Development of a Phase Noise Compensation Method for a Super Multi-Level Modulation System that achieves the World's Highest Frequency Usage Efficiency

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Abstract

Microwave communication systems are used for mobile backhaul worldwide. With the rapid growth in traffic over the past few years, the need for an efficient way to further expand capacity in microwave bands where bandwidths are limited has become critical. The optimal solution would be to introduce a super multi-level modulation system that has high frequency usage efficiency such as 1024 QAM. Before such a system can be introduced, however, it is necessary to find a solution to the problem of phase noise. This paper takes a look at the effect of phase noise on the super multi-level modulation system and introduces the phase noise compensation technology NEC has developed to maintain stable transmission quality. Thanks to the development of this technology, NEC has improved phase noise resistance by more than 10 dB compared to conventional systems and achieved 2048 QAM, making it the world's highest multi-level modulation system.

Keywords

super multi-level modulation, mobile backhaul, phase noise, carrier synchronization, frequency usage efficiency, PLL, PSAM, forward error correction (FEC)

1. Introduction

Loosely defined, wireless mobile backhaul is a network that connects mobile base stations using wireless communication systems operating in microwave bandwidths. These wireless communication systems are critical to the successful functioning of these networks. NEC is a leader in the development and deployment of wireless communications, delivering its PASOLINK system to telecom carriers around the world.

Explosive growth in smartphone use, along with video and music streaming, has led to massive growth in traffic, stretching these systems to the limit and making it imperative to increase transmission capacity.

This paper introduces our phase noise compensation technology, which is not only an effective means of expanding transmission capacity, it's also an example of how our component technologies are helping increase the level of modulation scheme.

2. Spectrum and Technology Issues for Multi-Level Modulation Systems

2.1 Microwave Bands: What they are and how they work

Usually the bandwidth in the range between 6 and 42 GHz - bandwidths that require a frequency usage license - are used for mobile backhaul. This bandwidth is called microwave band in this paper.

Although the microwave band can be attenuated by rain, its ability to transmit stable signals over relatively long distances (on the order of a few kilometers) has led to its widespread use in mobile backhaul.

In microwave band, the bandwidth usable by a given signal is specified by public standards. Even in higher-frequency bandwidths where wider bandwidths can be ensured, the upper limit is 56 MHz (recently expanded to 112 MHz in some high-frequency bands). As is clear from the Shannon–Hartley theorem, the simplest way to expand transmission capacity is by expanding bandwidth. However, when bandwidth use is restricted, the most effective way to achieve greater transmission capacity is to transform the modulation system into a multi-level system.

Doubling the modulation level makes it possible to increase the number of bits - which can be transmitted at one time - by one increment. This does not just increase overall transmission capacity, it also means that frequency usage efficiency (transmission capacity per 1 Hz) can also be improved. Because telecom carriers must pay a spectrum fee to the local regulatory authority, they will benefit from any improvement in frequency usage efficiency as this will help reduce operation expenses. Multi-level modulation systems are increasingly employed in microwave frequency - for instance, a modulation level at 256 QAM (8-bit/symbol) has already become a standard. When 256 QAM is used, transmission capacity of about 350 Mbps and frequency usage efficiency of about 7 bps/Hz are typically achieved.

2.2 Technology and Quality Issues with Super Multi-level Modulation Scheme

To meet the demand for expanded capacity, it is necessary to go beyond existing modulation level systems and introduce a super multi-level modulation scheme such as 1024 QAM (10-bit/symbol) as shown in **Fig. 1** (b). Some of the issues involved in developing a super multi-level modulation system are discussed below.

When the modulation system is increased by one step - in other words, when the modulation level is doubled - the minimum symbol distance is shortened to $1/\sqrt{2}$ with respect to the original modulation system, provided that the average power is constant. For this reason, the required carrier-to-noise power ratio (CNR) to obtain the same bit error rate (BER) increases by 3 dB, making it more difficult to achieve under finite conditions. The increase in the required CNR can be reduced by improving the coding gain. We have made significant improvements in coding gain by developing low-density parity check (LDPC) code suited for wireless backhaul systems.

Another issue is the degradation in transmission quality caused by phase noise. Usually, microwave communication equipment executes QAM modulation according to the digital signal to be sent at the baseband and converts it into an RF frequency band. This frequency conversion is executed by multiplying the modulated signal by the RF frequency sinusoidal wave (local oscillator [LO] signal). The LO signal is not an ideal single-frequency signal as shown in **Fig. 2** (a), however it contains unwanted frequency components called phase noise as shown in Fig. 2 (b).This phase noise ends up being added to the modulated signal in the RF band after the frequency conversion.

On the receiving side, the same operation is performed in reverse. Thus, the phase noise in the LO signal on the receiving side is also added to the modulation signal, creating fluctuation in the phase direction as shown in **Fig. 3** in the modulated baseband QAM signals.

This, of course, can be an occurrence factor for a

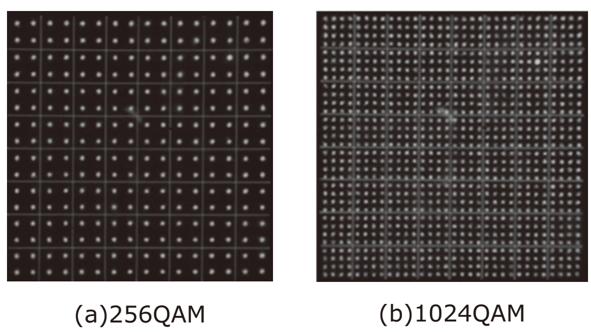

Fig. 1 Signal points constellation of QAM modulation level.

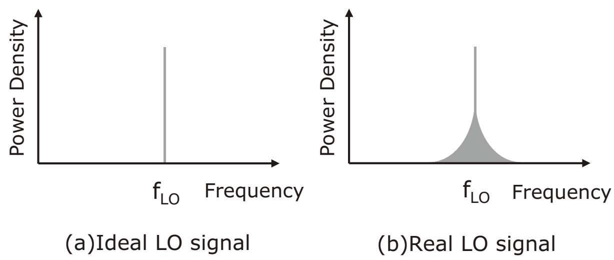

Fig. 2 LO signal spectrum.

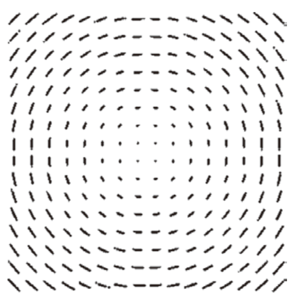

Fig. 3 256 QAM demodulated constellation to which phase noise is added.

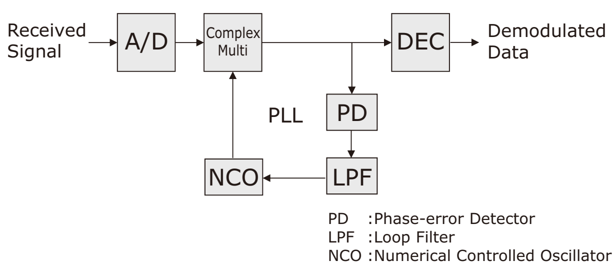

Fig. 4 Conventional carrier synchronization circuit using PLL.

transmission error. However, attempting to improve the characteristics of the phase noise is not an option as doing so would increase the equipment manufacturing cost. Although the conventional carrier synchronization circuit employing phase-locked-loop (PLL) shown in **Fig. 4** can suppress phase noise, it is difficult to ensure that the amount of noise suppressed will be sufficient to perform the super multi-level modulation transmission. When the noise level in the received signals is high, errors increase in the control data for the synchronization circuit, making the system unstable and causing burst errors that cannot be corrected. Due to the improvement in coding gain mentioned earlier, the environment in which stable operation of carrier synchronization circuit is required has been shifted in a lower CNR direction. By making it more difficult to maintain stable carrier synchronization of the super multi-level modulation scheme by conventional PLL circuit, this further exacerbates the problem.

3. Development of a Phase Noise Compensation Method

3.1 Introduction of the PSAM System

Extensive study of the carrier synchronization circuit that uses a PLL circuit to acquire control information solely from ordinary transmission signals has made it clear to us that the occurrence of burst errors cannot be prevented even when PLL parameters are optimized. Consequently, we determined that a pilot-symbol assisted modulation (PSAM) system would be required to maintain stable control in a low CNR environment, while limiting any deterioration in transmission efficiency to a few percent. A block diagram of the carrier synchronization circuit in the PSAM system is shown in **Fig. 5**.

Phase control in the PSAM system is executed by interpolating a known QPSK signal (pilot signal) between super multi-value modulation system transmission signals in a predefined cycle on the transmitting side. On the receiving side, phase control is performed using extracted pilot signals as the sole information source. Because the known signal is used, phase errors can be accurately known even if high-level thermal noise is added. As a result, stabilization of phase control can be accomplished.

It is, however, impossible to track high-speed phase fluctuation caused by high-frequency phase noise since the refresh speed of control data is decreased to one divided by the frequency of the pilot signal. Consequently, symbol judgment errors frequently occur in the super multi-value modulation system - which is caused by the phase shift.

3.2 PLL Circuit with Built-in Error Correction

Although the introduction of the PSAM system makes it possible to stabilize synchronization in a low CNR environment, it is not sufficient on its own as the BER cannot be suppressed at a low level. Attempting to solve this by introducing a PLL circuit allocated after the PSAM circuit simply reproduces the problems of the original PLL circuit. Our solution was to use an FEC decoder (DEC) circuit to reduce symbol decision errors in the phase information source - the main problem in the PLL circuit. The overall configuration of our proposed carrier synchronization circuit is shown in **Fig. 6**.

In this new configuration, PSAM circuit output signals are passed through the DEC circuit first. Symbol decision errors are reduced by the error correction effect. The phase error data derived from this is input to the PLL circuit to reduce the phase error remained in the PSAM circuit output signals. The enhanced signal is input to the DEC circuit again to eliminate any symbol decision errors. By repeating this cycle, the precision of the phase control of demodulated signals can be increased; in other words, the BER can be reduced, without triggering burst errors.

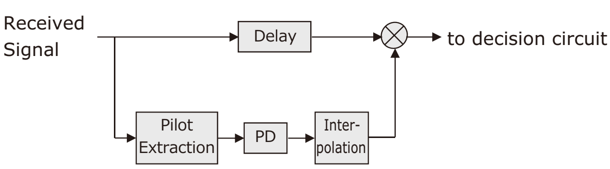

Fig. 5 Block diagram of the carrier synchronization circuit of the PSAM system.

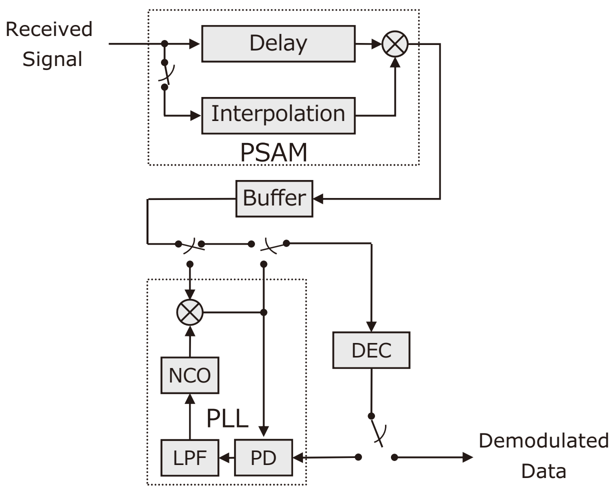

Fig. 6 Block diagram of the proposed carrier synchronization circuit.

By operating the DEC circuit at higher speed than usual, it is possible to repeat multiple cycles while receiving the signals continuously. Also because the processing is performed on accumulated signals received over a period of time, there is no degradation of performance caused by delay in the loop - a common problem in feedback control systems such as PLL.

As described above, stabilizing synchronization using the PSAM and then improving the precision of the phase control through repeated operation of the PLL and DEC has made it possible to improve the demodulation performance of the super multi-level modulation scheme. In addition, in the case of the combination of PLL and DEC without the PSAM, stable carrier synchronization cannot be achieved at low CNR, and the original problem still remains.

3.3 Evaluation of Performance

The measured data of the resistance properties against the phase noise measured using 1024 QAM are shown in **Fig. 7**. Compared to the conventional method, the resistance to phase noise has been improved by more than 10 dB while the basic CNR noise has been improved by more than 1 dB. Based on these results, we have confirmed that sufficiently stable characteristics can be obtained even when taking into consideration variations in the phase noise level of the LO signal.

The CNR versus BER performance of 2048 QAM measured in the system with a noise level at −100 dBc/Hz are shown in **Fig. 8**. This graph elucidates that there is no possibility that an error floor will occur - a phenomenon in which the decrease of the BER stops with respect to the increase of the CNR.

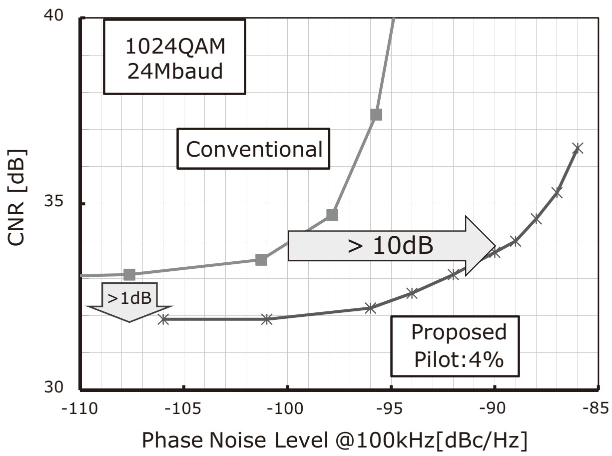

Fig. 7 Phase noise versus CNR @ BER = 10^{-6} (measured data).

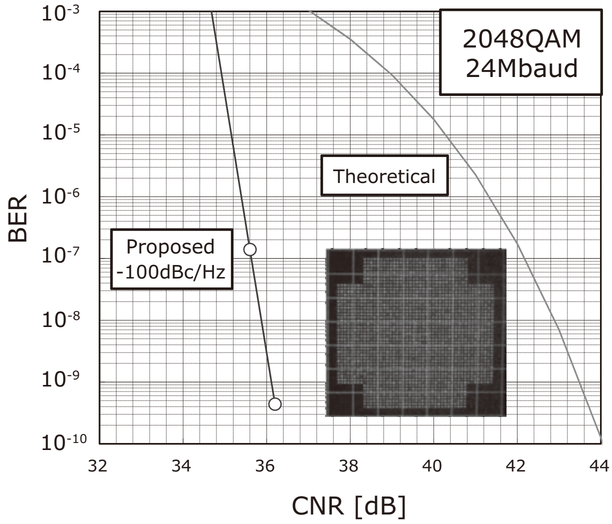

Fig. 8 CNR-versus-BER performance of 2048 QAM (measured data).

4. Conclusion

In the above, we have seen the effects of phase noise on the microwave super multi-level modulation system and introduced a phase noise compensation method we have developed to suppress those effects. By combining modulation/demodulation technology and error correction technology - technologies that resulted from our experience in the development of microwave communication systems - we were able to successfully achieve an effective super multi-level modulation system.

The development of this method has enabled us to commercialize 1024 QAM and 2048 QAM systems capable of boosting transmission capacity and frequency usage efficiency by 25% and 38% respectively (compared to 256 QAM, standard modulation system for microwave band) without having to improve the characteristics of LO signals, which would significantly increase costs.

NEC will continue to develop products that will contribute to advancement of telecommunications infrastructure worldwide.

Reference

1) N. Kamiya, E. Sasaki; Pilot-symbol assisted and code-aided phase error estimation for high-order QAM transmission, IEEE Trans. Comm., vol.61, no.10, pp.4369–4380, 2013.10
2) A. Spalvieri, L. Barletta; Pilot-aided carrier recovery in the presence of phase noise, IEEE Trans. Comm. Vol.59, no.7, pp.1966-1974, 2011.7

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