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Research on a Method to Increase Waveform Capture Rate

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Abstract: Waveform capture rate is one of the key indices of digital storage oscilloscope (DSO), which indicates mean speed of a system in waveform capture in a unit time. The higher the waveform capture rate, the larger the chance to capture abnormal event. In the article, statistic histogram of waveform is established in the first place with random process theory. On the basis of which, template for waveform detection is derived. Cache architecture is then utilized to store sampling point of the highest hit count in detection template, thus reducing the number of read-write access to external memory when mapping waveform data, lowering down dead time and increasing waveform capture rate. In conjunction with engineering application, materialization and verification have been made upon detection-template-based waveform rapid mapping technology, results of which demonstrate that the proposed technology can increase waveform capture rate effectively and can improve cost effectiveness of the related products.

Key words: Digital storage oscilloscope, waveform capture rate, dead time, histogram.

1. Introduction

At present, main indices for evaluating performance of a DSO are: analog bandwidth, real-time sampling rate, record length and waveform capture rate [1]. The first three types of indices are widely applied in traditional DSO field, while waveform capture rate is a key index for evaluating processing speed of data mapping system of modern DSOs. It represents speed of waveform mapping in a unit time of data mapping module of an oscilloscope. Under a same test environment, the higher the index, the faster and more reliable of the system in capture each instance of waveform, even to the extent of no loss at all. Dead time is other concept in relation to waveform capture rate. It describes the size of time loss occurring between continuous capture of two waveforms by acquisition system. Apparently, the shorter the dead time, the higher the waveform capture rate of an oscilloscope, the larger the probability to capture incidentally occurred abnormal events in signals.

From the perspective of application, high waveform capture rate can increase notably reliability of measuring process, reduce detection time and cost, and can expedite debugging process. Measurement of clock jitter of high-speed serial bus, eye pattern detection, incidental underthrown distortion and glitch as well as other common abnormal signals depends heavily upon waveform capture rate.

At present, scope of waveform capture rate of main-stream DSO products ranges between thousands to millions of waveform per second. For example, TDS3000 series DSO manufactured by Tektronix Corporation of U.S.A has a waveform capture rate of 3,600 wfms/s, the highest waveform capture rate of DPO70000 series digital phosphor oscilloscope is up to 300,000 wfms/s, and the maximum waveform capture rate of WaveMaster 8 Zi-A series DSO produced by LeCroy Corporation is as high as

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1,250,000 wfms/s.

Although methods to achieve high waveform capture rate adopted by various manufacturers differs from each other, the basic idea is to adopt parallel processing architecture in which functions of data acquisition and data mapping are separated, and specialized hardware is used to realize data mapping and to store digital 3-D waveform [2-4]. Memory space required for storage of digital 3-D waveform ranges between a couple of kilobytes to several Megabytes. Waveform is generally stored in off-chip memory. For that reason, access to off-chip memory is required each time a data is mapped. Apparently, access speed of off-chip memory has greatly affected mapping speed of waveform. In order to increase waveform capture rate, high-speed memory becomes a must. But the fact is that the faster the memory, the higher the price. How to strike a balance between performance and price is a question to be solved in the design of oscilloscopes. The article presents a detection-template-based waveform rapid mapping method, in which cache architecture is used to store detection template, thus achieving reduced the number of access to off-chip memory, increased mapping speed and enhanced capacity in capture incidentally-occurred abnormal events. Tests verified that the method can increase effectively waveform capture rate.

2. Construction of Detection Template

For the purpose of constructing waveform detection template, a quantity of N waveform shall be collected as sample. Displayed waveform is shown in Fig. 1.

Corresponding digital 3-D waveform image of the waveform is stored in high-speed off-chip memory, which can be taken as a 2-D matrix. Magnitude of element of the matrix represents number of times of appearance of the data during the process of N times of acquisition [5].

$$\mathbf{A} = \begin{pmatrix} a_{11}, a_{12}, \cdots, a_{1k} \\ a_{21}, a_{22}, \cdots, a_{2k} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ a_{m1}, a_{m2}, \cdots, a_{mk} \end{pmatrix} \quad (1)$$

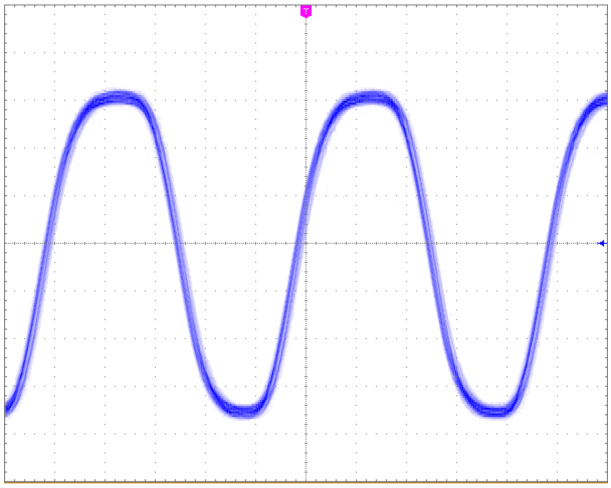

Fig. 1 The digital three-dimensional waveform.

Each column of matrix $\mathbf{A}$ represents distribution status of values of sampling point of the time, and $\sum_{i=1}^{m} a_{ij} = N, 1 \le j \le k$, Thus:

$$\mathbf{P} = \frac{\mathbf{A}}{N} = \begin{pmatrix} p_{11}, p_{12}, \cdots, p_{1k} \\ p_{21}, p_{22}, \cdots, p_{2k} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ p_{m1}, p_{m2}, \cdots, p_{mk} \end{pmatrix} \quad (2)$$

In which, $\sum_{i=1}^{m} p_{ij} = \sum_{i=1}^{m} \frac{a_{ij}}{N} = 1$, and $0 \le p_{ij} \le 1$. As per the law of large numbers, when N is large enough, each column of vectors of matrix $\mathbf{P}$ represents probability of value of sampling point upon $1, 2, \cdots, m$ at the time.

Presume that vector of j column of matrix $\mathbf{A}$ is $\boldsymbol{\beta}_j = (a_{1j}, a_{2j}, \cdots, a_{mj})^T$, and $a_{ij} = 0$, the following definition is made:

$$\overline{a}_{ij} = (a_{i,j-1} + a_{i,j+1} + a_{i-1,j} + a_{i+1,j}) / 4 \quad (3)$$

In particular, when $j-1 \le 0$, $a_{i,j-1} = 0$, when $j+1 > \mathrm{k}$, $a_{i,j+1} = 0$, when $i-1 \le 0$, $a_{i-1,j} = 0$, and when $i+1 > m$, $a_{i+1,j} = 0$.

As for vector $\boldsymbol{\beta}_j$ of column j, point set T_j can be defined as:

$$T_j = \{ i \mid a_{ij} \ge \rho N \,\|\, \overline{a}_{ij} \ge \rho N \} \quad (4)$$

In which, $\rho \geq 0$ is a sensitive parameter set by the user. Thus, it is a random event that sampling point falls into point set T_j. When it falls outside of point set T_j, abnormal event occurs.

On the basis of which, a $m \times 1$ column vector can be constructed:

$$\mathbf{B}_j = (b_1, b_2, \cdots, b_m)^T \tag{5}$$

In which:

$$b_i = \begin{cases} 0, & i \notin T_j \\ 1, & i \in T_j \end{cases}$$

Traversing all the columns of matrix $\mathbf{A}$, k number of $m \times 1$ column vector can be constructed, which can be combined into a $m \times k$ matrix as the follows:

$$\mathbf{B} = \left(\mathbf{B}_1, \mathbf{B}_2, \cdots, \mathbf{B}_k\right) \tag{6}$$

The matrix is the detection template desired, in which elements with value 1 represent the most possible occurrence of value position of pixels in waveform image. If a pixel is mapped to positions in the matrix where value of elements is 0, it represents the occurrence of abnormal event.

3. Utilize Cache to Increase Waveform Capture Rate

For a $m \times k$ matrix, if c bits are used to store its elements, the required memory space is: $m \times k \times 2^c / 8$ byte. Generally, the matrix is stored within external high-speed memory. Therefore, each mapping of a data means access of the external memory has to be done. It goes without saying that frequent access to external memory will reduce dramatically speed of data mapping and waveform capture rate. In order to avoid such circumstance, a cache is required to be added into waveform mapping module. In addition to the above, for most signals, in a short time interval (corresponding to each column of the matrix), mapping addresses of waveform data tend to concentrate in a very small range in the memory space. Taking advantage of locality, a cache can be provided between external memory and waveform mapping module. When hit count of waveform data is stored in cache, waveform mapping module does not have to read data from external memory, instead, it will direct access the cache [6-10].

Fig. 2 shows storage of a $m \times k$ matrix in external memory, in which number of elements in each column is m, and width of each element is c bits. Operation speed of cache is several times of that of external memory, basic structure of which is shown in Fig. 3 hereunder. Each block of the cache corresponds with each column of the matrix. The total blocks of cache are k, and each unit of cache is divided into three parts. The first part is "Flag", indicating whether the unit is valid or not. The second part is "Data", which is the mapped waveform data and accounts for d bits, $m = 2^d$. The third part is "Hit", representing number of hit count to which the waveform data corresponds.

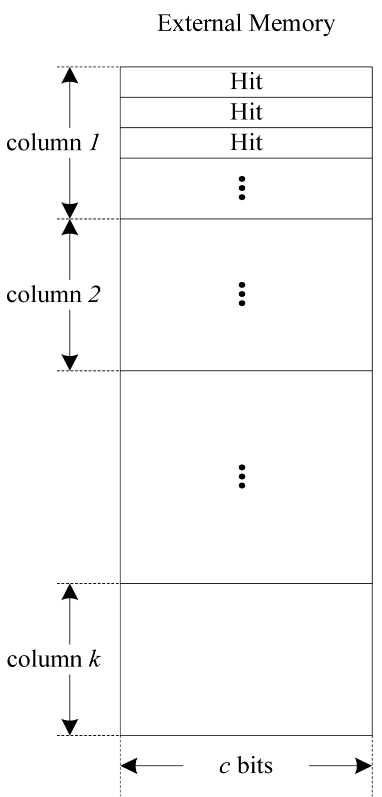

Fig. 2 The diagram of Matrix stored in external memory.

Since the column i of external memory can be mapped only upon the block i of cache, if number of unit contained in each block of cache is presumed to be 2^r, a 2^d number of waveform data are required to be mapped upon 2^r number of cache unit, and $2^r < 2^d = m$. In accordance with the principle of locality, the following definition is made:

$$j = x \bmod 2^r \quad (7)$$

In which j is the address within block of a particular block of cache, and x is the mapped waveform data complying with the condition of $0 \le x \le 2^d - 1$. Under direct mapping mode, corresponding relationship between one column of external memory and one block of cache is that as shown in Fig. 4, in which one column of external memory is divided into 2^{d-r} blocks.

When waveform mapping module is mapping the i th number of waveform data x, in which $1 \le i \le k$, $0 \le x \le 2^d - 1$, by making comparison between x and value of "Data" of unit $x \bmod 2^r$

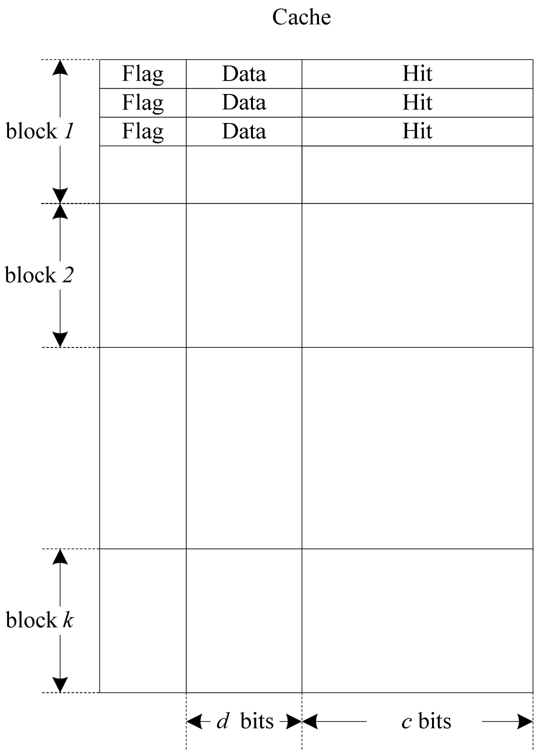

Fig. 3 The Basic structure of cache.

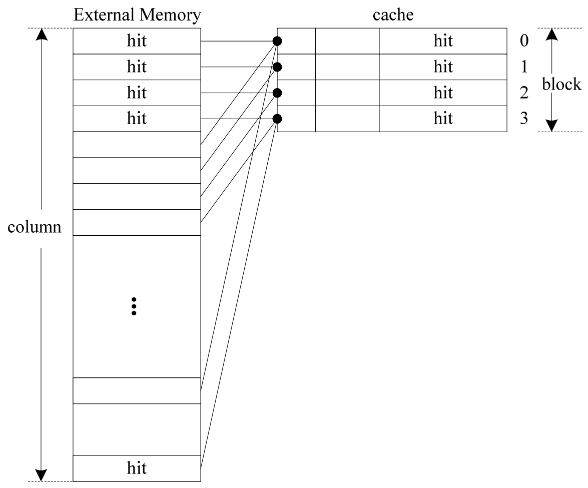

Fig. 4 Direct-mapped cache organization.

of the i th block of cache, the following two circumstances can be achieved as per whether the results of comparison is equal or not: if results of comparison is equal, it indicates that data is within cache, therefore, direct access to cache can be made; if results of comparison is not equal, it means the required "Hit" data has not been transferred to cache. Under the later circumstances, validity in "Flag" shall be judged. If it is found valid, "Hit" value of the current unit of cache shall be written into external memory as per contents of "Data", and then read contents in external memory as per the value of x, as well as update cache unit. If it is found not valid, it represents that the current unit of cache has not been utilized. Thus, value of "Hit" in external memory can be read directly into cache as per value of x.

4. Detection-Template-Based Waveform Rapid Mapping Method

In the first place, sampling of the measured waveform is made in the shortest possible time period. After sufficient quantity of waveform is gathered, the following digital 3-D waveform image as shown in Fig. 1 can be generated. Then, with the possible abnormal value eliminated, and utilizing sensitivity as set by the user, value of each column of sampling point is calculated as per formula (4) to construct a detection template.

In order to take full advantage of cache architecture, initialization shall be made to it: sorting elements in T_j as per size of the corresponding hit count, and mapping to unit 2^r of block j of cache successively in a sequence from the largest to the smallest. According to formula (7), if the corresponding unit of cache has been initialized, the value shall be discarded, and next data shall be mapped until 2^r number of cache units have been initialized or points within range of T_j have been processed completely.

Under normal operational period, for sampling point sequence $x_1, x_2, \cdots, x_k$ collected each time, the corresponding cache address is calculated as per sequence, which will be judged as to whether it falls within cache. If cache is hit, the corresponding value of “Hit” will be added with 1 before the next sampling point is processed. If cache is not hit, value of “Hit” stored in the corresponding storage unit of external memory will be read to update corresponding cache unit, before the next sampling point is processed, until all sampling points are processed. Waveform mapping procedure is shown in Fig. 5.

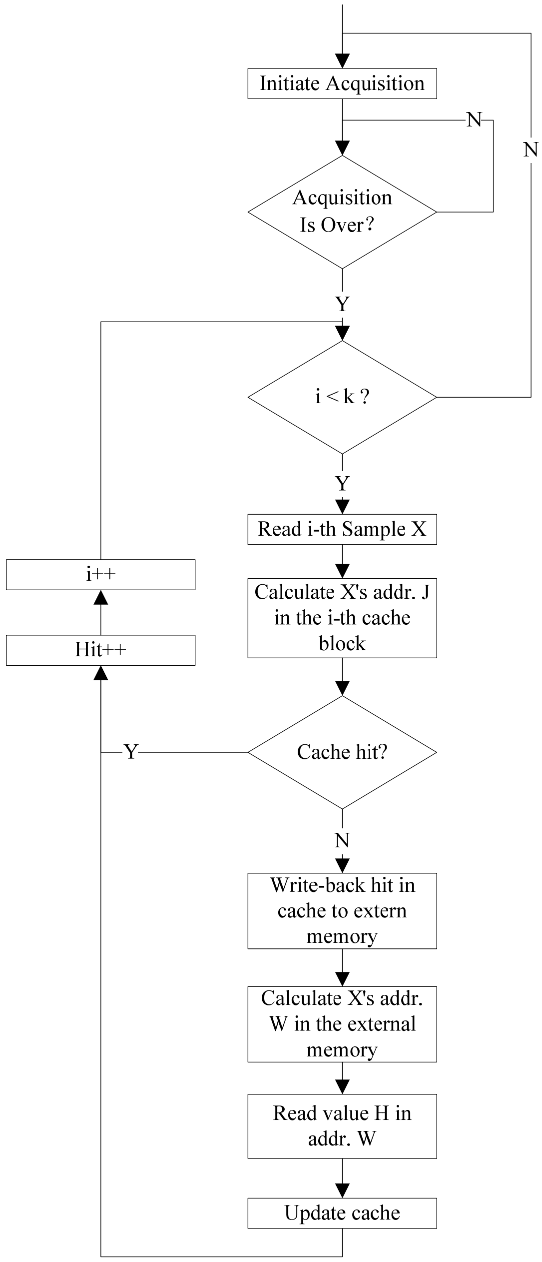

Fig. 5 The working flow chart of waveform mapping.

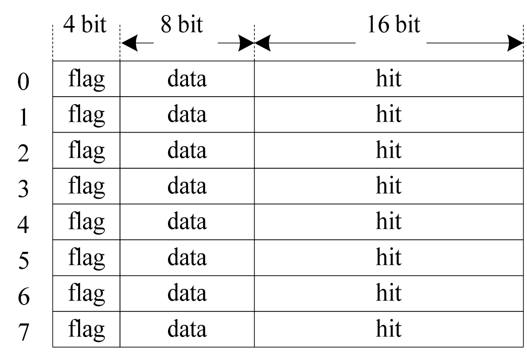

Fig. 6 The block structure of Cache.

5. Experiment and Results

Detection-template-based waveform rapid mapping method as presented in the article is materialized in a DSO with a sampling rate of 2GSPS and a bandwidth of 100 MHz. Resolution of the adopted ADC is 8 bits, and block structure of cache is shown in Fig. 6.

Fig. 7 is a digital 3-D waveform image generated with conventional waveform direct mapping technology, and Fig. 8 is that generated with waveform rapid mapping technology presented in the article.

Under identical testing conditions, tests are carried out with both technologies on a same signal to measure its waveform capture rate. Results of the test are shown in Table 1.

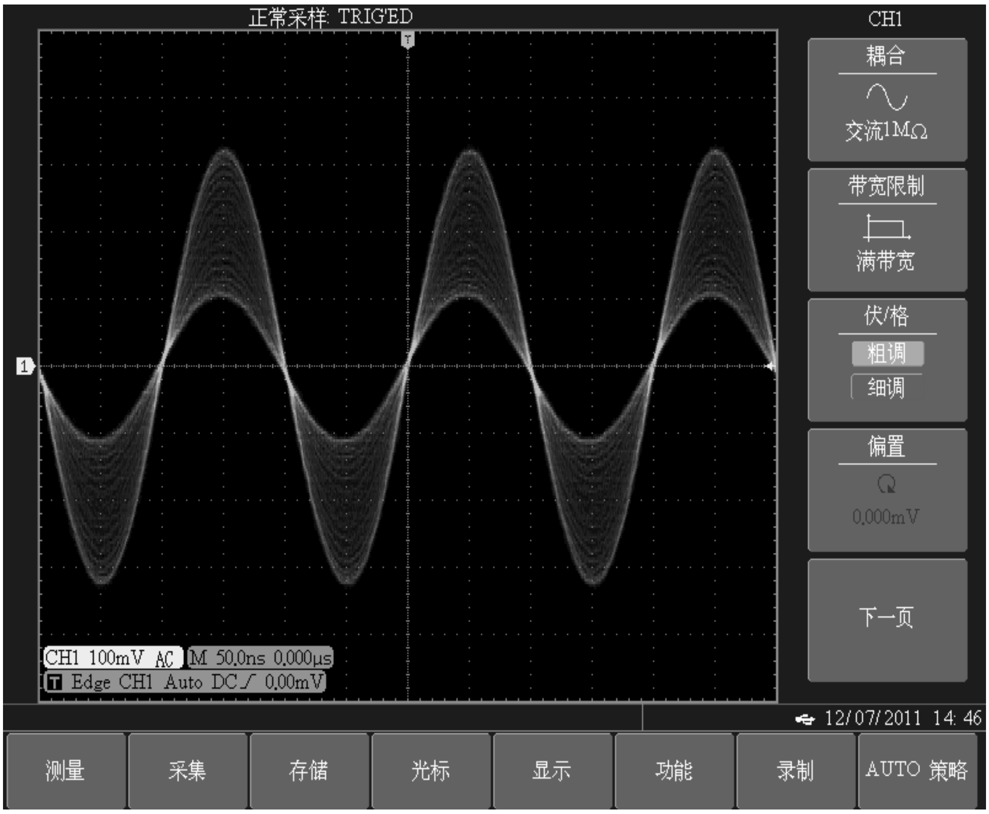

Fig. 7 The 3D waveform based on waveform direct mapping technology.

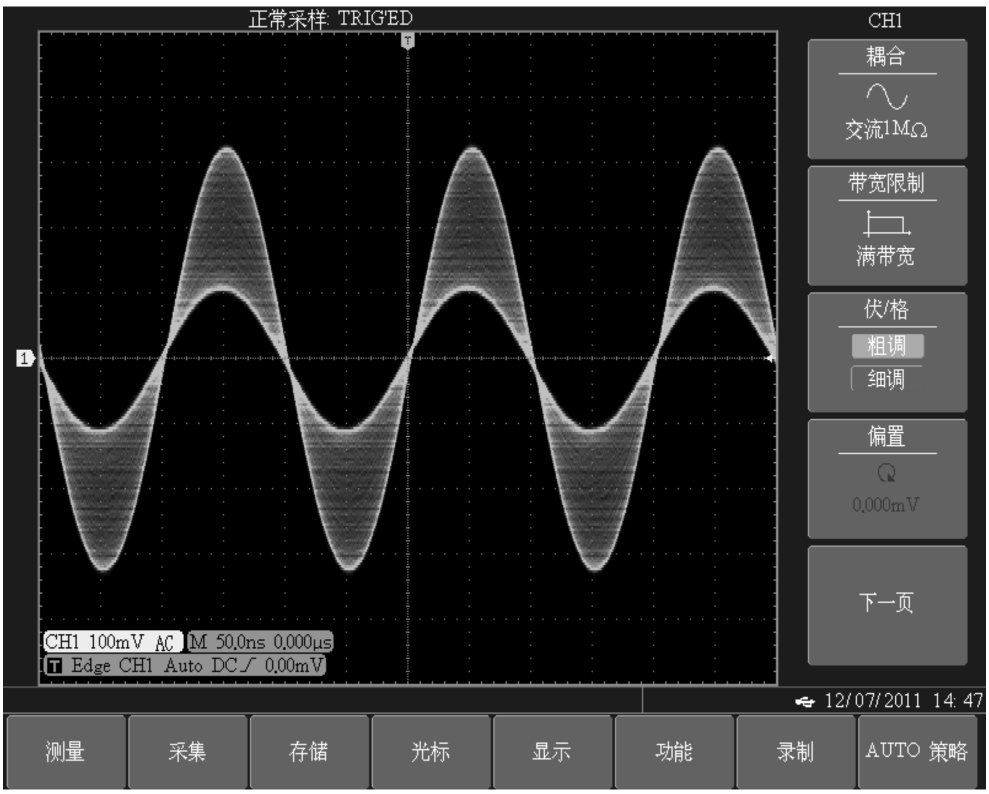

Fig. 8 The 3D waveform based on waveform rapid mapping technology.

Table 1 The testing results of waveform capture rate.

Capture method	Waveform direct mapping technology	Waveform rapid mapping technology
Waveform Capture Rate (wfms/s)	15k	25k

6. Conclusions

The article focuses on detection-template-based waveform rapid mapping technology applied on DSO, and its materialization and verification in FPGA. As compared with general waveform direct mapping process, the proposed technology takes full advantage of sampling points with the highest hit probability in storage detection template of cache, thus reduces effectively read-write access of external memory, increases waveform capture rate and improves cost-performance of products. The tests demonstrate that, under normal circumstances, if detection template is appropriately set, waveform capture rate can be greatly increased along with improvement of hit rate of cache.

References

[1] G.J. Cheng, H.J. Wang, S.L. Tian, Modern testing technology, University of Electronic Science & Technology of China Press, 2002.

[2] C.Q. Zhu, C.J. Feng, DPO and the development of oscilloscope technology, China Instrumentation (2000).

[3] Ye Peng, H, Zeng, J. Jiang, Research on the digital storage oscilloscope with a parallel structure, Chinese Journal of Scientific Instrument 29 (2008) 624-626.

[4] G. Dai, L.N. Wu, X. Wang, Implementation of digital phosphorescence processor in DPO, The 7th International Conference on Electronic Measurement and Instruments, 2005.

[5] H. Zeng, P. Ye, H.J. Wang, C.Y. Xiang, Research on waveform mapping technology of digital three-dimensional oscilloscope, Chinese Journal of Scientific Instrument (2009).

[6] C.Y. Chang, J.P. Sheu, H.C. Chen, Reducing cache conflicts by multi-level cache partitioning and array elements mapping, The Journal of Supercomputing 22 (2009) 197-219.

[7] Li. Hong, Z.G. Mao, The design of PLRU cache in embedded system, Microprocessors (2010).

[8] Y.H. Luo, C.S. Xie, C.F. Zhang, Central cache replacement algorithm for storage system, Journal of Huazhong University of Science and Technology (Nature Science Edition), 2006.

[9] S. Lu, H. Zhu, A discussion about the test method of outliers in statistical data, Journal of Northeast Normal University (1993).

[10] X.H. Tian, D. Guo, M.X. Zhang, Replacement policy for compressed cache based on modified LRU, Computer Engineering (2008).