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CROSS-MODULATION IN THE TIME AND FREQUENCY DOMAINS

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CONTENTS

ABSTRACT

This paper reviews the definitions of amplitude cross-modulation in the time and frequency domains with respect to modulation depths of the video carrier. It is shown that the variations in the percentage of modulation of the desired video carrier can change the compatibility of cross-modulation ratio between the time and frequency domains when cross-modulation ratio is defined as per Broadcast Procedure 23 and 24. By comparison of cross-modulation measurements of various modulating signals, it also showed that different modulating signals can have different just-perceptible cross-modulation ratios. The sensitivity of the picture to cross-modulation interference can be indicated by the first-order 15.75 KHz sidebands of the 87.5% modulated carrier. A threshold of just-perceptible cross-modulation interference can be established in the frequency domain at 58 dB below the unmodulated peak of the desired carrier which is also similar to the threshold for composite triple beats.

I. Introduction

Technical standards for various non-linear distortions in CATV systems in Canada were established in Broadcast Procedure 23 (BP 23) in 1971 to assure quality television signals being delivered by these systems. Cross-modulation ratio has been one of the parameters of major concern.

Besides the usual problem of interpretation between the NCTA (4) and the BP23/24 standard, ambiguities of cross-modulation measurements have been attributed to phase cross-modulation, triple beats, harmonically-related carrier systems, and difficulties experienced by consulting engineers and cable operators in carrying out proof of performance testings. Attempts to clarify some of the ambiguities were undertaken by the Department in August 1977. This paper is the summary of the author's work (8, 9) in evaluating the compatibility of the present BP 23/24 definition of amplitude cross-modulation in the time and frequency domain.

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II. Review of Cross-Modulation Ratio in the Time and Frequency Domain

The "original" definition of cross-modulation ratio as detailed in BP 23/24 can be represented by the following equation:

$$XM\ (dB) = 20 \log x/y$$

where x = peak to peak voltage of the undesired modulation envelope.

y = peak voltage of the unmodulated video carrier.

The maximum cross-modulation ratio permitted in BP 23 (1971) is -48 dB. The above definition is a time domain definition; whereas, in the frequency domain, cross-modulation ratio is generally measured as the ratio of the level of the first order 15.75 kHz sidebands of the interference to the level of the 15.75 kHz sidebands of the desired signal which BP 24 generalized to be typically 18 dB below the level of the peak video carrier. Under this definition, the interfering sidebands have to be 66 dB below the peak of the video carrier to meet the minimum requirement.

The "original" definition and generalization have failed to produce compatible measurements of cross-modulation ratio in the time and frequency domain. For example, a cross-modulation ratio of -48 dB for 100% square wave modulation has sidebands -58 dB below the peak of the unmodulated carrier in the frequency domain. If the desired square wave modulation is reduced 50%, and the interfering modulation remains at 100%, the cross-modulation ratio becomes -42 dB in the frequency domain as compared to -48 dB in the time domain.

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In order to have measurements in the frequency and time domain compatible, the type of modulating signal and the percentage of modulation have to be identified, and when percentages of modulation other than 87.5% have to be considered, a modification to the "original" definition of cross-modulation is required. Although ideally all TV signals should be modulated at 87.5%, because of the use of modulators and demodulators, the percentage of modulation can often be very different from the ideal case. In order to take into account the depth of modulation, we can redefine the cross-modulation ratio as the ratio of the maximum peak to peak variation of the interfering modulation to the maximum peak to peak modulation envlope of the desired signal.

$$\text{i.e. } XM dB = 20 \log \frac{\text{p-p envelope of interfering modulation*}}{\text{p-p envelope of desired modulation}}$$

This definition identifies as a reference the maximum peak to peak modulation envelope of the desired signal instead of the peak of the unmodulated video carrier.

* A similar definition is also given by C.A. Collin and A.D. Williams as:

$$XM = 20 \log \frac{\text{\% of wanted modulation}}{\text{\% of unwanted modulation}}$$

in their paper of "Nosie and intermodulation problems in multichannel closed-circuit television system." AIEE Transaction, Part 1 - Communication and Electronics, November 1961.

III. Experimental Verification of Time and Frequency Domain Compatibility

The set-up for cross-modulation testing and the method of time and frequency domain measurements and comparison are explained in Appendix (I).

Table A shows the summarized results of an experiment which compares cross-modulation ratio in the time and frequency domains according to the modified definition and the original definition with various combinations of modulation percentage of the desired and interfering carrier.

%Modulation		Original Definition		Modified Definition	
Interfering Color bar signal	Desired staircase signal	Time domain XM (dB)	Frequency domain XM (dB)	Time domain XM (dB)	Frequency domain XM (dB)
87%	87%	-43	-43	-42	-43
87%	50%	-43*	-38*	-38*	-38*
50%	50%	-47	-42	-42	-42

Comparison of cross-modulation ratio in the time and frequency domains according to the original and modified definition.

TABLE A

*cross-modulation definitely perceptible.

It can be seen that the results obtained with the original definition of cross-modulation ratio are not consistent in both the frequency and time domains, whereas those obtained with the modified definition indicate similar just-perceptible cross-modulation ratios. Results for other combinations of modulation percentages also indicated compatibility between time and frequency domains for just-perceptible interference using the modified definition.

In case of severe cross-modulation, the carriers will be hardlimited with severe distortion of both the desired and interfering envelope resulting in inconsistent results in both time and frequency domain measurements.

IV. Discussion on Just-perceptible cross-modulation

The carrier of a television channel has innumerable modulating signals which are known to have first order sidebands at various levels below the peak of the unmodulated carrier. BP 24 has generalized this sideband level to be 18 dB below the video carrier level, hence the accuracy of the measurement of cross-modulation ratio is dependent on how close the generalization is to the first order sideband of the 87.5% modulated desired signal. The problem of referring to the first order sidebands can be circumvented by measuring the ratio of the first order sidebands of the interference to the unmodulated carrier; cross-modulation interference will be just visible to most people when the ratio is greater than -58 dB*. Fig. 5 in Appendix I.

* Although this threshold was obtained under typical viewing conditions and by using a small number of observers, the correlation of the results with other established results using defined viewing conditions and a large variety of observers indicated that the threshold can be 3 dB worse, i.e. 61 dB below the unmodulated carrier.

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Fig. 5 shows a comparison of the first order sidebands of NCTA's 100% square wave modulation, the 87% staircase modulation and the just-perceptible cross-modulation threshold. The fact that cross-modulation ratio for NCTA's 100% square wave modulation is different from an 87% staircase modulation implies that the picture of square wave modulation is more sensitive to cross-modulation interference than that of the staircase modulation, i.e. different modulating signal can have different just-perceptible cross-modulation ratio. The first order sidebands of the 87.5% modulated carrier can be used to indicate the sensitivity of the desired signal to cross-modulation interference.

A full field staircase NTSC test signal with 10 steps and color subcarrier was used to generalize as an "average" modulating signal in the experiment because it has steps with modulation depth varying from peak white to black, and also has average sensitivity to cross-modulation interference. Therefore, in the time domain, the just-perceptible cross-modulation ratio for a staircase picture is expected to be -42 dB. Other reference signals can be used, for example, 100% modulated square wave modulation in the NCTA standard will have just-perceptible cross-modulation ratio of -48 dB since its picture is more sensitive to interference.

A number of test signals were used as desired signals to determine the threshold of cross-modulation interference in the frequency domain, Appendix (II). Some of these test signals are more sensitive to cross-modulation interference than others; however, the threshold of just-perceptible cross-modulation has a range between 58 dB to 61 dB below the unmodulated carrier level.

. . . 9

V. Conclusions

(1) Unless television signals in cable systems are maintained at 87.5% standard modulation all the time, measurements of cross-modulation ratio will have to account for any discrepancies in percentage of modulation in order to have compatibility in both domains.

(2) By comparison of cross-modulation measurements of the NCTA, 100% square wave and a NTSC staircase signal, it was shown that different modulating signals can have different just-perceptible cross-modulation ratio and the first order 15.75 kHz sidebands of the 87% modulated video carrier in the frequency domain can be used to indicate the sensitivity of the picture to cross-modulation interference.

(3) A threshold of just-perceptible cross-modulation interference can be established at 58 dB below the unmodulated peak of the desired carrier.

(4) The experiment also revealed that just-perceptible cross-modulation threshold in the frequency domain is similar to the level of just-perceptible composite triple beat interference. This suggests that it may be only necessary to specify one minimum standard requirement in the frequency domain for both cross-modulation and composite triple beat, but the use of a time domain measurement method for cross-modulation will require a conversion factor to transform its measurements into frequency domain.

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APPENDIX (I)

Comparison of Amplitude Cross-Modulation Ratios Measured in the Time and Frequency Domains

1) Set-up for Cross-modulation Testing, (Fig. 1)

a) A three channel cross-modulation testing technique was employed. All channels were initially set to the same level on the combined output of the R.F. carrier generator without any modulation. Channel 2 was then modulated by a NTSC color bar test signal. Channel 3 and 4 were modulated by a NTSC full field staircase test signal with 10 steps and color subcarrier.

b) In order to obtain the desired modulation depth, the IF's of both modulators were monitored on the oscilloscope so that the percentage of modulation could be set to 100% with no attenuation on the input attenuators. Once that 100% modulation level was obtained, the input attenuator to the modulators can be used to adjust the desired modulation to 87%.

c) The combined output of the R.F. carrier generator was examined visually and also with a spectrum analyzer for any inherent cross-modulation. The sidebands to unmodulated carrier ratio should be better than 65 dB.

d) The modulation on Channel 4 was removed when measuring cross-modulation.

e) The amplifier cascade was set-up for unity gain using the flat loss of the attenuators.

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1) Set-up for Cross-modulation Testing, (Fig. 1)

a) A three channel cross-modulation measuring technique was employed here. Channel 2 and Channel 3 were modulated by a staircase and a color bar test signal respectively. Channel 4 was left unmodulated as a test carrier for measurement.

b) In order to obtain the desired amount of modulation, the IF's of both modulators were monitored on the oscilloscope so that the percentage of modulation could be set to 100% with no attenuation on the input attenuators. Once the 100% modulation level was obtained, the input attenuator to the modulators can be used to adjust the desired to modulation to 87%.

c) All channels were set to the same level on the combined output of the Benavac generator and then the modulation on Channel 4 was removed to serve as an unmodulated test carrier.

d) The combined output of the R.F. carrier generator were examined visually and also with a spectrum analyzer for any inherent cross-modulation. The sideband to unmodulated carrier ratio on Channel 4 should be better than 65 dB.

e) The amplifier cascade was set up for unity gain using the flat loss of the attenuators.

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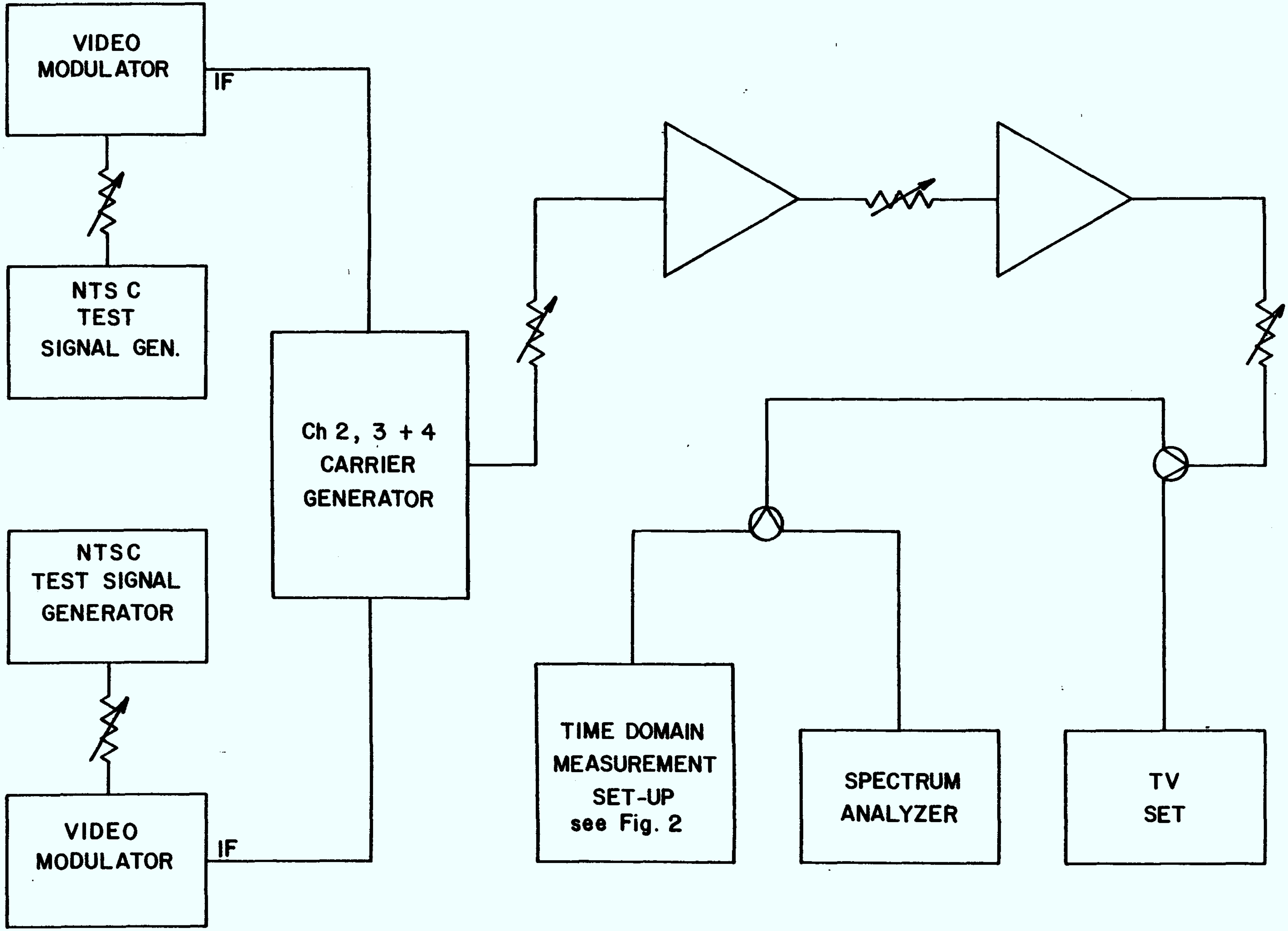

FIG I. Set-up for Cross modulation Testing

f) The input attenuator to the amplifier cascade was adjusted so that cross-modulation was just-perceptible. It should be noted that the amplifier cascade should be set so that the carrier to noise ratio is at least 40 dB.

g) Upon completion of the foregoing, the amount of cross modulation could be measured in both the time and frequency domain for comparison.

2) <u>Measurement of Cross Modulation in the Time Domain</u>

The following method was developed to obtain small amounts of cross modulation, typically 50 dB below the peak of the unmodulated carrier.

The equipment was set up as shown in Fig. 2. This set-up employs the use of a field strength meter as an RF detector; the notch filter and the low-pass filter were used to eliminate the IF and other spurious that exists on the video output of the detector.

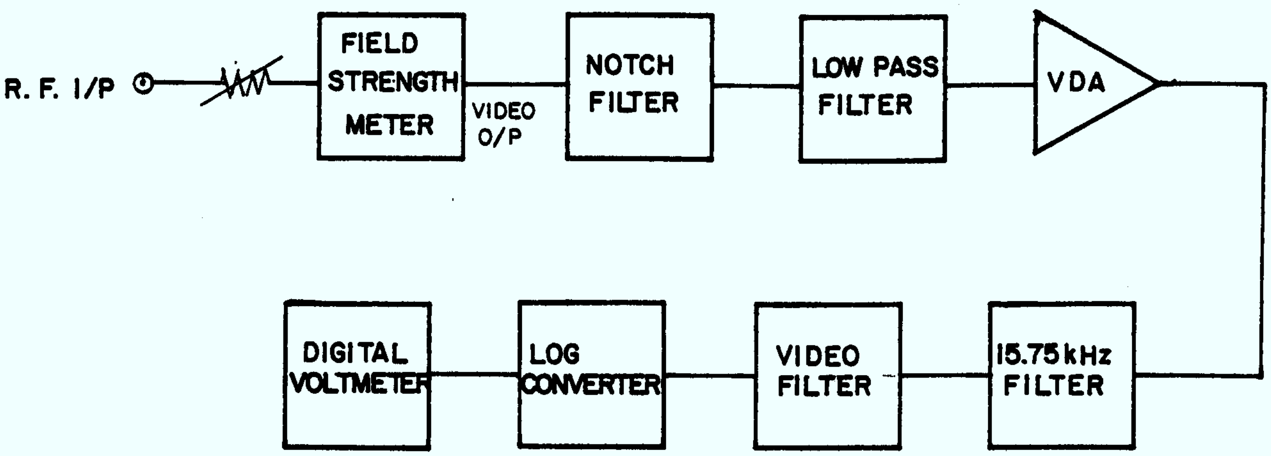

Fig. 2 TIME DOMAIN MEASUREMENT SET-UP

The advantages of this set-up are that the field strength meter is always seeing the same RF level throughout the experiment; the video noise on the 15.75 kHz modulation is filtered out and the log converter provides a linear D.C. output with both high and low percentage of modulation. The dynamic range of modulation obtainable from this set-up was from 100% to 0.1% minimum. It can be seen from the calibration curve in Fig. 3. that the sensitivity for changes in modulation is very good, especially for low percentages of modulation.

This set-up can be calibrated either by a sine wave, square wave or a NTSC test signal when the proper correction factor is taken into account. In this experiment, a video test signal was used for calibration; hence, the non-linearity of the modulator, especially at low percentage of modulation, has to be taken into account. The set-up was calibrated by providing a 100% modulated test signal to the R.F. carrier generator and the field strength meter tuned to the modulated pilot carrier. The video output of the field strength meter was then adjusted to a level such that when the modulated signal is 60 dB down, the filtered 15.75 kHz will have at least the minimum level required by the log converter. The RF level to the field strength meter should be maintained the same throughout the experiment. The equivalent peak to peak 15.75 kHz level can be obtained in D.C. voltages by the digital voltage for different percentages of modulation.

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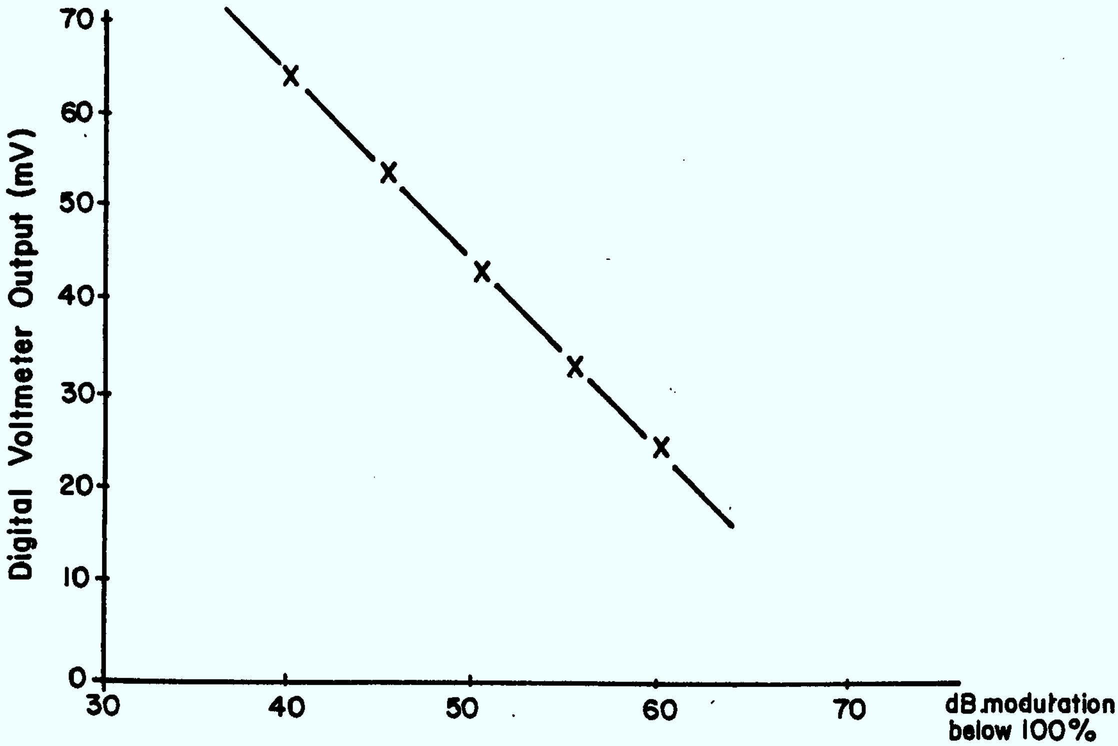

Fig.3 Calibration Curve for Various Percentage of Modulation

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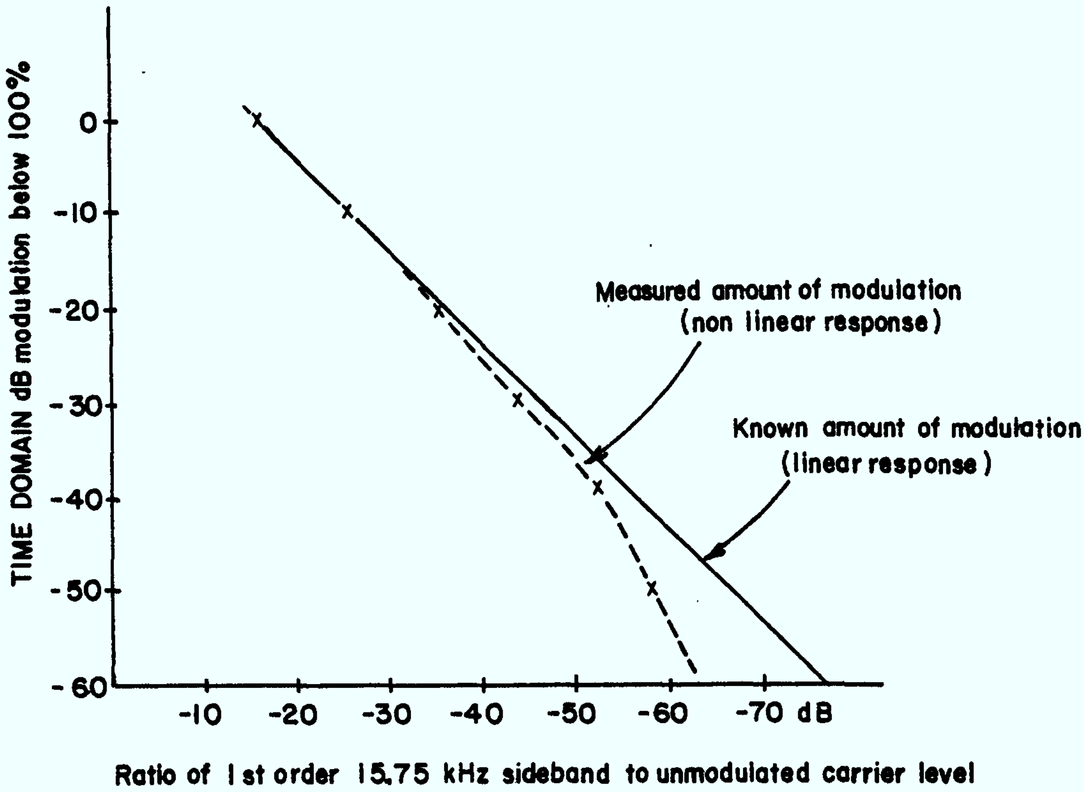

Fig. 4 Correction of modulator non - linearity

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In order to correct for the non-linearity of the modulator used for calibration, a correction curve is obtained by the use of a spectrum analyzer. It may be seen from Fig. 4 that calibrated amounts of modulation can be provided and is compared against the amount of modulation measured by the spectrum analyzer.

c) <u>Cross Modulation Data Obtained in the Time and Frequency Domain</u>

The following data was obtained with the input level to the amplifier cascade remaining constant when the cross modulation interference was just-perceptible while the modulations of both NTSC test signals were set at -1 dB below 100% modulation.

TABLE 1

Cross modulation Data with the input to the Amplifier Cascade Remaining Constant

Interfering Signal % Modulation	Desired Signal % Modulation	Time Domain X-mod. as per original definition	Freq. Domain X-mod. sideband to Unmodulated carrier ratio	
			Not corrected for modulator linearity	Corrected for modulator linearity
87%	87%	-43 dB	-55 dB	-59 dB
87%	50%	-43 dB**	-55 dB**	-59 dB**
50%	50%	-47 dB	-57 dB	-63 dB

After correction for the linearity of the modulator the results in the frequency domain are compared to those in the time domain as in Table 2.

. . . 19

TABLE 2

Corrected results in the frequency and time domain.

Interfering Signal % Modulation	Desired Signal % Modulation	Time Domain XM (dB) as per "original" definition	Freq. Domain XM (dB) interfering sideband to desired sideband
87%	87%	- 43	-(59 - 16) = -43
87%	50%	-43**	-(59 - 21) = -38**
50%	50%	-47	-(63 - 21) = -42

** Cross modulation interference was definitely perceptible.

Upon close examination of the picture when the modulation of the interfering signal was 87% and the desired signal was 50%, it was noticed that the interference on the picture was worse than when both signals were modulated at 87% due to the lower desired modulation. However, when both the desired and interfering carriers were both modulated at 50% the cross modulation interference became just imperceptible.

From TABLE 2, it can be seen that due to changes in modulation the results agreed only in one case, that is when both desired and interfering signals were modulated at approximately 87%.

Table 3 is obtained by applying the following modified definition for cross modulation ratio to the results obtained in Table 2:

$$\text{XM (dB)} = 20 \log \frac{\text{peak-to-peak envelope of interfering modulation}}{\text{peak-to-peak envelope of desired modulation}}$$

TABLE 3

Cross modulation Ratio in the Time and Frequency Domain as per modified definition

Interfering Signal Modulation below 100%	Desired Signal Modulation below 100%	Time Domain XM (dB)	Freq. Domain XM (dB)
87%	87%	-(43 - 1) = -42	-(59 - 16) = -43 dB
87%	50%	-(43 - 5) = -38**	-(59 - 21) = -38 dB**
50%	50%	-(47 - 5) = -42	-(63 - 21) = -42 dB

** Cross modulation interference was definitely perceptible.

The results from TABLE 3 indicate that the time and frequency domain cross modulation ratios agreed at just-perceptible interference. Possible human error was estimated to be up to -3 dB.

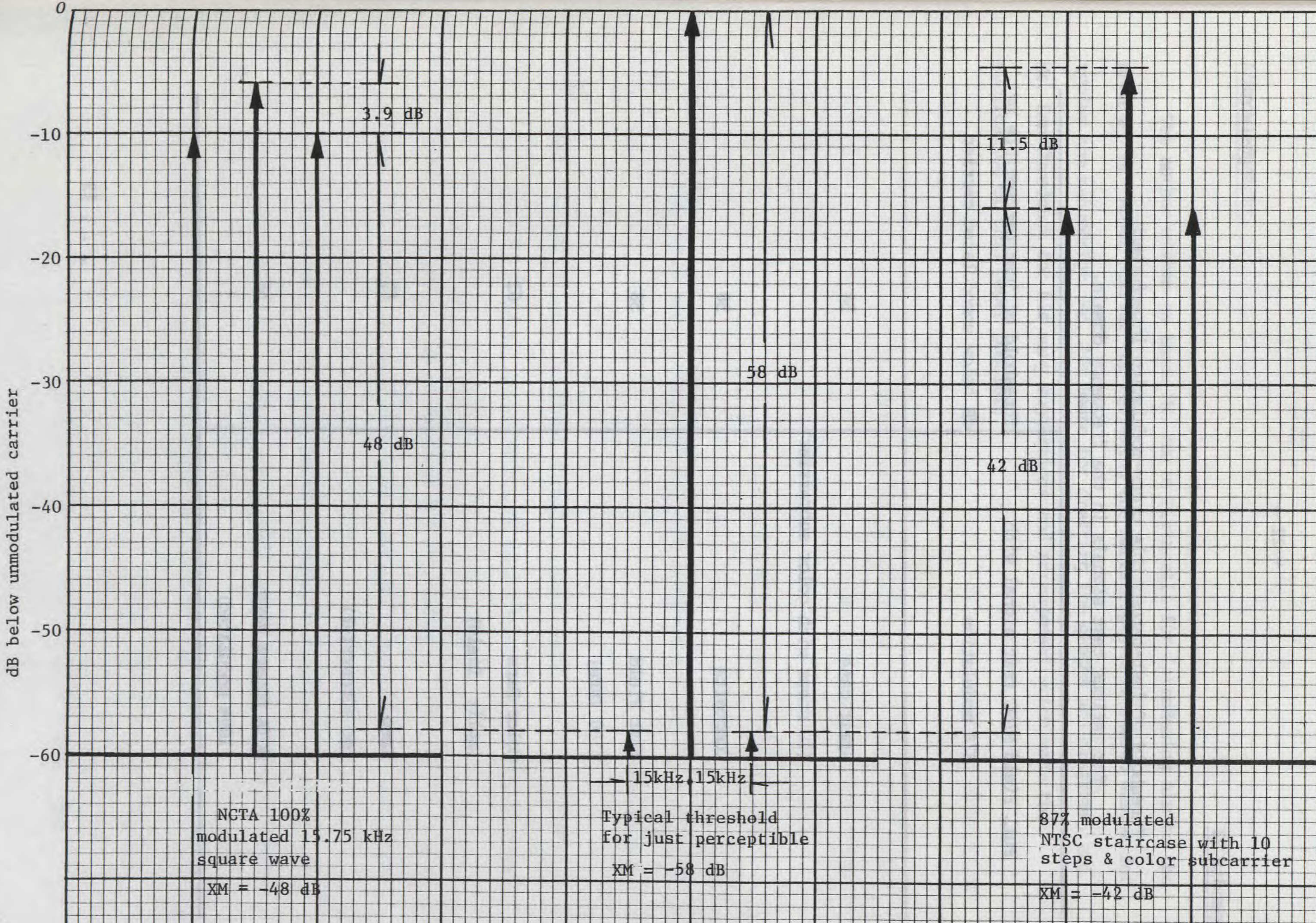

Fig. 5 A comparison of the spectral components of the NCTA 100% modulated square wave, the NTSC staircase and the just perceptible threshold.

Appendix II

Threshold of just-perceptible cross-modulation interference for various test signals in the frequency domain.

Full Field NTSC test signal with 87% modulation	Threshold of just perceptible XM dB below unmodulated carrier
Stair case (10 steps with color subcarrier)	58
Composite	58
Flat Field (100 IREs)	58
Color Bars (split field)	61
Ramp (no subcarrier)	61
NCTA Square Wave (100% modulated)	58

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