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THE I-V CHARACTERISTIC COMPARISON METHOD IN ELECTRONIC COMPONENT DIAGNOSTICS

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Abstract: I-V characteristics of individual electronic components or electronic circuits have been playing a very important role in diagnostics for many years. The latest technological advance has extended the analytical potential of that method even more. This paper presents some examples how the I-V characteristic comparison can reveal the differences between the chosen approved model component and some other alternative components manufactured by different producers. The differences might be caused also with a treatment history like thermal or electrostatic discharge exposition.

Keywords: I-V characteristic, scan profile, pin print, comparison criteria, model component.

1. INTRODUCTION

The electronic component I-V characteristic expresses a relationship between the current flowing via a chosen couple of pins, and the voltage applied on those pins. The applied voltage varies between two limits during the I-V characteristic recording process. The applied voltage variation follows a certain time function – waveform $V_W(t)$, usually sinus, triangle, or ramp. The expression (1) represents a general relation between the current I flowing through two pins of a component and an applied voltage waveform V_W swept in set limits, for instance ±10 Volts peak-to-peak.

$$I = f\left(V_W\right) \tag{1}$$

The slightly modified Shockley diode dc model illustrates the basic simplified relation for the p-n junction with parameters influencing the I-V characteristic course. Those parameters are much more complex in a real component structure. As an example, the expression (2) represents a static relation between the current and the applied voltage for a diode p-n junction model, and expression (3) is its dynamic modification, where i_D is a time dependent current through the junction, V_D is the applied time dependent voltage, q is the carrier charge, n is the electron density, k is the Boltzman´s constant, T is the junction temperature in absolute scale, and I_0 is a temperature-dependent device parameter reflecting various semiconductor material properties and junction design [1].

$$I = I_0\left(e^{\frac{qV}{nkT}} - 1\right) \tag{2}$$

$$i_D\left(t\right) = I_0\left(e^{\frac{qV_D(t)}{nkT}} - 1\right) \tag{3}$$

Besides the voltage waveform choice and its voltage range, we can influence the final I-V characteristic course also with the sweep frequency and voltage source resistance settings. Those settings are component type and its production technology specific. We will call those parameters and waveform settings complex a scan profile.

Components with two pins, like resistors, capacitors, inductors and diodes, have just one I-V characteristic for certain scanning conditions. Components with more than two pins have a set of I-V characteristics, and there is necessary to find out the best way how to combine pins in pairs for I-V characteristic recording. One possibility is to use the single combining mode where the component ground pin serves as a reference pin for each other pin pairing providing such pin exists in that particular pin out case. In general, we can combine any two pins in a pair if they create a measurable current loop. The other possibility is to use the overall combining mode (sometimes called the matrix mode) where each pin is successively paired with all other pins. I-V characteristic set recorded or saved under defined conditions represents a signature of component current sate and it is called pin print.

I-V characteristic set of an individual component type can naturally differ according to the production technology, according to the particular manufacturer, or according to the measurement conditions itself. Those so called natural differences can be registered by the study of statistically significant model component population with known origin and history, and they could be subsumed in the comparison master pin print. That comparison master pin print is subsequently used as a criterion for discovering differences caused by component improper treatment, failure or even by the component unauthentic manufacturing process. I-V characteristics comparison method has been used since many years ago, and it is called ASA – Analogue Signature Analysis. Nevertheless, the recent component input quality testing requirements call for that method revival.

2. EXPERIMENT EQUIPMENT

Our analytical laboratory is equipped with a 256 channels curve tracer. That equipment has three scanning modes related to the way of pins pairing. The first mode called manual mode uses the reference pin allocated by the operator (the ground pin is recommended as a default reference) for creating pairs with all other pins. The second mode uses all possible pin pairing (matrix mode) among the component pins. The third mode is automatic. Automatic mode checks first all pin combinations for the current flow level, and it excludes combinations with zero or very small current then. The third mode is similar to the first one, only the reference pins are selected automatically.

The voltage range is adjustable anywhere between the limits ±10 Volts. The voltage waveform can be selected among sinus, triangle and ramp. The source resistance values of 1 kOhm, 10 kOhm and 100 kOhm are available. The frequency of the test signal used for the scan profile can be set from 100 Hz to 5 kHz in a 1-2-5 sequence. The comparison criteria can be set for I-V characteristic tolerance range and for pins and component evaluation. The tolerance range for I-V characteristics comparison can be set individually for horizontal and vertical axis from 0.1% up to 5% in 0.1% steps [2].

3. EXPERIMENT RESULTS

We have tested all modes with various electronic component samples. Nevertheless, we have concentrated on the automatic mode recently because it could be approached as the easiest mode for users with little previous experience in praxis, and they can start to build the component I-V characteristics database almost from zero.

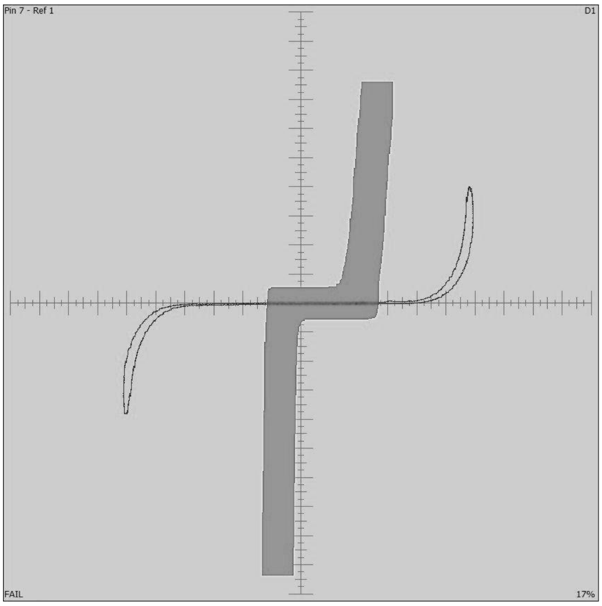

Fig. 1 Analysed component pin #7 I-V characteristic with model component pin #7 tolerance range of 5%.

Fig. 1 and Fig. 2 are illustrating an integrated microcontroller component I-V characteristics comparison analysis results. The comparison analysis was realized in the automatic mode with 5% default tolerance range. We had an approved model component and some equivalent samples for our analysis. The equivalent samples were assembled in an electronic module which was failing repeatedly at the in-circuit test stage in production. The test operator assumption that pin #9 is not connected has been confirmed (see Fig. 2). Even the other pins I-V characteristics were radically different (see Fig. 1). We had also opportunity to compare our pin print results with micro-focus x-ray CT analysis.

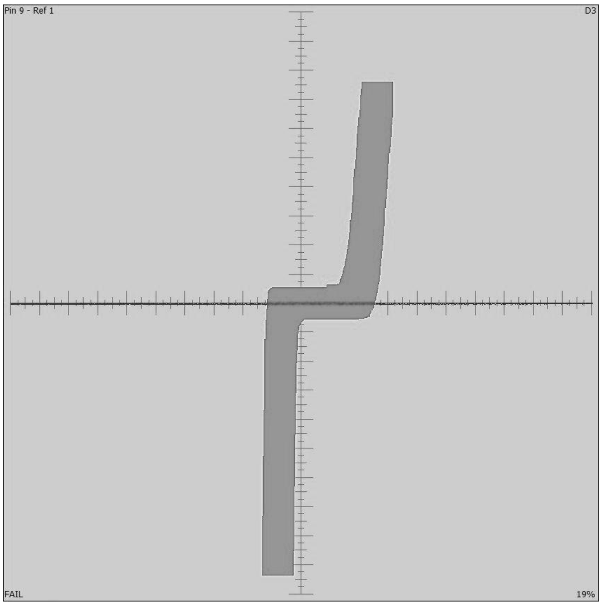

Fig. 2 Analysed component pin #9 I-V characteristic with model component pin #9 tolerance range of 5%.

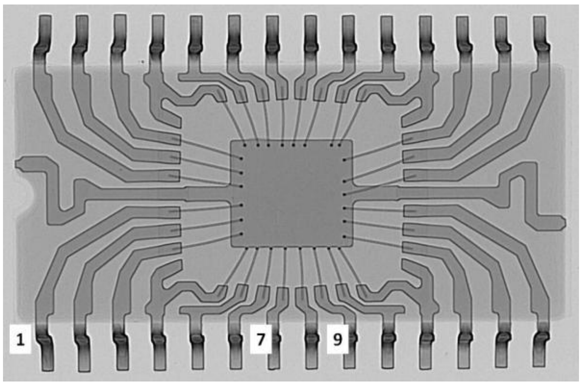

Fig. 3 The X-ray image of the model component.

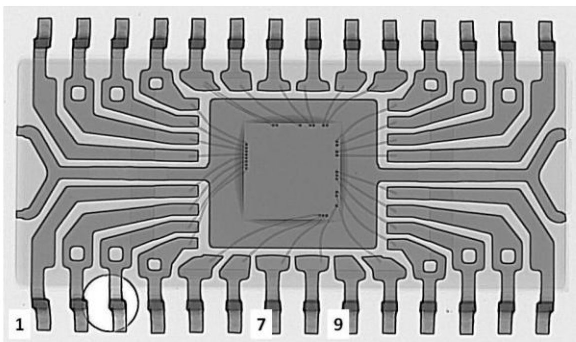

Fig. 4 The X-ray image of the analysed component.

We have x-rayed both the model component and the analysed components to see any structural differences if there any would be. The x-ray analysis was accomplished on the CT Phoenix Micromex DXR-HD. The x-ray images are in Fig. 3 and Fig. 4. As you can see in Fig. 4, pin #9 is really not connected in the analysed equivalent components, and there are many other structural differences.

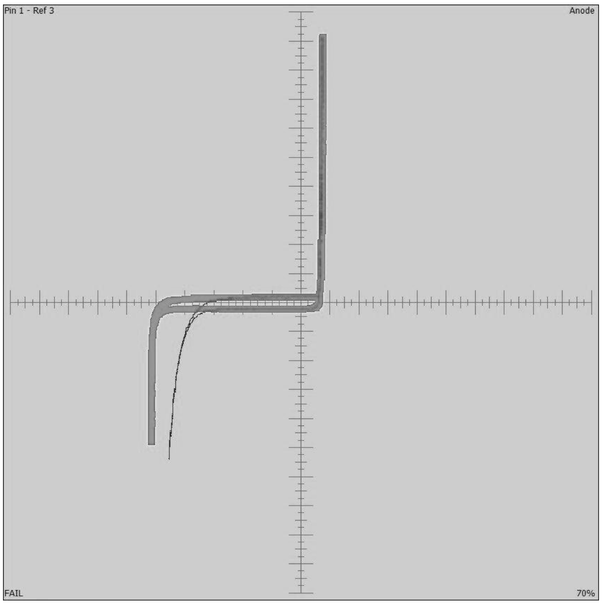

Fig. 5 An analysed Zener 5V1 diode I-V characteristic with model diode 1% tolerance range.

Fig. 5 illustrates another case where the analyzed Zener diode was reported not being able to stabilize the nominal voltage for small current like expected according to the data sheet and specifications. The comparison of the model diode tolerance range and equivalent I-V characteristic shows clearly why. The tolerance range was set both horizontally and vertically to 1% in this case.

When analysing transistors, we need to choose a suitable reference pin in the manual mode mentioned above. That choice mostly depends on sensitivity to I-V characteristic changes caused by analysed differences. The following Table 1 to 4 displays an example of five analysed MOSFET power transistors samples comparison results according to the mode and to the Manual Mode reference pin variant in summary. The analysis tolerance range was set both horizontally and vertically to 3%. Table 1 summarizes the sample transistors results in Matrix Mode and with transistor sample 1 chosen randomly as a comparison model for all analysis variants at the beginning. Three other variants related to the Table 2, Table 3 and Table 4 differ in reference pin choice which is successively Gate, Drain and Source. Numbers in Pin1, Pin2 and Pin3 columns indicate the similarity percentage. The dissimilar sub-group consisting from samples 2 and 3 is highlighted dark. The dissimilarity is only very small and belongs to the natural variations because there were two different lot codes in the sample group. One lot code is related to the sub-group of samples 1, 4 and 5. The other lot code is related to the sub-group of samples 2 and 3. There is also possible to see in Table 2 that manual mode referred to the Gate pin is insensitive to differences between both lots. Both other manual mode alternatives expressed with the Table 3 and Table 4 correspond with the matrix mode alternative expressed with the Table 1 and divide the sample group in two sub-groups identically. The Gate pin 1 percentage identity is same in all modes and reference variants.

POWER MOSFET				
Sample	MATRIX MODE			Result
	Pin1	Pin2	Pin3	
1	100	100	100	Ref.
2	100	97	95	fail
3	100	97	95	fail
4	100	100	100	ok
5	100	100	100	ok

Table 1 Matrix mode comparison results overview.

POWER MOSFET				
Sample	MANUAL MODE Ref – 1 (Gate)			Result
	Pin1	Pin2	Pin3	
1	100	100	100	Ref.
2	100	100	100	ok
3	100	100	100	ok
4	100	100	100	ok
5	100	100	100	ok

Table 2 Manual mode reference pin 1 (Gate) comparison results overview.

POWER MOSFET				
Sample	MANUAL MODE Ref – 2 (Drain)			Result
	Pin1	Pin2	Pin3	
1	100	100	100	Ref.
2	100	100	85	fail
3	100	100	85	fail
4	100	100	100	ok
5	100	100	100	ok

Table 3 Manual mode reference pin 2 (Drain) comparison results overview.

POWER MOSFET				
Sample	MANUAL MODE Ref – 3 (Source)			Result
	Pin1	Pin2	Pin3	
1	100	100	100	Ref.
2	100	89	100	fail
3	100	89	100	fail
4	100	100	100	ok
5	100	100	100	ok

Table 4 Manual mode reference pin 3 (Source) comparison results overview.

The most difference sensitive diagnostic comparison variant is the manual mode referred to the Drain pin 2 in this particular case. Nevertheless, the majority of problematic cases will exhibit much coarser differences in their I-V characteristics or pin prints.

Fig. 6 illustrates another I-V characteristic comparison case. It is quite a simple but important diagnostic example. There was a problem with a MKP capacitor delivery for filtering in EMC application. That delivery had a very unstable electrodes layer so that the electrode area was decreasing during operation causing the capacity ebb. The model 3% tolerance range is related to the model capacitor nominal capacity whereas the analysed I-V characteristic course shows a remarkable capacity decrease.

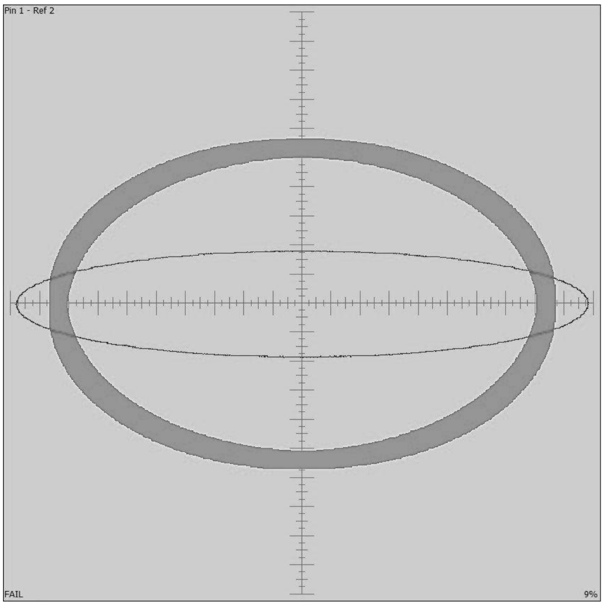

Fig. 6 An analysed MKP capacitor 47 nF.

Fig. 7 illustrates a three pin heat sensor analyse result where a structural difference did manifest in Source to Drain I-V characteristic remarkable difference.

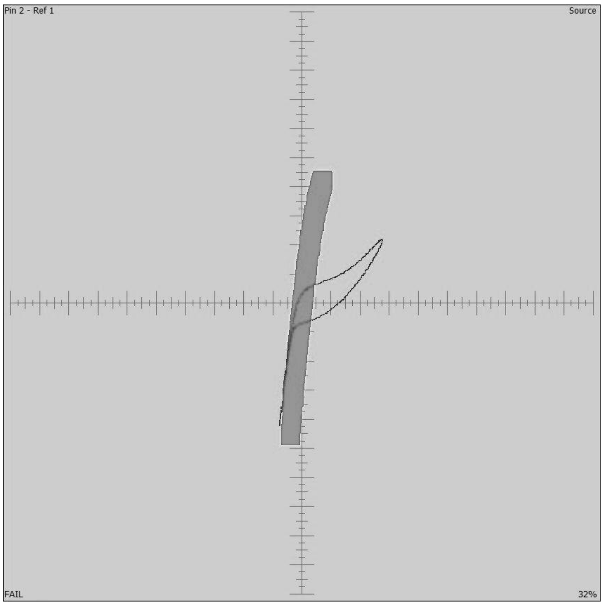

Fig. 7 An analysed heat sensor

4. SUMMARY

The presented results for a microcontroller, a Zener diode and a MOSFET power transistor are illustrating the V-I characteristic comparative analysis possibilities for detecting and monitoring differences caused by diverse reasons and influences. Such differences can be caused by the natural manufacturing process dispersion at the same producer, by parameters variations among different producers, by differences caused by latent or apparent damages, for instance with thermal or electrostatic discharge exposition, and frequently also differences caused by unauthorized processes [3]. We need always an approved authentic specimen I-V characteristics set, so called pin prints, prepared in advance for a reliable analysis and decisions based on it. The comparison criteria setting for analysis evaluation and the scan profile choice depends individually on the authentic component type analysis database to incorporate lot or inter-lot dispersion. Our experiments show even the diagnostic potential of the automatic mode which is very easy to be applied by person with only little experience with this method. However, we need to bear in mind that unlike the parametric and functional testing methods, the I-V characteristic comparison method approaches components only via pin pair loop. That is why it can react only on the differences with influence on that loop structure and with I-V characteristic change manifestation. This method is not a replacement for parametric and functional test methods, but it can still serve as a quick and cost effective filter for damaged and unauthentic components before letting them to enter the manufacturing process.

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