NEW PRECISION JITTER MEASUREMENT SOLUTION ON TMU -- CHALLENGE ON PRBS RECONSTRUCTION

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ABSTRACT

Jitter Measurement is an important part of High Speed test. With customer's test requirement rapidly growing, result only include RJ and DJ is not acceptable. The solution of test specific kinds of jitter (such as DDJ, DCD, ISI…) to verify the IC transform performance is strongly demanded by customers.

So far, the industry of existing jitter measurement method include strobe method and Time-stamp method on TMU. However, the limitations are either complex or just measure several types of jitter.

An industry leading solution of high accuracy jitter measurement by TMU directly sampling with new PRBS pattern reconstruction method is proposed in this paper. All types of jitter can be skillfully tested with the condition of no cost increase.

Keywords—TMU (Time Measurement Unit); Jitter; PRBS reconstruction

INTRODUCTION

Background of Semiconductors and ATE

In recent years, integrated circuits has a rapid development toward complexity, which is immensely promoting the research and innovation of test method. More integrated SOC device, especially SerDes module, more test parameters are concerned. In the semiconductor industry, ATE (Automatic Test Equipment) plays an important role in meeting the complicated parameters test requirements.

ATE system performs various tests on UUT (unit under test). In general, an ATE test system is the result of this merging of test instrumentation (test card, such as digital card, high-speed card) with a computer. And the computer controls the test hardware by executing a set of instructions called the test program [1]. Moreover, ATE calibration reference sources are used by the tester as the "golden" standard for the volt, ohm, ampere, second [2], which guarantee the highest test reliability.

High-Speed Test on ATE

The high-speed test of the industry covers SerDes, high-speed ADC/DAC, protocol test (PCIE/SAS/SATA). In these different test applications, jitter measurement is indispensable. Figure 1 illustrates the ATE test solution with high-speed test card (PSSL). TMU is an excellent resource integrated in the PSSL. It records timestamps the instant that a signal crosses over a specified threshold.

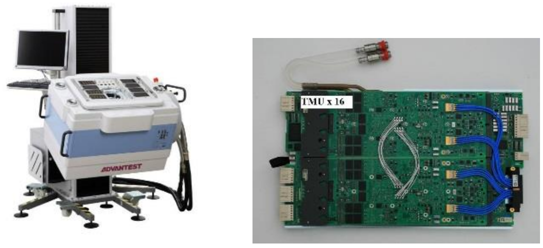

Figure 1: ATE Tester and High-Speed Test Card (PSSL)

TEST CHALLENGE AND SOLUTION

Traditional jitter measurement in industry include strobe test method based on over sampling, time-stamp interpolation test method on TMU and Frequency test method on TMU. However, the limitations of strobe is complex and a long time data process. And for the existing TMU test method, the former is limited by accuracy because of interpolation technology, the latter could not measure ISI/DCD directly. Therefore, all of them could not meet the new test requirement described in abstract very well.

Time-stamp based on TMU

Figure 2 demonstrates the TMU's internal frame from the programming point of view. "RISE_FALL" mode captures rising and falling edges of input signal under test while sweeping threshold, which is applied in this paper to recognize all types of jitter. The Prescaler parameter defines how much the frequency of the signal is to be reduced before it is passed on to the event speed block. Possible Prescaler values (PSSL) are up to 49 under "RISE_FALL" mode. A value of 1 means no prescaling. InitialDiscard parameter is the event to be discarded at the beginning of sampling. Inter SampleDiscard parameter represents the number of events to discard between two samples. After these parameters of TMU are configured, the input signal is captured accurately to acquire time-stamp values of each edge.

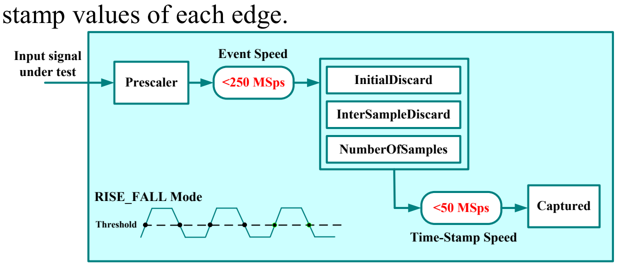

Figure 2: TMU internal frame

Figure 3 illustrates a TMU setting case recording the time-stamp value (T[0], T[1], T[2]). The Pink-marked is rising edge. Green-marked is falling edge. When Prescaler is programmed to 2, that means four edges are omitted after one time-stamp is recorded. It is noteworthy that only rising edges or falling edges are captured when InterSampleDiscard is configured to 1. For this reason, the parameter should be set to an even number.

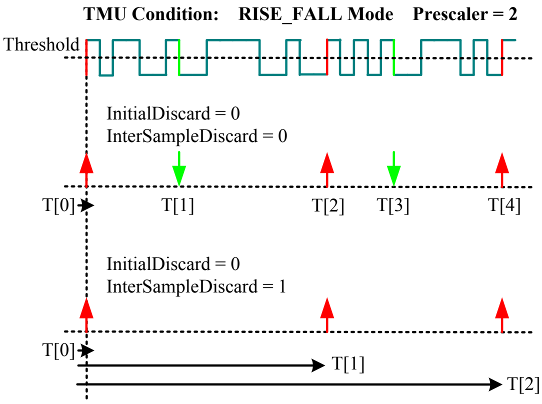

Figure 3: Time-Stamps

PRBS Reconstruction Solution

In order to acquire much more signal characteristic, rising edge position and falling edge position relative to input signal under test should be recognized from the captured time-stamp data. Accordingly, a kind of edge reconstruction solution based on PRBS is provided.

For simplicity, prescaling is ignored and PRBS4 signal is regarded as input signal under test. Two cases are explained here. For case1, InterSampleDiscard is set to 2 and two sampling action are skipped between two capture position of TMU. PRBS4 is consist of 15 bit streams, which is named as segment in this paper. Segment also describes the unique edge position. For PRBS4, there are 8 unique edge position from e1 to e8, including rising and falling edge. As demonstrated in Figure 4, when three PRBS4 segments are continuously captured by TMU, the captured time-stamps should be e1, e4, e7, e2, e5, e8, e3, e6, e1. Obviously, the final edge number is the same as the beginning edge number. Moreover, there are 8 unique patterns (UP) corresponding to 8 unique edge number in this case.

However, time-stamps captured by TMU is just a set of number in real case. And edge number in PRBS segment is not directly known. If the edge number is n and time-stamp value is $T(n)$ as assumed in Figure 4, it can be truly reconstructed by integral multiple of PRBS segment and do not need interpolation technology, as expressed in Eq. (1).

$$n = round\left(\frac{T(n)-(N_{segment}-1)*\mathrm{UI}_{ps}*L_{\mathrm{PRBS}Length}}{\mathrm{UI}_{ps}}\right)+1 \quad (1)$$

Where $N_{segment}$, $L_{\mathrm{PRBS}Length}$ and UI_{ps} represent the PRBS segment number of n, bit stream length of PRBS and the unit interval widely used in jitter measurement respectively.

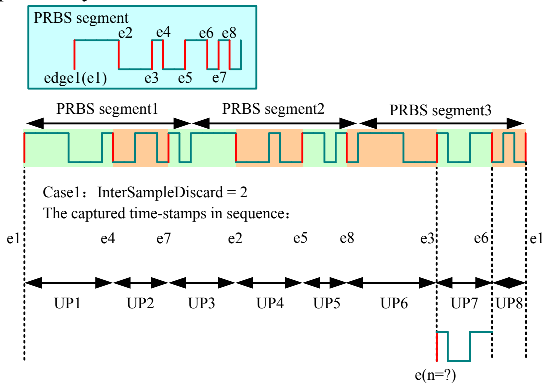

Figure 4: TMU case1 (InterSampleDiscard=2)

So far, the rising and falling position edge in PRBS segment is extracted accurately, which is meaningful to research signal performance with specific bit combination.

Case2 is similar to case1. In Figure 5, it is certain that the unique pattern number is also 8. Generally, for PRBS N, the bit length of PRBS, the number of edge in PRBS segment and the number of unique pattern should be 2^{N}-1, 2^{N-1} and 2^{N-1} respectively.

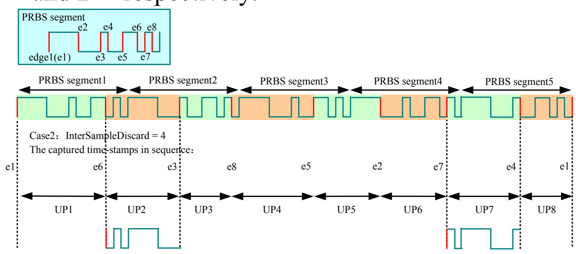

Figure 5: TMU case2 (InterSampleDiscard=4)

Jitter Separation and Computation Solution

In this paper, the measurement is based on TIE (Time Interval Error), which defines the difference between measured arrival time of an edge and expected arrival time for the edge. The expected arrival time of each edge position can be estimated from the above PRBS reconstruction solution. Then TIE of each edge can be obtained as described in Figure 6.

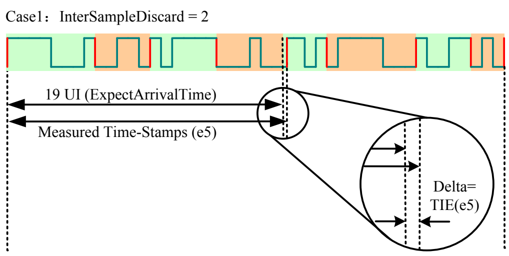

Figure 6: TIE computation

If each edge number is sampled by 128 times, the TIE mean of each edge number can be computed as explained in Figure 7.

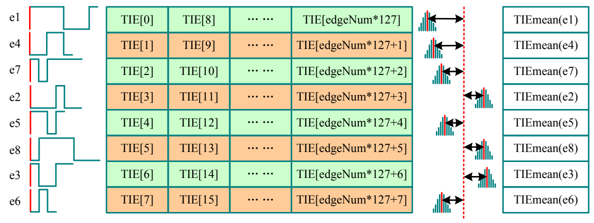

Figure 7: TIE mean of each edge number

Then In time domain, DCD and ISI can be calculated as in Eq. (2) and (3), which are generally represented with peak to peak (pp).

$$DCD = \left| \frac{\sum_{n=1}^{N_{odd}} TIE[2n-1]}{N_{odd}} - \left| \frac{\sum_{n=0}^{N_{even}} TIE[2n]}{N_{even}} \right| \right| \tag{2}$$

$$ISI = \max\left(\max_{1 \le n \le N_{odd}} TIE[2n-1] - \min_{1 \le n \le N_{odd}} TIE[2n-1],\ \max_{0 \le n \le N_{even}} TIE[2n] - \min_{0 \le n \le N_{even}} TIE[2n] \right) \tag{3}$$

Where N_{odd} and N_{even} represent the number of TIE corresponding to falling and rising edge respectively.

In case1, 8 edges are captured during three PRBS4 segments, which is equal to be sampled 8 times at the equivalent sample rate, i.e. 5.625 UI. Then in frequency domain, jitter spectrum of TIE by applying FFT to TIE can be analyzed to get other common types of jitter, i.e. Total Jitter (TJ), Random Jitter (RJ), Periodic Jitter (PJ) and Data Dependent Jitter (DDJ). The square-root of total jitter spectrum power is used to calculate TJ, which usually convert to unit of peak to peak so that the computational result is multiplied by 2.

In Figure 7, TIE means in each row is based on TIE data of the same edge number, which actually is caused by DDJ. In order to recognize the RJ and PJ in jitter spectrum, DDJ need to be removed in TIE data firstly by Eq. (4).

$$TIE_{RJ+PJ}[\mathrm{i}] = \mathrm{TIE}[\mathrm{i}] - \mathrm{TIE}_{mean} \tag{4}$$

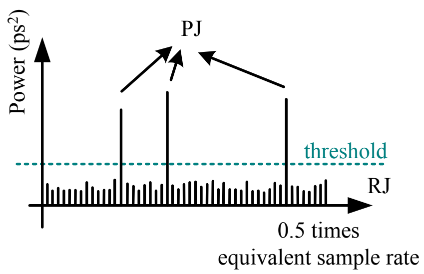

Figure 8: New Jitter Spectrum (DDJ is removed)

TABLE I. MEASUREMENT RESULT

Test Method	Jitter Parameter (ps)					
	ISI	***DCD***	***DDJ***	***RJ***	***PJ***	***TJ***
Strobe	27.1	0.97	27.32	5.9	99.42	104.8
Proposed	26.0	1.02	26.1	6.2	98.9	103.4
Error (%)	4	5.1	4.5	5	0.5	1.3

Then new jitter spectrum based on TIE data of Eq. (4) should only include RJ and PJ, which can be separated by designated threshold as shown in Figure 8. The computation of PJ is similar to TJ. While the RJ is usually represented with rms so that the power of RJ is square-rooted and divided by square-root of 2. Finally, the DDJ power can be acquired from the difference between two jitter spectrums.

The proposed technique is realized on Advantest SOC test platform for hardware validation. Result is based on PSSL external loopback mode and a 2 MHz 100 ps-pp sinusoidal jitter is injected. 4Gbps PRBS7 is applied to input signal under test and 64 unique patterns including 89 PRBS7 segment are sampled 128 times by TMU. Then equivalent sample rate is 375.046875 UI, which means approximately 10.7 Msps for 4Gbps. Table I shows the measurement result. The first row lists strobe result for reference, which is based on over sampling. In last row, the relative measurement error is within 6%, which is acceptable in most project development. Furthermore, less sample is required in proposed method and no need a long time data process.

LIMITATION OF THE TECHNIQUE

Proposed technique in this paper is based on TMU hardware. The signal frequency under test is thus limited to Prescaler parameter and event speed of 250 Msps.

CONCLUSION

This paper introduces a new precision jitter measure solution using TMU intended to get all types of jitter and easy to use in lab and production line. Moreover, due to acceptable measurement error, less samples and no cost increase, this solution can meet the challenge of the industry such as SerDes.

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