

# Low-Resolution TV: Subjective Effects of Frame Repetition and Picture Replenishment

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*Using the experimental television facility described in a companion paper, frame repeating and point-by-point selective replenishment of picture elements have been accomplished in real time. On the basis of initial experiments, using the head-and-shoulder view of a person as the picture source, such as is likely to be encountered in a visual communication system, the following tentative conclusions have been reached:*

- (i) *The motion rendition with a 15 new pictures/second frame repeating system, while not flawless, is reasonably good.*
- (ii) *Selectively replenishing one-quarter of the picture points per frame gives a better continuity of motion but results in objectionable patterns.*
- (iii) *Picture quality greatly depends on the pattern of picture replenishment. Of the five replenishment patterns tested, two result in pictures which are significantly better than the other three.*
- (iv) *In informal viewings, opinion has been so divided that no preference has been established between simple 15 new pictures/second frame repeating and the more satisfying schemes for picture replenishment.*
- (v) *The frame repeating and replenishment systems produce gross impairment during zooming and panning; consequently, these systems in their present form are unlikely to be useful for broadcast television.*

*The impairments observed in these systems are subjective and not yet predictable. This emphasizes the importance of subjective testing of systems in real time.*

## I. INTRODUCTION

Experiments on real-time operation of various frame repeating and replenishment systems were performed with a low-resolution TV system described in a companion paper.<sup>1</sup> The head-and-shoulder view of a person was used as the picture source as might be used in a visual communication system.

As is well-known, the lower bound on the number of presentations per second in a television system is set by the flicker requirements. No systematic study of motion in TV pictures has been possible in the past because the flicker requirements dictate that for a screen luminance of, say,  $85 \text{ cd/m}^2$  (25 fL), something of the order of 60 presentations must be presented every second to alleviate the flicker problem. The presentation requirements for producing smooth perceived motion for most of the common types of movements are much less than this. In the past, suitable means have not been available for the study of the lower bound on the picture rate necessary for the satisfactory rendition of motion in television systems.

With the availability of large-capacity, high-speed ultrasonic delay lines,<sup>2</sup> it is now possible to store, in digital form, large quantities of information. Delay lines with a total storage capacity of 25 kilobits and an input-output rate of approximately 1.5 megabits/second are readily available now. Using eight assemblies of lines and a picture format of 160 samples per line, 160 lines per frame sequentially scanned at 60 frames per second, allows storage of one complete picture frame encoded as 8-digit PCM at a sampling rate of 1.536 MHz.

The stored information can be displayed several times on the display monitor at a suitable rate to satisfy the requirements for display flicker. This allows sending new information through the channel to satisfy only the condition of suitable rendition of motion. The availability of frame storage has made it possible to study motion rendition separated from display flicker effects.

The rendition of motion by rapid superimposition of a sequence of still pictures is based on the exploitation of a perceptual property of the viewer, namely, the persistence of vision. Our knowledge of the human perceptual mechanism is still quite incomplete and primitive. Hence, it is obvious that a system exploiting perceptual redundancy can only be evaluated by obtaining the subjective responses of the viewers in controlled experiments. To obtain the subjective responses, the operation or simulation of the systems on the time scale identical to the original motion is imperative and its importance cannot be over-emphasized.

Frame repetition is taken to mean that one complete frame is transmitted to the receiver, stored in the memory and then shown repetitively a number of times on the TV screen. In a replenishment system a portion of the picture information from each frame is transmitted during that frame time. At the receiver this information must be inserted in the memory in the appropriate time slots. Complete pictures are read out of the memory each frame time for display, but the picture changes from frame to frame as the new information is added.

## II. SYSTEM DESCRIPTION

A block diagram of the basic system is shown in Fig. 1. The details of the system's components are described elsewhere.<sup>1</sup> The video signal is generated by a vidicon camera system designed to sequentially scan the vidicon at 60 frames per second with a square raster of 160 lines. Suitable low-pass filtering limits the bandwidth of the signal to less than 768 kHz. Unless otherwise stated, the picture was restricted to a head-and-shoulder view of a person.

The video signal is sampled at the rate of 1.536 MHz and the samples are encoded by an 8-digit PCM encoder. The output digits of the encoder are in parallel form. Each digit is routed to a 1/60 second delay line. The switch *S* in Fig. 1, at any instant, connects each delay line input either to the respective encoder output or to its own output. If the switch is at position *A*, new data is inserted into each delay line and is also decoded and displayed. If the switch is at position *B*, the

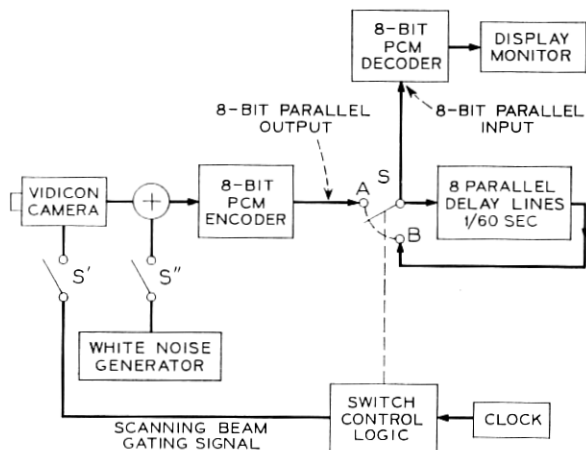


Fig. 1 — Basic frame repeating and replenishment systems.

data, which has been previously stored and displayed, is displayed again and is recirculated through the delay lines. Whatever the switch position, the monitor display rate remains constant at 60 frames/second. The switch S operates fast enough that any selected sample or group of samples can be replaced.

By generating different switch control waveforms, we can make the basic system operate as different frame repeating or replenishment systems. By constraining switch S to remain at position B, we can operate the memory in the circulating mode and store its contents indefinitely. This feature allows close scrutiny of any particular frame and also eases the problem of taking still photographs.

While the subject is producing exaggerated hand and head motion, the memory may be placed in the circulating mode. This ensures that a single frame is frozen in the memory and is available for photographing. This procedure has been followed for taking all the photographs included in this paper.

Observations were conducted in the laboratory at a reduced room illumination of approximately 300 lux (30 fc). The monitor was adjusted to have a highlight luminance of approximately 340 cd/m<sup>2</sup> (100 fL).

### 2.1 *Frame Repeating Systems*

The basic frame repeating principle can be illustrated by Fig. 2. The vidicon is sequentially scanned every 1/60 second. However, only every  $n$ th frame is displayed on the monitor and stored in the memory. This frame is then repeated ( $n - 1$ ) times on the monitor. The presentation rate is maintained at 60 frames per second to combat flicker. In other words, every  $n$ th frame is sent to the receiver which uses zero-order interpolation to fill in the missing frames.

In the basic experiment described above, the camera is sequentially scanned every 1/60 second. Switch S' is open. Thus, the visual signal is integrated on the camera photo-cathode for 1/60 second. The problem of the optimum integration period will be discussed later. Switch S'' from the noise generator is open for these experiments.

### 2.2 *Replenishment Systems*

In a replenishment system, only a fraction of the total picture information is replenished during each frame period. Using signal storage, replenishment systems build up a picture by sending 1/ $n$  of the total number of samples contained in a frame in one frame period. Thereafter, in every presentation, 1/ $n$  of the samples are new while

the rest are old.\* Thus, new samples continually replenish old ones according to some predetermined scheme.

III. SOME RESULTS

Several frame repeating and replenishment systems have been operated in real time. Impairments are produced only in those areas where there is real or apparent movement, i.e., where the luminance at

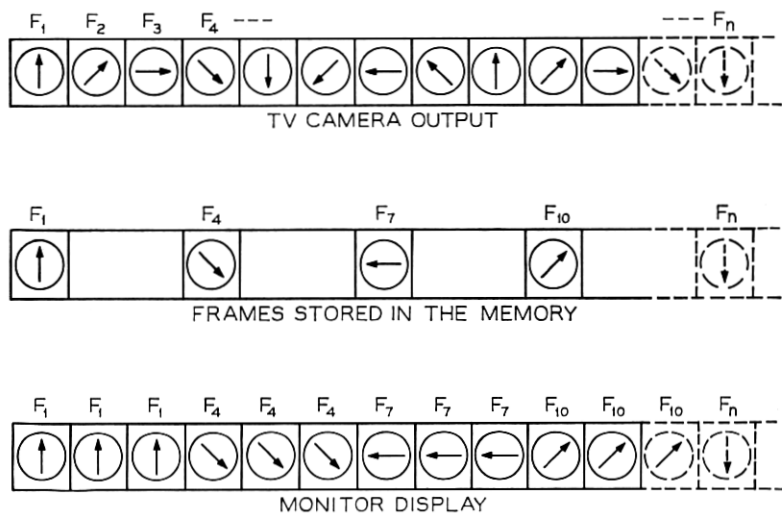


Fig. 2 — Frame repeating.

a point changes from frame-to-frame. Further, the type of impairment for a particular system depends on the type of motion. The impairments introduced in motion rendition are subjective and are extremely difficult to describe. However, these will be described as best as possible. Photographs will be used to illustrate the effects wherever possible. As all the impairments are produced only in the presence of motion, photographs are not very satisfactory. Fig. 3(a) and 4(a) show a picture when no frame repeating or replenishment is used.

3.1 Frame Repeating Systems

Using a vidicon integration time of 1/60 second, frame repeating was observed using rates of 30, 20, 15, 12, 10, 8.6, 7.5, 6.7, and 6 new pictures/second.

\* This assumes replenishment of equal number of samples every frame time. This assumption is not necessary in a general case.

As we go from higher rates to lower rates, the impairment, which appears in the form of a jerky motion, increases. For the head-and-shoulder view of a person conversing, no impairment is noted at 30 new pictures/second. At 20 new pictures/second, fast large-area motion produces a slight amount of jerkiness. At 15 new pictures/second, noticeable jerkiness is observed for large-area motion, such as head motion. However, the lip motion still appears natural. At 12 new pictures/second, the jerkiness is quite pronounced and some discrepancy can be noticed in the lip region also. As we go down to lower rates, further gradual increase in jerkiness occurs. At 6 new pictures/second the picture is quite jerky. The coordination between the lip motion and the sound is almost completely lacking.

Responses of several engineers after informal viewing suggests that the threshold of acceptability may be between 12 and 15 new pictures/second. The change in quality as we go from 15 new pictures/second to 12 new pictures/second seems more drastic than for any other pair of adjacent rates. It is proposed to check this observation by careful subjective experiments.

In another experiment, a broadcast TV program was displayed on a TV receiver and was used as the picture source for the system's vidicon camera. Everything else remained the same. It was observed that frame repeating produced gross impairment during zooming and panning of the broadcast studio camera which is quite common in entertainment TV programs.

### 3.2 *Replenishment Systems*

The following replenishment systems have been observed in real time:

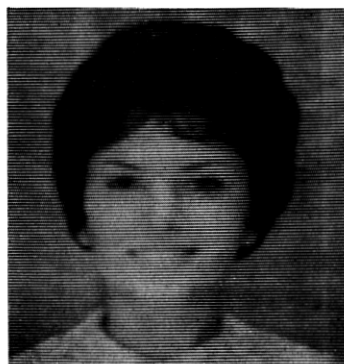
#### 3.2.1 *2 : 1 Replenishment.*

The replenishment pattern is shown in Fig. 3(b). The camera was scanned sequentially at the rate of 60 frames/second. The samples marked 1 were replenished in frame 1 and the samples marked 2 were replenished in frame 2. Thus, the total replenishment time was  $1/30$  second. A still photograph depicting the system output is shown in Fig. 3(b).

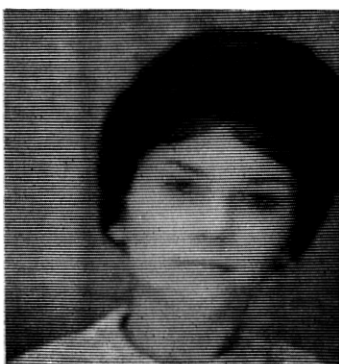
Very slight impairment in the rendition of motion was observed for this condition.

#### 3.2.2 *4 : 1 Replenishment.*

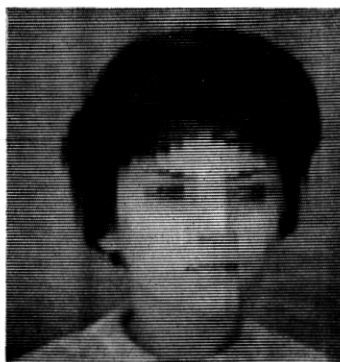
The camera was scanned sequentially at the rate of 60 frames/second. Samples were replenished according to five different replenishment



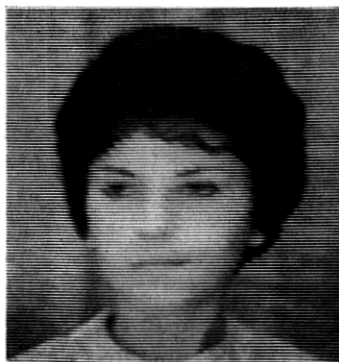
(a)  
ORIGINAL



(b)  
2:1 REPLENISHMENT  
PATTERN:  
1 2 1 2 1 . . .  
2 1 2 1 . . .  
1 2 1 . . .  
2 1 . . .  
1 . . .  
. . .  
. . .  
. . .



(c)  
4:1 REPLENISHMENT  
PATTERN:  
4 3 2 1 4 . . .  
4 3 2 1 . . .  
4 3 2 . . .  
4 3 . . .  
4 . . .  
. . .  
. . .  
. . .



(d)  
4:1 REPLENISHMENT  
PATTERN:  
4 3 2 1 4 . . .  
1 4 3 2 . . .  
2 1 4 . . .  
3 2 . . .  
4 . . .  
. . .  
. . .  
. . .

Fig. 3 — Photographs illustrating replenishment patterns.

patterns to be described. In each case, the sample positions marked 1 were replenished in frame 1, 2 in frame 2, 3 in frame 3, and 4 in frame 4. Total replenishment time was 1/15 second.

**3.2.2.1 Pattern 1.** The replenishment pattern is shown in Fig. 3(c). The replenishment pattern is vertical. Vertical bars were quite visible in the presence of motion. The impairment was substantial. Fig. 3(c) shows a still photograph depicting the output of the system in the presence of exaggerated head motion.

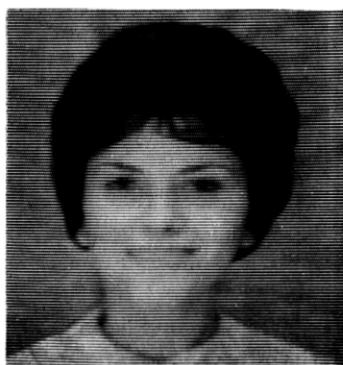
**3.2.2.2 Pattern 2.** The replenishment pattern is as shown in Fig. 3(d). As the replenishment pattern is diagonal, the visible bars in the photograph (Fig. 3(d)), are diagonal. In real time observations, these are less visible than the vertical bars in pattern 1. However, the patterns were still visible enough to be objectionable.

**3.2.2.3 Pattern 3.** The replenishment pattern is as shown in Fig. 4(b). As can be seen by an inspection of the replenishment pattern, simple vertical or diagonal patterns are nonexistent for the replenished points. This system performs much better than the two previously described replenishment systems of corresponding rate. Moderate and fast motions do cause some "ragged"-edge effects.

**3.2.2.4 Pattern 4.** Another replenishment pattern is shown in Fig. 4(c). This figure also shows a still photograph depicting the output of the system in the presence of exaggerated head motion. The performance of this system is similar to that of the system described in Section 3.2.2.3 above.

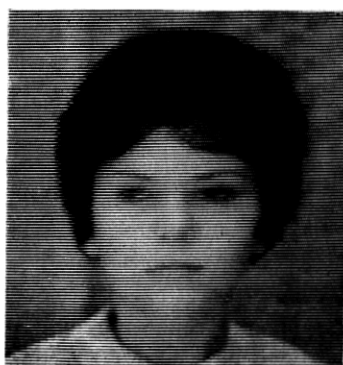
**3.2.2.5 Pattern 5.** The pseudo-random pattern. In this system, the average bit rate is the same as in the other 4 : 1 replenishment systems described above. However, the pattern of replenishment is not regular over blocks of 4 picture elements but is pseudo-random. One quarter of the total number of samples stored in the memory is replenished, in a random pattern, each TV frame period. All information stored in the memory is replenished once and only once during any four consecutive TV frame periods. The same replenishment pattern is repeated every four TV frame periods. Fig. 4(d) shows a still photograph depicting the output of the system in the presence of exaggerated head motion. The system performance is not satisfactory. Moving edges break up and produce a sparkling effect.





(a)

ORIGINAL



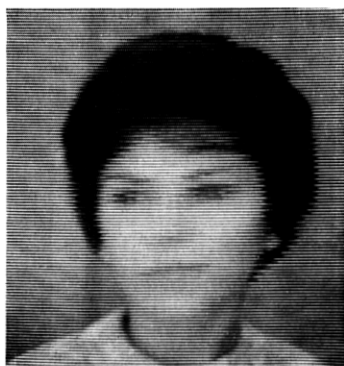
(b)

4:1 REPLENISHMENT  
PATTERN:

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4 1 4 1 4 . . .
2 3 2 3 . . .
4 1 4 . . .
2 3 . . .
4 . . .
. . .
. . .
. . .

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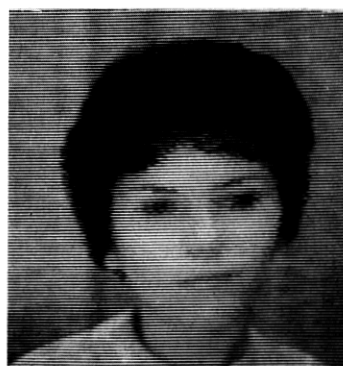
(c)

4:1 REPLENISHMENT  
PATTERN:

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2 1 2 1 2 . . .
3 4 3 4 . . .
2 1 2 . . .
3 4 . . .
2 . . .
. . .
. . .
. . .

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(d)

4:1 REPLENISHMENT  
PATTERN:  
PSEUDO RANDOM

Fig. 4—Photographs illustrating replenishment patterns.

### 3.3 *Frame Repeating With Increased Vidicon Integration Time*

The vidicon is a storage type of camera tube. In the standard sequential operation, the light distribution of the scene is integrated on the camera photosensitive element for  $1/60$  second. For fast motions this integration produces a blur. This effect can be contrasted with a shuttered or a nonstorage type of camera unit that would have produced jerkiness in such a situation. It is felt that a trade-off between sharp but jerky pictures and blurred but smooth pictures exists and there may be a subjectively optimum integration time and characteristic for different uses of television.

In the frame repeating experiments described in Section 3.1, the integration time was  $1/60$  second. On the other hand, if the camera is read out only when a new picture is desired, the image will be integrated on the camera photosensitive element for the full  $n/60$  second if the system uses  $60/n$  new pictures/second. Possibilities exist to obtain any arbitrary integration characteristic if we use external storage.

A preliminary experiment was tried using the vidicon itself as the integration element. No conclusive results were obtained. The Switch  $S'$  in Fig. 1 is closed to pass a gating signal to the vidicon to read out the integrated picture every fourth frame time for storage in the memory. However, the nonlinear brightness-current characteristic of the vidicon, the increased stickiness, and the effect of lateral leakage in a vidicon system with increased integration time could have contributed more detrimentally to the resulting display than the improvement from the anticipated integration characteristic.

### 3.4 *Frame Repeating With Noisy Signal*

The effect of frame repeating on the visibility of additive noise was observed. The switch  $S''$  in Fig. 1 was closed to add noise to the picture signal.

For a reduced number of pictures per second, the noise pattern remained frozen and then suddenly changed to another pattern as a new picture was read in. The noisy picture lost its "busy" look to a certain extent. The impression gained was one of a superimposed noise pattern moving jerkily. The visibility of the noise increased as the number of new pictures/second was decreased.

## IV. DISCUSSION

The impairments produced by the frame repeating systems and the replenishment systems are very different.

In the frame repeating systems, the impairments are in the form of jerky motions. These are most visible where the moving edges are the outlining contours of large areas. There also seems to be a correlation between the average brightness of the area and the visibility of jerkiness. It is an apparent flicker effect.

In the replenishment systems, the jerkiness is missing. However, the impairment appears in the form of ragged edges of the moving objects and the superimposition of visible patterns. The replenishment experiments described clearly bring out the importance of operation or simulation of systems on the time scale identical to the original motion for the purpose of subjective evaluation. It may be recalled that for the same bit rate, the performance of the replenishment systems varied widely depending on slight changes in the replenishment patterns. On the basis of observations made so far, there seems to exist a correlation between the visibility of undesired patterns and the spacing of the points replenished in the same frame. For example, in Fig. 3(c), all the points replenished in any particular frame, say those designated by 1, are in a vertical column, and this produces a vertical bar pattern. In Fig. 3(d), all the points replenished in frame 1 are along a diagonal. In this case, we see spurious diagonal bar patterns.

In Figs. 4(b) and (c), all the picture points designated 1 are separated by only one sample of another frame in both horizontal and vertical directions. Of the five cases studied, patterns are least visible in these cases. It is interesting to note that the pseudo-random replenishment pattern did not perform as well.

#### V. ACKNOWLEDGMENTS

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