

Cross-Modulation Distortion Testing for the Motion Picture Laboratory

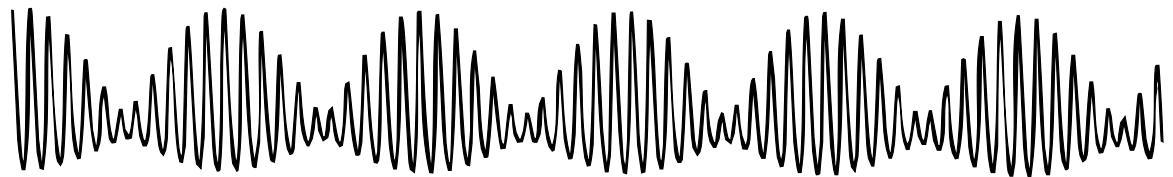
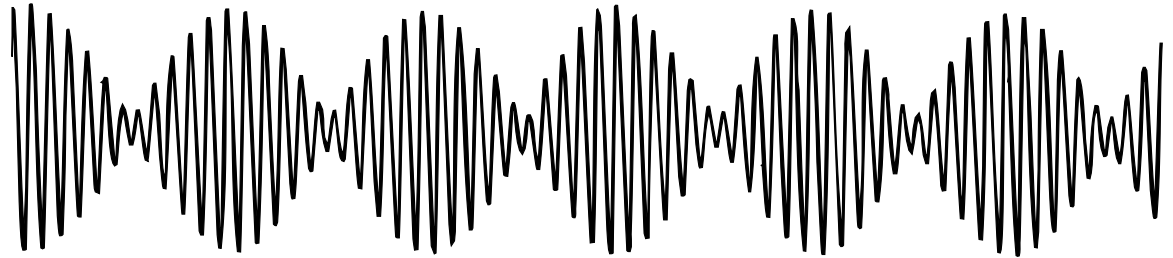


Table of Contents

Section I	
The Information	3
How and Why the Cross-Modulation Tests Are Used	3
Section II	
The Techniques	10
Equipment Required for Cross-Modulation Test	10
The Cross-Modulation Family	10
Recording the Cross-Modulation Test	11
Reading Cross-Modulation Distortion	11
The Positive Print Series	12
Day-to-Day Operation	14
Appendix	16
Correction of Amplitude Errors in the Cross-Modulation Signal.	16

Section I

The Information

This document has been divided into several sections to maintain simplicity and to separate the functional and hardware segments from the theories of cross-modulation testing. To obtain the maximum benefits these tests can provide and have laboratory personnel adequately prepared to perform them, read the entire document carefully, including the appendix, before starting actual test procedures.

How and Why the Cross-Modulation Tests Are Used

The cross-modulation test serves recording engineers very much as the light meter serves photographers. That is, it helps them determine the proper light exposure to be used when producing a photographic image. The photographer judges the quality of the photograph by viewing it. Similarly, the sound engineer can judge the quality of the sound recording by listening to it. However, judging a photograph by looking at it or judging a sound track by listening to it are subjective measurements; they represent the opinion of the viewer or listener. In addition, they can be time-consuming and inaccurate. The photographer and the sound engineer, therefore, are likely to look for a more scientific method of determining the exposure necessary for exposing and printing images. The photographer might well include in the scene an 18-percent reflectance neutral test card. The gray surface represents a calibrated input signal to the photographer's system. The photographer can then measure the density of the area of the negative containing the test card and use the reading, together with experience from previous tests, to decide how to print the negative.

The photographer may decide to go back and rephotograph the scene if the original exposure was too far off aim to make a good print. Once the print is made, the density of the test patch can be checked to determine if the print was properly made.

Similarly, sound engineers can use a series of tests to make sure of the quality of their product. The calibrated input to the sound engineer's system is an electronic signal, namely, the cross-modulation signal. When sound engineers get back the exposed and processed negative, they can measure the cross-modulation signal and determine whether or not the negative was properly exposed and how the negative should be printed. They do not make their measurements on a densitometer as does the photographer, but rather on special equipment for measuring cross-modulation distortion. They will have made, however, as did the photographer, a previous series of tests (the cross-modulation family) on which they will base their decision on how to print the negative. Finally, when sound engineers receive the print of the sound track, they can again measure the cross-modulation signal to determine whether or not the negative was correctly printed. Used this way, the cross-modulation test provides the sound engineer with a method of determining the correct exposure for a photographic sound track. This method does not rely on *subjective judgments*. It provides the engineer with a consistently high quality product.

Many questions arise when discussing the cross-modulation test. Why be concerned about exposure at all? What happens if the wrong exposure is used? Why use the cross-modulation distortion test and not some other type of test? Before getting into the specifics of exactly how to conduct the cross-modulation test, this publication answers some of those questions.

There are several reasons why it is important to control the exposure used when recording the negative and printing it. Lets look at the print first. Ideally, as an accurate reproduction of a waveform, a photographic sound track should be completely opaque in the exposed areas and completely clear in the unexposed areas. This is not possible. In practice, we can't even use the maximum density obtainable on the film. Many films, if given enough exposure, will yield a density in excess of 5.0. However, all films exhibit a greater or less amount of what is called image spread.

Image spread can be illustrated simply as follows. Suppose a small, sharply focused spot of light is exposed on a piece of film, and the film is processed. The developed image is likely to be larger than the spot of light originally imaged on the film. If this is repeated with a greater exposure, the image on the film will grow even larger. In other words, the image has spread.

Figure 1 shows the effect of image spread on an image. Needless to say, the same thing happens to the image of a sound track.

Figure 1

NEGATIVE

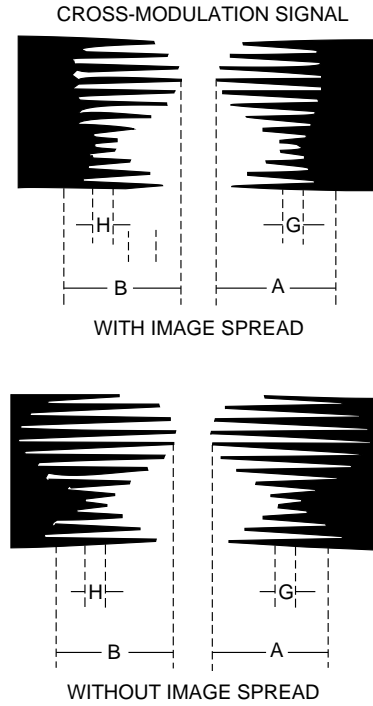


PRINT

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Figure 2 shows greatly enlarged images of the cross-modulation signal; with and without image spread. You can easily see the effect of image spread when the areas marked A, B, G, and H in the two drawings are compared. (Also notice the differences in curves drawn along the white peaks with both drawings.) This much overexposure will cause a drastic loss of fidelity.

Figure 2



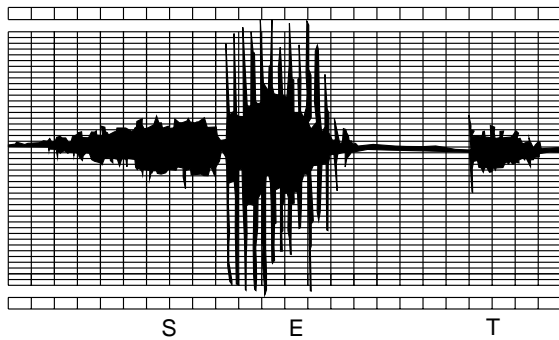
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On the other hand, the sound track must not be underexposed very much either. As the density of the exposed area of a sound track decreases, the light-modulating ability of the sound track also decreases. That is, both the output level and the signal-to-noise ratio will decrease.

For reasons noted in the following pages, the most desirable density for a print of a photographic sound track is in the range of 1.0 to 1.6. The aim density will vary from lab to lab and from print film to print film, but it is generally in this range.

However, there are other considerations. If a negative containing both music and voice passages is printed onto a print film at several different densities over the range from 1.0 to 1.6, the average listener may find the quality of music fairly acceptable over the whole range. Some of the voice passages, however, will contain an excessive amount of sibilant distortion.* That is, many of the sibilant speech sounds (s, sh, ch, z, etc.) and some of the voiced and voiceless stop sounds (B, P, and T) will be distorted and spitty. To examine why this happens, let us look closely at a sibilant speech sound. Figure 3 shows an oscillograph of the word "set." The sounds for the three letters are distinctly visible.

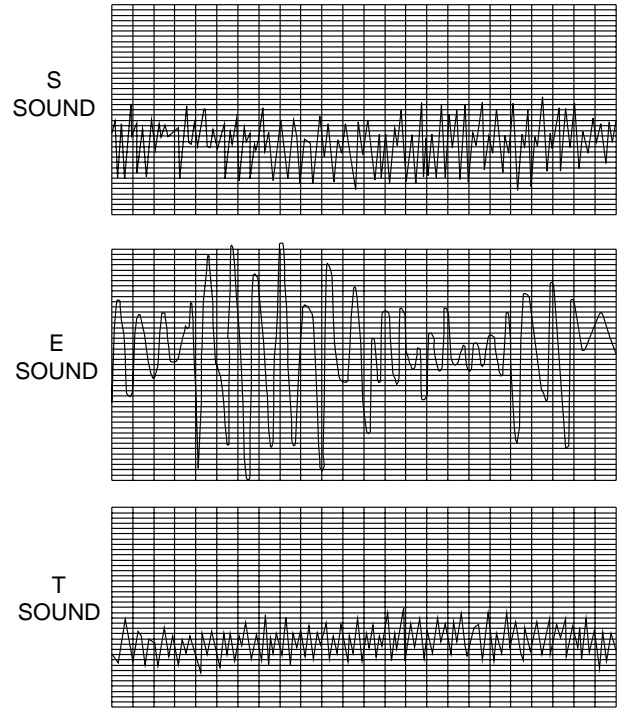
Figure 3



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Figure 4 shows portions of the three sounds with the time axis magnified. It should be noted that the "s" and "t" sounds are fairly high frequencies and the "e" sound is much lower. Looking more closely at the "s" sound, you can see that the frequency is fairly constant throughout the fraction of a second shown, but the amplitude varies over a wide range.

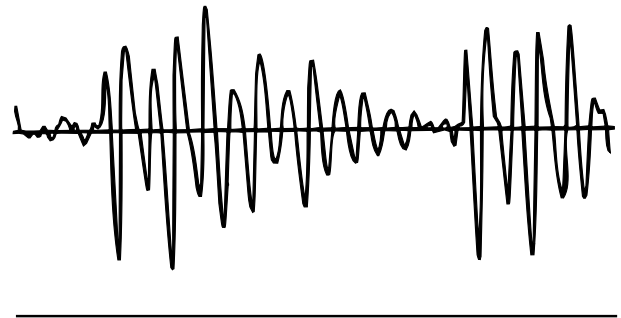
Figure 4



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The variation in amplitude is shown even more dramatically in Figure 5, which is a further enlargement of the "s" sound.

Figure 5

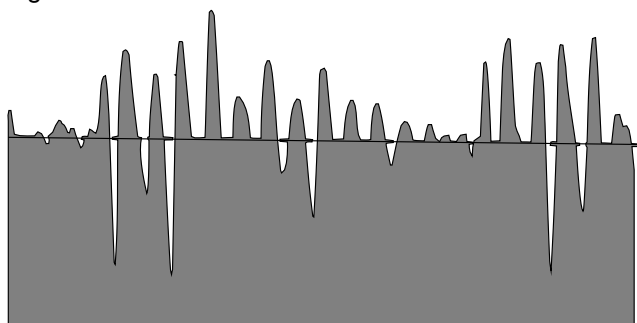


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* Distortion in the music passages in this case are generally considered more difficult to identify, but are, nevertheless, still present.

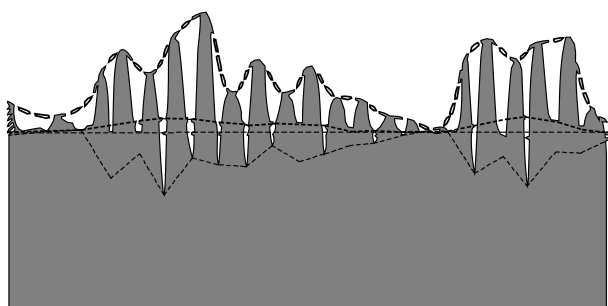
Now let's relate this to a photographic sound track. The Figure 6 is the same as Figure 5 but with one side shaded. This is how the signal would appear on a section of variable-area sound track. Figure 7 shows what might happen if you increase the exposure used to make the print in Figure 6. As stated earlier, the amount of image spread will increase. You can see that the image spread has caused most of the valleys to "fill-in" You can also see that the peak-to-valley distance has decreased somewhat from what it was in Figure 6, ; there is a loss in signal. However, this loss is fairly small and not too important. Something else has happened that is more important. Looking back at the Figure 6, you can see that, despite the fact that the amplitude varies greatly, all the modulations are fairly symmetrical with respect to the rest position or quiet area.

Figure 6



In the Figure 7, this is no longer the case. It appears that the rest, or zero-signal, position has shifted in certain places. The places where the zero position has shifted the most are where the amplitude of the modulations was great.

Figure 7

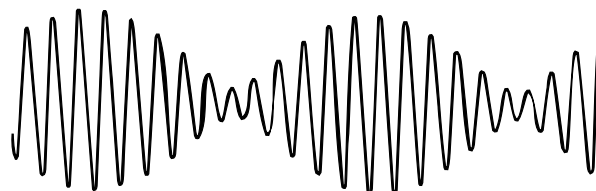


To put it another way, the zero *shift* is variable and depends on the modulation amplitude. Since the amplitude of the modulation is varying quite rapidly, the shift also varies rapidly. The variation in the zero position is heard as another sound. Distortion has been added and the sibilant sound will not sound natural. Why are only the sibilant sounds affected? Look back at Figure 4 (the "e" sound). You can see that the amplitude here is also varying.

There are two reasons why we do not hear distortion in the "e" sound. First, the fundamental frequency is much lower, so we have much less shift due to image spread. Second, since the fundamental frequency is lower, the rate at which the amplitude varies is also much lower. Any distortion that is created, therefore, occurs at a frequency that is too low to hear.

It is perhaps now obvious why the cross-modulation signal is used to minimize the type of distortion just described. Figure 8 shows the cross-modulation signal. If you compare Figure 8 with Figure 5, you can see they are very similar. The major difference is that the variation of the amplitude of the cross-modulation signal occurs at a regular rate of 400 times per second.

Figure 8 Cross-Modulation Signal

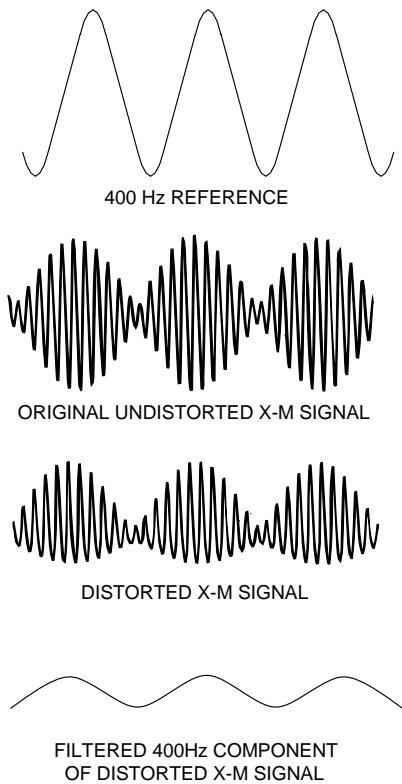


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You can now use an electrical filter to separate the signal due to image spread from the original cross-modulation signal and measure its amplitude (Figure 9). The amplitude of the 400 Hz signal component is a direct measure of the amount of image spread that has taken place. If there were no image spread, the final image on the film would be symmetrical (just as was the original signal applied to the recorder), and there would be no shift in the image position and, consequently, no 400 Hz signal generated. As the amount of image spread increases, so does the amplitude of the 400 Hz signal.

Generally, when the cross-modulation signal is recorded, a 400 Hz sine wave of the same amplitude is also recorded. When the cross-modulation signal is analyzed, the voltage due to the 400 Hz signal present in the cross-modulation signal is divided by the voltage of the 400 Hz reference, this figure is then multiplied by 100 to give percent distortion.

Figure 9



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For example, if the voltage for the 400 Hz component of the cross-modulation signal is 0.15 volts, and the 400 Hz reference voltage is 1.5 volts, the amount of cross-modulation distortion is $0.15/1.5 \times 100$ percent = 10 percent. At one time, it was customary to express the amount of distortion in decibels rather than percent. It was then called the “cross-modulation product” and it was calculated as follows:

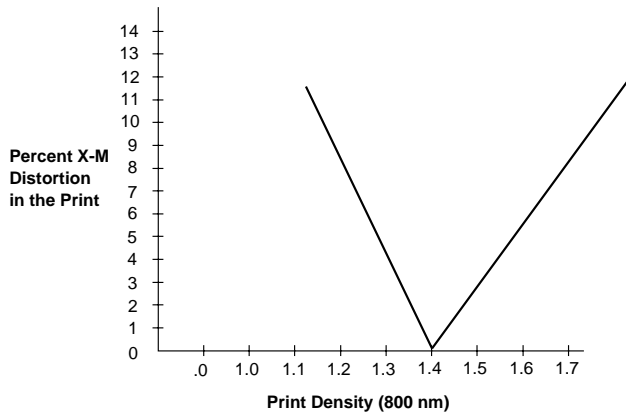
$$\text{Cross-modulation product} = 20 \log_{10} \frac{\text{volts (cross-mod. signal)}}{\text{volts (reference)}}$$

Thus for the above example, the cross-modulation product would be $20 \log_{10}(0.15/1.5) = -20$ dB.

So far there has been no distinction made regarding negatives or prints. Actually, the same process takes place in both the negative exposing and positive printing steps. You could easily expose a negative so that it had virtually no cross-modulation distortion. You would find that such a negative had a density of about 0.9 to 1.1. If you increased the exposure, you would find that the amount of cross-modulation distortion would increase as exposure is increased. If the negative with very little cross-modulation distortion were printed onto a standard positive print stock, the density at which the print had little or no cross-modulation distortion would be about 0.3, which is too low for practical purposes. It is, therefore, customary to increase the negative exposure, to yield a negative with a higher density, but also a relatively large amount of cross-modulation distortion.

When a higher density negative is printed, the printing exposure is also increased, causing image spread in the print, which is essentially opposite in direction to the image spread in the negative. If the proper printing exposure is used, all cross-modulation distortion in the negative is cancelled out. The density at which the distortion-cancelling effect occurs in the print is known as the optimum print density. If the printing exposure is either above or below this point, cross-modulation distortion will result. Figure 10 shows a typical plot of percent cross-modulation distortion versus print density.

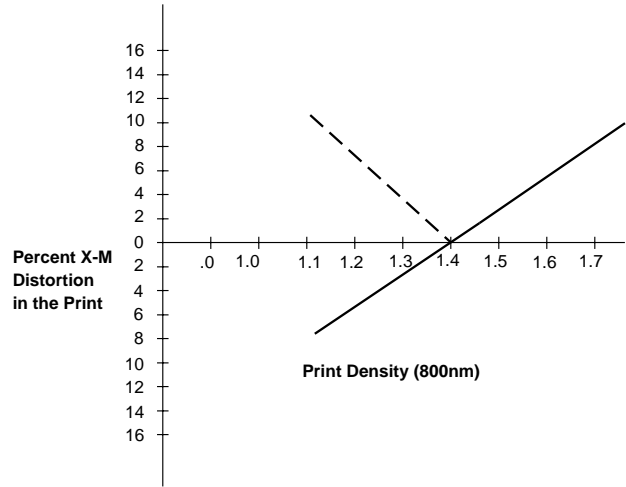
Figure 10



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Information for such a graph is obtained by printing a single negative containing a cross-modulation test at a series of printing exposures (called a cross-modulation series). The optimum printing exposure would be the one that corresponds to the lowest point on the “V.” It is customary to plot those points that fall on the left leg of the “V” on the opposite side of the horizontal axis, as shown in Figure 11.

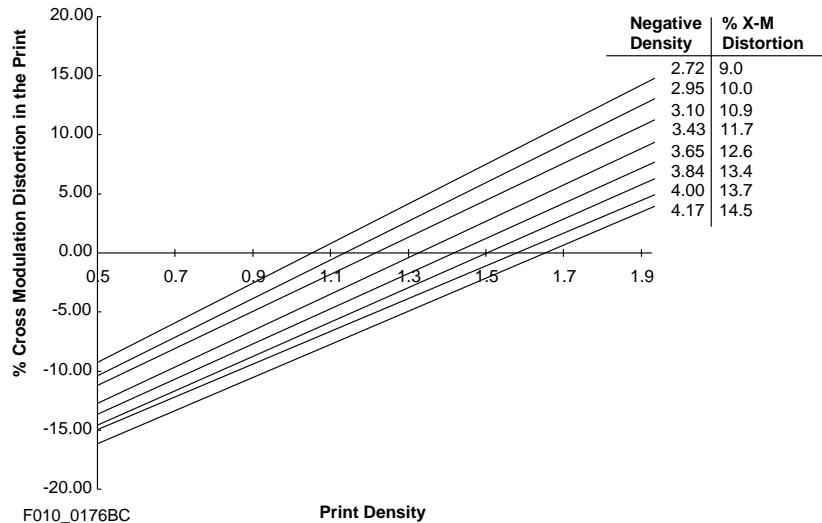
Figure 11



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Then the optimum printing exposure is easily determined as the point where the slanting line intersects the horizontal axis. If several negatives are made and each negative is printed at a series of different printing exposures, the result is a cross-modulation family. A typical cross-modulation family is shown in Figure 12.

Figure 12



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Each negative in a cross-modulation family has a different density, and, therefore, each negative optimizes at a different print density. Since each negative has a different density, each also has a different amount of cross-modulation distortion. If the cross-modulation distortion in a sound track negative is measured, the distortion for useful negatives will lie in the range of 10 to 16 percent. However, as a common practice in the field, the amount of cross-modulation distortion in the negative is often not measured. The reason for not measuring has been, that in the end, all that was important was that the print optimize within the range of useful densities. *Nonetheless, the amount of cross-modulation distortion in the negative is more important to know than its actual density.*

The cross-modulation distortion of a negative is a much better predictor of the print density at which a negative will optimize than is the density of the negative. To put it another way, several negatives may have widely different densities; but if they have the same amount of cross-modulation distortion, they will optimize at nearly the same print density.

Thus the cross-modulation test can be a valuable tool for recording engineers. They first record a section of the cross-modulation test signal (along with a section of the reference signal) when the sound negative is exposed. After the negative is processed, the recording engineer can measure the amount of cross-modulation spread in the negative. With this information, and data from a previous series of tests, the recording engineer can predict how the print should be exposed to yield an optimum print (one with practically no cross-modulation distortion). Finally, after the print has been processed, the amount of cross-modulation distortion in the print can be measured to determine if it has been printed properly. The recording engineer and laboratory are then certain of putting out only top quality work.

Section II

The Techniques

Equipment Required for Cross-Modulation Test

1. Photographic recorder. The recorder should be in good condition; that is, the optics will be clean and properly adjusted for azimuth and focus and the mechanical system should be properly adjusted for minimum flutter and accurate image placement. Refer to manufacturer's instruction manual for proper maintenance.
2. NUOPTIX Optical Recording System, or equivalent.
3. A densitometer with a narrow aperture for reading sound track densities. It should be capable of both visual and infrared (800 nm) responses.
4. Sensitometer. This is helpful for checking the control of the negative process.
5. Digital multimeter.
6. 400 Hz filter.
7. Computer system (optional).

The Cross-Modulation Family

In this test, the data for a cross-modulation family will be obtained from films generated with your photographic sound recorder. Prior experience or a thorough understanding of the theory of cross-modulation testing is not necessary. Knowledge of the operation of your photographic sound recorder is essential. The manufacturer's instruction manual for your recorder should supply all the necessary information. Since the instructions given here are intended for use with all types of recorders, detailed information on the setup for specific brands of recorders cannot be given. Optimum results depend on the equipment being in top working order, clean, and correctly adjusted before starting the test procedures that follow.

A series of negatives of varying, increasing densities will have to be made. Cross-modulation tests should be run using a series of lamp currents above and below the useful lamp current range for your system. A minimum of ten different lamp currents is recommended. For example, if your lamp is rated at 7.8 amps and you normally run at 5.5 amps, you might consider a 2-percent increment series starting at 5.0 amps, increasing current for each exposure by 0.1 amp and extending to 6.0 amps. This will provide 11 steps in the exposure series. If you have no idea what an appropriate current for your recorder is, you should run a series from about 60 to 90 percent of maximum lamp current. In the above case, where maximum lamp current is 7.8 amps, you could start at 4.8 amps, and in 0.2 amp increments, complete a 12-step exposure series to 7.0 amps.

Recording the Cross-Modulation Test

- Set lamp current to the lowest setting as determined in the first paragraph of *The Cross-Modulation Family* section (on page 10).
- When the recorder is up to speed, switch Nuoptix control to 400 position for at least 5 seconds, then to the CROSS-MOD. position for at least 5 seconds, and then back to OFF.
- Expose density patches (follow the recorder manufacturer's instructions).
- Repeat the 4 steps for each lamp current in the series.
 1. Using the sensitometer, expose a standard sensitometric strip on the negative recording film.
 2. Have the film processed, including the sensitometric exposures. For a stable control system, the negative process must be reliable and repeatable. The sensitometric exposure will allow you to monitor the process. Established process-control procedures should be followed.

Reading Cross-Modulation Distortion

1. Read the data as follows:

Using the microprojector or microscope, check to be sure that the modulations are at the correct level.

Note: Instructions on how to measure and correct for incorrect signal level are given in the appendix. However, these should be used only after considerable experience has been gained with the cross-modulation test (and only as an emergency measure to save time). A superior quality end product (your sound track production) will result if recording levels are correct. *Repeat the cross-modulation tests now if there is any doubt as to the correct recording level.*

2. You will have one cross-modulation reading for each lamp current used. Record the data for each sample of the cross-modulation test data sheet (Figure 13) in the area marked NEGATIVE DATA.
3. Measure the density of each section, using a densitometer having a visual response and a narrow aperture. Enter the readings on the data sheet also.

Figure 13 Cross Modulation Test Data Sheet

Date: 6-6-01 Recorder No. #1 Printer No. B-6, MPL Operator: V.S.
 Negative Film: 2374 Process: D-07, Dev. Time 4 min @ 75°F
 Print Time: 2383 Process: ECP-2D

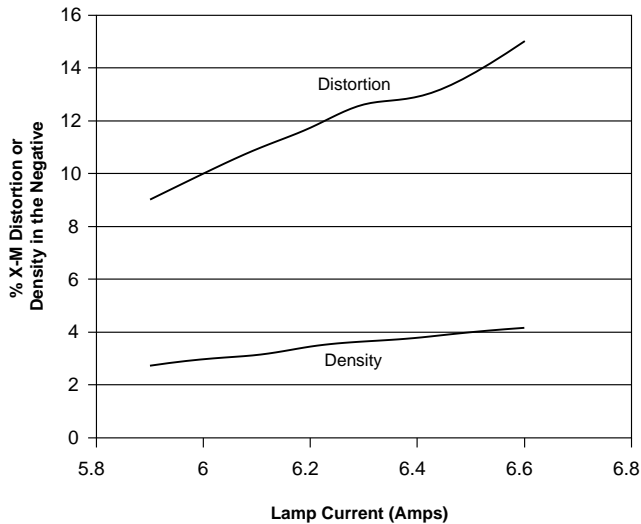
NEGATIVE DATA				PRINT DATA									OPTIMUM PRINT				
NEG. NO.	LAMP CURRENT	DENSITY	% X-M DIST.	PRINT NO.	1	2	3	4	5	6	7	8	D	EXP			
				LAMP VOLT.	12	13	14	15	16	17	18	19			DENSITY	0.67	0.88
1	5.9	2.72	9.0		-5.3	-2.9	-0.6	2.6	5.4	7.7	10.0	11.7					
2	6.0	2.95	10.0		-7.0	-4.2	-1.9	1.0	4.3	6.0	8.0	10.5					
3	6.1	3.10	10.9		-7.9	-5.2	-2.8	-0.8	2.3	5.1	6.8	8.7					
4	6.2	3.43	11.7		-9.4	-6.7	-4.3	-1.8	1.0	3.6	5.4	6.9					
5	6.3	3.65	12.6		-10.3	-7.9	-5.5	-3.4	-0.7	2.4	3.5	5.3					
6	6.4	3.84	13.4		-11.3	-9.0	-6.7	-4.4	-2.0	1.2	2.5	3.9					
7	6.5	4.00	13.7		-12.0	-9.6	-7.2	-5.1	-2.6	-1.0	1.8	3.2					
8	6.6	4.17	14.5		-13.4	-11.1	-8.8	-6.2	-3.6	-1.6	0.9	1.7					
													1.06	14.0			
													1.15	14.5			
													1.24	15.0			
													1.33	15.5			
													1.43	16.0			
													1.51	16.5			
													1.58	17.1			
													1.66	17.9			

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The Positive Print Series

1. Plot the data on a graph, as shown in Figure 14. This is a combination plot of percent cross-modulation distortion versus lamp current and density versus lamp current. Do not plot the distortion data for lamp current settings that produced densities of less than 1.0. The plot will allow you to determine the lamp current required for a given density or percent cross-modulation distortion.

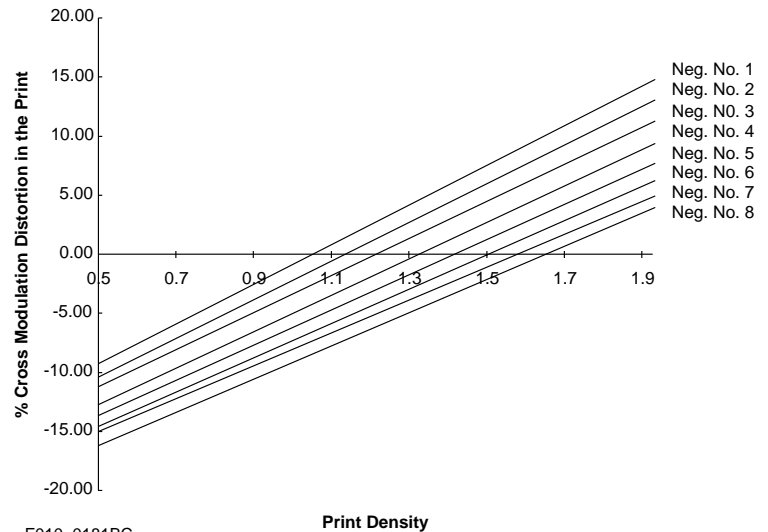
Figure 14



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2. Discard those exposure sections whose percent cross-modulation distortion does not fall in the range of 10 to 30 percent. Negatives outside this range are too light or too dark for proper printing onto current print films.
3. Print the negative at a series of exposures onto the print film that is being used. It is again necessary to choose an exposure range that produces densities both above and below the density you plan to use. For example, if you plan to use a print density in the range of 1.2 to 1.3, you should make a print exposure series that produces densities from approximately 1.0 to 1.6. At least 4 to 8 exposures are recommended. If your negatives are commonly printed onto more than one type or batch of print film, it will be necessary to perform an exposure series on each type of print film.
4. Have the print processed.
5. Read the cross-modulation data as described on page 11. The total number of cross-modulation readings will be equal to the number of different exposures made on the negative times the number of exposures made on the print. Thus if you make 6 different exposures on the negative, and 7 exposures on the print, there would be a total of 42 cross-modulation readings to make. This may seem like a large number of readings; but remember, the test is done infrequently and it is worth your while to do a complete job. Enter the data on the data sheet.
6. Plot the data on a graph, as shown in Figure 15.

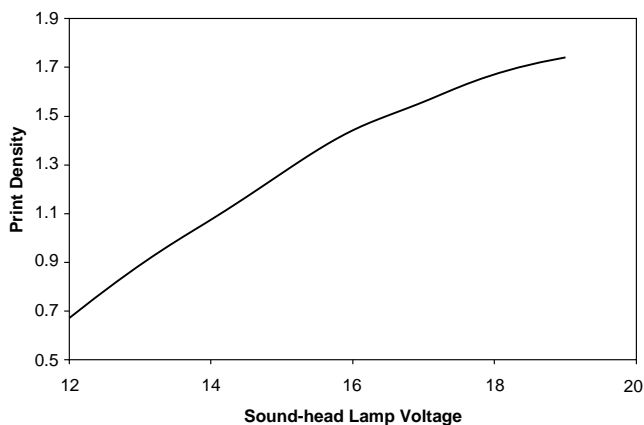
Figure 15



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The horizontal scale may be either print density or some measure of print exposure (such as sound-head lamp voltage). In either case, it would also be desirable to make a graph of print exposure (volts, for example) versus print density (Figure 16). The print density should be read on a densitometer specially designed for reading sound track densities (peak spectral response at a wavelength of 800 nm). Figure 15 is actually the cross-modulation family. Note that the data from each negative are plotted in Figure 15 in a straight line extending from lower left to upper right. The underexposed values are plotted under or below the axis, and the overexposed values are plotted over or above the axis. It may be necessary to use a little trial and error in the plotting process to determine whether some of the points, especially those with fairly low values of distortion, should be plotted above or below the axis.

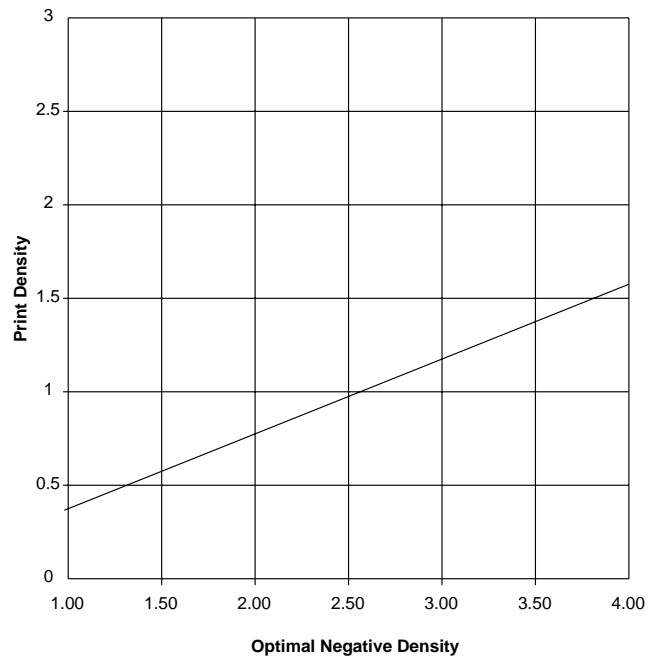
Figure 16



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7. For each of the lines that crosses the zero distortion axis, the optimum print exposure or density is the point of intersection with the axis. The information should be entered on the data sheet.
8. From the above data, another graph can be made in the negative density (or % X-M distortion) versus optimum print density (Figure 17).

Figure 17



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The cross-modulation family test is now complete. The following section, *Day-to-Day Operation*, will describe how to use the data to determine negative and print exposure aims.

Day-to-Day Operation

1. Using the data obtained from the cross-modulation family test, it is possible to determine how future negatives should be exposed and printed.
2. It is first necessary to choose the print density that is to be used. The print density range is generally chosen on the basis of signal-to-noise ratio and frequency response factors. It is a good idea to choose a print density in the range recommended in the print film specification sheet. (The statements given in parentheses throughout this section represent examples given only to indicate the use of the graphs shown in the previous section. The data are not meant to represent standard or recommended values for the products and equipment used.)

(As an example, you might choose a print density of 1.45 for KODAK VISION Color Print Film / 2383.)

3. Using the graph of print density versus percent distortion in the negative (Figure 17), determine the amount of cross-modulation distortion in the negative that is necessary to obtain minimum cross-modulation in the print at the desired print density.

(Example: For a print density of 1.45, a negative with 13-percent cross-modulation distortion is required.)

4. Using the graph of cross-modulation distortion and density versus recorder lamp current (Figure 14), determine the lamp current necessary to obtain a negative with the amount of distortion determined above.

(Example: The recorder lamp current required for a 13-percent negative is 6.34 amps. The density should be about 3.68.)

5. The lamp current determined in the previous step should be used for recording negatives of the same emulsion number as used to generate the cross-modulation family.

Every time a negative is made, a short cross-modulation test should be recorded on the front end of the roll. After the negative is processed, the amount of distortion in the negative should be read (refer to page 11, *Reading Cross-Modulation Distortion*). If the lamp current used was that determined in Step 4 above, the amount of distortion should be as determined in Step 3 above. If this is the case, the sound-head lamp voltage is determined from the graph of print density versus sound-head lamp voltage (Figure 16) for the print density decided upon in Step 2.

However, if it is not the same, the graph of percent distortion in the negative versus print density (Figure 17) can be used to predict the printing density necessary to obtain an optimized print from the negative. Thus if the negative does not come out exactly as planned, there is no need to remake it. A change can be made in the print exposure to obtain an optimized print.

Some labs may find that it is not necessary to record a cross-modulation test on every roll of film exposed. If the recording system and the processing are fairly stable, it may be necessary to record a cross-modulation test every 3rd or 5th roll, or perhaps only once per shift. However, if a roll is recorded without cross-modulation signal, and for some reason the negative is improperly made, there will be no way of accurately determining how it should be printed to obtain an optimized print.

(Example: Suppose a negative is recorded using a recorder lamp current of 5.45 amps, setting the recorder as accurately as possible. After the negative is processed, you measure the amount of distortion in the negative, using the method described on page 11, [*Reading Cross-Modulation Distortion*]. It is found to be 13 percent. You can conclude that the negative was properly exposed and should optimize if printed to a density of 1.45. Using Figure 16, you can determine that a sound-head lamp voltage of 16.1 volts is required to obtain a 1.45 print.

(On the other hand, if the negative does not have 13-percent distortion, our course of action is somewhat different. If it had only 12 percent instead of 13 percent, you would first go to the graph of distortion in the negative versus print density [Figure 17] to determine the proper print density for a negative with 12-percent distortion.

(You can see that it is 1.3, considerably lighter than our aim of 1.45. However, the 12-percent negative will sound best if printed to this density, because sibilant distortion is minimized. An alternative to printing to a density of 1.3 is to remake the negative, hoping to obtain 13-percent distortion. If you want to obtain an optimized print from the 12-percent negative, you then check again with the graph of sound-head lamp voltage versus print density [Figure 16] and find that you should use a sound-head voltage of 15 volts.)

6. The sound-head voltage determined in the previous step should be used to make a print from the negative. If at all possible, the cross-modulation test should be retained on the negative and printed. The print can then be checked after processing for cross-modulation distortion. A print with less than 2 1/2 percent cross-modulation distortion does not contain enough distortion to be objectionable and is considered satisfactory.

Appendix

Correction of Amplitude Errors in the Cross-Modulation Signal

The accuracy of a cross-modulation distortion determination depends on the accuracy of the test signals recorded on the film.

This procedure should not be considered a substitute for recording-level accuracy in the initial steps of the cross-modulation test. Rather, it serves as a possible alternative when signal levels have not been recorded as accurately as they should, and where time does not permit a retake of that part of the test. It should also be understood at this time that recording-level accuracy is of utmost importance where high quality sound reproduction and repeatability of test results are concerned.

There are at least three sources of error, each of which may cause an incorrect cross-modulation measurement:

1. The amplitude of the reference frequency signal.
2. The amplitude of the cross-modulation signal.
3. The degree of amplitude modulation of the carrier in the cross-modulation signal.

It is possible to correct for these errors. Following is a description of a procedure that will produce a number that, when multiplied by the measured percent cross-modulation, will produce the correct value.

This description covers cross-modulation tests in both 16 mm and 35 mm formats with both bilateral and dual-bilateral sound tracks. It is assumed that a correctly modulated track has the following characteristics:

1. The reference frequency is 80 percent of maximum amplitude.
2. The cross-modulation signal is also recorded at 80 percent of maximum amplitude.
3. The carrier of the cross-modulation signal is 80 percent amplitude-modulated.

Correction Procedure

1. Make the following measurements (all distances are measured in mils; 1 mil = 0.001 inch).

Bilateral: C, D, A, B, G, and H (refer to Table 1 and Figure 18).

Dual-Bilateral: A, B, C, D, G, H, I, J, K, L, M, and N (refer to Table 1 and Figure 19).

2. Calculate amplitude of reference:

$$\text{Bilateral} = C + D$$

$$\text{Dual-Bilateral} = A + B + C + D$$

3. Calculate cross-modulation amplitude (X-MA):

$$\text{Bilateral: X-MA} = (A+B) \frac{(A+B)-(G+H)}{(A+B)+(G+H)}$$

$$\text{Bilateral: X-MA} = (G+H+I+J) \frac{(G+H+I+J)-(K+L+M+N)}{(G+H+I+J)+(K+L+M+N)}$$

4. Use the formula below to find the correction factor that should be *multiplied by* the percent cross-modulation distortion as read to obtain the corrected cross-modulation distortion.

$$\text{Correction factor} = \frac{\text{Reference amplitude}}{\text{X-MA}} \times 0.8$$

The reader is referred to the article by Baker and Robinson* for a complete discussion of cross-modulation distortion measurements.

Note: Cross-modulation distortion is often described in terms of a cross-modulation product rather than percent cross-modulation distortion. The two are related by the following formula:

$$\text{Cross-modulation product} = 20 \log_{10} \frac{\text{Percent cross-modulation distortion}}{100}$$

* J. O. Baker and D. H. Robinson, "Modulated High-Frequency Recording as a Means of Determining Conditions for Optimal Processing," *Jour. SMPE*, 30:3-17, January 1938, or SMPTE Recommended Practice RP104-1994, "Cross Modulation Tests for Variable-Area Photographic Sound Tracks," available from the SMPTE website at <http://www.smpete.org>.

The formula for correcting cross-modulation products is:

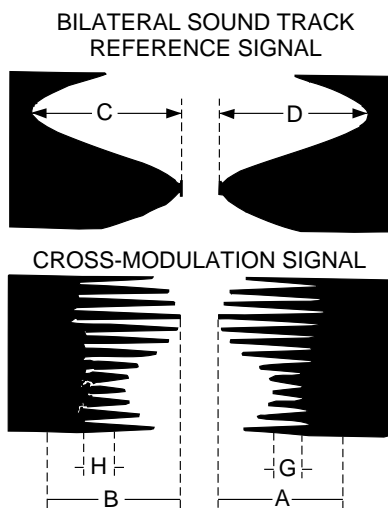
$$\text{Cross-modulation product} = 20 \log_{10} \frac{\text{Reference amplitude}}{X-MA} \times 0.8$$

This correction is added to the cross-modulation product. The graph in Figure 20 can be used in lieu of the above formula to obtain the correction.

Table 1 Distances to be Measured to Determine Correction Factor

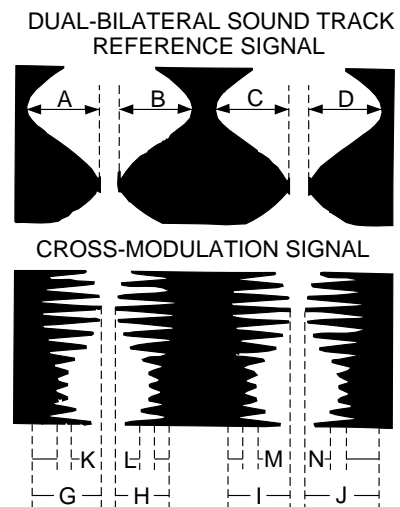
Type of Track	Dimension	Description
Bilateral	C, D	The peak-to-valley distance of each half of the bilateral reference signal.
Bilateral	A, B	The <i>maximum</i> peak-to-valley distance occurring in each half of the bilateral cross-modulation signal.
Bilateral	G, H	The <i>minimum</i> peak-to-valley distance occurring in each half of the bilateral cross-modulation signal.
Dual-Bilateral	A, B, C, D	The peak-to-valley distance of each quarter of the dual-bilateral reference signal.
Dual-Bilateral	G, H, I, J	The maximum peak-to-valley distance occurring in each quarter of the dual-bilateral cross-modulation signal.
Dual-Bilateral	K, L, M, N	The minimum peak-to-valley distance occurring in each quarter of the dual-bilateral cross-modulation signal.

Figure 18



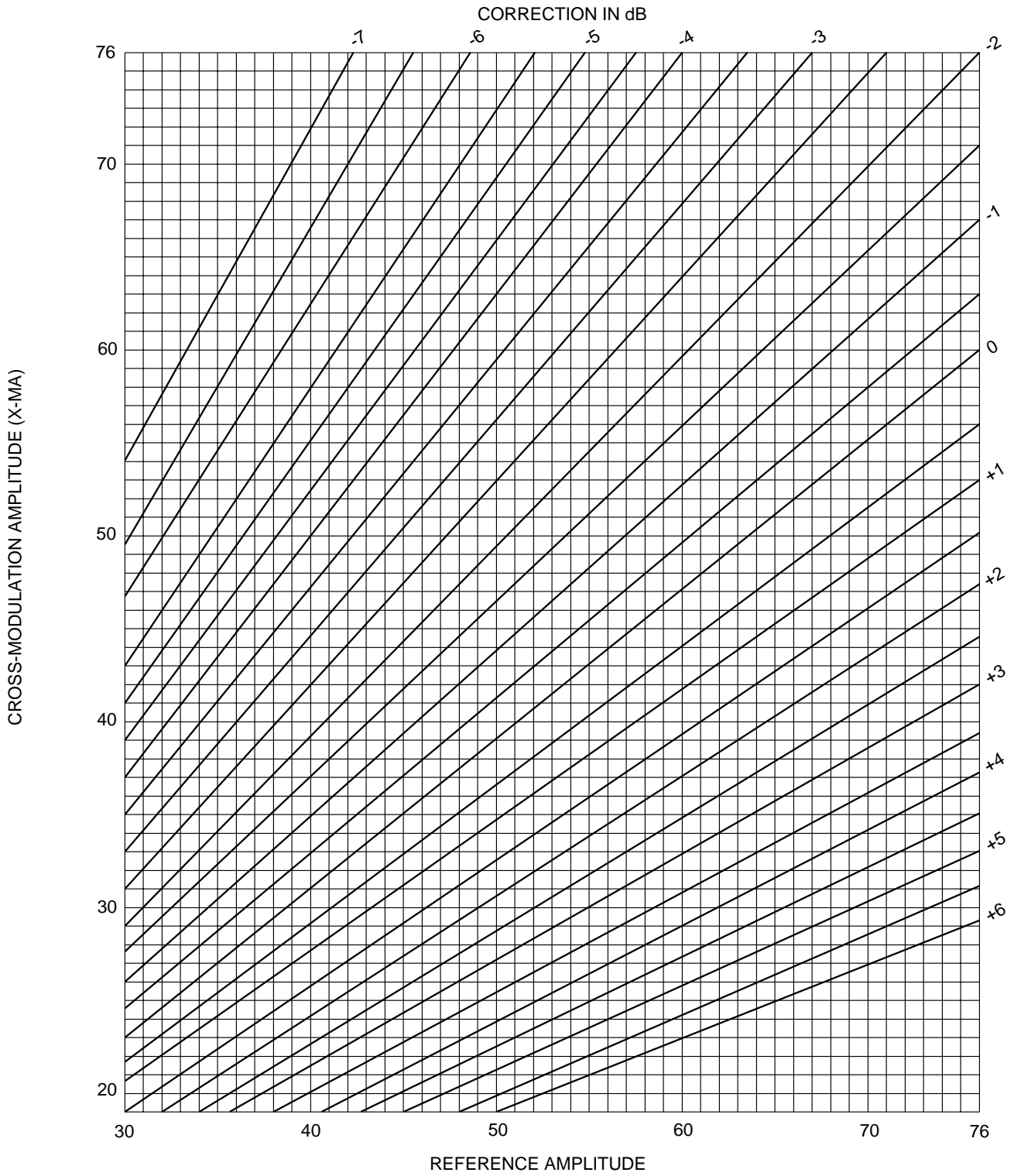
F010_0184AC

Figure 19



F010_0185AC

Figure 20 Corrections for Cross-Modulation Signal Amplitude Errors



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Cross-Modulation Distortion Testing for the Motion Picture Laboratory



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