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July 10, 1986

Dear Broadcaster:

Thank you very much for your interest in OPTIMOD-FMX.

Enclosed is a package of information from both Orban and CBS. I'm sure you will find it interesting.

In our articles, we explain why the Orban OPTIMOD-FMX will be substantially different and better than units offering only the CBS "developmental" design.

Until IC chips become available, FMX receivers will be very scarce. The latest information from CBS is that the first chips will roll off the line during the summer of 1987, permitting receivers to be available just prior to Christmas 1987.

Orban expects to begin accepting orders for OPTIMOD-FMX in the Fall, with deliveries beginning late in the year. As we have more information available, we will send it to you.

If you have any additional questions, feel free to call me on our toll-free number: 800-227-4498.

Thank you for your confidence in OPTIMOD-FMX.

Best regards,

Howard Mullinack

Howard Mullinack
Marketing and Sales Manager
Broadcast Products

Orban Associates Inc. 645 Bryant Street San Francisco, CA 94107-1693
Main: (415) 957-1063 (Sales): (415) 957-1067 Telex: 17-1480 Cable: ORBANAUDIO

The Orban 8150A OPTIMOD-FMX™ FMX Stereo Generator

Preliminary information

Highlights

- ☐ Increases stereo coverage area—to almost that of the mono coverage area—for receivers equipped with FMX decoders.
- ☐ Fully compatible with non-FMX equipped receivers.
- ☐ Orban's proprietary program-dependent FMX control circuitry achieves optimum noise reduction without danger of overmodulation.
- ☐ Works with OPTIMOD-FM of any vintage, and some other audio processors.
- ☐ Projected delivery: Late Fall 1986.

The Model 8150A OPTIMOD-FMX is a complete, self-contained stereo generator. It combines a newly-designed ultra-high-performance stereo encoder with the Orban FMX compander and subcarrier generator, including remote control facilities and an integral power supply.

It installs directly below OPTIMOD-FM Models 8000A, 8100A, and 8100A/1, and can work with the Studio Chassis and/or XT Six-Band Limiter. Your current OPTIMOD can be easily adapted for FMX. Just add an easy-to-install interface connector. And OPTIMOD-FMX can be used with nearly any audio processor that offers a peak-controlled output signal tightly bandlimited to 15kHz and has output attenuators.

As development and on-air testing continues, Orban will release further progress information.

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ORBAN TECHNICAL NOTES ON FMX — #1

by Howard Mullinack

FMX improves stereo coverage

FM stereo reception suffers from significantly increased noise as compared to mono reception—typically 23 to 26dB. This noise increase restricts the coverage area of acceptable stereo reception to approximately one-fourth the coverage area of acceptable mono reception. FMX was developed by CBS Technology Center and the National Association of Broadcasters in an attempt to solve this problem.

Stations equipped with FMX can increase their stereo coverage area—up to about that of their mono coverage area—*for those receivers equipped with FMX decoders.* Yet FMX broadcasts are completely compatible with non-FMX receivers, which will continue to receive stereo or mono normally.

How FMX works

FMX is a companding system: The L-R audio (which is the source of the noise increase in stereo) is compressed before transmission and expanded at the receiver.

To assure compatability with existing radios, the L-R stereo subcarrier is transmitted at 38kHz in the normal manner. In addition, a second L-R subcarrier (the FMX subcarrier) is transmitted at the same frequency in *quadrature* (90° out of phase) with the original subcarrier. The FMX subcarrier is *compressed,* and includes a 10Hz pilot tone.

In the FMX-equipped receiver, both the "original L-R" and "FMX" subcarriers are detected. The receiver sums the "original L-R" and "FMX" signal, and then expands the audio on this sum to match the dynamics of the "original L-R" audio. Since the receiver uses the "original L-R" as a reference, it can accurately reconstruct the FMX signal without the FMX generator's having to maintain precisely defined compression characteristics. This is called "adaptive expansion": the expander adapts to match a wide variety of compression characteristics.

The noise reduction is achieved when the FMX L-R audio is expanded: low level signals, and the noise, are reduced in level. Typically, up to 20dB of noise reduction can be achieved.

FMX compression characteristics vs. "real-world" radio

CBS, in their design of FMX, introduced a "developmental" compressor to permit initial field trials and to prove the basic FMX principles. But the compression characteristics of this "developmental" compressor are not applicable to many stations. Fortunately, "adaptive expansion" allows Orban to optimize the compressor characteristics of FMX while maintaining full recovery of the original signal on standard and FMX-equipped receivers.

The first area of concern in the design of the OPTIMOD-FMX compressor is *overmodulation.* Under certain sound field conditions, the CBS "developmental" compressor can create continuous overmodulation—not just overshoots—of up to 26%.

Another factor is *loudness* and *audio processing*. The FMX system adds an additional subcarrier (and additional modulation) to the composite signal. Normally, modulation must be reduced to accommodate an additional subcarrier. The CBS "developmental" compressor has a reentrant characteristic: As the level of the "original L-R" subcarrier increases toward 100% modulation, the level of the "FMX" subcarrier decreases. With full modulation of the "original" L-R subcarrier, the "FMX" subcarrier actually disappears, with all of the benefits of FMX disappearing with it.

The advantages of FMX become less and less apparent as more processing is used to load the composite more and more heavily. If the composite always looks like it has been shaved with a buzzsaw, there won't be any room for the added subcarrier. The FMX compressor will stay in its "reentrant mode" much of the time, and little or no noise reduction will be available (except possibly when the announcer pauses for air). Of course, with high modulation levels, the noise will be somewhat less apparent.

OPTIMOD-FMX—our approach

It's clear that the design of a "real-world" FMX compressor is quite a complex endeavor. FMX encoders will be highly differentiated according to the skills of the various manufacturers.

OPTIMOD-FMX®: AN INTRODUCTION

At Orban, four goals were foremost in the design of the OPTIMOD-FMX Stereo Generator: (1) It cannot produce overmodulation; (2) the on-air sound must not suffer from audible loss of loudness; (3) compression characteristics that produce audible processing artifacts will not be acceptable; and (4) the design must not degrade SCA performance.

Real-world on-air testing

So far, FMX has been on-air tested by CBS at only a few "public" stations using very conservative processing. We feel that if FMX is to be successful, it must work with all types of formats and processing preferences, with various exciters and STLs, and on stations with and without SCA. It must not significantly increase the deleterious effects of multipath.

If FMX encoders are released prematurely, without thorough research of potential drawbacks *and* extensive on-air testing to assure that those drawbacks are overcome, FMX will be doomed to failure. First impressions are lasting impressions. We are now beginning our *own* series of extensive on-air tests.

Availability of FMX receivers

IC manufacturers are just starting development of FMX decoder chips, so receivers for the mass market will not be available before mid-1987. Two high-end hi-fi manufacturers, NAD and Apt, expect to have a limited supply of receivers available later this year, with FMX implemented using discrete circuitry.

Availability of OPTIMOD-FMX

Orban may be first to market, but only if we have a finely tuned product that will satisfy the needs of our customers. The necessary design and field testing must be done carefully, and will take some time.

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OPTIMOD-FMX®: AN OVERVIEW

by Robert Orban

FMX™ is an FM stereo companding system which offers up to 20dB noise reduction in stereo mode, yet is compatible with existing receivers. Developed jointly by Emil Torick of CBS Technology and Tom Keller of NAB, it promises the first fundamental improvement in FM stereo technology since the system was approved almost 25 years ago.

Nevertheless, to assure the success of FMX in the mass market, there are a number of potential pitfalls which must be addressed. Some of these include overmodulation control, noise modulation effects, multipath distortion, system performance in the automotive environment, and the effects of audio processing. Orban is taking all of these into account in the development of our FMX generator.

Thanks to the novel concept of "adaptive expansion" in the receiver, an FMX receiver can adapt to a wide variety of transmission compression characteristics. By comparing the existing L-R subchannel to a new compressed L-R subchannel, the adaptive expander in the receiver "knows" exactly how much expansion to apply to achieve correct decoding and high separation. This means that each FMX encoder manufacturer can design the FMX compressor as he sees fit, and that different manufacturers' FMX encoders are likely to be highly differentiated.

The CBS "developmental" compressor was designed to prove the basic principles of the system. However, this prototype design can cause steady-state overmodulation of up to 126% with certain soundfields. The usefulness of the "developmental" compressor is thus limited by the fact that average modulation must be reduced by about 2.5dB to ensure overmodulation protection.

Orban therefore embarked on the development of a second-generation FMX compressor—one without this limitation. Our OPTIMOD® -FMX design (patent pending) is a compressor whose characteristics are program-dependent, instead of fixed (like those of the "developmental" compressor). L-R compression threshold and ratio adapt to the needs of the program material on a moment-to-moment basis to achieve optimum noise reduction without danger of overmodulation.

Applicability Of FMX

FMX is not a cure-all. It works best when the stereo signal-to-noise ratio is already fairly high. And it does nothing to reduce multipath effects. If a station is highly processed, noise reduction will probably be noticeable only on program material with short periods of silence, such as announcers' voices.

The benefits of FMX *increase* as processing is reduced. In marginal signal areas it dramatically improves wide dynamic range program material like classical music. It is also ideally suited for "beautiful" formats and for public and educational stations.

Receiver Design

As long as the uncompanded stereo signal-to-noise ratio exceeds about 45-50dB (i.e., about the noise level of a cheap cassette with no noise reduction), then noise modulation is unlikely to be audible even with "difficult" program material like solo piano. But, like any other compander system, FMX can produce noise modulation or "breathing" effects when the channel noise level gets too high.

Especially during mobile reception, FM stereo signal-to-noise ratios can deteriorate to the point where the FMX process breaks down and produces noise modulation or even fails to produce any noise reduction whatever. For this reason, FMX-equipped receivers will also need traditional variable-blend processing to deal with extremely poor signal conditions. Such variable-blend processing is "single-ended" noise reduction that reduces the level of the L-R subchannel (or rolls off its high frequencies) as a function of received signal strength, dynamically varying stereo separation (possibly in a frequency-dependent way) to prevent objectional noise from appearing at the receiver's output.

Multipath

The stereo subchannel is much more subject to the effects of multipath distortion than is the main channel (L + R). Because FMX transmissions usually modulate the subchannel region much more heavily than do conventional transmissions, it is necessary to experimentally investigate how much of an additional problem this may cause in both FMX and conventional receivers. Both Orban and CBS Technology Center are presently performing such field tests. The parameters of our design will be adjusted as necessary to take such effects into account.

OPTIMOD-FMX And The Broadcast Chain

OPTIMOD-FMX is to be a self-powered stand-alone unit containing the FMX compressor and a newly-designed high-performance stereo generator which produces the FMX (quadrature) subchannel in addition to the normal stereo baseband components. OPTIMOD-FMX is designed to plug directly into an OPTIMOD-FM of any vintage (including the old 8000A) and to operate without further adjustment.

OPTIMOD-FMX can also be used with nearly any audio processor equipped with output attenuator controls, and with a peak-controlled output signal that is tightly bandlimited to 15kHz. (Older FM peak limiters manufactured by CBS Labs, Harris, etc. are usually not sufficiently bandlimited.)

OPTIMOD-FMX And The SCA Channels

The FMX compressor can increase the modulation in the L-R subchannel (23-53kHz) by up to 20dB. The FMX modulation process can thus amplify out-of-band energy due to insufficient audio filtering, thereby increasing subchannel-to-main-channel crosstalk and interference to the SCA region of the baseband. So bandlimiting the L-R signal is more crucial than in standard FM stereo. Composite clipping (which can cause splatter throughout the SCA region) is particulary inappropriate for FMX.

Fig. 1 shows the spectrum control of a system consisting of an OPTIMOD-FM Model 8100A/1 and an OPTIMOD-FMX. An FFT spectrum analyzer was set to display the highest peak value observed at each point in the spectrum over the time of the measurement. A typical commercially-successful recording (Mr. Mister's "Broken Wings") was played through the system, and the entire cut was observed for maximum spectral content. It can be seen that the 19kHz pilot tone was very well protected and that energy in the SCA region above 60kHz was limited to −75dB below 100% modulation (top of screen = 100% modulation = ± 75kHz deviation). This performance is unusually good, even for a competitively-loud processor producing a conventional FM stereo signal without FMX.

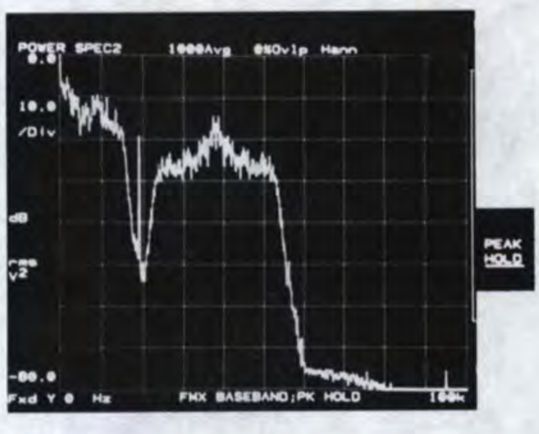

Fig. 1: OPTIMOD-FMX Baseband On Peak Hold.

FMX And Program Directors

FMX might be the breakthrough that finally ends the FM loudness wars and increases the overall quality of FM broadcasting. Although quality increases have been futilely predicted so many times that most people take such prophecies about as seriously as astrological prognostications regarding the end of the world, this time there is a carrot: FMX's effectiveness is *improved* as audio processing is backed off. This means that, on an FMX receiver, stereo coverage area *increases* as less processing is used. Given the enormous commercial success of Compact Discs (which offer by far the highest audio quality ever provided to the average consumer), even the toughest P.D. may be swayed in the direction of better audio when he is told he can finally have his cake and eat it too!

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PRELIMINARY INFORMATION

ORBAN
MODEL 8150A OPTIMOD-FMX®
FMX STEREO GENERATOR

- **[ ] Increases stereo coverage area up to four times for FMX-equipped receivers.**
- **[ ] Reduces FM stereo noise.**
- **[ ] Orban's FMX prevents overmodulation and audible loss of loudness.**
- **[ ] Works with OPTIMOD-FM of any vintage, and some other audio processors.**
- **[ ] Projected price: $2,995.00.**
- **[ ] Projected delivery: Fall 1986.**

The FMX Solution to FM Stereo Noise

FM stereo suffers from the main compromise of significantly increased noise as compared to mono. As a result, the stereo coverage area is restricted (usually to one-fourth the area of the mono coverage).

In response to this problem, CBS Technology Center and the National Association of Broadcasters developed the FMX technology. Stations equipped with FMX can increase their stereo coverage area to about that of their mono coverage area for those receivers equipped with FMX decoders. Yet FMX broadcasts are completely compatible with non-FMX receivers, which will continue to receive stereo or mono normally.

Loudness and Over Modulation

The FMX system adds an additional subcarrier (and additional modulation) to the composite signal. Under some input signal conditions, this additional modulation can increase the overall instantaneous peak level of the composite by up to 26%! Few commercial FM stations would be willing to reduce modulation to accommodate such peaks.

Fortunately, Orban has been able to adapt the characteristics of FMX within the confines of the system to solve this problem while maintaining full recovery of the original signal on standard and FMX-equipped receivers.

OPTIMOD-FMX exacts no loudness penalty! Orban's proprietary circuitry controls modulation under all sound field conditions. This results in a signal that *sounds just as loud* as a non-FMX signal with the same amount of processing.

OPTIMOD-FMX

OPTIMOD-FMX is a complete, self-contained stereo generator. It combines a newly-designed ultra-high-performance stereo encoder, an FMX compander and subcarrier generator, FMX over modulation control circuitry, setup controls, remote control capability, and an integral power supply.

It works with OPTIMOD-FM of any vintage, even our earliest Model 8000A. OPTIMOD-FMX can also work with non-Orban broadcast processors that have effective peak and bandwidth control.

Easy to install: OPTIMOD-FMX is an Accessory Chassis that installs directly below OPTIMOD-FM Models 8100A or 8000A. Your current OPTIMOD-FM can be easily adapted for FMX: Just add an easy-to-install interface connector in a knock-out hole provided. For non-Orban broadcast audio processors, rear panel L and R audio inputs are provided.

A composite output feeds your exciter or composite STL. No modifications or special adjustments to the exciter or STL are required.

Easy to set up: No level matching is required with any OPTIMOD-FM. For non-Orban broadcast audio processing, a pair of LEDs makes level matching quick and simple. No adjustment of stereo pilot phase will be required since the pilot is unconditionally phase-locked to the subcarrier.

Connectors and switching for an external generator are provided so than the existing stereo generator in OPTIMOD-FM (or another stereo generator) can remain connected as a back-up.

Remote control connections are provided for switching between STEREO/MONO-L/MONO-R, FMX ON/OFF, and INTERNAL/EXTERNAL COMPOSITE.

How FMX Works

FMX is a companding system: The L-R audio is compressed before transmission and expanded at the receiver.

The L-R stereo subcarrier is transmitted at 38kHz in the normal manner. In addition, a second L-R subcarrier (the FMX subcarrier) is transmitted at the same frequency in quadrature (90° out of phase) to the original subcarrier. The FMX subcarrier is compressed, and includes a 10Hz pilot.

Adaptive expansion: In the FMX-equipped receiver, both the "original L-R" and "FMX" subcarriers are detected. The audio on the FMX subcarrier is expanded to match the dynamics of the "original L-R" audio.

Since the receiver uses the "original L-R" as a reference, it can accurately reconstruct the FMX signal without the FMX generator having to maintain precisely defined compression characteristics. The expander thus "adapts" to match a wide variety of compression characteristics. Orban has made use of this "adaptive expansion" to design a system that optimizes the compression characteristics of FMX to eliminate over modulation, loss of loudness, and processing artifacts.

Noise reduction is achieved when the FMX L-R audio is expanded. Low level signals (including noise) are substantially reduced in level.

Additional technical information about FMX: CBS Technology Center has published a technical bulletin describing the FMX system and a technical paper published in the Journal of the Audio Engineering Society, Vol. 33, No. 12, December 1985, under the title "Improving the Signal-to-Noise Ratio and Coverage of FM Stereophonic Broadcasts."

Reprints are available from Orban or CBS Technology Center.

Availability

On-air testing: So far, FMX has been on-air tested by CBS at only a few "public" stations using very conservative processing.

Orban feels that to be successful, FMX must work with all types of formats and processing preferences, with various exciters and STLs, and on stations with and without SCA. And it must allow no over modulation or loss in loudness. We are now conducting extensive tests to assure that it will work for *all* stations. OPTIMOD-FMX will be released for general use when these tests are successfully completed.

FMX receivers will probably not be commonly available in the marketplace before the end of 1986, although one manufacturer (NAD) will have a very limited supply of receivers before then.

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TECHNICAL BULLETIN

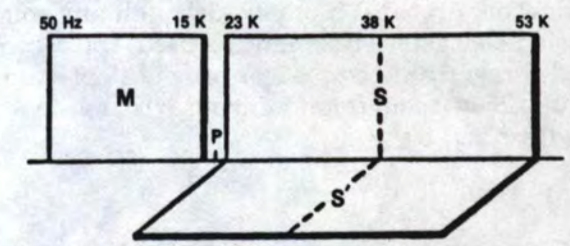
CBS TECHNOLOGY CENTER

FMX™

EXTENDED RANGE FM STEREO RECEPTION

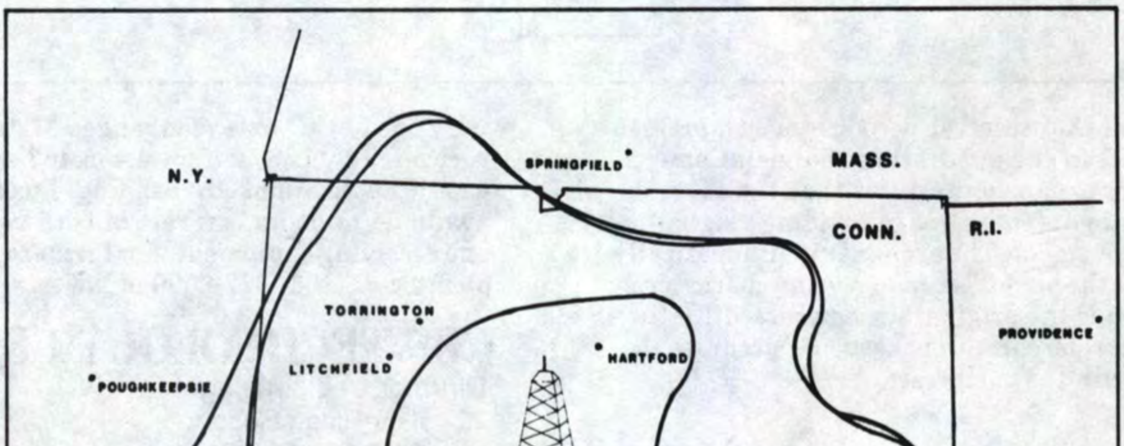
The new FMX™ extended range FM stereo system developed by the CBS Technology Center and the National Association of Broadcasters improves FM stereo fidelity and increases the useful range over which an FM stereo signal can be received. The new system is compatible with, and will not affect, existing FM broadcasting methods and present consumer receivers. The consumer with a new FMX™ tuner will enjoy improved reception at greater distances.

The map illustrates the proven effectiveness of FMX™ reception in Connecticut tests. The new system eliminates the noise penalty of stereo in comparison with monophonic reception. The result is dramatically decreased noise and an increase in reception area up to four times that for conventional stereo.

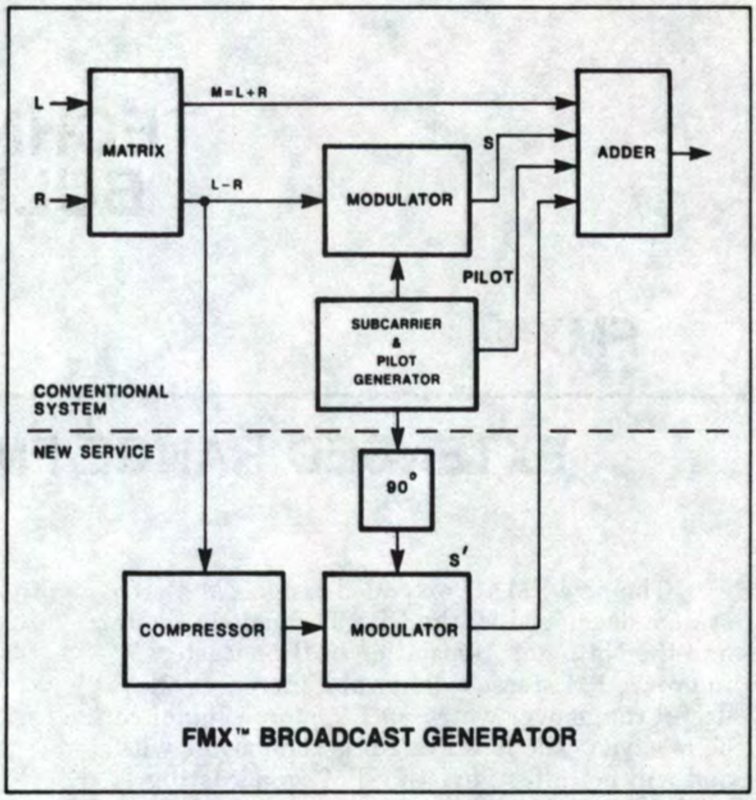


SPECTRUM OF COMPOSITE SIGNAL

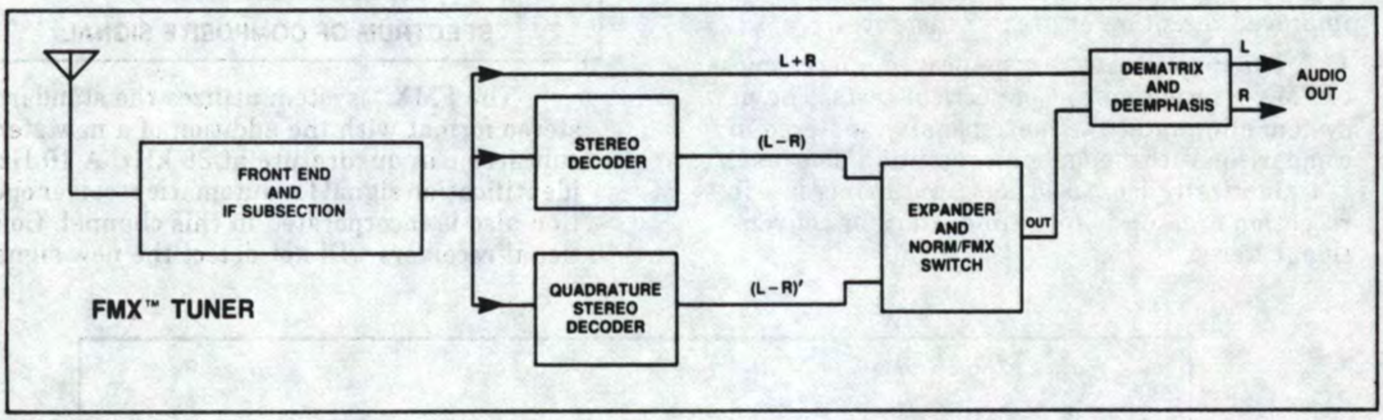
The FMX™ system utilizes the standard FM stereo format with the addition of a new stereo subcarrier in quadrature at 38 kHz. A 10 Hz identification signal for automatic receiver operation also is incorporated in this channel. Conventional receivers will not detect the new signals.



60 dB RECEPTION CONTOURS



The broadcaster transmits a compressed audio version of the L − R difference signal within the new quadrature channel. Although any compression characteristic might be used, the recommended reentrant compressor provides optimum modulation without compromising existing broadcast service.



The FMX™ receiver decodes the compressed L − R signal in the quadrature channel. Complementary expansion restores the original dynamic range of this signal, providing a signal-to-noise improvement. The expander is automatically adaptive to the broadcast compression characteristic. It utilizes the original uncompressed L − R signal as a reference, thus assuring accurate tracking with the compressor.

The FMX™ extended range FM stereo system is covered by U.S. Patent 4,485,483 and other patent applications are pending. Licenses will be available to manufacturers of both transmitting and receiving equipment. For further information, please call (203) 327-2000 or write:

CBS TECHNOLOGY CENTER
Director of Licensing
227 High Ridge Road
Stamford, CT 06905
USA

Improving the Signal-to-Noise Ratio and Coverage of FM Stereophonic Broadcasts*

EMIL L. TORICK

CBS Technology Center, Stamford, CT 06905, USA

AND

THOMAS B. KELLER

National Association of Broadcasters, Washington, DC 20036, USA

It is a well-known phenomenon that the presently authorized system for FM stereophonic radio broadcasting imposes a significant degradation of the received signal-to-noise ratio when such broadcasts are compared with monophonic transmission. As a consequence, the station coverage area is reduced for both monophonic and stereophonic reception. A new broadcast service, designated FMX, has been developed as a solution to this problem. The improvements that may be achieved are analyzed, and it is demonstrated how audio companding may be implemented in future broadcast transmissions without compromising existing service.

0 INTRODUCTION

The potential of FM sound broadcasting as a high-fidelity medium has been recognized since the earliest commercial FM radio broadcasts in the 1940s. A decade later, with the advent of television broadcasting, frequency modulation was also selected as the transmission method for television sound because of its relative immunity to electromagnetic interference and the ability to provide full audio bandwidth with low noise. Although FM radio was hardly a universal success in the commercial sense when stereophonic broadcasts were first authorized in 1961, it was not long before the attraction of two-channel high-fidelity sound helped elevate FM to the status it enjoys today. But while stereophony adds a new acoustical dimension to radio reception, it does so only at the expense of serious degradation of another high-fidelity parameter—the signal-to-noise ratio.

This noise penalty in stereophonic broadcasting is well known. However, less obvious is the restrictive influence this phenomenon has on station coverage. Often the limits of stereophonic reception shrink the coverage typically to one-fourth or one-fifth the area of simple monophonic broadcasts.

* Presented under the title "The FMX Stereo Broadcast System" at the 79th Convention of the Audio Engineering Society, New York, 1985 October 12–16.

1 THE NOISE PENALTY

Several factors contribute to the higher noise levels and coverage losses resulting from multichannel transmissions. When a station converts to stereophonic service, monophonic coverage is reduced since signal power must be divided among the various components of the more complex baseband signal. The stereophonic signal-to-noise ratio is less than the monophonic signal-to-noise ratio because of the wide bandwidth of the composite signal. The equation of this signal is familiar:

$$f(t) = M + p \sin \omega/2t + S \sin \omega t$$

where M is the monophonic sum signal, p is the pilot, S is the stereophonic difference signal, and $\omega = 2\pi 38$ kHz. With a baseband spectrum extending to 53 kHz for stereo transmissions, the noise level is particularly high because of the rising spectral characteristic due to frequency modulation. As illustrated in Fig. 1, the so-called triangular noise spectrum increases 6 dB per octave with increasing frequency of the composite signal. Audio deemphasis counteracts this somewhat, as shown in this figure, but the noise problem is still severe. After demodulation, the noise components of the difference channel subcarrier—statistically independent—are added to the noise already present in the monophonic signal during audio dematrixing.

A precise computation of the theoretical loss of the signal-to-noise ratio must take into account factors such as the effect of deemphasis, the format of the audio test signal that is assumed, and interleaving. Interleaving is an interesting phenomenon. With certain audio signals the peak amplitude of the sum of the main and subchannels may be less than the sum of the peak amplitudes of these channels, thus permitting the interleaved signals to be raised to higher modulation. The result is an improvement in the signal-to-noise ratio.

A calculation of the signal-to-noise degradation in stereophonic reception was published by Parker and Ruby [1] in 1962. In it, they assumed the transmission of the peak monophonic power available, that is, no modulation of the subcarrier ($L - R = 0$). While their conclusion of 23-dB degradation has received widespread acceptance, this figure is not representative of all programming. More recently, under EIA auspices, the National Quadraphonic Radio Committee (NQRC) studied the subject in greater detail. In its final report [2] the NQRC reaffirmed the 23-dB penalty for a monophonic test signal, but also, by using a wide variety of audio test signals, demonstrated that the penalty may be as high as 26 dB. With typical programming, however, the interleaving effect appears to reduce the actual stereo noise penalty to approximately 20 dB. For monophonic receivers, the NQRC data also predict noise degradation of 1–7 dB, depending on the particular type of test signal used.

Such losses of signal-to-noise ratio furthermore cause a reduction in the effective area of coverage for a broadcast station. Fig. 2, based on NQRC data [3], illustrates this effect for a representative set of transmission and reception conditions.[1] For reception at a 50-dB signal-to-noise ratio, station coverage extends to a radius of 128 mi (206 km) when monophonic transmission only is employed. But with stereophonic transmission, monophonic reception is limited to 100 mi (160 km), and two-channel reception to 60 mi (97 km). Although in reality station service areas are often limited by co-channel interference rather than by noise, Fig. 2 represents a useful comparison of the theoretical limits.

2 NOISE REDUCTION BY COMPANDING

The application of companding systems offers a potential solution to the problem of the noise penalty. Companding systems achieve noise reduction by first compressing the dynamic range of an audio program before transmission and then expanding it to its original dynamic range at the receiver. Fig. 3 illustrates this process. On the left, the original program signal is represented, with a wide dynamic range and a low noise level. In the center, for this example, the upper region of dynamic range is compressed prior to transmission. Following transmission and reception, additional noise is detected at a level below that of the compressed program, but at a level that would have intruded on the program had it not been compressed. Finally the expanded program is shown reconstituted to its original dynamic range and with the noise simultaneously reduced to an unobtrusive level.

Companding systems have achieved success in various audio applications, including tape and disk recording. For broadcasting, tests were conducted in Sweden in the early 1960s utilizing companding in the S channels of FM–AM and FM–FM transmission systems. Favorable results were reported for the FM–FM transmissions, although the system was never fully implemented. More recently, significant improvements in companding systems have been achieved. Renewed interest in broadcast applications is now evident in the

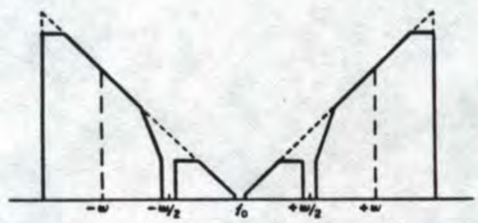


Fig. 1. FM noise spectrum with deemphasis.

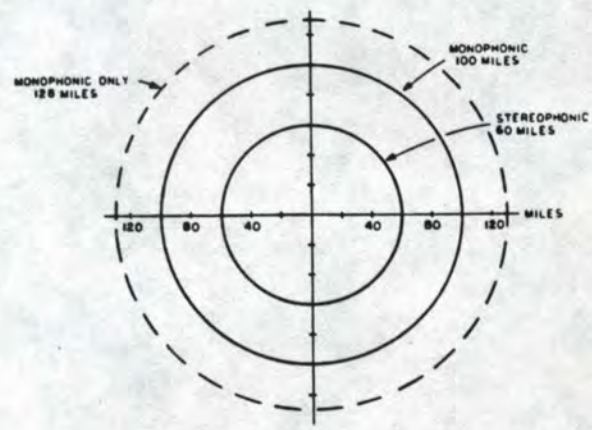


Fig. 2. Reception limits for 50-dB signal-to-noise ratio (NQRC criteria).

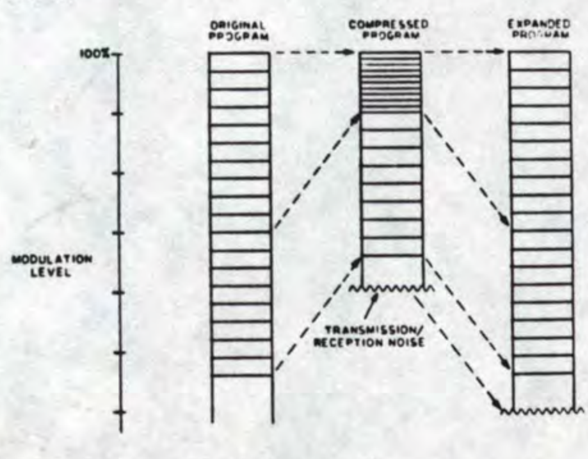


Fig. 3. Companding.

[1] The NQRC used the FCC FM engineering charts for the estimated field strength exceeded at 50% of the potential receiver locations for at least 50% of the time, with a dipole receiving antenna height of 30 ft (9 m). The transmitter height was assumed to be 1000 ft (305 m), with a 10-kW effective radiated power at 98 MHz. The receiver was assumed to have a 10-dB noise figure.

industrywide studies of methods for transmitting multichannel sound in television broadcasts. Under EIA and NAB auspices, the Multichannel Sound Committee of the Broadcast Television Systems Committee recommended, and the FCC endorsed, the use of companding both in the *S* channel and the second audio program (SAP) channel in television audio [4]. Although the stereo noise penalty is less severe in television (<15 dB) than in radio broadcasting, companding permits reception with acceptable sound quality at least to the geographical limits of acceptable picture quality.

3 COMPANDING IN FM RADIO BROADCASTING

Given the recent advances in the art of audio companding, it is once again appropriate to consider its application to FM radio broadcasting. Some broadcasters have experimented with companding in the left and right audio channels to provide modest noise reduction in receivers equipped with appropriate expanders and, through simple receivers without expanding capability, relatively acceptable playback. However, the need to maintain compatibility with existing receivers inhibits the potential for truly significant noise reduction in other (more capable) receivers. Alternatively, the use of companding in the *S* channel of an FM broadcast would allow full compatibility with monophonic reception and the potential for a significant reduction of the stereophonic reception noise penalty, but at the cost of a serious degradation of stereophonic reception in existing receivers which are not equipped with expanders.

The new FMX[2] system provides an alternative approach that achieves both better noise reduction and compatibility with existing receivers, and which avoids any modification of the audio signals in either the *M* or the *S* channel. In this scheme a companded *S'* channel is transmitted, in addition, to provide noisefree stereo reception to a new class of receivers. (Existing receivers will continue to utilize the conventional *S* channel.) The new *S'* channel is transmitted in quadrature with the existing stereophonic subcarrier as follows:

$$f(t) = M + p \sin \omega/2t + S \sin \omega t + S' \cos \omega t \ .$$

Fig. 4 represents the baseband spectrum of the new service. The quadrature subcarrier modulation requires no additional spectrum space, and as will be shown herein, may be configured to avoid any loss of modulation potential for existing service.

Fig. 5 is a block diagram of the encoder for the new composite signal. A conventional audio matrix is used to derive the sum and difference signals. A carrier generator provides the 19-kHz pilot tone and the sine and cosine functions of the 38-kHz subcarrier. The L–R difference signal modulates the sine carrier. The same L–R difference signal, but compressed, along with an identification (ID) signal of approximately 10 Hz (at a level which produces 1% deviation of the main carrier), modulate the cosine subcarrier to produce the new *S'* signal. The *M*, *S*, *S'*, and pilot signals are added together to constitute the complete composite signal.

4 A NEW COMPANDOR

Conventional companding systems generally operate with a compression slope of 2:1 or 3:1. In some applications such slopes are desired for compatibility reasons, that is, playback without complementary expansion. Also, in conventional systems where expanding is employed, a finite positive slope is required to provide sufficient signal level discrimination for complementary tracking by the expander. A higher compression ratio would permit more effective loading of the transmission channel, but proper decoding would be difficult or impossible. If companding is employed in the difference channel of a broadcast system, errors in expansion will cause a degradation of stereo separation. Fig. 6 illustrates several separation contours as a function of amplitude and phase errors in the sum and difference signals. As shown here, even assuming no audio phase

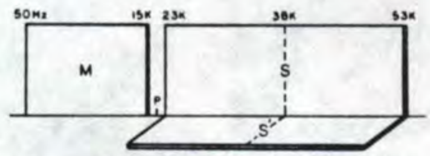


Fig. 4. Baseband spectrum.

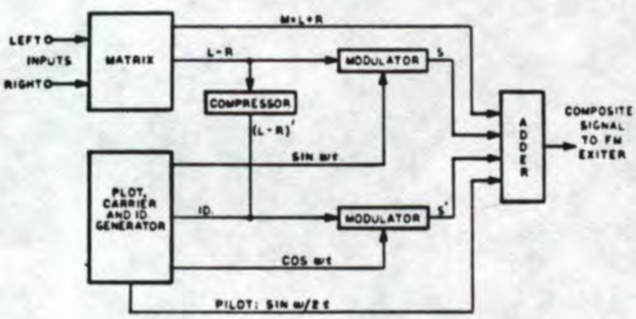


Fig. 5. Encoder.

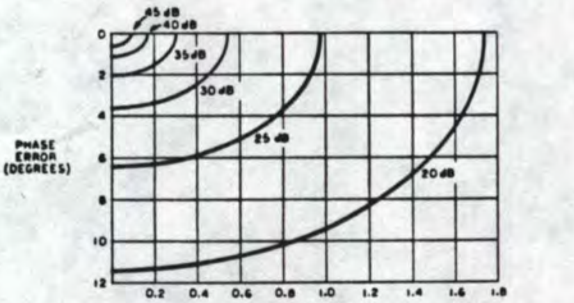


Fig. 6. Separation contours as a function of amplitude and phase inaccuracy in the sum and difference signals.

[2] Registered trademark of CBS, Inc.

mistracking, 25 dB of separation will require amplitude tracking within 1 dB, and 35 dB of separation will require tracking within 0.3 dB.

A unique companding system [5] is employed in the new broadcast service. Designed to minimize tracking errors, it also avoids a potential modulation penalty due to the added S' signal. Fig. 7 illustrates the compression characteristic. At low signal levels the response of the compressor is linear, but at 20-dB higher gain than that of the uncompressed $L-R$ channel. At midlevel inputs the compression characteristic exhibits a nearly flat slope, changing at high levels to a rapidly falling slope. When the compressed and uncompressed signals are combined, the result is shown here as the broken line of total subcarrier modulation. This characteristic has an important significance to the broadcaster. If instead of reducing S' gain as the signal approaches 100% modulation, as shown here, the S' signal were allowed to approach the same level as that of the S signal, a penalty of overall modulation level to the existing service would be incurred. For left (or right) signals only, this penalty would be approximately 1.6 dB; for more complex signals, the penalty could be significantly greater. The compression characteristic of Fig. 7 results in a negligible penalty, since it is primarily the levels of the original M and S signals that establish modulation constraints.

Accurate decoding of audio signals compressed according to the above "reentrant" characteristic requires the implementation of new expansion principles. To contend with the signal level ambiguities present in the compressed signal, the expander employs a tracking-reference signal. Fortunately such a signal is already present in the form of the uncompressed S signal. Fig. 8 shows how it is implemented. The audio signal to be

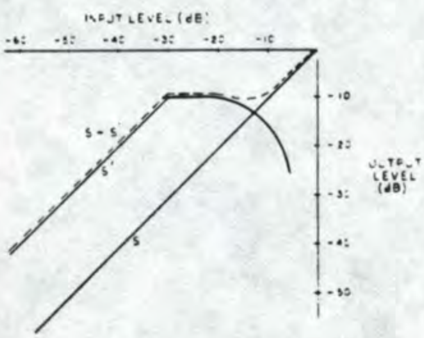


Fig. 7. Reentrant compression characteristic.

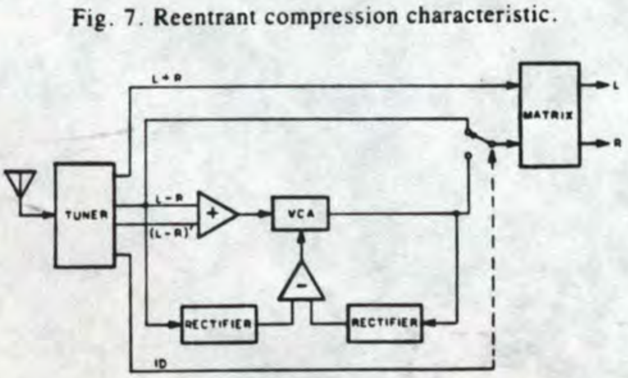


Fig. 8. Receiver/expander.

expanded is made up of the sum of the compressed and uncompressed $L-R$ signals. The control signal for the voltage-controlled amplifier (VCA) is derived from the level difference between the expanded difference signal and the original (reference) difference signal. The circuit functions as a servo amplifier, restoring the compressed signal to be equivalent to the original. For signals below the threshold of compression, the expander reverts to linear operation, thus avoiding decoding errors in the region where the reference signal may be noisy. Finally detection of the identification (ID) signal provides automatic switching to the new noisefree difference signal for broadcasts that incorporate the new service.

5 COMPATIBILITY CONSIDERATIONS

Compatibility considerations fall into two categories—transmission and reception. As previously shown, the use of the reentrant compression characteristic precludes transmission concerns about modulation levels for conventional reception. Futhermore, since the new quadrature channel falls within the same 53-kHz bandwidth as the existing transmissions, no transmitter modifications are required. The broadcaster needs only to replace a conventional stereo generator with a new one which also provides the compressed quadrature signal.

For reception, crosstalk is the major consideration. Since any potential crosstalk will be program related, it may add to or subtract from the conventional signal components. Fig. 9 shows the effect on stereo separation caused by crosstalk from the S' channel to the S channel. The effect shown is a function of both the amount of compression (gain) of the S' channel and the misalignment of the receiver with respect to proper 38-kHz phase. If the phase error is negative, the crosstalk will be in phase and may contribute to a potential narrowing of the apparent stage width. If the phase error is positive, the crosstalk will be out of phase and may contribute to an apparent widening of the stage width, an effect intentionally sought by some broadcasters who add additional gain to the S channel of their transmissions. In actual practice neither effect is likely to be noticed. The reentrant compression characteristic (Fig. 7) effectively limits program peaks in the S' channel to levels which are equal to or lower than those in the S channel. Thus the crosstalk factor for the sig-

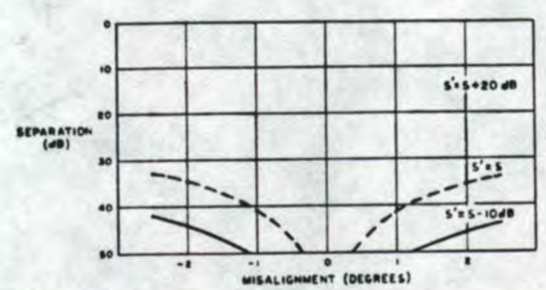


Fig. 9. Separation compatibility due to 38-kHz phase misalignment in receivers.

nificant program transients that dominate the psychoacoustic localization process is minimized.

6 SYSTEM EFFECTIVENESS

The reception benefits offered by the new broadcast service may be viewed both as improving the signal-to-noise ratio of reception and extending the useful range of reception. Fig. 10 illustrates the degree of improvement that may be expected in a good receiver as a function of the existing stereophonic signal-to-noise ratio. In strong signal areas, the monophonic and stereophonic signal-to-noise ratios in most receivers are better than 70 dB, and little further improvement can be expected. For stereo reception poorer than a 60-dB signal-to-noise ratio, the new service offers dramatic improvement to the full capability of the system. Near the limit of effectiveness (<35 dB S/N), some improvement is theoretically possible but potentially subject to audible noise modulation. In this region a fixed blend or monophonic playback is preferred.

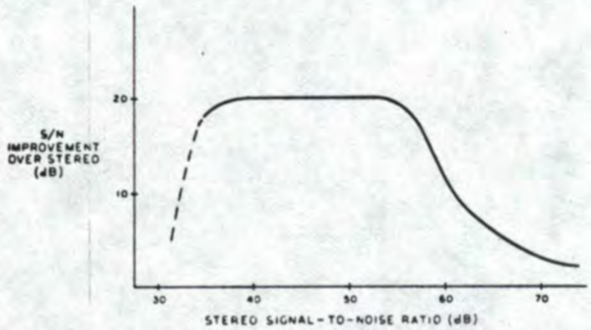


Fig. 10. Typical improvement in a good receiver.

Initial broadcast tests were conducted in cooperation with Connecticut Public Radio Station WPKT. Transmitting a 19-kW signal at 90.5 MHz, the station provides a broad range of programming to a discriminating statewide audience. Broadcast reception measurements were made along 10 radial routes from the transmitter site in Meriden, CT. Fig. 11 compares the contours of reception for a received signal-to-noise ratio of 60 dB for conventional stereo, mono, and the new service. A high-fidelity receiver with adjacent channel selectivity greater than 70 dB was used, with a dipole antenna at a height 10 ft (3 m) for the measurements. Except for a small area in a mountainous section of the western sector, the stereophonic service extends all the way to the monophonic contour. Although for nondirectional transmissions, theory predicts an approximate threefold increase in coverage area, the combination of WPKT directional transmission and the boundary of Long Island Sound at the southern limit of station coverage resulted in even greater improvment. In this case the extended 60-dB stereo service area effectively has been quadrupled from approximately 1200 to 4800 mi^2 (from 3100 to 12 400 km^3), with the corresponding coverage of significant new market areas.

7 CONCLUSIONS

Sufficient evidence exists to warrant the adoption of new companded service for FM radio broadcasting. As shown herein, such transmission has the potential for providing stereo service nearly equivalent to that provided by monophonic receivers.

Compatibility with existing receivers can be maintained if the compressed signal is encoded in a new channel, which is in quadrature with the *S* channel.

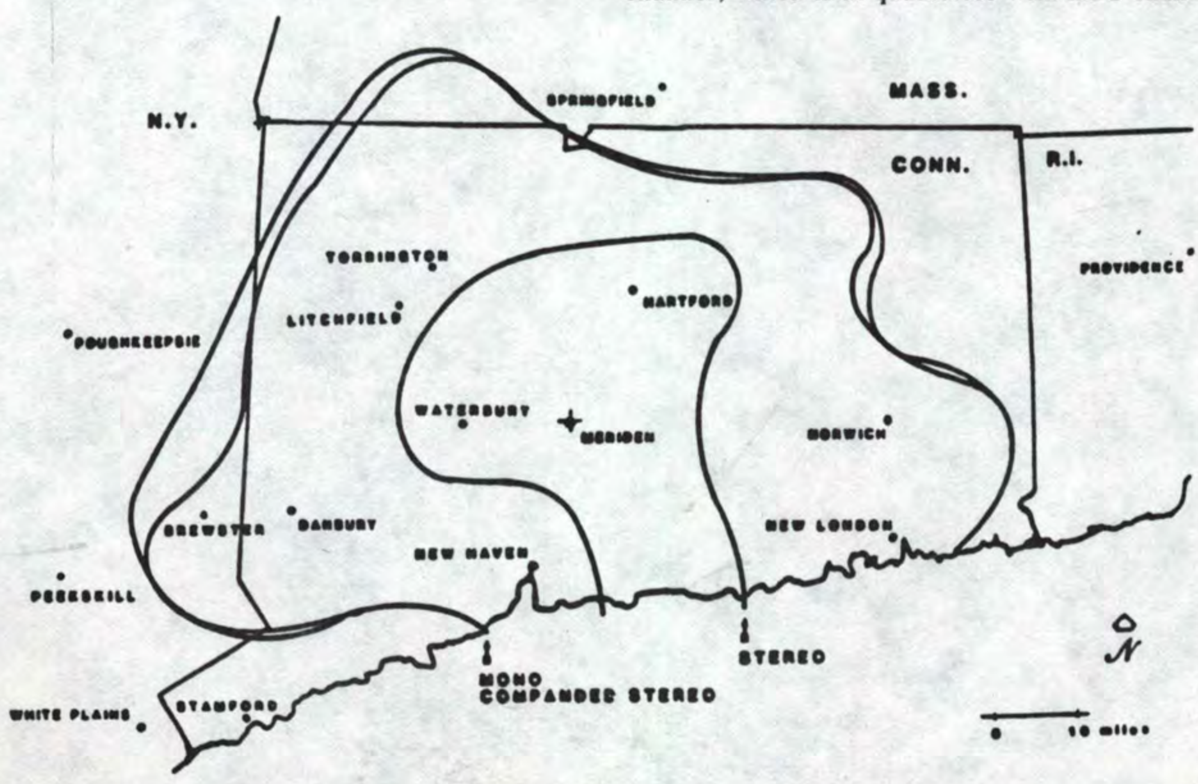


Fig. 11. 60-dB reception contours.

The implementation of appropriate transmission equipment is easy to achieve.

Finally, a sufficient number of quality-conscious radio listeners will provide a ready market for the new class of receivers.

8 ACKNOWLEDGMENT

The authors gratefully acknowledge the numerous contributions to the development and test of the new broadcast system by Messrs. John C. Burne, Aldo G. Cugnini, Daniel W. Gravereaux, Jeffrey B. Kadin, Thomas E. Rucketenwald, and David W. Stebbings, all of the CBS Technology Center.

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T. Keller

Emil L. Torick, vice president, audio technology, for CBS Inc., has been a member of the professional staff of the CBS Technology Center (formerly CBS Laboratories) since 1958. Prior to joining CBS, Mr. Torick served as an officer in the United States Air Force. He earned the B.M. degree from Duquesne University, has the B.S. degree in physics from the University of Pittsburgh, and the M.B.A. degree in business administration from the University of Connecticut. Initially a professional symphony violinist and church organist/choir director, he continues to enjoy these activities on an avocational basis.

Mr. Torick has been a member of the Audio Engineering Society since 1959. He was named a fellow in 1968, was elected to the board of governors for the period 1972–1975, and served as president in 1977–1978. In 1979 he was named an honorary member, and in 1984 he was awarded the AES Bronze Medal. He has served as the chairman of the working group on digital sampling frequencies, as convention technical sessions chairman, on the awards committee, the publications awards committee, and, since 1968, on the editorial review board. He is currently president of the AES Educational Foundation.

Mr. Torick is a recognized authority on broadcasting, recording, musical instrument and consumer electronic technologies. He is a senior member of the IEEE. Under the auspices of the State Department, he serves as U.S. chairman for sound broadcasting in the CCIR. He is the author of more than 40 technical publications, and has been awarded 14 U.S. patents.

In 1981, Thomas B. Keller joined the NAB staff as senior vice president of the science and technology department. He is responsible for the operations of the department which involve FCC filings and establishing broadcast engineering standards in AM/FM radio and television. In addition, Mr. Keller presently holds a patent for an improved FM broadcast transmission system.

Prior to joining NAB, he served as director of engineering development for the Public Broadçasting Service (PBS) in Washington, DC. During his three years with PBS, his department improved UHF TV transmitter efficiency and worked extensively on TV multichannel sound standards.

From 1961 until 1979, Mr. Keller served as director of engineering for the WGBH Educational Foundation in Boston, MA. During this time, he was responsible for all of the engineering and technical operations of the WGBH facilities, as well as for the construction and engineering of two new television stations—WGBX, the foundation's second channel, Channel 44 (Boston) and WGBY, Channel 57 (Springfield, MA).

Before 1961, he was special projects engineer for the Walter Reed Army Medical Center, a pioneer in closed-circuit medical television.

An active participant in numerous industry organizations, Mr. Keller serves as chairman of the EIA BTS Multichannel Television Sound Subcommittee, is a fellow of the Society of Motion Picture and Television Engineers (SMPTE), and a member of the Institute of Electrical and Electronics Engineers (IEEE).

