PROPOSED CDMA-QAM MODULATION METHOD AND APPLICATION TO HIGH-SPEED RAIL TRANSMISSION TECHNOLOGY FOR RAILWAY SIGNALING

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Abstract: In this paper, we propose a new modulation method combining code-division multiple access (CDMA) and quadrature amplitude modulation (QAM), called CDMA-QAM. It transmits QAM symbols allocated based on a CDMA signal, and it has the benefit that QAM errors can be recovered if they are in a range where they can be absorbed by CDMA demodulation. We applied the method to railway signaling and developed a CDMA-QAM rail transmission system having a transmission speed of 1500 bps using digital signal processors. We also conducted a field experiment using an actual rail and verified that the system can achieve favorable constellation characteristics.

1. Introduction

Railway signaling systems that transmit control information via rails have been deployed in many applications, such as digital automatic train control (ATC) systems for controlling train speed. Since the performance of digital ATC systems depends on the transmission speed, recently there has been a great deal of research aimed at realizing higher data transmission speeds [1]. Using the rail as a transmission medium has several benefits, such as superior security and cost performance as compared to wireless communication methods. However, it is difficult to increase the transmission speed because rails exhibit strong attenuation at frequencies above about 10 kHz. Therefore, the present transmission speed of digital ATC using rails is limited to about 300 bps. To overcome this restriction, we aimed to increase the transmission speed by improving the modulation method.

2. Overview of CDMA-QAM method

In this paper, we propose a new modulation method combining code-division multiple access (CDMA) and quadrature amplitude modulation (QAM), called CDMA-QAM. Figure 1 shows a block diagram of the CDMA-QAM method. The CDMA-QAM method transmits QAM symbols allocated based on a multiplexed CDMA signal. Specifically, the transmitter first divides the transmit data into 63 parallel data channels. The multiplexed CDMA signal is generated by adding all channels after subjecting them to CDMA modulation. Finally multiplexed signal is allocated to 64QAM symbols according to the amplitude of the multiplexed signal, from 0 to 63, and is transmitted on the transmission line. After the amplitude of the multiplexed signal is converted into binary, the three higher-order bits are allocated to an I (in phase) channel, and the three lower-order bits are allocated to a Q (quadrature) channel. Figure 2 shows the amplitude data allocation of each symbol in the CDMA-QAM method. At the receiver, after demodulating the 64QAM and CDMA signals, the parallel data is converted into the receive data. One benefit of the proposed method is that, even if the QAM demodulation has errors, they can be reduced by CDMA. Since QAM does not allocate the transmit data directly, but the multiplexed CDMA signal, QAM errors can be recovered if they are in a range that can be absorbed by the CDMA demodulation.

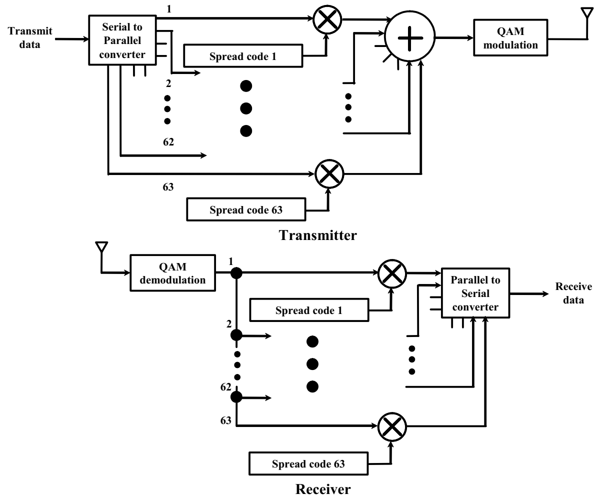


Figure 1. Block diagram of CDMA-QAM method.

Next, we propose a symbol allocation for the CDMA-QAM method. Figure 3 shows the results of analysis of the frequency distribution of the multiplexed CDMA signal amplitude in the transmitter. This figure shows that the frequency distribution is not a uniform distribution but is like a normalized distribution centered on 32 (almost the median value of the multiplexed signal amplitude). This means that the QAM symbols are centered near the Q-axis. On the other hand, the I channel is more important than Q channel for the bit error rate (BER) characteristics. This is because I channel is allocated three higher-order bits of the multiplexed CDMA signal. Based on these facts, we designed a symbol allocation scheme in which the symbol interval of the I channel is wider than that of the Q channel, as shown in Figure 4. With this design, the CDMA-QAM method can improve the BER characteristics without substantially increasing the total electrical power consumption of the system.

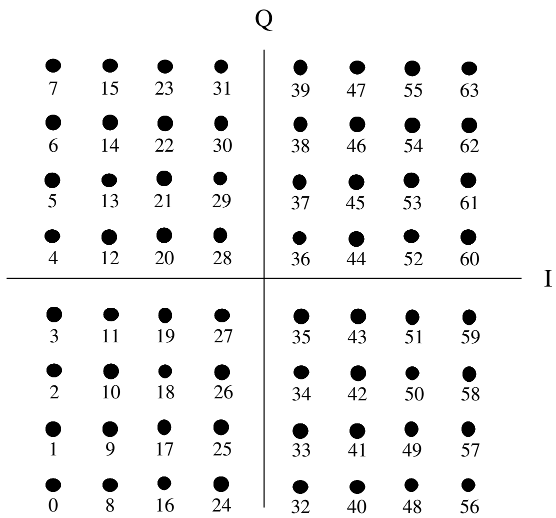


Figure 2. Amplitude data allocation of each symbol in the CDMA-QAM method.

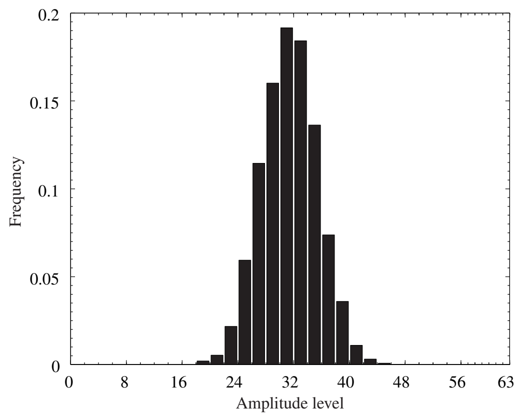


Figure 3. Frequency distribution of multiplexed CDMA signal amplitude.

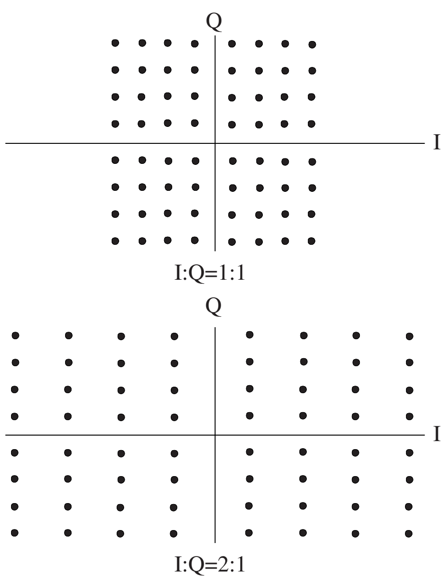


Figure 4. Symbol allocation in CDMA-QAM method.

3. Application to railway signaling and evaluation using computer simulation

We applied the CDMA-QAM method to railway signaling; we call it a CDMA-QAM rail transmission system. Table 1 shows the specifications of the CDMA-QAM rail transmission system. Based on these specifications, we carried out computer simulation in which the I/Q symbol interval rate was varied from I:Q=1:1 to I:Q=4:1. Figure 5 shows a comparison of the constellation characteristics by I/Q symbol interval rate. Here, the characteristic for I:Q=4:1 is normalized with respect to the scale for I:Q=1:1. From this figure, in the characteristic for I:Q=4:1, it is possible to reduce the error vector magnitude (EVM) of the I channel, though the EVM of the Q channel is worse than that of I:Q=1:1. As mentioned above, since the I channel is more important than the Q channel for the BER characteristics, I:Q=4:1 is superior. In addition, Figure 6 shows the BER characteristics of the CDMA-QAM rail transmission system. From this figure, we verified that the BER characteristics improved in proportion to I/Q symbol interval rate; we showed that for I:Q=4:1, the system realized a BER of 10^{-5}, the standard value used in railway signaling, even when transmission speed was about 2000 bps, which is much higher than the transmission speed of current systems [2].

Table 1. Specifications of CDMA-QAM rail transmission system.

Parameter	Value
Carrier frequency	4096 Hz
Number of multiple access channels	63
Transmission speed per channel	32 bps
Total transmission speed	2016 bps
Rail length	1 km
Rail noise	Measured data

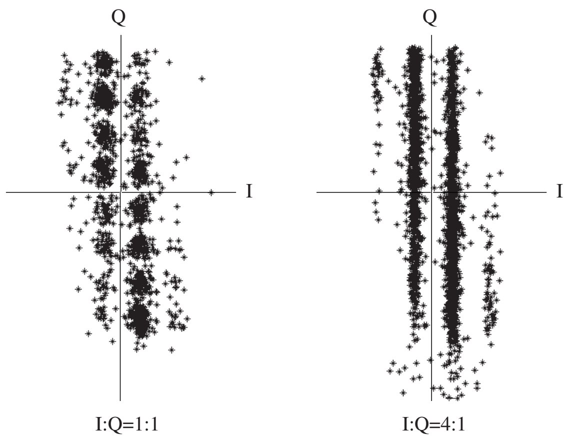


Figure 5. Comparison of constellation characteristics by I/Q symbol interval rate. (The characteristic for I:Q=4:1 is normalized by the I-axis.)

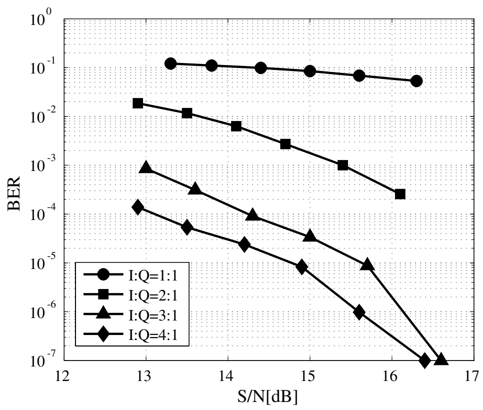


Figure 6. BER characteristics of CDMA-QAM rail transmission system.

4. Hardware development of CDMA-QAM transceiver using DSPs

Based on the results in the preceding section, we developed a CDMA-QAM transceiver using DSPs. As mentioned above, a rail exhibits strong attenuation at frequencies above about 10 kHz. Therefore, we used a standard audio interface provided in the DSP. Table 2 shows the specifications of the CDMA-QAM transceiver using DSPs.

Table 2. Specifications of CDMA-QAM transceiver using DSPs.

Parameter	Value
Carrier frequency	3000 Hz
Number of multiple access channels	63
Transmission speed per channel	23.4375 bps
Total transmission speed	1476.5625 bps
Sampling frequency	48 kHz

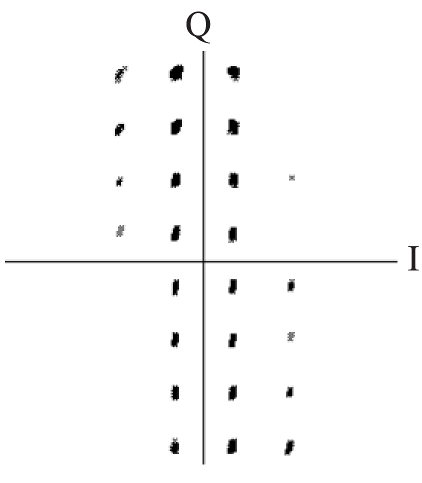


Figure 7. Constellation characteristics of QAM receiver.

We conducted experiments to verify the basic functions of the CDMA-QAM modulator and demodulator developed based on the specifications in Table 2. Figure 7 shows the constellation characteristics of the QAM receiver. From this figure, we verified that this demodulator successfully performed basic functions in real time, such as synchronous detection, and achieved favorable constellation characteristics.

5. Field experiment using a rail

We conducted a field experiment using an actual rail based on the setup shown in Figure 8. As the results of this field experiment, we obtained the spectral distribution shown in Figure 9 and the constellation characteristics shown in Figure 10. From these figures, we verified that this modulator and demodulator achieved favorable constellation characteristics for the I channel, which is more important for the BER characteristics, with a received signal attenuation of about 20 dB at a carrier frequency of 3 kHz.

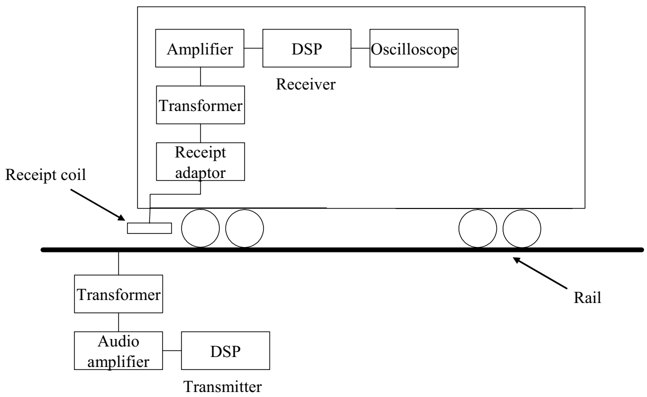


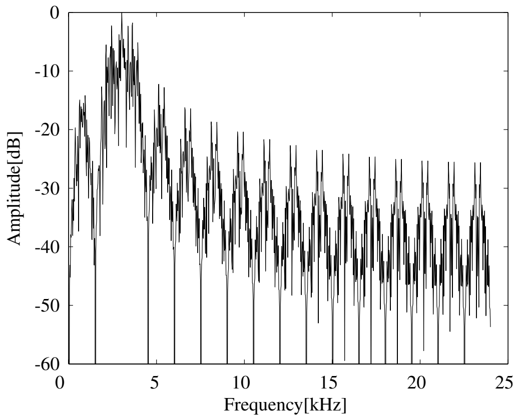
Figure 8. Setup of field experiment using an actual rail.

6. Conclusion

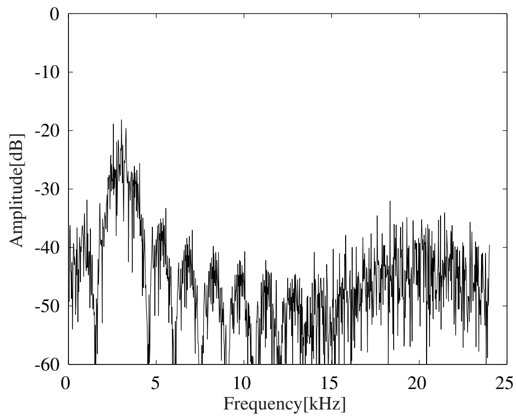
In this paper, we proposed a novel CDMA-QAM modulation method and applied it to a rail transmission system for improving the transmission speed of rail-based signaling. First, we studied the QAM symbol allocation, and based on the results, we designed a symbol allocation scheme in which the symbol interval of the I channel is wider than that of the Q channel. We verified that the BER characteristics improved in proportion to the I/Q symbol interval rate.

Next we designed and developed a CDMA-QAM transceiver, and we verified that this transceiver successfully performed basic functions in real time, such as synchronous detection.

In addition, we conducted a field experiment using an actual rail. We achieved favorable constellation characteristics for the I channel, which is more important for the BER characteristics, with received signal attenuation of about 20 dB at a carrier frequency of 3 kHz. In future research, we plan to measure the BER characteristics after combining a CDMA-QAM transceiver with a matched filter, which we have already developed using FPGA [3], and evaluate the proposed system quantitatively.



(a) Signal before passing through the rail.



(b) Signal after passing through the rail.

Figure 9. Spectral distribution at the receiver.

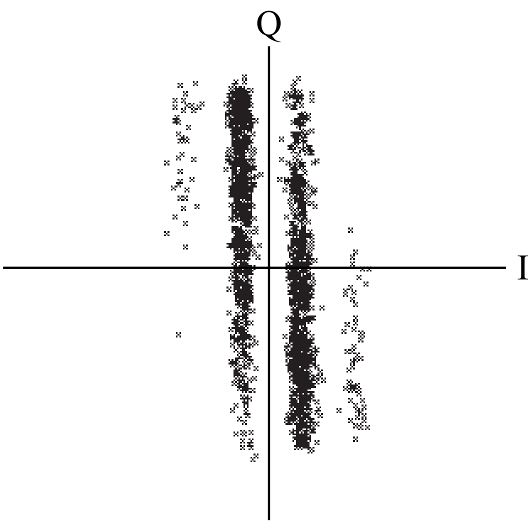


Figure 10. Constellation characteristics in field experiment.

Acknowledgments

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