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ORIGINAL FILE

17 November 1987

Mr. William J. Tricarico
Secretary
FCC
1919 M Street NW
Washington, D.C. 20554

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Dear Sir:

The Del Rey Group is pleased to be given the opportunity to respond to the Notice of Inquiry #87-268 regarding Advanced Television Systems.

The Del Rey Group was formed in order to develop and promote a proposal for a single-channel, compatible HDTV delivery protocol known as HD-NTSC™. The proposal was first published last fall at the SMPTE Conference in New York City; a copy of that paper is attached. Although a full year has passed since this document was first released, we believe the words are as valid today as they were then. All that we would wish to add is that the original paper specified a system having an aspect ratio of 14:9, while recent evidence suggests that the HD-NTSC protocol could actually support a full 5:3 aspect ratio, a ratio identical with the original NHK HDTV specification.

We have little doubt that some responses to the NOI will be rather lengthy and complex. In contrast, this response will be characterized by brevity. The philosophy behind the HD-NTSC proposal is that the less that is changed within the television delivery infrastructure the better, consistent with the need to offer a product that is competitive with alternative delivery systems such as VCR and DBS.

"HD-NTSC" defines a system consisting of a single-channel encoding process and a complementary decoding process. The encoding process uses a novel form of subsampling to compress a high definition image down to the standard NTSC bandwidth. By way of example, NHK's Muse system also uses a subsampling technique. The HD-NTSC signal format is also slightly different from conventioanl NTSC in that it uses a wider aspect ratio and fits in a digital stereo signal. An HD-NTSC receiver employs a progressive scan and special chrominance filtering in order to remove NTSC defects as described in section II of the NOI.

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HD-NTSC differs from other single-channel proposals in several significant ways. First, HD-NTSC employs vertical and horizontal subsampling, which appear to offer enormous gains in resolution compared to other resolution enhancement techniques currently under discussion. Secondly, the encoded HD-NTSC signal does not require quadrature modulation at the transmitter or a dual-channel studio. Thirdly, the wider aspect ratio is carried as a single contiguous area, without side panels or "wings" and therefore without any compromises in resolution or sensitivity to miscellaneous transmission distortions. Finally, the HD-NTSC process is naturally suited to digital signal processing circuitry, and such VLSI circuitry is rapidly decreasing in cost on the order of 40% per annum.

Included below are questions posed by the NOI:

1. What criteria, such as video/audio quality performance, transmission bandwidth, NTSC compatibility, etc., should the Commission use to evaluate and compare the various ATV technologies? What are the appropriate trade-offs between the various criteria?

It is clear that one can improve quality by increasing bandwidth or increasing the sophistication of encoding/decoding. We believe that the circumstances insist that not only must a new format fit within a single 6Mhz window but also that the signal must be viewable on conventional receivers. We find it remarkable that some would throw away the NTSC system without first using the best that digital signal processing and microelectronics had to offer.

When NHK set out to create a super-quality system a decade ago, they did so under a different set of constraints than those existing today. As a result, the 1125 line system is quite different and quite incompatible with NTSC. Today it is possible to use modern digital signal processing techniques such as represented by HD-NTSC to get high quality <u>and</u> compatibility, and to us it makes little sense to do otherwise.

2. What changes in ATV technologies should be anticipated for the near future? At what stage is the development of an all-digital ATV system using digital signal processing and IC technologies?

It is impossible to predict invention. It is clear, however, that at this point in time, analog offers the advantage of compatibility with the existing system and is frugal with bandwidth. The digital benefits of signal ruggedness and ease of manipulation are best utilized for special applications in the studio at present. It is not clear what digital delivery would offer to consmers. A PC spreadsheet is nearly worthless if a bit is misplaced, while a video image is not much affected by an occasional pixel error.

The HD-NTSC protocol is an example of sophisticated digital signal processing both at the encoder in the studio and in the receiver. The transmission format, however, remains analog.

3. How quickly are developments of the various ATV technologies progressing? What are now operational? Which are in prototype stage? Developmental stage? How long until these systems are realized?

The development speed of HD-NTSC or any system for that matter is a function of funding. What began as simply a concept on paper a year ago has now reached the stage where VAX computer simulations are taking place. Because HD-NTSC does not push the limits of the knowledge envelope as much as other proposals (i.e.dual channel system behavior in a multipath environment), we are optimistic that development can take place rapidly once sufficient funds become available. Prototype hardware could be demonstrated in late 1988.

4. What are the relative costs of these new transmission systems for programming producers? For broadcasters? For consumers?

<u>For software producers:</u>
HD-NTSC requires a high definition source. 35mm motion picture film is nearly ideal, with the only limitations being a less than digital quality audio track and a 24 frame/second motion portrayal. Feature films already include a wider aspect ratio, though made-for-TV productions generally do not. The impact to software producers therefore will be minimal, though a higher quality delivery system will highlight the need for increased production precision.

<u>For broadcasters:</u>
There is minimal change from current practice, since an encoded HD-NTSC signal offers nearly identical characteristics as conventional NTSC. Multiple channels within the plant are not necessary, and over-the-air transmission characteristics should be the same. Since HD-NTSC is capable of carrying digital audio, it may be necessary to update the audio portion of the plant to match the higher specs.

Although broadcasters will be able to test the waters of high definition gradually via feature film conversions, they will eventually wish to local programming such as news in the new format. Such a desire will of course require the purchase of specific high definition cameras and other equipment. It

is important to remember, however, that such a changeover can take place gradually in the HD-NTSC environment.

For consumers:

The key behind HD-NTSC is that a high definition broadcast is still viewable on conventional receivers, thereby repeating the situation in the 1950's when the switch was begun from monochrome broadcast to color. Consumers wishing the high quality image and the digital audio will, of course, need to purchase a new receiver.

The subsampling process that is the foundation of HD-NTSC creates artifacts on a conventional receiver, much as color information does on a monochrome receiver. The primary artifact has the general nature of color crawl. The first simulations of HD-NTSC were addressing the nature and severity of this artifact, and the results appeared quite promising. The degree of the artifact is inversely proportional to the theoretical resolution limit of the system. It is therefore an interesting possibility that an increased-definition service could be phased in over a number of years, with gradually increasing resolution on new receivers (and gradually increasing artifact on conventional receivers) over time. No changes to either old NTSC receivers or new HD-NTSC receivers would have to be made over this period.

The new HD-NTSC receiver will incorporate sophisticated signal processing circuitry. In addition the very nature of high definition television begs for large screens. Therefore, such receivers will not be inexpensive. One estimate suggests a 1992 price of about $3,500 for a one-meter screen diagonal receiver. The portion of the cost attributable to the digital circuitry will drop rapidly.

5. From a technical perspective, what are the advantages and disadvantages of augmenting the channel capacity of existing television assignments? What is the appropriate bandwidth for the augmentation channel? Must it be contiguous with the main channel?

The advantage of augmenting the conventional channel capacity is that it is possible to get more information across in a given time if there is more bandwidth available. Nonetheless, The Del Rey Group believes the appropriate bandwidth of the augmentation channel should be "0", given the constraints of the current broadcast environment. The NHK Muse system has demonstrated very effectively that a typical observer is willing to make a tradeoff of slightly softened moving images in exchange for much sharper still images.

Questions 6 through 29 in the NOI deal with spectrum availability issues that are best left for others to answer, since the questions are not directly relevant to the HD-NTSC single-channel solution.

We wish the FCC and the rest of the television industry much success in reaching a common decision in the complex world of high definition television. We will be pleased to assist in any way possible.

Sincerely,

Richard J. Iredale

attachment

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A PROPOSAL FOR A NEW HIGH-DEFINITION NTSC BROADCAST PROTOCOL

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A Proposal for a New High-Definition NTSC Broadcast Protocol

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Abstract

This paper describes a new process referred to as HD-NTSC. This signal has all the appearances of a conventional NTSC signal, and can be edited, stored, transmitted, and received by conventional NTSC equipment. A receiver constructed to interpret the HD-NTSC protocol will be able to build an HD-NTSC image having substantially improved resolution in both the vertical and horizontal axes for those parts of the image that are nearly stationary over time. Those parts of the image exhibiting motion will show resolution equivalent to a conventional top-quality NTSC picture. The HD-NTSC receiver will also display the image at 60 frames per second, eliminating most interlace and flicker defects. An optional technique widens the image aspect ratio and creates bandwidth within the original NTSC standard large enough to transmit a digitally-encoded stereo audio signal to match the improved visual characteristics.

Background

With an estimated 132 million NTSC home television receivers in use in the United States alone[1], along with associated enormous investments in recording, editing, and delivery systems, it is no surprise that many in the television industry are taking a wistful but cold look at the spectacular picture quality afforded by the NHK HDTV process[2]. It is not enough that someone has realized that a better picture lies in higher line count and much higher bandwidth; this should be obvious to anyone who has spent more than a few casual moments learning about the television process. The real challenge is in delivering an HDTV-like picture to the masses on an economical basis.

The great assets of HDTV are also, ironically, its drawbacks. It is <u>too</u> different from the solidly-entrenched NTSC standard to fit gracefully within the conventional delivery systems. It appears that even if new Direct Broadcast Satellites are used to broadcast to consumers equipped with half-meter diameter rooftop dishes operating in the 12 GHz K band, the associated costs per channel for both broadcaster and consumer will be very high[3].

Wendland[4] mentions that the television industry could support several standards, depending on the application. For example, television studios could rely on an HDTV-like process in order to maximize quality at the source and approach a "35mm film" look[5]. The software created by the studios could be edited and stored using HDTV-specific hardware, displayed in theaters on HDTV equipment via fiber optic trunks, video tape, or perhaps in a slightly coarsened form via DBS satellite (NHK's Muse protocol[6]). Meanwhile, another standard

such as NTSC could coexist to serve those functions it does best, such as to retain compatibility with the enormous base of installed hardware.

The best of all worlds would be if some process were available that remained wholly within the world of NTSC while retaining most of the image quality of HDTV. This paper proposes such a process.

NTSC Defects

In viewing the image created by a typical NTSC receiver we see that it is flawed in a number of respects, including the following:

1. General Defects:

(a) **Aspect Ratio:** Back in the days when the original NTSC specification was drafted, a 4:3 ratio was chosen because 35mm movie film had a similar ratio, and the viewing public was comfortable with that format. Today, of course, the "wide-screen" look is common, and in fact studies at NHK as reported by Fugio and others[7,8] demonstrate that a 5:3 or even 2:1 ratio is preferred. It is not clear whether the viewers say so because they are familiar with high-quality images in movie theaters with these aspect ratios, or because these aspect ratios are a better match to the human visual system.

(b) **Limited Vertical Resolution:** Out of 525 scanning lines, only 483 are "active" in creating an image. The other 42 lines comprise the Vertical Interval and are used for timing, retrace delay, and transmission of non-image data, such as test signals and close-caption services. Under the best of circumstances, then, we could expect to resolve 483 lines (242 black-white line pairs or cycles), but in reality several effects conspire to reduce that figure substantially: the "Kell Factor" and an "Interlace Factor" reduce observable resolution as measured by test pattern wedge to at most about 330 lines[9].

(c) **Limited Horizontal Resolution:** An assumption that horizontal resolution should approximately equal vertical was made, thereby fixing the horizontal figure at 330 lines also (440 lines for the full screen width). Achieving this resolution requires a frequency response flat to about 4.2 MHz. This upper frequency limit cannot be easily extended, since television channel allocations are for the most part immediately adjacent with each other[10].

(d) **Very Limited Chrominance Resolution:** Based on studies of the human visual system, it was decided to take advantage of the eye's limited color resolution by similarly limiting the frequency response of

the chrominance system. Since the eye can resolve some colors better than others, NTSC uses a two-axis scheme, with one axis (Q) limited to just 500 KHz bandwidth and the other (I) good up to 1.3 MHz. Though this scheme has proved to be an excellent means of fitting chrominance information into what was originally a monochrome transmission standard, production facilities are finding it much more effective to work with RGB primaries or Y, B-Y, G-Y components during editing in order to minimize image degradation. Only the finished product is then encoded into an NTSC composite signal suitable for broadcast.

2. Interlace Defects:

(a) **Interline Flicker:** This term (which some researchers in Britain refer to as "twitter," a richly descriptive definition) refers to the flickering effect caused by the horizontal borders of objects on the screen. It is the result of having too much resolution in the camera--for example, line 51 (odd field) is turned on, while line 52, the line immediately adjacent (even field), is black. Line 51, representing the edge of some object in the image, will then be flashing on the screen at a 30 Hz rate, a rate low enough to be irritating.

(b) **Line Crawl:** Due to the short-persistence phosphor used in modern CRT displays, an individual line on the screen decays very rapidly in brightness; a new line then appears 1/60 th of a second later just above (part of the next field). It is very easy for the eye to jump to the new line, which is then followed by a new line a short distance above, and so on. The net effect is that the eye is fooled into thinking that the line is actually moving upwards (or downwards) at a rate that will traverse the height of the screen in about 8 seconds. Once the eye is locked into this moving pattern it no longer "sees" a 483 line image, but rather one comprised of just 242 lines, and image quality thereby suffers.

(c) **Vertical Aliasing:** An effect also resulting from the short-persistence of the CRT phosphor, vertical aliasing is the result of sampling an image having vertical detail with just the 241 active lines that make up one field. The Moiré patterns created would be cancelled out by similar patterns created by the following field, but the eye/screen combination does not integrate the two fields completely, and the result is a bizarre "busyness" on the screen that accompanies vertical detail (the tweed jacket example).

(d) **Interlace Factor:** Conventional scanning practice using tube imagers requires that a choice be made between high resolution (small scanning spot size) or low lag (spot size large enough to completely "drain" the image charge during one field scan)[11]. Because of interlace, the image is scanned with only half of the 483 line total at a time, and spot size must be enlarged to ensure that all active area is drained of charge. Because of this,

our effective resolution is more what one would expect for a 242-line system. Research at NHK[12] has suggested an interlace factor of about 0.6, reducing vertical resolution by that value compared to an identical image progressively scanned.

3. Miscellaneous Defects:

(a) **Static Raster:** As television displays grew in size and quality, viewers began to be able to see the individual scanning lines making up the frame, which many find objectionable. Simply defocussing the scanning spot would have the drawback of reducing horizontal definition at the same time.

(b) **Large Area Flicker:** Studies show that the eye is capable of perceiving varying scene brightness up to a surprisingly high frequency, depending on field of view and brightness level. For normal viewing levels, the 50 Hz Pal/SEACAM European television field rates are probably too low for many, and tests have shown that 100 Hz is clearly high enough for even the most critical. The 59.94 Hz NTSC field rate is satisfactory for most, though purists will probably object when viewing a bright image from a relatively close distance. "Screen Flicker" is a different effect than the perception of motion from viewing a series of still pictures; recall that the film industry discovered many years ago that although a repetition rate of 24 still frames per second provided a convincing illusion of fluid motion, the screen flicker was highly irritating,which was solved by flashing a single frame twice before advancing to the next, effectively doubling the flicker rate to 48 flashes per second.

(c) **Cross Color:** This is the effect of viewing bizarre color patterns in the weave of a newscaster's tweed jacket, and is a result of the NTSC's mixing of high-frequency luminance and chrominance information in the same composite signal. This effect can be minimized by either limiting the luminance bandwidth to about 3 MHz (the inexpensive route and popular up until a few years ago) or by employing a comb filter to "sieve" the chrominance information from luminance.

(d) **Cross Luminance:** The result of color information leaking into the luminance channel, particularly on a monochrome receiver. The effect is a matrix of closely-spaced dots on a monochrome screen. Cross Luminance can be eliminated by the same techniques mentioned above for cross color.

(e) **Temporal Aliasing:** The classic effect of wagon wheels appearing to turn backwards is the result of the 30 frame per second sampling rate. It has been suggested that interframe processing might filter out such

defects, though one might argue the public is quite familiar with the aberration and accepting of it after having viewed countless John Wayne westerns.

Proposals by Others in the Industry:

The current thoughts (as reflected in industry journals) seem to be divided into several camps, namely, those proposing improvements totally compatible, quasi-compatible, or incompatible:

(a) **Totally Compatible with NTSC:** Wendland, Nadan[13], and others[14] have proposed attacking the interlace and flicker defects by use of a frame store in the receiver. Such a frame store could read field data at the transmitted rate, but then display a complete frame at a much higher scan rate. Elimination of the above-mentioned defects should increase vertical resolution by perhaps 25% as well as make for a much more pleasing display. Such a process would do nothing for horizontal resolution. Wendland also mentions that diagonal sampling[15] would more closely match the resolution characteristics of the eye, and provide for greater horizontal resolution. Chroma/luma separation defects can be minimized using techniques such as adaptive digital comb filtering[16,17] and luminance/chrominance prefiltering before encoding[18].

(b) **Quasi-Compatible with NTSC:** In this category are those processes that take the original NTSC signal and effectively increase resolution by appending an additional NTSC channel. Efforts by Glenn[19] and LoCicero[20] have taken this approach; a conventional receiver continues to receive a conventional picture, while a "smart" set will simultaneously tune two channels and create a high definition image from the two signals using a variety of techniques. While there is no doubt this approach can be made to work, it seems a shame to sacrifice additional channels in the process, considering that the FCC has already cut out UHF channels 70-83 for mobile phone service and assuming that public demand for channel capacity will continue to increase. One is also reminded of Murphy's Laws, which will surely create technical challenges for a system involving <u>two</u> separate channels.

(c) **Incompatible with NTSC:** We here define "incompatible" to mean any coding or transmission process that cannot be directly received and normally presented via a conventional NTSC receiver. HDTV would of course fit the description, as would the reduced-bandwidth NHK Muse format. There is much to recommend the Multiplexed Analog Component (MAC)[21,22] format, but it too requires a decoder before the signal is usable by a home receiver. As mentioned in the beginning, this is not to say that these various

improved formats might not find a valuable place in the production environment, much as component (versus composite) video is becoming an accepted means of minimizing signal degradation during editing.

Assumptions Underlying the Creation of the HD-NTSC Process:

In creating a "new" transmission format, a number of factors had their influence, namely:

1. Acceptability to the FCC:

(a) Absolute direct compatibility with the NTSC standard must be maintained. The new process must be able to provide a conventional NTSC receiver with a conventional picture without any need for "black box" converters.

(b) The new process should not require additional bandwidth in the form of additional NTSC channels. The public will demand more, not fewer, channels as time goes by, and to sacrifice extra channel capacity in the short term would no doubt be regretted later.

2. Marketability:

(a) The new process must provide an obvious improvement in picture and/or audio quality with little if any tradeoff. By definition.

(b) A receiver using the new process should be immediately recognizable as such by some distinguishing characteristic. Since the new receiver will carry a premium price, it needs something that really sets it apart from the crowd. A screen with a wider aspect ratio would make for instant physical identification, even when the receiver is not operating.

3. Technology Trends:

(a) Signal processing "horsepower" is cheap today, and memory costs are continuing to drop by perhaps 50% every few years.

(b) Digital processing is gradually overtaking analog in the world of television.

(c) Direct-Broadcast Satellites will one day be practical, but the added channel capacity will at best supplant NTSC broadcast services, not eliminate them. This will be especially the case if an improved NTSC process is able to approach the broadcast quality of NHK's Muse system.

(d) Solid-State imaging chips will obsolete vacuum tube devices within a few years, creating the possibility someday of a one-chip digital camera.

The HD-NTSC Process--Description of Operation

The NTSC Pixel

Under ideal conditions, the NTSC process is able to present an image comprised of 483 active lines. If the effects of scanning device integration are minimized, then we can say that the vertical dimension of the smallest resolvable object would have a height equal to 1/483rd the screen height.

In a similar fashion, for a system having a Y bandwidth flat to 4.2 MHz, 220 complete black-white cycles could fit on the active portion (52.5 us) of a single horizontal line. If we define our pixel to be two to a cycle (one white and one black) then our smallest divisible area will have a width 1/440th the screen width.

Note that this derivation is exclusive of such considerations as overscan and Kell Factor. We are instead regarding the image as similar to one created by a personal computer (i.e. one pixel for one memory location), and are asking what the dimensions are of the smallest addressable point on the screen, a valid question. Figure 1 indicates that our pixel is actually rectangular in shape, having a horizontal dimension 1.46 for a vertical dimension of 1.

In Figure 1 we had chosen a rectangular form to represent our pixel. The actual light distribution will, of course, not be rectangular on a CRT display, but will instead take on a Gaussian shape (actually, new display technologies such as liquid crystal would presumably see no reason to have to mimic the Gaussian pixel shape, and probably will have pixels that are polygonal in form). Suffice it to say that any geometrical shape for our pixels will do, as long as it provides a reasonable approximation to the actual light distribution, and that the pixels collectively describe the entire imaging area. For example, pixels comprised of triangles are shown in Figure 2.

One way to increase the number of addressable points of an image is to subdivide our pixels into smaller units, termed Subpixels. Figure 3 illustrates our earlier triangular pixels split into a "Trio" of subpixel areas labelled 1, 2, and 3.

The TriScan Concept

Imagine a "smart" television camera that was able to scan only Subpixel "1" areas on the first pass. After finishing the frame 1/30th second later, it would begin again, but this time just hit the Subpixel "2" areas, and finally Subpixel "3" areas. What we would have done (assuming the camera/imager system was capable of resolving subpixels) was to have tripled the number of pixels transmitted through the system. This is referred to as the "TriScan" technique, and is further described in Figure 4.

What happens on the receiving end? A conventional NTSC receiver knows nothing about subpixels, and will simply paint areas 1, 2, and 3 on top of each other as they come across on successive frames, resulting in an image identical to before. A "smart" receiver however would (given a suitable sync pulse to tell it when Subpixel 1 areas were coming across) be able to reconstruct the same image seen by the camera by placing subpixels in their correct offset positions on the CRT. Note, however, that we cannot get something for nothing, and what we are sacrificing is temporal resolution--it will now take 3/30th or 1/10th of a second to build a complete high resolution image. For stationary objects this is no penalty, nor is it for abrupt scene changes, as Seyler[23] has demonstrated that the human visual system requires about 1/2 second to perceive fine detail on the screen following an abrupt scene transition.

With a conventional short time-constant CRT phosphor, the reduced refresh rate 1/10th second for any one subpixel area will have the effect of image scintillation[24], not unlike looking at stars on a clear night. This effect can be minimized by increasing the phosphor time constant, though at the cost of smearing rapidly-moving objects. An alternative is to use a display buffer, which appears doubly attractive due to miscellaneous benefits cited earlier by others in the industry.

Even with a display buffer, our high resolution image will show a defect in displaying objects in motion. Such objects will appear to have a "smear" also, though of a different decay shape from the typical phosphor time-constant curve. This new smear will take on the form of "shadow bands" trailing behind sharp scene brightness transitions, due to the delay in updating the various subpixels being affected by the motion, as outlined in Figure 5. This smear will occur for vertical as well as horizontal motion.

The receiver must have some way of synchronizing with the source regarding subpixel frames 1, 2, and 3, and therefore a TriSync Pulse is transmitted every third frame. This pulse can be located anywhere within the vertical interval (perhaps as part of a VIT or VIR signal), or in a new "Data Window" to be described shortly.

In addition to providing synchronizing information, the TriSync pulse indicates by its absence when a conventional NTSC signal is being transmitted, and HD-NTSC receivers can readjust accordingly.

Summarizing, we have created a mechanism via the TriScan process, that:

1. maintains complete compatibility with NTSC equipment, because the signal transmitted is an NTSC signal;
2. can be received by a conventional NTSC receiver to produce a conventional NTSC image;
3. is capable of producing a high-resolution image on a receiver that knows about subpixel Trios;
4. will produce a high-resolution image for still or slow-moving objects on the screen, but will exhibit a sort of "smear" for objects in motion.

The Dual Resolution Processor

The function of the Dual Resolution Processor (DRP) is to convert those parts of the image that are in motion into a low spatial resolution (but high temporal resolution) format. It does this without the need for any motion vectors such as proposed for the NHK Muse system, and without any additional information transmitted with the NTSC signal. Although a detailed description is outside the scope of this paper, Figure 6 shows the basic idea. The DRP circuit determines, on a real-time basis, the amount of movement present in a scene and adjusts between the High Spatial Resolution / High Temporal Resolution modes accordingly.

Aliasing

The subpixel samples contain frequency information ranging, conceivably, up to one-half the original sampling frequency. When viewed via a conventional receiver, or for those portions in motion on an HD-NTSC receiver, aliasing will occur, since the frequency content could easily exceed the Nyquist frequency of the subsampling rate. It is felt, however, that the relative high-frequency content will be rather small for most scene material, and aliasing effects should be quite minor[25].

Edge Effect

One possible effect of viewing an HD-NTSC signal via a conventional receiver might be the appearance of a 10 Hz flicker located at sharp luminance transitions; for example a black box surrounded by a bright

background. This effect is caused by the three subpixels making up a pixel located right at the box edge having significantly different luminance values. If this proves to be significant enough to be distracting, the set's sharpness control can be adjusted to reduce high-frequency response. Another option is to limit the luminance frequency response at the source to a value somewhat less than maximum. In any event, it can be argued that the average viewer will tolerate a moderate amount of edge flicker, since he or she has already experienced the effect and accepts it as normal, like the backwards-turning wagon wheel effect (temporal aliasing) described earlier.

HD-NTSC Aspect Ratio

The primary focus of this paper is the compatible increase in resolution using the TriScan technique. A secondary focus is to investigate another concept that would serve to shape NTSC in line with current thinking. Studies mentioned earlier have indicated that the average viewer will strongly prefer a screen having a wider aspect ratio, up to a limit of about 2:1. What format do we choose for our HD-NTSC system? There are several options:

--The obvious option is to keep 4:3. This is the simple solution, but it means that there will be one less reason for a consumer to buy an HD-NTSC receiver. We have considered this option to be unacceptable in light of the expressed strong preference for a wider format in the literature, as well as the need for a unique marketing characteristic.

--an anamorphic-type process similar to that used in the film industry (having the same problem of adapting a wide-screen format to the 35mm 4:3 film format) could compress horizontal information that would be viewable in that condition on a conventional receiver, or decompressed for display on the wide-screen receiver. This approach is analogous to the Dolby-B™ process with audio cassette tapes; the source is encoded, and the cassette tape can be used as-is without decoding, though without benefit of noise reduction. The only reason consumers accept this compromise is because inexpensive non-Dolby decks usually leave something to be desired in the high-frequency range anyway, so boosting the highs on playback can't hurt much.

The same is not true of the anamorphic process. A viewer will tolerate a significant geometric distortion only for a limited time, as one can learn for oneself by watching the horizontally-compressed film credits on some televised material. Therefore, given the requirement for compatibility with NTSC receivers, horizontal compression is out.

--Yet another approach is to use the multichannel NTSC. While, say, channel 4 would provide the NTSC backbone signal, channel 44 might supply the extra image data that could be assembled by a new receiver process. As discussed earlier, this approach robs frequency spectrum, and while it certainly could be made to work given the effort, it will not be considered further here. We are looking for a process that does not need to resort to such tactics.

--The wide-screen image could be reduced slightly in size both horizontally and vertically so that it just fits within the NTSC horizontal dimension. If we were to settle on a 14:9 aspect ratio (nearly identical to the 15:9 that Japanese test subjects strongly favored over conventional 4:3) then we would be forced to sacrifice only about 14% of the vertical image dimension, and the sacrifice would actually be less than that, as explained later.

Accordingly, the new HD-NTSC standard provides for a 14:9 aspect ratio, attained by keeping the full width of the conventional presentation and reducing slightly the vertical dimension from 483 active horizontal lines down to 414, as shown in Figure 7.

This new aspect ratio is different enough from conventional NTSC that one will immediately recognize a receiver built to the HD-NTSC specification, even when turned off. This distinction is actually very important for marketing considerations; though the digital hardware that is part of the new process will rapidly drop in cost over time, a purchaser will still be paying a premium price, and it is important to provide ample justification for the differential price. In other words, not only does the HD-NTSC receiver provide a far superior picture with a more pleasing aspect ratio, but it also just <u>looks</u> newer. (Remarkably, a 14:9 aspect ratio is very close to the "Golden Mean" rectanglar shape that ancient Greek artists revered so highly. An interesting coincidence.)

An immediate question becomes what one's reaction will be when viewing such a "chopped" picture on a conventional monitor. It first needs to be noted that a typical home receiver does not even show a full 483 scan lines, due to overscan (to allow for adjustment drift and undervoltage). If a 10% overscan is employed, the viewer sees about 435 lines, so the HD-NTSC image represents a vertical shrinkage of only about 4.8%, with 2.4% above and an equal gap below. With the recent trend towards less "rounding" of the receiver image, a clean cutoff top and bottom might even be preceived by the public as an improvement in its own right, even though the image is very slightly smaller in the vertical direction. Figure 8 demonstrates the effect.

One might classify television viewers into two general categories, the "laid-backs" and the "fanatics". A laid-back viewer will probably not even notice the vertical gap at first, and upon being told, his or her reaction

will probably be indifference, especially when it is also explained the new aspect ratio allows for greater fidelity with the original source material, eliminating bothersome mechanical pans that were required to fit wide-screen action within the narrow confines of the NTSC window.

A fanatic, on the contrary, will notice the difference immediately, but the criticism from this minority group will fade quickly, since a fanatic by definition has to have the latest hardware on the block. What was before an annoyance is now the greatest advance since color, as he will gladly demonstrate at his next party!

In summarizing, it is believed that although the vertical shrinkage technique will no doubt be challenged by senior members of the television standards community, it is the only way a wide picture can be carried over a single totally compatible NTSC channel, and upon further reflection the penalty is remarkably small, thanks to overscan. The writer believes the situation is analogous to the standard switch from monochrome to color back in 1953; going to color meant the appearance of a fine dot structure on a monochrome reciever (the chrominance sidebands) and an effective cut in luminance bandwidth to about 3 MHz (before the recent use of comb filters). This technique should cause no reduction in vertical resolution on a conventional receiver, since the slight loss due to the reduced image height will be compensated by a much better Kell Factor as a result of a more tightly controlled camera scan.

As mentioned earlier, the TriScan process is equally adaptable to either the old 4:3 or the proposed 14:9 aspect ratios. Choosing the better aspect ratio is a decision that will certainly be easier to make as public tests are conducted in the future.

Use of the HD-NTSC Data Window for Digital Audio

The HD-NTSC format creates 69 horizontal lines per frame that is no longer needed for the transmission of image information. This "Data Window" is available for other information; one interesting possibility is to encode stereo digital audio information. The recently-adopted MTS stereo format has been very favorably received by the public, proving the marketplace is willing to pay for higher quality. It would make sense that if we are substantially upgrading the visual portion of the NTSC system we should be taking a hard look at doing the same for audio. Now that consumers have been exposed to exceptional audio in the form of Compact Disc and VHS/Beta Hi-Fi, they will probably be highly receptive to audio of similar quality delivered over the HD-NTSC format.

The 69-line Data Window is capable of carrying a data rate of about 600 Kbits per second, using conventional encoding developed for the Teletext environment. This rate is able to support a stereo digital audio process based on adaptive delta modulation[26] that can accommodate the following audio specification:

Parameter	HD-NTSC (delta modulation)	MTS Stereo
Frequency Response:	20 Hz ~ 16 KHz	50 Hz - 15 KHz (13KHz typical)
Dynamic Range:	85+ db	45 db typical
Distortion:	less than 0.2%	less than 2.5%
Channel Separation:	60+ db	25 db typical at receiver

It will be important to choose modulation level carefully, since a conventional NTSC receiver will display such audio modulation on the very top and bottom portions of the screen. Due to the robustness of digital encoding, perhaps only transitions from black to dark grey will be necessary, rather than the 0 to 66 IRE Unit swing that teletext employs. With the plummeting costs of digital hardware it is conceivable that automatic adaptive filters in the receiver can be used to not only maximize Data Window security but also provide for a ghost-free video image.[27,28]

HD-NTSC Signal Sources

Because of the very fine resolution required to consistently scan subpixel areas, an HD-NTSC camera must use technology originally developed for the HDTV process. The camera must be able to resolve 828 horizontal lines and 1320 samples per line, within a scanning window having a 14:9 aspect ratio. Such performance is obtainable with the special imaging tubes currently used in HDTV cameras. In the near future, it is expected that technology advancements will allow the construction of a solid-state imaging device capable of this performance level and free of the complex calibration procedures currently needed by tube-type imagers[29].

A viable alternative is to work with HDTV images. HDTV uses 1,030 active lines, a Y bandwidth of 30 MHz, a 16:9 aspect ratio, 60 fields per second, and a 2:1 interlace. The 1,030 lines can be down-converted to 828 using a 5 to 4 conversion, aspect ratio cropped slightly, and the different field rate requires that one frame will be discarded every 1,001 frames.

Color Frame Compatibility

It takes four fields, not just two, before the NTSC scan process and the chrominance subcarrier phase both return to the starting condition. Professional editing policy dictatates that cuts be made only at these "Color Frame" multiples of four fields in order to avoid a slight "glitch" or "jump" in color at the edit point.

Since the HD-NTSC process involves a three-frame cycle, it would appear that we would now be allowed to cut only after every six frames, or 1/5th second. Fortunately, the inability of the eye to see fine detail for about a half-second after an abrupt scene change (as mentioned earlier) will effectively mask the fact that the HD-NTSC image reverts back to conventional resolution for three frames after an edit. We will still be allowed to edit using the Color Frame concept.

The HD-NTSC Receiver

As mentioned earler, the most striking characteristics of the HD-NTSC receiver will be the wide screen and the large viewing angle. Earlier efforts by Japanese vendors[30] have utilized several approaches, including screen masking of conventional high-quality CRTs and the development of totally new CRTs with the wider aspect ratio already built-in.

It can be assumed that the least expensive technique by far is to adapt current projection hardware to the new format. The very nature of HD-NTSC begs for large images, and it is debatable whether CRT displays of sufficient size will ever be available at a suitable price for the mass market. Figure 9 shows a rear-projection HD-NTSC receiver alongside a conventional NTSC CRT-type receiver. An average viewer about ten feet distant could just make out the smallest detail that both sets could display, assuming a Kell factor of ~.65 for the NTSC receiver and ~.9 for the other.

Figure 10 illustrates a functional block diagram of an HD-NTSC receiver with new circuits outlined in boldface. It can be seen that very little has changed with the exception of the final stages. In the absence of a TriSync pulse the receiver reverts back to conventional NTSC processing.

Chrominance

Throughout this discussion we have been referring to just the Y (luminance) signal, not the chrominance components. To ignore color completely would be incorrect, for our final image would have terrific luminance resolution but somewhat vague color placement, akin to the effect one gets by colorizing an old black and white

film. However, up until just last year[31] the I bandwidth in modern NTSC receivers was arbitrarily limited to .5 MHz even though the broadcast signal contained information out to 1.3 MHz[32]; by expanding the I channel in our HD-NTSC receiver out to the full width (employing new filter techniques to eliminate Cross Color and Cross Luminance) we will have achieved a substantial sharpness increase for much of the color spectrum without having to resort to temporal integration as we have done with the luminance channel. Image defects resulting from imperfect separation of luminance and chrominance signals are beyond the scope of this paper, but new processes (such as luminance pre-filtering before encoding for transmission[33]) should yield great improvements in this area also.

HD-NTSC versus Muse

Though Muse and HD-NTSC originated from two entirely different environments and have two entirely different design goals, there are some similarities. We'll start by taking a closer look at Muse:

First announced by NHK in January 1984, "Muse" (**Mu**ltiple **S**ub-Nyquist Sampling **E**ncoding) is a technique that allows a wide-bandwidth HDTV signal to be compressed in order to fit within the 8.1 MHz confines of a Direct-Broadcast Satellite. Muse accomplishes this objective by sub-sampling the original luminance channel; that is, the original luminance signal is "chopped" or sampled into discrete time increments and temporarily put into storage. Those samples are then recalled from memory in a particular sequence and at a much slower rate. After reassembly, they are then transmitted to a Muse decoder at the receiver, where they are again put into temporary storage. After all the samples have been delivered, the receiver is then able to display an image very similar to the original.

In order to minimize the smear caused by motion, several techniques are employed, such as the transmission of motion vectors that can be interpreted by a Muse receiver. Luminance and chrominance signals are time-compressed and transmitted serially, similar to the MAC concept.

Personal observation of the Muse encoding/decoding scheme in action at the Dallas NAB in April 1986 confirmed for the writer that Muse works well for most progam material. The only shortcoming seemed to be a definite "softening" of background detail the moment camera panning begins. One sequence, for example, was of a track event at the Los Angeles Coliseum during the 1984 Olympics. As the runners start and the camera begins panning to follow them, the sea of faces in the stands behind the runners suddenly softens. This effect is

probably preferable to smear, but it was easily noticed. This is an example of the danger of image processing--some compromises have to be made, and those compromises can create unintended side effects.

Similarities

--Both Muse and HD-NTSC use the subsampling philosophy, but towards entirely different ends and with substantially different sampling patterns, as shown in Figure 11. Muse requires four fields to complete; HD-NTSC takes six.

--Both deliver an image with a wide aspect ratio.

--Both deliver high quality digital audio.

--Both Muse and HD-NTSC are able to use HDTV information as a source signal.

--Both rely heavily on sophisticated digital processing.

--Both processes employ techniques to reduce the effect of motion within a scene, though the techniques differ.

--Both use a single channel (though channel bandwidths are substantially different for the two).

Differences

--Compatibility with NTSC. No contest here, but it's really comparing apples and oranges. Muse was conceived to be a satellite encoding system and totally ignores NTSC, while HD-NTSC was specifically designed with compatibility in mind.

--Muse is capable of delivering a higher-definition image comprised of 1,030 pixel rows (V) and 1,496 pixel columns (H), while HD-NTSC displays 828 pixel rows and 1,320 pixel columns. We're using the rows and columns nomenclature here rather than "pixels" since both Muse and HD-NTSC use an offset pixel technique to maximize pixel efficiency. However, while a side-by side comparison would give the nod to Muse, both should offer such an obvious improvement over regular NTSC that Muse-versus- HD-NTSC resolution will be an issue only within the engineering community.

--A Muse signal is not subject to the cross-contamination of luma and chroma that bothers NTSC, since there is no interleaving of luma/chroma information. In addition, chroma bandwidth in Muse is much wider. Muse wins here, though new developments are continuing to improve NTSC chrominance performance to levels thought unattainable a decade ago.

The HD-NTSC "Standard"

It has been shown, then, that the proposed HD-NTSC protocol is really nothing more than just an exact copy of the current NTSC standard, with the following modifications:

1. Provision for the inclusion of a TriSync pulse either in the vertical interval or in the Data Window;

2. Image aspect ratio change from 4:3 to 14:9 (reduction of active lines from 483 down to 414);

3. Use of the extra 69 horizontal lines as a Data Window for the transmission of digital stereo audio information.

Accordingly, it is recommended that the NTSC guidelines be amended with phraseology such as the following (subject to modification):

"1. A synchronizing pulse not to exceed the reference white and reference black signal levels may optionally be included in the transmitted signal. Inclusion of this pulse, to be known as the TriSync Pulse, will indicate that the signal includes additional information for the following six fields that may be interpreted by a receiver properly equipped. This TriSync pulse may not be transmitted unless the composite signal conforms to the modifications as outlined in this section.

"The TriSync pulse will be located within the vertical interval as part of a VIR waveform. The pulse must not cause timing difficulties or any other interference with equipment designed to operate properly with standard RS 170A. The pulse will be present no more often than every sixth field, and will be part of an odd field.

"2. If a TriSync pulse has been sent within the previous three frames then the visual information content of the signal will be derived from the TriScan process before encoding, as outlined elsewhere. A TriScan-derived signal must be receivable and conventionally viewable with equipment designed to operate properly with standard RS 170A.

"3. If a TriSync pulse has been sent within the previous three frames then the first 35 lines and the last 34 lines of the 483 active lines in a single frame may either be set at reference black or they may be modulated with a process conveying stereo audio information. The exact specification for the modulation process will be

published at a later date. The modulation process must not cause visual annoyance when viewed via a conventional receiver by a casual observer.

"4. With the above-named exceptions, no other deviation from the established guidelines will be allowed."

Conclusion

HD-NTSC has been described as having the following characteristics:

1. **Complete compatibility with NTSC studio and home hardware (Figure 12)**

2. **Transmissible over a single NTSC channel allocation**

3. **Capable of delivering a high-definition wide-screen image with minimal temporal degradation**

4. **Capable of simultaneously delivering a digital high-quality stereo audio program in addition to conventional MTS audio**

5. **Achievable using a technology exhibiting rapidly declining hardware costs.**

Classical marketing theory tells us that there are three distinct stages to a product's life cycle: growth, maturity, and gradual decline into obsolesence. NTSC has been the standard-bearer for television over the past four decades, but with new technology waiting in the wings in the forms of HDTV/Muse and MAC, it has clearly reached the mature phase of life, and will most certainly gradually slip into oblivion unless gracefully adapting to new modes of thought. The proposed HD-NTSC standard will allow NTSC to remain a robust delivery system for many years to come.

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