# A Novel Structure Digital Receiver

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**Abstract.** This paper studies a novel structure digital receiver to demodulate signal with large frequency offset. When the carrier frequency offset is large, the matched filter will filter out part of the in-band signal, resulting in decrease of SNR and deterioration of BER. Different from traditional receiver structure, the novel receiver put a coarse frequency correction module before the matched filter, which will reduce the negative influence of matched filter under large frequency offset. Simulation results show that the new structure displays similar performance to the traditional structure under small frequency offset and great performance improvement when the frequency offset is large.

**Keywords:** Frequency offset · Matched filter

## 1 Introduction

The commonly used digital receiver structure is shown in Fig. 1. The baseband signal obtained after the digital down conversion and sampling rate conversion will pass through the matched filter, the timing module, the frequency synchronization module, phase synchronization module and the decoding module. After decoding we can get the bit stream [1]. Sometimes the received signal comes from different transmitters, so the feedback structure in reference [1, 2] can't be used. The structure shown in Fig. 1 has broader applicability.

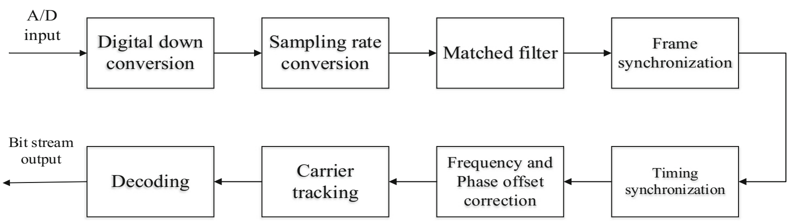


**Fig. 1.** The commonly used digital receiver structure

Matched filtering operation has two roles, the first is to ensure that the timing data has no inter symbol interference (ISI). The second is to make the SNR at the timing point has the largest value.


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The signal transmitter and receiver's crystal instability and other factors will cause the existence of the carrier frequency offset and phase offset. The purpose of the frequency offset correction module and the phase correction module is to estimate the frequency offset and phase offset on the signal and then compensate it respectively. Based on whether the pilot sequence is used, frequency offset estimation algorithm can be divided into DA (data aided) and NDA (non-data aided) estimation algorithm, which is the same in phase offset estimation.

For DA algorithm, The KAY algorithm [3], LR algorithm [4], Fitz algorithm [5] are commonly used. The KAY algorithm has larger frequency offset estimation range but lower accuracy compared to the LR algorithm. Therefore, in practical applications, we could first use the KAY algorithm to do a coarse frequency offset correction, and then use the LR algorithm to do a fine frequency offset correction. The signal after these two frequency corrections will only have a small residual frequency offset [6].

ML algorithm is commonly used in phase correction, after the phase compensation, there will be a small residual phase offset on the signal.

Usually a carrier tracking is performed to further reduce the residual frequency offset and residual phase offset, and tracking the carrier frequency and phase's changes, the PLL (phase-locked loop) is commonly used for tracking, the output of the PLL is the data symbols.

After decoding, the data symbols are transformed to bit stream.

With the increase of the carrier frequency offset, the receiver's performance will drop. To solve this problem, they use a feedback structure for more accurate digital down conversion in DVB-S2 [1], but if the received signal comes from different transmitters, this method can't be used. In this paper, a novel structure is proposed to solve the problem.

## 2 Performance Degradation Due to Frequency Offset

In this part, we discuss why the receiver's bit error rate increase significantly due to the large frequency offset.

Through the investigation of the receiver modules, it's found that when the carrier frequency offset is large, the matched filter will cause a great deterioration of the SNR.

This phenomenon can be visually observed in the frequency domain, as shown in Fig. 2, when the signal has no carrier frequency offset, all the signals filtered out by matched filter are out band noise, but when carrier frequency offset exists, part of the signal spectrum will appear outside the band of the matched filter, the filtering operation will filter out this part of signal spectrum, which will cause a significant deterioration of the SNR.

The Fig. 3 further demonstrates the phenomenon.

The $E_S/N_0$ value is fixed to 18 dB before match filtering. The SNR of the matched filter's output decreases gradually as the increase of normalized frequency offset, which will cause the rising of the system's BER.

We can also explain the problem through another perspective, for the sake of simplicity, we choose ideal low pass filter to be pulse-shaping filter and matched filter

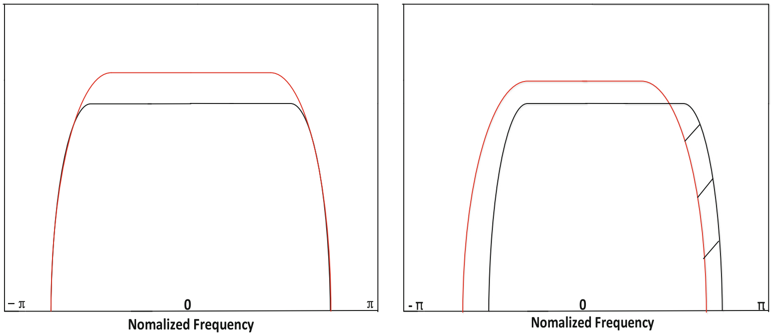


**Fig. 2.** Frequency domain of signal and matched filter. The red part represents the matched filter, the black part represents the signal. (Color figure online)

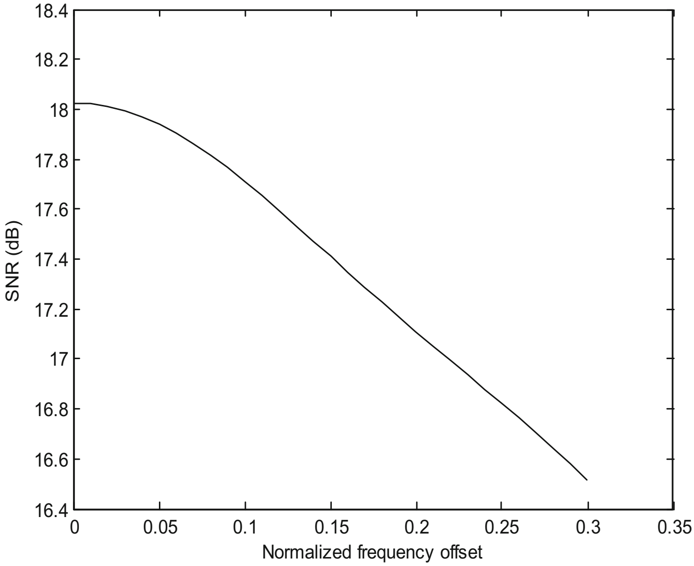


**Fig. 3.** The SNR of the match filter's output

(In practical applications we use root-raised cosine filter). If the total transfer function of baseband system satisfies the Nyquist first criterion:

$$\sum_{i} H\left(\frac{w + 2\pi}{T_s}\right) = T_s \quad |w| \le \frac{\pi}{T_S}, \tag{1}$$

the optimum sampling points have no ISI (inter symbol interfere). When there is no frequency offset, the transfer function is:

$$H(w) = \begin{cases} T_S & |w| \le \frac{\pi}{T_S} \\ 0 & \text{otherwise} \end{cases}, \tag{2}$$

which satisfies Nyquist first criterion. However, when carrier frequency exists, the transfer function is:

$$H(w) = \begin{cases} T_S & -\frac{\pi}{T_p} < w < \frac{\pi}{T_S} \quad T_p > T_s \\ 0 & \text{otherwise} \end{cases}, \tag{3}$$

Nyquist first criterion can't be satisfied anymore, thus producing the ISI and degrading the performance.

## 3 New Digital Receiver Structure

In order to solve the problem described above, this paper presents a new digital receiver structure. The core idea of this structure is to eliminate the SNR deterioration caused by the matched filter. For this purpose, we will compensate the carrier frequency offset as much as possible before match filtering, then match filter the compensated signal.

The digital receiver structure is shown in Fig. 4:

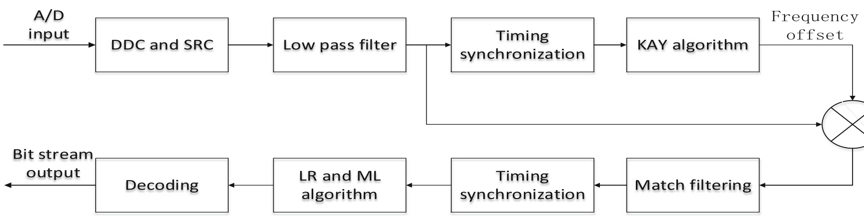


**Fig. 4.** The new digital receiver structure

The baseband signal after digital down conversion and sample rate conversion will pass through a low pass filter (LPF), whose bandwidth is sufficiently larger than the signal bandwidth to ensure that the signal with frequency offset can still lie in the pass band of the low pass filter, which ensures that the spectrum of the signal will not be filtered by the low-pass filter and out-of-band noise is filtered as much as possible. Commonly, the passband bandwidth can be set as the sum of the signal bandwidth and the maximal frequency offset.

The KAY algorithm is used to calculate the carrier frequency offset first due to its large estimates range. Before the frequency offset estimation, we use the OM timing algorithm to get the optimum sample point which is needed by the KAY algorithm. Since we use a LPF instead of matched filter, the best sample point is less accurate and has more noise, but it is enough for coarse frequency offset estimation.

We use the frequency offset calculated by the KAY algorithm to compensate the output signal of the low-pass filter. This operation aims to move the spectral center of the signal to zero frequency as much as possible. And then we use the compensated signal to do the match filtering, which will not filter out the spectrum of the signal anymore, thus further enhancing the SNR.

After match filtering, we do timing operation and carrier recovery with higher precision to get the data symbols. We use the OM timing algorithm to do the timing operation, the LR algorithm to do the frequency offset compensation with higher accuracy and ML algorithm to compensate the phase offset. Finally we get the bit stream.

The Fig. 5 shows the SNR curve of the match filter's output.

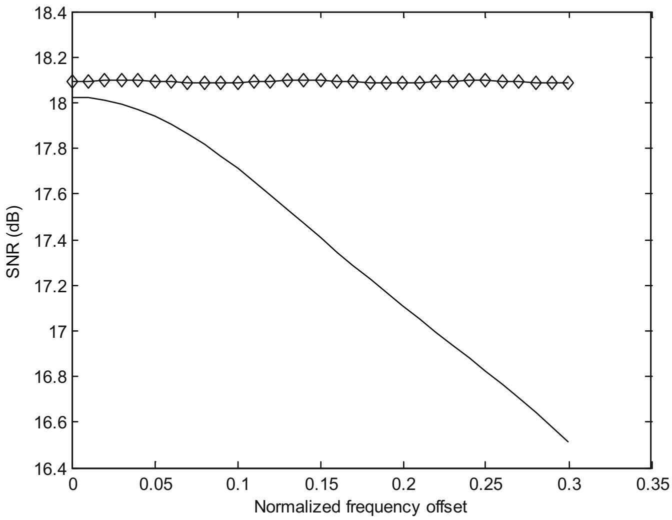


**Fig. 5.** The SNR of the match filter's output

The $E_S/N_0$ value of the system's input is fixed to 18 dB and the normalized carrier frequency offset changes. In this figure the ordinary line represents the SNR in the old structure receiver and the line with diamond marks represents the SNR in the new structure receiver. Compared with the old structure, we can see the SNR in the new structure has been greatly improved, and the receiver with new structure can work under a larger carrier frequency offset. Thus the performance of the new structure digital receiver can be significantly improved.

## 4 Simulation Results

The simulation results compare the performance of the two different structures of digital receiver. Test signal is 16QAM. Each frame contains the unique word portion and the data portion. The channel is an additive white Gaussian noise channel.

When the normalized frequency offset between the transceivers is fixed to 0.07 [7], $E_S/N_0$ is set to 18 dB, the output constellation of the two kinds of digital receivers is shown in Fig. 6. It can be seen in the case of relatively small frequency offset, constellation quality improves slightly.

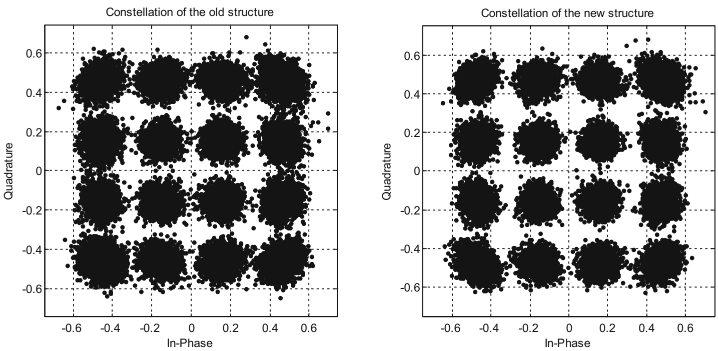


**Fig. 6.** The constellation of the two receivers.

The Fig. 7 shows the bit error rate curve of the two receivers. For convenience, we use the hard decision method [8] to demodulate the constellation. The ordinary line indicates the bit error rate curve of the old structure receiver, and the line with diamond marks represents the bit error rate curve of the new structure receiver. It can be seen that the performance of the two receivers is almost the same when the normalized frequency offset is small.

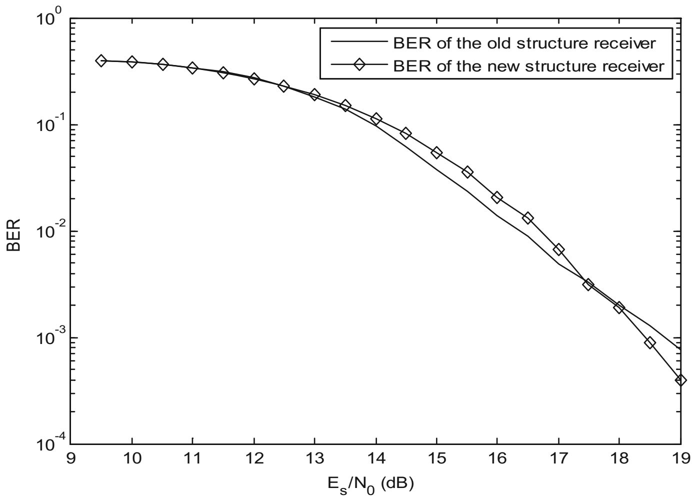


**Fig. 7.** The BER of the two receivers.

When the normalized frequency offset between the transceivers is increased to 0.15 while $E_S/N_0$ is still 18 dB, the constellation of the two receivers is shown in Fig. 8. It

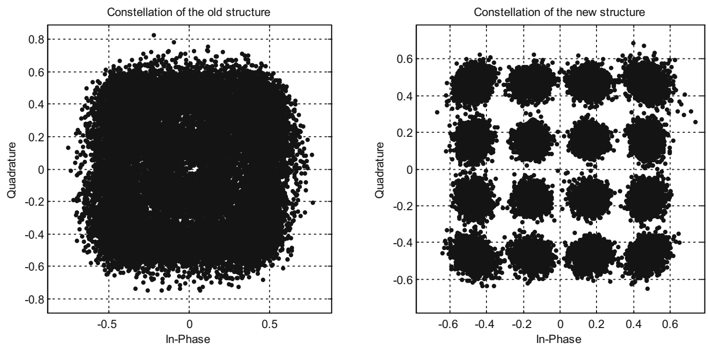


**Fig. 8.** The constellation of the two receivers.

can be seen that in the case of large frequency offset, the traditional structure receiver can't work normally, but the new structure receiver still shows perfect performance.

The Fig. 9 shows the bit error rate curves of these two different receivers. The ordinary line represents the bit error rate curve of the old structure receiver, and the line with diamond marks represents the bit error rate curve of the new structure receiver. We can see that when the frequency offset is relatively large, the new structure receiver's bit error rate has been significantly improved.

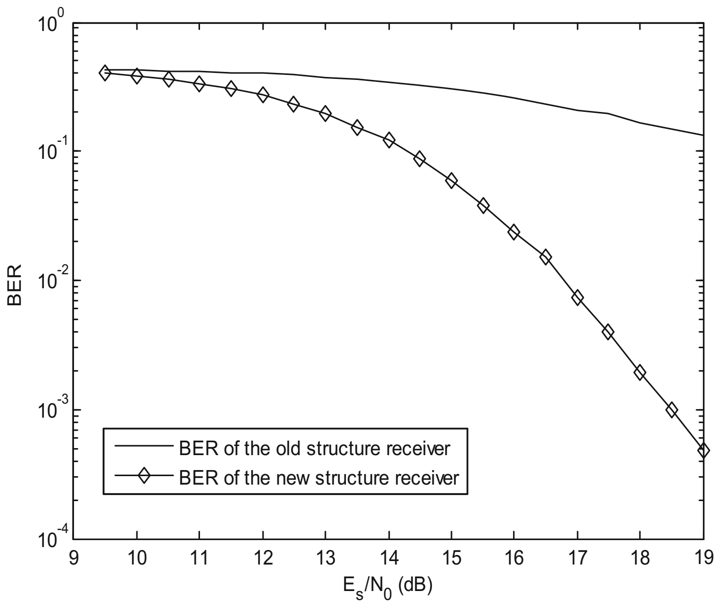


**Fig. 9.** The BER of the two receivers.

## 5 Conclusion

The new structure receiver shows similar performance to the old one when the frequency offset is small enough. But when the frequency offset increases, the match filtering operation will cause the damage to the signal spectrum and reduce the SNR, so that the bit error rate will increase. In this paper, a new structure of digital receiver is proposed. The front end uses a low-pass filter and a frequency compensation module to reduce the frequency offset, and then uses match filtering to improve the SNR, followed by carrier synchronization with higher accuracy. This new structure digital receiver can work normally under large frequency offset. When the normalized frequency offset is larger than 0.07, the performance will be better compared to the traditional digital receiver, while the cost is very little. The new structure receiver has a high value of engineering use.

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