Apparent Increase in Noise Level When Television Pictures Are Frame-Repeated

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Subjective measurements were made of the apparent increase in noise level which occurs when television pictures are frame-repeated. We show that in all cases of practical interest this increase is small (less than 3 dB), that it is dependent on the type of scanning (greater increases with line-sequential than with line-interlaced scanning), and that it is relatively independent of the picture signal-to-noise ratio. At smaller numbers of repetitions—the region which shows most promise for practical schemes of bandwidth saving—the increase in apparent noise level with increased frame-repetition is most rapid.

I. INTRODUCTION

Seemingly attractive schemes for compressing the bandwidth of television signals sometimes render the signal highly sensitive to noise. As a result, the signal-to-noise ratio requirement for the channel becomes extremely large.[1] If this requirement is not met, the errors caused by the noise degrade the picture to an intolerable degree. Thus, noise is a great obstacle to the success of bandwidth-saving schemes, and the authors of any such schemes should always take care to check the noise-sensitivity of their compressed signals.

We report in this paper on some measurements we have made of the noise-vulnerability of picture signals in a frame-repeated television system. In a previous paper concerned with the possibilities of bandwidth-saving by frame-repetition or frame-replenishment, Brainard, Mounts, and Prasada made the observation that with increasing numbers of repeated television frames there appears to be an increase in the picture noise level.[2] The noise pattern is "frozen" for the repetition period; this tends to make it more visible to the eye. Any source noise, such as that created by delta modulation or pulse code modulation (PCM), or any channel noise, such as random gaussian noise, has its effective power raised by the process of frame-repetition. We attempted to measure this apparent increase in noise power in quantitative terms to determine what improvements in modulation methods or channel noise levels would be required if television pictures were frame-repeated.

II. EXPERIMENTAL EQUIPMENT

The equipment used to produce the frame-repeated pictures has been fully described in Ref. 3. For the experiments reported in this paper random noise was added to the video signal prior to frame-repetition. An automatically-timed switch was arranged to present, alternately, on a single display monitor, frame-repeated and non-frame-repeated (standard) versions of the same picture. Controlled amounts of noise could be added to the frame-repeated picture by the experimenter and to the standard comparison picture by the subject. This arrangement permitted the subject to carry out a visual match of the levels of noise in the frame-repeated and standard pictures. A block diagram is given in Fig. 4; a more detailed description of the apparatus is given in Appendix A.

III. EXPERIMENTAL METHOD

The method we used to measure the apparent increase in noise level in a frame-repeated picture was to ask 24 subjects to view in succession frame-repeated and standard versions of the same picture. With controlled amounts of noise added to the frame-repeated picture by the experimenter, the subjects were required to adjust the noise level in the standard picture until the noise level in the two pictures appeared to be the same. The difference in the actual or measured noise levels was taken as the apparent increase in noise level. Judgments were obtained for various numbers of repeated frames, for both interlaced and sequentially-scanned pictures, and for several values of signal-to-noise ratio. The study was restricted to band-limited white gaussian noise. A single still picture (Fig. 1) was used in all the trials as a background against which the noise was viewed. Details of the test conditions and subject instructions are given in Appendix B.

Fig. 1 — Test picture used in the experiment.

IV. RESULTS

Averaged results for the 24 subjects are shown in graphical form in Figs. 2 and 3. In both sets of graphs the average apparent increase in noise level is plotted as a function of the repetition ratio. With sequential scanning (Fig. 2) the time taken to scan a complete frame

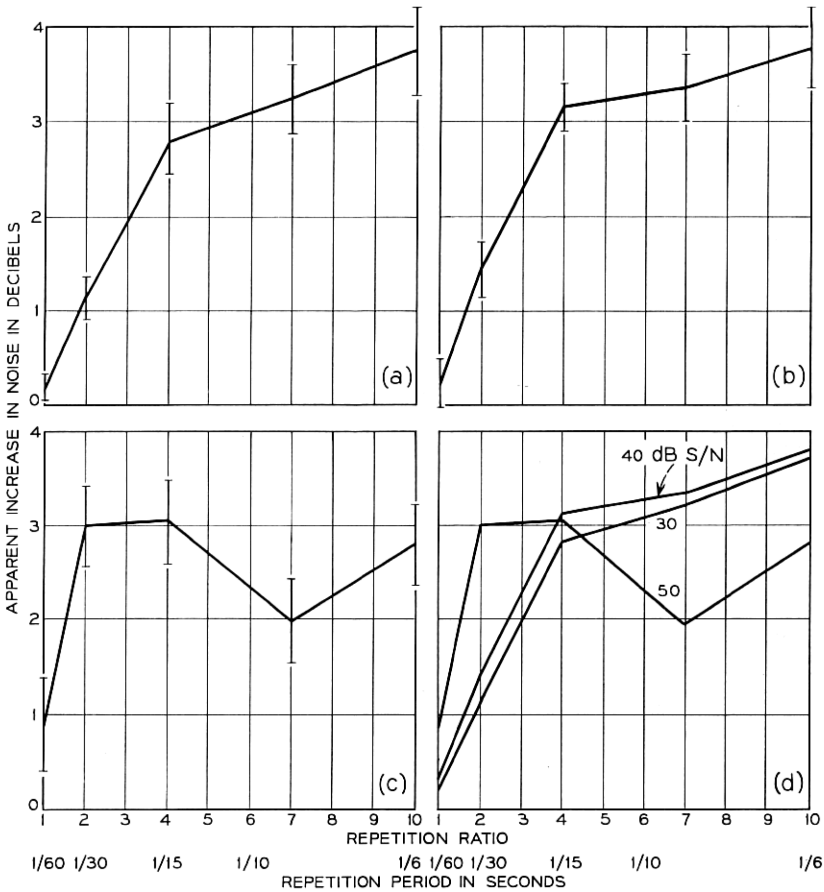

Fig. 2 — Sequential scanning: (a) 30 dB signal-to-noise ratio; (b) 40 dB signal-to-noise ratio; (c) 50 dB signal-to-noise ratio; (d) combined results.

was 1/60 second, whereas with interlaced scanning (Fig. 3) it was 1/30 second. This fact often leads to semantic confusion when comparing the two cases; what we have termed 2:1 frame-repetition of an interlaced picture is sometimes loosely referred to as 4:1 frame-repetition by virtue of the fact that the time period during which the picture is repeated is the same as that for 4:1 sequentially-scanned pictures. To emphasize our usage we have indicated the repetition period in seconds along the horizontal axis in all graphs.

Separate curves are plotted for each of the three signal-to-noise ratios used in both sequential- and interlaced-scan conditions. These signal-to-noise ratios are the true or measured ratios and refer to the frame-repeated picture, not the standard picture used for a comparison; thus, at higher numbers of repetitions the apparent signal-to-noise ratios are less than the stated figures by an amount equal to the ordinate of the curve. No attempt has been made to fit a smooth curve to the measured points as there was no way of knowing what type of curve to fit. Instead, the points have been connected by straight-line sections.

Several subjects experienced difficulty in adjusting for subjective

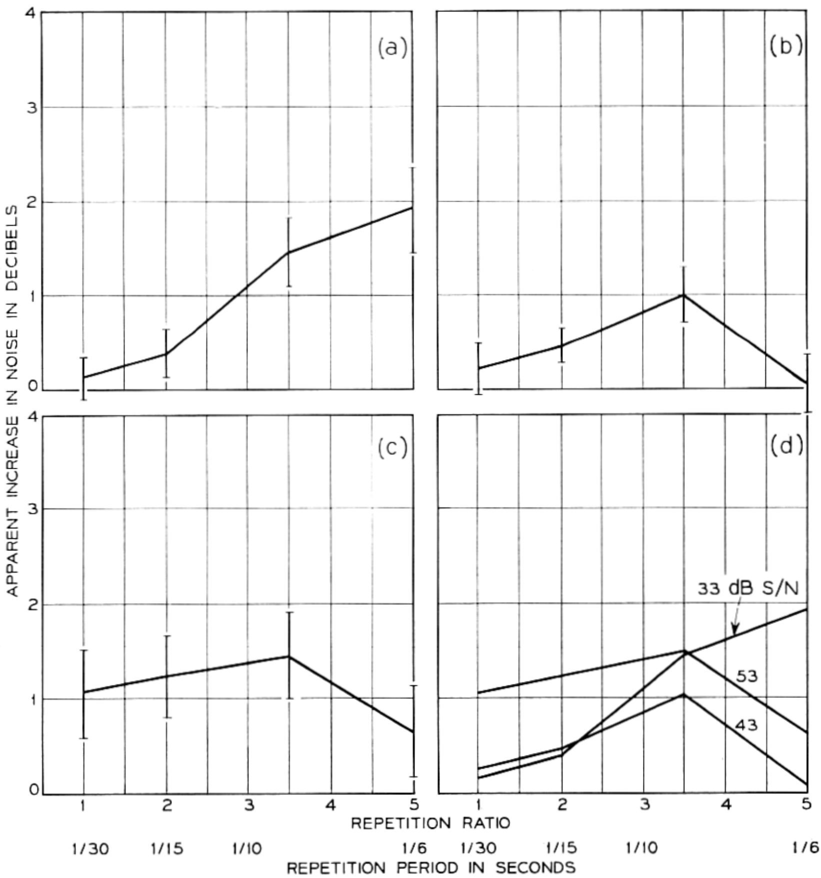

Fig. 3 — Interlaced scanning: (a) 33 dB signal-to-noise ratio; (b) 43 dB signal-to-noise ratio; (c) 53 dB signal-to-noise ratio; (d) combined results.

equality when the signal-to-noise ratio was 50 dB in the sequential case and 53 dB in the interlaced case. At these levels the noise is very near the threshold of visibility, and even allowing for the increase in noisiness with frame-repetition, the noise is barely perceptible. Furthermore, at these signal-to-noise ratios small alterations in noise level are much less noticeable than at 30 dB or 40 dB signal-to-noise ratios. The subjects discovered that for a 50 dB signal-to-noise ratio they could rotate their attenuator control through a number of steps without affecting the relative appearance of the two pictures. Two subjects maintained that altering the attenuator over its full range made no perceptible difference to the picture at 50 dB, and in consequence, when presented with a comparison at this noise level, merely reiterated their setting for the previous presentation. The variability of the 50 dB settings, as compared with the 30 dB and 40 dB settings, reflects these difficulties. In Figs. 2a, b, and c, and 3a, b, and c the standard deviations σ of the plotted means are shown. These were calculated according to the formula

$$\sigma = \left[\frac{1}{24} \sum_{i=1}^{24} (X_i - \langle X \rangle_{av})^2\right]^{\frac{1}{2}}$$

where the X_i are the 24 results whose mean $\langle X \rangle_{av}$ is plotted in the graph. The vertical lines about each plotted point extend to $\pm\sigma$. Figure 2d is a superimposition of Figs. 2a, b, and c for comparison purposes. Similarly Fig. 3d is a superimposition of Figs. 3a, b, and c.

V. DISCUSSION

A point of interest about the results is the obvious difference between the graphs for interlaced and sequentially-scanned pictures. The apparent increases in noise level are substantially larger in the sequential case (Fig. 2) than in the interlaced case (Fig. 3). For example, consider four presentations of each picture. From Fig. 2d the average increase in noise level for sequential scanning is about 3 dB, while from Fig. 3d the increase is seen to be a little over 1 dB. If this comparison is deemed to be unfair because the period of repetition is not the same in each case, then consider the 4:1 frame-repeated sequential case against the 2:1 frame-repeated interlaced case. Again, the difference is substantial.

A partial explanation of this difference may be given in terms of the time period of repetition. The scanning of a single frame takes twice as long in the interlaced case as it does in the sequential case. Thus, in standard or non-frame-repeated interlaced pictures every noise sample or element on the screen is seen for twice as long (1/30 second) before replenishment by a different noise sample as it is in sequentially-scanned pictures (1/60 second).* With a 2:1 frame-repeated sequentially-scanned picture, noise samples are replenished by different samples every other frame, that is, also at 1/30 second intervals. Therefore, crudely speaking, a standard interlaced picture is a 2:1 frame-repeated sequentially-scanned picture with a different order of line presentation. Hence, from Fig. 2 we would expect about 1.5 dB difference in the apparent noise level between standard interlaced and standard sequential pictures having the same added noise pattern, with the sequential picture having the higher apparent signal-to-noise ratio.† We have observed with our system that, by taking a picture with a fixed amount of added noise and changing the read-out method from sequential to interlaced with no frame-repetition, there appears indeed to be a slight increase in noise level.‡ This observation is only that of the authors, however, and we have yet to confirm it under properly-controlled conditions with a larger sample of subjects. Until this experiment is performed it should not be assumed, from Fig. 2 and 3, that a 4:1 frame-repeated sequential picture looks noisier than a 2:1 frame-repeated interlaced picture, each having the same signal-to-noise ratio.

If an ordinary interlaced picture can be equated to a 2:1 frame-repeated sequential picture, it follows that the upper portion of Fig. 2d, above a horizontal line drawn through 1.5 dB, should correspond to Fig. 3d. It can be seen that this correspondence is by no means exact, although in the case of the 30 dB signal-to-noise ratio curve it is quite close. The 50 dB curves are unreliable because of the previously-mentioned difficulties of adjustment at low noise levels, so that the 40 dB curve represents the main discrepancy and obstacle to accepting the correspondence. In Fig. 2d the 40 dB curve closely follows that of the 30 dB curve (an analysis of variance showed no significant difference between the plotted points) while in Fig. 3d the 43 dB curve diverges from the 33 dB curve and dips down to zero at higher repetitions. We carefully examined this phenomenon and

* The decay time of the phosphor may be considerably less than 1/30 second, but the sample is seen for a longer period owing to the persistence of vision.

† Having the same added noise pattern implies a 3 dB difference in their signal-to-noise ratios (see Appendix A). The interlaced picture has the higher actual S/N.

‡ Roughly estimated at between 1 and 3 dB.

conclude that it may well be explicable in terms of an interference or masking effect due to the interline flicker. At high levels of noise the masking is inoperative, but at lower levels it becomes predominant and acts to reduce the apparent noisiness. It also has a greater effect on the large-grain slow-moving noise produced by the higher repetitions. These conclusions are derived from personal observation and are tentative, but they do explain the shape of the Fig. 3 curves to some extent. A further point which should be clearly borne in mind in evaluating the curves is that the difference limen for random noise is probably at least 1 dB at 30 and 40 dB signal-to-noise ratios and greater at 50 dB signal-to-noise ratio; the increases in apparent noise level and variations in the apparent increase which are being considered are therefore quite small and, to the average person, frequently indiscernible.

Another point of interest in the graphs (more evident in Fig. 2 than Fig. 3) is the rapid rise in apparent noise level at small numbers of repetitions followed by a general flattening out or saturation above 1/15–1/10 second (66–100 milliseconds). This corresponds roughly to the integration period or critical duration of the eye.[4] Below the critical duration, the eye sums "frozen" noise frames and sees increasing granularity with increasing frame-repetition. Above the critical duration the granularity stays constant, but the apparent spatial movement of the noise becomes slightly more noticeable with larger numbers of repetitions. It is unfortunate that in the region which shows most promise from the point of view of useful band-compression without noticeable picture deterioration (2:1, 3:1, or 4:1 sequential and 2:1 interlaced) the increase in noise level is most rapid.

Notice finally, that subjects exhibited a slight bias in preference in the experiment toward the standard comparison picture. This can be seen in Figs. 2 and 3 by the positive intercept in apparent noise level increase at the 1:1 repetition ratio in all the graphs. This bias may have been due to slight differences in the brightness and contrast of the frame-repeated and standard pictures, as well as to difficulties in measuring signal-to-noise ratio to an accuracy of less than 1 dB.

VI. CONCLUSIONS

The apparent increase in noise level due to frame-repeating is fairly small: between 1 and 3 dB in the range of repetition ratios which are likely to be of practical interest for bandwidth-savings (up to 4:1 with sequential-scanning, 2:1 with interlacing).

With sequentially-scanned pictures the increase in apparent noise level is greater than with interlaced pictures, but interlaced pictures appear to be noisier to start with. Without further experimentation it is not possible to say with certainty whether a frame-repeated sequential picture is noisier than a frame-repeated interlaced picture, when each has the same signal-to-noise ratio.

The rate of increase in apparent noise level is greatest in the region which shows most promise from the point of view of useful bandwidth-saving without picture deterioration (up to 4:1 frame-repetition with sequential scanning, 2:1 interlaced).

The apparent increase in noise level is largely independent of signal-to-noise ratio, with one possible exception: low-level noise in interlaced pictures appears to be masked by interline flicker at the higher numbers of repetitions.

VII. ACKNOWLEDGMENT

The authors gratefully acknowledge the assistance of J. B. Pestrichelli in setting up and carrying out the experiments.

APPENDIX A

Details of the Experimental Apparatus

A block diagram of the experimental equipment is shown in Fig. 4. A 60 frame per second, 160-line, sequentially-scanned video signal was derived from a vidicon camera. To this signal random gaussian noise at one of two levels was added, dependent on the setting of switch S_1. In position A, corresponding to frame-repetition (see linked switch S_2), the noise level was completely and solely under the control of the experimenter (attenuator I), and in practice was set such that the signal-to-noise ratio (measured as the peak-white to black-level signal voltage divided by the rms noise voltage) was, in the case of line-sequential scanning, either 30, 40 or 50 dB at the display monitors. For line-interlaced scanning the levels of added noise were not changed, giving values of signal-to-noise ratios 3 dB higher at the display monitors, that is, 33, 43 and 53 dB. This was because the different manner of readout from the frame store with interlacing effectively reduced both signal and noise bandwidths by a factor of 2. In the B position the noise level was determined in part by the experimenter (attenuator II) and in part by the subject. The experimenter would, in practice, set attenuator II to 8 dB less than attenua-

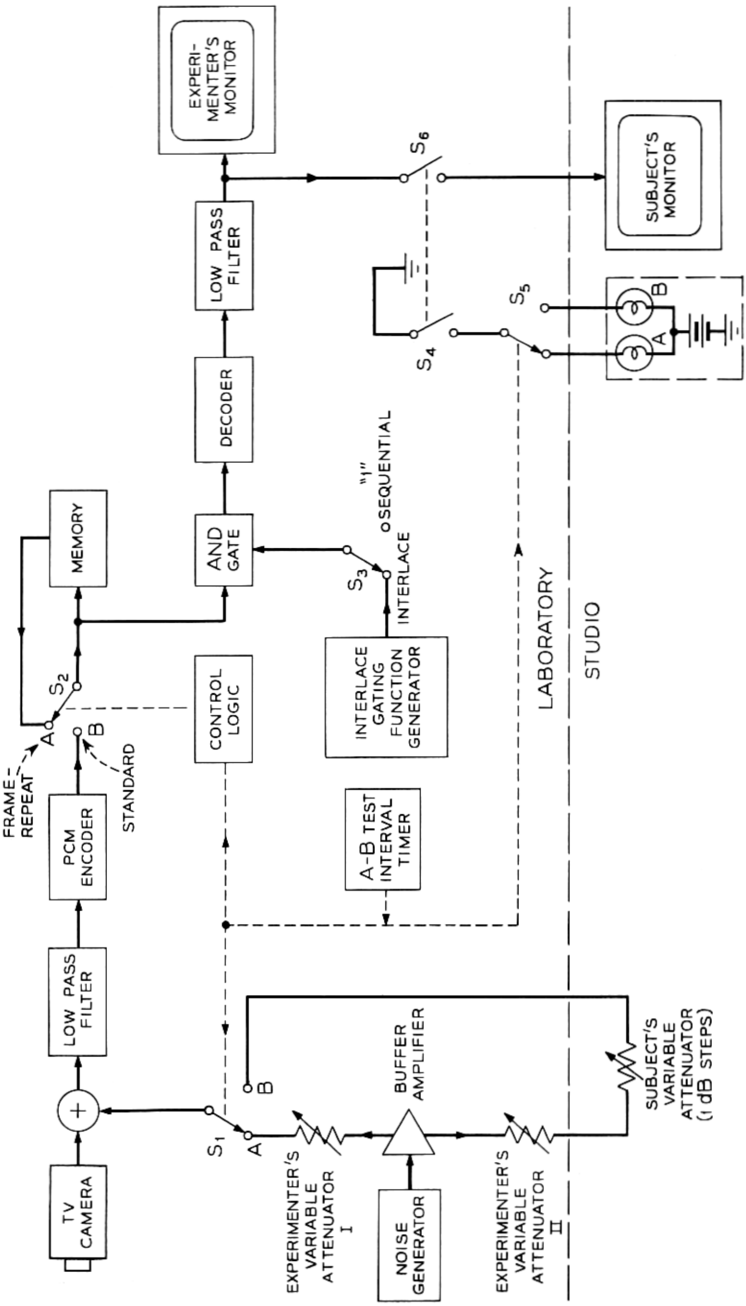

Fig. 4 — Block diagram of the experimental equipment.

tor I, that is, to give a 22, 32 or 42 dB signal-to-noise ratio (sequential scanning). The subject's attenuator was adjustable in steps of 1 dB over a range of 10 dB, so that, given, for example, a 32 dB setting on the experimenter's attenuator II and 40 dB on attenuator I, the subject could vary the signal-to-noise ratio over the range 32-42 dB. This proved to be an adequate adjustment for the subject to match A and B noise levels in almost all cases.

Subsequent to the addition of noise, the video signal was passed through a low-pass filter of bandwidth 768 kHz to the frame-repeating equipment.* This equipment, consisting of a PCM encoder, memory, decoder, and control logic, has been fully described in Ref. 3. With switch S_2 in position B no frame-repetition occurred and the picture seen on the subject's and the experimenter's monitor screens was a standard 60 frame per second picture with added noise. With the switch in position A, however, every nth frame was stored in the memory and read out to the display monitors n times in succession. The experimenter was able to select any n in the range 1–11. By means of switch S_3 (independently controlled and not linked to any of the other switches) the experimenter could choose to display the contents of the memory in either line-sequential or line-interlaced fashion. In both cases readout from the memory was line-sequential, the interlacing being produced by subsequently blanking every alternate line of the readout (the blanking signal was delayed by one line period in alternate readout scans to give the interlacing effect). The subjective effect of this type of interlacing is exactly equivalent to conventional interlacing when a still picture is used. For example, consider a single stored frame of a plain white picture to which noise has been added. In both the conventional interlaced readout and the sequential alternate-line readout, the noise patterns as seen on the display monitor will be identical. Viewers will not appreciate that, in the alternate-line blanking case, the lines are scanned at twice the rate with pauses in between lines. With conventional interlaced readout the noise bandwidth and the noise power are halved, and the peak-signal to rms noise ratio increased by 3 dB. A corresponding 3 dB increase in signal-to-noise ratio has, therefore, been assumed for the alternate-line blanking method used in this instance.

In both interlaced and sequential cases the memory readout was displayed on a sequentially-scanned monitor. Linked to S_3, but not shown, was an arrangement of attenuators in the video path to the

* The characteristics of this filter are fully described in Ref. 3.

display monitors such that the screen brightness and contrast was unchanged in switching from sequential to interlaced pictures. This ensured that interlaced and sequentially-scanned pictures were seen under exactly similar conditions.

Linked switches S_1, S_2, and S_5 were controlled by an automatic timer which repeatedly switched between A and B conditions, each condition being presented for 2½ seconds. To avoid visible transients these switches were arranged to operate only during the frame fly-back interval. Switch S_5 controlled two lights labeled A and B, visible to the subject, in order to indicate to him which presentation he was currently viewing. Linked switches S_4 and S_6 enabled the experimenter to set up a condition on his own monitor before presentation to the subject.

APPENDIX B

Test Conditions

The viewing distance for each subject was approximately 25 inches, the picture size being 5 inches × 5 inches. Screen highlight and low-light luminances were maintained at 60 foot-lamberts (206 cd/m^2) and 3 foot-lamberts (10 cd/m^2) respectively. Ambient illuminance was approximately 5 foot-candles (54 lm/m^2).

Noise level matching was carried out by the method of adjustment.[5] Subjects were introduced to the method in the following way. On arrival for their test, an A-B pair was presented to them (the A and B presentations occurring successively on the same screen for 2½ seconds each) in which the B presentation was noticeably noisier than the A. It was then demonstrated that by adjustment of the step attenuator (see Fig. 4) it was possible to lower the noise level in B until it matched the noise level in A. Subjects were invited to try the matching for themselves, and in all cases, with very little practice, succeeded in mastering the technique. It was explained that a number of similar pairs would be presented to them, and that for each pair they were required to adjust the attenuator until the noise levels in the A and B pictures were the same. An unlimited time was allowed for the adjustment, most subjects taking about one minute, with a few taking as much as two minutes. When the pictures were matched to their satisfaction the subjects reported the attenuator setting to the experimenter. The quantity: Attenuator I setting − (Subject's attenuator setting + attenuator II setting) was taken as the apparent increase in noise level due to frame-repeating.

All of the presentations were made with the same still picture, a portrait of a girl (Fig. 1). Had a moving picture been used, the subject's judgment would have been confounded by the motion break-up with frame-repetition. By using a still picture, the only visible difference between the two pictures was in respect to noise level.

Based on the results of preliminary experiments, repetition ratios of 1:1, 2:1, 4:1, 7:1, and 10:1 (60, 30, 15, 8.6, and 6 new frames per second respectively) were chosen to cover the range of interest for sequentially-scanned pictures. For interlaced pictures 1:1, 2:1, 3.5:1, and 5:1 (30, 15, 8.6 and 6 new frames per second respectively) were used. The 1:1 repetition here was identical to a standard or non-repeated picture, and was included as a check on the validity and accuracy of the *A-B* comparisons.

The 27 *A-B* presentations, consisting of all combinations of the 3 signal-to-noise ratios, the two methods of scanning and the various frame-repetition ratios (5 for sequential, 4 for interlaced scanning) were presented to subjects in random order, the order being different for each subject. Subjects made only one match per *A-B* pair. Twenty-four subjects were tested and the mean increases in apparent noise level, together with the standard deviation between subjects, were calculated for each of the 27 conditions.

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