

Performance Analysis and Implementation of a DVB-C2 Transceiver

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Abstract— This paper depicts a results of field test for an implemented digital video broadcasting for cable system (DVB-C2) transceiver, which has been implemented using field programmable gate arrays (FPGAs). The test results show the physical channel status and performance of the DVB-C2 transceiver, which includes the sampling clock offset (SCO), the frequency offset (FO), the frequency response of the hybrid fiber coax (HFC) channel, the uncoded-bit error rate (BER) before the forward error correction (FEC) decoder, and the BER after the FEC decoder. Since the moving picture experts group-transport stream (MPEG-TS) is received successfully with a raw data rate of 55 Mbps through a commercial in-service HFC network, a high data rate such as ultra-high definition (UHD) can be expected to be serviced. In addition, because the measured uncoded-BER satisfies the requirement of 10^{-2} uncoded-BER, the implemented DVB-C2 transceiver can support 4096QAM as well as 16384QAM. Therefore, it can be used as a cable modem supporting DVB-C2 and the data-over-cable-service-interface-specifications (DOCSIS) 3.1.

Keywords— HFC, DVB-C2 transceiver, field test, 4096QAM, 16384QAM, BER.

I. INTRODUCTION

European data over cable service interface specifications (DOCSIS) for downstream transmissions is currently used for cable networks with single carrier modulation and a maximum of 256QAM with a data rate of 38.8 Mbps. However, multiple system operators (MSOs) require higher data rates to deliver such content as video-on-demand (VOD) and ultra-high definition television (UHDTV).

To meet these requirements, digital video broadcasting for cable systems (DVB-C2) was published in 2010, and provides at least a 30% increase in capacity compared to European DOCSIS. It uses 4096-point FFT, inverse FFT (IFFT), and a low density parity check (LDPC) for its channel coding. In addition, it uses 64-, 256-, 1024-, and 4096 QAM [1], [2].

Although MSOs in Korea already service UHDTV using a single carrier transceiver, this requires more frequency resources compared with the DVB-C2. Therefore, it is more preferable to use a DVB-C2 transceiver with the higher spectral efficiency than European DOCSIS. The maximum spectral efficiency of European DOCSIS and DVB-C2 is 8 and 12 bits per Hertz individually.

This paper deals with the field trial test and results using a DVB-C2 transceiver implemented with FPGAs based on a computer simulation. The rest of this paper is organized as follows. Section II introduces the structure and performance of a DVB-C2 receiver with a computer simulation. In addition, the field test and results are presented. Finally, concluding remarks are given in section III.

II. MEASUREMENT OF IMPLEMENTED DVB-C2 TRANSCEIVER

The major parameters of DVB-C2 transceiver for 6 MHz bandwidth are shown in Table 1 [1].

TABLE 1. PARAMETERS OF DOWNSTREAM TRANSMITTER

Parameter	Value
Code rate of LDPC	2/3, 3/4, 4/5, 5/6, 9/10
Number of total subcarriers per OFDM symbol, N	4096
Number of used subcarriers per OFDM symbol, N_{sub}	3409
Number of CP, L	64 samples
Number of preamble OFDM symbols, N_{pr}	1, 2, 4, 8
Number of payload OFDM symbols, N_{pa}	448
Subcarrier spacing, Δf	1.674 kHz
IFFT/FFT period, T_{FFT}	597.3 us
Guard interval duration	9.33 us
Sampling frequency, F_s ($\Delta f \times N$)	6.85 MHz

A. Performance analysis of DVB-C2 transceiver

The structure of the DVB-C2 transmitter is depicted in Figure 1. As shown in Figure 1, the DVB-C2 transmitter consists of an FEC encoder, modulator, digital-to-analog converter (DAC), and radio frequency (RF) up-converter. The FEC encoder consists of a Bose Chaudhuri Hocquenghem (BCH) encoder, LDPC encoder, and bit interleaver [1]. The modulator consists of a mapper, guard band generation, serial-to-parallel (S/P) conversion, N-point IFFT, CP generation, and parallel-to-serial (P/S) conversion. The mapper provides a differential BPSK (DBPSK) for pilot

symbols of the preamble and payload, 16QAM for the preamble data, and 64, 256, 1024, and 4096QAM for the payload data. There are two types of pilots. One is a comb type for a preamble and another is a lattice type for a payload. Nulls are inserted for the guard band to reduce the adjacent channel interference (ACI) [1], [2].

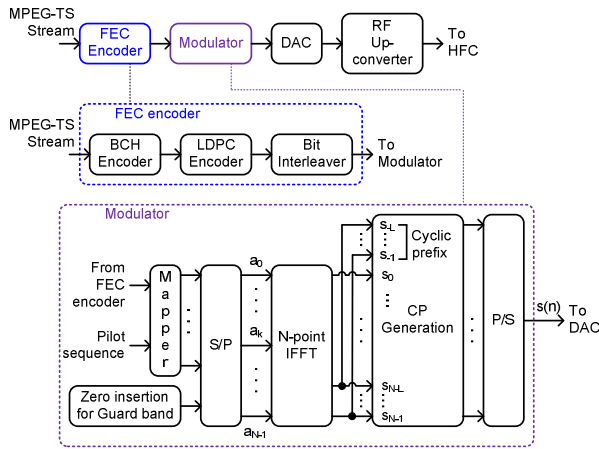


Figure 1. Structure of DVB-C2 transmitter.

The DVB-C2 receiver is shown in Figure 2.

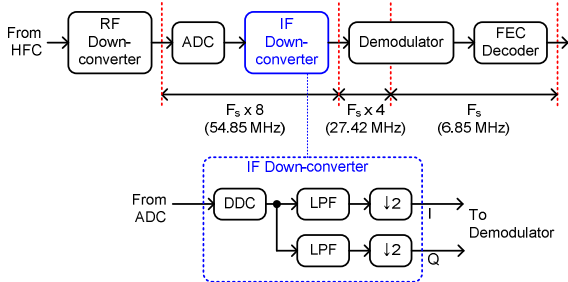


Figure 2. Structure of DVB-C2 receiver.

As shown in Figure 2, the receiver consists of an RF down-converter, analog-to-digital converter (ADC), intermediate frequency (IF) down-converter, demodulator, and FEC decoder. The RF signal from the HFC is down-converted to an IF frequency of 44 MHz.

The IF down-converter consists of a digital down-converter (DDC), low pass filter (LPF), and decimator denoted by $\downarrow 2$ and operates at 8-times the sampling frequency (54.85 MHz). The down-converted signal passes through the LPF to eliminate the image of the baseband signal, and then down-sampled by 2 by the decimator.

The demodulator shown in Figure 3 consists of SYNC, an equalizer (EQ), and common phase error corrector (CPEC), and pilot remover (PR) [3]. Some parts of the demodulator operate at 4-times the sampling frequency (27.42 MHz), and the others operate at a sampling frequency of 6.85 MHz. The FEC decoder consists of a soft-decision demapper, bit deinterleaver, LDPC decoder, and BCH decoder [4], [5].

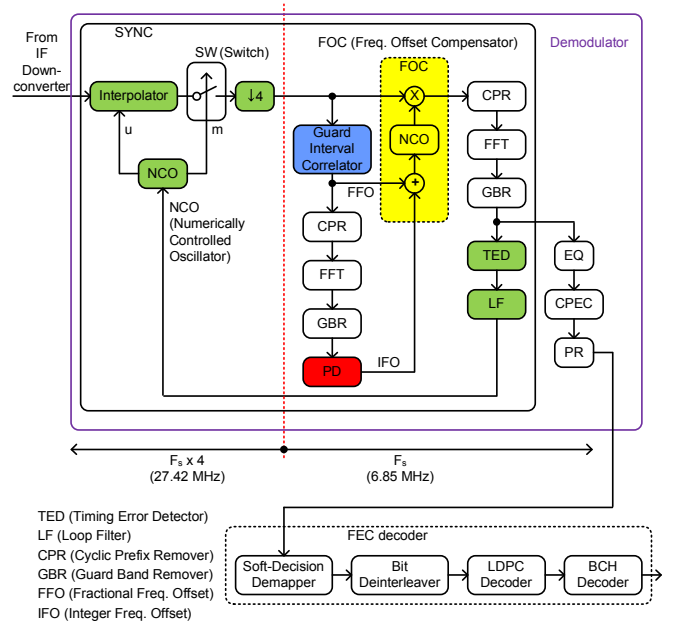


Figure 3. Demodulator and FEC decoder of DVB-C2 receiver.

The uncoded-BER and BER has been simulated with the C program and is shown in Figure 4 when the CP length (L) is 64. “Pre-FEC” shown in Figure 4, means the demodulator before the FEC decoder, and the uncoded-BER is then the performance of the demodulator. “After LDPC” indicates the output of LDPC decoder, and the BER is obtained from it [3].

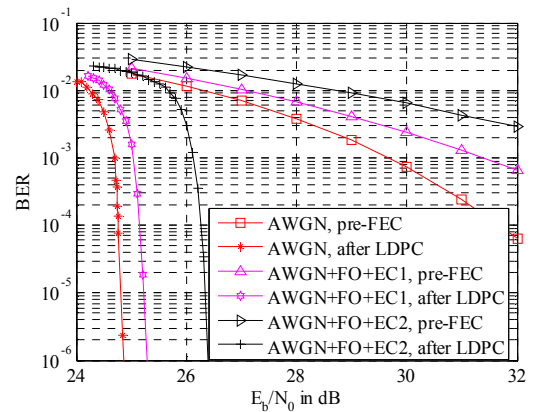


Figure 4. BER performances of 4096QAM after LDPC decoding when L is 64.

B. Measurements

For the field test, a test bed has been built in Seoul, South Korea, and the field test area is as shown in Figure 5.

As shown in Figure 5, the DVB-C2 transmitter denoted by a red flag in Headend is located at Yangchen in Seoul, and the DVB-C2 receiver denoted by a blue flag is located at the Sangam digital media center (DMC) in Seoul. The distance between Sangam DMC and Yangchen is approximately 11.8 km.

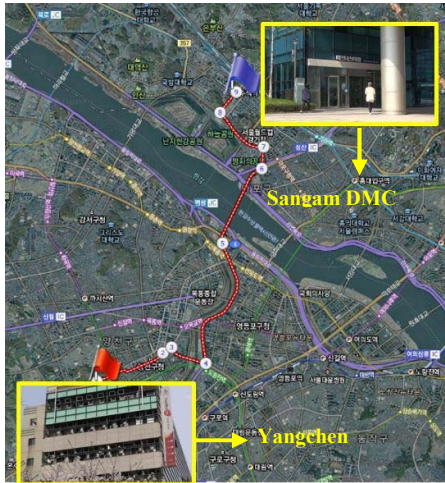


Figure 5. Field test area.

The DVB-C2 transmitter in Yangchen and the DVB-C2 receiver in Sangam DMC are described individually in Figure 6. The DVB-C2 transmitter receives a bit stream from the MPEG-TS stream player, and the modulated OFDM signal is transmitted to the HFC channel with an RF center frequency of 225 MHz. The DVB-C2 receiver in Figure 6 demodulates and decodes the received OFDM signal, and the decoded MPEG-TS stream is displayed on a notebook after the MPEG analyzer.

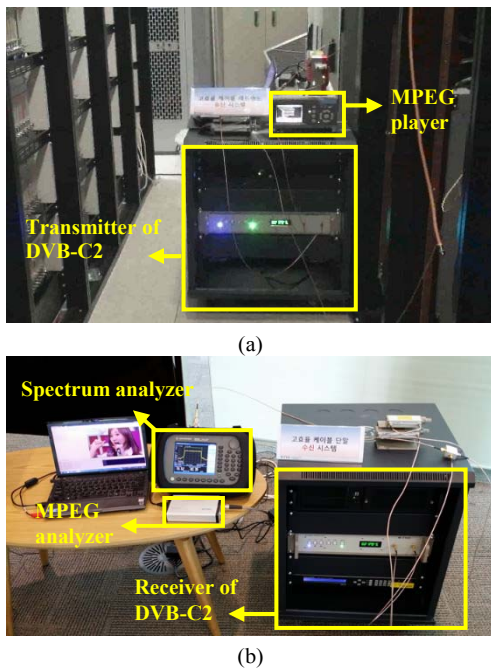


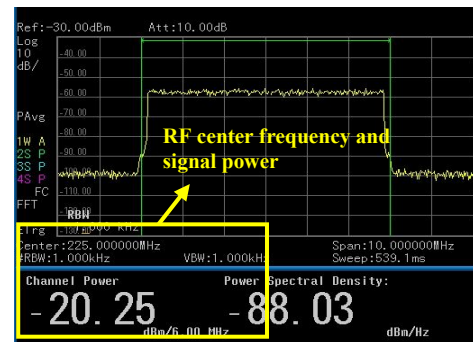
Figure 6. Test environment. (a) DVB-C2 transmitter and MPEG player built in Yangchen. (b) DVB-C2 receiver and MPEG analyzer and spectrum analyzer installed in Sangam DMC.

The chosen parameters of the DVB-C2 transceiver for the field test are listed in Table 2.

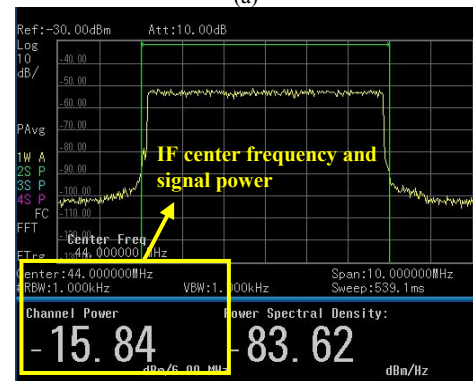
TABLE 2. PARAMETERS OF DVB-C2 TRANSCEIVER FOR FIELD TEST

Parameter	Value
Code rate of LDPC	9/10
QAM order	4096
Number of CP, L	64 samples
Number of preamble OFDM symbols, Npr	8
Number of payload OFDM symbols, Npa	448
Frame duration	276.62 ms
IF center	44 MHz
RF center frequency	225 MHz
Channel bandwidth	6 MHz

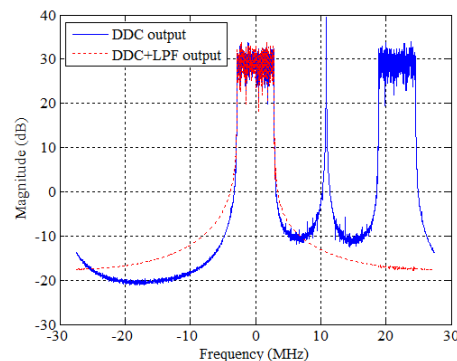
The analog OFDM signal generated by the DVB-C2 transmitter in Yangchen with an RF center frequency of 225 MHz is passed through a commercial HFC channel.



(a)



(b)



(c)

Figure 7. Measured spectrum. (a) RF spectrum with a center frequency of 225 MHz with a span of 10 MHz. (b) IF spectrum with a center frequency of 44 MHz with a span of 10 MHz. (c) Baseband spectrum of DDC output

The RF center frequency and OFDM signal power under test is 225 MHz and -20 dBm/6MHz as individually depicted in Figure 7(a). Figure 7(b) shows that the IF center frequency and down-converted OFDM signal power are 44 MHz and -15 dBm/6 MHz. The blue line in Figure 7(c) is the spectrum after DDC output, and the red line in it is the spectrum after DDC plus the LPF output. Because the DDC and LPF are implemented digitally, their spectra are obtained from internal FPGA tools.

As the received OFDM signal is passed through a demodulator and FEC decoder, the physical channel parameters and the performance are measured. The physical channel parameters indicate the SCO measured in the TR, the FO obtained from GIC, and the PD and frequency response of the HFC channel evaluated in the EQ. The performance is uncoded-BER measured before the FEC decoder, and BER measured after the FEC decoder.

Figure 8 shows the output of the TED in TR after TR locking. Theoretically, if the TR is locked, the TED output is zero. Otherwise, the TED output diverges. Because the output of the TED is almost zero, the TR is locked correctly.

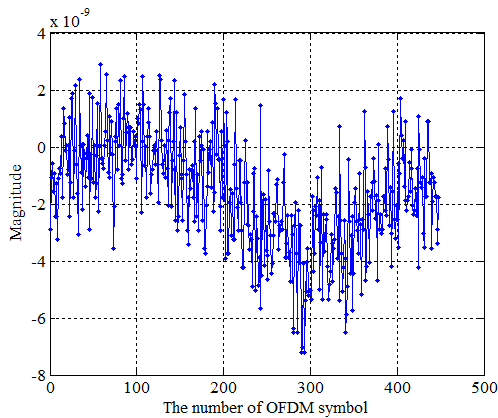


Figure 8. TED output after TR locking.

The frequency offset (FO) must be estimated precisely regardless of the IF signal power because that of the OFDM is more serious than a single carrier modulation. Table 3 lists the estimated FO with respect to the IF signal power, and shows that it is not influenced by the IF signal power. As listed in Table3, the measured FO is greater than the subcarrier spacing (Δf) and smaller than twice the subcarrier ($2 \times \Delta f$). In addition, there is a slight Hz difference between the measured FOs because of noise.

TABLE 3. MEASURED FREQUENCY OFFSET

IF signal power (dBm/6MHz)	Value (kHz)
-3	2.2757
-9	2.2766
-15	2.2751

Figure 9 shows the evaluated frequency response of the HFC channel with an RF center frequency of 225 MHz with respect to the IF signal power. If the IF signal power is -15 dBm, as shown in Figure 9, the magnitude response of the channel seems to be flat. However, when it is -3dBm, the channel response is not flat. This means that, as the signal power is increased, the frequency response is more accurate.

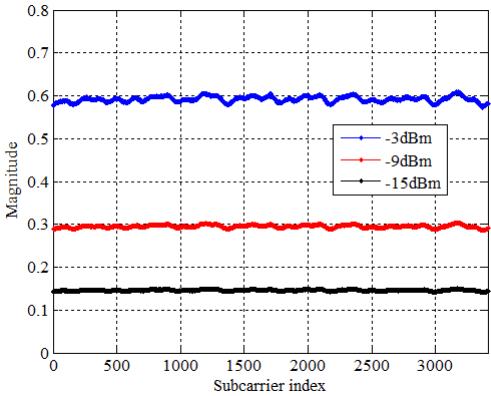


Figure 9. Magnitude response of the HFC channel with RF center frequency of 225 MHz with respect to the IF signal power.

The constellation of 4096QAM after CPEC is shown in Figure 10 when the IF signal power is -15 dBm/6MHz. The shape of the constellation shown in Figure 10 is a square, which means that there is no CPE, residual SCO, or residual FO. Because there are distinct boundaries between QAM symbols as shown in Figure 10, the HFC channel is thought to be good enough to support 4096QAM and even 16384QAM. Therefore, the uncoded-BER has been measured to make sure of whether the implemented DVB-C2 transceiver can support 16384QAM or not.

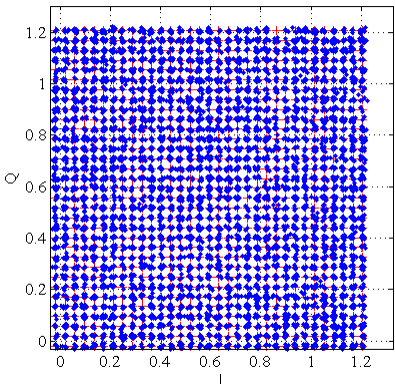


Figure 10. Measured one-quarter constellation of CPEC output when the IF signal power is -15 dBm/6MHz.

Table 4 lists the uncoded-BER evaluated before the FEC decoder with respect to the IF signal power.

TABLE 4. UNCODED-BER OF 4096QAM AND 16384QAM

IF signal power (dBm/6MHz)	Uncoded-BER of 4096QAM	Uncoded-BER of 16384QAM
-3	2.6292×10^{-4}	1.2896×10^{-2}
-9	1.9988×10^{-4}	1.0768×10^{-2}
-15	3.4448×10^{-4}	1.3532×10^{-2}

As the signal power increases, the undoded-BER or BER increases theoretically because the noise enhancement of the linear equalizer is reduced. The best uncoded-BER for 4096QAM and 16384QAM, as listed in Table 4, is 1.9988×10^{-4} and 1.0768×10^{-2} individually when the IF signal power is -9 dBm/6MHz, which is not the strongest signal power. This is because the RF power amplifier operates at the edge of the saturation region.

Because the DVB-C2 specification requires the uncoded-BER to be less than or equal to 10^{-2} , the implemented DVB-C2 transceiver satisfies the demand for both 4096QAM and 16384QAM, and can support even 16384QAM. The FEC supporting 16384QAM is under development for future field tests.

TABLE 5. BER OF 4096QAM

IF signal power (dBm/6MHz)	BER
-3	5.2540×10^{-9}
-9	3.9244×10^{-9}
-15	7.6066×10^{-9}

Table 5 lists the BER evaluated after the FEC decoder with respect to the IF signal power. The best BER is 3.9244×10^{-9} when the IF signal power is -9 dBm/6MHz. In addition, the received MPEG-TS has been displayed on a notebook successfully for all IF signal powers.

III. CONCLUSION

The performance of a DVB-C2 transceiver has been evaluated with computer simulation, and the DVB-C2 transceiver using FPGAs has been implemented and tested over a commercial in-service HFC network. As a result, it has been confirmed that video broadcasting service such as UHD has been working successfully. The measurement results including a BER of 4096QAM and physical network status are shown in this paper.

These test results can provide basic information for cable technology in many countries, and may lead to the development of specifications for a next-generation cable system.

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