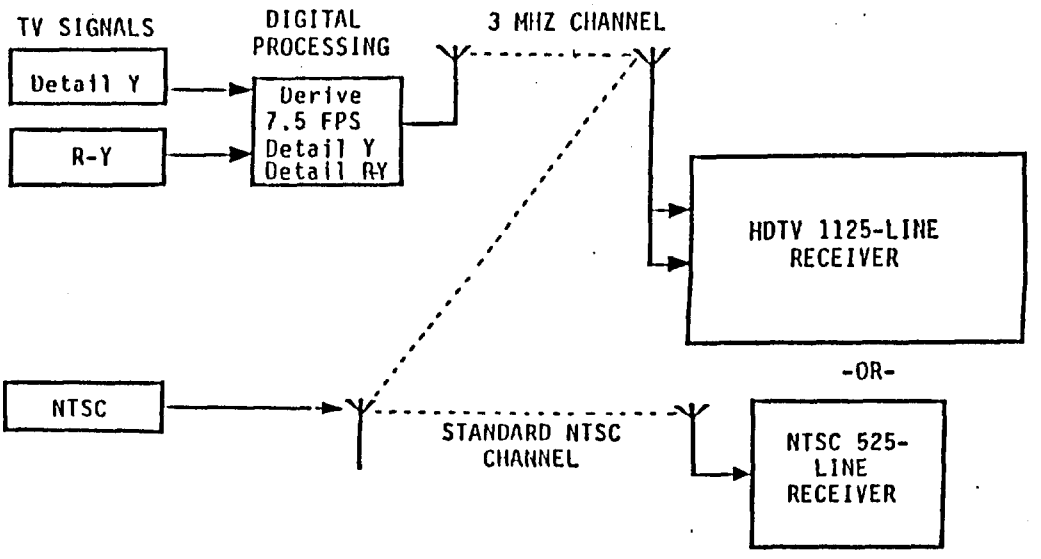

Figure 1. Proposed HDTV Compatible Transmission System

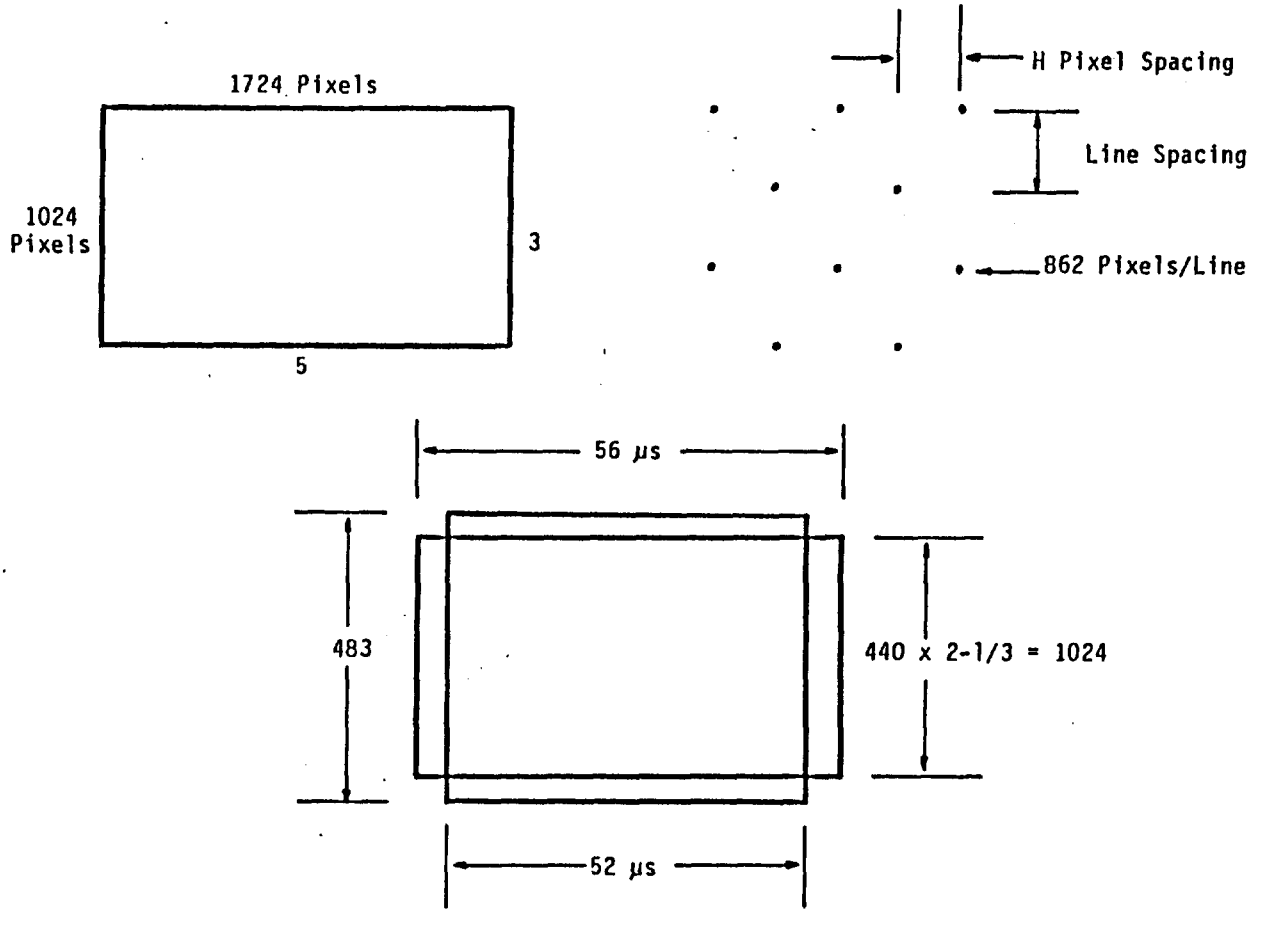

Figure 2. (Top Left) HDTV Detail Signal Pixel Format.
(Top Right) Magnified View of Pixel Format.
(Bottom) Method for Achieving Aspect Ratio Compatibility for 3x4 and 3x5 Video Signals [See Text for Explanation]

the proposed HDTV transmission scheme under development. A closed-circuit version of this scheme has been demonstrated at recent meetings of the National Association of Broadcasters in the USA. Equipment for doing actual transmission experiments has been constructed and is undergoing preliminary tests.

Aspect Ratio Compatibility

Figure 2 illustrates a method for integrating the 3:5 HDTV and 3:4 NTSC, or other formats. Relative to a 3:4 image, the wider aspect ratio of an HDTV display can be achieved by producing an image that is 10% greater in horizontal extent and 10% less in vertical extent. To provide the greater width, we propose to allow the HDTV signal to invade the horizontal blanking interval by 4 μsec. The video starts immediately after the burst pulse and ends immediately before the synch pulse. Thus, an HDTV receiver will display active video for 56 μsec, 4 μsec more than will be displayed by a standard 3:4 receiver. No modifications will be required for a standard receiver which will automatically crop this additional 10% width transmitted during the period of horizontal blanking.

To achieve proportionately less extent in the vertical dimension, the HDTV image will use only 440 of the 483 NTSC active lines, prior to scan-conversion to the 1125-line HDTV format. Thus, the HDTV receiver will crop 10% of the height of the NTSC signal and will use 10% more of its width to yield a 3:5 aspect ratio. The detail signal will be transmitted in a 3:5 format, as it is received only by HDTV receivers. We have successfully simulated this method by computer.

Although NYIT has proposed a two-channel HDTV system, it is important to note that the greater width of the HDTV image is <u>not</u> achieved by splicing "wings" carried by an augmentation channel, onto the 525-line image. Such an approach can be expected to yield visible discontinuities in position, intensity, multipath echoes or signal-to-noise ratio in the regions where the wings are spliced onto the display of the standard channel. These artifacts may be difficult to overcome as the visual system can detect lateral displacements between abutted lines down to about 5 sec. of arc ("vernier acuity"). The design of the NYIT-HDTV system (see above) spreads the additional detail information uniformly throughout the display. Without "wings," there can be no visible discontinuities.

Since the field-of-view differences between the two formats are divided between height and width, the program production needs only a 10% "protection" area on all edges. This eliminates the need for "pan and scan" required for many systems. Ten percent protection on all edges is normal in production practice.

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Upward Compatibility

Although HDTV has yet to be available to the viewing public, over the last few years, equipment manufacturers have shown HDTV cameras, VTR's, and production equipment at industry-wide trade shows. As of mid-1987, five HDTV studios have begun production using this new technology.[1]

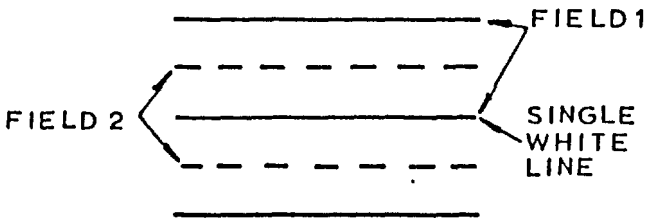
The NYIT-HDTV system has been designed to achieve upward compatibility with existing HDTV equipment. At recent demonstrations[2,3] the signal that conveyed detail information originated from a two-channel HDTV camera, designed and built by our laboratory. The output of this camera had both a standard 525-line image and an 1125-line HDTV image. However, the detail signal input into the digital spatial filter may originate from conventional HDTV cameras or VTR's. By substituting electrical frame stores for the storage in the detail camera tube, scan-converters can be built to transform the HDTV signal originating from an 1125-line, 2:1 interlaced camera, into a signal that can be processed by the NYIT system. This will permit the compatible NYIT-HDTV transmission system to function as a link between existing 525-line systems and currently available HDTV production equipment.

Progressive Scan in the Camera and Display

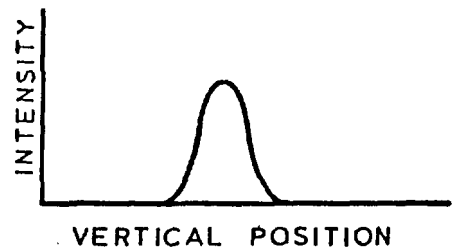
Currently available HDTV cameras and displays use interlace 2:1 scanning in order to conserve bandwidth. This procedure results in a loss of vertical resolution of about 30% (.7 Kell factor). In comparison, progressive scanning yields better vertical resolution, with losses less than 10% (.9 Kell factor). In the past, the benefit of progressive scanning has been unrealized, as it either requires excessive bandwidth or produces objectionable motion artifacts. These artifacts can be avoided by using different signal processing for high and low spatial-frequency information, as is done by the NYIT-HDTV system.

Before describing this scheme in detail, we shall consider the progressive/interlaced scanning issue from the perspective of what the visual system perceives.

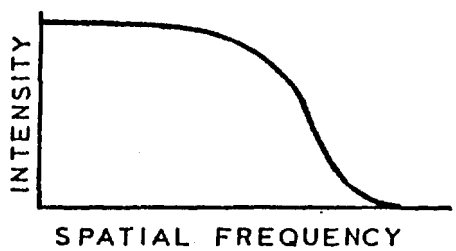
For images scanned (and/or displayed) in an interlaced format, in one field half the total number of lines are displayed for 1/60th sec. For a simple case, let us assume that pixels across one horizontal line are illuminated in only one field (Figure 3A), which yields an intensity profile as shown in Figure 3B. A Fourier analysis of the luminance waveform in Figure 3B is depicted by Figure 3C. This diagram reveals that a single line is acutually comprised of a wide range of spatial frequencies, including both low and high frequencies. Visually, this single line will appear to flicker if it is displayed in an interlaced format (at 30 times/sec). This is a simple case of what is



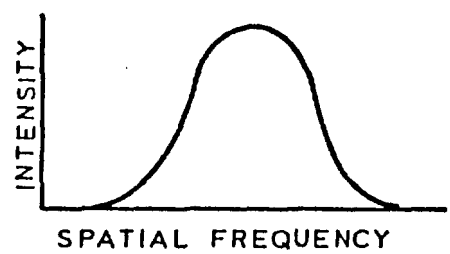
3a



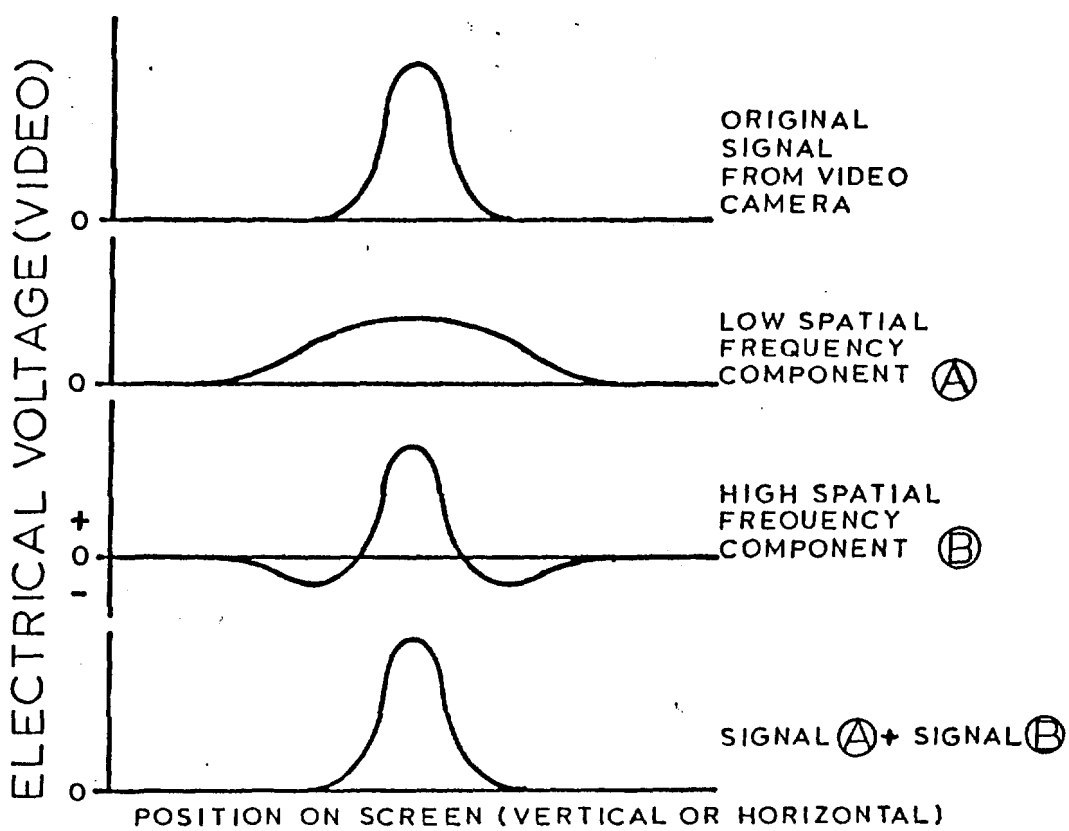
3b



3c



3d



3e

FIG.3 SINGLE LINE IMAGE DISPLAYED PROGRESSIVELY

termed "inter-line" flicker. This apparent flickering is a result of the slow temporal rate, of the low spatial frequencies present in the image. Generally, the slow temporal rate is considered as the sole cause of this artifact. However, it has been shown that the visual system is insensitive to counterphase flicker of high spatial-frequency information, but maximally sensistive to low spatial-frequency flicker.[4] Thus, the on-off transients produced by illuminating a single line in an interlaced scan, provide the ideal stimulus for the "transient" visual channel. Indeed, were the flickering patterns comprised purely of high spatial frequencies, the temporal variations (1/30 sec) would not yield perceptible flicker.

This analysis suggests a solution to the problem of interline flicker. Digital signal processing allows the construction of a band-pass spatial filter (Figure 3D), that effectively separates the high from low spatial frequency information. Once separated, the highs and lows can be treated differently in the temporal domain, in order to best match the characteristics of the visual system.

Figure 3E shows a diagram of the video signals. Note that the high spatial frequency information is bipolar (goes both positive and negative electrically). These bipolar signals must be added to the low spatial-frequency information before the information can be displayed (since a display cannot produce negative light). Therefore, in order to take advantage of this processing, to eliminate interline flicker, all lines in the display must be scanned progressively every 1/60 second.

In the NYIT-HDTV system, (Figure 4) the 1125-line detail signal, derived from the progressively scanned HDTV camera, is read into a frame store. The information from the current field of the 525-line image is scan-converted to 1125-line progressive format by line interpolation. This signal is simply added to the detail signal that is read out of the detail frame store in 1125-line progressive format at 60 frames per second.

In summary, the NYIT-HDTV system has been designed to have the "best of both worlds" - high rate of temporal processing for low resolution information and high spatial resolution (with reduced bandwidth) based on a slower, but progressively scanned signal for detail information.

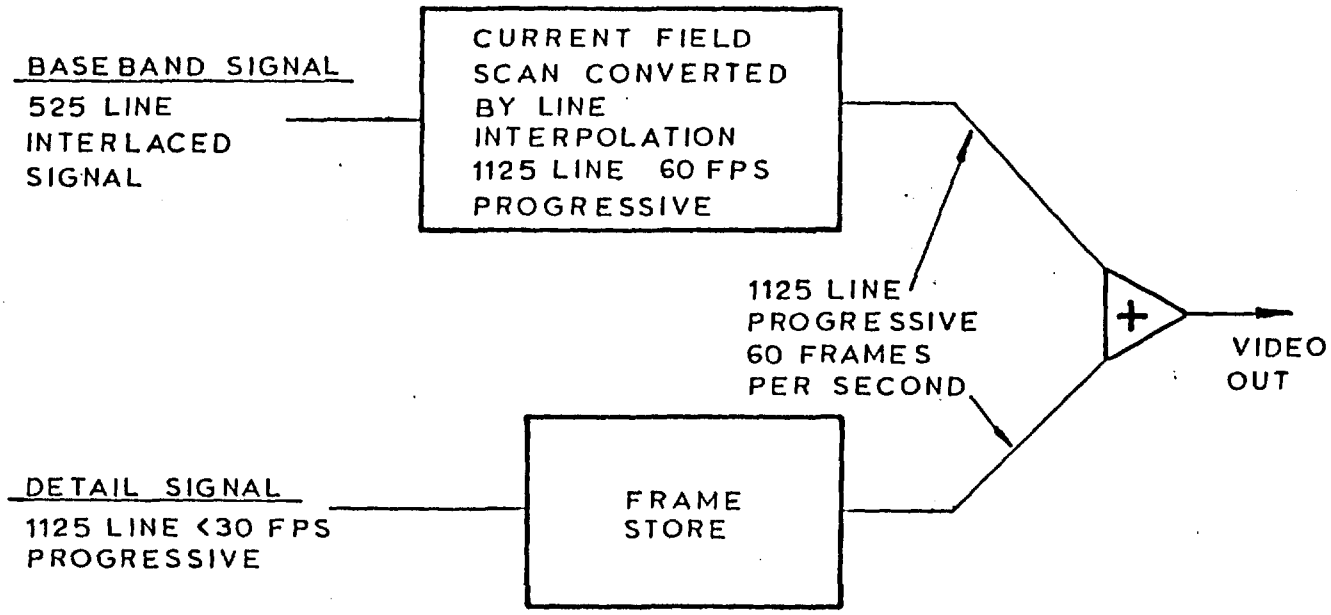


FIG. 4 SIGNAL PROCESSING IN HDTV RECEIVER

Apparent Sharpness of Moving Images

Studies of visual masking and the spatial-temporal properties of the visual system[4,5] indicate that slow updating of color and detail luminance information will not produce motion artifacts if the viewer fixates on a stationary point in the image.

For stationary and very low velocities there is no loss of resolution caused by camera integration. However, when image motion is sustained, and of an angular velocity less than about 2 deg/sec it is slow enough to be visually tracked by the viewer. In this case, the image in effect, stationary on the retina. Under these conditions, how perceptible is the loss of dynamic resolution caused by the longer integration time of the detail information? Early work by Baldwin,[6] later confirmed by our psychophysical studies, provides a model for understanding the perceived sharpness of an image moving slowly enough to be stationary on the retina.

Baldwin discovered that if pixels were elongated in an image (up to an aspect ratio of 3 to 1) the sharpness appears to be the same as an image with round pixels of the same pixel area. In the NYIT-HDTV transmission system, the detail information has elongated pixels in the direction of motion, due to "image blur" when an object moves. Because the spatial filters do not pass

frequencies lower than half the limiting resolution of the system, this elongation is limited to about two pixels. There is no loss in resolution perpendicular to the direction of motion. Thus, a moving object will appear to have detail with a pixel area that is seldom larger than 2 x 1 pixels. This is the same sharpness as an image with 1.41 x 1.41 pixel dimensions. In other words, in the moving image, resolution is typically .7 times the limiting resolution of a static image. This has been confirmed experimentally by psychophysical measurements described in an earlier paper.[7]

We have also made informal comparisons of apparent sharpness of slowly moving parts of an HDTV image, produced by the NYIT-HDTV system, both with and without augmentation by the detail signal. Improvement in image sharpness is clearly observed for moving portions of the picture, when the detail augmentation is added.

Temporal Enhancement

Psychophysical studies of perceived image sharpness during motion indicate that one of the most critical physical parameters for perceived sharpness is good contrast in the low spatial-resolution parts of the picture. At these slow speeds (< 2 deg/sec.), we have found that observers perceive a half-resolution, high-contrast image as sharper than a full-resolution one, with contrast degraded at low spatial frequencies. The method for boosting contrast of the slowly moving low spatial-resolution parts of an image involves a type of temporal enhancement. This process is an analogue in the temporal domain to the process of digital edge enhancement in the spatial domain. Stored field and frame information, adjacent in time to the current field, is multiplied by appropriate coefficients (usually negative) and added to the current field of information. In this way one can construct a temporal filter to compensate for the loss in low spatial frequency contrast in moving parts of the image caused by camera tube integration and lag. With temporal enhancement, the 525-line image will have better motion rendition than it normally does without this processing.

Summary

The NYIT-HDTV transmission system succeeds becauase it matches the requirements of the human visual system for the generation of realistic electronic images. The design and development of this conceptually new system has yielded several insights that may be used for improving both HDTV and conventional 525-line television.

The viewers of the compatible transmission with HDTV eceivers will have images with greater than 800-line resolution

both vertically and horizontally for static and slowly moving portions of the image. This clarity of the image can only be achieved in the 1125-line format by the use of progressive scanning in both the camera and display. At slightly higher velocities the sharpness will appear to be about 600-line resolution.

Viewers of this same transmission who have standard 525-line sets will enjoy better sharpness than usual, since the detail for the 525-line image can be derived from the HDTV camera. Moving objects will appear sharper because of the use of temporal enhancement on the signals from the 525-line image.

The NYIT system, because of its compatibility with both 525-line 3 x 4 transmissions, and 1125-line 3 x 5 program material and displays, will allow both the broadcaster and the viewer to gradually upgrade to HDTV without making the existing broadcast system obsolete.

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