frequency of the spurious emission.

Any, or all, of the above factors could contribute to a discrepancy between calculated margins and operational experience, but no information is yet available about the overall differences which could occur.

Also, the actual operational constraints at a specific facility need to be taken into account.

1.5 Summaries of the methods described in Parts 2 to 5 of this Annex

1.5.1 Canada (see Part 2)

Computerized techniques permit the plotting of potential type A1, A2, B1 and B2 interference areas directly on aeronautical charts or on service area diagrams. The compatibility criteria of the Geneva Agreement, 1984 are used in the general model. Moreover, a detailed case assignment analysis is possible utilizing other parameters or criteria. This enhancement permits a closer approach to the operational environment.

1.5.2 United States of America (see Part 3)

In the United States an automated computer based model is employed to predict compatibility between FM broadcast transmissions and the ILS localizer system. Some important features are: The ICAO minimum specified signal level of 40 μV/m is used throughout the entire ILS service volume. Bench tests of 28 receivers, validated by flight tests, were used to derive interference criteria for the B1 type mechanism. Criteria for types A2 and B2 mechanism are the same as used in the Geneva Argeement, 1984, except, the greater restriction is employed where the two differ for a given Δf. The minimum default search range is 30 NM beyond the bounds of the ILS service volume. Larger ranges can be selected as appropriate.

1.5.3 The LEGBAC Unified Assessment Method for Aeronautical-Broadcast Compatibility (see Part 4).

The method was developed by a "Limited Exploratory Group for Broadcast to Aeronautical Compatibility" (LEGBAC) comprising the Administrations of Germany (Fed. Rep. of), Belgium, France, Ireland, Luxembourg, Netherlands (Kingdom of the) and United Kingdom.

The Unified Assessment Method, UAM, provides a computerised analysis tool for international coordination in relation to the compatibility problem. The UAM applies the compatibility criteria contained in the Geneva Agreement, 1984 with a correction factor which takes into account the antenna characteristics of broadcasting stations. All significant potential incompatibilities are identified using a reasonable number of test points. Given that the nighest level of potential incompatibility will always occur in the vicinity of a broadcasting station, the method is based upon test points generated in their vicinity. These broadcast station related test points are additional to fixed ILS test points.

This approach has resulted in an efficient computational tool which provides a list of potential interference margins at the test points.

1.5.4 Poland (see Part 5)

The compatibility assessment method created in Poland in principle utilizes the compatibility criteria of the Geneva Agreement, 1984. However, certain refinements have been introduced.

Compatibility for ILS, VOR and VHF COM is assessed. In the case of VOR and VHF COM, test points are created along flight paths.

References

Gierhard G.D., Johnson M.E., "The IF-77 Electromagnetic Wave Propagation Model", DOT Rept. FAA-ES-83-3, Boulder, Colorado, September 1983.

Part 2 of Annex II

Automated Compatibility Analysis Models Developed by Canada

2.1 System Overview

2.1.1 The FM/ILS/VOR/COM Interference Analysis System consists of 2 main components: the Interference Analysis Subsystem and the Mapping Subsystem.

2.1.2 The Interference Analysis Subsystem, running on a mainframe computer, has access to data bases containing:

(a) all Canadian FM stations;

(b) USA FM stations up to 320 km (172 NM) from the common border;

(c) all Canadian ILS, VOR and COM facilities;

(d) USA ILS facilities within 240 km (130 NM) from the border and USA VOR facilities within 1020 km (550 NM) from the border (note: distances shown are those in bilateral agreements with the USA).

It carries out Type A1, A2, B1 and B2 analyses to produce an interference report which prints out all cases where an interference contour overlaps the service area of an aeronautical facility. This report provides an approximate size of the potential interference areas. The Mapping Subsystem is then used to provide an interference plot.

2.1.3 The interference Mapping Subsystem is implemented on a microcomputer, and is used to plot ILS/VOR/COM service areas, FM transmitter sites, Type A1/A2/B1/B2 interference contours and the results of test point analyses. This subsystem stores FM/ILS/VOR/COM information obtained from the interference report, as well as measured data on aircraft antenna characteristics, receiver interference immunity characteristics, FM antenna radiation patterns, ILS transmitter antenna radiation patterns and ILS signal levels.

2.2 Assumptions and Criteria

2.2.1 General model: This model considers the following:

a.	FM antenna pattern:	an idealized omnidirectional H.R.P. pattern based on maximum e.r.p.
b.	FM signal propagation:	free-space model
c.	Aircraft antenna system model:	the model of the Geneva Agreement, 1984
d.	ILS signal level:	-89 dBm throughout
e.	ILS/VOR receiver characteristics:	those embodied in the criteria of the Geneva Agreement, 1984

Figure 29 shows the output of such an analysis.

2.2.2 Enhanced model: One or more of the following may be substituted for their equivalent in the general model:

a.	FM antenna pattern:	calculated or measured VRP, measured HRP
b.	FM signal propagation:	the ITS IF-77 [Gierhard and Johnson, 1983] propagation model Reference: which considers free-space losses within line-of-sight and diffraction losses beyond: radio horizon is actual instead of calculated
c.	Aircraft antenna model:	characteristics in terms of radiation pattern and frequency response for a specific aircraft/antenna combination
d.	ILS signal level:	as measured or as derived from an idealized or measured ILS antenna pattern
e.	ILS/VOR receiver characteristics:	specific receiver characteristics under varying ILS signal levels

Figure 30 shows the output of an analysis considering actual localizer signals and a specific receiver (with 10 dB less immunity than was used in Fig. 29) other factors remaining within the assumptions of the Geneva Agreement, 1984.

2.2.3 Software is being modified to print interference margin numbers along flight paths (or at selected test points), rather than just identifying if interference is or is not being predicted. This will assist in interpreting the presentation. Flight tests on a number of ILS facilities across Canada will be carried out in a continuing evaluation and refinement of the enhanced analysis technique.

2.3 Usage

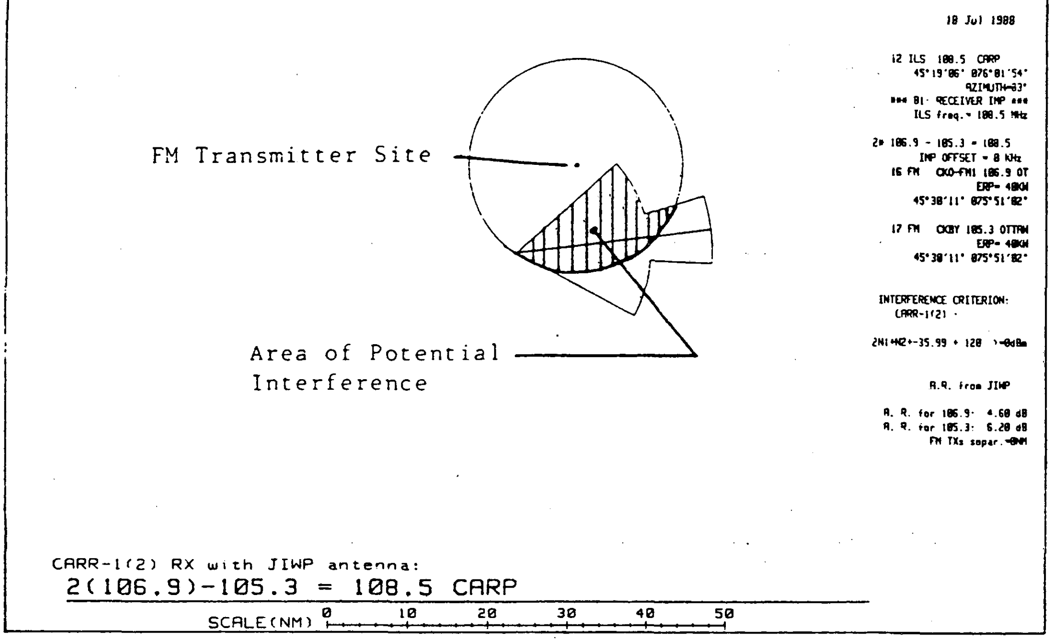
The general model is used as a preliminary analysis for each assignment case. The enhanced techniques may be used as the circumstances require. Finally, both models may be used as a tool to design and implement compatible FM and aeronautical navigation assignments.

Reference

Gierhard G.D., Johnson M.E., "The IF-77 Electromagnetic Wave Propagation Model", DOT Rept. FAA-ES-83-3, Boulder, Colorado, September 1983

FIG. 29 - GENEVA AGREEMENT, 1984 - ANALYSIS WITH AIRCRAFT ANTENNA SYSTEM RESPONSE CURVE OF THE SAME AGREEMENT

ERP = 40 kW (both FM)



B1 EMI CONTOUR: 2*106.9-105.3=108.5 CARP 1000 feet

ID	FREQ	LATITUDE	LONGITUDE	ERP(W)	DIST(NM)	BEAR(°)	G (dBi)
CARP 180	108.5	4519 6	076 154	--	--	--	-3.5
CKO1 OTT	106.9	453011	07551 2	40000	13.5	34.5	-4.6
CKBY OTT	105.3	453011	07551 2	40000	13.5	34.5	-6.2

Variables considered in this analysis:

LOCALIZER antenna type: YES
LOCALIZER signal level: YES
FM1 antenna directivity: OMNI
FM2 antenna directivity: OMNI

Details

LOC. AZIMUTH : 83 °
LOC. TX ANT. 216ELEM
Aircraft RX : K
Aircraft ANT gain JIWP-8/12
RX DELTA f cubed = 9.192

Measured LOC. signal CARP 1000 feet 108.50	
LOC. ANT. DIST (NM)	FIELD E (dBuV/m)
1.0	82.0
2.0	81.0
4.0	75.0
6.0	71.0
8.0	65.0
10.0	61.0
12.0	58.0
14.0	55.0
16.0	52.0
18.0	51.0
20.0	49.0
22.0	46.0
24.0	43.0
25.0	43.0
Flight alt.	1000 FT ASL

COMMENTS:
LOC Signal Model
RX K JIWP antenna.

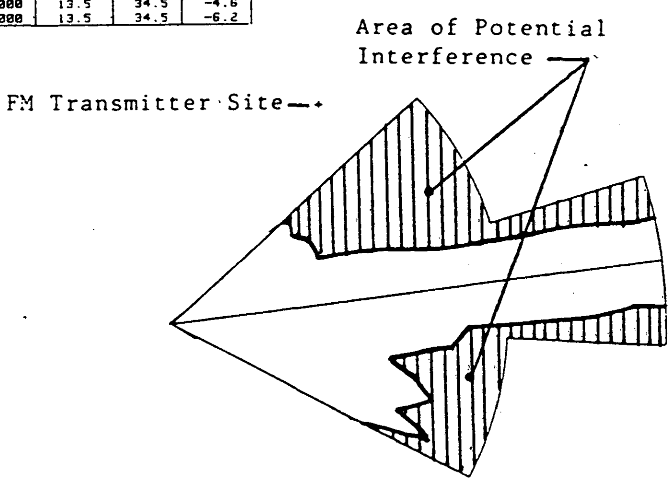


FIG. 30 - LOC SIGNAL MODEL WITH AIRCRAFT ANTENNA SYSTEM CURVE OF THE GENEVA AGREEMENT, 1984

ERP = 40 KW (both FM)

0 5 10 15 20 16 Jul 1988

Part 3 of Annex II

A Computer Based Mathematical Model to Evaluate Compatibility Between Proposed FM Broadcast Stations and the Instrument Landing System (ILS) Localizer of the United States of America

In the United States an automated computer based model is employed to predict compatibility between FM broadcast transmission and ILS localizer system.

In summary, the primary factors of the model are:

Localizer Signal in Space - The ICAO minimum specified signal level of 40 µV/m is used throughout the entire ILS service volume.

Aircraft Antenna System - The antenna system response curve of the Geneva Agreement, 1984 is used. Horizontal or vertical directivity of the aircraft antenna are not considered.

Receiver - Bench tests of 28 receivers, validated by flight tests, were used to derive unique interference criteria for the B1 type mechanism. Criteria for types A2 and B2 mechanisms are the same as used in the Geneva Agreement, 1984 except, where the two differ for a given Δf, the greater restriction is employed.

FM Antenna - Horizontal and vertical radiation patterns based on manufacturers' specifications are used, if known. If unknown, an omnidirectional horizontal pattern is used, along with an assumption for vertical radiation pattern with a $\pm 5^{\circ}$ main beam and -14 dB for all other elevations (generic antenna).

FM Signal in Space - Line of sight inverse distance propagation is used, normally from a search distance up to 55 km (30 NM) from any point on the ILS service volume. Greater search distances are used if necessary.

Test Points - A pre-screening horizontal grid of 2400 x 2400 m (8000 x 8000 ft.) spacing throughout the ILS volume is first applied without any FM antenna pattern correction and with a +12 dB value added to the computed field strength of each FM station. Only if an interference criterion is exceeded in pre-screening an intensive analysis is made on a 300 x 300 m (1000 x 1000 ft.) horizontal grid at any user selectable altitude. Default values are; bottom of service volume, top, elevation of FM tower. In the special case where an FM antenna is within the service volume, a 30 x 30 m (100 x 100 ft.) 2-dimensional grid is created for test points in the vicinity of the FM location.

3.1.1 Introduction

3.1.1.1 In the United States of America, a case-by-case coordination procedure, which starts at or before the building permit stage, is used on a continuing basis to ensure that the present, satisfactory level of compatibility between the aeronautical and broadcast services, continues. As a result, the U.S. has not had to adopt blanket limitations on the aeronautical service to solve interference problems. Several techniques have been used in an effort to evaluate the electromagnetic compatibility (EMC) between the aeronautical radio services in the 108-137 MHz band and FM broadcasting stations in the 88-108 MHz band. Many of these techniques, most notably the "Venn diagram" approach have by necessity employed a simplified approach due to the many calculations involved in a precise analysis of a compatibility problem. The ready availability of computers has provided the impetus to develop a computer-based mathematical model which, when combined with empirical data derived from bench and flight measurements would provide a full analysis of any given compatibility question.

3.1.1.2 The United States has developed such a computer based mathematical model, known as the Airspace Analysis Model (AAM) that is the most powerful tool yet developed in the U.S for the evaluation of the compatibility between FM broadcasting and the aeronautical radionavigation (ILS) services. It relies on actual data collected by flight checks of existing radio stations as well as bench tests of radio equipment used in the field. It uses broadcasting antenna patterns (where provided) to ensure that the interference "zones" predicted are as exact as possible.

3.1.1.3 Model implementation to date is limited to the evaluation of the compatibility between FM broadcasting transmitters and the Instrument Landing System (ILS) localizer avionics. The output of this model consists of computer generated plots which indicate areas within the three dimensional localizer service volume where A2, B2 and/or B1 interference is to be expected under certain conditions. This model differs significantly from earlier methods of analyzing compatibility in that a three dimensional analysis is performed which takes into consideration the vertical structure of the localizer service volume as well as the vertical pattern of the FM broadcasting antennas involved. The operator has the option of selecting any search distance for FM stations as measured from the edge of the service volume. The default (and minimum allowable) value is 55 km (30 NM) to minimize computation time.

3.1.2 Empirical data

3.1.2.1 The results of a joint Canadian/United States ILS/VOR receiver bench test program comprise the first set of data incorporated into the model. (Annex I, Part 3). Additional testing has been completed in the United States, and the results have been incorporated into this database. A total of 28 receivers underwent bench testing to determine their sensitivity to A1, A2, B1 & B2 interference from FM broadcasting signals (See Table XXXIV). In some cases multiple units of the same model were tested to gain insight into the repeatability of the data. Those models, which are among the most popular, did exhibit remarkable repeatability. A detailed description of this additional testing is the subject of a separate document to be published by the United States Federal Aviation Administration.

3.1.2.2 A total of 15 different antennas, mounted on 14 different airframes, are included in the data which forms the basis of the model. A listing of the airframes and antenna models is included in Table XXXV. The frequency response curve of the Geneva Agreement, 1984 is the curve currently incorporated into the model. Horizontal or vertical directivity of the aircraft antenna is not considered.

3.1.2.3 Vertical radiation patterns of 11 different types of FM broadcasting antennas was provided by antenna manufacturers and is included in this model. Table XXXVI lists the types and Figure 31 is a sample pattern.

3.1.3 Model Formulation

3.1.3.1 The model calculates predicted areas of A2, B1 & B2 interference within the ILS localizer service volume. For A2/B2 interference field strengths of FM broadcasting signals are calculated and compared to the immunity criteria presented in Figure 32, the adopted curve of the Geneva Agreement, 1984. At the upper end of the curve, near 108 MHz, A2 predominates over B2 and is the determining factor.

3.1.3.2 Criteria for type B1 interference (3rd order, 2-signal and 3-signal receiver intermodulation) is based on the data taken by the United States and Canada, some of which appears in Annex I, Part 3.

The 2-signal compatibility occurs when:

$$2N_1 + N_2 \leq 26.4 \log [\Delta f^2_1 \times \Delta f_2] - 133.8$$

The 3-signal compatibility occurs when:

$$N_1 + N_2 + N_3 \leq 27.1 \log [\Delta f_1 \times \Delta f_2 \times \Delta f_3] - 141.3$$

where:

N_i = $_i$th FM received power, dBm

$\Delta f_i = f_{loc} - f_i$ (FM), MHz

3.1.3.3 The interference threshold equations in the AAM assume a localizer signal of -86 dBm (the ICAO minimum field strength converted to dBm) throughout the entire service volume (Figure 33). Terrain shielding (Figure 34), aircraft shielding and monitor thresholds can create areas where the actual received signal is less than would be predicted using standard propagation analysis techniques. (Operationally, receiving antenna reception patterns can vary considerably for various aircraft attitudes and orientations, thus further degrading the signal level.) Should terrain shielding reduce the actual field strength below the minimum level allowed by flight check (-90.5 dBm) a reduced or modified service volume may be declared and published. Also, the ILS transmitter monitor will allow a 3 dB reduction in transmitter power before turning off the ILS transmitter.

3.1.3.4 The AAM looks for possible interference anywhere in the entire ILS service volume in order to ensure that it is interference free as opposed to only the centerline approach region. A pilot off course relies on the directional guidance provided by the ILS to his course deviation indicator (CDI) to steer the aircraft in the direction necessary to regain the course. Radio frequency interference to the localizer could give unpredictable readings and may even result in centering the needle of the CDI, the normal indication that the pilot is on course. Additionally, providing less than full protection of the Service Volume would reduce the flexibility of air traffic control operations and could jeopardize the viability of a given approach. Since it is extremely costly and difficult to relocate an airport, the decision was made in the U.S. to check for interference in the entire service volume and protect all usable airspace within it.

NOTE (1). ICAO Annex 10, Volume 1, Part 1, Section 3.1.3.3.2 specifies 40 µV/m as the minimum signal level within the localizer coverage volume. This is equivalent to -86 dBm at the terminals of a lossless isotropic antenna.

3.1.3.5 Bench data indicates that in most receivers, FM broadcasting interference tends to widen the course. However, in at least one popular model, the needle can be made to veer to one side of the CDI (Annex I, Part 3, Section 3.7). It is critical that the entire service volume be protected from such FM broadcasting signal induced interference.

3.1.3.6 The computer implementation of the model performs FM broadcasting signal level calculations at hundreds of locations throughout the ILS localizer service volume under investigation. Calculations are performed over a grid with points every 300 m (1000 ft.) horizontally. For all FM stations within the service volume, a 30 x 30 m (100 x 100 ft.) horizontal grid of test points is used in the vicinity of the stations. The model can also plot a vertical slice of interference areas at the users option. Such a three dimensional matrix of signal levels from all FM transmitters under investigation is calculated. These levels are combined and compared with the B1 intermodulation criteria for 3rd order, 2- and 3-signal intermodulation, A2 and B2 criteria. At each location where compatibility criteria are violated, a dot is placed on a computer generated plot. Examples of such graphic plots are depicted in Figures 34-38. As can be seen, the results are sensitive to both the vertical dimension of the service volume and vertical antenna pattern of the FM broadcasting station radiating elements. This result is then used to assess the compatibility between the FM broadcasting environment and the ILS localizer system.

3.1.4 <u>U.S. Experience with the Model</u>

3.1.4.1 In an effort to reduce the computing time, the U.S. has made a number of modifications to the model. The U.S. model now performs the compatibility assessment in two phases. During the first phase (pre-screening phase), the model performs the analysis on test points based on 2400 x 2400 m (8000 x 8000 ft.) horizontal spacing with 30 x 30 m (100 x 100 ft.) vertical increments. For the second phase, the model uses 300 x 300 m (1000 x 1000 ft.) horizontal spacing with the same 30 x 30 m vertical increments.

In order to avoid the possibility of missing any potential problems during the pre-screening phase, the analysis is made under the following special conditions:

(1) 12 dB is added to the e.r.p. of each FM station
(2) No vertical pattern corrections are made for the FM stations
(3) Airborne receivers are in the FM main beam

If any potential interference problems are detected during the pre-screening process, the model automatically starts the analysis over again with the 300 x 300 m horizontal spacing.

The two-phase analysis technique used in the U.S. model essentially doubles the speed of the entire analysis.

3.1.4.2 The FM station search is now conducted in an elliptical pattern surrounding the service volume, instead of a circular search from the localizer. The minimum ellipse is determined such that at no point it is less than 55 km (30 NM) from the edge of the service volume.

3.1.4.3 Other improvements include addition of VOR stations as an interfering source and a number of cosmetic changes to make the model more user friendly.

3.1.4.4 Operation of the AAM itself has yielded some surprising results. In one recent case, an applicant proposed to relocate his antenna. The "Venn diagram" method showed that at the proposed site, the predicted interference would have been no worse than that at his existing site. This normally would have meant granting the proposal with a conditional statement added.

3.1.4.5 Subsequently, the data was run through the AAM. Using the generic antenna pattern, the predicted interference was worse by a negligible amount (an additional 15 - 22.5 m (50 - 75 feet) up into the service volume). As is the procedure when interference is predicted using the generic antenna model, the more precise antenna model was used. Once the appropriate antenna type model was included, the AAM showed that interference would have been present throughout a significant portion of the service volume. Figure 39 illustrates a characterization of the interference in a vertical plane through the ILS transmitter and the FM transmitter site.

3.1.4.6 Another recent case, the AAM predicted interference in such graphic detail that examination of the plots by the applicant's engineer along with his knowledge of the operation of the model, resulted in them withdrawing their own engineering study until further notice. Figure 40 illustrates a vertical characterization of this interference along a radial through the FM transmitter location.

3.1.4.7 The AAM can also assist in interference investigations. Characteristics of aircraft type, receiver and antenna system, when included into the AAM submodels, will represent a specific aircraft. The characteristics of several flight inspection aircraft are included in the databases and it is possible to specify a particular aircraft and configuration. By using a new antenna calibration facility at the Atlantic City, New Jersey the flight inspection aircraft antenna patterns will be documented. Having a calibrated aircraft will allow the analysis of an interference situation prior to actual flight measurement as was illustrated recently in an interference case at Greenville, North Carolina. There was a report of FM interference to the localizer at Pitt-Greenville Airport. The AAM predicted that the interference was not FM. A subsequent flight check verified this.

3.1.5 Validation

3.1.5.1 Validation of the model is being accomplished by comparing calculated performance of ILS localizer avionics with measured performance under actual flight conditions employing a specially equipped aircraft. This aircraft is particularly valuable for this function since both its avionics receiver and antenna characteristics have been measured and calibrated as part of this model development effort. The avionics receiver was measured during the bench test program. The antenna was calibrated in both its horizontal pattern and frequency response at the Canadian antenna measurement range. Validation of the model is in progress, with encouraging results from initial flight testing efforts.

3.1.5.2 Recently, there was a report of radio frequency interference to the localizer (110.5 MHz) at Marquette, Michigan. This interference was reported on runway centerline and was indicated by a drop in localizer flag current.

3.1.5.3 Using the Airspace Analysis Model, it was determined that the cause of the centerline interference was intermodulation between the Marquette VOR (109.0 MHz) and WMQT. The VOR is located 3 km (1.6 miles) from the threshold, 2 degrees right of the centerline extension. While other navaids are not usually considered in FM interference cases, this particular one offered a unique situation due to the location of the VOR. The VOR was treated as a radiating source just like an FM broadcasting station.

3.1.5.4 This case offered a good opportunity to validate the AAM predictions, since both the localizer and the VOR could be reduced in power or shut off completely to determine the effects of the interference. Consequently, the specially instrumented airplane was deployed to conduct flight measurements. Repeated approaches were made to the localizer and the following results were noted:

Run No.	VOR Status	TUNED FM Trap	CDI Indication	Flag Indication
1.	Normal	Not used	Slight Waiver	Fully visible
2.	Normal	Inserted	Steady	Barely visible
3.	Reduced 3 dB	Inserted	Steady	Flag Hidden
4.	New freq.	Not used	Steady	Flag Hidden

3.1.5.5 The existence of type B1 is clearly indicated by the above data since an attenuation of either the VOR or FM station signal eliminated the interference. The location and coverage of the measured interference corresponds to AAM predictions.

3.1.5.6 The operating frequency of the VOR was changed to eliminate the intermodulation and subsequent flight measurements indicate that the localizer interference is no longer present.

3.1.6 Future Enhancements

3.1.6.1 Presently, the Airspace Analysis Model will evaluate the effects of FM broadcasting stations to ILS localizers. This is being expanded to include the evaluation of FM broadcasting interference and VOR and COM service volumes. In the future, the AAM will evaluate the effects of VHF and UHF television stations to all aeronautical facilities in the 108-137 MHz band.

3.1.6.2 As these future enhancements are added, the capabilities of a micro-computer will be greatly taxed. Plans include adaptation of the AAM to operate on a supermini or possibly a mainframe computer. This will allow the evaluation of many more stations and the potential problems they may cause.

3.1.7 Interference Prediction Technique for Spurious Emissions Interference (type A1)

3.1.7.1 The spurious interference occurs when the receiver responds to components of the FM signal which are introduced into the aeronautical frequency bands, and thus, within the receiver (IF) response. The major factors involved in calculating interference of this form are the receiver sensitivity, the FM spurious emission limits, and the power (e.i.r.p.) of the FM station. The antenna, filter, and receiver selectivity of the aeronautical systems under these conditions have no effect as the FM spurious emission is an on-frequency interfering signal. Thus, spurious interference to VHF aeronautical systems can occur when:

e.i.r.p. $- L_D - S_R > R_S$ and,

where:

e.i.r.p.:	equivalent isotropic radiated power of the FM station (dBm) (e.i.r.p. = e.r.p. + 2.15 dB);
L_D:	free space transmission loss in dB;
S_R:	spurious emission limit in dB below the FM station power;
R_S:	receiver sensitivity in dBm.

3.1.7.2 For FM station No. 2 provided in the Figure 41 COM example:

e.i.r.p. =	164 kW or 82 dBm (for e.r.p. = 100 kW) including vertical antenna patterns as appropriate;
L_D =	37.8 + 20 log (119.3) + 20 log (3) = 89 dB;
S_R =	80 dB (required minimum suppression in U.S. for frequencies more than 600 kHz from carrier);
R_S =	-104 dBm (typical ground receiver).

Therefore: 82 dBm - 89 dB - 80 dB = -87 dBm which is approximately 17 dB greater than the typical aeronautical ground receiver sensitivity, therefore, spurious interference is possible under these conditions. If FM station No. 2 in Figure 41 was moved to a location approximately 38 km (21 NM) from the airport, or if the power of the FM station was reduced by 17 dB, or if the maximum spurious radiation was limited to 97 dB below the carrier the aeronautical ground facilities at the airport would be protected from FM broadcasting spurious interference.

3.1.8 Interference Prediction Technique for Aeronautical Receiver Oveaload (type B2)

3.1.8.1 Front end overload or desensitization of an aeronautical receiver occurs when the receiver RF section is driven into non-linear operation by the high-power FM signal. Intermediate frequency selectivity will not provide any protection as the overload occurs in the broadband RF section which will usually respond to most signals in the FM broadcasting frequency band. The current criteria for type B2 interference for airborne VHF communications receivers is -10 dBm at the input of the receiver and -4 dBm for ground VHF communications equipment. Overload (B2) and intermodulation (B1) interference contours for communications avionics from FM broadcasting stations is shown in Figure 41.

3.1.9 Venn Diagram Approach for Type B1 Interference to Communications and VOR Receivers

3.1.9.1 The following procedures, known as the "Venn Diagram" approach, continue to be used to evaluate the effect of FM broadcasting stations on airborne VHF communications and VOR navigations systems. This technique is to be phased out in favor of a more powerful computer model described in section 3.1.3. Until a sufficient empirical receiver data base is developed to support such an approach, the Venn Diagram approach will continue to be used. The necessary data base is being developed via bench testing of VOR and communications receivers in the United States.

3.1.9.2 Tests performed in 1978 on airborne communications receivers indicate that at least one strong FM signal (prime signal) is required to force the receiver RF part into non-linear operation. Once the receiver was operating in the non-linear mode, the prime signal could mix with other signals 10 to 20 dB lower in level (secondary signals) to produce harmful intermodulation products. Testing of receivers indicated that the minimum prime signal level at the input to the receiver was approximately -10 dBm for airborne communication receivers and -20 dBm for airborne navigation receivers. The minimum secondary signal level for both types of airborne systems was approximately -30 dBm. By assuming a lossless isotropic receiver antenna, no line loss, and free space propagation loss,* contour distances corresponding to received power levels of -10, -20, and -30 dBm can be calculated using the following formula:

$$d = \frac{\log^{-1}(e.i.r.p. - P - C - L_R)/20}{f}$$

---

* Free space loss closely approximates median transmission loss curves when transmitter and receiver are within line-of-sight (LOS). LOS for an aircraft at about 1500 m (5000 ft.) would be a minimum of 87 NM regardless of FM station antenna height.

where:

d: contour radius (nautical miles);

C: 37.8 for d in nautical miles, or 32.4 for d in kilometres;

e.i.r.p.: equivalent isotropic radiated power of the FM broadcasting station (dBm)(e.i.r.p. = e.r.p. + 2.15 dB) including vertical radiation patterns as appropriate;

f: FM centre frequency (MHz);

P: contour power level desired, either -10, -20, or -30 dBm;

L_R: avionics antenna out-of-band rejection.

Out-of-band avionic antenna rejection (L_R) is approximated as follows:

For a navigation antenna:

L_R = 3 dB; plus 1 dB/MHz below 108 MHz.

For a communication antenna:

L_R = 10 dB; plus 2 dB/MHz below 100 MHz.

3.1.9.3 The out-of-band antenna rejection value (L_R) is subject to wide variations which are a function of airborne antennas and installation differences.

3.1.9.4 Communications example

3.1.9.4.1 Figure 41 gives a pictorial presentation of the interference prediction method using the Venn diagram technique.

3.1.9.4.2 In this example, FM station No. 1 is presently operating on 96.5 MHz with 100 kW e.r.p. and is located approximately 55 km (30 NM) from the airport. FM station No. 2 is being proposed to operate on 107.9 MHz with 100 kW e.r.p. at a location approximately 5.6 km (3 NM) from the airport. An interfering intermodulation signal is predicted on the airport tower frequency 119.3 MHz (2 x 107.9 - 96.5 = 119.3). The solid circle indicates the -30 and -10 dB contours for FM stations No. 1 and No. 2, respectively. The crosshatched area indicates the area where intermodulation interference in COM receivers is likely. When the antenna rejection of the airborne communication antenna is considered, the respective interference contours would recede to those shown by broken circles. In this case intermodulation interference is significant only when the airborne communication antenna provides no rejection of the FM band. Even if FM station No. 1 was not involved, interference could result from the assignment or FM station No. 2 within the service volume of the tower frequency due to receiver front end overload (type B2) or spurious interference (type A1).

TABLE XXXIV

RECEIVERS TESTED

ARC	RT-384A
	RT-385A
Arizona Avionics	MX 300
Bendix	RNA 26C
	RNA 34A
Collins	VIR-30
	VIR-351 (2 units tested)
	51RV 1
	51RV 1A
	51RV 2B
	ILS 70
King	KX 155
	KX 170B
	KX 175B (2 units tested)
	KN 53 (2 units tested)
	KNS 80
	KNS 81
	KNR 615 (2 units tested)
NARCO	NAV 121 (3 units tested)
	NAV 824
	NAV 825
	MK 12D

TABLE XXXV

AIRFRAME CONFIGURATIONS

Airframe and antenna configurations measured for the antenna data base.

Piper Arrow IV	Dorne and Margolin DMN-42-1
Cessna 172	Antenna Specialists AL 12-L
Mooney M20C	VRP-37
Mooney 201	Dorne and Margolin DMN-48-1
Beechcraft Bonanza	Communications Components 35-50-11
A-36	Dorne and Margolin DMN-4-17E
	Dorne and Margolin DMN-48-1
Piper Twin Comanche	Unknown manufacturer, cat's whisker
Beechcraft Baron	Dorne and Margolin DMN-4-17
Beechcraft King Air	ARC AS580A
Model 100	Collins 137X-1
	Dorne and Margolin DMN-4-15-3
Beechcraft King Air Model 200	Dorne and Margolin DMN-4-15
Rockwell Saberliner NA265 Model 80	Dorne and Margolin DMN-4-15-3
Grumman Gulfstream GII	Collins 837B-1
	Dorne and Margolin DMN-20-1-9
McDonnel Douglas DC-9	Flush mount, vertical stabilizer
Boeing B-727	Flush mount, vertical stabilizer

TABLE XXXVI

FM BROADCASTING ANTENNA TYPES

FM broadcasting antenna types used for model vertical patterns.

3-bay	no beam-tilt	no null-fill
4-bay	no beam-tilt	no null-fill
6-bay	no beam-tilt	no null-fill
6-bay	-1.0° beam-tilt	no null-fill
6-bay	-0.5° beam-tilt	10% null-fill
7-bay	no beam-tilt	no null-fill
8-bay	-0.5° beam-tilt	20% null-fill
10-bay	no beam-tilt	no null-fill
12-bay	no beam-tilt	no null-fill
12-bay	-0.6° beam-tilt	12% first/5% second null-fill
14-bay	-0.5° beam-tilt	20% null-fill

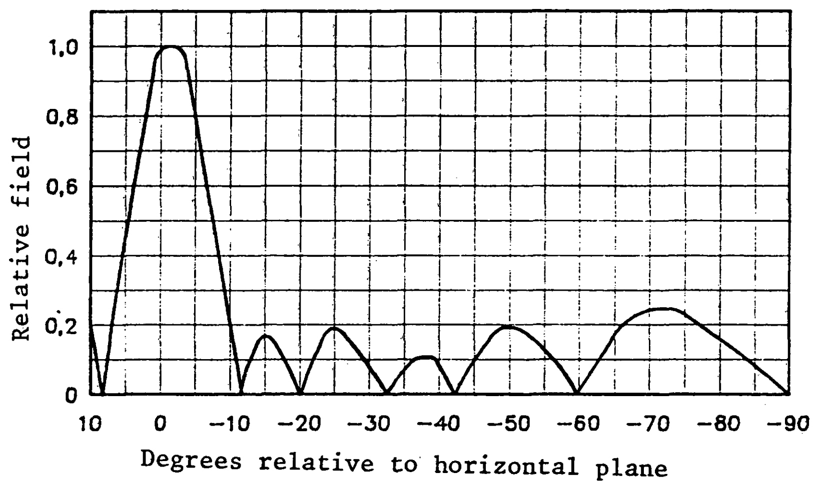


FIGURE 31 - Typical vertical radiation patter of an FM broadcasting antenna

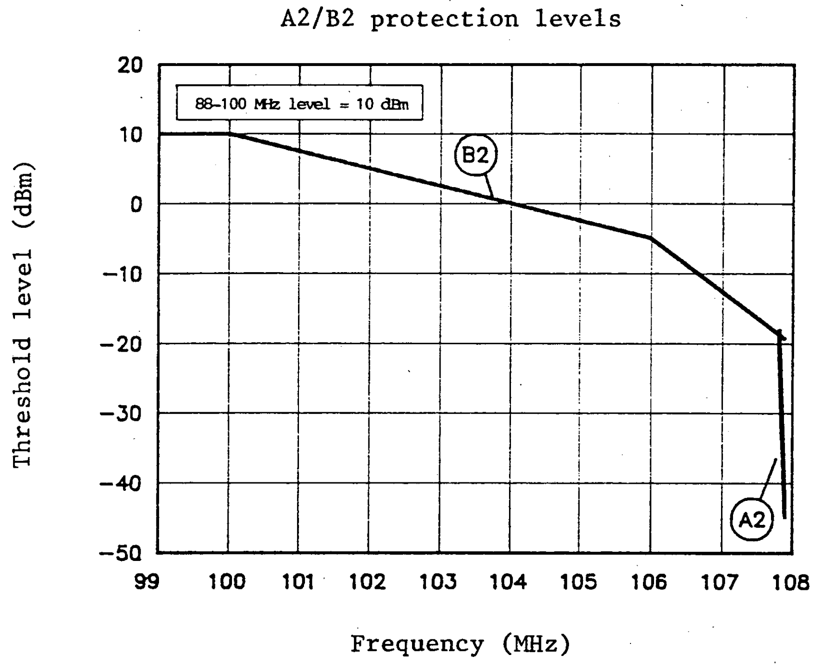


Figure 32 – A2/B2 Criteria used in the model

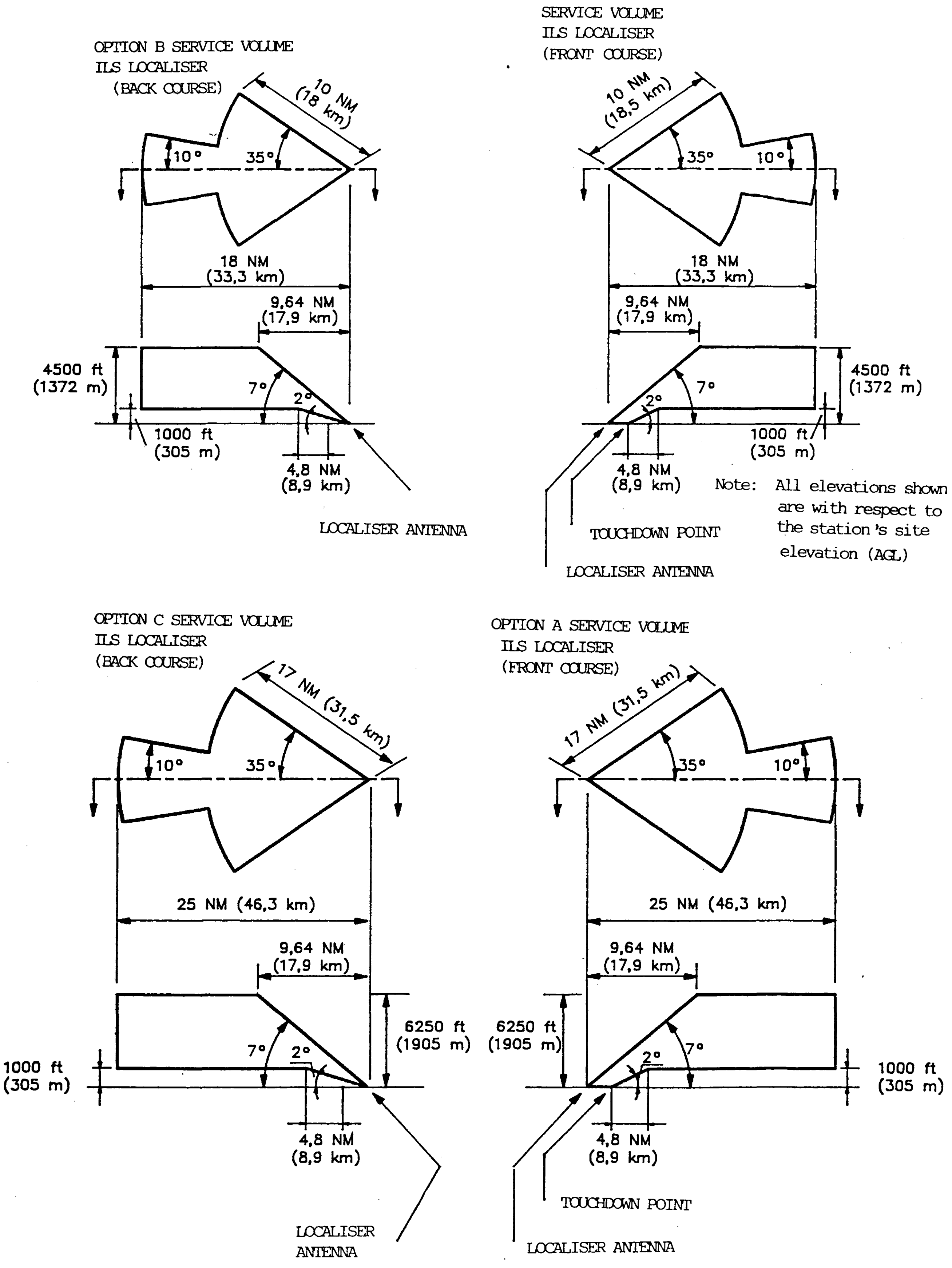


Figure 33- ILS Service Volumes in the United States

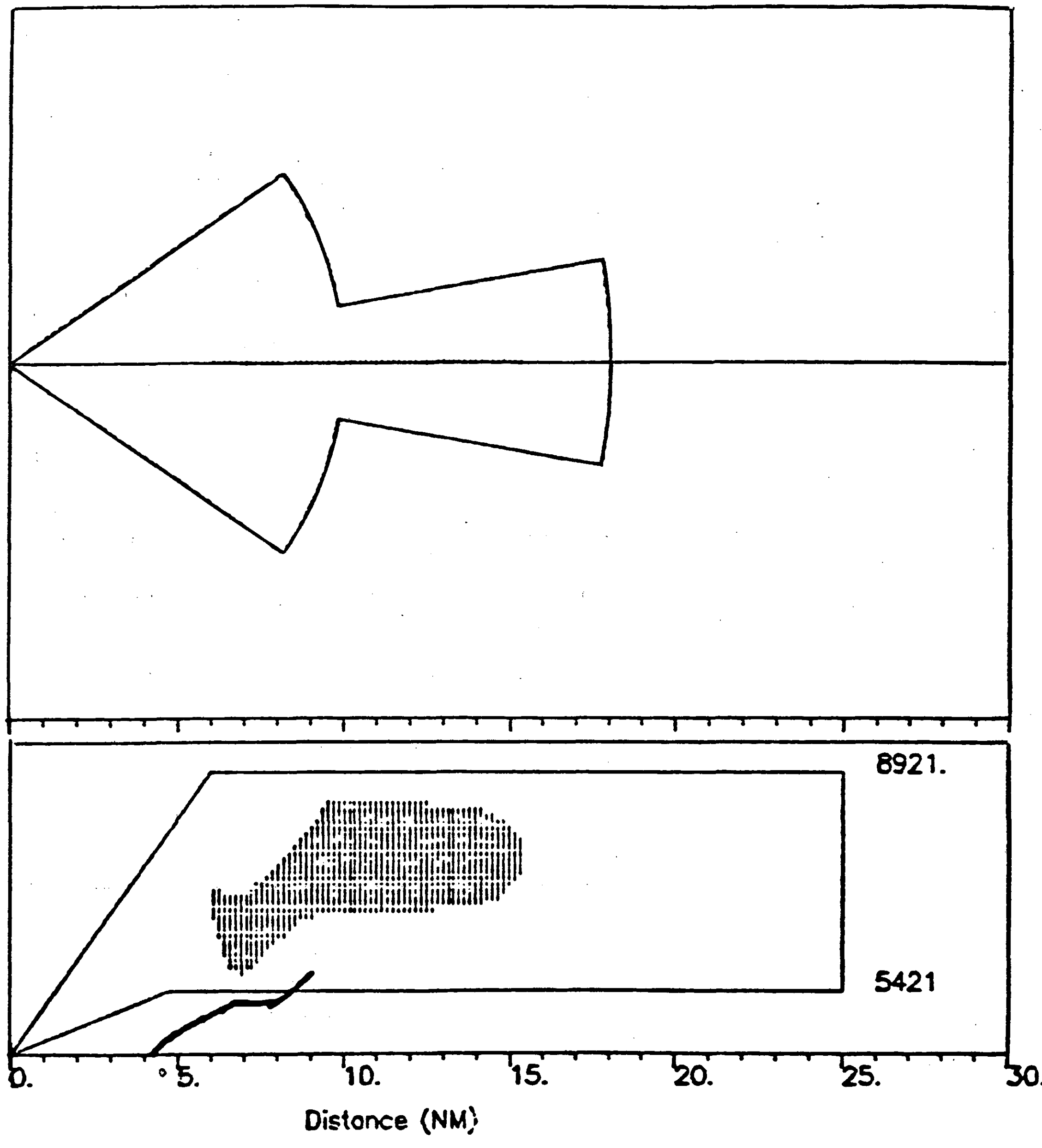


Figure 34 - Three Signal Intermodulation Product 100.9 MHz + 105.7 MH: - 97.3 MHz = 109.3 MHz. The solid line in the vertical slice shows the terrain contour protruding into the service volume.

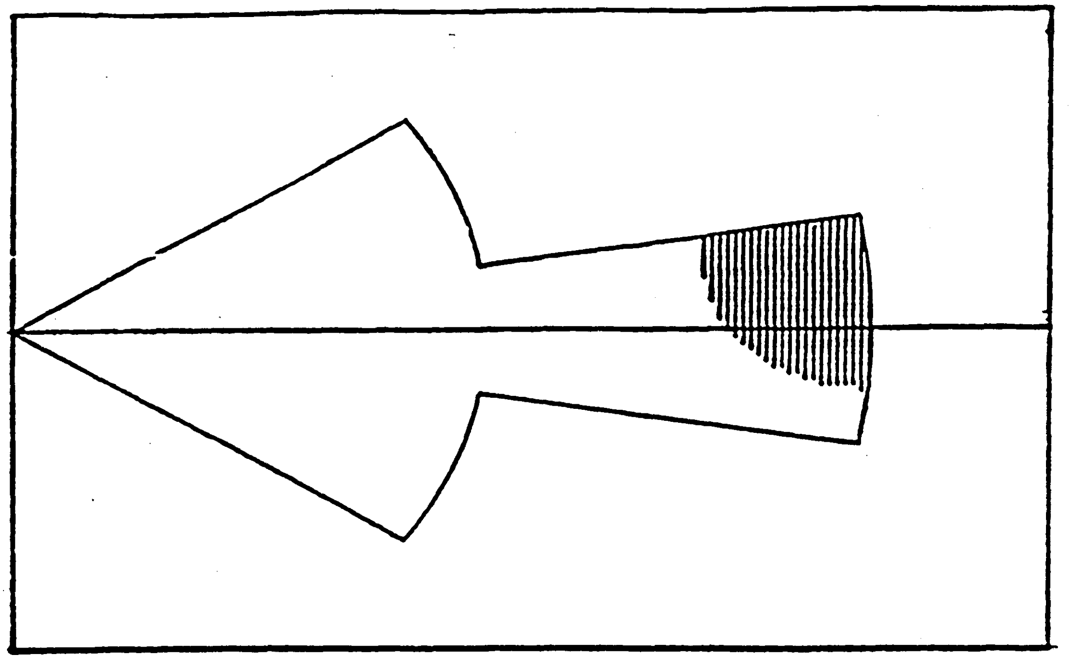


Figure 35 - Plot of -20 dBm (or greater) signal strength contour from a proposed FM transmitter antenna located at the edge of the service volume as calculated from the Venn diagram model.

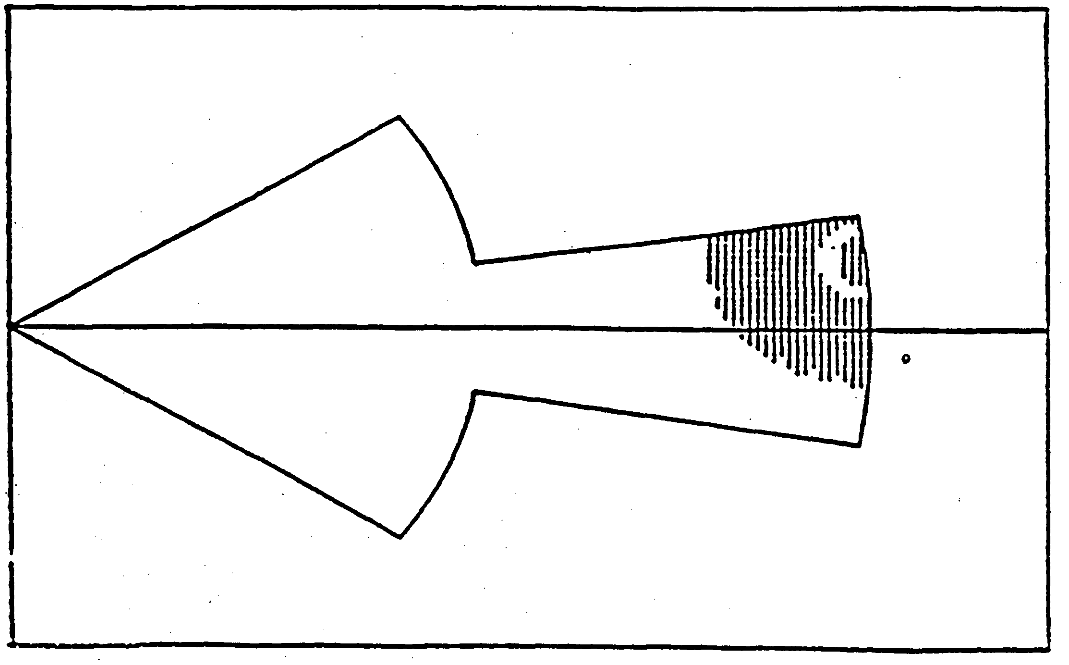


Figure 36 - Same scenario as in Figure 35, but using the computer mathematical model. The effect of the vertical FM antenna pattern manifests itself the clear circle within the contour where the signal strength falls below the threshold due to vertical lobing.

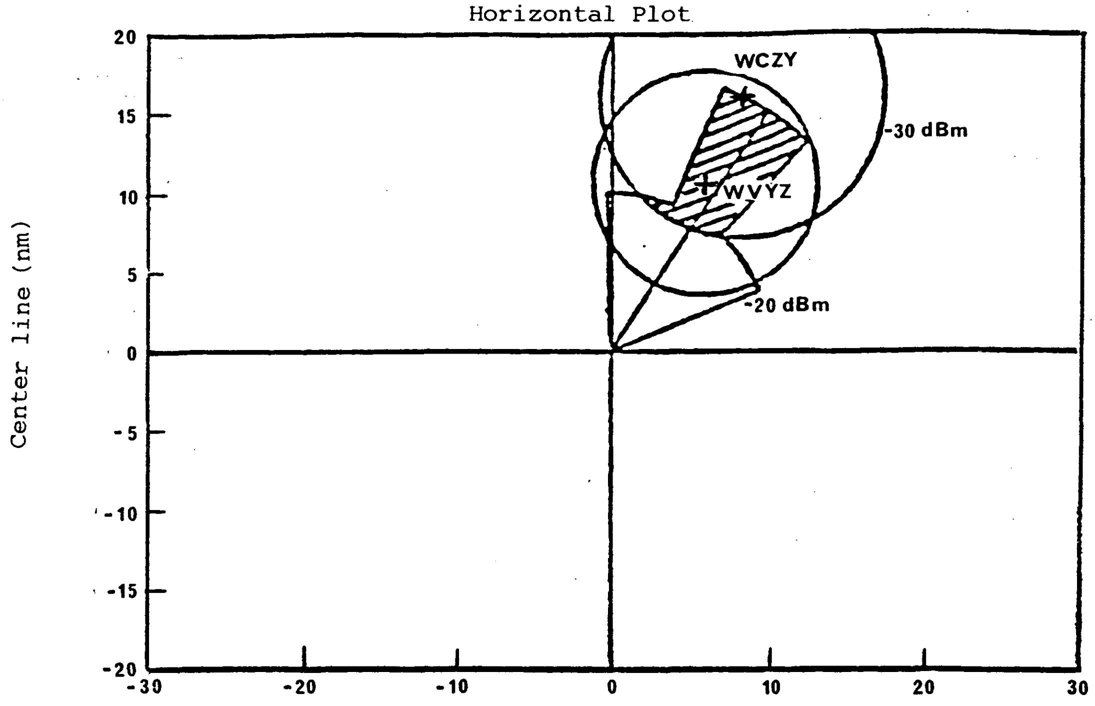


Figure 37 – Venn diagram approach to B1 intermod analysis for a typical FM antenna location.

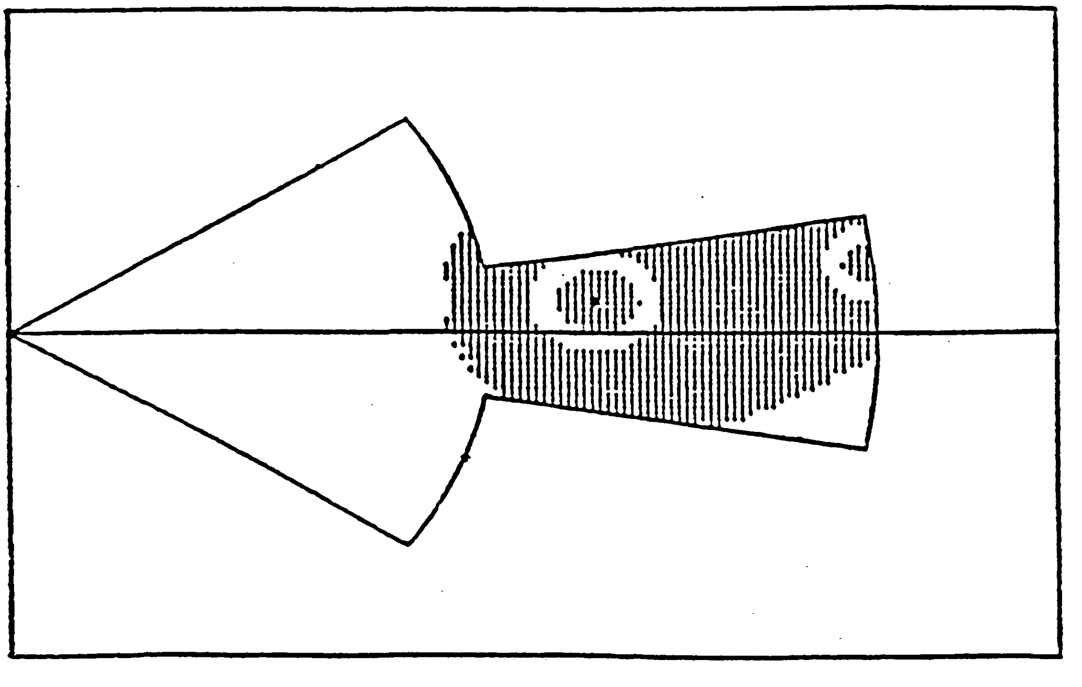


Figure 38 – Same scenario as in Figure 37, but using the computer mathematical model on the floor of the service volume and incorporating vertical FM broadcast antenna pattern data. Note the correlation with the shaded area in Figure 37. The notable exception is the clear circular areas where the interference criteria is not exceeded due to the vertical lobing of the FM antenna.

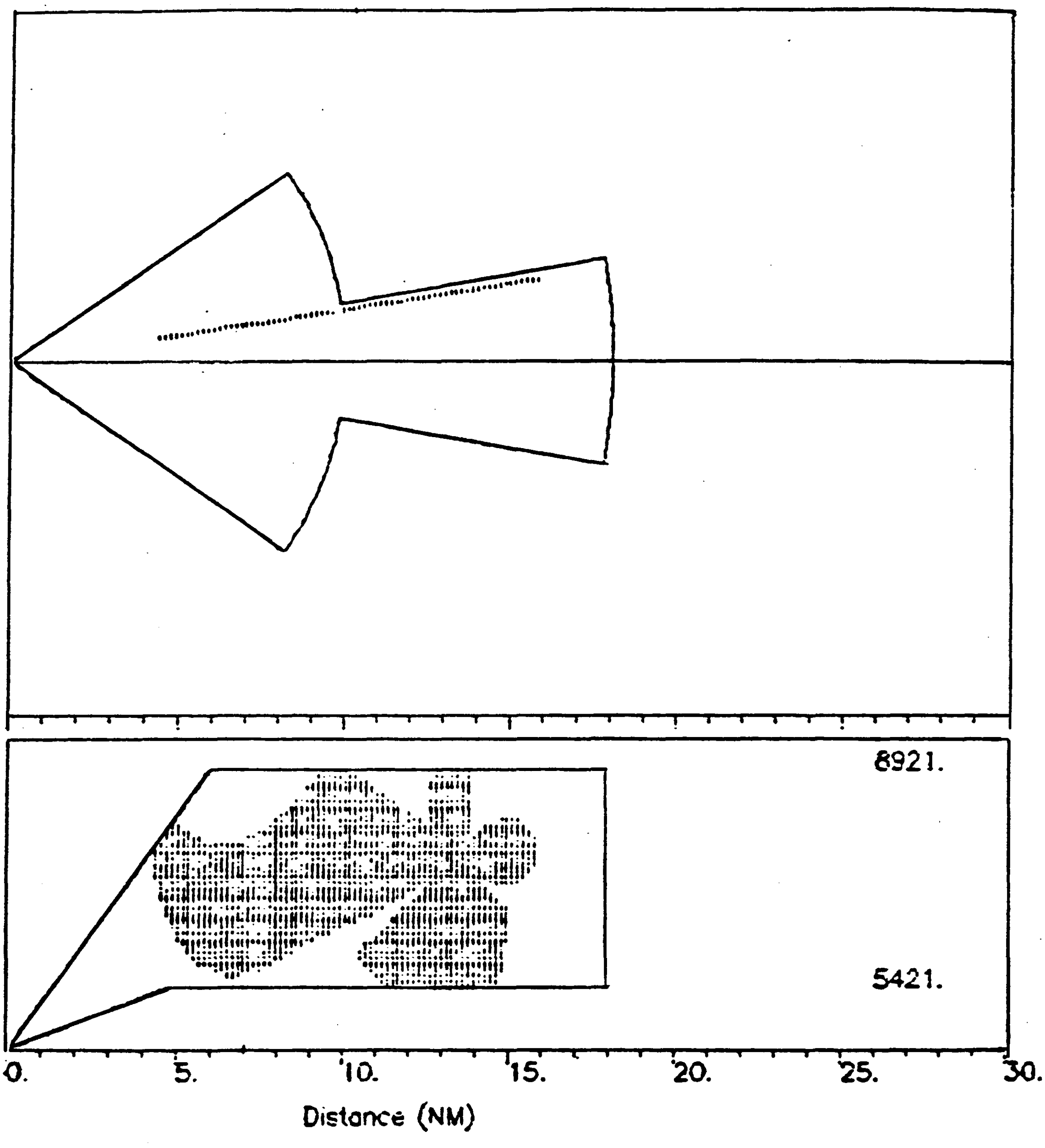


Figure 39 - Three signal intermodulation product of 105.7 MHz + 104.5 MHz - 100.9 MHz = 109.9 MHz showing distinctive lobing patterns in a vertical plane along a radial through the FM station.

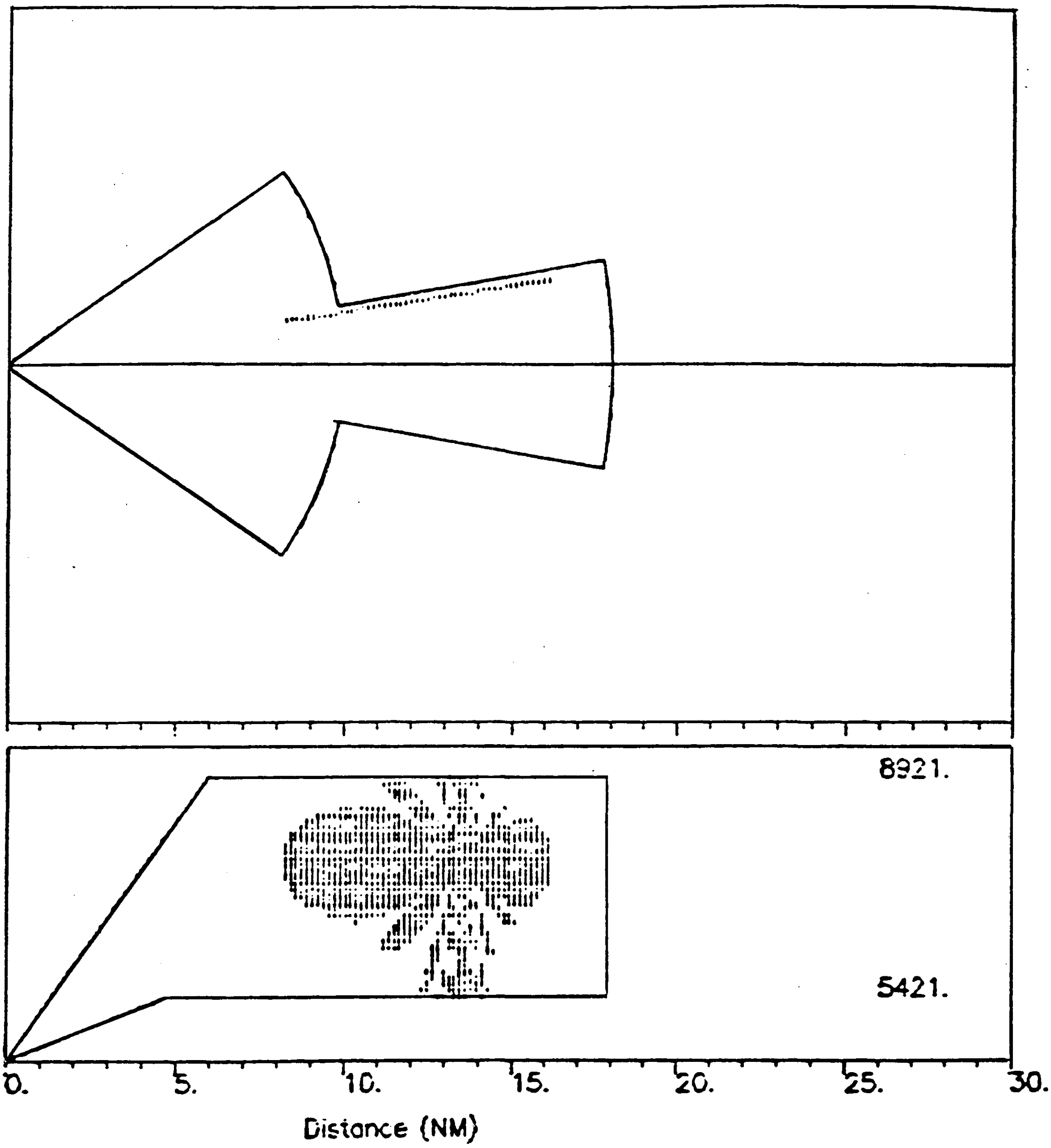


Figure 40 - Three signal intermodulation product of 100.9 MHz + 105.7 MHz - 97.3 MHz = 109.9 MHz showing distinctive lobing patterns in a vertical plane along a radial through the FM antenna

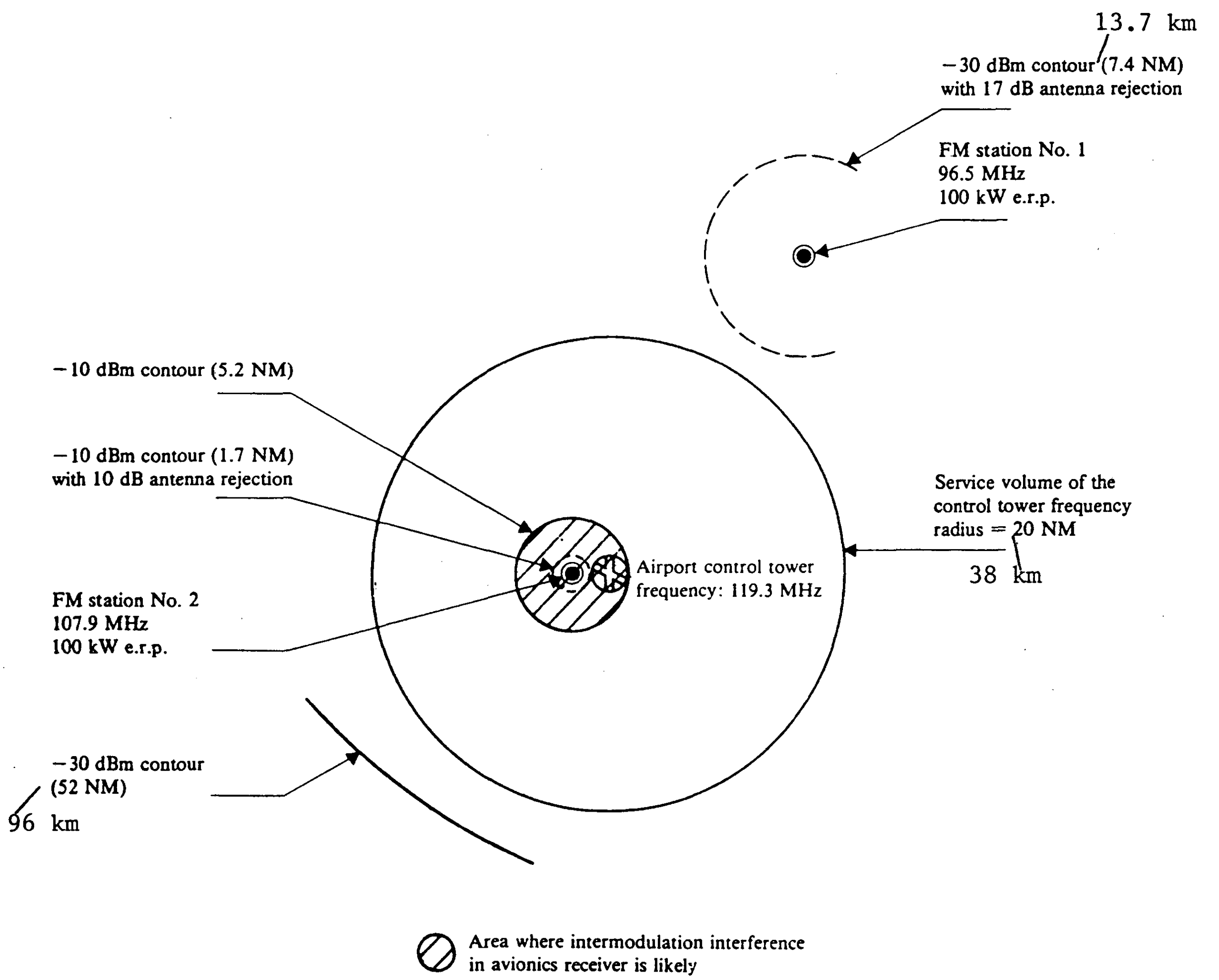


FIGURE 41 – *Example of method used to predict interference to communications receivers*

Bibliography

SAWTELLE, E.M. and DONG, J.G. [July, 1978] Interference in communications and navigation avionics from commercial FM stations. FAA-RD-78-35, National Technical Information Service (NTIS) US Dept. of Commerce, Washington DC, USA.

Part 4 of Annex II

The LEGBAC Unified Assessment Method for Aeronautical-Broadcast Compatibility

4.1 General

The central objective of the Unified Assessment Method is to define test or calculation points within the aeronautical service volume such that all significant potential incompatibilities are identified. These points will establish the maximum degree of potential incompatibility associated with a particular aeronautical service.

A method, different from that contained in the Geneva Agreement, 1984, was necessary because the principles used at that Conference to identify potential interference cases were not complete, mainly because of the lack of sufficient test points.

The Unified Assessment Method is based upon protection of the aeronautical radionavigation service down to a height of 600 metres above local terrain. In areas where aircraft are approaching or landing at or departing from an aerodrome, protection is assumed down to ground level. For VOR where the antenna of the broadcasting station is more than 300 metres above local terrain, a minimum vertical separation between an aircraft and the top of the antenna is assumed to be 300 m while the minimum lateral separation would not be less than 3 km.

From the aeronautical operational point of view these lower limits were considered to reflect in general the normal operational use of these radionavigation facilities.

When setting a minimum altitude for the testpoints the effect of the vertical radiation pattern of the broadcasting antenna may be used in compatibility calculations.

Although they are based upon the same principles, two different methods for assessing compatibility were agreed, one for ILS and one for VOR.

The method to be used for assessing compatibility with ILS is based upon a sufficient number of fixed test points within the ILS service volume to identify every potential interference case using, within certain limitations, the vertical radiation pattern and the actual slant path.

This method indicates the protection margins or interference margins at the test points.

When assessing compatibility with VOR, test points inside the VOR service volume will be selected vertically above the broadcasting station. In this case the reduction of the e.r.p. due to the vertical radiation pattern is at a fixed value.

4.2 Antenna Corrections

4.2.1 Polarization

In general no account is taken of any polarization discrimination between broadcast and aeronautical radionavigation transmissions. In the special case of mixed polarization with equal horizontal and vertical components, an allowance, indicated in Section 7.4 of Annex 2 of Geneva Agreement, 1984, is made by adding 1 dB to the e.r.p. of the polarization component in the same plane as that used by the radionavigation system.

4.2.2 Horizontal Radiation Pattern (HRP)

For a broadcast station having a directional antenna in the Geneva Plan, 1984, HRP data are specified at 10 degree azimuth intervals. HRP corrections are generated using linear azimuthal interpolation of values expressed in dB.

4.2.3 Vertical Radiation Pattern (VRP)

With a view to reducing the number of potential incompatibilities advantage can be obtained by taking account of the attenuation due to the VRP of broadcast antennas. Such VRP corrections would be applied only for angles above the horizon from the broadcast antenna.

Within the design of broadcasting antennas a number of configurations is available. These can vary from a simple antenna such as a dipole, as often used at low power stations, to the more complex multi-tiered antenna normally used at high power stations.

Table VI can be used as a guide to the relation between the maximum total e.r.p. and the vertical aperture in wavelength.

TABLE XXXVII

MAXIMUM TOTAL e.r.p.	VERTICAL APERTURE IN WAVELENGTHS
e.r.p. > = 44 dBW	8
37 dBW < = e.r.p. < 44 dBW	4
30 dBW < = e.r.p. < 37 dBW	2
30 dBW > = e.r.p.	1

4.2.3.1 VRP corrections for vertical apertures of two or more wavelengths

In order to calculate the VRP correction, V, the following formula can be used:

$$V = -20 \log (\pi . N . \sin\theta) \text{ dB}$$

where N = vertical aperture in wavelength

θ = elevation angle relative to the maximum (normally horizontal).

It should be noted that for small elevation angles this expression can produce positive values for V. In such cases V is set to 0 dB (i.e.: no VRP correction is applied).

For high elevation angles the VRP correction is limited to a value of -14 dB.

i.e.: 0 >= VRP correction >= -14 dB.

This formula has been chosen as a suitable compromise for all polarizations.

4.2.3.2 VRP corrections for vertical apertures less than two wavelengths

In order to determine the VRP corrections, the values in Table XXXVIII should be applied.

The table specifies the correction values for every ten degrees. For intermediate angles linear interpolation should be used.

These values in this table have been chosen as a suitable compromise for all polarizations.

The limiting value of -8 dB takes account of the worst case slant path.

TABLE XXXVIII

Elevation angle (degrees)	VRP Correction dB
0	0
10	0
20	-1
30	-2
40	-4
50	-6
60	-8
70	-8
80	-8
90	-8

4.2.3.3 VRP correction for spurious emissions in the band 108-118 MHz

Taking account of the approximations inherent in the formula given in 2.3.1 and in Table XXXVIII these VRP corrections may be assumed to apply also to spurious emissions in the band 108-118 MHz.

4.2.4 Combining VRP and HRP corrections

Experience has shown that it is very rarely necessary to take HRP corrections into account for elevation angles of more than 10 degrees.

At the elevation angle of 90 degrees no HRP correction is applied.

HRP and VRP corrections in dB should be added arithmetically subject to a maximum total reduction of 20 dB.

4.3 Application of Unified Assessment Method

4.3.1 General considerations

In applying the Unified Assessment Method the compatibility criteria contained in the Geneva Agreement, 1984 (Annex 2, para 7.6) except regarding the cut-off values (see Appendix 1), shall be used.

Broadcast stations to be included in a particular analysis at a test point, are subject to the distance limits given in Attachment 1, consistent with an overall upper limit of 125 km in the cases of A1, A2 and B2 type interference.

Spurious emissions (A1 type) except radiated intermodulation products (IP), should, as a general measure, be kept at such a low level that there will be no incompatibility to be considered further in the compatibility analysis. Hence A1 calculations are to be made only for the case of radiated IP from co-sited transmissions.

Transmissions are considered to be co-sited when the geographical coordinates are the same.

To allow for the variation of A1 suppression with transmitter power, the following values are to be used:

-e.r.p. > 48 dBW suppression = 85 dB;
-e.r.p. = 30 dBW suppression = 76 dB;

between the given values, linear interpolation is to be used.

-e.r.p. < 30 dBW suppression = 46 + e.r.p. (in dBW) dB;

To calculate A1 margins consistently, the following procedure has been adopted.

For each of the possible contributors:

- calculate the interfering field-strength level at the test point, taking account of the e.r.p. of the broadcasting transmission in the relevant direction and subtracting the relevant A1 suppression value;

- derive the A1 margin from the highest value of interfering field strength, the level of the wanted signal (32 dB (μV/m) or 39 dB (μV/m)) and the protection ratio appropriate for the frequency difference between the intermodulation product and the aeronautical frequency;

- in the case of mixed polarized transmissions the suppression ratio and the assumed vertical aperture are derived on the basis of the total e.r.p. However, the e.r.p. to be used for the determination of protection margins shall be:

  - the larger of the VP and HP components in cases where they differ in value;

  - the total e.r.p. reduced by 2 dB in cases where the VP and HP components are of equal value.

The procedure described above for the determination of antenna vertical apertures in the case of mixed polarized transmissions applies also for calculation of B1 and B2 margins.

Information on actual radiated IP levels as well as antenna gain will be used if available when calculating A1.

In an analysis the B2 type interference is calculated before B1.

4.3.2 Compatibility calculations for ILS service volumes

4.3.2.1 Test point location and height

The distance and bearing, relative to the ILS localizer site and centre line, for each test point are given in Table VIII.

The convention adopted for bearings is that locations which are clockwise of the ILS centre line, as viewed from above, are to be regarded as having positive bearings.

Calculations for test points A, E, F and G, which are within the ILS critical zone and within 9 km of the touch down point, are to be made for a height of 300 m above the localizer site.

Calculations for the remaining test points are to be made for a height of 600 m above the localizer site.

4.3.2.2 Minimum separation distance

The slant path distance between the BC antenna and a test point is to be used in field strength calculations. However, the following minimum values of lateral separation distance are to be used:

100 m if the BC station is within or below the ILS critical zone.

300 m if the BC station is not within or below the ILS critical zone.

4.3.2.3 VRP Correction

The VRP correction procedure described in Section 4.2.3 is to be applied.

4.3.2.4 Calculations for B1 compatibility

Within or below any ILS service volume, calculations for B1 compatibility shall be made for the test point specified in Section 4.3.2.1 taking account of the special provisions of Sections 4.3.2.2 and 4.3.2.3.

The resultant protection margins shall be printed if worse than 0 dB recognizing that the worst margin may not be representative.

4.3.2.5 Calculations for A1, A2 and B2 compatibility

Calculations are to be made for the test points specified in Section 4.3.2.1 account being taken of the special provisions of Sections 4.3.2.2 and 4.3.2.3. the results are to be printed if the protection margins are worse than 0 dB.

If the BC antenna is within or below the ILS critical zone, calculations are also made for a lateral separation distance of 100 m in the horizontal plane through the BC antenna, using the maximum value of the e.r.p. If the protection margin is worse than 0 dB, the results are printed together with the distance and bearing of the BC station from the localizer site.

If the BC station is within or below the ILS service volume but outside the ILS critical zone, calculations are also made for a test point location above the BC station (for a height of 600 m above the localizer site). The relevant maximum VRP correction derived from Section 4.2 is applied. However, if the BC antenna is more than 500 m above the localiser site, these calculationa are made for a lateral separation distance of 300 m in the horizontal plane through the BC antenna using the maximum value of the e.r.p. If the protection margin is worse than 0 dB, the results are printed as in the previous paragraph.

4.3.3 Compatibility calculations for VOR service volumes

Test points are selected in accordance with the criteria set out in 4.3.3.1 and 4.3.3.2 below. For each of these test points field strength calculations are carried out and th values obtained may be used directly for A1, A2 and B2 analyses. At any test point where the signal level is above the B1 trigger level, the test point is retained for further B1 calculations. However, the B1 potential incompatibility is printed only if it involves one of the transmitters on the site of the transmitter which caused the test point to be generated.

4.3.3.1 Test point height

Test points should be selected within the designated operational coverage (DOC) as promulgated by ICAO.

The lower boundary of the DOC is assumed to be:

- 600 metres above local terrain as determined by the site height of any relevant broadcasting station;

- 300 metres above the relevant broadcasting antenna;

- the height derived from Figure 43, to which is added the height above mean sea level of the VOR site, if known;

whichever is the greatest.

The minimum altitude of the aircraft antenna is, for compatibility assessment purposes, at least 600 m above ground level. This implies that interference to the VOR at heights below 600 m, within line-of-sight of the VOR, is not calculated.

The minimum height of the test points determines the vertical separation from the BC antenna. When a VRP reduction of 14 dB is assumed (see para 4.2.3.1), a vertical separation of 300 to 600 metres corresponds to a lateral separation distance of 1500 to 3000 metres. This excludes the need to define a minimum lateral separation distance. It provides also for adequate test points when the VOR is used as an intermediate or final approach aid, since the minimum separation distance between an aircraft and a broadcasting antenna is assumed to be not less than 3 km.

4.3.3.2 Test point location

4.3.3.2.1 Test points related to broadcasting transmitters that are inside the DOC

Test points are located above the broadcasting antenna, as indicated in 4.3.3.1.

4.3.3.2.2 Test points related to broadcasting transmitters that are outside the DOC

Broadcasting stations in the near vicinity of the DOC within an extended zone of 3 km should be treated as in 4.3.3.2.1; for stations outside this zone an appropriate test point will be generated at the nearest point on the edge of the DOC, and at a height which is the greatest of

- BC antenna height above mean sea level;
- the height derived from Figure 43, to which is added the height above mean sea level of the VOR site, if known;
- 600 m above mean sea level.

4.3.3.3 Results shall be printed for each test point at which the protection margin is worse than 0 dB.

TABLE XXXIX

Test point locations

Identification	Distance in km	Relative bearing in degrees	
A	0	0	)
E	3	0	)
F	6	0	) Within ILS
G	9	0	) critical zone
H	12	0	)
I	15	0	)
J	21.25	0	)
K	27.5	0	)
L	33.75	0	) along centre
M	40	0	) line
D	46.3	0	)
B	31.5	-35	
C	31.5	35	
X0	7.7	- 6	
Y0	7.7	35	
X1	12.9	-25.5	
Y1	12.9	25.5	
X2	18.8	-17.2	
Y2	18.8	17.2	
X3	24.9	-12.9	
Y3	24.9	12.9	
X4	31.5	-10	
Y4	31.5	10	
X5	37.3	-8.6	
Y5	37.3	8.6	
X6	43.5	-7.3	
Y6	43.5	7.3	
X7	18.5	-35	
Y7	18.5	35	
X8	24.0	-27.6	
Y8	24.0	27.6	
X9	29.6	-22.1	
Y9	29.6	22.1	

TESTPOINT LOCATIONS

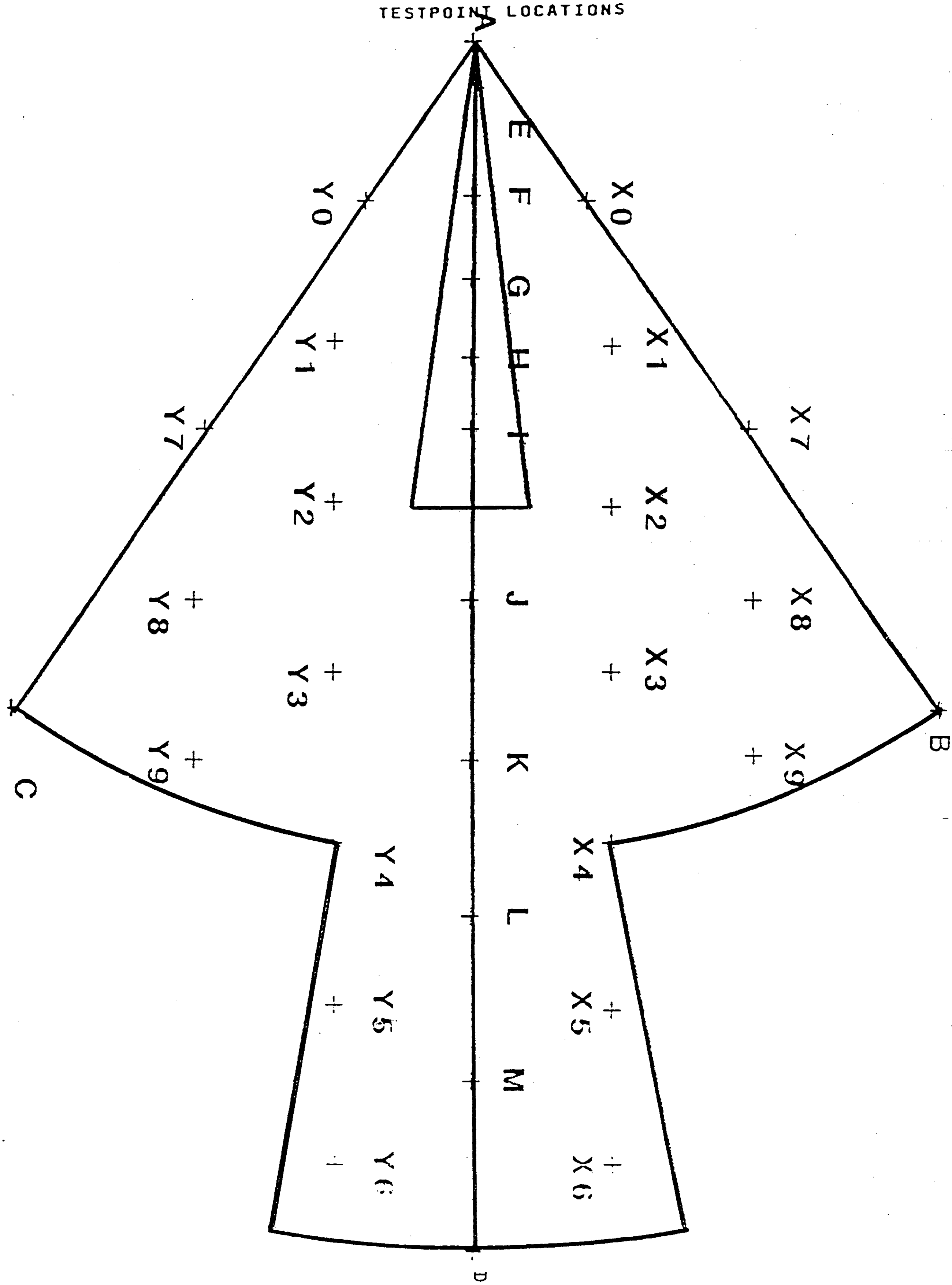
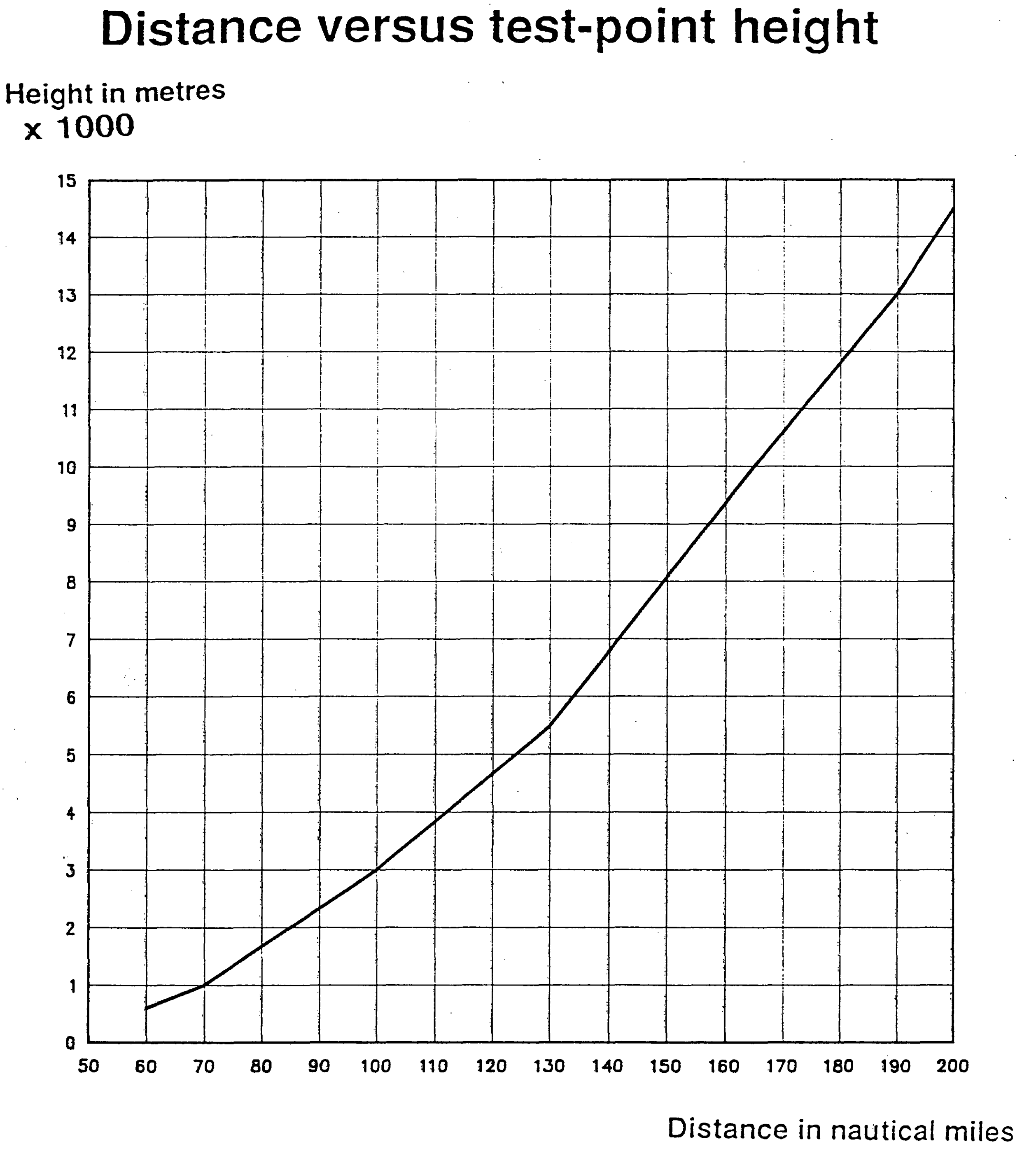


Figure 42



This curve is derived from ICAO documentation and shows the minimum height at which a satisfactory VOR service can be expected for any particular range.

Figure 43

TABLE XL

Coordination distances

Effective radiated power of Broadcasting station.		Broadcasting station frequency (MHz)						
		≤ 100	102	104	105	106	107	107.9
dBW	kW	Separation distance (km)						
55	300	125	210	400	500	500	500	500
50	100	75	120	230	340	500	500	500
45	30	40	65	125	190	310	500	500
40	10	25	40	70	105	180	380	500
35	3	20	20	40	60	95	210	500
30	1	20	20	25	35	55	120	370
25	0.300	20	20	20	20	30	65	200
20	0.100	20	20	20	20	20	40	115
≤ 15	≤0.030	20	20	20	20	20	20	65

Linear interpolation shall be used for e.r.p. (dBW) and frequency values not appearing in the table.

These coordination distances assume a cut off value of

$$-66 + 20 \log \frac{\max\ (0.4;\ 108.1-f)}{0.4}$$

Part 5 of Annex II to Report 929

Compatibility assessment method used in Poland

In general terms, the compatibility criteria and procedure specified in the Geneva Agreement, 1984 are applied, although some of them have been modified, as indicated below:

1. FM antenna vertical radiation pattern. A model similar to that proposed in Report 1198, Annex III Section 2, is used with the value of maximum reduction modified to correspond with the performance of antennas produced in Poland.

2. Interfering signal propagation model. Free space propagation is assumed with an attenuation value of 20 dB applied beyond the radio horizon.

3. Receiver model. The model of the Geneva Agreement, 1984 is applied with an improvement taking into account the level of wanted signal:

   - A1: the predicted wanted signal field strength is taken to calculations instead of the minimum signal level.

   - B1: the constant in the B1 criterion is reduced by the value of the difference between the predicted wanted signal level and the minimum signal level.

The test point distributions assumed are given in Figures 44 and 45.

In the case of ILS test points, the heights chosen correspond to the minimum glide slope. Points at a given distance are all assigned the same height value.

In the case of VOR and VHF COM, heights of 2000, 5000, 7600 and 10000 m are used for each test point location.

The test points are located along the airways at 15 km intervals. However, any point near a broadcasting station will be moved:

- to be coincident with the station, if this is under the airway, or,

- to the edge of the airway for stations just outside the horizontal limit of the airway (see Figure 45).

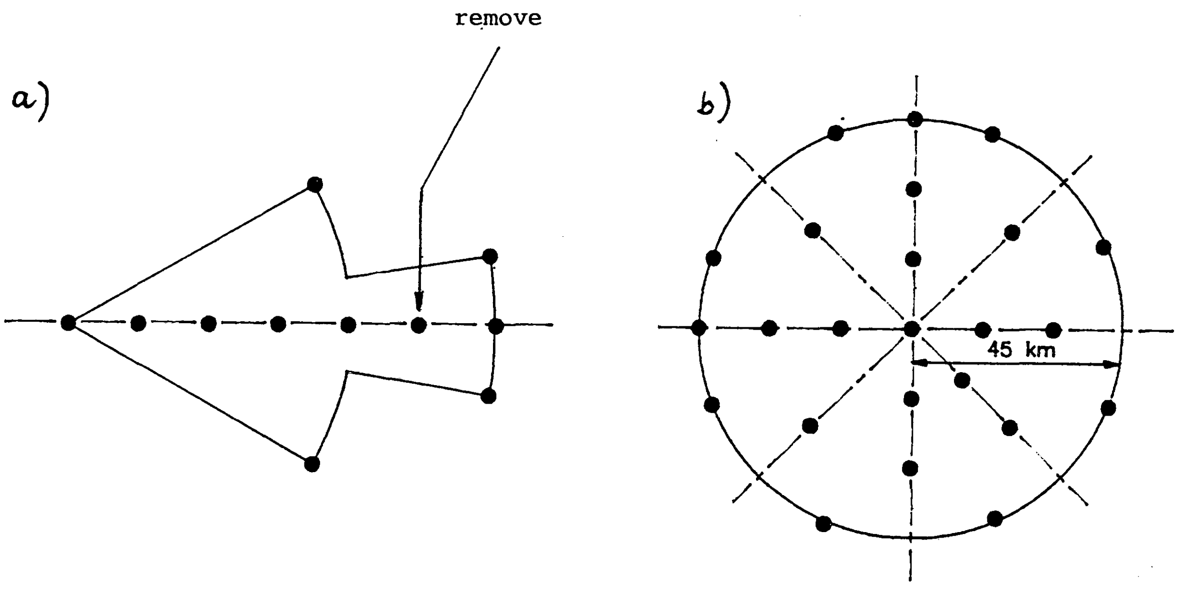
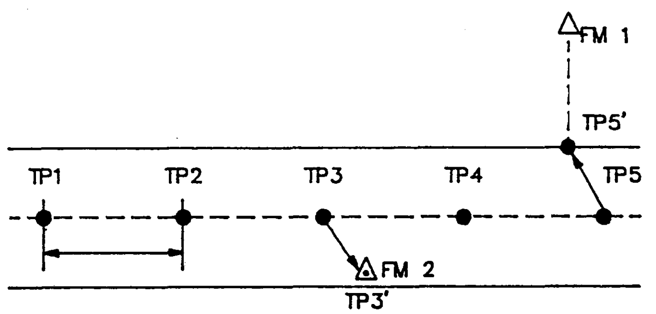


Fig. 44 - Test point distribution for a) ILS, and b) VHF COM, e.g. tower communications



TP 3' instead of TP 3
TP 5' instead of TP 5

Fig. 45 Test points for VOR and VHF COM

Part 6 of Annex II

Analyses and Practical Experience

6.1 Region 1 Analyses

Analyses of the Geneva Plan, 1984, in Region 1 indicates a considerable number of potential theoretical incompatibilities with the aeronautical radionavigation services resulting from application of the protection criteria contained in the Geneva Agreement, 1984.

6.2 Region 2 Analyses and Practical Experience

With regard to Region 2, studies have been made to apply the FM/Aeronautical compatibility criteria embodied in the Geneva Agreement, 1984, to the North American area where thousands of FM broadcasting stations have been operating for many years throughout the band 88-108 MHz, at maximum e.r.p. values of 100 kW. ILS localizer systems at Washington, D.C.; San Diego; St. Louis; Miami; New York City and Denver were analyzed using FM stations selected using the table in Annex 5.1. of the Geneva Agreement, 1984, implicating FM transmitters currently operational, (see Figures 46 to 51). The theoretical analyses did not take into account terrain effects, flight operation, restrictions on traffic flow due to saturation of airway facilities in high density terminal areas or physical obstructions.

In practice, all of the FM stations included in the ILS analyses for the above mentioned cities operate compatibly with the indicated aeronautical facilities.

PLOT OF FM STATIONS (+) CENTERED AROUND THE WASHINGTON, D.C. ILS TRANSMITTER LOCATION (O)

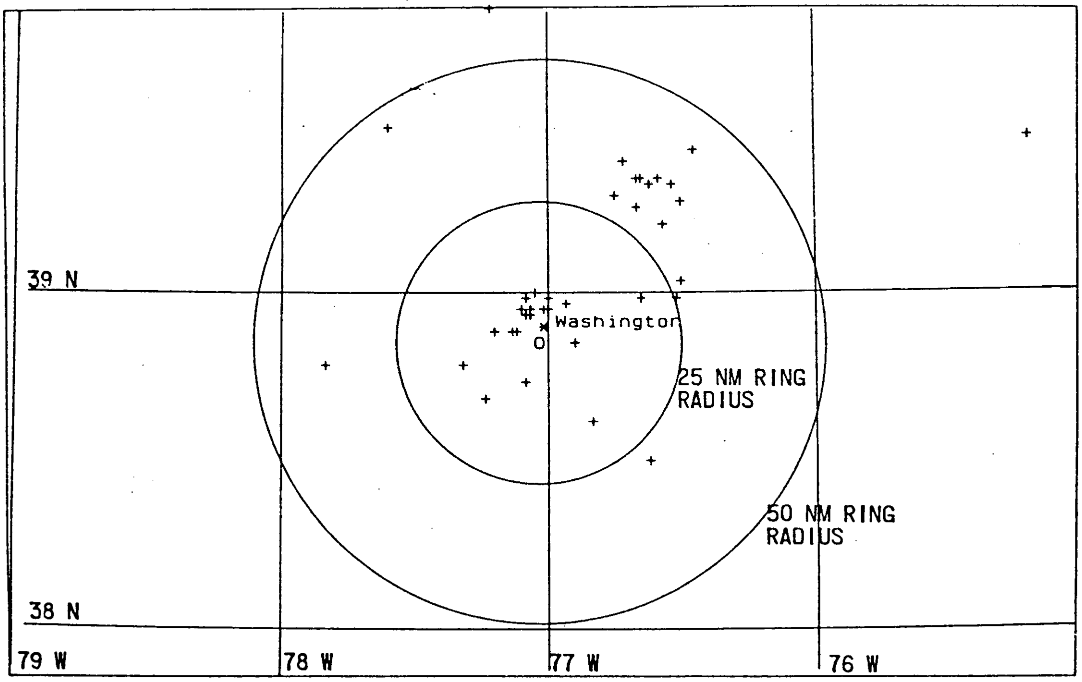


FIGURE 46

PLOT OF FM STATIONS (+) CENTERED AROUND THE SAN DIEGO ILS TRANSMITTER LOCATION (O)

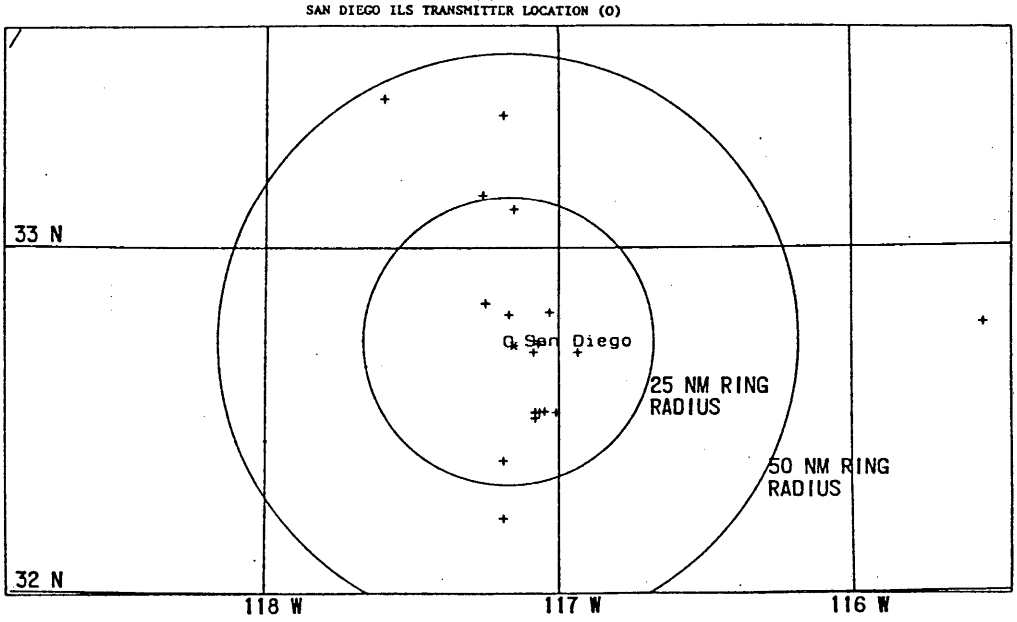


FIGURE 47

PLOT OF FM STATIONS (+) CENTERED AROUND THE
ST. LOUIS, MISSOURI ILS TRANSMITTER LOCATION (O)

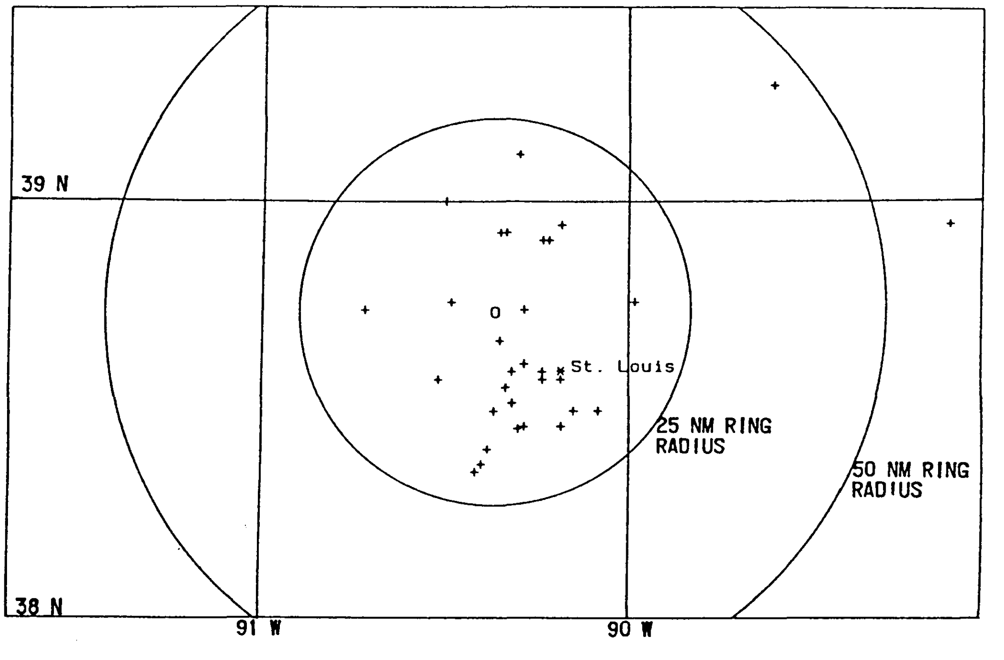


FIGURE 48

PLOT OF FM STATIONS (+) CENTERED AROUND THE
MIAMI, FLORIDA ILS TRANSMITTER LOCATION (O)

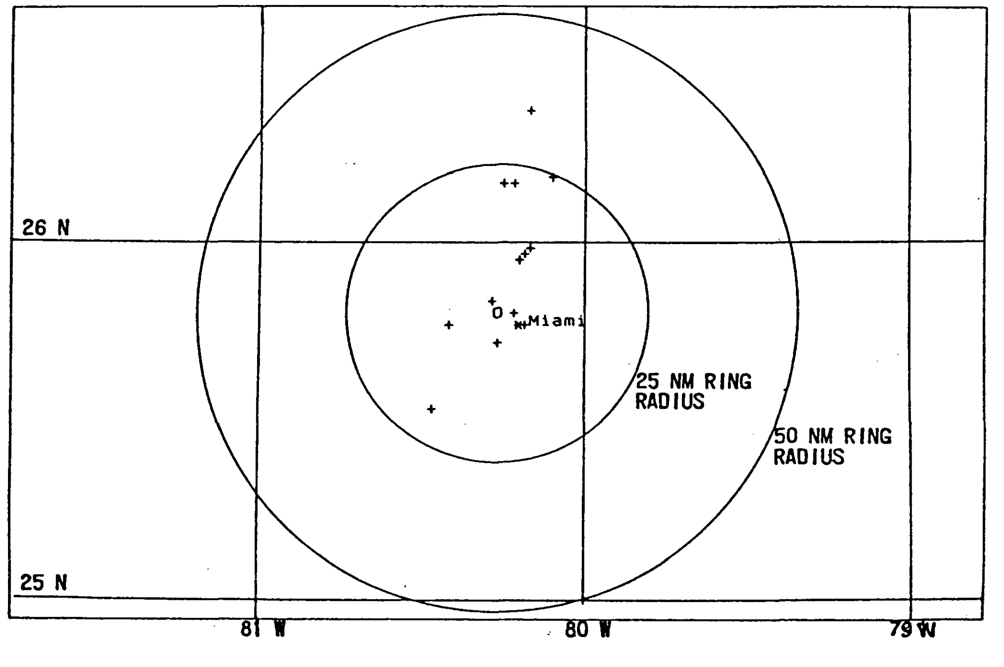


FIGURE 49

PLOT OF FM STATIONS (+) CENTERED AROUND THE NEW YORK CITY ILS TRANSMITTER LOCATION (O)

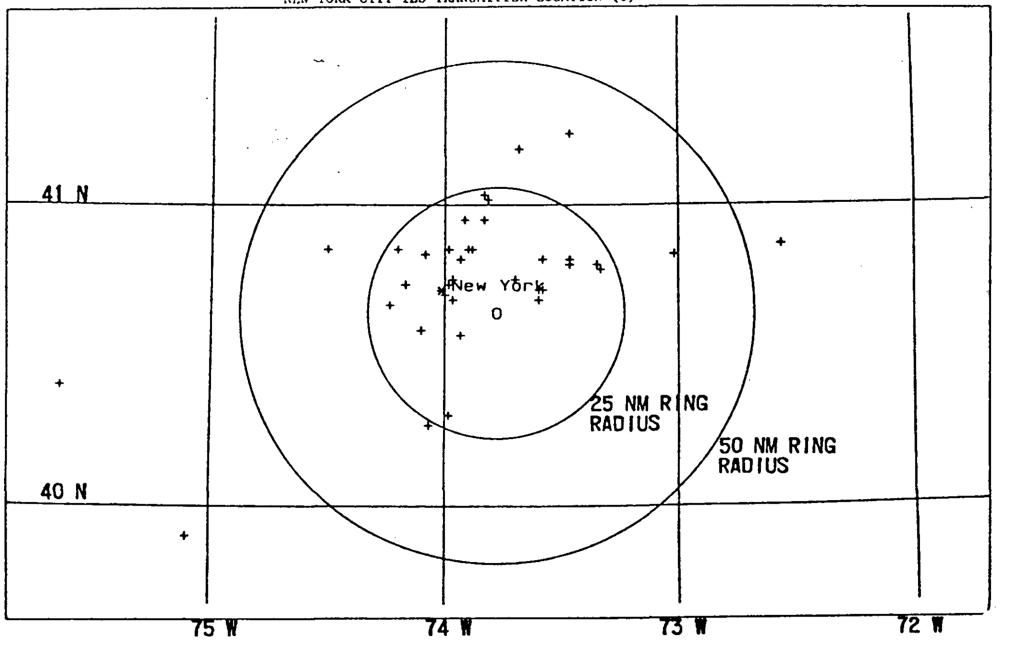


FIGURE 50

PLOT OF FM STATIONS (+) CENTERED AROUND THE DENVER-STAPLETON ILS TRANSMITTER LOCATION (O)

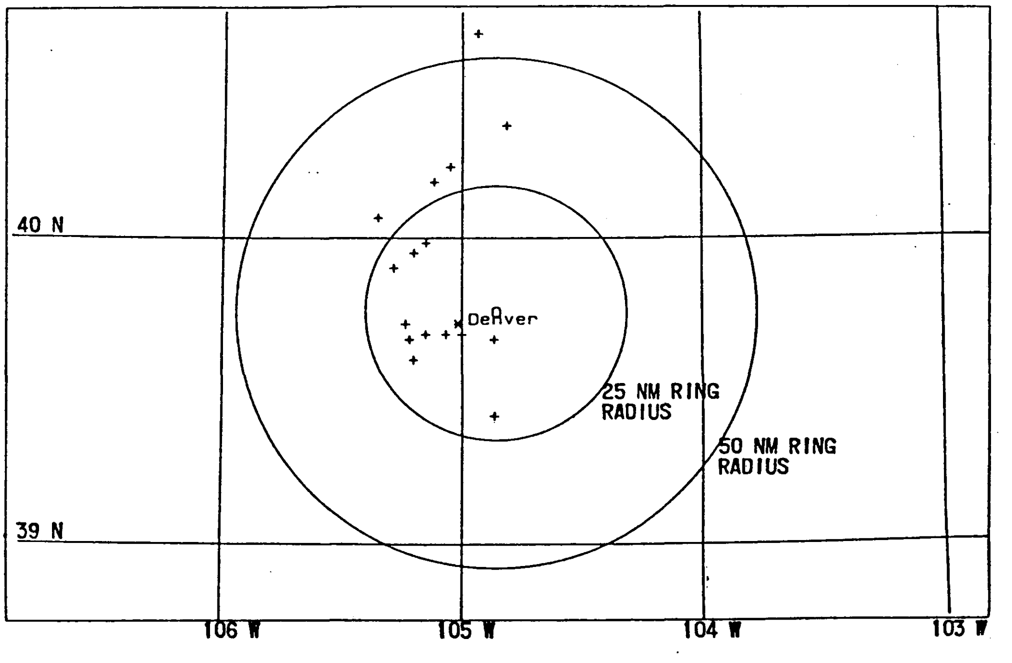


FIGURE 51

ANNEX III

SUMMARY OF INTERFERENCE THRESHOLD CRITERIA

1. Localizer/VOR receiver immunity formulae

1.1 *Third-order intermodulation interference (type B1)*

Let: f_i = the i^{th} FM frequency: f_1, f_2, f_3 (MHz)

and: N_i = the i^{th} FM received power level (dBm)

then: a_i = max {0.4; 108.1 − f_i}/0.4

and: $a(f_i)$ = 20 log (a_i)

Note. – No interference when formulae are satisfied.

1.1.1 ICAO Annex 10 - future immunity

Reference: ICAO Annex 10, §§ 3.1.4 (ILS) and 3.3.8 (VOR)

1.1.1.1 *2 signal*

$$2N_1 + N_2 - 3a(f_1) + 72 < 0$$

1.1.2 Geneva Agreement 1984 – *future immunity*

Reference: Geneva Agreement 1984, Annex 5, § 1.2.1.

1.1.2.1 *2 signal*

$$2N_1 + N_2 - 3a(f_1) + 72 < 0$$

1.1.2.2 *3 signal*

The Geneva Agreement 1984 specifies a future immunity formula for the 2-signal case only, but states that a comparable relaxation in the criterion for the 3-signal case could possibly be expected. Based on this assumption, expansion of the 2-signal case to the 3-signal case yields:

$$N_1 + N_2 + N_3 - 3a(f_1) + 78 < 0$$

1.1.3 Geneva Agreement 1984 – *type B1 correction term*

Reference: Geneva Agreement 1984, Annex 2, § 7.6.5.3

where: N_i (corrected) = N_i − correction term

and: i = 1, 2, 3

TABLE XLI

Δf $f_{(ILS)} - f_{(intermod)}$ (kHz)	Correction term (dB)
0	0
± 50	2
±100	8
±150	16
±200	26

1.2 *Desensitization (B2 type)*

See Fig. 52.

1.3 *Co-channel interference (type A1)*

Reference: Geneva Agreement 1984, Annex 2, § 7.6.3.3 (current and future immunity)

TABLE XLII

Δf (kHz)	Geneva Agreement 1984 protection ratio (dB)
0	17
± 50	10
±100	− 4
±150	−19
±200	−38

1.4 *Side-band interference (type A2)*

Reference: Geneva Agreement 1984, Annex 2, § 7.6.4 (current and future immunity)

TABLE XLIII

Δf (kHz)	Geneva Agreement 1984 protection ratio (dB)
100	−41
200	−50
250	−59
300	−68
500	−

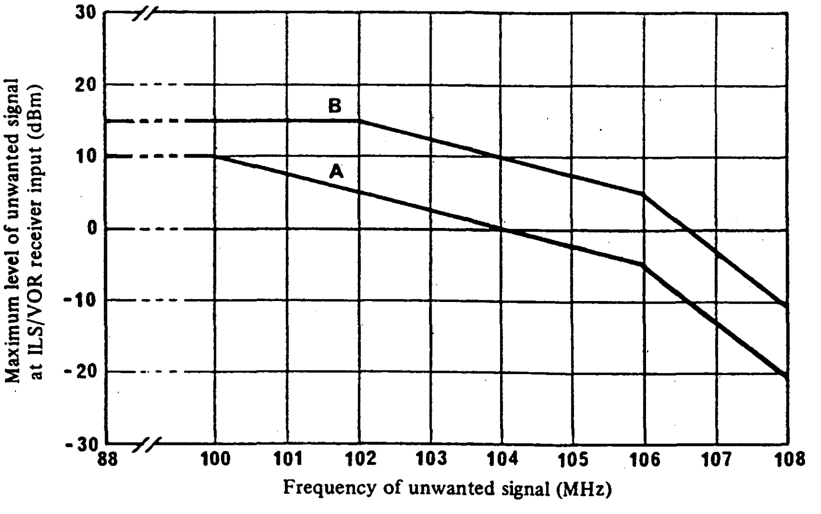


FIGURE 52 – *ILS/VOR desensitization immunity criteria (type B2)*

A: existing immunity:

– Geneva Agreement 1984, Annex 2, § 7.6.6

B: future immunity:

– Geneva Agreement 1984, Annex 5, § 1.2.2
ICAO Annex 10
Amendment 65, § 3.1.4.2

REPORT 1198*

COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND 87.5 - 108 MHz AND THE AERONAUTICAL SERVICES IN THE BAND 108 - 137 MHz

(Study Programme 46J/10)

(1990)

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* The Director of the CCIR is requested to bring this report to the attention of Study Group 8 and of the ICAO.

** Alternative terms for transmitter combining units include transmitter combiner or diplexer, channel combiner, star filter and hybrid filter.

1. Introduction

Region 2 has been operating VHF/FM stations for many years in the frequency band 88 - 108 MHz. The World Administrative Radio Conference (Geneva, 1979) extended the VHF/FM band to 108 MHz on a world-wide basis. The possibility that the existence of broadcasting and aeronautical radionavigation services in adjacent frequency bands might lead to problems of incompatibility was recognized by the WARC 1979 (Recommendation 704) and also in the agenda of the Regional Administrative Conference for FM Sound Broadcasting in the VHF band (Region 1 and certain countries in Region 3). This conference was held in Geneva in 1982 and 1984 to determine the technical constraints to be used in planning the new band for the broadcasting service and to produce a Regional Plan taking these constraints into consideration. Those technical constraints have been used in calculating compatibility results for existing situations in North America [CCIR, 1986-90].

This Report considers relevant characteristics of broadcast stations in relation to the aeronautical compatibility problem.

2. Terminology

The Final Acts of the CARR-1(2) and Report 929 identify several mechanisms by which interference to aeronautical services from FM broadcasting can arise. These can be divided into two general types. Those arising from components radiated from broadcasting transmitters at or near the frequency of the aeronautical service constitute Type A interference, whereas those arising within the aeronautical receiver constitute Type B.

2.1 Type A interference

In the normal operation of broadcast transmitters Type A interference may arise in two ways. First, a single transmitter may generate spurious emissions or several broadcast transmitters may intermodulate to produce terms in the aeronautical frequency bands; this is termed Type A1. Second, the sidebands of a broadcast transmitter may include non-negligible components in the aeronautical bands; this mechanism, which is designated Type A2, will in practice arise only from transmitters having frequencies near to 108 MHz.

From the viewpoint of the aviation receiver the spectral characteristics of the unwanted signal are of particular significance. To a first approximation the effects of modulated FM broadcasting signals are likely to be "noise-like" in the receivers, with a consequential reduction in the wanted operational performance of aeronautical receivers.

In addition, adverse effects in the ILS/VOR audio (identification) channel can occur.

However, if unmodulated broadcast transmissions were to produce stable frequency components close to the ILS modulation signal frequencies (e.g $\pm$15 Hz of the modulation frequencies 90 Hz and 150 Hz) then highly significant interference could occur even at very low levels of unwanted signals (see Report 927).

2.2 Type A1 interference

This is variously described as "in-band" or "on-channel", and is caused by spurious emissions (including intermodulation products) from the broadcast transmitter station. This is generally a low-level effect and can be regarded as harmful interference, as defined in the Radio Regulations, in cases where the level is sufficient to affect the performance of aeronautical receivers. No rejection can be provided at the airborne receiver. Suppression at source, the choice of broadcast assignment, and/or distance separation are the only practical solutions.

2.3 Type A2 interference

This is interference to ILS channels near to the 108 MHz band edge owing to out-of-band emissions from broadcasting stations operating on carrier frequencies at the upper end of the broadcasting band.

2.4 Type B1 interference

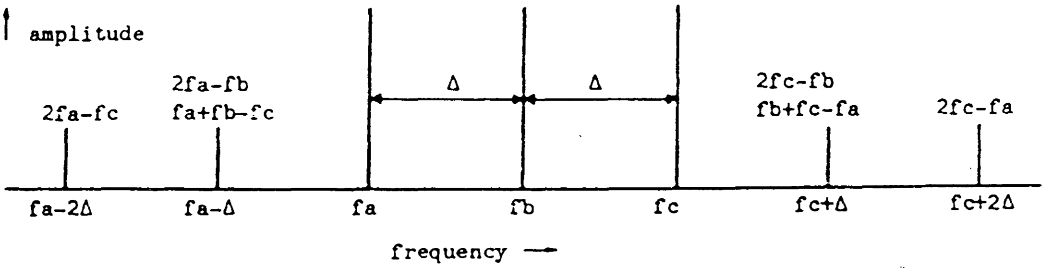
Intermodulation generated in an airborne receiver as a result of the receiver being driven into non-linearity by a high-powered broadcasting signal outside the aeronautical band. In order for this type of interference to occur, normally at least two broadcasting signals need to be present and they must have a frequency relationship which, in non-linear combination, can produce an intermodulation product within the wanted RF channel in use by the airborne receiver. One of the broadcasting signals must be powerful enough to drive the receiver into regions of non-linearity but interference may then be produced even though the other signal(s) may be significantly less powerful. Under certain conditions, type B1 interference can occur with a combination of only one broadcasting signal and an aeronautical ground signal.

Perhaps the most serious practical aspect of this mechanism from the frequency planning viewpoint is that an acceptable existing situation involving FM broadcasting signals at non-critical levels can be transformed into a practical problem by, for example, the addition of a new broadcasting station, an increase in power at an existing broadcasting station or implementation of aeronautical stations.

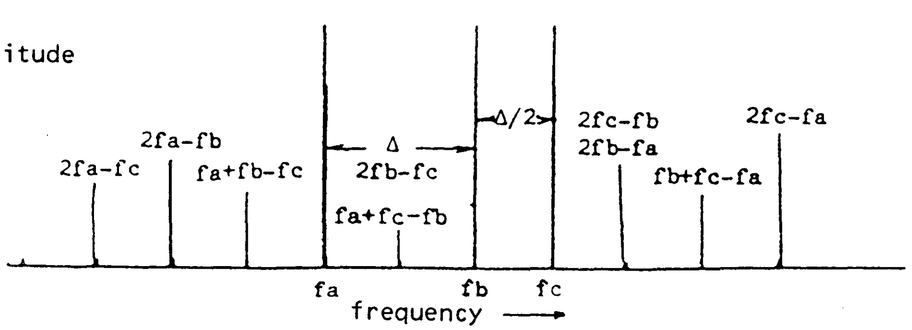
3. Improving the suppression of intermodulation products and out-of band emissions at broadcast transmitting stations and determination of protection ratios

3.1 Intermodulation in a transmission system

When two or more transmission frequencies f_a, f_b, f_c ... are combined into one antenna system or where separate antennas are in close proximity there is a possibility of intermodulation taking place somewhere in the transmission system. At VHF the intermodulation frequencies which are most likely to cause interference with other services are of the form $(2f_a - f_b)$ or $(f_a + f_b - f_c)$ because these frequencies remain in the VHF band and are therefore radiated efficiently by the antenna system. They are also more difficult to filter out than those which appear close to the harmonic frequencies. The disposition of these intermodulation frequencies is shown diagrammatically in Fig. 1a for the case of three transmitters having equally-spaced frequencies. Figure 1b shows a more general case for unequally-spaced frequencies, in this case for Δ and Δ/2, where multiple intermodulation products need not occur at one frequency, and the number of frequencies with intermodulation products is greater.



(a) - Equally-spaced transmission, Δ



(b) - Unequally-spaced transmission, Δ and Δ/2

FIGURE 1 - Occurence of third-order intermodulation products at a three-frequency transmitting station

Intermodulation at the transmitting station may take place by either of two distinct processes. By the first process the transmitter combining unit* may allow a low level of voltage from one transmitter (frequency f_a) to reach the output stage of another transmitter (frequency f_b) where mixing takes place to produce a frequency $(2f_b - f_a)$. The production involves a conversion loss in going from the input level of fa to the output level of $(2f_b - f_a)$. The conversion loss is dependent on the working conditions of the amplifier, i.e. class B, C or D, the terminating impedances for the mixing products and other relevant frequencies: $(f_b - f_a)$, $(f_b + f_a)$, harmonics, etc., and the frequency response of the output circuit at the frequency f_a and that of the intermodulation products. In addition to the conversion loss, power matching between the combiners and the mixing function in the transmitter affects the final levels of the intermodulation products. This factor depends on the electrical length of the connecting feeders between the combiners and the transmitters. With valve transmitters, variations of intermodulation product levels of up to 10 dB have been observed with changes of feeder length.

* Alternative terms for transmitter combining units include transmitter combiner or diplexer, channel combiner, star filter and hybrid filter.

Data on various arrangements for combining transmitters, including methods of calculation and measurements on some representative installations, are given in Annex I.

The second process takes place in the transmission system after frequencies have been combined and may be due to arcing or to the non-linear resistance of metal-to-metal contacts within the feeder and antenna system. In general, however, the levels thus produced are likely to be lower than those produced due to an imperfect transmitter combining unit. The possibility of intermodulation having taken place by the second process can be checked by comparing the levels of products measured in the radiated field with those measured in the main feeders.

When considering levels that are likely to be produced it is necessary to consider:

- the circuit of the transmitter combining unit and its transfer characteristics at all relevant frequencies; and

- the loss in the conversion process.

Because of the complicated nature of the terminating impedances at the various frequencies, especially in transistorized power amplifiers where the mixing occurs in a number of combined amplifiers, conversion losses cannot be accurately predicted. Conversion losses for valve transmitters, including matching effects, have been reported as being between 9 and 26 dB, typically 20 dB.

For transistorized amplifiers, conversion losses of 6 to 25 dB have been reported but further investigations are needed.

The above values are based on 1.8 MHz spacing between carriers. Unintentional mistuning of a tuned amplifier can increase intermodulation products by up to 10 dB. Care must also be taken to ensure the final amplifier has been correctly neutralized.

3.2 Possibilities and techniques for improving suppression of intermodulation products at broadcast transmitting stations

It is possible to design and build broadcast transmitting stations that will have intermodulation products suppressed to a level lower than that required by the Radio Regulations and such levels can be maintained over a long period of time. It has also been shown that still lower levels may be obtained at individual stations where the additional cost and effort are justified. It remains to be seen whether these levels can equally be maintained in service.

The ITU Radio Regulations (1982) require that the mean power of an intermodulation product supplied by a transmitter of mean power above 25 W to the antenna transmission line shall be at least 60 dB below the wanted signal and shall not exceed 1 mW. Thus for a transmitter power of 1 kW the highest relative level for the i.p. is -60 dB while for one of 40 kW the relative level must not exceed -76 dB. From Table I-II of Annex I, it may be seen that old UK stations exhibit i.p. levels 5 dB or more below the ITU requirement and the two new stations achieve even lower levels, at least in the short term. It seems likely that levels at least 10 dB below the ITU requirement can be achieved and maintained in service for transmitters of 25 W or more. For transmitters of powers below 25 W it is believed that no improvement is necessary.

The United States FCC-rules specify the level of a spurious emission as a function of its frequency separation from the transmitter frequency. Out of band emission must be attenuated by at least $43 + 10 \log_{10}$ (transmitter power) below the level of the unmodulated carrier, or by 80 dB, whichever is the smaller attenuation. Measurements of multiple (up to 15) operations at common sites show that stations in the United States have achieved, or exceeded, this level of intermodulation product suppression in the aeronautical band when the separation between transmitter frequencies is 800 kHz or more. In addition, almost all intermodulation products, from transmissions of 50 kW e.r.p. or more, met the 85 dB suppression requirement given in Annex II, para. 7.6.3.2 of the Geneva Agreement, 1984.

In order to achieve the required levels of suppression of intermodulation products it is necessary to design and engineer the transmitter installation with meticulous attention to detail. In particular, the following aspects have been found to be important.

3.2.1 Combining units and frequency-separation dependence of transmitter conversion loss

With regard to the generation of intermodulation products within broadcasting transmitters, measurements in the UK have confirmed that transmitter conversion losses for the generation of two-frequency intermodulation products increase as the frequency separation increases. Hence, if the broadcast transmitter frequencies that may cause third-order intermodulation products in the aeronautical bands above 108 MHz are relatively widely spaced (i.e. by more than about 3.0 MHz) it follows that the required low levels of intermodulation products will generally be achieved without significant increase in the cost or complexity of the transmitter combining units.

Additional measurements in the United States of America show that the conversion loss :

- can be a function of the type of device with the non-linear characteristic and the type of output circuit;
- can be a function of the relationship of the interfering signal and the resulting intermodulation products to the FM transmitter frequency ;
- will be least when the interfering signal is within the FM transmitter's passband and
- may remain almost constant when the level of the interfering signal is reduced below a certain level.

The conversion losses for three-frequency intermodulation products have been found to be higher than in the two-frequency case so that it is probably unnecessary to make special provision in the combining unit design for the suppression of intermodulation products in the three-frequency case.

The required isolation between transmitters sharing an antenna should be calculated taking into account the conversion loss at the transmitter and any attenuation of the intermodulation product in the combiner as discussed in Section 3.2 above.

3.2.2 Antennas

If transmitters are fed into separate antennas, the mutual coupling between them should be taken into consideration when deciding what additional filters will be required.

If a common antenna is used, one having a large aperture and a relatively low power-density would be expected to have a better linearity than a small-aperture, high power-density antenna.

The antenna construction should take into account the local environment. Materials and finishes should be chosen to minimize the possibility of rectification effects at junctions.

In calculating the effect of radiated intermodulation products, the result will be more accurate if allowance is made for the radiation pattern of the antenna taking into account the beam tilt where appropriate (see example given in Annex II).

Where possible, data on the radiation pattern for the intermodulation product frequency should be used in the case of A1 interference. In the example in Annex II the pattern at the intermodulation frequency is approximately the same as the pattern at frequencies within the broadcast band but this may not always be the case.

3.2.3 Antenna transmission line

The use of multiple contacts in a transmission line should be minimized as these may become non-linear with oxidation. Thus a continuous semi-flexible transmission line would be preferable to a rigid, sectionalized line.

3.2.4 Transmitter drives

Any significant coupling between transmitter drives, albeit low level, can give rise to intermodulation products which will degrade the overall performance. If a number of drives are mounted close together the electro-magnetic screening should be of high standard. Similarly, if the coaxial transmission lines between the drives and the power amplifiers run together, e.g. in a duct, the screening between the lines should be of a high order; it may be necessary to use double screened cable or feeder having a solid outer conductor.

As a guide, transmitter drives should carry no stray pick-up of unwanted frequencies higher than -75 dB relative level. Screening must be sufficient to reduce direct pick-up of the radiated signals from transmitters on other frequencies, as well as reducing the mutual coupling mentioned above.

3.2.5 Position of combining unit for optimum attenuation of intermodulation products

Adjustment of the length of feeder between the transmitter and combining unit is necessary to achieve optimum performance.

3.2.6 Suppression of intermodulation products in solid-state amplifiers

For transmitters with solid-state amplifiers it has been suggested that conversion loss can be increased up to about 25 dB by combining two amplifier stages by means of 90° phase shifting networks.

3.3 Discussion regarding Type A1 interference

3.3.1 In Region 1, particularly in Europe, FM broadcast stations with multiple transmitters are usually multiplexed into the same antenna, although in other areas, e.g. in the USA, this is exceptional. The use of multiplexed transmitters can cause difficult cases of spurious emission, viz, third-order intermodulation products falling in the frequency band allocated to the aeronautical services (108-137 MHz). Consequently, Footnote 10 to Appendix 8 of the International Radio Regulations specifically applies to FM broadcasting transmitters operating in the band 87.5-108 MHz. Other relevant Radio Regulations are RR 304, 343 and 1813.

3.3.2 Spurious emission measurements reported by a number of administrations showed wide variations in values. All experiences reported concerned spurious emissions from transmitters operating with less than 50 kW transmitter power. Measurements ranged from about -60 dB to about -100 dB, depending upon transmitter filtering used, age of the systems, and particular installation characteristics. Difficulties may arise if transmitter powers of greater than about 50 kW are used, particularly in multiplexed installations.

3.3.3 Recognizing that broadcasters must contribute towards overcoming incompatibility problems between the broadcasting and aeronautical services operating in adjacent bands, the spurious emission limits suggested should be a significant improvement on the requirements of the Radio Regulations.

3.3.4 Although the appropriate spurious emission limits are specified relative to transmitter power, it is important to be able to calculate the limits relative to effective radiated power.

3.3.5 It is technically feasible to reduce the radiated power of the third-order intermodulation products to -85 dB relative to the effective radiated power. (The reference in this case is the maximum e.r.p. of the highest powered broadcast transmission). Since measurements on the broadcast transmitter comprise the sum of all intermodulation products falling on any one frequency, it is not necessary to add an allowance for multiple interference from a single broadcasting site.

3.3.6 Head Note 4 to Appendix 8 of the Radio Regulations is also specifically applicable to the FM broadcasting service. Tighter spurious emission limits than those specified by Appendix 8 are feasible for the following reasons:

- suitable equipment is available;
- most transmitter installations have a better performance;

  and

- some administrations' domestic regulations already stipulate tighter limits.

3.4 Discussion regarding Type A2 interference

From the limited information made available, it is possible to indicate the approximate spectral characteristic of an FM broadcast emission (Report 1065).

In view of the rapid fall-off of an FM transmission spectrum with frequency difference from the nominal carrier frequency it is likely that further reduction of energy outside ± 150 kHz would give negligible benefit.

Various options of possible utilization of filtering out-of-band emissions (for example, notch filters and band-pass filters) have been considered. However, the utilization of certain types of filters may affect the spectral characteristics, introduce asymmetry of spectrum and degrade the quality of sound.

In practice, where the frequency separation between broadcast and aeronautical services is small, it is difficult to distinguish between interference due to out-of-band emissions and that due to in-broadcast band emissions received as a result of the selectivity response of the aeronautical receiver. Tests have indicated that with existing receivers the latter is the more important at separations exceeding 250 kHz. Improved selectivity may therefore modify A2 protection criteria even though the broadcast spectrum remains unchanged.

4. Other aspects of compatibility assessment

4.1 Interference to ILS by unmodulated broadcasting signals

Concern has been expressed about the degree of co-channel interference from the third-order intermodulation product from two (or three) broadcast transmissions when the transmitters are unmodulated or have simultaneous pauses in modulation. This problem might arise for Type A1 or B1 interference.

The reason for concern is that CCIR Report 927 (Section 3.1 of Annex I) gives a protection ratio of 46 dB for cases where a CW signal may have a stable frequency difference of 90 Hz or 150 Hz from the ILS carrier frequency, thus producing amplitude modulation to which the receiver is most sensitive. This exceeds the planning co-channel protection ratio of 17 dB by 29 dB, thus suggesting up to 29 dB greater sensitivity to interference than would be expected using the normal criteria.

However, the actual situation at broadcast transmitters is that during normal programme transmission there is a residual noise level causing a minimum of ± 20 Hz deviation of each transmitter, giving about ± 35 Hz deviation on a third-order product. It may therefore be unnecessary to take further precautions against the radiation of intermodulation products of very low deviation. Further tests are required to establish the position. Studies carried out by one administration show that, if it should prove necessary in certain cases, at least one acceptable solution to the problem exists, as described below. This means that it will not be necessary to make special allowance for the problem in planning.

Having studied some alternative solutions, the one proposed by one administration is a small frequency offset from the nominal frequency for either the broadcast transmitters or the ILS transmitter, to ensure that the intermodulation product is never closer than 160 Hz from the ILS carrier. Tests with ILS receivers have confirmed that this is sufficient to remove the problem.

With practical frequency tolerances, e.g. ± 1 kHz for broadcast and ± 2 kHz for ILS (somewhat smaller than the maximum tolerances in the Radio Regulations) an example of a possible solution is as follows. The broadcast transmitters would operate with a nominal 2 kHz offset in such directions that a nominal offset of 6 kHz is created on the third-order intermodulation product. With adverse extremes of the suggested tolerances this would reduce the offset to a minimum of 1 kHz.

A similar example can be given for the offset applied instead to the ILS transmitter. In this case (assuming that the ILS tolerance is improved to ± 1 kHz) an offset of 4.5 kHz is sufficient. This value of offset is used in two-frequency ILS localizer installations.

4.2 Interference to ILS and VOR during FM station testing

A common practice in many countries is for FM broadcast stations to perform operational tests using varying modulation frequencies and modulation levels. Generally, the modulation is sinusoidal. The FM modulation sidebands during tests are typically higher in amplitude than during normal stereophonic transmissions.

Available information on testing procedures show that, in the USA, the test periods are infrequent and are executed at times of low aviation activity (See Annex IV-1).

Finland, however, has indicated that transmission measurements are performed in a regular manner at smaller intervals and during daytime (see Annex IV-2).

The characteristics of these tests are such that special consideration of interference mechanisms may be warranted, taking into account all frequency tolerances. This is particularly true if the resulting baseband signal in the ILS/VOR receiver contains frequency components of 30, 90 or 150 Hz plus a tolerance about these frequencies. An important case could be for transmitters where a compatibility analysis shows that there is only a small positive protection margin.

4.3 FM broadcast antenna pattern

Both horizontal and vertical radiation patterns of proposed and existing FM broadcast stations can be taken into account in compatibility analysis for both type A and type B interference.

4.3.1 Horizontal patterns

If an FM station utilizes a directional antenna and the directivity parameters are known, the field strength corrections can be performed.

The horizontal radiation patterns of nominally omni-directional antennas should receive particular consideration if they deviate more than ± 2dB from the ideal circular shape.

According to experience gained in Canada this could be the case when utilizing side-mounted dipole antennas. This type of broadcast antenna typically consists of a single vertical stack of dipole radiating elements mounted on a corner or a face of the supporting structure. Airborne measurements for horizontal polarization showed possible differences between maximum and minimum antenna gain of the order of 15dB in the horizontal plane for this type of antenna. Similar deviations are to be expected for vertical polarization.

4.3.2 Vertical patterns

The vertical radiation pattern of a broadcasting station may also be of considerable significance in compatibility assessments.

Different methods exist for the theoretical modelling of the radiation pattern of an antenna and some of these are given in Annex III. In such modelling it is normal to set some limit to the maximum value of reduction achieved. However, a measured pattern for a given antenna may show that a reduction approaching 20 dB can be achieved for all side lobes and measured values should be used, where available.

When two or three signals with different frequencies are radiated from the same antenna, the actual measured antenna pattern on each frequency should be taken into account, where available. Because the side-lobe maxima for different frequencies will not necessarily coincide, there can be a significant reduction of potential interference.

4.3.3 Combination of horizontal and vertical patterns

The relevant values, in dB, of the horizontal and vertical radiation pattern corrections should be added arithmetically, subject to a combined maximum reduction of 20 dB.

Experience has shown that with large aperture antennas, it is rarely necessary to take the horizontal radiation pattern into account if the elevation angle (to a point for which calculations are being made) is more than about 10 degrees.

At elevation angles near to 90 degrees no horizontal radiation pattern corrections should be made, regardless of the antenna type.

5. Conclusions

5.1 On the maximum obtainable suppression of spurious emissions in the band 108 - 137 MHz, from broadcasting stations operating in the band 87.5 - 108 MHz

In the North American experience, it has not been necessary to require generally the suppression of spurious emissions of more than 80 dB.

Considering special circumstances within Region 1 and some areas of Region 3, the following values for spurious emissions were recommended by JIWP 8-10/1 for assessment and planning purposes in the VHF/FM broadcasting band in cases where Type A1 interference in the aeronautical band can be expected.

TABLE I

Maximum relative level of spurious emissions

Transmitter power (kW)	Maximum relative level of spurious emissions	
	Appendix 8 of the Radio Regulations (dB)	Values recommended by JIWP 8-10/1 (dB)
0.01	-56	-56
0.02	-59	-59
0.1	-60	-66
0.2	-60	-69
1.0	-60	-72
4.0	-66	-82
10.0	-70	-85
20.0	-73	-85
40.0	-76	-85

The recommendations relate to the total mean power level of all spurious components at any one frequency in the aeronautical band, supplied to the antenna system transmission line at FM broadcasting stations. The level is measured after taking into consideration all filters, combiners, multiplexers, etc. which may affect the radiated level of spurious emission.

To meet the recommendations, the power level of spurious components from an FM broadcasting station should not exceed 25 uW for transmitter powers up to approximately 8 kW. The actual radiated power of a spurious emission, however, depends on the gain of the antenna at the frequency of the spurious emission which is likely to be less than the gain at the broadcasting frequency.

Also the attenuation (mean power within the necessary bandwidth to the mean power of the spurious component concerned) for transmitter powers above approximately 8 kW should be at least 85 dB (see Table I and graph (Fig. 2)).

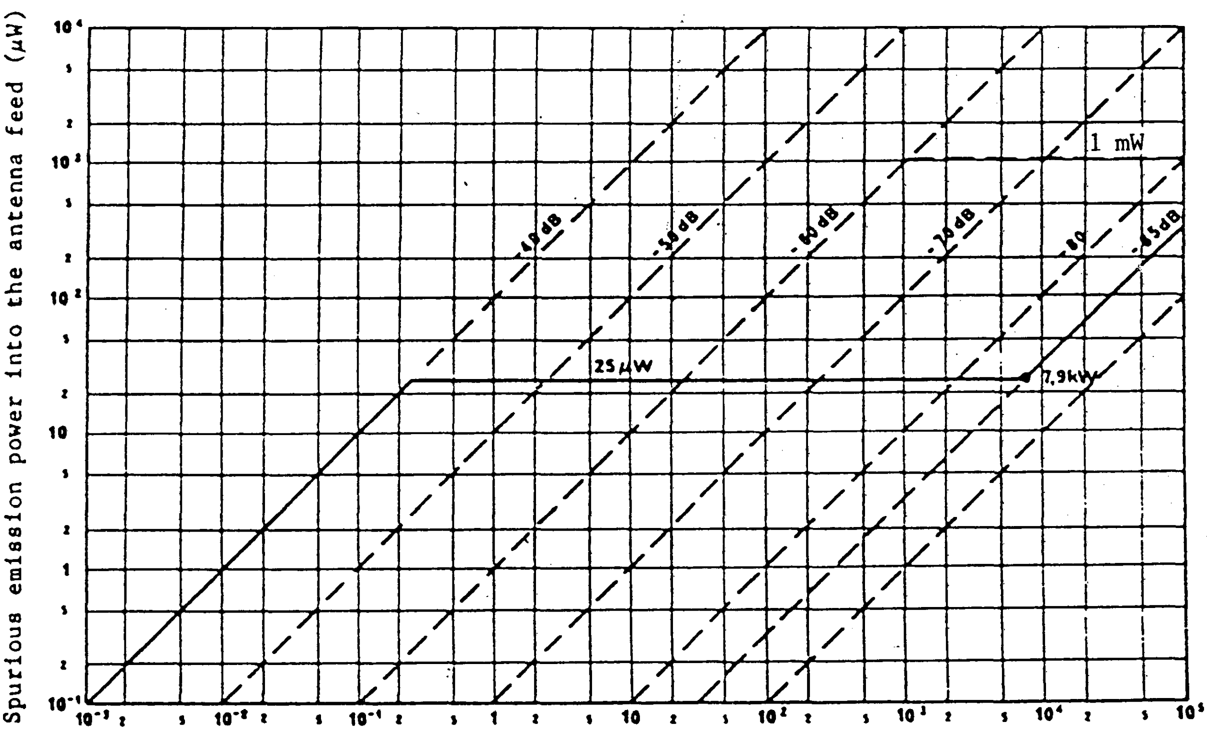


FIGURE 2

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/1986-90/: 10/30 (United Kingdom).

ANNEX I

DATA ON TRANSMITTER COMBINING UNITS*

1. Types of combining units

Several different types of units are in use for combining two or more broadcast transmitters into a common antenna.

Figures I-1a, I-1b, I-2a and I-2b show representative arrangements for combining two transmitters which are in use by the RAI and also within the countries mentioned below.

1.1 Situation in France

In France, when there is a risk of intermodulation products, TDF uses modules of the type described in Figure I.2a. Each module is designed so that the passband filters centred on f1 display an attenuation of at least 25 dB at frequencies f2 and 2f1 - f2. Moreover, a decoupling between the inputs of 40 dB at frequency f1 and 50 dB at frequency f2 is required. These values can be attained without a drop in signal quality even for transmission frequency separations of 800 kHz. In this case, the passband filters have three cavities.

If f1 is greater than f2, the intermodulation product likely to affect the aeronautical services is situated at the frequency 2f1 - f2. In view of the above attenuation and decoupling values and for a conversion factor of 10 dB, the product at frequency 2f1 - f2 will be transmitted to the antenna at a level less than at least 85 dB (50 + 25 + 10) lower than the wanted signals.

1.2 Situation in the United States

Combining units used in the United States of America are generally characterized by their impedance performance (non-constant impedance or constant impedance)

Non-constant impedance devices generally consist of two banks of filters, each feeding a coaxial (tee) network where the electrical length between each filter output and the centerline of the (tee) network is frequency sensitive. The application of this type of filter is limited as all of the electrical parameters are a function of the filter characteristics (such as standing wave ratio, insertion loss, rejection/isolation characteristics etc.) This type of combiner is seldom used where the frequency spacing between the carriers is less than 1 MHz (see also Fig. I-1a and 1b).

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* Alternative terms for transmitter combining units include transmitter combiner or diplexer, channel combiner, star filter and hybrid filter.

Constant impedance combining units, typically use 3 dB hybrid combiners and filters with a terminating load on the isolated port. The filters in this type of circuitry can be either a notch or bandpass type. The performance characteristics will be different for the two filter types. These types of combining units have a wider application as they are less frequency sensitive and can achieve a significant suppression level when the frequency spacing between the FM carriers is 800 kHz or more (see also Fig. I-2a and 2b).

1.3 Situation in the United Kingdom

A variation of the arrangement of Fig. I-2b recently used in BBC stations for combining three transmitters is shown in Fig. I-3. This will be explained in greater detail to illustrate the principles involved, and to calculate the levels of the third-order radiated intermodulation products based on measurements of cross insertion loss on the combining units. The results of these calculations (Table I-I) can then be compared with actual measurements of the radiated intermodulation products from the BBC high power station, Wrotham (see Table I-II).

It may be seen from Fig. I-3 that the combining unit installation is in two sections comprising 3 dB directional couplers connected together by equal-length lines carrying resonators. The cross insertion losses from transmitter T1 to transmitter T2 and T3 at frequency f_1 are mainly determined by the Q of the f_1 resonators and this is related to their physical size. The same is true of the cross-loss from transmitter T2 to transmitter T3 at frequency f_2. However, the cross-losses from transmitter T3 to transmitter T2 and from T2 and T3 to T1 are determined solely by the 3 dB couplers. This means that, if no other factors were involved, the levels of the intermodulation products $(2f_2 - f_3)$, $(2f_1 - f_2)$ and $(2f_1 - f_3)$ could be relatively high. However, intermodulation products generated in T1 and T2 are diverted to the load and so couple weakly with the antenna. The net result of these factors may be seen in Table I-I, where the levels of intermodulation products are calculated from cross-loss measurements on the combining unit.

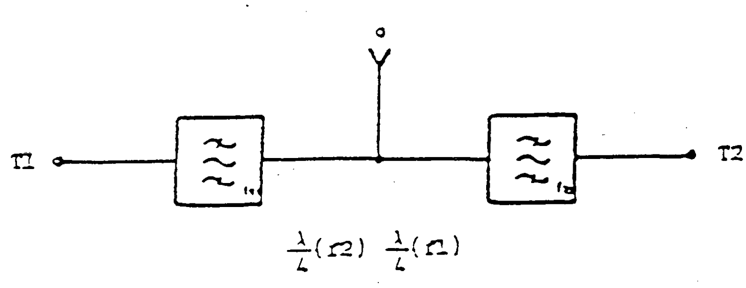


FIGURE I-1a

Star filter with passband cavity

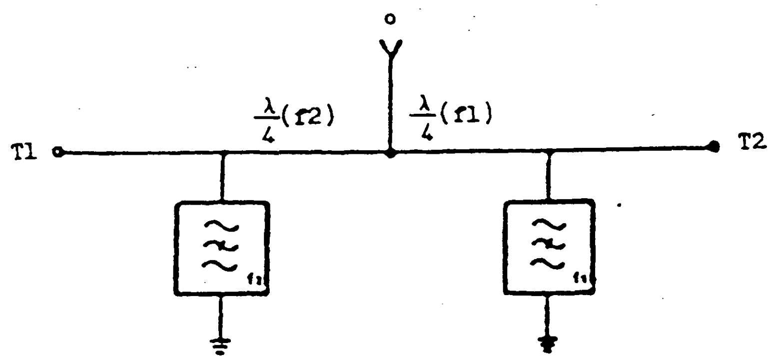


FIGURE I-1b

Star filter with compensated stop-band cavities

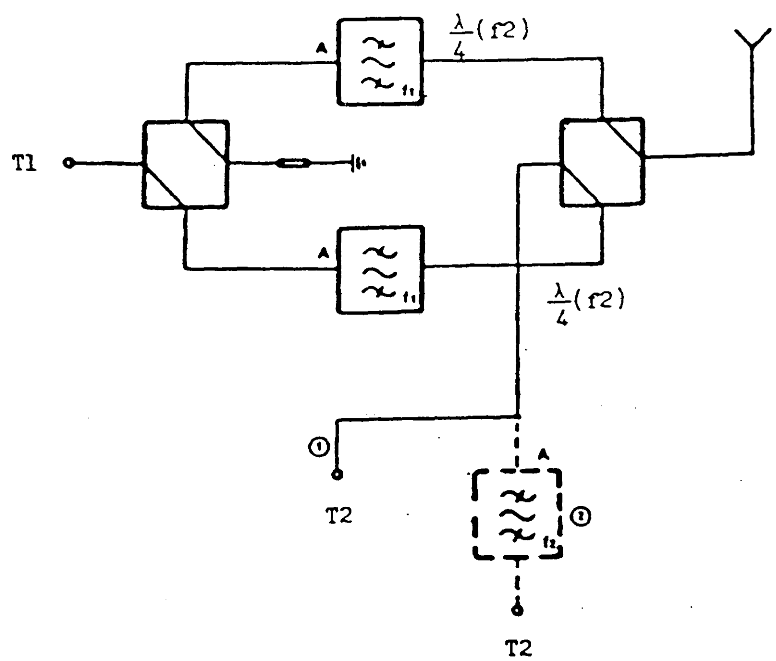


FIGURE I-2a

Hybrid filter with passband cavity

In Fig. I-2a, two variations are considered:

- in case 1, the normal case, the spurious frequency ($2f_2 - f_1$) has a much higher level than ($2f_1 - f_2$);
- in case 2, this is overcome by the additional cavity at the T2 output.

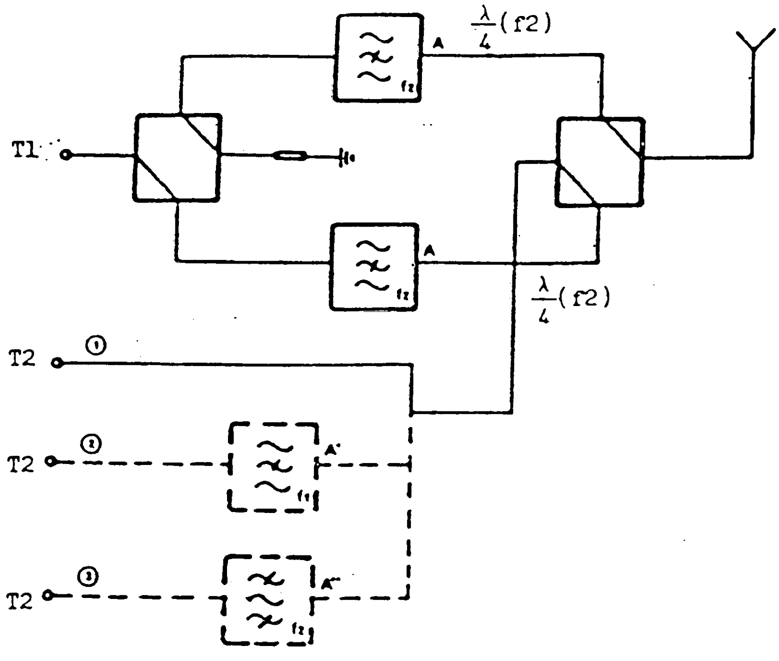


FIGURE I-2b

Hybrid filter with stop-band cavities

In Fig. I-2b, three variations are considered:

- in case 1, the normal case, the spurious frequency ($2f_2 - f_1$) has a much higher level than ($2f_1 - f_2$);
- in case 2, there is an additional stop-band cavity A′ at the T2 output;
- in case 3, the additional stop-band cavity is replaced by pass band cavity A". The spurious suppression is very high, especially in case 3.

TABLE I-1

Calculation of intermodulation product levels (2.2 MHz spacing)

Frequency	Cross-insertion loss (dB)	Conversion loss (assumed) (dB)	Cross-insertion loss to antenna (dB)	Relative level of i.p. (dB)
$2f_1 - f_3$	T1, T3 at f_3 -51	-22	T1->ant at $2f_1-f_3$ -36	-109
$2f_1 - f_2$	T1, T2 at f_2 -63	-14	T1->ant at $2f_1-f_2$ -15	-92
$2f_3 - f_2$	T3, T2 at f_2 -88	-14	T3->ant at $2f_3-f_2$ 0	-102
$2f_3 - f_1$	T3, T1 at f_1 -72	-22	T3->ant at $2f_3-f_1$ 0	-94

Some refinements to the arrangement of Fig. I-3 are possible. First, additional notch filters may be added to attempt greater suppression of particular i.p.s. Whilst in principle it would be possible to attenuate the i.p. directly on the antenna feeder, it will usually be preferable to fit the notch filter to the output of the generating transmitter, where the total power level is lower. Another refinement is to adjust the impedance of the load on the section closest to the antenna as shown in Fig. I-3. This has the effect of controlling the level of frequency f_2 that reaches transmitter T1 and so affects the level of the i.p. at frequency $(2f_1 - f_2)$.

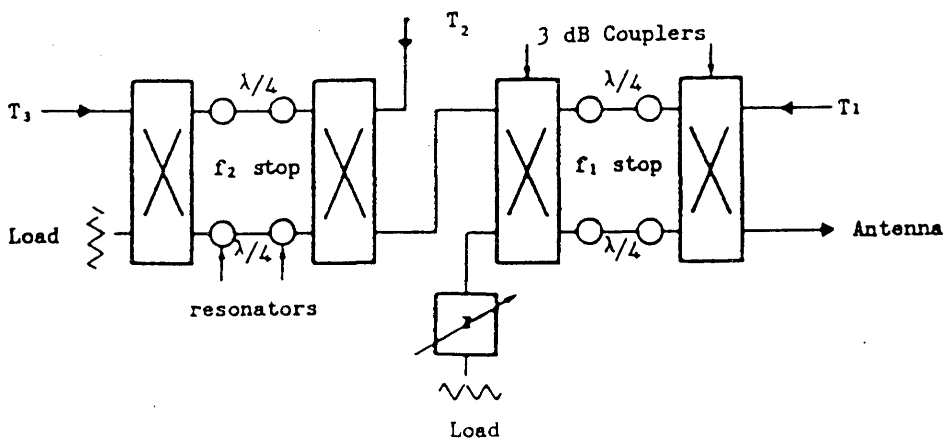
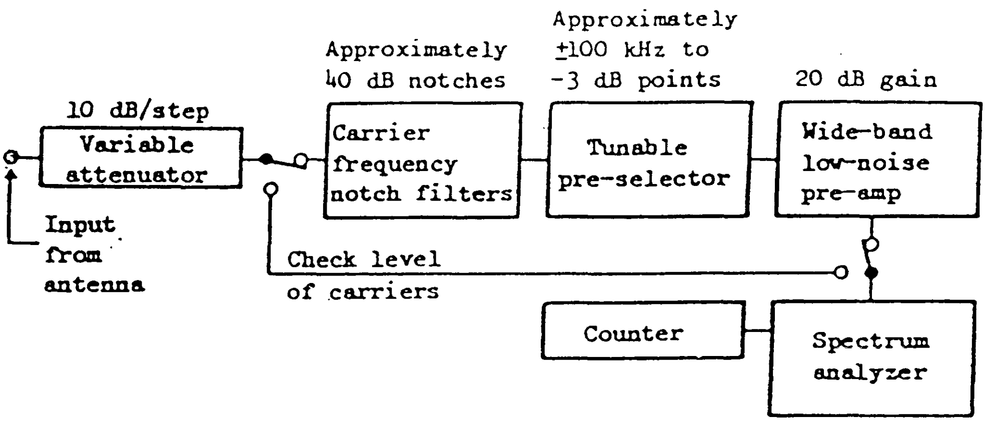
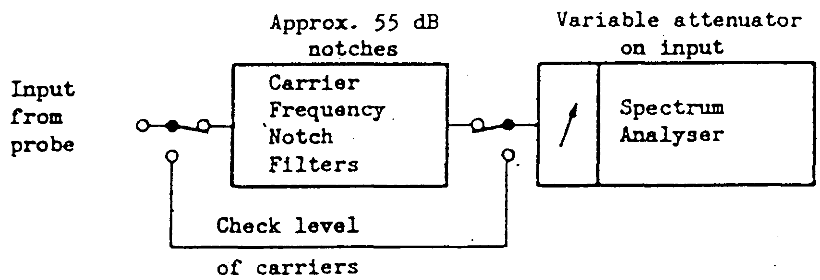


FIGURE I-3

A three-frequency combining unit



(a) Measurement of radiated levels



(b) Measurement of levels in transmitter feeders

FIGURE I-4

Methods of measurement

2. Measurements of intermodulation product levels at representative broadcast transmitting stations

The majority of UK stations transmit three equally-spaced frequencies from a common antenna. The spacing is usually 2.2 MHz. Measurements of intermodulation products made at a selection of these stations are shown in summary in Table I-II and include examples of high, medium and low-powered stations. Two of the stations are newly built, the remainder were built between 15 and 30 years ago. In each case the measurements were made on forward-wave directional couplers installed in the antenna feeders after these measurements were supplemented by measurements of the radiated levels made on the same day. The methods of measurement are shown in Fig. I-4.

TABLE I-II

Measurements at stations with regularly (2.2 MHz) spaced channels

Station	Relative level of intermode product (dB)				Where measured
	$f_1 - 2\Delta$	$f_1 - \Delta$	$f_3 + \Delta$	$f_3 + 2\Delta$	
Wrotham (new; high power valved transmitters)	-104 -104	-94 -93	-102 -102	-102 -104	feeders field
Tacolneston (old; high power valved transmitters)	-90 -96	-81 -82	-79 -80	-86 -86	feeders field
Peterborough (old; low power solid-state transmitters)	-94 -87	-83 -71	-82 -76	-90 -86	feeders field
Cambridge (old; low power solid-state transmitters)	-72	-78	-75	-72	feeders
Northampton (new; low power solid-state transmitters)	-70	-82	-86	-78	feeders

The above results are similar to those obtained in other countries.

It may be seen from Table I-II that for the valved transmitters, with the exception of Wrotham, the levels of the $(f_1 - \Delta)$ and $(f_3 + \Delta)$ terms are in the neighbourhood of -80 dB, while those of the $(f_1 - 2\Delta)$ and $(f_3 + 2\Delta)$ are nearer to -90 dB. This difference is ascribed to the frequency selectivity of the output circuit of the transmitter in which the term is generated; the wider the frequency spacing the greater is the conversion loss of the intermodulation process. It is also an indication that the levels of the $(f_1 - \Delta)$ and $(f_3 + \Delta)$ terms are determined by intermodulation taking place in the transmitters and not to any great extent elsewhere.

It is to be noted that the policy of the BBC at the time the stations described as "old" were built was to suppress intermodulation products to a much higher degree than that required by the Radio Regulations in order to protect mobile services then using frequencies below 88 MHz and above 97.6 MHz. The target was in fact a relative level of −100 dB [Hayes, 1957]. This was never achieved, despite strenuous efforts, including a detailed investigation into some of the mechanisms by which intermodulation products are generated. Nevertheless, the levels achieved were, and for the most part still are, appreciably lower than those required by the Radio Regulations.

There are two stations in the list described as "new"; both are several years old and radiate lower levels of intermodulation products than earlier stations of a similar type. Recent measurements at Wrotham have demonstrated that such levels can be maintained in service without inordinate effort.

REFERENCES

HAYES, W. E. and PAGE, H. [1957] The BBC sound broadcasting service on very high frequencies. Proc. IEE., Vol. 104, Part B.

ANNEX II

EXAMPLES OF MEASURED ANTENNA PATTERN

Some examples of measured field strengths of a broadcast transmitter have been provided by Sweden. When a vertical aperture of several wavelengths is employed, the vertical radiation will reduce the variation of field strength, at a fixed height of the order of 1000 feet, as a function of horizontal distance from the transmitter. Figure II-1 gives an example of a measurement of a broadcast signal at 97.5 MHz. The antenna in this case was an 8-tier array with a downward tilt of the main beam of 1°; measurements were made at a constant altitude of 1000 feet above the mast-top. Further measurements of an unwanted product at a frequency near 107 MHz showed a similar type of curve for the variation with distance. These and other measurements suggest that the pattern for frequencies above 108 MHz would be approximately but not exactly the same as for the broadcast frequency.

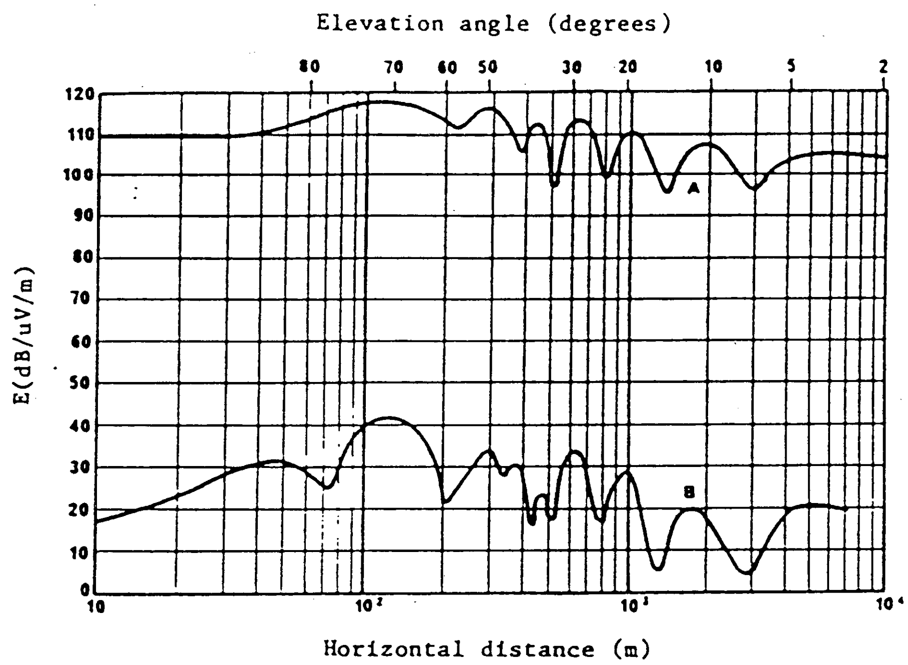


FIGURE II-1

Example of a measurement of a broadcast signal at 97.5 MHz

A : transmitter f : 97.5 MHz
B : spurious f : 107.290 MHz

Note - Broadcasting FM antenna: an antenna consisting of 24 elements mounted in 3 directions and 8 levels.

Transmitter frequencies: 88.9, 95.1, 97.5 MHz.
Maximum e.r.p. : 60 kW

ANNEX III

THEORETICAL MODELLING OF THE VERTICAL RADIATION PATTERN OF AN FM BROADCASTING ANTENNA

1. Modelling of 3 dB beam width of main lobe

To determine an aircraft's position with respect to the main beam of an FM antenna vertical radiation pattern, consider the geometry shown in Fig. III-1 [Augstman and Lubienietzky, 1982].

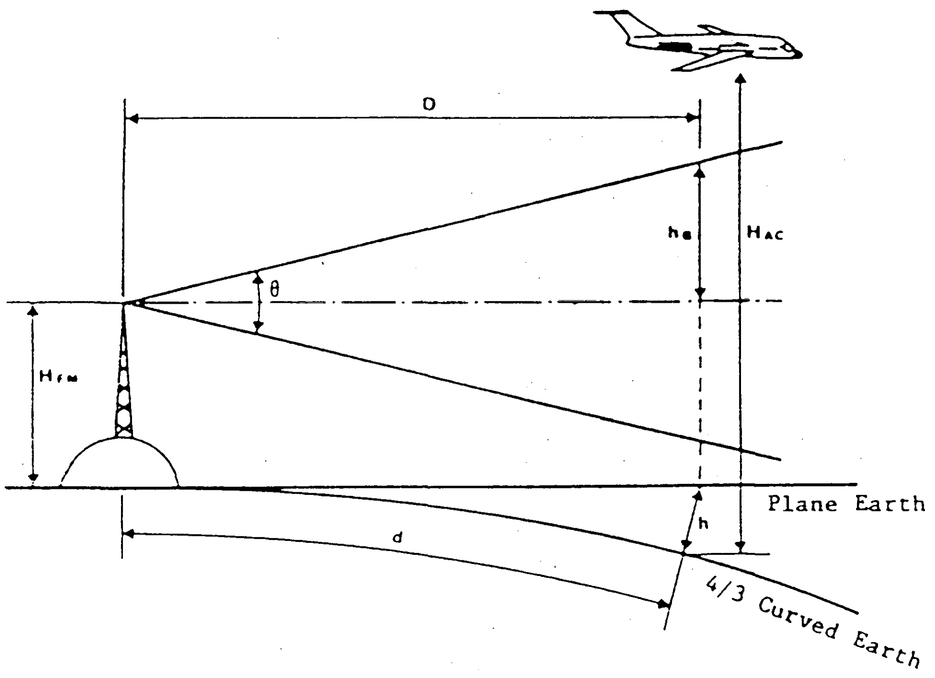


FIGURE III-1

Aircraft position with respect to main beam of
FM antenna vertical radiation pattern

In Figure III-1, let:

- H_{AC} : aircraft altitude (m ASL)
- H_{FM} : height of centre of FM antenna radiating elements (m ASL)
- θ : 3 dB beam width of FM main lobe (degrees)
- h : correction factor for 4/3 earth's curvature (m)
- D : distance between aircraft and FM antenna over plane earth (km)
- h_β : half of 3 dB beam width of FM main beam at distance D (m)
- d : distance measured along the surface of the Earth from a point directly beneath the aircraft to the base of the FM antenna (km).

Let the maximum height of the top of the FM main beam at distance d over 4/3 curved earth = HMB (m)

Therefore, $HMB = H_{FM} + h_\beta + h$ (1)

$= H_{FM} + 1000\ [D \tan (1/2\ \theta)] + 0.06D^2$ (2)

Taking antenna beam tilt (β) (depression angle, in degrees) into account, equation (2) becomes:

$$HMB = H_{FM} + 1000\ [D \tan (1/2\ \theta - \beta)] + 0.06D^2 \quad (3)$$

An aircraft is in the main beam of the FM antenna radiation pattern if:

$$H_{AC} < H_{FM} + 1000\ [D \tan (1/2\ \theta - \beta)] + 0.06D^2 \quad (4)$$

Equation (4) assumes that the aircraft is within radio line-of-sight of the FM broadcasting antenna. When broadcasting stations at several different locations are involved, such as in a three-signal intermodulation case, equation (4) has to be satisfied for each of the stations.

2. Modelling of vertical radiation pattern envelope

Another antenna modelling technique characterizes the envelope of the vertical radiation pattern with a set of nominal values [CCIR, 1982-86]. Consider the vertical radiation pattern of the high gain antenna shown in Fig. III-2.

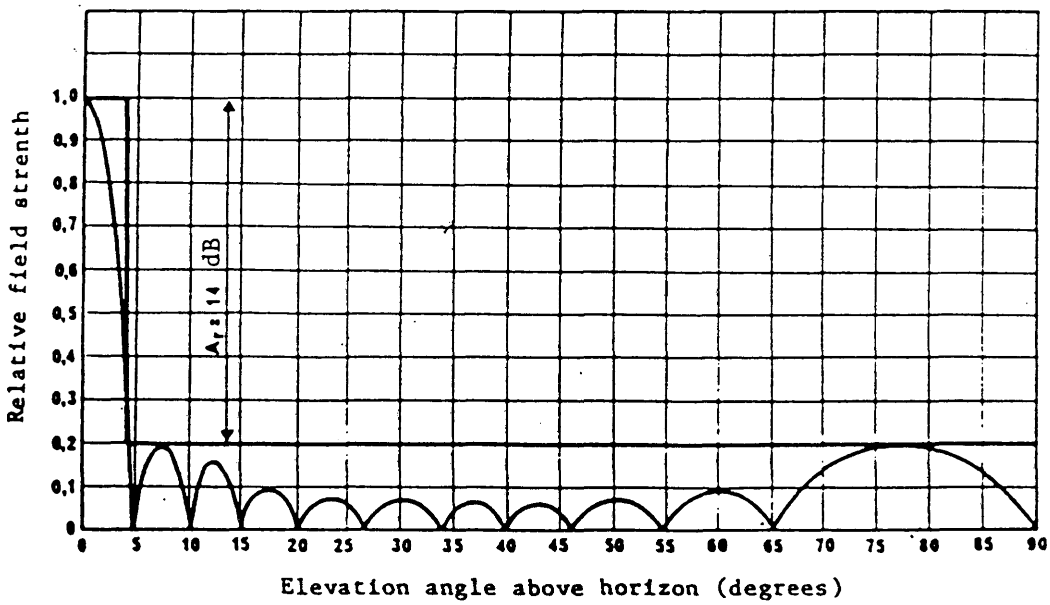


FIGURE III-2

Example of vertical radiation pattern for high gain antenna

A_r = 0 dB for $\alpha < 4^o$
and A_r = 14 dB for $4^o \leq \alpha \leq 90^o$

where:

A_r : attenuation of vertical radiation pattern for a fixed elevation angle α (in degrees) above horizon. This factor can approach 20 dB for some antennas.

Techniques such a cosecant-squared modelling of the vertical radiation pattern can also be used.

2.1 Antenna aperture of 2 wavelengths or more

In order to model the envelope of the vertical radiation pattern of antennas with apertures of 2 or more wavelengths the VRP correction, V, can be calculated by using the following formula:

$$V = -20 \log (\pi . N . \sin\theta) \text{ dB}$$

where N = vertical aperture in wavelength

θ = elevation angle relative to the maximum (normally horizontal).

It should be noted that for small elevation angles this expression can produce positive values for V. In such cases V is set to 0 dB (ie: no VRP correction is applied).

For high elevation angles the VRP correction is limited to a value of -14 dB,

ie: 0 > VRP correction > -14 dB.

This formula has been chosen as a suitable compromise for all polarizations.

2.2 Antenna aperture of less than two wavelengths

When using low gain antennas (those with vertical apertures of less than two wavelengths) the values in Table III-1 characterize the envelope of the vertical radiation pattern.

For intermediate angles linear interpolation should be used.

TABLE III-1

Elevation angle (degrees)	VRP correction (dB)
0	0
10	0
20	-1
30	-2
40	-4
50	-6
60	-8
70	-8
80	-8
90	-8

REFERENCES

AUGSTMAN, E. and LUBIENIETZY, A. [1982] - Interference to aircraft VHF NAV/COM receivers from FM broadcast stations. Departments of Communications and of Transport, Ottawa, Ontario, Canada.

CCIR Documents

[1982-1986]: JIWP 8-10/11 (Yugoslavia).

ANNEX IV

INFORMATION ON TRANSMITTER TEST AND LINE-UP PROCEDURES

1. Transmitter tests in the United States of America

Common practice in the U.S. for FM broadcast stations is to conduct transmitter measurements while radiating on an average of once a year. These tests encompass audio frequency response, harmonic distortion, FM signal to noise ratio and AM noise level measurements. During these tests, discrete modulating frequencies of 50, 100, 400, 1000, 5000, 7,500, 10,000, and 15,000 hertz are used at 25, 50 and 100% modulation levels. Although testing is usually conducted while transmitting in the monophonic mode, some stations may also conduct the same measurements while transmitting in the stereophonic mode, or with subsidiary subcarriers activated. The amplitudes of FM modulation sidebands during stereophonic transmissions or with subsidiary subcarriers are lower in amplitude and more widely distributed due to the greater dispersion of energy within the baseband modulating signal.

These tests usually require approximately 3 hours to conduct and are almost exclusively performed during the 0001 to 0600 hours local time.
The time required for these tests depends on whether measuring equipment with automatic level and nulling features is used.

Only those stations that are operating on FM channels immediately below 108 MHz could produce possible sidebands during testing at discrete modulating frequencies that would fall on specific aeronautical assigned frequencies. The analysis for a particular interference potential of such testing would have to be done on a case-by-case basis. However, the potential for interference due to such testing is negligible.

2. Transmitter tests in Finland

Measurements are conducted twice a month for each network during the daytime on Mondays:

network I and II from 1 to 2 p.m. in alternate weeks
network III together with network II
network IV from 9 to 10 a.m.

Measurement programme is as follows:

Frequency	Duration	Purpose
1000 Hz	4 min	Level control
Pause	90 s	Signal to Noise Ratio
40 Hz	45 s	L-channel
1000 Hz	45 s	frequency
15000 Hz	45 s	response
40 Hz	45 s	R-channel
1000 Hz	45 s	frequency
15000 Hz	45 s	response

This programme is repeated after a 90 s pause and after the cross talk is measured with:

1000 Hz	90 s	cross talk M - S
1000 Hz	45 s	cross talk L - R
1000 Hz	45 s	cross talk R - L

Measurements are conducted in the stereophonic mode and for all signals the deviation used is ± 47 kHz including the pilot-tone.

In future, these measurements will be automated and the measurement time will be reduced to about 5 to 10 seconds.

DECISION 71-1*

CONTINUATION OF STUDIES ON COMPATIBILITY BETWEEN THE AERONAUTICAL RADIONAVIGATION SERVICE IN THE BAND 108-117.975 MHz, THE AERONAUTICAL MOBILE (R) SERVICE IN THE BAND 117.975-137 MHz AND THE FM SOUND BROADCASTING STATIONS IN THE BAND ABOUT 87-108 MHz

(1985-1989)

CCIR Study Groups 8 and 10, at their Final Meetings, Geneva, 1989

CONSIDERING

(a) Question 61/8 and Question 46/10;

(b) Recommendations Nos. 4 and 5 of the Regional Administrative Conference for FM Sound Broadcasting in the VHF Band (Region 1 and certain countries concerned in Region 3), Geneva, 1984;

(c) the provisions of Resolution 24;

(d) that the need for compatibility between the broadcasting and aeronautical services is recognized as a world-wide matter;

(e) that there is a need to provide guidance to the organizations responsible for the sound broadcasting service and the aeronautical services on methods for:

- prediction of potential incompatibility, as part of the frequency assignment process;
- prevention of incompatibilities in practical situations;

(f) that the studies could best be carried out jointly between Study Groups 8 and 10,

DECIDE

1. that Joint Interim Working Party 8-10/1 should continue its work;

2. that this Joint Interim Working Party should study:

2.1 compatibility between the aeronautical radionavigation service and the sound-broadcasting stations in the bands concerned;

2.2 compatibility between the aeronautical mobile (R) service and the sound-broadcasting service in the bands concerned;

2.3 compatibility criteria that can be used to predict potential interference in an assignment decision context including the determination of the correlation of bench tests with in-service operational performance of aeronautical receivers;

2.4 The Joint Interim Working Party should consider the items listed in Annex I.

* The Director, CCIR, is requested to bring this Decision to the attention of the ICAO.

3. The JIWP shall prepare a consolidated draft Report to be based on existing CCIR texts and on the results of ongoing studies. This draft report shall be available before the next Interim Meetings of Study Group 8 and 10, in a form which will allow the CCIR to issue it as a separate publication after approval by both Study Groups 8 and 10.

4. In preparation of its Report, the JIWP shall give highest priorities to the study of methods for prediction of potential incompatibilities and to the reduction of apparent discrepancies between predicted results and practical experience (see Annex I).

5. The JIWP shall prepare a draft Recommendation containing the essential conclusions of its studies, before the next Final Meetings of Study Groups 8 and 10 for approval by both of these Study Groups*.

6. that, as far as practicable, the work should be conducted by correspondence, but that it may meet on the proposal of its Chairman, following consultation with the Director of the CCIR;

7. that the Chairman and the composition of Joint Interim Working Party 8-10/1 shall be as shown in Annex II.

ANNEX I

ITEMS SUGGESTED FOR PARTICULAR STUDY

It is suggested that the JIWP in its decisions on priorities regarding its work on the compatibility between the aeronautical radionavigation service, the aeronautical mobile (R) service and the FM sound broadcasting stations in the bands concerned, considers the following items:

- protection ratio values for future airborne receivers against spurious emissions from sound-broadcasting stations (referred to as A1 type of interference) in cases where the frequency of the spurious emissions does not coincide with the aeronautical frequency;
- protection ratio values for present and future aeronautical receivers against out-of-band emissions from sound-broadcasting stations (referred to as A2 type of interference);
- criteria for prediction of third-order intermodulation (referred to as B1 type of interference) generated in airborne receivers by three unwanted signals, for receivers meeting the ICAO standard for two-signal intermodulation for future receivers;
- the effect of sinusoidal modulation of the sound-broadcasting transmitters during test and line-up and any precautions or procedures to be adopted at broadcasting stations in order to maintain the agreed protection of the aeronautical radionavigation service;

and in particular,

- a more exact mathematical representation of the immunity characteristics of aircraft receivers for B1 and B2 types of interference;
- arrangements of test points which lead to the detection of all relevant interference potentials;
- a value for the cut-off level which would ensure that no relevant interference potential of the B1 type of interference remains undetected;
- additional tests for communications receivers.

---

* This Recommendation shall be published by the CCIR in both Volume VIII, Volume X and in the separate publication identified in DECIDES 3.

ANNEX II

1. At the first meeting of JIWP 8-10/1 the following Administrations, International Organizations and Recognized Private Operating Agency were members of the Joint Interim Working Party.

Administrations:

Germany (Federal Republic of)
Australia
Austria
Belgium
Canada
United States of America
Finland
France
Italy
Norway
Netherlands
United Kingdom
Sweden
Switzerland
Yugoslavia (Socialist Federal Republic of)

International Organizations and Recognized Private Operating Agencies:

IATA
ICAO
EBU
Norddeutscher Rundfunk
Rhode and Schwarz

1.1 At the Final Meetings of Study Groups 8 and 10, the following administrations expressed the wish to participate:

Administrations:

Brazil (Federative Republic of)
Hungarian People's Republic
Iran (Islamic Republic of)
Japan
New Zealand
USSR

2. The Chairman of the Joint Interim Working Party will be:

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