TV PICTURE INTERFERENCE STUDY
PART I - ENGINEERING ASPECTS

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ABSTRACT

A comprehensive study of viewer ratings for certain kinds of television picture interference experienced in cable television was recommended by the Cable TV Technical Advisory Committee (CTAC) Panel 2 and funded by the National Science Foundation. The study encompasses 30-channel intermodulation noise, discrete frequency interference, synchronous cross-modulation, and, for control purposes, random noise. Stimulus pictures were recorded on 2-inch quad video tape, and observed on a studio monitor under controlled conditions by over 700 viewers representative of the population as a whole. Part I describes the methods of simulating interference and recording stimulus pictures, and discusses the significance of the findings.

INTRODUCTION

One of the working panels[1] of the Cable TV Technical Advisory Committee (CTAC) established by the Federal Communications Commission in 1972 was assigned the task of determining "... either by properly controlled subjective testing or by ... analysis of existing literature, the significant relationships between picture quality ratings and ..." certain designated types of signal impairment (Fig. 1). The panel did analyze in detail the extensive and rigorous studies conducted in this area by the Bell Telephone Laboratories,[2][3][4][5][6][7] but additional subjective tests proved to be beyond the scope of the volunteer panel. The present project was undertaken on recommendation of CTAC Panel 2, with funds provided by the National Science Foundation.

The purpose of this project was to determine, by scientific experiment under controlled conditions, (1) the level at which certain kinds of interference can barely be seen, and (2) the level at which the interference is annoying. (Fig. 2) The data obtained from these experiments should prove useful guidelines for the engineering design and evaluation of cable television system performance.

OBSERVERS

Over 700 observers were carefully selected to match the adult population as to age and sex. Although most observers live in St. Louis, they were drawn from all economic and educational levels, including diverse racial and ethnic orgins. Some had good eyesight without glasses, others had poor eyesight and many wore glasses. All were paid a small stipend.

VIEWING CONDITIONS

The stimulus pictures were observed in a small carpeted room with homelike decor, in subdued lighting, 11 lumens/m^2 (1 foot candle) at the face of the picture tube. This is 50 times as bright as the room lighting in the Bell Telephone Laboratory[8] tests, and nearly twice as bright as in the TASO tests.[9] Even so, most of the observers reported that the room in which they normally watch TV is even brighter yet. Picture screen luminance contrast between reference white and black averaged about 92:1 in the center, ranging from 66 to 153 in the corners. Since screen brightness at reference white (about 79 cd/m^2) was somewhat higher than in most of the BTL and TASO tests, the actual scene contrast ratio was of about the same order. Viewing distance was 6 times picture height, as recommended by CCIR.[10] Bell Telephone Laboratory tests were at 4 times; and TASO, at 6-8.5 times.

TYPES OF INTERFERENCE

Three kinds of interference were selected for the tests because of their particular significance in cable television. (Fig. 3) Interference due to thermal noise was included in addition as a control so that the findings might be compared with the earlier findings of other investigators.

One kind of interference tested is intermodulation noise, perhaps better known as the composite triple beat, which has emerged as the principal factor controlling operational carrier levels in conventional cable TV systems. Arnold [11] [12], Pranke [13] and others have published some information in this area, based on somewhat limited investigations.

Discrete frequency interference (beats) was included because of wide discrepancies in the literature. Figure 4 is a composite chart showing four versions of the subjective effect of beats of various frequencies. Jeffers [14] and Schwarz [15] are in close agreement, with regard to the threshold of perceptibility for critical observers. The FCC report [16] gives very little information from which to deduce reasons for the much less critical ratings. No measured data have been published to support the CRTC curve specified in its BP-24 regulations. [17]

Although the industry has long recognized that the very high stability of the scanning rate for color television virtually eliminates "windshield wiper" cross-modulation, no scientific determination has been published upon which to base a new guideline to replace the long familiar 51-52 dB specification. While it is generally true that cross-modulation is no longer important as the limiting factor in conventional 30-channel systems, it is important in phase-locked systems, with either the harmonically related or constant interval channelling plan.

DISPLAY MONITOR

The physical characteristics of a photograph, such as grain size, modulation transfer, and contrast ratio can be measured with instruments directly on the face of the photo, for correlation with the psychological impression of sharpness in the minds of selected viewers in subjective tests. [18] [19] This is not (yet) possible with respect to the television image where the physical characteristics of the picture itself, as it appears on the face of the tube, cannot be analyzed directly. Instead, it is necessary to measure the characteristics of the electrical signal which produces the picture. Ideally, the measurement of signal characteristics should be made at a point in the circuit as close to the CRT screen as possible (See Figure 5). Since there are three signals at the cathode of the picture tube, containing red, green, and blue picture information, with luminance information encoded into all three, the closest test point to the CRT screen lies just ahead of the chrominance separator.

Unfortunately such a point does not exist in many TV receivers. For a variety of reasons, receiver designers frequently depart from the simple block diagram, often using special circuits to compensate for all kinds of signal errors and distortions. They are guided, quite logically, by the quality and cost of the end product, rather than by the convenience of a textbook block diagram.

It is apparent, however, that the portion of the diagram in Figure 5 following the indicated test point is a simplified representation of a video monitor, whose characteristics closely approach the NTSC ideal, are quite stable, and can readily be measured. Therefore, rather than using a particular make and quality TV receiver, the viewing experiments were designed around the latest model professional studio monitor, the Conrac RHB-19.

Thus, the thresholds of perceptibility and acceptability were determined in these experiments in terms of a signal to interference ratio measured at the test point in Figure 5. To translate these findings to the ratios at the RF antenna terminals requires only certain measurements in the laboratory, with appropriate instruments; additional viewing tests should not be necessary.

As an example, the experiments showed that the median observer could see interference at a signal to random noise ratio of 37 dB, peak-to-peak signal without sync relative to weighted rms noise, but did not consider it annoying. Dr. Tom Straus, of Theta Com, has shown [20] that, for an "ideal receiver," with correct Nyquist slope and flat i.f. response to 4.2 MHz, the weighted signal to noise ratio will be 37 dB at the test point when the carrier to noise ratio measured in accordance with the NCTA standard [21] (which incidentally is the same as the FCC Definition in Part 76) is 37.2 dB. However, if video peaking equivalent to, say 10 dB at 1.5 MHz, has been introduced to compensate for loss of luminance resolution, [22] then the NCTA ratio equivalent to 37 dB at the test point would have to be somewhat greater than 37 dB, perhaps 40 dB, depending on peaking frequency and magnitude. This effect can be measured in a laboratory without relying on viewing tests, so long as the CCIR noise weighting curve is valid.

Similarly, the relative amplitude of beats obviously depends on the i.f. selectivity curve, which can be measured in the laboratory. An r.f. beat at 0.5 MHz below the visual carrier frequency would have to be considerably stronger at the antenna terminals than one at 0.5 MHz above the visual carrier, to produce a signal to interference ratio at the test point which the experiment shows would be visible but not annoying.

Use of the video monitor reliably relates interference ratings to known amounts of signal impairment delivered to the receiver display circuitry. These data can then be related to interference ratios at the antenna terminals of any TV receiver by measuring the appropriate transmission characteristic of the receiver. Thus, video monitor data can be universally applied to any receiver, good or bad, and to future design improvements, as well.

STIMULUS PICTURES

A great deal of study and effort went into selection and production of the scenes to be displayed with impairments for the viewing tests. Three scenes were designed, and arrangements were made with Eastman Kodak Co. to produce both slides and movies in their Rochester studios. The slides and 35 mm motion picture film clips were made on negative film, using identical models, settings, lighting, exposures, and processing. The three slides and film clips were first generation positive prints. The Kitchen scene (Fig. 6) was deliberately staged as a very "busy" picture with lots of detail. The Exercise scene (Fig. 7) was deliberately designed to have large unbroken areas of moderately high luminance. The scene with Susan (Fig. 8) was designed to be "typical" of television, with a fairly close shot of head and shoulders, some background detail, and definite focus of attention. All scenes have areas of saturated reds, and all have flesh tones. The vertical stripes on the kitchen door were expected to show strobe effects in the presence of beats. For the special split screen tests, the center portion of two prints was cut and mounted in a split frame format with identical images on the two sides. (Fig. 9, 10, 11) One experiment was designed to compare interference ratings using slides with ratings for motion picture film clips. Ratings at different viewing distances were compared. Ratings by TV station technicians and TV repairmen were compared with ratings by the general public. The results of the experiments based on these slides, properly interpreted, are expected to provide reasonable guides for evaluating or specifying system performance.

VIDEO RECORDING

All of the stimulus pictures were recorded by the Public Broadcasting Service on 2-inch video tape, using Ampex AVR-1 equipment. Programmable attenuators were controlled by a microcomputer to produce preset ratios of signal to interference. Precise 5 and 10 second timing intervals were obtained by accurate cueing marks prerecorded on the tape. It is unlikely that the project could have been completed at all without the tape recorded stimuli. The inevitable human errors in setting attenuation ratios as well as in timing were also completely avoided by this technique. Inherent video tape noise was measured at 55 to 59 dB below 0.714 volt, weighted.

SIMULATION OF SIGNAL IMPAIRMENT

In conducting any scientific experiment, the variables under investigation must be varied in a controlled manner, with all other variables held as nearly constant as possible. To this extent, all scientific experiments are simplified simulations of a sample slice of "real life," in which certain variables are isolated for test purposes.

In these experiments random noise was isolated from all other sources of interference. A signal from an essentially flat noise source was passed through a 4.5 MHz band limiting filter, Fig. 12 and a special filter designed to simulate the effect of incoherence between upper and lower vestigial noise sidebands in the NTSC receiver/demodulator. (Fig. 13) By using the CCIR noise weighting filter [23] [24] [25] for the measurement, (Fig. 14) reasonable allowance was made for the reduced subjective effect of high frequency components of random noise. Figure 15 is a sample of the result, photographed from the monitor. This represents 28 dB S/N ratio.

A discrete frequency beat at approximately 1.25 MHz was selected as a reference on the basis of previous work indicating this to be the most sensitive portion of the video pass band of a TV receiver. Work is still in progress to compare the effect of beats at other frequencies (0.5, 0.75, 2.00, 2.50, 3.25, and 3.50 MHz) with the effect of the 1.25 MHz reference beat. (Fig. 16) For this experiment, observers viewing two monitors side by side will be asked to adjust the signal-to-interference ratio of one of the beats, using a conveniently arranged attenuator, until the interference appears to be equivalent to that of the reference beat.

It can readily be shown that a change of beat frequency of approximately 30 Hz results in a marked change in ability to perceive the beat. This is one of the reasons why beats on an actual TV screen usually seem to dance in and out of the range of perception. In order to isolate and control the variables, therefore, a synthesizer was used to generate the beat frequency with stability well within 0.1 Hz. Both the synthesizer and the sync generator were locked to a rubidium standard. (Fig. 12)

At integral multiples of the horizontal scanning frequency (i.e. even multiples of half the line rate), the beat pattern consists of stationary vertical bars. When the beat frequency differs from an integral multiple of the line scanning rate by an integral multiple of the field rate, the pattern consists of stationary bars, slanting at an angle depending on the ratio of vertical to horizontal multiples. Halfway between each stationary pattern, the visibility of the beat is greatly reduced. Tests are underway to determine how much it is reduced. Informal tests indicate that a frequency shift of only 30 Hz produces reductions of 10-20 dB. Between the stationary and the low visibility pattern, the bars are in motion across the screen.

The resultant reference beat is shown in Figure 17. Signal to interference ratio is 30 dB; frequency is 1,244,813.1 ±0.1 Hz. In the video tape display, the slanting bars moved to the left at approximately 2 inches per second.

For beats in the chrominance band, 3.0-4.2 MHz, the beat frequency must be referenced to the chrominance subcarrier frequency. In addition to the six nominal beat frequencies listed above, one or more beats within ±30 Hz of the reference will be compared in order to measure the improvement due to field and line interlace.

The frequency of beats occurring in a television system is usually controlled by source frequencies which are independently subject to drifting, often much more than 30 Hz. Obviously, therefore, "real life" beats will often tend to drift rapidly from worst case to best case. Furthermore, most beats result from modulated carriers, and are themselves modulated, though not always in a simple manner. The experiments did not include these effects, either of drifting or of modulation, because of the complexity of designing a suitable program for generating and displaying the effects in a systematic fashion without bias.

Intermodulation noise was generated by transmitting 28 unmodulated carriers (30 less Channels 5 and 6) through a wide band trunk amplifier at high enough level to produce a severe effect. (Fig. 18) A carrier approximately in the center of the array (Channel 8) was demodulated, along with its complement of several hundred triple beats. The detected video was then added, through a variable attenuator, to the desired video signal. The carrier frequencies were generated by run-of-production crystals used in the Dix-Hills Model SX-15 multi-carrier generator, and deviated from 5.1 kHz below nominal frequency to 8.4 kHz above. The "desired" Channel 8 carrier frequency was 2.1 kHz below its nominal value. The composite beat before demodulation was measured at 28 dB below the Channel 8 carrier, using the spectrum analyzer at 30 kHz bandwidth, with a 10 Hz video averaging filter. (Fig. 19) The detected composite beat was also measured at 26 dB below 0.714 rms V, using the HP-3400A RMS voltmeter, confirming within 1 dB the spectrum analyzer result, after appropriate adjustment.

Severe intermodulation noise generated by modulated carriers is always accompanied by sideband intermodulation effects which could not effectively be utilized for these experiments. These effects consist of patches of colored beats, phantom images, and moving patterns in a constantly, but slowly changing kaleidoscope which would have to be mentally integrated by each observer over a period of at least several minutes. Figure 20 is a photo showing the appearance of the simulated IM noise at 27 dB signal to interference ratio.

At the threshold of visibility, the use of CW carriers for the intermodulation noise test is reasonably representative of the actual situation, providing an adjustment is made, as suggested by Arnold [12], Pranke [13] and others to account for the shift in rms carrier level under clamped downward modulation. However, it seems more than likely that if an appropriate test could be designed, the threshold of annoyance due to the sideband effects would be at a higher signal-to-interference ratio than was the case with the unmodulated carriers, due to the cross-modulation effects.

One decisive fact demonstrated during the project was that video cross-talk and cross-modulation was definitely not the same. This is because the former is the sum of signal voltages, while the latter results from the multiplication of at least three signal waveforms. Whereas in cross-talk, the waveform of the undesired signal is not subjected to non-linear distortion, it is severely distorted by extreme sync stretch and white compression as a consequence of the cross-modulation process. The visual manifestation of cross-talk, as reported by Fowler and others, is a rapid "windshield wiper" effect whenever there is an appreciable difference between desired and undesired scanning rates. This stabilizes in a strong phantom image when the scanning rates are the same. (Fig. 21) Cross-modulation also produces a rapid "windshield wiper" effect when the scanning rates are unequal. But when they are equal, the extremely stretched sync and blanking predominate, while the phantom picture is so compressed as to be scarcely visible. (Fig. 22)

Interference stimuli due to cross-modulation were generated in a straightforward manner, using two modulators, feeding a trunk amplifier at high level, and a demodulator to detect the desired but impaired channel. (Fig. 23) Separate sync generators were used for each channel, locked to a common frequency standard, but slewed vertically and horizontally so that the undesired blanking bars were visible and stationary. The trouble encountered in this procedure was that the back porch clamps in the video monitor were confused by the undesired vertical sync and blanking, producing abnormal effects which would not occur in TV receivers with dc restoration. Because of this difficulty, it appears that the ratings for cross-modulation interference may be somewhat more severe than they would have been with a TV receiver. On the other hand, a sufficient difference in scanning rates so that the blanking bars moved across the screen at 15 second intervals would probably have been rated more critically.

To the extent that these two anomalies tend to cancel themselves, the results of the experiment may be considered to be reasonably reliable.

RESULTS

The next speaker will describe the psychometric procedures used and will summarize the results of the tests. Following this presentation, an interpretation and evaluation of the results will be presented.

REFERENCES

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[23] CCIR Recommendation 418-2.

[24] J.R. Cavenaugh; "A single weighting characteristic for random noise in monochrome and NTSC color television"; Jour. SMPTE, Vol. 79, pp 105-109; February 1970. (See Table I.)

[25] Note: The Rhode & Schwarz noise meter was not equipped with the new unified noise weighting filter adopted by CCIR in Geneva in 1974. See CCIR Report 410-1 (Rev. 74), Doc. CMTT/1058 E for the new curve. See also ref. 7 above, section 5 and figure 14, page 834.