THE RELATIONSHIP BETWEEN THE NCTA, EIA, AND CCIR DEFINITIONS OF SIGNAL-TO-NOISE RATIO

T. M. Straus
Theta-Com of California
Phoenix, Arizona

One might think that such a common term as signal-to-noise ratio has only one definition, but this is unfortunately not the case. The definition depends upon what is meant by "signal" and what is meant by "noise" and these meanings determine how the measurement is made. To compare an NCTA S/N measurement made at VHF with an EIA or CCIR S/N measurement made at video baseband one must follow the vestigial sideband television signal through an ideal vestigial sideband demodulator. The resulting relationships show that there is only a small difference between the various definitions. Experimental results which back up the theoretical findings are described.

A. Definitions

The following are some of the definitions commonly used to define TV signal quality.

1. NCTA : Signal - rms power of the VHF signal during the synch pulse.

   Noise - rms noise power in a 4 MHz wide VHF channel.

The measurement is necessarily made at VHF and generally with a field strength meter. Signal power is read directly from the field strength meter. Noise power is also read off the meter after the signal is removed but a correction factor of 3.9 dB, (at +5 needle reading) which accounts for the fact that the meter bandwidth is less than 4 MHz and also that the meter attempts to read noise peaks rather than rms value, is added to the reading.

Alternatively, a VHF spectrum analyzer may be used to make the measurement. The sweep speed must be sufficiently lowered, and the sweep width decreased so as to insure that one does see the true synch pulse peak. For the noise measurement, video filtering can help establish the rms value but the true noise bandwidth must also be carefully established.

2. TASO : Signal - rms power of VHF signal during the synch pulse.

   Noise - rms noise power in a 6 MHz wide VHF channel.

Note that this is exactly the NCTA definition except for the different noise bandwidth. Thus the TASO and NCTA definitions are related to each other by a simple bandwidth correction factor. On the other hand, they are distinctly different from the definitions which follow.

3. EIA : Signal - difference in voltage between the synch tip and the reference white.

   Noise - rms noise voltage (nominally between 10 KHz and 4 MHz) weighted by the curve shown in Figure 1.

The measurement is necessarily made at baseband frequencies. A wide band oscilloscope is used to measure the peak-to-peak volts at the output of the weighting network shown in Figure 2. An rms indication meter is then used to measure the noise voltage with the signal removed. Low frequency noise due to hum is excluded.

4. CCIR : Signal - difference in voltage between the blanking pulse and the reference white.

   Noise - rms noise voltage weighted by the curve shown in Figure 3.

The measurement is made as for EIA except that the signal is defined as above and the weighting network shown in Figure 4 is used.

To be more precise, this definition applies only to the CCIR Norm M television signals used in Canada and the United States. In other countries, different weighting networks are applied.

In addition, one often hears reference to an unweighted CCIR signal to noise ratio. One could view the "unweighted" case as one where the weighting network has a flat frequency response.

5. BTL : Signal - difference in voltage between the synch tip and the reference white.

Noise - rms noise voltage weighted by curve shown in Figure 3.

This is clearly a hybrid description in which signal is defined as in EIA but the CCIR noise weighting is used. Here also the "unweighted" definition exists. The unweighted and weighted ratios are simply related by the appropriate weighting factors which will be given later in this paper. The relation is such that the weighted signal to noise is always larger than the unweighted signal to noise ratio.

B. Relation Between RF and Baseband S/N

Within the definitions given in Section A of this paper, there are obviously two classes of S/N, i.e. measurements made at VHF and measurements made at video baseband. For the latter type measurements, a noise weighting is applied which attempts to take into account the variation in subjective evaluation to interference at various baseband frequencies. In that sense the latter definitions are more nearly a measure of the true quality of the TV picture delivered to the customer. Both EIA and CCIR noise weighting shows that in general, noise at high baseband frequencies is less objectionable than noise at low video baseband frequencies. The difference between the two is that the EIA applies to color TV while the CCIR is only applicable to black and white. The greatest confusion arises from imprecision in stating which baseband definition, whether weighted or unweighted, is to be compared to the NCTA definition.

In this section, we derive a general relation between the baseband and rf signal to noise ratio.[1] As a starting point, we begin with the familiar equation for a double sideband amplitude modulated wave

$$g(t) = A_c(1+mf(t)) \cos \omega_c t \quad (1)$$

where m = modulation ratio
ω_c = carrier frequency
A_c = carrier amplitude
$f(t)$ = modulation function

The carrier envelope varies from A_c (1+m) to A_c (1-m) because $|f(t)| \leq 1$. The detected peak to peak signal voltage is therefore proportional to $2mA_c$.

This signal is accompanied by noise assumed to have a uniform spectral power density, η, over the full 2B rf bandwidth of the receiver. B is the spectral width of the video modulating signal. If the noise on one side of the carrier is uncorrelated with noise on the other side of the carrier, the noise voltages from the two "side bands" add in an rms fashion upon detection. This is the case when the predominant noise is generated at rf as in most CATV systems. The ratio of the detected peak to peak signal power to the detected rms noise power is then

$$\left(\frac{S}{N}\right)_{AM} = \left(\frac{2mA_c}{2B\eta}\right)^2 \quad (2)$$

The rms carrier power during the peak of the modulating cycle is given by

$$C_p = (1+m)^2 \frac{A_c^2}{2} \quad (3)$$

Substituting this into (2) one obtains

$$\left(\frac{S}{N}\right)_{AM} = \left(\frac{2m}{1+m}\right)^2 \left(\frac{C_p}{\eta B}\right) \quad (4)$$

The factor $2m/(1+m)$ represents the envelope variation relative to the peak envelope. Clearly if the definition of peak to peak signal changes, as for instance between CCIR and EIA, then we would accordingly adjust the modulation factor. The second factor in equation (4) could be the NCTA definition of carrier to noise.

In ideal vestigial sideband receivers, the signal and noise are first passed through a filter having the characteristics shown in Figure 5 and only then detected. The filter serves to just compensate for the extra low frequency ($f \leq .75$ MHz) vestigial sideband which is transmitted. The detected signal output is then a nearly undistorted replica of the modulation waveform applied at the transmitter. This is achieved by adjusting the filter so that the voltage response at the carrier frequency is just $\frac{1}{2}$ of the response at frequencies above 0.75 MHz. Since the two sidebands of the signal are correlated, the voltage on either side of the carrier are added and the post detection signal voltage characteristic is independent of frequency up to the upper limit of the receiver response.

The receiver filter effectively eliminates half the sideband voltage. However, since the carrier voltage is also reduced by $\frac{1}{2}$, the envelope variation as a fraction of the peak carrier remains the same as it was immediately following the double sideband AM process in the transmitter. Thus the factor $2m/(1+m)^2$ retains its validity and meaning for vestigial sideband.

Consider now the effect on noise of the receiver filter. Because the two noise sidebands are uncorrelated, they add in rms fashion in the detection process. The resultant noise spectral density is shown in Figure 6. It is 3 dB down at zero frequency and increases quadratically to 0.75 MHz when it becomes flat. The equivalent noise power bandwidth is given by

$$B_N = \int_0^{f_m} n(f)df \tag{5}$$

where n(f) represents the distribution of baseband noise with frequency and f_m is the maximum frequency of the receiver response.

By rewriting the second factor in equation (4) as $(2\ C_p / 2B\eta)$, one can now modify this factor for the vestigial sideband case. In particular the equivalent noise bandwidth, 2B, for double sideband is replaced in vestigial sideband by B_N. Also, the carrier power is reduced by a factor of 4. Thus the second factor becomes $(\frac{1}{2} C_p / B_N \eta)$.

Consider now the possibility of noise weighting. Let the weighting filter be characterized by a frequency response w(f). Then the weighting factor is defined by

$$K_w = \frac{\int_0^{f_m} n(f)df}{\int_0^{f_m} n(f)w(f)df} \tag{6}$$

The general equation relating baseband signal to noise with vestigial sideband rf peak rms carrier to noise is then

$$\left(\frac{S}{N}\right) = \frac{1}{2}\left(\frac{2m}{1+m}\right)^2 \left(\frac{C_p}{\eta B}\right)_{rf} \left(\frac{B_{rf}}{B_N}\right) \frac{B_N}{\int_0^{f_m} n(f)w(f)df} \tag{7}$$

Alternatively,

$$\left(\frac{S}{N}\right) = \frac{1}{2}\left(\frac{2m}{1+m}\right)^2 \left(\frac{C_p}{\eta B}\right)_{rf} \left(\frac{B_{rf}}{B_{NW}}\right) \tag{8}$$

Where B_{NW} is the equivalent weighted noise bandwidth given by

$$B_{NW} = \int_0^{f_m} n(f)w(f)df \tag{9}$$

Equation (8) is the simpler form since it involves only one integral. However, it is most useful to express equation (7) in logarithmic form since weighting factors are generally given in dB and defined as in equation (6).

$$\left(\frac{S}{N}\right)_{baseband} = 10 \log\left\{\frac{1}{2}\left(\frac{2m}{1+m}\right)^2 \left(\frac{C_p}{\eta B}\right)_{rf} \left(\frac{B_{rf}}{B_N}\right) K_w\right\} dB \tag{10}$$

C. Tabular Results

Equation (6) is a very general form for the weighting function. If n(f) has the form shown in Figure 6, the weighting applies to vestigial sideband. If n(f) is "flat", then the weighting applies to double sideband AM. If $n(f) \sim f^2$ it is because the rf noise spectrum is triangular, as in FM systems. Table I summarizes the noise weighting, in dB, for each of these cases for both CCIR and EIA weighting curves.

TABLE I. Noise Weighting (dB)

	"White" Noise (AM)	"Triangular" Noise (FM)	Vestigial Side Band Noise
EIA (color)	4.0	6.4	4.1
CCIR (monochrome)	6.1	10.2	6.7

In any one of the three types of systems, deviations from the "ideal" noise spectrum, in particular excess noise at low detected baseband frequencies, would reduce the actual improvement factor obtained from noise weighting and correspondingly result in degraded picture quality.

Table II shows the relationship between the NCTA signal to noise ratio and the various other signal to notse ratios defined in Section A.

TABLE II. S/N Relationships

$(S/N)_{TASO}$	=	$(S/N)_{NCTA}$	- 1.8 db
$(S/N)_{EIA}$	=	$(S/N)_{NCTA}$	+ 0.1 db
$(S/N)_{CCIR}$	=	$(S/N)_{NCTA}$	- 0.2 db
$(S/N)_{BTL}$	=	$(S/N)_{NCTA}$	+ 2.7 db

As an example, consider the relationship between $(S/N)_{EIA}$ and $(S/N)_{NCTA}$. The synch tip to reference white voltage is .875 of the peak signal. The NCTA bandwidth is 4 MHz and B_N obtained from integration of Figure 6 is 3.8 MHz. Rewriting equation (10), we have

$$\left(\frac{S}{N}\right)_{EIA} = 10 \log\left\{\frac{1}{2}(.875)^2 \left(\frac{S}{N}\right)_{NCTA} \left(\frac{4}{3.8}\right) K_w\right\} dB$$

$$= \left[-3.0 - 1.2 + \left(\frac{S}{N}\right)_{NCTA} + 0.2 + 4.1\right] dB$$

$$= \left(\frac{S}{N}\right)_{NCTA} + 0.1 \text{ dB}$$

Note that the relation between unweighted baseband signal to noise and the NCTA signal to noise can be readily determined from the two tables. Thus, for instance, unweighted BTL is given by

$$(\frac{S}{N})_{BTL,\ unweighted} = [(\frac{S}{N})_{NCTA} + 2.7 - 6.7]\ dB$$

$$= [(\frac{S}{N})_{NCTA} - 4]\ dB$$

D. Experimental Verification

The experimental verification of the theoretical relationships obtained in section C are not so easy to come by as one might think. Aside from the normal instrument calibration problems, one is faced with the fact that vestigial sideband demodulators are only rarely a good approximation to the ideal assumed in the theory. Other factors enter in as well. For instance, the rf noise generator does have to have a fairly high output level without clipping the thermal noise peaks. This is best done by bandlimiting the noise before bringing it to full power in an output amplifier.

Nevertheless, verification of the theoretical expectations has been obtained. The most thorough experiment was recently carried out at a working session of the CTAC working group on noise.[2] This work, which was performed in February 1974, did verify, within ±1 dB experimental error, the predicted relationship between CCIR and NCTA signal to noise.

E. TASO Revisited

Although only peripherally related to the foregoing discussion, the following information may be of particular interest to CATV. The question concerns the subjective quality of television pictures as the S/N is varied over a wide range of values. The most extensive work along this line is, of course, the TASO study.

Some 14 years ago, the Television Allocations Study Organization undertook a comprehensive study of the subjective effect of random noise at various interference levels on the quality of the TV picture. The experimental program first established a set of optimum psychological definitions which were printed on the observer's scoring sheet, reproduced in Figure 7.[3] Several still scenes were viewed on good quality black and white and color 21-inch receivers. Viewing distance was between 90 and 126 inches and the average room illumination was 0.6 foot-candles. A 40 dB range of interfering noise ranging from not perceptible to completely masking was employed. Test results varied very little with the scene used. For the most extensive tests with the "Miss TASO picture" a total of 76 observers were asked to rate 20 showings of the subject with 10 different signal-to-interferance ratios each repeated twice in a random order. The results are tabulated in Figure 8.[4] Note that this data presentation is in a percentile form. For instance, at a $(S/N)_{TASO}$ of 27.5 dB, 50% of the viewers considered the picture "passable" or better, but also the most critical 10% of the viewers considered the picture "inferior". This lies 4 dB below the EIA recommendation of 33 dB[5] which is to be considered as an "outage" for microwave propagation fades.

In order to see if the TASO results could be used as a guide to the application of LDS microwave in CATV, a brief experiment was conducted at Theta-Com during one of the AML technical training seminars. The idea was to repeat the TASO type evaluation although necessarily under quite different conditions. An off-the-air television signal was processed through an AML microwave system and displayed on a 17" Sony television receiver. The $(S/N)_{NCTA}$ was varied from 50 dB down to 14 dB in 4 dB steps. This was controlled by a microwave attenuator placed between the AML transmitter and receiver. In all, 20 scenes were shown, 2 each at the same S/N, but in a completely random sequence.

The 24 students were mostly CATV technicians and engineers. They were each given a copy of the TASO Scoring Sheet and asked to evaluate the pictures on a personal rather than professional basis. The students were arranged in 4 rows of seats, the furthest being some 18 feet from the television screen. The room light was extinguished but enough illumination was available to permit the score sheets to be filled out. An A-B switch was used to switch the signal directly to the head end during the intervals when the microwave attenuation was reset.

Figure 9 summarizes the results of these tests. It is seen that the results are quite similar to the TASO results. As might be expected, the viewers in the front row were slightly more critical than those furthest from the screen. On the average, the CATV technicians and engineers were about 2 dB more critical than the TASO volunteers were back in 1960. Perhaps this is more a reflection of our rising expectations for good signal quality rather than any other factor which impacted these experiments.

REFERENCES

(1) Similar arguments are given in an unpublished memorandum by J. J. Bisaga. Other workers, notably J. J. Gibson, have followed slightly different lines but with essentially the same results.

(2) J. J. Gibson, private communication.

(3) G. L. Fredendall and W. L. Behrend, "Picture Quality Procedures for Evaluating Subjective Effects of Interference" PROC IRE 48, 1030-1034 (June 1960).

(4) C. E. Dean, "Measurements of the Subjective Effects of Interference in Television Reception" PROC IRE 48, 1035-1049 (June 1960)

(5) EIA Standard RS-250A (February 1967)

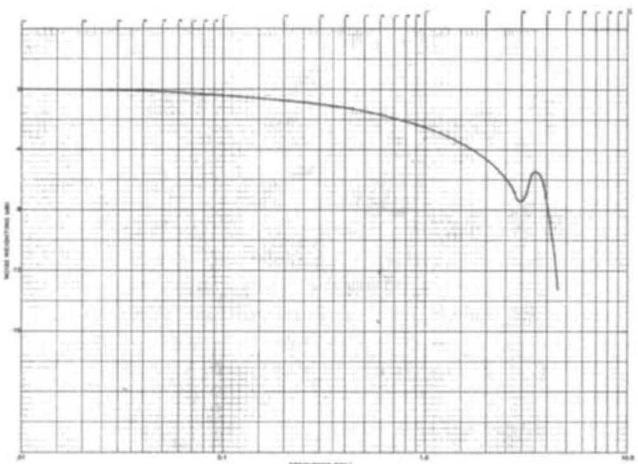

FIGURE 1. EIA NOISE WEIGHTING

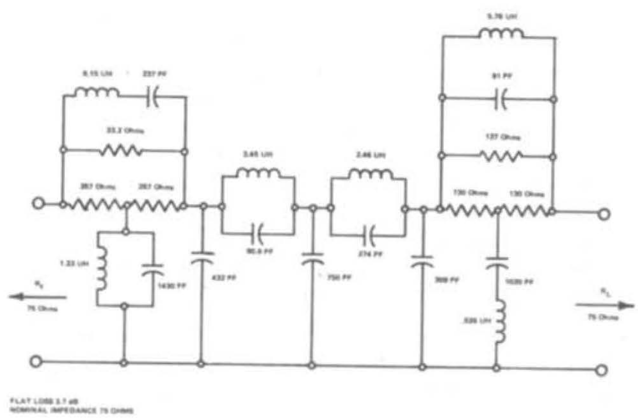

FIGURE 2. EIA NOISE WEIGHTING NETWORK

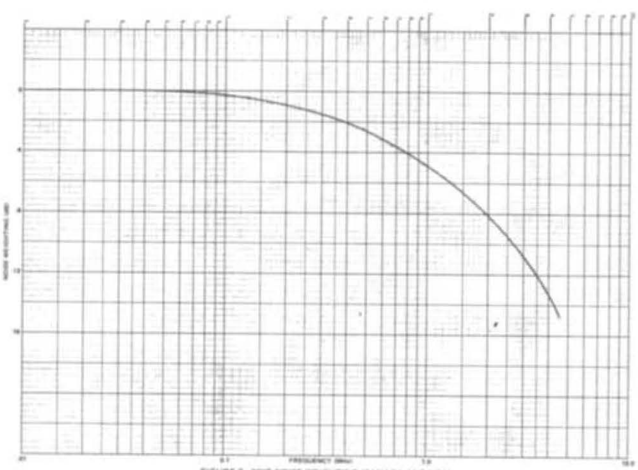

FIGURE 3. CCIR NOISE WEIGHTING (CANADA AND USA)

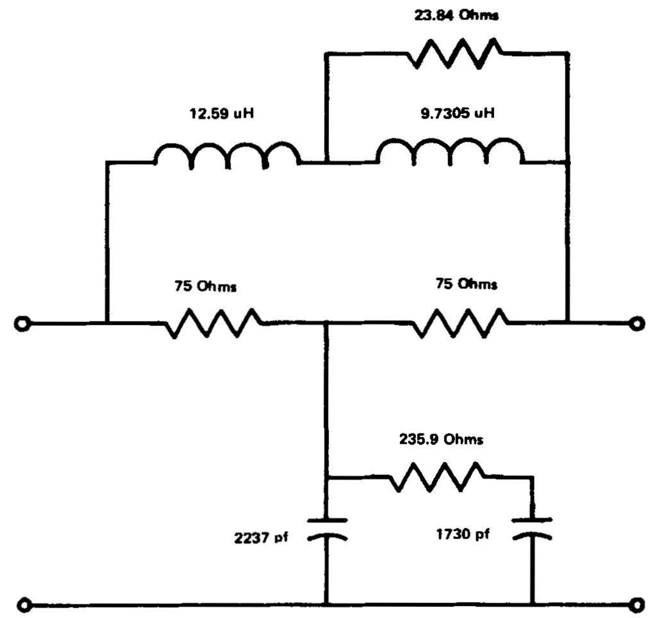

FIGURE 4. CCIR NOISE WEIGHTING NETWORK

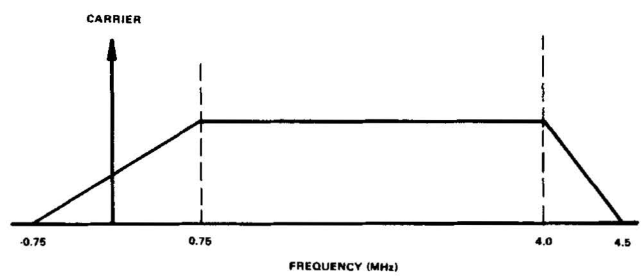

FIGURE 5. RECEIVER TRANSFER CHARACTERISTIC

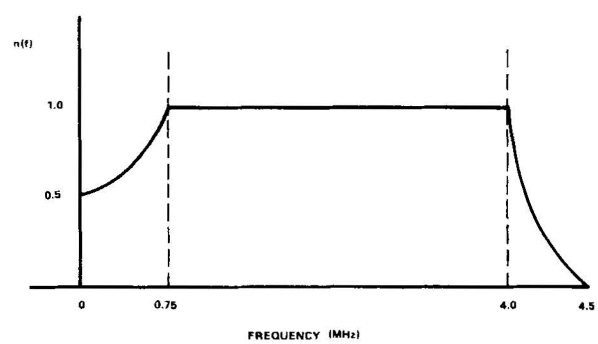

FIGURE 6. DETECTED NOISE SPECTRAL DENSITY

506

TELEVISION ALLOCATIONS STUDY ORGANIZATION

Panel 6

TEST NO ________ TV SET ________ OBSERVER ____________

EXCELLENT. The picture is of extremely high quality as good as you could desire.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

FINE. The picture is of high quality providing enjoyable viewing. Interference is perceptible.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

PASSABLE. The picture is of acceptable quality. Interference is not objectionable.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

MARGINAL. The picture is poor in quality and you wish you could improve it. Interference is somewhat objectionable.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

INFERIOR. The picture is very poor but you could watch it. Definitely objectionable interference is present.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

UNUSABLE. The picture is so bad that you could not watch it.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

DATE______________ TAB _______

FIGURE 7. TASO OBSERVER SCORING SHEET

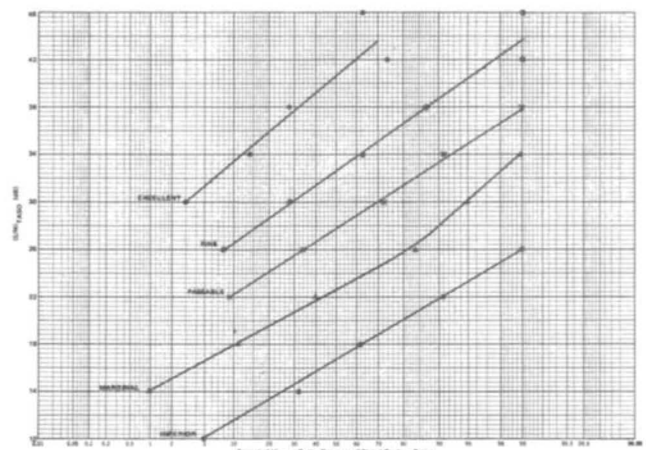

FIGURE 8. TASO RESULTS FOR RANDOM NOISE INTERFERENCE

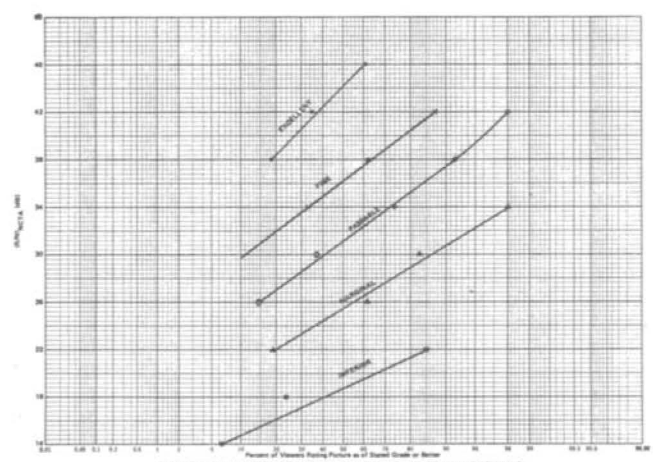

FIGURE 9. EVALUATION OF PICTURE QUALITY AT AML TRAINING SEMINAR