디지털 변조를 적용하여 전송거리가 확장된 HD-CCTV 시스템 설계

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HD-CCTV System Design with Extended Transmission Distance using Digital Modulation

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요 약

본 논문에서는 영상의 화질을 유지하면서 전송거리를 늘이기 위하여 디지털 변조를 적용한 CCTV 전송 시스템인 ER-SDI 시스템을 제안하였다. 기존 CCTV 표준인 HD-SDI 시스템은 최대 전송 거리가 약 200m 이다. 최근 최대 전송 거리를 확장하기 위하여 디지털 신호를 다시 아날로그로 변환하여 색신호를 변조하는 방법과 영상을 압축하여 IP 네트워크를 사용하는 방법이 제안되었다. 그러나 아날로그로 변환하는 방법은 화질의 열화가 발생하고 IP 네트워크를 사용하는 방법은 신호 지연이 발생한다는 단점이 있다. 이에 본 논문에서는 디지털 변조를 HD-SDI 시스템에 적용하여 최대 전송 거리를 약 518m까지 늘릴 수 있는 시스템을 설계하였다. 제안한 시스템의 최대 달성 거리는 기존의 HD-SDI 시스템의 제원을 사용하여 동축 케이블 환경에서의 실험을 통하여 계산되었다.

Abstract

In this paper, a digital closed-circuit television (CCTV) transmission system called the extended reach high definition serial digital interface (ER-SDI) is proposed to increase the transmission distance while preserving the quality using digital modulation. The current standard of HD-serial digital interface (HD-SDI) has the maximum transmission distance of 200 m. Recently, one system which transforms the digital signal to an analog signal and modulates color signal to extend the transmission distance is proposed. Another system which uses IP network is also proposed. However, the former system has a disadvantage of video quality and the latter system has high latency. The proposed ER-SDI is designed to extend the transmission distance of 518 m by adopting multilevel constellations and a channel code for a data rate of 1.485 Gbps. The maximum transmission distance of the proposed system is calculated using the specification of HD-SDI and the experiment result under coaxial cable environment.

Keyword : HD-SDI, closed-circuit television, QAM, transmission

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Ⅰ. Introduction

Recently, the video quality of closed-circuit television (CCTV) is rapidly changing from standard definition (SD) to high definition (HD). At the same time, the transmission scheme for CCTV with HD quality is also to be general. There is a CCTV transmission standard called the high definition-serial digital interface (HD-SDI). The HD-SDI standard defines the transmission parameters and video formats for transmitting HD quality videos [1]. HD-SDI adopted the line code of non-return-to-zero inverted (NRZI). The maximum data rate of HD-SDI is 1.485 Gbps. The NRZI encoding requires a bandwidth of 1.485 GHz to get the data rate of 1.485 Gbps. HD-SDI uses the coaxial cable for transmitting video signals without compressions. Because of no compression, the video quality is very high. However, the transmission distance is short due to the attenuation characteristics of coaxial cables at high frequencies. If the transmission bandwidth can be reduced, the transmission distance can be longer than the conventional HD-SDI system.

The two types of HD-CCTV transmission systems were proposed to solve the short transmission distance problem of HD-SDI system. One is the analog transmission systems which are called analog HD (AHD) [2], HD-composite video interface (CVI) and HD-transport video interface (TVI) [3]. The common approach of these systems for transmitting signal is low frequency analog modulation. For example, the color (or luminance) signal is only modulated by the analog quadrature amplitude modulation (QAM). The analog QAM can reduce the transmission bandwidth. Therefore, these systems can transmit HD-CCTV signals much longer than HD-SDI system. However, the video quality gets a little bit lower than HD-SDI system.

Another is internet protocol (IP) camera systems. IP camera systems transmit highly compressed video signals over the internet based on transmission control protocol (TCP) /IP [4]. IP camera systems have the advantage that the video signals can be shown in anywhere if the client can access the internet. However, IP camera systems also have the high communication latency due to the reliability of the TCP / IP protocol. And the video compression causes the quality degradation.

In this paper, a new transmission system called the extended reach HD-SDI (ER-SDI) is proposed for HD-CCTV. The digital QAM is adapted to the HD-SDI system. If the QAM modulation is used to get a high spectral efficiency, the bit error performance of the system gets worse because of the reduced Euclidean distance for multi-level constellations [5]. Although the bit error performance gets worse, the QAM modulation has a high spectral efficiency and reduces the effect of the coaxial cable attenuation.

Conventional HD-SDI systems and the characteristics of the coaxial cable are introduced in Section II. The ER-SDI system is proposed in Section III. The transmission distance is evaluated for the proposed ER-SDI system under coaxial cable channels in Section IV. Finally, conclusions are reported in Section V.
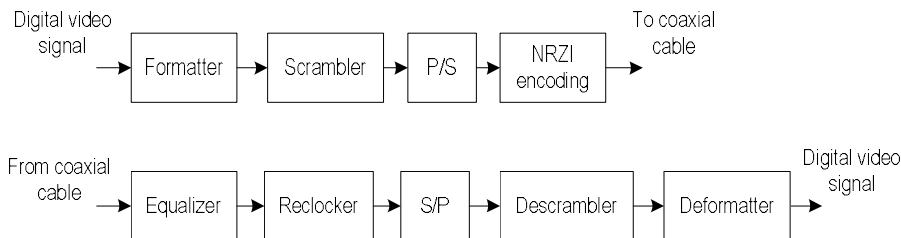

그림 1. HD-SDI 시스템의 블록도
Fig. 1. Block diagram for the conventional HD-SDI system

Ⅱ. Conventional HD-SDI system

The HD-SDI system enables transmitting an HD image through a coaxial cable without compressing it. The block diagram of the conventional HD-SDI system is shown in Fig. 1.

The HD quality video signals are formatted to the parallel digital data conformed to Society of Motion Picture and Television Engineers (SMPTE) 292M standard [6]. After scrambling, the parallel digital data are converted to serial data which has the data rate of 1.485 Gbps. And then the serial data are encoded by NRZI. The NRZI coded signals have a bandwidth of 1.485 GHz. These raw data signals are transmitted over the coaxial cable. Characteristics of the coaxial cables are shown in Table 1.

As shown in Table 1, the higher the frequency of the transmitted signal, the more the transmitted signal is attenuated. This means that the signal of the conventional HD-SDI system cannot be transmitted longer. Generally, the conventional HD-SDI system transmits the signal up to about 200 meters [8]. If a thicker cable is used, the trans-

mission distance can be extended. However, this leads to a higher cost to install the system. Therefore, a novel transmission scheme must be developed for the cost efficiency. In Section III, the ER-SDI system is proposed to extend the transmission distance with the same coaxial cable.

Ⅲ. Proposed ER-SDI System

1. ER-SDI System

A novel HD-CCTV stream transmission system is proposed in this section. The proposed system which is called ER-SDI adopts QAM modulation to the conventional HD-SDI system to extend the transmission distance. Fig. 2 shows the block diagram for the proposed system. After the parallel-to-serial converter in Fig. 1, QAM modulation is adapted to transmit signals.

The advantage of QAM modulation is the high spectral efficiency. If the spectral efficiency is high, the data occu-

표 1. 여러 동축 케이블들의 감쇄 특성
Table 1. The attenuation characteristics of coaxial cables [7]

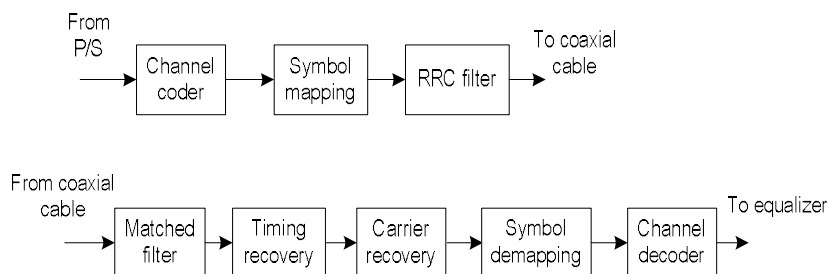| Frequency	Attenuation in dB/100m				
	RG-59	RG-6	RG-7	RG-11	5C-HFBT
50	6.17	4.92	4	3.12	4.72
250	12.76	10.24	8.17	6.5	9.89
350	15.22	12.2	9.78	7.74	11.71
450	17.39	14.04	11.19	8.83	13.70
750	22.83	18.44	14.76	11.75	18.50

그림 2. 제안하는 ER-SDI 시스템의 블록도
Fig. 2. Block diagram for the proposed ER-SDI system

pies a narrow bandwidth to get the same data rate. It means that the system can avoid the signal attenuation due to the coaxial cables' transfer function at high frequency bands. Therefore, the transmission distance will be longer than the conventional HD-SDI system. The signal-to-noise ratio (SNR) gain G_d at a certain distance d of the proposed ER-SDI system can be expressed as

$$G_d = (\alpha_{750\text{MHz}} - \alpha_{750\text{MHz}/b})d - 10\log b \qquad (1)$$

where $\alpha_{750\text{MHz}}$ is the attenuation in dB/100ft at 750MHz frequency and b is the number of bits for a symbol. The first term of the equation represents the attenuation effect of the coaxial cable. And the second term represents the effect of the performance loss due to the high order QAM modulation. Equation (1) says that the effect of the attenuation characteristic of the coaxial cable is much larger than the effect of the performance loss due to the high order QAM modulation.

The proposed ER-SDI system must consider the channel coding to compensate the fading from coaxial cable channels. Even though the coaxial cable channel is relatively good compared to mobile terrestrial channels, there must be performance degradation. Also, the synchronization process must be considered. The QAM modulation which is used in ER-SDI system is the passband modulation unlike the HD-SDI system. Therefore, the carrier and symbol timing synchronizations are included in the proposed system.

The HD-SDI system can transmit just only one video stream over the one coaxial cable. Comparatively, the proposed system can transmit two or more video streams over one coaxial cable. Because the proposed system uses QAM modulation, the transmission bandwidth of the proposed system is narrower than that of the conventional system.

Therefore, the proposed system can transmit two or more video streams over a single coaxial cable using frequency division multiplexing (FDM).

2. Mathematical Analysis of the Maximum Transmission Distance

The maximum transmission distance is evaluated for the proposed system in this subsection. The HD-CCTV video signal follows the SMPTE 292M standard. The signal level defined by SMPTE 292M is 800 mVp-p. Its root mean square value (RMS) is 282.8 mVrms. The impedance of the coaxial cable is 75Ω and the actual signal level loaded to the coaxial cable is a half of the RMS value. Therefore, the transmission power is $V_s^2/4R = 0.00025[\text{W}] = -6[\text{dBm}]$.

The maximum transmission distance can be obtained by using the attenuation of coaxial cable and the required SNR at a bit error rate (BER) of 10-9 as

$$E[\text{m}] = \frac{B[\text{dB}] - C[\text{dB}]}{A[\text{dB}/100\text{m}]} \times 100 \qquad (2)$$

where B is (transmission power - receiver noise power) and C is the SNR at a BER of 10-9. A is the loss at center frequency of specific coaxial cable. The noise power is calculated as

$$N = kTB \qquad (3)$$

where k is the Boltzmann's constant ($1.381 \times 10^{-23}[\text{J/K}]$), T is the absolute temperature in Kelvin, and B is the transmission bandwidth. C can be obtained by the generally known error probability equation such as [9]-[11]:

where M is modulation level and $k = \log_2 M$ is the number of bits in a QAM symbol. $Q(x) = (1/\sqrt{2\pi}) \int_x^\infty e^{-t^2/2} dt$ is the Gaussian Q-function. Finally, the bit error probability P_b can be expressed as

$$P_s = 4\frac{\sqrt{M}-1}{\sqrt{M}} Q\left(\sqrt{\frac{3}{M-1}\frac{kE_b}{N_0}}\right) - 4\left(\frac{\sqrt{M}-1}{\sqrt{M}}\right)^2 Q^2\left(\sqrt{\frac{3}{M-1}\frac{kE_b}{N_0}}\right) \qquad (4)$$

$$P_b \approx \frac{P_s}{k/2} \tag{5}$$

From (4) and (5), the required SNR can be easily obtained under the AWGN channel.

Ⅳ. Performance Evaluation

In this section, the transmission distance of the proposed ER-SDI system is evaluated under both additive white Gaussian noise (AWGN) channel and coaxial cable channel environments. Table 2 shows the required bandwidth to

표 2. AWGN 환경에서 변조 레벨에 따른 요구 대역폭 및 수신기 잡음 전력
Table 2. Required bandwidth and receiver noise power according to modulation level under AWGN channel

Modulation level	Required bandwidth [MHz]	Receiver noise power [dBm]
QPSK	375	-85.22
16-QAM	187.5	-88.23
64-QAM	125	-89.99
256-QAM	93.75	-91.24
1024-QAM	75	-92.21

표 3. 동축 케이블 환경에서 변조 레벨에 따른 요구 대역폭 및 수신기 잡음 전력
Table 3. Required bandwidth and receiver noise power according to modulation level under coaxial cable channel

Modulation level	Required bandwidth [MHz]	Receiver noise power [dBm]
QPSK	675	-82.67
16-QAM	337.5	-85.68
64-QAM	225	-87.44
256-QAM	168.75	-88.69
1024-QAM	135	-89.66

getthe transmission rate of 1.485 Gbps and the noise power at the receiver side under AWGN channel environments. Table 3 also shows the required bandwidth and the noise power for the proposed system under a coaxial cable channel environments.

The channel property of the coaxial cable is following the digital video broadcasting - cable 2 (DVB-C2) channel as in Table 4 [12]. Figs. 3 and 4 show the symbol error probabilities of 16-QAM and 64-QAM under both AWGN and the coaxial cable channel environments, respectively. When the modulation level is 64, the symbol error proba
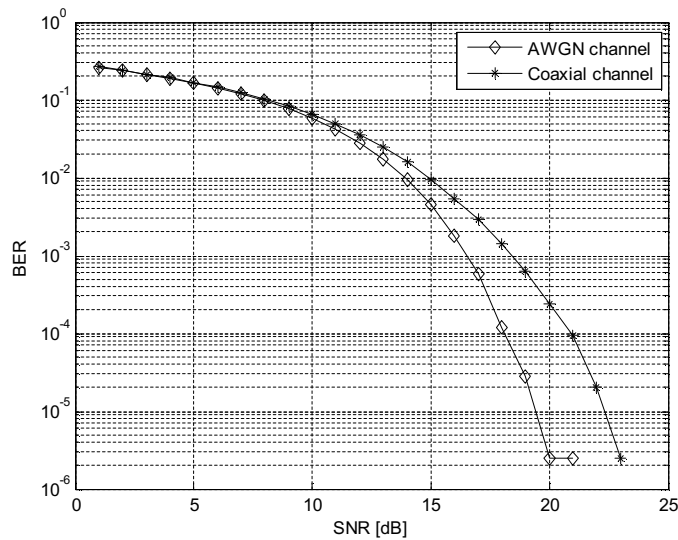

그림 3. AWGN 환경과 동축 케이블 환경에서 16-QAM 시스템의 비트 오류율
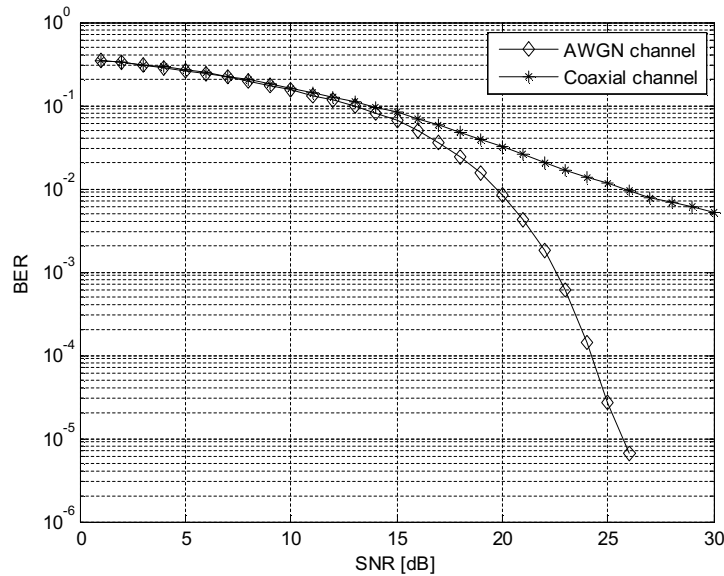Fig. 3. Bit error probabilities of 16-QAM under AWGN and coaxial cable channel

그림 4. AWGN 환경과 동축 케이블 환경에서 64-QAM 시스템의 비트 오류율
Fig. 4. Bit error probabilities of 64-QAM under AWGN and coaxial cable channel

표 4. DVB-C2에서 정의된 동축 케이블 채널의 딜레이 프로파일
Table 4. The delay profile of the coaxial cable channel defined in DVB-C2

Power [dB]	Delay [ns]	Phase [rad]
-11	38	0.95
-14	181	1.67
-17	427	0.26
-23	809	1.20
-32	1633	1.12
-40	3708	0.81

bility cannot converge to zero. Therefore, the channel coding scheme must be required under the coaxial cable channel environment.

However, the channel coding causes a decrease in the data rate. Therefore, a larger bandwidth greater than the minimum required bandwidth is allocated to compensate the decreased data rate due to the channel coding. In this paper, a convolutional code is adopted for the proposed system with the code rate of 2/3. The convolutional code can be easily implemented. Therefore, the simple con-

volutional code is considered to minimize the system complexity.

Fig. 5 shows BERs of the quadrature phase shift keying (QPSK), 16-QAM and 64-QAM systems under coaxial cable channels with a code rate of 2/3. For QPSK and 16-QAM systems, there exist required SNRs to satisfy a BER of 10-9. However, the 64-QAM system doesn't satisfy a BER of 10-9, even though SNR is very high. Therefore, the higher code rate is required for the 64-QAM system.

As shown in fig. 5, the required SNR of 16-QAM system to satisfy a BER of 10-9 can be expected about 19 dB. And baseband bandwidth for 16-QAM system with code rate 2/3 is 337.5 MHz to get 1.485 Gbps. Using (2) and Table 3, the maximum transmission distance of 16-QAM system can be calculated as 518 m.

Fig. 6 shows the bit error probability of the 64-QAM with a code rate of 1/2. A BER of the 64-QAM system with a code rate of 1/2 converges to the required SNR.
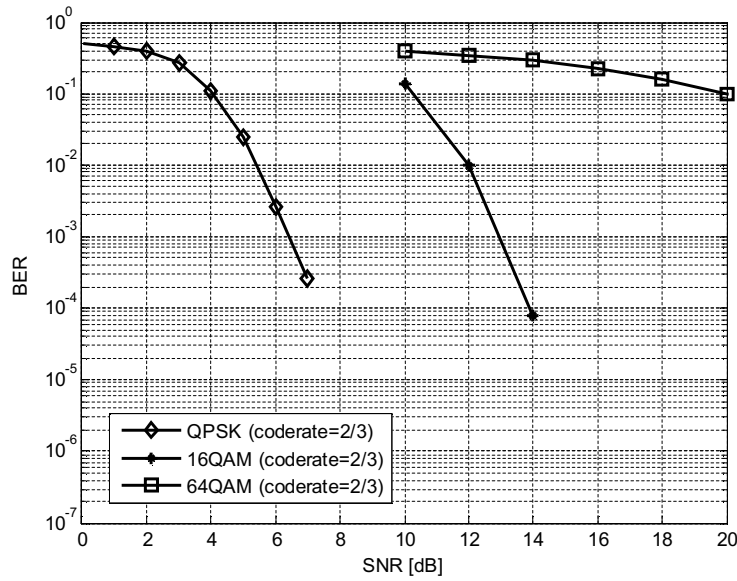
그림 5. 동축 케이블 환경에서 코드율 2/3의 채널 코드가 적용된 QPSK, 16-QAM, 64-QAM 시스템의 비트 오류율
Fig. 5. Bit error probabilities of QPSK, 16-QAM, 64-QAM under coaxial cable channel with code rate of 2/3
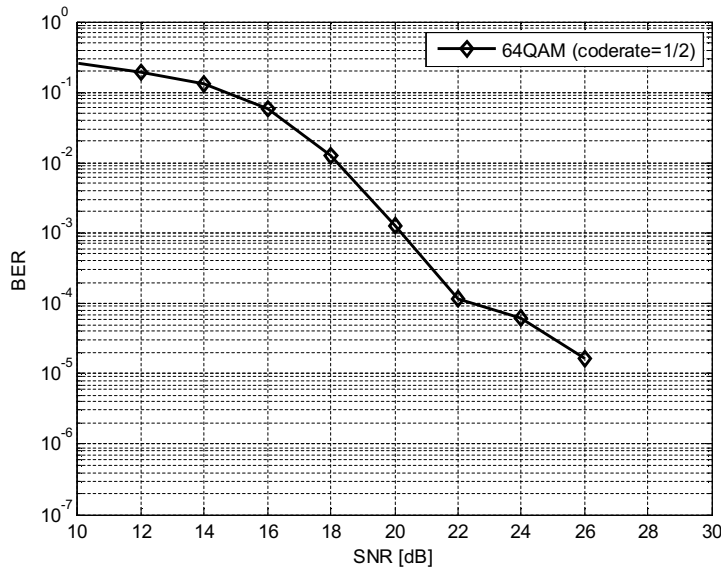

그림 6. 동축 케이블 환경에서 코드율 1/2의 채널 코드가 적용된 64-QAM 시스템의 비트 오류율
Fig. 6. Bit error probability of 64-QAM under coaxial cable channel with code rate of 1/2

The simulation for the higher order modulation has not been carried out. A BER of higher order modulation such as 256-QAM and 1024-QAM never converged to the re-quired SNR with convolutional code. If the effective chan-nel code is adopted such as a low-density parity-check (LDPC) code [13], the BER of higher order modulation can

표 5. 동축 케이블 채널 환경에서 최대 전송 거리
Table 5. Maximum transmission distance under coaxial cable channel environment

Modulation	Required bandwidth [MHz]	Attenuation [dB/100m]	Maximum acceptable loss [dB]	Maximum transmission distance [m]
QPSK	675	18.5	66.7	361
16-QAM	337.5	11.71	60.7	518
64-QAM	225	12.3	53.2	433
256-QAM	168.75	8	-	-
1024-QAM	135	7.2	-	-

converged to the required SNR. However, this leads to increase a system complexity.

Table 5 shows the maximum transmission distance according to modulation level under coaxial cable environment. From Table 5, the proposed system can transmit video streams up to 518 m for 16-QAM with code rate 2/3. It is about two times longer than that of the HD-SDI standard.

Ⅴ. Conclusions

In this paper, an HD-CCTV transmission system was proposed with QAM modulation. The proposed ER-SDI system is two times longer in terms of transmission distance compared to the HD-SDI standard. Its distance can cover a wide area without any repeaters. In the future work, the effective channel code shall be investigated for improving the bit error performance without loss of the data rate.

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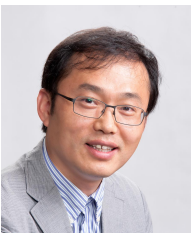
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