Thermal Imaging: A Technique for Thermal Analysis of Active Electronic Component

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ABSTRACT
Any electronic circuit is a combination of various components. These electronic components can be categorized in two types viz. as Passive components and active components. Active components changes or add gain to the input energy. Whereas, active components need assistance of passive components. In electronic circuits, heat is the resultant of energy gain provided by active electronic components. This heat generated can cause harmful effects to the circuitry and permanent damage to the device. Because of this, component selection is crucial part in designing. Moreover, predicting thermal behavior of component at any specific operating condition is equally important. There are several methods adopted till date for this cause but very countable among them are reliable and have ease in use. For the same, thermal images of components can be used to derive solution on such critical problem. Generally, to address this, tedious mathematics and formulations are carried out. With advanced thermal image processing techniques, this can be simplified to greater extent.

Keywords
Color Histogram, Thermal Analysis, Thermal Image Processing, Feature extraction, Thermal management, Contactless Temperature measurement

1. INTRODUCTION
With development of technology, electronic circuits are shrinking and resulting in miniature circuits. As circuits will continue to shrink, it will need basic but very effective changes to manage its reliability constraint. Electronic component converts or changes energy from one form to another. Some of the input energy is dissipated at the atomic level as the operates and chip perform its function. This energy results as rise in case temperature of the semiconductor device. Electronic components by their nature produce heat as a resultant of operation. This generated heat can lead to premature failure, degraded life or reduced reliability of devices or component itself, if not controlled within the limits [1].

The general rule is, for an approximately 1°C rise in the case temperature above about 100°C, the chip failure rate get increased by about 5%. Due to this physical relationship, the design goal is to bind the component temperature to a maximum of about 100°C to 120°C for power semiconductors and about 90°C for microprocessors. Specifically, in case of BJT as temperature increases, leakage current increases significantly.

Depending on the design of the circuit, this rise in leakage current increases the current flow through the transistor and thus the power dissipation as resultant. In Power MOSFETs, rise in temperature typically increase their on-resistance. As this generated heat not only depends upon the operating conditions but also on the component selected for specific work. This leads to the need of thermal analysis of specific electronic component. Electronic component manufacturers provide thermal characteristics in datasheet in the form of maximum and minimum operating temperatures and thermal resistances for various conditions. But these thresholds are captured for specific operating condition and strictly derived with specific procedures. Whereas, these conditions have mere possibility to be followed in practice by the designers due to need of application or design. For this reason, it is important to monitor the thermal behavior of electronic components as per the way it is used in the specific application within a device or circuit. Following the tedious calculus can only navigates to the nearest possible condition but some extra assumptions have to be made to attest the reliability of components and device. To avoid this, in-circuit thermal analysis of electronic components has to be done to assure the reliability and other related phenomenon of components.

There are various methods which were adopted previously but have limited impact. Some of old methods use thermistors, liquid crystals which are limited due to area covered, complexity and uncertainty involved. As the heat generated by any specific component will always be same if the component has same task to do. This means its thermal behavior will almost be constant depending upon its use within the circuitry or device. So, taking advantage of this condition, it is possible to map thermal behavior of specific component using thermal imaging techniques [2].

2. THERMAL IMAGING TECHNIQUE
From the basics of physics, any object which has temperature above absolute zero (0 K = -273.15 °C) emits radiations. These emitted radiations are in IR range and it's possible to map these radiations [3]. These radiations have direct correlation with the temperature of the object which is stated below equation (1).

$$W=\sigma\varepsilon T^4 \qquad (1)$$

The equation (1) stated above is known as Stefan-Boltzmann's law. This law states that the total radiant energy (W) of a body is directly proportional to the emissivity (ε) and to the fourth power of temperature (T). The constant term (σ) is known as Boltzmann's constant and takes value 5.6704 x 10-8 W m^{-2} K^{-4}.

A. Infrared Radiation in Electromagnetic Spectrum

Infrared radiations are radiated from every object which is above absolute zero temperature because of movement of atoms and molecules. Intensity of these IR radiations is directly proportional to the object's temperature. This means, more the temperature of object more will be the IR radiations emitted by object. The wavelength spectrum of infrared radiation is 0.78 to 1000µm (micrometers). This is longer than the wavelength of visible light yet shorter that radio waves. Because of this, these IR radiations are invisible to human eyes and need special setup. The wavelengths of infrared radiation are classified from the near infrared to the far infrared. The intensity of the emitted energy from an object varies with temperature and radiation wavelength. If the object is colder than about 500 °C, emitted radiation lies completely within IR wavelengths. Following figure 1 shows Electromagnetic Spectrum.

B. Absorption, Reflection and Transmission

Every object (except perfect black body) when experiences change in temperature, performs basic three functions viz., Emission, reflection and absorption of heat. In case of perfect black body, it re-radiated whole energy absorbed by it but such perfect black body does not exist.

The amount of total energy (W) of any object is sum of absorbed energy ($W\alpha$), reflected energy ($W\rho$) and transmitted energy ($W\Gamma$). This can be stated in equation form with equation (2) as follows:

$$W = W\alpha + W\rho + W\Gamma \qquad (2)$$

According to the theory of conservation of energy, the extent to which object reflect, absorb and transmit IR energy is known as the emissivity of the material. This property of emissivity will vary with material to material with change in color, surface roughness, wavelength, field of view. In case of perfect black body, emissivity is unity. In actual, Emissivity is the ratio of energy radiated from an object under test to the exterior and energy radiated from a perfect blackbody. If value of emissivity is not accurate, then the true temperature cannot be measured with thermal image.

C. Thermal Imaging Device

There are two techniques which are used for detecting infrared radiations. They are thermal detectors and quantum detectors. A common type of thermal detector is an uncooled microbolometer which is made of a metal or semiconductor material. These type of detectors typically have lower cost and a broader IR spectral response than quantum detectors. Uncooled microbolometers reacts to incident radiant energy and are slower to a great extent and less sensitive as compared to quantum detectors. Quantum detectors are made up of materials such as InSb, InGaAs, PtSi, HgCdTe (MCT) and layered GaAs/AlGaAs for QWIP (Quantum Well Infrared Photon) detectors. The principle of operation of a quantum detector is based on the change of state of electrons in a crystalline structure reacting to incident photons. This type of detectors are generally faster and more sensitive than thermal detectors. However, they require cooling, sometimes down to extremely low temperatures using liquid nitrogen or some other method of refrigeration. Thermal Imaging devices will transform IR radiations into electrically evaluable signals. The electronic unit will calculate temperature by means of these signals and convert them into an image which is visible to human eye [4]. In short, thermal imaging is a science of converting invisible IR radiations into thermal images having temperature distribution information for human perception. These thermal images are radiometric which means each pixel in image is in fact a temperature measurement. Thermal images are affected by surrounding sources of IR radiations. But this effect can be cancelled out by adapting some methods of image processing. Thermal images can be captured in darkness as they totally depend upon the IR radiations radiated by object. These thermal images can be used for further analysis of object.

D. Thermal Imaging in Electronics Engineering

Among the various mature applications of thermal imaging in various other branches of engineering and electronics engineering, it can be used to form another matured application of managing thermal behavior of electronic components [4]. Some of mature applications of thermal imaging in electronics are detection of shorts, cracked conducting tracks or vias, testing of BGAs (Ball Grid Array), HotSpot detection and many others. Figure 2 shows thermal image electronic component.

3. DESIGN

Any system is a combination of various sub systems. This project is totally created by interfacing various components to yield the desired system. The system uses thermal imaging camera, semiconductor device and and artificially trained module set. Each component has its unique work in the system. Thermal camera is for acquiring thermal image of active electronic component under test and computer for performing mathematical calculations in automated manner. Figure 3 below shows block diagram of thermal imaging camera. IR radiations emitted by any object above absolute zero temperature are focused on IR detector by lens.

These detected IR radiations are then amplified and electronically processed by thermal imaging camera. The processed thermal image is then displayed on screen of thermal camera. This image can be viewed on camera display as well as it can be retrieved to any digital device with portability of image format.

As shown in figure 4 above, semiconductor device under test is powered up in circuit. As the circuit will work, the thermal behavior of component will exhibit thermal behavioral change. This change will be captured using Thermal Vision Camera in terms of thermal images. These captured images will be processed in thermal image processing environment to yield expected results.

4. SOFTWARE

The thermal image captured by thermal imaging camera will be used for temperature computation. The thermal image will consist of various colors generated as a result of change in temperature. This change in color indicates variation in temperature. As thermal imaging camera cannot be focused on specific area or limited zone, it will capture the surrounding of the electronic component also. Because of this, the total computation will go on rise. To make it simple, thermal image captured by thermal imaging camera will be cropped in such a way that it will select the electronic component only. The resultant of this will be a custom sized image which depends on the area selected for further use. This cropping of image will be done so as to make the area similar to a rectangle or square. This cropped image will be of key interest [5]. This is shown in figure 5.

In any thermal image, every pixel has a particular value. This value of pixel is a combination of red, green and blue. With this case, it is clear that a thermal image is a three dimensional array consisting of varying values for all of red, green and blue. The maximum value that any specific color can constitute is from 0 to 255. This means, for any specific color, there will be 256^3 combinations. From this, it is clear that the whole data will grow in size resulting in time consuming process. To pass this hassle, images can be converted to grayscale. In grayscale image, each pixel has single value of gray color starting from 0 to 255. This means such grayscale images will acquire less space in memory and also will be fast enough for performing image processing techniques.

A histogram is a type graphical representation of the gray value distribution in an image. In image histogram, number of pixels for each gray value is plotted. This histogram is then equalized to enhance the contrast information of image. While equalizing histogram, values of intensity are spread over the entire range and image enhancement is carried out. Because of this histogram equalization, overall perception of image is changed with changes in lightness and darkness of image. This can be noted in figure 6 below.

A color histogram is a type of bar graph, in which each bar represents a particular color. The bars in a color histogram are referred to as bins. These bins are represented on the x-axis. The number of bins will be totally dependent on the number of colors in an image. Y-axis of Color histogram denotes the numbers of pixels of each bin. Evaluating color histogram will facilitate system to identify number of pixels of each bin so that region of interest within a thermal image can be identified easily. Following figure 7 shows thermal image of active electronic component and its color histogram.

As it's known, colors among themselves can be classified depending upon the hotness and coldness. As per interest in thermal analysis, main concentration is maintained only on hot colors only. The reason behind this is, as temperature of electronic component will increase, IR radiations emitted by it will go on increasing. On the other hand, this change in radiation will make transition of color from cold to hot. This transition of change in color as well as temperature rise can be easily identified with change in histogram. As temperature of component will increase, pixel bins for higher count of red, green and blue will shift from left to right. This is clearly shown in figure 9.

This change in Color can be used for feature extraction and training an artificial intelligence system which will detect case temperature of semiconductor device. This feature extraction can be carried out in various ways. For simplicity and effective utilization, minimum distance classifier has been used. For this training set, image should be captured in controlled environment. To satisfy this need of controlled environment, a chamber mimicking JEDEC chamber is designed to isolate external reflection which may affect thermal image. External interference can not only degrade quality of thermal image but it can also lead to false temperature detection. Also, semiconductor device under test is masked with thin, anti-reflective black paint to avoid reflection. Thermal image captured are then used for extracting color features. These features are then compared with other unknown thermal image [10].

Temperature of thermal image retrieved from developed system provides case temperature of semiconductor device. This discovered case temperature of semiconductor device can be formulated for managing thermal parameters of semiconductor device.

5. CONCLUSION

Thermal image captured by thermal camera contains information of temperature distribution in terms of changes in color. This change of color with respect to rise in temperature can be verified by color histogram method. Color feature extraction of various thermal images has provided temperature of unknown thermal image fed as input to the system designed to read temperature of thermal image. This case temperature can be used for evaluating critical thermal parameters irrespective of need of bulky calculations to dissipate heat generated from device. This also provides space for simplifying thermal management processes.

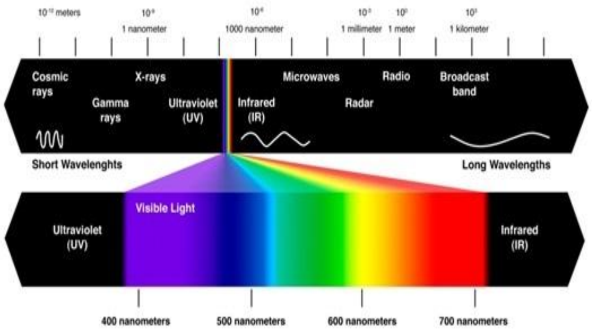

Figure 1 Electromagnetic Spectrum [3]

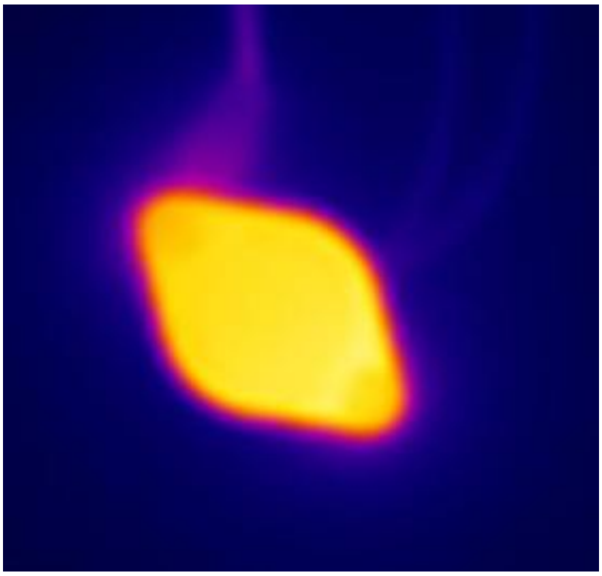

Figure 2 Thermal image of Electronic Component

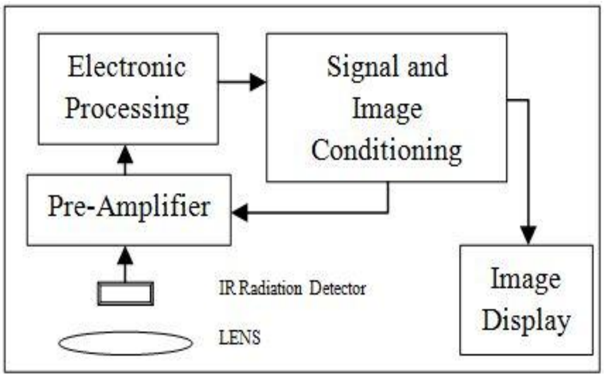

Figure 3 Block diagram of Thermal Imaging Camera

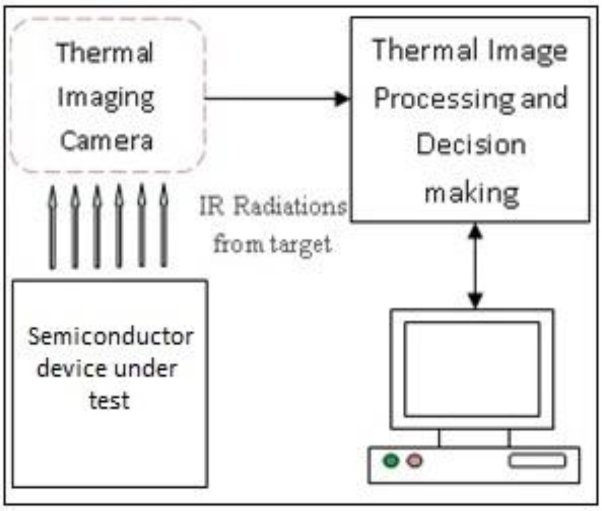

Figure 4 Block diagram of System for Thermal Analysis of Semiconductor device

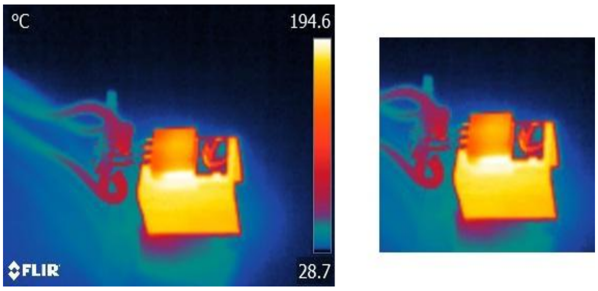

Figure 5 Original Thermal Image (left) and Cropped Thermal Image (right)

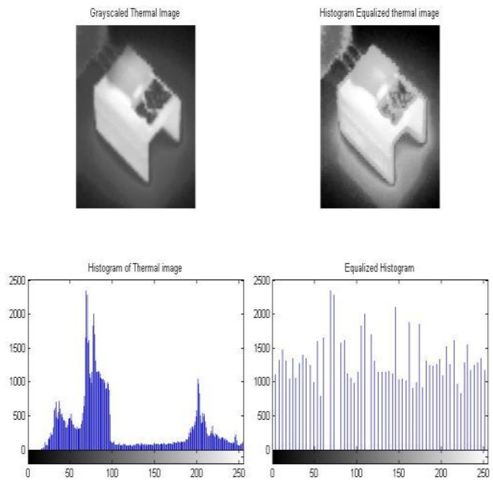

Figure 6 Image histogram and histogram equalized image

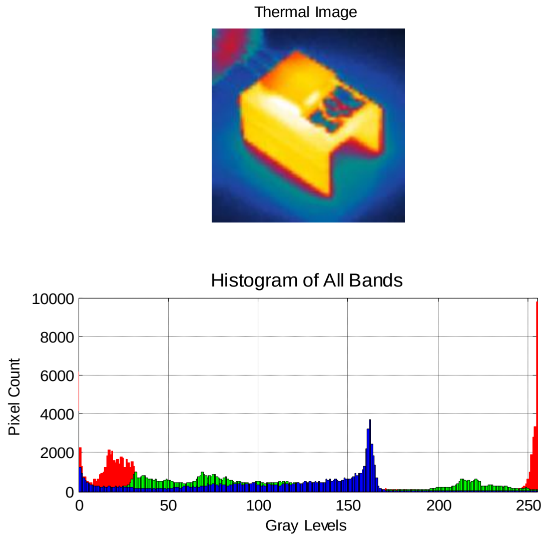

Figure 7 Thermal Image of Electronic Component and its Color Histogram

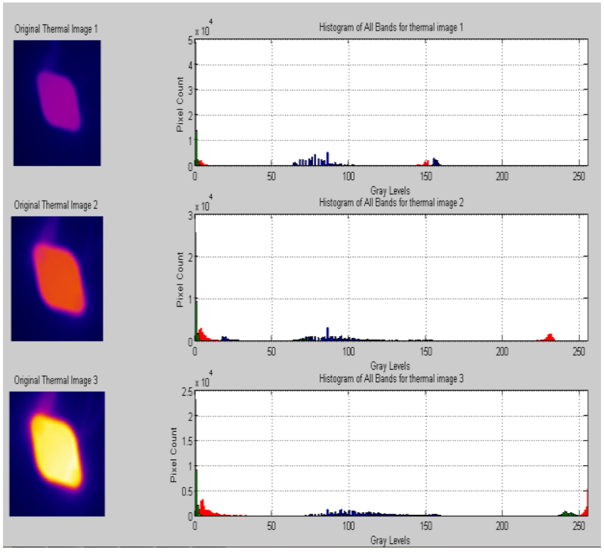

Figure 8 Thermal Image and relative Color Histogram

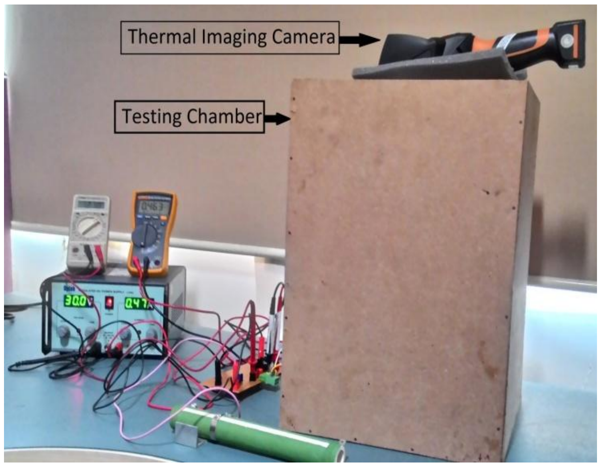

Figure 9 Thermal Imaging Setup

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