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A Perfect Calibration Method of Two Points Based on Waveform Average and the Optimal Measuring Region

Gun Li[1], Binxia Du[1], Yong Cao[1] and Feijiang Huang[2,*]

[1]*School of Aeronautics and Astronautics, University of Electronic Science and Technology of China, Chengdu, 611731, China*
[2]*Department of Electronic Information and Electrical Engineering, Changsha University, Changsha, 410022, China*
ccsuhfj@163.com

Abstract

In response to the influence of calibration parameter on measurement accuracy of characteristic impedance tester, the paper comes up with a perfect calibration method of two points based on waveform average and the optimal measuring region. The method is based on calibration method of two points. First, waveform average can reduce random errors in the testing process of characteristic impedance tester. Second, automatically selection for the optimal measuring region can reach a high precision. Last, each tube has a separate calibration parameter, increasing its consistency and Independence, which implement highly calibration for the tester. Making an integrated comparison of testing results among three algorithms, including Tektronix instrument and original method of two-point calibration, validates the accuracy of new algorithm. The method was put into the design of characteristic impedance tester using advanced measurement accuracy.

Keywords: *Characteristic impedance tester, Waveform average, Measuring region, Calibration method*

1. Introduction

With the rapidly development market of PCB industry, characteristic impedance tester which tests PCB has had a wide range of application by making a feedback for characteristic impedance tester varied with PCB traces[1]. Characteristic impedance is instantaneous impedance to reflect the feature of PCB transmission line [2-4]. And it also is key terms to describe all important feature of electricity on interconnection. Manufacturer must inspect characteristic impedance to ensure its quality before PCB leaves the factory. A fast and precise impedance test can inspect whether PCB property meet design norm, which provides useful information for engineers in order to find problem and adjust impedance timely [5]. In actual test, the condition of characteristic impedance tester will vary with its temperature and internal electronic components. Meanwhile the instrument doesn't contain cables and probes, and then any change of components of the instrument need to be calibrated again. In actual test, value of characteristic impedance tester are based on calibration parameter, therefore its precision will impact directly on the instrument's result [6].

Here are several commonly used calibration methods, such as online calibration method, the standard transfer calibration method, storing reference waveform calibration method (two point calibration method) and frequency domain calibration method [7]. Online calibration method means that each time when testing the characteristic impedance, it must be calibrated by using a standard calibration component to get the calibration parameters, and then calculate the characteristic impedance value of the

[*] Corresponding Author: Feijiang Huang, E-mail:ccsuhfj@163.com

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measured object by using the obtained calibration parameters. The method is relatively simple, but the disadvantage is that each time when performing the test of the characteristic impedance, it must use the standard calibration component, it is highly cost and easily damaged when frequent using of standard calibration component, and in the actual use of the characteristic impedance instrument, it is less used. Standard transfer calibration method uses the calibration component with a very high standard level to calibrate the reference air lines which replace the standard calibration component, thereby obtaining the true value of the characteristic impedance and the relevant parameters of a reference air line, but this method is more complex than the other calibration methods, the accuracy is also limited. Frequency domain calibration method first analyzes the error sources and establishes the error model based on the actual situation of time domain reflection (TDR) and time domain transmission (TDT) [8], and then converts the acquired data from time domain into the frequency domain based on the error model and calculates the calibration parameters, the last is dealing the calibration parameters obtained in frequency domain with normalization and filtering and converting the parameters into the time domain. This calibration method has high calibration accuracy, but it is not easy to establish the error model in line with error source of instrument, in addition the calibration method also requires not only hardware portion based on time domain reflection, but also hardware portion based on time domain transmission [9]. Through comparative analysis of the existing calibration method, this paper improves the original two point calibration method to achieve an strengthened two point calibration algorithm based on the average waveform and the best measurement area, which can calibrate the parameters of characteristics impedance instrument with high precision.

2. The Principle of Storing Reference Waveform Calibration

The principle of storing reference waveform calibration is record the tested waveform, relevant data and parameters when using a standard calibration component to calibrate the instrument. During the measurement of the characteristic impedance, compare the waveform and data to be tested with the previous corresponding results recorded when calibrating, and then calculate the size of characteristic impedance values of the measured object. The algorithm calculates the calibration parameters in the actual test of the measured object based on the characteristic impedance value obtained by calibration. If the calibration parameter is not correct, then the test result calculated in accordance with calibration parameters will be a large error with the actual characteristic impedance value of measured object. The independence of channels, selection of measurement region, calculation method of calibration parameter in calibration algorithm all significantly affect the accuracy of the calibration parameters, leading to the error of characteristic impedance in the calculation process. So when we use this calibration method, hardware circuit of instrument must have a high stability. This calibration technique can be subdivided into two point calibration techniques and multi-point calibration techniques, the difference between the two lies in the different number of standard calibration component used in the calibration, two point calibration technique uses only two standard calibration components, typically 50 ohms and 75 ohms, multi-point calibration technique uses three or more calibration standard components, and therefore the calibration accuracy is more accurate.

3. The Average of Waveform and Selection of the Best Measurement Region

3.1. The Average of Waveform

In order to obtain more accurate calibration parameters, before calculate the calibration parameters each time, we should get the N measuring waveform to average processing, then calculate the calibration parameters according to the averaged waveform, calculation formula for the average of waveform is shown in Formula (1) .

$$y[i] = \sum_{j=0}^{N} x_j[i] / N \quad (1)$$

Wherein, $y[i]$ is the average value of the N waveform at the i -th point, $x_j[i]$ is the i -th point on the j waveform.

The value of N of average number for waveform that is not too large nor too small, too large values of N will not only increase the amount of computation also make calibration slower, too small value of N will cause waveform averaging effects ineffective. Determining test results and conditions of the processing time of instrument by setting different values of N on instrument, using the same calibration component of 75 ohm when testing, uploaded data of hardware does not pass through other types of filtering processing and using the same measurement area and same measurement channels, The processing time of instrument can use QueryPerformanceCounter () function which can achieve the accuracy of microsecond level to obtain the time of the calibration command issued by the test and the calculation time of results, The difference between these two times is the measurement time. By setting the different average number, conducting analysis and comparison, to find a more appropriate average number of waveform. In an example of a single-ended test, the result is shown in Table 1, it can be seen from the table, the larger the average number of waveform, the longer the time of the test results calculated by instrument ; with the greater of average number of the waveform, the difference between the results of the characteristic impedance instrument and the actual value of the characteristic impedance for the measured object firstly becomes smaller and smaller, then substantially tends to 0.17 and 0.18, it can be concluded, When the value of N is 20 you can get more accurate test results and data processing time increased only about 1 millisecond, it also will not have much effect on the test speed of characteristic impedance instrument.

Table 1. Test Value and Processing Time of Data with Different Values of N

Average number for waveform	The difference between the test value and actual value	Processing time (ms)
1	0.27	180.367
5	0.24	180.591
10	0.21	180.846
15	0.19	181.109
20	0.18	181.715
25	0.18	182.018
30	0.17	182.543
35	0.18	182.962
40	0.17	183.124

When calibrating by the original two point calibration algorithm, we calculate calibration parameters based only on one measured waveform, and strengthened two point calibration algorithm needs to obtain the N test waveforms, then we need to add a calibration parameters Count represents the number of test waveforms to get in the communication protocol of the calibration, the user can set average number of waveforms by entering the Count's value during calibration, then get the N waveforms to be tested by issued the calibration command, and finally through the upper layer software performing average processing for all waveforms obtained.

3.2. Automatically Selection of the Optimum Measurement Area

The calibration method used in the characteristic impedance instrument is two point calibration method, the characteristic impedance value of the measured object is calculated based on calibration parameters obtained by the calibration, calibration parameters are obtained by calibration component that be used as an international or national standards through characteristic impedance test and closely related to instruments, the accuracy of calibration parameters largely affect the accuracy of the instrument test results. Characteristic impedance instrument in the actual testing process due to the influence of various factors, will lead to the existence of pre-impulse , slope foot, overshoot, ringing and other cases, to obtain accurate calibration and measurement results, we need to find a period of stable region after the arrival of the incident wave and before the arrival of a new reflection wave in tested waveform, So as to maximize avoid the influence of pre-impulse, slope foot, overshoot, ringing and other conditions, making the true value of calibration component closer to the characteristic impedance value in instrument testing, to obtain a more accurate calibration parameters. Optimal measurement area is difficult to achieve through manual input, so this paper through automatic selection algorithm to achieve optimum measurement area. Specific steps are as follows:

(1) According to the waveform of the actual test to find signal range of measured object (including calibration component and PCB board), source resistance of the characteristic impedance instrument is 50 ohms, when the measured object is 50 ohms, the entire test waveforms only have a rising edge; when the measured object is greater than 50 ohms, the entire test waveforms includes two rising edges; when the measured object is less than 50 ohms, the entire test waveform includes a rising edge and a falling edge. In this paper, using measured object greater than 50 ohms as example, shows as Figure 1, to determine the waveform range of measured object, we first to find the position of the 10% of amplitude in reflected rising edge and the 90% amplitude in of incidence rising edge, that determining the location of point A in the incidence rising edge and the location of point B in the reflected rising edge.

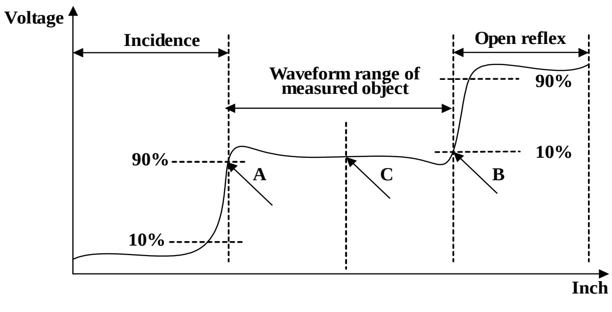

Figure 1. The Waveform Range of Measured Object

To determine the location of point A and point B, firstly we should separate the incident step from reflecting step, that is determine the point C in the intermediate position of the entire test waveform, in order to avoid the two steps treated as one step to calculate. Determine point A, B and C are all using amplitude histogram method, the waveform be divided according to a certain interval of space, and then use the statistical approach to identify the overhead of the waveform, the position of bottom or the intermediate of the waveform corresponding to the first several point throughout the test waveform. Which, space should select an appropriate value, the too larger value will increase the amount of calculation, if the value is too small, the calculated results will imprecise, the lower limit of space is determined by the resolution of the magnitude in the sampling system, that is, determined by the resolution of A / D, usually chosen an integer multiple of the resolution as space value [10]. Due to the resolution of characteristic impedance instrument A / D is 5mV, so the space value is 10mV.

Due to determining the position of A, B and C of the three point need to firstly find the amplitude of the top and bottom and the index corresponding to the top and bottom of the waveforms to be processed throughout the test waveform , such as to determine the index value at point C, we should find the index corresponding to the top and bottom values throughout the test waveform, then sum the two index value obtained and divided by 2, namely index value at point C; If you want to determine the index value at point A, it is necessary to process the first step of tested waveform, first, find the magnitude of value corresponding to the top and bottom values in the first step, and then find the amplitude values at 90% (A point) amplitude in first step of the signal, and finally determining the index value of A point by the obtained magnitude; if you want to determine the index value of point B, it is necessary process the second step of tested waveform, first, find the magnitude of value corresponding to the top and bottom values in the second step, and then find the amplitude values at 10% (B point) amplitude in second step of the signal, and finally determining the index value of B point by the obtained magnitude.

(2) To find the optimum measurement region from 25% to 85% of the testWave area with waveform range of the measured object, assuming at 25% the index of left margin in the entire test waveforms is testLIndex at 85% the right boundary uses testRIndex to represented index throughout the test waveform. Determining the optimum measurement region by fixing one of the boundary, according to certain steps gradually adjust another boundary to obtain a new measurement area and the characteristic impedance value is calculated by using the area, Among them, the step size of excessively small will increase the amount of computation, impact computing speed, step length of excessively larger will lead the final result inaccurate, due to the length of measured object in the actual test is about 30cm, so this paper selected step size is 2 % of testWave .

(3) For the result array, the results of each region minus characteristic impedance value of the actual measured object to obtain the array DeResult, due to the test results of current instrument is small, so choosing area with the minimum absolute deviation, if absolute value of two or more deviations are the same, then selecting measurement region corresponding to negative deviations. Since one-dimensional index and two-dimensional index of the array respectively denote the corresponding index of the right boundary and the left edge of the measurement area throughout the test waveform, So to get the best measurement region also need to use the function GetLengthFromPoint() converts the index value of the corresponding right border and left border to the value in units of length, where the unit of the length is a unit of the user's current settings, default to inches.

4. Strengthened Two Point Calibration Algorithm based on the Average Waveform and the Optimum Measurement Region

4.1. The Principle of the Algorithm

Through inadequate analysis of the existing storing reference waveform calibration method (two point calibration method), the paper improved the original algorithm in the following three aspects:

Via the way of automatically selection of the optimum measurement area to improve the accuracy of calibration parameters. In order to obtain a more accurate calibration parameters and reduce the influence of the rise time Tr of pulse source and non-perfect waveform, it is necessary to determine the optimum measurement area for different values of characteristic impedance based on actual tested waveform , in this paper through design and realize the search algorithm of automatically selection of the optimum measurement area, the instrument can automatically find the optimum measurement area according to the actual tested waveform when calibrating, to obtain a more accurate calibration parameters.

Using the average waveform to reduce the random error in the testing process of characteristic impedance. The original two point calibration algorithm directly calculates the calibration parameters based on one measurement of waveform. Since improper operation or transient electromagnetic interference in the process of single measurement can cause the generation of deviation for the calibration parameters, it is very necessary to reduce the random errors in calibration process by the averaged waveform, calculating calibration parameters according to the averaged waveform.

Improving the independence and consistency between channels through configure independent calibration parameters for each channel. The two channels of the original software only have one set of calibration parameters, when calibrating any channel it will result in the calibration parameters of the other channel changed, because of the actual conditions it is impossible exactly the same for both channels, Both using the same calibration parameters during the test may lead to the test results of one channel more accurate than the test results of another channel, in order to solve this problem, by providing calibration parameters for each channel, achieved independent calibration between the channels and improved consistency of test results between the different channels.

4.2. Steps of the Algorithm

Since the two channels of the original calibration algorithm using the same calibration parameters, in order to enhance the independence between the channels, improve the consistency of test between different channels, we need to increase independent calibration parameters for each channel, so that each channel have 20 independent calibration parameters, wherein the meaning and name of the calibration parameters of one channel shown in Table 2. In differential calibration, every differential channel (composed by two single-ended channels) also need to have independent calibration parameters, wherein names and meanings of calibration parameters of the differential 1 & 2 channel, as shown in Table 3. After increasing the calibration parameters, each channel is required independently calibrate and calculate the calibration parameters in accordance with the actual situation of the tested waveform.

Table 2. Calibration Parameters for Each Channel During Single-ended Calibration

Sequence number	The name of parameters	The meaning of the parameters
1	Zstd75	The typical impedance value of 75Ω standard component
2	Vio75	75Ω incident voltage
3	VStd75	75Ω calibration component voltage (mV)
4	VOpen75	75Ω open circuit voltage (mV)
5	t1Ref75	The starting point of 75Ω standard component
6	t2Ref75	The ending point of 75Ω standard component
7	rtRef75	The waveform interval length of 75Ω standard component
8	tiRef75	The measurement interval starting point of 75Ω standard component
9	tfRef75	The measurement interval ending point of 75Ω standard component

10	t1TL75	75Ω probe terminal
11	Zstd50	The typical impedance value of 50Ω standard component
12	Vio50	50Ω incident voltage
13	VStd50	50Ω calibration component voltage (mV)
14	VOpen50	50Ω open circuit voltage (mV)
15	t1Ref50	The starting point of 50Ω standard component
16	t2Ref50	The ending point of 50Ω standard component
17	rtRef50	The waveform interval length of 50Ω standard component
18	tiRef50	The measurement interval starting point of 50Ω standard component
19	tfRef50	The measurement interval ending point of 50Ω standard component
20	t1TL50	50Ω probe terminal

Table 3. Calibration Parameters during Differential Calibration

The name of parameters	The meaning of the parameters
a0	The compensation parameters of channel 1
b0	The compensation parameters of channel 2
Vstd25	The differential calibration voltage

4.2.1. Steps of Single-ended Calibration

(1) Determining the starting point of the air line, in the case of the calibration member is not connected, the time of $t_{1,Ref}$ that the test signal used reaching the cable end, $t_{1,Ref}$ is half of the time that signal used from transmitted to reflected back . In the case of the signal rate is known, the length of the cable can be calculated based on the value of $t_{1,Ref}$, as shown in Figure 2.

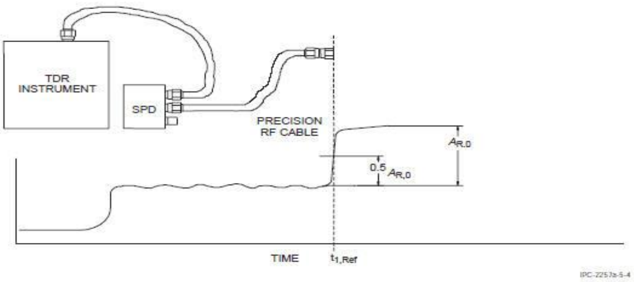

Figure 2. Determine the Starting Point of the Air Line

(2) In the end of the cable connecting calibration component for calibration, divided into the following steps:

1) Connect the 75 (or 50 ohm) ohm calibration component, and then measuring the $t_{2,Ref}$ as the termination point of calibration component, the position of the end of calibration component can be obtained by $t_{2,Ref}$, shown in Figure 3.

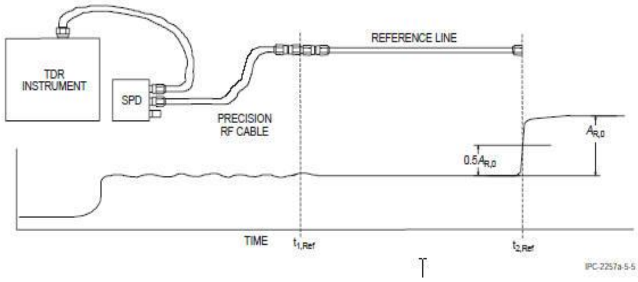

Figure 3. Determine the End of the Air Line

2) Determining the length of the measurement area for the reference line, using the formula as Formula (2).

$$T_{rt,\mathrm{Ref}} = t_{2,\mathrm{Ref}} - t_{1,\mathrm{Ref}} \quad (2)$$

3) Determine the starting time of $t_{i,\mathrm{Ref}}$ calculating the characteristic impedance region, assuming that $T_{rt,\mathrm{Ref}}$ represents the stability region that reflected waveform tends to stabilize and the new reflected wave is not arrival caused by the calibration component, since the transition between the incident and reflected signals takes some time, so in the choice of the region calculating the characteristic impedance, we should choose a certain period of stable region in $T_{rt,\mathrm{Ref}}$. Generally expressed as a percentage of the interval $T_{rt,\mathrm{Ref}}$, IPC-TM-650 also recommend to select the intermediate region of $T_{rt,\mathrm{Ref}}$, after repeated testing and comparison, we selected this region about 30% to 70% of $T_{rt,\mathrm{Ref}}$, $t_{i,\mathrm{Ref}}$ is calculated as (3), wherein $x_{i\%}$ is the starting point about 30% of the measurement area.

$$t_{i,\mathrm{Ref}} = t_{1,\mathrm{Ref}} + x_{i\%} T_{rt,\mathrm{Ref}} \quad (3)$$

4) Determining end time of $t_{f,\mathrm{Ref}}$ calculating characteristic impedance area, $t_{f,\mathrm{Ref}}$ is calculated as formula (4), in which $x_{f\%}$ is 70% of the calibration area of $T_{rt,\mathrm{Ref}}$.

$$t_{f,\mathrm{Ref}} = t_{1,\mathrm{Ref}} + x_{f\%} T_{rt,\mathrm{Ref}} \quad (4)$$

5) Calculated the values of $V_{i,o}$, V_{std} and V_{open}, shown in Figure 4, in Figure $V_{i,o}$ shows the reflected voltage value, $V_{tran,o}$ is the required parameters of the V_{std}, V_{std} represents the measured voltage of the interval $t_{i,\mathrm{Ref}}$ and $t_{f,\mathrm{Ref}}$ when connecting calibration component; V_{open} is the open-circuit voltage, according to equation (5) reflected voltage of $V_{i,o}$ can be obtained.

$$V_{i,o} = V_{open} - V_{std} \quad (5)$$

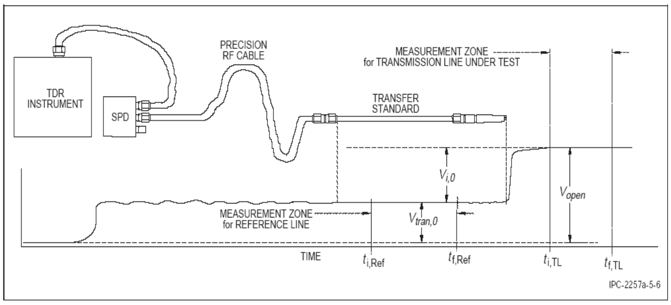

Figure 4. Determine the Three Voltage of Reflection, Calibration and Open Circuit

(3) Calibrating the end of probe. This is the final step in the calibration, since the actual measurement process needs to complete the connection between the cable and the analysis through the probe, so before measurement, the probe must be calibrated to remove the effects of the probe in the signal transmission process, As shown in Figure 5, testing the time point at 50% of the rising edge of the waveform of open circuit, this value is t_{1TL}, Here 20 parameters of calibration are all available, in the official measurement calibration component are removed, connect the probe and connect the measured object

(DUT), based on the collected reflected voltage $V_{C,X}$ of the DUT and (6) characteristic impedance value of Z_{DUT} for the DUT can be obtained .

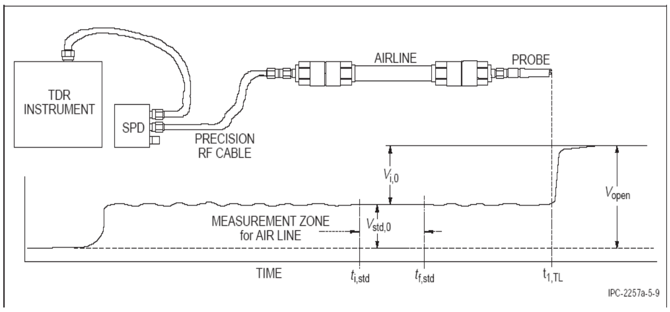

Figure 5. Calibrating the Probe

$$Z_{DUT} = Z_0 \frac{1+\rho}{1-\rho} = Z_0 \frac{1+\frac{V_{r,0}}{V_{i,0}}}{1-\frac{V_{r,0}}{V_{i,0}}} = Z_0 \frac{V_{i,0} + (V_{C,x} - V_{std,0})}{V_{i,0} - (V_{C,x} - V_{std,0})} = Z_0 \frac{(V_{open} - V_{std,0}) + (V_{C,x} - V_{std,0})}{(V_{open} - V_{std,0}) - (V_{C,x} - V_{std,0})} \quad (6)$$

Wherein, Z_0 is the source resistance of instrument, $V_{r,0}$ is the reflected voltage connected to the DUT, $V_{i,0}$ is the incident voltage, $V_{std,0}$ and V_{open} are respectively calibration voltage and open circuit voltage obtained through the averaged waveform.

4.2.2. Differential Calibration Steps

Differential impedance is the characteristic impedance value between the two channels, differential calibration based on single-ended calibration, firstly perform a single-end calibration on channel 1 and channel 2, then channels 1 and 2 were simultaneously connected to the calibration kit to conducting calibration, and finally performing the calibration of the probe, judgment the calibration results shows as formula (7) below.

$$V_{diff} = \left| \frac{V_{check,n} - V_{check,n+1}}{V_{i,0}} \right| \quad (7)$$

Wherein, $V_{check,n}$ represents the voltage value of the n-th calibration, $V_{check,n+1}$ represents the voltage value of the n + 1-th calibration, $V_{i,0}$ represents the incident voltage, V_{diff} represents the ratio of the difference between two consecutive calibration voltage to the incident voltage. If $V_{diff} > 0.002$, you need to re-calibrate, through several calibration relatively accurate calibration parameters can be obtained.

5. The Result Analysis of Measurement

Respectively, using the strengthened two point calibration algorithm and the original two point calibration algorithm conduct strict calibration for characteristic impedance instrument, and then for measured objects of 15 different sets of characteristic impedance values with single-ended 28Ω , 40Ω , 50Ω , 60Ω , 75Ω , 80Ω , 90Ω , 100Ω and differential DIF 56Ω , DIF 80Ω , DIF 100Ω , DIF 120Ω , DIF 140Ω , DIF 150Ω , DIF 200Ω , using four channels1, 2, 3 and 4 to conduct a lot of testing, each test group of measured object are used the same configuration, for example, the tolerance range, the number of tests, etc, using the average of each set of test results as the final result.

Because calibration method of Tektronix instrument is two point calibration method, so the test results of the two calibration methods are compared with test results of Tektronix , as shown in Tables 4 and 5, it can be seen from the table, test results of characteristic impedance using strengthened two point calibration algorithm are closer with test results of Tektronix (absolute deviation with Tektronix is smaller), while the standard deviation of test results for strengthened two point calibration algorithm is smaller than the standard deviation of the original two point calibration algorithm.

Table 4. Comparison of Single-ended Test Results between Strengthened Two Point Calibration Algorithm and Original Two Point Calibration Algorithm

Test object	Tek test results		he original two point test results			The strengthened two point test results		
The measured impedance (Ω)	Average value (Ω)	Standard deviation	Average value (Ω)	Standard deviation	The absolute deviation with Tek	Average value (Ω)	Standard deviation	The absolute deviation with Tek
28	28.78	0.23	29.53	0.51	0.75	28.84	0.30	0.06
40	39.76	0.09	40.35	0.43	0.59	39.77	0.21	0.01
50	49.98	0.07	49.80	0.12	0.18	49.94	0.10	0.04
60	59.78	0.15	59.39	0.31	0.39	59.61	0.18	0.17
75	74.85	0.08	74.57	0.26	0.28	74.83	0.16	0.02
80	79.46	0.12	79.15	0.85	0.31	79.37	0.24	0.09
90	89.13	0.18	88.72	1.47	0.41	88.94	0.51	0.19
100	98.65	0.46	98.23	1.39	0.42	98.42	0.63	0.23

Table 5. Comparison of Differential Test Results between Strengthened Two Point Calibration Algorithm and Original Two Point Calibration Algorithm

Test object	Tek test results		The original two point test results			The strengthened two point test results		
The measured impadence (Ω)	Average value (Ω)	Standard deviation	Average value (Ω)	Standard deviation	The absolute deviation with Tek	Average value (Ω)	Standard deviation	The absolute deviation with Tek
DIF 56	58.29	0.19	58.78	0.73	0.49	58.34	0.41	0.05
DIF 80	78.61	0.13	77.85	0.63	0.76	78.29	0.27	0.32
DIF 100	97.51	0.09	96.95	0.34	0.56	97.12	0.15	0.39
DIF 120	116.84	0.20	115.82	0.93	1.02	116.22	0.29	0.62
DIF 140	135.32	0.19	132.85	1.27	2.47	134.84	0.56	0.48
DIF 150	143.54	0.14	140.46	0.69	3.08	143.19	0.32	0.35
DIF 200	191.82	0.42	189.03	2.01	2.79	191.28	0.64	0.54

6. Conclusions

According to the practical test, the characteristic impedance value is the result which is calculated by the standard of calibration parameters of characteristic impedance instrument, the accuracy of the calibration parameters will directly affect the measurement accuracy of the instrument, studied parameter calibration method of characteristic impedance instrument, we proposed an strengthened two point calibration algorithm based on the average waveform and the optimum measurement region. In single-ended test cases and differential test cases, we respectively compared with the test results of strengthened two point algorithms and original two point algorithms with calibration results of Tektronix instrument, the results show that using strengthened two point calibration algorithm to conduct the calibration of instrument can not only improve accuracy of characteristic impedance measurement, but also strengthen the consistency among the channels. The results of these studies can be used to design the instrument of characteristic impedance with greater stability and help to improve the instrument's measurement accuracy.

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References

[1] H. Zhou, “Design of the Characteristic Impedance Tester Data Processing Module Based On Omap-L138”, Master Dissertation, University of Electronic Science and Technology of China, **(2013)**.
[2] J. Li, “The Research on Test Method of Characteristic Impedance in PCB”, Electronic Science and Technology, vol. 11, **(2013)**.
[3] W. Tang and H. Huang, “Design of precise characteristic impedance for high-speed pcb”, Digital Communication, vol. 4, **(2014)**.
[4] H. Liu, “Controlling of Characteristic Impedance of Signal Transmission on PCB”, Safety & EMC, vol. 1, **(2011)**.
[5] G. Qin, N. Wu and X. Li, “The Test Technique of Characteristic Impedance in PCB”, Printed Circuit Information, vol. 11, **(2004)**.
[6] Y. J. Lei, “Research on the Key Technology of Characteristic Impedance Measurement and Calibration based on Time Domain Reflectometry”, Master Dissertation, University of Electronic Science and Technology of China, **(2010)**.
[7] IPC, IPC-2141 Controlled Impedance Circuit Boards and High Speed Logic Design, **(1996)**.
[8] Y. J. Lei, K. Qin, Y. Cao, Q. Liang and L. Mei, “Measurement of Characteristic Impedance Based on Time Domain Reflectometry”, Electronic Measurement Technology, vol. 4, no. 32, **(2009)**.
[9] W. S. Su and S. M. Riad, “Calibration of Time Domain Network Analyzers”, Instrumentation and Measurement, IEEE Trans., vol. 2, no. 42, **(1993)**.
[10] Y. Li, S. Zhou and A. Qi, “New Method for Accurate Measurement of Clock Jitter Based on Equivalent-time Sampling System Engineering and Electronics, vol. 4, no. 28, **(2006)**.