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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

Commissioner Harold Furchtgott-Roth
8th Floor, A302 Portals
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Dear Commissioner Furchtgott-Roth,

I hope you will take a few moments to scan these two older articles from the IRE, the Institute of Radio Engineers, which is now known as the IEEE, the Institute of Electrical and Electronics Engineers. It is the largest engineering society in the world.

I am sending you this material today via fax, and have mailed original copies to you via priority mail. The fax copy was sent to meet the one week deadline so that you may consider this material in your January 20th meeting. The originals are being mailed to you in the event the fax copy is difficult to read.

Please take time to scan this material. It is my effort to show you that the FCC staff engineers have given you an erroneous conclusion to the LPFM issue, by measuring a quantity which is only indirectly related to the interference issue. To put it bluntly, your engineers data is flawed, and you should ask if their method has ever been used in the past as the primary determination used to set interference criteria. To my knowledge, the answer is "no".

I have given you three articles in this package.

The first is an article published in "IRE Transactions" in April, 1962. It shows how to calculate the signal-to-noise ratio for FM stereophonic service. This directly relates to LPFM and its impact on existing stations.

The second is a study of the interference effects caused by SCA (Subsidiary Communications Authorization), also from the IRE proceedings. This study is included as an example of the proper way to calculate and measure interference. It is a short technical "hop" to transition from the study of SCA interference to the study of adjacent channel interference caused by LPFM.

The third article is a chapter from a Bell Telephone tutorial on radio communications, and shows how to calculate the interference from one transmitter to another. It is particularly significant, as the article was written by engineers to be an entry level tutorial, and is not particularly difficult to understand. Remember that the phone company depended heavily on microwave radio communication for its long distance networks, and had to learn to calculate, measure, and compromise, in the real world, everything there was about interference and crosstalk for its systems to work properly. The compatibility and interference issue is also a requirement for LPFM.

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Note that all of the studies use signal to noise as the measure of interference -- this is the basic method of measuring impairment to a service, even if it is weighted subjectively.

All of these studies are over thirty years old, and I have chosen them to demonstrate that this is not new physics -- the rules of the technical game were set infinitesimal moments after universe was created in the "Big Bang" and they will remain the same to this day.

I would like you to consider that several items must be worked through first before you enter into Low Power FM rulemaking:

First, you must bring the non-commercial FM second adjacent channel standard up to that of the commercial FM second adjacent channel standard. Physics does not allow you to have two standards for the same exact physical situation.

Second, you must enact non-commercial FM adjacent channel "grandfathered" standards equivalent to that of the commercial FM adjacent channel "grandfathered" standards. Good public policy requires you to treat the same exact physical situations with the same regulations.

Third, you must allow existing broadcasters an adequate period to upgrade their facilities to the new standards if they so wish, and you should allow them encouragement to change their transmitter locations and/or channel allocations by minor amounts so that they can optimize service area and minimize interference potential -- this can only make more efficient use of the FM band.

Fourth, you must establish a protected secondary service area for FM stations. FM is the only service without a recognized secondary service area, and again, good public policy requires you to give FM broadcasters the equivalent secondary service protection as you give AM broadcasters, VHF-TV low band and high band and UHF band broadcasters.

Fifth, you must determine the technical specification for Digital Audio Broadcasting and determine the impact of existing FM stations to the transition to digital broadcasting, just as you have for digital television.

Then, and only then, you may consider the addition of additional channels to all the broadcasting bands for use by the general public, both an aural service, and a television service. Yet again, good public policy requires you to treat the similar situations similarly, and there is no reason that there cannot be a Low Power "People's" AM and FM Service, a Low Power "People's" Digital AM and FM Service, and a Low Power "People's" Analog and Digital Television Service, all logically allocated within these same regulations.

But it must be properly and correctly planned and allocated, and that will take a prudent amount of time and study. It is your charge to regulate in a prudent, logical, and responsible manner, just as those who are regulated by you must operate their facilities in a prudent, logical, and responsible manner.

Sincerely,

Deborah S. Proctor, BSEE, CPBE
General Manager

IRE Transactions

ON BROADCAST AND TELEVISION RECEIVERS

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PROFESSIONAL GROUP ON BROADCAST AND TELEVISION RECEIVERS

SOME NOTES ON THE CALCULATION OF THE S/N RATIO FOR A FM SYSTEM EMPLOYING A DOUBLE SIDEBAND AM MULTIPLEX SIGNAL

From Some Unpublished Calculations By:

Norman Parker
Motorola, Inc.
Franklin Park, Illinois

By: Donald W. Ruby
Zenith Radio Corporation
Chicago, Illinois

SUMMARY: Equations are developed which determine the S/N ratio for both a monophonic and stereophonic signal including the effect of deemphasis. A S/N ratio loss of 23 Db is indicated.

It is first desirable to obtain an expression for S/N ratio in an FM receiver which is operating with sufficient signal level to produce coherent or above threshold reception.

Assume that the IF is flat topped and sufficient B.W. to transmit the signal given by

$$M(t) = A_c \sin\left(\omega_c t + \frac{F}{f_v} \sin \omega_v t\right) \quad (1)$$

where M(t) is the instantaneous signal at the output of the IF and A_c = peak carrier voltage

W_c = angular velocity of the carrier signal.
F = maximum deviation of the carrier in cps.
f_v = modulating frequency in cps.
w_v = modulation angular velocity.

Now if the signal is passed through a discriminator having a slope

m = volt/radian of discriminator

(m is such that $e_s \equiv 0$ when F = 0)

$$e_s = m w_F \cos w_v t \quad (2)$$

= discriminator signal voltage and the signal power (normalized to a 1 ohm load)

$$S_o = \frac{m^2 \omega_F^2}{2} \text{ watts of signal power} \quad (3)$$

At the same time the electrical noise output of the discriminator caused by an electrical noise component ΔN volts in the IF output is given by

$$e_n = m \frac{\Delta N}{A_c} \omega_n \cos(\omega_n t + \phi) \quad (4)$$

w_n = angular noise velocity
A_c = peak carrier voltage
ΔN = incremental IF noise voltage
m = discriminator slope volts/radian

The incremental detector noise power is given by

$$dN_n = \frac{m^2}{2} \cdot \left(\frac{\Delta N}{A_c}\right)^2 \cdot \omega_n^2 \quad (5)$$

If the incremental IF noise power in watts/cycle is given by n then

$$N = \sqrt{2n\,df} \quad \text{or} \quad \frac{\Delta N^2}{2} = n\,df$$

where n = watts/cycle of IF noise

N = peak IF noise voltage in increments of df and

$$dN_n = \frac{m^2 \omega_n^2}{A_c^2} n\,df$$

Now since A_c is the peak carrier voltage, the IF peak carrier power (normalized to 1 ohm) is given by

$$P_c = \frac{A_c^2}{2} \quad (6)$$

$$dN_n = \frac{m^2 \omega_n^2}{2 P_c} n\,df = \frac{2\pi^2 m^2 n f_n^2}{P_c} df \quad (7)$$

The total noise in the discriminator output is produced by all noise components which can beat with the carrier to produce a signal falling within the passband of B of the audio or useable signal channel. This includes components from B cycles below to B cycles above, and the bandwidth of the IF does not affect the S/N when operating above threshold.

Therefore,

$$N_o = \frac{n m^2}{2 P_c} \int_{-B}^{+B} \omega_n\, df \quad (8)$$

$$= \frac{4\pi^2 m^2 n}{3 P_c} B^3.$$

N_o = total noise power in audio system

B = audio system bandwidth assumed flat to B and zero beyond.

The S/N power ratio is

$$(S_o/N_o)\ fm = \frac{m^2/2 \cdot 4\pi^2 F^2}{4/3\,\pi^2 m^2\, n/P_c\, B^3} \qquad (9)$$

$$= \frac{3}{2}\cdot\left[\frac{F}{B}\right]^2 \frac{1}{B}\cdot\frac{P_c}{N}$$

If the audio passband is equipped with a deemphasis filter which reduces the noise output in the ratio

$$P_o/P_{in} = \frac{1}{1 + f^2/f_o^2} \qquad (10)$$

, simple RC filter only

P_o = power output of the deemphasis filter

P_{in} = power input to the filter

f = instantaneous frequency in passband B

f_o = frequency at which RC network is down 3 Db or turnover frequency

The noise output is

$$N_a = \int_{-B}^{B} \frac{d(N_a)}{1 + f^2/f_o^2}\,df = \frac{4\pi^2 m^2 n}{P_c}\int_0^B \frac{f^2}{1+f^2/f_o^2}\,df \qquad (11)$$

$$= \frac{4\pi^2 m^2 n}{P_c}\left[B f_o^2 - f_o^3 \tan^{-1} B/f_o\right]$$

N_a = audio noise output with deemphasis filter

The audio S/N power ratio is given by

$$S_o/N_a = \frac{\frac{m^2}{2}\cdot 4\pi^2\cdot F^2}{\frac{4\pi^2 m^2 n}{P_c}\left[B f_o^2 - f_o^3 \tan^{-1} B/f_o\right]} \qquad (12)$$

$$= \frac{F^2}{2\left[B f_o^2 - f_o^3 \tan^{-1} B/f_o\right]}\cdot\frac{P_c}{n}$$

The improvement factor due to the deemphasis filter is

$$\frac{S_o/N_a}{S_o/N_o} = \frac{B^3}{3\left[B f_o^2 - f_o^3 \tan^{-1} B/f_o\right]}\,. \qquad (13)$$

For a 75 u sec deemphasis circuit, $f_o = 2.125 \times 10^3$ and $\tan^{-1} B/f_o = 1.43$ when B = 15,000. The deemphasis improvement is 13.2 Db.

Subcarrier Multiplex Operation

If the carrier is modulated by a single subcarrier frequency such that

$$M(t) = A_c \sin(W_c t + F/f_s \sin W_s t) \qquad (14)$$

f_s = subcarrier frequency, the output voltage is given by

$$e_{sc} = m\, w_F \cos w_s t, \text{ and } P_{sc} = \frac{m^2 4\pi^2 F^2}{2}$$

e_{sc} = subcarrier voltage at discriminator

P_{sc} = subcarrier power at discriminator

If the subcarrier signal is passed through a bandpass filter having a low frequency cut off B_1 and an upper frequency cut off B_2, the noise output is given by

$$N_{BP} = \frac{m^2 2\pi^2 n}{P_c}\left[\int_{-B_2}^{-B_1} f^2\,df + \int_{B_1}^{B_2} f^2\,df\right] \qquad (15)$$

$$= \frac{4\pi^2 m^2 n}{3 P_c}\left(B_2^3 - B_1^3\right)$$

B_2 = upper bandpass cuttoff frequency

B_1 = lower bandpass cuttoff frequency

The filter is assumed ideal and rectangular in passband shape. The S/N power ratio at the output of the Multiplex bandpass filter is

$$\frac{P_{sc}}{N_{BP}} = \frac{3F^2 P_c}{2n(B_2^3 - B_1^3)}\,. \qquad (16)$$

Now if F is taken to be the maximum allowable frequency deviation in the transmitted signal, and the subcarrier uses a portion p_1 of this deviation, the signal power is reduced by p_1^2, and the S/N ratio becomes

$$\frac{P_{sc}'}{N_{BP}} = \frac{3 p_1^2 F^2 P_c}{2n(B_2^3 - B_1^3)} \qquad (17)$$

p_1 = the portion of the total deviation used for the subcarrier. If the subcarrier f_s is located midway between B_1 and B_2, such that $B_2 = f_s + B_a$ and $B_1 = f_s - B_a$, where B_a is maximum modulating frequency, then $(B_2^3 - B_1^3) = 6 f_s^2 B_a + 2 B_a^3$, and

$$\frac{P_{sc}}{N_{BP}} = \frac{3 p_1^2 F^2}{4(3 f_s^2 B_a + B_a^3)} \cdot \frac{P_c}{n} \qquad (18)$$

An approximate form of this equation can be derived by assuming the noise power in the passband is constant as a function of frequency rather than parabolic.

If the power is assumed constant with frequency at a level determined by the center of the passband or subcarrier frequency,

$$dN_n = \frac{2\pi^2 m^2 n f_s^2}{P_c} df, \qquad (19)$$

$$N_{BP}' = \frac{2\pi m^2 n f_s^2}{P_c}\left[\int_{-B_2}^{-B_1} df + \int_{B_1}^{B_2} df\right] \qquad (20)$$

$$N_{BP}' = \frac{8\pi^2 m^2 n}{P_c} f_s^2 B_a \qquad (21)$$

N_{BP}' = approximate bandpass noise,

and
$$N_{BP} = \frac{8\pi^2 m^2 n}{P_c}\left(3 f_s^2 B_a + B_a^3\right); \qquad (22)$$

the B_a^3 term represents the parabolic correction term. The maximum error introduced by neglecting B_a^3 can be observed by assuming certain limiting characteristics. When the subcarrier f_s which is modulated by B_a has a lower sideband extending to $f_s - B_a$, and the main channel is modulated by signal frequencies extending to B_a, f_s is equal to or greater than 2 B_a. When this is the case, the parabolic correction term provides less than 1 db of correction and the rectangular spectrum can be assumed with negligible error.

Considering the case where the subcarrier is amplitude modulated, the signal output of the bandpass filter is

$$e_f = m p_1 F \pi\left[(1) + K V(t)\right] \cos(\omega_{sc} t + \phi), \qquad (22)$$

where K = Modulation factor

V(t) = audio modulation for subcarrier

e_f = bandpass output voltage

ϕ = subcarrier phase at t = 0.

W_{sc} = subcarrier angular velocity

If suppressed carrier modulation is used

$$e_f = m p_1 2\pi F K V(t) \cos(\omega_{sc} t + \phi) \qquad (23)$$

whose peak value is $2\pi m p_1 F = \hat{e}_f$, and $P_f = 2\pi^2 m^2 p_1^2 F^2$

P_f = peak signal power derived from subcarrier detector obtained by restoring the carrier and detecting the envelope voltage. The envelope voltage is taken to be $e_v = m p_1 2\pi F K V(t)$;

e_v = the envelope signal voltage.

The detector noise from the bandpass filter can be obtained by summing the noise which beats with the restored carrier:

$$N_d = \frac{2\pi m^2 n f_s^2}{P_c}\left[\int_{-f_s - B_a}^{-f_s + B_a} df + \int_{f_s - B_a}^{f_s + B_a} df\right] \qquad (24)$$

$$= \frac{8\pi^2 m^2 n f_s^2}{P_c} B_a$$

The signal to noise power ratio at the subcarrier detector is

$$\frac{P_f}{N_d} = \frac{p_1^2 F^2}{4 f_s^2 B_a} \cdot \frac{P_c}{n} \qquad (25)$$

For the case where F = 75 kcps,

$$\frac{P_f}{N_d} = \frac{1.4 \times 10^9 p_1^2}{f_s^2 B_a} \cdot \frac{P_c}{n}. \qquad (26)$$

When the subcarrier signal is passed through a deemphasis filter, the subcarrier audio noise is reduced by

$$\frac{P_o}{P_{in}} = \frac{1}{1 + \frac{f^2}{B_c^2}} \qquad \left\{\begin{matrix}\text{single}\\ \text{RC}\\ \text{filter}\end{matrix}\right\} \qquad (27)$$

Where P_o = deemphasis power output

P_{in} = deemphasis power input

B_a = max. audio in subcarrier channel

B_o = 3 db cuttoff frequency of simple RC filter

f = instantaneous audio frequency in the subcarrier channel

The subcarrier audio incremental noise becomes

$$dN' = \frac{2\pi^2 m^2 n f_a^2}{P_c} \cdot \frac{1}{1 + \frac{B_a^2}{B_o^2}} \qquad (28)$$

and the total subcarrier noise is

$$N_d' = \frac{8\pi^2 m^2 n f_a^2}{P_c} \int_0^{B_a} \frac{1}{1 + \frac{f^2}{B_o^2}} df \qquad (29)$$

$$= \frac{8\pi^2 m^2 n f_a^2}{P_c} B_o \tan^{-1} \frac{B_a}{B_o}$$

being the total subcarrier noise with deemphasis.

The noise reduction produced by deemphasis network in the subcarrier is given by (30)

$$\frac{N_d}{N_d'} = \frac{B_a}{B_o \tan^{-1} B_a/B_o}$$

When B_o = 2.125 kcps, B_a = 15 kcps, the noise reduction is 6.8 db in the subcarrier deemphasis, while on the main channel a similar network produced a 13.2 db noise reduction. The difference is caused by the triangular noise voltage spectrum present in the main channel; however, since the subcarrier is suppressed carrier AM, the noise spectrum is rectangular, and the deemphasis is less effective in reducing noise. The Signal to Noise power ratio in the subcarrier channel is

$$\frac{P_f}{N_d'} = \frac{P_c}{m} \cdot \frac{p_1^2 F^2}{4 f_a^2 B_o \tan^{-1} \frac{B_a}{B_o}} \qquad (31)$$

Again, where F = 75 kcps, (32)

$$\frac{P_f}{N_d'} = \frac{1.4 \times 10^9 p_1^2}{f_a^2 B_o \tan^{-1} \frac{B_a}{B_o}}$$

In practice the multiplex channel used for stereo operation, and the main channel contains the sum of two stereo channels while the subcarrier contains the difference as given by:

$e_l + e_r$ = main channel output voltage and

$e_l - e_r$ = subcarrier channel output voltage.

In order to recover e_l and e_r, the main and sub channels can be added resistively to provide

$$\frac{\begin{array}{c} e_l + e_r \\ e_l - e_r \end{array}}{2e_l} \quad \text{or} \quad \frac{\begin{array}{c} e_l + e_r \\ -e_l + e_r \end{array}}{2e_r}$$

where e_l is the signal voltage for the left channel and e_r is the signal voltage for the right channel.

From this it can be seen that when

$$\hat{e}_l = \hat{e}_r, \quad \hat{e}_l - \hat{e}_r = 0$$

$2\hat{e}_l$ = peak left channel voltage

$2\hat{e}_r$ = peak right channel voltage

Using $e_l - e_r$ to modulate the suppressed subcarrier channel, when $\hat{e}_l = \hat{e}_r$ the subcarrier is zero. Letting

$$p_2 \hat{e}_l + p_3 \hat{e}_r + p_4 \hat{e}_{pc} = e_m \qquad (33)$$

$$(p_2 + p_3 + p_4 = 1),$$

where $\hat{e}_{pc}$ = peak pilot carrier voltage, and

e_m = maximum signal that could appear at the output for a monophonic signal. If p_4 = .1 and $p_2 = p_3$ = .45 (max. value), then $2\hat{e}_l = .9e_m$ and $2\hat{e}_r$ = $.9e_m$, then $P_{cl} = 4p_2^2 P_{cm}$, and P_{cr} = $4p_3^2 P_{cm}$. P_{cl} and P_{cr} are max. power available from stereo output, and P_{om} is peak monophonic power available. Thus, the stereo signal to noise ratio is

$$\frac{P_{cl}}{N_r} = \qquad (34)$$

$$\frac{P_c}{m} \cdot \frac{4 p_2^2 P_{om}}{\left[8\pi^2 m^2 f_a^2 B_o \tan^{-1} \frac{B_a}{B_o} + 4\pi^2 m^2 \left(B f_o^2 - f_o^3 \tan^{-1} \frac{B}{f_o}\right)\right]}$$

$$\frac{P_{o\ell}}{N_\ell} = \frac{P_c}{m} \cdot \frac{4 p_2^2 m^2 2\pi^2 F^2}{\left[8\pi^2 m^2 f_s^2 B_0 \tan^{-1}\frac{B_s}{B_0} + 4\pi^2 m^2 \left(B f_0^2 - f_0^3 \tan^{-1}\frac{B}{f_0}\right)\right]} \quad (35)$$

$$\frac{P_{o\ell}}{N_\ell} = \frac{P_c}{m} \cdot \frac{2 p_2^2 F^2}{\left[2 f_s^2 B_0 \tan^{-1}\frac{B_s}{B_0} + B f_0^2 - f_0^3 \tan^{-1}\frac{B}{f_0}\right]} \quad (36)$$

N_ℓ = stereo noise power in the left or right channel. The stereo signal to noise power ratio to monophonic signal to noise power ratio gives the loss in S/N ratio when multiplex stereo is added.

$$\left(P_{om} = S_o = m^2 2\pi^2 F^2\right)$$

$$\frac{P_{om}/N_\ell}{P_{o\ell}/N_\ell} = \frac{\frac{P_c}{m} \cdot \frac{F^2}{2\left[2 B f_0^2 - f_0^3 \tan^{-1} B/f_0\right]}}{\frac{P_c}{m} \cdot \frac{2 p_2^2 F^2}{2\left[f_s^2 B \tan^{-1}\frac{B_s}{B_0} + B f_0^2 - f_0^3 \tan^{-1}\frac{B}{f_0}\right]}} \quad (37)$$

$$= \frac{2 f_s^2 B_0 \tan^{-1}\frac{B_s}{B_0}}{4 p_2^2 \left[B f_0^2 - f_0^3 \tan^{-1}\frac{B}{f_0}\right]} + \frac{1}{4 p_2^2}$$

Using the conditions:

$B = B_s = 15$kcps

$B_0 = f_0 = 2.125$kcps

$f_s = 38$kcps

$p_2 = .45$

the stereo S/N loss is 23Db.

This figure is the same when either the main or the subcarrier channel is carrying full modulation, and the same condition exists for identical modulation on the main and subcarrier channel. From the preceding notes and calculations it should be observed that the signal to noise ratio is attenuated by three major factors when detecting an FM multiplex signal. Specifically, these are the effect of noise triangulation, the restricted amount of carrier deviation, and the resultant effect of deemphasis.

REFERENCE:

1. Modulation Theory

   By: Harold S. Black,
   Bell Telephone Laboratories, Inc.

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PROFESSIONAL TECHNICAL GROUP ON BROADCAST AND TELEVISION RECEIVERS

THE STUDY OF SCA INTERFERENCE IN STEREO FM RECEIVERS

Don J. Popp
Zenith Radio Corporation
Chicago, Illinois

Summary

The FM Stereo Broadcast System as adopted by the FCC two years ago included the accommodation for the transmission of an SCA background channel service on the RF carrier along with the two stereo channels. This simultaneous transmission of a third channel with the stereo program can result in an intermodulation interference in improperly designed or aligned stereo FM receivers.

In evaluating SCA interference, this paper shall consider:

1. The nature of SCA interference;

2. Possible sources of the interference in a stereo FM receiver;

3. Results of the testing of a cross-section of the stereo FM receiver market; and

4. Methods of minimizing the interference.

Introduction

Approximately 250 FM radio stations across the country are now broadcasting in Stereo FM. A recent tabulation indicates that 92 of these are authorized for SCA background channel operations.

Following is a summary of Engineering Standards for Subsidiary Communications Multiplex Operations for stereophonic broadcasting as contained in the Report and Order of Docket #13506 issued by the Federal Communications Commission in 1961.

1. Frequency Modulation of SCA subcarriers shall be used.

2. Instantaneous frequency of SCA subcarriers shall at all times be within the range of 53 KC to 75 KC.

3. The modulation of the main carrier by the SCA subcarrier shall not exceed 10 per cent.

It is current practice for broadcasters who are programming both in the stereo and the SCA channels to select 67 KC as the SCA subcarrier frequency. This subcarrier is then frequency modulated by the SCA program with a frequency deviation of $\pm$ 6 KC being common. These parameters shall be used for the purposes of this evaluation.

Figure 1 shows the frequency spectrum of the composite stereo modulation with an SCA channel. This composite modulation can be expressed as follows:

$$(1)\quad H = (L+R) + (L-R)\cos \omega t + \ldots X\cos\frac{\omega t}{2} + Q\cos B(t)$$

where:
- L = left channel modulation
- R = right channel modulation
- ω = stereophonic subcarrier angular frequency
- X and Q = modulation constants
- $\cos B(t)$ = frequency modulated SCA channel
- $B(t) = (bt + \frac{M}{a}\cos at)$

where:
- b = SCA subcarrier angular frequency
- M = Frequency deviation
- a = SCA audio angular frequency

It can be recalled from the FCC Rules on Stereophonic Broadcasting that the (L+R) MAIN channel and the (L-R) 38 KC SUBCARRIER channel both frequency modulate the main radiated carrier 80 per cent. The 19 KC PILOT subcarrier modulates the radiated carrier 10 per cent which leaves the remaining 10 per cent of the main carrier modulation for the addition of the SCA channel subcarrier. As can be seen from Figure 1, the opportunity for intermodulation exists between the various components of the stereo modulation, should this modulation be passed through non-linear circuits either in the transmitter or in a stereo receiver. To remain within the scope of this paper, it can be assumed the Stereo FM station broadcasting the SCA channel does not transmit any intermodulation.

The Nature Of SCA Interference

Studies have shown SCA interference is caused by the forming of intermodulation groups between the modulated SCA channel and the 19 KC PILOT subcarrier and its harmonics. As an aid in explaining how SCA intermodulation becomes audio interference in the stereo receiver, the 67 KC SCA subcarrier can be visualized as being deviated $\pm$ 6 KC by a low frequency modulation so that any instantaneous frequency (S) of the frequency modulated SCA channel will lie somewhere between 61 KC and 73 KC. If the 19 KC PILOT of

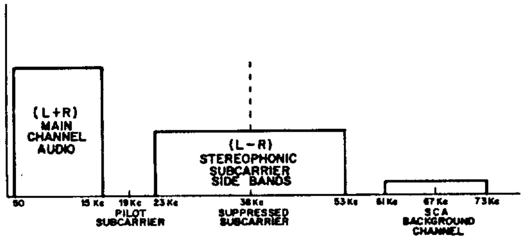

Figure 1—FM Spectrum Containing Stereo Composite Modulation.

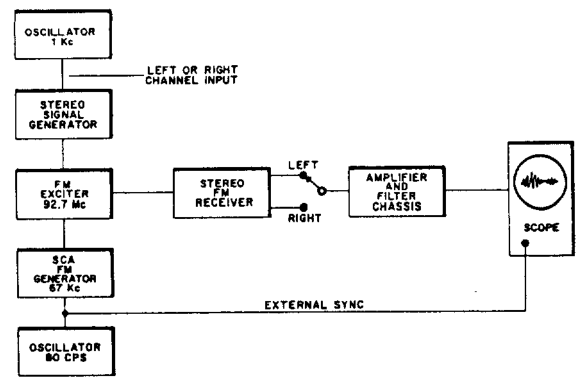

Figure 4—Equipment Diagram for Measuring SCA Interference.

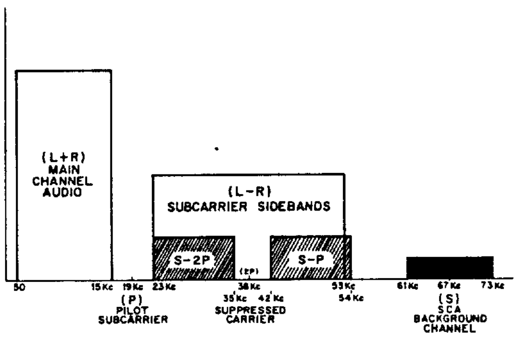

Figure 2—FM Stereophonic Frequency Spectrum With SCA Intermodulation Products.

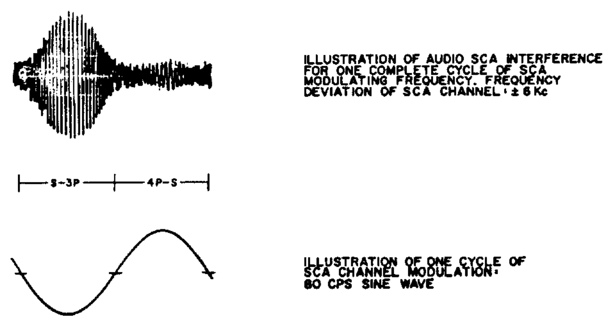

Figure 5

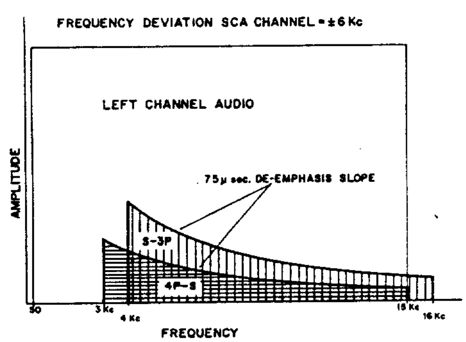

Figure 3—Spectrum of Detected Left Channel Audio Showing Range of SCA Interference.

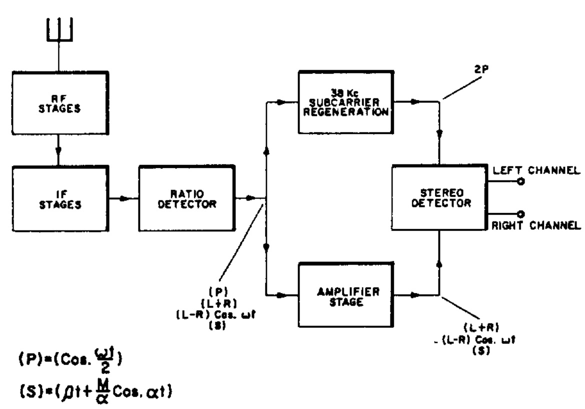

Figure 6—Simplified Block Diagram Ideal Stereo FM Receiver.

the stereo composite signal is designated as (P), the most prominent intermodulation groups formed in a stereo receiver can be identified as (S-P) and (S-2P). These intermodulation product groups fall in the frequency spectrum of the 38 KC SUBCARRIER sidebands as shown in Figure 2. If these product groups are allowed to have access to the 38 KC stereo detector in a receiver, direct amplitude demodulation at (2P) takes place which produces the audio SCA interference.

Analytically, this can be seen if we multiply a demodulation function with a single channel modulated stereo signal which contains SCA intermodulation groups; thereby simulating stereo detector action. The single channel stereo modulation (in this example, left channel is used) with SCA intermodulation groups added can be expressed by:

$$(2) \quad H = L + L\cos\omega t + K_1\cos\left[B(t) - \frac{\omega t}{2}\right] + \ldots K_2\cos\left[B(t) - \omega t\right]$$

where: K_1 and K_2 are intermodulation constants

If the demodulating function $(1+2\cos\omega t)$ is used as the multiplier, the detected product becomes:

$$(3) \quad N = L + L\cos\omega t + 2L\cos\omega t + 2L\cos^2\omega t + \ldots K_1\cos\left[B(t) - \frac{\omega t}{2}\right] + K_1\cos\left[B(t) + \frac{\omega t}{2}\right] + \ldots K_1\cos\left[B(t) - \frac{3\omega t}{2}\right] + K_2\cos\left[B(t) - \omega t\right] + \ldots K_2\cos B(t) + K_2\cos\left[B(t) - 2\omega t\right]$$

Simplifying and eliminating all frequencies above audio, the detected output will be:

$$(4) \quad N = 2L + K_1\cos\left[B(t) - \frac{3\omega t}{2}\right] - K_2\cos\left[2\omega t - B(t)\right]$$

Identical audio SCA interference will result in the right channel as a product of the demodulating function $(1-2\cos\omega t)$ used there.

Inspection of these terms reveal several properties of SCA interference:

1. It is independent of amplitude level and modulation of the stereo channels.

2. It is the result of both second and third order intermodulation; therefore, two audio interference components are present simultaneously.

3. It is dependent on the modulation of the SCA channel for its character.

4. It is dependent on the frequency deviation of the SCA channel for its audio range.

5. The amplitude of SCA interference tends to a de-emphasis curve which is illustrated in Figure 3.

Figure 4 is an equipment diagram for measuring SCA interference in Stereo FM Receivers. It was necessary to insert an AMPLIFIER AND FILTER CHASSIS between the outputs of the receiver and the oscilloscope to obtain a measurable voltage waveform. The AMPLIFIER AND FILTER CHASSIS contain the following:

1. Audio pentode amplifier

2. 15 KC low pass filter

3. 60 CPS hum rejection filter

4. Switchable 50 DB attenuation pad.

Interference waveforms for high frequency modulation of the SCA Channel are not very revealing. If a low frequency sine wave is used to modulate the SCA Channel and the oscilloscope is synchronized with this low frequency as in Figure 4, a waveform can be obtained which illustrates the unique character of SCA interference. The top waveform in Figure 5 is such an illustration and is the resulting audio SCA interference for one complete cycle of SCA modulating frequency. In this example, the modulating frequency is 80 CPS; one cycle of which is illustrated in the bottom waveform of Figure 5. As can be seen, there are two components of SCA interference containing varying audio frequencies with 75 µsec de-emphasis amplitude characteristics.

Sources Of SCA Interference

Since the audio SCA interference is caused by the intermodulation groups (S-P) and (S-2P), the principal sources of the interference can be traced to those circuits producing these intermodulation signals. Figure 6 is a simplified block diagram of an ideal stereo receiver showing circuit locations of desired signals. By contrast, Figure 7 is an identical block diagram showing circuit locations of signals, both desired and undesired, which might be found in an actual stereo receiver.

Perhaps the source of SCA intermodulation most overlooked are those circuits which are located prior to the multiplex circuits. These circuits, between the RF STAGES to the RATIO

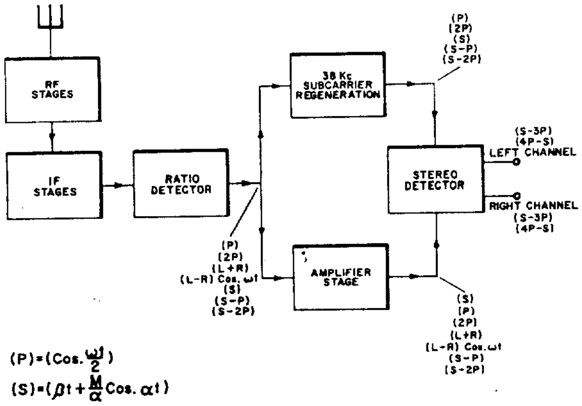

Figure 7—Simplified Block Diagram Actual Stereo FM Receiver.

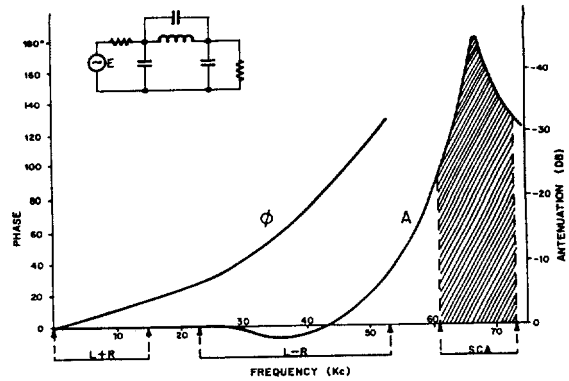

Figure 10—Amplitude and Phase Response of a Typical SCA Rejection Filter.

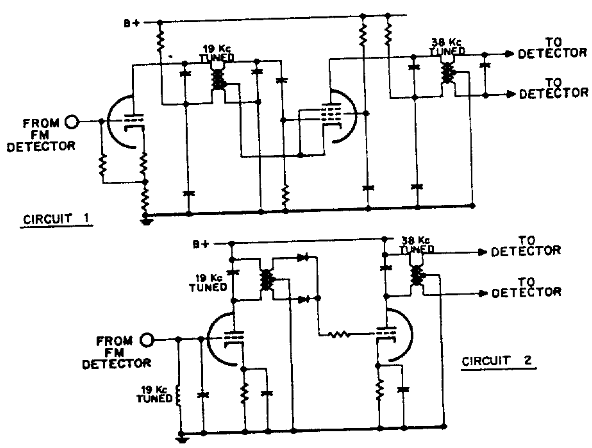

Figure 8—38 Kc Subcarrier Regeneration Techniques.

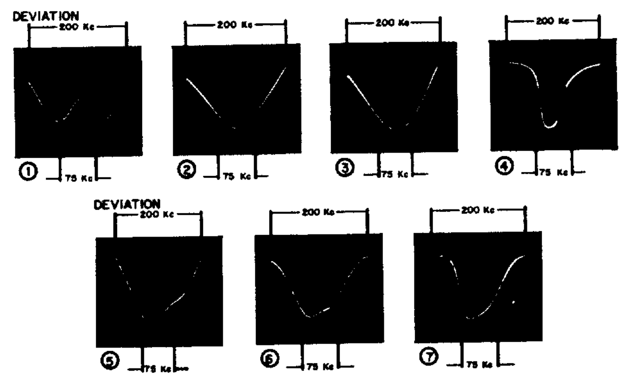

Figure 11—Amplitude Characteristics—IF Stages of Test Receivers.

TEST RECEIVER	TYPE	SCA INTERMODULATION AT FREQUENCY DESCRIMINATOR Reference: 1 Kc (L+R) Signal		SCA INTERFERENCE AT RECEIVER OUTPUT Reference: 1Kc Desired Channel		SCA FILTER (NO. USED)	STEREO CHANNEL SEPARATION
		S-P	S-2P	S-3P	4P-S		
1	Large Console	-41 db	-41 db	-35 db	-30 db	1	29 db
2	Large Console	-55 db	—	-50 db	-55 db	2	35 db
3	Table Model	-54 db	—	-48 db	-55 db	2	25 db
4	Small Console	-24 db	-38 db	-35 db	-45 db	1	20 db
5	Small Console	-41 db	—	-44 db	-50 db	1	18 db
6	Small Console	-44 db	—	-53 db	-55 db	1	25 db
7	Component Tuner	-42 db	-47 db	-53 db	-55 db	1	35 db

Figure 9—Results of SCA Interference Test.

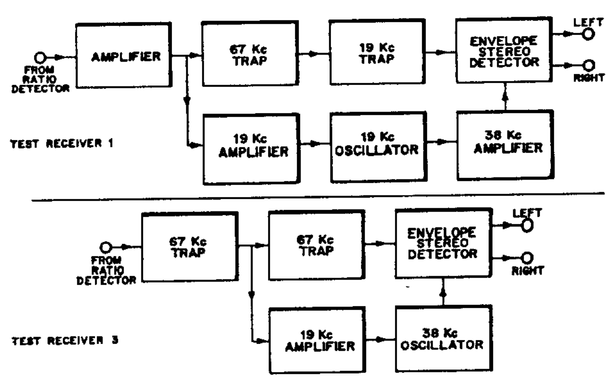

Figure 12—Multiplex Circuit Block Diagrams of Two Test Receivers.

DETECTOR, can assert non-linear properties on the desired composite signal and produce amounts of intermodulation varying with the quality and alignment of these stages. Since the instantaneous frequency of the SCA intermodulation groups will lie between 23 KC and 54 KC as shown in Figure 2, this intermodulation has direct access to the stereo detector.

As can be seen in Figure 7, another possible source of SCA intermodulation are the 38 KC REGENERATION STAGES where the 19 KC is amplified, doubled in frequency, and injected at a high level into the STEREO DETECTOR. The susceptibility of these stages to SCA intermodulation is partly due to the high amplification found in these circuits. Also, any (S-P) and (S-2P) intermodulation formed in these stages may not be effectively filtered out by the final 38 KC selective stage. Of the many actual design approaches used in production receivers, only two techniques will be discussed from the SCA interference point of view.

One technique commonly used is called the locked oscillator approach. A 19 KC oscillator becomes phase-locked with the 19 KC PILOT present at the receiver ratio detector. This output is doubled by means of a tuned circuit at 38 KC which is then amplified to drive the detector. An example of a circuit of this type is presented in Circuit 1 of Figure 8. This approach can be rich in 19 KC harmonic content; therefore, should there be any SCA channel modulation present in these stages, (S-P) and (S-2P) will be generated. Just as important, these harmonics of 19 KC can later cause direct intermodulation in the STEREO DETECTOR. This source is not restricted to 19 KC locked oscillator circuits alone but is typical of many tuned amplifier approaches used.

For comparison, another method which can be used for regeneration of the 38 KC SUBCARRIER is the type used in Circuit 2 of Figure 8. In this approach, the 19 KC PILOT present at the ratio detector is filtered, amplified, and by means of two diodes, doubled into a full wave rectified function. This signal is then amplified and filtered again at 38 KC before insertion into the demodulator. The grid resistor of the second triode in Circuit 2 can also provide clipping of the full-wave rectified function which further reduces the possibility of unwanted harmonics of 19 KC riding through. The over-all advantage of this approach to subcarrier regeneration is that only harmonics of 38 KC are present in the subcarrier; thus only (S-2P) SCA intermodulation will be of any consequence.

The AMPLIFIER STAGE shown in Figures 6 and 7 may or may not be necessary depending on the particular design of the stereo multiplex circuits. Should such an amplifier be necessary, linear phase response and broad-band frequency response are mandatory to both minimize the SCA intermodulation and maximize the efficiency of the STEREO DETECTOR.

Another source of SCA interference is the STEREO DETECTOR itself. It should first be mentioned that any (S-P) and (S-2P) intermodulation present at the detector will result in SCA audio interference. If the modulated SCA Channel (S) is present, the non-linear action of the STEREO DETECTOR can directly produce SCA interference in certain detector circuits. For example, if an "average" detector is used with an ideal switching waveform having a 50 per cent duty cycle, the harmonic content of this waveform will be 2P, 6P, 10P, etc..... by Fourier Series. Any intermodulation formed with the SCA Channel (S) will not produce audio SCA interference. Should the duty cycle of the switching waveform not be 50 per cent however, the harmonic content will be 2P, 4P, 6P, etc... and intermodulation with (S) will produce audio SCA interference (4P-S). This same phenomena occurs when an envelope detector is used, since in an envelope detector, the diodes conduct for a short period of time only.

The STEREO DETECTOR can also become a source of SCA interference should the CARRIER REGENERATION STAGES not provide an ideal switching waveform, but one which is rich in harmonics of the 19 KC PILOT. The third and fourth harmonic of 19 KC will beat with the SCA Channel present and directly form (S-3P) and (4P-S) interference.

Testing Of A Cross-Section Of The Stereo FM Receiver Market

The question must properly arise as to what level of SCA interference could be called objectionable interference. Qualitative listening tests were conducted in a quiet room using a high RF signal strength. It was concluded that the SCA interference level of -60 DB could be considered negligible to a critical listener. It was further thought that an SCA interference level of -55 DB would be unnoticeable to the average listener.

To determine what level of SCA audio interference might be found in a stereo FM receiver purchased today, a group of receivers which could be considered a cross-section of the stereo FM receiver market were acquired and measured as they came from the manufacturer using the test set-up of Figure 4. During measurements, all receivers were center-tuned on station thereby providing maximum reference signal and minimum SCA interference. The function below was used as reference for the levels of SCA interference measured at receiver output.

$$\text{Level of SCA interference} = 20 \ \text{LOG}_{10} \frac{\text{Maximum amplitude of interference}}{\text{Amplitude of desired 1 KC audio}}$$

Results of these measurements are seen in Figure 9. All of the test receivers contained at least one SCA rejection filter. SCA interference seems to be a serious problem in at least three of the receivers tested. Although none of the receivers achieved a measured SCA interference of -60 db, some receivers could have attained this level with greater care in alignment.

Minimizing SCA Interference

It would be impossible to discuss methods necessary to minimize SCA interference in all Stereo FM Receivers, however, the following four considerations might suffice:

1. Quality of SCA Filter

2. Location of SCA Filter

3. Regeneration of clean 38 KC switching voltage

4. Reduction of intermodulation in tuner portion of receiver.

1. Perhaps the most commonly used method of reducing SCA interference has been the insertion of simple 67 KC rejection filters somewhere in the multiplex circuits. Design specifications for an ideal SCA filter are rather rigid. Such a filter should provide a flat pass-band and linear phase response up to 53 KC for maximum efficiency of the STEREO DETECTOR. It must provide infinite attenuation from 61 KC to 73 KC for suppression of the SCA Channel. Complex filters, such as the Bode or Butterworth configurations, can be made which would approximate these specifications, however, neither their physical size or cost make their use practical in production receivers. Figure 10 is an example of a simple one coil rejection filter which serves well as a compromise. This simple filter cannot provide good attenuation over the entire SCA frequency spectrum, however it can be adequate for some receivers having other multiplex circuit design features. Circuit designers apparently have ignored the two section filter because of its increased phase non-linearity and higher cost. On the other hand, some designers have used two single coil traps at different multiplex circuit locations with good effect.

2. The actual circuit location of the SCA filter is as important as the amplitude attenuation characteristic. Unfortunately, multiplex circuit designers have frequently placed the SCA filter directly at the input to the STEREO DETECTOR ignoring the 38 KC SUBCARRIER REGENERATION stages as a source of intermodulation. In experiments on a particular model of receiver, it was found that SCA audio interference could be reduced 6 to 10 DB simply by placing the input to the SUBCARRIER REGENERATION stages after the SCA filter.

3. The importance of regenerating a clean 38 KC switching voltage cannot be over-emphasized. Some multiplex circuit designers have overlooked this in their rush to provide stereo indicator lights and automatic monaural-to-stereo mode switching. The addition of a highly selective 38 KC stage would improve the harmonic output of many subcarrier regeneration circuits used in receivers.

4. As can be seen from Figure 9, SCA intermodulation is formed in the tuner portion of production receivers in varying quantities. The (S-P) intermodulation seems to be predominant. Two approaches can be used to minimize interference caused by this intermodulation.

Since all the necessary stereo information is carried by either sideband of the (L-R) suppressed subcarrier channel, vestigial sideband detection utilizing the lower sideband could be used in the multiplex circuits. This approach would necessitate attenuation of the upper sideband or, in effect, attenuation of the (S-P) intermodulation. The major disadvantage of this approach is the resulting 6 DB loss in recovered stereo output which is undesirable in production receivers.

A more logical approach would be to determine the apparent cause of this intermodulation and minimize it. Perhaps, the prime suspect for intermodulation in the tuner portion of receivers would be a non-linear phase response in the IF STAGES. Many production alignment procedures for these stages stress <u>maximum</u> amplitude characteristics for maximum receiver sensitivity rather than symmetrical amplitude characteristics for most linear phase response. A visual inspection of the amplitude characteristics of the IF STAGES of the Test Receivers supports this conclusion as can be seen in Figure 11. Test Receivers 2 and 3, which exhibited the least amount of SCA intermodulation, both possess symmetrical amplitude characteristics in the IF STAGES. Test Receivers 1, 4, 5, 6, and 7 possess varying asymmetrical IF amplitude characteristics and it can be seen from Figure 9, they exhibit substantially more SCA intermodulation than the other two. Test Receivers 1 and 4 appear to have basic design deficiencies. The intermodulation found in Test Receivers 5, 6, and 7 could have been substantially reduced by symmetrical alignment of the IF STAGES. Perhaps it is time for re-evaluation of tuner alignment procedures on the part of some manufacturers.

Figure 12 serves as a comparison illustrating some of the methods emphasized in this section. Both Test Receivers compared used envelope detection and both included one or more SCA filters in the multiplex circuits. The SCA interference level of -48 DB for Test Receiver 3 could be considered marginal since the receiver is a table model with reduced high frequency response. This particular approach used two simple 67 KC traps quite effectively with an envelope detector. The SCA interference level of -30 DB for Test Receiver 1 does not speak well of the large console that came with it. Test Receiver 1 has probable serious intermodulation sources in the IF STAGES, SUBCARRIER REGENERATION STAGES, and consequently, the ENVELOPE DETECTOR. A significant improvement could be achieved if the IF amplitude response were improved and the 67 KC trap relocated in front of the 19 KC amplifier stage.

Conclusions

Since, potentially all of the FM Stereo Stations could elect to broadcast an SCA channel, it is necessary for receiver manufacturers to take SCA interference into consideration for quality Stereo FM receiver design. It can be concluded that some manufacturers have minimized SCA interference in their production receivers so that it could be considered negligible to the average listener. Other manufacturers have not.

There are other factors not included in this evaluation which influence SCA interference found in production receivers:

1. If a particular receiver is producing excessive SCA interference, the consumer will tend to blame the FM broadcast station rather than the receiver manufacturer. It is conceivable that some such manufacturers do not realize SCA interference is a problem in their receivers.

2. Within present FCC specifications, stereo FM broadcast stations can, and some do, use a frequency deviation of $\pm$ 8 KC for the SCA channel.

MEMORANDUM

To: Commissioner Harold Furchtgott-Roth January 12, 2000

Fr: Deborah S. Proctor

Re: LPFM Considerations

Dear Commissioner Furchtgott-Roth,

Thank you for meeting with me and the other broadcasters from North Carolina last month; we appreciate the time which you gave to us.

Here is the copy of the technical papers which I said I would send to you at that meeting.

> **At that meeting, you impressed me with your openness and concern for trying to understand our worries about LPFM. I understand that three of the Commissioners might vote in favor of LPFM, and I know that you have stood alone before. Please, although it's lonely, please consider being our advocate next week. There can be a citizen's radio service, but it needs to be thought out better than this.**

I do apologize for taking so long to get these to you, but I had the flu and some Y2K problems -- I hope you can scan through this material and consider that there is a specific and proven way to measure and calculate signal impairment to radio transmissions, and it is not congruent with the way which the FCC staff made their recent determination concerning the impact of LPFM on FM broadcasting.

Deborah