THE KEY ASPECTS OF SIGNAL-TO-NOISE IN TELEVISION VIEWING.

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Summary

This paper discusses the various types of noise that are encountered in the transmission of television picture signals from the studio camera to the home receiver. A number of different methods of measuring and computing signal-to-random noise ratios are then discussed and are then compared in a normalized fashion using the CCIR* recommended method of measurement. Subsequently typical random noise levels measured on television systems and equipment are reported. Finally, some signal-to-noise targets for CATV systems are suggested.

Introduction

Noise being a major cause of picture quality degradation in television broadcasting has been the focus of much attention and subjective evaluation since the early days of television. Schade [1] showed that, in the perception of random noise in television, the eye is much less sensitive to the high frequency components than to the low frequency components. Mertz [2] confirmed this phenomenon and further suggested a weighting function corresponding to the visibility of random noise as a function of its frequency and at a viewing distance equal to 4 times the height of the picture. Subsequently, Barstow and Christopher [3] proposed an electrical noise weighting network for the measurement of random noise in monochrome television pictures.

Later, additional work by Barstow and Christopher [4] with both color and monochrome television pictures led them to propose a modified monochrome network and a separate network for color television pictures. The monochrome network has since become known as the "CCIR weighting network" as it became the recommended network by that body for both monochrome and color television transmissions [5]. The Electronics Industry Association adopted the color weighting for radio-relay facilities [6]. The frequency response of the Barstow and Christopher monochrome and color weighting networks are reproduced in Figure 1. These networks have proved to be invaluable to the television systems designer in that the cumulative effects of noise having different power spectra in systems operated in tandem can readily be predicted. Cavanaugh [7] has recently shown that the Barstow's and Christopher's results are still valid today and that their monochrome weighting is acceptable for color pictures. This supports the CCIR contention of a single weighting network for both types of transmission. In the United Kingdom a 'weighting' method was developed, applicable to linear waveform distortions, by Lewis [8]. This permitted linear distortions to be rated as to their subjective effect on picture quality. Later Lewis and Allnatt [9] suggested that the 'Impairment Unit' (imp); a method whereby unrelated distortions can be assigned an imp rating and that the resulting composite imp rating would be equal to the sum of the individual imps.

*International Radio Consultative Committee.

Siocos [10] using differential gain and differential phase subjective data reported by Cavanaugh and Lessman [11] found that the summability of imps at least for these two types of distortions proved to be reasonably valid.

The subjective effect of video-to-video crosstalk can be very severe even when the interfering signal level is relatively low. Fowler [12] reported a need for up to 60 dB flat coupling loss across the video band to obtain a "just perceptible" response from his 'median observer'. Fowler did indicate that a greater degree of coupling could be tolerated at the higher end of the video band but added that many of the mechanisms that caused crosstalk, such as near-end crosstalk on cable circuits, between an outgoing video and an incoming video, where the incoming video is low in level and also requires high frequency compensation, tends to negate the tolerance at higher frequencies to crosstalk. Fowler conducted his tests with monochrome pictures only, and therefore his findings are not fully valid for color pictures. CCIR [13] recommends that for color and monochrome pictures the coupling loss between video channels should not be less than 58 dB and should be flat across the video band.

Periodic noise which is noise occurring at a single frequency is generally considered most disturbing if it lies in the 1 KHz to 1 MHz frequency range. The CCIR objective for this type of noise is 59 dB. Fowler [14] in subjective tests conducted to determine tolerable levels for low-frequency periodic noise (power frequency pickup) showed that it was most objectionable when the interfering signal caused a 5 cycles/sec flicker on the interfered with picture. Such interfering signals require to be 54 dB down from the picture signal in order to be adjudged "just perceptible" by the "median observer" For a low flicker rate (~0.5 cycles/sec) or a high flicker rate (~30 cycles/sec) a 40 dB difference between the picture signal and the interfering signal was comparable in impairment to the 5 cycle/sec rate at the level mentioned above.

Impulsive noise which is defined [5] as noise of sporadic or infrequently occurring nature has always been a difficult type of noise for which to stipulate tolerable levels of interference. To the authors' knowledge there never has been a definitive study on the subjectives effects of impulsive noise on television pictures. The CCIR [5] merely states that the peak-to-peak amplitude of impulsive noise should be 25 dB below the peak-to-peak amplitude of the television picture signal (excluding synch.). No mention is made of the time distribution of the noise. Recently however [15] an attempt has been made to state objectives for impulsive noise in terms of both amplitude and time allowing higher amplitude impulsive noise to occur with less frequency than lower amplitude impulsive noise. Perhaps as was the case for telephony the need to transmit some form of digital data [16] will spur a more definitive study of this type of noise in television.

Random Noise Computations and Measurements

The CCIR [5] recommended method of specifying signal-to-weighted random noise is "the ratio in decibels of the peak-to-peak amplitude of the picture signal (see Figure 2) to the r.m.s. amplitude of the noise, within the range between 10 KHz and the nominal upper limit of the video frequency band of the system f_c". For the 525-line NTSC color system f_c = 4.2 MHz. [17]. The weighting network that should be used when taking the noise measurement is the Barstow and Christopher monochrome network shown in Figure 1.

The random noise data reported by the Bell System over the last twenty years or so has always referred the noise level to the over all video signal as shown in Figure 2 i.e. including the synchronizing signal. Accordingly signal-to-noise ratios quoted using the Bell method appear to be approximately 2.9 dB better than those using the CCIR method. Today in North America the CCIR method seems to be in greatest use. Therefore for the purpose of this paper the CCIR method will be used when stating signal-to-noise ratios except where otherwise indicated.

The Barstow and Christopher monochrome network has the following effect on noise within the 4.2 MHz video signal bandwidth:

White noise - 6.2 dB
Triangular noise - 10.3 dB

[White noise has a flat power spectrum and triangular noise has a power spectrum which increases at a 6 dB/octave rate.]

Frequency modulation (FM) is used in both terrestrial radio-relay and satellite radio-relay systems to transmit television signals. In both types of systems the identical signal pre-emphasis is used [18]. The shape of the pre-emphasis characteristic is shown in Figure 3. The use of signal pre-emphasis (and its complementary de-emphasis network) effects a net improvement on the signal-to-noise ratio in the above systems of about 2.5 dB [19]. [The random noise power spectra in both terrestrial and satellite systems are nominally triangular in shape. Signal emphasis tends to flatten this noise while at the same time it emphasizes the high frequency components of the television signal.] In consequence, the signal emphasis and signal weighting combined improvement factors in both terrestrial and satellite FM radio-relay systems is 10.3 + 2.5 = 12.8 dB. [Barstow and Christopher's monochrome weighting is assumed in the above.]

In calculating the signal-to-noise ratio in an FM system it can be shown, after Downing, [20] that for a television signal,

$$\frac{s}{n} = 3\,D^2 \left(\frac{B}{2}\,fv\right)\left(\frac{C}{KTB}\right)$$

where $\frac{s}{n} = \frac{\text{average sine-wave signal power}}{\text{r.m.s. noise power}}$

D = modulation index of FM system

$= \frac{f_d}{f_v}$

where f_d = Peak frequency deviation (Hz)

f_v = Top video frequency (Hz)

B = Pre-detection noise bandwidth (Hz)

C = Received carrier power (watts)

K = Boltzmann's constant $= 1.38 \times 10^{-23}$ $WS/^{o}K$

T = noise temperature of total system (^{o}K)

In dB the equation becomes

$$\left[\frac{S}{N}\right]_{dB} = 1.76 + 20\log_{10} D + \left[\frac{C}{T}\right]_{dB} - \left[f_v\right]_{dB} - 10\log_{10} K$$

The conversion factor of the power ratio of a peak-to-peak sine wave to average is

$$\left[\frac{2}{0.707}\right]^2 = 8 \text{ or in decibels} = 9\text{dB}.$$

Further, to convert from peak-to-peak video signal to peak-to-peak picture signal one must subtract 2.9 dB.

Thus

$$\frac{\text{Peak-to-peak Picture Signal}}{\text{r.m.s. noise power}} = 236.46 + 20\log_{10} D + \left[\frac{C}{T}\right]_{dB} - \left[f_v\right]_{dB}$$

Adding pre-emphasis and weighting improvement which is 12.8 dB the

$$\frac{\text{Peak-to-Peak Picture Signal}}{\text{r.m.s. weighted noise}} = 249.26 + 20\log_{10} D + \left[\frac{C}{T}\right]_{dB} - \left[f_v\right]_{dB}$$

for f_v = 4.2 MHz,

$$\left[F_v\right]_{dB} = 66.2 \text{ dB Hz}$$

$$\therefore \frac{\text{Peak-to-Peak Picture Signal}}{\text{r.m.s. Weighted Noise}} = 183.06 + 20\log_{10} D + \left[\frac{C}{T}\right]_{dB}$$

Typically satellite radio-relay systems employ a high modulation index. For example in the present generation of satellites in the Intelsat* System (Intelsat IV) the modulation index used for 525-line NTSC transmissions is D = 2.57 (8.2 dB) and the carrier-to-noise temperature $\left[\frac{C}{T}\right]_{dB}$ of the total system is -137.6 dB. Thus the Intelsat IV television channel

$$\frac{\text{Peak-to-Peak Picture Signal}}{\text{r.m.s. Weighted Noise}} = 53.7 \text{ dB}$$

*International Telecommunication Satellite Consortium.

The carrier-to-noise ratio $\left|\frac{C}{N}\right|_{dB} = \left|\frac{C}{KTB}\right|_{dB}$

and the Intelsat*IV television channel pre-detection noise bandwidth B = 30 MHz
= 75 dBHz

$$\therefore \left|\frac{C}{N}\right|_{dB} = -137.6 + 228.6 - 75$$
$$= 16 \text{ dB}$$

It is interesting to note that despite the fact that the Intelsat television channel is provided in the'C' band [earth-to-satellite link is at 6 GHz and the satellite-to-earth link is at 4 GHz] the carrier-to-noise margin above threshold is small as fading is not a significant problem.

Terrestrial radio-relay systems contrast sharply with the satellite systems in that the carrier-to-noise fading margins are often in the 35 - 40 dB range. Another difference is that at or near the FM threshold $\left(\frac{C}{N} \simeq 10 \text{ dB}\right)$ when the carrier-to-noise is in the 10 - 15 dB range, the random noise level becomes very high in the terrestrial system. 'Thresholding' on the other hand in the satellite system can be characterized more as a sudden increase in impulsive noise. It was this aspect of satellite transmissions that lead PBS and the three commercial networks to specify an impulsive noise objective for the satellite link as a function of time [15] .

Probably the most frequently used reference on the subjective effects of random noise on television picture quality is the TASO** data. In the TASO tests that were conducted more than fourteen years ago almost 200 observers were used to make about 38,000 individual assessment of picture quality. While other forms of interference were also assessed, random noise type interference was exhaustively evaluated over a wide range of signal-to-noise ratios [21]. Fine [22] in a subsequent analysis reduced the signal-to-random noise ratio measured by TASO which was in fact the ratio of the r.m.s. carrier (on synch. peaks) to the unweighted r.m.s. noise voltage measured in the 6 MHz TV channel radio-frequency bandwidth.

Two subsequent independent studies by Bisaga [23] and Jansen et al [24] showed that the TASO signal-to-noise ratio equated to within ~0.6 dB of the CCIR signal-to-noise weighted noise ratio as previously defined. To convert from TASO to CCIR one would add 0.6 dB. An exceedingly small difference when one is dealing with subjective data results. Siocos [25] showed that a straight mathematical conversion of the TASO signal-to-noise to CCIR signal-to-weighted noise gave a conversion factor of -1.1 dB

It is clear from the above that the difference between the TASO and CCIR signal-to-noise ratios is indeed small and can be ignored in any practical application. Accordingly the right hand coordinate of Figure 4 shows the CCIR signal-to-weighted-noise ratio against what is otherwise TASO data.

Typical Signal-to-Noise Measurements

Using the CCIR method of specifying signal-to-weighted random noise, a list of typical measurements have been tabulated below in Table 1.

Table I - Typical Television Noise Measurements. [Peak-to-Peak Picture Signal-to-Weighted* r.m.s. noise.]

A. Transmission Systems

1. Intra-City Video Channel (A2A type)	57 dB
2. Long-Haul Radio-Relay** (TD-2 type)	
a. Single hop	73 dB
b. Multi-hop (1600 Miles or ~ 50 hops).	56 dB
c. Multi-hop (4000 miles or ~ 130 hops).	52 dB
3. Studio-to-Transmitter Link	60 dB

*International Telecommunications Satellite Consortium.

**Television Allocations Study Organization.

*Barstow and Christopher monochrome weighting.

**Under non-fading conditions.

4. Satellite Systems

Intelsat I & II	45 dB
Intelsat III	49 dB
Intelsat IV	54 dB
Domestic*	56 dB
Canadian Telesat	54 dB

B. Broadcasting Equipment

1. Video Recorders	
a. Quadruplex -	
1st Generation	49 DB
2nd Generation	47 dB
3rd Generation	45 dB
b. Helical -	
1st Generation	44 dB
2. Cameras	
a. Vidicon	50 dB
b. Image Orthicon	45 dB
3. Broadcast Transmitter	54 dB

In 1959 TASO [21] reported that commercially available TV receivers had a noise factor N_f as follows:

Low channel	VHF = 5.5 dB
High channel	VHF = 7.5 dB
	UHF = 13 dB

There is no real evidence that the performance of today's receiver has improved any. Although as reported by O'Connor [26] the use of antenna-mounted low-noise, preamplifiers has probably helped some in fringe area reception. In Europe, however, Mertens [27] has reported commercially available receivers having a noise factor of N_f = 8 dB in the UHF band. A 5 dB improvement in the noise factor of UHF on commercially available TV receivers would translate, in TASO terms, for the median viewer, a 'marginal' picture into a 'passable' picture or a 'passable' picture into a 'fine' picture.

Suggested CATV System Performance Targets

In the previous sections of the paper the following types of noise have been discussed:

a) Video-to-Video crosstalk
b) Periodic noise
c) Impulsive noise, and
d) Random noise

An attempt will be made in this section to assign performance targets for these noise types for CATV systems.

*Specified by PBS and the commercial networks.

Video-to-Video Crosstalk

Using the data reported by Fowler [12] and choosing his median observer response at a comment level of 3 (i.e., "Definitely perceptible but only slight impairment to picture") would suggest a requirement of 54 dB on 'flat' crosstalk.

Periodic Noise

Again using Fowler's data [14] for low-frequency periodic noise interference, a comment 3 from the median observer would be evoked with the noise at a -49 dB level.

Impulsive Noise

No real data is available on impulsive noise which could be applied herein. As defined by CCIR [5] a -20 dB level for at least 99% of any month would seem to be adequate.

Random Noise

Using Barstow and Christopher's data [4] the median observers' comment 3 would require the video channel noise (weighted) as defined by CCIR to be at a -44 dB level. Allowing for noise to be present elsewhere in the overall broadcasting system at an equal level would provide the CATV system subscriber with a signal having a signal-to-noise ratio of about 41 dB.

In summary, the following performance targets are suggested for future CATV systems:

a)	Video-to-video crosstalk	54 dB (flat)
b)	Periodic noise (< 1 kHz)	49 dB
c)	Impulsive noise (90% of month)	20 dB
d)	Random noise (weighted)	44 dB

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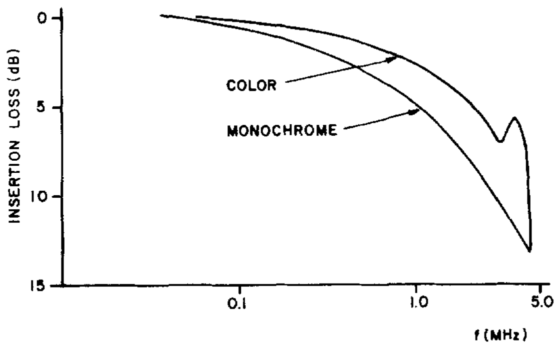

FIGURE 1
BARSTOW & CHRISTOPHER MONOCHROME & COLOR WEIGHTING NETWORKS

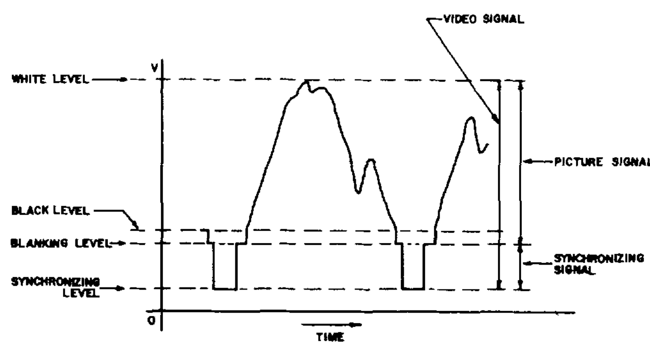

FIGURE 2
CCIR DEFINITION OF VIDEO SIGNAL

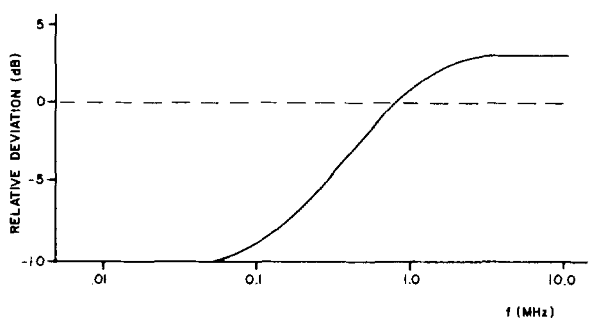

FIGURE 3
CCIR VIDEO PRE-EMPHASIS CHARACTERISTIC

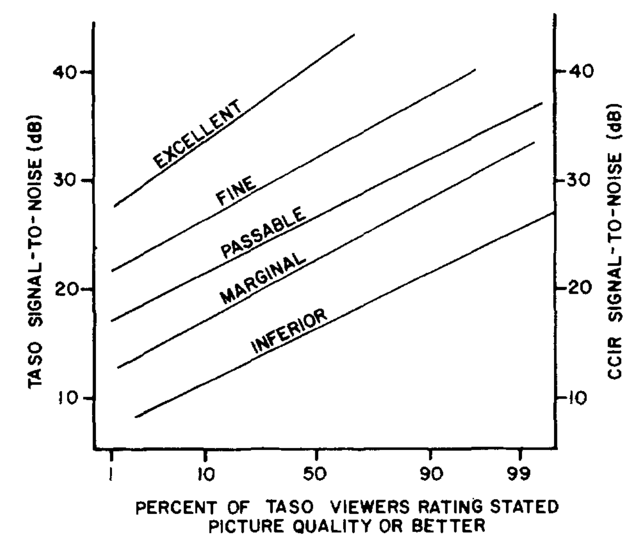

FIGURE 4
TASO VIEWERS RATING OF RANDOM NOISE INTERFERENCE