ADVANCED TELEVISION SYSTEMS

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ABSTRACT

This paper was first presented as a tutorial to engineers at the Federal Communications Commission (FCC) in January 1987 to acquaint them with the progress in advanced television systems. It was revised and presented as a workshop paper at the NAB Convention in March 1987 for the broadcasting community. Because of the high level of activity on advanced television systems, it is now further revised for the consumer electronics community.

This paper reviews the NTSC television system, improved NTSC, component systems, the 1125/60 high definition television (HDTV) studio system, and proposals for transmitting HDTV programs to the public.

BACKGROUND

The 525 lines per frame, 60 fields per second, 2:1 interlaced scan television system has been serving the United States public for almost 50 years. Performance of this television system has improved significantly over the years, clearly one of the reasons for its long life.

The most significant single improvement was the addition of color. Engineers were able to add color information to the black and white signal without increasing the transmission bandwidth. To achieve this, luminance information was decreased and a subcarrier, containing color information, was introduced. The result for black and white receivers was lower resolution and the appearance of a dot structure, a loss that was considered to be acceptable.

Other improvements have taken many forms and arise from constantly expanding technology. Both pick-up devices and display devices have improved dramatically. Solid state circuits now perform complex functions which were not possible when the system was designed.

Current technology will permit another significant improvement, high definition television. Although everyone recognizes that HDTV is here to stay, there have been many debates on the need for it, the precise timing of various services and, of course, the technical standards.

This paper will first review the NTSC system and point out some of the artifacts. Proposals that have been made to improve the NTSC system will be examined.

A review of multiplexed analog components (MAC) will follow. MAC systems have been proposed for direct broadcast satellite (DBS) services in several parts of the world. Also, some of the proposed HDTV transmission systems use MAC technology. It is appropriate, therefore, to establish an understanding of MAC systems before covering the proposed HDTV transmission systems. The 525/60 B-MAC system will be reviewed in this section.

The next topic will be the 1125 lines per frame, 60 fields per second, 2:1 interlaced scan, HDTV studio system, the only HDTV studio system that has been designed and marketed. Standards efforts in the International Radio Consultative Committee (CCIR) have concentrated on a studio standard as a first priority.

Broadcasting high definition television programs to the public is the final topic. The general approaches will be noted followed by descriptions of specific proposals. The similarities and differences of the proposals are examined.

The reference materials used to prepare this paper are listed by topic at the end of the text. For those wishing to study advanced television systems in greater detail, these papers, in addition to the references cited in the individual papers, would constitute a remarkable library.

NTSC

Although many people are not aware of this fact, there have been two NTSC's. The first National Television System Committee was convened around 1940 to establish the technical standards for an American black and white television system. The agreed upon standards were 525 lines per frame, 60 fields per second, 2:1 interlaced scan and 4:3 aspect ratio. The field frequency was precisely 60 Hertz. Channel spacing for broadcasting was set at 6.0 MHz. The picture carrier frequency was 1.25 MHz above the lower end of the channel. The maximum video bandwidth transmitted was 4.2 MHz. Vestigial sideband amplitude modulation (VSB-AM) was chosen -- single sideband for the upper frequency components and double sideband for the lower frequency components. The sound carrier frequency was set 4.5 MHz above the picture carrier frequency.

The second NTSC was convened in the early 1950's to establish technical standards for an American color television system. The black and white parameters were maintained with the exception of the horizontal scanning frequency and thus the field frequency. Each frequency was increased 0.1%. This will be explained later in this paper.

The color information was added to the black and white signal by inserting a subcarrier modulated in quadrature by two color-difference signals. The two color-difference signals, called the I and Q signals, are in quadrature on a color diagram. The I signal was specified with a bandwidth of about 1.5 MHz while the Q signal specification was only .5 MHz. The human eye has greater color

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resolution for colors near the I axis than near the Q axis and thus, to conserve bandwidth, these axes were chosen. The equations for the luminance signal (Y) and the color-difference signals are derived from the red, green and blue signals as follows:

$$Y = 0.59G + 0.11B + 0.30R$$
$$I = -0.27(B-Y) + 0.74(R-Y)$$
$$Q = 0.41(B-Y) + 0.48(R-Y)$$

The color subcarrier frequency (f_{SC}) was chosen to be an odd multiple of one half the horizontal scanning frequency (f_H) to minimize the appearance of the subcarrier in the picture. The multiple was also selected to have small factors. The resulting relationship is given by:

$$f_{SC} = (13)(7)(5)/2\ f_H = 455/2\ f_H$$

This frequency is about 3.58 MHz. Since there were concerns that the color subcarrier and sound carrier would cause mutual interference, and that the sound carrier frequency could not be changed and maintain compatibility with receivers already in use, the horizontal scanning frequency (and thus the field frequency) was changed. The color subcarrier was interleaved with the sound carrier to minimize interference. The ratio of the sound carrier frequency (f_A) and the horizontal scanning frequency had been:

$$f_A/f_H = 4{,}500{,}000/15{,}750 = 285.71$$

The horizontal scanning frequency was changed so that the sound carrier frequency would be an even multiple of the horizontal scanning frequency. The factor closest to 285.71 satisfying this requirement, 286, was selected. The new field frequency was precisely 1000/1001 times 60 Hertz, or 59.94 Hertz.

Figure 1 is a block diagram of an NTSC encoder while Figure 2 is a diagram of the spectrum of the transmitted NTSC signal.

The manner in which the color information was added gives rise to some of the artifacts observed in the NTSC system. High spatial frequencies in the imaged scene can produce luminance information which is treated by the NTSC decoder as if it were color information. A wide bandwidth luminance channel in a receiver can cause the subcarrier to be displayed as a dot structure. In both cases, the artifacts come about because of the mutual interference of the luminance signal and the color signal.

Another artifact arises from interlaced scanning. The raster appears to slowly move up the screen and, once the human eye has locked onto this movement, the resolution of the picture appears to be lower. The scanning structure becomes obvious. If the viewer's eye follows objects in motion in the displayed image, again, the resolution of the picture appears to be lower and the scanning structure becomes obvious.

IMPROVED NTSC

The most promising concepts for improving NTSC are:

1) progressive scanning in the display,
2) progressive scanning in camera and display maintaining the interlaced scan transmission,
3) pre-combing luminance and chrominance prior to transmission,
4) the Fukinuki proposal which sacrifices a small amount of color information to increase the luminance information, and
5) the QUME proposal, quadrature modulation of the picture carrier with new information.

Progressive Scan in Display

All current television systems use 2:1 interlace scanning. Two vertical scans, or fields, are required to complete one picture, or frame, of the picture. Each field contains half the scanning lines. The first field provides every other line of the frame; the second field contains the other set of every other line. Figure 3 illustrates the 525 line 2:1 interlaced scanning raster.

A progressive scan system (also called sequential scan) contains all the scanning lines in each field. Scanning all 525 lines each field produces a better picture than interlaced scanning but it doubles the bandwidth.

The picture can be improved by converting the interlaced scan signal into a progressive scan signal. With twice the number of scan lines, the scan line visibility decreases by a factor of two. This does not increase the signal resolution but it does increase the perceived resolution by improving the Kell Factor.

The easiest way to implement this improvement is to display every scan line twice during the normal scan line period. One line store is required and the horizontal scanning frequency is doubled. However, diagonal lines in the picture become distorted.

A further improvement, requiring two line stores, inserts the average of two time-adjacent scan lines between the said two lines. The distortion of diagonal lines is decreased.

Both of these techniques effectively create a new scan line between the existing scan lines. Note that there is a scan line in this location, the scan line in the other field. This is illustrated in Figure 3. By adding a field store this line in the other field can be displayed. This process results in very good still pictures. However, it also produces motion defects because the line in the other field is separated in time by 1/60 of a second. Motion compensation circuitry is required for best results.

Progressive Scan in Camera/Display with Interlaced Scan Transmission

Still greater picture improvement can be obtained if the camera and the display use progressive scan with the signal converted to an interlaced scan signal prior to transmission. In this case extra information is available at the transmitting end to process the transmitted lines in such a way that, when the receiver re-converts the signal to progressive scan using a pre-determined process, the final picture will be improved. Even greater benefits could be obtained if auxiliary data were transmitted to tell the receiver the best way to put the picture together again.

This approach may create a problem for current receivers since the vertical resolution of the signal would be higher than can be displayed on a normal 525 line interlaced scan receiver. The result could be greater aliasing.

This technique does not require still another standard for studio cameras. The high definition television studio signal can be an input to this system with the signal scan converted to 525 line interlaced scan anticipating progressive scan in the receiver. This approach, more scan lines in the camera and in the display with interlaced scan transmission, has been proposed to increase vertical resolution in HDTV transmission systems.

Pre-Combing

An artifact extremely visible in the NTSC system results from interference between high frequency luminance information and the color signal. This occurs because of the overlapping spectra. If the luminance and chrominance signals are filtered to eliminate overlapping spectra prior to the NTSC encoder, these artifacts are greatly diminished.

The phase of the color subcarrier on successive scanning lines is shown in Figure 4. The phase shift from one line to the next line is exactly 180^o since the color subcarrier frequency is an odd multiple of one-half the horizontal scanning frequency. This characteristic can be used in special filters, called comb filters, to separate luminance and color information. If the signal is in phase from one line to the next line, it is assumed to be luminance information. If the signal is out of phase from one line to the next line, it is assumed to be color information.

Figure 5 is a comb filter block diagram which will pass only luminance information. The resulting spectrum is shown in Figure 6. If the signal between the delay lines is inverted prior to the adder, only the color information passes through the filter. The resulting spectrum is identical to that shown in Figure 6 except that the nulls, rather than the peaks, occur at multiples of the horizontal scanning frequency.

Circuits for pre-combing luminance and chrominance signals are shown in Figure 7. These circuits could be added to Figure 1 at the points shown as "chrominance signal" and "luminance signal." It may not be a good practice, however, to add these circuits to every camera since current practice in the studio is to use several NTSC encoders and decoders (to perform digital video effects, for example) which may degrade the signal. Such an improvement may be more appropriate in a component studio in which NTSC encoding is done one time only, immediately prior to transmission.

Proponents of this improvement claim significant improvements are visible in receivers with comb filter decoders. They further claim that some improvements are seen with traditional receivers.

Fukinuki Proposal

Dr. Fukinuki, Hitachi Central Research Laboratory, proposes interleaving higher definition luminance information with color in much the same way as color information is already interleaved with the luminance information. He points out that a portion of the spectrum devoted to color is poorly used and this portion could be dedicated to high resolution luminance information. This technique produces motion defects and motion compensation circuitry must be included in the receiver.

Figure 8 shows the television signal in a three dimensional representation with the horizontal scanning lines parallel to the x-axis, vertical scans parallel to the y-axis, and time the third dimension. In this case, each field, separated in time by 1/60 second, represents a plane. Just as the color subcarrier has a 180^o phase shift from line to line as illustrated in Figure 4, it also has a 180^o phase shift from field to field and frame to frame. This characteristic can be used to carry color information with one phase shift and high resolution luminance information with another phase shift. If the signal is in phase following a 262 line delay, it is assumed to be color information as shown by the dashed lines rising to the right in Figure 8. If the signal is in phase after a 263 line delay, it is assumed to be high resolution luminance information as shown by the dashed lines falling to the right.

The decoder block diagram is given in Figure 9. Signals out of phase after a 262 line delay are decoded as high resolution information. Signals out of phase after a 263 line delay are decoded as color information.

Quadrature Modulation of the Picture Carrier

The Wireless Research Laboratory of the Matsushita Electric Industrial Company proposed a QUadrature Modulating Extended definition television system (QUME) in which quadrature modulation of the NTSC picture carrier is used to increase the horizontal resolution or to increase the aspect ratio.

The unmodulated picture carrier is phase shifted by 90^o and then modulated with the additional information signal. The resulting signal is band limited, filtered, and added to the normally modulated picture carrier. This process is shown in Figure 10. Figure 10a is a diagram of the modulating circuit. Figure 10b shows the band limit characteristic. Figure 10c shows the filter characteristic. Figure 10d is a diagram of the spectrum of the QUME signal.

At the point of reception, a QUME receiver would use a synchronous detector to separately extract the normal signal and the additional information signal and properly combine them to produce an improved picture. Current receivers with a synchronous detector would ignore the additional information signal. Current receivers with an envelope detector would display some crosstalk from the additional information signal. In order to decrease crosstalk, the filter characteristic shown in Figure 10c was chosen to be symmetrical to the filter at the video IF stage. According to Matsushita, the filtering reduces the amount of crosstalk about 10 dB.

MAC SYSTEMS

Several different MAC systems have been proposed in the standards efforts around the world. Their similarities are great -- the differences are in the precise choice of numbers. The 525/60 B-MAC system is illustrated in this paper.

Before proceeding it would be helpful to note that television was developed primarily as a service for the public. After engineers reached agreement on the transmission parameters, broadcasters used the same parameters to make television programs. It was convenient, perhaps mandatory, to use the same format for studio production since separate components were difficult to use because of timing constraints. As technology has advanced (digital video effects) the need for higher performance in the studio has increased. Sufficient headroom should exist for full transmission quality after all post-production.

MAC systems came about as a convenient way to maintain separate components without having to worry about maintaining the critical timing of three separate signals on three separate cables. Figure 11 shows the B-MAC waveform. The luminance and color-difference and multiple digital sound signals are compressed in time and placed on the same signal line. Various MAC systems differ in their compression ratios, data rates, and number of sound channels. B-MAC compresses luminance by the factor 3/2 and compresses color-difference signals by a factor of 3. Six high quality digital sound channels are provided. The color system uses a line sequential format; the R-Y and B-Y signals are carried on alternate lines.

The B-MAC system can accommodate the wider aspect ratio of 16:9. Consider first the compression and expansion technique used when a 4:3 aspect ratio signal is displayed. Each line of the luminance signal, 750 samples, is placed in a line store with a 910 f_H clock. The samples are removed from the line store with a 1365 f_H clock, compressing the luminance signal by the factor 3/2. At the decoder the 750 samples are placed in a line store with a 1365 f_H clock and removed from the line store for display with a 910 f_H clock, thus expanding the luminance signal by the factor 3/2 and restoring its original form. The identical process is used when a 16:9 aspect ratio signal is displayed on a 16:9 aspect ratio monitor. If, however, the 16:9 aspect ratio signal is displayed on a 4:3 aspect ratio monitor, the decoder must expand the luminance signal by the factor

$$(3/2)(16/9) / (4/3) = 2$$

In this case, after the 750 samples are placed in a line store in the decoder with a 1365 f_H clock, the samples are removed from the line store for display with a 1365/2 f_H clock. Pan and scan is accomplished by having the signal include data telling the decoder which portion of the signal to display.

MAC systems can offer higher performance than composite systems because of separation of the luminance and color-difference signals, inclusion of full bandwidth luminance, and resulting lack of cross-modulation. On the negative side, color vertical resolution is lower because of the line sequential format. Also, baseband bandwidth is increased by the luminance compression ratio, 50% for B-MAC.

1125/60 HDTV STUDIO SYSTEM

NHK, the Japan Broadcasting Corporation, has been studying and developing HDTV for several years. Their scientists assumed that there were many applications of HDTV besides broadcasting. They conducted psychophysical experiments on the size of screen, the aspect ratio, the angle of vision, the sense of reality, etc. After the experiments were completed NHK designed a system which met the requirements, the 1125/60 HDTV system.

Many people around the world support this system for a single world-wide production standard. They argue that a single world-wide high definition electronic production standard is desirable, that the 1125/60 system exists, and that the 1125/60 system meets production requirements. Resolution is comparable to 35mm releases, a world standard for motion pictures.

Figure 12 lists parameters agreed on for a high definition television studio using the 1125/60 parameters; NHK originally proposed the following basic parameters:

1125	lines per frame
60	fields per second
2:1	interlaced scan
5:3	aspect ratio

The number of lines was selected to be greater than 1000 but not twice 525 or 625, a compromise between the two scanning standards in existence today. They chose 60 fields per second, rather than 50 fields per second, because of the reduced flicker and the higher temporal sampling rate. They selected interlace scanning over progressive scanning because of the reduced bandwidth. They believed the aspect ratio should be at least 5:3, perhaps as wide as 2:1, and selected 5:3.

Studies in the United States supported each of these parameters except the aspect ratio. The U.S. proposed an aspect ratio of 16:9 to give greater flexibility in shooting and releasing a program. By using a "shoot and protect" scheme with a 16:9 aspect ratio, releases could be made conveniently in any aspect ratio between 4:3 and 2.35:1. If the master has a 16:9 aspect ratio, a 4:3 aspect ratio release would use the full height of the master and the appropriate width as shown in Figure 13. A release with 2.35:1 aspect ratio would use the full width of the master and the appropriate height, also illustrated in Figure 13. Releases with an aspect ratio between these two extremes would use either the full width or the full height. The outer rectangle represents the 16:9 aspect ratio master. The inner rectangle represents the image area in which the critical portions of the image should be contained.

Several engineers wanted a progressive scanning format to be used, arguing that post-production would be easier and artifacts would be reduced. However, with twice the number of lines per field, the bandwidth doubles, a serious problem. Camera sensitivity, already limited, is reduced. Video tape recorders cannot handle the extra bandwidth. Most engineers felt that the number of lines should not be decreased below 1000 to compensate for the greater bandwidth. On the other hand, some argued that if the bandwidth were to be doubled, it would be preferable to continue to use interlaced scanning but with twice the number of lines.

NHK proposed that the studio system have separate luminance and color-difference signals. However, the bandwidths being considered today are greater than those first proposed by NHK. The Advanced Television Systems Committee (ATSC) suggested that sampled representations of the signal should be specified as well as specific bandwidths. The European Broadcasting Union (EBU) suggested that only sampled representations should be specified. In order to decide how many samples per line should be used, the ATSC argued that the CCIR has defined HDTV as having about twice the horizontal and vertical resolution of current television systems. CCIR Recommendation 601 specifies 720 luminance samples during the active line and half that number for each of the two color-difference signals for current television systems. Twice the resolution would then imply twice 720 samples multiplied by the ratio of aspect ratios (16:9 divided by 4:3) resulting in 1920 samples per active line for the luminance and half that number for each of the two color-difference signals. The resulting bandwidths would be about 30 MHz for luminance and 15 MHz for each color-difference signal. Recently, the Society of Motion Picture and Television Engineers (SMPTE) decided that the bandwidths should be 30 MHz for the luminance and for each of the color-difference signals.

The ATSC also proposed that the sampling frequency should be 74.25 MHz which results in 2200 samples per total line. With 1920 samples in the active line, 280 samples are left for blanking, 3.77 uS. These figures are being specified by the various standards organizations for the 1125/60 system.

The standards organizations are specifying SMPTE "C" colorimetry. The equation for the luminance is:

$$Y = 0.701G + 0.087B + 0.212R$$

This equation applies following gamma correction, also fully specified. The gamma was not fully specified in the NTSC system.

NHK proposed a new concept for the synchronizing signal, a three level signal shown in Figure 14. The precise timing information is carried by zero crossings between negative and positive pulses rather than negative going edges. NHK believes the timing accuracy improves significantly with this waveform.

The ATSC agreed in March 1985 to recommend to the U.S. Department of State that the 1125/60 system be proposed to the CCIR as a single world-wide standard for HDTV studios. After the U.S. CCIR National Committee unanimously agreed, this was submitted to the CCIR as the U.S. position. The governments of Canada and Japan submitted similar positions. At the CCIR Plenary Assembly meeting in Dubrovnik in May 1986 the decision on a studio standard was postponed until the end of the next Study Period, 1990. The Plenary Assembly agreed unanimously to attach these parameters to CCIR Report 801 making them the only parameters so acknowledged in Report 801.

Since the time of the Plenary Assembly, activities around the world suggest that the 1125/60 system will become a de facto standard for 60 Hz HDTV studios. Standards organizations are proceeding to document the system as a standard. What is not clear is whether the system will be accepted as a single world-wide standard.

HDTV TRANSMISSION

HDTV programs will be distributed via VCR, video disc, optical/electrical cable systems, DBS, and terrestrial transmission. The most difficult will be terrestrial transmission because of standards and regulatory issues. However, it is my opinion that the terrestrial broadcasters will find a way to make significant improvements in the technical quality of their transmissions when the other distribution outlets begin using HDTV.

Will the technical standards for each of these media be the same? There may be advantages if they are the same, but it is not clear that they must be the same. Bandwidth is most limited for terrestrial transmission and compromises will be necessary. In audio systems, sound input devices (FM radio, AM radio, TV sound, LP's, CD's, reel to reel recorders, cassette recorders) vary widely but feed a common amplifier and speakers. Perhaps the consumer HDTV system will consist of a display driven by a frame store with multiple inputs to the frame store (NTSC, HDTV-VCR, HDTV-UHF).

Compatibility is a term that is often used and too often misused. I propose that we define levels of compatibility related to receivers. The highest level (LEVEL 5) is represented by a system which allows HDTV transmissions to be received by an NTSC receiver and displayed as an HDTV picture. Although this seems absurd, the concept represents the highest attainable level of compatibility. The next lower level (LEVEL 4) is represented by a system which allows HDTV transmissions to be received by an NTSC receiver and displayed with the same quality as current NTSC transmissions. LEVEL 3 is represented by a system which allows HDTV transmissions to be received by an NTSC receiver and displayed with reduced performance when compared with the picture from an NTSC transmission -- this was the situation when the United States added color to the black and white television transmissions. LEVEL 2 is represented by a system which allows HDTV transmissions to be received and displayed by an NTSC receiver using a low cost adapter box -- this was the situation when UHF transmissions first began. LEVEL 1 is represented by a system which requires a high cost adapter box, perhaps so expensive that consumers would prefer to purchase the new system. In the cases of LEVEL 2 and LEVEL 1, I assume that a new receiver can be designed to operate on both the current system and the HDTV system. LEVEL 0 is the lowest level -- and the only level which I would call non-compatible. It is represented by a system with which NTSC receivers cannot display HDTV transmissions in any form, even with adapter boxes, and new receivers cannot display an NTSC transmission. The levels of compatibility are illustrated in Figure 15.

I believe that high performance HDTV transmission systems will have lower levels of compatibility. Also, I believe that high level compatibility systems will be lower performance HDTV systems. This must be acknowledged when making a decision. The trade-off is today's level of compatibility versus tomorrow's level of performance.

CCIR Report 801 defines HDTV in comparison with current television systems as having twice the vertical spatial resolution, twice the horizontal spatial resolution, separate color-difference and luminance signals, improved color rendition, wider aspect ratio, and multiple channel high fidelity sound. If one assumes these requirements for the transmitted signal, the bandwidth (BW) of the luminance signal becomes:

$$BW = (4.2)(2)(2)(16/9)/(4/3) \text{ MHz} = 22.4 \text{ MHz}$$

The HDTV luminance bandwidth, compared to the NTSC 4.2 MHz luminance bandwidth, is increased by two factors of two because of the doubled vertical and horizontal resolution and by the degree to which the HDTV aspect ratio, 16:9, exceeds the NTSC aspect ratio, 4:3. Recognizing that 22.4 MHz bandwidth is required merely for the luminance signal -- an additional bandwidth of 5-10 MHz would be needed for the separate color-difference signals and about 0.6 MHz would be needed for high fidelity digital stereo sound -- it seems clear that the task of "compressing" this amount of information to fit within the current 6 MHz NTSC channel is difficult. Many organizations are searching for a transmission system which, in their view, represents an appropriate compromise in bandwidth, quality, complexity, and level of compatibility. The compromises taken by any one organization may result in characteristics which do not meet the definition given above. In this paper, I do not intend to pass judgment on the compromises and will refer to all the proposals examined below as "HDTV transmission systems" since, in each case, HDTV program material is the input to the transmission system.

Eight proposals for HDTV transmission in the United States are examined in this paper:

1) MUSE Proposal
2) BELL Laboratories Proposal
3) CBS Proposal
4) GLENN Proposal
5) DEL REY Group Proposal
6) North American Philips (NAP) Proposal
7) Scientific Atlanta (SA) Proposal
8) NBC Proposal

The proposals fall into three categories with respect to channel requirements:

A) one channel wider than current channels,
B) two channels with one channel carrying a "compatible" signal, or
C) one "compatible" current channel

The MUSE proposal requires one channel, wider than an NTSC channel, and has LEVEL 1 compatibility. The BELL proposal uses two NTSC channels where one channel has LEVEL 3 compatibility and contains an NTSC signal. The CBS proposal is a two channel DBS system which uses a MAC approach, rather than NTSC, for the first channel and thus has LEVEL 2 compatibility with respect to NTSC receivers. The GLENN proposal uses one NTSC channel and another low bandwidth channel. The first channel contains NTSC and has LEVEL 3 compatibility. The DEL REY proposal requires only one NTSC channel and has LEVEL 3 compatibility. The NAP proposal can be implemented in two forms, a two NTSC channel system or a MAC system. The first form contains NTSC in one channel and has LEVEL 3 compatibility. The second form has LEVEL 2 compatibility. The SA proposal is based on the B-MAC system and has LEVEL 2 compatibility. The NBC proposal requires one NTSC channel and has LEVEL 3 compatibility.

MUSE Proposal

Multiple Sub-Nyquist Encoding (MUSE) was proposed by NHK for DBS HDTV transmission. The signal is derived directly from the 1125/60 studio system. The luminance and color-difference signals are band limited then sampled. One out of every four samples is transmitted each field and, after four fields, every sample is transmitted. During each line 373 actual luminance samples are transmitted. The minimum horizontal spacing of samples is about 1/1500 of the picture width. The minimum vertical spacing of samples is about 1/1035 of the picture height. This process, depicted in Figure 16, produces high resolution still pictures but the resolution of objects in motion is lower than the resolution of stationary objects.

Receivers require a frame store. Motion detectors are used in the encoder to fully compensate for some types of motion such as a camera pan. This information is transmitted to the receiver as a digital signal. The transmission includes digital stereo sound. Luminance and color-difference signals are separate in a MAC format. The full signal requires a baseband bandwidth of 8.1 MHz.

The MUSE system was designed for FM transmission. However, the MST-NAB demonstration (Washington, DC, January 1987) used the MUSE system with VSB-AM transmission occupying two UHF channels (58 and 59). The picture carrier was set 3 MHz into the 12 MHz channel.

Consumer electronics manufacturers in Japan are designing consumer equipment to operate with this system. Plans are being made in Japan for a DBS service, starting around 1990, using this system.

Bell Laboratories Proposal

Bell Labs proposed a two channel system in which the first channel contains an NTSC signal derived from a high definition signal with 1050 lines. The 1050 line signal, after vertical filtering, is scan converted into the 525 line format. The horizontal resolution of the signal transmitted in the first channel is normal NTSC. The second channel contains higher frequency luminance and color-difference signal information. Horizontal resolution of the combined signals is essentially two times NTSC resolution. Bell claims an NTSC receiver recovers the signal in the first channel with only slight degradation. An HDTV receiver recovers the signals in both channels and combines them in a frame store scan converting the output to 1050 lines producing a high definition picture.

Bell Labs claims the second channel has sufficient capacity to transmit multiple channel sound. They have also described several methods for obtaining wider aspect ratio pictures.

Figure 17 shows the transmitted spectrum. This figure shows two adjacent channels. However, two non-adjacent channels can be used. Figure 18 is a block diagram of the encoder. The decoder uses the inverse function.

CBS Proposal

CBS proposed a two channel transmission system for an HDTV service using two DBS channels. Each channel carries a time multiplex component (TMC) signal. In this paper, the TMC signal should be considered the same as a MAC signal. The CBS system first converts the HDTV studio signal into a 1050 line interlaced format with a 5:3 aspect ratio. Every second pair of lines of the 1050 line signal is averaged to generate a 525 line interlaced signal with a 5:3 aspect ratio. The central 4:3 aspect ratio portion of this signal is transmitted in the first channel which is shown in Figure 19. The second channel carries every other line of the 1050 line signal in a 5:3 aspect ratio format. It also carries the "side panels" of the first channel.

Vertical filtering is applied to the first channel (averaging each two lines of the 1050 line signal) so there will be no loss in the single channel receiver. The "side panels" have lower horizontal resolution than the central portion of the picture since they are transmitted in the second channel which is compressed by a greater factor. This is illustrated in a scanning format in Figure 20. The horizontal spatial resolution of the resulting high definition picture is the same as it is for the signal in the first channel which, it should be noted, is about 50% higher than an NTSC signal since the DBS channels permit transmission of a wider bandwidth signal. The vertical resolution of the high definition picture is two times the vertical resolution of an NTSC picture.

An NTSC receiver, with an adapter box, uses the signal in the first channel to display a 525 line picture with 4:3 aspect ratio. An HDTV receiver combines the two signals to display a 1050 line picture with 5:3 aspect ratio. This system can be implemented without using a frame store in the receiver. The TMC format for each channel is illustrated in Figure 21.

<u>Glenn Proposal</u>

William E. Glenn of the New York Institute of Technology proposed a system using one NTSC signal and an auxiliary signal which occupies about one half an NTSC channel. Dr. Glenn made studies of human vision and found that humans have two types of vision receptors which have different functions for spatial resolution and temporal resolution. One type of vision receptor has high spatial resolution but low temporal resolution while the other type of vision receptor has high temporal resolution but low spatial resolution. His system takes advantage of these properties of human vision to reduce the transmitted bandwidth. High temporal resolution information is transmitted using the NTSC signal and high spatial resolution information is transmitted in the second channel at a lower frame rate.

The NTSC signal is subjected to improvements using techniques described in the improved NTSC section of this paper. The auxiliary signal contains high frequency, low temporal rate luminance information and high resolution color information. The high frequency luminance information consists of 862 picture elements per active line and 1024 active lines in a quincunx (checkerboard) pattern. All this information is transmitted in a MAC format to the receiver. The receiver uses a frame store to reconstruct the picture. A block diagram of the encoder for this system is shown in Figure 22. In this diagram the high resolution luminance signal is derived from a separate camera tube. This is not a requirement. The transmitted signal could be derived from an HDTV studio signal.

A wider aspect ratio is accommodated in the NTSC channel by reducing horizontal blanking by 10% and decreasing the number of active lines by 10%.

<u>Del Rey Group Proposal</u>

The Del Rey Group has proposed a 525/60/2:1 high definition transmission system using a single NTSC channel. The sampling pattern is illustrated in Figure 23. The transmitted signal can be derived from an 1125/60 studio output. The easiest way to examine this proposal, though, is to assume an original luminance signal with twice 525 lines and three times the horizontal resolution. Each NTSC luminance picture element (pixel) is replaced by three new pixels as shown. The pixels designated A-F are transmitted in place of the normal NTSC pixels, and, after six fields, all six pixels are transmitted. A frame store is used in the HDTV receiver to recover the full signal. The Del Rey Group claims that this signal could be directly displayed on a current NTSC receiver with little loss compared with a conventional NTSC picture. Normal NTSC color-difference bandwidths are used in the system. The minimum spacing of horizontal samples is about 1/1320 of the picture width. The minimum spacing of vertical samples is about 1/828 of the picture height.

The Del Rey Group also proposes that 69 fewer active video lines be transmitted each frame which results in a wider aspect ratio picture. The Del Rey Group claims that most NTSC receivers overscan to such an extent that the loss of the transmitted lines would not be observed in a typical receiver. Those lines are then used to transmit digital sound. Figure 24 shows this approach.

<u>North American Philips Proposal</u>

North American Philips (NAP) proposed a concept for HDTV transmission which can be implemented in two forms. One form is a MAC system suitable for satellite transmission. The other form, easily derived from the first, is a two channel system in which the first channel carries an NTSC signal and the second channel carries the wide aspect ratio panels, higher resolution information and digital stereo sound. NAP proposes that the MAC signal could be distributed by satellite and converted to the two channel signal for local service either by terrestrial broadcasting or cable distribution.

The description given here is based on the two channel NTSC system demonstrated in April 1987. Although the transmitted signals can be derived from an 1125/60 studio output, the easiest way to examine this proposal is to look at an original 525 line progressive scan 16:9 aspect ratio signal as shown in Figure 25. The NTSC signal for the first channel is obtained by selecting a 4:3 aspect ratio portion of every other line of the source signal. The second channel carries four signals during each "line scan." The first signal is the left panel for the wide aspect ratio and the second signal is the right panel for the wide aspect ratio. These two signals are processed as a normal NTSC signal. The two panels are not necessarily of equal width since provisions are included for a pan and scan feature. The third signal is a "line difference" signal necessary for a progressive scan display in the receiver -- the average value of two adjacent lines transmitted in the first channel is subtracted from the luminance portion of the lines discarded for generating the NTSC signal and compressed by a factor of 8/3. The fourth signal contains "bursts" of a Dolby digital encoded 16 bit stereo sound signal.

An NTSC receiver would receive only the first channel and display a normal NTSC picture. HDTV receivers would receive both channels, combine the signals in an appropriate manner, and display wide aspect ratio progressive scan pictures using 525 lines. Although the horizontal resolution and color resolution demonstrated by NAP are normal NTSC resolution, they are working on techniques to increase both. The vertical luminance resolution is higher than NTSC because of the progressive scan. A frame store is not required. The picture does not suffer when motion is present.

The MAC system has not been demonstrated but is described as a four field sequence, 525 line progressive scan signal with baseband bandwidth of 9.5 MHz. In a given field, every fourth line has full luminance bandwidth of 16.8 MHz -- equivalent in spatial resolution to a 6.3 MHz NTSC signal. Every second line is a "line difference" signal, as described above, band limited to about 28% full luminance bandwidth. All other lines are band limited to about 56% full bandwidth. One of the two color-difference signals is sent every other line on an alternate basis. The color-difference signal has either 14% or 28% of the full luminance bandwidth. Figure 26 shows the contents of each line and the spatial-temporal resolution.

<u>Scientific Atlanta Proposal</u>

Scientific Atlanta has proposed that the B-MAC system could be used to carry an HDTV signal via satellite. The input signal could be either 1050 lines interlaced scan or 525 lines progressive scan. This technique is used to increase the vertical resolution of the signal. The B-MAC system, described earlier in this paper, already handles wide aspect ratio pictures.

Figure 27 diagrams the encoding procedure using 525 lines progressive scan as the input. The signal is filtered in a diagonal manner decreasing the diagonal resolution. The resulting signal is sampled in a quincunx pattern to eliminate every other sample. The samples from every second line are moved into the empty spot in the line above. Every second line then contains no samples and it can be discarded. The resulting signal is a 525 interlaced scan signal which can be transmitted through a regular B-MAC channel.

The normal B-MAC receiver would display the signal in the normal fashion. A high definition B-MAC receiver would regenerate the 525 line progressive scan picture by reversing the procedure described above. The samples which were moved into the line above would be moved back into place and missing samples would be calculated based on surrounding samples. This entire procedure is accomplished with a small number of line stores.

<u>NBC Proposal</u>

NBC and the David Sarnoff Research Center have proposed a system which can be transmitted in a single NTSC channel by combining several of the concepts described in the improved NTSC portion of this paper -- higher line number in the camera and the display, pre-combing, the Fukinuki procedure, and the QUME procedure.

The origination signal is a high line number, wide aspect ratio signal from which an NTSC signal is derived. The wide aspect ratio is maintained in the NTSC signal by compressing the side panels to occupy about 1 uS each. NBC claims that receivers overscan and this portion of the picture would not appear in current receivers as a result. With a receiver designed to recover this signal, though, the side panels would be stretched to their proper size. This technique results in low bandwidth side panels. The higher frequency information for the side panels, including the encoded color for the side panels, is placed on a subcarrier which uses the portion of the spectrum inefficiently used by the color information (Fukinuki). This new subcarrier, about 3.1 MHz, is modulated in quadrature by a signal containing higher frequency luminance information for the 4:3 aspect ratio portion of the picture. The main signal and these additional signals must be filtered (similar to pre-combing with a field delay) prior to combining them, otherwise artifacts would be introduced. The additional signals are band-limited to about 1.2 MHz each.

Vertical information, needed to reconstruct the higher line number generated by the source, is carried by another signal. That signal is band-limited to 750 kHz and then used to modulate the picture carrier in quadrature with the main signal (QUME). NBC claims that little crosstalk will be seen on current receivers from this signal since it is coherent with the information in the main signal.

A diagram of this system is shown in Figure 28. Figure 29 is a diagram of the spectrum of the transmitted signal.

<u>Similarities and Differences of Proposals</u>

It is difficult to make direct comparisons between the proposals. Demonstrating the systems side by side using test signals and program material would provide the best comparison. However, this cannot be done today since only one of the systems has been thoroughly developed. The other systems are in various stages of development.

As a general rule, systems requiring the greatest bandwidth will probably have the best performance. Likewise, systems using the least bandwidth will probably have the poorest performance. Trade-offs can be made to enhance any one aspect of system performance but, almost certainly, another aspect will be degraded. The two channel systems require the greatest bandwidth. However, they have been designed to maintain a high level of compatibility and may have been subjected to compromises which do not use the bandwidth in the most efficient manner.

Techniques used to increase the resolution are:

1) increase the total bandwidth,
2) decrease the temporal resolution,
3) decrease the diagonal resolution, or
4) combinations of the above.

All of the proposed systems increase the vertical and horizontal resolution when compared with NTSC. However, all of them are expected to suffer in one way or another when motion is present. Systems by BELL, CBS, and SA have full temporal resolution. However, BELL converts to higher line number which can introduce artifacts, CBS treats side panels in the second channel which can introduce artifacts, and SA uses Sub-Nyquist sampling which can also introduce artifacts. The other systems require more than one frame to update the picture. GLENN is a 7.5 frame per second (fps) update, DEL REY is 10 fps, MUSE is 15 fps, and NAP is 15 fps. NBC uses intraframe averaging which introduces some loss of temporal resolution.

Four different techniques are used to increase the vertical resolution. CBS transmits two times the number of lines. NAP and NBC transmit about twice as many lines but remove most of the horizontal information from half the lines. MUSE, GLENN, DEL REY, and SA transmit about twice as many lines but remove half the horizontal information from every line. BELL converts to a higher line number at the receiver to increase the perceived vertical resolution.

Two different techniques are used to increase the horizontal resolution. BELL and CBS increase the bandwidth. MUSE, GLENN, DEL REY, NAP, SA, and NBC transmit information from extra horizontal samples using an interleaved technique. Only CBS has full diagonal resolution.

MUSE, BELL, CBS, GLENN, NAP, and SA increase the color resolution when compared with NTSC. MUSE, CBS, NAP in their MAC system, and SA transmit separate luminance and color information. BELL, GLENN, DEL REY, NAP in their NTSC system, and NBC use the NTSC system to transmit color information.

All of the proposed systems include a wide aspect ratio picture. MUSE, GLENN, DEL REY, NAP in their MAC system, and SA treat the wide aspect ratio as an integral part of the system rather than send the side panels in a separate manner. Only CBS and SA do not require a field store (or more) for full performance. The NAP system could have a lower performance option which would not require a field store. MUSE, GLENN, and DEL REY have the greatest memory requirements.

The BELL, GLENN, DEL REY, NAP in their NTSC system, and NBC signals can be displayed on a current NTSC receiver without an adapter box. All of the systems could use the 1125/60 studio signal as an input signal. Figure 30 contains a table showing many of these comparisons.

SUMMARY

This paper examined many proposals for delivering higher definition pictures to the public. The proposals range from improvements to the NTSC system to HDTV transmission systems requiring a greater bandwidth than is available in a single NTSC channel. While it seems quite likely that the 1125/60 HDTV studio system will become the 60 Hz studio standard, standards for delivery to the public are an open question.

Bandwidth considerations may lead to the use of different standards for different HDTV delivery systems.

Extensive misuse of the word "compatibility" led to a definition of a range of compatibility levels rather than a definition of the word. Systems with a high level of compatibility may result in lower levels of performance while systems with a low level of compatibility may result in higher levels of performance.

A number of alternative and innovative systems have been proposed for HDTV transmission. These systems have been developed to different levels ranging from computer simulations to developed hardware. Each is based on different assumptions regarding the most appropriate set of compromises. The HDTV delivery system that is most developed is being used by Japanese manufacturers to design consumer equipment. That system would most likely be usable for terrestrial broadcasting in the UHF band, but its use raises a number of standards and regulatory issues.

In this paper only general comparisons are made between the proposed systems. Comparisons also can be found in the reference documents for this paper, often in a competitive manner, stressing the benefits of the proponent's system and the weaknesses of the competitive systems. Care must be taken to understand the assumptions made in each case.

One final note. Dr. Glenn has compared the NTSC, improved NTSC, enhanced TV and HDTV systems in terms of achieving equal resolution on the retina of the viewer. He assumes that improvements made to NTSC can also be made to enhanced and HDTV systems. His comparison is shown in Figure 31.

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BIOGRAPHY

Robert Hopkins received the Bachelor of Science in Electrical Engineering from Purdue University in West Lafayette, Indiana and the PhD from Rutgers University in New Brunswick, New Jersey. He was employed by the RCA David Sarnoff Research Center in Princeton, New Jersey where he received two RCA Laboratories Outstanding Achievement Awards. He transferred to RCA Broadcast Systems in Gibbsboro, New Jersey, and then RCA Jersey Limited, Jersey Channel Islands, Great Britain. He joined ATSC as Executive Director in January, 1985. He is a past chairman of the SMPTE Standards Committee, SMPTE Committee on New Technology, and SMPTE Working Group on Digital Video Standards.

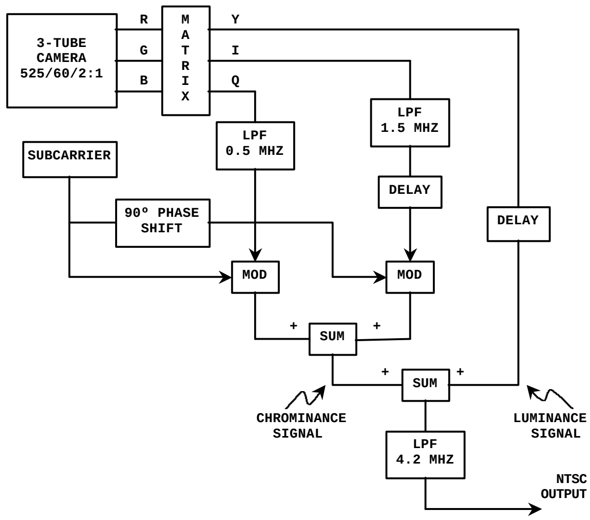


FIGURE 1 NTSC ENCODER

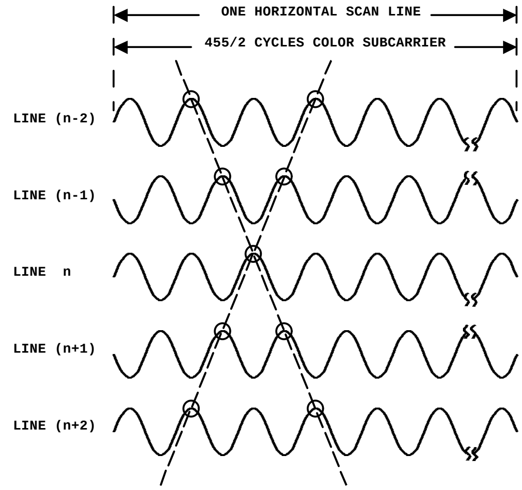


FIGURE 4 PHASE OF COLOR SUBCARRIER

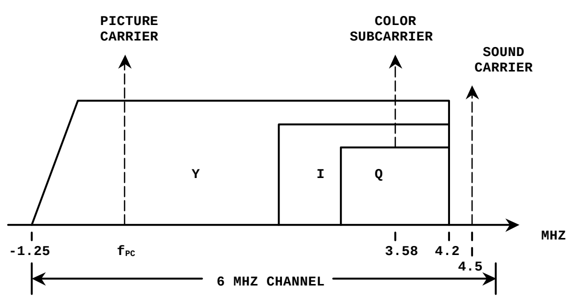


FIGURE 2 SPECTRUM OF TRANSMITTED NTSC SIGNAL

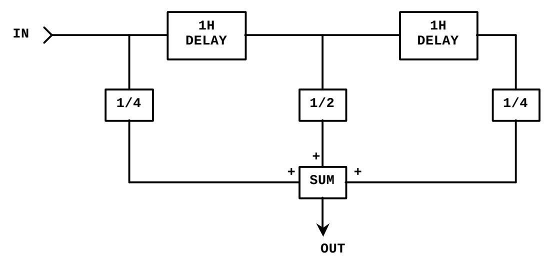


FIGURE 5 COMB FILTER

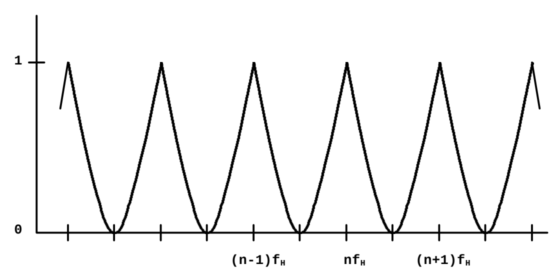
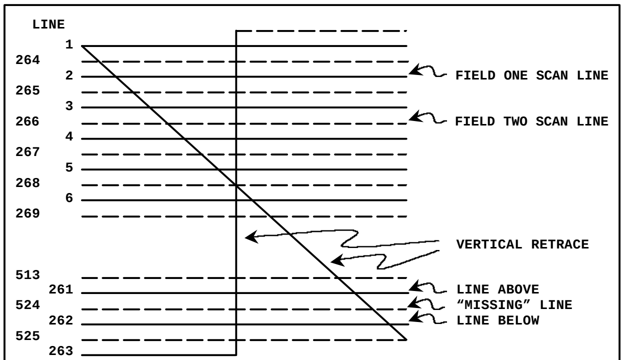


FIGURE 6 COMB FILTER OUTPUT SPECTRUM



AN ILLUSTRATION OF TEH 525 LINE, 2:1 INTERLACE SCAN SYSTEM. THE SOLID LINES ARE DISPLAYED IN 1/60 SECOND. THE DASHED LINES ARE DISPLAYED IN THE NEXT 1/60 SECOND. THE PICTURE CAN BE IMPROVED BY DISPLAYING 525 LINES EVERY FIELD, ALTHOUGH ONLY 262 1/2 LINES ARE TRANSMITTED EACH FIELD, BY:

A) DISPLAYING EACH LINE TWO TIMES IN SUCCESSION (POOR APPROXIMATION OF “MISSING” LINE, DISTORTS DIAGONAL LINES)
B) DISPLAYING THE AVERAGE OF THE LINE ABOVE AND THE LINE BELOW THE “MISSING” LINE (BETTER, BUT STILL HAS DISTORTION OF DIAGONAL LINES)
C) DISPLAYING THE “MISSING” LINE USING A FIELD STORE (VERY GOOD FOR STILL PICTURES BUT MOTION COMPENSATION CIRCUITRY IS REQUIRED)

FIGURE 3 525 LINE 2:1 INTERLACE SCAN

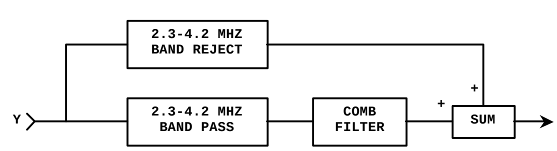


FIGURE 7A LUMINANCE “PRE-COMB”

FIGURE 7B CHROMINANCE “PRE-COMB”

FIGURE 7 CIRCUITS TO “PRE-COMB” NTSC

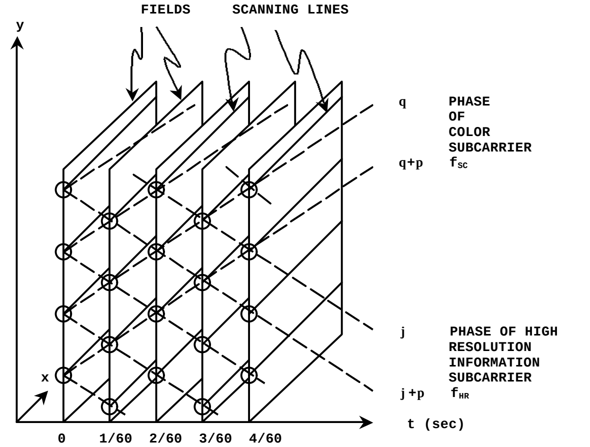
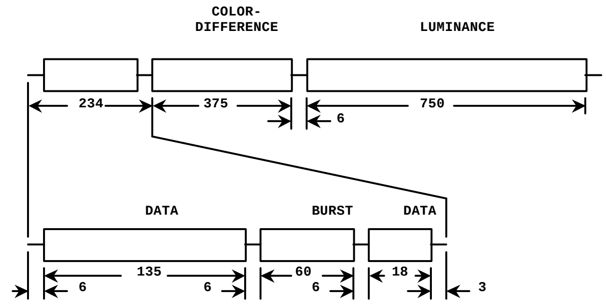


FIGURE 8 SCANNING LINE STRUCTURE, PHASE OF COLOR SUBCARRIER, PHASE OF HIGH RESOLUTION INFORMATION -- FUKINUKI PROPOSAL



THE NUMBER OF CLOCK PERIODS FOR EACH PORTION OF THE WAVEFORM IS INDICATED. THERE ARE 1365 TOTAL CLOCK PERIODS IN THE LINE.

THREE CLOCK PERIODS ARE REQUIRED FOR EACH DATA SYMBOL. EACH DATA SYMBOL CARRIES TWO BITS. THE DITITAL DATA RATE IS 910 BITS PER LINE.

LUMINANCE SIGNAL COMPRESSION RATIO = 3:2

COLOR-DIFFERENCE SIGNAL COMPRESSION RATIO = 3:2

FIGURE 11 B-MAC HORIZONTAL LINE

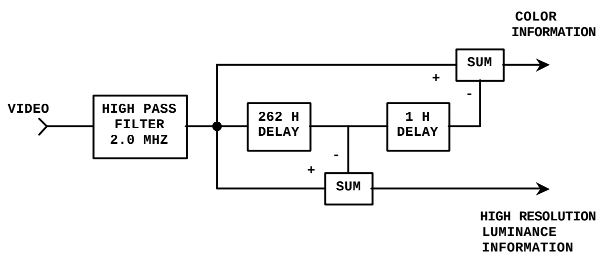


FIGURE 9 EXTRACTION OF COLOR INFORMATION AND HIGH RESOLUTION LUMINANCE INFORMATION -- FUKINUKI

1125	TOTAL LINES PER FRAME
60 HZ	FIELD FREQUENCY
2:1	INTERLACE FACTOR
16:9	ASPECT RATIO
1035	ACTIVE LINES PER FRAME
30 MHZ	ANALOG BANDWIDTH FOR PRIMARY SIGNALS
74.25 MHZ	SAMPLING FREQUENCY FOR DIGITAL PROCESSING
2200	SAMPLES PER TOTAL LINE
1920	LUMINANCE SAMPLES PER ACTIVE LINE
960	COLOR-DIFFERENCE SAMPLES PER ACTIVE LINE
280	BLANKING SAMPLES PER LINE

FIGURE 12 1125/60/2:1 STUDIO SYSTEM

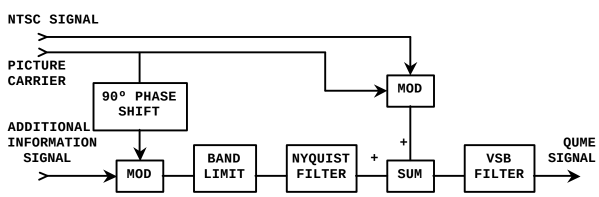


FIGURE 10A QUME MODULATING CIRCUIT

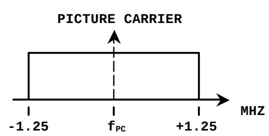


FIGURE 10B BAND LIMIT FILTER CHARACTERISTIC

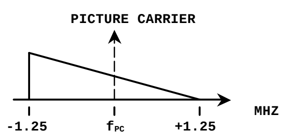


FIGURE 10C NYQUIST FILTER CHARACTERISTIC

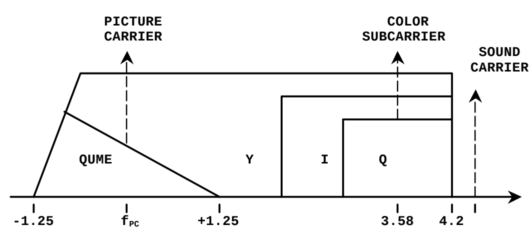
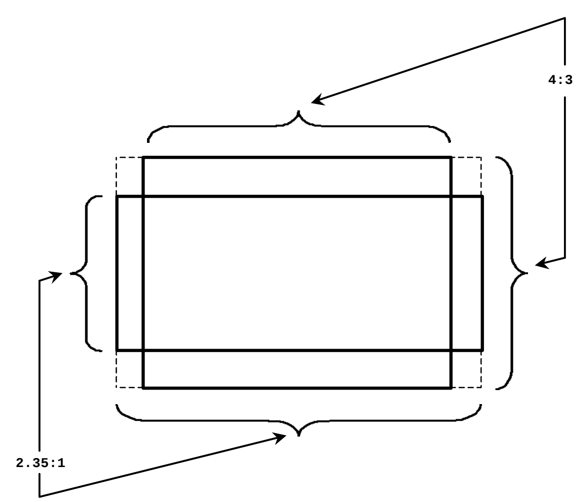


FIGURE 10D SPECTRUM OF THE QUME SIGNAL

FIGURE 10 QUME PROCESS



INNER RECTANGLE ASPECT RATIO = OUTER RECTANGLE ASPECT RATIO

$$= \sqrt{\frac{4}{3} \times \frac{2.35}{1}} = 1.770$$

NOTE THAT 16:9 = 1.777

FIGURE 13 SHOOT AND PROTECT WITH 16:9 ASPECT RATIO

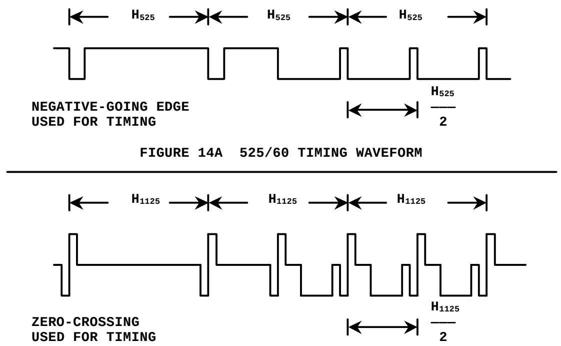


FIGURE 14A 525/60 TIMING WAVEFORM

FIGURE 14B 1125/60 TIMING WAVEFORM

FIGURE 14 NHK PROPOSAL FOR 1125/60 SYNC WAVEFORM

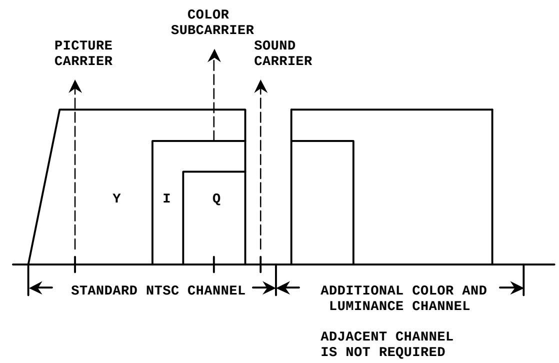


FIGURE 17 TRANSMITTED SPECTRUM -- BELL LABS

INCREASING COMPATIBILITY

LEVEL 5 HDTV RECEIVED AND DISPLAYED AS HDTV ON NTSC RECEIVER

LEVEL 4 HDTV RECEIVED AND DISPLAYED AS HIGHEST QUALITY NTSC ON NTSC RECEIVER

LEVEL 3 HDTV RECEIVED AND DISPLAYED AS REDUCED QUALITY NTSC ON NTSC RECIEVER

LEVEL 2 HDTV RECEIVED WITH EXPENSIVE ADAPTER FOR DISPLAY ON NTSC RECIEVER

LEVEL 1 HDTV CANNOT BE RECEIVED FOR DISPLAY IN ANY FORM ON NTSC RECEIVER AND HDTV RECEIVER CANNOT DISPLAY NTSC

DECREASING COMPATIBILITY

GENERAL RULE OF THUMB HIGHER LEVELS OF COMPATIBILITY PROBABLY RESULT IN LOWER PERFORMANCE LEVELS FOR THE HDTV SYSTEM

FIGURE 15 COMPATIBILITY LEVELS

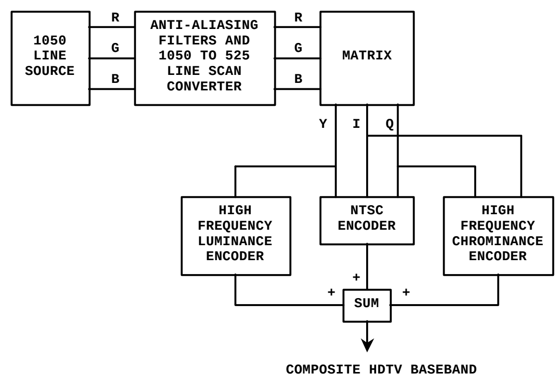


FIGURE 18 HDTV ENCODER -- BELL LABS

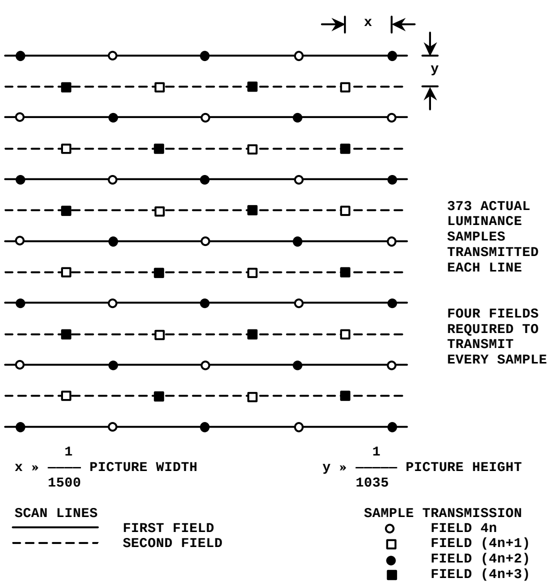


FIGURE 16 MUSE SAMPLING PATTERN

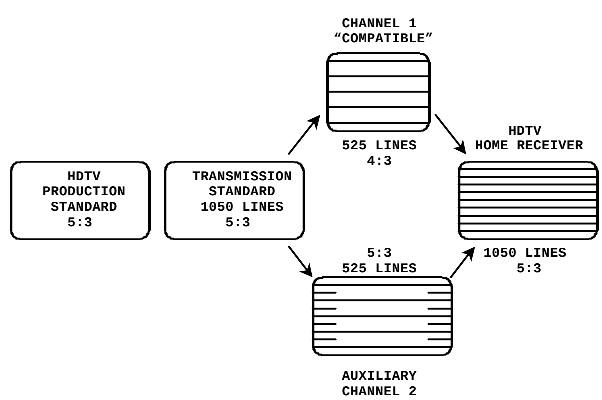


FIGURE 19 DBS HDTV 2-CHANNEL SYSTEM -- CBS

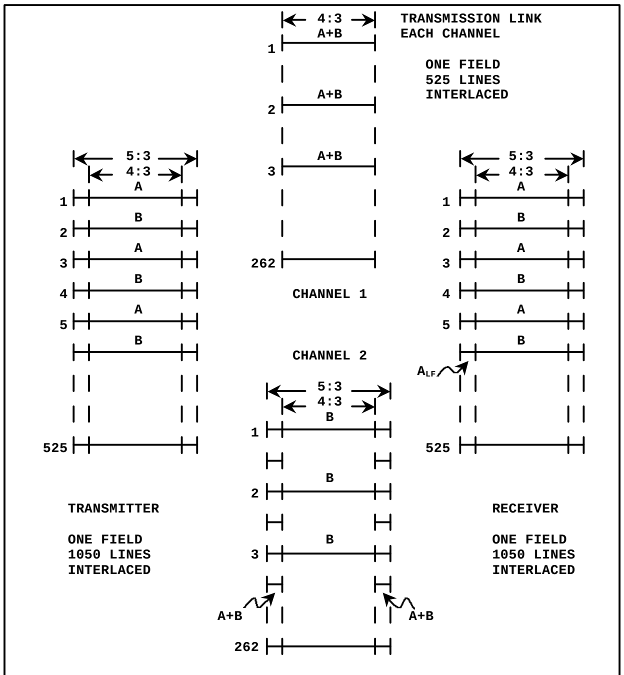


FIGURE 20 SIMPLIFIED SCANNING GEOMETRY -- CBS

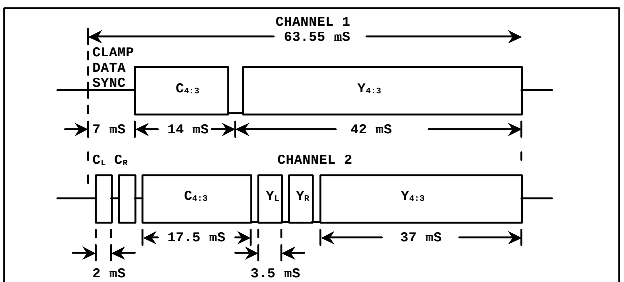


FIGURE 21 TMC FORMATS -- CBS

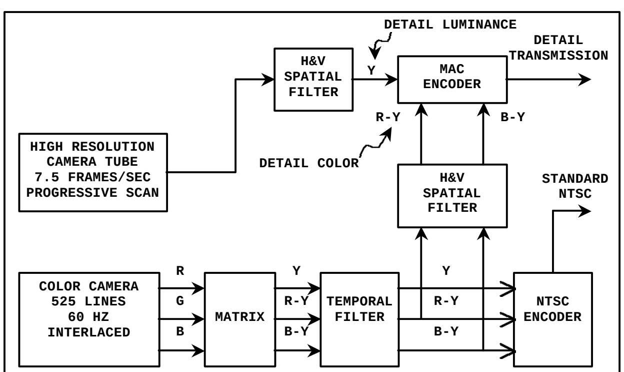


FIGURE 22 HDTV ENCODER -- GLENN

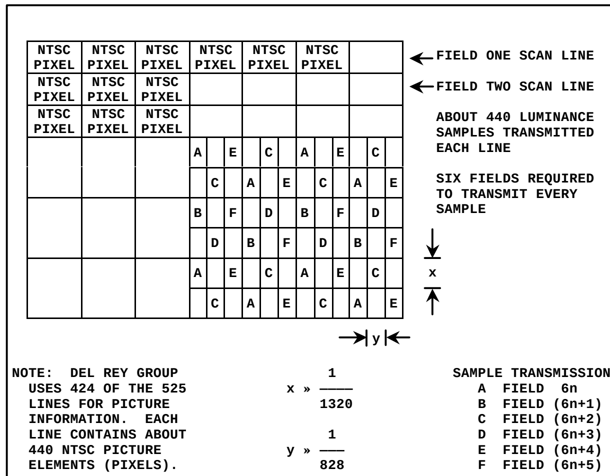
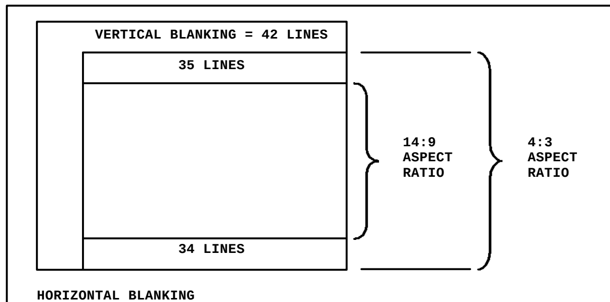


FIGURE 23 DEL REY GROUP SAMPLING PATTERN



A TOTAL OF 69 LINES. TAKEN FROM THE TOP AND BOTTOM OF THE PICTURE. COULD BE USED FOR DIGITAL SOUND DURING HIGH DEFINITION TELEVISION TRANSMISSIONS.

FIGURE 24 14:9 ASPECT RATIO -- DEL REY GROUP

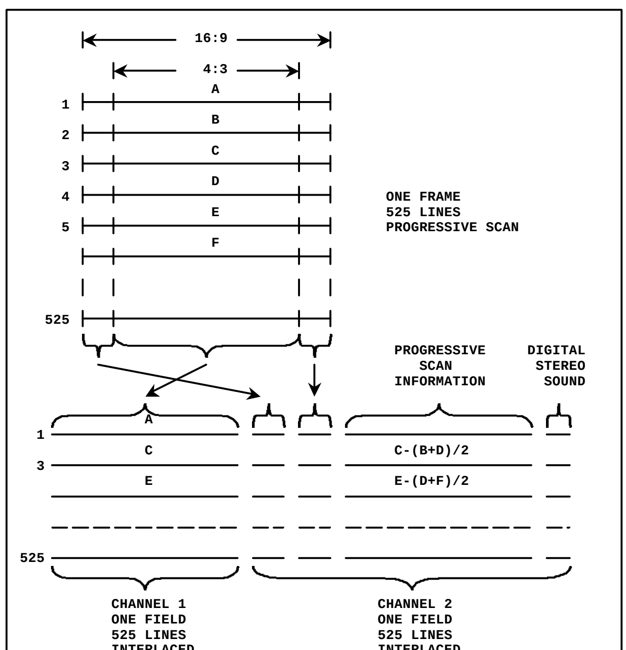
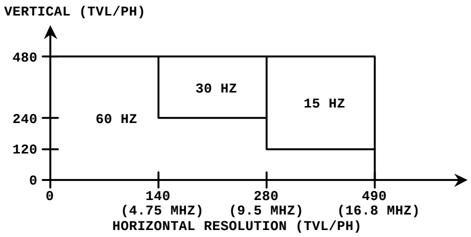


FIGURE 25 TWO NTSC CHANNEL TRANSMISSION SYSTEM -- N.A.PHILIPS

	RESOLUTION Y	U	V
LINE n	56%	14%	-
LINE (n+1)	28%	-	-
LINE (n+2)	100%	-	28%
LINE (n+3)	28%	-	-
LINE (n+4)	56%	28%	-
LINE (n+5)	28%	-	-
LINE (n+6)	100%	-	14%
LINE (n+7)	28%	-	-



TO CONSERVE SPECTRUM THE N.A.PHILIPS MAC SYSTEM TRANSMITS ONLY A PORTION OF THE CONTENTS OF SOME LINES BY FIRST USING A LOW PASS FILTER. THE TABLE SHOWS THE RESOLUTION OF EACH LUMINANCE AND COLOR-DIFFERENCE LINE. THIS PATTERN REPEATS EVERY 8 LINES. THE LUMINANCE PATTERN MOVES UP ONE LINE EVERY FRAME. THE COLOR-DIFFERENCE SIGNAL PATTERN MOVES UP TWO LINES EVERY FRAME. THE SIGNAL IS 525 LINE PROGRESSIVE SCAN. THE RESULTING LUMINANCE TEMPORAL-SPATIAL RESOLUTION IS ALSO SHOWN.

FIGURE 26 SPATIAL AND TEMPORAL RESOLUTION
HD-MAC SYSTEM -- N.A.PHILIPS

THE ORIGINAL SIGNAL IS A 525 LINE PROGRESSIVE SCAN SIGNAL

```
X  X  X  X  X  X  X
X  X  X  X  X  X  X
X  X  X  X  X  X  X
X  X  X  X  X  X  X
X  X  X  X  X  X  X
```

B-MAC HAS 750 SAMPLES PER LINE

THE SIGNAL IS FILTERED TO REMOVE THE HIGHER FREQUENCY DIAGONAL COMPONENTS

```
X1  X1  X1  X1  X1  X1  X1
X2  X2  X2  X2  X2  X2  X2
X3  X3  X3  X3  X3  X3  X3
X4  X4  X4  X4  X4  X4  X4
X5  X5  X5  X5  X5  X5  X5
```

NUMBERS INDICATE ORIGINAL LINE LOCATION

THE SIGNAL IS SAMPLED IN A QUINCUNX FASHION DISCARDING EVERY OTHER SAMPLE

```
X1  --  X1  --  X1  --  X1
--  X2  --  X2  --  X2  --
X3  --  X3  --  X3  --  X3
--  X4  --  X4  --  X4  --
X5  --  X5  --  X5  --  X5
```

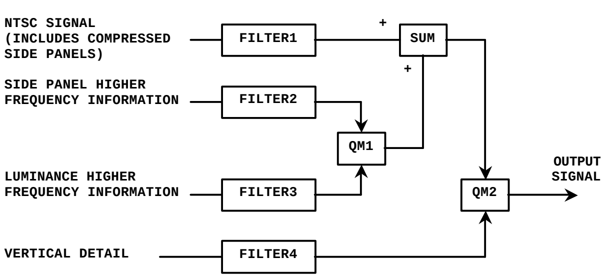
-- MISSING SAMPLE

SAMPLES IN ALL EVEN LINES ARE MOVED INTO THE EMPTY SPACE IN THE LINE ABOVE

```
X1  X2  X1  X2  X1  X2  X1
--  --  --  --  --  --  --
X3  X4  X3  X4  X3  X4  X3
--  --  --  --  --  --  --
X5  X6  X5  X6  X5  X6  X5
```

RESULTING SIGNAL IS 525 LINES INTERLACED SCAN

FIGURE 27 ENCODING PROCEDURE TO ENHANCE VERTICAL
RESOLUTION WITH B-MAC -- SCIENTIFIC ATLANTA



FILTERS 1,2,3 ARE INTRA-FRAME FILTERS. FILTER 4 IS A 750 KHZ LOW PASS FILTER. QM1 IS A QUADRATURE MODULATOR WITH THE SUBCARRIER FREQUENCY ABOUT 3.1 MHZ AND ALL SIDEBANDS “HIDDEN” IN THE FUKINUKI HOLES. QM2 IS A QUADRATURE MODULATOR WHERE THE CARRIER IS THE NORMAL PICTURE CARRIER.

FIGURE 28 SIGNAL ENCODER BLOCK DIAGRAM -- NBC

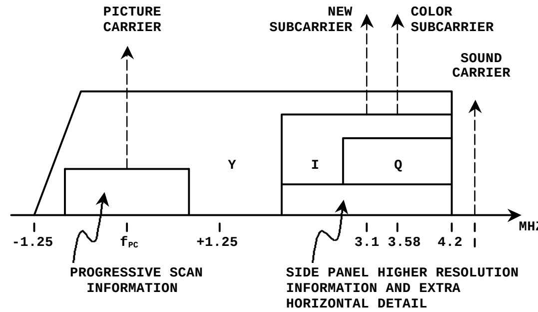


FIGURE 29 SPECTRUM OF THE NBC SIGNAL

		BANDWIDTH MHZ	H-RES TVL/PH	V-RES TVL/PH	FULL DIAG	FULL TEMP	INTEG SIDES	SEP COLOR	FLD STOR	IMPR AUD
MUSE		8.1	555	720	NO	NO	YES	YES	YES	YES
BELL		12	600	480	NO	YES	NO	NO	YES	YES
CBS		16	500	660	YES	YES	NO	YES	NO	YES
GLENN		9	800	800	NO	NO	YES	NO	YES	NO
DEL REY		6	635	580	NO	NO	YES	NO	YES	YES
NAP	NTSC	12	490	480	NO	NO	NO	NO	OPT	YES
	MAC	9.5	490	480	NO	NO	YES	YES	OPT	YES
SA		10.8	420	480	NO	YES	YES	YES	NO	YES
NBC		6	410	480	NO	NO	NO	NO	YES	NO

KEY: BANDWIDTH IS THE BASE-BAND BANDWIDTH OF THE SIGNAL IN MHZ.

H-RES AND V-RES ARE THE HORIZONTAL AND VERICAL RESOLUTION OF THE SIGNAL GIVEN IN TV LINES PER OPICTURE HEIGHT. DATA IS TAKEN, OR DERIVED, FROM PUBLISHED INFORMATION.

FULL DIAG MEANS THE SIGNAL HAS FULL DIAGONAL RESOLUTION. NOTE THAT NTSC DOES NOT HAVE FULL DIAGONAL RESOLUTION BECAUSE OF THE PRESENCE OF THE COLOR SUBCARRIER.

FULL TEMP MEANS THE SIGNAL IS FULLY UPDATED EVERY FRAME.

INTEG SIDES MEANS THE WIDE ASPECT RATIO PORTION OF THE SIGNAL IS TRANSMITTED IN AN INTEGRAL MANNER WITH THE CENTER OF THE PICTURE.

SEP COLOR MEANS THE COLOR INFORMATION IS TRANSMITTED SEPARATE FROM THE LUMINANCE INFORMATION.

FLD STOR MEANS THE SYSTEM REQUIRES A FIELD STORE (OR MORE) IN THE RECEIVER. OPT MEANS OPTIONAL.

IMPR AUD MEANS THE SYSTEM OFFERS IMPROVED AUDIO COMPARED WITH THE CURRENT NTSC SYSTEM.

FIGURE 80 COMPARISON OF THE VARIOUS TRANSMISSION SYSTEMS

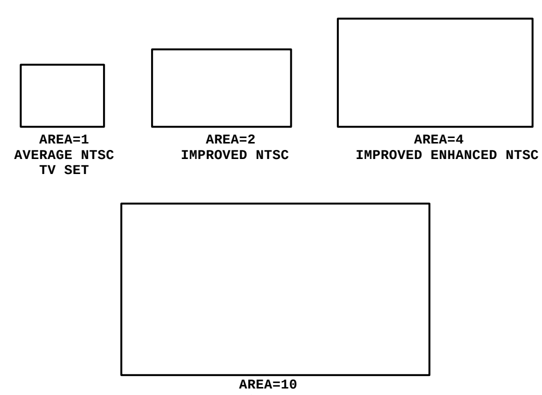


FIGURE 31 RELATIVE SIZES OF IMAGES DISPLAYED WITH SAME RESOLUTION OF VIEWER’S RETINA -- GLENN