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Designing and Modeling of an Infrared Scene Generator Using SMD Resistor Arrays for Use in the Simulator of Hardware in the Loop

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Abstract: Infrared scene generator produces thermal images using heated elements. In this study, an infrared scene generator using SMD resistor arrays has been designed and built. The size of resistor array is 50×50 pixels. The temperature resistance control is in current form. The maximum temperature and the radiated power of one pixel of the array reach 43°C and 50 mW, respectively. Different patterns and images were sent to infrared scene generator for testing. The images were displayed by infrared scene generator. Finally, electro-thermal behavior modeling of one pixel of the resistance array has been done in various fields. This modeling has been done with Software PSPICE. The results of the modeling are shown in chart. Of results of this modeling can be referred to reduced thermal time constant by increasing the voltage applied to the resistance. The minimum time constant for one pixel is 603.8 msec. Another, result of modeling is that the majority of applied power is transferred to board by conduction. In fact what was expected in the electro-thermal behavior of resistance was accomplished in this modeling.

Key words: Infrared scene generator, hardware in the loop, electro-thermal, SMD resistance array, pixel

INTRODUCTION

Infrared technology in recent decades, considering the modern military and civilian needs has had substantial progress and many researchers are researching in this field. Parallel to these scientific developments in the field of applying infrared detectors in military industries a significant mutation has been occurred and new generations of infrared-guided missile have been produced and used. Currently most of tactical missiles with small dimensions use infrared guidance system (Milnet, 2003).

One of the main subsystems used in hardware simulation system in the missile loop is infrared scene production system. In this system, one resistance or crystal network is used to simulate the infrared image (Zhou, 2009). One of the most widely used methods for the production of infrared radiation is the array of resistive emitter pixels method. In the resistor network method to produce infrared pixels, controlled current flow from one resistance is used. This method has many advantages over other methods. Resistance arrays attract much attention by designers. This is because these pieces have little risk and provide middle performance as well as these pieces can be manufactured in different sizes. In this project design and construction of one prototype infrared scene generator using SMD resistors is done.

MATERIALS AND METHODS

The hardware in the loop: The hardware simulator in the loop simulation is a kind of simulation in which one or more subsystems of a closed loop system as hardware and the rest of sub-systems as software models are placed in the simulation loop. The main purpose of the hardware simulation in the loop is the examination of effect of one or more subsystems hardware performance of main system subsystems on the behavior of the entire closed loop system. According to this the hardware simulation for the closed loop is important and in open-loop systems isn't important. In a closed-loop system considering the hardware performance of a subsystem with the size of subsystems are effective on its inputs it is necessary the simulation is done as hardware in loop in order to the performance of entire system in the presence of system's hardware is examined.

Now, the closed-loop system shown in Fig. 1 is considered. As can be seen the subsystems of G1-G3 forming a closed loop and performance of each subsystem effect on its inputs and inputs of other subsystems via the feedback. This means that each of the inputs and outputs of r_1, r_2 and y is proportional to the subsystem performance varies every moment of time and a series of predetermined data can't be used for them. So, in such a system to assess the overall performance of the

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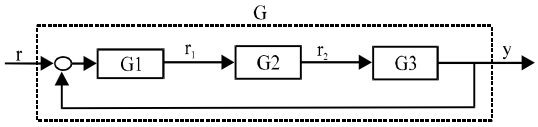

Fig. 1: Closed loop system G

system affected by the presence of hardware of each subsystem it is necessary that the dynamics of other systems had been modeled simulation that this is the same hardware simulation in the loop. Sajjad (2010) the process of design hardware simulation lab in loop has been studied generally.

Infrared scene generator: Infrared scene simulation includes dynamic infrared simulation technology and the production of infrared scene technology. Infrared simulation is performed using the methods resistance array, fluorescent (blazed) liquid crystal tubes, laser researcher the laser diodes array, Cathode Ray Tube (CRT) and Digital Mirror Device (DMD). All mentioned technologies are evolving and progressing. For example, consider a system that demands high dynamic range and high data transfer speed while flashing is not important in this system. In this case the laser diode array can be an appropriate option. While if the data transfer speed was slow, this system would no longer be offered. If infrared scene generator is the type of scanning detector, CRT system is proposed. Infrared seeker dynamic scene simulation technology including infrared technology and dynamic simulation technology is the infrared scene.

The simulation technology of dynamic scene of infrared seeker includes the simulation technology of dynamic infrared and production technology of infrared scene. The infrared scene stimulator is a device that can convert image signals to infrared images. Optimal performance to simulate infrared scene includes features such as high-speed, real-time the high temperature differences between different parts of the image, high resolution, appropriate broadband, lack of flicker, image consistency and low cost of the construction and maintenance (Zhou, 2009).

Infrared scene generators with SMD resistors: SMD stands for surface mounted devices. These devices use SMT technology. This technology is known as surface mounting technology. All the devices which are made with this technology are mounted and soldered on printed circuit board superficially. These devices have small dimensions and this is an advantage. These devices in most of today's portable devices and devices that are present in a limited space are used. Almost can be said for any type of electronic device there is also its SMD type. The SMD resistance in infrared scene generator is used because of some features such as small size, easy installation, similar to the structure of the thin film resistor array the availability and cost-effectiveness. Figure 2 shows the general structure of a SMD resistance of thin film.

Table 1: The size (dimensions) and tolerable power of various SMD resistances

Packages	Length (mm)	Width (mm)	Height (mm)	Watts
0402 (1005 metric)	1.0	0.50	0.35	0.100
0603 (1608 metric)	1.6	0.80	0.50	0.100
0805 (2012 metric)	2.0	1.25	0.50	0.125
1206 (3216 metric)	3.2	1.60	0.60	0.250
1210 (3225 metric)	3.2	2.50	0.50	0.500
1210 (5025 metric)	5.0	2.50	0.70	0.750
2512 (6432 metric)	6.4	3.20	0.50	1.000

Considering the SMD resistor size (dimensions) its tolerable amount of power is determined. The greater the resistance of the power it will be more tolerable. Table 1 shows an overview of the size (dimensions) and tolerable amount of power of any resistance.

The arrangement of elements of infrared scene generator: The substrate or substrate which the SMD resistor is placed on it plays an important role in the of infrared scene generator. In the design of structure of this substrate the considerations related to resistance distances, transference of heat and addressing must be taken into account. To have a good and acceptable quality image the pixel or heated resistances distances must be the lowest possible amount. But the distance of resistances shouldn't be so close that cause the thermal interference among resistances. These resistances are controlled as matrix and in row and column form. Figure 3 shows a snapshot of the row and column of a 5×5 a resistance array (Maxfield, 2004).

Diode used in the design is the type of fast. The reason for using this type of diode is fast response time, as well as low voltage drop of this type of diode. Because of appropriate price as well as abundance in the market, LL4148 diode has been selected in design.

Thermal analysis of SMD resistor: Ceramic SMD components (devices) when the current is entered to them, transfer heat through the following mechanisms (Durgin, 2006):

- Radiation
- Convection (if completely sealed or is wholly in outdoor)
- Conduction

Through physical ways and mathematical models can be seen that the majority of heat transfer from resistance

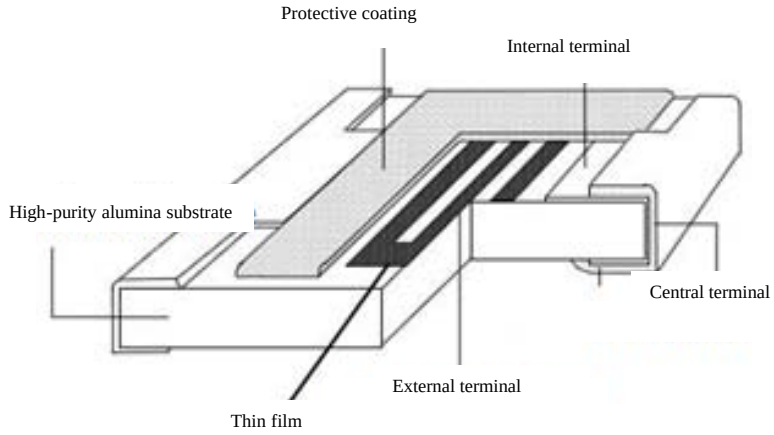

Fig. 2: Structure of SMD resistances

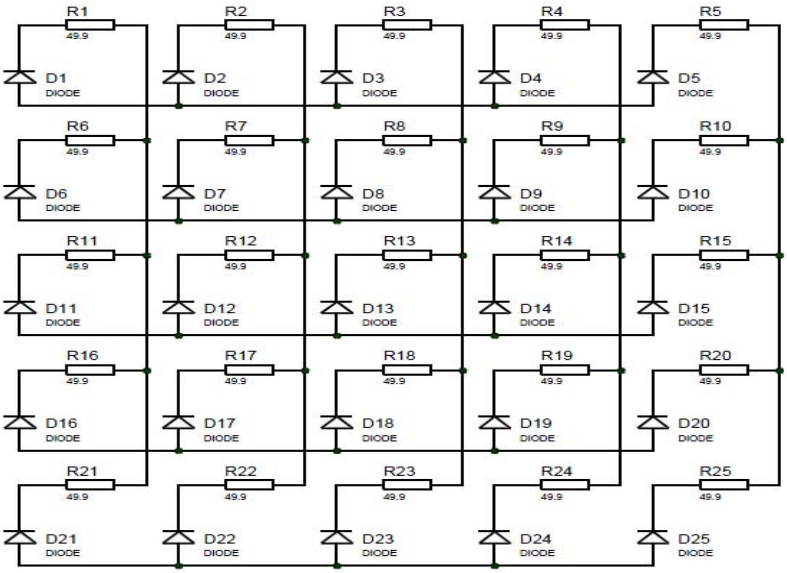

Fig. 3: The arrangement of resistances in the structure of infrared scene generator (Maxfield, 2004)

is the thermal conductivity. This condition is true for SMD resistors as well. In these resistances the majority of heat is transmitted (transferred) through joints of resistance to board. This is mainly because the ceramic parts (components) (such as aluminum, nitrate aluminum, beryllium oxide, etc.) in terms of thermal have good conductivity.

Figure 4 shows the thermal management on a board. It shows that by placing a good thermal path between plots (device) and ground circuits, heat generated by the piece (device) can be transmitted well. Of course this thermal ground should be kept at a constant temperature. In this case, this thermal ground acts as a heat sink. It should be noted that this path and intended ground aren't exist naturally. What should be done to thermal management is that the paths and thermal ground be thick enough to food thermal transfer. According to the foregoing and the information available it is known that the thermal conductivity of SMD components should be increased. This is because with this thermal performance (and thus the overall performance of RF) of SMD devices is improved. Of course, this is regardless of the substance of the overall circuit substrate layer.

The control circuit: The control circuit of infrared scene generator is composed of three main components of sending and receiving information, main process and the conduction of rows and columns. The main chip which is used to control the pixels of infrared scene generator is FPGA (Field Programmable Logic Gate Array). The FPGAs

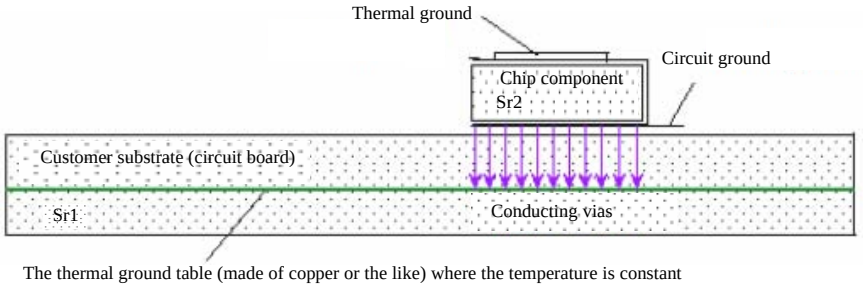

Fig. 4: Generating thermal ground tablet on the board with SMD resistance

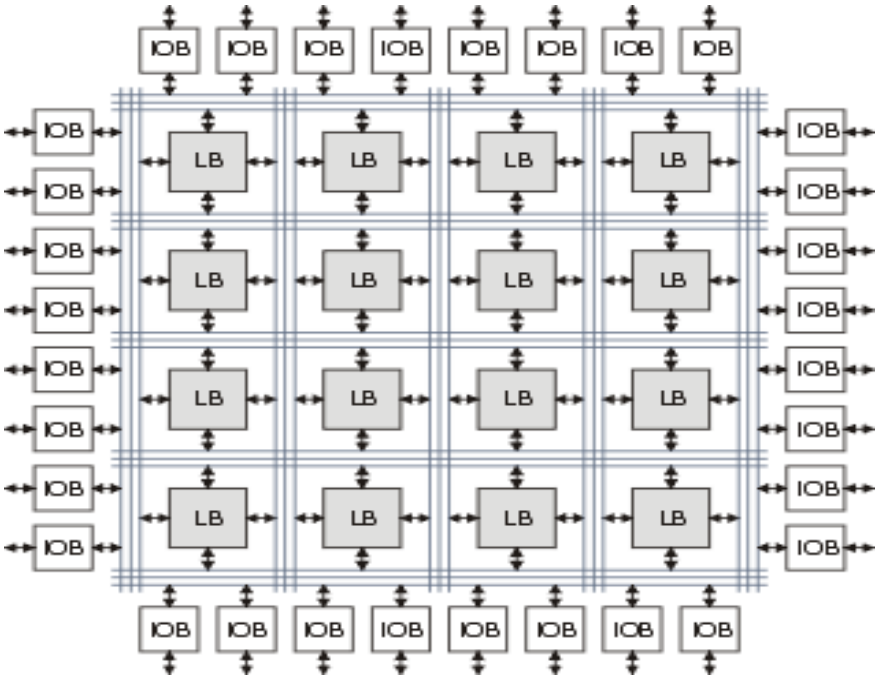

Fig. 5: The block diagram of an FPGA

are new generation of programmable digital integrated circuits which are used as central processing unit. The rate of logic functions in FPGAs is very high and in nano seconds. If we want to simply explain the FPGAs are a chip which composed of a high number of logic blocks, communication lines and Input/Output (IO) bases that are beside each other in an array form. Block diagram of an FPGA simply is shown in Fig. 5 (Jansson *et al*., 1995).

Of course, many logic cells are made based on LUT (Look Up Table) tables. LUT is made of a number of SRAM memory cells that are initialized during FPGA planning. In short LUT is to produce ready-to-use functions to apply in logic cells. There are 2500 pixels in the structure of infrared scene generator that need to be controlled separately. About 50 pixels are in one row of infrared scene generator which must be controlled simultaneously. This needs applying 50 PWM signals at the same time. For the reasons mentioned above the main chip which controls the pixels of infrared scene generator is the type of FPGA. The programming and circuits design with FPGAs are generally performed through two as follows:

- Using hardware description languages such as VHDL, Very High Speed Integrated Circuit (VHSIC) hardware description language), Verilog and ...
- Using the circuit schematic design

Because of the benefits of VHDL language this language has been used as hardware description for FPGA.

VHDL (Hardware Description Language): VHDL is one of hardware description languages. VHDL language was first designed and used by the defense department America to design and describe high-speed integrated circuits. Then in 1987 was presented in a standard format of IEEE 1076-1987 by the IEEE (association of electrical and electronics engineers). After several years and a number of corrections, second standard of this language as IEEE1076-1993 in was presented to people.

RESULTS AND DISCUSSION

Thermal cameras characteristics: TBIR 90 thermal camera to test the infrared scene generator has been used. This camera is a third-generation IR imager made of micro bolometer detectors of amorphous silicon which research in the 14-8 range. Figure 6 and 7 show the appearance of this camera. To transfer images from this camera to computer ADVANTECH converter DVP 7010B model has been used. This output converter turns video of the camera to digital and transfer to a computer. This converter has a program that is installed on the computer. With this app the images sent by thermal camera can be records and stored.

Testing phase: In this study, firstly information (data) is transmitted by computer to control circuit. The data (information) is transferred to serial port and from there to the FPGA. The FPGA chip is programmed by VHDL. The control circuit on the printed circuit board fiberglass with

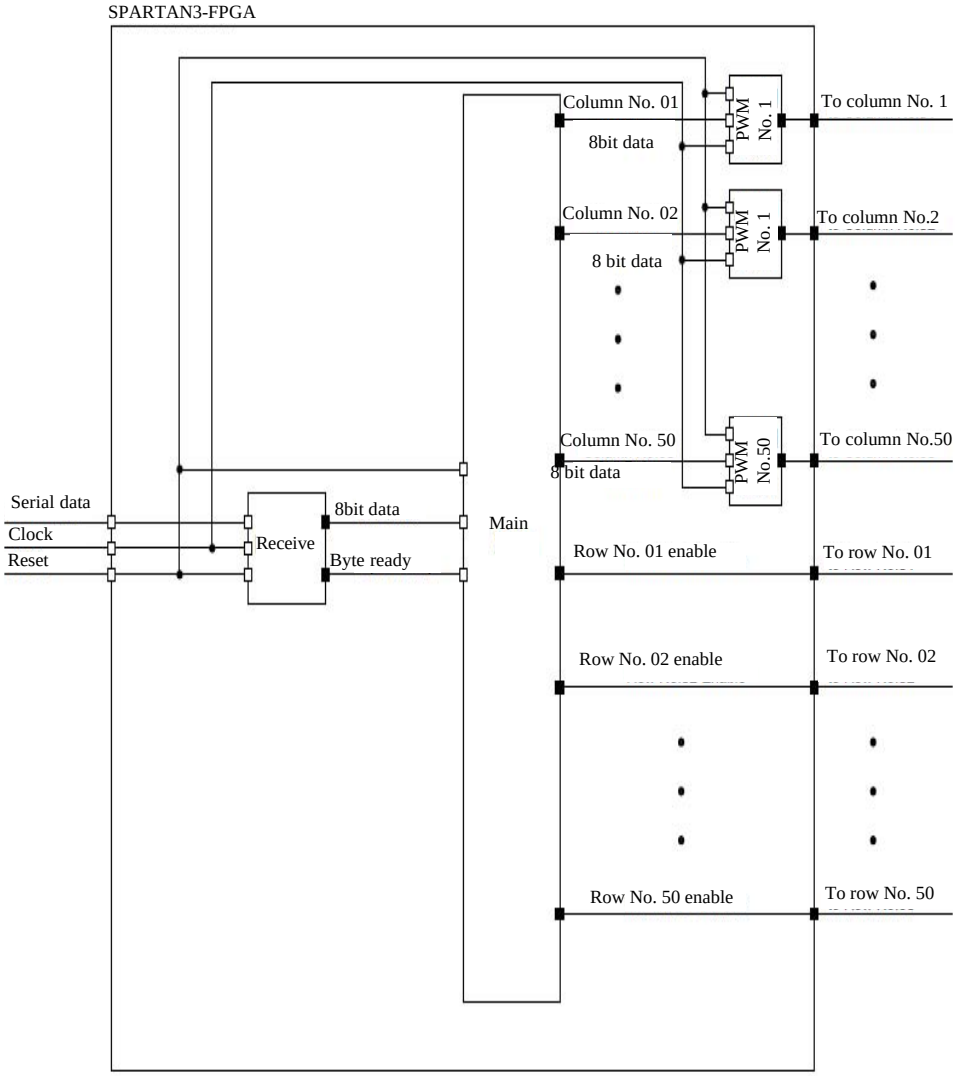

Fig. 6: Overall circuit schematic implemented on the FPGA

Fig. 7: TBIR90 Thermal camera appearance

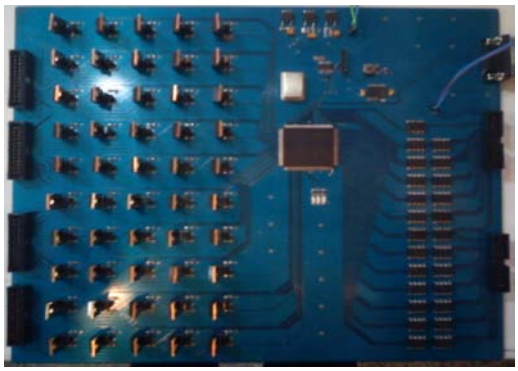

Fig. 8: Appearance of control circuit

copper thickness of 0.35 mμ has been implemented. Figure 8 shows the appearance of built control circuit. Figure 9a shows 50×50 resistance array. The connection between the control circuit and resistance array using flat cables has been established. Final test was conducted using a thermal camera. The placement of resistance array must in front of the camera is such that firstly the distance with the camera to proper coverage should be observed (Fig. 9b). This distance depends on the characteristics of the camera. The minimal distance for thermal camera of laboratory is equal to 2.3 which have been obtained empirically. If the camera distance to infrared scene generator is more the camera must be adjusted to the new distance. This is done using the possibility of adjusting the lens of the camera. After setting the distance the back of resistance array which can be seen in images should be uniformed to not affect the original image. This has been carried out in the laboratory by a wooden plate on the back of resistance array on the table. If the camera has a zoom feature is not required to do so.

After proper placement of resistance array in front of camera, turns to the final stage that is testing the infrared scene generator. To test infrared scene generator a simple triangular pattern to display has been used. Figure 10 shows this pattern and reconstructed pattern on the infrared scene generator.

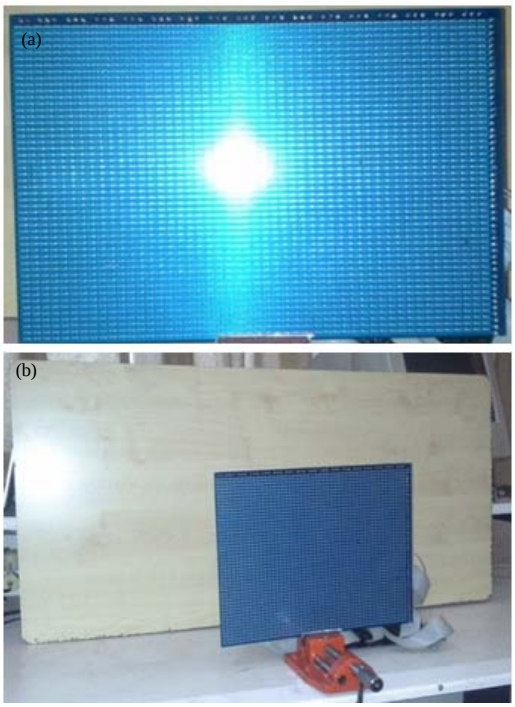

Fig. 9: a) Appearance of main resistance array and b) Placement of main resistance array in front of the camera

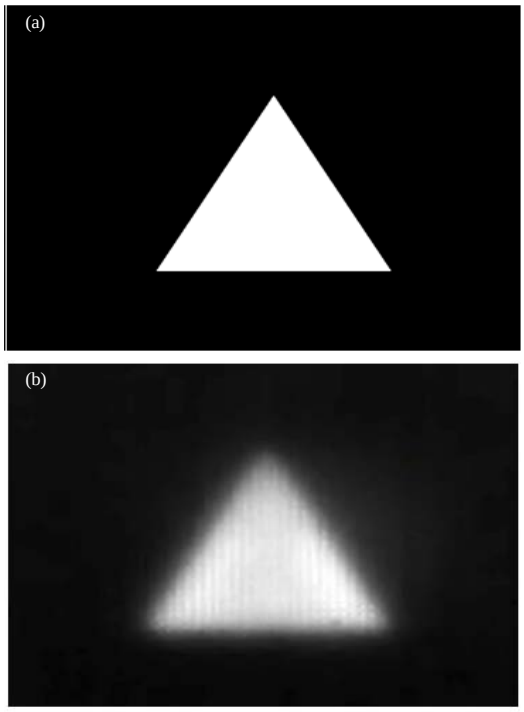

Fig. 10: a) Square pattern, original image and b) Reconstructed image

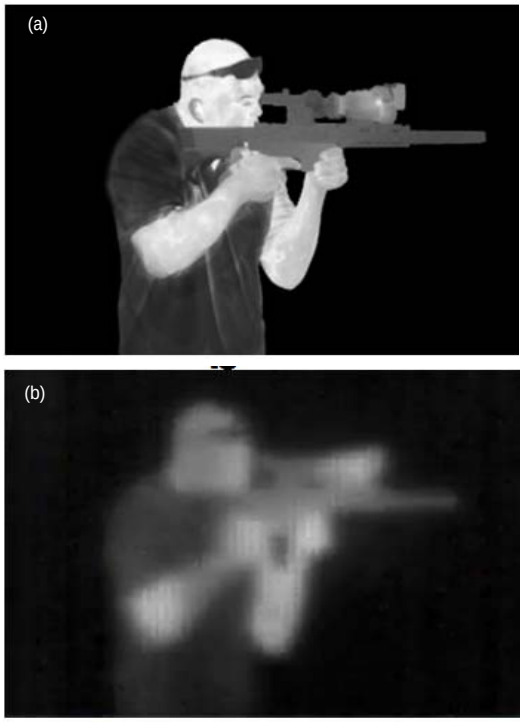

Fig. 11: Human being in shooting; a) Original image) and b) Reconstructed image

As it can be seen this model has been implemented satisfactorily by infrared scene generator. Following in order to test the performance of infrared scene generator, normal infrared image of a man being shot (Fig. 11a) was sent to the generator that reconstructed image is obtained for as Fig. 11b.

Modeling of infrared scene generator: In order to more accurate examination of infrared scene generator its modeling has been performed using the electric model. As seen in Fig. 12 each pixel of infrared scene generator with a MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) and series diode and is controlled by applied voltage of PWM signal.

According to the current that passes through each pixel, a certain amount of heat is released. This heat by conduction to the board and radiation to the environment (according to the formulas in Chapter 3) is transferred. Considering the low rate of heat transfer by convection, this type of heat transfer has been ignored. The parallel combination of H Heat capacity and Z thermal resistance can provide a pixel thermal behavior (Shie *et al*., 1996; Swart and Nathan, 1992). Figure 13 presents circuit diagram of thermal model. In the absence of convection, heat loss is comprised of two components:

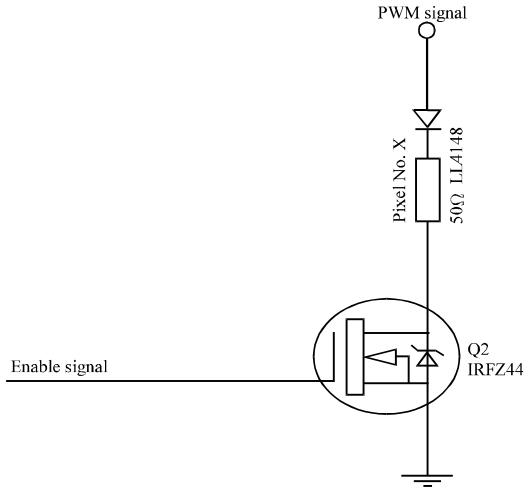

Fig. 12: Overview of a pixel of resistance array

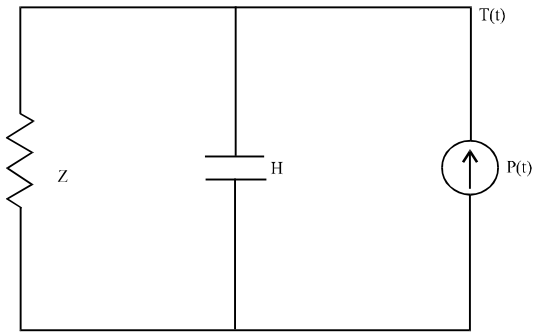

Fig. 13: Circuit diagram thermal model of a pixel of resistance array

- The waste through radiation to the surrounding environment (Q_R)
- The waste through conduction to board (Q_C)

Input Power P (t) is the thermal (heat) which is formed through resistance and due to current passing. This parameter also depends on the amount of electrical resistance. The equation of SMD resistance that provides its thermal behavior is as follows:

$$H\frac{d}{dt}T(t) = P(t) - \frac{\left[T(t) - T(0)\right]}{z} \quad (1)$$

Equation 1, T(0) is the substrate temperature the printed circuit board. This amount in the equation means that the temperature of resistance goes up just because of heat capacity and self-heating P(t). The thermal response of resistance can be modeled by an R_C circuit

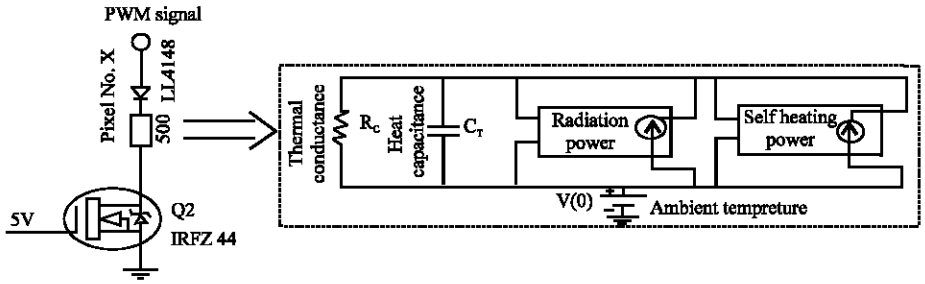

Fig. 14: The electro-thermal model of simulated circuit

Table 2: Equivalent electrical and thermal parameters

Thermal parameters	Electrical parameters
Z (K/W)	R_T(V/A)
H (J/K)	C_T(As/V)
T (t)(K)	V(t)(V)
P (t)(W)	I(t)(A)

(Auerbach *et al*., 1994). This circuit model can be implemented by PSPICE program and its behavior can be analyzed. The equivalent circuit parameters with thermal parameters are shown in Table 2. Following we address the equivalent circuit parameters with thermal parameters which have been used in PSPICE program to model the thermal resistance. Placing the electrical parameters in Eq. 2 the equivalent equation which offers the electric thermal behavior pixels is obtained:

$$C_T \frac{d}{dt} V(t) = I(t) - \frac{[V(t) - V(0)]}{R_T} \quad (2)$$

In Eq. 2 early potential V(0) is equivalent to T(0). As well as C_T and R_T are equivalent to the heat (thermal) capacity and thermal resistance, respectively. Voltage V(t) is equivalent to resistance temperature that is the function of radiant heat the heat directed to the board and self-heating power of resistance. Electrical properties and resistance thermal in PSPISE and using techniques of Analog Behavioral Modeling (ABM) is simulated. The self-heating resistance P(t) depends on passing current from pixel I_B and electrical resistance R(t). Electrical resistance is also a function of temperature. The hart of electrical resistance in terms of temperature is shown in Fig. 13. The self-heating power of resistance is obtained from Eq. 3:

$$P = I_B^2 R(t) \quad (3)$$

The self-heating power presents the thermal behavior of pixel. The value of this power depends on the resistance temperature. From Eq. 3, it can be concluded that self-heating can be presented by temperature-based controlled source. The electrical equivalent of this source the voltage-controlled current source is modeled in PSPICE. Thermal conductivity and thermal radiation are other heat (thermal) parameters that must be considered. Equation 4 puts the electrical equivalent of these parameters:

$$I_C = R_C(V(t) - V(0)) \quad (4)$$

Where:

I_C = Expresses the power conducted to board
R_C = Equal to thermal conductivity or the same kA/d
V(t)-V(0) = Equal to the temperature difference between resistance and board

Radiation or thermal radiation to the surrounding environment is calculated by the Stefan-Boltzmann law. Equation 5 is the electrical equivalent to this law:

$$I_R = \varepsilon\sigma A(V^4(t) - V^4(0)) \quad (5)$$

The temperature equation is obtained through equating of self-heating power with conductive and radiation losses. With the combination of Eq. 3-5 the self-heating power becomes as follows:

$$I_B^2 R(t) = R_C(V(t) - V(0)) + \varepsilon\sigma A(V^4(t) - V^4(0)) \quad (6)$$

Now using Eq. 2 and 5 the simulation of resistance temperature behavior can be done in Software PSPICE. These equations are shown schematically in Fig. 14 and 15. MOSFET gate voltage is considered V5. MOSFET drain current is equal to I_B. Considering the self-heating depends on the temperature also taking into account the parameters of the MOSFET and the diode in the technical information leaflet, simulation process is performed. According to the discussions, Fig. 16 shows an overview of circuit simulation. The I_B current is controlled by the PWM signal. The self-heating power has been simulated by ABM-VCCS. Heat (thermal) capacity and thermal

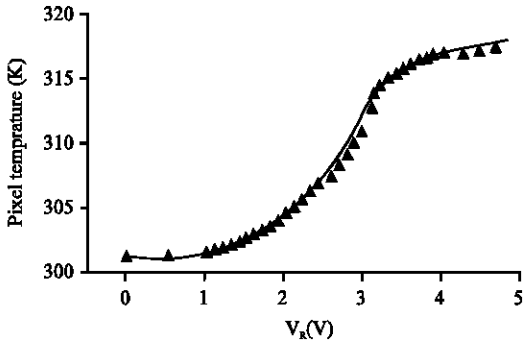

Fig. 15: The resistance temperature changes for changes in input voltage

conductivity to board has been simulated by C_C and R_C, respectively. The radiation power has been simulated by ABM-VCCS using Eq. 5. The environment temperature is with the value V(0). This temperature has been considered equal to 300 K. Changes in the internal circuit voltage in dotted place are the temperature changes. The heat (thermal) capacity is considered equal to 18.86 mF.

In order to validate the simulated thermal model the resistance temperature for different voltages applied to both ends of it have been obtained. First the various voltages have been applied across the resistor then the resistance temperature has been registered with a thermometer in the laboratory. The experimental values are specified in Fig. 15. The obtained values (amounts) in simulation also are specified in Fig. 15. As it observed these simulated and experimental values (amounts) are close each other in a reasonable rate. In Fig. 15, the V_R is the voltage of across resistance.

As seen in Fig. 15 in the high voltage resistor temperature behavior tends to saturation. This is for two reasons: with high currents, voltage drop across the resistor, so that can turn the NMOS from saturation to linear mode. Therefore, the current is limited and the temperature doesn't rise linear. Changes of resistance (resistor) in this temperature range are low. However with rising temperature this change is very low. Therefore, we can conclude that by increasing the voltage the temperature doesn't rise high in linear.

As mentioned in the previous section by increasing the brightness of a pixel the error high rate increases. From the recent chart can be concluded that one of the sources of error in infrared scene generator is non-linear relationship between applied voltage and resistance temperature. In order to better understand the thermal behavior of resistance in terms of speed performance, transient behavior of a pixel of the resistance array has been investigated. Equation 7 shows the thermal time constant and also the calculation of this parameter. The G parameter in this equation with respect to the

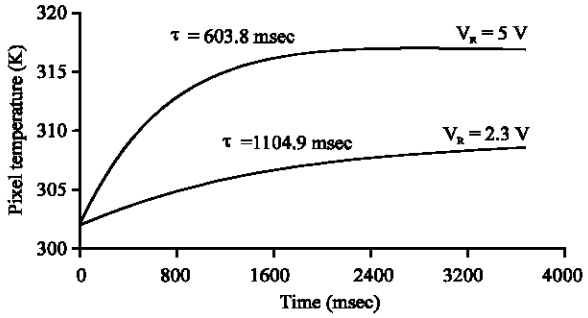

Fig. 16: The plot of resistor temperature changes over time

simulated circuit is the conductivity seen from the capacitor or heat (thermal) capacity. Figure 16 shows temperature changes of resistance over time:

$$\tau = \frac{H}{G} \quad (6)$$

Figure 16 shows the response of simulated circuit. This circuit is a first class circuit. It is observed that the obtained amount for the constant time in V5 mode with Baud Rate used in synchronized circuit. In other words the thermal constant time is close to circuit constant time of infrared scene generator. Figure 16 is considered that by increasing the voltage the time constant of the circuit is diminished. In terms of circuit, this indicates that by increasing voltage the amount of radiation increases and consequently the amount of passing current through the thermal resistance increases. This reduces the resistance of the capacitor and reduces constant time. From the perspective of heat (thermal) by increasing voltage and consequently the operating temperature the thermal resistance and the time constant decrease. Recent graph (plot) shows that simulation can also analyze the transient behavior of a pixel.

The split (division) of input power between conduction and radiation losses in simulation has been also investigated. Figure 17 shows the comparison of the input and output powers in terms of the input voltage. With the increase in input voltage and increasing block temperature, conduction and radiation losses increase. As expected, most of the losses include the conduction losses. These losses (wastes) are transferred to substrate by the connections between the resistance and board.

Using the technique mentioned, electro-thermal resistance can be carried out using the Software PSPICE. The conclusions drawn in the previous sections with experimental results obtained during final testing resistance have acceptable match. In addition the results of transient behavior can be used in order to optimize the

Table 3: Profile (characteristics) of built infrared scene generator

Variables	Values
Infrared scene generator	
Generator type	Resistance array
Array size	50×50
Generator size	30×35 cm
The amount of pixels resistance	50 Ω
Maximum applied power to a pixel	500 mW
The way of pixels control	Current
Maximum temperature of a pixel	43°C
Frequency of renovation of pictures (images)	2Hz
Cooling time	180 sec
Type of generated images	Constant images (pictures)
The maximum radiation of a single pixel	50mW
Minimum constant time of a pixel	603.8 ms
Minimum PSNR of a pixel	37.2 dB

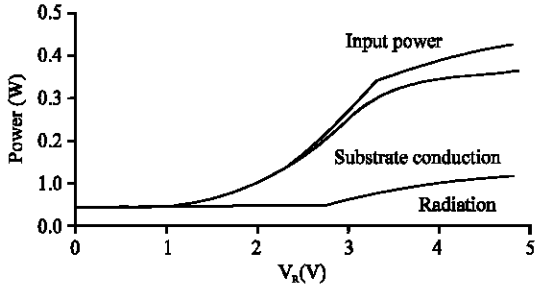

Fig. 17: The charts of comparison of the input and output power based on supply (input) voltage

speed. This simulation can also help in estimating the amount of conduction and radiation losses. This simulation has the capability that can be fully coordinated with changes to the original system. The possibility of extraction various parameters from this simulation and measuring and different amounts allows the designer to apply changes and optimization the design. Table 3 shows in short the characteristics of built infrared scene generator.

CONCLUSION

One important result of this research is the construction and operation of the system of infrared scene generator. This generator was built using resistive array. Different pictures (images) and patterns were observed using a thermal camera.

Using the on-board heat transmission routes such as thermal highways was effective in improving the response of infrared scene generator. The intervals between resistances were appropriate and heat exchange between them didn't taken place. Totally the response of built infrared scene generator was appropriate and satisfactory.

The most important result of this study was the simulation of the thermal behavior of a pixel using resistance (resistor) array be\u the use of Software PSPICE. In the latest section of research, electro-thermal behavior of resistance (resistor) pixel was studied in various fields. The results of this simulation are consistent satisfactorily with the experimental results. The possibility of extraction various parameters from this simulation and measuring and different amounts allows the designer to apply changes and optimization the design. In this simulation, firstly the thermal behavior of resistance (resistor) by changes in input voltage was assessed. Then the transient behavior of resistance was examined. After that the dispersion of losses was simulated through radiation conduction ways and presented as charts.

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