I FUTURE BROADCASTING AND HIGH-DEFINITION TELEVISION

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1. INTRODUCTION

NHK began studying what it calls "high-definition television" as a future television system about twelve years ago, which we labeled "HDTV".

Forecasting that the diversity and high level of a future information society would require high-definition television with visual information processing based on electronics technology, the initial research aimed at developing a TV system appropriate to this concept.

Prior to starting research and development of this TV system, extensive studies and tests were conducted regarding characteristics of the human visual system, physical requirements of the TV system needed to satisfy these characteristics, and the future television system expected and desired by viewers. Based on the results of this research, the provisional standards for high-definition TV were decided and all of the equipment needed within the system developed, including camera, film to video transfer, VTR, encoder, tansmitter and receiver, and display unit. Recently, a variety of field, transmission, and recording tests have been made, including satellite transmission, by using these units to verify the program effect with a high resolution and wide screen. Efforts have been made to verify the effects and to develop a system with wide ranging future applications, including for general imaging systems.

The results of NHK's research on high-definition TV have been shown to the public at annual exhibitions which the NHK Technical Research Laboratories have been sponsoring. All of the equipment has been in operation since 1978. Through three satellite transmission tests, a lecture tour in the United States, and through exhibitions, fairs, etc., the interest in high-definition television has further increased both in Japan and throughout the rest of the world, with both development and utilization being actively pursued.

2. WHAT KIND OF TV WILL BE NEEDED IN THE FUTURE?

2.1 Conventional TV and High-definition TV

While words and voice are descriptive, pictures permit the grasping of phenomena through direct viewing of large quantities of information, by visual systems which feature a high-level information processing capacity such as discrimination of differences in optical wavelengths as colors and pattern recognition. Pictures are also capalbe of transmitting large quantities of information at a single instant. The conventional TV system was established 40 years ago when a number of restrictions existed in radio-wave and hardware technology such as transmission lines, bandwidths, and display ability. Thus conventional TV systems fail to attain the level at which the functions of the human visual system can be effectively utilized. As a result, color TV can not be compared with movies or printing in terms of picture clarity, impact, or immediacy. This is why conventional color TV cannot thoroughly provide high level psychological satisfaction in terms of feelings and emotions.

For this reason, the TV system befitting a future information society will require expanding the framework of conventional TV to overcome its limitations so that the future system can appeal to a higher level of psychological sensation and emotion by transmitting highly intellectual information with detailed characters and graphics and by transmitting the quantity of information appropriate to new forms of visual expression.

2.2 High-definition TV System from the Perspective of Vision Characteristics

The TV system as the visual system of the future must be decided through consideration of information content to be transmitted and high level of psychological characteristics. The frequency characteristics of the eyes when viewing television are LPF type as shown both spatially and temporally in Fig. 1, and are such that the eyes fail to detect fine detail and sense high speed flicker. For this reason, the framework for TV system standards such as the number of scanning lines, number of images per second, and signal bandwidth, can be calculated from the physical characteristics of the visual system once viewing conditions are determined[1].

Table 1 shows the specifications of the TV system that correspond to the visual system[2]. The specifications show the TV standards required in terms of characteristics of the visual system, i.e., number of scanning lines (n) and signal frequency bandwidth (f_b), relative to various viewing distances from the TV. The viewing distances dH in the table are expressed by multiples of the screen height H. What is meant by 4 H is to watch TV at a distance

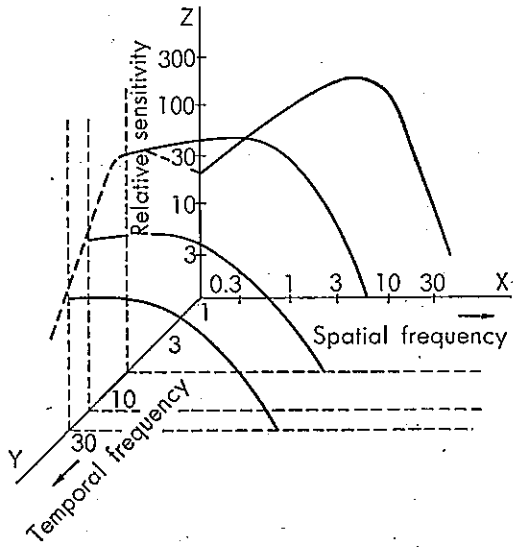


Fig. 1 Response of the human visual system.

Table 1 Required number of scanning lines as a parameter of viewing distance

Viewing distance (dH)	4H	3.3H	3H	2.5H	2H	7.2H
n (lines)	940	1125	1240	1480	1840	525
f_b (MHz)	11	16	19	27.5	42	2.8
Visual angle* (deg.)	23.5°	28.3°	31.0°	36.9°	45.2°	10.7°

when $a=5/3$, $\eta_v=0.935$, $\eta_h=0.835$
*Visual angle in horizontal direction viewed from optimum viewing distance of the system

four times the height of the screen. As this table shows, conventional TV is a video system with an optimal viewing distance of about 7 H. Watching the screen at a distance nearer than this, the viewer would find the picture coarse and blurred.

Then what should be the viewing distance for the future TV system?

Television is a system for taking moving pictures such as those of sports athletes and flying objects. However, the visual system cannot follow when the object is too fast. When the viewer sees pictures moving at a high speed from a distance which is too close to the screen a dizziness and fatigue would be felt. A test with movie films and TV pictures to determine what would be the ideal distance to watch moving pictures has shown that the minimum viewing distance permitting the viewer to watch moving pictures for a long time without fatigue is about 4 H[3][4][5]. As a result, the viewing distance for the future TV should be:

(a) A video system with a viewing distance of 4 H is recommended for movies, animation, and sports programs with quick movements.
(b) Pictures with fewer or slower movements are watched nearer to increase psychological effects such as immediacy, and the system should be such that pictures can be seen satisfactorily even at a distance of about 3 H[1].

This means that future TV systems will require 1200 scanning lines and a signal frequency bandwidth of about 20 MHz so that the picture quality does not degrade when watched from a viewing distance of at least 3 H.

2.3 TV Screen System that Satisfies Psychological Effects

We have already experienced with movies and other media that psychological effects such as immediacy and impact can be obtained by projecting beautiful, high-resolution pictures on a large screen.

By displaying a clear picture in a wide visual field as explained above, the area of the picture display and the space conciousness of the viewer almost converge, and the sense of presence of the display system is reduced, while the pictures themselves are felt with depth and naturalness. Such a psychological effect begins to develop at a viewing angle of 20 to 30° surrounding the display screen[6].

For this reason, the most effective technological means of producing psychological effects, such as immediacy and impact, with future television would be to widen the display screen. As shown in Table 1, the viewing angle at the optimal viewing distance of the conventional television system is up to 10°, and with these values pictures cannot be expected to be psychologically satisfying. To convert this system to a realistic future TV screen system with a viewing angle of at least some 30°, the viewing distance should be about 3 H, and the screen should be wider than the conventional screen. When the viewing distance is fixed, a large screen wider than that of the conventional television system will be required.

2.4 Viewer Expectations Regarding Future TV Systems

The items shown in Table 2 were studied and tested to determine the screen system and picture quality viewers expect in the future television system. In these experiments high definition computer simulated still pictures were used by changing the number of scanning lines and signal bandwidth. (4″×5″ and 8″×10″ slide pictures); 70 mm movie films; a high-definition TV system operating with variable scanning lines and interlace ratio (monochrome, 265~2125 scanning lines); and picture reproduction using an experimental high-definition TV system on a high-resolution large-screen display newly developed by

Table 2 Viewers' requirements and HDTV standards

Factors		Items		Equipment and systems used (※)	HDTV system
Viewing		Desirable viewing distance		Movie F, Slide F, Simulation F	HDTV Standard
Picture aspect		Aspect ratio		Slide F	HDTV Standard
		Picture size		Slide F, Simulation F	Quality factor (Q)
		Contrast and brightness		〃 〃	Quality factor (Q)
Scanning system		Effect of interlace scan and nonlinear scan		Variable-scan TV, Simulation F	Quality factor (Q)
Picture information	Still picture	Y	n	ST-TV, HDTV, Variable-scan TV	Quality factor (Q)
			f_b	HDTV, Simulation F	Quality factor (Q)
		C	Transmission primaries	ST-TV, HDTV	Preferable color
			f_W, f_N	HDTV, Simulation F	Signal Standard
		Y⇄C crosstalk		ST-TV, HDTV	Signal Standard
	Moving picture	Smoothness, Tracking, Desirable resolution		16mm film, ST-TV	Frame frequency, Display system
	Noise impairment, Desirable S/N			ST-TV, HDTV	Broadcasting system, Size
Note	(※) Movie F : Movie films (35mm, 70mm) ST-TV : Standard TV system Simulation F : 4″×5″, 8″×10″ Simulated slide HDTV : HDTV system Slide F : 4″×5″ Slide				

NHK[7]~[10]. The results of these tests have shown the following that are important in designing high-definition television system:

(a) In the future TV system, a large screen with an aspect ratio larger than that of the conventional TV will be absolutely necessary.

(b) For a TV scanning system to most effectively utilize signal bandwidth, a scanning system with a 2:1 line-interlace ratio is desireable.

(c) The picture does not blur even at a distance of 3 H when the luminance signal bandwidth is 20 MHz (aspect ratio 5:3) and the television has 1125 scanning lines.

Extensive studies and tests have been made as to what signals should be used to send future color TV information[15]. As a result of these studies, a system has been selected as a tentative standard[12] to transmit color signals corresponding to a broad-band axis of a spatial frequency characteristic of the chromaticity of the human visual system[11] and to transmit color signals corresponding to the chromaticity axis that crosses perpendicularly with this broad-band axis on the UCS chromaticity diagram.

2.5 Standard Desired for High-definition Television and Relative Position of NHK's System

Table 3 shows the basic standard for NHK's high-definition television set based on the results of the above indicated studies[13]. The number of scanning lines means this system has an optimal viewing distance of 3.3 H when viewed with the vision characteristics shown in Table 1. However, when the bandwidth of the luminance signals is chosen as 20 MHz, the picture quality of this system does not degrade significantly. This system is considered to meet the requirements desirable for the future TV system[14].

Table 3 Provisional standards for the HDTV proposed by NHK

Number of scanning lines	1125
Aspect ratio	5:3
Line-interlace ratio	2:1
Field-repetition frequency	60Hz
Video frequency bandwidth	
Luminance (Y) signal	20MHz
Chrominance (C) signal	
Wideband (Cw)	7.0MHz
Narrow band (CN)	5.5MHz

$$\begin{pmatrix} Y \\ C_W \\ C_N \end{pmatrix} = \begin{pmatrix} 0.30, & 0.59, & 0.11 \\ 0.63, & -0.47, & -0.16 \\ -0.03, & -0.38, & 0.41 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

Y : Luminance signal R : Red
C_W : C_W signal G : Green
C_N : C_N signal B : Blue

Until recently, equipment for high-definition TV has been developed in accordance with the standard contained in Table 3. Furthermore, pickup, transmission, and other tests have been undertaken regarding the broadcasting system.

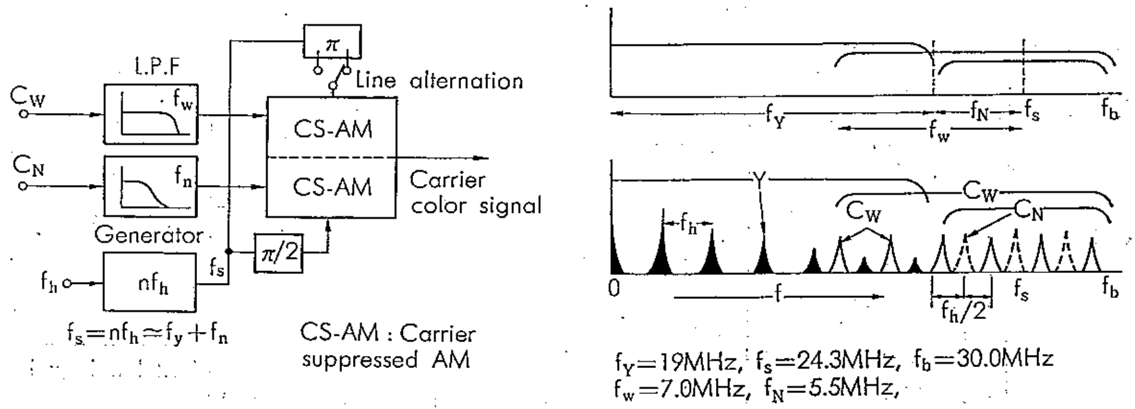
3. SIGNAL AND TRANSMISSION SYSTEMS FOR HIGH-DEFINITION TELEVISION

3.1 Signal System to Secure Beautiful and Stable Pictures[14][15]

The signal systems of standard color television are categorized into three systems, namely, NTSC, PAL, and SECAM according to the method used to multiplex the color signals onto the luminance signals. All these system have excellent characteristics for compatibility with monochrome TV. However, as future television signal systems to reproduce stable high-definition TV pictures, these systems require a review.

Considering a broadcasting and transmission system for high-definition TV, the vestigial sideband AM system (VSB-AM) will continue to be used as a broadcasting system high in frequency utilization factor. When broadcasting via satellite with low power, the FM system will be used. The signal system must have a mode that conforms to these transmission systems and that maintains stable picture quality. In both broadcasting systems, the condition for the signal system indispensable to high-definition television is that the system should not cause interference and disturbance between luminance (Y) and color (C) signals which would result in instable pictures.

Regarding the signal system for high-definition television, a study was made principally on a composite signal system to frequency multiplex Y and C signals in respective spatial and temporal frequency



(a) Block diagram of the chrominance modulator   (b) Frequency spectrum

Fig. 2 The HLO-PAL system.

domains and on a time compressed integration (TCI) signal system for time-division multiplexing of Y and C signals in one or two line units after time compressing them as to multiplexing of transmission signals—luminance signals Y and two color signals C: C_W, C_N shown in Table 3.

In the composite signal system, signal encoding and decoding are simple, and TV signal spectra can be utilized effectively. Another characteristic of this system is a high baseband signal frequency utilization factor.

In the TCI system, signal processing is not necessarily simple. However, the transmission quantity between Y and C does not become unbalanced very much depending on the broadcasting system[14].

When covering FM transmission, the system to transmit signals after splitting them, such as the mode of transmitting Y and C signals independently (YC separation system),[15] excels in transmission efficiency.

Figure 2 shows a composite signal[15] called the half-line offset subcarrier PAL (HLO-PAL) system. Even though its frequency utilization factor slightly decreases, there is no interference between Y and C; it excels in color resolution and stable picture quality with respect to transmission characteristic degradation, etc. It has been used in transmission tests employing optical fibers, terrestrial SHF VSB-AM, FM, etc.

3.2 Transmission and Broadcasting of High-definition Television[16]

Because high-definition television signals are broadband and high quality information transmission is required, SHF and EHF bands will be used in broadcasting as well as optical fiber cables. At WARC-ST in 1971 and at WARC in 1979, frequency bands for satellite broadcasting services were allocated and modified. In consideration of the possible start of new broadcasting services such as high-definition television, Japan was allocated bands of 22.5 to 23, 40.5 to 42.5 and 84 to 86 GHz. Satellite brodacasting is most economical for nationwide broadcasting, and development of transmission technology in the 22 and 41 GHz bands has to be actively undertaken.

4. DEVELOPMENT AND TESTING OF HIGH-DEFINITION TELEVISION EQUIPMENT

4.1 High-definition Television Equipment[17)-(20]

In order to carry out signal transmission tests and clarify hardware problems in broadcasting system configurations, a TV camera, various high-definition display units, a new film to video transfer unit (for 70 mm movies) using a laser-beam flying spot scanning system, VTR, color signal multiplexer, broad-band FM transmission and receiving units, satellite transmission receiver, etc, have been developed. Table 4 outlines all this equipment. The equipment has been tested to verify the picture quality and program effects of the high-definition wide-screen television, and still other experiments have been conducted using optical fiber cable and satellite transmission in an effort to achieve high-definition television broadcasting.

Table 4 HDTV equipment developed by NHK

	Scanning specifications	Cameras	Display devices	Encoders, Transmission equipment
Monochrome	265~2125 lines 50/60 fields 1:1~5:1 interlace ratios	2-inch RBS camera 1-inch DIS camera	27-inch CRT (4:3 aspect ratio)	Composite signal (NTSC, PAL, SECAM HLO-PAL Linear gamma system Y-C separate transmission device Wideband FM modulator, demodulator Optical fiber transmission devices
Color	1125 lines 50/60 fields 2:1 interlace ratio f_y: 19~20MHz f_w: 7.0MHz f_N: 5.5MHz	Live cameras 2-inch 3 tube RBS 1-inch 3 tube DIS Film cameras 1.5-inch 3 tube vidicon 70mm 2-3 pulldown movie projector Laser FSS (continuous running)	Laser display 22-inch CRT (a=4:3, P=310μm) 26-inch CRT×3 (0.5m×1.0m size) 30-inch CRT (a=5:3, P=340μm) 55-inch projector (3 tubes) Light-Valve 26-inch CRT (a=5:3, P=370μm)	VTR (analogue)

Note RBS: Return Beam Saticon, DIS: Diode-gun Impregnated-cathode Saticon,
a: Aspect ratio, P: Shadow mask

4.2 Satellite Transmission Tests

In 1978 and 1979, three transmission tests of high-definition television using FM were made via an experimental broadcast satellite (12 GHz band) to study broadcasting system of the future. The YC separate transmission system was used because of the limited transmission power of the satellite and much noise interference in the color signals when composite signals such as HLO-PAL signals were transmitted.

Y signals and line-sequential multiplexed C signals were transmitted in the 75 and 25 MHz transmission bands and were received by antennas measuring 1.6 m in diameter installed in Tokyo and Osaka. Pictures with a quality rating of four (on a five level rating scale) could be obtained[23].

Audio signals were transmitted by multiplexing high quality stereo PCM signals (sampling frequency 33.75 kHz, quantization number 14 bits compressed to 12 bits, multiplexing bit rate 12.15 Mbps) into the horizontal blanking interval of the Y signals.

4.3 Testing High-definition Television in the Field

The high-definition television developed by NHK has the ability to transmit and reproduce sufficient picture information moving across a wide field of vision in minute detail, so that there is no need to depend on the high magnification of the zooming lens used in conventional TV. High-definition television broadcasts are particularly effective for sports events or spectacular scenes unfolding in large exterior spaces.

To verify these effects, a high-definition TV camera and wide display equipment were installed in a baseball stadium in August, 1981 to pickup the semifinal and final matches of an inter-high school baseball tournament from various angles. A test was made to evaluate the pictures. (See Photo A on page I.) The test showed that high-definition television offered a highly attractive broadcast in vividly described pictures, impossible with the conventional TV systems lacking in information quantity. Diverse forms of visual expression were also possible using broad ranging production methods.

4.4 Public Showing in the United States (SMPTE and FCC)

At the strong request of SMPTE (Society of Motion Picture and Television Engineers, USA), NHK staff presented a lecture on the present state of research and development of the high-definition TV system at the 15th Annual SMPTE Television Conference held in San Francisco from February 5 to 7, 1981. A live domonstration was conducted using a camera, color signal multiplexer, receiver, and monitor. Following the event in San Francisco, demonstrations were also presented to the FCC (the Federal Com-

Fig. 3 HDTV demonstration at the SMPTE Winter Conference in San Francisco.

munication Committee), the primary radiowave administrative agency of the United States, and to government representatives in Washington, D. C.

These events constituted the first time that the world's only high-definition TV system was shown outside Japan, and a large number of engineers in the TV, film, and movie industries gathered from the United States, Canada, and even from Europe. The high-definition TV system of NHK attracted great attention as an indication of the future direction of TV broadcasting and video information society. (See Figure 3)

Such attention provided a specific clue to the way future TV broadcasting and the new utilization mode of broadcasting satellites should be prepared for the Regional Administrative Radio Conference (RARC) for Region 2 to be held in 1983.

5. FUTURE OF HIGH-DEFINITION TELEVISION

5.1 New Technology and High-definition Television System[2][14]

When a display with new functions and large-capacity video memory modules can be used in home entertaiment video receivers, a more efficint high-definition TV system can be built.

Research and development of new gas-discharge displays and other types are under way. With a television display unit in which luminescence is maintained for 90 to 95% of a field period, the field frequency of high-definition television can be as low as about 40 Hz[24].

When the number of frames can be changed on the receiving side by utilization of a frame memory, or other means, high-definition television system offering good picture quality can be produced without greatly increasing signal bandwidth.

5.2 High-definition Television and Future Imaging Systems

After digitization of TV signals has become a reality, processing of a two-dimensional picture and processing of temporal frequency domain (removing only motionless portions, extraction and accentuation of moving portions) will become possible. Extensive video processing, previously difficult in the field of optical technology, such as insertion and superimposing of pictures, and correction and extracting of colors of specific chromaticity, can be freely undertaken through utilization of television signals.

This will hold great attraction for ordinary imaging systems such as in printing, photography, and cinema. In the information society of the future, which is expected to diversify, all imaging systems will be formed based on television technology, i.e. video technology.

The amount of information in the present television system is not sufficient, and its range of application is limited. Quality as good as that of large printing and large-screen movies cannot be obtained. The high-definition TV system being developed by NHK has an ability to reproduce an amount of information five times greater than that of the conventional TV system. All video systems required in the future information society, such as transmission of high-definition paintings and pictures, wide-screen television conferences, photography and printing, and electronic-cinematography, will be created using the high-definition television and high-resolution video as a base.

6. CONCLUSION

Forecasting the diversity of future information society, NHK had already undertaken the world's first research and development of high-definition television and super-fine wide-screen television in 1968.

Based on this Japanese research, high-definition television was adopted as a Question (Study Program, proposed by Japan in 1972) by the CCIR (International Radio Consultative Committee) in 1974. In 1977, a report was added on the technical feasibility of high-definition television by satellite broadcasting in the 22 GHz band based on the research results of NHK Technical Research Laboratories. Thus viewed, high-definition television has been selected and studied throughout the world as a research theme.

In the United States, a research group related to high-definition television was organized within the SMPTE in May, 1977. NHK was requested to co-operate with this research group and joined it as a committee member to supply research results and status of developments at the NHK laboratories. Thus, NHK greatly contributed in compiling a final report submitted by the research group.

Aside from demonstrations and displays in San Francisco and in Washington, D. C., high-definition television was also introduced at the ITS (International Television Symposium) held in Montreux. Through these exhibitions, the state of development of high-definition TV and attractive live pictures have been shown to be a reality. World interest has since then greatly increased. The interest in the high-definition television has increased to the extent that American broadcasting companies are preparing to submit a broadcast plan for high-definition television in conjunction with RARC scheduled in 1983 to allocate satellite broadcasting frequency bands (12 GHz) for the American continent. There have been active movements for the utilization of high-definition television in CATV, printing and photography, television conferences, movie production, and in other ordinary picture systems.

The high-definition television is one of the research and development themes NHK has vigorously pursued on a long-term basis. We at NHK consider it our duty to promote the adoption of this high-definition television system, conceived and developed in Japan, as a uniform world standard for future TV broadcasting and video systems, including utilization in ordinary video systems, jointly with the broadcasting and electronic industries under Japanese leadership.

In conclusion, the author wishes to thank Matsushita Electronic Corporation and the Central Research Laboratories and Television Division of Matsushita Electric Industrial Company for their cooperation in developing the high-definition television equipment, particularly the high-definition CRT and monitor. The author also thanks Ikegami Electric Company for their cooperation in manufacturing the high-definition camera.

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