NOTE

Digital broadcasting in the world

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1 Introduction

The history of broadcasting began with radio broadcasts in the USA in the 1920s. Since then it has advanced to TV broadcasting, color TV broadcasting, and latterly digital broadcasting.

This technical note examines the global trends in digital broadcasting, the technology for digital broadcasting, and the problems for reception by mobiles

2 What "digital broadcasting" is

As opposed to transmission of continuous signals in conventional analog broadcasting, digital broadcasting uses various encoding and multiplexing techniques to transmit signals.

Digitalization of broadcasting permits realization of new services such as those listed below.

- **High visual and sound quality**
  Digital broadcasting permits enjoyment of more attractive and strongly realistic visuals and sound. And for radio it permits high sound quality with clarity on a par with CD.
- **Large number of channels**
  Thanks to its highly efficient frequency utilization, digital broadcasting can transmit many more programs in a given bandwidth than analog broadcasting.

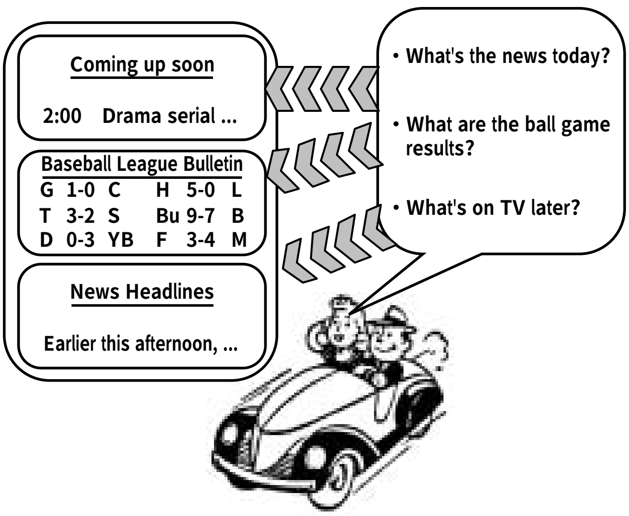

Fig.1 Concept of digital broadcasting

- **Advanced functions (data broadcasting / two-way capability)**
  Digital broadcasting's data broadcasting capability can enable viewers to, for example, check out player statistics and get weather forecasts, news and other information while watching a baseball program. And its two-way transmission capability can enable them to buy tickets or respond to polls, etc., during the program.

3 Global trends in digital broadcasting

[Europe]

Digitalized terrestrial audio broadcasting was the first digital broadcasting to be brought into practical use in Europe. DAB (digital audio broadcasting), which is broadcasting via terrestrial transmission of digitalized audio signals, began here in 1996. It permits users to enjoy services such as:

- High quality, CD-equivalent sound even in situations where multipath interference (reflected and other waves from hills and buildings, etc) is present.
- High quality reception even in mobiles such as cars.

The following year saw the start of satellite digital TV (DVB-S) and terrestrial digital TV (DVB-T) in Europe.

Table 1 Digital broadcasting in the world

	System name	Broadcasting		Starting year	Mobile reception
Europe	DVB-T	TV	Terrestrial	1998	△
	DVB-S	TV	Satellite	1998	×
	DAB	Audio	Terrestrial/Satellite	1996	○
USA	IBOC	Audio	Terrestrial	2003	○
	Sirius	Audio	Satellite	2001	○
	XM	Audio	Satellite	2001	○
Japan	ISDB-S	TV	Satellite	2000	×
	ISDB-T	TV/Audio	Terrestrial	2003	○
	MSB	Audio	Satellite	2003	○

※ Starting years in the future are projected
DVB : Digital Video Broadcasting
DAB : Digital Audio Broadcasting
IBOC : In-Band On Channel
Sirius : Sirius Satellite Radio
XM : XM Satellite Radio
ISDB : Integrated Service Digital Broadcasting
ISDB-T : ISDB-Terrestrial
ISDB-S : ISDB-Satellite
MSB : Mobile Satellite Broadcasting

[USA]

The USA has a fully developed road network that enables car travel over long distances inconceivable in Japan. The network has also however posed a problem for radio in that travelers could not continue listening to the same programs as they crossed into different service areas. The response to that problem is digital radio broadcasting via satellite, which can be received over the entire territory of the USA. This satellite digital radio is very much in the limelight, and has the following features:

- It broadcasts using the new waveband 2320-2345 MHz, via either 2 or 3 broadcasting satellites.
  In blind areas it uses terrestrial retransmission facilities called "repeaters," thus permitting broadcasting over the entire national territory.
- As of now 2 companies have entered the satellite digital radio arena: XM (XM Satellite Radio company) and Sirius (Sirius Satellite Radio company). The former began broadcasting in 2001 and latter in 2002.

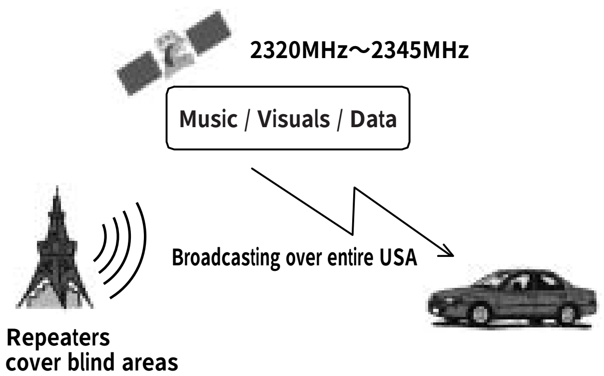

Fig.2 Concept of North American satellite digital radio

Table 2 Comparison of XM and Sirius companies

Broadcasting company	XM	Sirius
Broadcasting satellites	2 stationary orbit satellites, each with output 15 kW	3 elliptical orbit satellites, each with output 8 kW
Terrestrial repeaters	1700 units	100-200 units
Broadcast content	Music + voice (100 channels)	50 music channels + 50 voice channels
Reception fee	Around $10 / month	Around $10 / month

However there is also the fact that the USA has many FM and other radio stations that use terrestrial waves, serving small areas. Therefore efforts are being made to develop for practical use a method (IBOC: In-Band On Channel) that will permit digitalization within the frequency bands assigned to analog broadcasting. This method employs hybridization by adding digital signals within analog broadcasting wavebands; later it is planned to make a transition the all-digital method for all wavebands, with the aim of providing a higher grade of sound quality for both AM and FM.

The basis of the above-mentioned IBOC hybrid method is analog and digital streams with identical content. Analog broadcasts can be received with conventional radio tuners, but the hybrid method differs somewhat between AM and FM (refer to Fig. 3).

AM bands

The method is to apply low-level digital signals within the current analog signal wavebands and flanking both their side bands. This will give digital audio signals of equivalent quality to current FM signals. Transmission of simple data is also planned.

FM bands

The method is to flank both side bands of current analog signals with low-level digital signals. This gives digital audio signals of equivalent quality to CD. As with hybrid AM, transmission of simple data will also be possible.

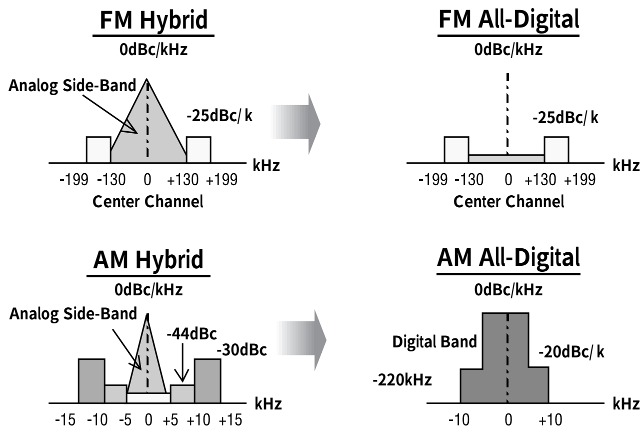

Fig.3 Image of IBOC

[Japan]

Following on the CS and BS satellite digital broadcasts that appeared in 1997 and 2001 respectively, Japan is currently moving ahead with preparations for mobile broadcasts (satellite digital radio) that are scheduled to begin in fiscal 2003. Compared to the existing CS and BS broadcasting this will be a completely new service since it will be possible to receive it while moving at high speed anywhere in the country. It will use the S (2.6 GHz) band. Through terrestrial retransmission facilities called "gap fillers" it is planned to provide multimedia broadcasting combining high-quality music, visuals and data to cars and other mobiles.

As regards digitalized terrestrial broadcasting, in 2003 the major cities of Tokyo, Nagoya and Osaka will begin receiving ISDB-T digitalized terrestrial TV broadcasts, which are expected to develop into nationwide

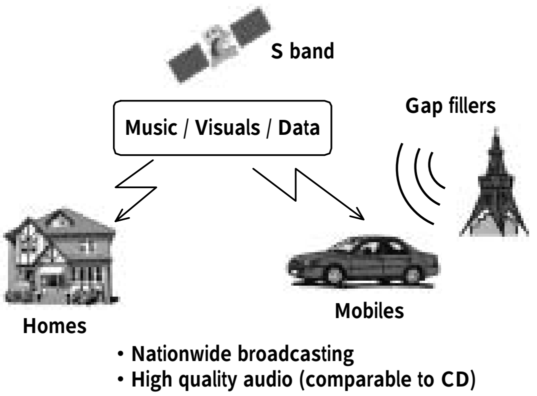

Fig.4 Concept of mobile (pay) broadcasting

broadcasts in the years from 2006 onward. ISDB-T uses UHF (470-770 MHz) waves, which it broadcasts with the same bandwidth as conventional analog broadcast waves (around 6 MHz) but divided into 13 segments. By using 12 or all 13 of these segments it can implement high visual quality HD (high definition) TV broadcasts. Alternatively it can split the 13 segments into up to 3 layers to provide multiple SDTV (standard definition TV) programs, or partial reception[i] broadcasting of single programs (simulcasts[ii] using MPEG4[iii]) for mobiles. Digitalized terrestrial TV broadcasts will eventually replace conventional analog terrestrial broadcasting, which is scheduled to end in July 2011.

The introduction of digitalized terrestrial TV broadcasting will permit realization of services such as the following:

- High quality visuals and audio thanks to employment of a method that is not susceptible to the influence of noise and is robust against ghost signals.

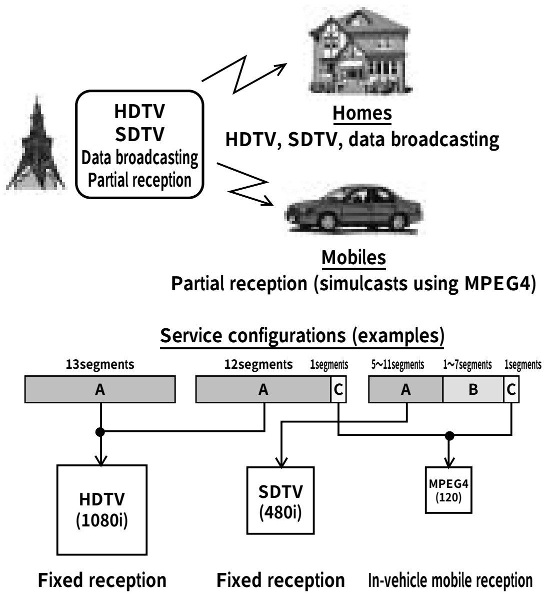

Fig.5 Concept of digitalized terrestrial TV broadcasting

- Reception by mobiles thanks to employment of a method that is robust against multipath interference and fading.
- Broadcasting of 2 or 3 programs using the same bandwidth that conventional analog broadcasting needs for a single channel.
- Users will be able to search for information on their screens and find with ease the channels they want to watch. And by storing text and static image data on their receiver they will be able to view news and event information etc., whenever desired.

Preparations are also underway for the start of digitalized terrestrial audio broadcasting, which will use narrow-band. As a rule digitalized terrestrial audio broadcasting uses VHF bands, but due to the deployment of the current analog TV channels it is planned to use channel 7 (188-192 MHz) for this broadcasting.

The broadcasting configuration will employ 1 segment or 3 segments to provide enjoyment of audio with CD-level high quality plus simple visuals. And since it will be mandatory to provide a partial reception segment in 3-segment broadcasting, users with 1-segment receivers will be able to enjoy a part of 3-segment broadcasts.

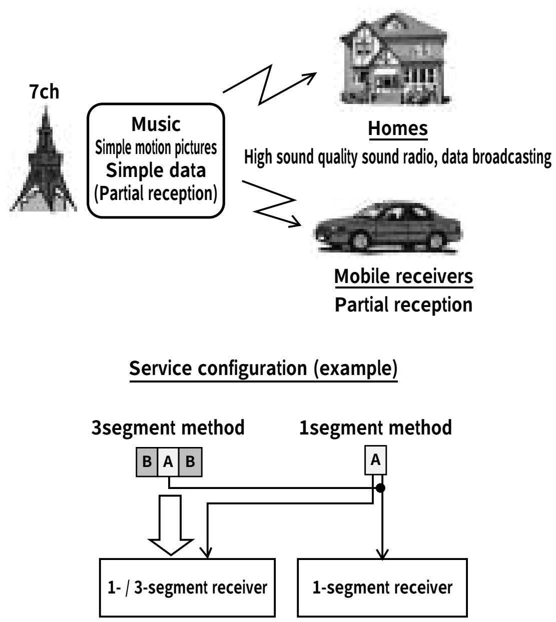

Fig.6 Concept of digitalized terrestrial audio broadcasting

The next section presents the technology used in Japan's digitalized terrestrial broadcasting.

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i: Reception of the band-central segment only. Enables enjoyment of a part of the broadcast without receiving all of the segments.
ii: Simultaneous broadcasting of the same program via multiple channels or media.
iii: Standardized method with the purpose of achieving high visual quality with a low bit rate. (simulcast)

4 Technology for Japan's digital broadcasting

The various technologies used in digital broadcasting can be broadly divided into 3 categories: ①data source encoding technology, ②multiplexing technology, and ③ transmission path encoding technology (modulation and error correction).

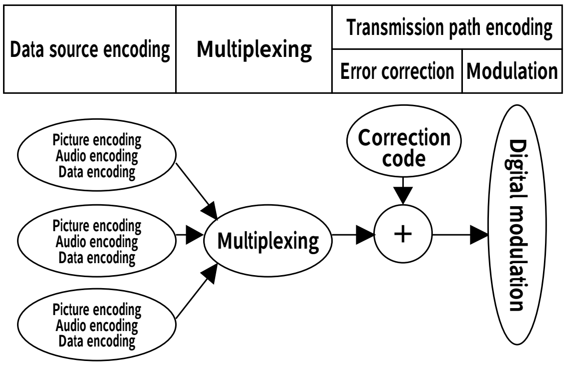

Fig.7 Technology used in digital broadcasting

4.1 Data source encoding technology

"Data source encoding" refers to the encoding (digitalization) of sounds and visuals, etc. It mainly uses the multimedia encoding technology known as "MPEG" (moving picture expert group). Japan's digitalized terrestrial TV employs the MPEG methods given in Table 3.

Table 3 Encoding methods used in digitalized terrestrial TV broadcasting

Visuals	MPEG2―VIDEO
Audio	MPEG2―AAC (Advanced Audio Coding)

MPEG2―VIDEO
Premised on use in wide-ranging applications such as broadcasting, telecommunications and storage media etc.
MPEG2―AAC
Multi-channel capability audio encoding method achieving high sound quality and high compression rates.

4.2 Multiplexing technology

"Multiplexing technology" is technology that treats multiple encoded data sources as single data items and permits the data sources to be mutually linked. The type of this technology used in Japan's digitalized terrestrial TV is called MPEG2-SYSTEMS. It is a method that multiplexes individual streams of encoded visuals, audio and appended data, etc., and synchronizes the streams as they are played back. 2 types of stream have been stipulated for MPEG2-SYSTEMS: program streams (PS) and transport streams (TS). The former type is applied in storage media, of which digital versatile discs are the prime example, and the latter in fields such as broadcasting and telecommunications. The basic configuration, known as "packetized elementary stream" (PES), is composed of both stream types and permits reciprocal conversion between the two. PES packets contain packetized data of a single medium in particular units; often a PES packet will consist of the data for a single image frame.

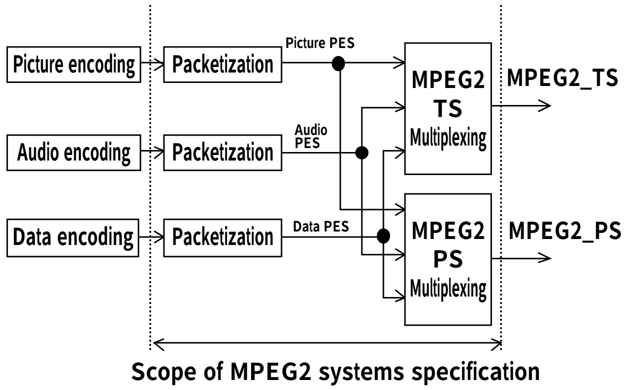

Fig.8 Outline of MPEG2 systems specification

4.3 Transmission path encoding technology (modulation and error correction)

4.3.1 Error correction technology

"Error correction" is technology that corrects errors occurring in the transmission path by means of pre-appended codes. The codes used for this purpose in Japan's digitalized terrestrial broadcasting are the Viterbi and the Reed-Solomon codes.

Viterbi algorithm

The features of this code are that it can correctly decode code sequences containing errors and has high corrective ability for random errors.

Reed-Solomon code

This is a block code system that divides the original data into blocks by appending multiple check bits and uses such blocks as the units for correction. It is able to detect and correct "burst" errors (concentrated occurrences of bit errors).

4.3.2 Digital modulation technology

Digital modulation consists of varying the carrier wave's amplitude, frequency or phase (or some combination of these) via the 0 / 1 information content of digital signals. The types of digital modulation method are ASK (amplitude shift keying) for modulating amplitude, FSK (frequency shift keying) for modulating frequency and PSK (phase shift keying) for modulating phase; each of these is able to transmit 1 bit of data with 1 symbol. Additional methods for transmitting large amounts of data at once include QPSK (quadrature phase shift keying), DQPSK (differential QPSK), QAM (quadrature amplitude modulation) and 16QAM (16-value QAM).

QPSK is able to transmit 2 bits of data with 1 symbol by changing the carrier's phase in 90 degree increments according to the information content of the digital signals.

Whereas QPSK makes the information correspond directly to the carrier wave's phase, DQPSK modulates the information onto the carrier phase differential (as its name implies) and thus does not require a synchronous carrier for demodulation in the receiver. QAM is a method that implements high-efficiency transmission by varying the amplitude via 2 additional carrier waves with 90 degree phase differential (in orthogonal relation) and is able to transmit 2 bits of data with 1 symbol. 16QAM can transmit 4 bits with 1 symbol and 64QAM can transmit 6 bits.

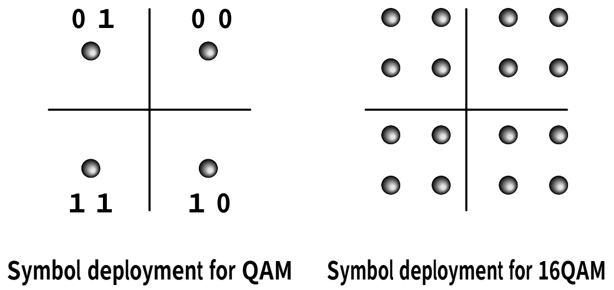

Fig.9 Digital modulation methods

For Japan's digital broadcasting it is planned to use either DQPSK, 16QAM or 64QAM to implement modulation. Each of these employ the multi-carrier method, a common variant of which is known as OFDM (orthogonal frequency division multiplexing) and is employed in Europe's DAB. Using this method permits good reception in mobiles since it is robust against multipath interference and fading. Other variants of the multi-carrier method include the CDM (code division multiplexing) used in Japan's S-band satellite digital audio broadcasting.

The multi-carrier modulation method is an important technology and we provide here a brief description of its OFDM variant. As can be seen from Fig. 10, the spectrum of OFDM is close to trapezoidal in shape. Enlarging part of it reveals that it is composed of multiple superimposed carriers. In fact it is made up of multiple digitally modulated carriers with symbol interval TS that have undergone inverse Fourier transformation and are arranged in sequence at a carrier spacing fc = 1/TS (each carrier being in an orthogonal relation to the others). Because of this any desired carrier can be extracted via integration by its symbol interval, without being affected by the other carriers. And since OFDM makes the symbol interval TS longer, or in other words makes the carrier spacing fc narrower, it has heightened resistance to multipath interference, frequency-selective fading and the like.

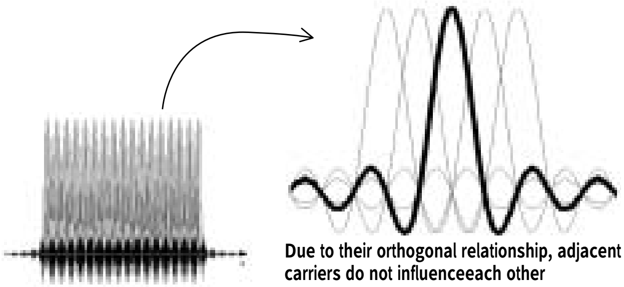

Fig.10 Spectrum of OFDM

But when retardation due to multipath interference becomes very large, the orthogonality among the carriers can no longer be maintained nor errors averted. To counter this a method using redundant intervals called "guard intervals" has been devised. This involves increasing the symbol length by just the assumed retardation time of the multipath interference waves (that is, by the guard interval), without changing the frequency spacing of the carriers; the receiver ignores the guard interval data, which are assumed to contain interference among symbols resulting from multipath interference, and receives the rest of the data normally by OFDM demodulation.

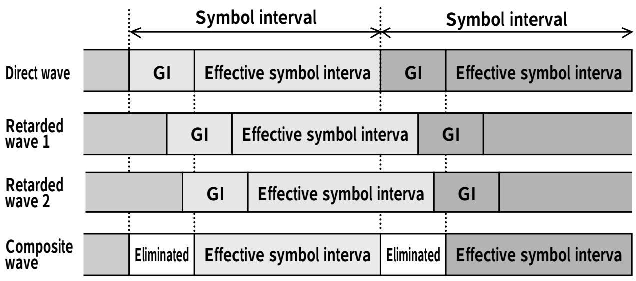

Fig.11 Image of guard interval

These guard intervals enable digitalized terrestrial broadcasting to relay broadcast waves via what is termed a "single frequency network" (SFN), which as the name implies uses just a single frequency. With traditional analog broadcasting, the signal interference that occurs among relay stations makes it problematic to use a single frequency. OFDM however will be free from such interference as long as retardation is within the guard interval, and this means that it can relay broadcast waves without changing the frequency for each broadcasting area.

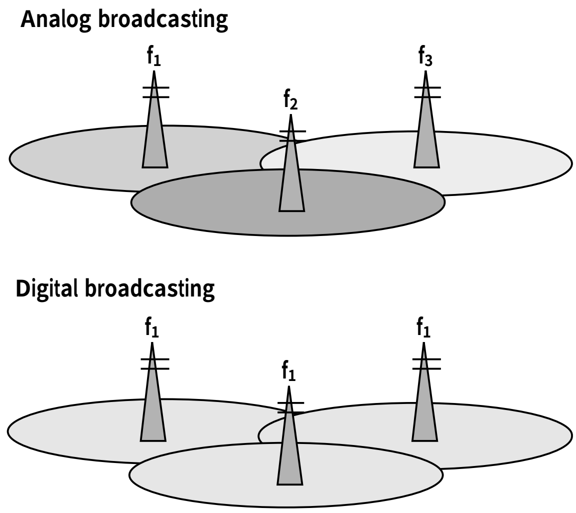

Fig.12 Concept of SFN

Thus, digital broadcasting makes use of various different technologies which are expected to enable high quality multichannel and multimedia service reception in mobiles as well as stationary locations. Nevertheless many problems arise in reception of broadcasts by mobiles, particularly cars. In the next section we examine the problems for reception of digitalized terrestrial broadcasts by mobiles.

Table 4 Transmission parameters for digitalized terrestrial TV broadcasting

Transmission parameters	MODE1	MODE2	MODE3
Number of OFDM segments	13		
Bandwidth	5.575MHz	5.573MHz	5.572MHz
Carrier spacing	3.968kHz	1.984kHz	0.992kHz
Number of carriers	1405	2809	5617
Modulation method	DQPSK, 16QAM, 64QAM		
Effective symbol length	0.252ms	0.504ms	1.008ms
Guard interval length	1/4, 1/8, 1/16, 1/32 of effective symbol length Maximum value of each setting		
Inner code	Convolution coding (1/2, 2/3, 3/4, 5/6, 7/8)		
Outer code	Reed-Solomon (204, 188)		
Data bit rate	3.65-23.23 Mbps		

3 Problems for reception by mobiles

5.1 Problems of antenna

With analog TV broadcasting, a fall in the electrical field strength will cause only mild deterioration in the visual quality and the picture will still be discernible. But with digital broadcasting, if the electrical field strength drops below a certain level the reception quality will fall drastically so that the picture will not be discernible and furthermore the audio will stop. This means that with digital broadcasting it is necessary to obtain some increase in gain via the antenna. Yagi antennas are often used for fixed (home) reception, and pole antennas are commonly used for in-vehicle reception. There is a large gain difference between these two antenna types, and in-vehicle reception is less advantageous than fixed reception. While fixed reception circuitry is designed for antenna gain of 8 dBi (14-element Yagi antenna), the gain of an in-vehicle TV antenna (pole antenna) is -7 dBi, some 15 dB too low for fixed reception. In addition, the fixed reception Yagi antennas are installed at locations approximately 10 meters in height, whereas most in-vehicle reception antennas are installed at a height of approximately 1.2 meters. Because it is for the most part more advantageous to mount antennas in high locations, there is an additional 13dB loss for a total gain difference of 28dB.

It is assumed that both broadcasters and users will desire HDTV when digitalized terrestrial TV broadcasting is actually introduced. Broadcasting HDTV requires a data rate of 20 Mbps (1080 p) or higher. Table 5 shows the relationship among the reception method, data rate and required C/N. Securing a data rate of 20 Mbps or higher will mean broadcasting using 64QAM. Reception of 64QAM will in turn mean required C/N of 22.0 dB.

Table 5 Relationship between reception method, data rate and required CNR

Modulation method	Data rate 13 segments	Required C/N No multipath interference, vehicle stopped
64QAM	21.0Mbps (7/8)	22.0dB
16QAM	10.8Mbps (2/3)	13.5dB
DQPSK	5.4Mbps (2/3)	7.7dB

*Values in parentheses are encoding rates

But it is extremely difficult to secure C/N of 22 dB or higher with in-vehicle reception antennas, so that the reception area possible with in-vehicle reception will be much smaller than that with fixed reception (refer to Fig.13).

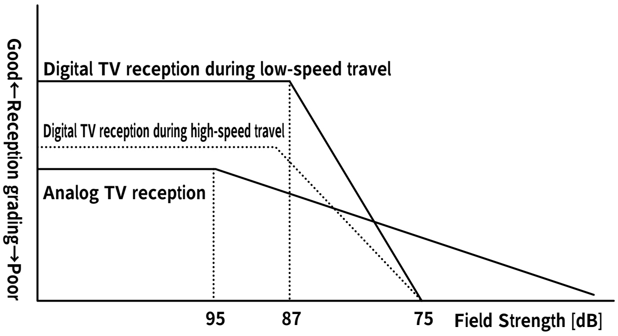

Fig.13 Mobile reception characteristics for digitalized terrestrial TV broadcasting

A further problem with in-vehicle reception antennas is orientation. Fixed-reception Yagi antennas can be oriented to point in the direction of arrival of the radio waves (direct waves), thus adequately suppressing the effects of multipath interference (reflected, diffracted and other waves due to buildings and so on). But in-vehicle reception antennas essentially have no particular orientation and therefore receive both direct waves and multipath or other retarded waves.

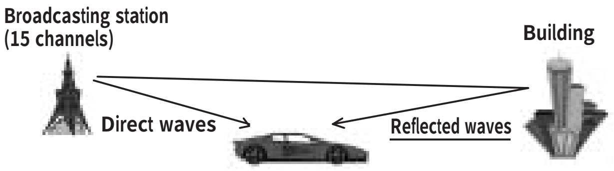

Fig.14 Problems with in-vehicle reception

Multipath interference due to retarded waves causes interference among and within the symbols in the ODFM signals received. Provided that the retardation amount is within the guard interval, interference among symbols can be prevented by discarding the guard interval as mentioned earlier (refer to Fig. 11). Interference within symbols on the other hand will result in the direct wave being influenced by the retarded waves, so that a portion of the characteristic trapezoidal OFDM spectrum takes on a collapsed form as shown in Fig. 15. When this happens the carrier affected by the interference cannot be extracted and errors occur in the data transmission.

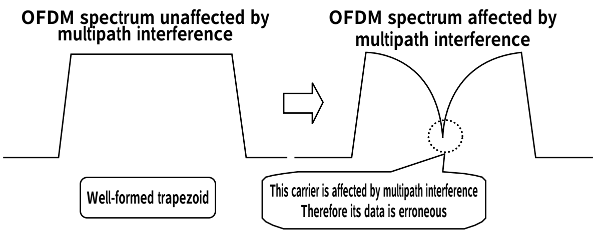

Fig.15 Influence of multipath interference on OFDM

5.2 Doppler shift due to high-speed travel

With in-vehicle reception the frequency received fc will be shifted by a Doppler frequency ±Δ fd because the vehicle is constantly in motion. Assuming low-speed travel the Doppler shift due to motion will be correctible because the transmission path will be inferred via the pilot signal within the OFDM signal. In general, reception is held to be possible with Doppler shift frequency up to 2.5% of the carrier spacing; Table 6 gives the limit Doppler shift frequency for reception in each mode. In the case of mode 3 in the table, the theoretical top speed allowing reception is 35 km/h and reception is not possible at high speeds above that limit.

Table 6 Reception limits imposed by Doppler shift

	Limit for Doppler shift frequency	Limit travel speed for reception
MODE1	100Hz	140km/h
MODE2	50Hz	70km/h
MODE3	25Hz	35km/h

The limit travel speeds are for 62 ch (770 MHz), 64QAM.

The conditions during actual travel will be even severer since they will involve multipath interference mixed in with the Doppler shift. An examination of multipath interference during low-speed and high-speed travel such as in Fig. 16 shows that whereas correction based on the pilot signal is possible with low-speed travel, with high-speed travel each carrier is shifted by ±Δ fd (the Doppler shift frequency) and such correction is no longer possible.

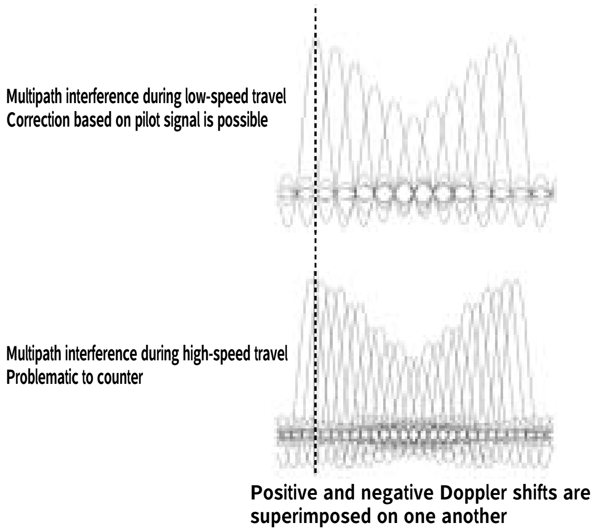

Fig.16 Influence of multipath interference and Doppler shift on in-vehicle reception

A further problem concerns the SFN discussed earlier. Whereas mode 3 with its long symbol interval is advantageous from the viewpoint of SFN, it is the mode that is most susceptible to the effects of Doppler shift (as Table 6 shows) and is therefore disadvantageous for mobiles.

The problems for reception by mobiles discussed above can be summarized in the form of the following trade-off relationship (refer to Table 7)

- Modulation using the 64QAM method is necessary for HDTV broadcasting, although this method is extremely disadvantageous for mobile reception antennas.
- Mode 3 with its long symbol interval is advantageous for SFN, although it is susceptible to the effects of Doppler shift and therefore disadvantageous for mobiles.

Table 7 Mobile reception characteristics with different methods

	Mobiles	SFN
MODE1	Advantage	Disadvantage
MODE2	↑	↓
MODE3	Disadvantage	Advantage

	Mobiles	Bit rate
DQPSK	Advantage	Disadvantage
16QAM	↑	↓
64QAM	Disadvantage	Advantage

It can be appreciated from this trade-off relationship that reception of HDTV by mobiles is extremely problematic; indeed they also have many difficulties in receiving SDTV with its intended product quality. For this reason the use of a partial reception segment (simulcasting of MPEG4) is envisaged in order to allow users to enjoy digitalized terrestrial TV in mobiles as well as stationary locations.

6 Conclusion

This technical note has set forth the trends in the rapidly accelerating digitalization of the broadcasting field, together with the technologies involved. It has also described in outline the problems that antenna gain, multipath interference and Doppler shift pose for reception of digital broadcasts by moving objects.

The future will see a shift from "viewing" and "listening to" broadcasts toward "utilizing" broadcasts, and the need to receive digital broadcasts in vehicles is anticipated to rise steadily in line with that shift.

Our company has had experience in the development of DAB receivers for Europe, and is currently utilizing that experience to forge ahead with development aimed at launching receivers onto the market for IBOC broadcasting in the USA and later for the start of domestic digitalized terrestrial broadcasting in 2003.

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