THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 62, No. 7, September 1983
Printed in U.S.A.

A Compatible High-Definition Television System

By T. S. RZESZEWSKI*

(Manuscript received March 11, 1983)

A compatible HDTV system with the potential of having significantly better picture quality than the present NTSC color TV system is proposed. It realizes an increase in horizontal and vertical resolution and has considerably less crosstalk between the composite signal components compared to the NTSC signal. The increased resolution will allow a display as large as present home projection televisions with a sharper-looking and more detailed image than is possible with the present NTSC system. Also, the elimination of crosstalk adds to picture quality. A large screen size together with improved image quality should provide the user with a feeling of realism and involvement. This system also allows the use of more detailed graphics and more text per page for new services such as teletext.

I. INTRODUCTION

A compatible high-definition television (HDTV) system capable of producing an image quality significantly better than NTSC is proposed. Viewing the pictures produced by this system on a large screen should result in an increased sense of realism over the present NTSC television. This new system uses a split-luminance and split-chrominance (SLSC) type of transmission. The areas where the primary benefits are expected from this HDTV system over the National Television System Committee (NTSC) system are:

1. Increased horizontal resolution,
2. Increased vertical resolution, and
3. Less crosstalk between the components of the signal.

* Bell Laboratories.

Several different approaches to HDTV can offer excellent quality. However, there are quality-independent attributes that will aid the acceptance of this type of service. In particular, compatibility with present NTSC receivers and a bandwidth of no more than twice the present 6-MHz channel for broadcast are critical.

Many different forms of compatibility are discussed today. However, as used here, compatibility means receiver compatibility. The signal must be able to feed an HDTV and an NTSC TV simultaneously and be received on the NTSC receiver with substantially the same quality picture that those sets presently realize, while the HDTV receiver realizes all the benefits, such as increased resolution.

Spectrum usage is another problem with some HDTV approaches. The NHK (Japanese) system uses 30 MHz of baseband.[1] This bandwidth is so large that this type of service could not be broadcast in the same manner as the present broadcast service, and would leave this service with fewer delivery systems. Of course, video tape or cable are still possible delivery systems. Direct broadcast by satellite (DBS) is also possible; however, the prime allocations that are not affected by the weather are likely to be used for DBS of NTSC in the near future.

Some other proposed systems have preserved some aspect of compatibility.[2,3] They retain the scanning format, but change the encoding such that a present receiver will not operate correctly.

A format is proposed here that uses a 10-MHz baseband composite signal that can be transmitted as a vestigial sideband, amplitude-modulated signal in a bandwidth of 12 MHz. Also, an NTSC receiver will operate with the same quality as at present when receiving this signal. The NTSC receiver must be tuned to the lower 6-MHz portion of the 12-MHz spectrum. The price that is paid for this compatibility is a reduction in the number of broadcast or CATV channels to approximately one half the present NTSC allocations. However, VHF stations are normally spaced at least every second channel allocation apart in a given location for broadcast, and UHF channels are spaced even further apart. Therefore, the impact on the present broadcast service is likely to be small. Also, new systems with bandwidth requirements like the NHK system would produce at least a six-to-one reduction in the number of channels compared to an NTSC service.

II. A COMPATIBLE APPROACH

2.1 System description

This new system is built around the NTSC baseband spectrum shown in Fig. 1. The NTSC baseband signal is modulated for broadcast as a vestigial-sideband, amplitude-modulated signal as shown in Fig. 2. The composite HDTV baseband is illustrated in Fig. 3. Note that there is approximately 0.75 MHz of spectrum left over for other

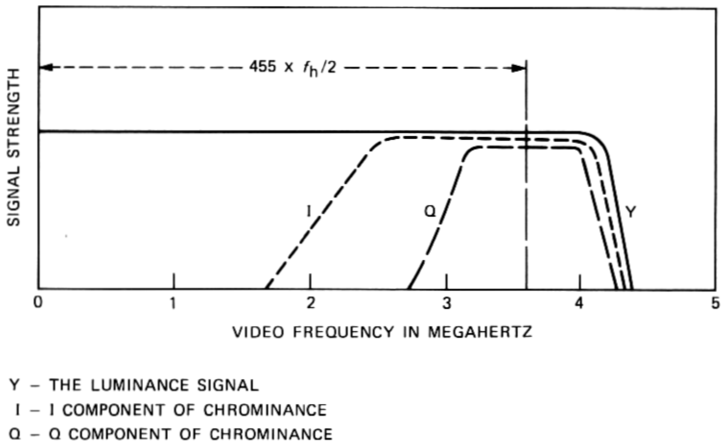

Fig. 1—NTSC luminance and chrominance bandwidth allocation.

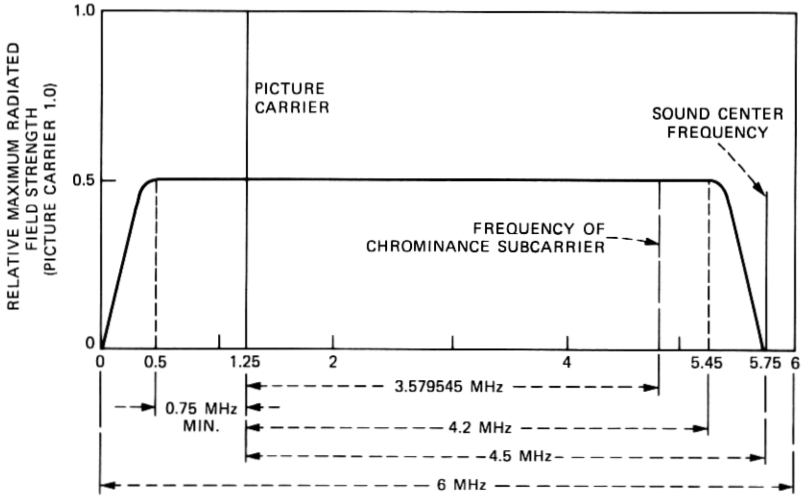

Fig. 2—Idealized picture transmission amplitude characteristic for NTSC.

services such as teletext and/or multichannel sound. The composite HDTV baseband signal could be modulated as a vestigial-sideband, amplitude-modulated signal for broadcast, as illustrated in Fig. 4. The selectivity of the NTSC receiver will reject the additional high-frequency portion of this signal at least as well if not better than an adjacent NTSC station.

The composite signal of Fig. 3 is obtained by starting with a 1050-line progressive scan source of wide-bandwidth red, green, blue (R, G, B) signals. The technique for improved vertical resolution is described

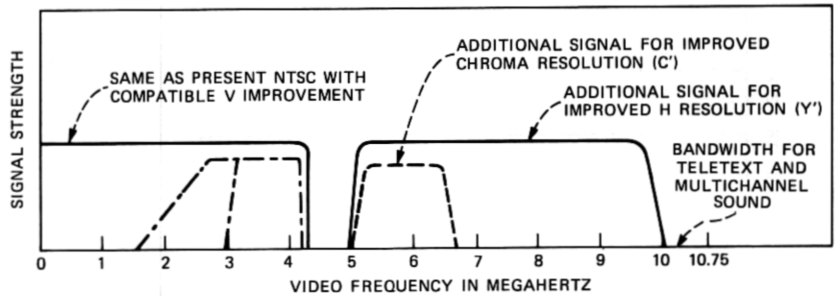

Fig. 3—SLSC HDTV baseband spectrum.

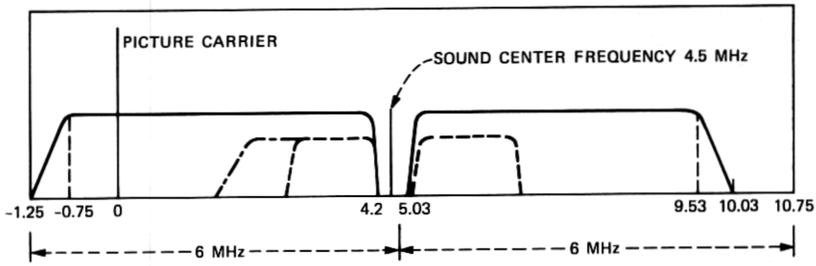

Fig. 4—Idealized broadcast picture transmission amplitude characteristic for SLSC HDTV.

in the literature.[4] That technique will be described in greater depth later. For now, it is sufficient to say that the wideband R, G, B signals are filtered and converted to a 525-line signal by a scan conversion that deletes every second line to obtain a 525-line signal suitable for transmission. Next, the wideband R, G, B signals are matrixed into a Y, I, Q format. This process is illustrated in Fig. 5. The NTSC encoder provides the appropriate selectivity and processing to create a standard NTSC signal that occupies the lower 4.2 MHz of the baseband spectrum in Fig. 3. The additional signal for improved horizontal resolution (Y′) that occupies the frequency region of approximately 5 to 10 MHz in the baseband is processed by the High Frequency Luminance Encoder. The High Frequency Chrominance Encoder creates the signal C′.* These signals are added to the signal obtained from the NTSC encoder to produce the composite HDTV baseband signal of Fig. 3. A detailed block diagram that elaborates on the encoding of these extra signals will be given later.

* A method of recreating the high-frequency components of the composite NTSC signal that were filtered out at the transmitter has recently been developed.[5] If this technique is proven to be acceptable for this application, the additional signal for extra chrominance resolution (C′) is not needed.

The system description in this paper utilizes the anti-aliasing filtering of the R, G, B signals in the encoder, as shown in Fig. 5. Consequently, the interpolation filtering in the decoder will also be performed on R, G, B as described later. An alternative approach that may have some advantages is to transform the R, G, B signals into a Y, I, Q format before performing the anti-aliasing filtering. In that case the I and Q signals will be filtered to a smaller bandwidth before the anti-aliasing filter. This approach simplifies two of the anti-aliasing and interpolation-filter designs and requires less frame-store memory. It will be considered further in the section on system alternatives.

Figure 6 contains the general block diagram of the decoder. Not shown are the tuner, IF, and video detector that are required to select and demodulate the HDTV signal to a baseband signal if the composite signal is modulated for broadcast; these functions will be described later. In the decoder, the three portions of the HDTV signal (the low-frequency signals obtained from the NTSC composite signal, the

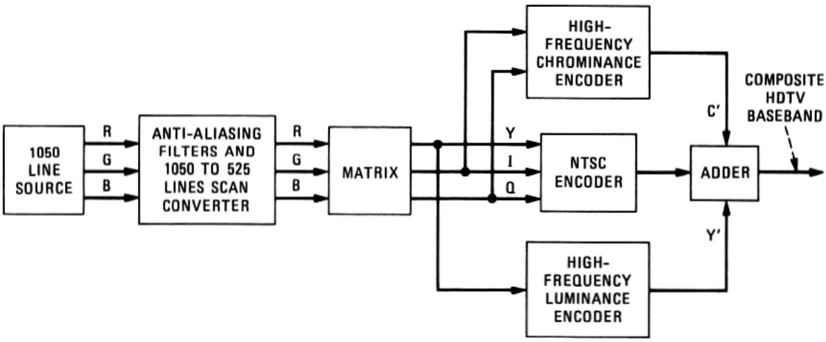

Fig. 5—SLSC HDTV encoder.

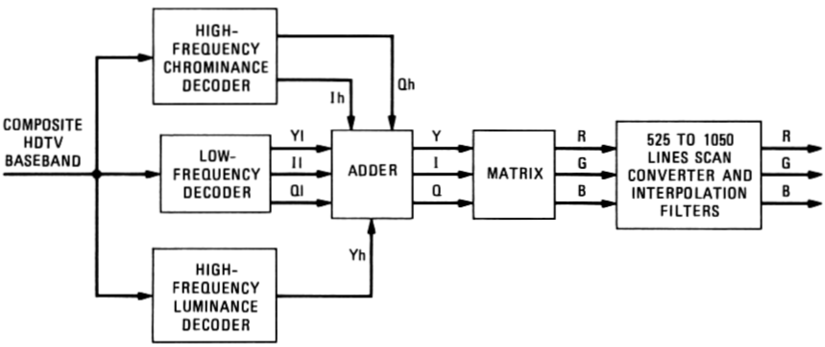

Fig. 6—SLSC HDTV decoder.

additional high-frequency chrominance signal, and the additional high-frequency luminance signal) are selected and processed in parallel. A detailed block diagram of these portions will be given later. The additional chrominance signals (Ih and Qh) are added to the chrominance produced by the low-frequency decoder to get I and Q signals that have a 2-MHz bandwidth each. These signals are then matrixed to produce 2-MHz color-difference signals. They are then added to the full 7.5-MHz-bandwidth luminance signal to produce R, G, B signals. The wideband luminance, Y, results from the addition of Yl and Yh.

However, before being fed to the display, the signals must be processed to realize the increased vertical resolution. The process consists of a scan conversion back to 1050 lines from the interlaced 525-line transmission format. The monitor may be either a 1050-line progressive scan or interlaced scan at the discretion of the manufacturer. However, progressive scan is needed to realize the full potential of this system. Interpolation filtering is performed in the scan-conversion process, and the high-definition R, G, B signals are fed to the display device.

2.2 Vertical resolution

An analysis of the resolution capability of the NTSC signal is helpful to assess the improvements that HDTV will realize. Resolution is expressed in terms of vertical and horizontal equivalent TV lines. The vertical resolution tells the number of horizontal lines alternating between black and white that can be resolved in the TV image. It is tempting to equate this to the total number of scan lines minus the lines in the vertical interval that are not used for display. Unfortunately, the scanning process that changes the image into an electrical signal in the camera and then reassembles the image on the display is really a sampling process. It is well known that sampled signals must first be bandlimited or aliasing will occur. It is the aliasing and the replicated spectra that further reduce the vertical resolution. Equation 1 below expresses the actual vertical resolution in a TV picture by the addition of a Kell factor (k) that takes this extra loss into account.

$$Rv = (Nt - 2Nv)k. \tag{1}$$

Rv is the vertical resolution; Nt is the total number of scan lines (525 for NTSC); Nv is the number of lines in the vertical interval (21 for NTSC); and k is the Kell factor. The Kell factor normally ranges between 0.6 and 0.7 for TV systems and results in an Rv range between 290 and 338 lines for NTSC TV. The method of vertical resolution improvement employed for the SLSC HDTV system allows the vertical resolution to approach the full 483 lines of the active video; the Kell factor approaches unity.[4]

The modulation transfer function (MTF) in the camera and the display are analogous to the frequency response in linear system theory. It can be adjusted by shaping the electron beam in the camera and a CRT display. The contour of the scanning spot can be thought of as a two-dimensional impulse response commonly called the point-spread function. A narrow scanning spot in the vertical direction means a wide vertical spatial frequency spectrum and aliasing, and a wide scanning spot means overlapping of adjacent lines and low-pass filtering in the vertical direction (defocusing). In NTSC, the scanning spot is adjusted to compromise between aliasing and defocusing. Anti-aliasing (prefiltering) on a 1050-line progressive-scan source signal and interpolation (postfiltering) that eliminates replicated spectra aid the compromise. These filters can be used together with more lines at the camera in a compatible fashion to increase the vertical resolution.[4]

2.3 Horizontal resolution

The horizontal resolution is also expressed in terms of lines (equivalent vertical lines) that are the same width as the horizontal lines used to determine the vertical resolution above. There are two lines per cycle of video bandwidth. In other words, in the time—and therefore the horizontal space—it takes to display a cycle of the highest-frequency signal that will pass through the system bandwidth, the system will produce two lines on the display, one white and one black. The width of the lines is the same as for the vertical resolution, and the 4-to-3 aspect ratio is taken into account. Equation 2 below can be used to determine the horizontal resolution of a television system per unit of video bandwidth (Rh').

$$Rh' = 2Ta/AR. \qquad (2)$$

Ta is the total active time for a horizontal line, and AR is the aspect ratio (these are 53.5 microseconds and 4/3 respectively for the NTSC system). This results in approximately 80 lines/MHz. Most NTSC receivers have at least 3 MHz of bandwidth, yielding a minimum of 240 lines of horizontal resolution. However, the total system luminance bandwidth can be 4.2 MHz if a comb filter is used in the NTSC receiver. This results in 336 lines.

The horizontal resolution is increased for the HDTV system proposed here by adding extra bandwidth to the baseband luminance signal. Figure 7a shows the 7.5-MHz bandwidth that is allocated to luminance in this compatible system. The same scanning format for transmission as NTSC is used; therefore, eq. (2) above indicates that the system will produce 80 lines/MHz. The 7.5-MHz bandwidth will

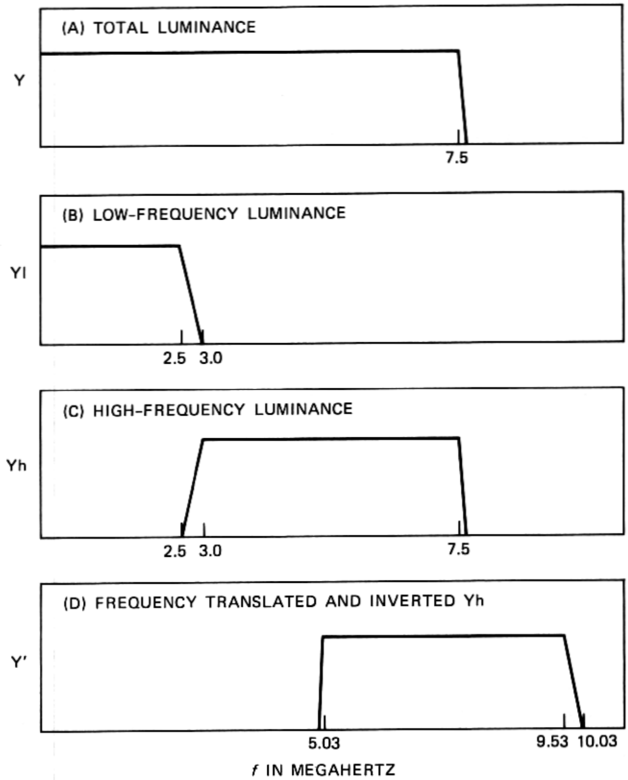

Fig. 7—Luminance (Y) processing in SLSC HDTV.

result in 600 lines of horizontal resolution.* This 7.5-MHz-bandwidth luminance spectrum feeds (1) an NTSC encoder that only uses the lower 4.2 MHz, and (2) a circuit that processes the high-frequency luminance detail (2.5 to 7.5 MHz) in a separate parallel channel.

Figures 7b through 7d illustrate the high-frequency luminance processing. Luminance (Y) is split up into a low-frequency portion (Yl) and high-frequency portion (Yh), each with a controlled roll off between 2.5 and 3 MHz (see Fig. 7c). If these two signals are added together, they will result in the original spectrum (Y) with a 7.5-MHz bandwidth. The high-frequency luminance will be processed so that it can be multiplexed with the NTSC baseband signal into a new, compatible HDTV baseband signal. This is accomplished by reversing

* This will result in 24 percent more horizontal resolution than vertical resolution for this system. There is the possibility of limiting the horizontal resolution to equal the vertical and simplifying the system. The amount of benefit produced by allowing greater horizontal resolution than vertical can be investigated when the system is implemented.

the frequency sense of Yh and translating it up in frequency to the location illustrated in Fig. 7d as Y′.

Note that the spectrum for Yh is cut off at a frequency below 2.5 MHz. Only the lower portion of the NTSC signal, which is substantially free from chrominance, is used for low-frequency luminance information (Yl).* Use of this lower cutoff frequency reduces the cross luminance problems that trouble the present NTSC system. An optimum cutoff frequency should be determined based on experiment since the higher the cutoff frequency the greater the horizontal resolution. The value indicated in Fig. 7 is a likely choice.

Figure 3 shows the complete baseband selectivity that defines the HDTV spectrum. Notice the additional signal for improved chrominance resolution (C′). Additional luminance resolution requires extra associated chrominance resolution and therefore additional chrominance bandwidth to appreciate the full improvement. The additional chrominance signal, C′, is time multiplexed between the Ih signal and the Qh signal components on alternating scan lines. However, unlike SECAM, the C′ signals are modulated as a single-sideband signal. The frequency of the carrier is selected to be a multiple of the horizontal frequency to minimize the crosstalk between this additional signal and the high-frequency luminance information, Y′. The purpose is to interleave the luminance (Y′) and chrominance (C′). The next section includes an explanation of the interleaving.

2.4 Detailed block diagrams

Figure 8 is a detailed block diagram of the encoder shown in Fig. 5. The method for increasing the vertical resolution mentioned previously is used,[4] so that a 1050-line progressive-scan source (camera) feeds an anti-aliasing filter. The R, G, B signals are all processed in the same fashion, each one is passed through a scan converter that converts from 1050 lines in a progressive-scan format to 525 lines in an interlaced format for compatible transmission. These signals are then matrixed into a Y, I, Q format.

The additional high-frequency signal for improved chrominance is time multiplexed to carry the Ih and Qh signals on alternate horizontal lines. However, it is not frequency modulated as in SECAM; rather, it is single-sideband amplitude modulated. This gives a spectrum that tends to cluster at multiples of the horizontal frequency and odd

---

* Yl will be completely free from any cross-luminance produced by the Q component of the color signal. If the I component is allowed the present specification of 1.5-MHz bandwidth, it can cause some cross-luminance. However, there is some question of whether that bandwidth should be transmitted since there are no consumer receivers that make use of this extra bandwidth; consequently, the extra bandwidth of the I signal can only cause cross-luminance problems in present NTSC receivers.

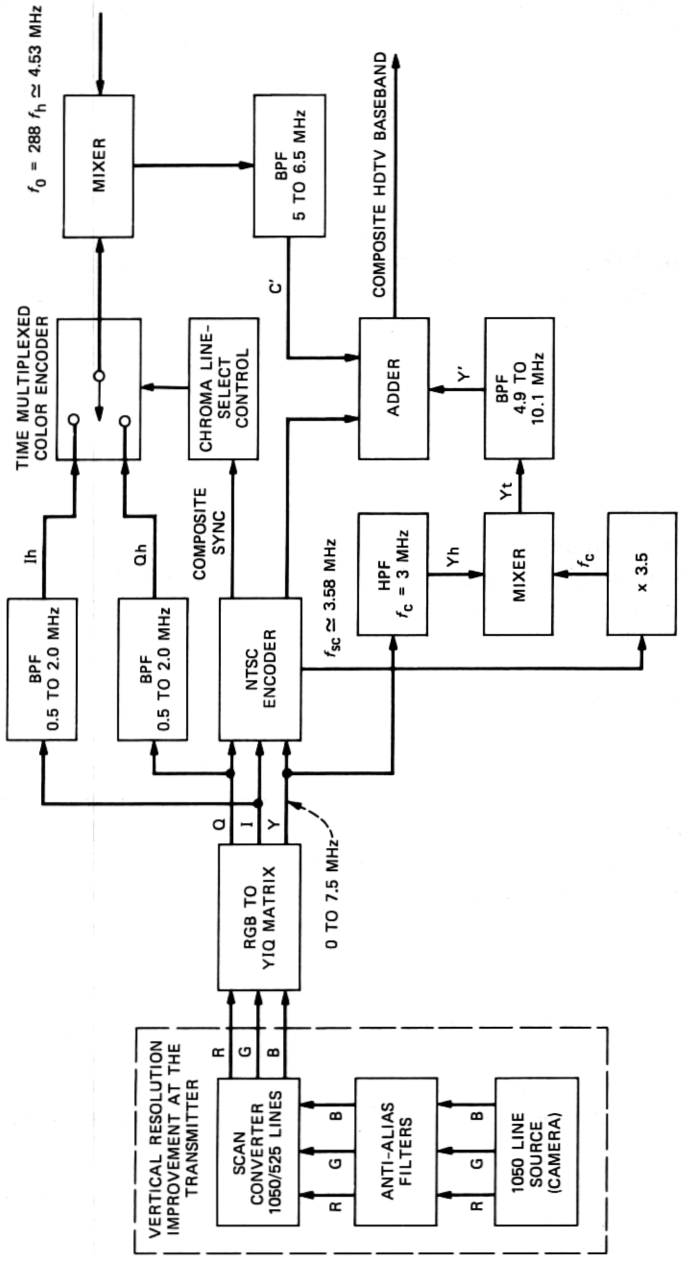

Fig. 8—Detailed block diagram of SLSC HDTV encoder.

multiples of half the horizontal frequency. The outputs of the two bandpass filters that select the Ih and Qh signals and the composite synchronization signal from the NTSC encoder feed the time-multiplexed color encoder (switch) that provides the additional signal for improved chrominance resolution, C′. The switch connects the Ih signal and then the Qh signal to the mixer on alternate scan lines. A carrier frequency, f_0, is the second input.*

$$f_0 = 288\, f_h \sim 4.53 \text{ MHz.} \tag{3}$$

A tone burst of frequency f_0 could be inserted into the vertical interval for phase reference at the receiver. The bandpass filter at the output of the modulator selects only the sum signal, C′, that is in the frequency range of 5 to 6.5 MHz.

The NTSC encoder functions as it would normally. It provides the composite synchronization signal to the line-select control for the high-frequency chrominance processing described above, and the color subcarrier for the high-frequency luminance processing.

The translated and frequency-inverted high-frequency luminance signal is formed by first high-pass filtering the 7.5-MHz luminance to produce Yh. When Yh is applied to the mixer illustrated in Fig. 8, a double-sideband suppressed carrier signal is created. The carrier input to the modulator is f_c.

$$f_c = 3.5\, f_{sc} = 3185(f_h/4) \sim 12.53 \text{ MHz.} \tag{4}$$

The NTSC color subcarrier, f_{sc}, is available from the NTSC encoder and can be used to derive f_c as indicated by eq. (4). However, a tone burst of f_c would be inserted into the vertical interval for phase reference at the receiver. The bandpass filter on the output only allows the frequency-inverted lower sideband, Y′, to pass. Y′ has a quarter-line frequency offset as can be seen from eq. (4). Consequently, f_0 is made equal to an exact multiple of f_h in eq. (3) so that the time-multiplexed signal C′ will interleave with Y′. This signal, Y′, is added to the output of the NTSC encoder and to the output of the high-frequency chrominance encoder, C′, to produce the composite HDTV signal of Fig. 3. Audio information is added just prior to transmission; this is the conventional manner of adding audio information to the NTSC broadcast signal. Additional subcarriers could be added to the baseband of the composite HDTV signal for multichannel sound or teletext as indicated in Fig. 3.

A detailed block diagram of the decoder is shown in Fig. 9. The decoder input comes from the video detector(s); more will be said

* This is just one of several strategies for selecting f_0. f_0 could be made 300 $F_h \sim 4.72$ MHz; then a low-level tone of this frequency can be inserted in the SLSC baseband.

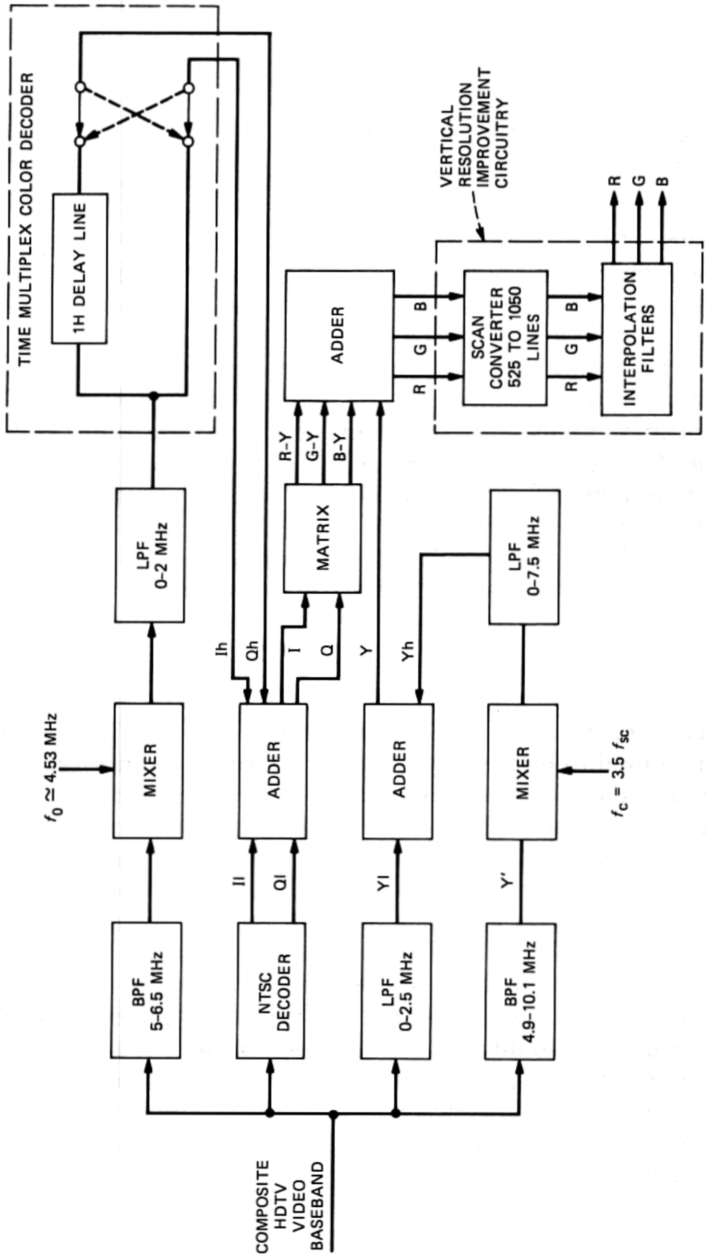

Fig. 9—Detailed block diagram of SLSC HDTV decoder.

about the receiver circuitry between the antenna and the decoder in Section 3.1. Since the composite HDTV signal was made up of three separate parts, each of these parts must be decoded. The high-frequency chrominance is decoded by first selecting it from the composite signal via the 5- to 6.5-MHz bandpass filter. This signal feeds a single-sideband demodulator that consists of a mixer and a bandpass filter that extracts the 0.5- to 2-MHz high-frequency color signal. However, this signal is still time multiplexed at the single-sideband demodulator output, so this output is fed into a time-multiplexed decoder to obtain simultaneous I and Q signals. The time-multiplexed decoder consists of a delay line that provides the storage of one horizontal line of color information, and the appropriate switches indicated in Fig. 9. The time-multiplexed decoder functions such that the present Ih (Qh) signal and the previous line Qh (Ih) signal are both present on the outputs providing the simultaneous Ih and Qh signals as outputs.

The NTSC decoder provides its normal I and Q color signals, called Il and Ql to emphasize that they convey the low-frequency portion (0 to 0.5 MHz) of the HDTV color signal. (Virtually all NTSC decoders produce I and Q signals of 0.5 MHz bandwidth in spite of the fact that the I channel should have extra bandwidth.) Il and Ql are added to Ih and Qh to form the complete 2-MHz I and Q signals. The high-frequency luminance, Y′, is passed by the 4.9- to 10.1-MHz bandpass filter and fed to the mixer. The carrier input is 3.5 f_{sc}, derived from the color subcarrier provided by the NTSC decoder with phase coherence obtained from a tone of f_c in the vertical interval. The demodulator output is filtered by a low-pass filter with a 7.5-MHz cutoff. The resultant signal, Yh′, which occupies a 2.5- to 7.5-MHz spectrum, is added to the 0- to 2.5-MHz low-frequency luminance signal obtained by passing the composite HDTV spectrum through a low-pass filter with a 2.5-MHz cutoff. The adder outputs the luminance signal, Y. Y, I, and Q are matrixed to provide color-difference signals and then added to Y to output R, G, B signals to the circuit that provides the vertical-resolution improvement. This circuit consists of a scan converter that inserts extra lines, converting the interlaced 525-line transmission standard to a progressive or interlaced 1050-line format along with interpolation filtering for each of the R, G, B signals. The resulting R, G, B signals feed circuitry that drives the picture display.

2.5 System alternatives

This system is flexible in that several variations are possible depending upon the needs and possibilities that surface during testing. The vertical resolution is limited to a maximum of 483 lines because the technique for vertical improvement can only promise a maximum resolution equal to the maximum number of active scan lines in the transmission standard. The actual resolution could be slightly less than this because the anti-aliasing filter and the interpolation filter may reduce the vertical frequency response somewhat. The maximum horizontal resolution that corresponds to 7.5 MHz of bandwidth is 600 lines. This resolution can be achieved by using a comb filter at the receiver (covering the 5- to 6.5-MHz portion of the baseband signal shown in Fig. 3), or by not transmitting C′ and using the inferred highs processing to restore wideband chrominance signals at the receiver.[5] Both approaches result in less vertical resolution (483 lines) than horizontal resolution (600 lines).

Alternatively, a horizontal resolution equal to the vertical resolution could be chosen, thus simplifying the system. If 480 lines of horizontal resolution were chosen, only 6 MHz of luminance bandwidth is required. The high-frequency luminance of Fig. 3 need not overlap the high-frequency chrominance. Therefore, a comb filter is not needed to realize the 480 lines of horizontal resolution while using a C′ signal. An additional simplification is possible; the carrier, f_c, used to translate the high-frequency luminance spectrum in Fig. 8 can be three times the color subcarrier, 3 f_{sc}, rather than three and one half times that frequency.

Less extensive changes are possible in the interest of optimizing the system. For example, the 2.5-MHz cutoff of the low-pass filter that forms Y1 (illustrated in Figs. 6 and 9) could be reduced to 2 or even 1.5 MHz in order to completely eliminate any possible crosstalk between low-frequency chrominance and luminance. Alternatively, the cutoff could be increased to 3 MHz if it is shown that the extra resolution is a more important benefit than the penalty of a small amount of extra crosstalk. The 2.5-MHz cutoff and many other parameters given are reasonable choices that may change somewhat once the system is tested. Another possibility is to bandlimit the I channel in the NTSC encoder to 0.5 MHz since virtually no NTSC decoders use more than 0.5 MHz at this time and the extra I channel bandwidth can only cause crosstalk in NTSC consumer receivers. With equal-bandwidth (0.5 MHz) I and Q channels in the NTSC encoder, the 2.5-MHz cutoff illustrated in Fig. 7 will result in no cross luminance from Ih and Qh.

A change in the encoder and decoder (illustrated in Figs. 5, 6, 8, and 9) is possible to simplify the system by taking the output of the 1050-line source in Figs. 5 and 8 and transforming to a Y, I, Q signal format immediately. Then the I and Q signals could be bandlimited to 4 MHz (twice the 2-MHz transmission bandwidth) rather than 15 MHz for R, G, B signals (twice the 7.5-MHz Y bandwidth) for a source with a 30-Hz frame rate. Anti-aliasing and interpolation filter implementation in these channels is simplified because of the lower-frequency operation. Framestore memory is also minimized because of the smaller bandwidth of I and Q.

III. DELIVERY SYSTEMS

3.1 AM broadcast

The front end of the HDTV set consists of a tuner, IF amplifier, and video detector. These functions can be handled in three basic ways, as illustrated in Fig. 10. Figures 10a and b represent the case where the two 6-MHz channels are adjacent to each other, as illustrated in Fig. 4.

Figure 10a illustrates a single wideband tuner and IF amplifier that is wide enough to pass the entire HDTV spectrum. The IF amplifier may be centered around the same IF frequency presently used, or a different center frequency may be chosen. Figure 10b uses a wideband tuner, but splits the spectrum up into two parts: an NTSC IF to receive that portion of the spectrum that is the same as the NTSC signal, paralleled by a second IF specially designed to receive the extra portion of the HDTV signal. After video detection in each channel, the two baseband spectra are added together to produce the baseband spectrum of Fig. 3.

A more versatile but complicated approach is illustrated in Fig. 10c; shown are two separate tuners for each portion of the spectrum, the NTSC portion and the extra portion. After processing by the respective IF amplifiers and detectors in each channel, the two portions of the baseband spectrum are added back together to obtain the spectrum of Fig. 3. If the arrangement of Fig. 10c is used, the extra 6-MHz spectrum for HDTV need not be located at the upper 6-MHz band shown in Fig. 4. It could be a totally separated channel of 6-MHz bandwidth. If the additional HDTV information is carried in the 6-MHz channel directly above the NTSC channel, 40.75 to 35.75 MHz is a likely IF frequency range for the additional IF. However, if the additional HDTV information is one or several channels away, another frequency may be chosen.

3.2 Cable

Modern CATV systems usually use a tree structure that has the capability of handling up to 50 or more NTSC TV channels per cable. Since present channel allocation is 6 MHz, any additional bandwidth requirement results in a minimum of two channels per HDTV signal. This two-to-one reduction in stations would be more acceptable to the CATV industry than HDTV systems requiring more than two 6-MHz channels per signal. It is almost certain that a higher-bandwidth system would cause the CATV industry large problems, since it would

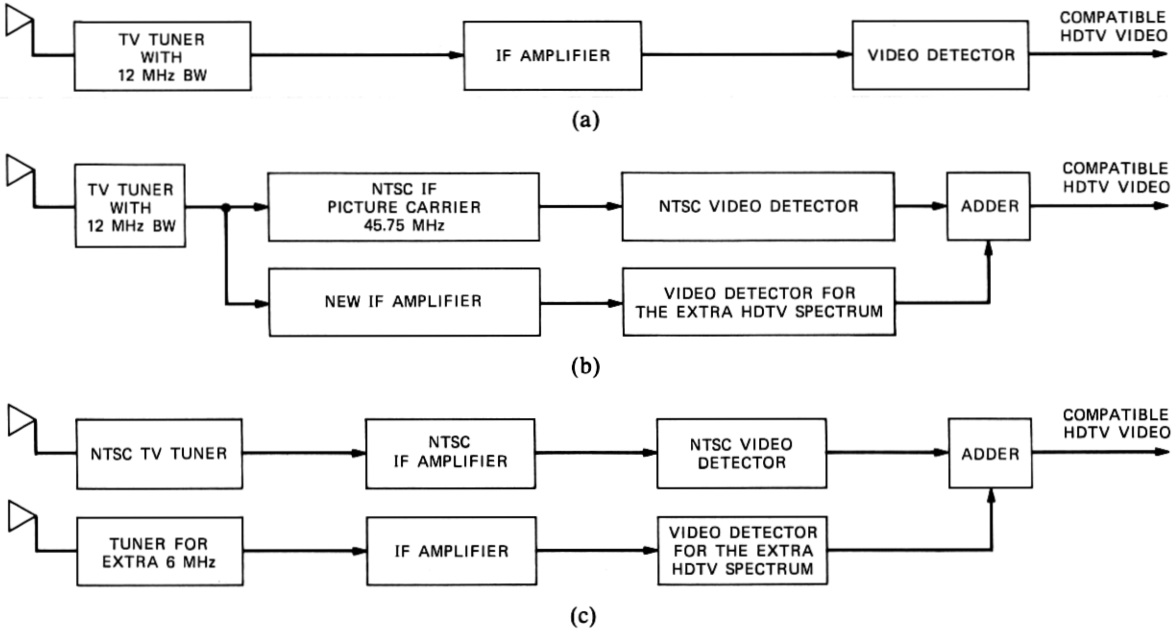

Fig. 10—Front-end alternatives for SLSC HDTV. (a) Single IF amplifier approach. (b) Single-tuner multiple IF amplifier approach. (c) Multiple-tuner approach.

severely limit the amount of programming that could be carried by a CATV system.

Switched video cable systems that have the ability to provide video on demand are just beginning to surface. It is very difficult to switch extremely wideband video; therefore, a reasonably compact HDTV spectrum is needed for this new type of cable system.

This compatible HDTV system has been carefully designed to occupy a 10-MHz baseband bandwidth. It will fully utilize two 6-MHz channels for transmission if desired. Therefore, it should have a minimum negative impact on present and future cable systems.

3.3 *Satellite*

Direct satellite broadcast to the home is a delivery system that is just about to become important. The modulation format and the frequency allocation of the service will eliminate compatibility with the present NTSC receivers. NTSC compatibility may lose some importance for this delivery system. However, bandwidth is always at a premium for satellite systems; thus the compact baseband as shown in Fig. 3 is very important. Also, the ability to modulate the HDTV signal into two NTSC channels could be advantageous.

3.4 *Prerecorded*

Even when the prerecorded media such as video tape and video disc are used as a delivery system, bandwidth is still important. It is much easier to record a 10-MHz baseband signal than a 30-MHz signal. Consequently, a tape recorder for the 10-MHz signal should be more economical. There may be a considerable problem with making a video disc unit that handles a 30-MHz baseband signal and still has sufficient playing time per disc.

IV. COMPARISONS

4.1 *Vertical resolution comparisons*

The vertical resolution, Rv, of a TV system is given by eq. (1). For the current NTSC system, the following is obtained:

$$Rv = (525 - 2\text{x}21)0.65 = 313 \text{ lines.} \tag{5}$$

This assumes a nominal Kell factor of 0.65. If the same Kell factor and 21-line vertical interval is applied to the NHK system, the result is 704 lines. For the Dortmund system using USA scanning standards and the proposed split-luminance, split-chrominance (SLSC) compatible system, the result should be the same as the NTSC with a Kell factor approaching unity.[4] Therefore, the vertical resolution should approach 483 lines. These comparisons together with modifications of the BBC and IBA systems for the USA scanning standards are shown in Table I.[2,3] (Note that there are actually two Dortmund systems described in the literature.[4] The system considered here is the diagonal sampling approach that provides both increased vertical and horizontal resolution over the present standard. The other system does not provide increased horizontal resolution.)

4.2 Horizontal resolution comparisons

Table I also contains a comparison of some HDTV systems with respect to horizontal resolution, crosstalk, and bandwidth requirements adapted to the NTSC environment where appropriate. The NTSC system is used as a reference. The horizontal resolution of the NTSC system ranges from 240 lines to 336 lines. The NHK system should be capable of approximately 30 lines/MHz based on eq. (2). This predicts a horizontal resolution, Rh, of approximately:

$$Rh = (30 \text{ lines/MHz})(20 \text{ MHz}) = 600 \text{ lines.} \tag{6}$$

The Dortmund system approach applied to the NTSC system should have the ability to reproduce the same horizontal resolution as vertical. Further, the vertical resolution should approximate the number of active scan lines. Therefore, it should result in 480 lines.[4]

4.3 Crosstalk

Crosstalk is a very important factor in the image quality of a video system. There are three types of component crosstalk in present television standards. They are cross luminance (crosstalk of chrominance into luminance), cross color (luminance crosstalking into chrominance), and chrominance to chrominance crosstalk. Cross luminance, also called dot crawl, normally shows up in the NTSC picture at the edges of color areas. The high-frequency subcarrier signal appears in the luminance channel as a dot pattern crawling up the edges of color areas. Cross color is most obvious when the scene contains a detailed pattern such as a striped shirt or tweed suit. It is

Table I—HDTV comparison chart

System	*V* Resolution (k = 0.65)	*H* Resolution	Min. No. NTSC Channels When Broadcast	Compatible	Crosstalk
NTSC	313	240–336	1	Yes	Bad–Small
NHK	704	600	—	No	Small
Dortmund*	483	480	1	—	—
BBC*	313†	336	2	Can Be	None
IBA*	313†	336	2	No	None
SLSC	483	600	2	Yes	Small–None

* The values are adapted to the USA scanning standard.
† This value can be made 483 by applying the vertical improvement technique.

seen as a color pattern over the area of detail that obviously does not belong, and destroys the ability to see the detail in that area. Chrominance-to-chrominance crosstalk is less obvious than the other two because it is correlated with the scene. It results in color distortions.

The first two types of crosstalk mentioned above can produce significant picture degradation in the NTSC system unless the luminance bandwidth is sacrificed or a comb filter is used. However, a comb filter tends to produce some luminance degradation of its own. It reduces vertical resolution by averaging two or more lines at a time and rejects diagonal lines in the picture. This situation can be improved for luminance by only comb filtering the high-frequency luminance where the actual crosstalk frequency components occur. Further, a comb filter will produce a dot crawl on horizontal edges of saturated colors in a picture that is not present without it.

As shown in Fig. 7, the low-frequency luminance (Yl) used by the SLSC HDTV system is the lower 2.5 MHz of the NTSC luminance. This portion of the NTSC luminance is not interleaved with any of the Q component of the NTSC color signal. There is some interleaving of the I component of the NTSC signal and the low-frequency luminance, Yl, of the HDTV signal. However, there is some question of whether the full frequency range of the I signal should be transmitted for NTSC receivers since there are no consumer receivers that make use of it, and it can only cause crosstalk in the present NTSC receivers.

Cross luminance in the high-frequency luminance (Yh) can also be minimized. The upper 1.5 MHz of the luminance—the 6-MHz to 7.5-MHz region of the original luminance signal—interleaves with the high-frequency chrominance. This upper end of the luminance ends up occupying the 5- to 6.5-MHz region of the frequency inverted and translated spectrum Y′ in Fig. 3. This region can be comb filtered—rolled off at 6 MHz (480 lines of resolution)—or simply allowed to pass with the small amount of cross luminance mentioned above.

The last alternative is possible with only a small amount of degradation because of the high-frequency nature of the cross luminance and the fact that the chrominance that is talking into the luminance will be down in level compared to the signal that is producing cross luminance in the NTSC system (it is only the 0.5- to 2-MHz region of the chrominance that will contribute to crosstalk here). Since this relatively low-level chrominance will also be producing a much smaller dot pattern in the luminance than the NTSC color subcarrier would cause in the NTSC system, the crosstalk should be much less obvious.

Cross color can be reduced in several ways. A comb filter could be used to remove that portion of the luminance that interferes with the low-frequency chrominance. Alternatively, use can be made of the fact that a portion of the luminance that represents 2.5 to 4.2 MHz of the

NTSC luminance is repeated in the high-frequency luminance portions of the composite HDTV signal. This portion of the high-frequency luminance is free of any interleaved chrominance. However, the corresponding portion of the NTSC part of the signal contains chrominance interleaved with the luminance. These two corresponding portions of luminance can be subtracted, leaving an uncontaminated chrominance signal. Also, the luminance above 3 MHz could be rolled off in the NTSC part of the baseband as another way to eliminate cross color without any degradation to the vast majority of NTSC receivers that do not use a comb filter. Cross color into C′ can be reduced with a comb filter.

4.4 Encoding errors

There are a number of color deficiencies in the NTSC color standard that degrade the quality of the reproduced image.[6–8] The crosstalk problems mentioned in the previous section are a part of these deficiencies. Encoding errors are another facet of these problems. The study of encoding errors or distortions in the NTSC system is an involved topic that will only be briefly mentioned here. The problems center around the fact that part of the luminance is carried by the chrominance when color is broadcasted, and it is aggravated by the nonlinear gamma characteristics of the system.[6] The transmitter corrects for a nominal gamma of 2.2 by raising the signal to the 1/2.2 power so that the overall response is linear. The result is that saturated (vivid) colors lose details. Also, there may be substantial errors in the transients between certain colors (usually complementary colors produce the worst transients). With wideband color signals, there will be fewer errors. The luminance is still carried partly by the chrominance, but the chrominance is now wideband and it degrades the end result less.

V. SUMMARY

A split-luminance, split-chrominance (SLSC) HDTV system has been described that is NTSC compatible and uses a 10-MHz baseband signal. This baseband signal can be modulated to produce an amplitude-modulated, vestigial-sideband signal in a 12-MHz bandwidth for broadcast. Alternatively, this compatible signal can also occupy two separate 6-MHz channels. Compatibility and bandwidth conservation are two of the most important attributes of this HDTV system. A compatible system is likely to penetrate the market place much more rapidly than a non-compatible system because of the huge investment in NTSC equipment. The two most common delivery systems are broadcast and CATV; both are very sensitive to the bandwidth requirements of a new system.

The present NTSC channels are 6 MHz. Conventional channel allocation forces additional bandwidth to come in increments of 6 MHz. A two-channel, 12-MHz requirement is the largest bandwidth that these systems can reasonably accommodate for this new HDTV service. Therefore, this new compatible system has been designed to occupy a 12-MHz bandwidth when using the present broadcast format of vestigial-sideband amplitude modulation.

The important parameters of this new compatible HDTV system are a horizontal resolution potential up to 600 lines, a vertical resolution potential up to 483 lines, and less crosstalk between the individual components of the color signal compared to the NTSC system. Further minimization of color-encoding errors may be possible by using recently developed processing techniques.[5]

VI. ACKNOWLEDGMENTS

The author gratefully acknowledges Joseph LoCicero for many useful discussions that aided his understanding of much of the HDTV area. The author expresses his gratitude to Bruce Briley, Kristin Kocan, and Harvey Lehman for their review of this paper.

REFERENCES

1. T. Fujio, "High-Definition Wide-Screen Television System for the Future-Present State of the Study of HD-TV Systems in Japan," IEEE Trans. Broadcasting, *BC-26* (December 1980), pp. 113–24.
2. C. Sandbank and M. Moffat, "High-Definition Television and Compatibility with Existing Standards," *Tomorrow's Television*, Scarsdale, New York: SMPTE, 1982, pp. 170–85.
3. T. Robson, "A Compatible High Fidelity TV Standard for Satellite Broadcasting," *Tomorrow's Television*, Scarsdale, New York: SMPTE, 1982, pp. 218–36.
4. B. Wendland, "High Definition Television Studies on Compatible Basis with Present Standards," *Television Technology in the 80's*, Scarsdale, New York: SMPTE, 1981, pp. 151–65.
5. D. Richman, "Color Television Receiving System Utilizing Inferred High Frequency Signal Components to Reduce Color Infidelities in Regions of Color Transitions," U.S. Patent 4,181,917, Jan. 1, 1980; "Color Television Receiving System Utilizing Multimode Inferred Highs Correction to Reduce Color Infidelities," U.S. Patent 4,183,051, Jan. 8, 1980; and "Color Television Receiving System Utilizing Inferred High Frequency Signal Components to Reduce Color Infidelities in Regions of High Color Saturation." U.S. Patent 4,245,239, Jan. 13, 1981.
6. K. McIlain and C. Dean, *Principles of Color Television*, New York: John Wiley, 1956, Chapter 11.
7. W. Gibson and A. Schroeder, "Color Television Luminance Detail Rendition," Proc. I.R.E., *43* (August 1955), pp. 918–23.
8. D. Livingston, "Reproduction of Luminance Detail by NTSC Color Television Systems," Proc. I.R.E., *42* (January 1954), pp. 228–34.

AUTHOR

Theodore S. Rzeszewski, B.S.E.E., 1964, M.S.E.E., 1965, University of Illinois; E.E., 1971, D.E. (honorary), 1973, Midwest College of Engineering; Bell Laboratories, 1982—. Mr. Rzeszewski is a member of the Exploratory Wideband Telecommunications Department. His current areas of interest include high-definition television and digital television. Before joining Bell Laboratories, he was Manager of Technical Operations of Matsushita Applied Research.