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Performance Evaluation of HD Radio System in Radio Environments

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Abstract: The advance of wireless communications brings in various schemes of wireless digital communication technology. Analog communication and broadcasting services convert into digital services in many countries. The IBOC (In-Band On-Channel) system has been developed to work in the same band with the conventional analog radio and broadcasting digital signal simultaneously. HDR (HD-Radio) standard of IBOC can use coherent demodulation using pilot subcarriers. In this paper, the performance of HD radio system is evaluated. To contribute to decision of digital radio standard and design of digital radio transmission network, the simulation results will give a help.

Keywords: IBOC, HD Radio, Transmission network.

1. INTRODUCTION

HD Radio is the trademark for iBiquity Digital Corporation's in-band on-band (IBOC) digital radio system. While there are differences between amplitude modulation (AM) and frequency modulation (FM) band HD Radio systems, an HD Radio signal can be generally described as a digitally modulated RF signal that is transmitted around, under and alongside the present-day analog AM and FM signals. It should be noted that, strictly speaking, a hybrid HD Radio signal actually has components - an analog modulated component is referred here [1-3]. There digital signals are composed of multiple orthogonal frequency division multiplexed (OFDM) subcarriers, which are transmitted at a level to meet the specifications of the RF masks (AM and FM) as mandated in the United States by the Federal Communications Commission (FCC), and as specified in the digital radio broadcasting standard (NRSC-5-A) of the National Radio Systems Committee (NRSC). Since the OFDM subcarriers of the HD Radio signals are contained with these masks, and are therefore considered to be contained within the allotted channel for a given station without allocating any additional spectrum, it is considered to be an "in-band on-channel" system.

The FM HD Radio signal has more spectrum space available than the AM HD Radio signal, as the FM channel has been allocated greater bandwidth. Therefore, the FM HD Radio signal can operate at a higher data rate than AM HD Radio signal. This greater data rate can be subdivided to allow additional audio channels to be transmitted on the frequency.

2. SYSTEM MODEL

2.1. Spectrum

There are three IBOC modes of operation. IBOC allows transition from analog to digital through a Hybrid and Extended Hybrid mode of operation, before adopting an All-Digital mode of operation [4]. The digital signal is modulated onto a large number of subcarriers, using orthogonal frequency division multiplexing (OFDM), which are transmitted simultaneously.

- **Hybrid Mode** In this mode, the digital signal is inserted within a 69.041 kHz bandwidth, 129.361 kHz on either side of the analog FM signal. The IBOC Hybrid mode digital is transmitted in sidebands either side of the analog FM signal and each sideband is approximately 23 dB below the total power in the FM signal. The hybrid sidebands are referred to as Primary Main (PM) sidebands. The host analog signal may be mono or stereo, and may include subsidiary communication channels. The total power of the digital sidebands is 20 dB below the nominal power of the FM analog carrier with power relative to the total analog FM power of -41.39 dB/kHz.
- **Extended Hybrid Mode** This mode includes the hybrid mode and additional digital signals are inserted closer to the analog signal, utilizing a 27.617 kHz bandwidth, 101.744 kHz on either side of the analog FM signal. The IBOC Extended Hybrid mode digital sidebands are referred to as Primary Extended (PX) sidebands. The total power of the FM analog carrier with power relative to total analog FM power of -41.39 dB/kHz.
- **All-Digital Mode** This mode replaces the analog signal with additional digital signals and also includes the digital signals of the Hybrid and Extended Hybrid

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modes. With IBOC All-Digital, the primary digital sidebands are extended as in IBOC Extended as in IBOC Extended Hybrid and the analog signal is removed and replaced by lower power digital secondary sidebands, thus expanding the digital capacity. The total power of the digital sidebands is 10 dB below the nominal power of the replaced FM analog carrier with power relative to the total analog FM power of -31.39 dB/kHz.

2.2. Components

A logical channel is a signal path that conducts Layer 2 PDUs (Protocol Data Unit) in transfer frames into Layer 1 with a specific grade of service, determined by service mode. Layer 1 of the FM air interface provides 11 logical channels to higher layer protocols [5, 6]. Not all logical channels are used in every service mode. There are five primary logical channels that can be used with the Hybrid, Extended Hybrid, and All-Digital waveforms. They are denoted as P1, P2, P3, P4, and PIDS. The PIDS channel transmits the Station Information Service (SIS) information. There are six secondary logical channels that are used only with the All-Digital waveform. They are denoted as S1, S2, S3, S4, S5, and SIDS.

The bits in each logical channel are scrambled to randomize the time-domain data. The inputs to the scramblers are the active logical channels as selected by the service mode. Channel encoding improves system performance by increasing the robustness of the signal in the presence of channel impairments. This function uses convolutional encoding. The size of the logical channel vectors is increased in inverse proportion to the code rate. The encoding techniques are configurable by service mode [7, 8]. Diversity delay is also imposed on selected logical channels. At the output of the channel encoder, the logical channel vectors retain their identity. The interleaving techniques are tailored to very high frequency fading environment and are configurable by service mode. In this process, the logical channels lose their identity. The interleaver output is structured in a matrix format, each matrix consists of one or more logical channels and is associated with a particular portion of the transmitted spectrum. OFDM subcarrier mapping assigns interleaver partitions to frequency partitions. One row of each active interleaver matrix is processed every OFDM symbol to produce one output vector which is a frequency-domain representation of the signal. The input vectors are transformed into a shaped time-domain baseband pulse for digital portion, defining one OFDM symbol. Then they are combined with the analog source for transmission, when transmitting the Hybrid waveform.

2.3. OFDM Signal Generation

OFDM Signal Generation receives complex, frequency-domain, OFDM symbols from OFDM Subcarrier Mapping, and outputs time-domain representing the digital portion of the FM HD Radio signal. The input to OFDM Signal Generation is a complex vector X_n of length L, representing the complex constellation values for each OFDM symbol n. The output of OFDM Signal Generation for the is a complex, baseband, time-domain pulse $y_n(t)$, representing the digital portion of the FM HD Radio signal for OFDM symbol n. Let $X_n[k]$ be the scaled constellation points from OFDM Subcarrier Mapping for the nth symbol, where k indexes the OFDM subcarriers such that $k = 0, 1, 2, 3, K\ , L-1$. Let $y_n(t)$ denote the time-domain output of OFDM Signal Generation for the nth symbol. Then, $y_n(t)$ is written in terms of $X_n[k]$ as follows:

$$y_n(t) = h(t - nT_s) \cdot \sum_{k=0}^{L-1} X_n[k] \cdot e^{j2\pi \cdot \Delta f \left[k - \frac{(L-1)}{2}\right] \cdot (t - nT_s)} \qquad (1)$$

where $n = 0, 1, 2, 3, K\ , \infty$ and $0 \le t \le \infty$. L is the total number of OFDM subcarriers. T_s and Δf are the OFDM symbol duration and OFDM subcarrier spacing, respectively. The pulse-shaping function $h(\xi)$ is defined as:

$$h(\xi) = \begin{cases} \cos\left(\pi \dfrac{\alpha T - \xi}{2\alpha T}\right) & \text{if } 0 < \xi < \alpha T \\ 1 & \text{if } \alpha T < \xi < T \\ \cos\left(\pi \dfrac{T - \xi}{2\alpha T}\right) & \text{if } T < \xi < T(1+\alpha) \\ 0 & \text{elsewhere} \end{cases} \qquad (2)$$

where α is the cyclic prefix width and $1/\Delta f$ is the reciprocal of the OFDM subcarrier spacing, respectively.

3. CHANNEL MODEL

From literature, several sets of radio channel profiles derived from measurements with channel sounders are known. Most of these profiles have been derived during the evaluation of modern digital mobile radio systems like GSM and UMTS at frequencies above 800 MHz. Therefore, they are not directly applicable for HD Radio. Well-known models for the radio channel in mobile radio macro cells are the so-called COST profiles, defined within the European COST 207 initiative [9]. These models are available for typical propagation scenarios like rural, urban and hilly terrain. An additional synthetic profile with extreme multipath distortion has been defined for testing the equalizer performance in GSM receivers.

In Europe a lot of channel measurements have also been made in the upper VHF band (band III) as well as in the UHF and L-Band during the specification of T-DAB and DVB-T with signal bandwidths between 1.5 and 8 MHz [10, 11]. In urban areas, the results are comparable to the models already defined by COST 207. That was one reason that CENELEC also proposed to use the COST “Typical Urban” and “Rural” profiles for testing the performance of T-DAB receivers [12]. Additionally, synthetic profiles have been defined for large-scale single frequency network (SFN) scenarios.

Table 1. System Parameters.

Parameters	HDR(MP3) HDR(MP5/MS1)	
Guard interval (us)	100	100
T_{FFT} (ms)	2.8	2.8
Sym. duration (ms)	2.9	2.9
FFT size (N)	4096	4096
# of Useful sub-carriers	458	1093
% of Pilot sub-carriers (%)	5.68	5.58
Sampling rate(Msps)	1.488	1.488
sub-carrier spacing(Hz)	363.37	363.37
Occupying BW (kHz)	167	400
Data symbol rate (ksps)	149	356
Data rate(kbps)	124	229
Spectral efficiency	0.74	0.57

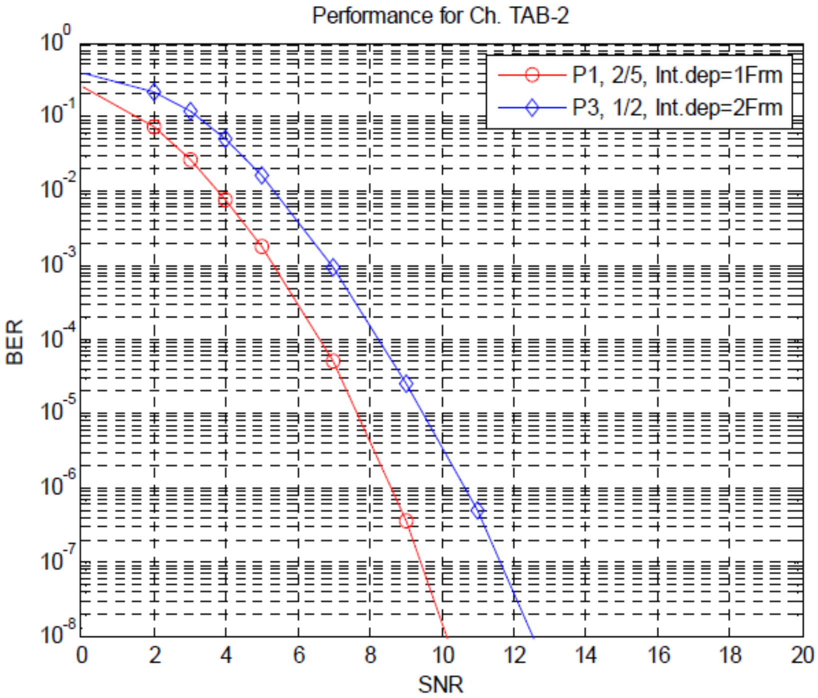
Table 2. Channel Parameters.

Path No.	TAB-2		TAB-3	
	Delsy(us)	Attn(dB)	Delsy(us)	Attn(dB)
1	0.0	2.0	0.0	4.0
2	0.2	0.0	0.3	8.0
3	0.5	3.0	0.5	0.0
4	0.9	4.0	0.9	5.0
5	1.2	2.0	1.2	16.0
6	1.4	0.0	1.9	18.0
7	2.0	3.0	2.1	14.0
8	2.4	5.0	2.5	20.0
9	3.0	10.0	3.0	25.0

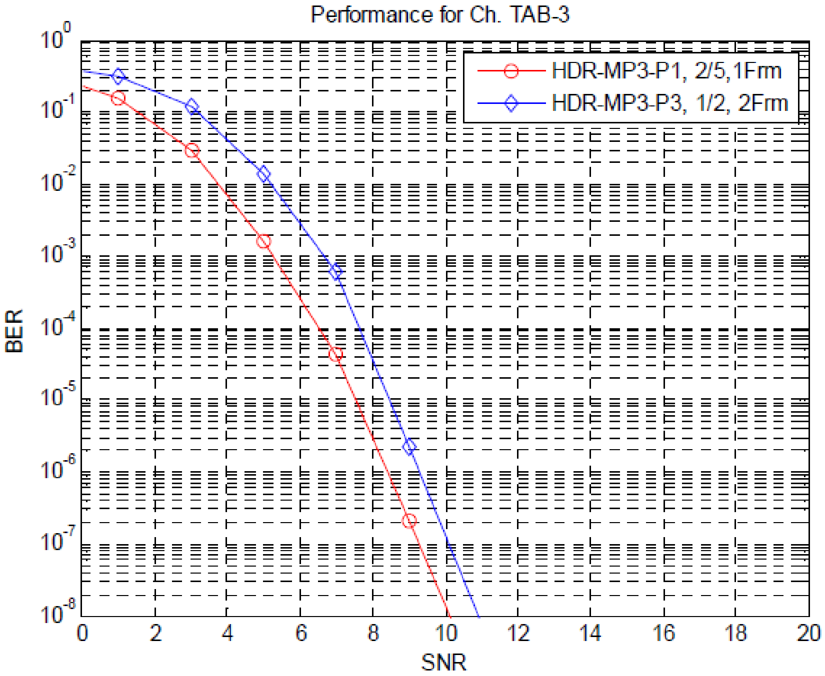
The only available results from channel sounder measurements at VHF frequencies below 120 MHz (unfortunately restricted to band II) originate from campaigns carried out in the USA during the development of IBOC digital audio broadcasting systems [13, 14]. An inspection of the channel profiles derived from those measurements for typical propagation situations has shown that they are also similar to those from the COST initiative.

4. SIMULATION RESULT

Table **1** is OFDM system standard parameter previous system. Simulation environment of HDR system in this paper is used as general multipath fading channel, whose velocity is 150km/h, given by Table **2**. Fig. (**1**) and Fig. (**2**) show BER performances for HDR-MP3 and HDR-MP5 respectively in multipath fading channel, i.e., TAB-2 and TAB-3. When the velocity is 60km/h and 150km/h, so Doppler shift frequency is 5.5Hz and 13.9Hz. In Fig. (**1**), the performance of P1 is better than P3, because the code rate of P1 is lower than P3. The code rate of P1 is 2/5, and P3 is 1/2. Interleaving depth of P3 (2 frame) is longer than P1(1 frame), and if velocity is increased, the gap is expected to be decreased since P3 may obtain more diversity gain. In Fig. (**2a**), performance of P1 is better than P3. P1 is 6.2dB, and P3 is 8dB by 10^{-4} BER. Also P1 is 8.8dB and P3 is 10.4dB by 10^{-6} BER. In Fig. (**2b**), performance of P1 is better than P3. P1 is 5.2dB, and P3 is 6.7dB by 10^{-3} BER. Also P1 is 8.3dB and P3 is 9.2dB by 10^{-6} BER. The reason of P1 better than P3 is each others code rate. Code rate of P1 is 2/5, and P3 is 1/2. So P1 is excellent for error correction performance.

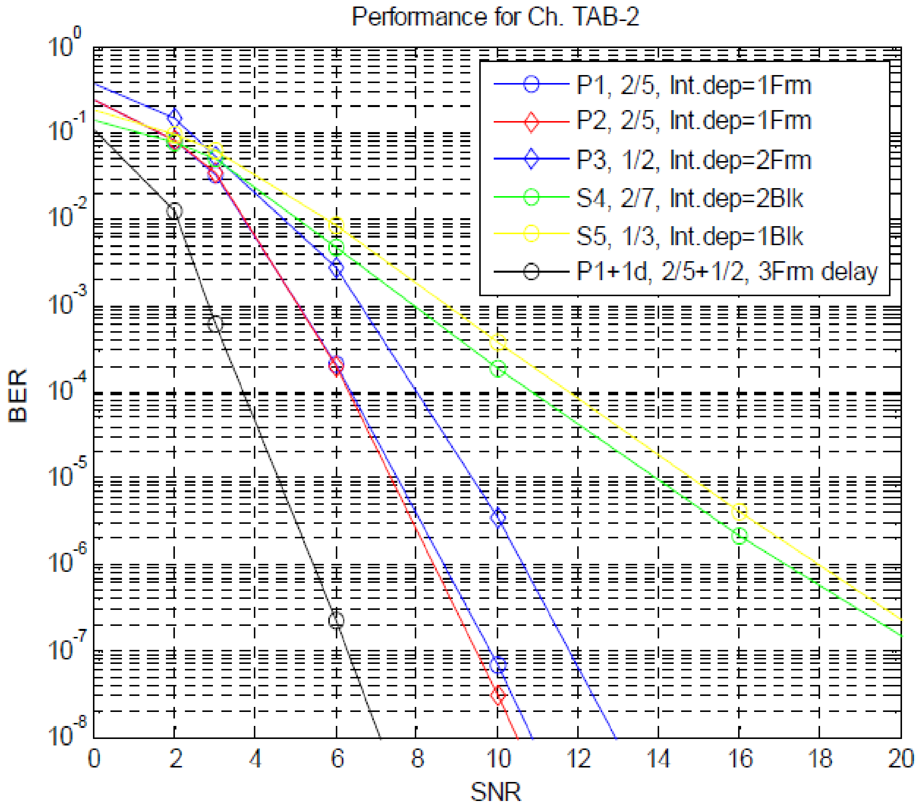


(**a**)

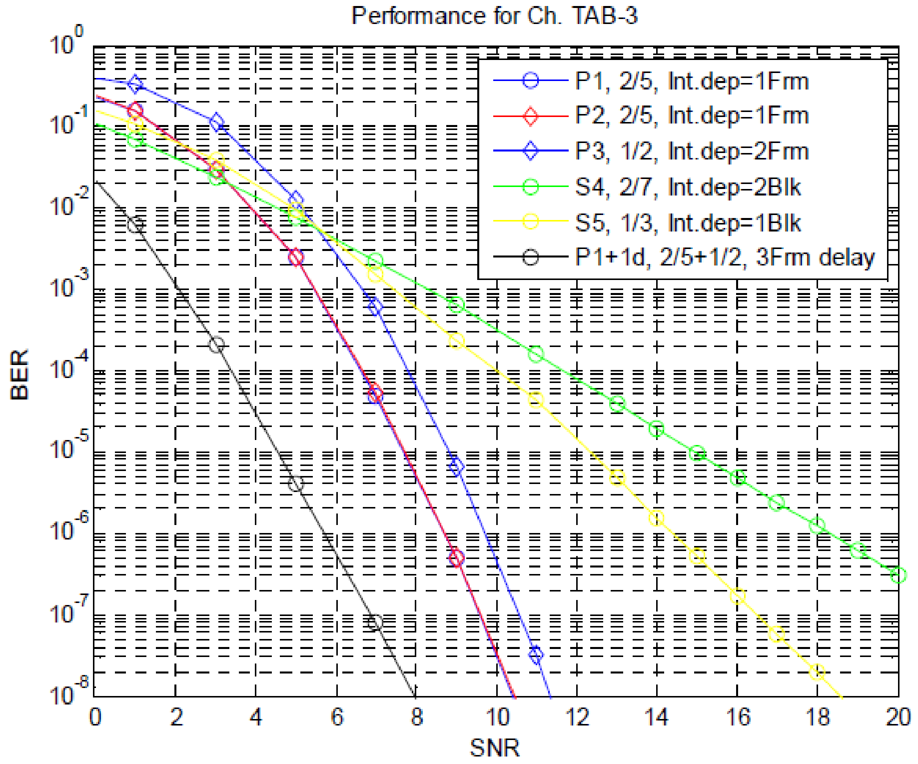


(**b**)

Fig. (1). BER performance for HDR-MP3.



(a)



(b)

Fig. (2). BER performance for HDR-MP5.

Interleaving depth of P3 (2 frame) is longer than P1 (1 frame). So if velocity increases, differences in performance decrease by time diversity. In the figure, P1+1d (Maximum Ratio Combining P1 and P1 delay) is best. This figure shows all of data dependent interleaving depth. In the transmission of MS1 BER floor occurs, so BER performance is bad because of short interleaving depth. Thus BER performance is P1+1d>P1=P2>P3>S5>S4. Also performance of S4 and S5 is reversed by about 5.5dB. The reason for reversion of the S4 and S5 due to the interleaving depth is the same as the former.

CONCLUSION

In this paper, we evaluated performance of HDR standard. Technically, HDR standard use coherent demodulation by pilot sub-carrier. From the simulation results, it can be clearly seen that the system performance can be maintained in a descent range under various channel rates. Performance analysis of HD radio system in this paper can used as reference data for experimental broadcasting. Also it can be used as basic materials of system to verify.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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