TITLE :

A STUDY INTO CURRENT FM RECEIVER PERFORMANCE AND THE RELEVANCE OF FM ALLOCATION CRITERIA

Prepared for:

DEPARTMENT OF COMMUNICATIONS

Ottawa, Ont.

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SECTION A: CONTRACT REFERENCES

A.1 CONTRACT TITLE: STUDY INTO CURRENT FM RECEIVER PERFORMANCE AND THE RELEVANCE OF FM ALLOCATION CRITERIA

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A.5 CONTRACT DATES: Telex - November 29, 1977
Document - December 9th, 1977.

A.6 CONTRACTOR: Peter Cahn and Associates
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Peter Cahn, Eng.,
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A.7 CONTRACT DATE OF SUBMISSION: April 25, 1978.

A.8 SEALS AND SIGNATURES OF CONTRACTOR:

A.G. Day, P.Eng., Peter Cahn, Eng.

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C.1: Purpose

This report covers the methods employed, the results achieved and the conclusions we have drawn from our study into current FM broadcast receiver performance and the relevance of FM allocation criteria presently in use in Canada.

The report was prepared by Mr. Peter Cahn, Eng. and Mr. A.G. Day, P.Eng., for the Department of Communications Ottawa, Ontario.

For convenience, the report is divided into two main parts:

a) FM broadcast receiver performance characteristics

b) FM broadcast allocation criteria for the 88 - 108 MHz frequency spectrum.

C.2: Methods and References Used

FM receiver performance characteristics were obtained with the aid of a questionnaire mailed to thirty (30) Canadian manufacturers and/or importers of FM receivers, from published performance specifications and from discussions held with various individuals directly associated with the broadcast industry.

FM allocation criteria were studied with the aid of numerous source documents and references in Department of Communications (DOC) and Federal Communications Commission (FCC) notices, orders, enquiries, rules and regulations. In addition, discussions were held with Canadian and U.S. broadcast consultants active in this field.

C.3: Terms and Definitions

This report contains a number of terms and abbreviations and for convenience of the reader the following lists are compiled.

C.3.1 "Alphabet" Nomenclature

AF	Audio Frequency
AFC	Automatic frequency control
AM	Amplitude modulation
CRTC	Canadian Radio-television & Telecommunications Commission
dB	Decibel, a dimensionless number representing a ratio
dBf	Power ratio, referred to 1 femtowatt (= 10^{-15} Watt)
dBu	Voltage ratio, referred to 1 microvolt (= 10^{-6} Volt)
DOC	Department of Communications
EHAAT	Effective height above average terrain
ERP	Effective radiated power
FCC	Federal Communications Commission
FET	Field effect transistor
FM	Frequency modulation
Hz	Hertz
IC	Integrated circuit
IHF	Institute of High Fidelity
IMP	Intermodulation product
IF	Intermediate frequency
kHz	Kilohertz (= 10^3 Hz)
kW	Kilowatt (= 10^3 Watts)
LO	Local Oscillator
MHz	Megahertz (= 10^6 Hz)
mV	Millivolt (= 10^{-3} Volt)

uV	Microvolt (= 10^{-6} Volt)
MOSFET	Metal-oxide semiconductor field effect transistor
RF	Radio frequency
SAW	Surface acoustic wave
SCMO	Subsidiary Communication Multiplex Operation
S/N	Signal-to-noise ratio
V	Volt
W	Watt

C.3.2: Definition of Terms

Capture Ratio (IHF): The ability of the FM receiver to respond to the desired RF signal in the presence of another RF signal on the same frequency.

Cross-Modulation: The transfer of modulation of an undesired signal to the modulated carrier of the desired signal. Cross-modulation in an FM receiver occurs only to the extent that the receiver is incidentally sensitive to amplitude modulation.

Intermodulation: The process of mixing of two or more undesired signals with the desired signal and producing a response within the passband of the receiver. The undesired signals may be received off-air by the antenna or one of them (or its harmonics) may be generated within the receiver itself.

Usable Sensitivity: (IHF) The highest of the signal input levels required at either 90, 98 or 106 MHz to result in an output signal whose S/N is 30 dB.

dB Quieting Sensitivity:	The unmodulated signal input level resulting in a specified receiver noise output level (dB) below the level corresponding to zero signal input level.
Alternate Channel Selectivity (IHF):	The ratio of the signal input level at the desired (tuned) frequency to the signal input level at $\pm$ 400 kHz removed from the desired signal frequency to produce the same output level.
Frequency Deviation: (Δf)	The frequency excursions of the FM carrier when a modulating signal (f_s) is impressed on it. Note: The amplitude of the modulating signal is proportional to the amount the instantaneous frequency swings from the centre frequency. The modulation index = $\frac{\Delta f}{f_s}$
Spurious Response Ratio:	The ratio of the level of the desired input signal to the level of any undesired input signal at another frequency resulting in the same output level.
Image Response Ratio:	The ratio of the level of the desired input signal to the level of an input signal 21.4 MHz below or above the desired signal depending on the frequency of the LO being above or below the frequency of the desired signal, and resulting in the same output level.
IF Response Ratio:	The ratio of the level of the desired input signal to the level of an input signal whose frequency is 10.7 MHz, and resulting in the same output level.

AM Suppression:	The ability of the receiver to suppress its response to amplitude modulation impressed on an FM carrier. Note: Ideally, an FM receiver does not respond to amplitude modulation. However, in every practical receiver, limiting action is not perfect and AM responses are obtained.
Stereo Separation:	The ability of the FM multiplex decoder circuits to separate the right and left channel information contained in a stereophonic signal.
Subcarrier Suppression:	The ability of the receiver to suppress all harmonics of the stereo subcarrier (38 kHz). Note: The fifth harmonic of the 38 kHz LO is only 10 kHz removed from an adjacent channel (200 kHz) assignment.

SECTION D: FM BROADCAST RECEIVERS

D.1: General Comments

The FM broadcast receiver available in the marketplace today appears in a large variety of forms, shapes and sizes. For example, there are FM receivers embodied in the so-called "Hi-Fi" (high fidelity) customer selected component system, in factory assembled TV and radio combination console models, in portable radios including multi-band facilities, in AM/FM automobile radios and in other consumer products such as home intercom systems, telephone hand-sets and a host of other "novelty" items. Rarely, if ever, does one find an FM radio receiver packaged entirely by itself, rather it is generally thought of as a "bonus" with the AM/FM/clock radio, the cartridge or cassette recorder/player, AM/FM radio complete with "Dolby" noise reduction circuitry and perhaps in the most recent combination AM/FM/CB car radio.

In view of these divers applications and uses it is not possible to ascertain the number of FM receivers in the hands of the public by any other means than a national survey. Although some figures are available for May 1977*, it is likely they are neither accurate nor meaningful for two reasons: (i) there are no Canadian manufacturers of FM receivers who in the past were required to report their production quantities, and (ii) importers of radio sets such as outlined above are not required to report or make a separate accounting of the FM portion of any radio combination.

Further, it serves no useful purpose to attempt a classification of FM receivers in terms of a cost/performance structure because the FM receiver is merely part of the package, and in many instances the electronic circuitry is shared with other sections of the product. Complete IC's are often shared for multi-purpose duty.**

In addition, we have found that the retail price of FM receivers varies by a ratio of two-to-one under certain conditions such as inventory sales, fast turn-over deals, and individual bargaining where a customer can negotiate the price he pays with the seller depending on the total amount of the transaction. It has also been noted that the reliable department store often sells the same products at "as marked" prices which are higher than those which can be negotiated at discount stores.

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*"Household Facilities & Equipment", Statistics Canada, May, 1977.

**"An AM/FM Radio Subsystem IC", Consumer Electronics, IEEE Vol. VR-23, No. 2 , May 1977;

"A single Chip AM/FM IC Radio", Consumer Electronics, IEEE, Vol. CE-23, No. 3, Aug. 1977.

Another observed trend of the electronic aspects of current FM receivers requires a comment. In the "Hi-Fi" component system market, the amount of audio power output per channel appears to be the overriding criterion by which these units are compared. In many instances, it is true that the excellence of the circuitry employed varies only marginally in a total product line. The emphasis is on available audio power, enclosure styling, functions and controls and rarely is the technical performance of the AM and FM sections questioned; the public is probably unaware of tuner performance specifications being in existence.

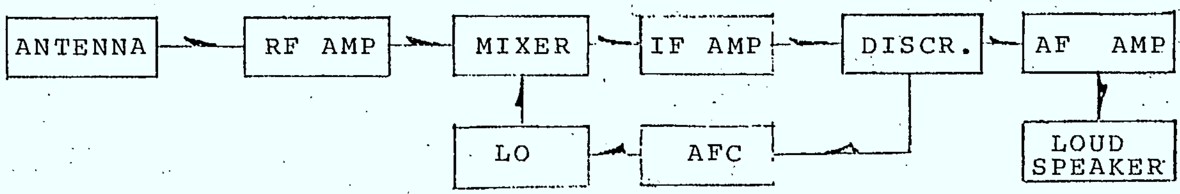
The foregoing arguments are ample evidence that for the purposes of this study a classification of receivers should be based on the actual receiver performance. We shall therefore examine in detail the electronic circuitry employed in certain parts of the receiver and assess how it copes with the now congested FM signal environment. Included in this assessment is the wiring, shielding and housing of the components as well as the electro-mechanical aspects of the receiver.

D.2 FM Receiver Performance

The approach we have selected in our study of current FM receiver design and performance requires some explanations. Whereas there is an abundance of technical specifications published by the manufacturers covering the performance of "Hi-Fi" tuners and receivers, there is a scarcity of information on all other types of FM receivers on the market today. The publicity and advertisements of receivers which generally perform extremely well are fully supported by technical data but almost nothing is known about any of the others.

Through the kind co-operation of one importer of FM receivers in the "novelty" class, we learnt of one typical specification normally issued to an off-shore manufacturer. The performance requirements are minimal: "... moreorless, the unit shall be capable of receiving FM broadcast/police/weather signals in the VHF bands..." Another importer sent us his purchase specification, and fortunately these were considerably more specific. Six or seven technical parameters were specified for minimum performance standards. The headings used were admirable, but the corresponding numbers were hardly satisfactory except from a pricing standpoint.

It is not considered necessary here to engage in a dissertation on the theory and practice of FM broadcast receivers, but nonetheless, it does serve a useful purpose to give a short description. All FM receivers built for the Canadian market in 1977 employ the superheterodyne principle and use an IF or 10.7 MHz. The receiver can be represented in its simplest form by the following block diagram:



For our purposes, the pivotal sections are the antenna system, the RF amplifier if used, the mixer, the local oscillator, the IF section and to a lesser extent the demodulator or discriminator.

(1) Antenna System

All FM receivers require either:

(i) An external antenna, roof-top mounted or a twin-lead dipole as supplied with some sets and connected to either the 300- Ohm or 75-Ohm terminals or connector:

(ii) a telescopic whip antenna, or

(iii) an internal capacitive-doupled device connected to the power line cord which acts as the antenna.

(2) RF Amplifier

Most "Hi-Fi" tuner/receivers use at least one or more well-screened stages of RF amplification of the received signal before it is mixed with the local oscillator frequency to obtain the IF. Most of the table, console or portable type receivers employ a separate mixer and oscillator circuit, but omit the RF amplifier and its associated pre-selective circuits.

(3) Mixer

Well designed circuitry employing FET's and good shielding in this stage result in correspondingly better performance figures than for those receivers where insufficient care is taken.

(4) IF Section

Many "Hi-Fi" sets employ ceramic or crystal, and more recently SAW filters to obtain excellent alternate channel rejection, while the majority of FM receivers still use IF transformers employing conventional tuned circuits.

Since the receiver is called upon to receive FM signals in the 88-108 MHz broadcast band, it must be fitted with a tuning mechanism to accept the desired signal and at the same time to reject all other undesired signals. It is this accept/reject capability of the receiver operating with vastly differing levels of field strengths of both desired and undesired signals which in the last analysis controls the performance of the FM receiver.

With the object therefore to determine the quality of FM receivers in use, it was decided to class all receivers into four categories. Each category is defined by the type of electronic or electro-mechancial circuitry employed between the antenna input point and the IF amplifier section. A detailed description of the four categories may be found in the introduction of the questionnaire appended to this report.

D.3 Questionnaire

The questionnaire sent to 30 Canadian manufacturers and/or importers was designed to identify the class of receivers and to obtain some performance characteristics. The number of gang-tunable sections embodied into the receiver permits a ready and quite accurate assessment of the performance characteristics of the particular receiver under review. A five-ganged tracking and tuning mechanism implies that the receiver is fitted with four stages of RF signal pre-selection leaving the fifth stage for the LO tuning and obviously resulting in far superior performance to say, a two-ganged device. The three or more ganged model is our category "A" receiver and the two-ganged version falls into our category "B".

The category "C" receiver employs a self-oscillating mixer stage and it seems there are not too many of these in use, as there are few if any performance figures for this type of receiver to be found anywhere and the most that can be said for this category is that it will "... moreorless receive FM signals".

None of the respondents offered any comments on the category "D" receiver. Apparently, at the present time there are no FM receivers in use in Canada employing any other type of tuning mechanism. A brief study of some European designs showed that different tuning systems are coming into use. One of the more advanced methods employs a frequency synthesizer combining the convenience, accuracy and simplicity of analog-tuning with the stability of digital synthesis. Other methods employing keyboard entry (digital-tuning) have also emerged.*

The questionnaire was divided into two parts, the first was to determine the types and numbers of FM receivers according to category, and the second part attempted to provide some answers to operational performance in present day environments. Only four respondents were able to carry out the laboratory-style tests but these showed significant results and may be assumed to be fairly representative of the normal performance to be expected.

22 out of 30 recipients of the questionnaire responded and useful discussions were held with four others. Overall, the results of the questionnaire were considered to be satisfactory, although too sketchy and certainly too incomplete to include in their entirety in this report. Rather, it is more useful to interpret the results based on the replies and on the additional material made available to us in the form of service manuals, circuit diagrams and test procedures not generally available to the public.

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*"An analogue-tuned digital Frequency Synthesizer tuning System for FM/AM Tuners", Consumer Electronics, IEEE, Vol. CE-23, No. 4, November 1977.

D.4 Summary Results of Questionnaire (See Table A in Appendix)

Part I

1.1 All respondents who replied in the affirmative mentioned only category "A" and "B" receivers, except one.

1.2 All respondents replied in the requested manner as to model numbers for each category referred to in 1.1.

1.3 The majority of receiver types were category "A" for component tuner and tuner/amplifiers and category "B" mainly for portable receivers and stereo consoles. Only one respondent referred to car radios, and two such models reported fell into category "A".

1.4 Most respondents produced only very approximate numbers, others entered no figures.

Part II

2.1 Three respondents only performed this test on a category "A" receiver, and of course the results showed that there was no deterioration in the recovered audio over the available input range of the sweep generator used.

One respondent performed this test on a category "B" receiver and five major spurious responses occurred at a signal input level of 25 mV and 12 major spurious responses at a signal input level of 250 mV.

(One additional respondent has promised to supply test results within a two week period, March 30, 1978).

2.2 Again, the same three respondents performed this test and of course no spurious intermodulation products were recorded using category "A" receivers.

The respondent who performed this test on a category "B" receiver reported two spurious frequencies for test condition 1, six spurious responses each under test conditions 2 and 3.

Summarizing, the reported results leave no doubt that additional tests under controlled conditions are essential to arrive at a fuller understanding of present day FM receiver performance.

D.5 Summary of Performance Standards for Category "A" Receivers

The following table was prepared from technical specifications either published by manufacturers or supplied to us for this study for category "A" receivers.

TABLE 1

Parameter	Grade I (Excellent)	Grade II (Above average)	Grade III (Satisfactory)
1. Usable Sensitivity (IHF)			
Mono	9 dBf	12 dBf	15 dBf
Stereo	15 dBf	20 dBf	25 dBf
2. Selectivity (IHF)	80 dB	70 dB	60 dB
3. Signal/Noise (IHF)			
Mono	75 dB	70 dB	65 dB
Stereo	70 dB	65 dB	60 dB
4. Capture Ratio (IHF)	1 dB	1.5 dB	2 dB
5. Image Response	-100 dB	-80 dB	-60 dB
6. IF Response	-110 dB	-90 dB	-70 dB
7. Spurious Response	-100 dB	-80 dB	-60 dB
8. Stereo Separation			
at 1 kHz	45 dB	40 dB	35 dB
at 30 - 15000 Hz	35 dB	32 dB	30 dB
9. AM Suppression	60 dB	55 dB	50 dB
10. Subcarrier Suppression	70 dB	60 dB	50 dB

D.6 Summary of Performance Standards for Category "B" Receivers

The following table was prepared from technical specifications supplied to us for this study for category "B" receivers.

TABLE 2.

Parameter	Range of Existing Performance Levels
1. Usable Sensitivity (IHF)	
mono	10 - 150 uV
stereo	50 - 250 uV
2. Selectivity (IHF)	15 - 25 dB
3. Signal/Noise (IHF)	
mono	35 - 55 dB
stereo	35 - 50 dB
4. Image Response	20 - 35 dB
5. IF Response	50 - 60 dB
6. Spurious Response	40 - 55 dB
7. Stereo Separation	20 - 30 dB
8. Subcarrier Suppression	30 dB
9. AM Suppression	unknown
10. Capture Ratio	unknown

D.7 Additional Receiver Performance Characteristics

Aside from the ten or so performance parameters examined in the previous sections, there are several other peculiarities pertaining to performance of FM receivers.

(1) The ½-IF Response

This spurious response occurs when the receiver is tuned to a weak station with a strong signal station transmitting on a frequency one-half the IF (10.7/2 MHz) above the desired signal frequency. For example, if the tuned frequency is 100 MHz, the LO frequency is therefore 110.7 MHz, then the receiver could produce an output from an undesired signal appearing at the input terminals of 105.3 MHz. The mechanism is simply this: the 2nd harmonic of the LO frequency (2 x 110.7 MHz) mixes with the 2nd harmonic of the strong signal (2 x 105.3 MHz) to produce a 10.8 MHz signal which cannot be stopped by the 10.7 MHz IF amplifier filter system. The effect of this spurious response is minimized by low-pass filtering of the output of the LO.

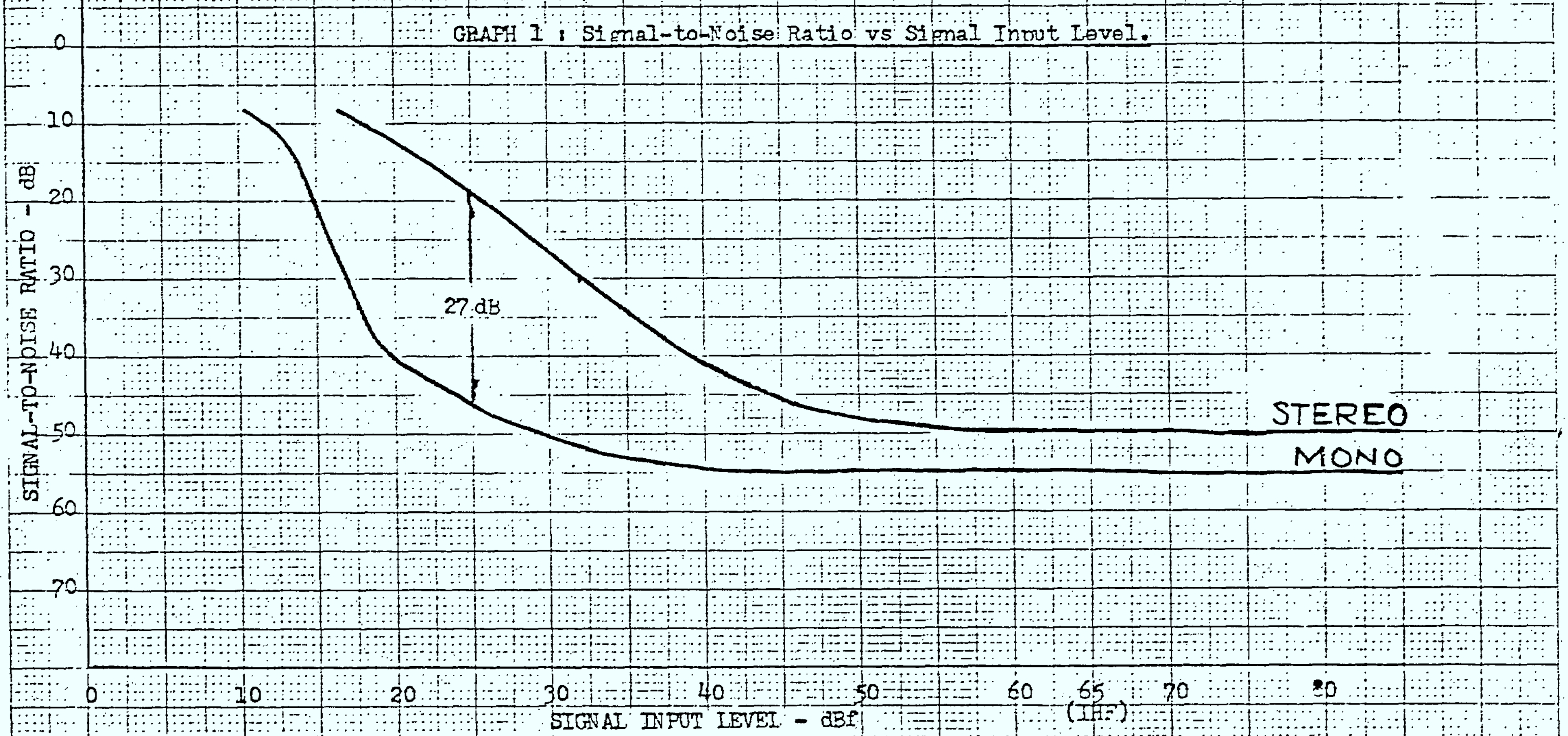
(2) The Pulling Action of the AFC Function

Just as the level of the input signal appearing at the terminals of an FM receiver alters the receiver's overall tuning response, the pulling action of the AFC circuitry often required for frequency stability also extends the spreading out effect of stations and results in interference with the reception of weak distant signals. In all categories, few FM receivers are fitted with AFC defeat controls. Some receiver designers however have provided an auto-lock frequency control system of excellent capability and they maintain that no external controls are necessary because during the tuning process the AFC is temporarily disabled.

(3) FM Stereophonic Effects

The decoder systems employed to separate the left and right stereo signal information all suffer from one defect: noise. As can be seen from Graph 1, at certain low level ranges of distant station signals, the S/N ratio can favour the mono signal by some 27 dB over the stereo signal. In other words, weak stereo signals are much more difficult to receive than their mono counterparts.

GRAPH 1 : Signal-to-Noise Ratio vs Signal Input Level.



At 300-Ohms:

10 dBf = 1.7 uV = 4.7 dBu
20 dBf = 5.4 uV = 14.7 dBu

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(4) Receiver Front-end Designs

Modern technology now permits the use of inexpensive FET's or MOSFET's in RF amplifier and mixer service resulting in transfer characteristics which are more linear and can suppress IMP's by as much as a further 20 dB.

The large-signal handling capability, which in the days of vacuum tubes was a relatively simple technique, with solid state circuitry is more difficult and expensive to achieve. A desirable addition to the simpler detection devices would be the re-introduction of the distant/remote switch which has of late been omitted for no valid reason with a further improvement of IMP suppression.

(5) FM Receiving Antennas

No FM receiver should be used without a proper antenna as it performs a most important function in the receiving process. The antenna required for good FM reception is of far greater importance than its AM counterpart. The urban listener, compared to the suburban and rural listener faces vastly different reception problems*. Therefore the selection of the receiving antenna assumes significant proportions and this requires a more knowledgeable approach.

(6) Dynamic Selectivity Curves

Graph 2 showing the dynamic selectivity curves of a typical better grade category "A" receiver is interesting in two respects. The unsymmetrical "bandwidth" versus signal strength variation is clearly evident and also the measure of rejection of signals away from the desired signal represented by the steepness of the curves. Both of these characteristics bear some relation to FM allocation criteria as will be discussed later.

Another useful characteristic of the FM receiver is the capture effect. On Graph 2, assume that the curve marked "X" indicates the desired signal level and relative frequency. An interfering signal now represented by the selectivity curve shows its relative strength adjusted so that only the desired signal appears in the output, thus capturing the receiver. At the frequency difference of 0Hz, the capture ratio is measured. This ratio is a direct measure of the receiver's ability to accept the stronger and reject the weaker signal. Note that the capture ratio varies slightly, improving as the strength of the desired signal increases. The IHF measurement stipulates that the level of the desired signal is set at 1 mV.

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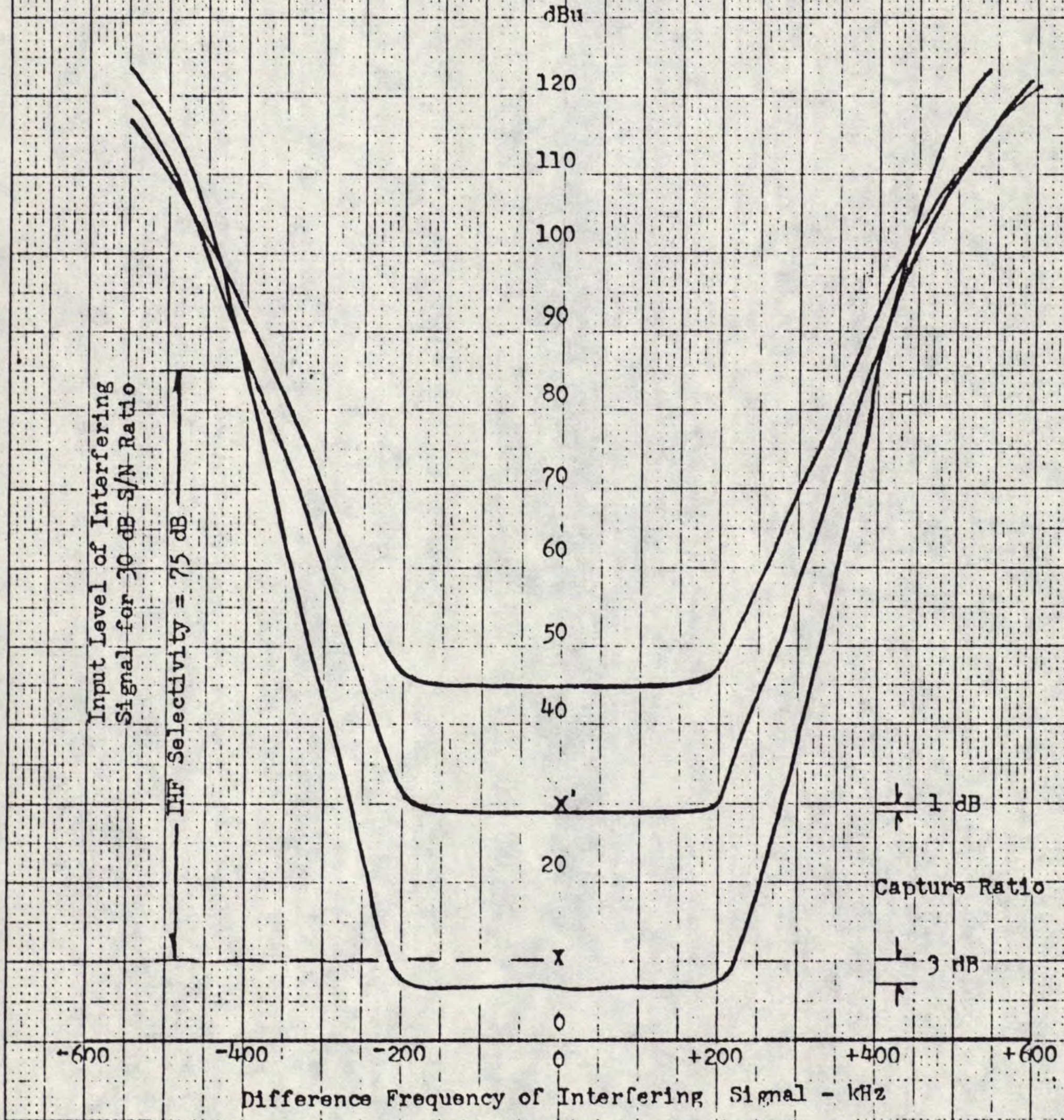
*The combined Effects of Receiver Sensitivity and Building Structures on FM Coverage". CBC Development Report 2954-8 June 73

GRAPH 2 : Dynamic Seldctivity Curves.



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SECTION E: FM BROADCAST ALLOCATION CRITERIA FOR THE 88-108 MHZ FREQUENCY SPECTRUM

E.1 History and Philosophy

Prior to 1962, FM allocations in the United States were based on protection of the one millivolt per metre contour with signal ratios which were considered adequate in the light of receiver performance at the time. These were:

Undesired-to-desired field ratios in dB	
Co-Channel	-20
First-adjacent (200 kHz)	- 6
Second-adjacent (400 kHz)	20
Third-adjacent (600 kHz)	40

Most stations at that time were operating with modest parameters, but some super-parameter stations were already on air, stations in excess of 100 kW E R P and with effective heights over 1000 feet.

The FCC, having gone through their normal consultation process, on July 25, 1962 issued their First Report and Order under Docket 14185. The replies received had indicated that the above ratios were minimal, but acceptable, and these ratios were adopted, not however to protect the one mV/m contour, but as equivalent mileages for co- and adjacent channel stations which would protect the one mV/m service contours. FCC decided, however, that on second and third adjacent channels, protection to the ratios suggested would be too restrictive in obtaining a satisfactory number of allocations. The mileages they proposed precluded the establishment of another station on second or third adjacent channel inside the one mV/m service contour. This would result in small bites out of service areas where such stations were sited at minimum distances, but following their "substitution of service" concept, more listeners would receive better signals under the proposed rules. Rather than "small islands of service in the midst of seas of interference" under the full protection to the one mV/m contour, the service areas would be closer together, though with small bites of interference, and the remaining "seas of interference" would be of smaller size.

FCC also proposed that FM allotments would be based on a specific plan which allotted specific channels to communities, as had been done on television, and contrary to the "first come, first served" principle which applied on AM radio. Among other reasons given was the argument that an agreement with Canada would be easily reached under a plan which would allot channels to specific locations near the common border.

Such a table was proposed in the Second Further Notice of Proposed Rule Making and provided some 2730 FM allotments in the continental United States. The Third Report Memorandum and Order finalized the table of assignments and made provisions for interface conditions between the commercial (channel 221-300) and the non-commercial educational allocations on the "technically-related" channels 218-220. (Channels 218 to 220 are adjacent to the commercial channels 221-223, and allotments on these were required to be considered in protection distances). The table also was in agreement with Canadian allotments along the border, the "Working Arrangement" with Canada having been negotiated. The Fourth Report and Order finalized rules regarding existing stations not consistent with the table of assignments and for the U.S. territories and possessions, Alaska, Puerto Rico, etc.

The table of allotments adopted was based on mileages as given in Table 3. Class A stations were confined to twenty specific channels. Class C stations were permitted in all the country except for a Northeastern Zone (Called Zone I) and a part of Southern California, and in these areas, Class B stations were the maximum parameters permitted.

Class A parameters were 3 kW ERP at 300 feet. Class C parameters were 100 kW at 2000 feet, stations designed to provide wide-area coverage in the more sparsely settled parts of the country. Class B stations, interestingly, were permitted 50 kW ERP at 500 feet or equivalent, since these parameters were found to be necessary to provide an adequate signal over the city of New York from the Empire State Building. Class D were low-power educational stations similar to LPFM stations in Canada.

The one mV/m contour, based on the F(50:50) curves in use at the time, for the Class A, B, or C stations, was calculated to be 14.5, 32, and 64 miles respectively. It was decided that in the crowded Zone I, the Class B protection should be extended to 40 miles, and in rounding off the table to the nearest five miles, the following contours were said to be protected:

Class	Protected miles	Protected Contours mV/m	dBu
A	15	927	59.34
B	40	562	55.0
C	65	944	59.5

TABLE: 3
Separation in Miles adopted by the U.S.A.
For Indicated Frequency Separations - kHz

Class	Class A				Class B				Class C				Class D			
kHz	Co-	200	400	600	Co-	200	400	600	Co-	200	400	600	Co-	200	400	600
A	65	40	15	15	-	65	40	40	-	105	65	65	-	30	15	15
B					150	105	40	40	170	135	65	65	-	-	40	40
C									180	150	65	65	-	-	65	65

The rules adopted permitted directional antennas with a maximum of 15 dB in field ratio. They also required 70 dBu (3160 mV/m) over the principal city and assumed a 54 dBu (500 uV/m) signal as a minimum for urban coverage though it was recognized that good receiving installations could obtain satisfactory reception down to 34 dBu (50 uV/m) in rural areas. Some of the allotments were "short-spaced", but it was ruled that the actual transmitter sites chosen should comply with the minimum mileage separations.

It should be noted, that, other than for the desired-to-undesired signal ratios assumed for co- and adjacent-channel, and that for co-location stations should be 800 kHz apart, the allocation criteria had no direct relationship to assumed receiver performance.

E.2 The U.S.-Canada "Working Arrangement"- Canadian Rules

The Canadian negotiators approached the question of allocation criteria with some assumptions fundamentally different from those of the FCC. Because of wider geographical spacings, a thinner population, and a lack of realization to what extent the demand for FM allotments would consume the spectrum available, the Canadians decided that the 54 dBu (500 uV/m) contour would define the service area to be protected, and this was to be applied to all protection spacings, not just to co- and adjacent channels. They also decided that the Class B parameters would be insufficient in the area of Canada designated as Zone I (the Windsor-Quebec City corridor). Canada proposed allocation of a Class C_1 station in this area, with parameters permitting 100 kW ERP with a height of 1,000 feet. These parameters resulted in fields about half way between B and C parameters. In other regards, the Canadian rules would parallel the American, except that the principal city contour would be 3,000 uV/m (69.5 dBu) rather than 70 dBu.

Canada also decided that Class A stations would be permitted on any channel rather than on the twenty channels only under the Amercian rules.

The mileages which resulted, and on which the "Working Arrangement"* was based are given in Table 4.

TABLE 4

Separations in Miles Adopted in Canada
For Indicated Frequency Separations - kHz

Class	Class A				Class B				Class C_1				Class C			
kHz	Co-	200	400	600	Co-	200	400	600	Co-	200	400	600	Co-	200	400	600
A	90	50	25	20	135	85	45	40	150	100	65	60	150	120	75	70
B					155	105	60	45	170	125	75	60	170	140	85	70
C_1									190	140	90	70	190	155	105	75
C													190	160	105	80

*Working Arrangement for Allocation of FM Broadcasting Stations on Channels 221-300 under the Canada-United States FM Agreement of 1947" - June 1963.

E.3 Assumed Performance of Receivers

There was no disagreement between Canada and the United States on receiver performance as it might affect the mileage separations on which the allotments were based. The original ratios of undesired-to-desired signals were accepted at face value, -20 dB co-channel, -6 dB first adjacent, 20 dB second adjacent, and 40 dB third-adjacent. FM allotments at the time were relatively sparse, and field experience with intermodulation insufficient to cause concern.

SECTION F: PROTECTION

F.1 Propagation Curves

The protection assumed at the time, based on the nominal 60 dBu for Classes A and C and 55 dBu for Class B in the United States, and the nominal 54 dBu in Canada, was predicted from the FCC Low VHF Band Television Curves of the 1950's then in use. These curves had been developed with a minimal amount of field experience and measurement and were known to be somewhat inaccurate.

Over an extended period, FCC and other measurement data led to the development of revised propagation curves. FCC, on September 7, 1966 published Report R-6602 "Development of VHF and UHF Propagation Curves for TV and FM Broadcasting". These curves included both F (50:50) and F (50:10) conditions, that is, 50 percent of locations at 50 and 10 percent of time respectively. Service is normally based on the former curves, and it has become common practice to employ the latter for interference calculations. This has the effect of protecting a given receiving location at the ratio determined for 90 percent of time.

The curves predict the field receivable at a 30 foot receiving antenna height and assume that the intervening terrain undulates by 50 metres in ground elevation. The report also proposed a "roughness factor" correction but this technique has been found to be inaccurate in mountainous regions.

The R-6602 curves have been adopted in the United States and are in process of adoption for FM coverage in Canada. Application of the "roughness factor" has been delayed pending a resolution of the inaccuracy found in mountainous regions.

The actual protection achieved, both in the United States and here is assessed in the next two sections of this report, based on the R-6602 curves, F(50:50) for service and F(50:10) for interference

Propagation has not changed, only our knowledge of it has been refined. Thus the original assumptions contained inaccuracies which are corrected in the analysis following.

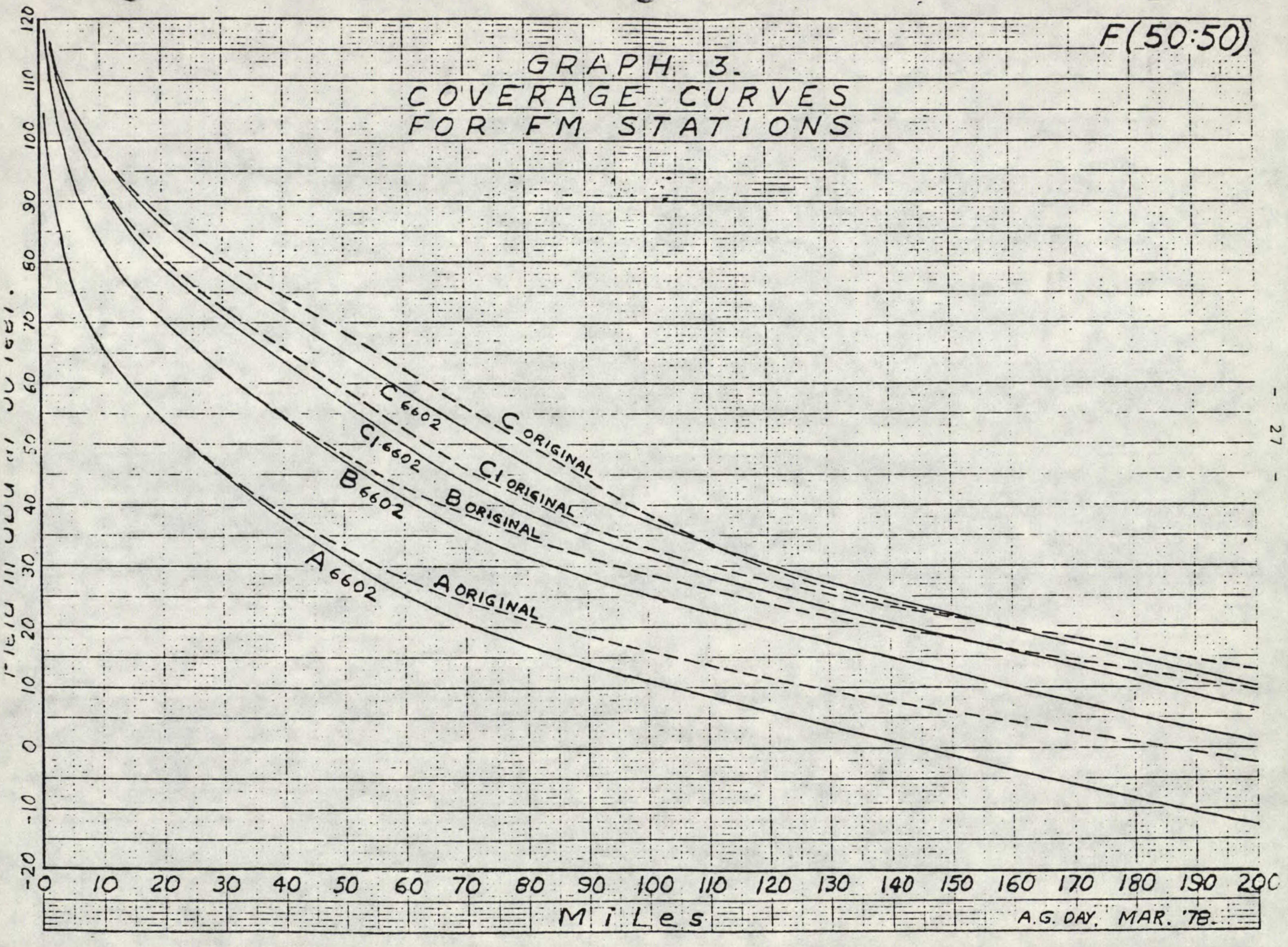
Graph 3 provides the original F(50:50) curves as dashed lines and the R-6602 curves as solid lines for the four classes of FM stations. An examination will show that for Class A and B stations, because of the relatively short distances involved, differences are minor. However, for Class C_1 and C stations, the differences are more significant.

At the 60 dBu (one mV/m) contour, Class A and B coverage does not change, but Class C_1 reduces by three miles and Class C by 5.5 miles.

Graph 4 provides the F(50:10) interference curves from R-6602 for the four classes of FM stations. These curves are developed for distances beyond ten miles, and where ratios are required using lesser distance, Graph 3 can be referred to since both sets of curves would coincide inside ten miles.

F.2 Protection under the U.S.A. Rules

Using Graph 3 and 4, the following results can be predicted. Of course only co- and adjacent-channel can be calculated since the interfering signal for 2nd- and 3rd- adjacent may be located right on the desired signal contour. Class A cannot have co-channel assignments of other Classes since all Class A are contained on twenty exclusive channels.


F(50:50)
GRAPH 3.
COVERAGE CURVES
FOR FM STATIONS
C 6602
C ORIGINAL
C1 6602
C1 ORIGINAL
B 6602
B ORIGINAL
A 6602
A ORIGINAL
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
MILES
A.G. DAY. MAR. '78.

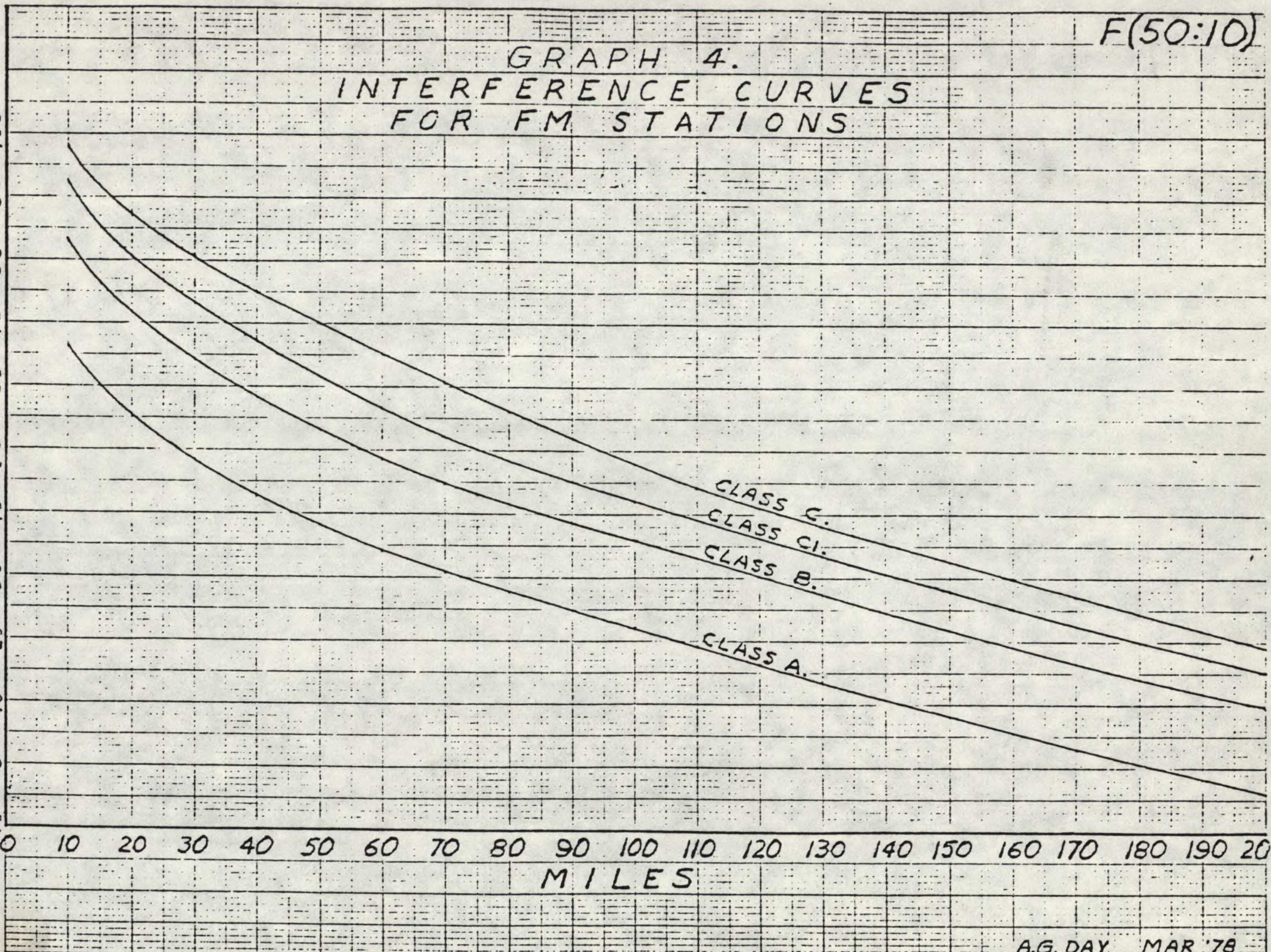

F(50:10)
GRAPH 4.
INTERFERENCE CURVES
FOR FM STATIONS
100
90
80
70
60
50
40
30
20
10
0
-10
CLASS C.
CLASS C1.
CLASS B.
CLASS A.
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
MILES
A.G. DAY. MAR '78.

TABLE 5

Protection Under USA Rules

Class Desired	Un-desired	Miles to desired 60 dBu	Co-Channel D/U Ratio dB *	Co-Channel Mi for 20 dB ratio	Co-Channel Desired field at this dist.	Adjacent-Channel D/U Radio dB *	Adjacent-Channel Mi for 6dB ratio	Adjacent-Channel Desired field at this dis
A	A	14.5	22.0	15.5	58.4	8.8	15.8	58.2
A	B	14.5	-	-	-	7.1	15.0	59.3
A	C	14.5	-	-	-	8.3	15.8	58.3
B	A	22.5	-	-	-	18.3	37.5	56.0
B	B	22.5	31.8	41.0	53.4	19.2	41.2	53.2
B	C	22.5	26.7	36.2	57.2	16.7	38.5	55.3
C	A	58.0	-	-	-	20.5	70.9	52.1
C	B	58.0	27.6	66.5	54.8	17.4	70.0	52.6
C	C	58.0	19.7	57.3	60.3	8.8	60.8	58.3

* at 60 dBu desired contour

It can be seen that each class of station is protected at least to its 60 dBu contour (60.3 for C to C co-channel) and in the case of Class B to an even greater extent, between 53.2 and 57.2 dBu depending on the frequency and class relationship. But only nominal protection is offered beyond the adjacent-channel, the interfering source being no closer than the nominal "service" contour of 15, 40 and 65 miles. In actual fact, Class C stations gain more protection from such stations because of the original assumption that the 60 dBu contour would reach 63 miles.

F.3 Protection under Canadian and International Rules

Again using Graphs 3 and 4, the ratios obtained can be predicted under the Canadian rules. So as to compare protection with that under the U.S. rules, the following tables give the ratios obtained at the one mV/m or 60 dBu contour, and at the 500 uV/m (54 dBu) contour.

TABLE 6: Summary of Canadian Protection at 60 dBu Contour

Desired Class	D/U Ratio in dB for undesired Class at freq. shown.															
	A				B				C_1				C			
	Co-	200	400	600	Co.	200	400	600	Co-	200	400	600	Co	200	400	600
A	30.8	14.8	-5.6	-16	29.9	15.4	-4.0	-7.4	28.2	15.4	-1.3	-4.2	23.4	14.2	-5.0	-7.4
B	41.7	26.6	6.6	2.3	33.3	19.2	0.2	-9.6	31.4	18.7	-0.3	-8.7	26.7	18.2	-4.1	-11.3
C_1	39.3	23.7	4.1	-0.7	31.0	18.3	-4.7	-15.8	30.6	16.3	-4.6	-17.0	25.9	15.7	-5.5	-20.8
C	35.7	26.5	1.8	-3.7	27.5	19.1	-6.3	-20.3	27.2	17.0	-3.3	-23.3	22.4	12.8	-11.5	-25.7
Acceptable	20	6	-20	-40	20	6	-20	-40	20	6	-20	-40	20	6	-20	-40

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It can be seen that substantially greater protection is afforded under the Canadian and International rules. This is understandable since the Canadian intent was to protect the 500 uV/m (54 dBu) contour.

The table following indicates the desired-to-undesired ratios which are obtained at the 500 uV/m (54 dBu) contour.

TABLE 7: Summary of Canadian Protection at 54 dBu Contour
D/U Ratio in dB for undesired class at freq. shown

Desired Class	A				B				C_1				C			
	Co-	200	400	600	Co-	200	400	600	Co-	200	400	600	Co-	200	400	600
A	23.0	5.6	-23.5	*	22.3	7.4	-13.7	-17.7	20.5	5.6	-10.3	-13.3	15.8	6.1	-13.6	-16.1
B	30.5	13.4	-25.0	*	22.2	7.2	-18.0	-40.0	20.4	7.3	-16.3	-26.9	15.7	6.0	-18.6	-26.7
C_1	30.9	14.0	-11.0	-20.5	22.6	9.5	-16.8	-29.2	22.3	7.6	-15.5	-30.3	17.5	6.4	-15.6	-32.5
C	26.8	16.8	-17.2	-38.0	18.8	10.0	-20.0	-54	18.4	8.1	-14.9	-44.2	13.6	3.0	-22.4	-40.8
Accept-able	20	6	-20	-40	20	6	-20	-40	20	6	-20	-40	20	6	-20	-40

* Interfering signal allowed on service contour.

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There are a few encroachments from the ratios deemed acceptable in the above table. Most of these involve Class C stations. They occur of course, for only ten percent of time. A convenient way to spot the actual effect is to present the figures as a chart showing the distances at which the nominal "acceptable" ratios are achieved and comparing these with the nominal "service"distance to the 500 uV/m (54 dBu) contours.

Class	Service Contour (54 dBu) in miles
A	20.0
B	40.3
C_1	54.0
C	67.8

TABLE 8: Canadian Protection-Distance in Miles to obtain Protection ratios shown for class and freq.

RATIO	20	6	-20	-40	20	6	-20	-40	20	6	-20	-40	20	6	-20	-40
Desired	Class A				Class B				Class C_1				Class C			
Class	Co-	200	400	600	Co-	200	400	600	Co-	200	400	600	Co-	200	400	600
A	22.5	19.8	19.0	18.4	21.7	21.0	23.8	30.5	20.5	19.8	26.5	38.0	16.9	20.0	24.3	37.6
B	51.0	46.3	39.0	38.5	42.5	41.3	41.5	40.0	40.9	41.2	43.0	47.5	36.1	40.0	41.2	50.0
C_1	65.4	60.9	57.5	57.8	56.5	57.5	56.1	54.4	56.4	55.6	57.4	58.8	51.3	54.5	57.6	58.8
C	75.2	78.0	68.5	68.2	66.4	71.8	67.7	65.2	66.1	70.0	72.0	66.5	60.5	64.7	65.5	67.3
					Desired Field in dBu at Distances Above											
A	51.5	54.3	55.0	55.5	52.2	53.0	50.3	44.7	53.5	54.3	48.0	38.8	57.2	53.9	50.0	39.2
B	46.6	49.7	55.0	55.4	52.3	53.2	53.1	54.0	53.6	53.2	52.0	48.9	57.2	54.1	53.3	47.2
C_1	46.3	49.4	51.6	51.5	52.2	51.6	52.5	53.7	52.4	52.9	51.7	50.7	55.8	53.7	51.5	50.7
C	49.4	47.9	53.6	53.7	54.8	51.5	54.0	55.5	55.0	52.7	51.5	54.8	58.4	55.9	55.3	54.2

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The encroachments on coverage are worst in the case of undesired co-channel Class C signals. These encroach about 3 to 4 miles into lower class station coverages and about seven miles into Class C coverage. Relationships of the other classes are such that encroachment is less than two miles where it does occur. The only exceptions are between Class C stations. These appear to crowd each other under any channel relationship.

F.4 Conclusion

In the light of the figures presented, it would appear that the table of distances used in Canadian allotments should not be altered unless either the protection ratios should change due to improved receivers or the protected service contour of 500 uV/m (54 dBu) is altered.

SECTION G: STRONG SIGNAL CONDITIONS

G.1 The Real World

The close-in fields from FM stations attain levels which exceed levels at which many receivers can be expected to perform adequately. The F(50:50) curves predict levels which do not take account of the beam shaping which occurs where transmitting antennas of gain greater than unity are used. Were unity gain antennas to be used, the 115 dBu level would be attained at about 0.7 miles from a Class A, 1.3 miles from a Class B, and 2.2 miles from a class C.

A study performed by T.J. Vaughan and Associates for the Canadian Broadcasting Corporation in 1977 has calculated the near-in fields from typical FM transmitting antennas. A summary of the results of this study appears in Table 9 and indicates that with antenna heights at 100 feet, almost any parameter FM station would exceed one volt per metre (120 dBu) inside one mile and could be as high as seven V/m. With heights of 500 feet maximum fields out to one mile range between 150 and 200 mV/m (103.5 to 121.6 dBu). With 1000 foot heights, maximum fields inside one mile range between 160 and 810 mV/m (104 to 118 dBu). The range of values depends on ERP and on the number of bays employed in the antenna.

TABLE 9: Summary of Field Intensity vs EHAAT and ERP.

Bays	Height	Max. F.I. Outside 0.1 mi.	Max. F.I. Outside 1 mi.	Max. F.I. Outside 5 mi.
For 100 kW ERP (From 8 bay/25 kW to 12 bay/20 kW)				
8	100	7000	500	23
12	100	2800	450	23
8	500	1200	600	98
12	500	670	290	92
8	1000	810	340	170
12	1000	740	250	170
8	2000	1300	250	170
12	2000	1100	160	120
For 50 kW ERP (From 8 bay/20 kW to 12 bay/10 kW)				
8	100	5000	350	16
12	100	2000	320	16
8	500	840	410	69
12	500	470	200	65
8	1000	570	180	120
12	1000	520	130	120
8	2000	950	240	120
12	2000	800	170	120
For 10 kW ERP (From 2 bay/10 kW to 12 bay/2 kW)				
2	100	≈6000	160	6
4	100	2000	140	6
8	100	1600	160	7
12	100	640	140	7
2	500	950	340	35
4	500	500	350	35
8	500	270	180	30
12	500	150	90	29
2	1000	540	340	49
4	1000	550	220	49
8	1000	180	110	54
12	1000	160	78	51
2	2000	320	230	67
4	2000	270	120	74
8	2000	300	78	51
12	2000	250	49	40

Unfortunately, because of civil aviation restrictions and economic factors few FM stations attain very high effective heights for their transmitting antennas*. The 52 FM stations on commercial channels in Southern Ontario average 652.5 feet in effective height. Among these are 14 stations located either on the CN Tower in Toronto or on the Ryan Tower in Ottawa. These average 1170 feet in height. The remaining Ontario stations average 461.8 feet. On this basis, we should assume that the typical station not having a favourably high location would attain perhaps 460 feet in effective height. This would be typical for 500 feet masts with TV antenna on top and a side-mounted FM antenna. Inside one mile, the maximum fields from these will range between about 200 and 800 mV/m (106 to 118 dBu). The minimum inside one mile from these same antennas will range about 20 dB lower, or 20 to 80 mV/m (86 to 98 dBu).

Outside one mile from such transmitters, the maximum fields will normally not exceed 500 mV/m (114 dBu) and for lower power stations, about 100 mV/m (100 dBu). With increasing distance, the fields will decay according to the F(50:50) curves.

We should therefore anticipate that the close-in receiving location, between 0.1 and 1.0 miles, will have a field available 30 feet above ground, ranging between about 20 mV/m (86 dBu) and 800 mV/m (118 dBu).

The Canadian Broadcasting Corporation has performed some studies on the actual signals delivered to receiver input stages from fields in urban areas. Rarely are external FM receiving antennas employed, and most FM receivers obtain their signals from vertical unipole antennas, from a connection to the power cord, or from built-in folded dipole antennas. (Receivers connected to CATV systems are supplied signals at levels ranging between about 150 and 500 uV).

According to the CBC report**, indoor fields were predicted to be less than the F(50:50) predictions by the following amounts, in dB:

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*"A Study into the Relevance of Existing UHF-TV Allocation Criteria in the Light of Current Receiver Performance". Report A.G. Day, July 14, 1978.

**"The Combined Effects of Receiver Sensitivity and Building Structures on FM Coverage". CBC Development Report 2594-8 June 1973.

Type of Area	Indoor Locations 50%	90%
urban highrise	-40	-52
urban non-highrise	-34	-40
suburban	-21	-31

The CBC report suggests that the typical FM receiver among the few they tested had an effective antenna length of 0.254 metres. This would have the result of developing an antenna terminal voltage some 12 dB less than the incident field in dBu, or in other words.

$$V(term)\ dBu = F\ dBu - 12\ dB$$

On this basis, the input voltages that could be assumed within one mile from our typical FM transmitters would be as follows:

	Max.	Min.
Field at 30 feet, dBu	118	86
Inside field, high-rise urban, 50%	78	46
" " non high-rise, 50%	84	52
" " suburban, 50%	97	65
Antenna terminal voltage, dBu:		
high-rise urban	66	34
non high-rise urban	72	40
suburban	85	53
Thus, antenna terminal voltage, uV:		
high-rise urban	2,000	50
non high-rise urban	4,000	100
suburban	17,800	450

Evidently the range of signal levels resulting from reception conditions in urban areas gives rise to two category "B" and "C" receiver problems: the first, signals barely adequate for proper stereo reception and the second overloading of receivers. (See TABLE 2)

G. 2 Intermodulation

It is already known that intermodulation between strong local signals is a problem on low-quality FM receivers. The predominant products which cause these problems appear to be of two types, and occur as follows:

$$2\ f_A - f_B$$

$$f_A + f_B - f_C$$

With few local stations on the FM dial, intermodulation rarely results in an unwanted product falling on or immediately adjacent to a desired signal channel. As the number of local stations increases, the number of possible products increases dramatically.

An example is an analysis of the situation in Ottawa, where seven Class C_1 and one Class B are co-located, and on-air, and where two Class A allotments are available. Assuming that both Class A allotments were to be assigned, the total number of intermodulation products which could be generated is 360. Many of these would fall outside the FM band. The number of products which would fall inside the band between the lowest frequency is use, CKCU-FM on 93.1 MHz, and the top frequency, 107.9 MHz having an available Class A, and including 200 kHz beyond these two frequencies, is two hundred.

One additional station reaches Ottawa with its 500 uV/m contour, CJET-FM, Smith Falls. Thus eleven channels could contain desired signals. Thirty-two of the intermodulation products fall directly on these channels, and fifty-six on adjacent channels.

SECTION H: CONCLUSIONS

H.1 FM Receiver Performance vs. Category

It is clear that most category "A" receivers can easily cope with the present allocation criteria which are based on mileage separation and arbitrary interference ratios. The main exception resulting in interference is due to receiver front-end overload. Since our study only included laboratory tests with signals not exceeding 100 mV (100 dBu), no such overload effects were noted. On the other hand, our studies from current literature reports* indicate that strong signals do adversely affect the performance of any FM receiver. Such strong signals result in intermodulation distortion products (intermods) and responses appear in several places on the turning dial. In addition, multipath distortion must be considered as interference, but usually problems arising there from such as the loss of stereo separation can be essentially eliminated by antenna relocation or rotation, and by insertion of a signal pad.

The situation for category "B" receivers is far worse, and these types comprise approximately two-thirds of the total FM receiver population. From the few tests performed, it was found that signals as low as 68 dBu result in intermods of equal magnitude to the desired signal. Furthermore, the alternate-channel selectivity figures for such receivers are inadequate to permit interference-free operation in the multi-signal environment. It is doubtful that any amount of juggling with the allocation parameters such as channel spacing, ERP and EHAAT could produce a suitable solution.

H.2 FM Receiver Performance vs Allocation Criteria

There are four major performance factors which to a limited extent reflect on the present allocation criteria.

(1) Usable Sensitivity;

(2) Alternate-channel Selectivity;

(3) Signal-to-Noise Ratio, and

(4) Spurious Responses

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* "ElectronicSystems - 6, More about reception and demodulation", Wireless World, Feb. 1977.

In the real world receiver, these four characteristics lend themselves to separate measurement, but in terms of performance they are inter-related, as can be seen from the definition in Section C.3.2.

(1) Usable Sensitivity - All category "A" receivers exhibit a usable sensitivity of at least 15 dBf for mono and 25 dBf for stereo. These numbers correspond to fields of 10 dBu and 20 dBu respectively, and the following table shows the theoretical coverage distances based on F(50:50) curves, R-6602 and using the maximum allowable operating parameters:

	Coverage in Miles	
	Mono	Stereo
Class A	104	71
Class B	160	120
Class C_1	185	143
Class C	200	158

- The worst case for category "B" receivers yields fields of around 40 dBu for mono and 48 dBu for stereo, and the corresponding table is

	Coverage in Miles	
	Mono	Stereo
Class A	36	27
Class B	62	49
Class C_1	77	63
Class C	94	77

Of course, interference conditions are usually encountered before most of these distances are reached. Therefore, in general the FM receiver is interference-limited and not signal-limited.

(2) Alternate-channel Selectivity - From the curves appearing in Graph 1 and from Table 8 it can be seen that no interference conditions would occur if the desired to undesired ratio for any Class of Station exceeds 20 dB at the 54 dBu protected contour. For category "A" receivers this represents no obstacle as even a Grade III receiver has a minimum selectivity of 60 dB. However, for the category "B" receiver, where selectivities as low as 15 dB are encountered, interference conditions could easily occur.

(3) Signal-to-Noise Ratio - Graph 2 shows that at certain levels of field strength, stereo signals require about 20 dB more signal before adequate signal-to-noise ratios comparable to mono are achieved. A steady 6 - 8 dB differential always remains on account of the noisier decoding systems employed. For this reason as well as the probable interference condition at half the locations and 10% of the time, the mileages given in (1) above are rarely obtained. The shapes of the selectivity curves also reflect on the signal-to-noise ratios particularly as the bandpass characteristics of most receivers are not smooth nor symmetrical, and this also increases audio distortion. Finally, the AM suppression characteristic of many receivers prevents S/N ratios in excess of 35 dB without meticulous care in the receiver design from antenna input to the discriminator output.

On the positive side of receiver performance with respect to noise is the capture effect displayed by FM receivers. The weak desired signal will capture the receiver as long as its level is 1-3 dB above the undesired co-channel signal, totally suppressing the "noisy", that is, interfering signal.
The capture ratio of category "B" receivers is unknown, but has been estimated between 6-10 dB.

(4) Spurious Responses - As has been stated before, the category "A" receiver when in proper adjustment in general is not prone to behave adversely due to spurious responses in the multi-signal environment. The category "B" receiver however encounters serious difficulties in this regard. Our limited tests have shown this, and some of the CBC's findings corroborate this effect. The significant design deficiencies embodied in this receiver and resulting in such poor performance are related to the lack of pre-selection, improper choice of transistors, inadequate screening of the components and the interconnecting wiring, poor strong signal handling capabilities, insufficient circuitry to filter internally-generated signals, not to mention poor quality control and even improper alignment procedures employed during the production of these receivers.

Basically, this class of receiver cannot function properly in any sort of frequency allocation scheme which must provide wide area coverage as well as the opportunity of choice of station selection. To obtain full coverage, high powered stations are required using maximum heights above ground: to obtain choice, channels must be assigned closely spaced in a narrow section of the overall frequency spectrum.

One conclusion which might have been drawn when the allocation criteria were determined was that allocation principles and receivers performance standards might have been integrated. Historically, this attempt was made but rejected.

H.3 Miscellaneous Conclusions

(1) In view of the difficulties encountered in obtaining laboratory measurements in response to our questionnaire, it should be noted that at least six suppliers responded with the explanation that either they do not possess the test equipment needed to carry out the test prescribed or that the test equipment was available in the shop but in continuous use by the service department and could not be freed for this survey.

For the sake of completeness of this report, it could rightfully be implied that several suppliers, although expressing their willingness and readiness to co-operate were not inclined to conduct the tests on their less expensive product line for fear of some form of self-incrimination. For this reason, it is recommended that during the next phase of this study, these tests as well as others be performed in the Department's own facilities.

(2) Several verbal comments were expressed during our studies that this survey represented only another form of government interference and where possible it should be 'stone-walled'. Fortunately, these comments were few as otherwise this study could not have been undertaken in the manner proposed. This position further strengthens the recommendation made in (1) above that additional tests be performed.

(3) The broadcaster also faces a serious dilemna. On the one hand he is aware that a large number of FM receivers "out there" do not perform at all well in one aspect or another, and on the other hand he must reach his listening audience in the greatest number possible in order to obtain favourable program ratings or in some instances at least justify his broadcast activities financed out of the private or public purse. Several CBC studies certainly indicate that reception problems in the FM band are of a serious nature from a coverage and saturation point of view. The economics of an increased number of stations operating at lower power versus fewer stations operating at a higher power was squarely faced by the Corporation. In the private sector, these questions have not taken on the same intensity and urgency partly because there is no need to establish a national network in the two official languages and partly because the rules and regulations covering the FM service tend to limit the interest of private investors.

(4) The rapidly progressing technology in solid state electronics has now provided single IC chips capable of performing most of the AM and FM detection and amplification processes. It will not be long before demand for the combined AM/FM radio receiver will completely supercede the AM only set. With the availability of so many stations capable of being tuned on the dial, this development will accelerate.

(5) Allocation parameters employed in the process of frequency or channel allotments in the FM broadcast band consist of the following:

- (i) A division into 4 Classes, A,B,C_1 and C, each limited to a maximum ERP and EHAAT;
- (ii) A channelling system of 200 kHz separation;
- (iii) A Broadcast Procedure, BP 13, describing the procedure for the allocation of FM channels 231-300 in Canada;
- (iv) Two additional Broadcast Procedures BP 6 and 7, containing the specifications for stereophonic FM broadcasting and for subsidiary communication multiplex operation.

Not employed extensively so far are other tools for allocation purposes such as the use of directional antenna radiation patterns as satisfactorily used in the television channel allocation procedures, freezing of the operating parameters of existing assignments to allow new FM channels to be "dropped-in" in specific locations, and the propagation characteristics over undulating or mountainous terrain effectively preventing signals reaching certain destinations.

A somewhat theoretical and inconclusive study has been made to predict the effects of reducing the adjacent channel frequency offset from 200 kHz to 150 kHz and 100 kHz*. This analysis shows that both the 100 kHz and 150 kHz offsets are more efficient in population and area coverage than the 200 kHz offset for both mono and stereo operation. However, in both instances extensive receiver filtering is required assuming that for low signal distortion purposes the present frequency deviation is maintained with the consequence of adding considerably to receiver costs. Needless to say, without these filters narrower channel operation is worse than with 200 kHz separations. It must be concluded that a reduction in channel frequency separations will not yield the desired effect of increasing the number of allotments in the existing FM band.

H.4 Recommendations

The Terms of Reference for this project divides the recommendations requested into four parts as follows:

"(i) If results are pessimistic in terms of providing new FM allocations, conduct a detailed study to find additional spectrum for a new FM band".

(1) It is clear that category "A" receivers easily can cope with the present FM allocation criteria with minor exceptions of course. It is equally clear that category "B" receivers in the main cannot cope with these criteria.

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*"FM Broadcast Channel Frequency Spacing", report prepared by the Research and Standards Division, Office of Chief Engineer, FCC, December 1975.

Since the Canadian and the US allocation procedures are if not identical at least compatible with each other, it is difficult to imagine that receivers built for the much larger US market would differ from receivers built for the Canadian market. It is therefore necessary to exploit the demand for a new FM band in conjunction with the Americans who after all suffer a similar kind of receiver "malaise".

"(ii) If results are optimistic in terms of providing new allocations, revise allocation criteria in terms of receiver grades and develop guidelines for a new allocation plan covering the 88-108 MHz band. Simultaneously, consider the possibilities of eliminating or controlling inferior grades of receivers".

(2) Even though the allocation criteria were developed without taking receiver performance into account, being based simply on a protected contour and mileage separation using arbitrary interference ratios, it is our opinion that no major changes of these criteria can be undertaken unilaterally without risking more than would be achieved. The present Canadian plan is a good compromise, and perhaps only a few minor extentions would resolve some problems in some areas. It is likely that in the congested Windsor-Quebec City corridor, very few additional FM channels would be found. The future requirements for more channels in many areas of Canada will increase as has also been anticipated by the CRTC*. The most likely solution to accommodate the future needs is the provision of a second FM broadcast band.

To the question of eliminating or controlling inferior grades of receivers, it is recommended that the Department does not take a position at this time. Historically, the AM receiver development underwent similar problems and it was not found necessary to bring in extensive rules and regulations. The fact that only very recently, the National Association of Broadcasters in the U.S. has struck an engineering committee to write AM receiver minimum performance standards has to to with the forthcoming AM stereo operation and the proposed extention of the AM broadcast band, and not with allocation criteria.

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*"Sound Broadcasting Requirements for Canada: A long-range Forecast", CRTC, March 1978.

The side issue of altering the present 10 kHz to a 9 kHz channel spacing may also be a factor, as there are some national and predominantly international pressures leaning towards such a system.

We do not recommend eliminating or controlling inferior grades of receivers for two reasons: a) It is believed that within a short period of time the FM receiver industry will introduce large-scale changes in receiver designs resulting in a more efficient product, and b) the cost/benefit ratio of setting up a grading, labelling and type-approval or acceptance system including the enforcement mechanism required subsequently is out of proportion to the results obtainable.

> "(iii) If results are optimistic in terms of minimizing or eliminating existing interference problems, develop appropriate guidelines for interference control."

(3) The members of the Technical Advisory Committee on Broadcasting through the sub-committee on FM-Channel Availability were provided with a Department document entitled: "Present and Possible Solutions to Interference Problems involving FM Broadcasting". This document listed some 25 types of problems which have been encountered, the present DOC solution, other possible solutions and comments. In addition, three different approaches were flow-charted to solve interference problems depending on the acceptability or unacceptability of establishing receiver standards.

On the basis of the results obtained in this study, it is premature to recommend the best approach to be taken in the solution of interference problems. Although the magnitude of these problems presently is not overwhelming, in some locations the severity is recognized, and we believe that on a case by case basis most of the problems which likely will increase in the near future can be intelligently treated and hopefully contained. It must be remembered that FM is a foreground educational and entertainment medium, and so the serious listener will outfit himself with good quality equipment not prone to excessive interference susceptibility. The listener on the move can equally well protect his interest. Finally, for the legions of background listeners their lot will improve in the future and so they must live with the problems in the present.

"(iv) If results are optimistic in terms of new receiver approach, develop terms of reference for a receiver design program".

(4) The concepts embodied in this recommendation are inconsistent with the overall terms of reference underlying the scope of this study. Visits to European, Japanese and American receiver design engineers would be required to develop such a program. Of course the budget limitations imposed and the time-frame limit expressed place any results expected herein out of reach.

H.5 Epilogue

There is a quotation we found while reading source material which in a sense sums up our findings and so deserves repetition here:

"Ultimately it is the front-end quality (of the FM receiver) which determines its capability as a selective receiver, raising it above the level of an RF dustbin of excellent audio quality but producing an output containing a large amount of unwanted information".

APPENDIX A

List of Recipients of Questionnarie and Tabulation of Responses

No.	Name	Replied	Part I	Part II	Sent Specs.	Out of FM Rx business
1	Jutan Int. Ltd.	yes	yes	no	yes	no
2	CESCO	yes	no	no	no	yes
3	Motorola	no	no	no	no	no
4	Sony	yes	yes	yes	yes	no
5	Lloyds	no	no	no	no	no
6	Superior	yes	no	no	no	no
7	Magnasonic	yes	no	no	yes	no
8	Sparton	yes	no	no	no	yes
9	Semperit	yes	no	no	no	no
10	Juliette	yes	no	no	yes	no
11	Queon	no	no	no	no	no
12	J.M. Saucier Ent.	no	no	no	no	yes
13	S.H. Parker	no	no	no	no	no
14	Radio Shack	no	no	no	no	no
15	Superscope	yes	yes	no	yes	no
16	Can. Admiral	yes	no	no	no	yes
17	Can. Gen. Electric	yes	no	no	yes	no
18	Gen. Tel & Elec.	yes	yes	yes	yes	no
19	Hitachi	yes	yes	yes	yes	no
20	Panasonic	yes	no	no	yes	no
21	Philips	no	no	no	no	no
22	Qusar	no	no	no	no	yes
23	RCA	yes	no	no	no	yes
24	Sanyo	yes	no	no	yes	no
25	Studer	yes	no	no	no	no
26	Toshiba	yes	yes	no	yes	no
27	Pioneer	yes	no	no	yes	no
28	Pro-Sound	yes	yes	no	yes	no
29	Noresco	no	no	no	no	no
30	Electrohome	yes	yes	yes	no	no

Summary:

No. of Addressees	:	30 (100%)
No. of Replies	:	21 (70%)
Questionnaire, Part I	:	8 (27%)
Questionnaire, Part II	:	4 (13%)
Sent Specifications	:	13 (43%)
Out of FM Business	:	6 (20%)

PETER CAHN & ASSOCIATES

Communications | Consulting Engineers | Broadcasting

Suite 4, 880 Decarie | (514) 744-0778 | Montreal, Que. H4L 3L9

February 6th, 1978

Note : This letter was mailed to 30 Canadian manufacturers and/or importers. Names and Addresses are available on request.

Under the terms of a contract awarded to us on behalf of Communications Canada, we are preparing a study of current FM broadcast receivers and some aspects of their performance. May we hereby enlist your co-operation to complete the attached questionnaire?

We appreciate that it will take a little time and effort on your part. However, the results may reveal findings of a general nature and these would of course be made available to you. Whatever remedies might be found either to improve the present spectrum utilization or to seek more spectrum space will in large measure depend on the performance of FM receivers in to-day's environment. This in turn will directly effect future sales considering the possible introduction of future receiver standards.

We would be very grateful if you would respond to our questionnaire and also furnish any other technical information such as circuit diagrams and data sheets normally available for the type of receivers covered in your response.

Can we count on you by March 1st?

Yours very truly,

Peter Cahn, Eng.
PC/cs

Encls.

Government of Canada Gouvernement du Canada

Department of Communications · Ministère des Communications

300 Slater Street
Ottawa, Ontario
K1A 0C8

December 14, 1977

TO WHOM IT MAY CONCERN:

This is to advise that Consulting Engineers Peter Cahn & Associates have been awarded a contract by Supply and Services Canada on behalf of the Department of Communications to assemble technical data on the performance of commercial receivers utilizing the FM broadcast band.

The results of this study will help to determine the form and content of future regulations which may become necessary to enable the most efficient use to be made of the present FM broadcast spectrum.

During the course of this study, Peter Cahn & Associates will request information on the performance of specific FM receivers presently being either manufactured in Canada or imported. Your co-operation in this work is essential to the promulgation of effective future regulations.

Both Mr. Cahn and this Department guarantee that information given to him will be held in strict confidence, if the responder so desires.

Yours very truly,

Franklin D. Reaume

Franklin D. Reaume, P. Eng.
Broadcast Spectrum Engineering Section
Broadcasting Regulatory Branch

INTRODUCTION TO QUESTIONNAIRE

The FM broadcast spectrum occupies the frequency band of 88-108 MHz. FM station assignments are made according to the Canadian FM Allotment Plan. After a long and laborious start, the utilization of this band is now extensively exploited by broadcasters. Unfortunately, in some regions of Canada, a saturation point appears to have been reached.

In order to continue the orderly development of FM broadcasting in the future and fill the needs of the public interest, a study of the FM receiver is necessary to determine its performance under present or modified rules underlying the Allotment Plan. Failing the achievement of an improved Plan, this study could also be used to support a Canadian position for additional FM broadcast spectrum at the forthcoming World Administrative Radio Conference in 1979.

This questionnaire is intended to serve such a study. FM receivers may be divided into four categories which are defined in a broad manner by the type of electronic or mechanical circuitry employed between the antenna input terminals and the intermediate (i.f.) amplifier strip. The behaviour of this circuitry, along with the overall sensitivity and selectivity of the receiver determines the performance of the receiver in a multi-level signal strength and multiple signal environment.

The following four categories will be considered:

CATEGORY "A" : Receivers having a minimum of one stage of tuneable radio frequency (r.f.) pre-selection as well as a separate local oscillator circuit as distinct from a self-oscillating mixer circuit. These receivers have at least a three-section ganged tuning arrangement.

CATEGORY "B" : Receivers having no tuneable r.f. pre-selection but having a separate local oscillator circuit. These receivers have a two-section ganged tuning arrangement.

CATEGORY "C" : Receivers having no r.f. pre-selection and a self-oscillating mixer circuit.

CATEGORY "D" : Receivers having a signal input circuitry different from any of the three categories defined above. (Please describe in detail).

It is realized that many AM/FM receivers share electronic circuitry. For the purpose of this questionnaire, the FM circuitry alone should be considered.

QUESTIONNAIRE

Note: This questionnaire is designed to be completed with a minimum of effort on your part. Two relatively simple laboratory measurements are to be performed and only on one sample of each receiver category defined above. However, the accuracy of the measurements is essential to the success of this project.

PART 1 - General Description of FM Receiver Product Line.

1.1 : As a manufacturer and/or importer of FM receivers, do you offer for sale in Canada receivers fitting into the four categories described above?

CATEGORY "A" :	☐	yes	☐	no
CATEGORY "B" :	☐	yes	☐	no
CATEGORY "C" :	☐	yes	☐	no
CATEGORY "D" :	☐	yes	☐	no

1.2 : Please fill in one or more current model numbers for each category marked 'yes' above.

CATEGORY "A" :

CATEGORY "B" :

CATEGORY "C" :

CATEGORY "D" :

1.3 : Please complete the following table showing which category of receiver ("A", "B", "C" and/or "D") is used in your current product line.

Type of Receiver:	Enter CATEGORIES "A", "B", "C" and or "D"
Portable Receiver	
Component Tuner & Tuner/Amplifier	
Stereo Console	
Car Radio	

1.4 : Using the data entered in 1.3 above, please indicate the volume in units handled in 1977.

Portable Receiver	A		B		C		D	
Component Tuner & Tuner/Amplifier	A		B		C		D	
Stereo Console	A		B		C		D	
Car Radio	A		B		C		D	

PART II - Laboratory Measurements.

2.1 : Receiver Saturation Characteristic Test.

Test Equipment Required: Frequency Sweep Generator:

Range	88-108 MHz
Sweep Rate	60 Hz (max.)
Output	100 mV

Oscilloscope:

Bandwidth	20 kHz
Sensitivity	10 mV/cm

Camera for recording CRO presentation.

Balun:	50/75 to 300 Ohms, bal.

Method of Connection:

a) Input:

Receivers having 50/75 Ohms input, use direct connection;

Receivers having 300 Ohms input, a suitable balun shall be used;

Receivers having telescopic rod antennas, disconnect the antenna and connect the terminated coaxial cable from the sweep generator via a 4.7 pFd (5%) capacitor to the high side of the input coil, keeping all leads very short.

b) Output:

Connect the oscilloscope across the full volume control.

Test: Tune the receiver under test to a mid-band channel (say, channel 251, 98.1 MHz). Set the output of the sweep generator such that the receiver output level is 70% (-3dB) of the input level at which full limiting occurs. Record this level of input in microvolts.

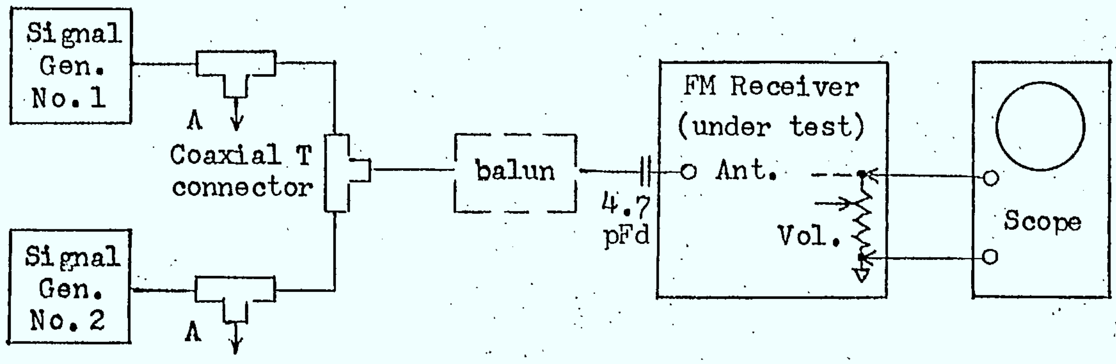
Increase the signal input level in steps of 10 X (20 dB) and with the camera record the scope display for each step.

2.2 : Two Signal Generator Test.

Test Equipment Required:

Two FM Signal Generators:		
	Frequency Range	88-108 MHz
	Output Range	1 µV to 100 mV
	Modulating Signal	400 or 1000 Hz
	Mod. Deviation	100% (±75 kHz)
Frequency Counter:		
	Frequency Range	88-108 MHz
	Accuracy	20 ppm
Oscilloscope		As in 2.1

Method of Connection:



A to frequency counter. Use balun only when applicable.

Keep all leads very short.

Test : a) Tune receiver under test to a mid-band channel (say 98.1 MHz) using S.G. No. 1 and the frequency counter. Turn S.G. No. 2 off.

b) Apply a 400 Hz (or 1000 Hz) 100% modulated signal to the receiver and increase the signal level until no change occurs in the audio output level as observed on the scope. Reduce the r.f. signal until the audio level is 70% (-3dB) of the previously displayed level. This level is the reference level.

Test : c) Remove the modulation of S.G. No. 1; increase the gain of the scope by 100 x (+40dB). Turn on S.G. No. 2, and apply a 400 Hz (or 1000 Hz) 100% modulated r.f. signal to the receiver.

d) Adjust the input levels of S.G. No. 1 and S.G. No. 2 in accordance with the following table, keeping the frequency of S.G. No. 1 set to 98.1 MHz and sweeping the full frequency band with S.G. No. 2. Note all frequencies which result in audio responses as displayed on the scope which are equal to or exceed the reference level established above.

Test Condition No.	S.G. No. 1 (Desired Signal)	S.G. No. 2 (Undesired Signal)
1	50 uV	5 mV
2	500 uV	50 mV
3	5 mV	50 mV

d) Complete the following table.

Test Condition No.	List of Frequencies of S.G. No. 2: (resulting in audio reference level)
1	
2	
3	

Response Prepared By: . . . .

. . . .

Organization . . . .

Date . . . .

If Information is Confidential, please state: Yes ☐ No ☐

Appendix C: Terms of Reference

A Study Into Current FM Receiver Performance and the Relevance of FM Allocation Criteria

Type of Study

This project will be an in-depth technical study consisting of (a) an analysis of performance tests of contemporary FM receivers (b) a comparison of measured results with the rationale for current FM allocation criteria (c) recommendations on revisions of criteria and development of new rules where warranted (d) an examination of the trends in FM receiver design which may be expected to result in receiver improvements within the near future.

Use of Results

The results of this study will be of immediate and direct use to the Broadcast Regulatory Branch of the Department of of Communications in assessing the feasibility of alleviating congestion in the FM band and may lead to legislation of minimum performance standards for FM receivers.

Statement of Work

a) Determine what types, varieties, and relative quantities of FM receivers are now being manufactured and marketed.

b) Conduct a literature search of available test reports (some of which are on file with DOC) on these receivers, and prepare a report on the various characteristics (e.g. selectivity, AFC, intermodulation, sensitivity, spurious response, frequency stability, stereo separation, high field strength overload threshold, etc.) according to their price ranges.

c) From the results of (b), establish a pattern of quality verses price, using a grading system for receivers (such as A,B,C... grades).

d) Determine the validity of existing FM allocation criteria by comparison with characteristics of receiver grades established in (c) above.

3) Recommendations, based on the foregoing studies, shall be prepared for the following alternatives:

   i) If results are pessimistic in terms of providing new FM allocations, conduct a detailed study to find additional spectrum for a new FM band.

ii) If results are optimistic in terms of providing new allocations, revise allocation criteria in terms of receiver grades and develop guidelines for a new allocation plan covering the 88-108 MHz band. Simultaneously, consider the possibilities of eliminating or controlling inferior grades of receivers.

iii) If results are optimistic in terms of minimizing or eliminating existing interference problems, develop appropriate guidelines for interference control.

iv) If results are optimistic in terms of new receiver design approach, develop terms of reference for a receiver design program.

4. <u>Time-Frame</u>

The work described above shall culminate in a final report to be submitted not later than two months following award of the contract.