NHK STRL is researching a wide range of technologies in areas related to video, audio and transmission with an eye toward the start of new 4K/8K satellite broadcasting slated for December 1, 2018, the future implementation of full-featured 8K Super Hi-Vision (SHV) and the terrestrial broadcasting of 4K/8K.

In our research on video formats, we standardized test signals for high-dynamic-range (HDR) program production and investigated the brightness of HDR video. We also developed 8K/120-Hz HDR live production equipment and conducted demonstration experiments. In our work on cameras and recording systems, we developed a 1.25-inch 8K image sensor with 33 megapixels that supports high-speed imaging at a 240-Hz frame frequency (with a maximum of 480 Hz). We also prototyped an 8K/240-Hz single-chip color imaging system and a slow-motion player capable of simultaneous 240-Hz recording and 60-Hz reproduction. In addition, we implemented a video compression (ProRes) feature into our compression recorders, increased the speed of our compact memory package and developed a system that gives real-time previews of 8K ProRes files on a PC. In our work on displays, we increased the luminance of our 8K sheet-type display composed of four 4K organic light-emitting diode (OLED) panels that use thin glass substrates and made it operable at a 120-Hz frame rate. We also developed a high-luminance 8K HDR liquid crystal display with a peak luminance of 3,500 cd/m², more than three times that of conventional displays. To improve the image quality and operability of our projector, we enhanced a color shading correction processor and downsized the signal processors that drive the liquid crystal devices. Regarding video coding, we continued with our development of an 8K/120-Hz codec that uses High Efficiency Video Coding (HEVC) and fabricated a prototype capable of real-time operation. We also developed advanced video coding technologies with higher efficiency and proposed some of them at an international standardization meeting. Moreover, we studied the application of machine learning and super-resolution techniques to video coding.

In our work on audio, we improved the performance of our adaptive downmixing technique, which generates high-quality stereo or 5.1 ch sound signals from 22.2 ch audio signals for the simultaneous production of program audio. We also developed a real-time encoder/decoder for 22.2 ch sound using the MPEG-H 3D Audio LC profile to investigate an audio coding scheme for next-generation terrestrial broadcasting. Regarding reproduction technologies, we studied a way of increasing the robustness of the binaural reproduction method and developed a thin loudspeaker using a piezoelectric electroacoustic transduction film.

In our work on transmission technologies, we investigated the use of MPEG Media Transport (MMT) technology as a multiplexing transmission method for next-generation terrestrial broadcasting. We also continued with our research on an IP multicast delivery technology using MMT, including the demonstration of IP delivery technologies for 4K/8K content and the development of a technology for synchronized presentation on multiple terminals. For the widespread use of satellite SHV broadcasting, we worked to improve the 12-GHz-band transmission performance and prepare the reception environment. We also investigated the next generation of satellite broadcasting such as the 21-GHz band for a larger transmission capacity. Our work included research on a new transmission scheme, a 12/21-GHz-band dual-polarized antenna and satellite systems. For the terrestrial broadcasting of 4K/8K, we worked on the detailed design and performance improvement of a preliminary standard for next-generation terrestrial broadcasting. We also prepared the environment for main-station-scale experimental transmission stations in Tokyo and Nagoya for large-scale experiments to verify the preliminary standard. In addition, we researched the use of space-time coding for single-frequency network (SFN) technology in order to reduce the deterioration of transmission performance, which occurs in an SFN area where radio waves arrive from multiple transmitting stations. Regarding wireless transmission technologies for program contributions, we researched a microwave-band field pick-up unit (FPU) with the aim of enabling SHV live broadcasting of emergency reports and sports coverage and worked on its standardization. We also continued with our research on 1.2-GHz/2.3-GHz-band FPUs for the purpose of SHV mobile relay broadcasting such as road race coverage. We investigated a rate-matching technique that adaptively controls the coding rate of error correction codes according to the variation in the channel response and demonstrated the mobile transmission of 8K video through field experiments. Regarding wired transmission technologies, we developed 8K IP transmission equipment necessary for IP-based program production and program contribution systems and researched a technology for interconnection between IP devices with different transmission formats and control methods. We also worked toward the practical retransmission of 4K/8K broadcasting over cable TV and investigated an in-building transmission system toward the development of a baseband transmission system, which is a future large-capacity transmission technology.
1.1 Video systems

High-dynamic-range television

We investigated the operational practice of the production of high-dynamic-range television (HDR-TV) programs in cooperation with program production engineers. As the reference level for the Hybrid Log Gamma (HLG) system, we determined that objects with a reflectance of 100% and white parts in characters and diagrams should be represented at 75% of the HLG signal level. We proposed a method for mapping SDR signals ranging from 0 to 100% to HLG signals ranging from 0 to 75% on the basis of the reference level to handle standard dynamic range (SDR) video materials in HDR programs. We also studied the luminance range which allows comfortable viewing of HDR-TV programs. The results of subjective evaluation experiments showed that viewers indicate the image on the display is too bright when its average luminance level exceeds 25% of the peak luminance of the display. We reflected these research results in Reports BT.2390(1) and BT.2408(2) issued by the International Telecommunication Union Radiocommunication Sector (ITU-R) and also compiled them in ARIB Technical Report TR-BT.2408(3,4) and ARIB Standard STD-B72(5). Regarding test signals (PLUGE signals) for adjusting the black level of displays, we investigated signal levels suited for the adjustment of HDR-TV displays. Our findings were incorporated into a revised version of ITU-R Recommendation BT.814(6).

We studied a metric for the color volume of HDR/wide-color-gamut displays. We demonstrated that the color volume can be estimated from a combination of the color gamut (the area) on the xy chromaticity diagram based on a conventional colorimetry method and the peak luminance of the display, without the need for complicated 3D volume calculations in a color space(7).

Full-featured 8K program production system

We are conducting R&D on program production equipment and systems that support a 120-Hz frame frequency with the goal of realizing full-featured 8K video production. At the NHK 8K/240-Hz capturing of slow-motion video using a high-speed camera using a color separation optical prism. For the high-speed camera, we made progress in our development of an image sensor and capture equipment that support a 240-Hz frame frequency. We prototyped a 1.25-inch CMOS image sensor with 33 megapixels (Figure 1-2). The image sensor contains a folding-integration analog-digital converter (ADC) with a three-stage pipelined ADC architecture and a digital correlated double sampling (CDS) circuit that suppresses fluctuations of the ADC circuit. This makes it possible to support both high-quality capture at a 120-Hz frame frequency and high-speed capture at 240-Hz or higher frame frequencies (up to 480 Hz). We fabricated an 8K/240-Hz single-chip color imaging system using the prototype image sensor. We also began developing a three-chip 8K high-speed camera using a color separation optical prism.

For the slow-motion player, we conducted experiments on 8K/240-Hz capturing of slow-motion video using a high-speed monochrome imaging system and a compression recorder that uses 4:2:0 color sampling. We also upgraded a slow-motion system capable of simultaneously recording and reproducing video both at 60 Hz, which we prototyped in FY 2016, to make it able to simultaneously record video at 240 Hz and reproduce it at 60 Hz. This system has two U-SDI input interfaces to support 4:4:4 color sampling. It also uses four signal processing boards, each of which can perform processing at 60 Hz, for the compression circuit and four SATA SSD recording units to support recording at 240 Hz. This system can be externally controlled by a general-purpose controller.

Meanwhile, we built an 8K 2X slow-motion system using our previously developed full-featured 8K SHV equipment (i.e., a

1.2 Cameras

8K 4X high-speed camera and slow-motion player

We are developing a high-speed camera system and a slow-motion player to achieve an 8K slow-motion system for sports programs.

For the high-speed camera, we made progress in our development of an image sensor and capture equipment that support a 240-Hz frame frequency. We prototyped a 1.25-inch CMOS image sensor with 33 megapixels (Figure 1-2). The image sensor contains a folding-integration analog-digital converter (ADC) with a three-stage pipelined ADC architecture and a digital correlated double sampling (CDS) circuit that suppresses fluctuations of the ADC circuit. This makes it possible to support both high-quality capture at a 120-Hz frame frequency and high-speed capture at 240-Hz or higher frame frequencies (up to 480 Hz). We fabricated an 8K/240-Hz single-chip color imaging system using the prototype image sensor. We also began developing a three-chip 8K high-speed camera using a color separation optical prism.

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References

(5) ARIB Standard STD-B72, “Colour Bar Test Pattern for the Hybrid Log-Gamma (HLG) High Dynamic Range Television (HDR-TV) System (1.0)” (2018)
120-Hz compact single-chip camera and a compression recorder and used the system for sports programs such as the NHK Trophy figure skating competition.

**Full-featured 8K compact camera**

With the aim of making a full-featured 8K SHV camera more compact and practical, we are developing a prototype three-chip 8K camera using a 1.25-inch optical system. For efficient development, we used the same components, such as a sensor drive board and a signal processing board, as those for our 4K high-speed camera.

As for a previously developed 133-megapixel full-resolution single-chip camera that operates at a 60-Hz frame frequency, we applied inter-line scanning (interlaced scanning) to enable 120-Hz capture. In the scanning, the skipped lines were interpolated by the adjoining lines when moving parts and by the prior frame when static parts in the image.

Using our previously developed full-featured 8K cameras and single-chip cameras, we recorded full-featured video outdoors, conducted live program production at the NHK STRL Open House 2017 and provided support for the production of NHK Special and other programs.

**Other camera-related technologies**

With the aim of developing a general-use 8K camcoder, we developed prototype equipment for verifying basic functions that can compress 8K video to 1/80 the file size by using an AVC/H.264 encoder and record video for more than one hour into four SD cards. The compressed video achieved a peak signal-to-noise ratio (PSNR) in excess of 48 dB.

To achieve autofocus (AF) capability, we developed an experimental imaging device using a hybrid AF system that combines phase-difference detection AF with contrast detection AF and exhibited it at the NHK STRL Open House 2017.

We fabricated a dimming element using metal salt precipitation-type materials and modifying the drive circuit shortened the response time (i.e., the time in which the light transmission rate decreases to 1/8 of its original value) to three seconds.

We analyzed the principle of the problem of bit depth degradation, which occurs when high-chroma objects are captured. Based on the analysis result, we demonstrated that bit depth reproduction can be improved by changing the processing order of the linear matrix and knee and clipping during signal processing within the camera.

We developed a system that can precisely measure the two-dimensional spatial resolution characteristics of a TV camera in real time and exhibited it at the NAB Show.

The research on image sensors was conducted in cooperation with Shizuoka University. The research on the electronic ND filter was conducted in cooperation with Murakami Corporation.

**Displays**

We have made progress in our development of various displays that can handle 8K SHV video and continued with our research on large sheet-type displays.

**SHV sheet-type display technologies**

We are developing lightweight, thin and sheet-type organic light-emitting diode (OLED) displays for future large SHV displays for home use. In FY 2017, we increased the luminance of our sheet-type display composed of four 65-inch 4K OLED panels that use thin glass substrates and made it operable at a 120-Hz frame rate. The display achieved high-quality 8K images (Figure 1-3). This display was demonstrated in cooperation with LG Display and ASTRODESIGN, Inc. We plan to develop a display that can show 8K images with a single panel and to research a flexible display that uses a more lightweight and flexible plastic film substrate.

**8K HDR liquid crystal display**

We developed an 8K HDR liquid crystal display that supports more than three times the luminance of conventional displays.
1.4 Recording systems

We are developing compression recorders and peripheral equipment with the aim of developing full-featured 8K SHV recording equipment. In FY 2017, we added a video compression (ProRes) feature to our compression recorder, improved the recording and reproduction speed of our small memory package and developed a system that shows real-time previews of recorded content on a PC.

In our work on compression recorders, we implemented a video compression capability into our prototype compression recorder to input/output recorded content via files to/from general-purpose editing software for direct editing. We also enabled 40-Hz or higher real-time compression processing by using the pipeline processing of three ProRes compression IP cores implemented into one FPGA. A ProRes compression IP core can perform 15-Hz processing of 8K resolution. We implemented this system into the three FPGAs on the compression signal processing board, which realized 120-Hz compression.

To allow the simultaneous processing of 2K proxy video and 8K video, we incorporated a circuit that switches between 2K images and 8K images at high speed within the IP. The combined use of a decoder IP core that we implemented in FY 2016 and the compression IP core that we newly developed achieved the simultaneous recording of 8K video and 2K proxy video and 8K reproduction at 120 Hz. In addition, we implemented support for a general-purpose remote controller to enable operation on an outside broadcast (OB) van.

Regarding the small memory package, we increased the speed of the NVMe interface which we developed in FY 2016 and implemented support for two slots. We investigated a way of maximizing the device performance of a small memory package with the NVMe interface and found that it is necessary for the host interface to support the simultaneous issuance of multiple commands and a larger transfer data block size. We therefore modified the host interface to support these capabilities, which enabled our compression recorder to achieve a recording speed in excess of 20 Gbps. We also equipped our small memory package with two slots and enabled it to record twice the number of hours of our prototype recorder fabricated in FY 2016. In addition, we developed backup software for small memory packages to enable data backup in raw data and video formats.

To allow easy previews of the content recorded in the compression recorder on a PC, we developed an 8K ProRes real-time preview board. The decoder IP core that we incorporated into the compression recorder can operate at 8K/60 Hz if a sufficient memory bandwidth is secured, we implemented the decoder IP core into an FPGA evaluation board and developed a PC driver. By installing these on a PC, we achieved the real-time preview of recorded video.

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**Full-featured SHV projector**

We improved the image quality of our full-featured SHV projector that uses red, green and blue laser diodes as light sources and supports a 120-Hz frame frequency. We reduced the luminance and color shadings on displayed images caused by the interference of laser beams by increasing the number of brightness correction points in the shading correction processor. We also improved the operability by downsizing the signal processing units that drives the liquid crystal device of the projector and incorporating them into the projector head.

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(Figure 1-4) in cooperation with Sharp Corporation. By employing a technology for increasing the backlight luminance, the display achieved a peak luminance of 3,500 cd/m² and a dynamic range of 400,000:1 (both in measured values).

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(Figure 1-5)
1.5 **Sound systems providing a strong sense of presence**

We are researching a 22.2 multichannel sound (22.2 ch sound) system for SHV and working on its standardization.

**SHV sound simultaneous production system**

We are studying technologies to produce high-quality 22.2 ch sound efficiently and simultaneously while producing stereo and 5.1 ch sound.

In FY 2016, we studied an energy spectrum correction technique for downmixing sound which focuses on the coherence between 22.2 ch audio signals. In FY 2017, we improved its performance and conducted subjective evaluations with sound engineers engaged in program production. As Table 1-1 shows, the sound obtained with the maximum amount of correction, both in the suppression process and the amplifying process, was rated as the most appropriate downmixed sound. This demonstrated the sound quality improvement effect of the proposed technique.

We are also studying an upmixing technology for using sound materials recorded in stereo for 22.2 ch sound production. We developed a technique for separating components according to the mutual correlation of stereo signals by using an adaptive filter to generate 22.2 ch sound materials.

**Reproduction of converted SHV sound**

We are researching technologies for the easy reproduction of 22.2 ch sound at home. We continued with our research on binaural reproduction using line array loudspeakers. In FY 2017, we devised a design method for a reproduction controller that increases the robustness against system perturbations and external disturbances and implemented it into the signal processor that we are developing in cooperation with Sharp Corporation.

We also proposed a method for the low-order and high-accuracy modeling of head-related transfer functions including the characteristics of an expected reproduction environment and developed a signal processor for reproducing 22.2 ch sound with headphones using this method.

**Standard test materials for 3D multichannel stereophonic sound systems**

In FY 2017, the Institute of Image Information and Television Engineers published Series A of standard test materials for 3D multichannel stereophonic sound systems. Toward this achievement, we contributed to the sound source production conducted by ARIB and prepared an explanatory document describing evaluation items and recording conditions.

![Figure 1-7. Appearance of thin loudspeakers](image)

<table>
<thead>
<tr>
<th>Selection rank</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tr>
<td>Amplification amount</td>
<td>Max</td>
<td>Medium</td>
<td>Small</td>
<td>None</td>
</tr>
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(A higher rank indicates a higher evaluation.)

**Acoustic devices**

We exhibited the 22.2 ch sound single-unit microphone that we developed in FY 2016 at the NHK STRL Open House 2017. We also contributed to the production of standard test materials for 3D multichannel stereophonic sound system. Using our microphone, we recorded various sounds such as the performance of octets by wind and string instruments and ambient sound at an amusement park. In addition, we studied beam forming method in order to improve the performance of separation between channels.

We developed a thin loudspeaker using a piezoelectric electroacoustic transduction film that could be applied to loudspeakers for flat-panel TV and 22.2 ch sound loudspeakers for home use and exhibited it at the NHK STRL Open House 2017. This research was conducted in cooperation with Fujifilm Corporation.

**Audio services for next-generation terrestrial broadcasting**

We developed a real-time encoder/decoder for 22.2 ch sound using the MPEG-H 3D Audio LC profile to study an audio coding scheme for next-generation terrestrial broadcasting. This research was conducted in cooperation with the Fraunhofer Institute for Integrated Circuits. We devised a serial form of audio definition model (ADM), which is metadata used for object-based audio, and a method to convey serial ADM. We also prototyped both transmitter and receiver of serial ADMs using a digital audio signal interface.

**Standardization**

At ITU-R, we prepared a Preliminary Draft New Recommen-
dation on serial ADMs on the basis of a joint proposal by Japan, the US and the UK. At the Society of Motion Picture and Televisi-
on Engineers (SMPTE), we proposed a draft of the standard for conveying serial ADMs using AES3 digital audio signal inter-
face. At ARIB, we set up a group to study the requirements for next-generation audio services and began activities.

At the Japan Electronics and Information Technology Associa-
tion (JEITA) and the International Electrotechnical Commis-
ion (IEC), we produced a committee draft for a vote on a standard for transmitting a 22.2 ch sound signal stream encod-
ed by MPEG-4 AAC using an optical interface to reproduce 22.2 ch sound at home. Additionally, we contributed to the revision of a standard for transmitting 22.2 ch sound signal stream encod-
ed by MPEG-4 AAC using an HDMI specified by the Con-
sumer Technology Association (CTA).

At JEITA and IEC, we continued with our works to revise a standard for the general channel allocation including 22.2 ch sound system to add channel labels for various multichannel sound systems.

### 1.6 Video coding

We are researching video coding techniques for full-featured 8K SHV and SHV terrestrial broadcasting.

#### 8K 120-Hz HEVC encoder

We are developing an encoder that supports 8K/120-Hz video (Figure 1-8). The encoder, which consists of twelve 4K/60-
Hz encoding units, is capable of real-time coding of 8K/120-Hz input video by parallel processing. This system conforms to the Main 10 profile using the HEVC/H.265 scheme and supports 4:2:0 10-bit coding of 8K/120-Hz video.

Its bitstream is compliant with ARIB standard STD-B32 Ver-
son 3.9, which allows not only an 8K/120-Hz decoder but also a decoder for 8K test broadcasting (an 8K/60-Hz decoder com-
pliant with ARIB standard STD-B32 Version 3.9) to partially de-
code the 60-Hz sub-bitstream. The system also supports video usability information (VUI) parameters for HDR that are compli-
ant with the above standard.

Since the encoder divides the video frame into four vertical slices for parallel processing, a degradation in image quality tends to appear around the boundaries between divided slices of video, especially when the video has vertical motion. To suppress the degradation, we employed a design that reduces 8K/120-Hz video to 4K/60-Hz video and analyzes the reduced video in advance to control the entire coding. We developed technologies for increasing the image quality, which include a technique to control the quantization value of the boundary ar-
as based on the amount of motion predicted by preliminary analysis. We conducted subjective evaluations using a software simulator to verify the effectiveness of these technologies and confirm the coding quality(10). This research was conducted in cooperation with Fujitsu Laboratories Ltd.

As part of R&D on 120-Hz video coding, we produced evalu-
ation images that are helpful for evaluating the performance of the processing of fast-moving images and coding control in co-
operation with NTT (Nippon Telegraph and Telephone Corpora-
tion).

#### 8K 120-Hz HEVC decoder

We are developing a decoder in parallel with the encoder. Our decoder consists of a software decoder that operates on a general-purpose workstation and an interface converter. In FY 2016, we implemented a video decoder unit of the software de-
coder. In FY 2017, we implemented its audio decoder unit and TS input unit. This enabled the real-time decoding of TS signals of 8K/120-Hz video and 22.2 ch sound. Decoded 8K/120-Hz video is generated from eight spatiotemporally divided DisplayPort outputs and converted by the interface converter to signals for a single U-SDI. Decoded audio signals are multiplexed with video signals for output.

#### Development and standardization of next-
generation video coding technologies

We are developing advanced high-efficiency video coding technologies for next-generation terrestrial broadcasting. For intra-frame prediction technology, we developed a method for the high-precision prediction of chroma signals using decoded luma samples in intra prediction and a method for improving entropy coding for chroma intra prediction modes(11). For in-
ter-frame prediction technology, we developed a motion compen-
sation method considering the continuity with the motion vector of neighboring blocks and a method for predicting the motion vector adaptively according to the shape of partitioned coding blocks. We also developed a way to improve the entropy coding of transform coefficients by estimating the residual signal energy and a deblocking filter control method that re-
duces significant coding degradation in HDR-format video. We confirmed that these technologies improve coding efficiency and proposed some of them to an international standardization conference on next-generation video coding as prospective el-
mental technologies for advanced video coding.

To promote the performance improvement of future video coding schemes for HDR video, we provided the JCT-VC and JVET international standardization conferences with test se-

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1. T. Sagimoto and T. Komori: “Tone compensation method for down-
3. K. Matsui, A. Uo, S. Mori, M. Inoue and S. Adachi: “A method to re-

5. “Loudness Guidelines for OTT and OVD Content,” Technical Docu-
ment AESTE1006.1-17-10 (2017)
quences of the HLG format and also jointly proposed efficient coding settings for using HEVC as comparative criteria with the BBC. These settings were adopted as the criteria for the performance comparison of future video coding schemes. They were also reflected in HEVC video coding guidelines for HDR coding (ISO/IEC TR 23008-15 | ITU-T H. Sup.18)(3)-(5).

As an overseas research effort, we developed HDR tone-mapping nonlinear functions suited for video coding in cooperation with Universitat Pompeu Fabra and demonstrated the improvement in coding efficiency(6).

■ Application of machine learning to coding tools

As an initial study to explore the feasibility of applying machine-learning-based coding tools to video coding, we conducted a basic evaluation on post-filters and intra prediction. We built a post-filter using a machine learning method based on convolutional neural networks and demonstrated that it can reduce mosquito noise and improve the PSNR. We also developed an intra prediction tool based on a multilayer perceptron, which is a type of neural network. The results of training and evaluation showed that it is possible to develop a single predictor that behaves as if it is equipped with multidirectional and planar prediction modes, indicating the feasibility of a new, efficient intra prediction tool.

Also, in cooperative research with Meiji University, we developed an intra prediction process using a neural network consisting of two convolutional layers and two fully connected layers and confirmed that it can increase the speed of a prediction mode that uses prediction samples and adjacent reference samples as an input(7).

Enhancement of super-resolution technology and its application to video coding

In our research for enhancing super-resolution technologies, we developed a technique for super-resolution reconstruction from 2K to 8K that uses an alignment and assignment method considering the frequency band by a registration process between wavelet multiscale components. The new technique achieved a higher speed and higher image quality than conventional methods(8)(9).

We are also studying a way of applying super-resolution reconstruction to video coding technology. As inter-frame prediction images, we newly introduced blurred prediction images and super-resolved prediction images that use registration super-resolution between wavelet multiscale components and observed improvements(10).

Noise reduction and band limitation equipment

We developed noise reduction and band limitation equipment that performs a pre-coding process to increase coding efficiency. The equipment applies shrinkage functions in each element position after the wavelet-packet decomposition of each frame and controls the amount of shrinkage according to the band limitation frequency and the pixel level, enabling a high-precision noise reduction and band limitation process(11). This research was conducted as a government-commissioned project from the Ministry of Internal Affairs and Communications titled “R&D on Advanced Technologies for Terrestrial Television Broadcasting.”

[References]

1.7 Media transport technologies

We are conducting R&D on the use of MPEG Media Transport (MMT) technology as a multiplexing transmission method for next-generation terrestrial broadcasting. We are also conducting research on IP multicast delivery technology using MMT, in which we demonstrated the IP delivery of 4K/8K live content and presented a new viewing experience using inter-terminal synchronization technology.

Multiplexing transmission method for next-generation terrestrial broadcasting

Aiming for next-generation terrestrial broadcasting, we researched a multiplexing scheme for IP packets that conforms to the channel coding system for terrestrial broadcasting and an IP transmission system used over studio to transmitter links (STLs) and transmitter to transmitter links (TTLs) to enable a single-frequency network (SFN). We compiled our findings into specifications and conducted verifications with a prototype remux(10). More specifically, we performed experiments at the Hitoyoshi and Mizukami experimental stations in Kumamoto Prefecture on transmitting output signals from the remux to multiple modulators over commercial IP networks. The results demonstrated that an IP transmission-based SFN can be built by using signaling information in the signals for synchronization control. To improve the quality of mobile services in next-generation terrestrial broadcasting, we proposed a broadcast signal complementary system that allows continuous program viewing even when broadcast waves are interrupted during travel by seamlessly switching to the reception by mobile communications. The results of field experiments (Figure 1-I-9) demonstrated the feasibility of the system(10). Part of this research was conducted as a government-commissioned project from the Ministry of Internal Affairs and Communications titled “Research and Development for Advanced Digital Terrestrial Television Broadcasting System.”
MMT-based IP multicast delivery technology

To promote 8K SHV broadcasting, we verified MMT-based IP multicast delivery technology that could be used for the IP retransmission of broadcasting in closed networks of cable TV stations and other service providers and for the IP delivery of the relevant content linked with broadcasting. We conducted a delivery experiment using live content from the ISU Grand Prix of Figure Skating 2017/2018, NHK Trophy, and demonstrated that 4K/8K content can be delivered to multiple content delivery service providers simultaneously with low latency. As an example of the application of a high-accuracy synchronization scheme using an absolute time stamp, which is a feature of MMT, we developed an inter-terminal synchronization technology that allows multiple content delivered by IP multicast distribution to be displayed in synchronization without delay by adjusting the timing to display video at the same time with clock synchronization among multiple reception terminals. We exhibited interactive content, “Domo’s Slapstick Race,” using this technology at the NHK STRL Open House 2017, CEATEC JAPAN 2017 and NHK Science Stadium 2017, demonstrating the feasibility of a new viewing experience.

[References]

1.8 Satellite broadcasting technology

We are researching 12-GHz-band satellite broadcasting system to improve the transmission performance for 8K UHDTV broadcasting, and researching next-generation satellite broadcasting systems such as 21-GHz-band satellite broadcasting for future broadcasting services.

Advanced transmission system for satellite broadcasting

We are researching 64APSK (Amplitude Phase Shift Keying) coded modulation using set partitioning in order to further increase the capacity of satellite transmission. As a way of improving the transmission performance through a channel with nonlinear distortion caused by the satellite transponder, we designed 64APSK coded modulation that considered the characteristics of the nonlinear distortion on the satellite and the performance of an adaptive equalizer using the LMS (Least Mean Squares) algorithm on the receiver side. Using the number of constellation points on the circles of 64APSK modulation as parameters, we designed the number of the points, bit allocation to signal points and LDPC (Low Density Parity Check) coding that obtain the best required carrier-to-noise ratio (C/N) after error correction under the condition of an output back-off of 5 dB, which is the optimum operation point of a 12-GHz-band satellite transponder during 64APSK transmission. Computer simulations showed that the designed 64APSK coded modulation (our proposed method) improved the required C/N by approximately 0.4 dB compared with the conventional method optimized by considering only AWGN (Additive White Gaussian Noise), when the output back-off was 5 dB (Figure 1-10).

We prototyped a cross-polarization interference cancellation device equipped with a negative-phase synthesized algorithm that reduced the deterioration in transmission performance caused by the simultaneous reception of right- and left-hand circularly polarized waves. We demonstrated that this interference cancellation function improved the required C/N by 0.2 dB when the cross-polarization discrimination was 25 dB and the modulation scheme of the desired waves was 32APSK (3/4).

Advanced satellite broadcasting systems

With the aim of increasing the capacity of 12-GHz-band satellite broadcasting by using multilevel coded modulation, we
are investigating a way of increasing the output power of the broadcasting satellite transmission. If the output power is increased, the side lobes of an on-board antenna need to be suppressed to keep radio wave interference to other countries below the level agreed by international adjustment. To develop an on-board 12-GHz dual-polarized reflector antenna with low side lobes, which is capable of separately receiving right- and left-hand circularly polarized waves, we selected and prototyped a corrugated horn antenna to be used as the feeder. The radiation patterns of our prototype feeder agreed with the designed values and a cross-polarization discrimination of 30 dB or more was obtained in the 300-MHz bandwidth. We plan to design a dual reflector antenna using two noncircular aperture reflectors based on the designed feeder to further reduce the side lobes of an on-board antenna.

We designed a 12/21-GHz-band dual-polarized feeder that allows a single antenna to receive both 12-GHz-band and 21-GHz-band satellite broadcasting by right- and left-hand circular polarization. The feeder has a multilayer structure of four-element microstrip array antennas, which enables the simultaneous arrangement of the focal point of the reflector (Figure 1-11). The feeder obtained a VSWR (Voltage Standing Wave Ratio) of 1.1 or less for both frequency bands. An evaluation using the feeder design values showed that an offset parabolic reflector antenna with 50 cm aperture diameter achieves gains more than 34 dB for the 12-GHz band and 38 dB for the 21-GHz band as well as a cross-polarization discrimination more than 25 dB.

Weak signals in the intermediate-frequency range (2.2 GHz to 3.2 GHz) for left-hand circular polarization leak from a reception system for 12-GHz-band 4K/8K satellite broadcasting. To measure these signals, we devised a method for improving the C/N of the measured signals (leaked signals) by correlation processing of the leaked signals and received signals, and we prototyped and evaluated a measurement tool capable of the high-precision measurement of the leaked power. We confirmed by the prototype that the C/N can be improved by 40 dB or more by limiting the band of correlation output signals with a narrow-band pass filter.

As a feeder that increases the output satellite transmission power by spatial synthesis using a 21-GHz-band array-fed reflector antenna, we prototyped a three-element partial model using a sequential array structure in which horn antennas are arranged with rotational symmetry. We confirmed that a cross-polarization discrimination 30 dB or more is obtained by reducing radio waves reflected inside the neighboring elements.

To conduct a wide-band transmission experiment using a 21-GHz-band experimental transponder of the BSAT-4a broadcasting satellite and evaluate rain attenuation characteristics in the 21GHz band, we set up 21-GHz-band reception equipment that combines a parabolic antenna with 1.5 m aperture diameter (48 dB gain) and an automatic satellite-tracking system.

For the terrestrial broadcasting of SHV, we made progress in our R&D on a next-generation terrestrial broadcasting system, the establishment of a large-scale experiment environment, channel planning and next-generation single-frequency network (SFN) technology. Part of this research was being performed under the auspices of the Ministry of Internal Affairs and Communications, Japan as part of its program titled “Research and Development for Advanced Digital Terrestrial Television Broadcasting System,” in cooperation with Sony Corporation, Panasonic Corporation, Tokyo University of Science and NHK Integrated Technology Inc.

### Next-generation terrestrial broadcasting system

We worked on the detailed design and performance improvement of a preliminary standard for next-generation terrestrial broadcasting. In FY 2017, we designed low-density parity-check (LDPC) codes, investigated a hierarchical transmission method, reexamined the transmission and multiplexing configuration and control (TMCC) transmission scheme and evaluated transmission characteristics of the preliminary standard through computer simulations.

Regarding the LDPC codes, we redesigned some of the 69,120-bit-length codes (long codes) that we designed in FY 2016 for the preliminary standard and also newly designed 17,280-bit-length codes (short codes). By using an appropriate (multidtype: MET) structure for codes with a low coding rate, we demonstrated that both long codes and short codes with any coding rate (2/16 to 14/16) can achieve the same or better performance than ATSC 3.0 (Figure 1-12).

For the hierarchical transmission method, we investigated...
layered division multiplexing (LDM) that transmits two signals with different transmission robustness after mapping and adding them\(^1\). We implemented a system to apply LDMA to the whole signal bandwidth and a system to apply LDMA only to the partial reception band into our modulator and demodulator. We also prototyped a demodulator for mobile reception that receives only the partial reception band (1.5-MHz bandwidth) and uses a sampling rate reduced to 1/4 that of a conventional device with the aim of reducing the power consumption of a frequency-division multiplexing (FDM) receiver. Moreover, as a technology for improving the characteristics, we implemented the TMCC transmission scheme using differential space frequency block codes (DSFBCs) and a frequency interleaver that performs a cyclic shift in segment units for each OFDM symbol. By 2.6 dB and the transmission efficiency was improved by 60% compared with those of One-Seg (Figure 1-13). We investigated the co-channel and adjacent channel protection ratios for the extended bandwidth signal through laboratory experiments. We assessed the protection ratios for the current terrestrial TV broadcasting signals interfered with by the extended bandwidth signal using 15 kinds of terrestrial TV receivers\(^{15}\).

To obtain licenses in both areas, we provided the relevant broadcasters with a prior explanation of the transmission specifications of the experimental stations and their possible impact on terrestrial TV broadcasting and gained approval for the transmission specifications (Table 1-2). We applied to the Regional Bureaus of Telecommunications for an experimental station license with the goal of starting radio emission in the autumn of 2018.

## Channel planning

Since FY 2016, we have been engaging in channel planning in cooperation with the Engineering Administration Department with the aim of enabling terrestrial SHV broadcasting that uses the same UHF band as current terrestrial TV broadcasting. In FY 2017, we studied new channels for terrestrial SHV broadcasting and frequency reallocation of existing digital terrestrial broadcasting. We reviewed selection criteria for determining the availability of channels and increased the number of calculation points, which improved the accuracy of the repacking scale estimation.

## Next-generation SFN technology

The remux equipment that we developed in FY 2016 has the capability of sending eXtensible Modulator Interface (XMI) signals that will be entered into an OFDM modulator. It therefore can control the signal output timing of the modulator according to each transmitting station’s transmission timing information.

<table>
<thead>
<tr>
<th>Location</th>
<th>Main station</th>
<th>Main station</th>
<th>Relay station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Tokyo</td>
<td>Nagoya</td>
<td>Tokyo</td>
</tr>
<tr>
<td>Location</td>
<td>Minato Ward, Tokyo</td>
<td>Nagoya City, Aichi</td>
<td>Yatomi City, Aichi</td>
</tr>
<tr>
<td>Transmission channel</td>
<td>UHF ch28</td>
<td>UHF ch35</td>
<td>UHF ch35</td>
</tr>
<tr>
<td>Polarization</td>
<td>Horizontal and vertical (Dual-polarized MIMO)</td>
<td>Horizontal 1 kW</td>
<td>Vertical 1 kW</td>
</tr>
<tr>
<td>Transmission Power</td>
<td>Horizontal 1 kW</td>
<td>Horizontal 1 kW</td>
<td>Horizontal 10 W</td>
</tr>
</tbody>
</table>
which is multiplexed with XMI packets, to enable an SFN.

In FY 2017, we conducted an SFN field experiment over an optical IP network in Hitoyoshi City, Kumamoto Prefecture. In the experiment, XMI packets sent from a remux installed at the Hitoyoshi experimental station were delivered to the Mizukami experimental station over the optical IP network. Then, OFDM signals generated by the modulators at the Hitoyoshi and Mizukami stations were transmitted from the two stations using the same frequency (UHF ch46). We confirmed at a reception point set up in a place where radio waves from the two stations arrive that video was successfully transmitted without errors in an SFN environment. We also observed the difference in the arrival time of radio waves from the two stations and confirmed the operation of the transmission timing control function (Figure 1-14).

We researched the use of space-time coding (STC) for SFN technology (coded SFN) to reduce the deterioration of transmission characteristics, which occurs when radio waves arrive from multiple transmitting stations in an SFN area. Computer simulations using channel characteristics collected in areas where an SFN is formed for terrestrial digital broadcasting showed that using the coded SFN technology can improve transmission characteristics by up to 4.8 dB even in cases where the characteristics degrade with a conventional SFN (Figure 1-15)(4).

As part of research toward next-generation terrestrial broadcasting, we enrolled in the 3rd Generation Partnership Project (3GPP), which standardizes mobile communication systems, and began investigating the standardization trend of 5G. We also began a study on the use of 5G systems for broadcasting in cooperation with the European Broadcasting Union (EBU).

We visited KBS and ETRI of South Korea to investigate the situation of terrestrial 4K broadcasting, which was started on May 31, 2017, and future mobile services.

We conducted a questionnaire-based survey about emergency warning broadcasting at the Future of Broadcast Television (FOBTV), where broadcasters around the world gather, and reported the collected results at meetings of the NAB Show in April and IBC 2017 in September.

As part of activities at the Digital Broadcasting Experts Group (DiBEG), we exchanged opinions about next-generation terrestrial broadcasting with SBTVD-Forum, a standardization organization in Brazil.

[References]

1.10 Wireless transmission technology for program contributions (FPU)

With the goal of realizing SHV live broadcasting of emergency reports and sports coverage, we are conducting R&D on field pick-up units (FPUs) for transmitting video and sound materials. In FY 2017, we researched a microwave-band FPU and a 1.2-GHz/2.3-GHz-band FPU.

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[References]
ple-output (MIMO) technology and orthogonal frequency-division multiplexing (OFDM) with a higher-order modulation scheme to expand the transmission capacity. Additionally, in FY 2017, we quadrupled the FFT size from 2,048 points to 8,192 points to increase the ratio of the effective symbol duration to the guard interval. We also introduced a non-uniform constellation, optimized the OFDM pilot signal level and improved the bit interleave and also used LDPC codes for error correction to reduce the required C/N. These improvements resulted in a maximum transmission capacity of 312 Mbps, 5.7 times that of current FPUs (55 Mbps), and a transmission capacity of 200 Mbps, 3.6 times that of current FPUs, under the same required C/N (Figure 1-16).

At ARIB, we contributed to the establishment of a new standard incorporating the above technologies, ARIB STD-B71 “Portable Microwave Band OFDM Digital Transmission System for Ultra High Definition Television Program Contribution.”

1.2-GHz/2.3-GHz-band FPU

To enable the mobile relay broadcasting of SHV signals by using the 1.2-GHz/2.3-GHz-band, we are researching a MIMO system with adaptive transmission control using the time division duplex (TDD) scheme.

In FY 2017, we improved functions to expand the transmission rate. For uplinks that transmit SHV video signals from a mobile station to a base station, we increased the amount of information that can be transmitted per OFDM carrier symbol from 14 bits to 16 bits and improved the time ratio of uplinks to downlinks that transmit signaling information from a base station. This achieved wireless transfer at a maximum rate of about 140 Mbps. We also developed a function for supporting multiple base stations to expand the transmission service area for a road race relay. This function selects four antennas having a good reception quality out of many antennas and uses them for demodulation.

In our work on rate matching, which controls the coding rate of error correction codes adaptively according to the varying channel quality to prevent transmission errors, we implemented a function to control the coding bit rate of 8K video according to the variation in the error correction coding rates into a prototype system. We connected the system with an HEVC/H.265 codec with a variable rate and demonstrated that it can transmit SHV video signals at a rate varying in the range from 50 Mbps to 140 Mbps.

Using this prototype system (Figure 1-17), we conducted field transmission experiments with assumed marathon courses around our laboratory and in urban areas. The experiments evaluated the mobile transmission characteristics of a MIMO system with adaptive transmission control, which dynamically changes the number of MIMO streams to be multiplexed, the modulation scheme and the error correction coding rate according to the channel status, and demonstrated the mobile transmission of SHV video signals in excess of 100 Mbps by the system connected with an 8K codec with a variable rate.

Part of this research was conducted as a government-commissioned project from the Ministry of Internal Affairs and Communications titled “R&D on Highly Efficient Frequency Usage for the Next-Generation Program Contribution Transmission.”

[References]


1.11 Wired transmission technology

We are researching a program production and program contribution system using Internet Protocol (IP) technology that can be used for 8K programs. We are also studying a channel bonding technology for transmitting 8K programs over cable TV networks and the FTTH (Fiber to the Home) digital baseband transmission system.

### IP-based program production and program contribution system

Applying IP technology to program production and program transmission allows signals of various formats for video, sound, synchronization and control to be temporally multiplexed and transmitted over a shared network at a low cost. In FY 2017, we worked on the following three R&D areas:

1. Experiment on remote audio mixing using 8K IP transmission

   While conventional live program production requires a conversion process to synchronize signals received from a venue with the broadcast station’s master clock, an IP-based program production system can use the same clock for the venue and the broadcast station by exchanging clock synchronization information between them using Precision Time Protocol (PTP). We verified the synchronization performance in the ISU Grand Prix of Figure Skating 2017/2018, NHK Trophy, by time-multiplexing and transmitting 8K video packets, 128 ch sound packets and PTP packets over commercial IP networks between Osaka and Tokyo. The results showed that sound from a live coverage venue in Osaka can be mixed at the NHK Broadcast Center in Tokyo if the jitter of PTP packets is about one microsecond. Meanwhile, some production devices failed in clock synchronization. We plan to improve the synchronization algorithm and consider a way of reducing the PTP jitter, which varies with the network structure.

2. Development of IP transmission equipment for mezzanine-compressed 8K signals

   8K program contributions used for program production need to be transmitted with high quality and low latency. However, transmitting a large amount of uncompressed signals incurs a higher network cost. We therefore developed equipment that applies mezzanine compression to 8K signals and transmits them over IP networks. This equipment can transmit 8K video at a reduced bandwidth with low latency while maintaining a high image quality comparable to that of uncompressed signals. For example, 8K program contribution signals (4:2:2 sampling, 60-Hz frame rate, 40-Gb/s video bandwidth) that are mezzanine-compressed to 1/5 (post-compression video bandwidth of 8 Gb/s) can be transmitted over a single cable for general 10 Gb Ethernet. Laboratory experiments demonstrated that the equipment can transmit mezzanine-compressed 8K signals stably with high image quality and low latency (Figure 1-18). We plan to conduct field transmission experiments, support a 120-Hz frame rate and implement an error correction function.

3. Development of an IP transmission system converter

   For the interconnection between devices that use different signal transmission formats and equipment control methods in an IP-based program production system, we developed a mechanism for converting the format and control method and fabricated a prototype converter.

   The IP video router (IPVR) system being developed in NHK as a network matrix uses a different transmission format and control method from those of devices for IP-based program production systems. Using our prototype converter, we conducted a connection test between the IPVR and an IP program production system that we prototyped in FY 2017. The results demonstrated that the control device of the IP program production system can control the IPVR and that IPVR video signals can be transmitted to the IP program production system.

### Cable TV transmission of SHV signals

We continued with our R&D on a channel bonding technology to transmit partitioned 8K signals over multiple channels so that 8K programs can be distributed through existing coaxial cable television networks. In FY 2016, we developed a compact receiver equipped with a demodulator LSI that supports channel bonding technology. In FY 2017, we conducted experiments on the retransmission of 8K satellite broadcasting over commercial cable networks using this receiver. The results showed that our compact receiver can receive retransmitted 8K signals stably. We also helped Japan Cable Laboratories compile requirements for a demonstration experiment on the retransmission operation specifications for new 4K/8K satellite broadcasting and prepare experimental procedures with the aim of realizing a 4K/8K retransmission service on cable TV.

### Digital baseband transmission system for FTTH

As a way of distributing broadcasts to homes using FTTH, we are studying a 10-Gbps-class digital baseband transmission system that divides multichannel streams of 8K and Hi-Vision broadcasting into IP packets and multiplexes them with baseband signals by using time-division multiplexing. In FY 2017, we studied an intra-building transmission system for condominium buildings installed only with coaxial cables, which cannot transmit baseband signals. The intra-building transmission system selects IP packets in response to a viewer request and converts them to radio frequency (RF) signals so that they can be transmitted over an existing coaxial cable. We prototyped a transmitter and receiver which comply with Data Over Cable Service Interface Specification (DOCSIS) used for internet communications on cable TV and added a function to improve the frequency usage efficiency and demonstrated the effectiveness of the system. We also investigated a way of migrating the existing FTTH equipment for RF signal transmission to the digital baseband transmission system in stages.

[References]

1.12 Domestic standardization of broadcasting systems

We are engaged in domestic standardization activities related to 4K and 8K ultra-high-definition television satellite broadcasting systems.

For the start of new 4K/8K satellite broadcasting in 2018, the Association for Promotion of Advanced Broadcasting Services (A-PAB) has been preparing operational guidelines (1). ARIB worked on revisions of its technical standards that specify the television systems in cooperation with A-PAB (Table 1-3). Members of NHK STRL contributed to these standardization efforts for ultra-high-definition television broadcasting by participating as committee chairperson of an ARIB development section and managers and members of the relevant ARIB working groups.

[References]

Table 1-3. Major revisions of the ARIB standards for ultra-high-definition television satellite broadcasting systems

<table>
<thead>
<tr>
<th>Domain</th>
<th>ARIB Standard</th>
<th>Major revisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiplexing (MMT/TLV)</td>
<td>STD-B60 (ver. 1.12)</td>
<td>Change in the specification for an HEVC video descriptors supporting HDR/wide color gamut and clarification of MMT specifications</td>
</tr>
<tr>
<td>Conditional access</td>
<td>STD-B61 (ver. 1.4)</td>
<td>Specification of the number of components (e.g., video, audio and data) and scramble keys that can be simultaneously processed by a receiver</td>
</tr>
<tr>
<td>Multimedia coding</td>
<td>STD-B62 (ver. 1.9)</td>
<td>Addition of the specification for handling ideographic variants, clarification of the receiver reference model, and clarification of the communication capability</td>
</tr>
<tr>
<td>Receiver</td>
<td>STD-B63 (ver. 1.7)</td>
<td>Addition of the specification for digital video and audio output supporting HDMI 1.4b and 2.1, and specification of performance requirements such as the number of components (e.g., video, audio and data) and scramble keys that can be simultaneously processed by a receiver and</td>
</tr>
</tbody>
</table>