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An Improved Algorithm for Q-scale Analysis in Jitter Decomposition

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INTRODUCTION

The increasing amount and speed of data generated by front-end electronic devices in high-energy physics (HEP) experiments place higher demands on data acquisition and processing systems. The probability of obtaining an erroneous signal from sampling will become larger when the signal transmission rate increases because the signal may not jump at the ideal moment, and the faster the data rate is, the easier error will be obtained. We can describe this by jitter, which represents the difference between the actual transition moment and the ideal transition moment, which is shown in Fig. 1. To determine the source of jitter and diminish the effect of jitter in system design, it is necessary to decompose total jitter (TJ) into deterministic jitter (DJ) and random jitter (RJ).

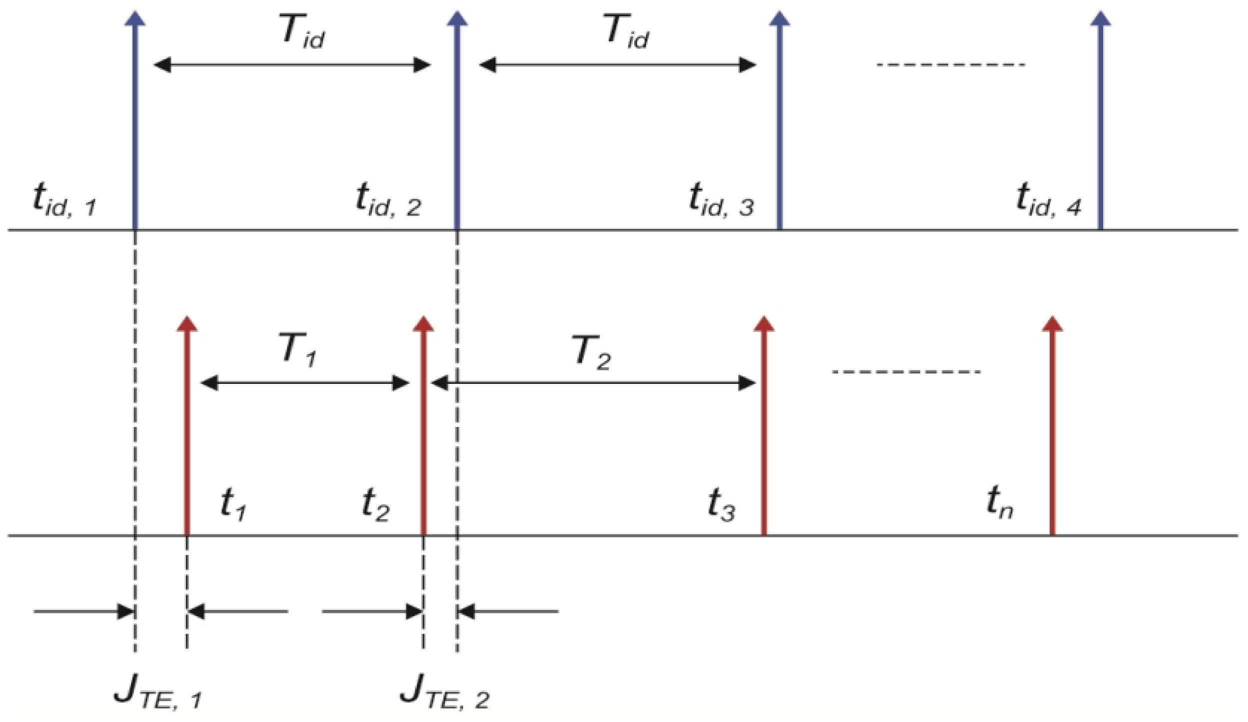

Fig. 1. Jitter example for a clock signal, where T_{id} is the ideal period.

METHODS: Jitter Module

A generalized example of the probability density function (PDF) of TJ $f_{TJ}(x)$ when ρ_L equals 0.75 is shown in Fig. 2. The unit of the horizontal axis is unit interval (UI), which is usually equal to a signal period or a clock period.

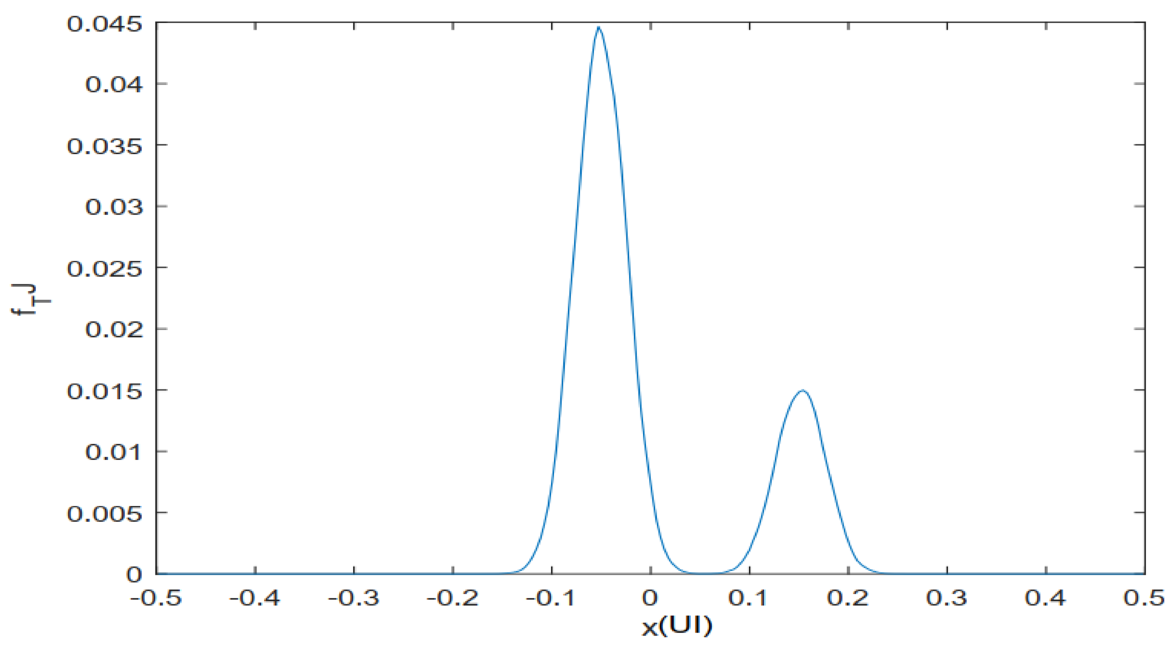

Fig. 2. A $f_{TJ}(x)$ example when $\rho_L = 0.75$.

METHODS: Q-scale Analysis

To decompose jitter more accurately, set $Q = \frac{x-\mu}{\sigma}$, where x denotes the sampling position. It is obvious that Q is linearly related to x. However, the parameters μ and σ, which denote DJ and RJ respectively are unknown, instead, they are the target of jitter decomposition. Once the correspondence of Q with x is obtained, we can perform a linear fit to obtain the estimated values of μ and σ. The BER(x) which means the bit error rate in sampling position x can associate Q and x. For instance, when the value of TJ is greater than sampling position x, a bit error occurs. After obtaining BER(x), we can inverse it to obtain x and substitute x in Q, then you can find that μ and σ are eliminated cleverly. There is still an unknown parameter ρ_L in the expression Q(x), in the traditional algorithm it is usually be set to 1 and 0 to perform a linear fit to the tails of Q-scale curves. As shown in Fig. 3, setting different values of ρ_L leads to asymptotic Q(x) curves at its tails. In this way, the data chosen for linear fit are restricted in tails with the result of a decrease in data usage efficiency. Therefore, it is important to propose an improved algorithm for high data utilization and accuracy.

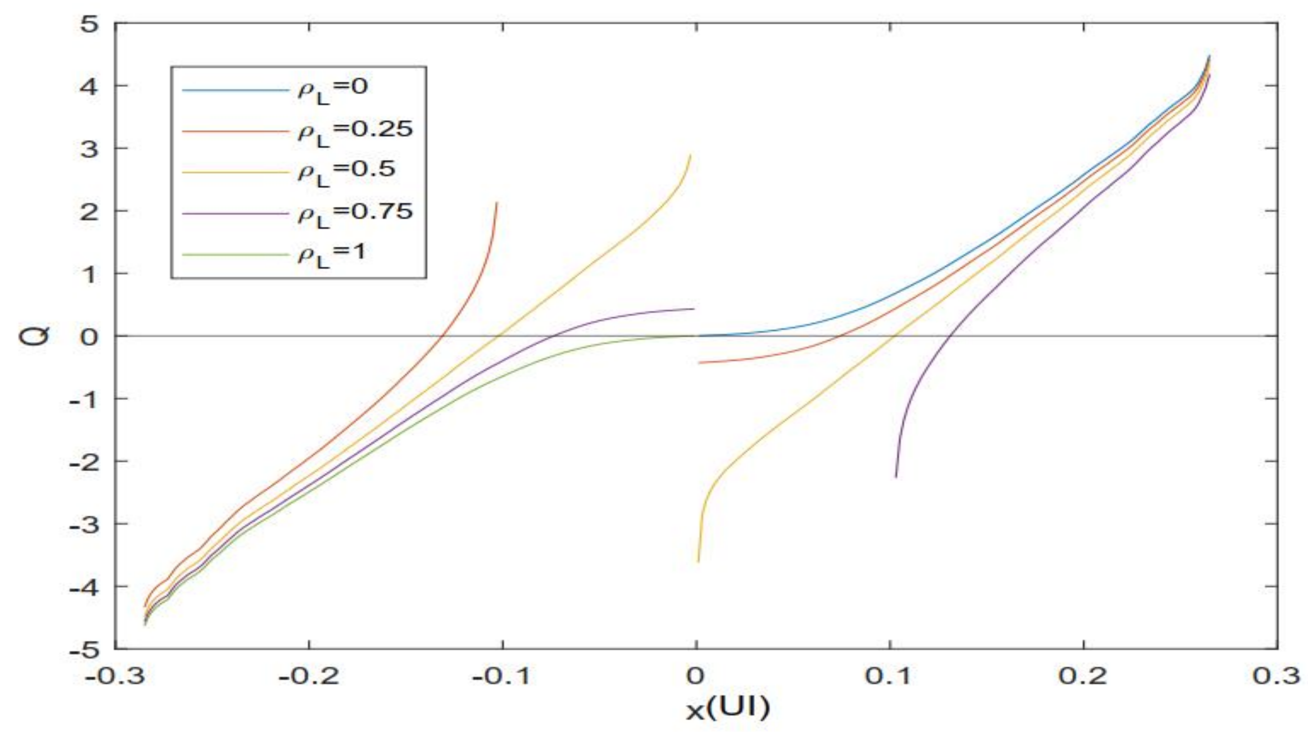

Fig. 3. Q(x) for different ρ_L.

METHODS: Improved Algorithm

Observing the Fig. 3 we can find that when ρ_L = 0.5, Q(x) is the most appropriate to do linear fit because it resembles one straight line the most and actually the ρ_L of DJ we set is 0.5. Inspired by this, can we use this property to estimate the value of ρ_L? The answer is yes. Define a variable to describe the linearity error of Q-scale curves as follows: $E_r = |r_L + r_R - 2|$. where r_L and r_R are the Pearson correlation coefficients of the two branches of Q-scale curves, respectively. As shown in Fig. 4, we can take the corresponding ρ_L when E_r achieves the minimum value as the estimate, which is very close to the actual value of ρ_L. For other values of ρ_L, we can obtain a similar result.

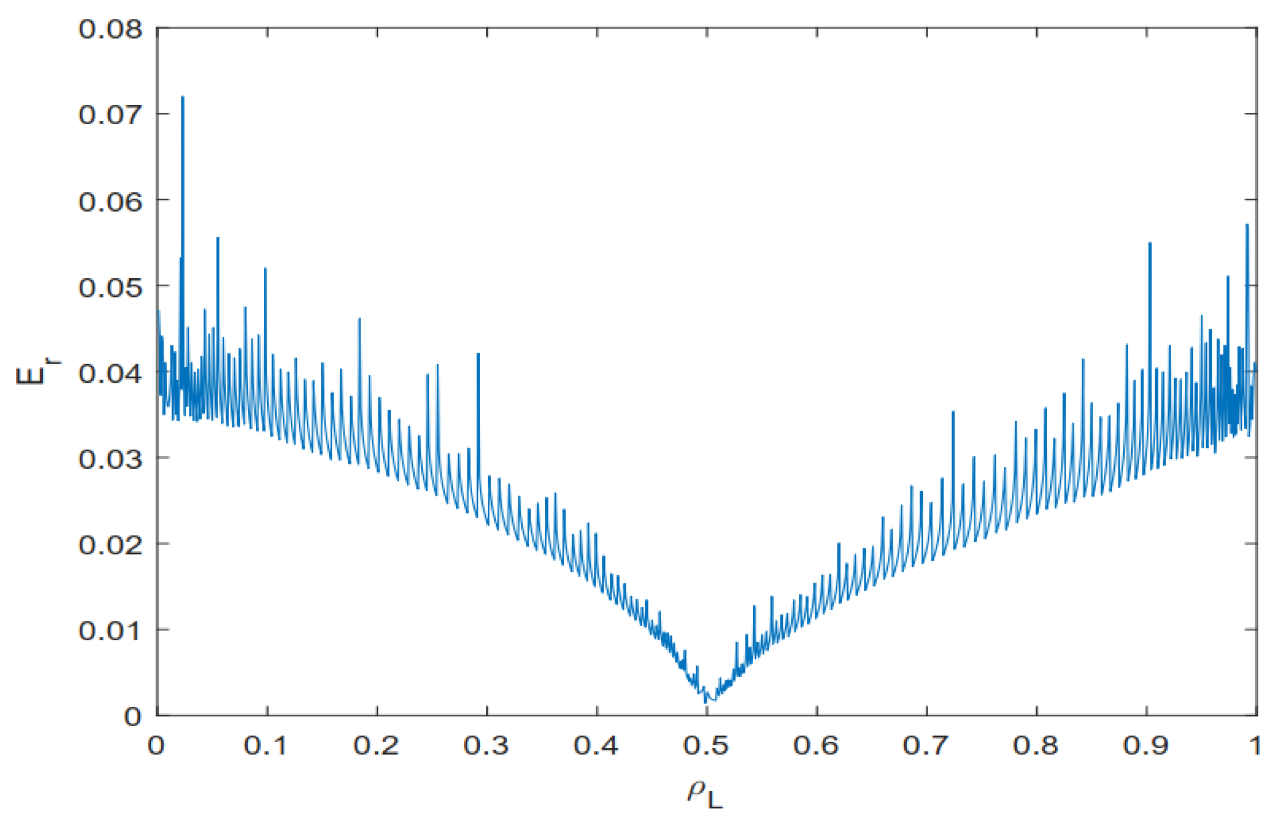

Fig. 4. E_r curve when actual $\rho_L = 0.5$.

TEST RESULT

The process of the improved algorithm is shown in Fig. 5, and the results are shown in Table I. It should be noted that the tail interval is just for the traditional algorithm. From the table we can observe a significant advantage for the improved algorithm in terms of errors. More importantly, an increase in data utilization implies a reduced need for data, which may be beneficial for real-time data processing.

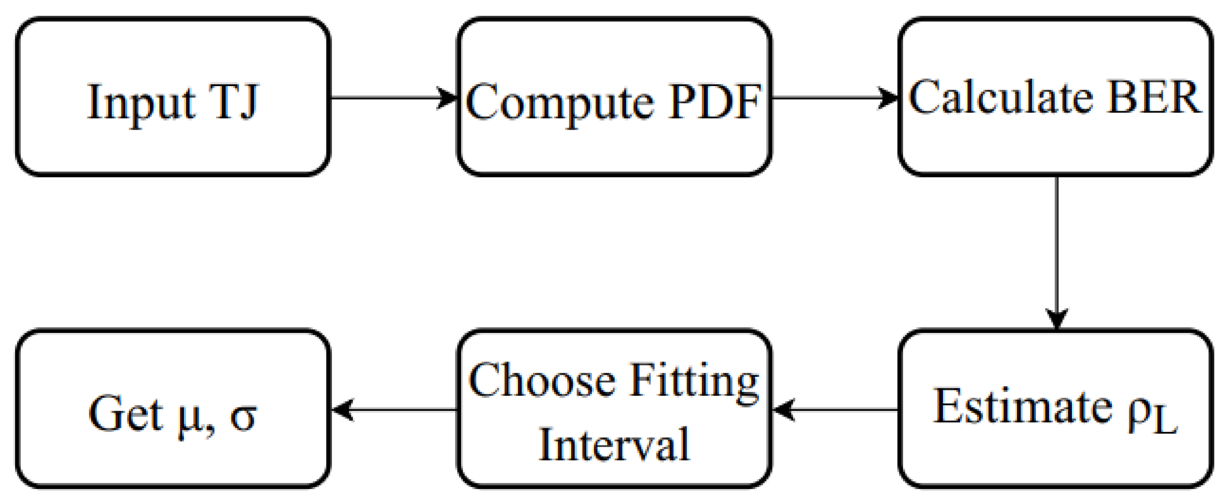

Fig. 5. Process diagram of jitter decomposition.

TABLE I
COMPARISON OF ERROR BEFORE AND AFTER IMPROVEMENT.

ρ_L	Tail Interval	μ Before	μ After	σ Before	σ After
0.25	20%	16.4%	1.33%	-12.6%	0.68%
0.50	20%	11.9%	3.13%	-6.99%	-0.51%
0.75	20%	2.88%	2.30%	-3.82%	-1.26%

CONCLUSION

This algorithm is an improvement upon the traditional algorithm and features advantages such as smaller errors, better measurement stability, and dynamic selection of the fitting interval. There are two main points of innovation: the first is that we do not set ρ_L directly but rather estimate it through a variable E_r, and the second is choosing a dynamic fitting interval instead of a fixed interval at the tail. This algorithm has a very broad application in data processing such as nuclear fusion devices.

ACKNOWLEDGEMENTS

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