Trends in Digital Transmission Technology for Cable Television

There are various transmission schemes for cable television in addition to those regarding retransmission of digital broadcasts. Installation of optical fiber is also progressing. This article gives an overview of the latest trends in digital transmission technology for cable television.

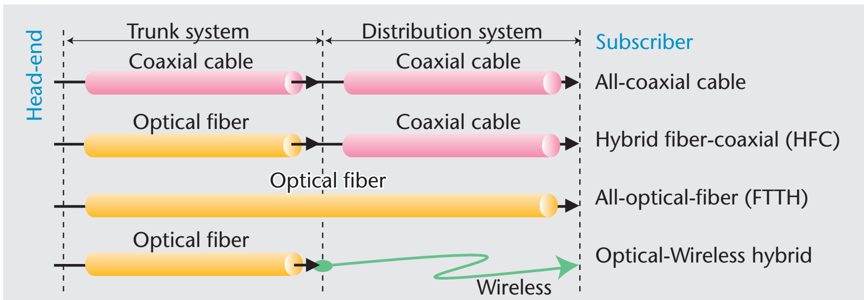

Figure 1: Categories of cable television by transmission media

1. Introduction

Cable television in Japan has a long history, having started just two years after television broadcasting began in 1955. Digital broadcasting over cable television began at about the same time as communications satellite (CS) digital broadcasting in 1996, and since then, various transmission schemes have been developed and commercialized, in addition to the standard for rebroadcasting digital radio-wave broadcasts over cable. There have also been changes in the medium used to transmit cable television signals. Coaxial cable was used at first, but the use of optical fiber has begun to supplement it in recent years.

Below, we give an overview of developed and developing digital transmission technologies for cable television.

2. Cable Television Categorized by Transmission Media Type

Most current cable television services transmit radio-frequency signals in the VHF[*1] and UHF[*2] bands. To do this, early cable television services used coaxial cable. Later, optical fiber became practical, and it began to be used in various forms, as shown in Figure 1. We describe each transmission medium below.

2.1 All-Coaxial-Cable Transmission

This is the basic form of cable television. To compensate for transmission losses in the coaxial cable, amplifiers must be position every few hundred meters. Large-scale cable television facilities are transitioning to Hybrid Fiber-Coaxial (HFC) media, but most small-scale facilities are still using all-coaxial cable.

2.2 Hybrid Fiber-Coaxial Media

In this form, optical fiber is used for the trunk systems, while coaxial cable is used for downstream distribution systems. Optical fiber incurs less transmission loss than coaxial cable, so transmission is possible over longer distances without amplifiers. These better transmission characteristics and the elimination of amplifiers result in benefits such as lower failure rates and easier maintenance. HFC is suitable for large-scale cable facilities covering a broad service area because trunk lines can be much longer. The end distribution systems are the same as for the all-coaxial form, so the transition from an all-coaxial system is also easy. At the end of FY2009, of all facilities authorized[*3] for independent broadcasting[*4] (682 facilities), 85.2% (581 facilities) had introduced optical fiber trunk lines, and in all of Japan, 46.4% of all trunk-line distance had been converted into optical fiber ones.

2.3 All-Optical-Fiber Transmission

In this form, optical fiber is used for transmission all of the way from the head-end[*5] to the subscriber's home. It is often called Fiber-To-The-Home (FTTH). It is now becoming more common to also use this for Internet communications connections. At the end of September 2010, 213 cable television facilities had introduced FTTH, with an increasing trend.

In some cases, for apartments and housing complexes, transmission from the head-end to the complex is done with optical fiber, while coaxial cable is used within the building. This type of arrangement is called Fiber-To-

[*1] 90 MHz to 222 MHz.
[*2] 470 MHz to 770 MHz.

[*3] Cable television facilities with 501 or more service terminals. Cable television facilities with fewer than 50 or from 51 to 500 service terminals, and conducting independent broadcasting are called "reporting facilities", and those with 50 or fewer terminals and not conducting independent broadcasting are called "small-scale facilities".
[*4] Broadcasting other than rebroadcasts of terrestrial or broadcast satellite (BS) broadcasts. This includes rebroadcasts of communications satellite (CS) broadcasts and broadcasts of independently produced or procured programming.
[*5] The equipment originating the broadcast in a cable television facility.

The-Building (FTTB). There are also transmission systems that only use coaxial cable near the subscriber's home, called Fiber-to-the-Curb (FTTC). These are intermediate between HFC and FTTH. We describe FTTH in more detail in Section 5.

2.4 Optical-Wireless Hybrid

Some cable television facilities have begun introducing wireless transmission. Figure 1 shows a form in which optical fiber is used for trunk systems and wireless is used to distribute to subscriber homes. Technologies are also being developed that do the opposite of that shown in Figure 1, using wireless transmission[*6] for part of the trunk systems. Such approaches are used for remote islands or mountainous regions where it is difficult to install optical fiber for the trunk system.

Transmitting high-frequency signals such as microwave or millimeter-wave signals over optical fiber in this way is called "Radio on Fiber" (RoF).

3. Pass-through and Transmodulation Schemes

Recently, some cable television facilities have begun transmitting high-frequency signals in bands other than VHF and UHF, such as the BS Intermediate Frequency (BS-IF)[*7] and CS-IF bands. These can be placed in the following two categories according to how re-transmission is done. These two approaches have been described earlier in the journals[1)2)], but we will introduce developments since those reports.

3.1 Pass-through Schemes

Schemes that take the radio-frequency broadcast signal and transmit it over cable television without changing the modulation scheme are called pass-through schemes. We describe schemes used for re-broadcasting of both terrestrial broadcasts and BS broadcasts below.

3.1.1 Pass-through Schemes for Terrestrial Broadcasts

Re-transmission of terrestrial analog broadcasts is done using pass-through schemes that transmits the radio-frequency broadcast signal as-is. Pass-through schemes can also be used to retransmit digital broadcasts. The most significant feature of pass-through schemes is that consumer digital television receivers can be used to receive the signal.

There are a several issues of concern when transmitting digital terrestrial broadcasts using a pass-through scheme. Digital terrestrial broadcasts use UHF-band channels, but for some cable television facilities are not able to transmit a UHF-band signal because the upper limit on frequencies they can transmit is too low. In such facilities, signals can be transmitted by converting to transmittable frequencies without changing the modulation scheme. This is also a type of pass through scheme, called a frequency-conversion pass-through scheme. Most digital terrestrial broadcast receivers on the market support frequency-conversion pass-through schemes.

3.1.2 BS Broadcast Pass-through Scheme

BS signals are broadcast using the 12-GHz band, and these frequencies cannot be transmitted over cable television. However, BS-IF signals are in the 1.0 to 1.3 GHz band, so cable television facilities that can transmit wide-band signals can transmit them using a pass-through scheme. The UHF band is the upper limit of frequencies that can be transmitted, so cable television facilities unable to transmit wide-band signals must use a frequency-conversion pass-through scheme[1)], converting the BS-IF signal to lower frequencies for transmission as shown in Figure 2. However, a frequency converter is required at subscriber residences to convert such frequency-converted pass-through signals back to the BS-IF band in order to receive them using a consumer BS digital receiver. Also, BS-IF signals use wide bandwidth-per-channel, and transmitting them by cable television does not use bandwidth efficiently, so such schemes are only used by the few facilities that do not use many of the channels and want to retransmit them at low cost.

3.2 Transmodulation Schemes

Cable television is transmitted by cable, so amplifiers can be introduced along the transmission path. Signals are also stable and high-quality because they are not affected by time-varying factors such as multi-path reflection or attenuation due to rainfall. A transmodulation scheme using quadrature amplitude modulation (QAM), which has higher transmission capacity per unit of frequency than digital terrestrial or BS broadcasts, has been standardized to take advantage of these transmission-path characteristics.

Regulations for cable television in Japan are established in the Ordinance for Enforcement of the Cable Television Broadcast Act. 64QAM was standardized as a transmodulation scheme for cable television when digital broadcasting started in 1996 and is currently used for broadcast. Later, in 2007, 256QAM was standardized to meet demand for higher programming capacity and to take advantage of improvements in cable television transmission quality. 1024QAM and higher schemes are also being developed[1)3)], but these are not yet in use.

The CN ratio required to guarantee a pre-error-correction bit error rate of 1×10^{-4}, and thus, pseudo-

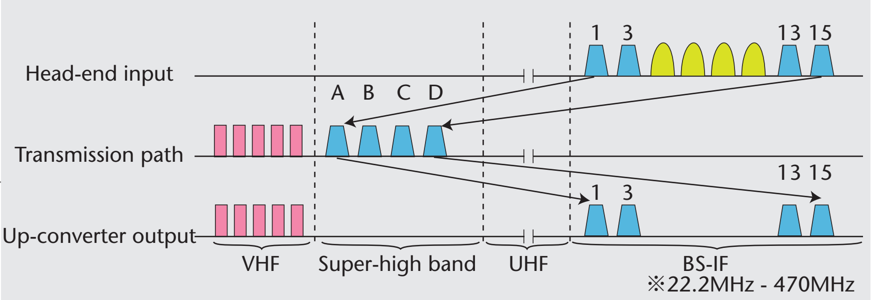

Figure 2: BS-IF frequency modulation pass-through scheme[1)]

[*6] A fixed 23GHz-band station for use by cable television broadcasters.

[*7] The frequency of the signal output from a BS antenna.

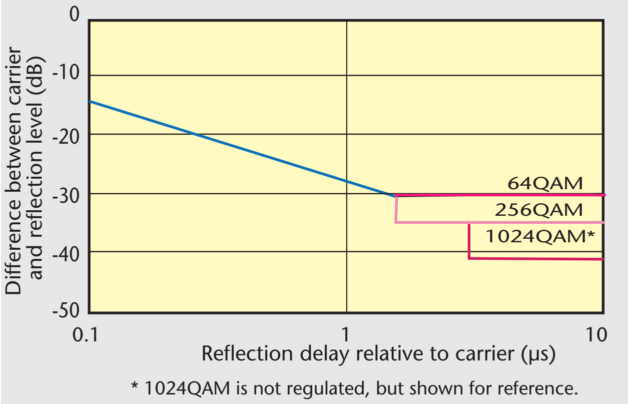

Figure 3: Reflection level tolerances for QAM transmission

error-free transmission after correction (recognized as error-free for practical purposes), is 26 dB or higher for 64QAM, and 34 dB or higher for 256QAM. In theory, the difference between 64QAM and 256QAM in CN ratio required for the same error rate is 6 dB, but the estimated fixed deterioration*8 for 256QAM is higher so a difference of 8 dB is used.

As shown in Figure 3, the upper limit on the level of reflected signals in the transmission path is determined as a function of the delay time.

An adaptive waveform equalizer*9 is generally used in QAM receivers, so the type of adaptive waveform equalizer used in the receiver must be considered when evaluating reflective interference. Simply put, adaptive waveform equalizers are able to equalize signals, even with large reflections, as long as the delay is below a particular threshold, but they cannot equalize the signal at all if the delay is over this value. Also, if the delay is extremely long, there is almost no correlation between desired and reflected signals, so the allowable level of the reflection is the same as for co-channel interference. Figure 4 (a) shows a conceptual representation of the allowable level of reflection.

With analog broadcasting, reflective interference in the transmission path appears as ghosting in the image. For reflections of the same level, those with less delay are subjectively perceived as less interference, and for delay above a certain threshold, further increases do not change the subjective perception of interference. Thus, the allowable level of reflective interference can be represented as in Figure 4 (b). Figure 3 shows the results of using the high levels of interference in Figure 4 (a) and (b).

There are three types of schemes in international standards for cable television, those used in Japan, Europe, and North America respectively. A comparison of these schemes is shown in Table 1. The schemes used in Japan and Europe are similar, differing in some parameters, while those used in North America differ from schemes used in both Japan and Europe.

4. MPEG-2 TS Transmission Formats

All information transmitted by digital broadcasting, including digital terrestrial broadcasts and digital BS broadcasts, is done using MPEG-2 Transport Streams (TS)*10, but the purpose and transmission path of

*8 Performance deterioration due to non-ideal behavior in receiver circuits, etc.

*9 A correction circuit that can automatically change the correction characteristics based on the input signal.

*10 "MPEG-2 Systems" is currently used as the stream format for digital broadcasts, but the recently standardized, advanced narrow-band CS digital broadcast and advanced BS digital broadcast specifications, as well as the One-Seg service, use the high-performance H.264 video codec in addition to MPEG-2.

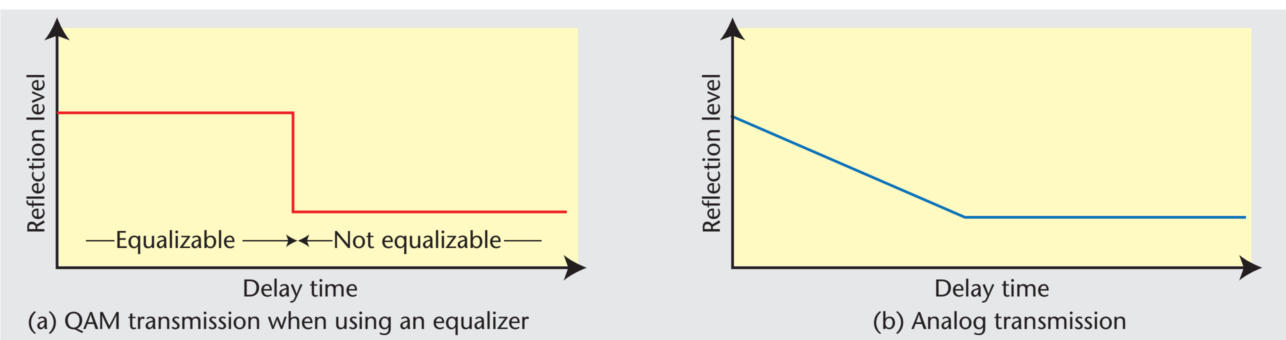

Figure 4: Reflection level tolerance characteristics

Table 1: Comparison of cable television formats in Japan, Europe, and North America

	Japan	Europe	North America	
Standard	Rec. ITU-T J.83 Annex C	Rec. ITU-T J.83 Annex A	Rec. ITU-T J.83 Annex B	Rec. ITU-T J.83 Annex D
Error-correction scheme	RS (204,188)*		Concatenation of RS (128, 122) and convolutional coding	RS (207,187)
Bandwidth	6MHz	8MHz	6MHz	6MHz
Modulation scheme	64/256QAM	64/32/64/128/256 QAM	64/256QAM	2/4/8/16VSB

* Reed-Solomon Coding

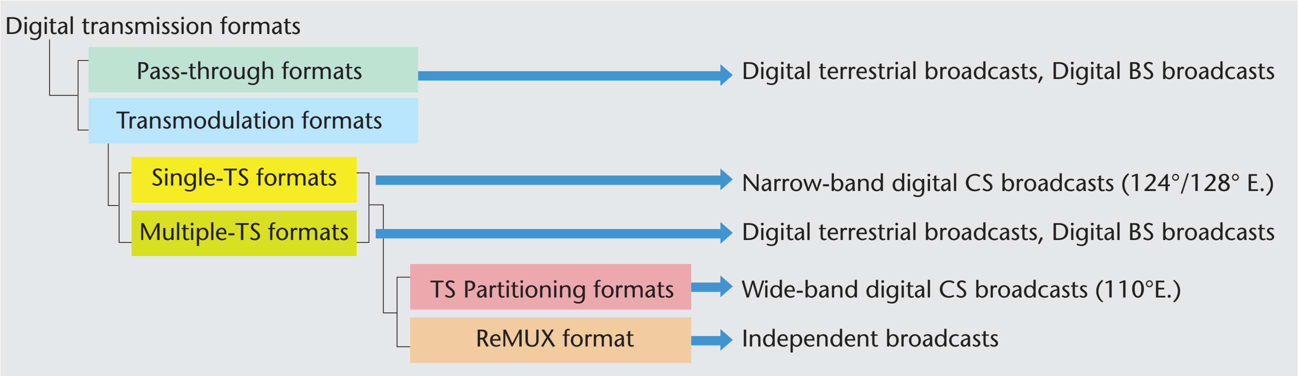

Figure 5: Cable television digital transmission formats

broadcasts differ, so there are various types of TS with differing transmission capacity. When retransmitting these broadcasts over cable television using pass-through formats, the modulation scheme is not changed, so differences in capacity of TSs do not generally result in difficulty. However, when retransmitting using transmodulation schemes, the fact that the transmission capacity of a single carrier is fixed must be considered, and various schemes for cable television are used to transmit the broadcasts efficiently. Standardized digital transmission formats are shown in Figure 5. A simple explanation of these formats is given below.

4.1 Single-TS Format

The single-TS format was standardized for retransmission of narrow-band CS digital broadcasts. Its transmission capacity is approximately 29 Mbps, the same as narrow-band CS digital broadcasts, and it allows a single TS, transmitted on one carrier of a narrow-band CS digital broadcast, to be retransmitted as-is.

4.2 Multiple-TS Format

This format was standardized in order to retransmit multiple TSs transmitted in a single BS digital carrier. The capacity of a BS digital broadcast transmission (approx. 52 Mbps) is larger than that of a narrow-band CS digital transmission, so this format was standardized to allow retransmission of the multiple TSs in a BS digital broadcast on a single cable television carrier, as-is.

The Multiple-TS format introduced a frame structure[4)] for multiplexing the multiple TSs, but the modulation scheme is the same as for the single-TS format, so tuners and demodulator circuits for the single-TS format can still be used.

4.3 TS Partition Formats

When a single TS containing multiple programs is transmitted on a single digital broadcast carrier, this format enables the TS to be partitioned into one TS per program, generating a new TS per program and retransmitting each of them on separate carriers.

The standard for wide-band CS digital broadcasts (110°E.) is the same as for BS digital broadcasts. However, in actual broadcasts, the QPSK modulation scheme, which has a coding rate that is 3/4 that of convolutional coding, is used so the transmission capacity is approximately 39 Mbps. Also, most transponders broadcast a single TS per carrier. The capacity of a single carrier in the single TS format for cable television is approximately 29 Mbps, so a single TS must be partitioned in order to retransmit a wide-band CS digital broadcast.

In the TS partition format, TS are partitioned in program units, so the receiver only needs to receive the carrier that is transmitting the desired program.

4.4 ReMUX Format

In principle, no changes are made to the content when retransmitting digital broadcasts. However, when re-transmitting programs such as CS distributions or independently procured programs, new TSs are generated and broadcast. The format for doing this called ReMUX.

5. FTTH

5.1 Optical Fiber Installation Topologies

Possible transmission network topologies are shown in Figure 6. These include the star topology[*11], which

[*11] Also called single-star topology to distinguish it from the double-star topology.

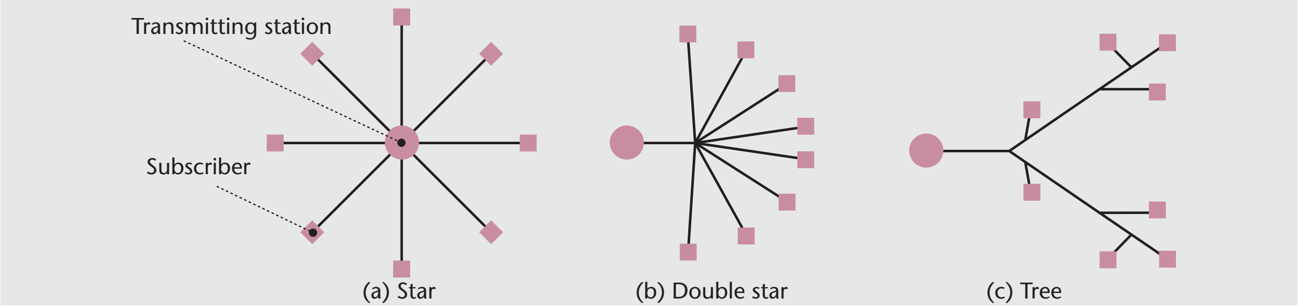

Figure 6: Types of transmission network topology

has one-to-one connections between transmitter and subscriber, the double-star topology, which has intermediate branches serving multiple subscribers, and the tree topology, which has multiple levels of branches serving many subscribers. Cable television facilities using coaxial cable usually have a tree topology. However, with optical fiber networks it is difficult to have multiple branches without using optical amplifiers, so star or double-star topologies are used.

The double-star topology has the benefit that the optical fiber leaving the transmission station is shared by multiple subscribers, so the total length of fiber required is less than that of star topology. This makes it suitable for service covering wide areas. Optical fiber networks using passive branch components to form a double-star topology are called Passive Optical Networks (PONs)[*12]. Currently, most services providing FTTH use a PON.

5.2 Communications Services with FTTH

FTTH can be used to provide communications services in addition to broadcast-distribution services. Full-duplex (bi-directional) service can also be offered using a single optical fiber by using wavelength multiplexing[*13]. Before describing how wavelength multiplexing is used, we will give a simple description of communications service mechanisms. The term PON is also used to refer to communications services that use PON, so to avoid confusion, we will use the term “PON services” when referring to communications services.

PON services provide full-duplex communications. Transmission on the downlink (from the provider to the subscriber) and the uplink (from the subscriber to the provider) are done using a scheme like that shown in Figure 7. Downlink information is sent using an optical signal transmitted from the provider, and reaches all subscriber terminals. Each subscriber terminal selects and outputs only the information for that subscriber. Uplink information is sent using an optical signal transmitted from the subscriber's terminal. To prevent the optical signals from different subscribers from overlapping, each subscriber terminal sends its optical signal in bursts during time slots allocated to the terminal. These bursts are received all together by the provider. Full-duplex communication on a single optical fiber is implemented by sending uplink and downlink information using optical signals of different wavelengths.

Gigabit-capable PON is a Giga-bit-class scheme specified in the Rec. ITU-T G.984 Series recommendations. Gigabit-Ethernet-PON (GE-PON) is a standard established in IEEE 802.3h from the Institute of Electrical and Electronic Engineers Inc. (IEEE)[*14]. A simple comparison of these two specifications is shown in Table 2. Use of GPON, which was developed based on Asynchronous Transfer Mode (ATM)[*15] is spreading mainly in Europe

[*12] Also called a Passive Double Star (PDS).

[*13] Transmitting multiple optical signals of different wavelengths over a single transmission path, with information transmitted on each optical signal. Wavelength Division Multiplexing (WDM).

[*14] The largest professional association in the electrical and electronics field in the world, with headquarters in the USA.

[*15] A multiplexing scheme used in communications networks.

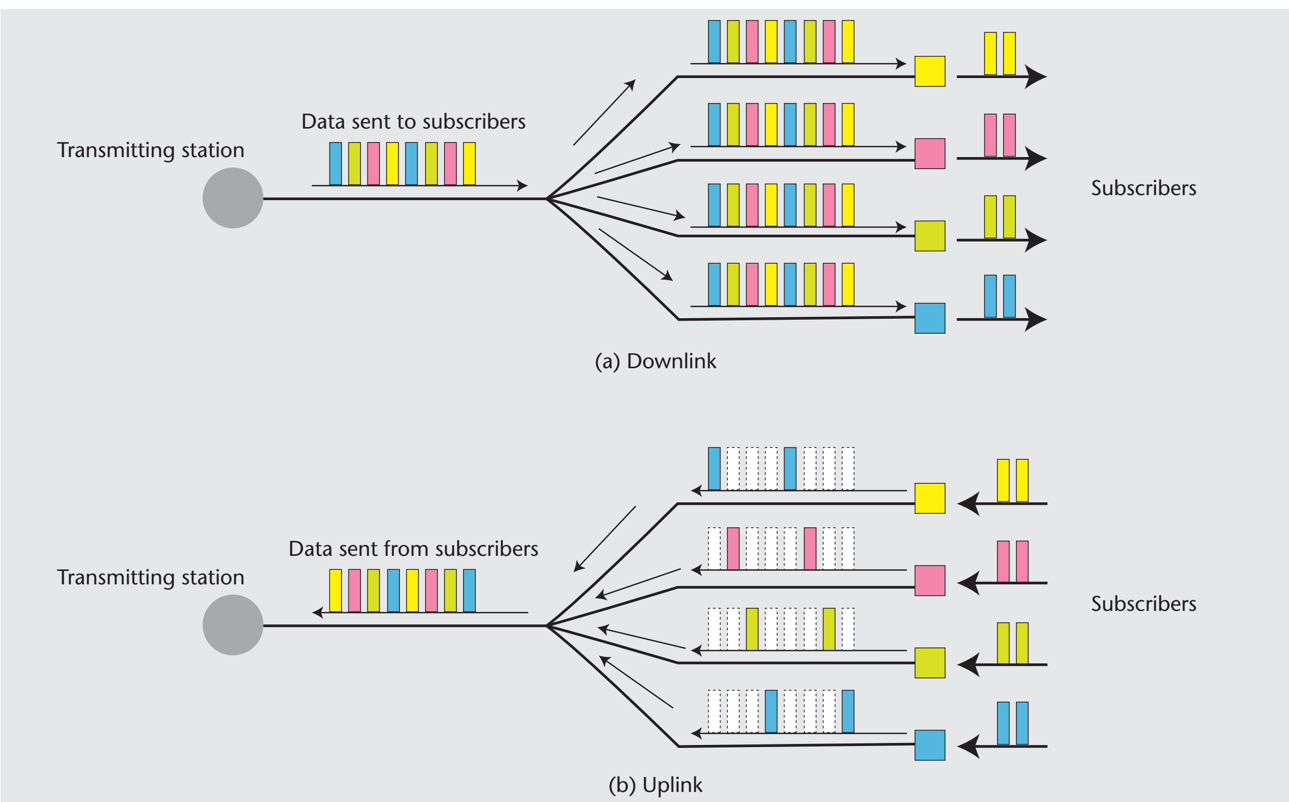

Figure 7: PON Service mechanism

Table 2: GPON and GE-PON

	GPON	GE-PON
Standard	Rec. ITU-T G.984	IEEE 802.3h
Transmission capacity	Uplink: 1.2/2.4Gbps Downlink: 2.4Gbps	Uplink: 1.25Gbps Downlink: 1.25Gbps
Notes	Used mainly in Europe and America	Used mainly in Japan

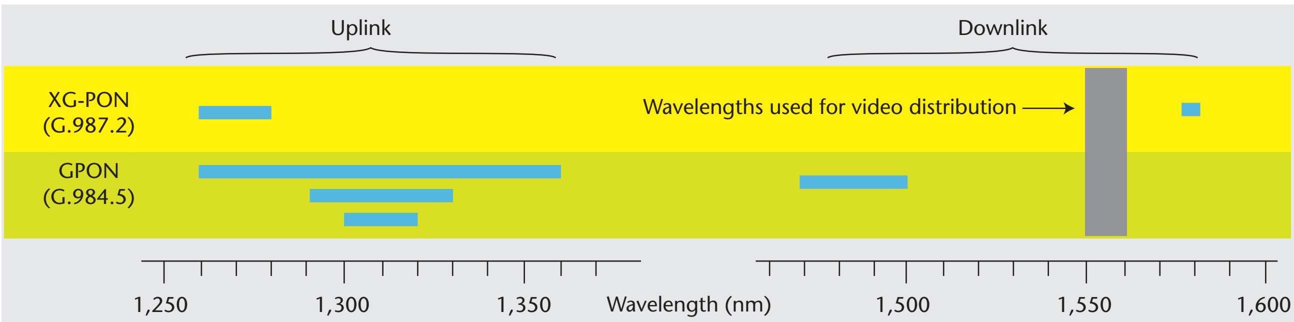

Figure 8: Wavelength bands used by GPON and XG-PON

and America, while use of GE-PON, which is based on Ethernet, is spreading in Japan. Standards for 10-Gbps-class PON services have also been established recently, including the Rec. ITU-T G.987 series (XG-PON[*16]) and IEEE 802.3av (10GE-PON).

The wavelength bands used for uplinks and downlinks in the GPON and XG-PON recommendations are specified as shown in Figure 8. Figure 8 shows the wavelengths recommended by ITU-T, but the IEEE standards specify wavelength bands similarly. The reason that multiple bands were specified for the GPON uplink is to support use of different semiconductor lasers with differing wavelength precision as the light source. These standards also specify wavelength bands for use by video distribution services. Both PON services and video distribution services can be provided at the same time over a single optical fiber using the wavelengths specified in these standards.

6. Transmission Formats for Video Distribution using Optical Fiber

6.1 Pass-through Optical Transmission including BS-IF/CS-IF Bands

High-frequency signals can also be transmitted optically using amplitude modulation, so the pass-through schemes used for coaxial cable can also be applied with optical fiber. Optical fiber can also transmit higher-frequency signals with less attenuation than coaxial cables, so pass-through transmission of BS-IF/CS-IF[*17] band signals as shown in Figure 9 is possible. As of September 2010, 81 facilities were using pass-through transmission for BS-IF band signals.

To transmit a large number of channels ranging from VHF and UHF bands to the BS-IF/CS-IF bands at once requires optical transmitters and receivers with very good linearity. Current analog broadcast signals must also be transmitted, so low-noise equipment is also necessary. Systems satisfying both of these requirements at the same time are expensive, so two types of systems have been implemented as shown in Figure 10, including a single-wavelength format using a high-performance semiconductor laser, and a two-wavelength multiplexing

*16 X is used to indicate the Roman numeral for 10.

*17 In this article we use CS-IF to refer only to 110° CS digital broadcasts, but narrow-band CS digital broadcasts (124°/148° CS digital broadcasts, etc.) are also transmitted as CS-IF signals.

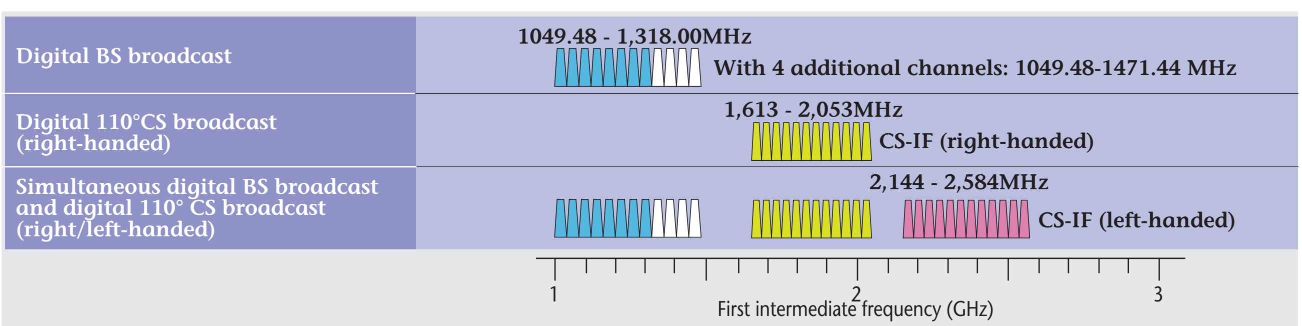

Figure 9: Frequencies for BS-IF/CS-IF bands

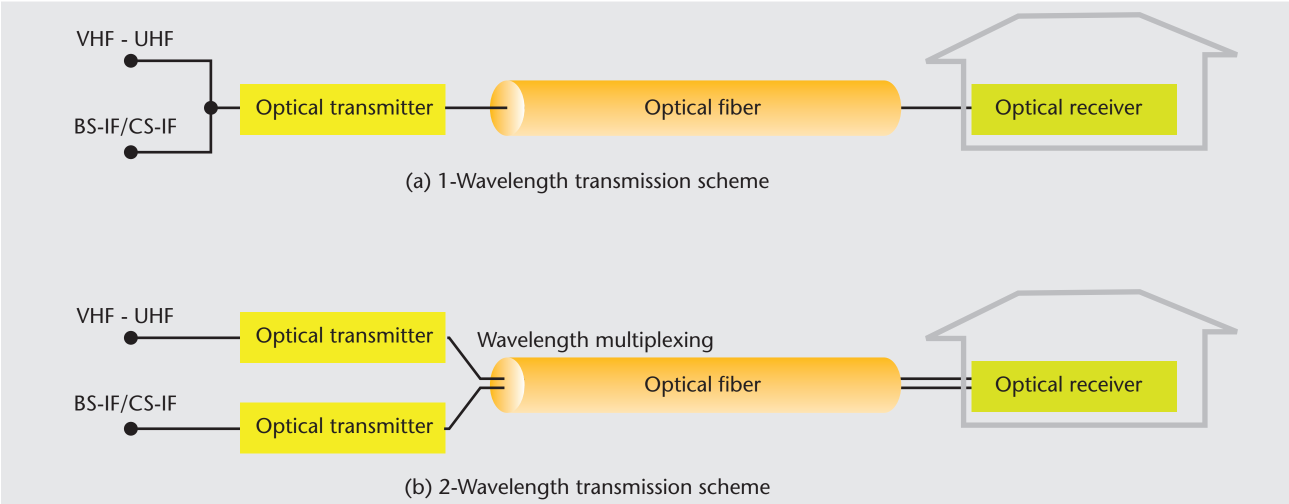

Figure 10: Pass-through optical transmission including BS-IF/CS-IF bands

format that divides the whole bandwidth into two or more partitions that each use independent modulation schemes.

6.2 Wide-band FM Conversion Scheme

As mentioned earlier, strict transmission characteristics must be satisfied in order to send broadcast signals by optical fiber. The wide-band FM conversion scheme[6] was developed to relieve these constraints. The scheme makes use of the wide transmission bandwidth of optical fiber and sophisticated optical device technology.

An overview of the optical video transmission employing wide-band FM conversion scheme is shown in Figure 11. A high-frequency signal multiplexing the multi-channel broadcast signal is input to an FM modulator, converting it to a wide-band FM signal. An optical signal modulated by this FM signal is transmitted on optical fiber. At the receiver, the optical signal is converted to an electrical signal and the FM signal is demodulated to obtain the multi-channel broadcast signal. The equipment is complex, but using FM modulation allows the resistance to noise and distortion of optical transmission to be utilized.

A high-frequency signal of approximately 1 GHz is input to the FM modulator, resulting in an output FM signal in the range of approximately 0.5 GHz to 6 GHz. It is extremely difficult to implement this sort of wide-band FM modulator using only electronic circuits, so it is implemented using semiconductor lasers as described below.

Semiconductor lasers output light with intensity proportional to the input current, but the wavelength (frequency) of light produced also changes with the current. The light frequency is extremely high, approximately 300 THz, so even a small change in wavelength can result in a significant frequency shift. A wide-band FM modulator using direct modulation is shown in Figure 12 (a). First, an FM-modulated optical

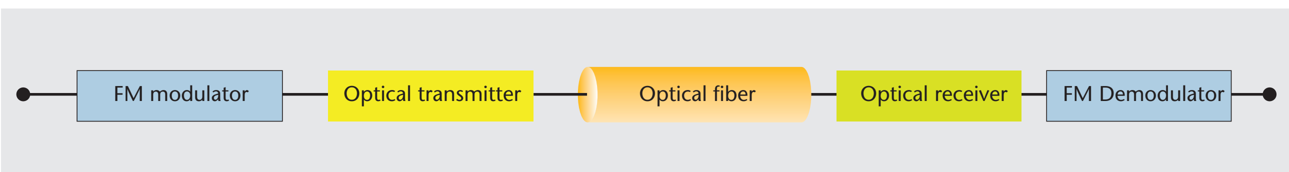

Figure 11: Optical video transmission employing wide-band FM conversion scheme

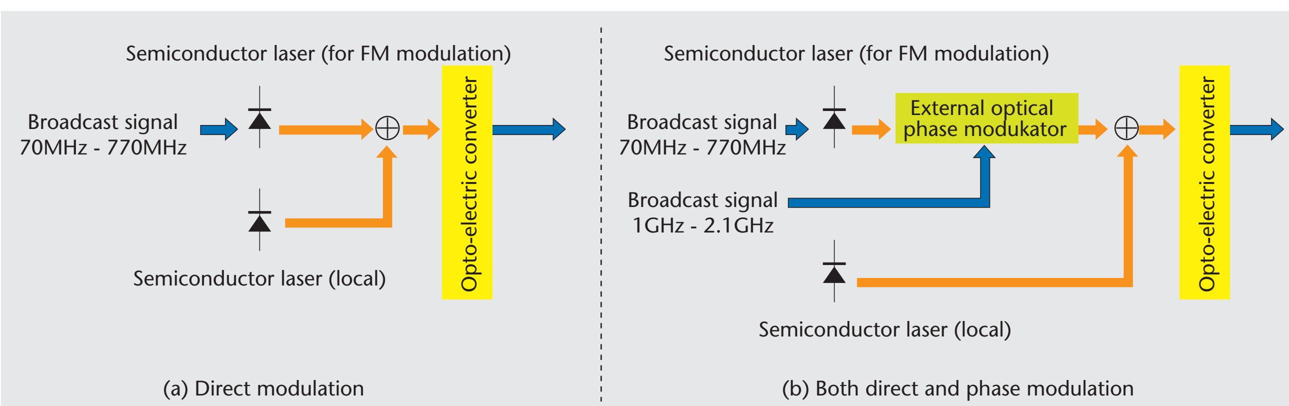

Figure 12: Optical FM modulator for wide-band FM conversion scheme

signal is produced using an FM-modulator semiconductor laser. Then, beats are created with another semiconductor laser of slightly different wavelength, and this signal is output as an electrical signal. A wide-band FM modulator using direct and phase modulation is shown in Figure 12 (b). It was developed for transmission up to 2.1 GHz, including the CS-IF band, and is used together with an external optical phase modulator.

6.3 Baseband Transmission Scheme

The schemes discussed in Sections 6.1 and 6.2 both transmit a frequency-multiplexed high-frequency analog signal, but optical fiber has a wide transmission band and it is more suitable for transmitting digital signals than analog signals. Schemes that transmit an analog optical signal modulated with a digital broadcast signal have been adopted to maintain compatibility with conventional cable television systems. If compatibility considerations are not important, there are many benefits to transmitting digital broadcasts directly as digital signals. Thus, at NHK STRL, we are conducting research on a system that transmits digital broadcasts as baseband digital signals, as a transmission scheme suitable for FTTH[7][8].

Below, we refer to conventional schemes that multiplex radio-frequency signals as Frequency Division Multiplexing (FDM) schemes, and schemes that multiplex baseband digital signals as Time Division Multiplexing (TDM) schemes. TDM schemes are more resistant to noise and distortion and can be received with lower optical power Thus, transmission distances can be longer and signals can be split more times, allowing for reduction in system costs. In particular, when broadcast signals are wavelength multiplexed with communications signals, they can be transmitted using the same scheme, and can share the same cables, as shown in Figure 13.

TDM formats have excellent features as described above, but they require a dedicated set-top box (STB) because they are not compatible with existing cable television systems. Also, they require optical fiber to be used to distribute the baseband digital signal within households. To resolve these issues, we are developing equipment[8] to convert the signal back to a radio-frequency signal for in-home distribution.

7. Conclusion

We have given an overview of cable television transmission technologies, focusing on standards. Cable television is very promising for taking on an important role as a comprehensive information and communications infrastructure, integrating not only retransmission of existing broadcasts, but also new broadcast services and services making use of communications technology. At NHK STRL, we will continue R&D efforts to advance development of broadcasting and cable television.

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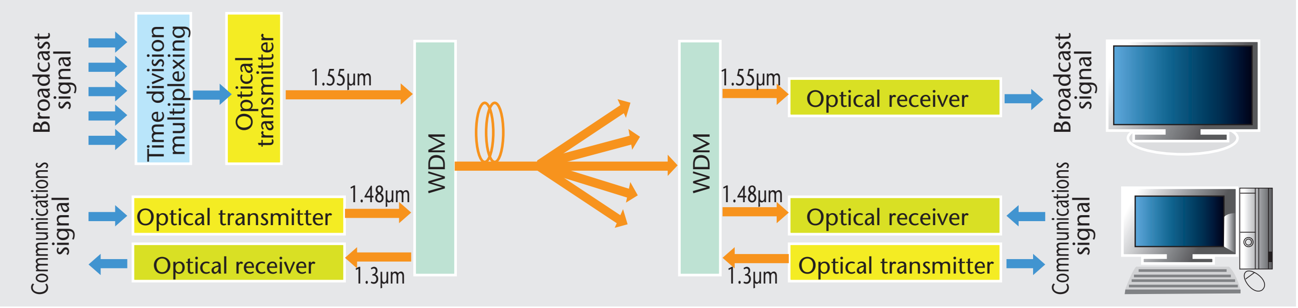

Figure 13: TDM-scheme transmission wavelength-multiplexed with communications services