CALIBRATION OF CROSS MODULATION MEASUREMENTS

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Cross modulation measurement is an especially important parameter in the determination of CATV system performance. In the industry today several cross modulation test sets are available to fulfill the need to measure cross modulation. However, for accurate measurements these test sets must be calibrated in an accurate and repeatable manner. This calibration is accomplished by the insertion of a known cross modulation level, which is then used as a standard for comparison.

Since detectors used in these signal measurements are basically non-linear devices (which can be approximated with a square law expansion), it becomes essential to have the calibration point near the region of expected cross modulation readings.

When one talks about percent modulation in terms of dB and spectral component levels in dB corresponding to a given cross modulation level, there has usually been a considerable amount of confusion over these terms. Let us attempt to clarify these terms by a look at the facts. See Figure 1. As illustrated by Figure 1, the difference between the NCTA definition and conventional definition of an amplitude modulated wave lies in the way the modulation excursion on the carrier is defined. By equating the two definitions and solving mathematically (see proof in Appendix A) we then can see that M_t (NCTA modulation) is equal to M_c (conventional modulation) plus a correction factor T. See Figure 2. As shown in Figure 2, the factor T is equal to 0 dB at 100% modulation and 6 dB at 0.1% modulation.

Let us first consider several modulation levels using the conventional modulation definition. For a 100% square wave modulated carrier the first spectral component away from the carrier is 3.9 dB below the carrier. See Figure 3. For a 100% CW (sinusoidal) amplitude-modulated wave the first (and only) spectral components are 6 dB below the carrier. It is then apparent that a 0.1% square wave modulated signal has a first spectral component 63.9 dB below the carrier and a 0.1% CW amplitude modulated wave has its first (and only) spectral component 66 dB below the carrier level. See Figure 4.

Now considering the NCTA defined modulation, a 0.1% modulated signal has its first spectral component 69.9 dB below the carrier. It should be noted here that -60 dB cross modulation means that there is 0.1% induced modulation; not that the first spectral component is down 60 dB.

To produce an accurate calibration point, it is necessary to calibrate at very low cross modulation levels (at least 60 dB below the carrier). At this point then one must decide whether to use square wave modulation or amplitude modulation. Since it is difficult to accurately fix a modulation index, the choice of modulation then must be one which is accurate and repeatable.

One way of accurately simulating a low modulation index is to linearly add and envelope detect two CW signals that are closely spaced in frequency. If one of the signals is sufficiently small when compared to the other, then the detected output is the same as that of a conventional amplitude modulated signal having a modulation index equal to the voltage ratios of the two signals.

Consider the addition of two sinusoids of different and arbitrary relative amplitude M:

$$\text{SIN } X + M \text{ SIN } Y = P \text{ SIN } \phi$$

where $P^2 = 1 + M^2 + 2\,M \text{ COS } (X - Y)$

and $\text{TAN } \phi = \dfrac{\text{SIN } X + M \text{ SIN } Y}{\text{COS } X + M \text{ COS } Y}$

The derivation of these relations is shown in Appendix B.

If M = 1, the Sin X + M Sin Y reduces to 2 Cos ½ (X - Y) Sin ½ (X - Y), which is not conventional amplitude modulation. However, under the conditions stated before; that is, a large relative amplitude difference ($M \ll 1$) and close frequency spacing ($X \simeq Y$), then ϕ is approximately equal to X. Expanding the square root of $1 + M^2 + 2\,M \text{ Cos } (X - Y)$ in a Taylor series about 1 yields

$$P = 1 + M \text{ COS } (X - Y) + \text{Higher Order Terms.}$$

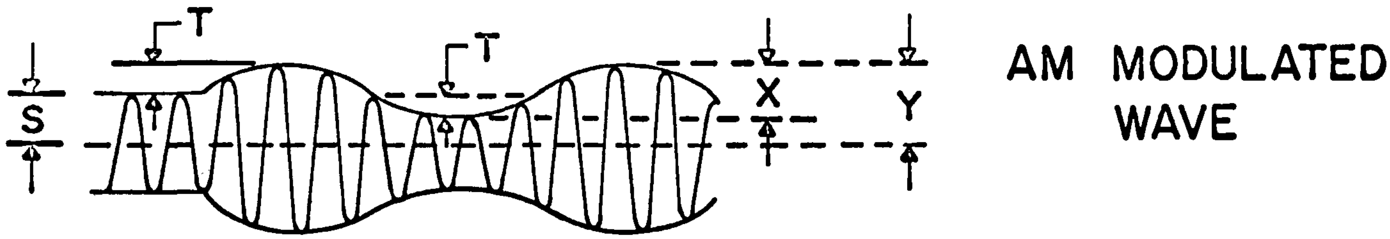
Therefore, for these conditions

$$\text{SIN } X + M \text{ SIN } Y \simeq \left[1 + M \text{ COS } (X - Y)\right] \text{ SIN } X$$

This does not mean that new spectral components have been added by the linear addition of the two sinusoids; it simply means that this linear addition under the above conditions represents a conventional AM signal to a very good approximation.

Since we use this simulated AM signal to calibrate the cross modulation test set, we must include the 6 dB correction factor as shown in Figure 2. The simulated signal must be at the -66 dB level which corresponds with a -60 dB square wave (NCTA) modulated signal. One more correction factor must be considered; that of the audio analyzer used to read the detected signal. Since the audio analyzer is a narrow band device, one must consider the difference between the first side band or spectral component of the amplitude modulated and the square wave modulated signal. Expanding both signals in a Fourier series and comparing the first two spectral components reveals that the square wave modulated signal is 2.1 dB greater than an AM signal for the same modulation index as was previously shown in Figure 3. Therefore, +2.1 dB must be added to the -66 dB calibrating wave. Consequently, a -63.9 dB amplitude modulated signal is equal to a -60 dB square wave (NCTA) modulated signal. Again, looking only at the first spectral components we can see the relationship between the NCTA, conventional, and simulated modulation levels. See Figure 5 for a comparison of these levels.

C-COR has related this theory of calibration to actual operation of a unit which C-COR has built and proven in use for calibration of cross modulation test sets. A block diagram of the C-COR calibrator is shown in Figure 6. Its operation follows the theory described to provide a -60 dB cross modulation calibration point. The calibrator employs two crystal controlled oscillators with a difference frequency of 15.75 kHz. The outputs of both oscillators are fed to directional couplers one leg of which is used for a test point. A calibration on one oscillator is used to equalize the amplitude of that oscillator's output to the second oscillator's output while monitoring both outputs at the test points. The first oscillator's output then is fed to a precision 63.9 dB attenuator (which has been calibrated using a secondary standard). The attenuator output is then fed into a combiner along with the output of the second oscillator. At the combiner output then the signals provide a simulated -60 dB cross modulation calibration reference. This calibrator has proven itself as an instrument for consistent accuracy and repeatability in calibrating cross modulation test sets.

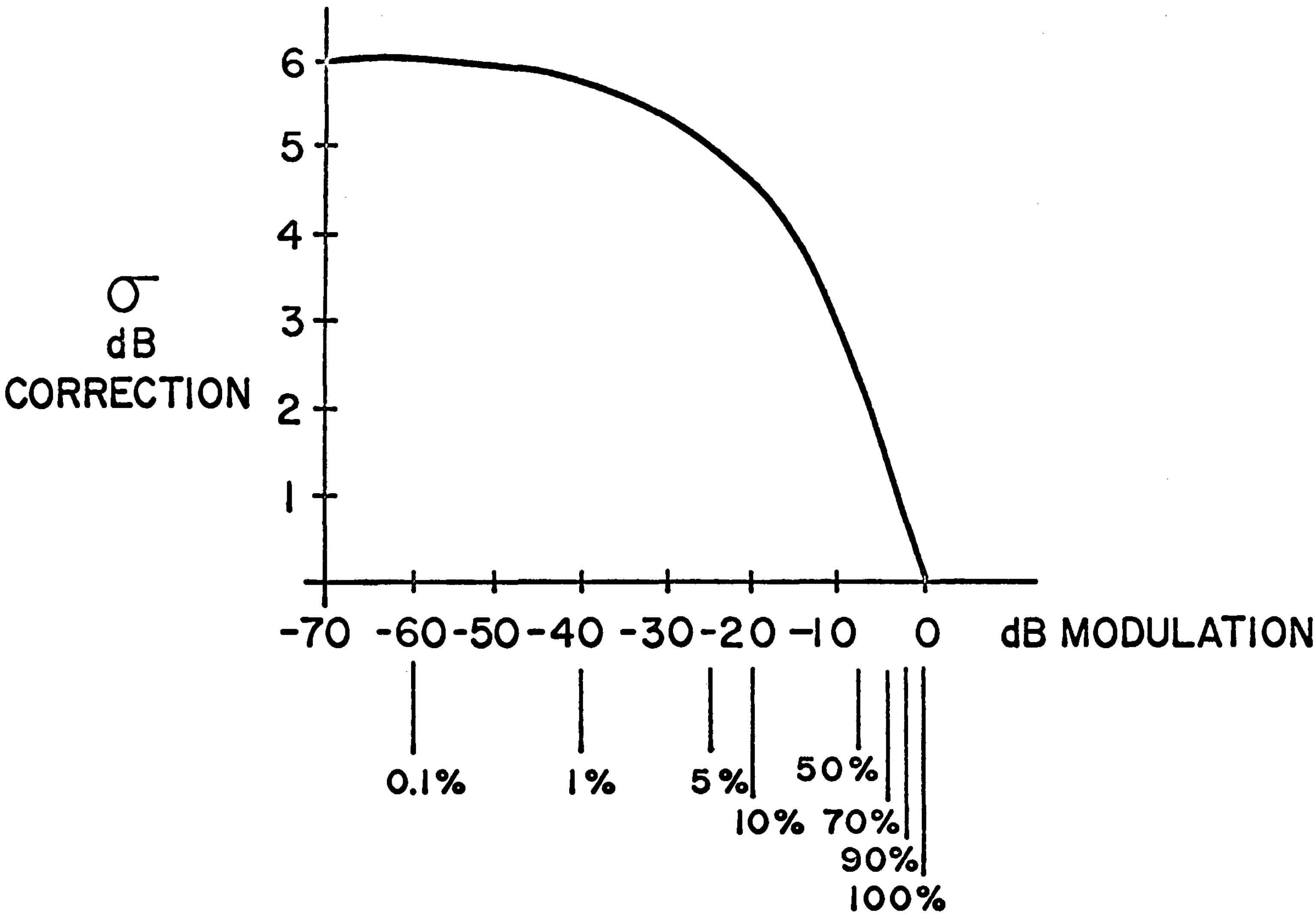


DEFINITION: CONVENTIONAL MODULATION $Mc = \frac{T}{S}$

DEFINITION: TELEVISION OR NCTA MODULATION $Mt = \frac{X}{Y}$

PERCENT MODULATION = $M \cdot 100$

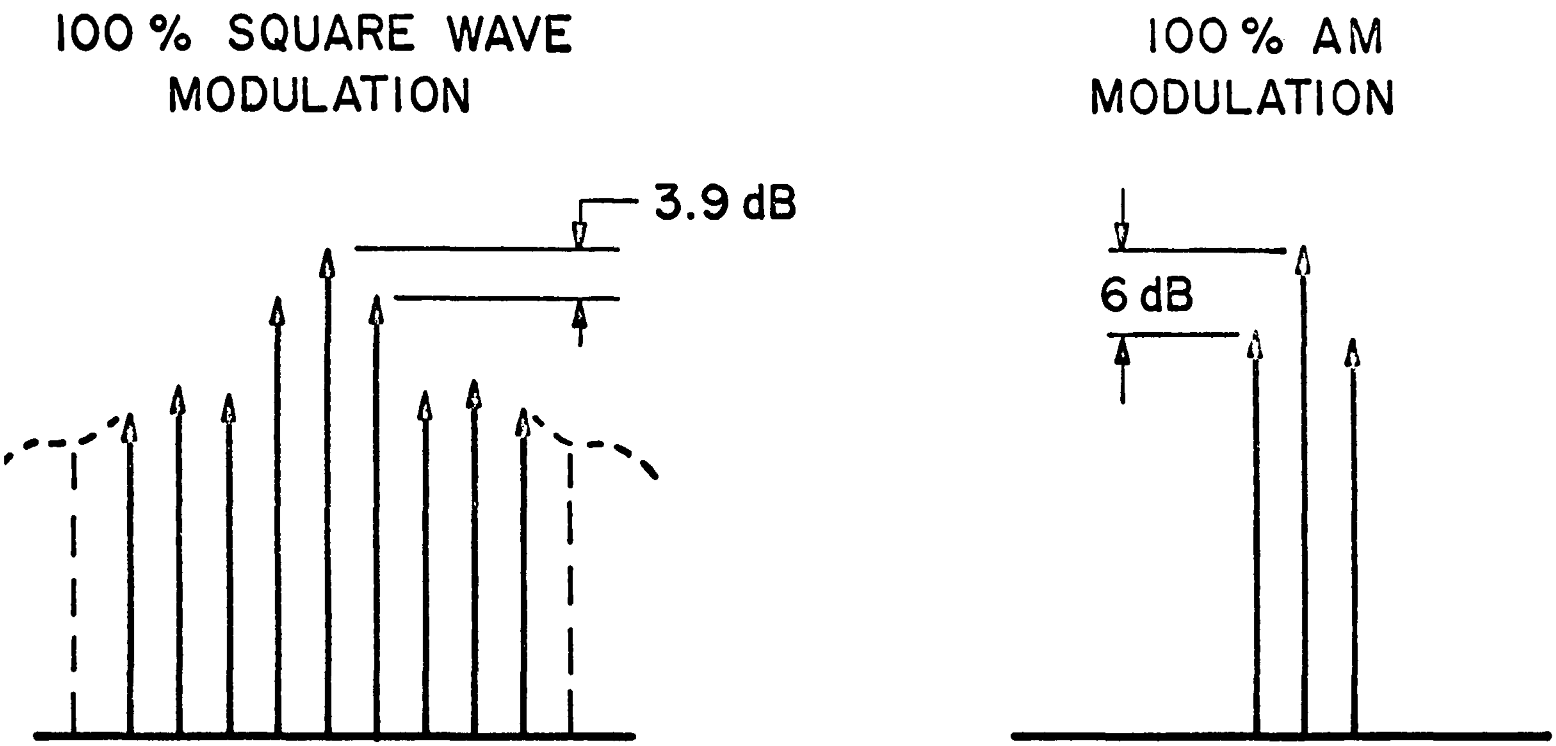
FIGURE 1



MODULATION LEVEL (NCTA)

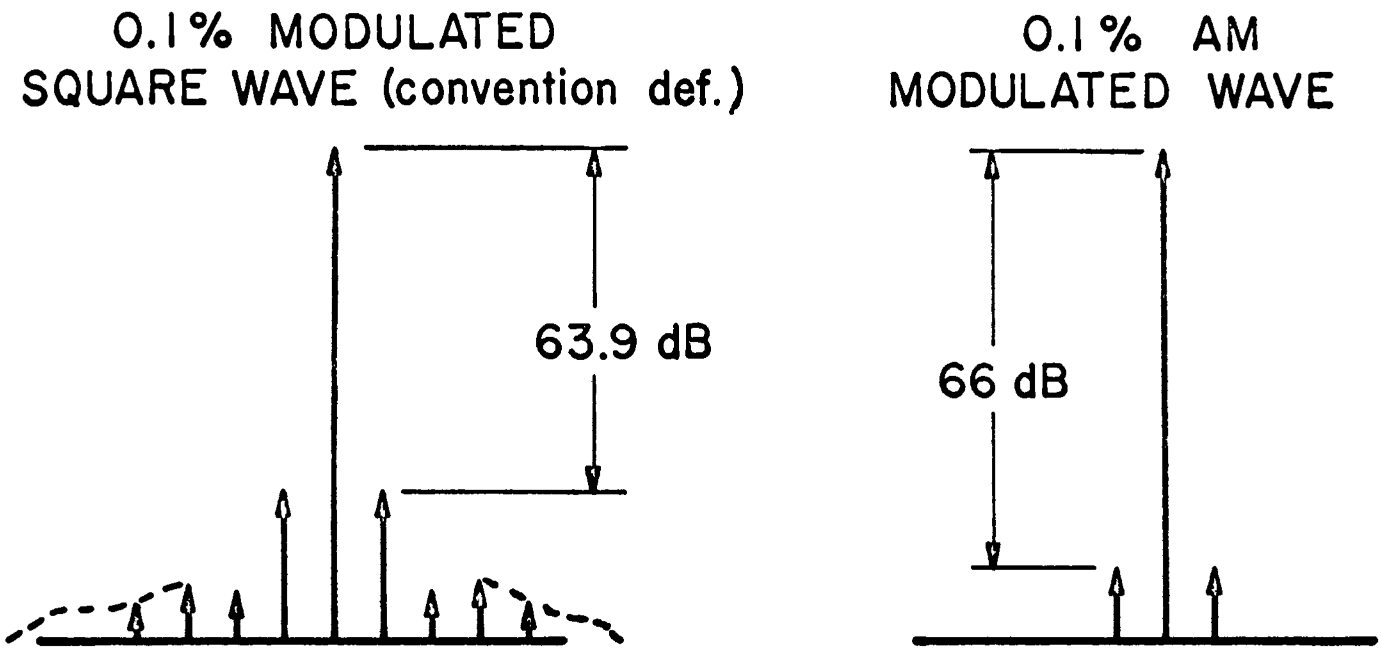
VERSES σ

FIGURE 2



SPECTRAL LINES OF A
CARRIER 100 % MODULATED
WITH A 15.75 KHz SIGNAL

FIGURE 3

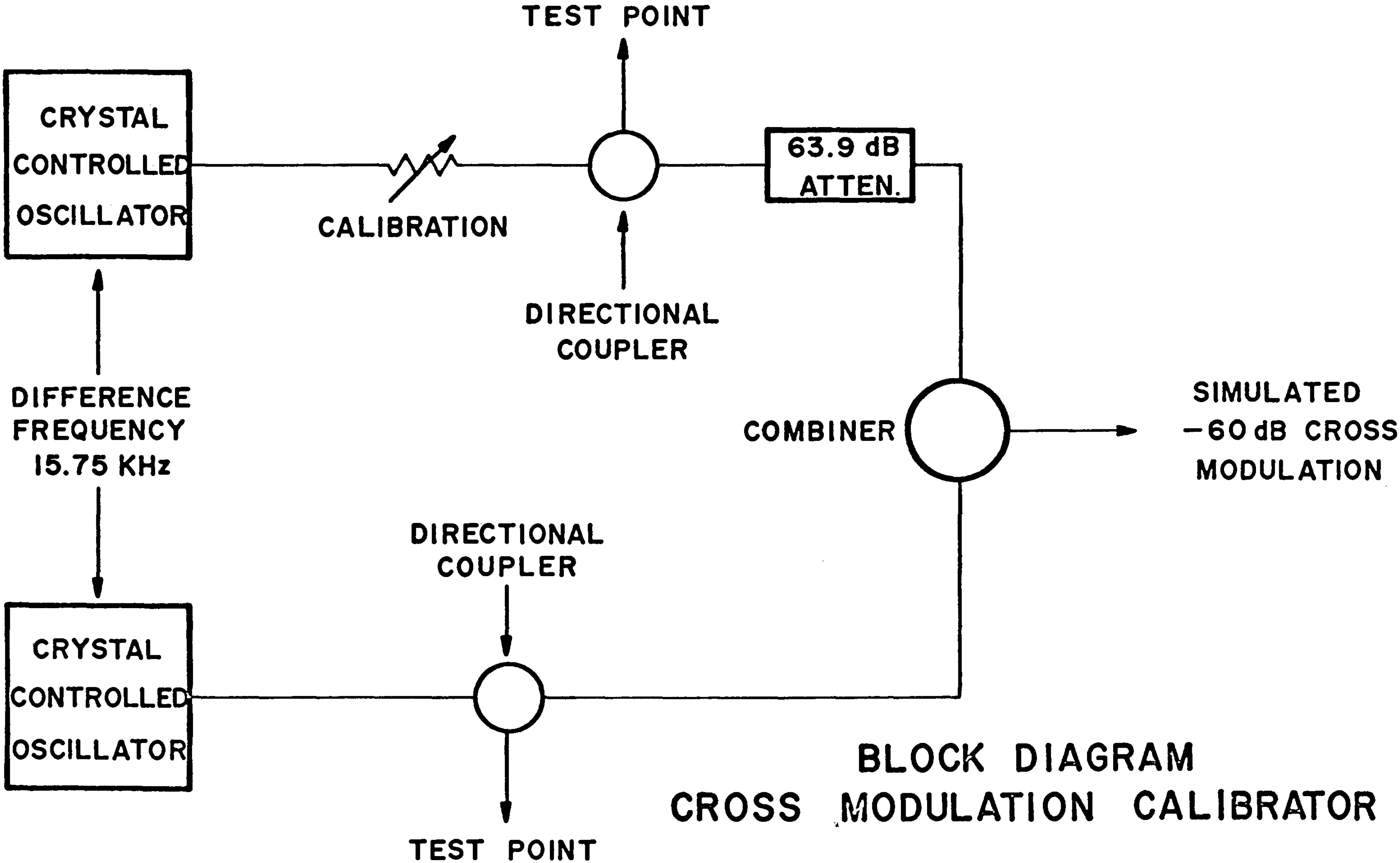


SPECTRAL LINES OF A
0.1% MODULATED SIGNAL

FIGURE 4

	FIRST SPECTRAL COMPONENT LEVEL FROM CARRIER
0.1% CONVENTIONAL PULSE MODULATION	− 63.9 dB
0.1% NCTA PULSE MODULATION	− 69.9 dB (−60 dB CROSS MOD)
0.1% CW CONVENTIONAL AM	− 66.0 dB
SINE X + 0.001 SINE Y (0.001: 60 dB ATTENUATION)	− 66.0 dB (SIMULATED)
SINE X + M SINE Y (M: CORRESPONDING TO 63.9 dB ATTENUATION)	− 69.9 dB (SIMULATED)

FIGURE 5



BLOCK DIAGRAM
CROSS MODULATION CALIBRATOR

FIGURE 6

APPENDIX A

Conventional Modulation - $M_c = T/S$ See Figure 1

NCTA Modulation - $M_t = \frac{X}{Y}$

M - Modulation Level = 20 log m

Percent Modulation = 100 x m

Equate the modulation formulas by reference to Figure.

$X = 2T = Y M_t$ $T = \frac{X}{2} = S M_c$

$Y = S + T = X/M_t$ $S = Y - T = T/M_c$

$$M_t = \frac{X}{Y} = \frac{2T}{S + T}$$

$$M_t = \frac{2 S M_c}{S + S M_c}$$

By factoring and cancelling: $M_t = \frac{2 M_c}{1 + M_c}$

Likewise: $M_c = T/S = \frac{X/2}{Y - T} = \frac{X/2}{Y - X/2}$

$$M_c = \frac{\frac{X}{2}}{\frac{2Y - X}{2}} = \frac{X}{2Y - X}$$

Again by substitution

$$M_c = \frac{Y M_t}{2Y - Y M_t}$$

Therefore $M_c = \frac{M_t}{2 - M_t}$

Taking the expression for M_t and expressing in dB yields

$$20 \log M_t = 20 \log 2 + 20 \log M_c - 20 \log (1 + M_c)$$

$$20 \log 2 = 20 (.3) = 6$$

Then let $T = 6 - 20 \log (1 + M_c)$

for which the original equation then becomes

$$\underbrace{20 \log M_t}_{M_t} = \underbrace{20 \log M_c}_{M_c} + T$$

$$M_t \quad = \quad M_c \quad = T$$

APPENDIX B

$$\text{SIN } x + \text{M SIN Y} = \text{P SIN } \phi \qquad (1)$$

Using trigonometric relationships and considering the addition of two phasors which then becomes

$$e^{jX} + Me^{jY} = Pe^{j\phi}$$

Since this holds identically then,

$$\text{COS X} + \text{M COS Y} = \text{P COS } \phi$$

Thus $\text{TAN}\phi = \dfrac{\text{SIN } \phi}{\text{COS } \phi} = \dfrac{\text{SIN X} + \text{M SIN Y}}{\text{COS X} + \text{M COS Y}}$

Then $P^2 = (e^{jX} + Me^{jY})\ (e^{-jX} + Me^{-jY})$

which yields $P^2 = 1 + M^2 + 2M \text{ COS } (X - Y)$

Equation (1) now becomes

$$\text{SIN X} + \text{M SIN Y} = \left[1 + M^2 + 2M \text{ COS } (X - Y)\right]^{1/2} \text{SIN } \phi$$

* For M 1

$$\text{SIN X} + \text{M SIN Y} = \left[1 + \frac{M^2 + 2M \text{ COS } (X - Y)}{2}\right] \text{SIN } \phi$$

$$+ \left[1 + M \text{ COS } (X - Y)\right] \text{SIN } \phi + \frac{M^2}{2} \text{ SIN } \phi$$

Which equation is like conventional amplitude modulation where M has the same meaning as in amplitude modulation.

If M = 1 $\quad P^2 = 2 + 2 \text{ COS } (X - Y)$

$$\text{or } P = \sqrt{2}\left[1 + \text{COS } (X - Y)\right]^{1/2}$$

$$= 2 \text{ COS } \tfrac{1}{2} (X - Y)$$

and when applied to equation (1), the equation becomes

$$\text{SIN X} + \text{SIN Y} = 2 \text{ COS } \tfrac{1}{2} (X - Y) \text{ SIN } \tfrac{1}{2} (X - Y)$$

Since $\text{TAN } \phi = \dfrac{\text{SIN X} + \text{SIN Y}}{\text{COS X} + \text{COS Y}} = \text{TAN } \tfrac{1}{2}(X - Y)$

it follows that

$$\phi = \frac{X + Y}{2}$$

* See No. 3 Bibliography.

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Attachment 2
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