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# Detection Of Electronic Card Failures Using The Analog Signature Analysis Technique

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**Abstract**

To diagnose failures in devices that use electronic cards, PCB [1] and consequently to repair their damages is more and more expensive if it is taken into account that the information of plans, diagrams, manuals, spare parts, training and tools are limited in repair shops and, added to this, the myriad of components and cards that exist. This paper shares a diagnostic technique that allows, by comparing figures or curves of voltage and current signals that are injected to suspicious cards or components with defects, to compare them with the responses that generate cards or equal, and then analyze them and make decisions based on the characterization of their responses. This technique is already being used but it is not widespread among repair technicians who use diagnostic methods that are based on the basic concepts of electronics and knowledge about the components. This technique allows the cards to be reused as long as the faults are found and they can be repaired with the spare parts available in the country and in this way recycle the electric-electronic items that deteriorate.

**Keywords:** PCB, Printed Circuit Board, Fault Detector, Analog components, V-I Signatures, Lissajous curves, electronic waste, electronic equipment WEEE.

## INTRODUCTION

Each technician has his own method of repairing electronic cards and with experience he refines and improves it. The diagnostic methods are generally classified as: simulation after test (SAT) and simulation before test (SBT) [2]. The detection and location of faults in electronic cards is always a complex and time-consuming job, so applying a fault-finding methodology using algorithms in embedded systems helps quickly find components that are damaged [3]. Yu X Liao [4] presents a similar method to the work here presented, to diagnose the winding of a transformer, using the Lissajous figures. As well as this, there are companies that use this technique [5] and have developed tools that help their application in a routine way [6], however, their costs are high to be acquired by a common technician.

The repair technique using analog signatures has several components that must work simultaneously, such as: the person who repairs, the operator, the tools he uses and the knowledge of the method to apply it. Repairing electronic cards efficiently and quickly allows them to be reused and to reduce the amount of electronic waste that is increasing on the planet with a growth rate of 4%-5% per year, reaching 49.8 Mt in 2018 [7]. There is then a business opportunity in developing countries, where the economic capacity of consumers of new electrical / electronic equipment is limited and therefore the need to repair damaged devices arises [8]. The WEEE reuse implies the concepts of updating, resale, repair, reconditioning and re-manufacturing [9].

The paper has six sections. In section II a brief explanation of the Lissajous figures [10] is given. Section III explains the technique of analog signatures applied to the repair of cards. Section IV shows the simulation, using the Matlab software, of the typical analog signatures of the most used components in the electronic boards and simulates the behavior of a simple circuit that has faults in one of its components. To conclude, section V illustrates a simple application of how to detect faults in electronic cards using described in this article and section VI give the conclusions.

## LISSAJOUS FIGURES

The French mathematician and physicist Jules Antoine Lissajous (1822-1880) [11], in the year 1857, built an optical system that took advantage of the persistence of the image in the human eye to visualize geometric figures that were produced by combining the vibrations of two sources, reflecting a ray of light through a mirror fixed to two vibratory sources. The Lissajous figures are drawings that appear when two periodic functions are represented in the X and Y coordinates of a coordinate system, as indicated in Figure 1.

$$x(t)= A \sin(\omega + \delta) \qquad (1)$$

$$y(t)= B \sin(\omega t) \qquad (2)$$

Where:

A y B = Amplitude of the signal peak voltage

$\omega = 2\pi f t$

f = Frequency in Hz

t = Time

$\delta$ = Offset in degrees or radians

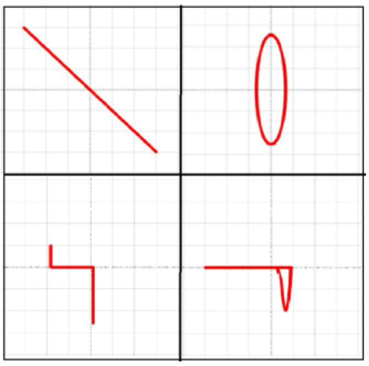

**Figure 1.** Lissajous figures

The oscilloscopes configured in the X-Y mode allow to visualize these figures if two different signals are applied in each one of the channels. Now, if it is taken advantage of the studies carried out by Lissajous and there is injected controlled signals in current and voltage to an electronic system (Figure 2 and 3) composed of: resistors, capacitors, semiconductors, diodes, integrated circuits, among others, it can be plotted the responses of its behavior when going through the circuits. This test is known as *Analysis Technology Of Analogic Signature* or PROOF V-I.

Next, the way of how the concepts of electronics are applied to the analysis of the analogical signatures in simple devices and of greater use in the electronic boards is presented.

## ANALOG SIGNATURE ANALYSIS TECHNIQUE (TEST V-I [VOLTAGE-INTENSITY])

This technique takes advantage of the formation of images that are the result of plotting the voltage and current signals in the X-Y mode of an oscilloscope [12]. The current is measured indirectly by applying the law of Ohm in the resistor R (Figure 2) limiting intensity, I = V / R. This current is the same as that circulating through the element that is being diagnosed because the topology of the circuit allows it. To which a sinusoidal signal is applied at a certain frequency and amplitude that excites the components and allows their response to be clearly seen.

Figure 2 shows the simplified circuit used in this technique. The test is done by comparing the graphics of a card or component that is working correctly with the card or component that is to be diagnosed. For this purpose, the operator must switch the signal injected into the good card and the bad card under the same conditions, i.e. the reference points and the test points must not be changed to force the signal to circulate through the same elements, Figure 3 shows the scheme used. The expertise and experience of the operator are key to interpret the figures and make the appropriate decisions to isolate the failure and corner it in the different nodes of the card. The technique is a tool that allows to find differences of impedances between the cards and this causes different figures that can be originated by the bad operation, it is the operator who must interpret these signals. Something similar to what a doctor performs which interprets the signals of an electrocardiogram to make the appropriate decisions that cure the patient, the electrocardiogram is the tool that gives information, the analog signatures give the information and who interprets them is the operator.

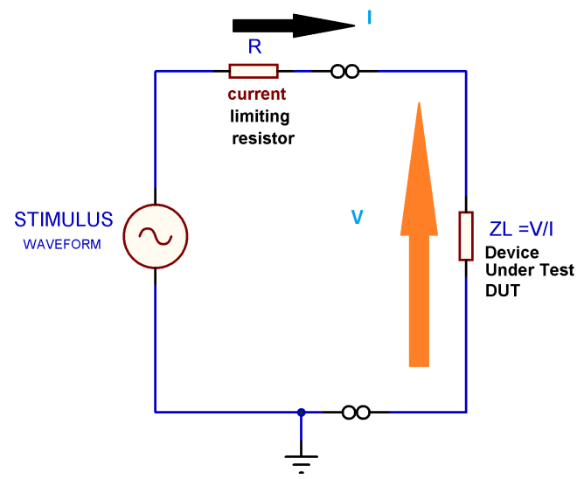


**Figure 2.** V-I Test Diagram

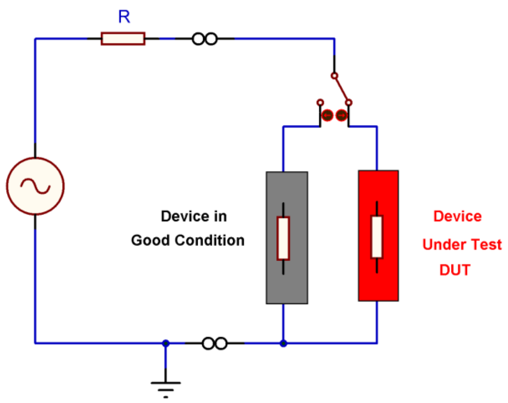


**Figure 3.** Schematic circuit to switch the signal between the device in good condition with the DBP

The wave applied to the previous circuit is the one indicated in Figure 4 and its equation is:

$$y(t) = A \sin(2\pi f t) \qquad (3)$$

Where:

A = Peak voltage = 18 V

$\omega = 2\pi f t$

f = 60 Hz

t = Time

$\delta = 0$

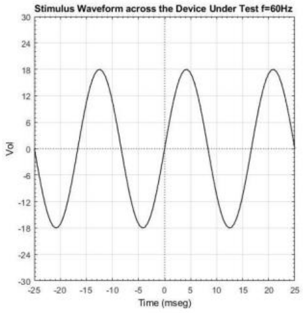


**Figure 4.** Signal applied to the circuit

## TYPICAL LISSAJOUS FIGURES IN BASIC ELECTRONIC COMPONENTS

The basic components most used in electronic cards are: resistors, capacitors, coils, wires, semiconductors, diodes, transistors, integrated circuits and the combinations that are made between them. As the technique is directed to the interpretation of graphs, the following are those that generate the devices to which the sinusoidal signal indicated in equation (3) is applied.

A short circuit would show a vertical line, because the current flow for any applied voltage would be theoretically infinite (Figure 5), while an open circuit would show a horizontal line because the current is zero regardless of the applied voltage (Figure 6).

More complex curves are obtained with frequency-dependent components, such as capacitors and inductors, and also for non-linear semiconductor devices, such as diodes, transistors and the different combinations that can be made between them.

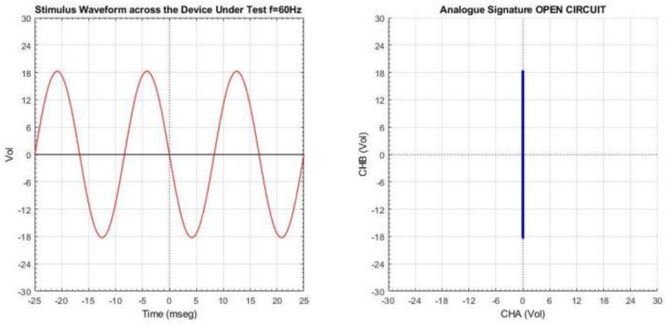


**Figure 5.** Short circuit response

Equations of the resulting signals for open circuit:

$x(t)= A \sin(\omega t)$ (4)

$y(t)= B \sin(\omega t + \delta)$ (5)

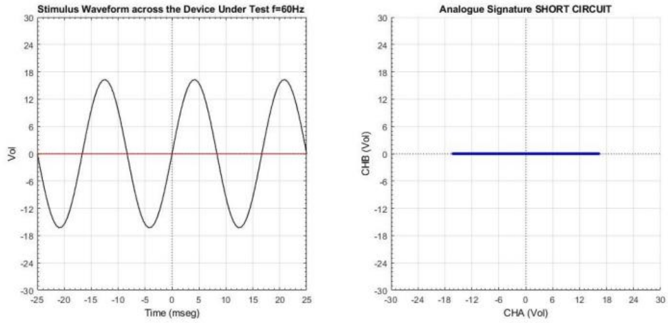


**Figure 6.** Open circuit response

Where:

A=16.3, B=0

$\omega = 2\pi ft$

f = 60

t = Time in ms

$\delta = \pi$

Equations of the resulting signals for short circuit: the values in the equations (4) and (5).

Where:

A=0, B=18.3

$\omega = 2\pi ft$

f = 60

t = Time in ms

$\delta = \pi$

Although the curves can sometimes be quite complex, it is not necessary to understand them to use the V-I test technique, comparing the curves between a card in good condition with another one suspected of having damage, often helps to identify faults with a minimum of knowledge. It must be taken into account that, in a typical circuit, the V-I curve shown would normally be for a series of components in parallel. A better understanding of the V-I analog signatures can be obtained, using the system with known components out of circuit, in other words, that they are loose. Card repair is optimal when the fault is found without performing re-work that damages tracks or components in good condition.

The signatures of the resistors are straight (Figure 7). The value of the resistor affects the slope of the line, so that the higher its value, the closer the line is to the horizontal (open circuit). By selecting the impedance of the V-I plotter closest to the test resistor, the figure will show a straight line with a 45 degree slope. A difference in the slope of the curve when comparing a good card and a suspicious one would indicate inequality in the resistor values on the cards.

Capacitors with relatively low values have elliptical signatures, capacitors with relatively high values have vertical flattened elliptical signatures (Figure 8). When excited by sinusoidal signals having the appropriate frequency, the greater the capacity, the lower the test impedance and the frequency. A leaking condenser would give an inclined curve due to the effective resistor in parallel with the capacitor.

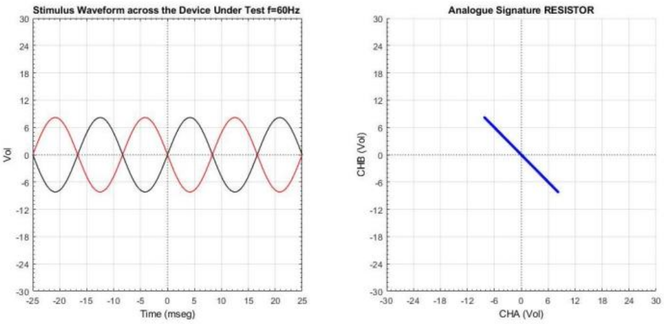


**Figure 7.** 1k Ω Resistor response

Equations of the resulting signals for Resistor: the values in the equations (4) and (5).

Where:

A = 8.2, B=8.2

$\omega = 2\pi ft$

f = 60

t = Time in ms

$\delta = \pi$

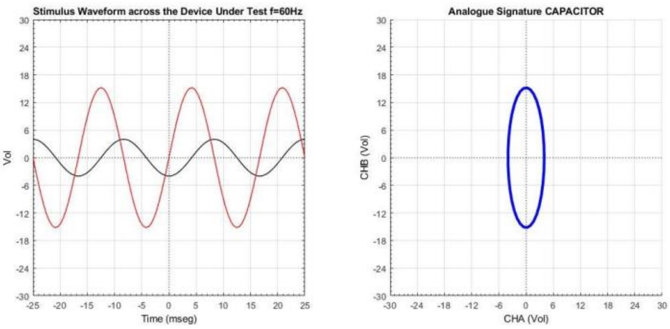


**Figure 8.** 10uF capacitor response

Equations of the resulting signals for Capacitor:

$x(t)= A \sin(\omega t)$ (6)

$y(t)= B \sin((\omega t + \delta) + \Theta)$ (7)

Where:

A = 14.2, B=4

$\omega = 2\pi ft$

f = 60

t = Time in ms

$\delta = \pi$, $\Theta = \pi/2$

The signature of a coil is elliptical or circular, sometimes showing hysteresis (Figure 9). The inductors with relatively high values have horizontal flattened elliptical signatures similar to those of the capacitors. The inductors can have iron, ferrite, brass or air cores, which can be varied or not. Inducers with the same value can have very different signatures if they use different materials in the core or if the core is positioned in another way. The inductors generally require a low impedance of the source and higher test frequencies to generate an elliptical signature. In this work, the fixed frequency of 60 Hz is used which would limit the analysis for devices that respond to high frequencies.

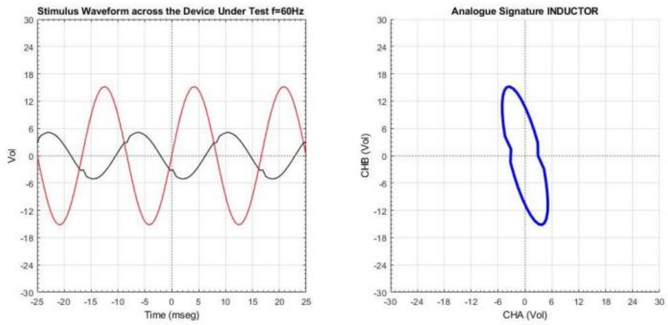


**Figure 9.** Coil response

Equations of the resulting signals for Coil: the values in the equations (6) and (7).

Where:

A = 15.2, B=1.7

$\omega = 2\pi ft$

f = 60

t = Time in ms

$\delta = \pi$, $\Theta = \pi/4$

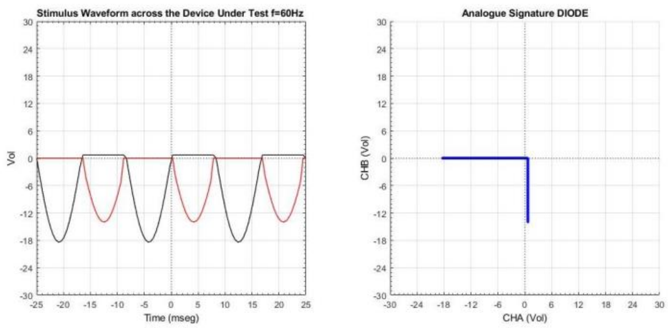


**Figure 10.** Diode response

Equations of the resulting signals for Diode: the values in the equations (6) and (7).

Where:

$A = 18.4$, $B=14$

$\omega = 2\pi ft$

$f = 60$

$t$ = Time in ms

$\delta = \pi$, $\Theta = \pi/4$

For:

$y(t) >= 2.7 \quad y(t)=0$

$x(t) >= 0.68 \; x(t)=0.68$

An open coil can be easily detected by the V-I curves that contrast strongly when comparing two boards.

The massification of LED technology, which is associated with on-off circuits, drivers and voltage sources, has turned them into key components in: panels, traffic lights, pedestrian signaling and backlight sources for screens, to name a few cases, which makes LEDs one of the components that can most fail [13], here are several analog signatures of these semiconductors.

The signature of a diode can be easily identified (Figure 10). The vertical part of the curve shows the direct polarization region, where the ignition voltage and direct voltage drop can be easily identified. The curved area of the trace shows the diode off and how it goes into conduction as the applied voltage increases. The horizontal part of the curve is the region of reverse voltage where the diode is not conductive and is effectively an open circuit. Figures 11, 12 and 13 show the analog signatures of blue, green and infra-red LED diodes, in which the displacement of the driving voltage is observed. Defective diodes can easily be identified by a deviation from this characteristic, for example, a diode that presents a significant inverse leak would have a diagonal curve in the reverse region, similar to a resistance.

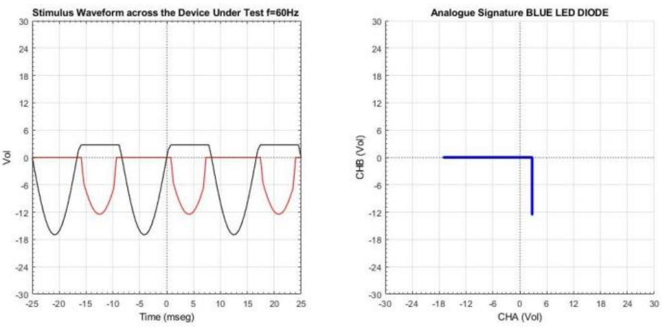


**Figure 11.** Blue LED diode response

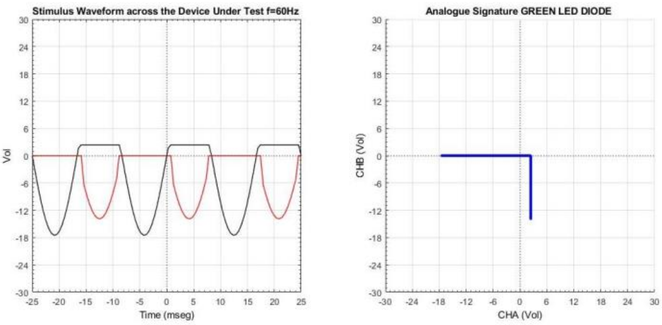


**Figure 12.** Green LED diode response

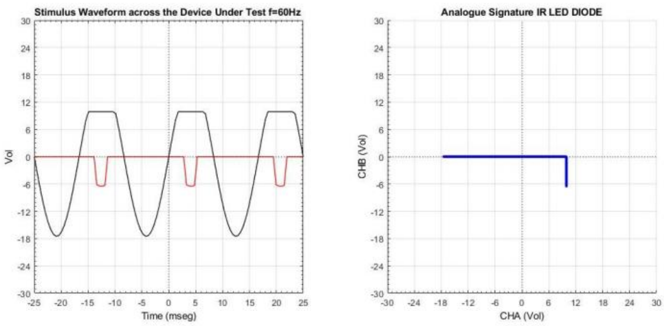


**Figure 13.** IR LED diode response

For circuit with Zener diodes, these lead in both directions. The direct current characteristic is similar to that of a diode (see above). The characteristic in the reverse direction is also similar to a diode until the break or the Zener voltage is reached, at which point the current increases rapidly and the voltage of the diode is set.

This results in the curve in Figure 14. The test voltage must be chosen to be higher than the Zener voltage to obtain this curve. A suspect Zener diode may not have a well-defined "elbow" and the horizontal part of the curve in the reverse region may exhibit leakage effects similar to a normal diode. Likewise, the characteristic signatures of a transistor, also very common in electronic cards, can be generated, such signatures are those indicated in Figures 15 and 16.

When analyzing a card, you will find combinations between the basic analog signatures like the one indicated in Figure 17. The circuit to which the signal is applied is indicated in Figure 18 (see red box), composed by diode D1 in series with the parallel of capacitor C1 of 10uF and resistor R3 of 1K Ω, connected to switch SW1 in the PTOB. In the terminal PTOA of the switch is the resistor R1 of 1K Ω. The resistor R2 of 1KΩ is responsible for limiting the current flowing through the DUT.

When comparing the two signatures generated, it is evident that they are different, detecting this discrepancy is the essence of the technique of analog signature analysis.

In the oscilloscope it is seen the analog signature of a resistor when the switch is in PTOA (Figure 19) and if it is in the PTOB it is observed the combination of the analog signatures of a diode, a capacitor and a resistor (Figure 20). The mathematical equation that models the signals is complex and is not shared in this article since it is not the main objective of it.

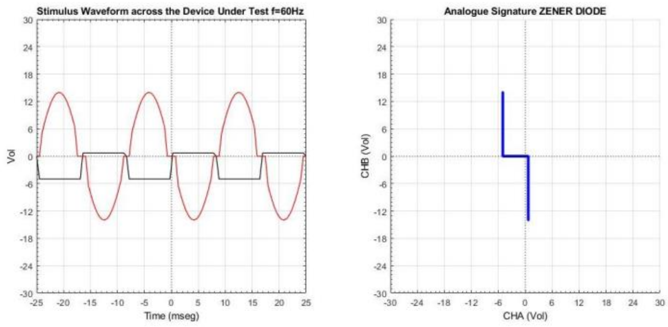


**Figure 14.** Zener response

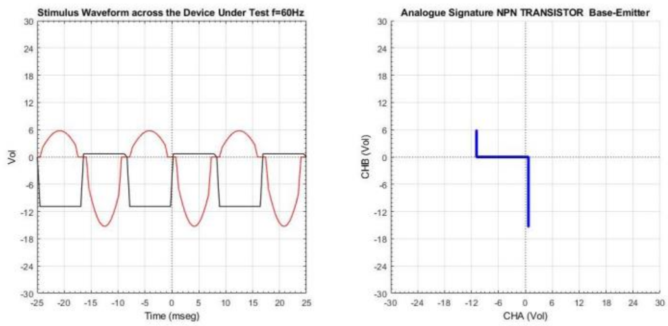


**Figure 15.** Transistor junction Base Emitter response

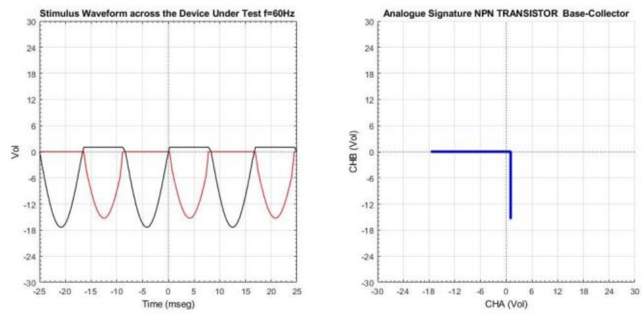


**Figure 16.** Transistor junction Base Collector response

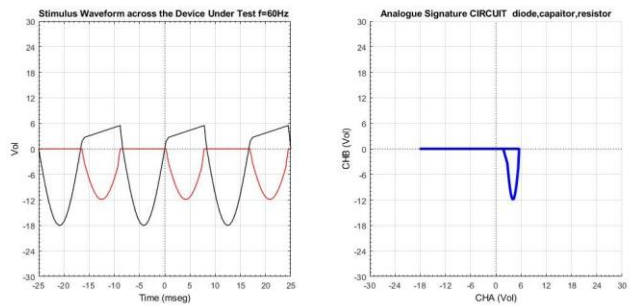


**Figure 17.** Response of a circuit with diode, capacitor and resistor

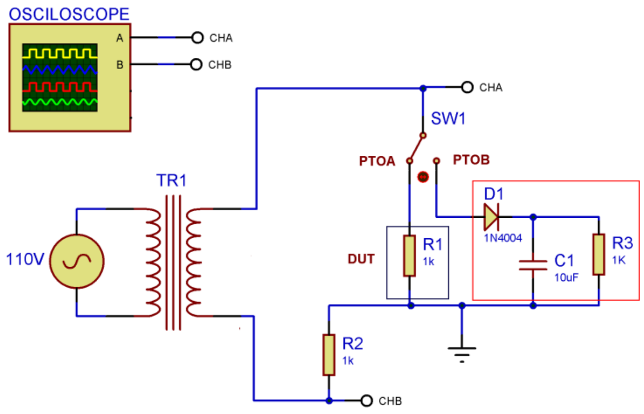


**Figure 18.** Circuit to obtain the analog signatures of two cards, one placed in the PTOA and another one in the PTOB

**Figure 19.** Analog signature of a resistor seen in the PTOA of the test circuit

**Figure 20.** Analog signature of a mixed circuit seen in the PTOB test circuit

## APPLICATION OF ANALYSIS TECHNIQUE OF ANALOG SIGNATURES

It is required to repair a card which generates error and another one is the same to characterize its analog signatures. For this purpose, the sinusoidal signal (Figure 4) of excitation is applied through the TEST V-I circuit whose topology is indicated in Figure 21.

To do the exercise, it is assumed that the analog signature that delivers the card located in the PTOA is the one indicated in

Figure 19 and the analog signature of the card located in the PTOB is similar to Figure 20. It is clear that the two analog signatures are different, therefore it can be concluded that there is some component that is defective in the node that goes from the point of reference to the PTOA. For this exercise, it is known in advance that the card located in the PTOB is working well and the one under test is the other card.

As mentioned above the important thing is to see the difference of the analog signatures, it could be inferred that in card A there is a shorted diode and an open capacitor since the response to the excitation is an analog signature of a resistor. This is one of the many alternatives that are used to explain the inequality of signatures, as previously mentioned, the operator's or repairman's expertise is the key to success in detecting the components that are failing.

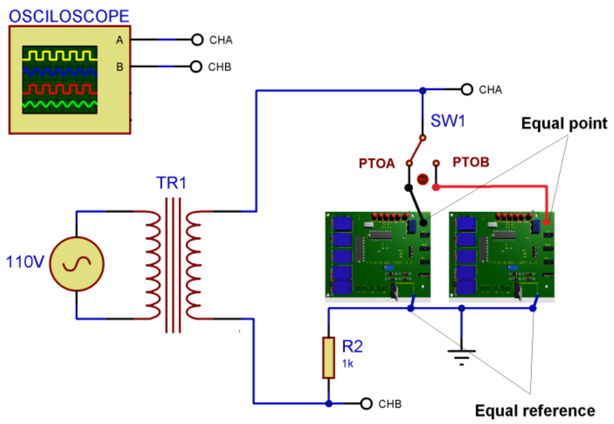


**Figure 21.** Technical application of analogical signature

## CONCLUSIONS

To use the technique of analog signatures in its full potential as a fault diagnosis tool, it is essential to focus on the differences between analog signatures, it is not necessary to delve into the operation of the components, the important thing is to compare the figures generated by the card or component in good condition, with the card under test. The majority of card failures are serious, such as short or open circuits, which are easy to detect with the V-I technique without complex analysis. In order for this repair technique to be widely used by repair technicians, it is necessary to have the tool that generates the Lissajous graphics in a simple, reliable and economical way so that the operator makes the correct decisions to repair the cards. If this technique is widely disseminated, it could be used to repair and reuse devices such as mobile phones that are generating environmental pollution due to their difficulty in recycling them [14] and take advantage of their components.

The simulated example in section V is intended to explain in a simple manner and based on what is stated in this work how to diagnose electronic cards using the V-I fault detection technique. Mathematical modeling for the most complex signals is tedious and time consuming, it can be done, but it does not help the diagnosis of the failure. It is recommended to memorize the analog signatures of the main components used in the electronic cards.

The following questions arise:

What happens when the repairman faces complex cards that have many elements, do not have the plans and do not have a good card to compare, is it possible to apply this method? Answer: If it can be applied as long as it is gotten a database of the characterization of the cards that are most damaged and in which the technician has specialized.

Is it necessary to remove the components of the cards to compare them? Answer: No, the ideal is to locate the damaged elements with the minimum re-work on the cards.

Is there any alternative equipment that replaces the oscilloscope, since they are expensive instruments to acquire them? Answer: Yes, there is and it can be a computer that has the software and the appropriate interface, its cost is high.

Is the basic V-I test circuit indicated in this article reliable and does it not deteriorate the components it will measure? Answer: The circuit is basic, it would need to improve its design for industrial applications.

Is it necessary to energize the cards under test to apply the repair technique? Answer: No, these must be without power.

Can the V-I test detect software defect in the microcontrollers? Answer: No, this technique only detects hardware malfunction.

To the extent that the technique is applied, greater experience is achieved and tolerances will be allowed to the inequality between the figures that will be regulated by the operator, not only the tool is necessary, knowledge and practice are necessary.

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