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POWER RATIO OF WANTED TO UNWANTED SIGNALS FOR FREQUENCY SHARING BETWEEN FM AND AM-VSB TELEVISION TRANSMISSION SYSTEMS

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16. Abstract

This paper describes experiments which determine that for barely perceptible interference, an interfering FM signal in the passband of an AM-VSB television channel should have an average power level from 37 to 48 dB below the sync peak average power of the AM-VSB signal, at the AM receiver input. Conversely, an AM-VSB interfering signal should have a sync peak average power level from 16 to 26 dB below the average power of the FM signal, at the FM receiver input. The experimental results are used to evaluate frequency-sharing between an FM transmitter in synchronous orbit and an AM-VSB television system on earth.

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SUMMARY

Laboratory tests of co-channel interference on amplitude and frequency modulated television transmission systems were conducted to determine the interference that exists when an FM television system is operated at the same frequencies as an AM-VSB television station. Tests were conducted for both the FM signal interfering on AM reception, and the AM signal interfering on FM reception. Results of these tests indicate that for barely perceptible interference, an interfering FM signal in the passband of an AM-VSB television channel should have an average power level from 37 to 48 dB below the sync peak average power of the AM-VSB signal, at the AM receiver input. Conversely, an AM-VSB interfering signal should have a sync peak average power level from 16 to 26 dB below the average power of the FM signal, at the FM receiver input.

The results of these experimental tests are then used to evaluate frequency-sharing between an FM transmitter in synchronous orbit and an AM-VSB television system on earth. The signal coverage patterns for each system are calculated for the area surrounding the terrestrial transmitter. The analysis indicates that the satellite transmitted FM signal can be received interference free over most of its target area. The AM-VSB signal can be received interference free over its principal coverage area, but interference is produced near the radio horizon of the AM transmitter.

INTRODUCTION

This report presents the results of experiments to determine the criteria for frequency sharing between frequency modulated (FM) television signals and amplitude modulated television signals with vestigial sidebands (AM-VSB). The experiments described determine the relative power ratios at the inputs to the FM and AM-VSB receivers, when the interference caused by the unwanted signal is just barely perceptible. These results are used to evaluate the possibilities for frequency sharing between geostationary satellites transmitting FM television signals and terrestrial television stations broadcasting AM-VSB television signals.

The question of frequency sharing arises because of the nearly total occupancy of the communications frequency spectrum. Analysis of television transmission from geostationary satellites shows that certain carrier frequencies are technically or economically optimum. However, because of the many demands for frequency allocations, these optimum frequencies are already being used for other types of communications. Frequency sharing between satellites and other users would allow dual use of the frequency spectrum and would accommodate both services.

One of the frequency bands that is technically advantageous for satellite television transmission is the upper UHF band (710 to 890 MHz). The use of a satellite downlink frequency in this band would insure maximum frequency compatibility with existing UHF television sets. However, use of these frequencies may cause objectionable interference to existing UHF terrestrial television stations. Similarly, frequencies near 2.5 gigahertz are technically advantageous for FM television transmission from satellites in that the satellite system components at 2.5 gigahertz are near optimum in size, weight, and power requirements. But again, there is the potential for interference with an existing service since the frequencies 2.500 to 2.680 gigahertz are allocated to instructional television in the United States.

In both the frequency bands mentioned, 710 to 890 megahertz and 2.500 to 2.680 gigahertz, the transmission format of the existing terrestrial television services is AM-VSB. For many projected applications of television satellites, a frequency modulated transmission format results in reduced satellite size, weight, and power. Thus, the situations of a satellite transmitted FM signal interfering upon an AM-VSB terrestrial television station, and vice versa, are real possibilities and are worthy of experiment and analysis to determine the prospects for frequency sharing.

The problems of co-channel and adjacent channel interference between AM-VSB television stations have been thoroughly measured and analyzed, and the results have been formalized into recommendations and reports of the CCIR (International Radio Consultative Committee; refs. 1 and 2). The case of mutual interference between FM and AM-VSB television signals has not yet been treated. Within the existing recommendations for AM-VSB operation, there are requirements for eliminating the interference between the FM sound subcarrier of one station, and the AM-VSB video signal of another station. These requirements are not applicable to the case of mutual interference between FM and AM-VSB television signals because of the following two reasons.

(1) In the case of the AM-VSB signal interfering on the FM sound, the aural interference is evaluated by listening. Since our senses of hearing and sight have different dynamic ranges, perception thresholds, and difference limens, the results can not be directly transferred.

(2) In the case of FM sound interference on AM-VSB video and color information, the situation is narrow band FM (50 kHz) interfering on wideband (4.5 MHz) AM-VSB. This results in only a portion of the composite AM-VSB signal being disrupted at one time.

The situation with video on both modulation types is wideband FM (20 to 40 MHz) interfering on wideband AM-VSB (4.5 MHz). With both wideband signals, the FM signal can simultaneously interfere with the luminance, chrominance, and audio portions of the AM-VSB composite signal. Thus, the case of mutual interference of FM and AM-VSB television signals is not covered by available data, and experimental analysis is required to determine the possibilities of joint usage of the limited frequency spectrum available.

Laboratory tests conducted at Lewis Research Center have experimentally determined the relative power levels that produce barely perceptible mutual interferences between an FM television signal and an AM-VSB television signal. These tests indicate: (1) the effect of FM transmission on reception of the AM-VSB signal, and (2) the effect of AM-VSB transmission on the reception of the FM signal.

The AM-VSB source is the signal of a terrestrial, commercial television broadcasting station; and the FM source is a video modulated 2.25-gigahertz FM signal. A laboratory oscillator and a mixer translate the frequencies as required for the different interference tests. The content of the AM-VSB transmissions used in the tests is the range of color programming available from daytime television programs. The FM program material used includes test slides, electronically generated test signals, and off-the-air programming from an alternate television station. The peak-to-peak frequency deviation used for all the FM signals is 18 megahertz from white to sync peak. The judgment of barely perceptible interference is determined by subjective evaluation of the video display as the interfering signal is swept across the spectrum of the desired signal.

In appendix B of the paper, mathematical models of typical receiving systems for simultaneous reception of FM and AM-VSB signals are developed using the results of the laboratory tests and the characteristic data of standard parabolic receiving antennas. Signal coverage patterns are then derived for simultaneous AM and FM television coverage over a given terrestrial viewing area in the vicinity of the AM-VSB transmitting station. These signal coverage patterns indicate areas of simultaneous AM and FM reception, AM reception only, FM reception only, and no AM or FM reception due to the cochannel interference. Signal coverage patterns are presented for transmission frequencies at L-band, S-band, and X-band.

APPARATUS AND PROCEDURES

Laboratory experiments to determine the FM interference on an AM signal and the AM interference on an FM signal are described. The first experiment establishes the

FM and AM-VSB relative power levels that cause only barely perceptible visual interference at the output of the AM-VSB receiver. The second experiment establishes the relative power levels that cause only barely perceptible interference at the output of the FM receiver.

For these experiments, barely perceptible interference is defined in the following ways:

(1) Video interference is judged barely perceptible when the interference is so slight that any change in power level or carrier frequency offset which would diminish the interfering effect of the unwanted signal would cause the interference to become imperceptible to the viewer.

Alternately,

(2) Barely perceptible video interference is the lowest interference level such that, once the viewer notices the presence of interference, he cannot deny its existence.

The barely perceptible criterion does not attempt to evaluate the annoying effect of the interference. It only establishes the threshold of perceptibility.

The following sections describe the two interference experiments.

FM Transmission Interfering on AM-VSB Reception

The block diagram of the experiment for determining the interference caused by the FM signal is shown in figure 1. The desired AM-VSB signal is off-the-air programming,

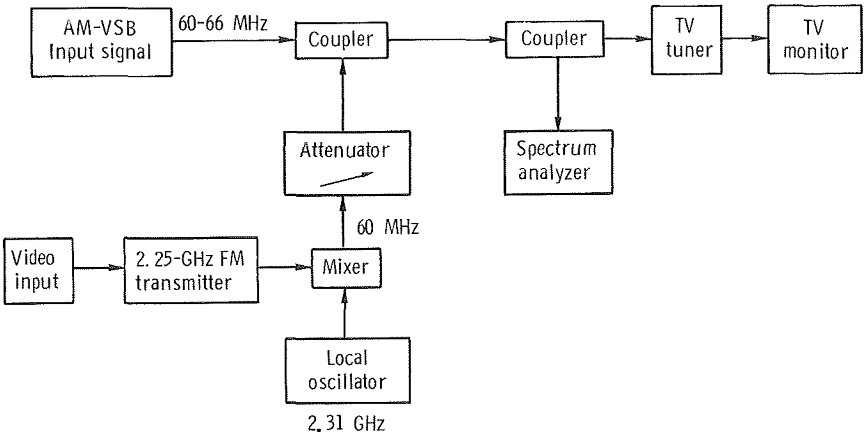


Figure 1. - Block diagram of experiment with FM signal interfering on AM-VSB signal.

channel 3 (60 to 66 MHz), received by a high-gain, roof-mounted antenna. The frequency spectrum of this signal is shown in figure 2. The interfering FM signal is obtained by

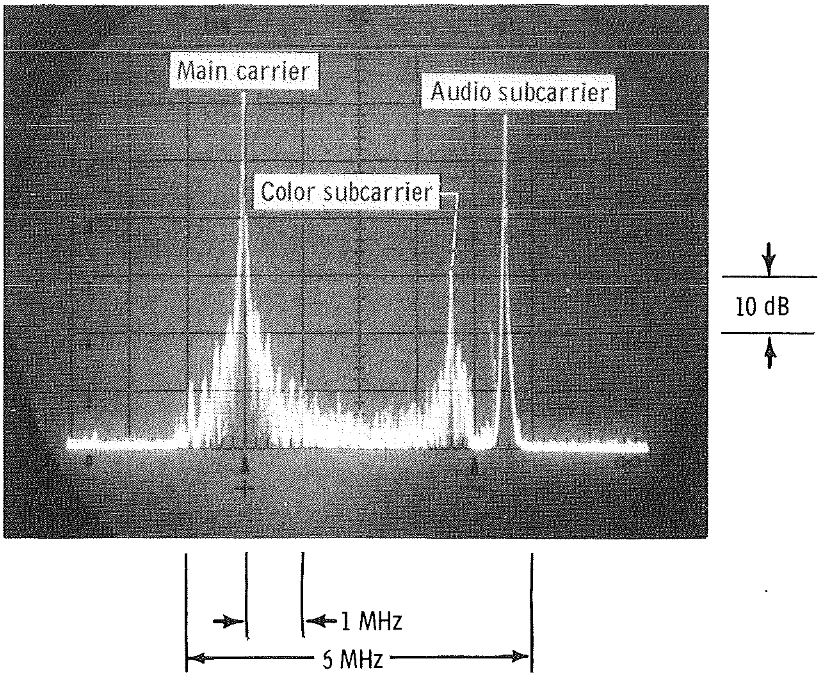


Figure 2. - AM-VSB television signal spectrum.

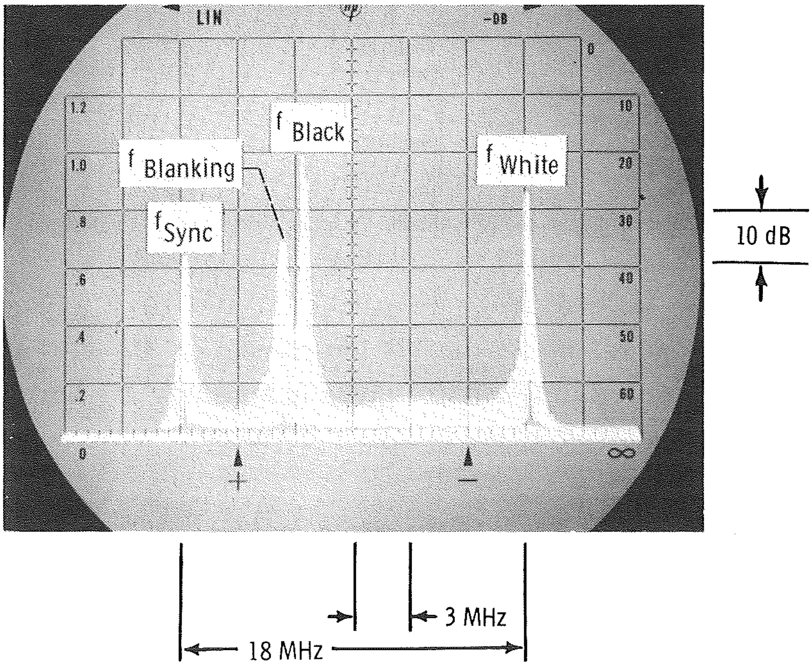


Figure 3. - FM television signal spectrum.

modulating a 2.25-gigahertz FM transmitter with the baseband NTSC (National Television Systems Committee) television signal without the audio subcarrier. The frequency spectrum of a typical FM signal is shown in figure 3. The mixer translates the FM signal down to the frequency of the AM-VSB channel, and the attenuator following the mixer controls the power level of the FM signal reaching the AM-VSB receiver. The FM and AM-VSB signals are coupled together and fed to the tuner input. The output video signal is displayed on the TV monitor. The spectrum analyzer is used to establish the relative average power levels of the FM and AM-VSB signals and to determine the frequency separation between the two carrier frequencies.

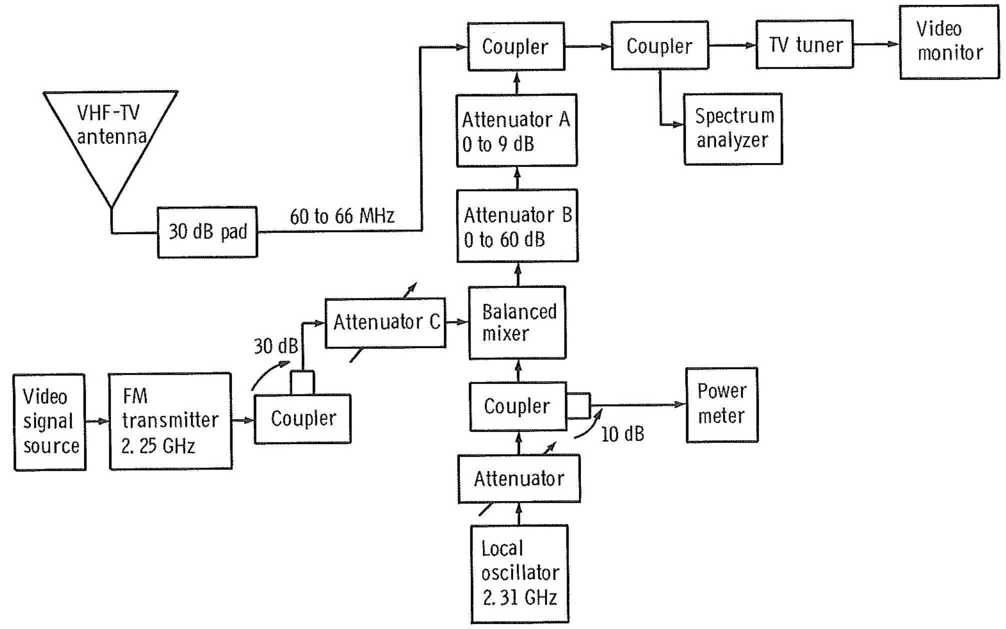


Figure 4. - Equipment diagram of experiment with FM signal interfering on AM-VSB signal.

The detailed equipment set-up for the FM interfering on AM-VSB experiment is shown in figure 4, and the procedures followed are given in appendix A. From appendix A, the power ratio $R_{AM/FM}$ is defined by the following equation.

$$R_{AM/FM} = \frac{\left(P_{SYNC\ PK\ AV}\right)_{AM-VSB}}{\left(P_{AV}\right)_{FM}}$$

The experiment determines $R_{AM/FM}$ for barely perceptible interference, as a function of the difference between the carrier frequencies of the FM and AM-VSB transmission systems. Repetitions of the experiment using video inputs of electronically generated test signals, 35-millimeter color test slides, and off-the-air programming, provide curves of $R_{AM/FM}$ versus frequency for the range of potential subject matter for FM television programming. The results of these experiments are presented and discussed in the section "Results and Discussion".

AM-VSB Transmission Interfering on FM Reception

The block diagram of the experiment for determining the interference caused by the AM-VSB signal is shown in figure 5. The same basic approach is used in this experiment as in the FM interfering on AM experiment, except that the roles of the AM-VSB signal and the FM signal are interchanged. The desired FM signal is obtained by modulating the 2.25-gigahertz FM transmitter with the baseband video signal composed of the NTSC standard luminance and chrominance signals. The FM spectrum for a typical video input is shown in figure 3. The interfering AM-VSB signal is obtained by frequency translating to 2.25 gigahertz a commercial VHF television channel. The variable attenuator following the mixer is used to control the power level of the interfering AM-VSB signal. The major features of the AM-VSB spectrum are shown in figure 2. The FM and the AM-VSB signals at 2.25 gigahertz are coupled together and fed to the FM receiver. The output video signal is displayed on the TV monitor. The spectrum analyzer is used to establish the relative average power levels of the FM and AM-VSB signals and to determine the frequency separation between the two carrier frequencies.

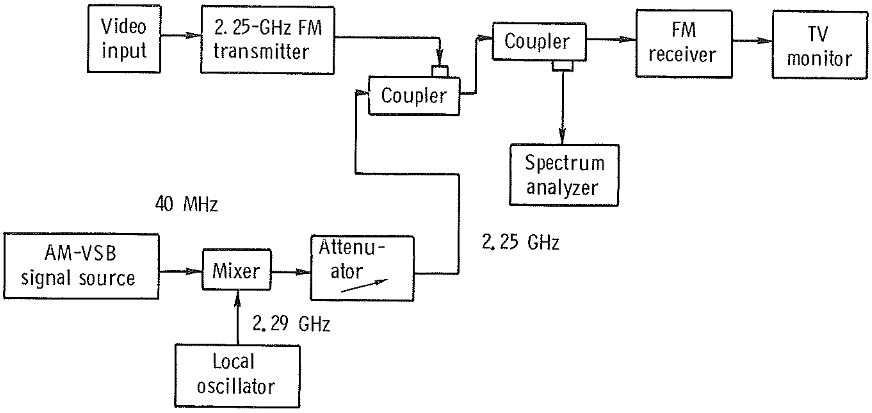


Figure 5. - Block diagram of experiment with AM-VSB signal interfering on FM signal.

The detailed experimental test set up for AM interference on FM as shown in figure 6 is more complex than that required for the alternate FM on AM tests. The additional com-

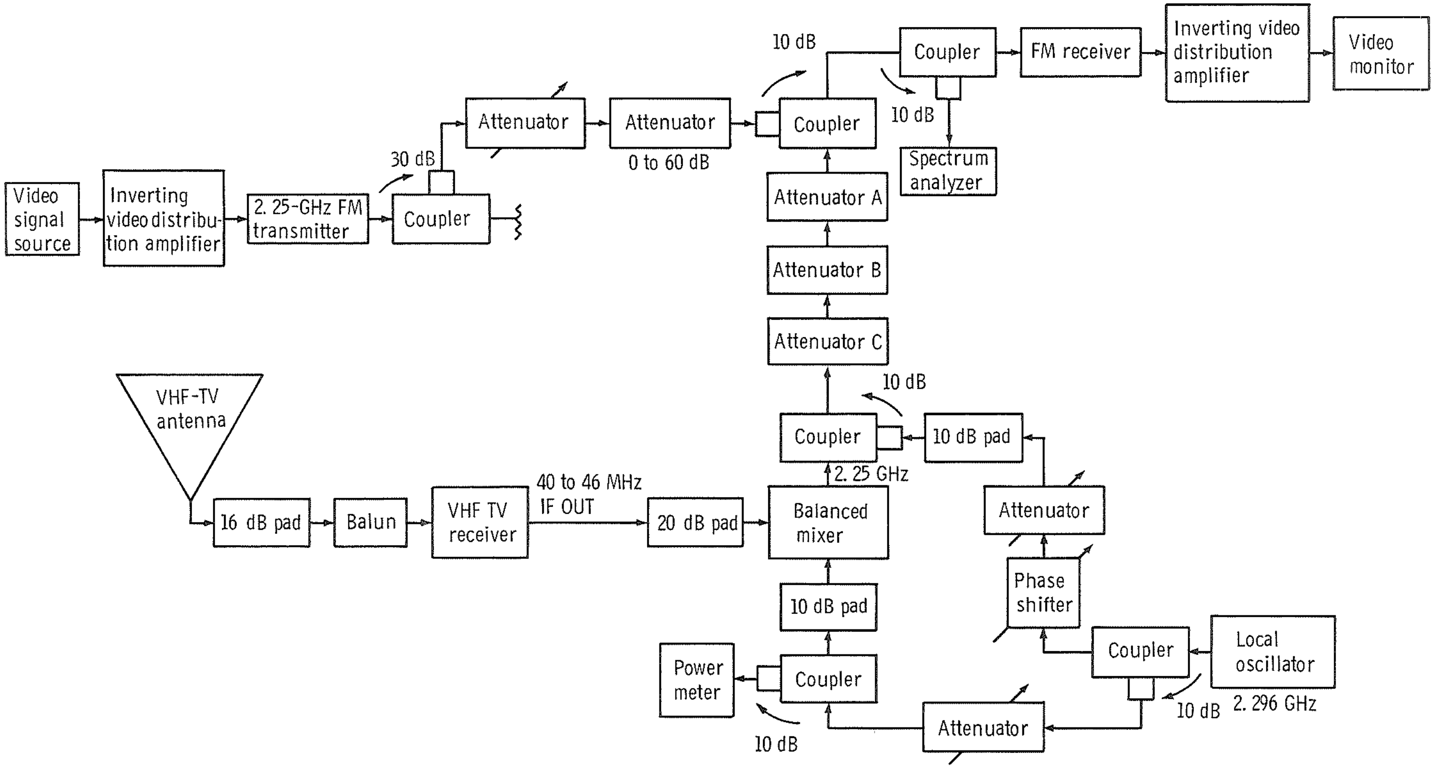


Figure 6. - Equipment diagram of experiment with AM-VSB signal interfering on FM signal.

ponents are required because of the problems encountered in obtaining a single AM-VSB television signal as the sole interfering signal. Television channel 8 (180 to 186 MHz), is used as the interfering channel, however, strong interfering signals received on the television antenna in the region of 130 to 140 megahertz also cause interference. In order to eliminate these spurious interfering signals, the rf and IF sections of the VHF television receiver are used as filters. As a result, only the AM-VSB channel is allowed to provide the interfering signal. The IF output of the receiver provides an AM-VSB signal with a 45.75 megahertz carrier frequency. Thus, the mixer output provides the AM-VSB signal at 45.75 megahertz above and below the local oscillator frequency. The lower sideband is used as the interfering AM-VSB signal, and the upper sideband is far enough away from the FM receiver center frequency to cause no problems. But, the local oscillator signal, even with the balanced mixer used to suppress its amplitude, is near enough in frequency and of sufficient amplitude to cause unwanted interference. A portion of the local oscillator signal is then injected immediately after the mixer to cancel the unwanted local oscillator signal present at the mixer output.

The detailed procedures of the experiment with AM-VSB transmission interfering on FM reception are given in appendix A. The power ratio $R_{FM/AM}$ is determined by the following equation from appendix A.

$$R_{FM/AM} = \frac{\left(P_{AV}\right)_{FM}}{\left(P_{SYNC\ PK\ AV}\right)_{AM\text{-}VSB}}$$

The experiment determines $R_{FM/AM}$ for barely perceptible interference, as a function of the difference between the carrier frequencies of the AM-VSB and FM transmission systems. Repeated experiments using test signals, slides, and off-the-air programming, provide curves of $R_{FM/AM}$ against frequency for a range of potential video sources. The results of these experiments are presented in the section "Results and Discussion".

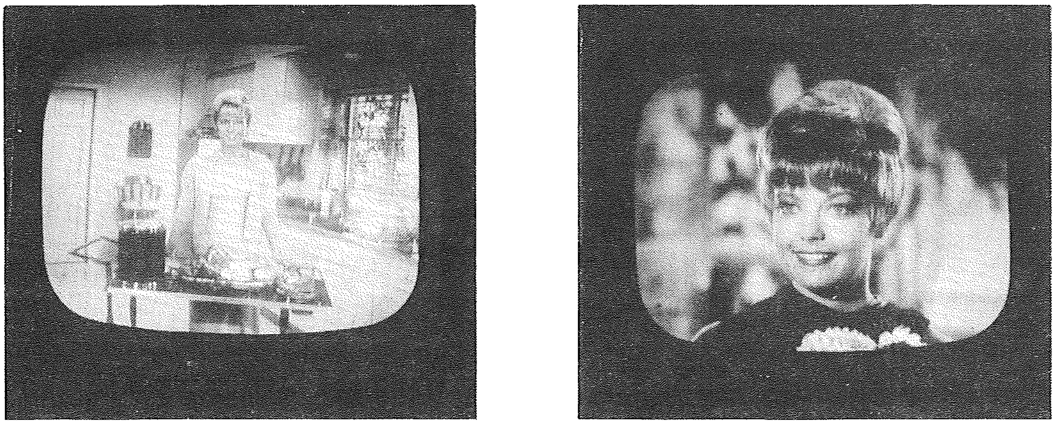
Test Conditions During Experiments

The FM system was operated without pre-emphasis and de-emphasis, and the peak-to-peak frequency deviation was 18 megahertz from white to sync peak. The frequency corresponding to the sync pulse of the video input signal was lower than the frequency of the unmodulated carrier, and the frequency corresponding to white was higher.

In both experiments, the horizontal line frequency of the FM system was locked to the sync of the AM-VSB system, but the phase was adjusted to produce 12 microseconds lag from the FM to the AM sync pulse. With the syncs locked but displaced, the interference during the sync portion of the unwanted signal is visible during the picture portion of the wanted signal. This provides a more noticeable interfering condition than when the syncs are locked but are not displaced.

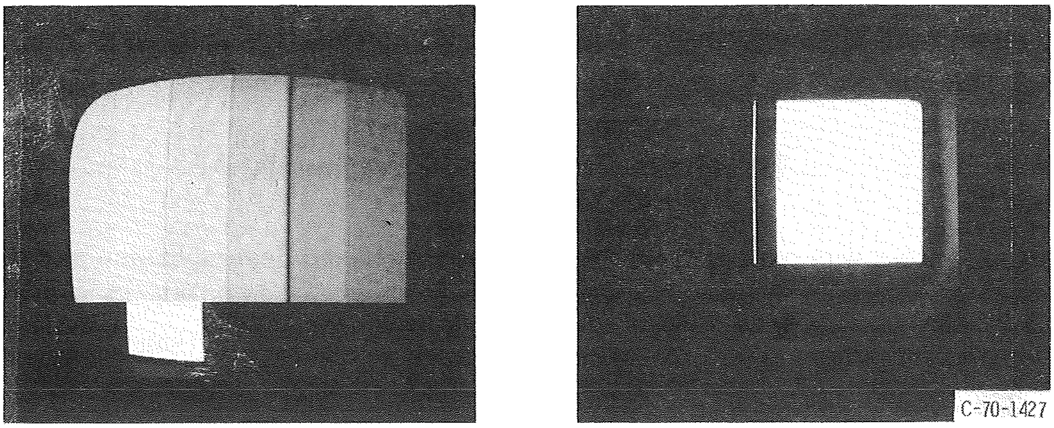
During the FM interfering on AM-VSB experiment the output signal-to-noise ratio of the AM system, with no interference, was approximately 43 dB, where the signal-to-noise ratio is defined as the ratio of the white to blanking voltage divided by the rms noise voltage in 4.5 megahertz bandwidth. In the other experiment, AM-VSB interfering on FM, the output signal-to-noise ratio in the FM system was approximately 44 dB. The signal-to-noise ratios in both cases do not include noise weighting.

In both the FM interfering on AM and the AM interfering on FM experiments, the AM-VSB signal was off-the-air programming from a commercial broadcast station. The subject matter ranged from fairly stationary scenes, such as views of the panel on a quiz program, to action sequences with rapid scene changes, as contained in some commercials. The FM television signal was one of the four stationary scenes, (shown in fig. 7),



(a) Kitchen scene.

(b) Girl slide.



(c) Color bars.

(d) White window.

Figure 7. - Still subjects used as FM transmitter video inputs.

or off-the-air programming different from that used for the AM-VSB signal. The kitchen scene and the girl slide are 35 millimeter color test slides projected into a color television camera. The color bar picture is the standard, electronically generated, split color bar pattern with the six saturated colors and gray, white, black, I, and Q signals. The white window pattern has a white rectangle on a black background with a $\sin^2$ pulse preceding the window. No color subcarrier is present in this signal.

Three viewers were used to judge the interferences as barely perceptible. They were an electronics technician and the two authors. Only one viewer was used for the complete range of values of $R_{AM/FM}$ or $R_{FM/AM}$ for each video input to the FM transmitter. Each viewer was found to be consistent in his judgments both with himself and the other two viewers. Most of the data taken is based upon interference evaluations made by the electronics technician.

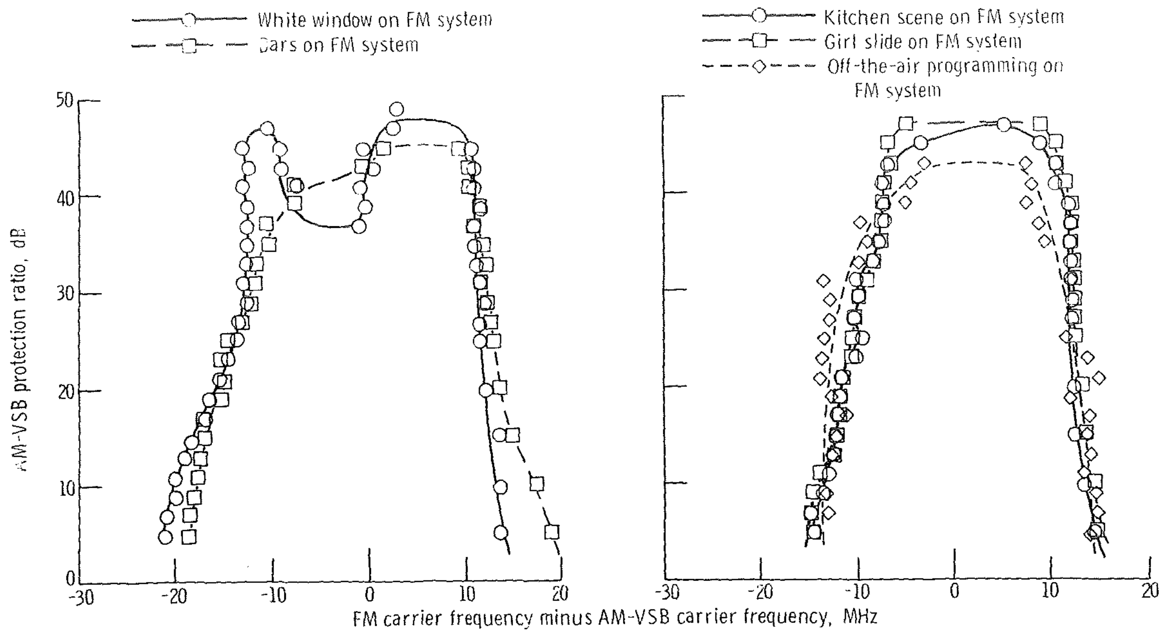
RESULTS AND DISCUSSION

Following the experimental procedures described in the previous sections, the power ratios $R_{AM/FM}$ and $R_{FM/AM}$ for barely perceptible visual interference are determined as functions of the carrier frequency offset. An interference power ratio of this kind is usually referred to as a "protection ratio", the ratio of the wanted to the unwanted signal power. $R_{AM/FM}$ is the AM-VSB television protection ratio against FM television interference, for barely perceptible interference. Similarly, $R_{FM/AM}$ is the FM television protection ratio against AM-VSB television interference, for barely perceptible interference. The results of the experiments are presented as curves of the protection ratios versus carrier frequency offset.

Results for FM Interfering on AM-VSB

The AM-VSB protection ratios determined for barely perceptible interference are shown in figures 8(a) and (b) for the five different video inputs to the FM transmitter. The shapes of the curves can be understood by considering how the FM signal produces interference in the AM-VSB receiver. The AM-VSB receiver will have a spurious output whenever the instantaneous frequency of the FM signal lies within the passband of the AM-VSB receiver. At any instant of time, the frequency of the spurious output is equal to the frequency difference between the AM carrier and the instantaneous value of the FM carrier.

The solid curve on figure 8(a) shows the AM-VSB protection ratio determined for barely perceptible interference with the white window as the interfering FM signal. The



(a) White window and color bars on FM system.

(b) Kitchen scene, girl slide, and off-the-air programming on FM system.

Figure 8. - AM-VSB protection ratio as function of carrier frequency offset. AM-VSB protection ratio = $(P_{SYNC\ PK\ AV})_{AM\text{-}VSB}/(P_{AV})_{FM}$.

peak in the protection ratio at -11 megahertz carrier offset is caused by the frequency corresponding to the white window lying within the AM-VSB receiver passband. The dip in the protection ratio occurs when the AM passband is located between the frequencies corresponding to black and white in the FM signal. The high protection ratio from zero to 10 megahertz is caused by the black, blanking, and sync frequencies being within the AM passband. The skirts of the protection ratio curve outline the IF passband characteristics of the AM receiver.

The dashed curve on figure 8(a) shows the AM-VSB protection ratio determined for barely perceptible interference with the color bars on the FM system. Because of the presence of the color subcarrier in the color bar test signal, the FM spectrum for the color bars has significant amplitude components over a greater frequency range than the FM spectrum for the white window signal. The greater frequency spectrum width of the FM signal for the color bars explains the difference in the widths of the skirts of the two curves in figure 8(a). Also, the more uniform density of significant amplitude spectral components explains the absence of peaks and valleys in the protection ratio curve for the color bars. The interference perceived with color bars on the FM system is a weak image of the two or three color bars whose luminance levels produce instantaneous frequencies within the passband of the AM-VSB receiver.

Figure 8(b) shows the AM-VSB protection ratios determined for barely perceptible interference with the color slides of the kitchen scene and the girl transmitted on the FM system. The frequency spectrums of the FM signals for these two subjects are similar. Both have an apparent continuum of spectral components with significant amplitude components occupying a bandwidth of less than 18 megahertz. The two protection ratio curves are nearly identical and the widths of the skirts are narrower than the first two curves discussed because of the narrower spectrums.

Figure 8(b) also shows the AM-VSB protection ratio determined with off-the-air programming on the interfering FM system. Well defined interference levels are not as apparent for this test condition as for the other test signals. For a given carrier frequency offset and fixed $R_{AM/FM}$, the interference is considered either perceptible or imperceptible, depending on the scene being broadcast. Also, because of movement in the interference patterns, the viewer cannot concentrate on an expected area of interference as he makes his judgment of perceptibility. These factors account for the lower protection ratio determined for off-the-air programming, and for the greater deviation of data points from the smooth curve.

If the curves on figures 8(a) and (b) are overlayed, and a straight line envelope is drawn to enclose the curves, one obtains the plot of the AM-VSB protection ratio versus carrier frequency offset shown in figure 9. This shaded band summarizes the results of the experiments with an FM television signal interfering on an AM-VSB television signal. In the portion of the curve, from approximately -10 to +10 megahertz, the protection

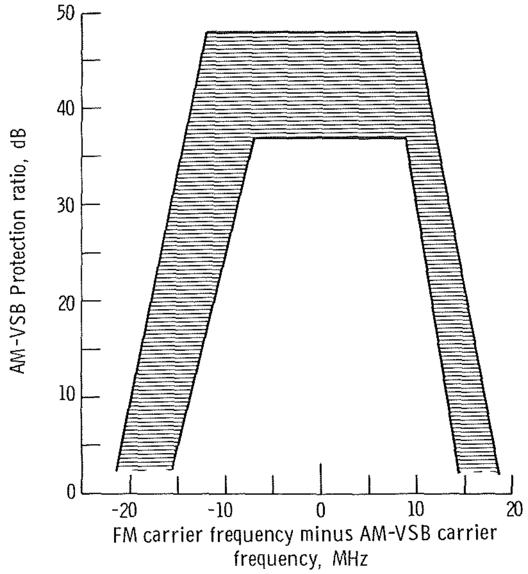


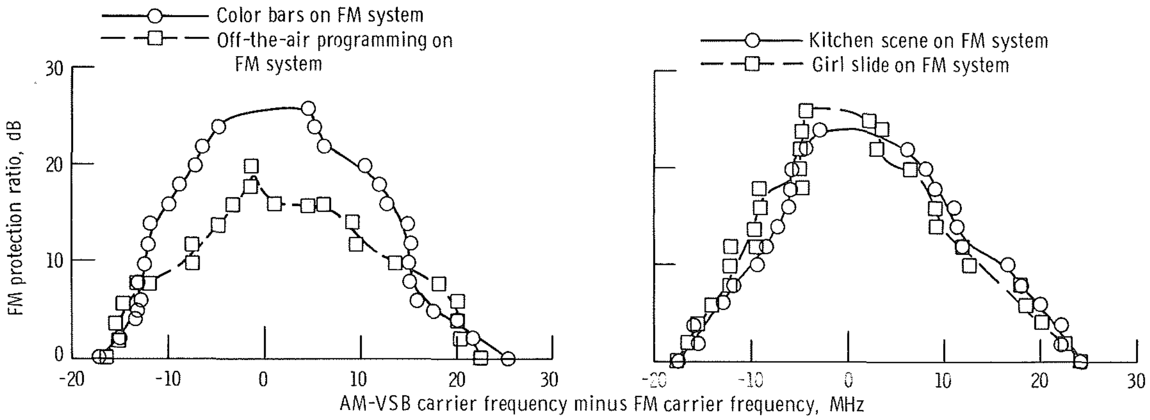
Figure 9. - Protection ratio required for barely perceptible interference in AM-VSB-TV system being interfered on by FM-TV system. AM-VSB protection ratio = $(P_{\text{SYNC PEAK AV}})_{\text{AM-VSB}}/(P_{\text{AV}})_{\text{FM}}$.

ratios near the upper edge of the shaded band are those required for nonmoving pictures on the interfering FM system. The protection ratios near the bottom edge of the shaded band result from experiments using off-the-air programming as the interfering FM signal. The spread in the skirts of the curve is due to the varying spectrum widths of the signals used.

The AM-VSB protection ratio for no carrier offset ranges from 37 to 48 dB as a function of the video input to the interfering FM transmitter. To avoid the extremes of being either too harsh or too lenient for general programming containing both still and moving scenes, the midband value of 43 dB may be used as the nominal value of the AM-VSB protection ratio.

Results for AM-VSB Interfering on FM

The FM protection ratios determined for barely perceptible interference are shown in figures 10(a) and (b) for four different types of signals transmitted on the FM system.



(a) Color bars and off-the-air programming on FM system.

(b) Kitchen scene and girl slide on FM station.

Figure 10. - FM protection ratio as function of carrier frequency offset. FM protection ratio = $(P_{AV})_{FM}/(P_{SYNC\ PEAK\ AV})_{AM\text{-}VSB}$.

In these cases the test condition is a narrower band AM-VSB signal interfering on the wideband FM signal. The video carrier of the AM-VSB signal is the main source of interference. If the AM-VSB carrier is displaced 10 megahertz from the unmodulated FM carrier, the AM interference will occur in those portions of the FM picture that have luminance levels corresponding to a 10 megahertz deviation from the unmodulated carrier. Thus, the general effect of the AM signal is to cause interference near a particular luminance level.

The FM protection ratio determined with the color bar test signal as the FM signal is shown in figure 10(a). The protection ratio is approximately 25 dB over a 12 megahertz range, the frequency deviation corresponding to the white to black signal range.

The FM protection ratio determined with off-the-air programming transmitted over the FM system is also shown in figure 10(a). In this case, as in the FM interfering on AM case with off-the-air programming on both systems, the levels of barely perceptible interference are not well-defined. If the FM signal contains no luminance levels corresponding to the frequency of the AM video carrier, the interference is imperceptible for a given value of $R_{FM/AM}$. However, if the FM transmitted scene changes and then contains that luminance level, the interference becomes perceptible. Also, with changing scenes and motion present, the viewer cannot concentrate on particular areas where the interference might be expected, as in the still scenes. These factors tend to reduce the FM protection ratio determined for off-the-air programming transmitted on both systems.

Figure 10(b) shows the FM protection ratio for the kitchen scene and the girl test slide. For the kitchen scene, the peak in the curve at -4 megahertz and the peak on the skirt near -9 megahertz have an approximate frequency separation of 4.5 megahertz, the difference between the video and audio carriers. These two peaks are due to the AM-VSB video and audio carriers causing interference in a portion of the FM transmitted picture where the interference is easily perceived.

Overlaying curves of figures 10(a) and (b), and drawing a straight line envelope to enclose the curves produces the plot of the FM protection ratio against carrier frequency offset shown in figure 11. The protection ratios for still scenes lie near the upper edge of the shaded band, while the lower edge of the band generally corresponds to the protection ratio for off-the-air programming. The midband value of 21 dB may be used as the nominal value of the FM protection ratio required for zero carrier frequency offset.

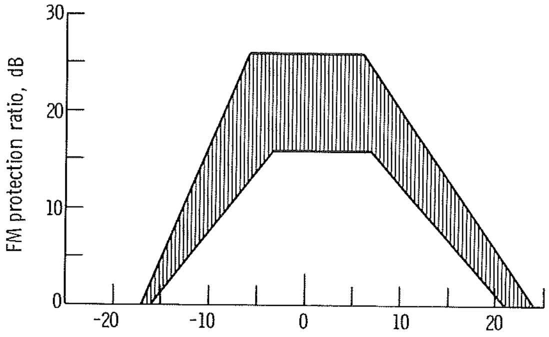


Figure 11. - Protection ratio required for barely perceptible interference in an FM TV system being interfered on by AM-VSB TV system. FM protection ratio = $(P_{AV})_{FM}/(P_{SYNC\ PEAK\ AV})_{AM\text{-}VSB}$.

Accuracy and Sources of Errors

The protection ratio curves presented are subject to small inaccuracies due to errors in determining (1) the protection ratios $R_{AM/FM}$ and $R_{FM/AM}$, and (2) the carrier frequency offset. Each of these sources of possible error will be discussed.

Errors in $R_{AM/FM}$ and $R_{FM/AM}$ can occur during the setting of the reference condition of equal FM average power and AM sync peak average power. The two spectrum peaks displayed can be set equal to within approximately ±0.5 dB, because of the observer's limited resolution of equality. Additional error occurs because the average AM carrier power, as read off the spectrum analyzer, varies as a function of picture content. The procedure used assumes a value of 5 dB for the ratio of AM sync peak average power to AM power as read off the spectrum analyzer. In actual operation with off-the-air programming the ratio of AM sync peak average power to AM average power lies in the range 5.0±0.75 dB, about 70 percent of the time. Thus, this source contributes an error of ±0.75 dB to the determination of equality of the two signals at the reference condition.

The spectrum analyzer used produces a variation in its display of approximately ±0.25 dB over a 30 megahertz display range, for constant input power. At the reference conditions the two carriers are separated by about 0.5 megahertz, which makes the spectrum analyzer response virturally identical at the two frequencies. Therefore, the spectrum analyzer contributes no error to the values of $R_{AM/FM}$ and $R_{FM/AM}$.

Since the equal power reference condition is established with a 0.5 megahertz offset, any variation in the mixer or coupler gain characteristic as a function of frequency affects the power ratios $R_{AM/FM}$ and $R_{FM/AM}$. Errors of ±0.25 dB and ±0 dB are attributed to the nonuniform gain of the mixers and couplers for $R_{AM/FM}$ and $R_{FM/AM}$, respectively. In addition, the input impedance of the VHF television tuner varies with frequency. This affects the power coupled into the tuner and contributes an error of ±0.5 dB in determining the equal power reference condition for the case of FM interfering on AM.

Attenuator A (0 to 9 dB in 1 dB steps), has a specified accuracy of ±0.4 dB. Attenuator B (0 to 60 dB in 10 dB steps), is specified as ±2.0 dB. Errors in the indicated values of these attenuators are errors in $R_{AM/FM}$ and $R_{FM/AM}$.

The numerical values of errors in $R_{AM/FM}$ and $R_{FM/AM}$ due to the sources listed above are summarized by (1) and (2) in table I.

Errors in determining the frequency offset of the two carriers also affect the accuracy of the results. The error due to reading the frequency offset from the spectrum analyzer is estimated to be ±0.5 megahertz. This estimate combines both the nonlinearity and the readibility of the display. The uncertainty in the viewer's judgment of interference as being barely perceptible further contributes a frequency uncertainty of ±0.4 megahertz. The numerical errors in determining the frequency offset are summarized by (3) in table I.

TABLE I. - ERRORS IN THE MEASURED PARAMETERS

Measured parameter	Root-sum-square error	Maximum error
(1) $R_{AM/FM}$	2.3 dB	±4.4 dB
(2) $R_{FM/AM}$	2.2 dB	±3.6 dB
(3) Frequency offset	0.6 MHz	±0.9 MHz

Effects of Variations in Test Conditions

The experiments were performed under a set of test conditions that have already been described. To increase the usefulness of the results, consider variations in the test conditions.

FM transmission interfering on AM-VSB reception. - The FM interfering on AM-VSB experiment was performed using a modulation index of two. Increasing the modulation index would disperse the FM spectrum over a greater bandwidth and interference would occur over a greater range of carrier frequency offsets. However, the value of the AM-VSB protection ratio for carrier frequency offsets near zero would not change. The interference produced is at a frequency equal to the frequency difference between the instantaneous FM carrier and the AM-VSB carrier, and the amplitude is proportional to the signal strength of the interfering signal. When the interfering FM signal is within the AM-VSB receiver passband, the full FM signal strength produces interference, independent of the modulation index. Thus, increasing the modulation index will not change the values of the AM-VSB protection ratio near zero carrier offset. Decreasing the modulation index will also produce similar values of the AM-VSB protection ratio except that the interference will occur over a narrower frequency range.

The unweighted signal-to-noise ratio at the AM-VSB receiver output was approximately 43 dB. In all the tests performed, the largest measured value of the AM-VSB protection ratio was 48 dB. As the signal-to-noise ratio of the desired signal is decreased, a given level of interference present at the receiver output will become less perceptible because the increased noise masks out the interference. The 5 dB difference between the AM-VSB protection ratio and the AM signal-to-noise ratio will remain constant for signal-to-noise ratios less than 43 dB. At higher signal-to-noise ratios, the AM protection ratio will approach the value of the AM signal-to-noise ratio because of the viewers' difficulty in perceiving the effects of the interference. The 43 dB signal-to-noise ratio used for these tests, however, is sufficiently close to the upper limits on the quality of picture sources that the difference of 5 dB between the AM-VSB protection ratio and the AM signal-to-noise ratio will be valid over the entire range of expected signal-to-noise ratios.

The FM interfering on AM-VSB experiment was performed with the horizontal line syncs of the two systems locked together. This resulted in a stationary interference pattern that is easily perceived. If the line syncs are at different frequencies, the interference rolls through the wanted picture. At some frequencies, the roll is rapid and the interference looks somewhat like random noise interference, while at other frequencies, an annoying flicker is produced. Preliminary experiments show that the AM-VSB protection ratio for barely perceptible interference may be reduced 8 to 10 dB by judiciously choosing the difference in horizontal line frequencies.

For the interfering FM signal used in the tests, the frequency corresponding to white was above the unmodulated carrier, and that frequency corresponding to the sync peak level was below the unmodulated carrier. If the FM spectrum were inverted, there would be little change in the results. The AM-VSB protection ratio near zero carrier frequency offset would remain the same. There might be small, relatively insignificant, changes in the skirt characteristics of the protection ratio curves.

The interfering FM transmitter was operated without pre-emphasis. Using pre-emphasis would decrease the width of the FM spectrum. No appreciable change would occur in the AM-VSB protection ratio other than the overall widths of the curves in figures 8 and 9 would be somewhat narrower.

AM-VSB transmission interfering on FM reception. - Consider changes in the test conditions for an AM-VSB signal interfering on an FM television signal. Changing the modulation index will vary the width of the FM spectrum and the width of the IF filters in the FM receiver. The FM receiver must always have an IF bandwidth of at least 4.2 megahertz regardless of the modulation index. Thus, both the FM signal and the interfering AM signal are passed without attenuation for carrier frequency offsets near zero. If we consider the desired FM carrier to be a sine wave and the interfering AM-VSB signal to be another sine wave of lesser amplitude, the interfering signal causes a constant rms phase error in the zero-crossings of the wanted signal, independent of the modulation index, since both signals are transmitted unattenuated through the receiver IF filters. For a higher modulation index, a given phase error is a smaller proportion of the total signal than for a lower modulation index. Thus, at higher modulation indices an FM system would be able to tolerate a greater absolute phase error, that is, a lower FM protection ratio, for barely perceptible interference.

The output signal-to-noise ratio of the FM system during the AM interfering on FM tests was 44 dB. In an FM television system with a modulation index of two, there is an FM improvement factor of 22 dB. Thus, the IF carrier-to-noise ratio in the FM receiver was approximately 22 dB. The highest measured value of the FM protection ratio for barely perceptible interference was 26 dB. This indicates that an interference power level 4 dB below the random noise level could cause perceptible interference, for the FM receiver operating above threshold. The masking effect of the random noise will tend to preserve this difference as the output signal-to-noise ratio is changed. For a modulation index of two, the difference of 4 dB between the IF carrier-to-noise ratio and the FM protection ratio is considered valid over the entire range of expected signal-to-noise ratios.

The effect of unlocking the syncs is similar to that for the AM-VSB experiments. With unlocked syncs, the interfering signal will roll through and appear somewhat like random noise. A reduction of 5 to 10 dB in the FM protection ratio for barely perceptible interference would result from the proper choice of the sync frequency of the interfering AM-VSB signal.

If the FM spectrum were to be inverted there would be no substantial change in the FM protection ratio. Near zero carrier frequency offset, the FM protection ratio would remain the same, however, there may be small changes in the skirt characteristics of the protection ratio curves.

The major effect of operating the FM system with pre-emphasis and de-emphasis would be to decrease the widths of the FM protection ratio curves in figures 10 and 11.

Applications of Frequency Sharing

The experimentally determined FM and AM-VSB protection ratios are used to evaluate the possibilities for frequency sharing between FM and AM-VSB television transmission systems. Appendix B of this report considers the case of a geostationary satellite transmitting an FM television signal to a terrestrial receiver located near an AM-VSB television transmitter where both transmitters are operating at the same frequencies. From the geometrical configuration of the two transmission systems, and using the directional characteristics of the receiving antennas, signal coverage patterns are calculated showing the mutual interference between the two transmission systems. Examples are given to indicate the possibilities for sharing in each of three frequency bands, UHF, S-band, and X-band. The S-band example is indicative of sharing between satellite transmitted signals and the existing instructional television stations in the band 2500 to 2690 megahertz. The UHF example is calculated for the top of the existing UHF-TV band, 890 megahertz. At X-band there are presently no terrestrial transmitters in the United States using the AM-VSB television format, but the example is included to indicate the degree of sharing possible at these frequencies.

The detailed conclusions drawn from the examples given are listed in appendix B. From the specific examples considered, the following generalizations may be made.

(1) The FM signal can be received interference free over most of its target area, except that there are areas of interference in the immediate vicinity of AM-VSB transmitters.

(2) The AM-VSB signal can be received interference free over its principal coverage

area, but at points near the radio horizon of the AM transmitter the FM signal produces interference.

(3) There may be areas where neither signal can be received satisfactorily.
The sizes and shapes of the areas of mutual interference are determined by the degree of cooperation between the two services and by the characteristics of the receiving antennas used for each system.

These results do not produce a definite yes or no to the possibility of frequency sharing. The examples considered assume cooperation between the two systems in establishing transmitter powers and selecting receiving antennas. The coverage patterns are calculated on the basis of the perceptibility of the interference, without attempting to evaluate the viewers' judgment of the tolerability of the interference. Furthermore, no attempt was made to assess the significance of the loss of coverage in particular portions of the viewing area. Thus, the final decision on a particular proposal to frequency share between FM and AM-VSB television systems will depend upon the amount of cooperation between the two services, the tolerable interference levels, and the significance of loss of coverage in the viewing areas.

CONCLUDING REMARKS

Laboratory tests of an FM television signal and an AM-VSB television signal occupying the same frequency range produce the following results.

1. For barely perceptible visual interference on an AM-VSB television channel, the average power of the interfering FM signal must be from 37 to 48 dB below the sync peak average power of the AM-VSB signal, both measured at the AM-VSB receiver input.

2. For barely perceptible visual interference on an FM television signal, the sync peak average power of the interfering AM-VSB signal must be from 16 to 26 dB below the average power level of the FM signal, both measured at the FM receiver input.

The spread in values of the protection ratios given in (1) and (2) is due to the varying picture content on the two transmission systems. The higher protection ratios are required for stationary scenes on the FM system. The lower protection ratios resulted from experiments using off-the-air programming on the FM system.

The protection ratios given in (1) and (2) are applicable when the frequency difference between the unmodulated FM carrier and the AM-VSB carrier is approximately 6 megahertz or less. For greater carrier frequency separations, the protection ratios are lower. The results given are based on experiments using 18-megahertz frequency deviation of the FM carrier, from white to sync peak. This corresponds to a modulation index of 2.0. During the tests, the wanted signal had an unweighted signal-to-noise ratio of approximately 43 dB with no interfering signal present.

Applying the experimentally determined protection ratios to the case of a synchronous satellite transmitting an FM television signal to a terrestrial receiver in the vicinity of an AM-VSB television transmitter, produces the following principal results, for both transmitters operating in the same frequency range.

(1) The FM signal can be received interference free over most of its target area except that there are areas of interference in the immediate vicinity of AM-VSB transmitters.

(2) The AM-VSB signal can be received interference free over its principal coverage area, but at points near the radio horizon of the AM transmitter the FM signal produces interference.

(3) There may be areas where neither signal can be received satisfactorily.

The sizes and shapes of the areas of mutual interference are determined by the degree of cooperation between the two services and by the characteristics of the receiving antennas used for each system.

Based on the results of the laboratory tests and on the analysis of the signal coverage areas for the specific examples considered, the feasibility of frequency sharing between AM-VSB and FM television transmission systems can neither be proven nor disproven in general. Each particular case must be judged on its own merits. The amount of user cooperation, the interference level that will be tolerated, and the significance of holes in either coverage pattern are all factors that influence the final decision in considering any proposal of frequency sharing between FM and AM-VSB television systems.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, May 13, 1970,
164-21.

APPENDIX A

EXPERIMENTAL PROCEDURES FOR DETERMINING FM AND AM-VSB PROTECTION RATIOS

This appendix presents the specific experimental procedures used to evaluate the mutual interfering effects of FM and AM-VSB television transmission systems. These detailed instructions are presented to allow critical evaluation of the results obtained and to allow other experimenters to duplicate the tests. The steps listed for each experiment are the exact instructions used to conduct repetitions of the experiments.

FM Transmission Interfering on AM-VSB Reception

The block diagram of the experiment for determining the interference caused by the FM signal is shown in figure 1. The laboratory equipment interconnect diagram is shown in figure 4. All laboratory equipment used is standard, commercially available, test equipment.

The procedures and test conditions used are listed in the following sequence.

(1) Interconnect equipment as shown in figure 4.

(2) Set up the FM transmitter.

(a) Set the video input to the transmitter to be one volt from the white level to the sync peak level.

(b) Operate the transmitter without video pre-emphasis.

(c) Calibrate the frequency display of the spectrum analyzer to 3 megahertz per centimeter using channel 3 to channel 5 spacing of 16 megahertz.

(d) Set the frequency deviation of the transmitter to be 18 megahertz from white to sync peak.

(3) Set up the AM-VSB receiver, with the FM interfering signal turned off.

(a) Tune to channel 3, adjust antenna rotor for best picture, and fine tune.

(b) Attenuate the antenna signal to approximately -40 dBm average carrier power level at the tuner input, using the spectrum analyzer to read the average power level.

(c) Fine tune and adjust the tuner output to 1 volt, peak to peak.

(d) Adjust the TV monitor brightness, contrast, and tint with laboratory overhead lights turned off.

(e) Set the monitor to internal synchronization.

(4) Add FM interference.

(a) Tune the local oscillator to 2.31 gigahertz and drive the mixer with +2 dBm local oscillator power. This choice of local oscillator frequency inverts the FM spectrum appearing at 60 megahertz and places the frequency corresponding to the sync peak below that corresponding to the white level.

(b) Lock the line sync frequency of the FM transmitter to the sync of channel 3, for laboratory generated FM video input signals. Adjust the sync phase so that the FM sync leads the AM-VSB sync by about 12 microseconds. This makes the blanking that occurs during the FM sync peak visible in the received AM-VSB picture and represents a worst-case interference condition. For off-the-air video into the FM transmitter, the FM sync is locked to the channel being used.

(5) Set up reference levels.

(a) With ATT_A = 5 dB and ATT_B = 0 dB, adjust ATT_C so that the unmodulated FM carrier has an amplitude equal to the AM-VSB carrier as viewed on the spectrum analyzer, when the carrier frequencies are separated by about 0.5 megahertz.

(b) Set ATT_A = 0 dB; ATT_B = 0 dB; but do not change ATT_C.

These attenuator settings comprise the reference condition for the measurements that follow. At the listed attenuator settings, the average AM carrier power during the sync peak is equal to the average FM carrier power. The spectrum analyzer display actually indicates the FM power to be 5 dB higher than the displayed peak at the AM carrier frequency. This occurs because the power during the AM sync peak is 5 dB greater than the AM power averaged over the entire video signal. The ratio of the AM sync peak power to the AM average power varies with picture content, but the value of 5 dB represents an average over a wide range of pictures. In the measurements that follow the AM-VSB to FM power ratio is given by

$$R_{AM/FM} = \frac{\left(P_{SYNC\ PK\ AV}\right)_{AM-VSB}}{\left(P_{AV}\right)_{FM}} = ATT_A + ATT_B$$

(6) Determine $R_{AM/FM}$, for barely perceptible interference, as a function of the frequency offset of the two carriers.

(a) For $R_{AM/FM}$ = 0 dB, vary the local oscillator frequency until there is barely perceptible interference visible in the AM-VSB video output.

(b) At each frequency where the interference is barely perceptible, determine the frequency offset between the unmodulated FM carrier and the AM carrier. Use the calibrated frequency display of the spectrum analyzer to determine the frequency offset.

(c) Repeat for increasing values of $R_{AM/FM}$ until no interference can be perceived at any carrier frequency offset.

At the completion of step (6c) sufficient data has been taken to plot the power ratio $R_{AM/FM}$ versus carrier frequency offset for barely perceptible interference, for the particular video signal used as the input to the FM transmitter. Repetitions of the experiment using video inputs of electronically generated test signals, 35-millimeter color test slides, and off-the-air programming, produce a series of power ratio curves representative of the range of potential subject matter for the FM broadcasts.

AM-VSB Transmission Interfering on FM Reception

Figure 5 shows the block diagram, and figure 6 shows the detailed equipment set up for the experiment. The procedures and test conditions used in the AM interfering on FM experiment are listed in the following sequence.

(1) Interconnect equipment as shown in figure 6.

(2) Set up the FM transmission system.

(a) Operate the transmitter and the receiver without pre-emphasis and de-emphasis, respectively. Use the 30 megahertz bandwidth IF filter in the receiver.

(b) Tune transmitter to the receiver using the discriminator meter, with no modulation on the carrier.

(c) Adjust the video signal source and the transmitter input to one volt from the white level to the sync peak level.

(d) Calibrate the frequency display of the spectrum analyzer to 3 megahertz per centimeter using a 1-megahertz crystal-controlled, comb-frequency generator.

(e) Set the frequency deviation of the transmitter to be 18 megahertz from white to sync peak.

(f) Adjust the FM receiver input power level to -67 dBm, (carrier to noise ratio approximately 20 dB).

(g) Adjust the FM receiver output and the inverting VDA output to one volt from white to sync peak.

(h) Adjust the monitor brightness, contrast, and tint with overhead lights turned off.

(i) Set the monitor to external sync.

(3) Set up the AM-VSB signal source.

(a) Rotate the antenna to the angular position for channel 8 reception.

(b) Fine tune the AM-VSB receiver so that the sound subcarrier is 10 dB below the main carrier as viewed on the spectrum analyzer connected to the IF output.

(4) Add the AM-VSB interference.

(a) Tune the local oscillator to 2.296 gigahertz and drive the mixer with 0 dBm local oscillator power.

(b) Lock the line sync frequency of the FM transmitter to the sync of channel 8 for laboratory generated FM video input signals. Adjust the sync phase so that the AM-VSB sync period is visible as interference in the FM video output display, (about 12 μsec lag from FM to AM syncs).

(5) Set up reference levels.

(a) With $ATT_A = 5$ dB and $ATT_B = 0$ dB, adjust ATT_C so that the AM-VSB carrier appears 10 dB below the unmodulated FM carrier, as viewed on the spectrum analyzer, with the carriers separated by about 0.5 megahertz.

(b) Then with $ATT_A = 0$ dB, $ATT_B = 0$ dB, and ATT_C unchanged, the AM-VSB average carrier power is 5 dB below the unmodulated FM carrier power. This condition is the reference condition where the FM average power is equal to the AM-VSB average carrier power during the sync peak. Thus, in the measurements that follow, the FM to AM-VSB power ratio is given by

$$R_{FM/AM} = \frac{\left(P_{AV}\right)_{FM}}{\left(P_{SYNC\ PK\ AV}\right)_{AM-VSB}} = ATT_A + ATT_B$$

(6) Determine $R_{FM/AM}$ for barely perceptible interference, as a function of the frequency offset of the two carriers.

(a) In all the following measurements, the judgement of the interference to be barely perceptible is made only after nulling out the local oscillator signal at the FM receiver input. The null is achieved by adjusting the amplitude and phase of the portion of the local oscillator signal reinserted after the mixer. The depth of null used is 20 dB below the level that causes perceptible interference due to the unwanted local oscillaotr signal.

(b) For $R_{FM/AM} = 0$ dB, vary the local oscillator frequency while maintaining the null until there is barely perceptible interference visible in the FM video output display.

(c) At each frequency where the interference is barely perceptible, determine the frequency offset between the AM-VSB carrier and the unmodulated FM carrier. Use the calibrated frequency display of the spectrum analyzer to determine the frequency offset.

(d) Repeat for increasing values of $R_{FM/AM}$ until no interference can be perceived at any carrier frequency offset.

Completion of step (6d) provides sufficient data to plot the power ratio $R_{FM/AM}$ for barely perceptible interference, for the particular video signal used as the input to the FM transmitter. Repeated experiments using test signals, slides, and off-the-air programming, representative of the range of potential video sources, provide curves of $R_{FM/AM}$ versus frequency for various FM program content.

APPENDIX B

DERIVATION OF TERRESTRIAL COVERAGE PATTERNS FOR INTERFERING FM AND AM-VSB TELEVISION SYSTEMS

The report "Power Ratio of Wanted to Unwanted Signals for Frequency Sharing Between FM and AM-VSB Television Transmission Systems" presents the results of laboratory experiments to determine the criteria for frequency sharing between frequency modulated (FM) television signals and amplitude modulated television signals with vestigial sidebands (AM-VSB). These experiments determine the relative power ratios at the inputs to the FM and AM-VSB receivers, when the interference caused by an unwanted signal is just barely perceptible.

In this appendix, the experimentally determined protection ratios are used to evaluate the possibilities for frequency sharing between a geostationary satellite transmitting FM television signals, and a terrestrial transmitter broadcasting AM-VSB television signals. A mathematical model to calculate the earth areas covered by each transmitter is derived. The model is then used to calculate the areas of mutual interference for transmitter frequencies in the UHF, S, and X bands.

Receiving System Model

In deriving the mathematical model for co-channel operation of the satellite signal beamed to an area in the vicinity of a ground-based station, the following conditions are considered:

AM terrestrial television system:

Instructional television
AM-VSB: UHF, S, or X bands
Radio horizon -80 kilometers (50 miles)
Guaranteed coverage radius -40 kilometers (25 miles)
Beam polarization - linear

FM satellite television system:

Instructional television
FM modulation index - two, bandwidth - 30 megahertz
Carrier frequency: UHF, S, or X band
Geostationary orbit
Satellite elevation 40° (44° N Latitude Target Point)

Satellite azimuth - 0° longitude relative to the satellite subpoint.

Desired coverage area - entire land area within the 3° half-power beam-width of the satellite antenna.

Beam polarization - circular

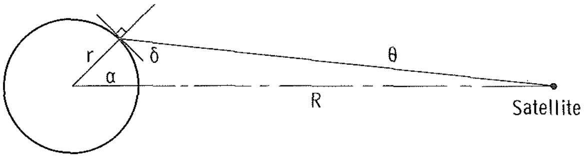


Figure 12. - Synchronous satellite elevation angle above terrestrial horizon.

The satellite elevation angle δ above the horizon is shown in figure 12 and given in equation (B1). At a given latitude α for the terrestrial viewing area:

$$\theta = \tan^{-1} \frac{r \sin \alpha}{R - r \cos \alpha} = \tan^{-1} \frac{\sin \alpha}{\frac{R}{r} - \cos \alpha}$$

$$\delta = 180^{\circ} - 90^{\circ} - \alpha - \theta \qquad \text{(B1)}$$

where

r radius of earth

R radius of the satellite orbit

α latitude of the target point for viewing the satellite

θ satellite antenna pointing angle

δ elevation angle of satellite above terrestrial horizon from target point

Since the Faraday (polarization) rotation from a synchronous satellite can be excessive at the lower frequencies during the peak of the solar cycle, circular polarization of the transmitted FM signal is highly desirable. The circular polarized FM format will also provide increased isolation between the received FM and the linear polarized AM-VSB received signals. The polarization discrimination (C/L disc.) between the circular and linear polarized antennas is considered to be 3 dB.

The terrestrial coverage from the 3° beamwidth satellite will be an area as shown in figure 13, and in some locations could simultaneously cover the area of several AM-VSB stations as shown.

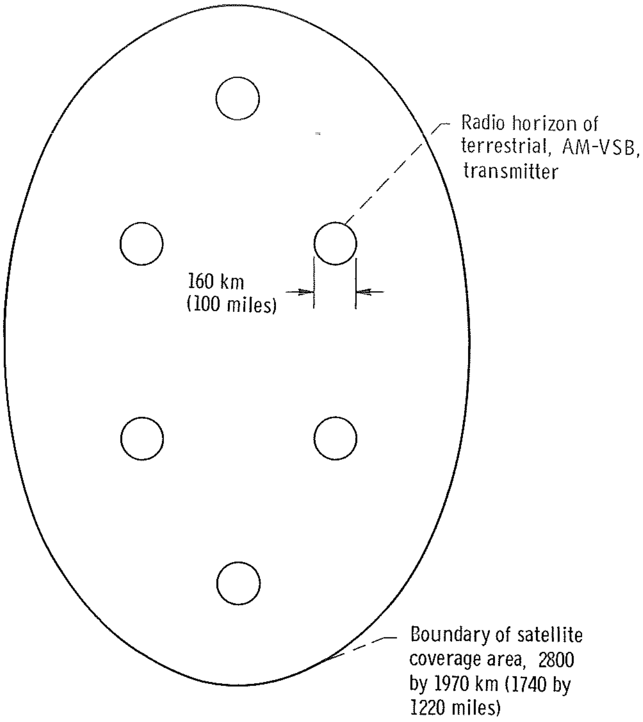


Figure 13. - Earth coverage pattern of 3° satellite beam width centered at 44° latitude.

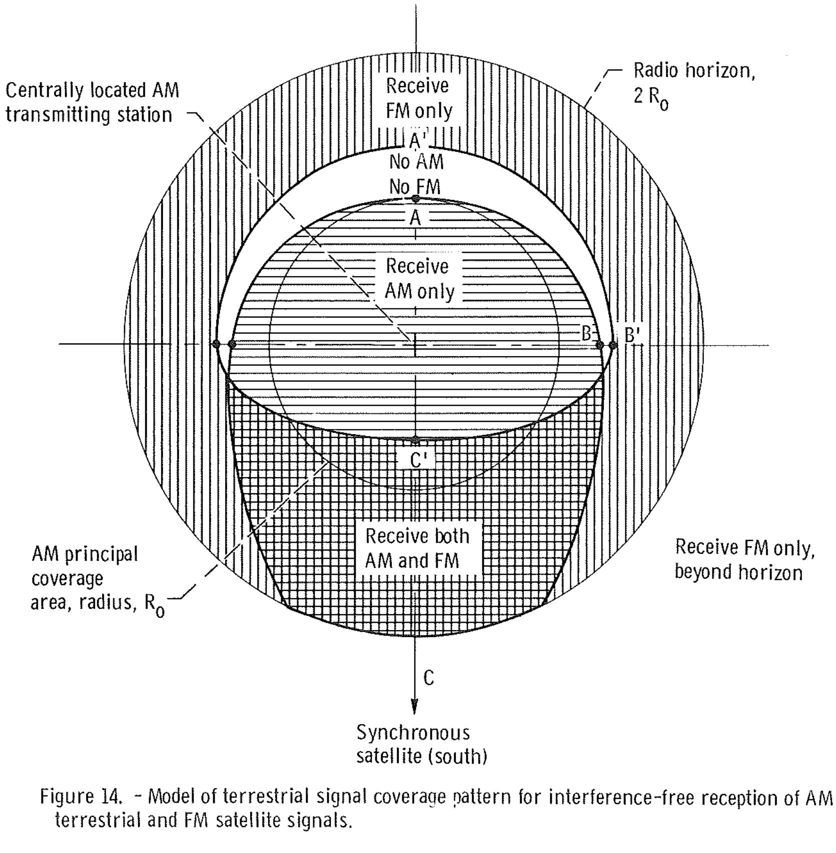


Figure 14. - Model of terrestrial signal coverage pattern for interference-free reception of AM terrestrial and FM satellite signals.

The terrestrial and satellite systems are considered cooperative in that

(1) The terrestrial transmitter radiated power is sufficient to guarantee only barely perceptible interference at the limit of its desired coverage radius in the presence of the interfering FM signal.

(2) The receivers in both systems use commercially available high-gain parabolic reflector antennas.

A typical signal coverage pattern for a centrally located AM transmitting station and a southerly located FM synchronous satellite would be as shown in figure 14.

The AM receiving antennas are directed toward the centrally located AM-VSB transmitting station. The FM receiving antennas are directed toward the satellite in the southerly direction, at an evaluation angle of 40°. With the receiving antennas properly directed so that the desired signals are in the main beams, maximum cochannel interference will occur near the 40° sidelobes. Greater protection from cochannel interference is provided by the 90° wide-angle lobes and the 140° back lobes for both the FM and AM receiving systems.

The curve defined by points (A), (B), and (C) of figure 14 shows the maximum terrestrial coverage radii for interference free AM reception. Beyond these points, AM signals cannot be received without perceptible cochannel interference. The satellite FM signal covers a terrestrial area several times larger than the AM radio horizon. Thus, FM signals can be received interference free beyond the radio horizon, but within the horizon area, can be received interference free only outside the closed curve connecting points A', B', and C'. The area within the A', B', C' curve and outside the AM coverage curve, A, B, C, can receive neither AM nor FM due to cochannel interference, both FM on AM, and AM on FM.

Using the laboratory established interference protection ratio required for no interference at the input to an AM receiver, and the discrimination to unwanted signals resulting from the receiving antenna 40° sidelobe and circular-to-linear polarization discrimination, the FM/AM field at the receiver input for point (A) can be derived. Since maximum interference to the AM receiver results when an AM receiving antenna is pointed in the direction of the satellite, and with a required AM coverage radius R_0, point (A) is established on the radius R_0 as the reference point. The interfering FM field as measured when the AM receiving antenna is normal to the direction of the satellite is indicated along the (B) axis and includes the protection from the wide-angle (90°) sidelobe and circular-to-linear polarization discrimination. The radius for barely perceptible interference at point (B), with reference to radius R_0, is derived from the receiving antenna 90° sidelobe discrimination as compared to the antenna discrimination at 40° and point (A). Similarly, the interference field and radius at which visual interference is perceptible at (C) is derived using discrimination of the AM receiving antenna 140° back lobe, since the AM receiving antenna is directed away from the FM satellite interfering signals. In a similar manner, the FM/AM field at the input to an FM receiver is derived using the laboratory established interference protection ratio required for barely perceptible interference at the input to an FM receiver and the discrimination characteristics of the FM receiving antenna for points A', B', and C'.

The coverage radii within the AM radio horizon to which to which the FM satellite signal can be received without perceptible interference from the AM terrestrial station are derived in relation to the field intensities at the input to the FM receiver at points A', B', and C', with respect to the reference field at (A).

The laboratory determined interference protection ratios, the receiving antenna discrimination characteristics, and the resultant derived field intensities are expressed in decibels (dB). These units are then converted to power ratios for transformation into the respective radii. In deriving the terrestrial signal coverage patterns, the AM received signal strength on the Earth's surface is assumed to be inversely proportional to the square of the distance from the centrally located AM transmitter over the principal coverage area one-half the distance to the horizon, and inversely proportional to the cube of the distance beyond the principal coverage area radius.

From the above described conditions and assumptions, the equations for solving the radii are as follows.

For FM interference at the input to an AM receiver, the coverage pattern radii for the cochannel interference protection required are

At (A) and R_o

$$\left(\frac{FM}{AM}\right)_{\text{field (A)}} = -\Big[(\text{cochannel interference protection required}) - (40^o \text{ S. L. disc.} + \text{C/L disc.})\Big] \tag{B2}$$

$$\left(\frac{R}{R_o}\right)^3_{(A)} = \text{Unity reference} \tag{B3}$$

At (B) 90^o

$$\left(\frac{FM}{AM}\right)_{\text{field (B)}} = -\Big[(\text{cochannel interference protection required}) - (90^o \text{ S. L. disc.} + \text{C/L disc.})\Big] \tag{B4}$$

$$\left(\frac{R}{R_o}\right)^3_{(B)} = (40^o \text{ S. L. disc.} - 90^o \text{ S. L. disc.}) \tag{B5}$$

At (C) 180°

$$\left(\frac{FM}{AM}\right)_{\text{field (C)}} = -\Big[(\text{co-channel interference protection required}) - (140^{\circ}\text{ B.L. disc.} + \text{C/L disc.})\Big] \qquad \text{(B6)}$$

$$\left(\frac{R}{R_o}\right)^3_{(C)} = (40^{\circ}\text{ S.L. disc. } - 140^{\circ}\text{ B.L. disc.}) \qquad \text{(B7)}$$

For AM interference at the input to an FM receiver, the coverage pattern radii for the RF interference protection are given by:

At A'

$$\left(\frac{FM}{AM}\right)_{\text{field A'}} = \Big[(\text{cochannel interference protection required}) - (40^{\circ}\text{ S.L. disc.} + \text{C/L disc.})\Big] \qquad \text{(B8)}$$

$$\left(\frac{R}{R_o}\right)^n_{A'} = \left[\left(\frac{FM}{AM}\right)_{\text{field A'}} - \left(\frac{FM}{AM}\right)_{\text{field (A)}}\right] \qquad \text{(B9)}$$

At B'

$$\left(\frac{FM}{AM}\right)_{\text{field B'}} = \Big[(\text{cochannel interference protection required}) - (90^{\circ}\text{ S.L. disc.} + \text{C/L disc.})\Big] \qquad \text{(B10)}$$

$$\left(\frac{R}{R_o}\right)^n_{B'} = \left[\left(\frac{FM}{AM}\right)_{\text{field B'}} - \left(\frac{FM}{AM}\right)_{\text{field (A)}}\right] \qquad \text{(B11)}$$

At C'

$$\left(\frac{FM}{AM}\right)_{\text{field C'}} = \Big[(\text{cochannel interference protection required}) - (140^{\circ}\text{ B.L. disc.} + \text{C/L disc.})\Big] \qquad \text{(B12)}$$

$$\left(\frac{R}{R_0}\right)^n_{C'} = \left[\left(\frac{FM}{AM}\right)_{\text{field } C'} - \left(\frac{FM}{AM}\right)_{\text{field } (A)}\right] \qquad \text{(B13)}$$

In the equations for $(R/R_0)^n$, n has either the value 2 or 3 depending on whether R is less than or greater than R_0. For $R < R_0$, the field decreases as $1/R^2$, and for $R > R_0$ the field decreases as $1/R^3$.

Coverage Patterns

In order to minimize the cochannel interference between the FM satellite and AM-VSB received signals, high-gain, low side lobe, parabolic reflector antennas are considered for both the FM and AM receiving systems. For the UHF and S-band frequencies, the FM receiving antennas are assumed to be 6-foot diameter parabolas, typical of the type that might be used for schools or institutions. The AM receiving antennas would be 4-foot diameter linear polarized parabolas, equivalent to the requirements for home reception in a fringe area. At X-band, the FM antennas considered are 4-foot parabolas and the AM antennas are 2-foot parabolas. Typical characteristics for these antennas are shown in table II.

TABLE II. - PARABOLIC ANTENNA CHARACTERISTICS

	Frequency range					
	UHF (890 MHz)		S-Band (2500 MHz)		X-Band (12.4 GHz)	
	Diameter, ft (m)					
	4 (1.2)	6 (1.8)	4 (1.2)	6 (1.8)	2 (0.6)	4 (1.2)
Gain	18.9 dB	21.5 dB	26.5 dB	30.0 dB	35.3 dB	41.4 dB
First sidelobe gain	-13	-15	-18	-20	-16	-18
40° Sidelobe gain	-17	-21	-24	-30	-36	-42
90° Sidelobe gain	-19	-22	-27	-30	-35	-40
140° Backlobe gain	-27	-30	-35	-38	-44	-50
Polarization	Linear	Circular	Linear	Circular	Linear	Circular

Results of the LeRC laboratory conducted experiments (fig. 9), indicate that for barely perceptible visual interference, an interfering FM signal in the pass band of an AM-VSB television channel should have an average power level of from 37 to 48 dB below the sync peak average power at the input to the AM receiver. An AM-VSB interfering signal (fig. 11) should have a sync peak average power level of 16 to 26 dB below the average power of the FM signal at the FM receiver input. The nominal values of the protection ratios, taken from the center of the bands in figures 9 and 11, are 43 dB for the AM-VSB protection ratio and 21 dB for the FM protection ratio.

Using the coverage - pattern-radii equations (B2) to (B13), antenna data table II, and the experimentally determined FM and AM-VSB protection ratios, the signal coverage patterns can be calculated for the UHF, S, and X-band frequency ranges. These results are shown in figures 15 to 19.

Figures 16 to 18 show the coverage patterns for AM and FM cochannel operation at S-band.

Protection ratios FM 16 dB/AM 37 dB are the lower band-edge ratios required for barely perceptible interference when viewing TV pictures with background clutter and motion where interference is less noticeable. Protection ratios FM 26 dB/AM 48 dB are the upper band-edge ratios as required when viewing stationary pictures with large uniform areas of a single color such as classroom programs with large charts or blackboards.

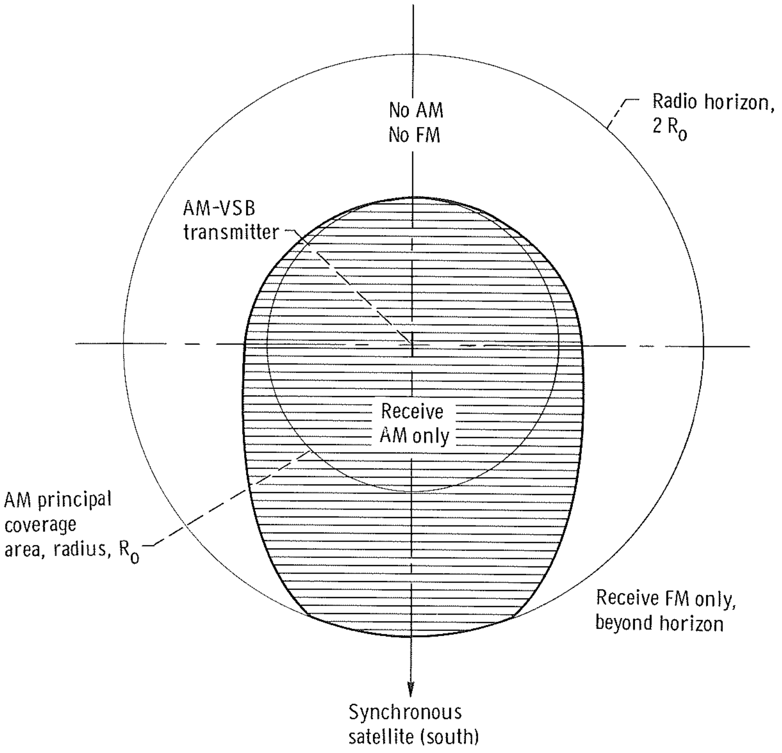


Figure 15. - Signal coverage pattern at UHF (890 MHz). FM protection ratio, 21 dB; AM-VSB protection ratio, 43 dB; transmitter location, 44° north latitude; FM receiving antenna, 6 foot (1.8 m) diameter, circular polarization; AM-VSB receiving antenna, 4 foot (1.2 m) diameter, linear polarization.

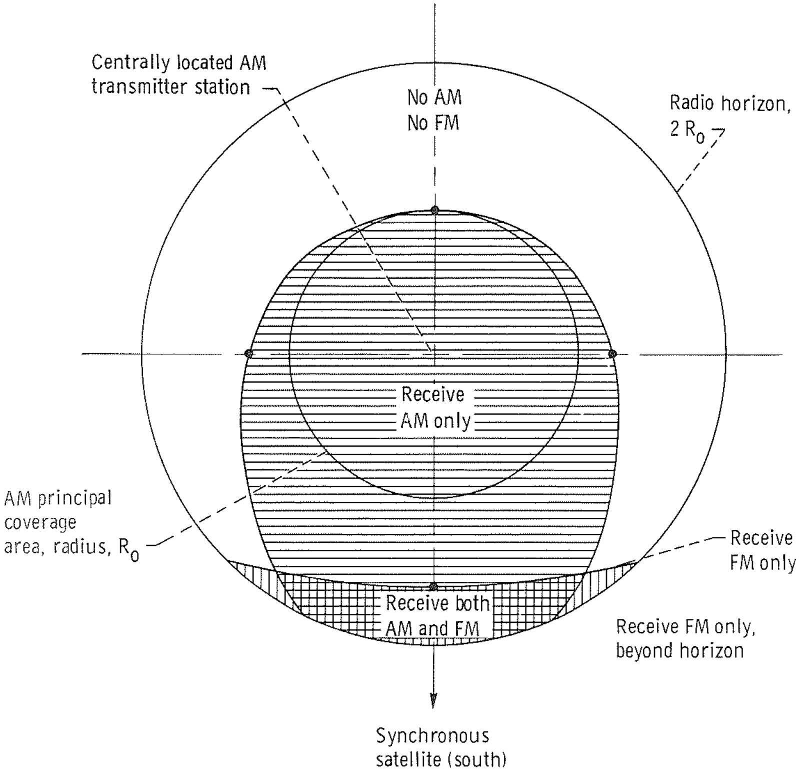


Figure 16. - Signal coverage pattern at S-band (2500 MHz). FM protection ratio, 26 dB; AM protection ratio, 48 dB; transmitter location, 44° north lattitude; FM receiving antenna, 6 feet (1.8 m) diameter, circular polarization; AM-VSB receiving antenna, 4 feet (1.2 m) diameter, linear polarization.

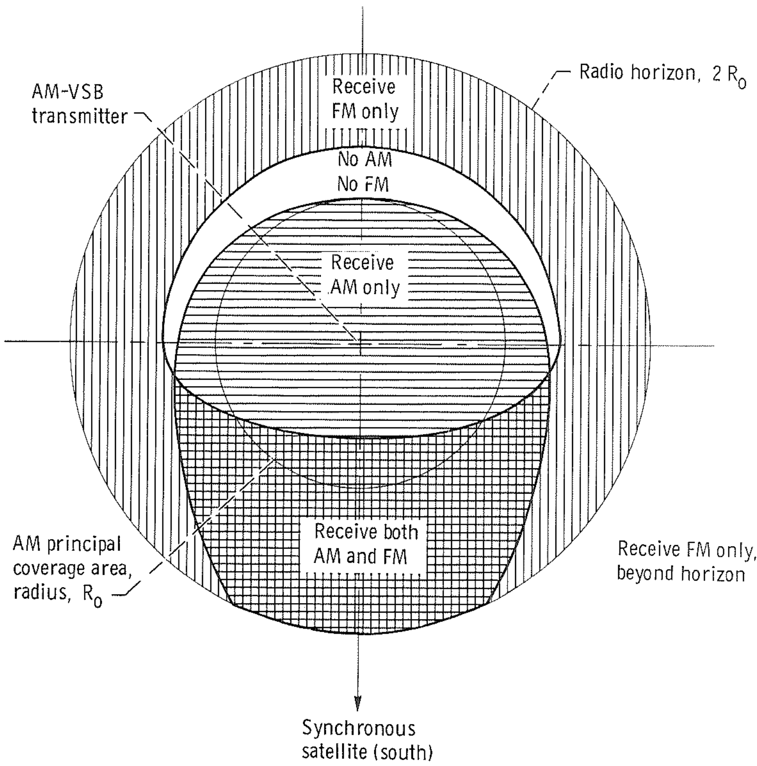


Figure 17. - Signal coverage pattern at S-band (2500 MHz). FM protection ratio, 21 dB; AM-VSB protection ratio, 43 dB; transmitter location 44° north latitude; FM receiving antenna, 6 foot (1.8 m) diameter, circular polarization; AM-VSB receiving antenna, 4 foot (1.2 m) diameter, linear polarization.

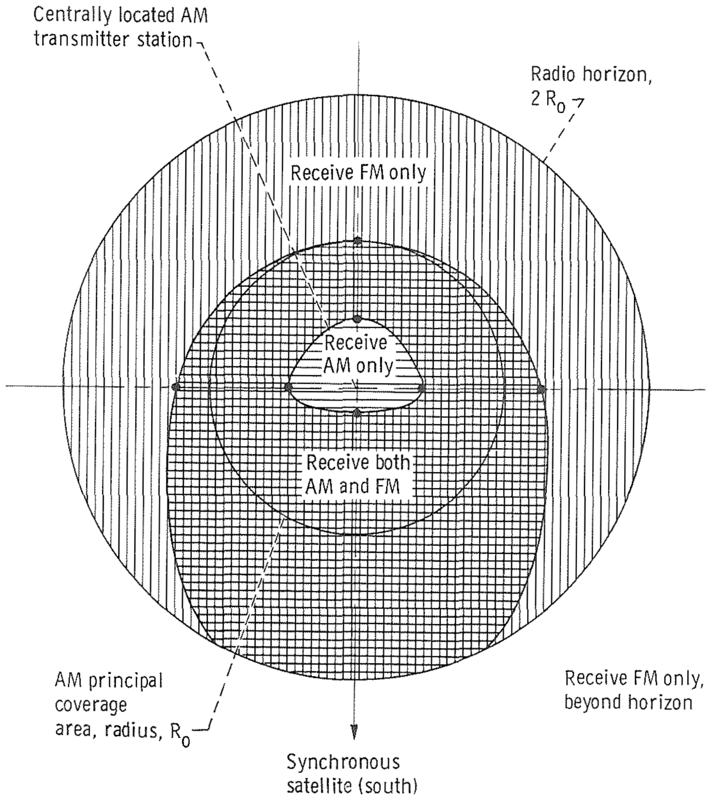


Figure 18. - Signal coverage pattern at S-band (2500 MHz). FM protection ratio, 16 dB; AM protection ratio, 37 dB; transmitter location, 44° north latitude; FM receiving antenna, 6 foot (1.8 m) diameter, circular polarization; AM-VSB receiving antenna, 4 foot (1.2 m) diameter, linear polarization.

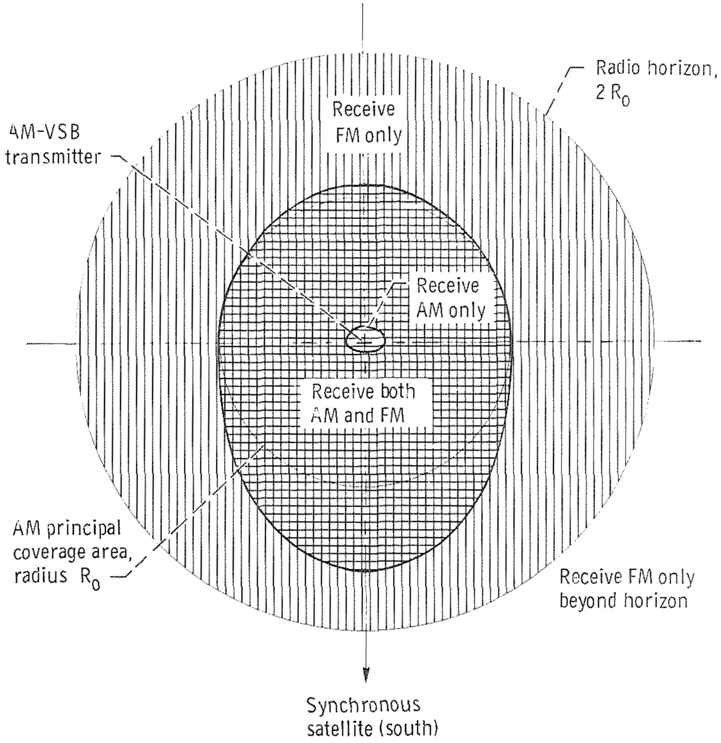


Figure 19. - Signal coverage pattern at X-band (12.4 GHz). FM protection ratio, 21 dB; AM-VSB protection ratio, 43 dB; transmitter location 44° north latitude; FM receiving antenna, 4 foot (1.2 m) diameter, circular polarization, AM-VSB receiving antenna, 2 feet (0.6 m) diameter, linear polarization.

Figures 15 and 19 show the coverage patterns at L-band and X-band for the mid-band protection - ratios of FM 21 dB/AM 43 dB. For the X-band condition (fig. 19) the discrimination of the AM-VSB receiving antenna is greater at 90° off-axis than at 40° off-axis. Thus, the AM coverage extends to R_0 along the east-west axis of the coverage area, and goes beyond R_0 in the northerly direction. For this case only, the roles of the AM antenna discriminations for 40° and 90° are interchanged in equations B2, B5, and B7.

The major features of the coverage patterns are

(1) The AM-VSB transmitted signal, by using a sufficiently high power level, can be received interference-free over approximately one-third of the area within the radio horizon of the AM transmitting station. Of this coverage area, there is complete coverage within the principal coverage area R_0 as assumed.

(2) The satellite transmitted FM signal can be received interference-free at points beyond the radio horizon of the AM-VSB transmitter.

(3) Within the radio-horizon of the AM transmitting station, the satellite FM signals can be received for the given frequency-bands and protection-ratios as follows:

Frequency band	Protection ratio	Approximate FM coverage area, percent
UHF	FM 21/AM 43 dB	None
S	FM 26/AM 48 dB	6
	FM 21/AM 43 dB	70
	FM 16/AM 37 dB	95
X	FM 21/AM 43 dB	98

(4) At UHF frequencies and at the higher protection-ratios of S-band, areas exist within the radio horizon of the AM transmitting station where neither AM nor FM can be received without noticeable interference.

Conclusions

The signal coverage patterns, plotted for given frequency bands and protection - ratios, indicate that cochannel operation of FM and AM satellite/terrestrial television systems would not provide complete television coverage to the area in the vicinity of the ground-based transmitter even with cooperative users. Persons in urban centers, (where terrestrial transmitters are usually located), would be unable to receive the satellite broadcast, while some of the persons in the suburban areas would be able to receive neither signal without interference from the other.

Within the area illuminated by a three degree satellite antenna beamwidth, (approximately 2400 km, (1500 mi.) in diam.), a number of AM terrestrial television transmitters would suffer the interference described. Within the satellite coverage area of $4.5 \cdot 10^6$ km^2 (1700 sq. mi.), there would be several areas of $2.0 \cdot 10^3$ km^2 (770 sq. mi.), each where interference would occur. Because these interference areas would most likely be near centers of population, the fraction of the population subject to interference would be greater than the ratio of the areas.

Thus, for the examples given, FM and AM-VSB cochannel operation would be permissible only if one were willing to tolerate the resultant holes in both the FM and AM coverage areas.

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