Using Thermal Imaging Cameras to Test Electronical Systems

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***Abstract*— Thermography, such as non-contact diagnostics, is well suited for detecting the abnormal operation of electrical devices, for checking connections and hot spots. Based on a thermal image, conclusions can be drawn about the status of the parts and the electrical system. It also can easily and quickly find critical overheating, avoiding potential malfunctions and fire hazards.**

I. INTRODUCTION

A. Testing electronic systems

There are no standard specifications in the electrical industry for thermal imaging measurements, but there are guidelines. Much of the measurements are based on the principle of comparison. Compared to normal operating conditions and the actual operating conditions, temperature deviations can be investigated, and the reason for abnormal operation can be inferred. The comparison may be based on an existing thermal imaging or thermal imaging database of the previously proper functional state of the unit under investigation. A component operating in similar circumstances may also be the basis for the comparison. Additionally, taking into account factory temperature tolerances has great importance.

For the differences in temperature found, the different directives distinguish emergency classes according to the difference in temperature. However, they agree that if there is a rise in temperature, then it is worth reviewing it regardless of its degree, because it may be a source of danger if the device gets a higher load.

There are recommendations to immediate intervention whenever the temperature difference between similar components is higher than 15 °C, or when the temperature difference between the component and the air has increased to over 40 °C - under the same conditions and loads. Besides, there are more detailed guidelines, and users can build their tolerance classes based on their experience.

B. Testing of three-phase systems

Examination of the three-phase systems can be easily done by thermography, imbalances between the phases or overloads are immediately visible on the thermal image. Non-uniform loads can be caused by several problems: connection errors, voltage asymmetry, or for example, the insulation fault of the three-phase motor. Even smaller voltage asymmetries can lead to faulty operation, a reduction in the output voltage can cause a reduction in the torque of the motors or other three-phase systems, and this may eventually lead to malfunctions. Non-uniform loads can also cause fuses to fail.

When defining faults, the components and connection points must be inspected at peak temperatures and under different load conditions. Ideally, under operating conditions, with removed casings, in a fully heated state, at minimum 40% of the load, it is advisable to perform the test – at this way can be best achieved the operating conditions. At the same load, approximately the same temperature values must be obtained. In the case of non-uniform loads usually, the laden phase(s) are in higher temperature(s). However, asymmetric operation, overload, or inadequate connections also lead to a rise in temperature. In the case of an inoperative or low-load phase or component, it is usually lower temperature. The use of a visual diagnostic tool does not lack the presence of electrical instruments since after the error has been discovered, it is necessary to determine the specific problem.

II. THEORY

All objects that are warmer than -273 °C emits infrared rays. These infrared rays are not visible to the human eye. Thermal cameras convert these rays into electrical signals, and these signs are converted to a thermal image – for the human eye.

A. Thermography theory

There is a relationship between infrared radiation and the temperature of a body. Practically used thermal imaging cameras are used to measure longwave infrared radiation in the wavelength range of 8 ... 15 μm (Fig. 1). The temperature distribution of the measured surfaces is calculated and displayed on this basis. The calculation takes into account the emission factor (ε) and reflected temperature (RTC) of the measured surface. Both values can be manually adjusted in the thermal imaging cameras or afterward in the software.

Each pixel of the detector contains a temperature sensor and displays a temperature point, which is clearly visible on display for the human eye (Fig. 2).

Thermography (temperature measurement with the thermal imager) is a passive non-contact measuring method. In this case, the temperature representation of the surface of the object can be displayed on the thermal image. So with the thermal camera, it is not possible to look inside or look through different surfaces.

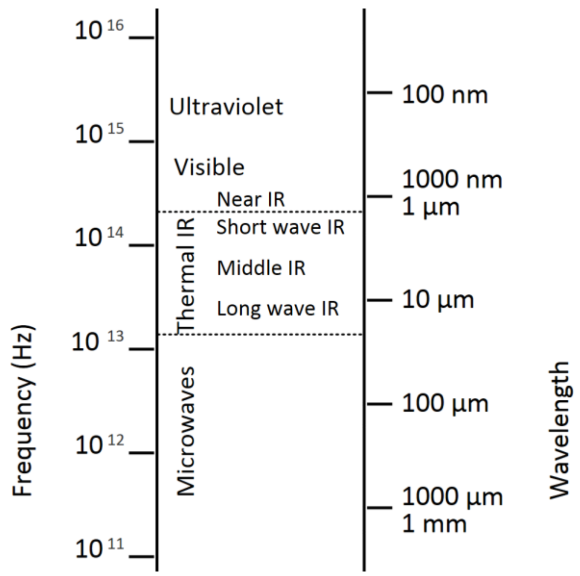


Fig. 1. Magnetization as a function of applied field. Note how the caption is centered in the column

B. *Emission, reflection, transmission*

Longwave radiation detected by a thermal imaging camera is a function of the emission, reflection, and transmission of the surface.

The infrared emission ability of a given substance is characterized by the emission factor (ε). The ε depends on the surface material, its design, and the temperature of the subject. Maximum emission coefficient is 1, in real circumstances do not occur. In practice, the real bodies are reflecting the radiation from their environment. In some cases, they are absorbing it. Non-metallic materials in general (for example: PVC, concrete, organic materials) have high emission rates (ε ≈ 0.8 ... 0.95), regardless of temperature, in the longwave infrared range. The ε coefficient of metals, exceptionally bright, shiny surfaces are low and fluctuates depending on the temperature (Fig. 3). The ε factor can be set manually in the thermal imager and software.

Reflection (ρ) is characterized by the body's reflective ability. ρ depends on the body's surface, temperature, and material. The material's reflection ability with a smooth and polished surface is higher than, a rough, matt surface. The temperature of the reflected radiation can be set manually in the thermal imaging camera. The RTC value is equal to the ambient temperature value, in most measurement applications – it can be measured with an air temperature meter. (The RTC can also be defined by the so-called Lambert radiation.) The exit angle of the reflecting infrared radiation is always the same as the incidence angle.

Transmission (τ) is a feature of infrared radiation transmission. τ depends on the type and thickness of the given material. Most materials are non-transmissible for the long-wave infrared radiation, so they do not pass the rays.

C. *Kirchhoff's Radiation Law*

The infrared radiation from the thermal imaging camera consists of the following: the emitted radiation of the subject of the measurement; the reflection of environmental radiation and the transmission of the radiation of the surface to be measured. The sum of these parameters always gives 1. Since in practice the transmission (τ) is rare, it is negligible.

D. *Usage of thermography*

Thermal imaging cameras can be used well in areas such as:

- electronic: for developing and debugging circuits (Fig. 3),
- electromechanics: testing of electric motors, pumps, generators, and compressors (Fig. 4),
- energy: transmission lines, high-voltage power lines, power distribution equipment, cables (Fig. 5), connections, circuit breakers (Fig. 6), transformers, connectors, illuminators,
- engineering: bearings, couplings, gears, gaskets, technological equipment, tanks, vessels, pipelines, valves, seals
- building energy: search for thermal bridges, search for heat loss, an inspection of facade insulation, searching for thermal insulation damage, check of doors and windows, check for moisture penetration, search for leaks,
- security technology: area protection, guarding and protection tasks,
- specific goals, eg: health and veterinary tasks.

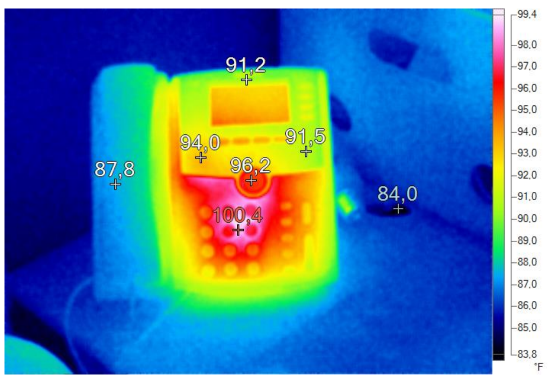


Fig. 2. Thermographic image of an electronic device

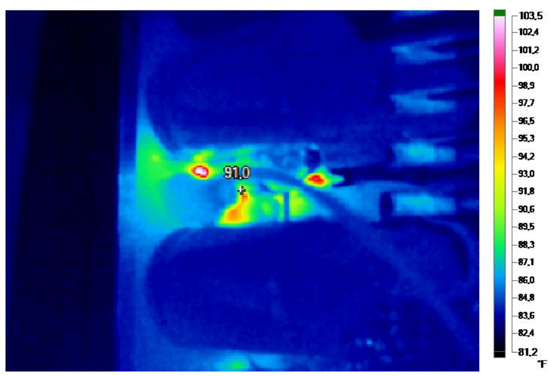


Fig. 3. Thermographic image of a printed circuit board

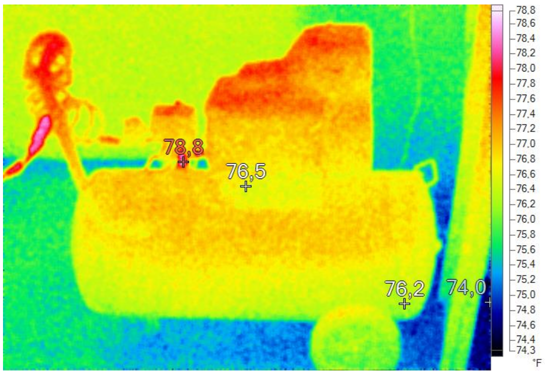


Fig. 4. Thermographic image of a recently loaded compressor

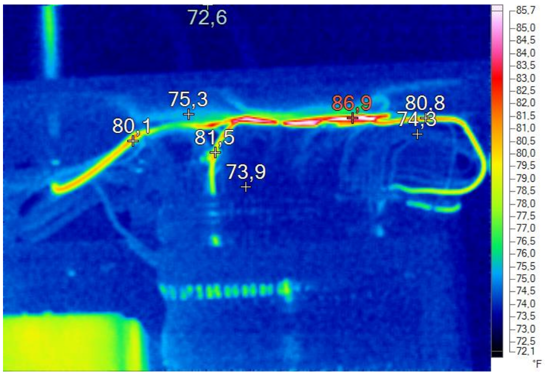


Fig. 5. Thermographic image of a loaded cable

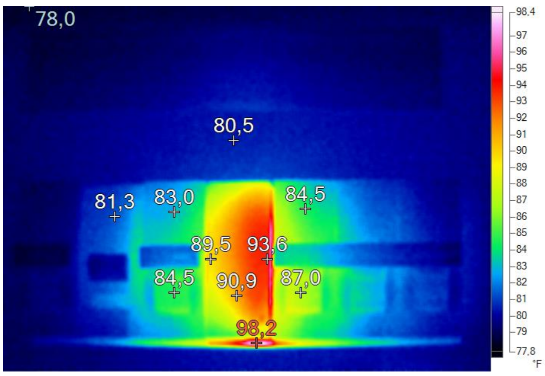


Fig. 6. Thermographic image of a circuit breaker

III. Thermal Management

A. Sources of power dissipation

In electronics, significant sources of power dissipation are leakage current, dynamic power consumption and short-circuits. Diode leakages, gate leakages, and tunnel currents give the main part of the leakage current. It is also present when the system is in standby mode. Charging and discharging current of gate capacitances cause dynamic power consumption. Logic gate output stages could create the highest momentary short-circuit currents, when the gates changing states. This phenomenon contributes 10% to power dissipation.

B. CMOS circuits

Thermal management is more and more critical in electronic products due to the increase in integration, size, and complexity of ICs. In chips, power dissipation can be decreased by providing different frequency clocks to different blocks of the IC.

Lowering supply voltage to reduce power consumption, but it also reduces the reliability of the IC, because of voltage swings and imperfections. The usage of dynamic power supply voltage could be a solution, with the additional disadvantages. Supply voltage reduction slowing down the logic gates, cells, and modules.

Adiabatic static CMOS logic ICs can reduce power consumption by 90% [1]. The technology is used in healthcare devices, however it is not suitable for high frequency operating central processing units.

C. Embedded systems

Higher speeds cause higher power consumption. With low-power microcontrollers, it is better to work faster in a short period of time. The devices can go to sleep, deep sleep or hibernation mode, when their job is done, to reduce power consumption. It is possible to increase performance with an interrupt. [2]

D. Low-power hybrid circuit design

Various modes of powering down, with the help of the firmware, and avoiding to adding not necessary parts to the circuit, and take care for other aspects, the power consumption of the system can be reduced. [3]

Despite the usage of low-power architectural design, wireless systems also consume much power when data is transmitted. The proper control of data transmission helps to reduce power consumption. [4]

IV. Design Recommendations

A. System architecture compromises

Making changes in system design is the most common way to reduce power consumption. An interesting dynamic power-reduction technique is clock gating. The clock can be turned off when the circuit after the gate is not needed. For additional feature, the technique can prevent the system from hazards. As a next step, unique components, multiplexers can also be used for the task. [5]

B. Component selection

In low-power devices, the component's quiescent current and operating power are critical parameters. The external tuning of power consumption is a requirement.

The usage of multiple power supply voltages for the different parts of the circuit is also a necessary option. Lower voltages also reduce leakage current. [6]

Power gating in a useful technique to reduce power dissipation. In many cases, there are parts of the device, parts of the circuit, or on-chip peripheries that can be turned off to save power. Leakage power also can be reduced with the mentioned technique. [7]

C. Measurement settings

From the point of view of thermography, this means: The lower the emission, the higher the reflected infrared radiation, the harder the exact temperature measurement, and the more critical it is to correctly compensate the reflected temperature compensation (RTC). [8]

Bodies with high emission factor ($\varepsilon \geq 0.8$) have a low reflection, and their temperature is measurable quite well with a thermal imager.

In case of bodies with medium emission factor ($0.6 < \varepsilon < 0.8$) have a medium reflection, their temperature are measurable well with a thermal imager.

In case of bodies with low emission factor ($\varepsilon \leq 0.6$) have a high reflection, their temperature is measurable with a thermal imager, but the evaluation of the results requires high precision.

The correct compensation of the reflected temperature (RTC) is essential, as it has a significant influence on the calculation of the temperature. In particular, it is crucial the proper adjustment of the emission factor, when there is a significant difference between the temperature of the measured object and the ambient temperature.

If the temperature of the measured object is higher than the ambient temperature, the too lowly set emission factor results in a too high-temperature display or the too highly set emission factor results in a too low-temperature display.

If the temperature of the measured object is lower than the ambient temperature, the too highly set emission factor results in a too high-temperature display or the too lowly set emission factor results in a too low-temperature display.

The larger the difference between the temperature of the measured object and the ambient temperature, and the lower the emission factor, the greater the measurement error. These faults will increase when the emission factor is incorrectly set.

To calculate the appropriate measuring distance and the maximum visible or measurable surface, three values are to be taken into account.

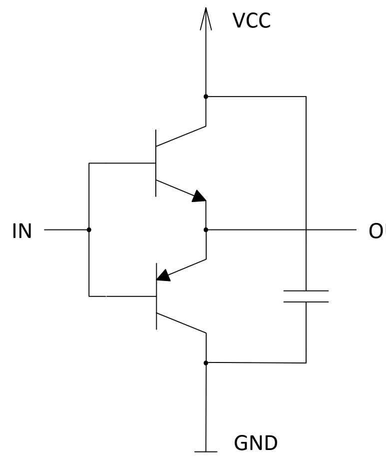
The Field of View (FOV) displays the size of the surface visible with the camera, and it depends on the lens angle used by the camera and the distance from the measured surface [10].

The parameter that determines the smallest recognizable object size is the IFOV. IFOV shows the size of a pixel as a function of distance, and it depends on the resolution of the camera and the distance from the measured surface.

V. PRACTICE APPLICATION

In many applications, driving a MOSFET can cause problems for the engineers, because of the limited drive current of the controller. In order to solve these problems, external MOSFET driver integrated circuits are often used. However, there is a much more cost-effective solution, made of discrete components [11].

In Fig. 7 a complementary bipolar junction transistor pair can be seen, which can be used as a buffer stage between the controller's output and the MOSFET's gate. Fig. 8 shows a similar but insulated solution for power supplies. The transformer's input signal can be symmetrical. The transformer's output signal is driving the buffer stage, and also ensure power, with the help of



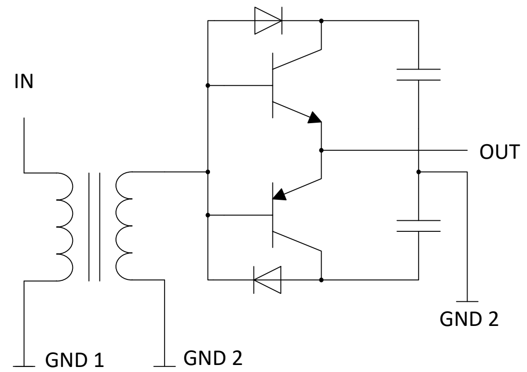


Fig. 8. An isolated NPN/PNP emitter follower pair

the diodes.

This particular circuit's efficiency is the best with a 50% duty cycle input signal. With a DC component in the symmetrical input signal, or not driven with a 50% duty cycle input signal, the ringing can be decreased with a snubber – the MOSFET would not turn on again due to switching transients.

The solution moves the switching power dissipation – mostly made by gate-drive losses –from the controller's output driver stage to the external components. Besides, it removes the high switching currents from the controller, so the regulation and noise performance is improved.

The circuit can easily provide more than 2A switching current without any damage or overheating. In the BJT's datasheet, the h_{FE} curve (see in Fig. 9) not allows that high current, but in practice, in pulse mode, it is working fine.

The thermal imager helps to check the functionality of the solution (Fig. 10. and Fig. 11).

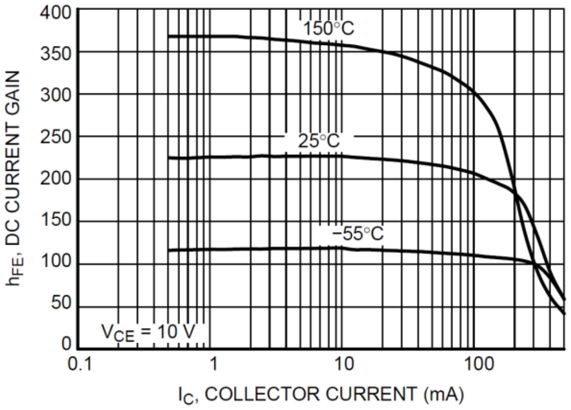


Fig. 9. DC current gain curve of an 2N2222A BJT [9]

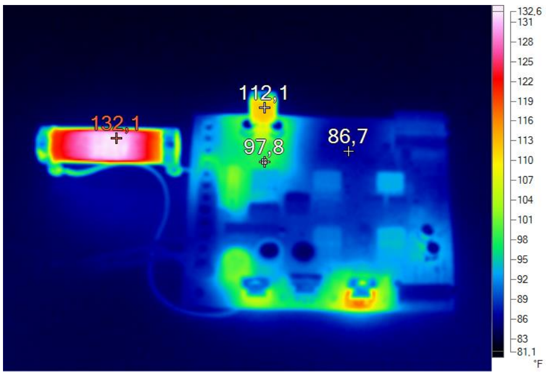


Fig. 10. Thermographic image of the tested board under load

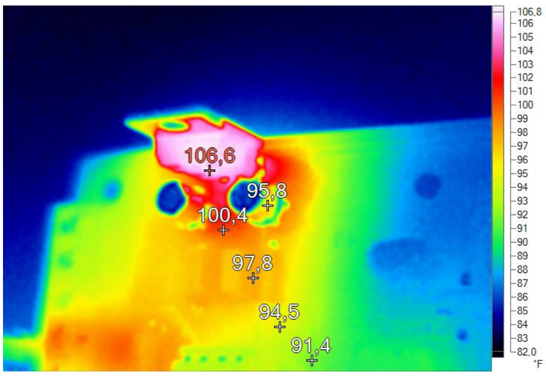


Fig. 11. Thermographic image of the tested component under load

Conclusion

Thermal imaging diagnostics make it easy to detect, document, and analyze faults. It also helps to investigate electronic and electrical devices, highly supports circuit and product design and the implementation of development opportunities. This paper proposes some useful design recommendations for reducing power consumption in the area of embedded systems and hybrid circuits. The measurement of the power dissipation is also more comfortable with the proposed thermal imaging technique than using an in-circuit, real-time power meter.

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