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L. D. Collins

Signal-to-Noise Ratios for Television Transmission

14 March 1969

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Lexington, Massachusetts

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

SIGNAL-TO-NOISE RATIOS FOR TELEVISION TRANSMISSION

L. D. COLLINS

Group 67

TECHNICAL NOTE 1969-12

14 MARCH 1969

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LEXINGTON MASSACHUSETTS

ABSTRACT

This note is concerned with the effects of random noise interference in television transmission systems. Such systems are finding increasing application in surveillance and telefactor systems. Numerous results which have been scattered throughout the literature are collected and unified. Three topics are covered:

1. The calculation of the video signal-to-noise ratio for the commonly used television transmission systems (amplitude and frequency modulation),

2. A summary of the signal-to-noise ratio definitions (including noise weighting standards) currently in use for video transmission and conversion between these definitions, and

3. A brief discussion of the subjective evaluation of television picture quality in terms of signal-to-noise ratio.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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Signal-to-Noise Ratios for Television Transmissions

The Lincoln Laboratory's long involvement in R&D associated with the transmission of data and voice signals over communication links of various sorts has produced a satisfactory understanding of the way in which system performance for such links can be calculated. For example, the required minimum signal-power-to-noise-power-density ratio (P_r/N_o) for acceptable operation of a particular vocoder modem between airplanes in flight via a UHF satellite transponder is known. Until recently, there had been no strong necessity to establish at the Laboratory a similar understanding of system-performance calculation for TV links.

The prospects for operation of TV cameras from drone vehicles (more generally, as parts of telefactor systems) are sufficiently compelling that it seems worthwhile to have available a rational process for the calculation of TV-link performance under rather general assumptions. The subjective evaluation of picture quality (the ultimate basis for acceptance or rejection by the potential user) is more difficult to characterize than the rate and error frequency of a stream of digital data, for example.

The specific requirements of a particular application have led to the compilation and study of the detector relationships for VSB-AM and FM transmission as modified by measuring techniques intended to simulate some of the subjective effects of the human observer. Standards have been promulgated by many laboratories, associations, and agencies in the past. Those currently encountered include the International Radio Consultative Committee (CCIR), Electronics Industries Association (EIA), Television Allocation Study Organization (TASO), the Bell System, and the Defense Communications Agency (DCA).

Some contractors calculate link performance one way, some another. The equivalence transformations among these various possibilities have been collected in this note. Three topics are covered:

(1) The calculation of the video signal-to-noise ratio for amplitude and frequency-modulated television transmission,

(2) The definitions currently in use for video transmission, and

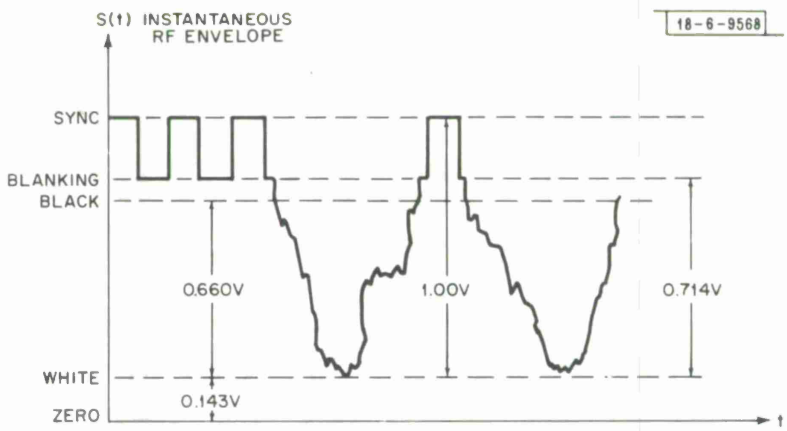
(3) A summary of subjective evaluation of picture quality in terms of signal-to-noise ratio.

I. Video Signal-to-Noise Ratio

1.1 Amplitude Modulation

The most common means of video transmission is amplitude modulation. A typical video waveform is indicated in Fig. 1, with the vertical axis calibrated in terms of carrier amplitude. In this note, we consider only black-positive video signals. For black-negative, interchange the words "black" and "white". The video signal is clamped so that the transmitter output power is its rated peak value P on the sync peaks, averaged over a few RF cycles. Then the gain is set so the white reference level is the appropriate (non-zero) value.

In order to conserve bandwidth, vestigial sideband (VSB) transmission is used. Such a system has the same noise performance as a double sideband system (DSB) having the same signal power and noise spectral density, provided the vestigial sideband filter is properly chosen (see Ref. 2, page 576). However, for this situation, the input signal-to-noise ratio in the channel bandwidth will be smaller for the DSB system since its noise bandwidth is larger. The precise amount of difference depends on the relative bandwidth of the two transmission systems. This is summarized in Table I.



NOTE: AMPLITUDES REFER TO VIDEO MODULATING VOLTAGE v(t), IS NOMINALLY 1.0 VOLT PEAK-TO-PEAK

Fig. 1. Television composite signal waveform, amplitude modulation.

TABLE I

SNR for AM Television Systems

Modulation	Channel Bandwidth W	$(S/N)_{in}$	$(S/N)_{out}$	$\frac{(S/N)_{out}}{(S/N)_{in}}$
DSB	$2 f_m$	$\frac{P}{2N_o f_m}$	$\frac{P}{N_o f_m}$	2
VSB	$f_m + \Delta$	$\frac{P}{N_o (f_m + \Delta)}$	$\frac{P}{N_o f_m}$	$1 + \frac{\Delta}{f_m}$
SSB	f_m	$\frac{P}{N_o f_m}$	$\frac{P}{N_o f_m}$	1

where:

f_m = Video bandwidth

P = Signal power (peak RF or video power, including the white-level d.c. offset)

Δ = Bandwidth of the vestigial sideband

N_o = Single-sided noise power density

W = Channel bandwidth

These signal-to-noise ratios are for white noise in the appropriate bandwidth. In Section II we shall relate these results to the weighted noise power measurements incorporated in the video transmission standards currently in use. Also, we shall discuss other definitions of signal power which are commonly encountered.

1.2 Frequency Modulation

Frequency modulation is often used for satellite and microwave point-to-point television transmission. In this section we derive the video signal-to-noise ratio in terms of the RF carrier-to-noise ratio for such a system.

As our starting point, we cite the standard result for the signal-to-noise ratio at the output of an FM system operating above threshold with sinusoidal modulation (e.g., Hancock,[2] p. 54ff).

$$(S/N)_{out} = \frac{3P(\Delta f)^2}{2N_o f_m^3} \tag{1}$$

where

$(S/N)_{out}$ = output signal-to-noise ratio (mean-square signal and noise powers)

P = received signal power

N_o = (single-sided) noise power spectral density

Δf = maximum (one-way) frequency deviation

f_m = video bandwidth .

Note that Eq. 1 does not depend explicitly on the bandwidth W. However, the bandwidth is implicit in (1) in that it must be sufficiently large to pass the signal undistorted. Furthermore, $\frac{P}{N_o W}$ must be sufficiently large that we are operating

above threshold. Also note that the signal power in (1) is the mean-square for a sine-wave. Now we express Eq. 1 in terms of parameters appropriate to TV transmission.

The usual definition of signal "power" for video signals is the peak-to-peak voltage squared, rather than any average value, such as the mean-square. We define

$$S_{p-p} \triangleq (V_{peak-to-peak})^2 \quad . \tag{2}$$

The peak levels are constants of the system (see Fig. 1), while averages depend on the video waveform. Throughout the television industry, oscilloscopes are used to measure the video signal levels. Furthermore, the ratio of peak-to-peak voltage to rms noise voltage may be regarded as the number of distinguishable amplitude levels which a given system can transmit. Note that when expressed in decibels, as is the customary practice, this voltage SNR is equal to the power SNR obtained from (1) and (2).

Since Eq. 1 assumes a sinusoidal modulation,

$$S_{p-p} = 8S \tag{3}$$

therefore,

$$\left(\frac{S_{p-p}}{N}\right)_{out} = 12\,\frac{P(\Delta f)^2}{N_o\, f_m^{\,3}} \quad . \tag{4}$$

Furthermore, the video signal is clamped so that $f = f_c + \Delta f$ on the sync pulses. The frequency deviation is then adjusted so that $f = f_c - \Delta f$ for a white picture (see Fig. 2). Then the peak-to-peak frequency deviation F_{p-p} (the frequency swing from white picture to the sync pulse) is

$$F_{p-p} = 2\Delta f \quad . \tag{5}$$

The minimum bandwidth W required (at IF or RF) assuming large modulation index $m_f \triangleq \Delta f/f_m$, is*

$$W \simeq 2(\Delta f + f_m) = F_{p-p} + 2f_m = 2f_m(1 + m_f) \quad .$$

Therefore, the input signal-to-noise ratio in the channel bandwidth is

$$\begin{aligned}(S/N)_{in} &= \frac{P}{N_o W} \\ &= \frac{P}{N_o(F_{p-p} + 2f_m)} \quad .\end{aligned} \tag{6}$$

Substituting (5) and (6) in (4), we have

$$\left(\frac{S_{p-p}}{N}\right)_{out} = 24m_f^3 \, (S/N)_{in} \left(\frac{F_{p-p}}{f_m}\right)^3 \left(1 + \frac{2f_m}{F_{p-p}}\right) \quad . \tag{7}$$

Another standard form of this result is expressed in terms of modulation index m_f:

$$m_f = \Delta f/f_m = \frac{F_{p-p}}{2f_m} \tag{8}$$

$$\left(\frac{S_{p-p}}{N}\right)_{out} = 24m_f^3 \, (S/N)_{in} \left(1 + \frac{1}{m_f}\right) \quad . \tag{9}$$

*This approximation is commonly called "Carson's Rule." Some references instead give $W \simeq 2(\Delta f + 2f_m)$.

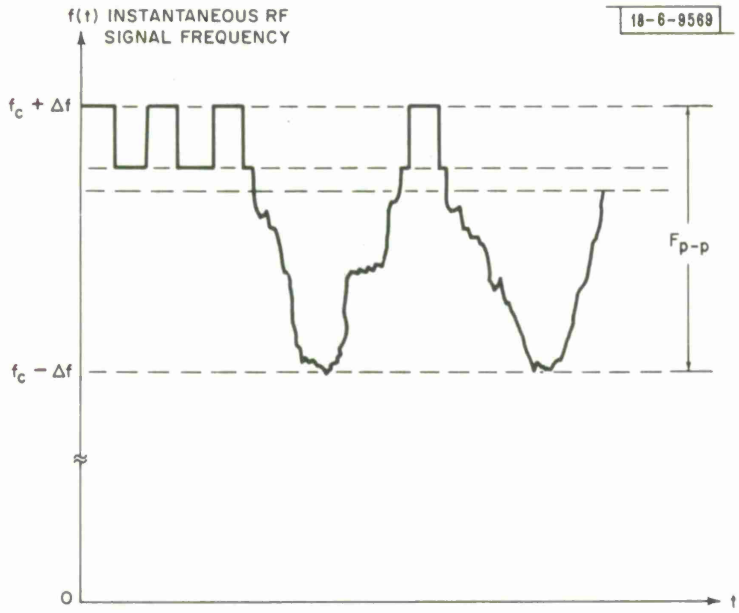


Fig. 2. Television composite signal waveform, frequency modulation.

Sometimes the input signal-to-noise ratio is referred to the message bandwidth rather than to the channel bandwidth. From Eq. 6,

$$(S/N)_{\substack{in \\ \text{message} \\ \text{B.W.}}} = (m_f + 1)\,(S/N)_{in} \quad , \tag{10}$$

then

$$\left(\frac{S_{p-p}}{N}\right)_{out} = 24 m_f^2 \,(S/N)_{\substack{in \\ \text{message} \\ \text{B.W.}}} \quad . \tag{11}$$

Equation 11 is useful for comparing AM and FM systems (c.f. Schwartz,[10] p. 303).

The output SNR in Eqs. 7 through 11 are for a peak-to-peak composite (i.e., one including the sync pulses) video signal and an unweighted, "triangular" noise spectrum (see p. 14). Notice that they differ by a factor of eight from the "standard results" quoted in various texts because of the different definition of signal "power". In Section II we shall discuss the conversion to other definitions.

Further note that the last factor in Eqs. 5 and 7 is often approximated by unity in the literature. For example, when $m_f = 5$, this factor is less than 1 db.

II. TV SNR Definitions

Over the years, a number of different definitions of the signal-to-noise ratio for video transmission have evolved. Not only do the definitions differ from one organization to another, but also they have been changed from time to time. In this memo we shall present only the current definitions.

One common definition of signal amplitude is the peak-to-peak voltage from the blanking level to the white-signal level.[4] The black-to-white voltage,

which differs by a fraction of a db, is also widely used[5,6] (see Fig. 1). This definition is intuitively pleasing for it is this signal which is applied to the grid of the cathode-ray tube. The Bell System and others concerned only with video transmission define the signal amplitude to be from sync pulse peak to the white level, which is the maximum voltage swing encountered in the transmission of a video signal.[7,8,9] On the other hand, the definition pertinent to the conventional AM broadcaster is the amplitude from zero to full transmitter output (P in Table I).[10]

The rms noise level definition is not standardized either. The simplest measurement is the rms noise level in the video bandwidth. However, the subjective effect of the noise varies across the video band, with noise in the low frequency portion of the video band being more objectionable. In an attempt at accounting for this effect, the rms noise is measured with an instrument whose sensitivity is frequency-dependent. Thus the purpose of the noise weighting network (part of the measuring instrument) is to make the noise measurements correspond more closely with observed picture quality.

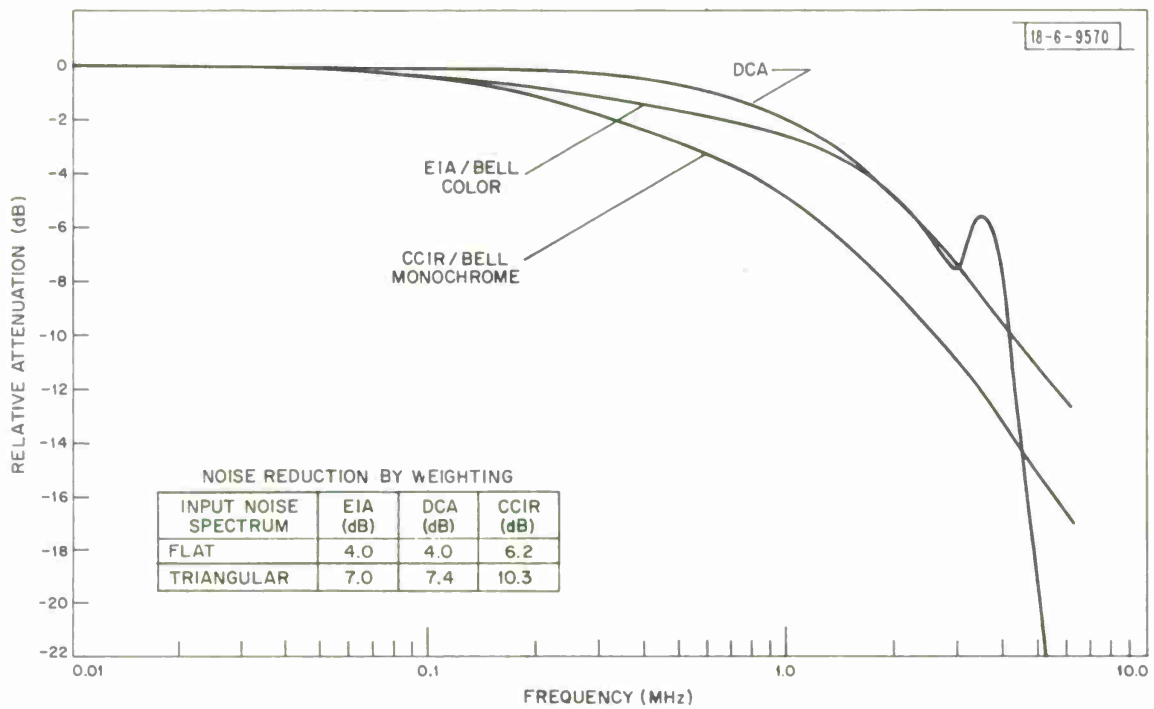
As long as we are only comparing systems (and defining standards) with a given video noise spectrum, the weighting serves no real purpose, for it merely adds a constant factor to the SNR (in db). However, the weighting factor depends on the shape of the video noise spectrum. Therefore, the weighted, rather than the unweighted, SNR is appropriate for comparing systems with different noise spectra. This is the case when FM transmission is used, for example.

The most widely used noise weighting network in the U.S. and Canada is the Bell System monochrome weighting network,[7] which has been used since 1962. This is the same network that the CCIR uses for the U.S. and Canada,

and since mid-1968 the Bell System has used it for color as well.[11] It is widely used by other organizations.[5, 20] The Bell System color weighting network has also been widely used since 1962, and this is the noise weighting recommended by the Electronic Industries Association (EIA). It does not roll off as rapidly as the monochrome weighting network, and it has a peak in the vicinity of the color subcarrier frequency. The Defense Communications Agency (DCA) recommends a single-pole noise weighting network which turns out to have substantially the same weighting effect as the Bell color/EIA network. The frequency response for each of these three noise weighting networks is given in Fig. 3. Observe that although their shapes differ considerably, the effects of the weighting differ by at most about 3 db. In Section III we shall see that this is probably not enough difference to make an appreciable difference in subjective viewing evaluations.

Table II provides a summary of the television SNR standards currently in use. Since the output noise spectrum is not the same in an AM and an FM system, the noise weighting has a different effect on the SNR for the two types of modulation. We, therefore, treat them separately. We should point out here that the noise weighting network, which is part of the noise measuring equipment, should not be confused with the pre- and de-emphasis networks which (when they are used) are part of the transmission system.

We observe that phase modulation and single-sideband AM transmission are not used for television transmission since the video signal has a DC component and appreciable energy at low frequencies. Therefore, these types of modulation are not discussed in this note.



NOISE REDUCTION BY WEIGHTING

INPUT NOISE SPECTRUM	EIA (dB)	DCA (dB)	CCIR (dB)
FLAT	4.0	4.0	6.2
TRIANGULAR	7.0	7.4	10.3

Fig. 3. Television noise weighting.

TABLE II

Television SNR Definitions

DEFINITION	SIGNAL AMPLITUDE	R.M.S. NOISE
Bell System 1968	Peak-to-Peak Composite Video (Sync to White)	Bell/CCIR Weighting Network
CCIR	Peak-to-Peak Noncomposite Video (Blanking to White)	Bell/CCIR Weighting Network
DCA	Peak-to-Peak Noncomposite Video (Black to White)	Single-Pole Weighting Network $\tau = .11\ \mu sec$
EIA	Peak-to-Peak Composite Video (Sync to White)	Bell color/EIA Weighting Network
TASO	R.M.S. RF or IF Signal During Sync Peaks	Unweighted 6 MHz Bandwidth
TRW	Peak-to-Peak Noncomposite Video (Black to White)	Bell/CCIR Weighting Network

NOTE: SNR is usually expressed as a power ratio. Therefore, the voltage ratio obtained from these definitions should be squared. Of course, the use of decibels to express these ratios eliminates this problem.

2.1 Amplitude Modulation

Comparing the appropriate entries in Tables I and II, we see that the definition of SNR in the TASO study is the input SNR for a vestigial sideband system. In this note we consider a nominal video bandwidth of 4.2 MHz. Then f_m = 4.2 MHz, Δ = 1.8 MHz, and the output SNR is 10 log 1.43 = 1.6 db greater than the input SNR, if we define the output signal amplitude to be that corresponding to the transition from zero to full transmitter power, as in Table I.

Table III gives the conversions between the remaining standards. The details of how the numbers in this table were obtained are relegated to the Appendices. It should be emphasized that while most of the entries in Table III are video SNR's appropriate to any AM system, the TASO definition and P/N_o W are input SNR's which are only applicable to VSB-AM transmission.

2.2 Frequency Modulation

The video noise spectrum for an FM system is not white, and therefore the noise weighting has a different effect than it does for white noise. If de-emphasis is not used, the video noise amplitude spectrum for the FM system is "triangular". That is, the video noise power spectral density is proportional to f^2. When de-emphasis is used, the video noise spectrum is even more complex. Thus the effect of the weighting networks must be recomputed for FM transmission. The results are tabulated in Table IV.

TABLE III

Conversion of TV SNR Definitions (in db) for AM Transmission

FROM \ TO	BELL SYSTEM	CCIR	DCA	EIA	TASO	TRW
BELL SYSTEM	0	−2.9	−5.8	−2.2	−3.6	−3.6
CCIR	+2.9	0	−2.9	+0.7	−0.7	−0.7
DCA	+5.8	+2.9	0	+3.6	+2.2	+2.2
EIA	+2.2	−0.7	−3.6	0	−1.4	−1.4
TASO	+3.6	+0.7	−2.2	+1.4	0	0
TRW	+3.6	+0.7	−2.2	+1.4	0	0
TABLE I $\left(\frac{P}{N_o W}\right)$	+2.0	−0.9	−3.8	−0.2	−1.6	−1.6

P = Peak RF power

$N_o W$ = Mean-square noise in channel bandwidth

III. Subjective Evaluation of Picture Quality in Terms of Signal-to-Noise Ratio

A number of studies (Refs. 6-8, 10, 12-19) have been made of the quality of a television picture in terms of signal-to-noise ratio. One of the more extensive studies, the results of which are readily available and often quoted, was performed for the Television Allocations Study Organization (TASO) by Dean.[1] Table V presents some of the results of this study. We should re-emphasize that the definition of SNR used in the TASO study is the ratio of average RF power on sync peaks to mean square white noise power in the channel bandwidth for VSB-AM transmission.

We have discussed in Section II of this note how a meaningful noise measurement, in terms of the subjective effects of the interference, is one made with an appropriate noise weighting network. Since the TASO study assumes a white RF noise spectrum and AM transmission, the video noise spectrum is also white and the noise weighting merely reduces the noise power by a constant factor. These factors are calculated in Appendix A, and were used to obtain Table III. This table can then be used to translate the results of the TASO study to other definitions of SNR. For example, 75% of the TASO reviewers required an RF SNR of 30 db for a "passable" picture. This translates to 31 db for the CCIR video SNR definition, and 34 db for that of the Bell System.

TABLE IV

Conversion of TV SNR Definition (in db)
For FM Transmission (without pre-emphasis)

DEFINITION	ADD TO $\left(\frac{S_{p-p}}{N}\right)_{out}$
BELL SYSTEM	+10.3
CCIR	+ 7.4
DCA	+ 3.6
EIA	+ 7.0
TASO	Only Applies to AM Transmission
TRW	+ 6.7

NOTE: $S_{p-p} \triangleq (V_{peak-to-peak})^2$

N = mean-square noise power

TABLE V

Results of TASO Study (Ref. 10)

GRADE	DESCRIPTION	Signal-to-noise ratio (db) adequate for given percentage of viewers		
		25%	50%	75%
Excellent	Extremely High Quality	38	44	50
Fine	High Quality, Enjoyable Viewing, But Perceptible Interference	30	34	38
Passable	Acceptable Quality, Interference Not Objectionable	25	27	30
Marginal	Poor Quality, Improvement Desirable, Interference Somewhat Objectionable	21	23	25
Inferior	Very Poor Quality, Could Be Watched, Interference Definitely Objectionable	15	17	19
Unusable	Picture Too Bad To Be Watched	12	14	16

Alternatively, we can proceed in the other direction and interpret other SNR definitions on the TASO rating scale. The CCIR, for example, recommends a weighted video SNR of 56 db for network transmission. Referring to Table III, we see that this is equivalent to 55 db on the TASO scale, which was rated as an "excellent" picture by more than 75% of the viewers. As another example, the DCA requires a median SNR of 52 db for a 6000 nautical mile circuit. Again from Table III, we find this corresponds to 54 db on the TASO scale, which is practically the same as the CCIR requirement. The motivation for these rather stringent requirements on the SNR for television relays is so that the random noise interference will not be visible, and hence any degradation in the picture quality will come from other parts of the system.

The situation is slightly more complicated for FM transmission, where the video noise spectrum is not white. In addition, de-emphasis is sometimes used (its use is recommended by the CCIR) and this makes the video noise spectrum even more complex. As an example of such a calculation, we consider a low-power microwave TV link with the following parameters:

$$N_o = -198.5 \text{ dbw/Hz (5.5 db NF)}$$

$$W = 20 \text{ MHz or } 73.0 \text{ db-Hz}$$

$$\Delta f = 4 \text{ MHz or } 66.0 \text{ db-Hz}$$

$$f_m = 4.3 \text{ MHz or } 66.3 \text{ db-Hz}$$

$$P = -109 \text{ dbw.}$$

Substituting into Eq. 1, we obtain

$$(S/N)_{\substack{out \\ unweighted}} = 24.4 \text{ db}$$

or

$$\left(\frac{S_{p-p}}{N}\right)_{\substack{out \\ unweighted}} = 33.4 \text{ db} \quad .$$

Now suppose we wish to use the DCA definition of video SNR. From Table IV,

$$(S/N)_{DCA} = \left(\frac{S_{p-p}}{N}\right) + 3.6 \text{ db}$$

$$= 37.0 \text{ db} \quad .$$

In Appendix A, we show that the use of CCIR pre-emphasis results in an improvement of 2.6 db for an FM system with the DCA weighting. Then

$$(S/N)_{\substack{DCA \\ pre\ emp.}} = 37.0 + 2.6$$

$$= 39.6 \text{ db} \quad .$$

To interpret this result on the TASO scale, we refer to Table III.

$$(S/N)_{TASO} = (S/N)_{DCA} + 2.2$$

$$= 41.8 \text{ db} \quad .$$

From Table V we see that this would be rated as a "Fine" picture by more than 75% of the viewers, and "Excellent" by more than 25%.

IV. Summary

In this note we discussed the effects of random noise interference in television transmission systems. We collected and unified numerous results which have been scattered throughout the literature. Three topics were covered:

(1) The calculation of the video signal-to-noise ratio for amplitude and frequency modulation television transmission systems,

(2) A summary of the signal-to-noise ratio definitions (including noise weighting standards) currently in use for video transmission and conversion between these definitions, and

(3) A brief discussion of the subjective evaluation of television picture quality in terms of signal-to-noise ratio.

APPENDIX A

Calculation of Noise Weighting Factors

This Appendix presents the details of the calculation of the noise weighting factors that were used in obtaining Tables III and IV. We present the details here so that the interested reader can see how the numerical values were obtained. Also, these calculations enable us to calculate weighting factors for a whole family of networks.

A-1 Single-pole weighting

A single-pole noise weighting network is recommended by the CCIR[4] for all countries except the U.S. and Canada. It is also used by DCA.[6]

A-1.1 White noise

$$\frac{N_{weighted}}{N_{white}} = \frac{\int_{-f_m}^{f_m} \frac{1}{1 + (2\pi f \tau)^2} \, df}{\int_{-f_m}^{f_m} df}$$

$$= \frac{1}{2\pi f_m \tau} \arctan (2\pi f_m \tau) \qquad \text{(A-1)}$$

A-1.2 Triangular noise

$$\frac{N_{weighted}}{N_{white}} = \frac{\int_{-f_m}^{f_m} \frac{f^2}{1 + (2\pi f \tau)^2} \, df}{\int_{-f_m}^{f_m} f^2 \, df} \qquad \text{(cont'd)}$$

$$= \frac{3}{(2\pi f_m \tau)^2} \left[1 - \frac{1}{2\pi f_m \tau} \arctan (2\pi f_m \tau) \right]. \quad \text{(A-2)}$$

Numerical values are presented in Table A-I.

TABLE A-I

Noise Reduction by Single-Pole Weighting Networks

Organization	$f_m \tau$	White Noise	Triangular Noise
DCA	.50	−4.0 db	− 7.4 db
CCIR	1.00	−6.5	−12.3
	1.66	−8.5	−16.3
	2.00	−9.3	−17.8

A-2 Bell/CCIR weighting

A-2.1 White noise

$$\frac{N_{weighted}}{N_{white}} = \int_{-f_m}^{f_m} \frac{(f/f_3)^2 + 1}{\left[(f/f_1)^2 + 1\right]\left[(f/f_2)^2 + 1\right]} \, df \quad .$$

Expanding in partial fractions and integrating, we obtain

$$\frac{N_{weighted}}{N_{white}} = \frac{1}{f_m(f_2^2 - f_1^2)} \left(\frac{f_1 f_2}{f_3}\right)^2 \left[\frac{f_3^2 - f_1^2}{f_1} \arctan\left(\frac{f_m}{f_1}\right)\right. \quad \text{(cont'd)}$$

$$+ \frac{f_2^2 - f_3^2}{f_2} \arctan\left(\frac{f_m}{f_2}\right)\Bigg] \quad . \qquad \text{(A-3)}$$

Substituting numerical values,

$f_1 = .27$ MHz

$f_2 = 1.37$ MHz

$f_3 = .39$ MHz

$f_m = 4.2$ MHz ,

we obtain

$$\frac{N_{weighted}}{N_{white}} = -6.2 \text{ db} \quad .$$

A-2.2 Triangular noise

$$\frac{N_{weighted}}{N_{white}} = \frac{\displaystyle\int_{-f_m}^{f_m} \frac{f^2\left[(f/f_3)^2 + 1\right]}{\left[(f/f_1)^2 + 1\right]\left[(f/f_2)^2 + 1\right]}\, df}{\displaystyle\int_{-f_m}^{f_m} f^2\, df}$$

$$= 3\left(\frac{f_1 f_2}{f_3 f_m}\right)^2 \left[1 - \frac{f_1}{f_m}\left(\frac{f_3^2 - f_1^2}{f_2^2 - f_1^2}\right) \arctan\left(\frac{f_m}{f_1}\right)\right. \qquad \text{(cont'd)}$$

$$- \frac{f_2}{f_m} \left(\frac{f_3^2 - f_1^2}{f_1^2 - f_2^2} \right) \arctan \left(\frac{f_m}{f_2} \right) \Bigg] \qquad \text{(A-4)}$$

$$= -10.3 \text{ db} \quad .$$

A-3 Triangular noise with de-emphasis

We shall consider de-emphasis networks of the form

$$|H(f)|^2 = A \frac{\left(f/f_2\right)^2 + 1}{\left(f/f_1\right)^2 + 1} \quad . \qquad \text{(A-5)}$$

The widely used CCIR network[4] is such a network, with

$$A = 10$$

$$f_1 = .185 \text{ MHz}$$

$$f_2 = .873 \text{ MHz} \quad .$$

A-3.1 Single-pole weighting

$$\frac{N_{\substack{\text{weighted} \\ \text{de-emphasis}}}}{N_{\text{unweighted}}} = \frac{\int_{-f_m}^{f_m} A f^2 \frac{(f/f_2)^2 + 1}{\left[(f/f_1)^2 + 1\right]\left[(f/f_o)^2 + 1\right]} df}{\int_{-f_m}^{f_m} f^2 \, df}$$

where

$$f_o = \frac{1}{2\pi\,\tau} \quad .$$

Notice that we did this same integral in A-2.2 above, with slightly different notation.

$$\frac{N_{\substack{\text{weighted}\\ \text{de-emphasis}}}}{N_{\text{unweighted}}} = 3A\left(\frac{f_o\,f_1}{f_m\,f_2}\right)^2 \left[1 - \frac{f_o}{f_m}\left(\frac{f_2^2 - f_o^2}{f_1^2 - f_o^2}\right) \arctan\left(\frac{f_m}{f_o}\right)\right.$$

$$\left. - \frac{f_1}{f_m}\left(\frac{f_2^2 - f_1^2}{f_o^2 - f_1^2}\right) \arctan\left(\frac{f_m}{f_1}\right)\right] \quad . \qquad \text{(A-6)}$$

For the DCA noise weighting

$$f_o = 1.44 \text{ MHz}$$

$$f_m = 4.5 \text{ MHz} \quad .$$

Thus

$$\frac{N_{\substack{\text{weighted}\\ \text{de-emphasis}}}}{N_{\text{unweighted}}} = -10.0 \text{ db} \quad .$$

Comparing this with the weighting factor when pre-emphasis is not used, Table A-I, we see that the use of pre-emphasis reduces the noise 2.6 db.

APPENDIX B

Vestigial Sideband (VSB) AM Transmission

In this Appendix, we relate the video and RF signal-to-noise ratios for conventional VSB-AM television transmission. We discuss only one of several possible definitions of video SNR here. The conversion to other definitions is given in Table III, and the details of the calculations are sketched in Appendix C.

The basic transmitter modulation is double-sideband AM:

$$S(t) = \sqrt{2P}\ m(t) \cos \omega_c t$$

$$= \sqrt{2P} \left(\frac{K + v(t)}{K + V} \right) \cos \omega_c t \qquad \text{(B-1)}$$

where

K = white level offset

$v(t)$ = video waveform, $0 \le v(t) \le V$ of peak-to-peak amplitude V.

The peak envelope transmitter power is therefore P.

For purposes of analysis, we assume a sinusoidal video waveform

$$v(t) = \frac{V}{2} (1 + \cos \omega_m t) \qquad . \qquad \text{(B-2)}$$

We use a sinusoid because the standard results for detector performance are obtained for sinusoids.[2,3] Since it is the peak-to-peak value that is pertinent to our calculations, our results are independent of the waveform.

Substituting and simplifying,

$$S(t) = \sqrt{2P_c}\ \left(1 + \frac{V/2}{K+V/2}\ \cos\omega_m t\right) \cos\omega_c t \quad , \qquad \text{(B-3)}$$

where

$$P_c \triangleq P\left(\frac{K+V/2}{K+V}\right)^2$$

is the average carrier power. The modulation index is therefore

$$m_a = \frac{K+2}{K+V/2} \quad .$$

For DSB-AM (from Hancock,[2] p. 41-47)

$$\left(\frac{S}{N}\right)_{\substack{out\\DSB}} = \frac{P_c\ m_a^2}{2N_o\ W} \quad . \qquad \text{(B-4)}$$

Therefore

$$\left(\frac{S_{p-p}}{N}\right)_{out} = 4\left(\frac{V/2}{K+V}\right)^2 \frac{P}{N_o\ W} \qquad \text{(B-5)}$$

For VSB-AM, the output noise power is decreased by a factor of two due to the reduced noise bandwidth. However, the output signal power is decreased by a factor of four, since the two sidebands add coherently in a DSB system.

$$\left(\frac{S_{p-p}}{N}\right)_{\substack{out\\VSB}} = 2\left(\frac{V/2}{K+V}\right)^2 \frac{P}{N_o\ W} \quad . \qquad \text{(B-6)}$$

In Section I we saw that

$$(S/N)_{\substack{in \\ VSB}} = \frac{P}{N_o(W+\Delta)} \quad . \tag{B-7}$$

Therefore,

$$\left(\frac{S_{p-p}}{N}\right)_{\substack{out \\ VSB}} = 2\left(\frac{V/2}{K+V}\right)^2 (S/N)_{\substack{in \\ VSB}} \left(1+\frac{\Delta}{W}\right) \tag{B-8}$$

The output SNR for any VSB-AM system can be obtained from Eq. B-8, when we allow for the noise weighting (calculated in Appendix A) and the definition of the signal amplitude.

For example, TRW[5, 20, 21] defines the video SNR as the black-to-white level squared, divided by the mean-square noise power weighted with the CCIR network.

$$(S/N)_{TRW} = \frac{2\left(\frac{V/2}{K+V}\right)^2 \left(\frac{V_{B-w}}{V}\right)^2 \left(1+\frac{\Delta}{W}\right)(S/N)_{\substack{in \\ VSB}}}{\frac{1}{W}\left(\frac{f_1 f_2}{f_3}\right)^2 \frac{1}{f_2^2 - f_1^2}\left[\frac{f_3^2 - f_1^2}{f_1}\arctan\left(\frac{f_m}{f_1}\right) + \frac{f_2^2 - f_3^2}{f_2}\arctan\left(\frac{f_m}{f_2}\right)\right]} \quad . \tag{B-9}$$

Substituting numerical values,

$V = 1.000$ v.

$V_{B-w} = .600$ v.

$K = .143$ v.

$W = 4.2$ MHz

$$\Delta = 1.8 \text{ MHz}$$

$$f_1 = .27 \text{ MHz}$$

$$f_2 = 1.37 \text{ MHz}$$

$$f_3 = .39 \text{ MHz}$$

we find that

$$(S/N)_{TRW} \cong (S/N)_{\substack{in \\ VSB}} \quad , \tag{B-10}$$

where the approximation is within about 0.1 db.

APPENDIX C

Conversion of SNR Definitions

There are two factors that enter into our conversion between the various SNR definitions. The first, which is the definition of signal amplitude, applies to both AM and FM transmission. However, the correction for the noise weighting network depends on the video noise spectrum, and therefore is different for the two types of transmission.

C-1 Signal amplitude

The standard signal amplitudes are given in Fig. 1.

$$S_{\text{sync-to-white}} = 1.00 \text{ v.}$$

$$S_{\text{blanking-to-white}} = .714 \text{ v.}$$

$$S_{\text{black-to-white}} = .660 \text{ v.}$$

Expressing the voltage ratios in db, we obtain

$$\frac{S_{\text{sync-to-white}}}{S_{\text{blanking-to-white}}} = 2.9 \text{ db}$$

$$\frac{S_{\text{blanking-to-white}}}{S_{\text{black-to-white}}} = 0.7 \text{ db}$$

C-2 Weighted noise

The conversion from Bell/CCIR to DCA noise weighting follows immediately from Appendix A.

For white noise,

$$\frac{N_{DCA}}{N_{white}} = -4.0 \text{ db}$$

$$\frac{N_{CCIR}}{N_{white}} = -6.2 \text{ db}$$

therefore

$$\frac{N_{DCA}}{N_{CCIR}} = +2.2 \text{ db} \quad .$$

We did not repeat the calculation for the EIA/Bell color weighting because of the complexity of the network. From Ref. 22,

$$\frac{N_{EIA}}{N_{white}} = -4.0 \text{ db} \quad .$$

Hence for white noise, $N_{EIA} = N_{DCA}$.

For triangular noise,

$$\frac{N_{DCA}}{N_{\Delta}} = -7.4 \text{ db}$$

$$\frac{N_{CCIR}}{N_{\Delta}} = -10.3 \text{ db}$$

$$\frac{N_{EIA}}{N_{\Delta}} = -7.0 \text{ db}$$

thus

$$\frac{N_{DCA}}{N_{CCIR}} = +2.9 \text{ db}$$

$$\frac{N_{EIA}}{N_{DCA}} = +0.4 \text{ db} \quad .$$

These results are summarized in Table C-I.

TABLE C-I

Summary of TV SNR Conversions

db SNR conversion	Noise Weighting / Signal Amplitude Definition	CCIR/ BELL	DCA	EIA
↓ +0.7 db ↓ +2.9 db	Black to White	TRW	DCA	
	Blanking to White	CCIR		
	Sync to White	Bell System		EIA
Noise Spectrum	White	+2.2 db ←	0.0 db ←	
	Triangular	+2.9 db ←	+0.4 db ←	

Glossary of Abbreviations

AM	Amplitude modulation
CCIR	International Radio Consultative Committee
DCA	Defense Communications Agency
DSB	Double sideband
EIA	Electronic Industries Association
FM	Frequency modulation
PM	Phase modulation
SNR	Signal-to-noise ratio
SSB	Single sideband
TASO	Television Allocation Study Organization
TRW	TRW Systems
VSB	Vestigial sideband

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13. ABSTRACT

This note is concerned with the effects of random noise interference in television transmission systems. Such systems are finding increasing application in surveillance and telefactor systems. Numerous results which have been scattered throughout the literature are collected and unified. Three topics are covered:

1. The calculation of the video signal-to-noise ratio for the commonly used television transmission systems (amplitude and frequency modulation),
2. A summary of the signal-to-noise ratio definitions (including noise weighting standards) currently in use for video transmission and conversion between these definitions, and
3. A brief discussion of the subjective evaluation of television picture quality in terms of signal-to-noise ratio.

14. KEY WORDS

signal-to-noise ratios
noise interference
amplitude modulation
frequency modulation
television transmission systems
video transmission
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