ORIGINAL: FRENCH

Laval University
Faculty of Science and Engineering
Department of Electrical Engineering
Telecommunications Laboratory

Final Report

Study of the use of the subsidiary communications channel (EMCS-SCMO) in a frequency modulation system and its assignment for other uses

By

Denis Angers, Gilles Y Delisle, Magella Bouchard

for

Government of Canada
Department of Communications, Ottawa

under

Contract OSU80-00162 of the
Department of Supply and Services
Period from August 21, 1980 to March 31, 1981
Report No LT-81-8277

checked 11/83

ORIGINAL: FRENCH

Laval University
Faculty of Science and Engineering
Department of Electrical Engineering
Telecommunications Laboratory

Final Report

Study of the use of the subsidiary communications channel (EMCS-SCMO) in a frequency modulation system and its assignment for other uses

By

Denis Angers, Gilles Y Delisle, Magella Bouchard

for

Government of Canada
Department of Communications, Ottawa

under

Contract OSU80-00162 of the
Department of Supply and Services
Period from August 21, 1980 to March 31, 1981
Report No LT-81-8277

Final Report

②

STUDY OF THE USE OF THE SUBSIDIARY COMMUNICATIONS CHANNEL (EMCS-SCMO) IN A FREQUENCY MODULATION SYSTEM AND ITS ASSIGNMENT TO OTHER USES

①

By: Dr Denis Angers, Senior Researcher
Dr Gilles Y Delisle, Collaborator
Mr Magella Bouchard, Engineer

Telecommunications Laboratory
Department of Electrical Engineering
Laval University, Quebec, Canada G1K 7P4

For: Department of Communications, Ottawa
Contract OSU80-00162 of the Department
of Supply and Services

Term: August 21, 1980 to March 31, 1981

July 1981
Report No LT-81-8277

Chapter 1 Introduction

1.1 General description of study

1.2 Context

1.3 Acknowledgements

1.4 Structure of report

Chapter 2 General considerations with the saturation of FM broadcast communication channels in Canada and use of the SCMO.

2.1 Description of the saturation problem with frequency allocation

2.2 Solutions considered and rejected

2.3 Subsidiary Communications Multiplex Operation

- 2.3.1 Introduction
- 2.3.2 Definition of SCMO
- 2.3.3 Regulations governing the operation of subsidiary communications
- 2.3.4 Outline of the use of the SCMO in Canada
- 2.3.5 Outine of the use of the SCMO in the United States

2.4 Conclusions

Chapter 3 Problems associated with the use of the SCMO

3.1 Introduction

3.2 Intermodulation noise in an FM system

- 3.2.1 Methods of measuring intermodulation noise

3.3 Interference of the SCMO signal with the stereo channel

- 3.3.1 Audio interference
- 3.3.2 Stereophonic demodulation
- 3.3.3 Intriguing case

3.4 Interference of the stereo channel with the SCMO channel

- 3.4.1 Stereophonic information distortion products
- 3.4.2 Effect of intermodulation components on the SCMO signal

3.4.3 Analytical approach to determine the effect of intermodulation components on the SCMO signal

3.5 Possible origins of the problems associated with the SCMO

3.5.1 Transmitter
- (A) Stereophonic modulator
- (B) SCMO Modulator
- (C) FM direct exciter*
- (D) RF amplifier and transmission antenna

3.5.2 Receiver
- (A) RF Amplifier/
- (B) IF Stage
- (C) FM demodulator
- (D) 38 kHz circuit regenerator
- (E) Stereophonic demodulator

3.5.3 Multipath

3.6 Conclusions

Chapter 4 Experimental evaluation

4.1 Introduction

4.2 Description of the receivers used

4.3 Frequency response and linearity of FM receivers used

4.3.1 Frequency response of FM receivers used
- (A) Experimental assembly
- (B) Results

4.3.2 Linearity
- (A) Assembly

4.4 Measurements with the Sound Technology modulator

4.4.1 Measurements of interference of the SCMO signal in the main channel

4.4.2 Measurements of interference caused by the main channel in the SCMO channel

4.4.3 Measurements of the spectrum of the base band signal of JVC, Sony and Advent FM receivers

4.5 Measurements of the interference and power spectrum of the composite signal of the FM receivers using the McMartin modulation system

4.5.1 Measurements of interference using the McMartin system
4.5.2 Power spectrums of the composite signal

---

* In English in original French text

Chapter 5 Conclusions

5.1 Results of the study

5.2 Subsequent work

Bibliography

Appendix A Detailed circuits of the JVC, Advent and Sony receivers

Appendix B SWTP and GI SCMO demodulators

Appendix C Detailed circuits of the McMartin receiver

Appendix D Circuits and operational diagrams of McMartin devices (stereophonic generator, SCA generator (SCMO), FM direct exciter)

Chapter 1

Introduction

1.1 General description of study

One of the many concerns of several of the sectors of the federal Department of Communications in Ottawa, particularly of those in charge of broadcasting spectrum management and the regulation of this type of communication, is to find a solution to a problem which is growing more serious every day, namely the saturation of the spectrum allocated to broadcasting.

Our study is to be viewed within this perspective and it deals exclusively with FM broadcasting. Later on, we will briefly describe the channels that are available to increase, within a given geographical area, the number of radio transmission channels.

The research carried out under this contract is aimed at finding a possible solution to the saturation problem in the FM band. It will show above all that the technical difficulties involved - if they really exist - can indeed be overcome.

1.2 Context

This is not the first foray by the Telecommunications Research Laboratory of the Department of Electrical Engineering of Laval University into the field of FM broadcasting. In 1979, under the direction of Mr H T Huynh,[1] a team carried out studies on the design of an improved FM receiver which would have greater selectivity and which would allow, within a given geographical area, a 400 kHz separation of channels centered on neighboring frequencies. Although this study had only limited success, the experience gained in this first project proved most useful in this project, part of which depended upon analysing the behaviour of standard receivers fitted with an additional composite signal component.

1.3 Acknowledgements

We would like to express our appreciation to Mr L K Chau of the Telecommunications Regulatory Service, Broadcast Spectrum Engineering, Department of Communications in Ottawa, as without his assistance both as a scientific consultant and in supplying indispensable measuring equipment, it would have been impossible to accomplish the main purpose of this study.

1.4 Structure of the report

We will now outline the format followed in this report. After briefly describing the saturation problem with the FM broadcast communication channels, we will describe a few of the solutions considered and which would be possible in order to reduce the size of this problem. The solution that we selected is the subsidiary communications multiplex operation (EMCS, SCMO, SCA). In Chapter 2, we will discuss this mode of communication, the elements its requires and the standards governing its use and then we will outline briefly the extent to which it is used in Canada and in the United States.

Chapter 3 will review the real problems associated with a subsidiary signal in a frequency modulation system, whether these problems arise with the transmitter, the radio transmission channel (as in the case we are investigating) or the receiver.

We will then present the results of the tests performed using an experimental assembly, which will evaluate the behavior of a typical group of receivers available on the market. The findings will enable us to determine the care and conditions to be used with an FM communications system equipped with a subsidiary communications channel in order to achieve minimum characteristics. The quality of these characteristics are such that, as we point out in our conclusion, it is possible to consider expanding the standards, and especially using SCMO in Canada for purposes other than the present ones.

Chapter 2

General Considerations with the Saturation of the FM Broadcast Communications Channels in Canada and the Use of the SCMO

2.1 Description of the frequency allocation saturation problem

For the last twenty years, FM broadcasting has been wide-spread in Canada to the extent that almost all conventional receivers sold on the market are of the AM/FM type. Penetration has reached, for all intents and purposes, the same level as in the United States, if the automobile is excluded. We would not be exaggerating to claim that FM broadcasting is no longer the privilege of certain classes and that the type of programming found on FM stations is no longer linked to the interesting characteristics of noise immunity originally attributed to it. This last observation, though it would not appear at first glance to have anything to do with the technical features of the study, is not irrelevant: the advance processing given to a message - in this case we are referring to the compression of a stereophonic musical message - can act in such a way that the quality requirements of the borrowed channel may no longer apply or might not in future apply in many instances. We will see the importance of this observation later on.

During this time, the number of transmitting stations increased, particularly in the most densely populated areas of the country. We are refering to the Quebec City-Windsor corridor where, in many locations, owing to the proximity of the American border, it is no longer possible to grant broadcast licences under the current standards: hence the frequency allocation saturation problem.

Nor can this situation be solved by turning to the AM frequencies as according to its last policy statement, Canada decided to defend maintaining the 10 kHz spacing in the AM band to prevent it experiencing the same problems as frequency modulation broadcasting.

2.2 Solutions considered and rejected

It must be remembered that any change in frequency allocation will also have repercussions on the transmitter, the receiver and even, in some instances, within the given geographical location, on the distribution of the listening clientele, resulting in possibly significant repercussions on the economic level. Nevertheless, increasing the number of channels in a given band can be analysed from the point of view of either the transmission or the receiver. Both approaches have already been examined in connection with FM broadcasting.

In 1978, Cahn & Associates[2] studied the quality of receivers sold on the Canadian market. Their results were revealing as to the poor average quality of receivers particularly the portable receivers.

One of the report's conclusions was that there is no need to alter the current frequency allocation if the quality of the receivers remains the same and if there is no change in the 500 μV/meter protected service contour.

This finding acknowledges that the average quality of receivers determines transmission standards. We can therefore set aside this first approach to a solution.

The second approach would be based on a better utilization of the coverage of an area by relying upon directional antennas.

This possibility was studied by L K Chau[3], and based on the models used, there was very little real gain leading the author to discontinue further investigation in this area.

Another solution considered was the gradual introduction of much stricter selectivity and immunity standards, provided that this were possible given our technology and at reasonable cost. H T Huynh[1] of the Telecommunications Laboratory was assigned to examine this question in 1979 and the results left no hope in this area.

The remaining solution is the use of the subsidiary communications multiplex operation in FM (EMCS, SCMO, SCA) which we have studied thoroughly and which would allow, at its maximum, a doubling of the number of channels used in frequency modulation.

2.3 Subsidiary Communications Multiplex Operation

2.3.1 Introduction

For all practical purposes, the general public is unaware of the existence of channels reserved for subsidiary communications within the

88-108 MHz band used for frequency modulation broadcasting. There are basically two reasons for this situation (which is different from that in the United States and which we will examine later):

(1) a gross underutilization of this technique in the major urban centres of the country. In January 1979, there were only 41 licences granted to Canadian stations throughout the country. Without examining in detail the actual use made of these channels and the nature of the licences granted, we can still identify two general utilization classes:

  (a) alphanumeric data transmission
  (b) transmission of musical programming for shopping centres (MUSAK). This type of undertaking rents the services of a channel of an FM broadcaster to transmit musical programming that has been well-researched, and then provides its own appropriate receivers. It should be noted that at present there are no standard FM receivers on the market for the general public with the demodulation features needed to capture this type of transmission.

(2) The second reason - which will be examined in detail in the following chapter - involves certain technical problems encountered by broadcasters which are associated with insufficient isolation between the main and subsidiary channels. Because of these problems, broadcasters either do not use this channel or limit its use to emergency or temporary communications between studios and the transmitting station.

As FM receiver manufacturers are under no pressure to include additional detection means in conventional receivers, the detection of SCMO signals is possible only for electronics handymen.

2.3.2 Definition of SCMO

The spectral breakdown of a base band stereophonic message (composite signal) is given in Figure 2.1.

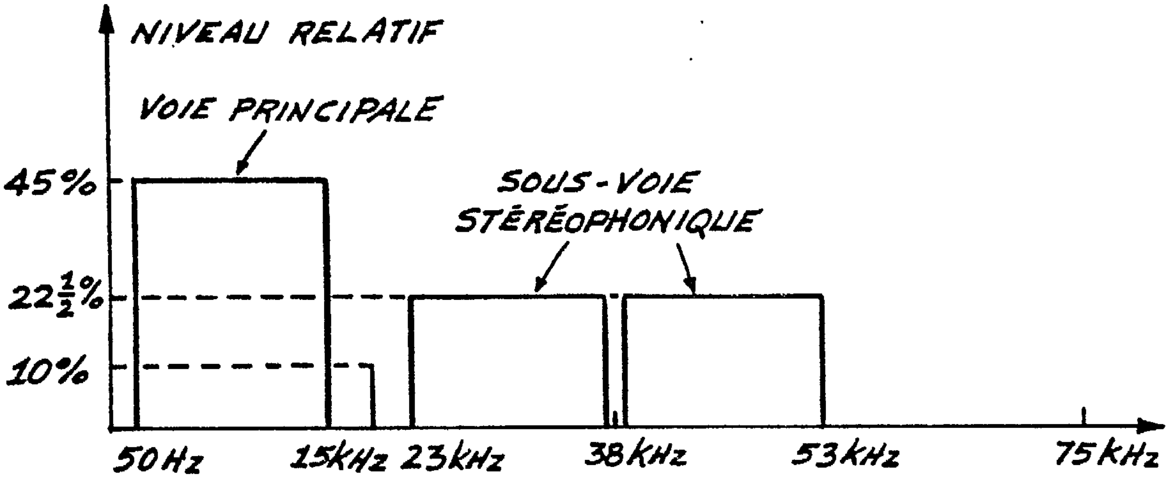


Fig 2.1: Breakdown of the components of the base band stereophonic signal

which also shows, in order, the maximum authorized contributions of each of the components to the deviation from the main carrier. Thus, the main channel represented in this case by D + G cannot exceed 45% of the carrier deviation. The same applies for the stereophonic subchannel, D - G, which modulates a 38 kHz subcarrier (suppressed). The pilot subcarrier P is restricted to 10%.

To add an additional component between 53 kHz and 75 kHz, the maximum authorized frequency for the composite signal, there must be a redistribution between the various parts so that the total does not exceed 100%. It is this component that is referred to as the subsidiary communication (SCMO).

Figure 2.2 illustrates schematically the redistribution of the components by showing their relative contributions given the addition of subsidiary communications.

Mathematically the base band signal becomes:

$$M(t) = \underbrace{(G + D)}_{\substack{\text{voie}\\ \text{principale}}} + \underbrace{(G - D) \cos 2\,\omega_p t}_{\substack{\text{sous-voie}\\ \text{stéréophonique}}} + \underbrace{A \cos \omega_p t}_{\substack{\text{sous-porteuse}\\ \text{pilote}}} + \underbrace{B \cos(\omega_s t + \int s(t)\,dt)}_{\substack{\text{communications}\\ \text{secondaires}}}$$

$\omega_p = 2\pi f_p$ avec $f_p = 19$ kHz

$\omega_s = 2\pi f_s$ avec f_s = fréquence de sous-porteuse secondaire (67 kHz).

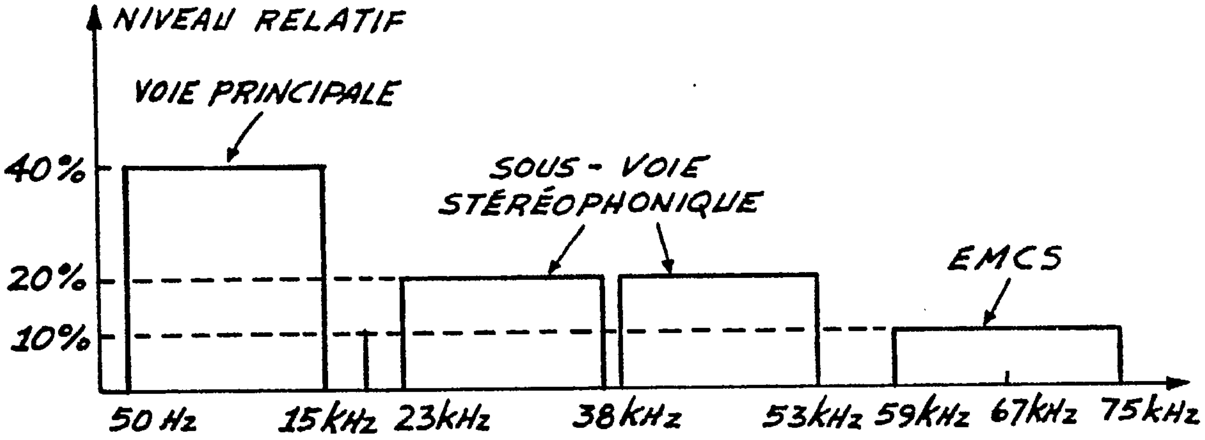


Fig 2.2: Base band spectrum of a composite signal including a subsidiary communications channel

The schematic of the transmitter's functions can also be shown for the generation of a composite signal with subsidiary communications which will modulate a frequency carrier (Figure 2.3).

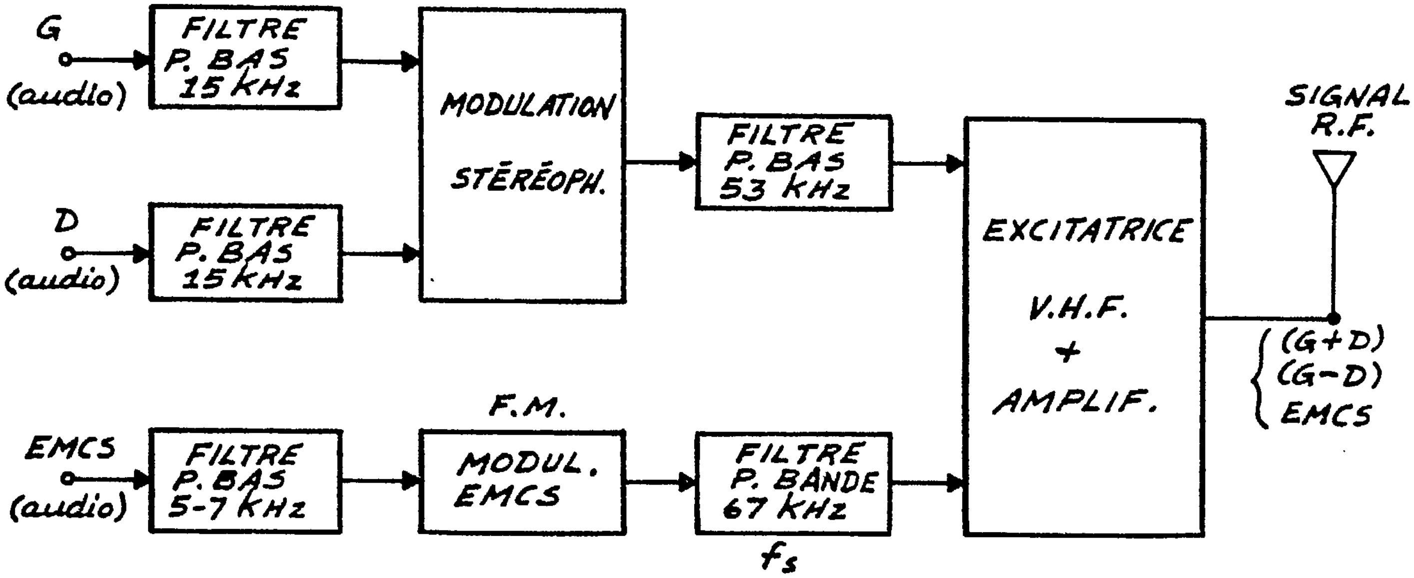


Fig. 2.3: Diagram of an FM modulator with SCMO

We can also show schematically an FM receiver with the elements needed to receive stereophonic signals and subsidiary communications (Figure 2.4).

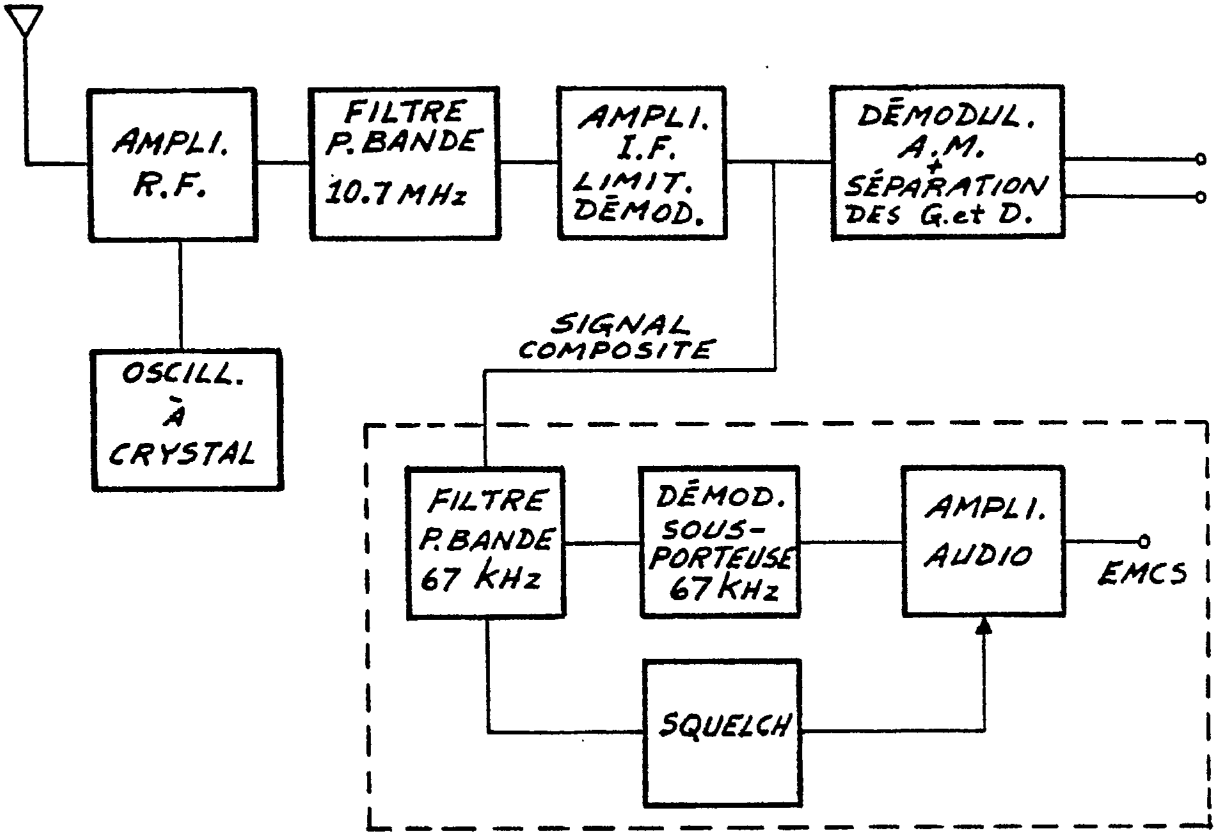


Fig. 2.4: Diagram of an FM receiver with SCMO detection elements (part inside dotted lines)

2.3.3 Standards for subsidiary communications operations

Now that we have identified the position of subsidiary communications in terms of the frequency, it would be interesting to review the regulations governing its use. We will therefore summarize the main points of Broadcasting Procedure No 7 (BP-7)[4]:

The points to note within our area of interest are:

(1) Frequency modulation of subsidiary communication subcarriers must be used;

(2) Instantaneous frequency of subcarriers must at all times remain between 53 kHz and 75 kHz.

(3) Even at the modulator, frequency modulation of the main carrier caused by subsidiary communication subcarrier operation in the band below 53 kHz (presence of intermodulation) must be at least 60 dB below 100% modulation at all times.

(4) Crosstalk between the main channel and a subsidiary communications channel must be at least 60 dB below 100% modulation (transmitter modulation).

These are the only regulations established and it is easy to see that they are not very restrictive.

2.3.4 Outline of SCMO use in Canada

As we mentioned at the start of this chapter, there were only 41 stations in Canada with licences to operate a subsidiary communications channel as of January 1979. For information purposes, the unofficial list of these stations is given in Table 2.1. This table, which is not very explicit, might erroneously lead the reader to assume that the holder of a licence is not also a user. We reached this conclusion upon examining a study by Mr Bach Vo[5] of the Department of Communications in Quebec City, which gives an excellent description of the situation in Quebec as of March 1980 (Table 2.2).

(See French text for Tables 2.1 and 2.2)

1)	Calgary	CKO-FM-5
2)	Kamloops	CFFM-FM
3)	Kelowna	CHIM-FM
4)	Trail	CBTA-FM
5)	Vancouver	CHQM-FM
6)	Vancouver	CKO-FM-4
7)	Vancouver	CKLG-FM
8)	Victoria	CFMS-FM
9)	Winnipeg	CHIQ-FM
10)	Winnipeg	CHMM-FM
11)	Winnipeg	CBW-FM
12)	Saint John	CFBC-FM
13)	Kentville	CKWM-FM
14)	Barrie	CHAY-FM
15)	Guelph	CKLA-FM
16)	Kitchener	CFCA-FM
17)	London	CKO-FM-3
18)	Burlington	CIGN-FM
19)	Oshawa	CKQS-FM
20)	Ottawa	CFMO-FM
21)	Ottawa	CBOF-FM
22)	Ottawa	CBO-FM
23)	Ottawa	CKBY-FM
24)	Toronto	CJRT-FM
25)	Toronto	CBL-FM
26)	Toronto	CHFI-FM
27)	Toronto	CKO-FM-2
28)	Toronto	CKFM-FM
29)	Drummondville	CBF-FM-1
30)	Montréal	CFQR-FM
31)	Montréal	CBM-FM
32)	Montréal	CKMF-FM
33)	Montréal	CJFM-FM
34)	Montréal	CKOI-FM
35)	Montréal	CBF-FM
36)	Montréal	CFGL-FM
37)	Québec	CKRL-FM
38)	Québec	CHOI-FM
39)	Regina	CFMQ-FM
40)	Saskatoon	CFMC-FM
41)	Halifax	CKO-FM

Tableau 2-1. Liste des stations de radiodiffusion MF canadiennes détentrices des permis EMCS (janvier 1979).

(document non officiel).

Indicatif de la station	Ville	Type d'utilisation et remarques
CFGL-MF	Montréal	Musique pour lieux commerciaux (abandonné à l'étape expérimentale à cause de problèmes techniques).
CBF-MF	Montréal	Relais studio-émetteur pour radio AM en cas de défectuosité de la ligne téléphonique (abandonné à cause de problèmes techniques).
CKMF-MF	Montréal	Relais studio-émetteur pour radio AM en cas de défectuosité de la ligne téléphonique (en service).
CKOI-MF	Montréal	Musique pour lieux commerciaux (abandonné à l'étape expérimentale à cause de problèmes techniques).
CFQR-MF	Montréal	Musique pour lieux commerciaux (abandonné à l'étape expérimentale à cause de problèmes techniques).
CBV-MF	Québec	Relais studio-émetteur pour radio AM en cas de défectuosité de la ligne téléphonique (en service).
CHOI-MF	Québec	Musique pour lieux commerciaux en service (opéré par MUSAK).
CJFM-MF	Montréal	Musique pour lieux commerciaux en service (opéré par MUSAK, filiale d'une compagnie new-yorkaise).
CKRL-MF	Québec	Inconnu du personnel en place (demande effectuée en 1974). Aucune application actuellement.
CBM-FM	Québec	Relais radio-émetteur pour radio CBV-AM.

Tableau 2-2. Utilisation du EMCS en territoire québécois (Source: Bach Vo [5]).

The summary of the uses made of the licences held by the nine Quebec licensees is:

(a) one antenna link between studio and antenna site (audio) (CBM-FM)

(b) two users (one in Montreal, CJFM-FM)
(one in Quebec City, CHOI-FM)

The other licensees discontinued use of the licence for technical reasons. It is therefore easy to conclude that the market for SCMO receivers for all of Quebec is non-existant. We were unable to obtain as detailed a breakdown for the rest of the country but, according to suppliers of this type of product, the market is not much greater.

Discussions with the technical personnel of a few stations, and particularly with Mr Yvon Roy, Technical Resources Consultant, CBC Engineering Department in Montreal, brought to light real technical problems which are likely to hinder use of subsidiary communications. According to several people, the intermodulation products generated in the main stereophonic channel by the presence of a signal in the band allocated to SCMO are intolerable if the transmitting station is to maintain an interesting range of programming for the devoted listener. We will examine the problem of parasites in detail in Chapter 3.

The important point to remember for the moment is that real technical problems are the reason for the underutilization of the SCMO channel by FM broadcasters in Canada.

2.3.5 Outline of the use of SCMO in the United States

We feel that the situation in the United States should be described, first because the number of users is so much greater than in Canada (all proportions being maintained) and they therefore seem to have overcome the technical problems, and secondly because of certain legislative features which Canadian laws would not allow. This latter reason is the key one, namely the ownership of the air waves.

Although we have not examined FCC legislation in this area, we would like to make the following observations 6, 7, 8:

(1) The content of the programs authorized can cover almost all nature of human activities as long as they are of interest to

a certain group of people and legal. The main authorized fields could be (for example): background music, weather reports, stock exchange reports, education, agriculture, business or professional activities, etc.

(2) The content could also be purely technical and deal with the transmission of numerical data for an FM station (studio-transmitting station relay (telemetering)).

(3) The subsidiary communications constitute a service to a specific group and <u>are aimed at subscribers</u>. This is why we spoke of the ownership of the air waves earlier. This concept is reflected in the fact that only <u>untunable</u> receivers are manufactured: an individual can obtain one from the holder of a SCMO broadcasting licence upon payment or under a special agreement.

Three major networks, among others, which cover a large number of American states are:

(a) reading network for the visually handicapped, operated by a social club which is responsible for distributing the receivers based on certain criteria;

(b) network broadcasting courses in the medical field which are aimed at practicing doctors and pharmacists, operated by a consortium of pharmaceutical product manufacturers, which is responsible for distributing the receivers to members of corresponding professional corporations;

(c) network providing courses on the grain and livestock market covering all of the American Midwest. In this instance businesses own the receivers and rent them out. These receivers have both audio and video capacity (slow scan, compressed video);

(d) there are no FCC regulations governing the minimum quality of SCMO. This means that a frequency deviation on the subcarrier of between ± 2.8 kHz and ± 6 kHz can be used depending on the needs of the user. Nor is there any restriction of the crosstalk between the main channel and SCMO.

However, it seems that the quality of main and subsidiary channels is fully satisfactory for the users of either channel and we were unable to find any examples where subsidiary communications are not used for technical reasons.

We would also like to mention the possible development of American SCMO networks as a result of requests by the major electronics firms to the FCC for the installation of quadraphonics in frequency modulation. We are aware that a number of projects are being examined which will affect fundamentally the distribution of the base band frequency spectrum of the modulating signal and which, according to reasonably pessimistic forecasts, will result in a shift of the subsidiary communications channel to frequency zones that will result in a noticeable drop in quality.

This is a development which should be watched even if it will not have any effect on the long-term objective of this study.

2.4 Conclusions

A summary of our observations indicates that the United States has a number of operational subsidiary communication networks of satisfactory quality which do not in any way - we will see how far we can go - interfere with the main stereophonic channel. In Canada, the reaction of technical staff at various stations is considerably different and is such that, to all intents and purposes, SCMO networks are non-existent. In spite of the fact that we have a shortage of broadcasting channels, it is obvious that we have to examine carefully all of the technical problems mentioned as a solution to these problems will permit a doubling of the choice of programming of frequency modulation broadcasters.

Chapter 3

Problems associated with the use of the SCMO

3.1 Introduction

The technical problems which we mentioned earlier are essentially problems with crosstalk and the transposition to varying degrees of the content from one channel to an adjacent one. This chapter contains a theoretical analysis of all of these forms of noise and we try to identify the origin of such noise within a communications network like the one in which we are interested, namely broadcast FM.

3.2 Intermodulation noise in an FM system

Intermodulation noise is caused by the presence of non-linearities in a system. These non-linearities produce harmonics of the signal and intermodulation products. If the system is designed to transmit several adjacent channels on the same carrier (FM multiplex system), the harmonics and intermodulation products of a given channel can give rise to non-intelligent noise on other channels. In an FM system, this type of noise can be attributed to three main causes:

(1) non-linearities in the transmitter (amplitude and phase)
(2) effects of multipaths
(3) non-linearities in the receiver (amplitude and phase)

The causes given above have all been described and analysed in general cases. Based on the findings of Garrison[9], it is possible to show that the passage of an FM signal through a linear transmission medium H (jw) (Figure 3.1) produces a distorted FM signal consisting of two induced components: an amplitude interference signal P(t) and phase interference Q(t).

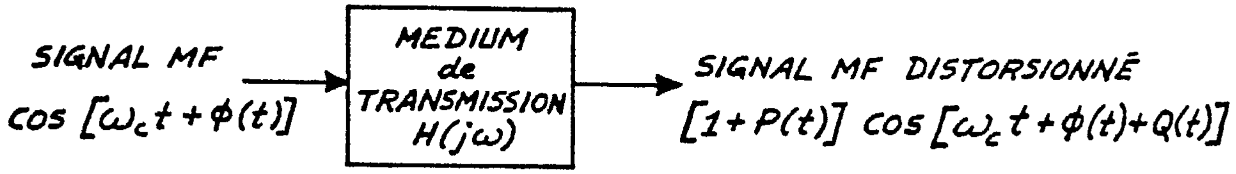
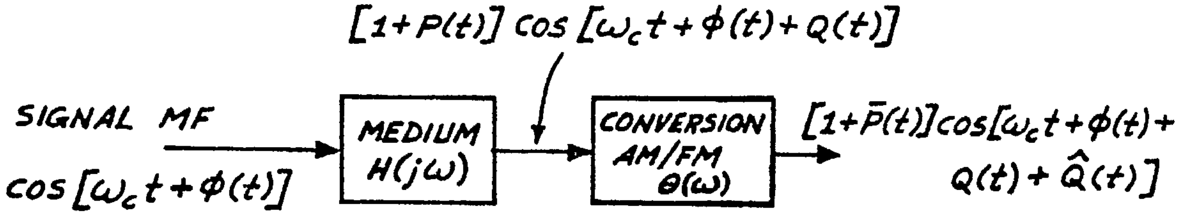


Fig 3.1: Transformation of an FM signal by a linear transfer function.

It is relatively easy to overcome amplitude interference in a receiver by using an <u>ideal</u> limiter. If this is not possible, the entire system has to be analysed, that is, the transfer function and the non-ideal limiter, while following Garrison's approach which uses a model including an AM/PM conversion inserted with the transmission medium.

The system, with the mathematical expressions for the entire system, is given below in Figure 3.2.



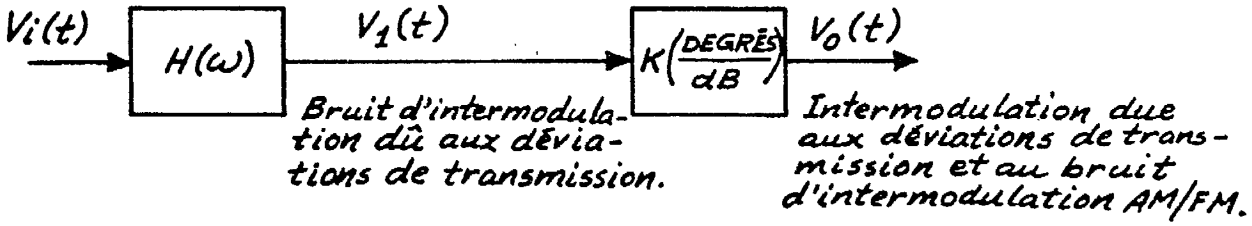
where: $\Theta(\omega)$ = coefficient de conversion AM/PM dépendant de la fréquence

$\hat{Q}(t)$ = modulation de phase résultant de la conversion AM/PM

$\bar{P}(t) \neq P(t)$. en général.

Fig 3.2: Transformation of an FM signal by a linear transfer function followed by an imperfect limiter.

A clearer description of the FM system is possible by trying to evaluate, with Cross[10], the importance of the presence of a single dephasing non-linearity in the interference signal generation mechanism. Here again, the author shows that an AM/PM converter is needed in processiong the signal. This concept of AM/PM conversion will be used throughout this chapter. The main points of this theory are given in Figure 3.3.



where:

$$V_i(t) = e^{j[\omega_c t + \phi(t)]}$$

$$V_1(t) = e^{a(t)}\, e^{j[\omega_c t + \phi_o(t)]}$$

$$V_o(t) = e^{a_1(t)}\, e^{j[\omega_c t + \phi_o(t) + ka(t)]}$$

$\phi(t)$ = fonction de modulation de phase due au signal multicanal.

$\phi_o(t)$ = $\phi(t)$ + termes de distorsion de phase

$k = 0.1516\ k$ = indice de modulation de phase divisée par l'indice de modulation d'amplitude
K = constante de conversion AM/PM

$a_1(t) \neq a(t)$ en général

$H(\omega)$ = fonction de transfert du médium de transmission avec déviations.

$$v_i(t) = e^{j[\omega_c t + \phi(t)]}$$

Fig 3.3: Processing of an FM signal in the presence of a phase non-linearity (according to Cross[10])

Similarly, the analysis of the distortion caused by the presence of multipaths in an FM communications system has been carried out by O'Hara[11], who tried to apply his method to the specific case in which we are interested, that is, crosstalk between the stereophonic channel and the SCMO.

The application of general methods to the transmission of a composite signal like the one which exists in stereophonics, particularly if it includes an additional SCMO component, becomes even more complex because of the following elements:

(1) the very nature of the components of this system: a signal between 50 Hz and 15 kHz, a highly sinusoidal carrier, another signal with a bandwidth double that of the first stereophonic subchannel, an FM component (SCMO) with a bandwidth of approximately 15 kHz.

(2) there are no ideal demodulators which can isolate the various sources of intermodulation, such as those discussed above, which means that an evaluation of the distortion in a real system can only be done on a <u>global basis</u>. For this reason, comparative measurements of the <u>base band</u> signals will be taken at the input and at the output of the FM transmission system.

3.2.1 Methods of measuring intermodulation noise

There are at least three methods of measuring intermodulation noise in an FM multiplex system (FDM-FM). These methods are based on the fact that non-linear noise varies with the level of the multiplex signal, while thermal noise does not. Thus, non-linear noise can be evaluated by measurements with a test multiplex signal. The three methods of non-linear noise measurement give a more or less complete qualitative evaluation of the system depending on the complexity of the test signal.

The general methods described in this document are designed for FDM (frequency division multiplex)* systems where the FM carrier is modulated by a signal composed of several identical channels. These same methods can nevertheless be used with more complex systems, such as the stereo FM system with SCMO-FM channel, but the results must be interpreted based on the special features of the system.

The three methods are as follows:

(1) ratio of the power of the signal to the non-linear noise (using the noise as a signal)

(2) ratio of the power of the signal to the intermodulation distortion (using two sinusoidal signals)

(3) ratio of the power of the signal to the harmonic distortion (using one sinusoidal signal).

These three methods are illustrated schematically in Figure 3.4.

The first method uses wideband white noise covering all of the multiplex band except for a narrow band corresponding to the bandwidth of one channel. The ratio between the power of the noise in the narrow band and some other band of the channel gives us the "signal-to-non-linear noise ratio.

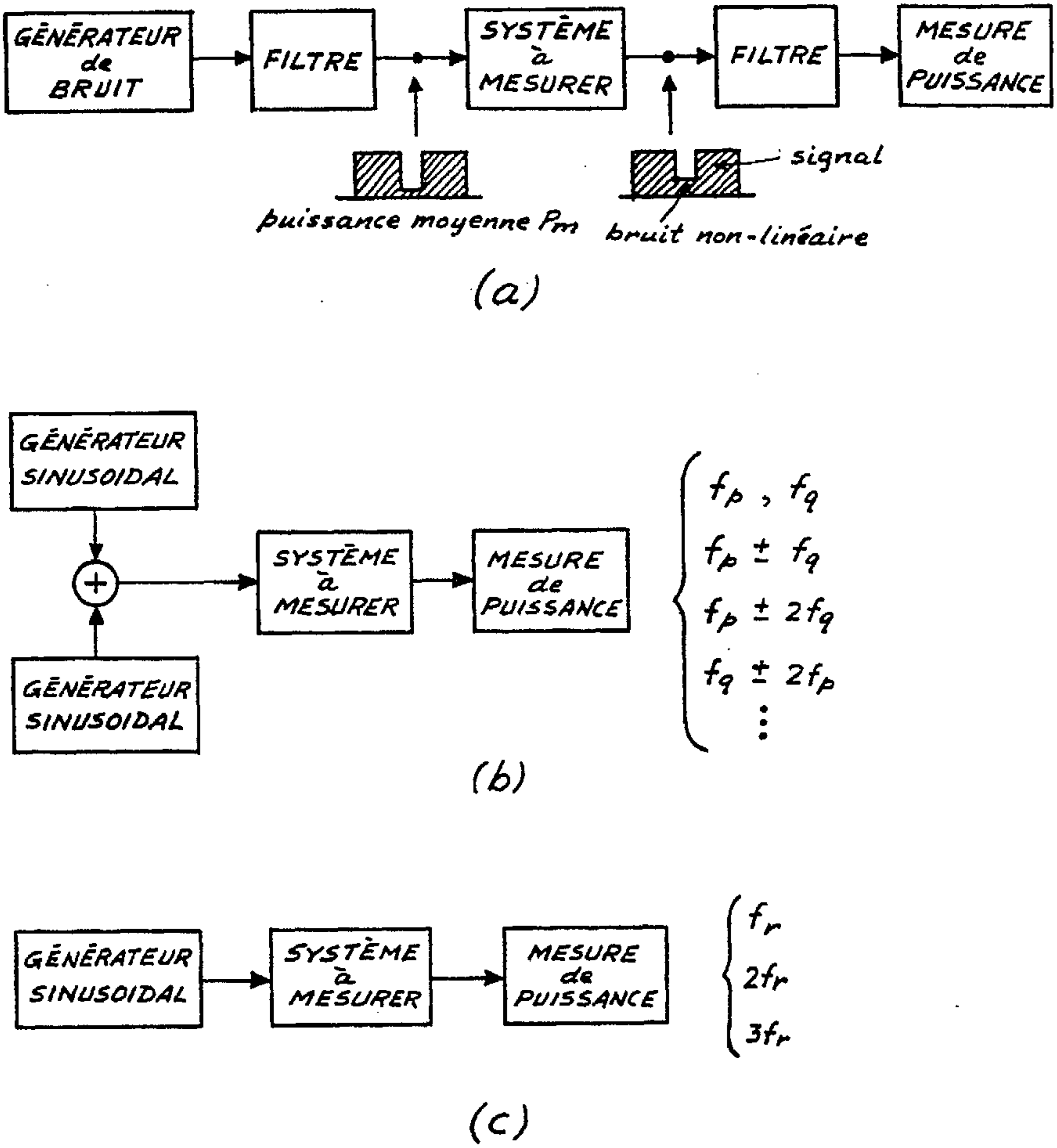


Fig. 3-4: a) Method using noise
b) Method using two sinusoidals
c) Method using une sinusoidal

With the method which uses two sinusoidal signals, one channel is modulated by two sinusoidals equal to the average RMS power of a multiplex channel. The power of the intermodulation signals and of the fundamental signals are measured at the output. This gives the ratio of the signal to the intermodulation distortion to the n^{th} order.

With the method which uses only one sinusoidal, a single signal of RMS power equal to the average RMS power of a multiplex signal modulates the system. The power of the harmonics distortions of different orders and the power of the fundamental are measured to obtain the ratio of the signal to the n^{th} harmonic.

The first of the three methods is the most realistic as it simulates the normal use of the system. However, the two tests using harmonic signals can be more helpful for the designer who is trying to identify the most predominant intermodulation group in a given case.

3.3 Interference of SCMO signal with main channel

The first type of interference is that caused in the stereophonic channel (mainly G - D) by the presence of an SCMO channel. This interference generally takes the form of an audible signal (tone)* in the left and right channels. This tone is generally a weak signal but one which is undesirable in systems where the dynamic range of the audio signal of the stereophonic channel is large.

The interference by the SCMO in the stereophonic channel is caused by intermodulation groups between the SCMO channel modulated by its information signal and the pilot information ($p \simeq 19$ kKz) and its harmonics, namely $2p \simeq 38$ kHz, $3p \simeq 57$ kHz and $4p \simeq 76$ kHz. The most important intermodulation groups are (s-p) and (s-2p), where 's' represents the instantaneous frequency of the SCMO carrier at 67 kHz and "p" represents the pilot frequency at 19 kHz. These intermodulation groups are centered at 48 kHz and 29 kHz respectively, that is:

$$s-p \simeq 67 \text{ kHz} - 19 \text{ kHz} \simeq 48 \text{ kHz} \qquad (3.1)$$

$$s-2p \simeq 67 \text{ kHz} - 38 \text{ kHz} \simeq 29 \text{ kHz} \qquad (3.2)$$

These intermodulation components therefore fall within the band reserved for channel (G-D) between 23 kHz and 53 kHz. This band (23-53 kHz) contains (G-D) information modulated in DSBSC around 38 kHz. Figure 3.5 shows the range covered by the (s-p) and (s-2p) intermodulation components.

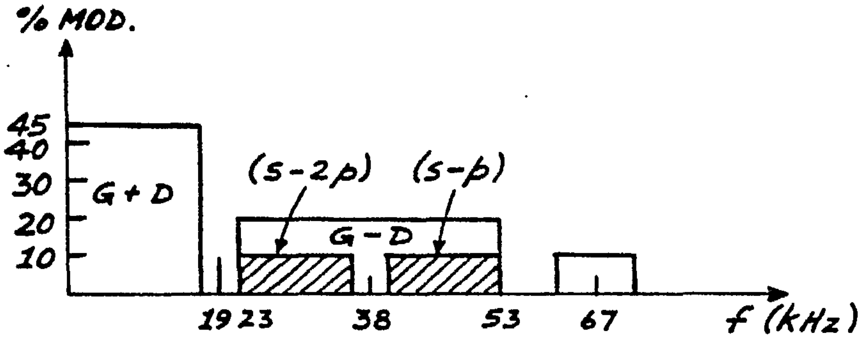


Fig. 3.5: Range covered by intermodulation groups (s-p) and (s-2p).

These intermodulation groups are present at the output of the FM demodulator and thus have access to the stereophonic detector. The equations given below show how the (s-p) and (s-2p) intermodulation produce audio interference after stereophonic detection.

3.3.1 Audio interference

The composite signal of the stereo modulation with an SCMO channel can be represented as[12]:

$$C(t) = (G + D) + (G - D) \cos 2\omega_p t + X \cos \omega_p t + Y \cos B(t) \quad (3.3)$$

where:

G = signal de modulation du canal de gauche

D = signal de modulation du canal de droite

ω_p = fréquence angulaire du pilote stéréophonique = $2\pi.19$ kHz

X et Y = constantes de modulation

$$B(t) = (\omega_s t + \int_0^t s(t)\, dt) \quad (3.4)$$

ω_s = fréquence angulaire de la porteuse EMCS ($2\pi.67$ kHz)

$s(t)$ = signal de modulation du canal EMCS

The C(t) signal can thus be found after the demodulator of an FM receiver, which is usually followed by a low-pass filter used to eliminate the components of signals over 53 kHz (Figure 3.6). We will assume that this is an ideal filter in order to simplify the calculations. The filtered signal then goes through a stereophonic demultiplexer which recovers the information from the left and right channels individually. When there is no interference, the signal at the input of the stereophonic demultiplexer is:

$$C_1\ (t) = (G + D) + (G - D)\cos 2\omega_p t + X\cos \omega_p t \qquad (3.5)$$

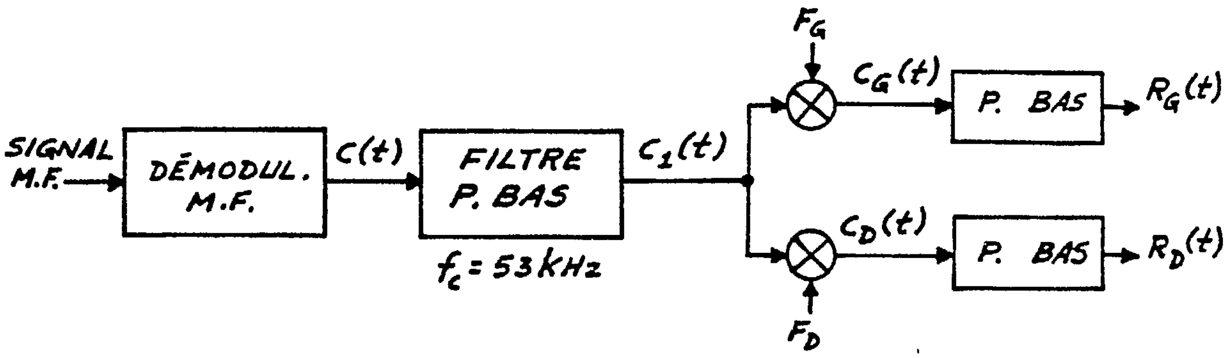


Fig 3.6: Diagrams of a stereophonic receiver

If we add the (s-p) and (s-2p) interference caused by the presence of an SCMO channel, we get:

$$\tilde{C}_1\ (t) = (G + D) + (G - D)\cos 2\omega_p t + X\cos \omega_p t + \ldots$$
$$K_1 \cos [B(t) - \omega_p t] + K_2 \cos [B(t) - 2\omega_p t] \qquad (3.6)$$

where: K_1 and K_2 are intermodulation constants.

3.3.2 Stereophonic demodulation

As shown in Figure 3.6, the stereophonic demodulation of channels G and D can be represented mathematically by the functions:

$$F_G = (1 + 2\cos 2\omega_p t) \qquad (3.7)$$

$$F_D = (1 - 2\cos 2\omega_p t) \qquad (3.8)$$

which multiplies the composite signal to give the left and right channel respectively.

Based on Figure 3.6, we can express the channel directly by:

$$C_G\ (t) = C_1\ (t) \times F_G\ (t) \qquad (3.9)$$

$$C_D\ (t) = C_1\ (t) \times F_D\ (t) \qquad (3.10)$$

If we write the $C_G(t)$ equation out in full, we obtain:

Si on écrit de façon explicite l'équation de C_G (t) on obtient:

$$C_G(t) = (G + D) + (G - D) \cos 2\omega_p t + K_1 \cos [B(t) - \omega_p t] +$$
$$K_2 \cos [B(t) - 2\omega_p t] + 2 (G + D) \cos 2\omega_p t +$$
$$2 (G + D) \cos^2 2\omega_p t + 2 K_1 \cos [B(t) - \omega_p t] \cos 2\omega_p t +$$
$$2 K_2 \cos [B(t) - 2\omega_p t] \cos 2\omega_p t \qquad (3.11)$$

Equation 3.11 can also be written as:

$$C_G(t) = (G + D) + (G - D) \cos 2\omega_p t + K_1 \cos [B(t) - \omega_p t] +$$
$$K_2 \cos [B(t) - 2\omega_p t] + 2 (G + D) \cos 2\omega_p t + (G - D) -$$
$$(G - D) \cos 4\omega_p t + 2 K_1 \cos [B(t) - \omega_p t] \cos 2\omega_p t +$$
$$2 K_2 \cos [B(t) - 2\omega_p t] \cos 2\omega_p t \qquad (3.12)$$

and when the terms are re-arranged, we get:

$$C_G(t) = 2 G + K_1 \cos [B(t) - 3\omega_p t] - K_2 \cos [4\omega_p t - B(t)] +$$
$$(G - D) \cos 2\omega_p t + 2 (G + D) \cos 2\omega_p t - (G - D) \cos 4\omega_p t +$$
$$K_1 \cos [B(t) + \omega_p t] + K_2 \cos [B(t)] + K_1 \cos [B(t) - \omega_p t] +$$
$$K_2 \cos [B(t) - 2\omega_p t] \qquad (3.13)$$

The $C_G(t)$ signal is then filtered through a low-pass filter to remove all components above 15 kHz. This then gives $R_G(t)$:

$$R_G(t) = 2 G + K_1 \cos [B(t) - 3\omega_p t] - K_2 \cos [4\omega_p t - B(t)] \qquad (3.14)$$

Thus, at the output of the left channel, there are two intermodulation components (Eq 3.14) and these components represent the audio interference of the SCMO channel.

The intermodulation components are therefore found in (s-3p) and (4p-s) respectively. Figure 3.7 shows the frequency range that the interference can occupy within the channel in question. It is possible to check that the same result is obtained for interference on the right channel by multiplying $C_1(t)$ by the function $F_D(t) = (1 - 2 \cos 2w_p t)$.

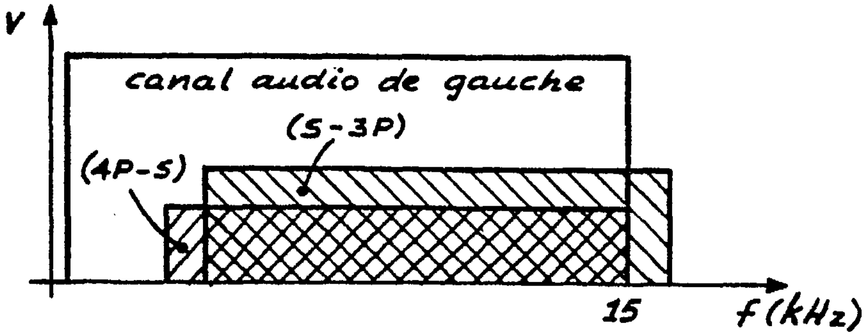


Fig. 3.7: Interference in (s-3p) and (4p-s).

3.3.3 Intriguing case

The (s-3p) and (4p-s) interference can take the form of a harmonic component when the SCMO channel is not modulated, that is, when there is a 67 kHz carrier that is not modulated. This will give:

$$(s-3p) = 67 \text{ kHz} - 57 \text{ kHz} = 10 \text{ kHz} \qquad (3.15)$$

$$(4p-s) = 76 \text{ kHz} - 67 \text{ kHz} = 9 \text{ kHz} \qquad (3.16)$$

In general, most of the energy of the audio interference signal will be concentrated around 10 kHz.

3.4 Interference of the stereo channel in the SCMO channel

One of the problems encountered in the operation of a subsidiary channel with a stereophonic channel is the interference created by the stereo information in the SCMO channel. To date, broadcasters have been most concerned with protecting the stereophonic channel from interference from the SCMO and in most instances, the SCMO quality requirements have not been very Strict.

The purpose of this section is thus to examine the interference problems of the stereophonic channel with the SCMO channel. We will start with a general analytical approach and then carry out a more specific examination of the problem of interference where a subsidiary channel is used according to existing standards (67 kHz modulated to ± 6 kHz, 10% modulation).

Very few authors have dealt with the SCMO and its related problems. Indeed, very little research has been done on the interference of the main channel with the SCMO. However, Bott[13] and Hedlund[14] broached the subject emphirically and evaluated the carrier-to-maximum interference ratio (C/N) to obtain a given signal-to-noise ratio.

We are relying upon Bott for our analysis of the effect of an interference signal on the SCMO carrier and then on Corrington[15] for the analytical study of the interference at the output of the discriminator by a modulated or unmodulated SCMO carrier. It presupposes the existence of an interference signal from the stereo channel and tries to assess its relative size at the SCMO demodulator output. Only the main points of the findings are presented and we refer the reader to the references cited for more detailed information.

3.4.1 Stereophonic information distortion products

At present, the subsidiary channel (SCMO) is generally used with an FM subcarrier located at 67 kHz with a deviation of ± 7.5 kHz. This channel occupies the frequency band from 59.5 kHz to 74.5 kHz. An intermodulation component in this band will generate interference in the subsidiary channel. The modulation and demodulation processes of the stereophonic channel inevitably also create certain levels of distortion products of the third and fourth order[13].

Generally speaking, it is possible to design systems in such a way as to minimize the amplitude of distortion products. To do so, it is important to determine the level of the maximum distortion products allowable to obtain a given signal-to-interference ratio.

As illustrated in Figure 3.8, the interference in the subsidiary channel consists of the components of the second harmonic of the modulated stereophonic subcarrier in double sideband to the suppressed carrier (DSB-SC). The components of the lower band are in the area of the spectrum reserved for the subsidiary channel.

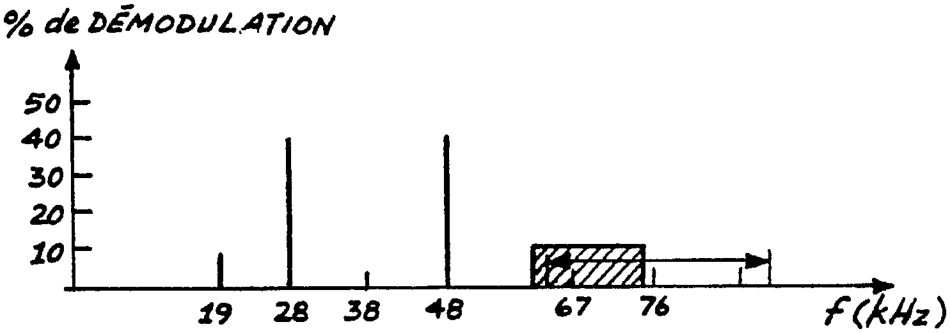


Fig 3.8: Interference spectrum of channel (G - D) (modulated at 10 kHz) in the SCMO.

In Figure 3.8, the stereophonic channel (G - D) is modulated 40% by a 10 kHz sinusoidal signal. The spectrum components of the (G - D) channel are at 28 kHz and 48 kHz. The spectrum components of the 38 kHz second harmonic will be located around 76 kHz, specifically at 66 kHz and 86 kHz. The component at 66 kHz is therefore within the SCMO band, just 1 kHz from the subcarrier at 67 kHz. Figure 3.8 also shows the frequency zone covered by the interference of the harmonic at 76 kHz. This interference can also be caused by intermodulation products centred around 57 kHz (third harmonic of 19 kHz).

The intermodulation components which fall within the subsidiary channel band will have access to the FM discriminator and will become audio interference. The level of audio interference will be proportional to the level of intermodulation and can be evaluated quantitatively.

3.4.2 Effect of intermodulation components on the SCMO signal

A non-modulated FM carrier can be illustrated using a stationary vector as shown in Figure 3.9.

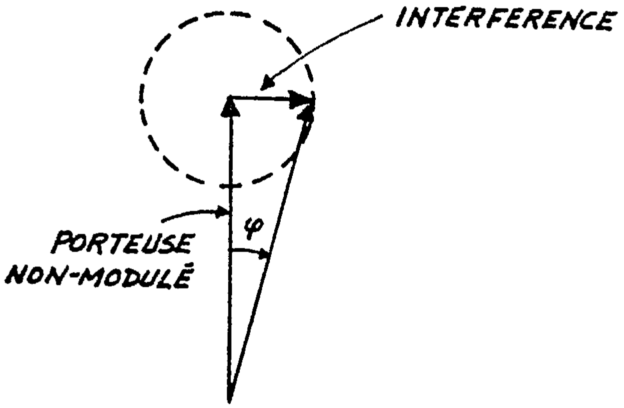


Fig 3.9: Vector representation of an FM carrier and an interference component.

Frequency modulation of the carrier turns the vector clockwise or anticlockwise from its original position. The phase deviation is proportional to the instantaneous amplitude multiplied by $1/f_m$ where f_m is the frequency of the modulation signal. For example, when the SCMO subcarrier is 100% modulated by a 500 Hz sinusoidal signal with a deviation of $\Delta f = \pm 7.5$ kHz, the phase deviation would be $\pm 850^\circ$. If the modulation frequency is 1000 Hz, the deviation will be 430°.

Let us assume that the interference component is located at 67.5 kHz, which corresponds to the component of the lower band of the second harmonic of channel (G - D) modulated by an 8.5 kHz signal. In this case, the frequency difference between the interference component and the SMCO subcarrier will be 500 Hz. This component can be represented by a vector of a length equal to the amplitude of the interference turning at an angular speed (2π x 500) times more rapidly than the vector representing the carrier. The maximum deviation in relation to the carrier is proportional to the ratio of the carrier amplitude to the interference. If we assume that the interference signal is -30 dB with respect to the SCMO carrier, then the maximum phase deviation will be

$$\Delta\phi = \text{arc tg}\left[\frac{1}{0.02}\right] = 1.8^\circ \qquad (3.17)$$

In order to determine the relative amplitude of a 500 Hz audio interference signal at the SCMO discriminator output, the phase deviation of the interference is compared to the phase deviation given by a 500 Hz signal modulating the SCMO carrier 100%, namely 850°. In the example given of a 67.5 kHz signal at -30 dB, the audio interference at the output would be -54 dB. Table 3.1 gives a few numeric examples of interference for different frequency deviations at the -30 dB level in relation to the subcarrier.

écart de f. Δf	ψ	$\psi/1.8^\circ$	$\psi/1.8^\circ$ (dB)
125	3400	2000	66
250	1700	1000	60
500	850	500	54
1000	430	250	48
2000	214	125	42
3000	142	79	38
5000	86	48	34
6000	71	39	32

Table 3.1: Examples of interference calculations.

The de-emphasizing filter that is often found in SCMO systems will tend to decrease the effect of this interference on the higher frequencies. Furthermore, these are only approximate results and do not take into account the non-linearities of the demodulator and the fact that the amplitude limiter will also tend to eliminate part of the interference.

These results show that to obtain a 50 dB signal-to-SCMO noise ratio, the C/N ratio has to be a minimum of 40 dB in relation to the SCMO subcarrier, or within -60 dB of 100% modulation of the main carrier. Under the regulations governing stereophonic modulation, the (G - D) channel is modulated 80%, the pilot (19 kHz) 10% and the SCMO channel 10%. The lower band of the (G - D) channel falling within the SCMO zone is therefore modulated to 40%. The harmonic distortion of channel (G - D) cannot therefore be attributed to the distortion of each of its spectrum components, but it can provide an idea of the size of the permissible level. In terms of percentage distortion, a performance better than 0.2% or -54 dB is required for an S/N objective of 50 dB in the SCMO channel.

3.4.3 Analytical approach to determine the effect of the intermodulation components on the SCMO signal

Given the following SCMO signal:

$$s_1(t) = E_1 \sin\left(\omega_c t + \frac{D}{\mu}\sin 2\pi\mu t\right) \qquad (3.18)$$

The interference signal e(t) is a sinusoidal of the angular frequency $(w_c + \alpha)$ and of the phase θ.

$$e(t) = E_2 \sin\{(\omega_c + \alpha)t + \theta\} \qquad (3.19)$$

The sum of the SCMO signal and of the interference is written:

$$s_1(t) + e(t) = E_1\sqrt{1 + x^2 \cos\beta} \; . \; \sin\left\{\omega_c t + \frac{D}{\mu}\sin 2\pi\mu t - \phi\right\} \qquad (3.20)$$

where:

$$x = \frac{E_2}{E_1} \qquad (3.21)$$

$$\beta = \frac{D}{\mu}\sin 2\pi\mu t - \alpha t - \theta \qquad (3.22)$$

$$\mathrm{tg}\phi = \frac{x \sin\beta}{1 + x\cos\beta} \qquad (3.23)$$

The instantaneous frequency of the resultant signal will be:[15]

$$f_i = \frac{\omega_c}{2\pi} + D \cos 2\pi\mu t + \frac{1}{2\pi} \frac{d}{dt} \left[tg^{-1} \frac{x \sin \beta}{1 + x \cos \beta} \right] \quad (3.24)$$

or with (3.22)

$$f_i = \frac{\omega_c}{2\pi} + D \cos 2\pi\mu t + \frac{x \cos \beta + x^2}{1 + x^2 + 2\, x \cos \beta} \left\{ D \cos 2\pi\mu t - \frac{\alpha}{2\pi} \right\} \quad (3.25)$$

Equation (3.25) can be expressed as:

$$f_i = \frac{\omega_c}{2\pi} + D \cos 2\pi\mu t - \frac{D \cos 2\pi\mu t - \alpha/2\pi}{\frac{\cos \beta + 1/x}{\cos \beta + x} + 1} \quad (3.26)$$

Using (3.26), it is possible to calculate the interference level at the demodulator in the case where the SCMO channel is disturbed by a sinusoidal signal. With a non-modulated SCMO channel, we would have:

$$f_i = \frac{\omega_c}{2\pi} + \frac{\alpha/2\pi}{\frac{\cos \beta + 1/x}{\cos \beta + x} + 1} \quad (3.27)$$

If the condition X << 1 is achieved, then (3.27) gives:

$$f_i = \frac{\omega_c}{2\pi} + \frac{x\, \alpha}{2\pi} \cos \beta \quad (3.28)$$

$$= \frac{\omega_c}{2\pi} + \frac{x\, \alpha}{2\pi} \cos (\alpha t + \Theta) \quad (3.29)$$

$$= f_c + x\, f_\alpha \cos (\alpha t + \Theta) \quad (3.30)$$

The level of audio interference is proportional to $x = \frac{E_2}{E_1}$ and to the frequency of the interference signal f_α.

The signal-to-interference ratio is defined, in terms of the useful signal, as:

$$S/I = 20 \log_{10} \frac{xf_\alpha}{D} \tag{3.31}$$

where: $x = \frac{E_2}{E_1}$

$$D = \Delta f = 7{,}5 \text{ kHz} \tag{3.32}$$

Finally, the desired result is obtained, that is:

$$S/I = x + 20 \log_{10} \frac{f_\alpha}{D} \tag{3.33}$$

where: x is in dB.

To obtain a numerical example, the parameter values are set at $x = 30$ dB, $F = 500$ Hz and $D = 7.5$ kHz, giving a signal-to-interference ratio of:

$$S/I = -53.5 \text{ dB} \tag{3.33}$$

which is almost identical to the results presented in the preceding subsection using the Bott approach[13].

3.5 Possible origins of the problems associated with SCMO

The interference caused by the SCMO channel in the stereophonic channel and by the stereophonic channel in the SCMO channel could originate in the various parts of the transmitting and receiving system. Generally, the causes of interference are many which means that attention must be given to all parts of the system.

The two main concerns with SCMO transmission are as follows[14]:

(1) To preserve the quality of the main stereophonic channel. The addition of a subsidiary channel on the FM carrier should not affect the reception quality of the stereophonic signal.

(2) To ensure the good quality of the SCMO signal. There are very few existing standards governing the subsidiary channel. Frequency response, distortion, signal-to-noise ratio and so forth are not specified in existing regulations. We will eventually define performance standards for the new subsidiary channel in terms of the achievable technological possibilities.

This section is intended as a first attempt at solving the problem in terms of the current system. We will identify three major areas which could produce interference. These are the transmitter, the receiver and multipath propagation. We will examine each possibility qualitatively in terms of the components which could be the cause of a certain level of interference in order to determine the design standards required for a quality system.

3.5.1 Transmitter

Figure 3.10 gives a block diagram of the main components of an FM stereo transmission system with a subsidiary channel.

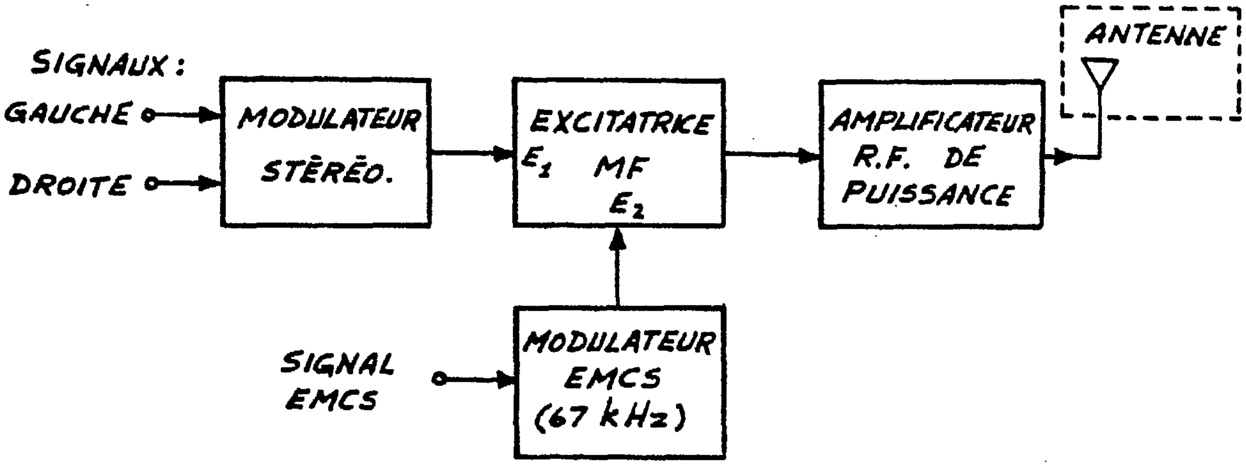


Fig. 3.10: Block diagram of an FM transmission system with an SCMO subsidiary channel.

The transmitter is divided into five parts, namely the stereophonic modulator, the SCMO modulator, the FM direct exciter, the power amplifier and the antenna. We will identify the characteristic of each of these components which are required in a system on order to accomodate an SCMO subsidiary channel.

(a) Stereophonic modulator

The stereophonic modulator is used to form the composite stereophonic signal consisting of the (G + D) information, a 19 kHz pilot frequency and a subcarrier modulated at 38 kHz in double sideband to the carrier suppressed by the (G - D) information. Harmonics of the pilot frequency and of the subcarrier (third harmonic (3p) at 57 kHz and fourth harmonic (4p) at 76 kHz) are detected at the output of the stereophonic modulator. The modulator could therefore be generating the harmonic distortion without having any negative effect on the quality of the stereophonic transmission while still producing intermodulation groups when there is a stereophonic transmission with the SCMO subsidiary channel at 67 kHz.

It is also important in a transmission with a subsidiary channel that the G and D signals, forming the input to the stereophonic modulator, do not exceed the allowable 15 kHz bandwidth. In the opposite situation, the composite signal may exceed the allowed 53 kHz bandwidth and give rise to linear intermodulation in the SCMO subsidiary channel (linear crosstalk)*. It is therefore important to ensure that the G and D signals are properly filtered to 15 kHz and that the output of the stereophonic composite signal is also filtered to 53 kHz. This will eliminate any problems of overlapping spectrums for the stereo composite signal and the SCMO subsidiary channel.

(b) SCMO modulator*

With modern technology, we can obtain an FM modulator with wide linearity at a low cost. The most delicate problem with the SCMO modulator would be with the low-pass filter (centred at 67 kHz for the present system) placed at the modulator output. This filer should ideally have linear phase and amplitude characteristics in the pass band.

As with the stereophonic modulator, the SCMO signal should be filtered to prevent any surpassing of the allowable band.

(c) FM direct exciter*

The FM direct exciter can be the source of intermodulation (particularly of the 3p and 4P) if it has a non-linear transfer characteristic. The problem of non-linearity in the modulator is found most often when an FM direct exciter is designed for stereophonic transmission and a subsidiary channel is added. The addition of this subsidiary channel increases the bandwidth of the composite signal and subsequently the linearity requirements of the FM direct exciter. However, modern technology can easily provide satisfactory linearity characteristics for a bandwidth as large as 100 kHz.

(d) RF amplifier and transmitting antenna

At the power stage, the major problems are the non-linearity of the phase of the amplitude, poor adaptation of the antenna to the amplifier, a too high VSWR and inadequate antenna bandwidth. All of these problems do not occur only when there is subsidiary channel modulation. The quality of the transmitted FM signal is affected significantly by general rules. However, the addition of a subsidiary channel increases, as in the case of the FM direct exciter, the quality requirements of the power stage. The larger bandwidth of the total composite signal (stereo + SCMO) requires wider linearity, better adaptation and especially a wide enough antenna bandwidth. When adding a subsidiary channel to a stereophonic FM carrier that is already in operation, it is important to ensure, through adequate testing, that the transmitting system is operating properly.

3.5.2 Receiver

The receiver is without a doubt the part of the FM transmitting and receiving system that is most often responsible, to some extent, for intermodulation interference problems. Some commercial FM receivers on the Canadian market are particularly sensitive to intermodulation. This is often merely as a result of alignment problems with the RF or IF stages. However, some of these receivers have design faults and would be unable to meet stricter standards. The use by broadcasters of an SCMO subsidiary channel could result in audible interference on receivers.

Figure 3.11 gives a block diagram of the main components of an FM stereophonic receiver with an SCMO demodulator (more detailed than that given in Chapter II). Intermodulation interference does not originate in any specific part of the receiver but can be caused by each and every one of the stages. However, some stages are more likely to create intermodulation.

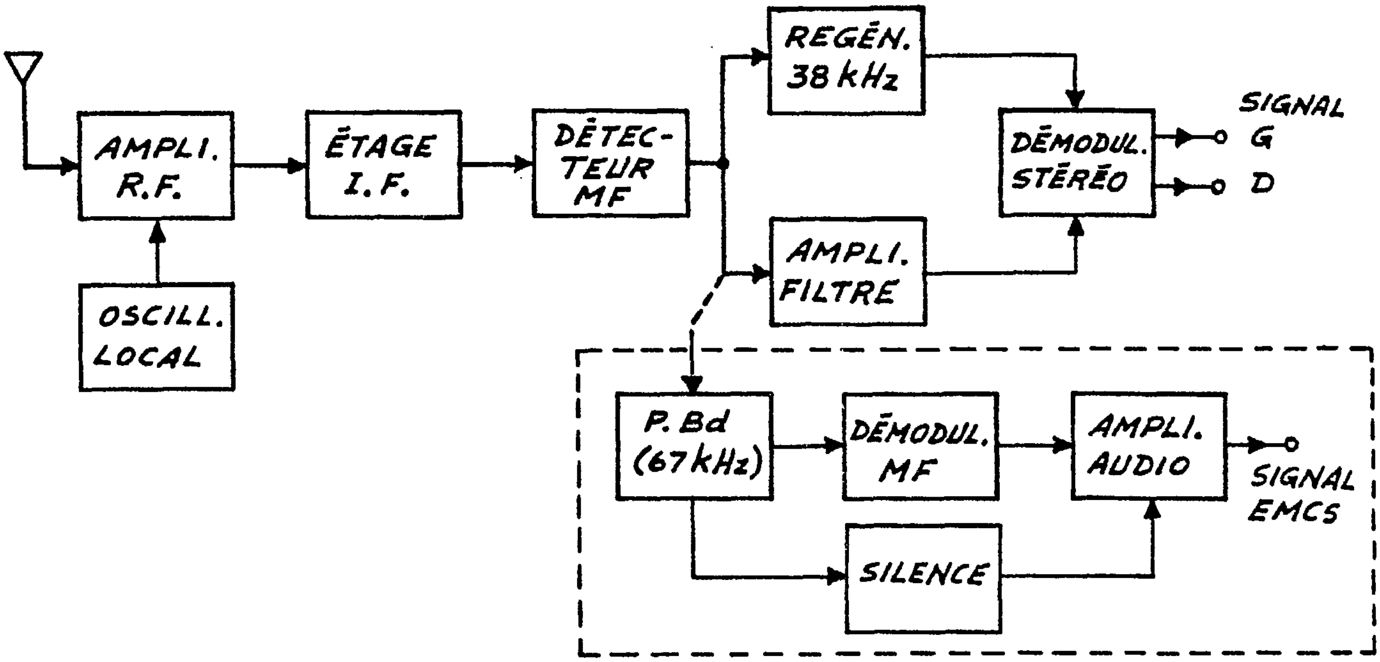


Fig 3.11: FM and SCMO receiver

We will examine each of the stages making up a stereophonic FM and SCMO receiver in order to identify their possible weaknesses. This will be only a qualitative examination: a more detailed study of the characteristics and performances required for a quality receiver will be included in later work.

(a) RF amplifier

The RF amplifier can often cause considerable distortion, the problem being related to saturation. This occurs most often with amplifiers that use bipolar transistors at the RF stage. Higher radio frequency signals can saturate the transistor at the input and thus change the RF amplifier into a mixer. This saturation problem has been largely overcome by JFET and MOSFET transistor technology.

Other common problems are the linearity of the RF amplifier and the adaptation of the antenna to the amplifier. These two problems are dependent primarily on the quality of the receiver and the user's installation.

(b) IF stage

It is very important to have perfect symetry between the amplifier and the limiter to avoid amplitude-to-phase and intermodulation conversions. This component is becoming increasingly common in the form of integrated circuits which improve the average quality significantly. IF pass-band filters are also very important. Currently, there are a variety of techniques for obtaining IF filters with highly satisfactory characteristics but the cost is still quite high when compared with that of integrated circuits.

(c) FM demodulator

The main characteristics of the demodulator are a sufficiently wide bandwidth (75 kHz) and wide linearity across the entire band. As a result of integrated circuit technology, FM demodulators on the market are improving in performance.

(d) 38 kHz circuit regenerator

It often occurs that the 38 kHz circuit regenerator used to double the pilot frequency (19 kHz) and to amplify it for the stereophonic demodulator, generates, at a considerable level, a second harmonic at 76 kHz. This signal at 76 kHz, when combined with the 67 kHz signal of the subsidiary channel, will produce at 9 kHz signal in the stereophonic channel by intermodulation interference.

(e) Stereophonic demodulator

Some stereophonic FM receivers use square-law stereophonic demodulators. This type of demodulator is often rich in the third harmonic of the pilot frequency at 19 kHz (3p = 57 kHz). This signal at 57 kHz can produce audio interference at 10 kHz on the stereophonic channel through interference with the 67 kHz frequency of the subsidiary channel. By adding an SCMO filter before the stereo demodulator it is possible to eliminate this problem indirectly.
The ideal SCMO filter would have a pass band of 53 kHz and infinite attenuation between 60 kHz and 75 kHz. A filter with these features would be very costly

to produce which would mean that compromises of varying acceptability would have to be made. Even reasonably priced receivers often have very poor SCMO filters. Thanks to integrated circuit technology it is now possible to introduce, at minimum cost, "phase lock loop"* stereophonic demodulators which have very good SCMO rejection characteristics and excellent stereophonic separation.

3.5.3 Multipaths

The problem of multipath propagation is dealt with separately because it is a problem unrelated to the receiver or transmitter. Multipaths are a significant cause of distortion particularly in stereophonic transmissions. This problem does not therefore relate specifically to the SCMO channel but to transmission in general in the FM band.

It is nevertheless important to know the effect of multiplexing an SCMO channel on the level of distortion caused by multipath propagation. O'Hara's document[11] deals with crosstalk* caused by multipath propagation in stereophonic FM modulation with a subsidiary channel. The analysis of the crosstalk is made using simulations on a digital computer in an effort to show the effect of the subsidiary channel. We are already aware that multipath problems are much more serious in stereophonic transmission than in monophonic transmission. It is therefore not surprising that multiplexing an SCMO subsidiary channel tends to make the situation even worse.

O'Hara concludes that multiplexing an SCMO channel can cause serious crosstalk problems owing to the presence of multipaths propagation, especially with relatively long propagation delays ($\simeq$ 20 s). The signal-to-interference ratio required to eliminate the crosstalk would be 20 dB for a delay of $5 \mu s$ and 30 dB for a delay of $30 \mu s$.

In our opinion, this is not a major obstacle to the use of a subsidiary channel. However, in environments where there is already a significant problem with the stereophonic channel, caution must be exerted when adding a subsidiary channel. We plan to carry out several tests on signals from a local station in Quebec City - a city which is strongly affected by the problem of multipath propagation - in order to measure the effect of the subsidiary channel. These tests would be made under an agreement between the authorities of the University, the owners of the station and the contracting parties.

3.6 Conclusion

In Chapter 3 we have tried to show, in what we feel is a logical order, the following elements: after introducing the notion of intermodulation noise, we briefly reported on three methods of measurement, each of which had an interesting part to play in the measuring of this noise. We then applied the general concept to the specific case of the FM signal containing all authorized features between 50 Hz and 75 kHz.

We first examined the transfer of information from the subsidiary channel to the main channel and showed analytically how this undesired information is transformed to return at the audio level (left or right).

The last step was a quantitative analysis of the undesired transfer of information from the main channel to the SCMO channel. A numerical example was given. We should point out that this type of problem is usually not of concern to designers or manufacturers of FM receivers.

Lastly, we reviewed briefly the various sources of intermodulation within each of the components of a complete FM network.

From this study we can conclude that we must consider the communication system as a whole when evaluating intermodulation levels, as the measurements are always made in the base band, at both the input and the output of the system.

It is only in the next phase of the study that we must evaluate the quality of each of the transmitting and receiving components and define the minimum standards required to ensure a specific quality level for an entire FM communications multiplex system.

Chapter 4

Experimental Evaluation

4.1 Introduction

The intermodulation phenomena of several FM communications systems were studied in depth in the laboratory. The components, equipment parts and testing equipment will be described throughout this chapter. The conditions under which the tests were conducted will also be defined. It will be apparent that the experience gained throughout this testing process will be of considerable assistance in the second phase which involves designing an SCMO receiver.

4.2 Description of receivers used

Three receivers of different quality were used in the tests to measure the effect of the subsidiary channel on stereophonic and monophonic reception. The JVC receiver is a monophonic instrument of good quality while the Sony is of average quality. The main characteristics of the receivers used are as follows:

(1) JVC, model JTV-77, high range stereo tuner
  - RF stage with FET
  - two-stage ceramic IF filters
  - FM demodulator circuit with PTL (phase tracking loop*)
  - automatic tuning control circuit

(2) Advent, model 400, monophonic table receiver
  - RF stage with FET
  - two-stage IF-LC filters
  - ratio-detector demodulator

(3) Sony, model ICF-9530 W, monophonic table receiver
  - RF stage with bipolar transistors
  - ceramic IF filters
  - radio-detector demodulator

The detailed diagrams of the circuits of the receivers are given in Appendix A.

To test the reception of the SCMO subsidiary channel, we used two demodulator models in the first phase which are sold in kit form to electronics enthusiasts. These consist of very rudimentary circuits using a LM-565 PLL integrated circuit. The circuits in question are:

(1) SWTP (Southwest Technical Products): SCA demodulator.
Demodulator circuit for subsidiary channel at 67 kHz using the LM-565 integrated circuit. It uses the composite signal at the output of the frequency discriminator of an FM receiver as its input signal.

(2) G I (Graymark International): CFM decoder
Demodulator circuit for a subsidiary channel at 67 kHz using the LM-565 integrated circuit. The input of this decoder is connected to the IF stage of an FM receiver. It uses an LA-1150 circuit to demodulate the composite signal.

The circuits of these two units are given in Appendix B.

In the second phase, we acquired a stereo and SCMO modulation system manufactured by McMartin Industries of Omaha, Nebraska. The modulation system was completed with an SCMO receiver specially designed to receive the subsidiary channel at 67 kHz. The McMartin receiver, model TR-55D, cannot be tuned externally as the tuning frequency is fixed by a crystal oscillator. It uses a PTD (Precise Tracking Decoder*) circuit and a D-MOS RF stage. The IF filters are ceramic and the demodulation circuits are integrated ones specially designed by McMartin. The output of the subsidiary channel has a 5 kHz pass band. A detailed circuit diagram of the unit is given in Appendix C.

4.3 Frequency response and linearity of the receivers used

The FM receivers sold on the Canadian market have, as we know, very different characteristics. While all meet the required standards for frequency modulation, they are of varying quality. Earlier we gave a technical description of three receivers used for testing carried out under this contract. We will now describe each of these receivers in terms of their main features at the IF stage and the frequency discriminator. To do this, we measured the frequency response of the discriminator and the linearity of the IF stage.

4.3.1 Frequency response at the discriminator output

(a) Experimental assembly

Figure 4.1 shows the assembly used to measure the frequency response of the receivers at the output of the frequency discriminator. The level of output signal is measured for seven different frequencies between 400 Hz and 67 kHz. The level of the 400 Hz signal is arbitrarily used as the reference level.

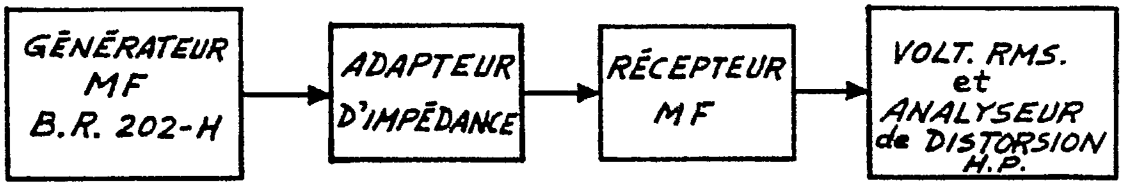


Fig 4.1: Assembly used to measure the frequency response of the receivers

(b) Results

Table 4.1 shows the frequency response of the JVC-JTV77, Advent and Sony receivers.

The JVC receiver gives good frequency response up to 67 kHz, showing a maximum drop of 0.6 dB. The Advent receiver gives the same response as the JVC receiver up to 15 kHz, but the signal output is attenuated 7 dB at 67 kHz. The Sony receiver had an even more unequal response in the audio band, shifting from 0 dB at 400 Hz to +3.5 dB at 1 kHz and then dropping gradually to +0.5 dB at 15 kHz. This represents a drop of 3 dB/decade which continued to 67 kHz where the level of the output signal was - 2.5 dB.

fmod.	JVC		ADVENT		SONY	
	A	B+THD	A	B+THD	A	B+THD
400	0 dB	0.35%	0 dB	2 %	0 dB	28 %
1 kHz	0	0.4	0	2 %	3.5	1.6%
3 kHz	-0.2	0.5	-0.2	2.8	2.5	1.7
7.5kHz	-0.3	0.5	-0.3	2.5	0.5	1.3
10 kHz	-0.2	0.65	-0.2	3.0	-0.5	1.5
67 kHz	-0.6	8.2	-0.7	3.2	-2.5	7.5

Table 4.1: Measurements of the frequency response of commercial receivers and their total corresponding harmonic distortion

where: A: rapport de l'amplitude du signal de sortie sur l'amplitude du signal à 400 Hz.

B+THD: Bruit + Distorsion harmonique totale.

référence: 0 dB à 400 Hz.

Δf: 75 kHz.

4.3.2 Linearity

(a) Assembly

The linearity of the IF stage and of the frequency discriminator of an FM receiver are determining factors for quality demodulation. These factors become even more important when an SCMO subsidiary channel is used on an FM carrier already carrying a stereophonic channel. The level of a receiver's distortion can be determined quite precisely on the basis of the pass band of the IF stage, the linearity of the discriminator and the response of the discriminator. The wider the band of the base band signal, the greater the constraints on these factors.

The linearity tests made under this study therefore give a good indication of the quality of the three commercial receivers used. These measurements give a good indication of the weaknesses that some receivers may have.

The Sound Technology FM generator with a Dual Sweep* function was used to make the tests. This function modulates the frequency of the FM carrier by a sinusoidal signal with large amplitude and low frequency (≤ 60 Hz) and simultaneously by a sinusoidal signal with low amplitude and high frequency (~ 10 kHz).

Using this technique, it is possible to see directly on the screen of an oscilloscope, the variation in amplitude of the 10 kHz, in terms of the frequency of the carrier, around a central frequency f_c to which the receiver and generator are tuned. Figure 4.2 gives the assembly used.

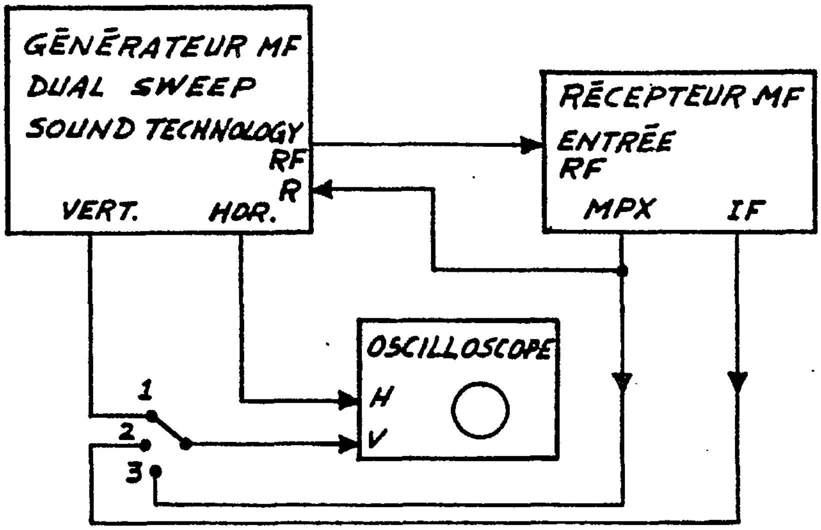


Figure 4.2: Assembly for measuring the linearity of the IF stage and of the discriminator of an FM receiver

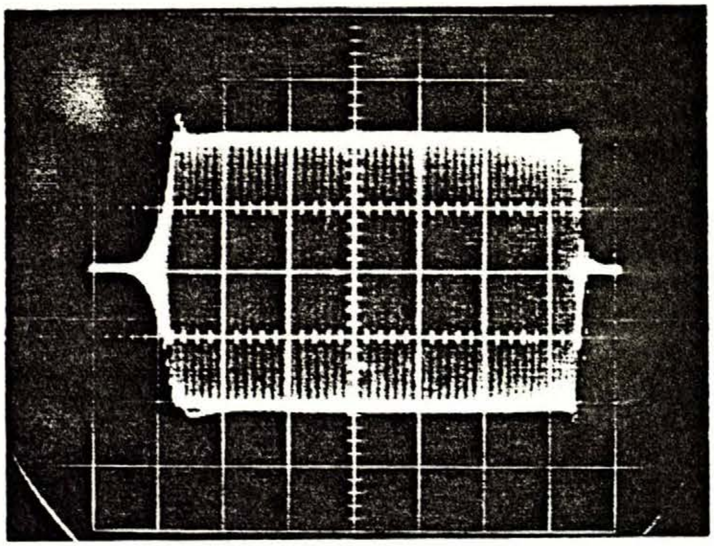
COMMUTATEUR:

Position 1 - Courbe de linéarité du discriminateur. Le rapport de la hauteur p. à p. sur la variation p. à p. représente la distorsion par intermodulation.

" 2 - Bande passante de l'étage IF

" 3 - Courbe de réponse du discriminateur.

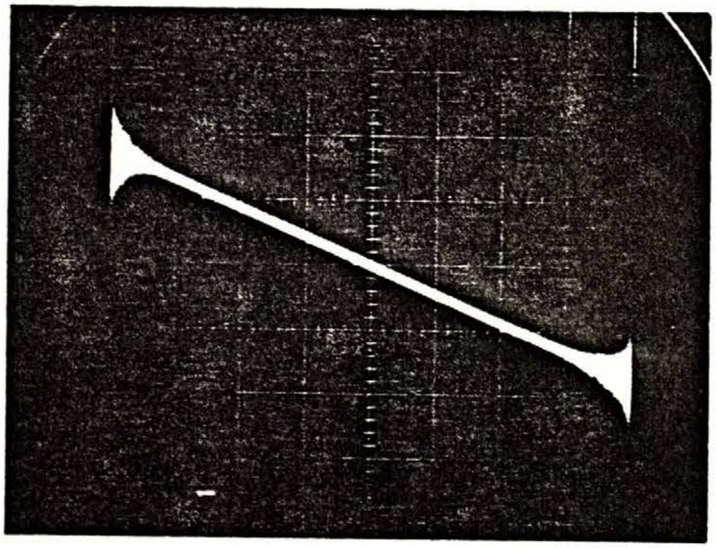
The results obtained are given in Figures 4.3 to 4.5 as photographs of the JVC, Advent and Sony receivers.



(a) Courbe de linéarité du discriminateu
de fréquence

H : 50 kHz/div.

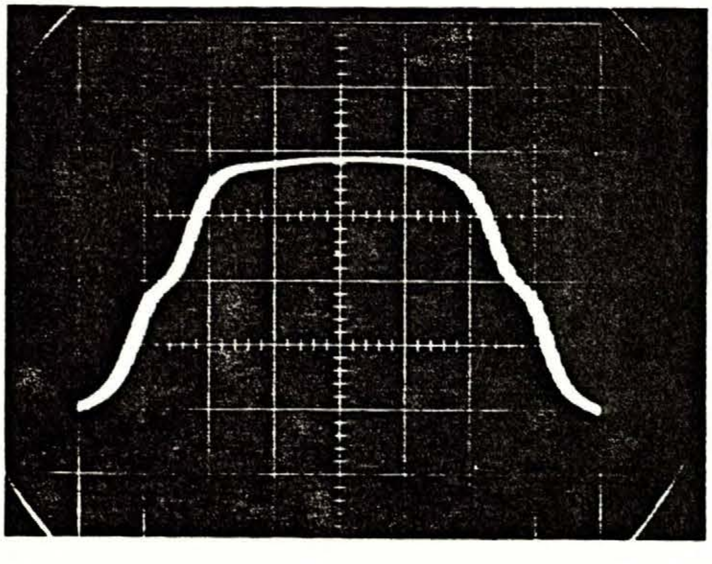
V : 0.2 V/div.



(b) Courbe de réponse du discriminateur

H : 75 kHz/div.

V : 0.5 V/div.

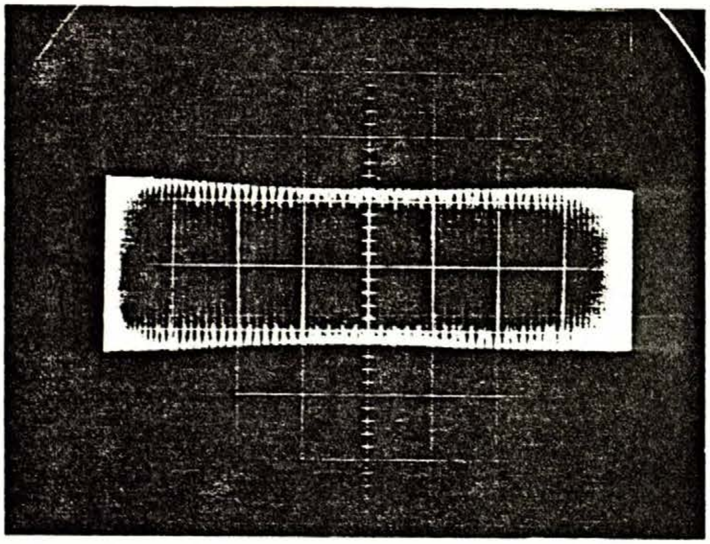


(c) Bande passante étage IF

H : 75 kHz/div.

V : 1 v./div.

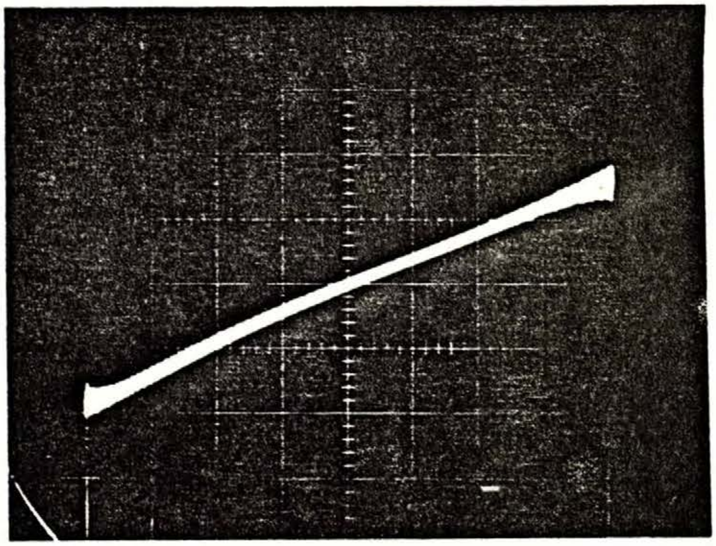
Figure 4-3. Mesures de linéarité du récepteur JVC-JTV77



(a) Courbe de linéarité du discriminateur de fréquence

H : 40 kHz/div.

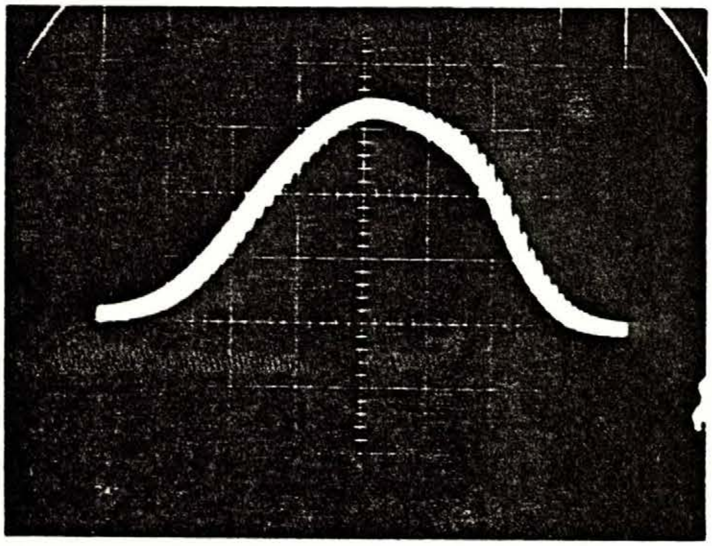
V : 0.2 v/div.



(b) Courbe de réponse du discriminateur

H : 75 kHz/div.

V : 0.5 v/div.

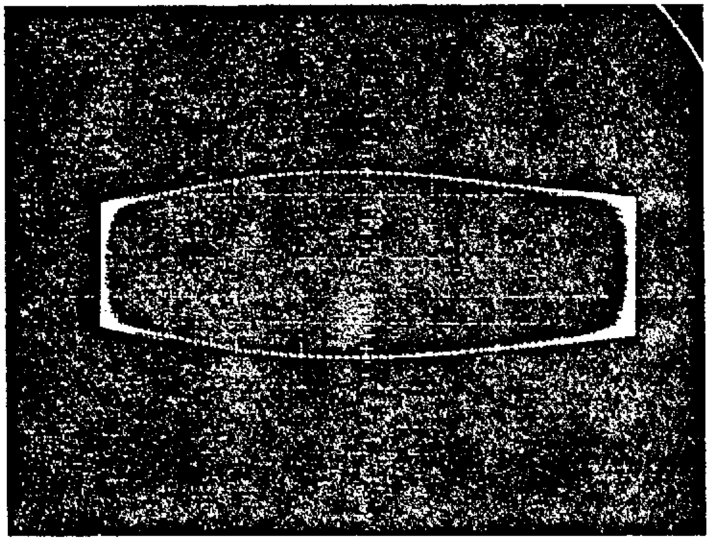


(c) Bande passante étage 1F

H : 75 kHz/div.

V : 1 v/div.

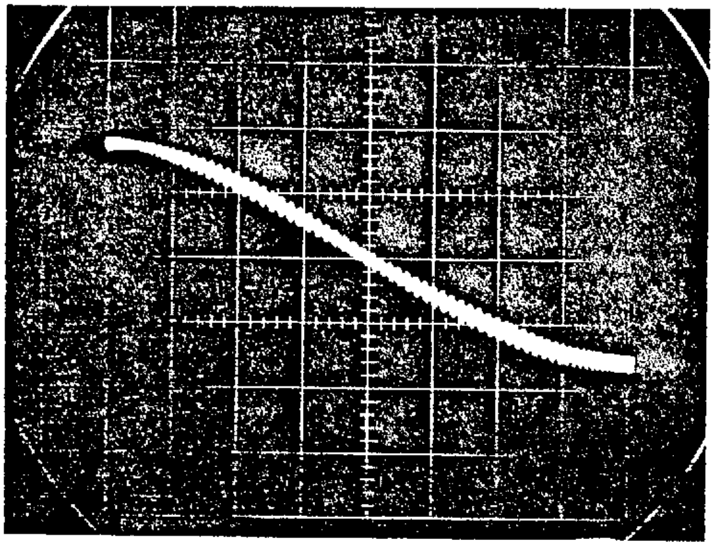
Figure 4-4. Mesures de linéarité du récepteur Advent.



(a) Courbe de linéarité du discriminateur de fréquence

H : 50 kHz/div.

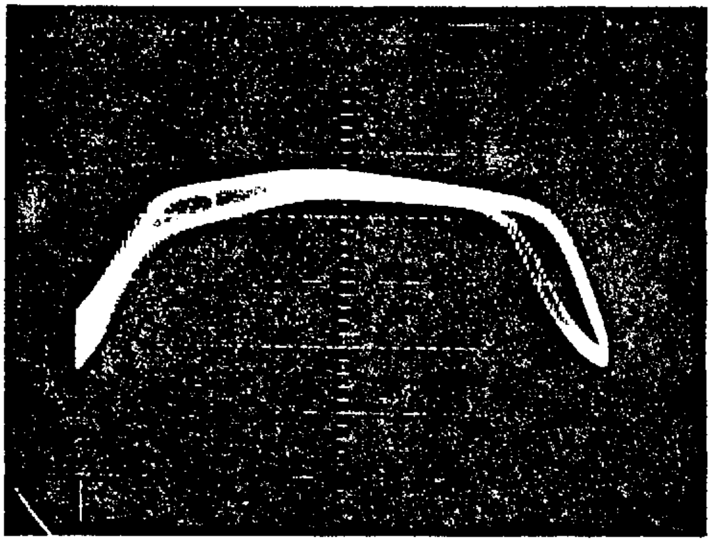
V : 0.2 v./div.



(b) Courbe de réponse du discriminateur

H : 75 kHz/div.

V : 0.5 v./div.



(c) Bande passante étage 1F

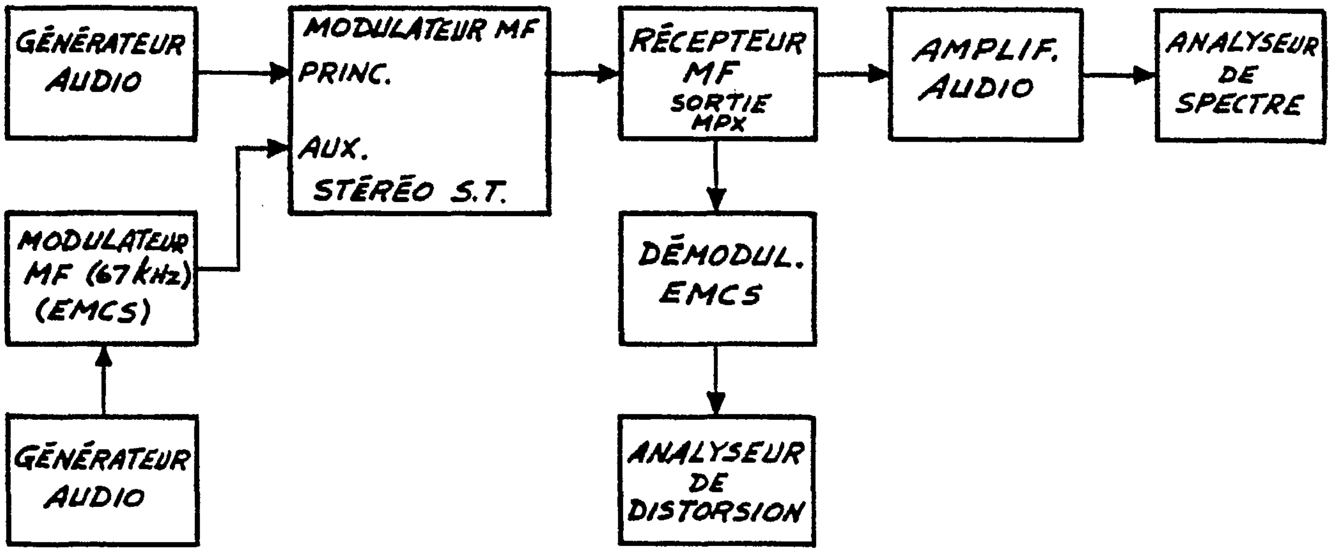
H : 75 kHz/div.

V : 1 v./div.

Figure 4-5. Mesures de linéarité du récepteur Sony.

4.4 Measurements with the Sound Technology modulator

In order to measure the interference between the stereo multiplex channel and the subsidiary channel, we used several modulation and demodulation instruments to take the measurements. The first part of the tests were made using a Sound Technology FM modulator. This instrument was used as both a stereophonic generator producing the composite signal with a pilot signal at 19 kHz and as the FM modulator. Figure 4.6 gives a schematic diagram of the assembly used in both the interference and spectral measurements. As the Sound Technology modulator does not have a specific input for modulation of the subsidiary channel, we therefore used an auxiliary input. We will see later on with the results obtained with the spectral analyser that the base band signal of the Sound Technology modulator has a recordable level of pilot and subcarrier harmonics at 38 kHz.



This device is designed for general purposes such as calibrating, adjusting and repairing commercial FM receivers.

4.4.1 Measurements of the interference of the SCMO signal with the main channel

Table 4.2 compares the signal-to-noise ratio (S/N) obtained with and without the SCMO subsidiary channel. The first column gives the S/N of the main channel (left channel in the case of the stereo assembly) when there is no SCMO carrier. The S/N ratio is defined here in relation to the level of the channel with 80% modulation, which is the maximum modulation on the stereo channel when there is a subsidiary channel. The second column gives the S/N ratios of the main channel obtained with an non-modulated SCMO carrier with 10% modulation.

	S/N Sans EMCS	S/N Avec EMCS
JVC (STEREO)	66 dB	65 dB
ADVENT (MONO)	64 dB	64 dB
SONY (MONO)	63 dB	63 dB

Table 4.2: Interference of SCMO in the main carrier

There is almost no change in the S/N measurements with or without the SCMO carrier. In the case of the JVC receiver, there was a slight difference of 1 dB. The JVC receiver is the only one tested that is a stereophonic receiver. This explains why there is slight interference by the SCMO as this interference is caused by (s-2p) intermodulation within the (G - D) channel (Ref: Chapter 2). The monophonic receivers only use the part of the signal between 0 and 15 kHz and therefore are not generally affected by (s-2p) and (s-p) interference.

4.4.2 Interference caused by the main channel in the SCMO channel

As we mentioned earlier, we used SCMO demodulators which are sold in kits for the first phase of tests. These demodulation circuits are relatively simple and are connected to either the output of the frequency discriminator in the case of the first SCMO (Southwest Technical Products) or at the IF stage as in the case of the second SCMO (Graymark International).

The interference measurements were made using four different base band signals. The 19 kHz pilot signal was present with 10% modulation[*] for all four signals. Figure 4.7 gives a description of each of these signals. The power of the modulation signal for the main channel was nil for signal #1 and increased to 80% in the (G - D) channel for signal #2 and to 80% in channel (G - D) for all four signals. The unmodulated SCMO subcarrier at 67 kHz had 10% modulation.

The signal-to-noise ratio (reference: 100% modulation of the SCMO channel) at the output of the SCMO demodulator is given in Table 4.3 for the two SCMO demodulators. In one case the SCMO circuits are connected to the JVC receiver and in the other to the Sony receiver.

	1	2	3	4
EMCS # 1 - JVC	-51 dB	-32 dB	-34 dB	-36 dB
EMCS # 1 - SONY	-50 dB	-27 dB	-38 dB	-37 dB
EMCS # 2 - JVC	-51 dB	-22 dB	-27 dB	-29 dB
EMCS # 2 - SONY	-51 dB	-24 dB	-24 dB	-29 dB

Table 4.3: Signal-to-noise ratio at the output of the demodulator of the SCMO channel (100% modulation)

The interference recorded at the SCMO demodulator is very high regardless of the FM receiver used. The quality of the demodulation is unacceptable in all instances where there was considerable modulation of the main channel. Main channel interference increased as the modulation power was concentrated in either the (G - D) channel or the (G + D) channel. SCMO circuit #1 does, however, appear to give slightly better results that the SCMO circuit #2.

---

[*] As defined by Mr L K Chan - DOC

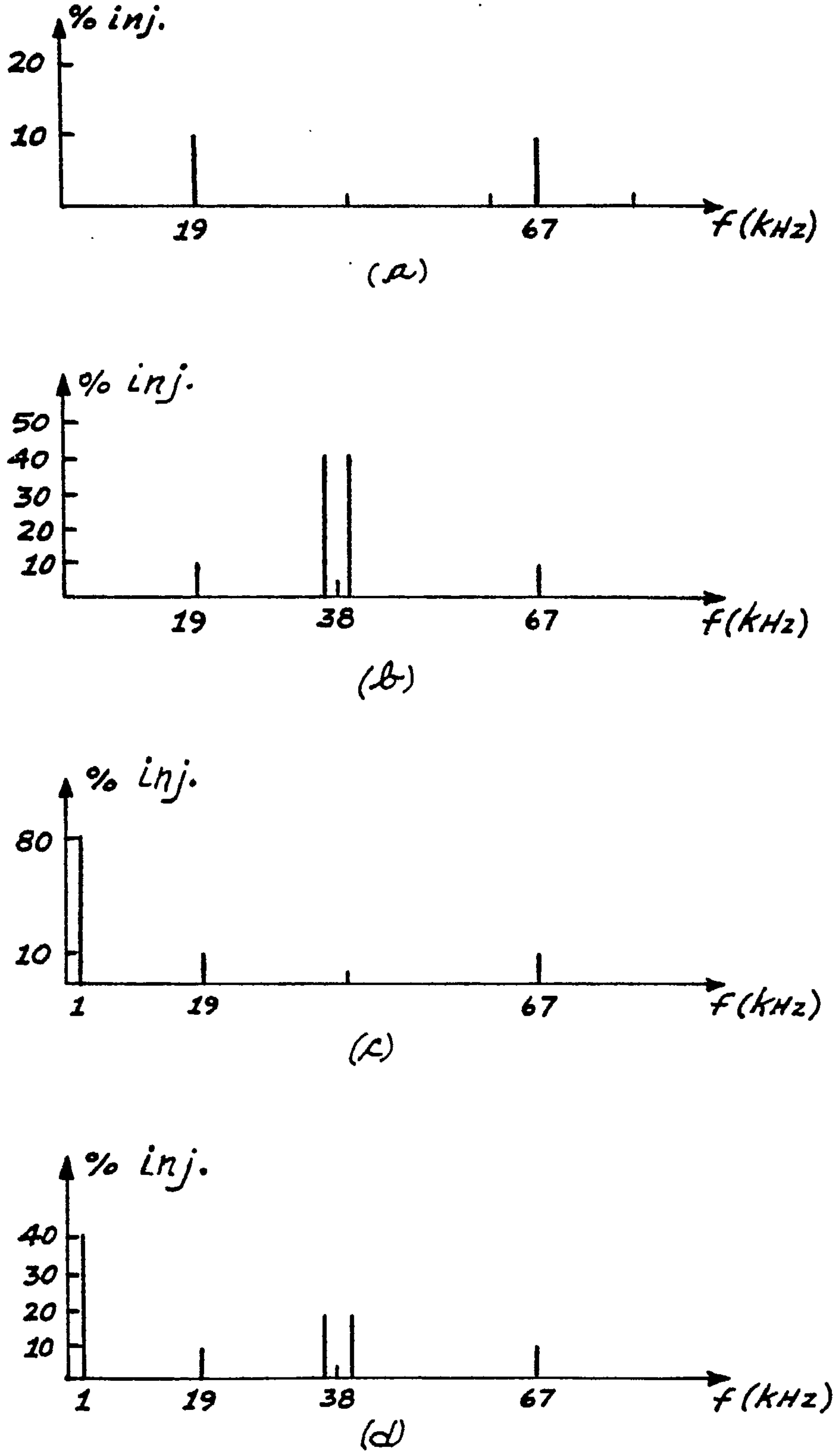


Figure 4-7. Signaux de bande utilisés pour les mesures d'interférence STEREO ⟶ EMCS.

4.4.3 Measurements of the spectrum of the base signal of the JVC, Sony and Advent FM receivers

The measurement of the level of interference at the audio output of the FM receivers and SCMO demodulators actually gave us very little information on the origin of the interference signals or their relative importance in terms of the modulation of the main channel and the receiver used. In order to obtain more complete information, we carried out spectrum measurements of the composite signal directly at the output of the frequency discriminator (See the assembly in Figure 4.8). Theoretically, the composite signal at the output of the frequency discriminator should (in an ideal system) be identical to the composite signal at the input of the frequency modulator.

Unfortunately, it is impossible to assess individually the disturbances which the composite signal undergoes during the FM modulation and demodulation processes. That is to say, it is impossible without an ideal demodulator to determine whether the interference comes from the FM modulator or from the demodulator. The significance of these considerations will be apparent when it is time to design a better SCMO receiver. For the moment, we will examine the degeneration which the composite signal experiences by comparing the signal at the input of the modulator with that obtained at the output of the demodulator. Figure 4.8 shows the points in the FM chain where the composite signals are captured.

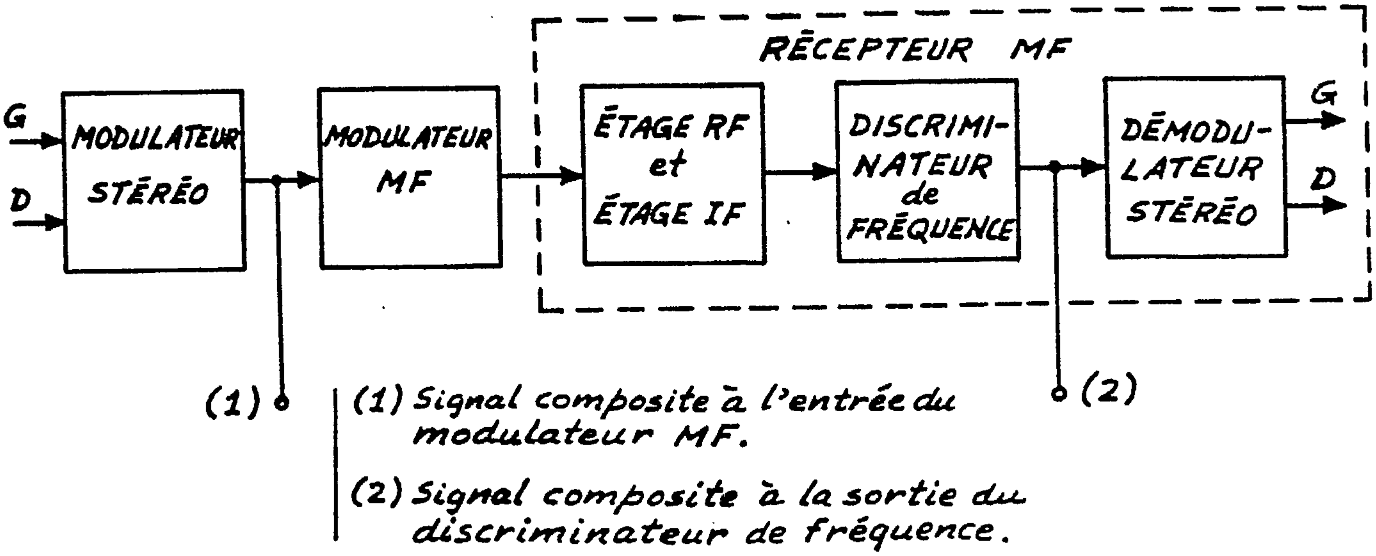


Fig 4.8: Diagram of the connections of the spectrum analyser

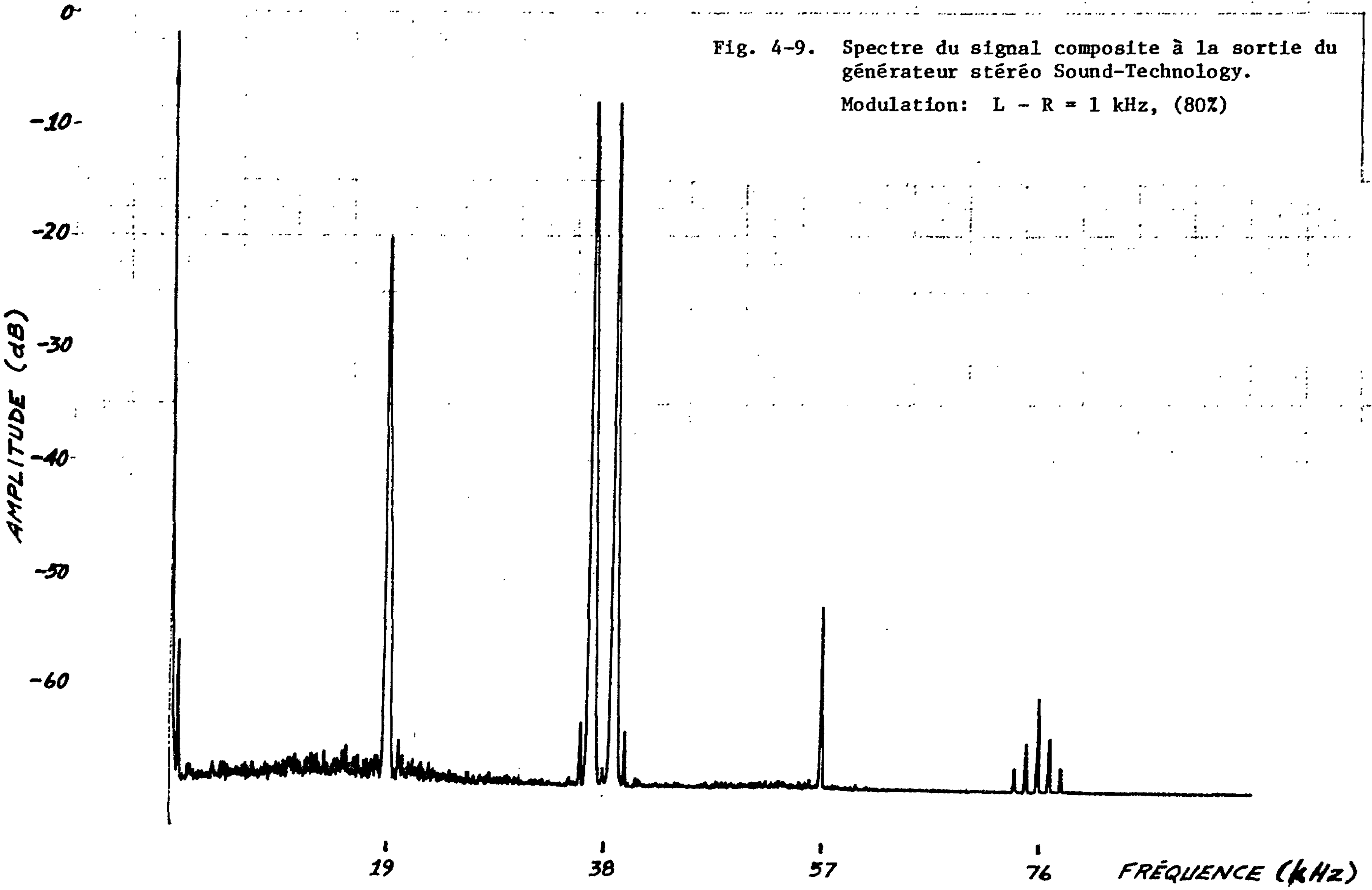


Fig. 4-9. Spectre du signal composite à la sortie du générateur stéréo Sound-Technology.
Modulation: L - R = 1 kHz, (80%)

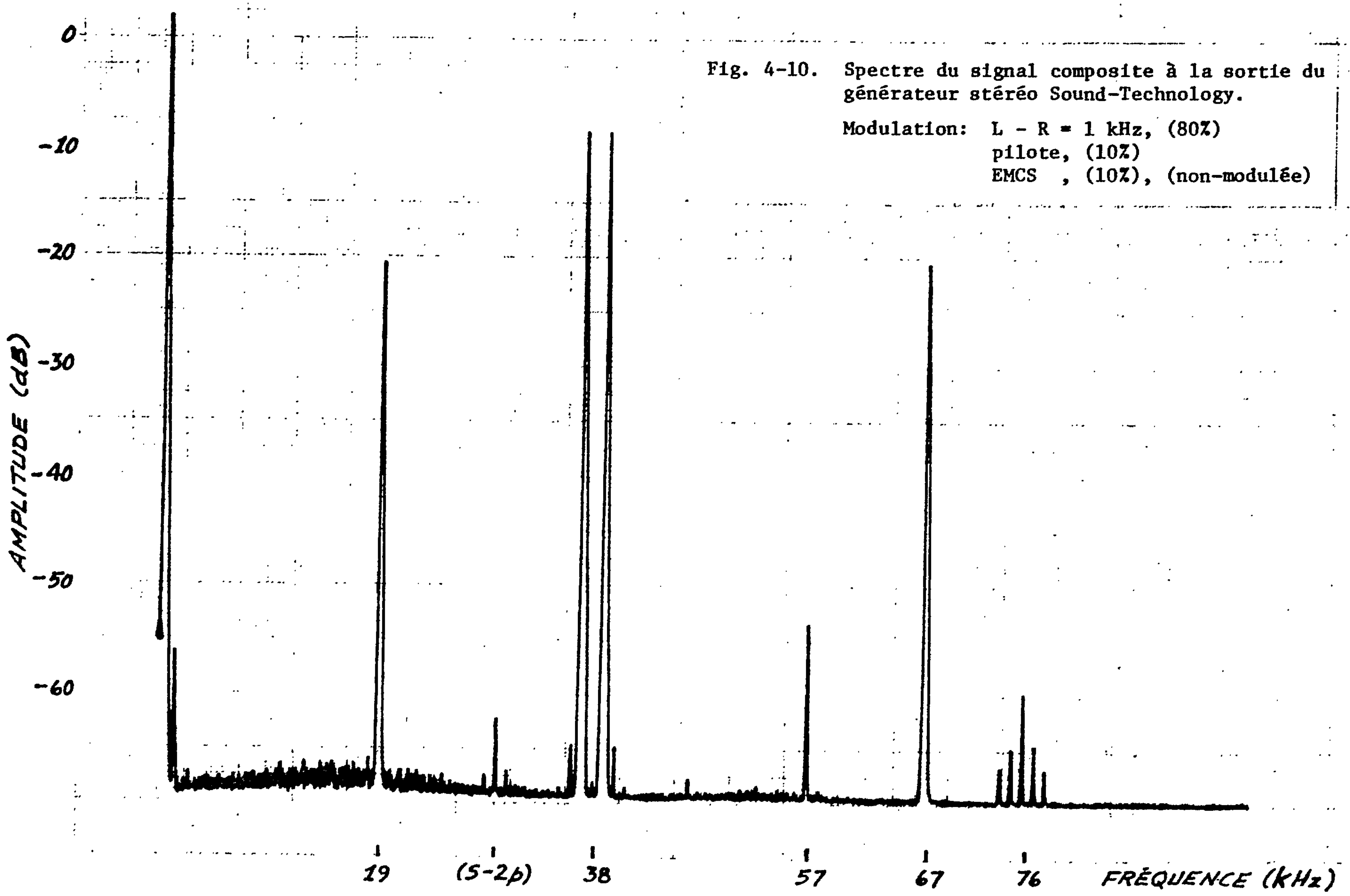


Fig. 4-10. Spectre du signal composite à la sortie du générateur stéréo Sound-Technology.

Modulation: L - R = 1 kHz, (80%)
pilote, (10%)
EMCS , (10%), (non-modulée)

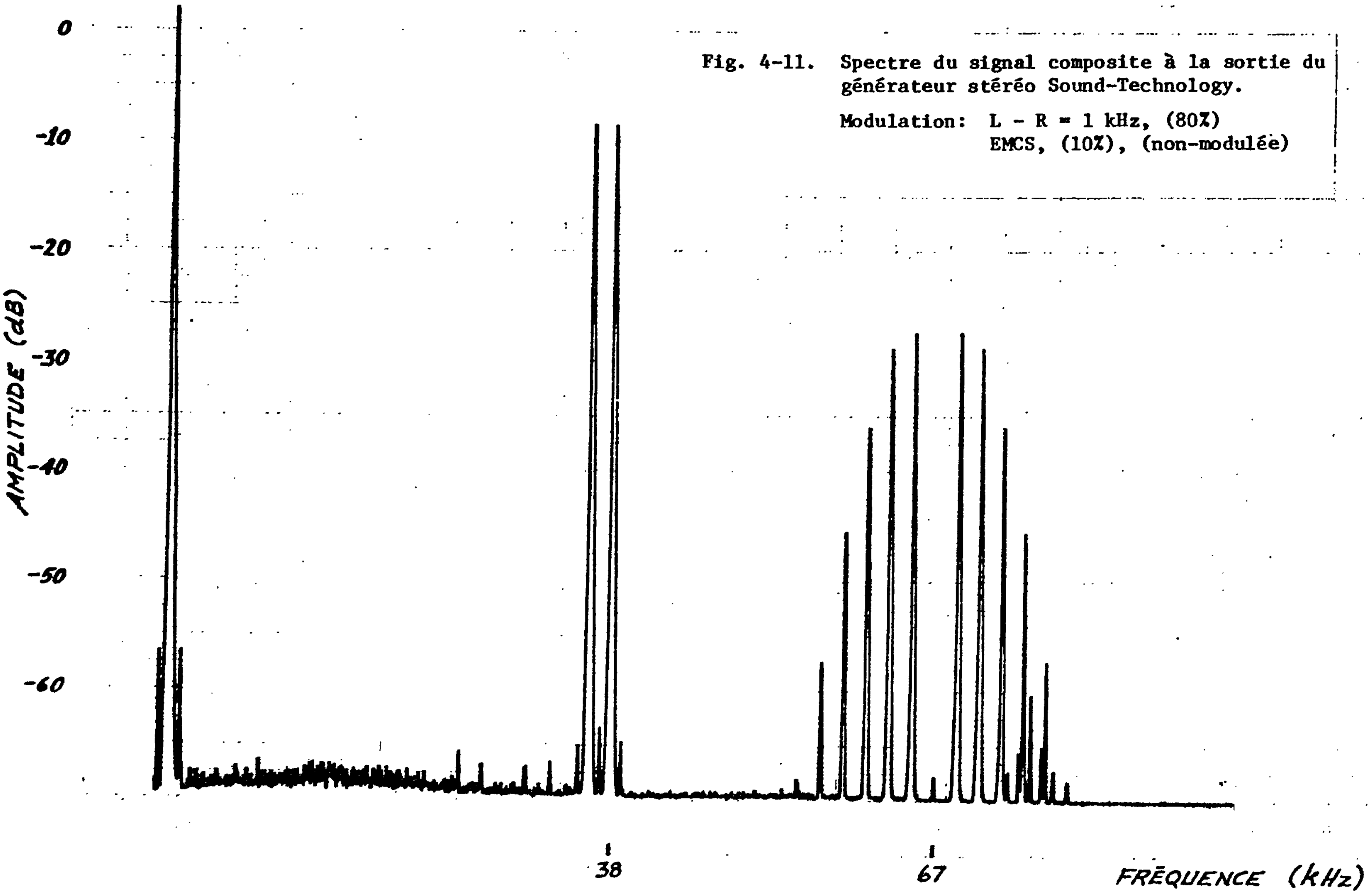


Fig. 4-11. Spectre du signal composite à la sortie du générateur stéréo Sound-Technology.

Modulation: L - R = 1 kHz, (80%)
EMCS, (10%), (non-modulée)

Figures 4.9, 4.10, 4.11 give the spectrums of the composite signal from the Sound Technology modulator (ref Fig 4.8, position "1") for three different modulation levels. It is apparent that the signal at the modulator's input already contains interference signals at 57 kHz and 76 kHz (Fig 4.9). These interference signals are caused respectively by the third harmonic of the pilot signal at 19 kHz and by the second harmonic of the stereo subcarrier at 38 kHz. The harmonic at 57 kHz is found at -53 dB below the level representing 100% modulation, while the harmonic at 76 kHz is at -61 dB. For a modulator, these are relatively large harmonics and will force the purchaser to buy a better quality modulation system.

Fig 4.10 also shows the presence of intermodulation interference in (s-2p) at the level of -62 dB below 100% modulation. This intermodulation signal is the main cause of subsidiary channel interference in the main stereo channel.

Fig 4.11 shows how the spectrum of the SCMO channel modulated 100% by a sinusoidal signal at 2.5 kHz overlaps the interference caused by harmonic distortion at 76 kHz. The intermodulation component at (s-2p) also tends to expand by dividing into several lines following modulation of the SCMO channel.

Figures 4.12, 4.13, 4.14, 4.15, 4.16 and 4.17 are plots of the power spectrums of the composite signals at the output of the frequency discriminator for the JVC, Sony and Advent FM receivers in two different tests.

(1) Figures 4,12, 4.13, 4.14:

G - D = 1 kHz, 80% modulation
19 kHz pilot signal, 10% modulation
67 kHz SCMO, unmodulated, 10% modulation

(2) Figures 4.15, 4.16, 4.17:

G = 1 kHz, 80% modulation
19 kHz pilot signal, 10% modulation
67 kHz SCMO, unmodulated, 10% modulation

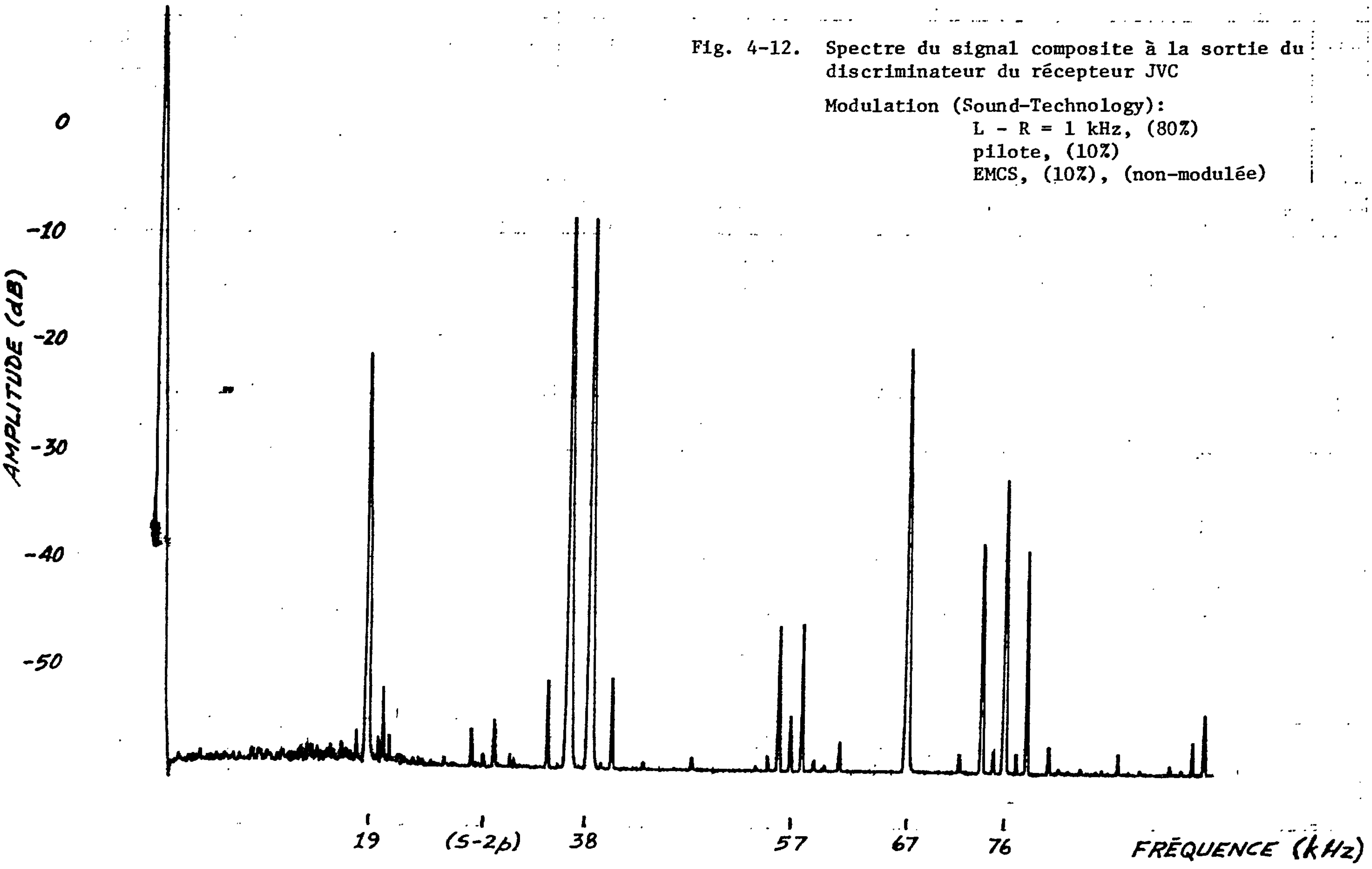


Fig. 4-12. Spectre du signal composite à la sortie du discriminateur du récepteur JVC

Modulation (Sound-Technology):
L - R = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%), (non-modulée)

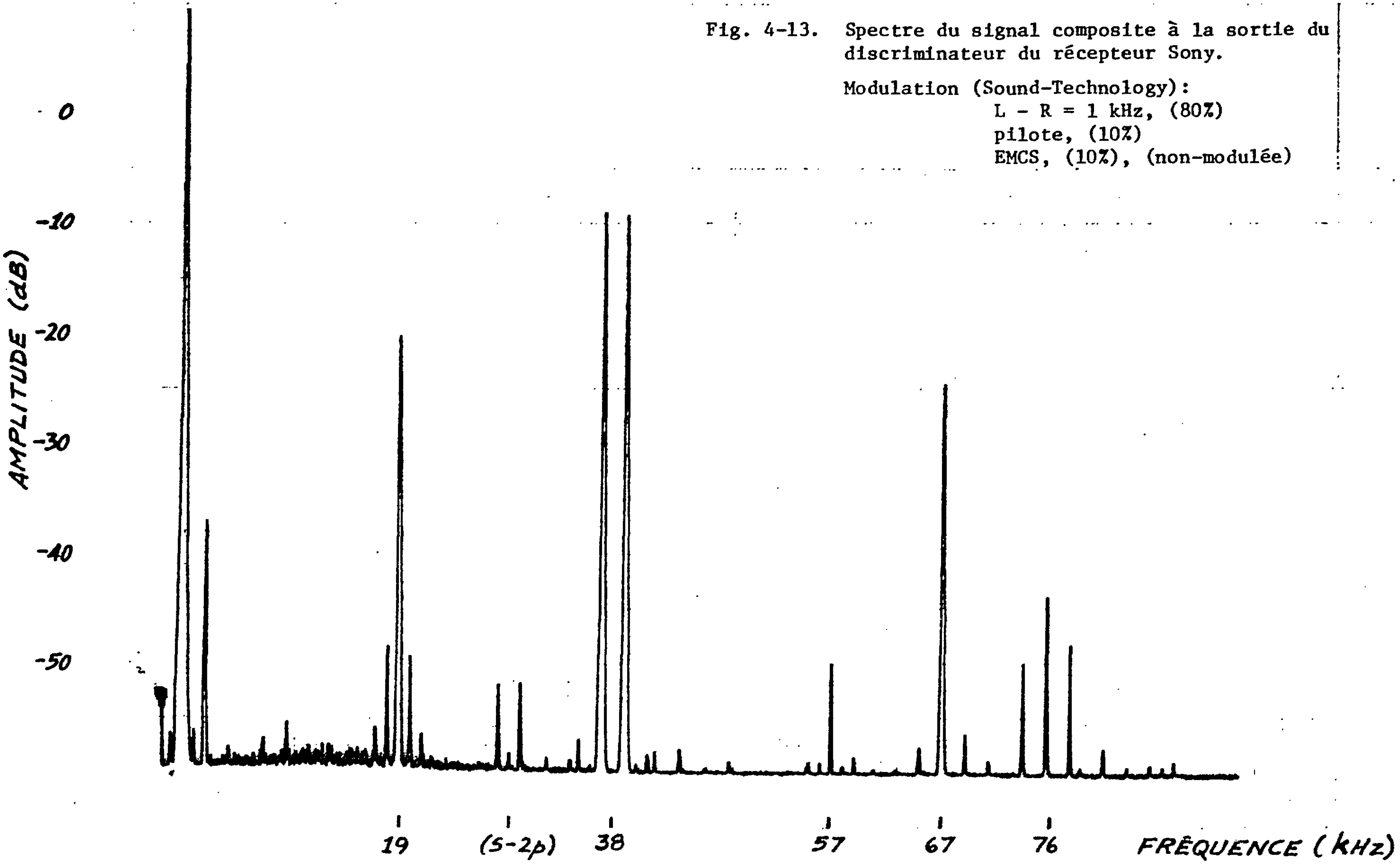
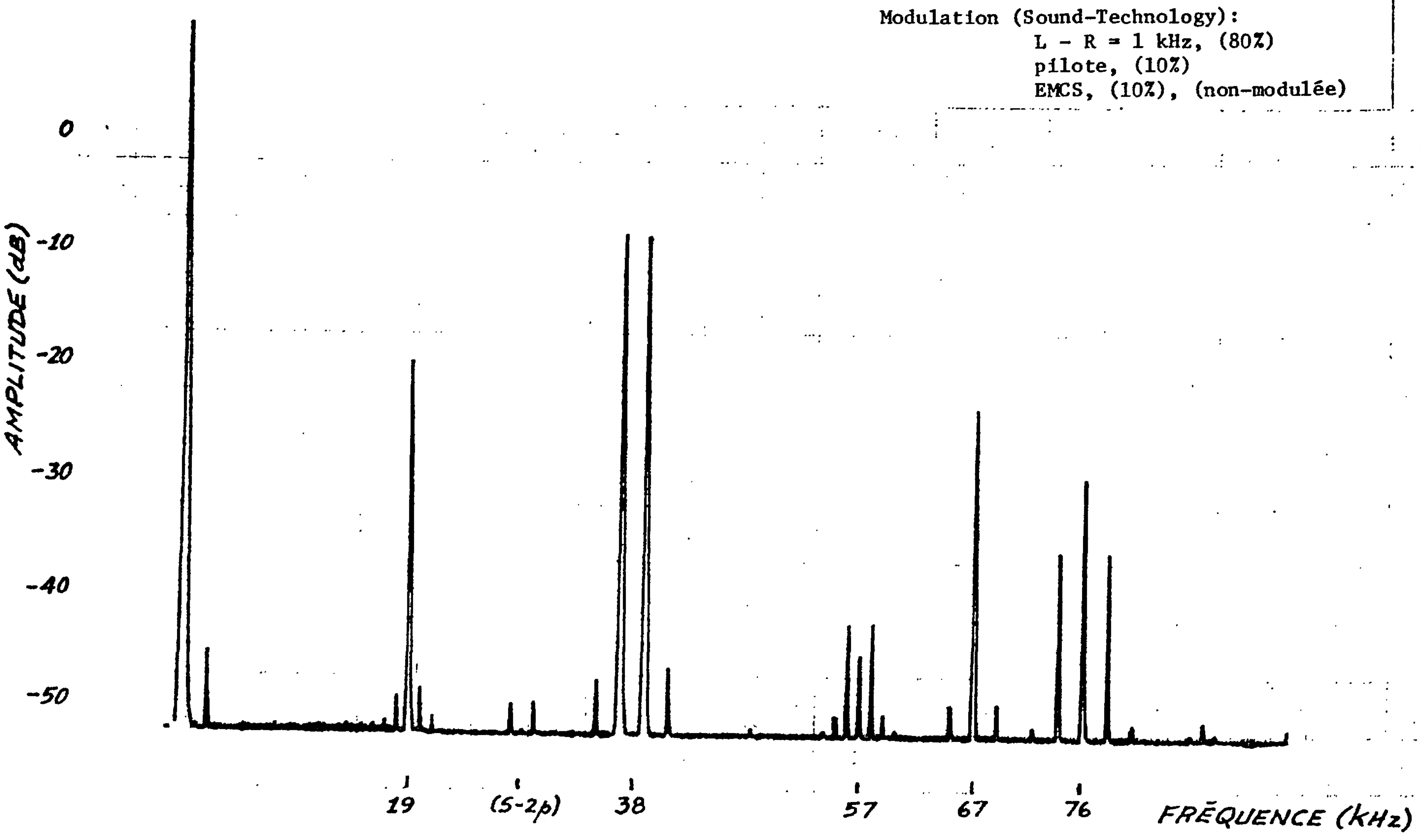


Fig. 4-13. Spectre du signal composite à la sortie du discriminateur du récepteur Sony.

Modulation (Sound-Technology):
L - R = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%), (non-modulée)

Fig. 4-14. Spectre du signal composite à la sortie du discriminateur du récepteur Advent.

Modulation (Sound-Technology):
L - R = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%), (non-modulée)



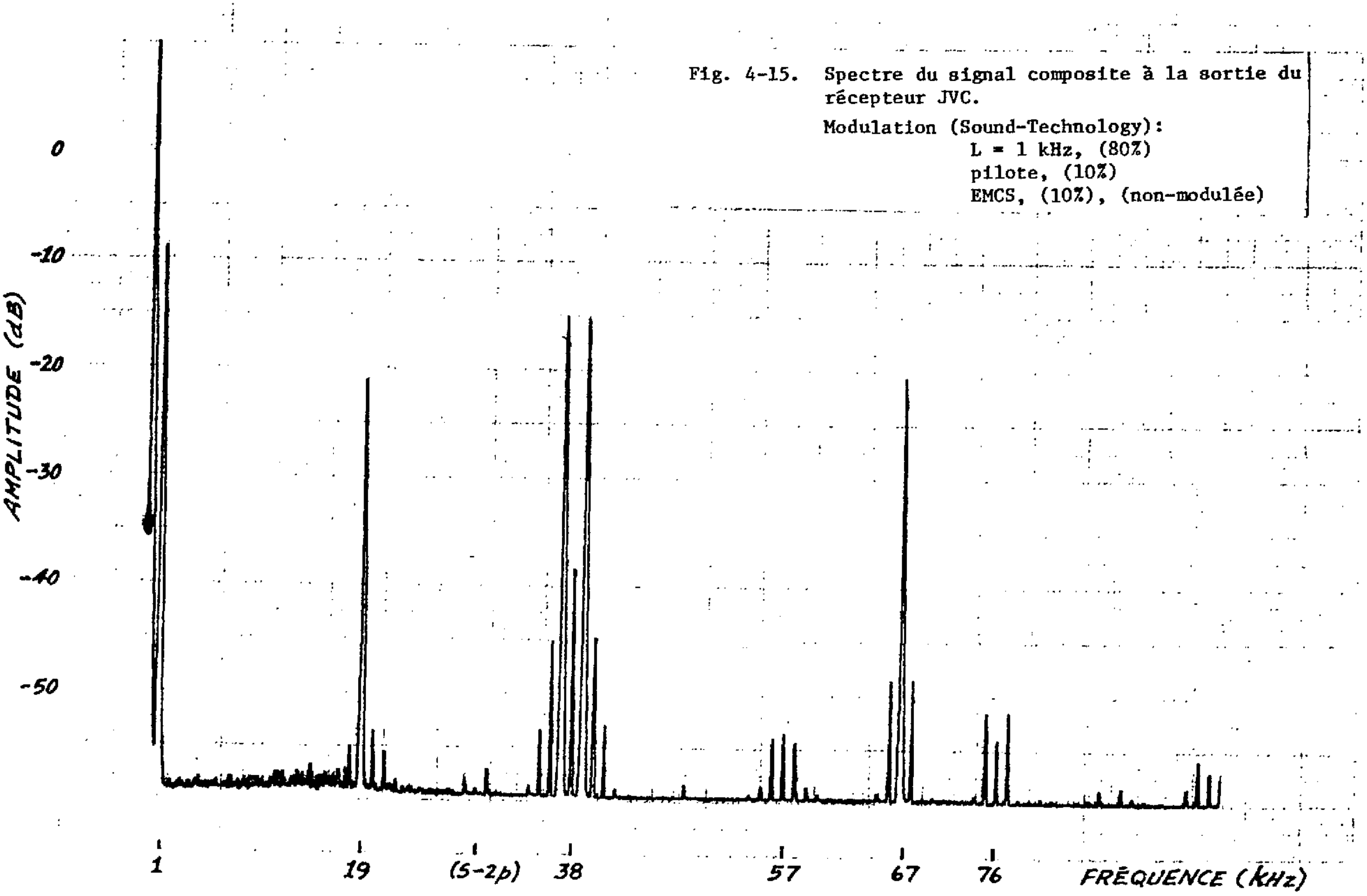


Fig. 4-15. Spectre du signal composite à la sortie du récepteur JVC.

Modulation (Sound-Technology):
L = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%), (non-modulée)

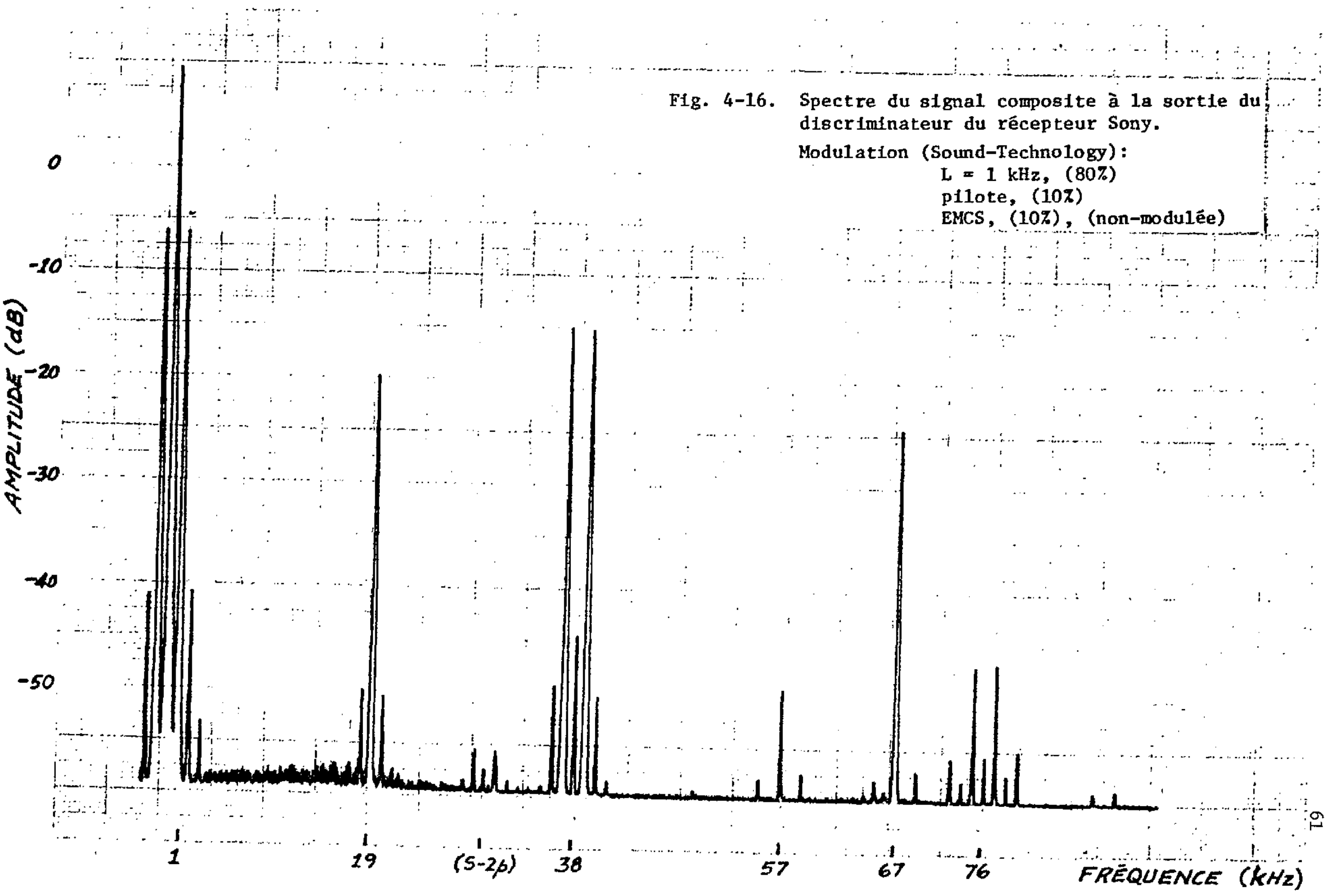
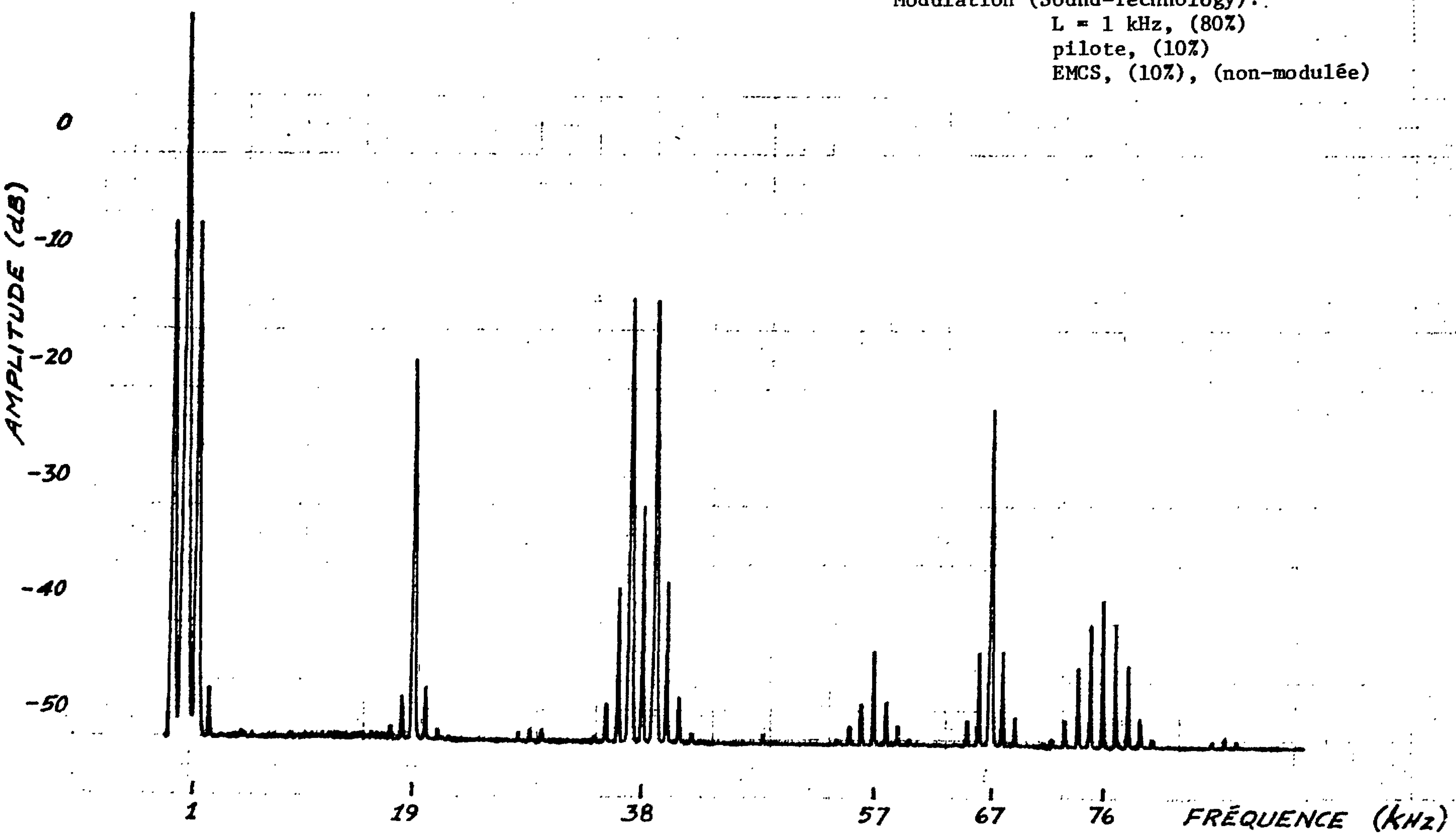


Fig. 4-16. Spectre du signal composite à la sortie du discriminateur du récepteur Sony.

Modulation (Sound-Technology):
L = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%), (non-modulée)

Fig. 4-17. Spectre du signal composite à la sortie du discriminateur du récepteur Advent.
Modulation (Sound-Technology):
L = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%), (non-modulée)



All three receivers have all of the interference signals that were observed in the composite signal from the modulator but the levels are different depending on the receiver.

The greatest distortion is caused by the second harmonic of the 38 kHz signal (4p) around 76 kHz. In the Advent receiver, the 76 kHz interference reaches - 30 dB which is the worst case recorded. The component of the third harmonic of the 19 kHz signal (3p) averages around -45 dB. The distortion created by AM-PM conversion is quite large in the JVC and Advent receivers. In fact, there are harmonics of the modulation signal just 1 kHz away from the 67 kHz SCMO subcarrier signal. This interference is noticeable only when the modulation of the main carrier has a line at 1 kHz in the base band.

4.5 Measurement of the interference and power spectrum of the composite signal of the FM receivers using the McMartin modulation system

As we mentioned earlier, we acquired an FM modulation system of the type used in radio stations. This FM modulation system uses the most advanced technology and can be viewed as one of the best on the market. The system is manufactured by the McMartin company, which we visited within the framework of this contract, and contains the following elements:

- Stereophonic generator	.....	BFM-1521 R
- SCA generator	....	BFM-153 R
- FM exciter	....	BFM 8000

The circuits and operating diagrams for these instruments are given in Appendix D.

Together these three instruments constitute an FM modulation system that can accommodate stereo modulation at the same time as modulation of an SCMO subsidiary channel. The McMartin equipment has been specially designed to allow the use of the SCMO subsidiary channel. All of the precautions which we mentioned in Chapter 3 appear to have been taken into consideration with the design of these instruments.

The McMartin system therefore represents, in our opinion, the current state of technology used by FM stations in Canada and the United States which broadcast programming on the SCMO subsidiary channel. We have measured the interference and power spectrums of the composite signals of the McMartin operators and JVC, Sony and Advent receivers. Figure 4.18 gives the schematic diagram of the assembly used for these tests.

4.5.1. Interference measurements with the McMartin system

The measurements of the interference caused by the SCMO subsidiary channel in the stereo channel gives the same results as recorded with the Sound Technology generator. This is not surprising since we are not measuring interference at the audio output of the receivers. The level of audio interference is therefore lower than the noise level and is not detectable when measuring RMS power. Table 4.4 gives the results obtained measuring the S/N ratio first without the SCMO carrier and then with the SCMO carrier with 10% modulation.

	S/N Sans EMCS	S/N Avec EMCS	distors. harmon.
JVC	66 dB	66 dB	60 dB
SONY	64 dB	64 dB	47 dB
ADVENT	63 dB	63 dB	46 dB

Table 4.4: Signal-to-noise ratio (S/N) at the audio output of FM receivers with and without an SCMO carrier

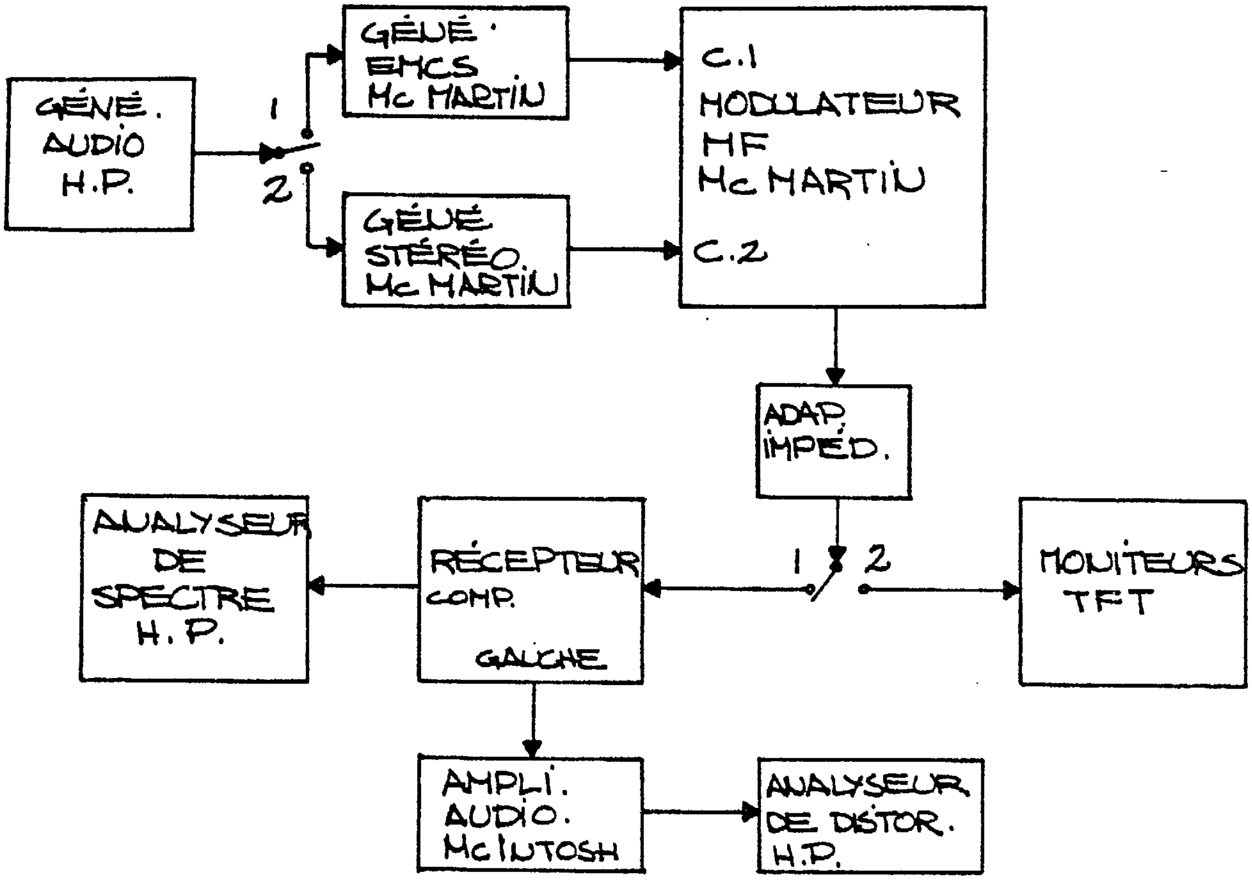


Fig. 4.18: Block diagram of the assembly used in interference measurements and spectrum analysis of the composite signal using McMartin equipment.

APPAREILS:

1 - Générateur SCMO, McMartin, modèle: BFM-153-R
2 - Générateur STEREO, McMartin, modèle: BFM-1521-R
3 - Générateur MF, McMartin, modèle: BFM-8000
4 - Générateur de fonction, H.P., modèle: 203-A
5 - Moniteur SCMO, TFT, modèle: 730-A
6 - Moniteur STEREO, TFT, modèle: 724-A
7 - Moniteur MF, TFT, modèle: 763
8 - Présélecteur MF, TFT, modèle: 764
9 - Analyseur de distorsion, H.P., modèle: 334-H
10 - Analyseur de spectre, H.P., modèle 141-T
11 - Amplificateur Audio, McIntosh, modèle: MC-275
12 - Récepteur SCMO, McMartin, modèle: TR 55-D

13 - Récepteur MF Stéréo, JVC, modèle: JTV-77
14 - Récepteur MF mono, Advent, modèle 400
15 - Récepteur MF mono, Sony, modèle: ICF-9530 W

COMMUTATEURS:

C_1: position 1 → modulation sinusoïdale du EMCS
position 2 → modulation sinusoïdale du canal stéréo G.

C_2: position 1 → signal RF à l'entrée du récepteur à l'essai
position 2 → signal RF à l'entrée du moniteur (ajustement du % de la modulation).

Table 4.5 shows the results of the measurements of the stereo channel interference in the SCMO channel for the McMartin receiver. The level of interference at the audio output of the SCMO receiver was measured for two modulation signals from the stereo channel. When the power of the modulation signal was concentrated in channel (G + D), the level of interference was -48 dB below 100% modulation of the SCMO carrier. This is quite good although in future a slightly lower interference level may be required for quality transmissions (classical music, for example). Under normal operating conditions, which is represented by the second case where the power is distributed in channel (G + D) and (G - D) (where G = 1 kHz, 80% modulation), the level of interference decreases to -54 dB. Thus with the McMartin receiver, there is an average drop of 10 dB in terms of the noise level which is -60 dB.

On the other hand, based on the records provided to the scientists in charge of this contract, the interference from the stereo channel is almost, if not totally inaudible in all tests which we carried out.

S/N (1) sans modul.	S/N (2) avec G = 1 kHz	S/N (3) G + D = 1 kHz
60 dB	54 dB	48 dB

Table 4.5: RSB at the audio output of the McMartin SCMO receiver with and without modulation of the main channel.

The conditions under which the measurements were taken for the three cases given in Table 4.5 are as follows:

Modulation Signals

(1) S/N without modulation
  - 19 kHz pilot = 10% modulation
  - SCMO subcarrier, unmodulated, 10% modulation

(2) S/N with G = 1 kHz
  - 19 kHz pilot, 10% modulation
  - SCMO subcarrier, unmodulated, 10% modulation
  - G = 1 kHz, 80% modulation

(3) S/N with G + D = 1 kHz
  - 10 kHz pilot, 10% modulation
  - SCMO subcarrier, unmodulated, 10% modulation
  - G + D = 1 kHz, 80% modulation

4.5.2 Power spectrums of the composite signal

Figures 4.19 and 4.20 gives the spectrum of the composite signals at the input of the McMartin FM modulator.

The McMartin stereo generator and SCA (SCMO) generator have no distortion of their spectrums at their outputs and the spectrums are very clean. Unlike our findings with the Sound Technology generator, there is no evidence of distortion by the harmonics of the 19 kHz or 38 kHz signals.

McMartin receiver (SCMO):

Figures 4.21 and 4.22 show the spectrums of the composite signal of the McMartin SCMO receiver. When the modulation of the main channel is concentrated in channel (G + D) (ie: L + R = 1 kHz, at 80% modulation), there are 1 kHz harmonics around the SCMO subcarrier at -53 kB. This distortion, due to AM-PM intermodulation, is quite large. This coincides with the interference measurements made in the preceding paragraph. When there is stereo modulation of the main channel (where G = 1 kHz, 80% modulation), the largest interference is caused by harmonic distortion in 3p (57 kHz) and 4p (76 kHz). The maximum level is still relatively low at -55 dB below 100% modulation.

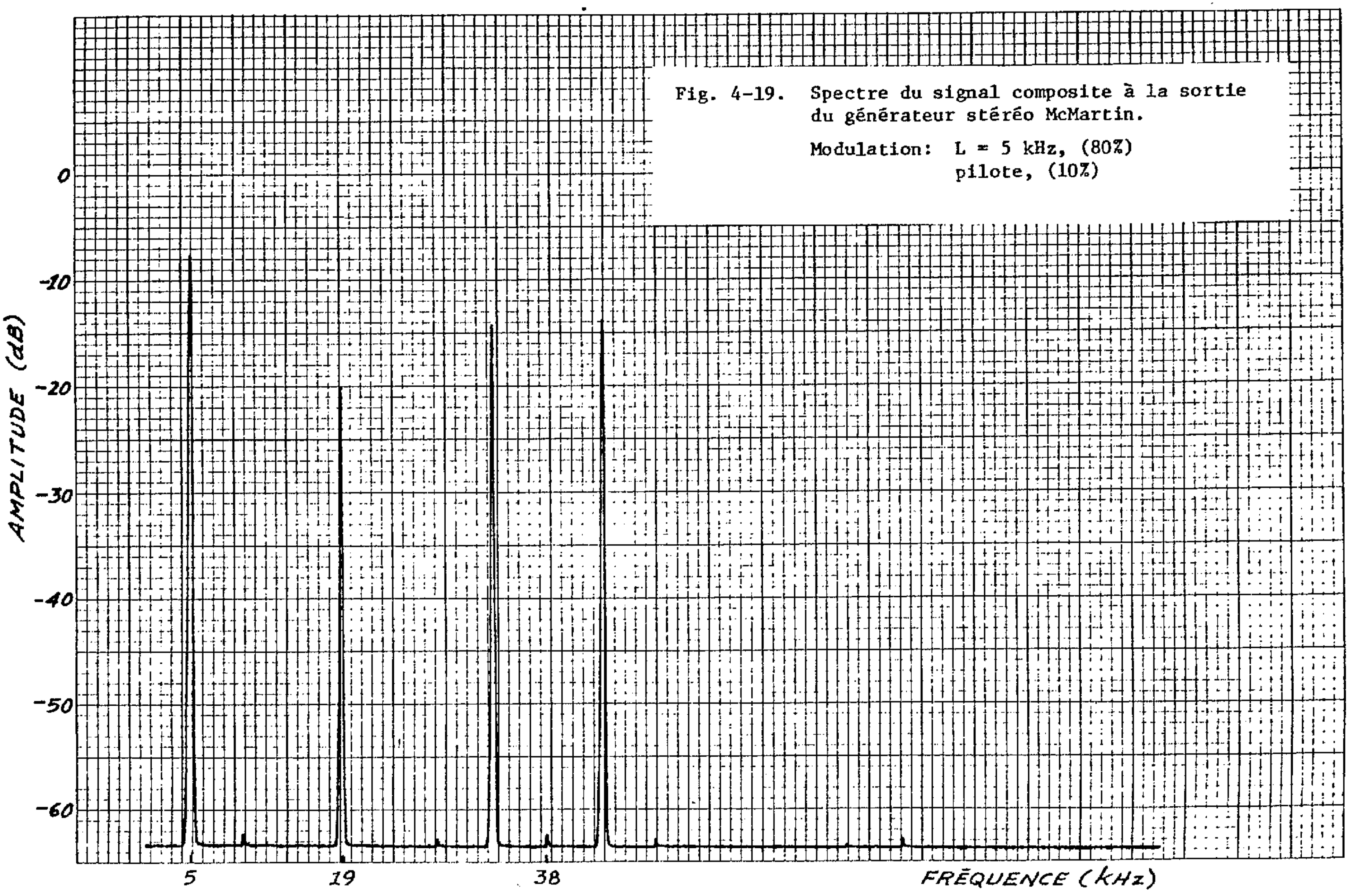


Fig. 4-19. Spectre du signal composite à la sortie du générateur stéréo McMartin.

Modulation: L = 5 kHz, (80%)
pilote, (10%)

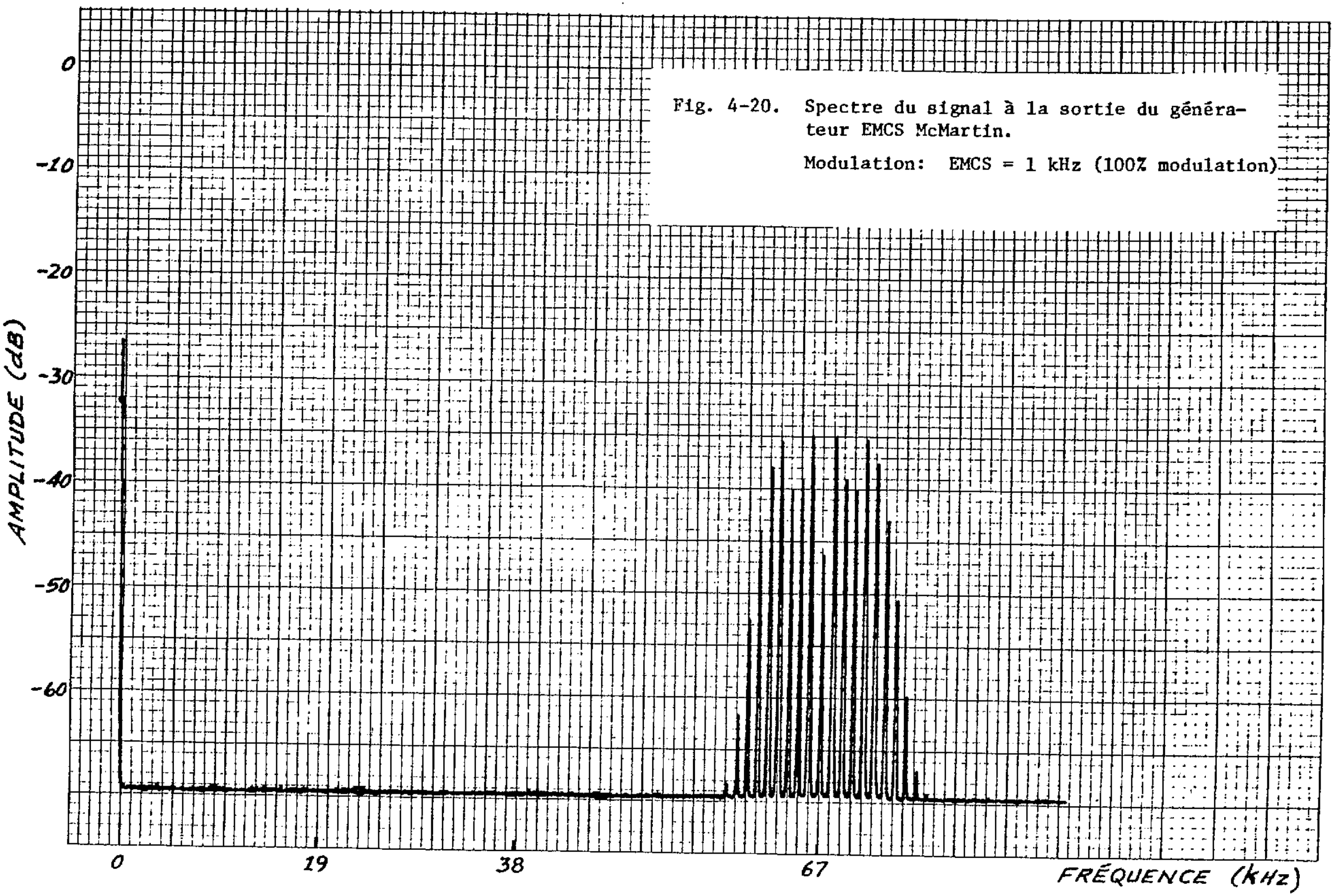


Fig. 4-20. Spectre du signal à la sortie du générateur EMCS McMartin.

Modulation: EMCS = 1 kHz (100% modulation)

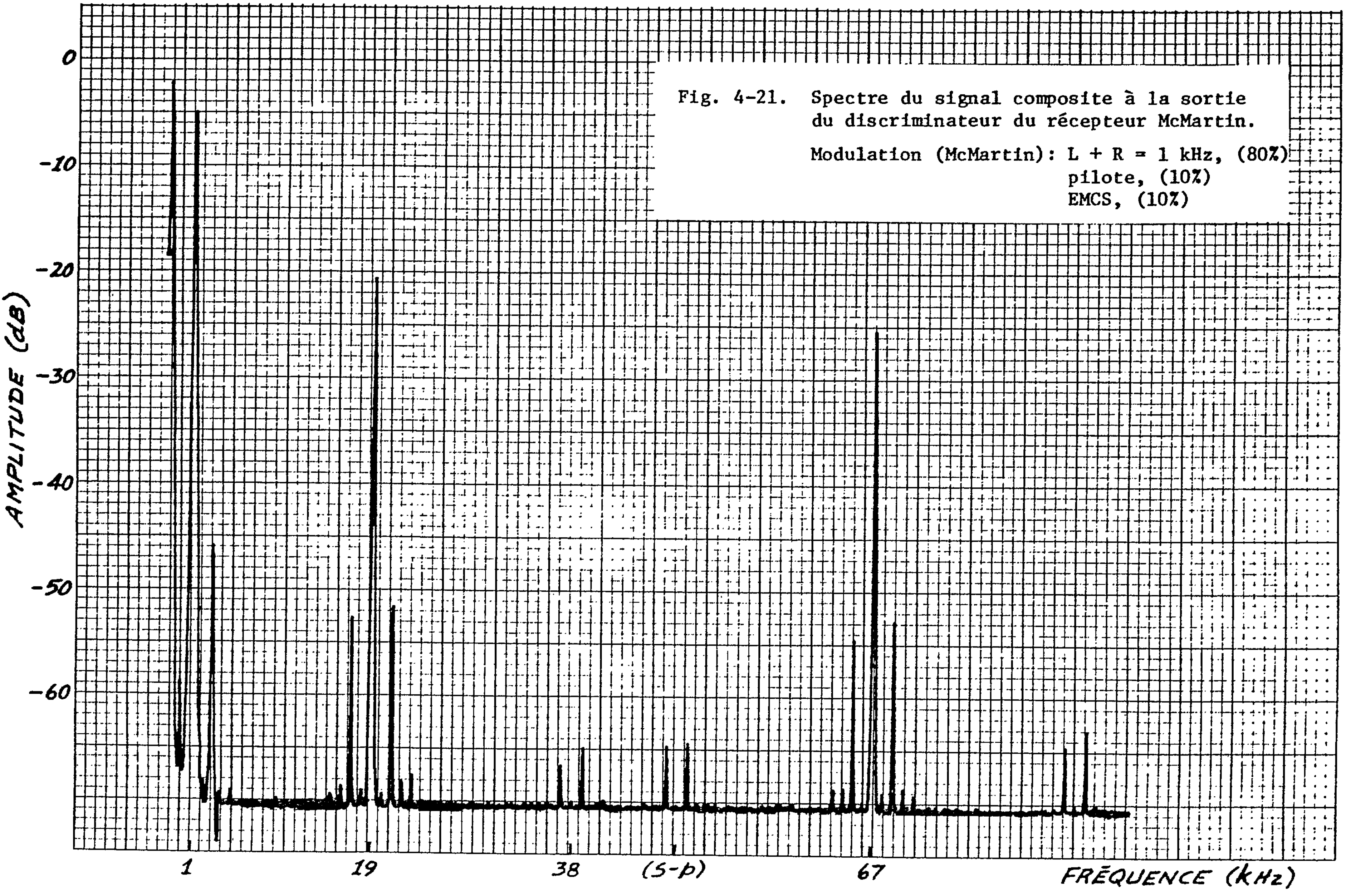


Fig. 4-21. Spectre du signal composite à la sortie du discriminateur du récepteur McMartin.

Modulation (McMartin): L + R = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%)

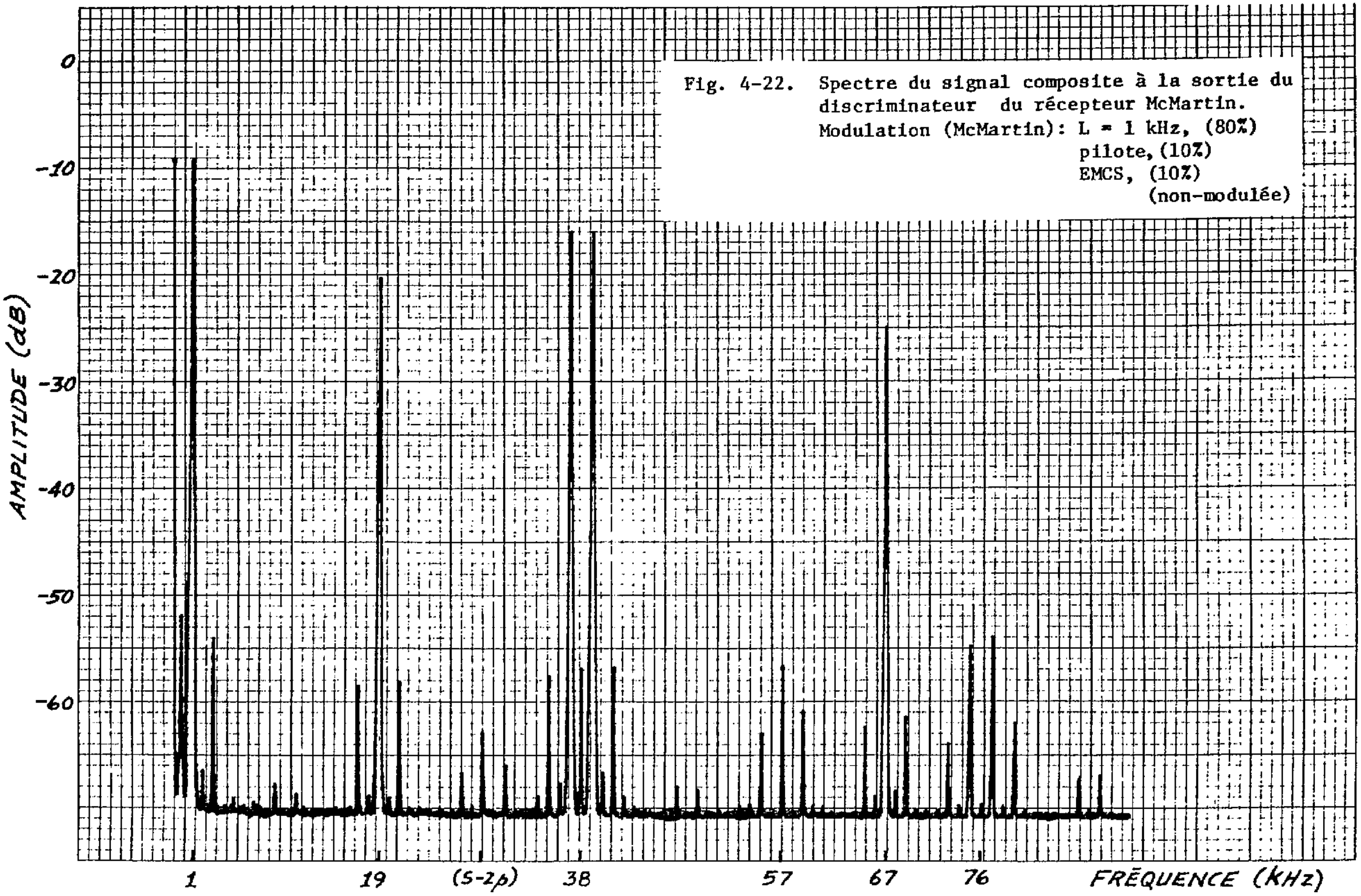


Fig. 4-22. Spectre du signal composite à la sortie du discriminateur du récepteur McMartin.
Modulation (McMartin): L = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%)
(non-modulée)

Figures 4.23, 4.24, 4.25, 4.26, 4.27 and 4.28 plot the power spectrums of the composite signals at the output of the frequency discriminators of the JVC, Sony and Advent receivers. The modulation signal of the main channel is G = 1 kHz with 80% modulation and the pilot (19 kHz) signal with 10% modulation. In Figure 4.26, 4.27 and 4.28, there was an SCMO subcarrier with 10% modulation.

In general, we recorded the same type of interference as with the Sound Technology generator, that is, (s-2p), (s-p), (s+p), (2p) and (4p). However, the levels of the interference were much lower and in most cases, even negligible. On the whole, we can say that there was a drop of approximately 12 dB in the level of the interference signals.

Note: We wish to remind the reader that care must be taken with the power scales. These can be misleading because they are not the same for all graphs.

The signals used to obtain the power spectrums for Fig 4.19 to 4.28 are shown for each graph.

4.6 Conclusions

In this chapter, we have defined the interference phenomena which are likely to interfere with the use of the SCMO subsidiary channel for purposes other than the current ones, or to make it unusable all together. First we described several commercial receivers primarily by their frequency response at the output of the discriminator and by the linearity of the IF stage. Knowledge of these parameters is essential to obtain a correct evaluation of the effect of the subsidiary channel on stereophonic and monophonic reception of the main channel. We concluded that there is only a slight difference in the level of the signal-to-noise ratio either with or without an SCMO carrier, and that this was true for all three receivers, namely the JVC, Sony and Advent. This indicates that, for all practical purposes, the interference in the main channel caused by SCMO intermodulation is negligible.

Next we tested SCMO signal receiving circuits of average quality and then a receiver specially designed for this purpose by the McMartin firm. As indicated in Table 4.3, the interference recorded at the SCMO demodulators of average quality was very high regardless of the receiver used. Generally, we can conclude that the quality of demodulation is unacceptable in these instances. As for the McMartin receiver, the results were much better than the ones mentioned above and even though the same type of interference was observed, the levels involved were significantly lower.

Lastly, a spectrum analysis of the levels of the base band and composite signals was made, but though these analyses enabled us to draw certain conclusions as to the origin of interference signals, they were not as conclusive as we would have liked. In particular, it proved virtually impossible, without an ideal modulator, to determine whether interference originated from the FM modulator or from the demodulator.

To summarized, it is difficult to draw firmer conclusions on the various phenomena observed during our tests, and more thorough analyses of the various parameters involved should be made to try to predict tendencies with the required accuracy. Nevertheless, we feel that this chapter covers all aspects of this type of measurement, of the techniques used and of the current state of technology and paves the way for a more in-depth synthesis of these phenomena in the next step.

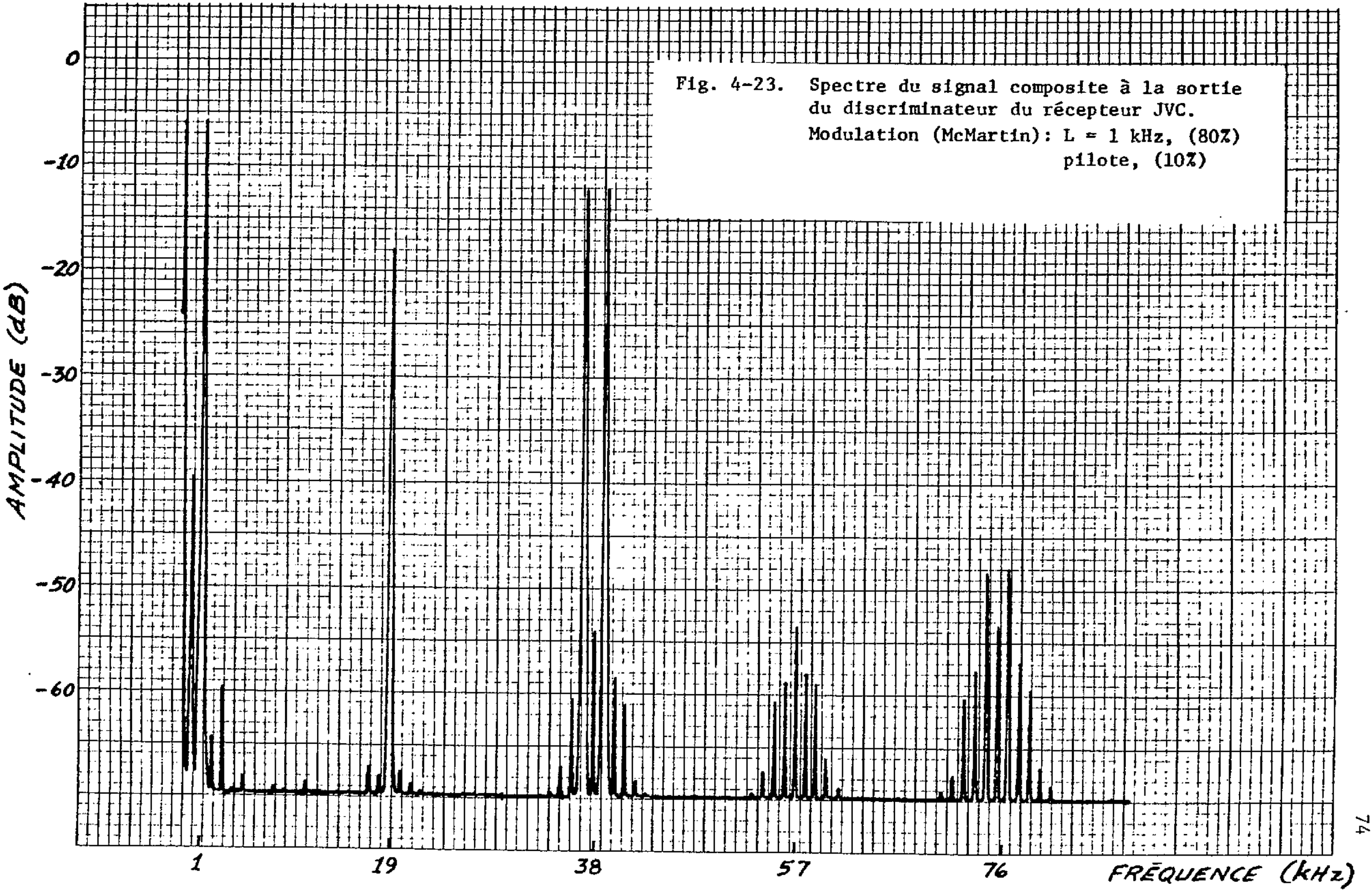


Fig. 4-23. Spectre du signal composite à la sortie du discriminateur du récepteur JVC.
Modulation (McMartin): L = 1 kHz, (80%)
pilote, (10%)

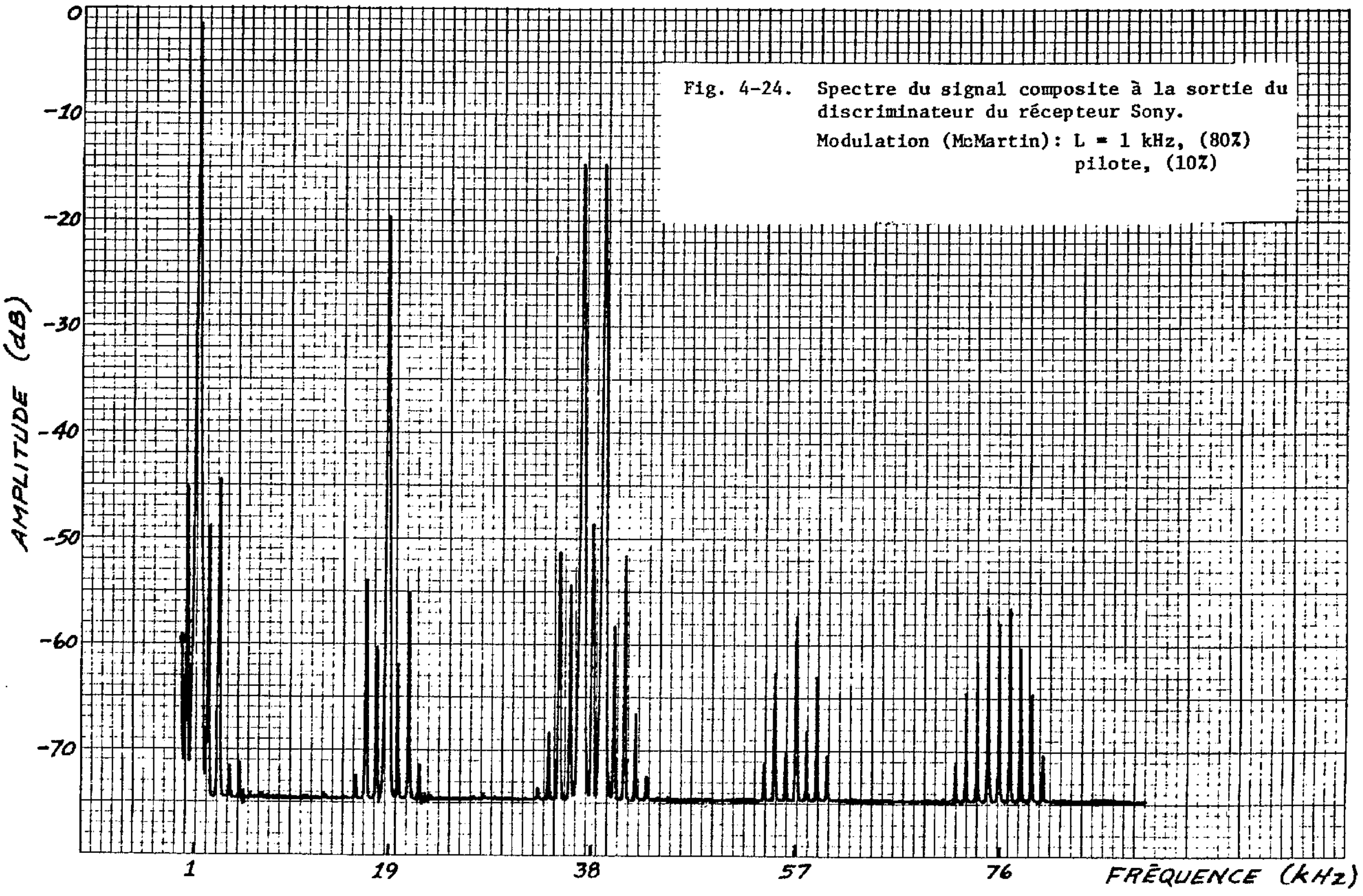


Fig. 4-24. Spectre du signal composite à la sortie du discriminateur du récepteur Sony.
Modulation (McMartin): L = 1 kHz, (80%)
pilote, (10%)

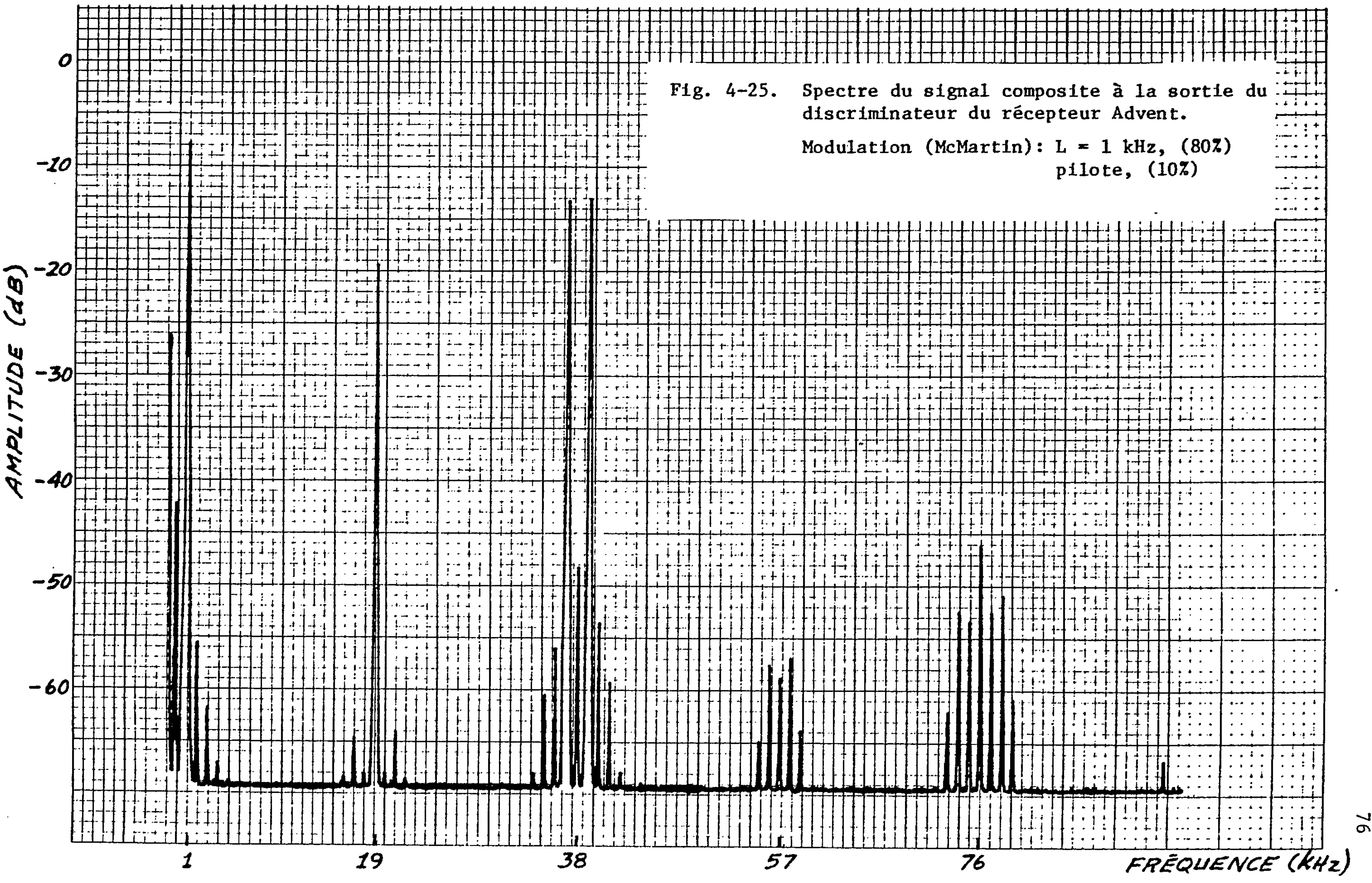


Fig. 4-25. Spectre du signal composite à la sortie du discriminateur du récepteur Advent.

Modulation (McMartin): L = 1 kHz, (80%)
pilote, (10%)

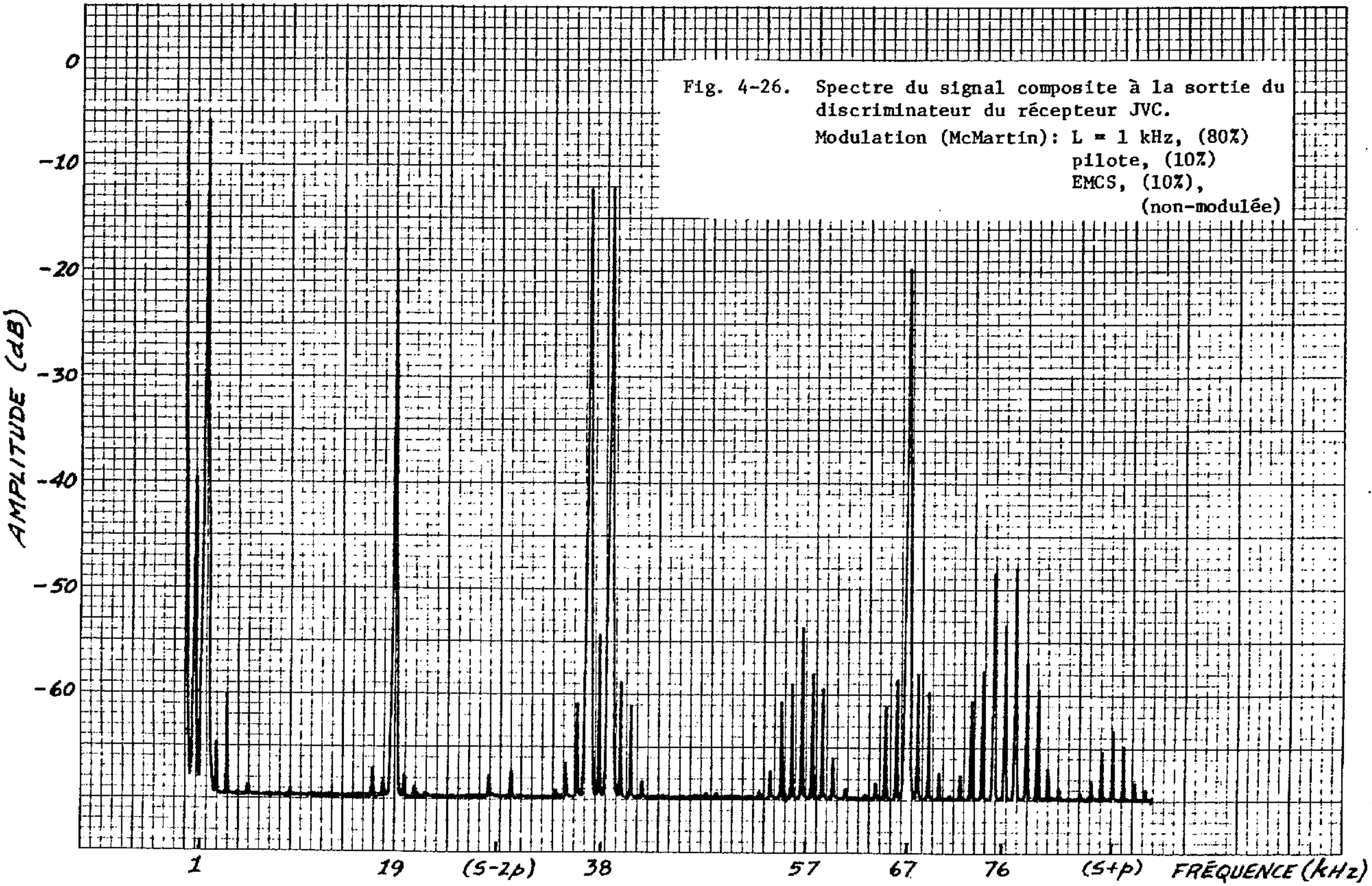


Fig. 4-26. Spectre du signal composite à la sortie du discriminateur du récepteur JVC.
Modulation (McMartin): L = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%),
(non-modulée)

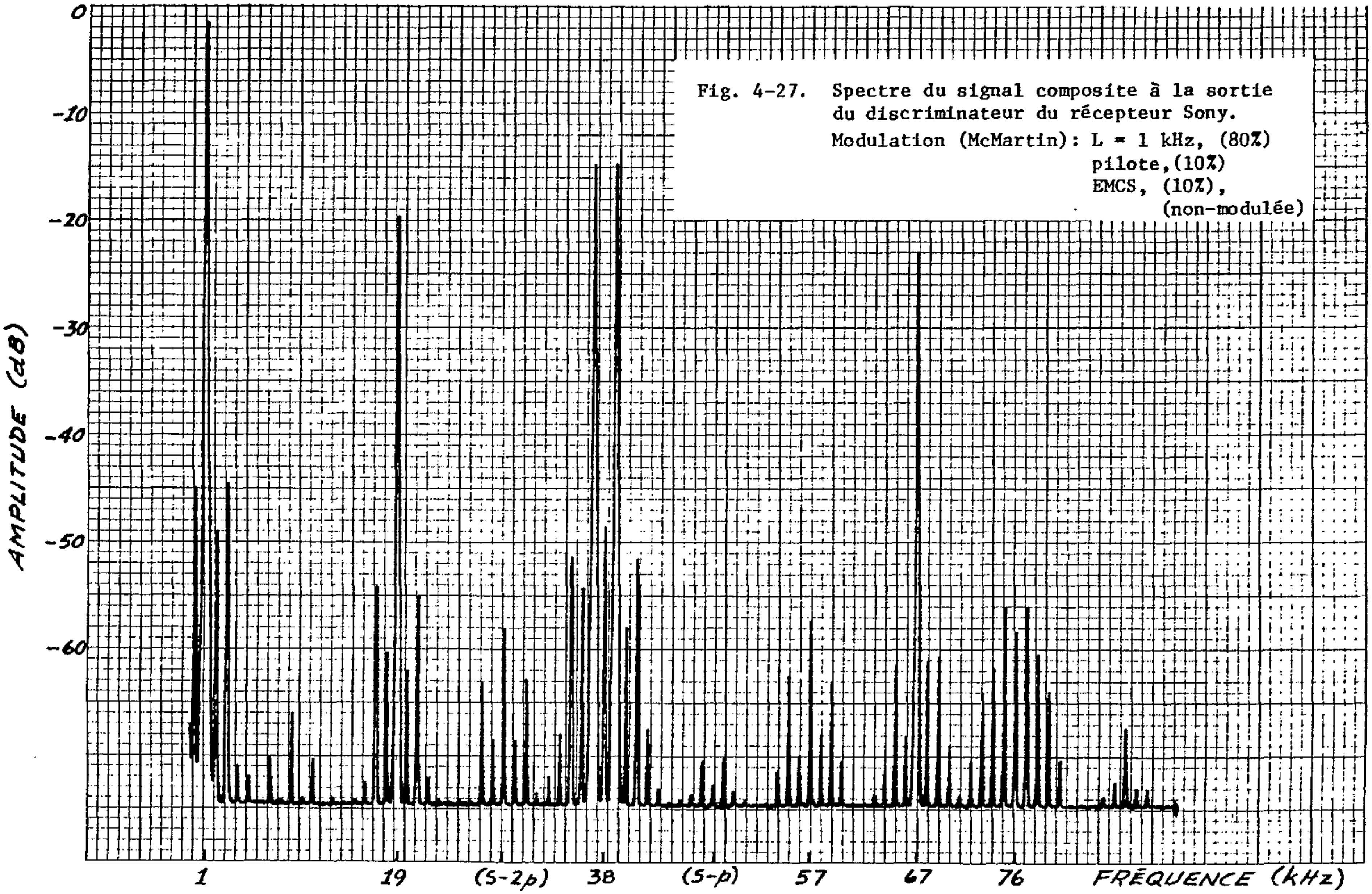


Fig. 4-27. Spectre du signal composite à la sortie du discriminateur du récepteur Sony.
Modulation (McMartin): L = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%),
(non-modulée)

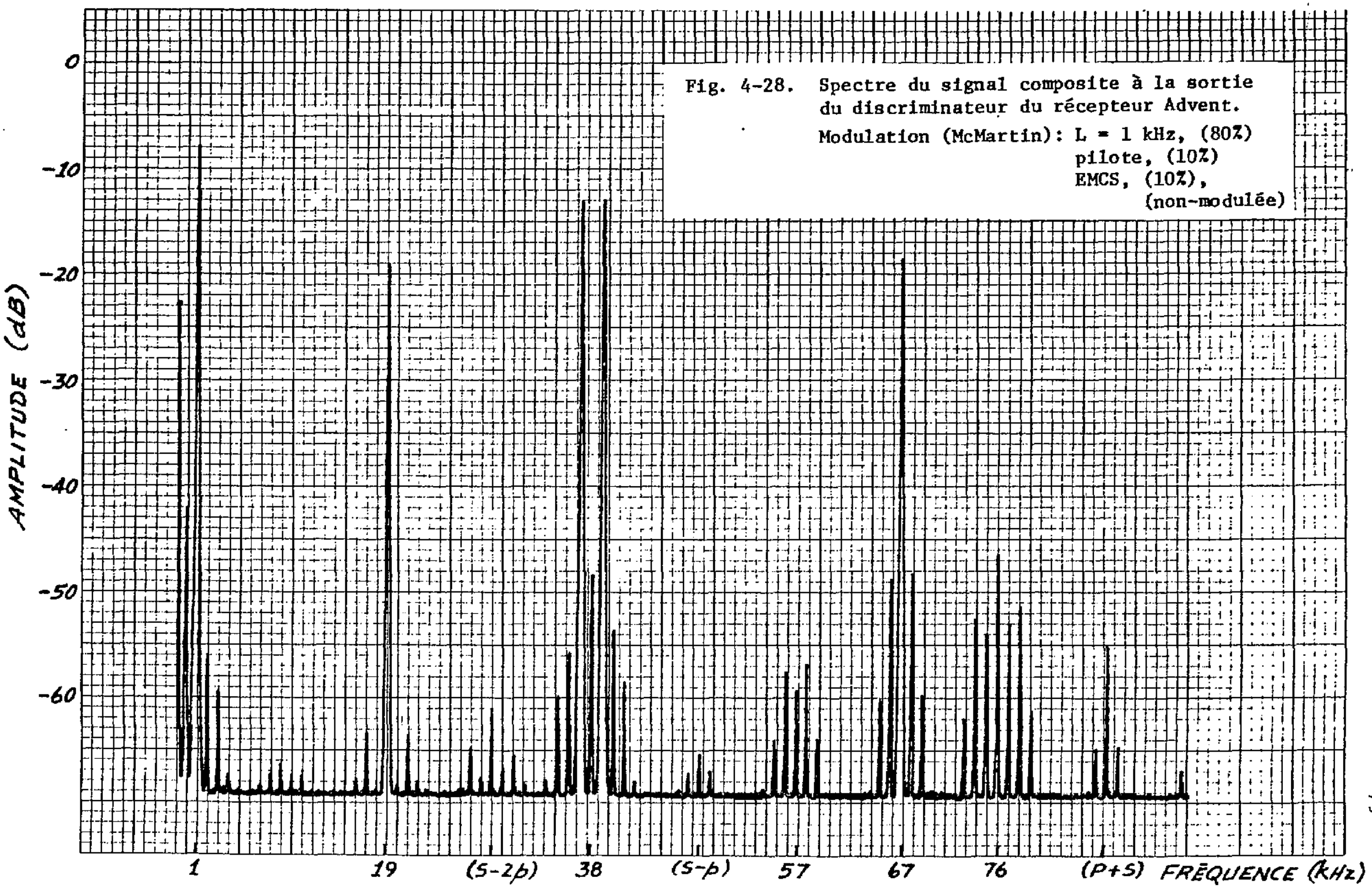


Fig. 4-28. Spectre du signal composite à la sortie du discriminateur du récepteur Advent.

Modulation (McMartin): L = 1 kHz, (80%)
pilote, (10%)
EMCS, (10%),
(non-modulée)

Chapter 5

Conclusions

5.1 Results of the study

The testing carried out to this point on the multiplex operation of subsidiary communications (SCMO) in FM broadcasting represents the first step in an effort to find a solution to the crucial problem in Canada of saturation of the use of frequency ranges set aside for this type of broadcasting.

It was entirely proper, once we had defined SCMO, to make a few observations on the very limited use made of it in Canada. Our enquiry was not sufficiently systematic to reach a definite conclusion. This does not change the fact that technical problems directly associated with transmodulation are the reasons given most often. This observation is surprising in view of the attitude of American broadcasters. They do not have our problem. They have developed a very lucrative SCMO network in many American states and the testimonies obtained indicate that everyone, broadcasters and users alike, are quite satisfied.

Transmodulation problems do exist. However, if the proper care is taken in designing and maintaining all aspects of the transmitter, the bandwidth, strict adaptation of impedances, and the linearity of amplifiers, the signal-to-noise ratio associated with an extension of the bandwidth from 53 kHz to 75 kHz and the extension of the RF bandwidth, (which is located slightly above 200 kHz) can be reduced to an acceptable level. Nowadays, it is only logical that the processing which a stereophonic signal of the main channel undergoes, which includes compression, reduction of the dynamic range for marketing purposes (an average level as high as possible) should also be accompanied by a relaxing of the standards governing noise levels.

Nevertheless, we have given considerable thought to the problem of transmodulation, its definition, the different techniques for measuring it within a multiplex system in general frequency, its application to the specific problem of composite signals, with a main stereophonic channel, a stereophonic subchannel and pilot and SCMO subchannels. This application is much harder to deal with, as we saw, because of the variety of component; audio , sinusoidal signals, DSBSC, FM elements. However, some techniques do enable us, in spite of everything, to interpret the various testing procedures. We did, for example, show that it was possible to establish relations between the numerical values of the carrier-to-interference ratio and the signal-to-noise ratio in the audio output of the SCMO.

One problem remains: we described qualitatively the mechanisms producing the most disturbing intermodulation products, both within the transmitter and within each of the components of the receiver, without actually quantifying these undesirable phenomena even at the locations they were produced. This is because of the complexity of such an undertaking. We would have required a testing bench allowing us to substitute several components in a receiver, without relying upon the availability of an ideal demodulator, in order to evaluate current modulators. We intend to come back to this aspect of the study at a later stage.

In spite of everything, we concluded in Chapter 4 that the problem of information from the SCMO channel entering the main channel is not a serious one.

This conclusion is based on the spectrum analyses contained in Fig 4.19 to 4.28 as well as on the tape recording provided with the original copy of this report.

This is not, however, the case with the transfer of information from the main channel to the SCMO channel. Our findings here were overwhelming. The SCMO demodulation circuits used with the various receivers made available to us provided unacceptable results.

It is quite obvious that all of the FM receivers on the market are not designed to decode SCMO. We cannot expect anything else. We must point out the significantly better performance of the receiver, model TR-55-D of McMartin Industries: although it produced undesirable components, components were on the average at least 10 dB lower than those of the other instruments.

We were able to make our tests using two modulators with significantly different characteristics: the Sound Technology modulator (instrument designed for tuning FM receivers with a composite signal containing components at 57 kHz and 76 kHz) cannot be used with an SCMO channel.

The McMartin modulator (BFM-8000, BFM-1521-R, BFM-1513-R) is of outstanding quality and can isolate, within one level of the receiver, the mechanisms generating intermodulation.

5.2 Subsequent work

The experience gained by the authors during this first step has enable them to plan a definite research program for the next two years. The ultimate objective of this program would be to produce in the laboratory, and to evaluate, a tunable FM receiver capable of receiving the main channel and SCMO channel and incorporating the latest electronics technology.

Once this has been accomplished the following tasks would remain:

(1) Marketing SCMO programming with a local broadcaster, perhaps CKRL-FM in Quebec City, and evaluating, in the field, the behaviour of a system over which we would have real control of the quality of the transmitter as well as a series of receiving tests using receivers already tested in the laboratory under various reception conditions (multipath, remote and close receiving stations; contours, given geographical context).

(2) Continuing quantitative measurements of the mechanisms producing intermodulation within the components of an FM receiver.

The result of such extensive testing would be the definition of tolerence levels for the reception of SCMO signals of a given quality, given current technology.

Once this was completed, it would be appropriate to consider a comparative analysis of the behaviour of the major techniques of FM reception, of the methods of demultiplexing the stereo signal in the presence of an SCMO signal; to examine the possibility of adding the SCMO discriminator to the RF level rather than the IF level (2 independent receivers); to evaluate the constraints on all elements in the network; to consider an expansion of the SCMO band (to allow the transmission of audio signals to 10 kHz); and to evaluate of the deterioration of the network that would result from an increase in the frequency deviation of the main carrier.

We realize that this program is an ambitious one that would stetch over several years. The stakes are certainly high, as the final result we seek is of great use to Canada, namely the doubling of FM broadcasting capabilities.

BIBLIOGRAPHIE

[1] H.T. HUYNH, M. BOUCHARD, "Analyse des choix de conception d'un récepteur MF amélioré", Rapport Final no LT-79-8239, Laboratoire de Télécommunications, Département de génie électrique, Université Laval, Québec, Mars 1979.

[2] Peter CAHN and Ass., A Study into Current FM Receiver Performance and the Relevance of FM Allocation Criteria, Projet 7-46-78. Préparé pour le Ministère des Communications, Ottawa, DSS File No. 1 12ST 36100-7-0545.

[3] L.K. CHAU, Receiver Improvement as an Aid to FM Channel Availability Planning (2nd report), Rapport interne, Ministère des Communications, Ottawa, Mars 1979.

[4] Procédure concernant la radiodiffusion: Règles régissant l'Exploitation multiplex des communications secondaires, PR7, 2ème Edition, Service de la réglementation des télécommunications, Ministère des Communications, Gouvernement du Canada, décembre 1976.

[5] Bach VO, La radiodiffusion MF, MA et MA Stéréo. Dossier ERT-04-106, Direction générale des Services techniques, Ministère des Communications, Gouvernement du Québec, Mars 1980.

[6] E. SOMMERS, "Digital Broadcasting piggybacking FM Subchannels", Broadcasting Systems & Operations, April 1979.

[7] E. SOMMERS, "The Growing Potential of FM/SCA", Radiactive, Vol. 5, No. 2, pp. 8-9, Feb. 1979.

[8] L. HENLUND, "SCMO: Biggrowth Potential", Broadcaster, Vol. 38, No. 10, October 1979.

[9] G.J. GARRISON, "Intermodulation Distortion in FDM/FM Systems - A Tutorial Summary", IEEE Trans. Commun. Tech., Vol. Com-16, April 1968.

[10] T.J. CROSS, "Intermodulation in FM Systems due to Transmission Deviations and AM/PM Conversion", Bell System Tech. J., vol. 45, Dec. 1966.

[11] M. OHARA, "Distortion and Crosstalk Caused by Multipath Propagation in Frequency Modulation Sound Broadcasting", IEEE Trans. on Broadcasting, Vol. BC-26, No. 3, pp. 70-81, Sept. 1980.

[12] D.J. POPP, "The study of SCA interference in stereo FM receivers", IEEE Trans. on Broadcasting and TV Receivers, Vol. BTR-9, No. 2, July 1963, pp. 41-47.

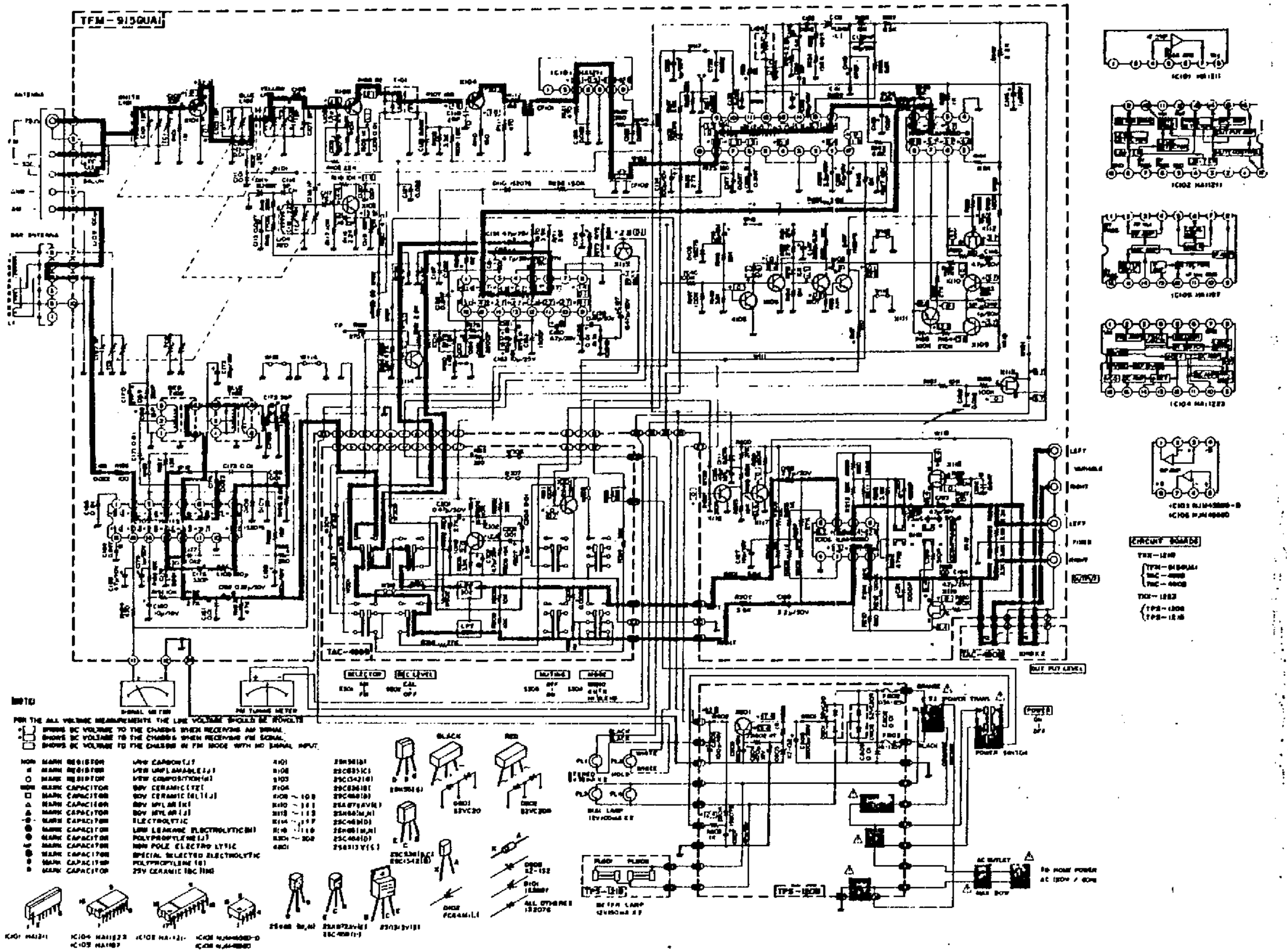
[13] A.H. BOTT, "Analysis of certain system characteristics of stereo and SCA operation", IEEE Trans. on Broascasting, Vol. BC-13, No. 1, January 1967, pp. 15-18.

[14] L.E. HEDLUND, "Stereo and SCA are totally compatible in FM broadcasting", Communications News, Vol. 11, No. 4, April 1974.

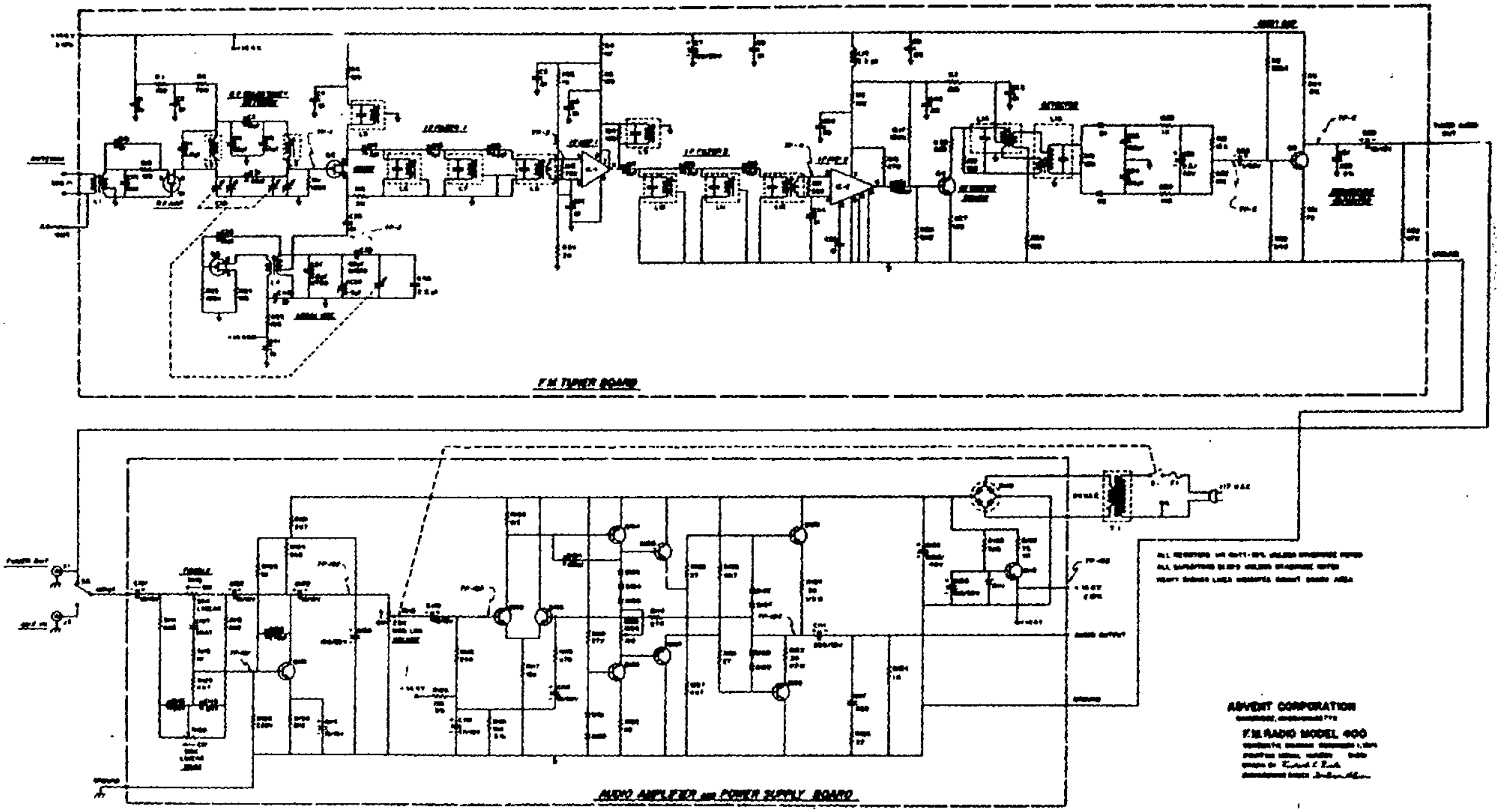
[15] M.S. CORRINGTON, "Frequency modulation distortion caused by common - and adjacent - channel interference", RCA Rev., Vol. 7, No. 4, Dec. 1946, pp. 522-560.

APPENDICES

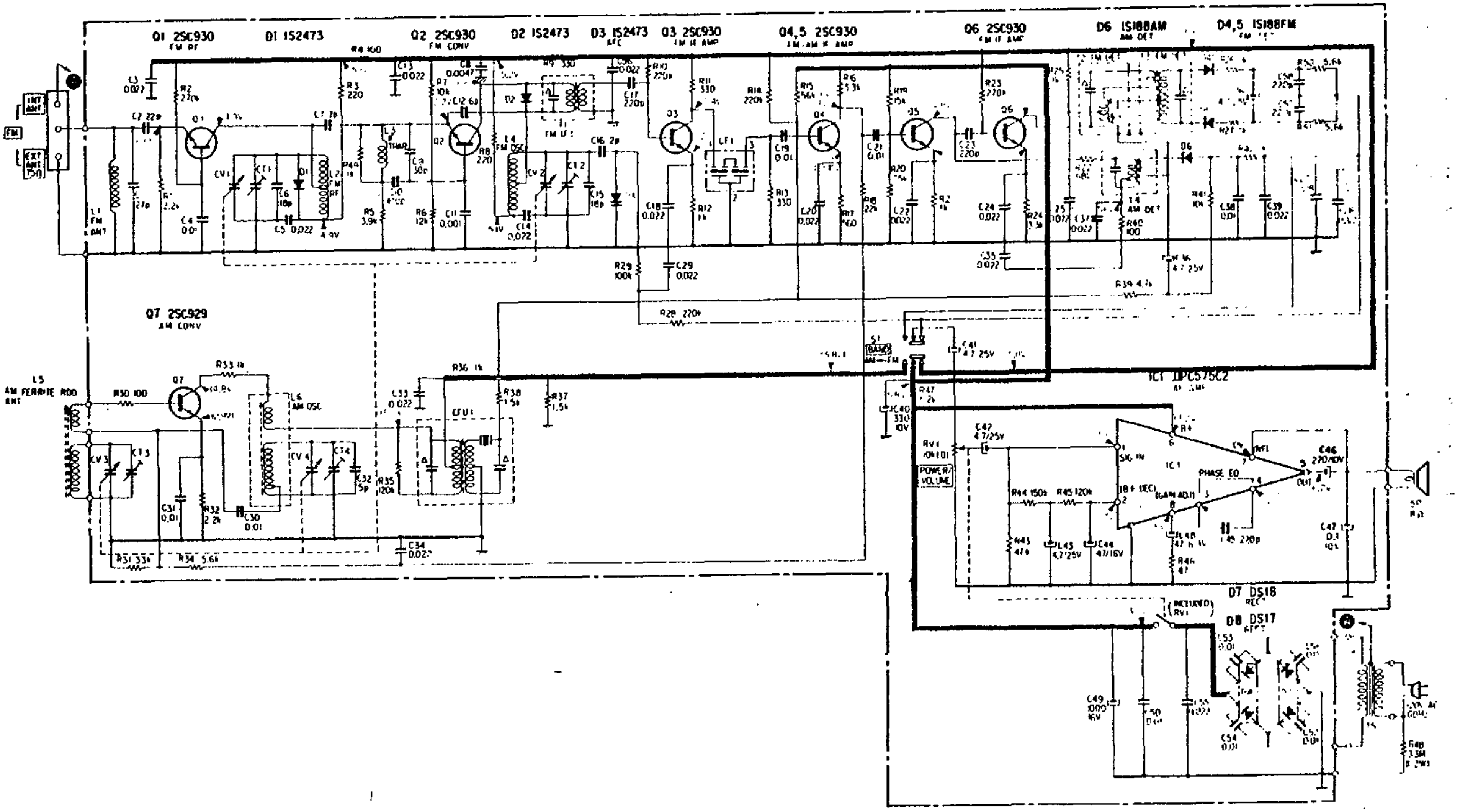
11-(2) JT-V77 Schematic Diagram (for U.S.A. and Canada)



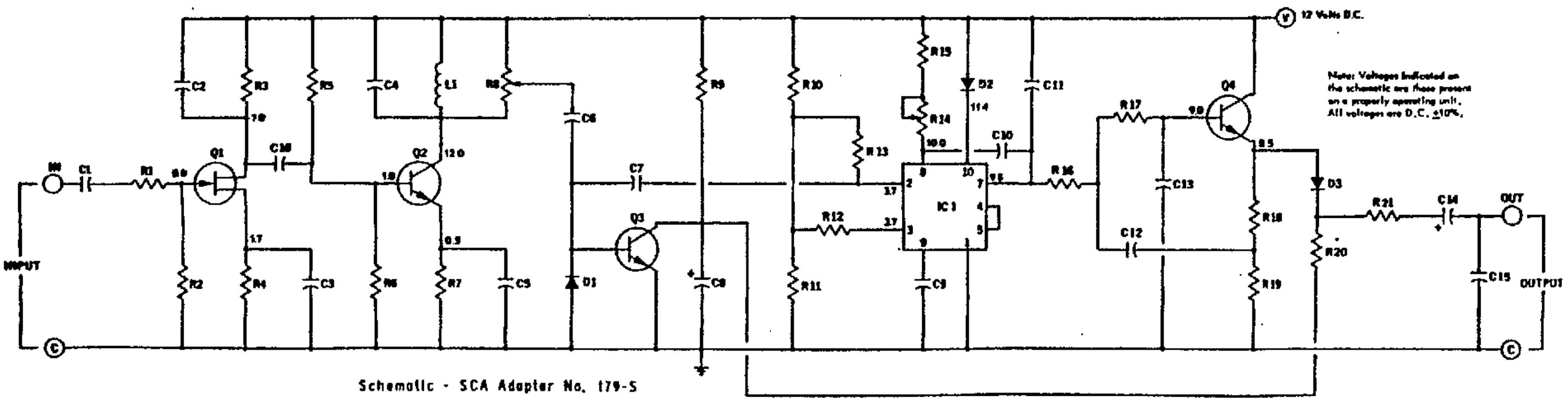
Appendice A: Circuit détaillé du récepteur JVC.



Appendice A: Circuit détaillé du récepteur Advent.

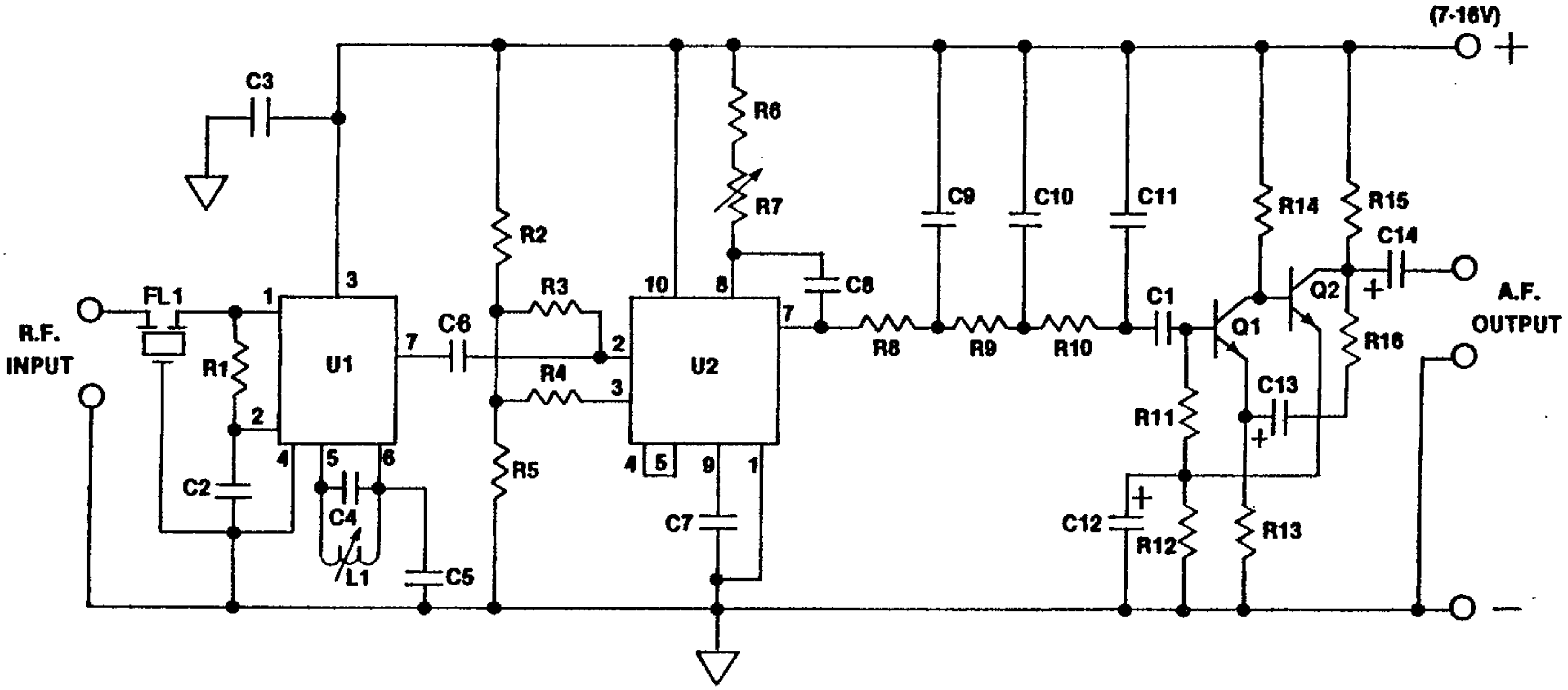


Appendice A: Circuit détaillé du récepteur Sony.



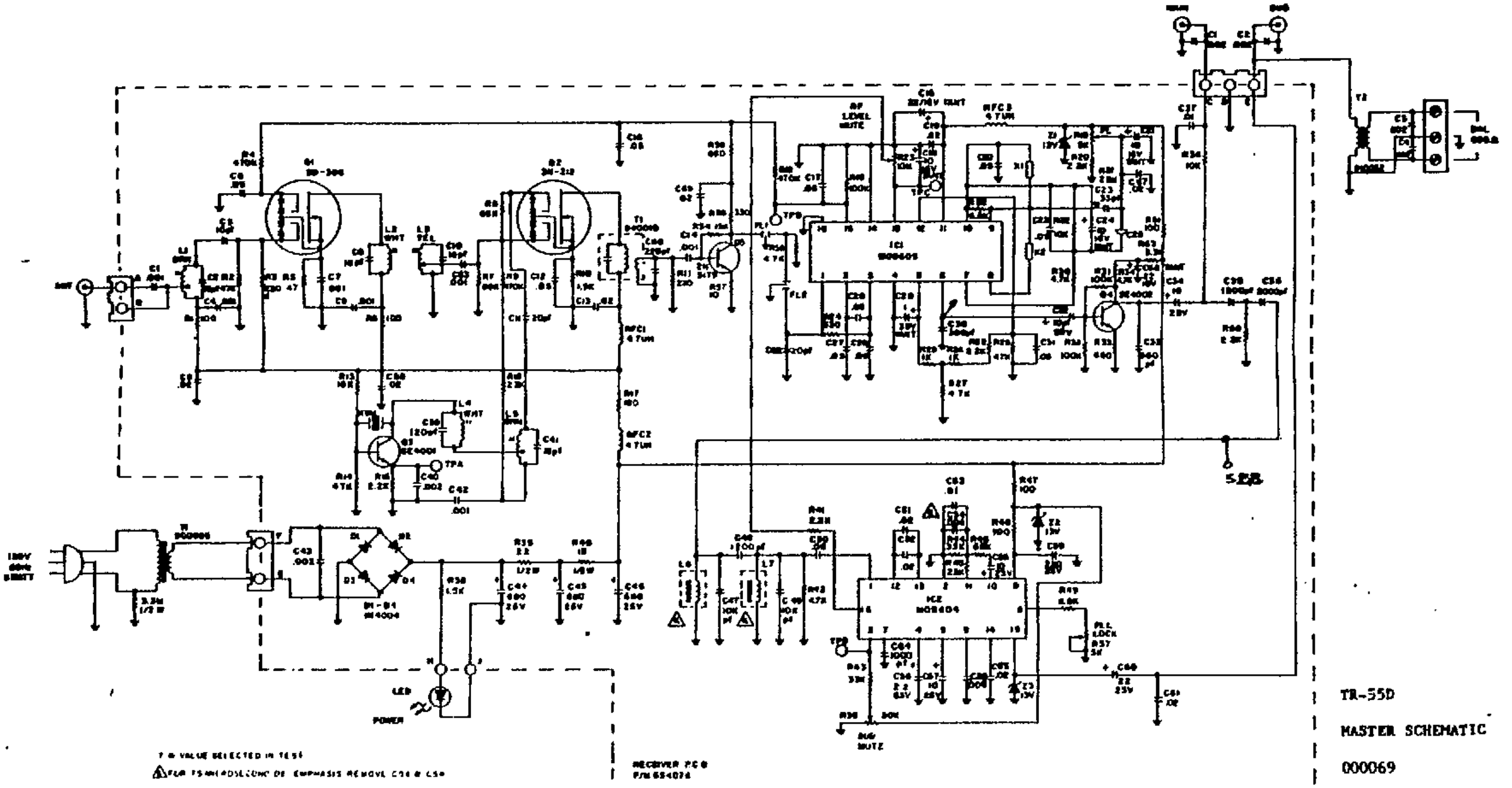
Schematic - SCA Adapter No. 179-S

Appendice B: Démodulateur EMCS de SWTP.



Appendice B: Démodulateur EMCS de GI.

MCMARTIN



* = VALUE SELECTED IN TEST

⚠ FOR 75 MICROSECOND DE-EMPHASIS REMOVE C34 & C54

⚠ FOR 38-41kHz OPERATION CHANGE L6 & L7 TO 920209 AND CHANGE C TO A 1400pf

3 ▭ DENOTES FRONT PANEL FUNCTIONS

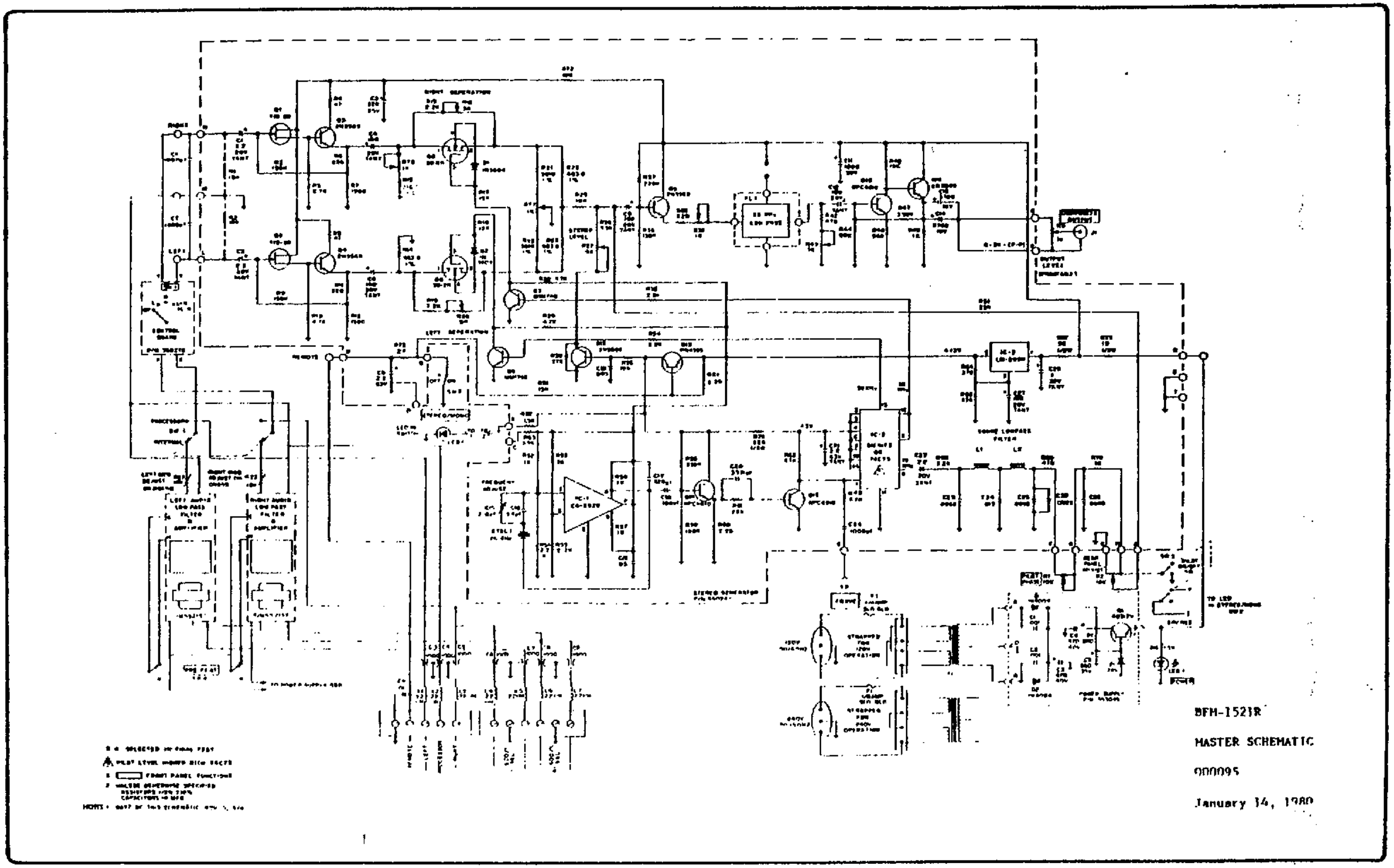
2 UNLESS OTHERWISE SPECIFIED
RESISTORS IN OHMS, 1/4W, 5%
CAPACITORS IN MFD

NOTES 1 DATE OF THIS SCHEMATIC OCT 4, 1979

TR-55D
MASTER SCHEMATIC
000069
July 1, 1980

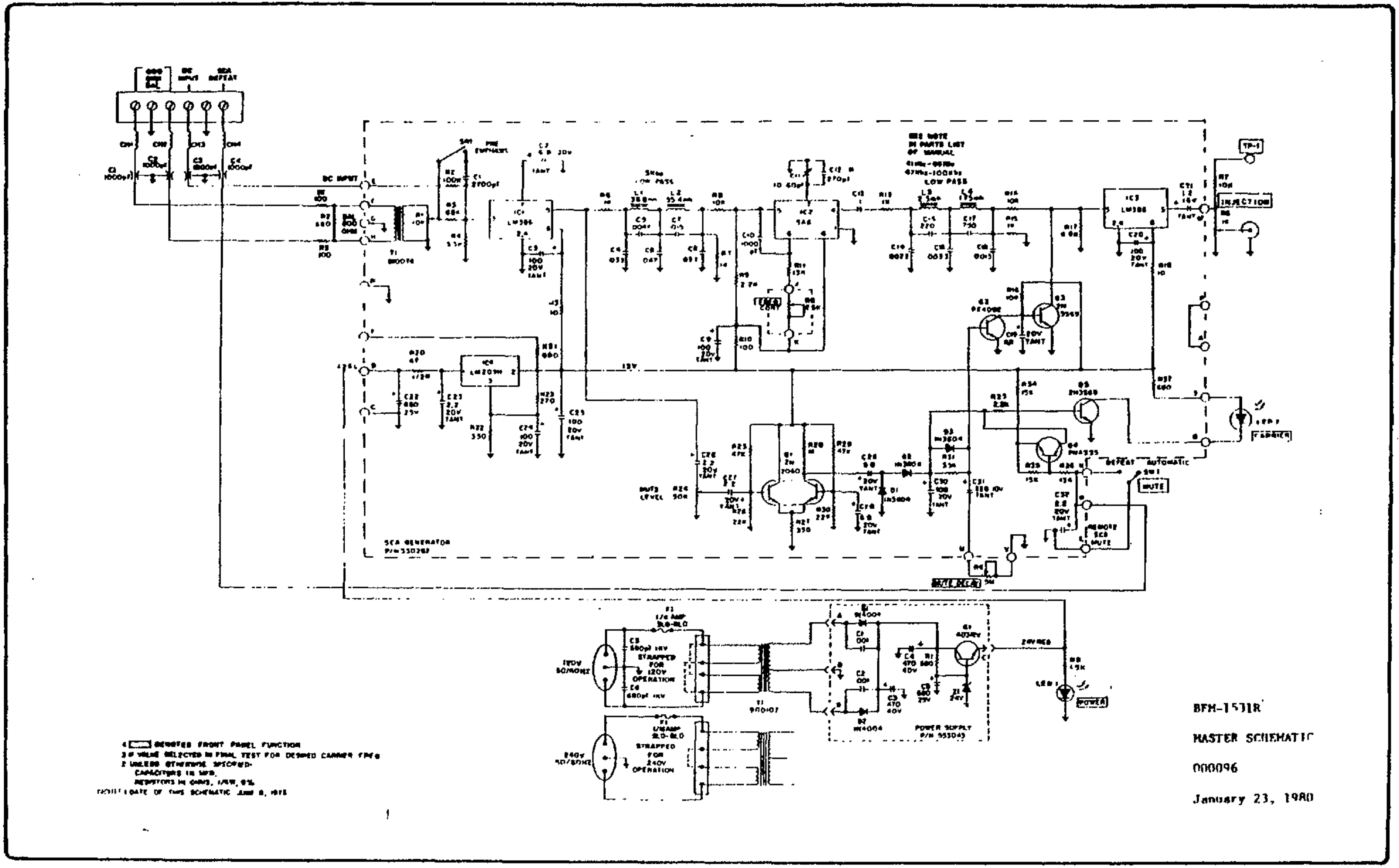
Appendice C: Circuits détaillés du récepteur McMartin.

MCMARTIN



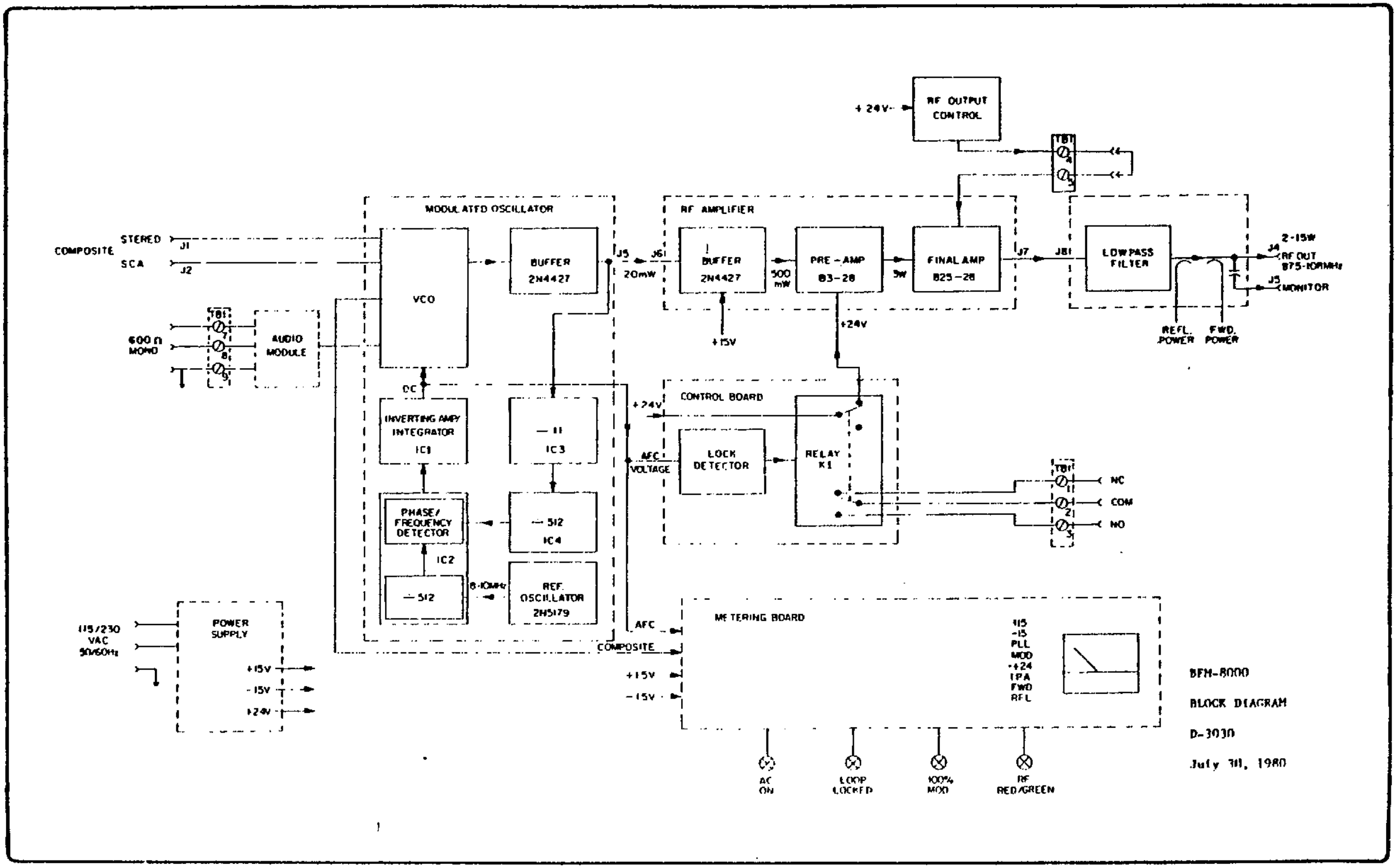
Appendice D: Circuit détaillé du générateur stéréo McMartin, modèle BFM-1521 R.

MCMARTIN



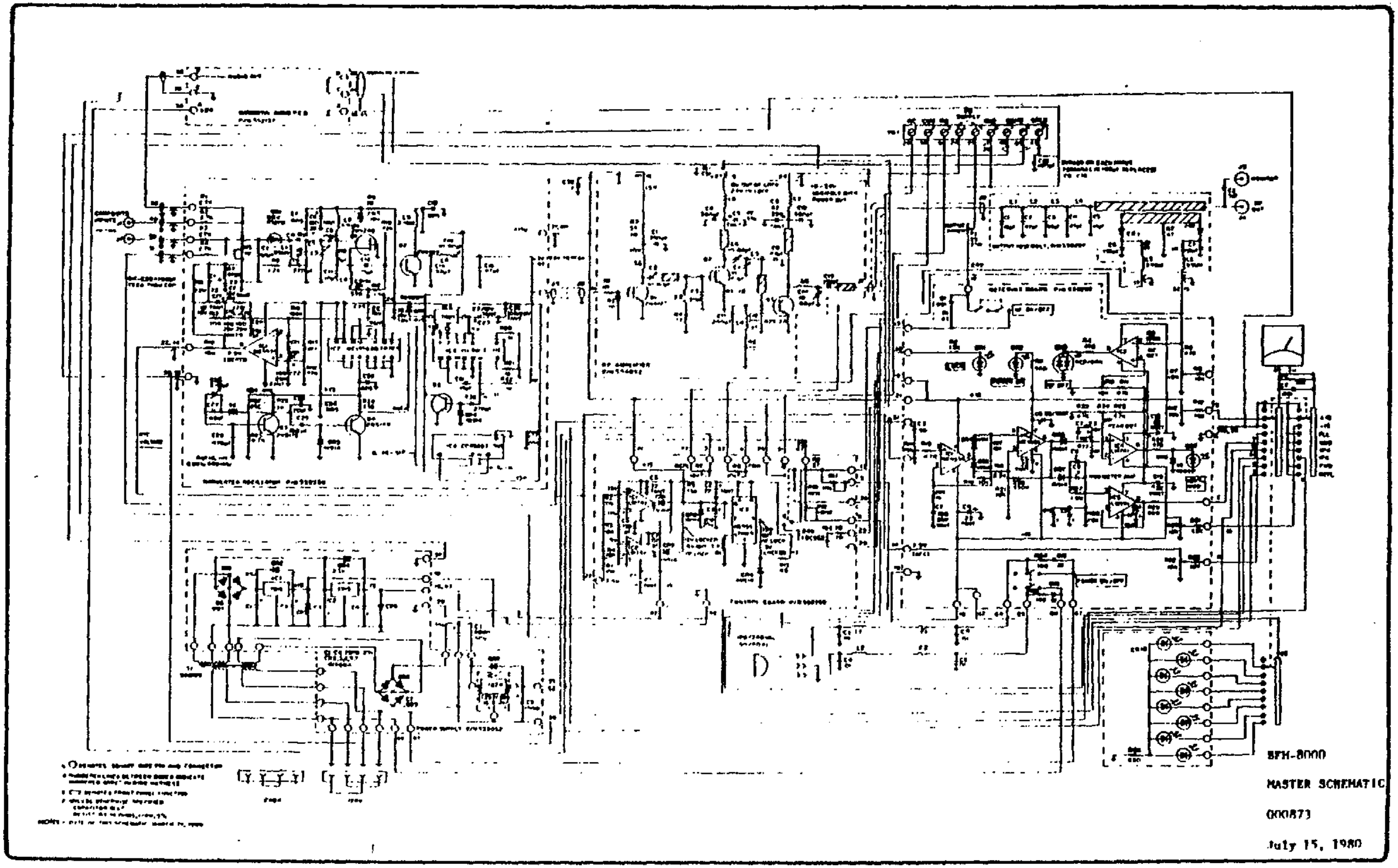
Appendice D: Circuit détaillé du générateur EMCS McMartin, modèle BFM-1531 R.

MCMARTIN



Appendice D: Diagramme fonctionnel du modulateur MF McMartin, modèle BFM-8000.

MCMARTIN



Appendice D: Circuit détaillé du modulateur MF McMartin, modèle BFM-8000.