Development of North America Terrestrial Digital Audio Broadcasting Receiver (HD Radio)

Osamu Mino
Takanori Fujiwara
Hideshi Nishizawa
Kazuo Takayama

Abstract

Digital radio broadcasts have begun worldwide and are beginning to progress from initiation to widespread acceptance. Terrestrial digital radio broadcasts in North America have been in service since October 2002 applying IBOC (In-Band On-Channel) technology. Terrestrial digital audio broadcasts in North America are conducted using the same frequency band as AM/FM broadcasts, and the bandwidth of digital audio broadcasts is wider than that of AM/FM broadcast waves. This has led to concerns that these broadcasts will interfere with those of existing stations. Additionally, although broadcasts can be switched between digital and analog output in accordance with reception quality, doing so causes poor reception during the switchover itself.

FUJITSU TEN developed a receiver that uses a reception bandwidth filter to switch over between digital/analog broadcasts, effectively preventing interference, and optimally processing the analog/digital switchover for clear, stable reception.

This report provides an overview of digital broadcasting worldwide and explains the North American terrestrial digital audio broadcast receiver developed at FUJITSU TEN to address the aforementioned issues.

1 Introduction

1996 saw the world's first digital radio broadcasts with the debut of Europe's DAB (Digital Audio Broadcasting).

2001 saw the launch of satellite digital radio broadcasting in North America, where it was followed in 2002 by the appearance of terrestrial digital audio broadcasting. Starting in October 2003 Japan has also experimented with terrestrial digital audio broadcasts. And mobile broadcasting using satellites began in October 2004.

Thus the digitizing trend is making steady progress in the world of radio as in other fields.

2 Digital radio broadcasting worldwide

Fig.1 Countries broadcasting digital radio in the world

The methods of digital radio broadcasting currently used in various countries can be broadly divided into the following:

- **DAB (Eureka 147) method, centered in Europe**
- **North America's IBOC (In-Band On-Channel)**
- **Japan's ISDB-T method**
- **Satellite digital method**

2.1 DAB method

Europe's broadcasting using the DAB method began in 1996, mainly in Germany, United Kingdom and France. This is digital radio that provides moving bodies with multiple ensembles of digital audio and data using 1.5 MHz bandwidths at VHF and 1.5 GHz frequencies. (Free service.)

Table 1 Start status of DAB broadcasting

Country	When broadcasts began	% population currently covered
UK	1996	86%
Germany	1996	
France	1996	
Israel	1996	85%
Singapore	Nov. 1999	100%
Canada	Nov. 1999	35%
Taiwan	Mar. 2000	40%
Turkey	Mar. 2002	17%

2.2 IBOC method

North America's terrestrial digital audio broadcasting makes use of established AM/FM frequencies used by radio stations. It is able to transmit digital signals simultaneously with analog broadcast waves. This is known as the In-Band On-Channel (IBOC) technique and was developed by the iBiquity Digital company. Broadcasts using it began in October 2002 as "HD Radio". In April 2002 the FCC had given "HD Radio" approval for full-time FM broadcasts. Regarding AM however it had only approved daytime broadcasts - approval for night broadcasting was made conditional on further testing. Then in April 2004 it issued additional items for a provisional bill. Submissions for approval of nocturnal AM broadcasts and of SAC (Supplemental Audio Channels) and data services, together with a compilation of comments from the industry, were completed in August. The final, detailed provisions from the FCC are expected to appear around the second quarter of 2005.

Currently 700 stations have been licensed, of which more than 300 are on air, covering 85% of the market.

At this year's biggest North American electronics show '05CES, a broadcasters' group announced they would be starting broadcasts of HD radio by a scheduled 2000-plus stations within a few years. (Free service.)

2.3 ISDB-T method

Experimental broadcasts by Japan to bring its ISDB-T method of terrestrial digital audio broadcasting into practical use began in October 2003.

Full-fledged broadcasting of this type is scheduled for after the cessation of analog TV broadcasts in 2011. (Free service.)

2.4 Satellite digital method

In North America, satellite digital broadcasting provides music of CD-comparable audio quality via 2.4 GHz S-band satellites. This is a digital radio service that can be received in homes, cars or any place desired for a monthly charge of $9.95. XM Radio started broadcasting this service in September 2001 and Sirius Satellite Radio in February 2002. XM currently has around 3 million subscribers and Sirius around 1 million. (In both cases the broadcasts are a pay service.)

In Japan, satellite digital broadcasting began in October 2004 in the form of mobile broadcasts in the 2.6 GHz S-band (a pay service.)

2.5 Other methods

China has begun digital TV broadcasts using satellites in 2005. It plans to start terrestrial digital broadcasts in 2008 and to end analog broadcasts in 2015.

Worldwide there exist 3 types of standard for such broadcasting - the Japanese, American and European, but it is highly likely that China will adopt a self-developed standard.

The above broadcasting methods are summarized in Tables 1 and 2 below.

Table 2 Digital radio broadcasting in the world (trends)

Category		Region	Service	2000	2001	2002	2003	2004	2005	～2010
Radio	Terrestrial	Japan	ISDB-T				● Experimental broadcasts began in fall 2003 (Tokyo and Osaka regions)			
		North America	IBOC-DAB				● Broadcasts began (CES)			
		Europe	Eureka147-DAB	※Broadcasts began 1996 Popularization proceeding slowly						
	Satellite	Japan	ISDB-S					● Broadcasts began 2004		
		North America	XM/Sirius		● Broadcasts began Sept. 2001 (receiver price $200-300, monthly charge $9.95/12.95)					
		Europe	DAB-S				※ Start of broadcasts undecided			

Table 3 Digital radio broadcasting in the world (format)

ITEM	DAB	IBOC	ISDB-T	XM	SIRIUS
Mod	DQPSK /COFDM	QPSK 16QAM 64QAM /COFDM	DQPSK QPSK 16QAM 64QAM /BST-OFDM	QPSK TDM /COFDM	QPSK TDM /COFDM
Error correction	Convolution	Convolution	RS+Convolution	RS+ Convolution	RS+ Convolution
Audio Encoding	MPEG-1 Layer2	HDC	MPEG-2 AAC	PAC	PAC
Freq.Band	VHF,UHF	AM,FM	VHF,UHF	2328.5-2332.5M	2332.5-2345M
Bandwidth	1.536MHz	400kHz (FM-Hybrid) 35kHz (AM-Hubrid)	430kHz (1Segment)	12.5MHz	12.5MHz
Effective Data rate	800～1700k	128k (hybrid)	280～1787k (1Segment)	4.4M	4.0M
Standardization	1995	2001	1999		
On Air	1997	2003	2003	2000	2001

These digital broadcasting methods all differ from one another and have no intercompatibility.

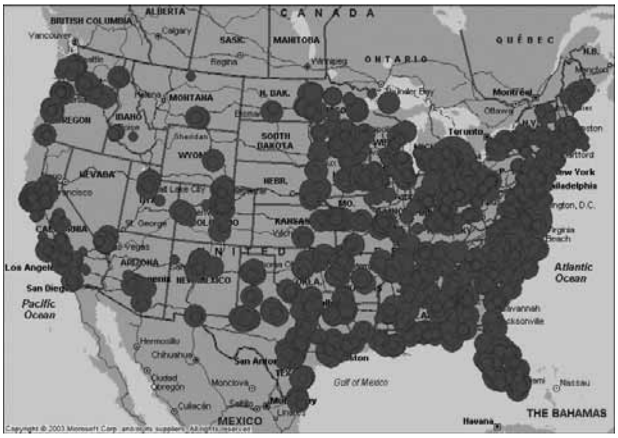

Fig.2 Service-in Forecast of HD radio station in the next few years (iBiquity materials)

3 Overview of IBOC (In-Band On-Channel) broadcasting method

There are two types of IBOC: a hybrid type for the transitional stage in which the shift is made from analog to digital AM/FM broadcasts, and an all-digital type for the stage where all broadcasting stations have completed the shift to digital broadcasts.

The current situation represents the transitional period with AM/FM analog waves and IBOC digital waves used alongside each other. The features of the hybrid type are described below.

3.1 Features of IBOC broadcasting method

North America's IBOC terrestrial digital audio broadcasting "HD Radio" is intercompatible with conventional analog AM/FM radio. Hence it enables high-quality digitization of conventional radio broadcasting just as it is - including frequencies, antennas, areas covered, and free service. Providing merits both for broadcasters and for users, it is anticipated to spread rapidly as the infrastructure is upgraded.

The features of the IBOC method "HD Radio" are the following:

- It is the world's only hybrid digital broadcasting, intercompatible with existing AM/FM. Employing the same broadcasting means as AM/FM, it offers digitized audio with the same content as analog broadcasts, and likewise free of charge.
- It permits in-vehicle signal reception that is strongly stable against multipath and fading noise.
- It can use the antennas and other equipment of conventional radio unchanged.
- It permits switching between digital for strong/medium electric field areas and analog for weak electric field areas, thus covering the same broadcasting areas as heretofore.

3.2 IBOC-FM method

In the IBOC-FM method, an OFDM wave approximately 70 kHz wide is added on both sides of the analog broadcast wave. The number of subcarriers is 190 on each side, for a total of 380. The carrier interval is 363.4 Hz.

OFDM stands for "Orthogonal Frequency Division Multiplexing". It is a transmission technique that is able to raise the speed of data transmission without changing the modulation method or symbol rate (modulation rate).

By employing multiple subcarriers with differing center frequencies, OFDM realizes a high frequency efficiency. It is a special multisource communication method that divides the data to be transmitted into small segments that it places onto multiple subcarriers so as to transmit them in parallel. By segmenting the data it is able to achieve a lower symbol transmission rate per transmission wave than with serial transmission, thus enabling supplementary signals to be inserted. As a result, the overall influence of fading (phenomenon whereby the strength, etc., of wireless transmission signals varies considerably over time and space) can be kept small. Further, transmission is effected with the adjacent subcarriers orthogonal to one another, so that their bands will not interfere even if they are brought so close as to overlap.

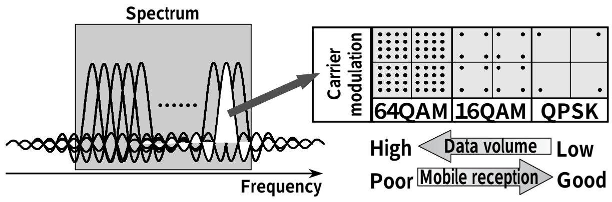

Fig.3 OFDM and carrier modulation

Table 4 IBOC-FM parameters

Parameter Name	Symbol	Units	Exact Value	Computed Value (to 4 significant figures)
OFDM Subcarrier Spacing	Δf	Hz	1488375/4096	363.4
Cyclic Prefix Width	α	none	7/128	5.469×10^{-2}
OFDM Symbol Duration	T_s	Sec.	$(1+\alpha)/\Delta f =$ $(135/128)\cdot(4096/1488375)$	2.902×10^{-3}
OFDM Symbol Rate	R_s	Hz	$= 1/T_s$	344.5
L1 Frame Duration	T_f	Sec.	$65536/44100 = 512 \cdot T_s$	1.486
L1 Frame Rate	R_f	Hz	$= 1/T_f$	6.729×10^{-1}
L1 Block Duration	T_b	Sec.	$= 32 \cdot T_s$	9.288×10^{-2}
L1 Block Rate	R_b	Hz	$= 1/T_b$	10.77
L1 Block Pair Duration	T_p	Sec.	$= 64 \cdot T_s$	1.858×10^{-1}
L1 Block Pair Rate	R_p	Hz	$= 1/T_p$	5.383
Diversity Delay Frames	N_{dd}	none	3 = number of L1 frames of diversity delay	3

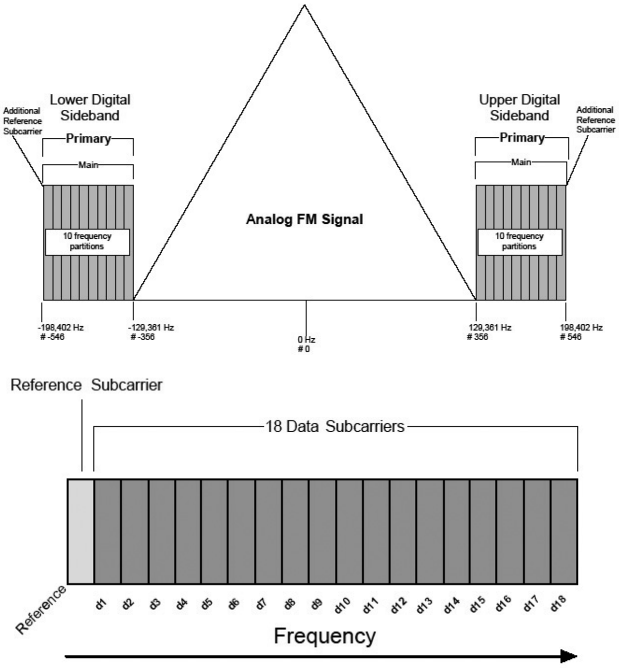

Fig.4 IBOC-FM spectrum

A reference subcarrier is deployed for every 18 data subcarriers. With this arrangement the transmission bit rate (in MP1 mode) is 98.4 kbps for digital audio (96 kbps for internal digital audio) and 0.9 kbps for other data.

3.3 IBOC-AM method

In the IBOC-AM method, 3 OFDM waves approximately 5 kHz wide are added on both sides of the analog broadcast wave. The number of carriers is 80 on each side, for a total of 160. The carrier interval is 181.7 Hz.

Table 5 IBOC-AM parameters

Parameter Name	Symbol	Units	Exact Value	Computed Value (to 4 significant figures)
OFDM Subcarrier Spacing	Δf	Hz	1488375/8192	181.7
Cyclic Prefix Width	α	none	7/128	5.469×10^{-2}
OFDM Symbol Duration	T_s	Sec.	$(1+\alpha)/\Delta f =$ $(135/128)\cdot(8192/1488375)$	5.805×10^{-3}
OFDM Symbol Rate	R_s	Hz	$= 1/T_s$	172.3
L1 Frame Duration	T_f	Sec.	$65536/44100 = 256 \cdot T_s$	1.486
L1 Frame Rate	R_f	Hz	$= 1/T_f$	6.729×10^{-1}
L1 Block Duration	T_b	Sec.	$= 32 \cdot T_s$	1.858×10^{-1}
L1 Block Rate	R_b	Hz	$= 1/T_b$	5.383
Digital Diversity Delay Frames	N_{dd}	none	3	3
Diversity Delay Time	T_{dd}	Sec.	$= N_{dd} \cdot T_f$	4.458

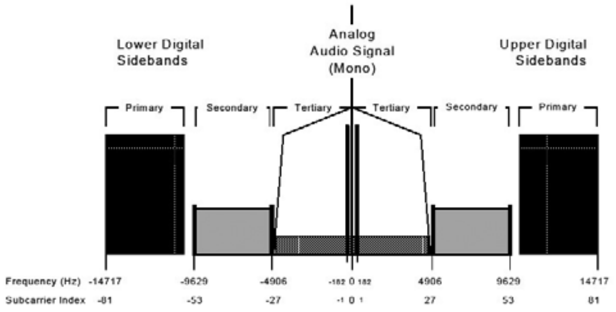

Fig.5 IBOC-AM spectrum

Both sides are modulated via 64 QAM, 16 QAM and QPSK digital modulation. The reference carriers are deployed so that frequency synchronization can be easily effected via BPSK modulation.

With this arrangement the transmission bit rate (in MA1 mode) is 36.4 kbps for digital audio (36 kbps for internal digital audio) and 0.4 kbps for other data.

3.4 Configuration of IBOC receiver

The receiver's regular configuration is shown below.

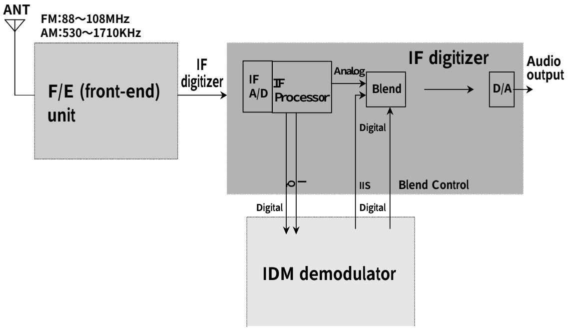

Fig.6 Receiver configuration

The circuits can be broadly divided into the front end (F/E) unit, the IF digitizer, and the IDM (IBOC Digital Module) demodulator.

A reception signal entering the antenna undergoes high-frequency amplification and frequency conversion in the F/E unit, being thereby converted to intermediate frequency (IF).

The signal now passes through filters to remove disturbing waves, etc., from it, then passes through automatic gain control (AGC) circuits before entering the IF digitizer.

It is in the IF digitizer that the reception signal undergoes digitization (IF A/D) to convert it into a digital signal. Further, it is split into streams for the IDM decoder, which performs demodulation of analog waves and decoding of digital waves.

In the IDM decoder the digital waves are demodulated and decoded, then a digital audio signal and blend signal are returned back to the IF digitizer.

Based on the blend signal, the IF digitizer synthesizes and performs switchover processing (blending operation) on the digital audio signal from the IDM decoder and the digital audio signal derived via analog wave demodulation.

The resulting digital output undergoes DA conversion (D/A) and exits as the audio output.

Overview of IBOC method: Blending operation

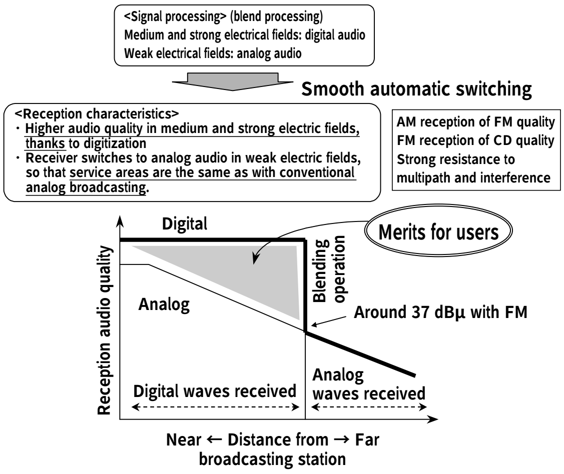

Fig.7 Blending operation

Digital waves are received when the broadcasting station is near (strong/medium electric field) and analog waves when it is far (weak field). The receiver effects smooth automatic switching of the audio between these two, with blending operation ensuring that no interruption to the audio takes place.

The smooth automatic switching is executed by the DSP, which performs synthesis while making corrections for the time and quality differences between the digital and analog audios in the receiver. DSP is dealt with later.

3.5 Technical issues of the IBOC receiver

①Achieving both broadband IF and elimination of interference and disturbance

IBOC waves are for digital broadcasting and have broad wavebands compared to AM/FM broadcast waves. Therefore filters with broad bands are used for IBOC waves.

This means that when an IBOC receiver receives conventional analog waves, disturbing waves will enter inside the band, rendering it prone to adjacent channel disturbance and hence to interference/disturbance.

- Switching of IF filters and optimization of the algorithms for it are important requirements.

②Smooth switching between analog and digital

When the limit point for reception of digital waves is reached, the digital audio suddenly stops or is suddenly switched to analog, which causes a marked auditory unpleasantness due to the large quality difference.

- Optimization of the blend processing will make for smooth reception at such times.

4 IBOC broadcast reception technology

Fig. 8 provides a block diagram of the receiver developed by FUJITSU TEN for the North American terrestrial digital audio broadcasts.

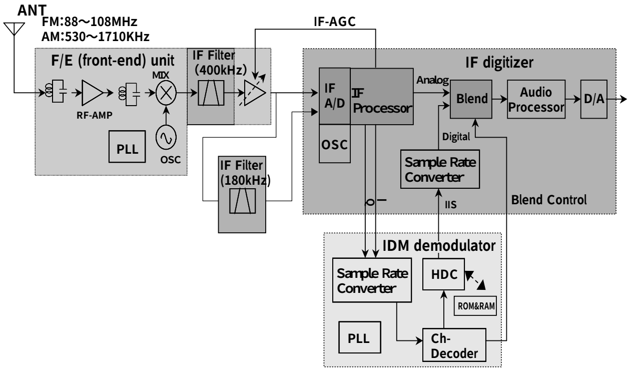

Fig.8 Block diagram of receiver configuration

For digital reception of "HD Radio" the F/E unit employs a 400 kHz broadband filter that allows the digital sidebands to pass. All IBOC modulated waves are output from the F/E unit to serve as an A/D input for the IF digitizer. Further, IF filter branching circuits are placed between the F/E unit and IF digitizer, so that the analog signal component is passed through a 180 kHz IF filter and output to serve as another A/D input for the IF digitizer. Thus the F/E unit inputs two IF output streams into the IF digitizer.

This is in order to improve the adjacent disturbance characteristics; the IF input streams and internal IF filter bandwidths are switched between digital and analog reception by means of a proprietary algorithm within the IF digitizer.

Moreover, during digital reception the IF digitizer makes its signal output branch into external digital modulation circuits (IDM modulation unit) and internal analog modulation circuits. The signals (digital and analog respectively) resulting from modulation by these circuits then undergo blend processing (DSP processing that takes account of the quality and time differences between the digital audio and analog audio when received) so that switchover is effected smoothly.

4.1 IF band switchover processing

Two filters are provided: a broadband filter, and a narrow-band filter for analog waves. Switching between the filters is effected by switching the input streams via the reception mode.

To realize rapid switching and a narrow-band filter during AM, a digital filter is formed inside the DSP so that bandwidth can be varied according to the reception mode.

IF bandwidth filters:
The analog wave filter is set to operate with a 180 kHz bandwidth, and the digital wave filter with a 400 kHz bandwidth.

Digital filter in DSP interior:
This is set to operate with:
a 9 kHz bandwidth during analog AM;
a 180 kHz bandwidth during analog FM;
a 35 kHz bandwidth during digital AM; and
a 400 kHz bandwidth during digital FM.

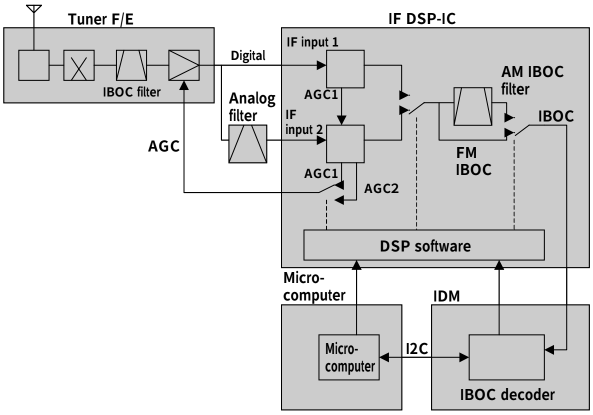

Fig.9 IF signal processing

AGC switching is as follows:

The microcomputer selects the AGC1 digital mode when digital signals are sensed, and selects the AGC2 analog mode at other times.

There are basically two IF inputs, one for digital and one for analog; sensing of digital signals triggers switching to the digital mode and switching of the interior AGC mode.

Thus, switching is effected inside the IF signal processing DSP in such a way that the analog and the digital signals each pass through the filter of optimal bandwidth. Further, operation is such that the internal digital filters automatically switch their bandwidth in response to the mode, thus eliminating adjacent disturbing waves.

4.2 Blend processing

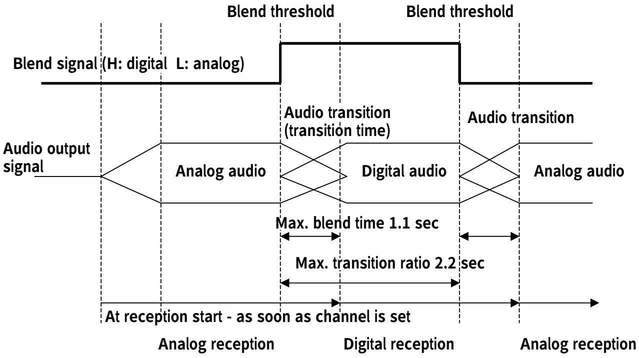

Fig.10 Blending transition process

After IBOC modulation, blend processing switches to analog audio signals or digital audio signals according to the reception quality.

The switchover thresholds for analog and digital were set at optimum levels via assessments made under actual driving conditions in North America, during which optimum blend time values were also determined via reception assessments.

Blend processing requires attention to the items below.

①Blend threshold value

The blend threshold value is the level at which a shift from one sound source to the other is effected. Thus it is a means of controlling the digital route audio quality. The receiver's host controller controls the selection of the threshold value. Using commands sent via the host controller bus, the host controller communicates to the IBOC processor which threshold level is to be used. Table 6 lists the 6 blend threshold levels, each corresponding to a degree of digital signal quality. The 6 threshold levels vary among 4 situations determined by whether digital or analog signals are selected and by the quality described for Q1-Q4.

Table 6 Blending threshold levels

Threshold level Q	Quality level
0	No blending - analog only
1	Best digital audio quality
2	Audio faults occur more or less rarely
3	Faults are salient but bearable
4	Faults ruin enjoyment
5	N/A
6	N/A
7	No blending - digital only

When the threshold level Q is 3, 2 or 1 digital audio quality is high (rising progressively in the order given), but on the other hand audio interruption is prone to occur. When Q is 3 or 4, digital audio quality is lower but no audio interruption occurs. Thus there is a trade-off between audio interruption and quality.

Table 7 Blending threshold evaluation

1-1. FM evaluation
Date and time: July 10, 2003, 17:30 onward
Place: Bethany Circle (around 25 kHz from transmission point)
fd: 105.1 MHz (induction voltage: 26, 39, 19 dBu)

BLEND TH MODE	Switchover frequency	Reception time ratio		DAT recording times(No.1)		comment
		DIGITAL	ANALOG	Start time	End time	
ALL DIGITAL	4 times			0:00:00	0:01:13	Audio interruption occurred
Q4	2 times	96%	4%	0:01:18	0:02:38	No audio interruption
Q3	6 times	75%	25%	0:02:44	0:04:05	↑
Q2	7 times	52%	48%	0:04:11	0:05:27	↑
Q1	4 times	48%	52%	0:05:31	0:06:48	↑
ALL ANALOG				0:06:53	0:08:07	↑
ALL DIGITAL				0:08:19	0:09:38	

Observations:
Q4 is the best, but its switchover time constant and curbs on frequent switchovers due to hysteresis need to be considered.
(Some lag in the signals occurs, causing large auditory discomfort. Should be made longer.)
Analog audio is still firmly popular. Good prospect of expanding digital cover area.

1-2. AM evaluation
Date and time: July 11, 2003, 17:00 onward
Place: Ann Arbor (hospital)
fd: 1,200 kHz (induction voltage: 30 dBu in parking lot)

BLEND TH MODE	Switchover frequency	Reception time ratio		DAT recording times(No.1)		comment
		DIGITAL	ANALOG	Start time	End time	
ALL DIGITAL				0:00:00	0:02:05	Audio interruption occurred
Q4	7 times	82%	18%	0:01:18	0:02:38	Audio interruption occurred
Q3	8 times	47%	53%	0:02:44	0:04:05	No audio interruption
Q2	2 times	5%	95%	0:04:11	0:05:27	↑
Q1	0 times	0%	100%	0:05:31	0:06:48	↑
ALL ANALOG				0:06:53	0:08:07	↑
ALL DIGITAL				0:08:19	0:09:38	

Observations:
Q3 is the best, but its switchover time constant and curbs on frequent switchovers due to hysteresis need to be considered.
(Q4 has occasional audio interruptions. Large sound quality difference at analog - digital switchover, causing large auditory discomfort. Should be made longer.)
Analog audio is still firmly popular. Good prospect of expanding digital cover area.

From these assessments the blend threshold for the FUJITSU TEN receivers was set at Q3. The threshold level also affects the systems for encoding and decoding the actual audio sound, and the receiver configuration.

②Blend time

The blend time is defined as the time required to switch from one sound source to the other. As a blend function, the switch must be smooth. Smooth transitioning lessens the substantive effects of the differences between the analog and digital sound quality and levels on the output audio signals. The blend time is dependent on the look-ahead lag for digital audio quality and the audio selection command. Thus, with a 1.1 second lag for digital audio a maximum of 1.1 second will be possible for the blend time.

The transition function is dependent on the maximum allowable lag between the sound source and the transition ratio. From a subjective assessment and the results of assessment in the field, a blend time of 400 msec is determined for the FUJITSU TEN receivers, as the optimum setting for the system. If this time were too long (1.1 sec for example), it would be hard to perceive the change from analog to digital, which would be discomfiting for users. Conversely, too short a blend time would - despite permitting rapid switchover - result in too sudden switching from digital to analog in cases where the preferred digital could be continued longer. This in turn would lower the digital reception rate.

Example: Volume of data that can be stored (maximum capacity)
With 1.1 sec lag:
44100×16bit×2 (for stereo) = 1.4 Mbit

③Transition frequency (maximum transition ratio)

This refers to the frequency with which switching from one sound source to the other occurs. It is also called the blending rate.

Normally the maximum transition ratio for IBOC receivers is set at 2.2 sec. When selected, this value means that the current sound source will continue for at least 1.1 sec. Transition any faster than this would not only be auditorily jarring but could lower the overall sound quality. Like the maximum practically allowable time discrepancy between analog and digital sound sources, this setting value is chosen because it is necessary to maintain audio quality along the digital path. This setting is also dependent on the audio format. There may be formats that permit a greater frequency of transitions, but any that exceed the maximum rate given here can not be recommended. The actual frequency will not exceed the maximum frequency and will vary with the digital path's audio quality.

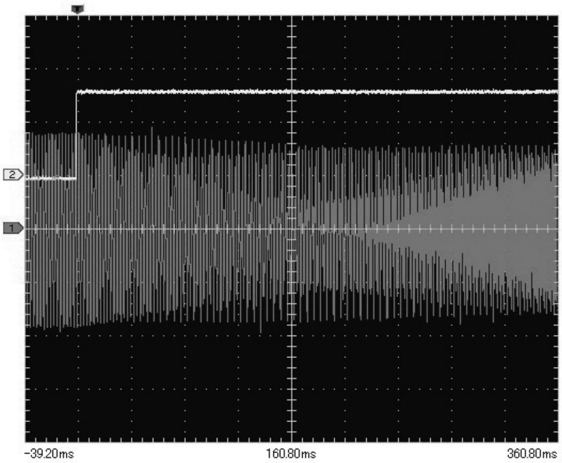

Fig.11 Blended waveform example (analog to digital)

④Time adjustment of analog and digital signals

Lag occurs in digital signals because of the time taken by encoding at the transmitter and decoding at the receiver. Time lag also results from blending of digital signals with analog signals in the receiver.

The various functions send signals back and forth between each other to exchange information necessary for correct operation. Signals specifically for the purpose are used for transition processing and the functions it requires (sound source selection). Time adjustment of the digital and analog audios is assured by the use of lag calibration adjustment (calibration values from initial calibration being stored inside the receiver).

5 Reception performance assessment

The results of assessment of the digital reception performance are set forth below.

For both AM and FM the digital reception characteristics are on a par with Hi-Fi audio: S/N around 80 dB, distortion rate around 0.03%, separation around 74 dB.

Table 8 IBOC-FM reception performance

IBOC-FM

Target item	Target	Result
Digital reception sensitivity	No more than 37 dBμ	25.5dBμ
S/N	75 dB or higher	79.8dB
Distortion rate	No more than 0.1%	0.032%
Stereo separation	70dB or higher L → R R → L	74.5dB 73.2dB
Frequency characteristics	Within 3 dB, 20 Hz to 20 kHz	Within 3 dB
Image interference elimination	50 dB or higher	50 dB or higher

Table 9 IBOC-AM reception performance

IBOC-AM

Target item	Target	Result
Digital reception sensitivity	No more than 37 dBμ	33dBμ
S/N	75 dB or higher	81.3dB
Distortion rate	No more than 0.1%	0.031%
Stereo separation	70dB or higher L → R R → L	74.1dB 74.2dB
Frequency characteristics	Within 3 dB, 20 Hz to 20 kHz	Within 3 dB
Image interference elimination	50 dB or higher	50 dB or higher

The table below gives the results of assessment of the analog reception performance. The sensitivity, selectivity and disturbance characteristics are all comparable to or better than regular reception characteristics.

Table 10 Analog reception performance of the prototypes

Target performance parameter	FM		AM	
	Target level	Result	Target level	Result
Actual sensitivity	No more than 6 dBμ	5.2	No more than 29 dBμ	27
Limiter sensitivity	8±5 dB	8.2		
AGC	65±7 dB			65
Large signal S/N	55 dB or higher	63.3	50 dB or high	62.2
Small signal S/N	45 dB or higher	49.8	25 dB or high	27.5
Residual noise ratio	18±5 dB	18.2	22±5 dB	22.5
IF disturbance ratio	40 dB or higher	118	40 dB or high	93
Image disturbance	40 dB or higher	54.6	40 dB or high	72.6
ATC	-4±5 dB	-4.1		
Residual distortion	No more than 0.3%	0.07	No more than 0.3%	0.1
Fidelity 100 Hz	0±3 dB	-0.18	0±3 dB	-0.23
Fidelity 10 kHz	-18±3 dB	-17.2	0±3 dB	-16.9
Search sensitivity DX	22±6 dB	23	30±6 dB μ	31.5
Search sensitivity LOC	47±7 dB	47.5	50±7 dB μ	51

5.1 C/N curves

Both for FM and AM the system shows stable C/N characteristics in all bands. There is no particular level difference due to frequency, nor any wild fluctuation of noise level due to input level. The system yields C/N results comparable to or better than the performance of an analog receiver.

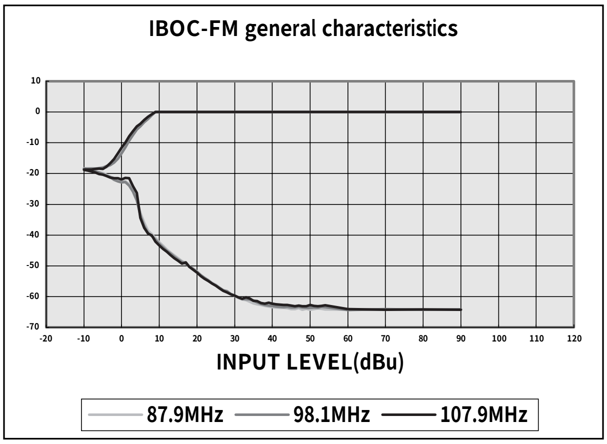

Fig.12 IBOC-FM general characteristics

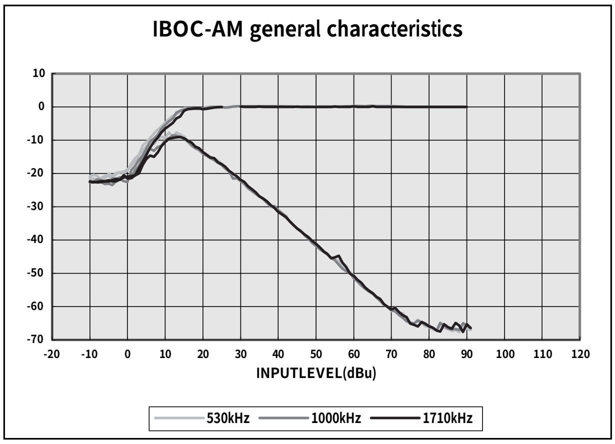

Fig.13 IBOC-AM general characteristics

5.2 Frequency characteristics

For IBOC-FM the characteristics are flat from 40 Hz to 20 kHz, and for IBOC-AM they are flat from 40 Hz to 15 kHz.

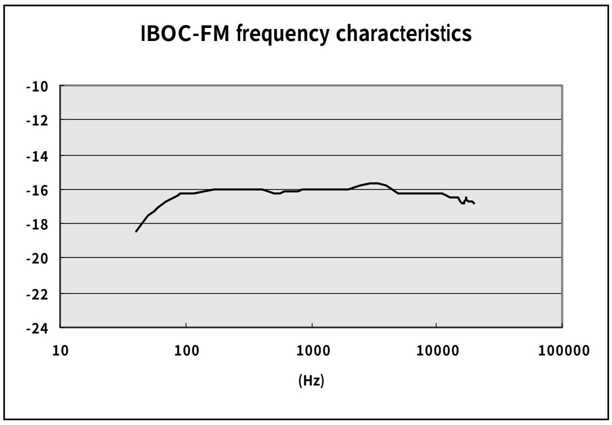

Fig.14 IBOC-FM (40Hz to 20kHz)

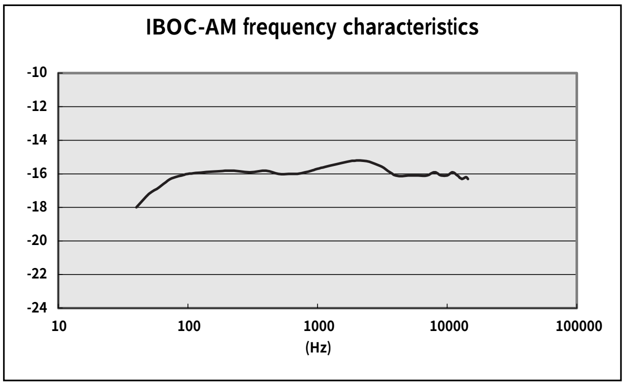

Fig.15 IBOC-AM (40Hz to 15kHz)

Despite a little level fluctuation, the characteristics are essentially flat from the low range through the high range.

5.3 Field assessment 1: Reception in 6 eastern cities

(Detroit, Boston, New York, Philadelphia, Baltimore, Washington DC)

Fig.16 Field test route on the East Coast

This region is the most densely populated in North America, with a large market population covered by IBOC. It is also packed with highrise buildings and other structures making it a reception environment prone to the effects of multipath and disturbance characteristics. Assessment was conducted in this region during real-condition driving over a distance of approximately 2000 miles. HD Radio broadcasts were received from about 30 stations in 6 cities, with assessments being made on digital data transmission and reception performance (multipath, fading, pulsation noise, etc). We also examined disturbance characteristics, etc., in strong electric field areas and acquired data for filter switchover setting and blend threshold level setting, etc.

Below are set forth the field assessment results for multipath characteristics in the representative Manhattan district of New York.

Results of reception assessment

- Reception was stable, pleasant and free of multipath even in the "urban canyons" between highrise buildings.
- Reception was clear and free of disturbance and interference even in strong electric fields.
- Data for filter switchover setting and blend threshold level setting, etc., were duly acquired.

Multipath assessment (in New York's Manhattan district)

Fig.17 Field test in Manhattan (Multipath evaluation)

Table 11 Evaluation in Manhattan

Date and time: August 24, 2004
Place: New York D/T (induction voltage: approx. dBu) Manhattan

	ECLIPSE	IBOC	A	B	C
	IBOC1M	1M-PC			
fd: 102.7 MHz IBOC stations (severe multipath in strong electric fields)					
S	4	4	4	4	4
N	4	4	4	4	4
ALL	4	4	4	4	4
COMMENT	All used digital reception 100%				
fd: 710 kHz IBOC stations					
S	4	4	4	4	4
N	4	4	4	4	4
ALL	4	4	4	4	4
COMMENT	(60%)	(65%)	(75%)	(70%)	(70%)
	Some analog reception. Parentheses give digital reception rates				
fd: 88.3 MHz Analog stations (severe multipath in strong electric fields)					
S	3	3-	3	3	3
N	3-	2.5+	2.5+	3-	3-
ALL	3	2.5+	3-	3-	3-
COMMENT					
fd: 820 kHz Analog stations					
S	3	3-	3-	3-	3-
N	2.5+	3-	3-	2.5+	3-
ALL	3-	3-	3-	2.5+	3-
COMMENT			Sound was soft and faint		Mono sound

Observations:
With digital reception, no multipath whatever occurred. Equipment is effective.
But in Manhattan, digital gave way to analog at times during IBOC AM reception; digital reception rate was 60 to 75% or so. This is probably due to reduced signal level behind buildings, and urban noise due to traffic lights, etc.

5.4 Field assessment 2: Reception on west coast

(Los Angeles district)

FUJITSU TEN has available several standard test courses for radio assessment in the Los Angeles district.

HD Radio station broadcasts were received, and the reception assessed, during driving along these courses.

The assessments made on a standard test course in an area with AM adjacent disturbance and strong electric fields (ex. Colombia Park) are described below by way of example.

Along this course there are dozens of power transmission lines in full view, and the antennas of an AM analog broadcasting station directly overhead, resulting in sensitivity curbs and disturbance/interference for IBOC-AM station reception in the vicinity, as regards frequency, as well as many other problems such as transmission line noise.

Reception conditions

1,020 kHz signals from an IBOC-AM station were received directly below the antennas of an analog AM station broadcasting at 1,070 kHz.

D/U: This is a locale with powerful disturbing waves of 40 dB and over.

Fig.18 Field test on the West Coast (AM high-field area)

Results of reception assessment

- No transmission line noise or similar occurred.
- There were no adjacent disturbance effects.
- Nor did any sensitivity curbing or similar due to AGC occur.

There was no particular influence from the surrounding environment, the results obtained being completely free from occurrence of noise, beats or similar.

6 Processing of reception software

6.1 Software specifications

Our company had already constructed a software platform called "FT-IPAS" (FUJITSU TEN - Integrate Platform for Automotive Software). FT-IPAS was employed in the present receiver in the interest of furthering software commonization and strengthening the equipment's fail-safe aspect.

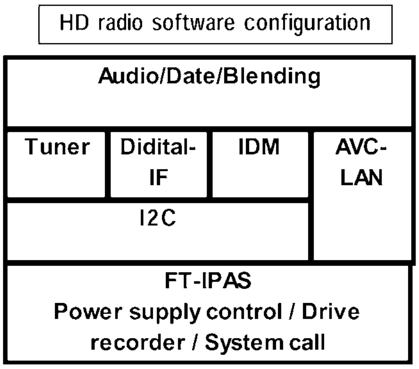

Fig.19 Software configuration

Table 12 Software functions

Function	
Broad category	
Tuner unit functions	FM/AM/IBOC mode-cyclic switching function
	Tuning function
	P. SCAN
	Presetting function
	Digital/Analog automatic reception switching
	SEEK UP function
	SEEK DOWN function
	ASM
Display	DISP switching (Frequency ⇒ Broadcasting station name ⇒ Track title ⇒ Artist ⇒ Album ⇒ Genre ⇒ Clock)
Processes/ hecks	Automatic checking

6.2 Digital data processing specifications

In the SIS (Station Information Service) and MPS (Main Program Service) data acquisition and analysis processing, SIS and MPS data acquisition and analysis are carried out, then results are stored in the buffer.

A part of data acquired is shown in Table 13.

Data acquired

Short Names: Station call signs, etc.
Long Names: Station nicknames, etc.
Title: Title data
Artist: Artist data
Album: Album data
Genre: Genre data

Table 13 A part of actual obtained data

SIS		MPS:PAD	
Short Name	Long Name	Title	Artist
WPEN	PEN-HD The Station of the Stars in Philadelphia		
WXTU	Philadelphia Country 92.5 XTU	Loco	DAVID LEE MURPHY
WPOC-FM	Baltimore	Clear Channel Radio	
WWIN-FM	Magic 95.9	Magic 95.9	HD Radio
WKDL	BE os6.1 v2.0.2	Radio Capital	HD Radio
WAMU	WAMU 88.5 FM AMERICAN UNIVERSITY RADIO		
WETA	WETA, WASHINGTON, DC Classical Music & NPR	WETA NPR & Classical Music	Now Broadcasting HD Radio
WHUR-FM	Sound Like Washington	Sound Like Washington	WHUR

7 Product lineup

All North American model 2005 ECLIPSE AVN systems and CD tuners are configured for "HD Radio" via hookup to a hideaway tuner unit.

Fig.20 Appearance of HD radio

The main units that can hook up to the hideaway unit are shown below. (All except LO-end models are compatible with the unit.)

When the hookup is made, all of the main unit's radio sections can be switched over to the hideaway unit's radio.


AVN

AVN5435

CD-Tuner

CD8455

CD8445

CD5435

CD5425

CD5415

Fig.21 Main unit of 2005 ECLIPSE

The hookup is via Ei-LAN of the FUJITSU TEN North American market specification, which enables a diversity of connections and digital data displays between the units.

8 Discussion

This first FUJITSU TEN's digital broadcast receiver for North America has been developed so as to bring out the merits of digitization without losing any of the performance of conventional radio. As a result it is strongly resistant to multipath, fading, transmission line noise and city noise in urban districts, thus realizing radio of higher sound quality and higher product quality that meets the demand for "AM of FM quality and FM of CD quality". As the infrastructure for digital broadcasting grows, we believe a shift from conventional to digital radio will steadily take place.

9 Prospects for the next generation of digital broadcasting

Digital radio in North America is anticipated to spread in the form of two types working in tandem, namely satellite digital for broadband mobile broadcasts and terrestrial digital for local area broadcasting.

The terrestrial digital audio broadcasting "HD Radio" in particular has potential to create diverse new data services that could transform people's lives, as it is intercompatible with AM/FM and is provided free.

New data services being considered include:

- **Second audio service**

  Plans for "Tomorrow Radio":

  This would involve broadcasts with the digital audio data bands split into two: main audio at 64 kbps and second audio at 32 kbps.

  It is under consideration by the NPR (National Public Radio) group, who are conducting trial broadcasts.

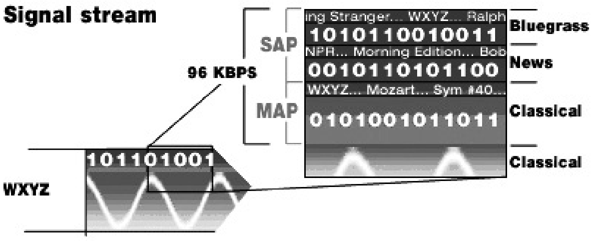

Fig.22 Tomorrow radio

- **Expansion of PAD**

  Expansion of ID3 tagging
- **Traffic information data service**

This system, which is implementing the shift to digital service while retaining the conventional broadcasting infrastructure that people have grown fond of, has merits both for radio stations and for users.

To assist in the realization of such system we will be proceeding with improvements aimed at achieving receivers with further enhanced reception performance, greater compactness, and lower price.

10 Acknowledgements

Our thanks go to all concerned in the development of the North America digital audio broadcast receiver for the advice and assistance they provided on so many occasions.

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   TEN TECHNICAL JOURNAL Vol. 20 No. 1, June 2002

Profiles of Writers

Osamu Mino

Entered the company in 1981. Since then, has engaged in development of digital broadcast receiver by way of development and design of information and communication equipment.
Currently in the Advanced R&D Department & R&D Department of Research & Development Group.

Takanori Fujiwara

Entered the company in 1986. Since then, has engaged in design and development of car audio electrical circuit.
Currently in the Engineering Department of Engineering Division 2, Business Division Group.

Hideshi Nishizawa

Entered the company in 1993. Since then, has engaged in software development for digital broadcast receiver.
Currently in the Engineering Department 2 of Engineering Division 1, Business Division Group.

Kazuo Takayama

Entered the company in 1976. Since then, has engaged in development of in-car analog broadcast receiver, digital broadcast receiver and antenna.
Currently the Department General Manager of the Antenna System Engineering Department of Engineering Division 3, Business Division Group & R&D Department of Research & Development Group.