

Development and assembly of Radio Frequency Module using components with SMD technology for educational purposes



Rodrigo Luiz Ximenes¹, Gabriel Duarte Meceneiro¹, Bruno Tavares de Souza Conrado², Leonardo Lorenzo Bravo Roger¹, Talía Simões dos Santos¹

¹Telecommunications Division, School of Technology, University of Campinas, Paschoal Marmo Street, 1888. Jardim Nova Itália, CEP. 13484-332. Limeira, SP - Brazil.

²Academic Department of Mathematics, University of Campinas, Sérgio Buarque de Holanda Street, 651. Cidade Universitária, CEP. 13083-859. Campinas, SP – Brazil.

E-mail: ximenes@ft.unicamp.br

(Received 24 March 2017, accepted 31 March 2017)

Abstract

Wireless communications devices such as mobile phones, tablets, laptops, routers, wireless sensor networking modules, etc. that are subject to a dynamic market that increasingly requires miniaturization. One of the strategies followed by technology to respond to this requirement, has been operating on increasingly radio frequencies, but higher the operating frequency, greater the complexity, not only the theoretical project, but especially the assembly of circuit boards of such devices. Expensive and complex robotic machines are used in industry for soldering components on the boards of the radio frequency circuit. This paper shows the step-by-step development of a radiofrequency module for assembly using an inexpensive soldering furnace developed for such. The experience is described in order to disclose a solution that can be useful for carrying out practical projects in university teaching laboratories, unable to acquire professional assembly machines, due to its high cost.

Keywords: Radio frequency module, SMD components, printed antenna, microcontroller, Printed Circuit Board.

PACS: 84.40.-x, 84.40.Ba, 85.40.-e

ISSN 1870-9095

I. INTRODUCTION

Among telecommunications areas with the highest market dynamics, we find wireless devices, whose technology is based on radio frequency circuits (RF) and microwave printed antennas integrated on the same board. These technologies due to high frequencies in which they operate, have stringent requirements in the assembly of the components on the printed circuit board, as they are very sensitive to parasitic inductances and capacitances present in the welds, the terminals of the components and including within the tracks of the printed circuit. Incorrect installation can cause malfunction or even the non-operation of the device. There are so many challenges in mounting a radio frequency and microwave module that there are specialized companies just to make the installation of RF cards, and the cost of such services is extremely high.

On university places where you have to perform practical demonstrations laboratories, these difficulties can affect the quality of education. As a possible solution to this problem, we shown the sequence of steps for the complete development of a RF module operating in 2.4 GHz, from a theoretical design, simulation, and finally the assembly of all circuit components. The success of the practical

realization of this project was due to the use of a solder oven designed for that purpose.

II. SMD COMPONENTS

The SMD (Surface Mount Devices) technology is one of the latest electronic devices technology developments. As its name indicates, it is designed to make the mounting of components on the surface of printed circuit boards. Nowadays, with this technology, called are produced, SMD components, among which are integrated circuits, resistors, capacitors, inductors, diodes, etc. Are components with their reduced wrappers and their specific welding process does not require the drilling of the board as in previous conventional components of THT technology (Through Hole Technology). The SMD technology increases the mounting reliability considerably reduces the circuit size [1], the parasitic inductances and capacitances present at the terminals of the components and the holes of the plates, but welding of such components becomes a technological challenge often solved with the use of high-cost robotized machines.

In this work we used SMD components with two package types which are: rectangular chips, figure 1 (a) and

QNF (Quad Flat No-Lead), Figure 1 (b). The chips are commonly built into small cubic bodies. Its two terminals are plated by thick film deposition [2]. The QNFs have IC housings of the flat type with connections on its four sides. The terminals are below the component [3]. Notice in Figure 1 the small dimensions between the terminals of the SMD type components and the reduced size of the tunnels, is evident that it is impossible to perform with conventional soldering irons.

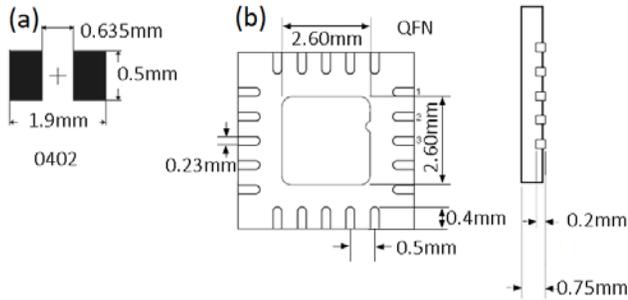


FIGURE 1. Size and dimensions of the components. (a) Rectangular chip and (b) QFN package.

III. RF MODULE

For the RF module used was the nRF24L01, whose functional diagram is shown in Figure 2. This IC (integrated circuit) can be divided into two large blocks. One RF block, which includes a modulator to a demodulator, filters and amplifiers, other baseband block where the data packets received and / or transmitted are processed. This block has a recorder and an external SPI communication output (Serial Peripheral Interface).

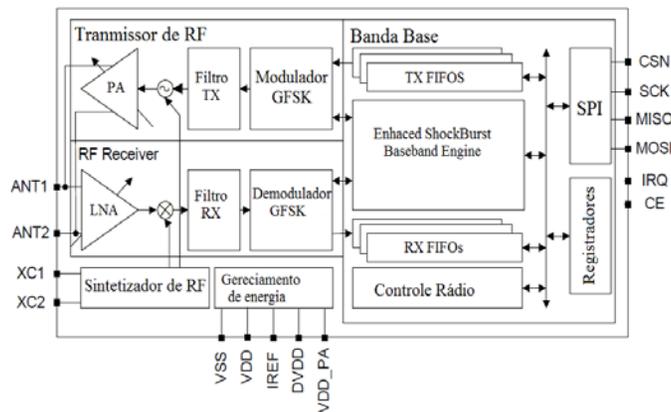


FIGURE 2. Integrated circuit diagram in block nRF24L01 adapted from [3].

This component was chosen for its wide use in many applications of wireless devices because their facilities to

implement functions such as remote control RF, voice transmission over IP (VoIP), low-power sensor networks, active label RFID, among others [3]. This paper proves its use coupled to different embedded systems: one 16F628A microcontroller, one Arduino board and a Freedom k125z. All cases are suggested practices and educational applications that are detailed in Section V.

The RF board proposed in this paper is designed to use a microstrip antenna implemented on a dielectric substrate and coupled to the nRF24L01. This technique allowed the antenna itself to be printed on the circuit board where the IC is mounted. Figure 3 shows the photo card designed to operate at a frequency of 2.4 GHz.

The III-A section provides the details of the developed antenna and its electrical characteristics.

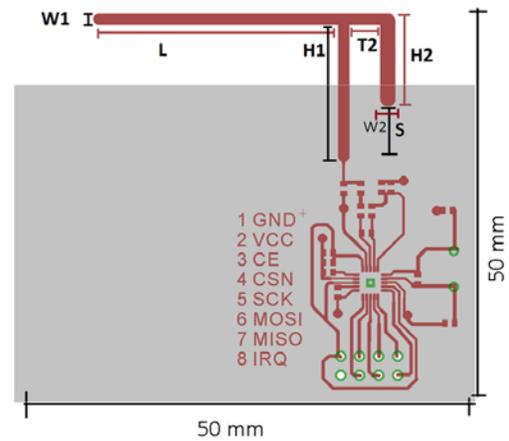


FIGURE 3. Trails RF module board connections.

Table I show the antenna dimensions, and Table II are detailed all components used for the project, including its physical dimensions. The abbreviations Ci, with $i = 1, 2, 3 \dots 9$, refers to capacitors, Li, with $i = 1, 2, 3$ are chip inductors, resistors R1 and R2 are chips U1 is the integrated circuit, and X1 is a piezoelectric crystal. The size 0402 is a code commonly used for chips, the dimensions of which are set out in Figure 1 (a) and QNF20 4X4 size is a package type whose dimensions appear in Figure 1 (b).

TABLE I. Antenna Dimensions.

Name	Size (mm)
W1	1.5
L	28.5
H1	15.0
T2	4.9
H2	14.6
W2	2.0
S	0.4

TABLE II. List of components.

Component	Name	Size	Description
22pF	C1	0402	NPO, +/- 2%
22pF	C2	0402	NPO, +/- 2%
2.2nF	C3	0402	X7R, +/- 10%
4.7pF	C4	0402	NPO, +/- 0.25pF
1.5pF	C5	0402	NPO, +/- 0.1pF
1pF	C6	0402	NPO, +/- 0.1pF
33nF	C7	0402	X7R, +/- 10%
1nF	C8	0402	X7R, +/- 10%
10nF	C9	0402	X7R, +/- 10%
8.2nH	L1	0402	Chip inductor +/-5%
2.7nH	L2	0402	Chip inductor +/-5%
3.9nH	L3	0402	Chip inductor +/-5%
1MΩ	R1	0402	+/-10%
22MΩ	R2	0402	+/- 1%
nRF24L01	U1	QFN20 4X4	
16MHz	X1		+/-60ppm, C _L =12pF

It is important to note that to build this RF module, all steps have been fulfilled: Design, simulation, assembly and operation tests in three practical applications.

A. ANTENNA

The inverted V antenna was chosen because it is widely used in wireless devices. The HFSS software was used to perform the antenna design. With an iterative analysis was possible to find the best dimensions and geometries in order to improve its operation. The radiation pattern in the 2.4 GHz operating frequency can be seen in Figure 4 in 3D and 2D in Figure 5, it is possible to observe good radiation coverage.

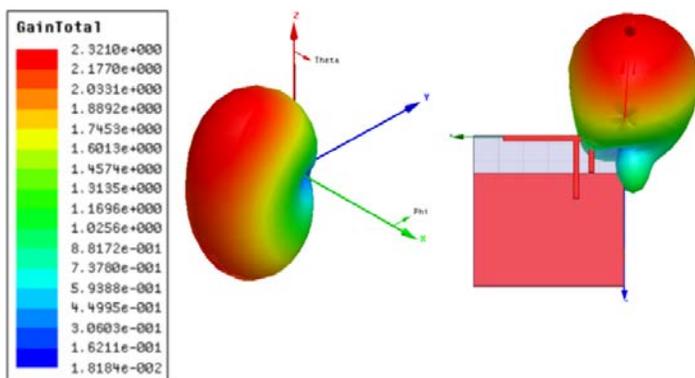


FIGURE 4. Three-dimensional radiation pattern of the antenna printed on 2.4 GHz.

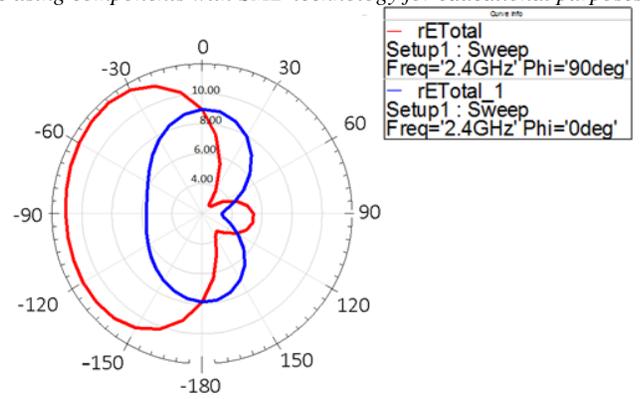


FIGURE 5. Simulation of the electric field at 2.4 GHz.

One important aspect to be considered on the integration of the antenna with the card is the impedance matching between the IC and the antenna input. The project is designed in such a way that the antenna has at its entrance, an impedance of 50 Ω. To evaluate the matching impedance of the antenna with the rest of the circuit we used the S11 parameter that represents the return loss in the antenna input. For practical purposes it is considered that a value of less than -10dB for S11 parameter ensures proper matching to the input impedance, this means a level of reflection at the entrance smaller antenna than 10 times the level of incident signal. Taking into account these criteria, in Figure 6 it can be seen the excellent matching of the antenna in the project's frequency 2.4 GHz.

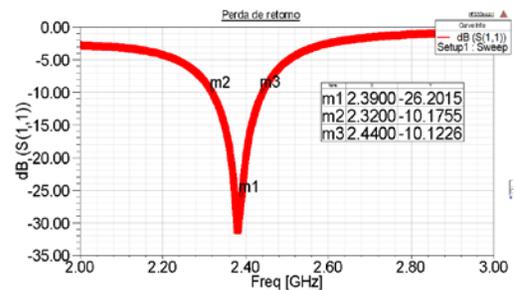


FIGURE 6. Return Loss graph in dB and Frequency in GHz.

IV. ASSEMBLY

This section shows the technique used to mount RF module board.

A. MATERIALS

For the construction of the module with SMD technology, the following tools were used: tweezers, solder paste 63% tin and 37% lead, bracelet / anti-static mat, bench microscope, drill 0.6mm and varnish.

B. TECHNICAL ASSEMBLY

The tracks of connections shown in Figure 3 were printed on the PCB (Printed Circuit Board) using thermal transfer technique and chemical corrosion of copper [4]. A PCB with dielectric constant, $\epsilon_r = 2.2$, loss tangent in the amount of 0.0009, copper thickness of 1/2 oz, height of substrate, $H = 30$ mil, was used. With the board already created, it started the manual assembly process of the components, using solder paste, tweezers and other tools.

The Figure 7 (a) the material for the plate assembly are shown. In Figure 7 (b), there is highlighted in red, one SMD component superimposed above the plate even without soldering. Similarly, in Figure 7 (c) the other components were placed in positions where they should be soldered, as shown in Figure 8 (a). Importantly, prior to placement of the components was deposited solder paste to secure them in their respective above board positions.

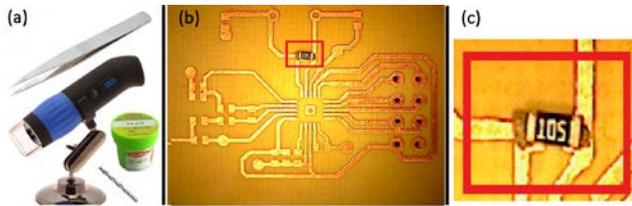


FIGURE 7. (a) Materials used, (b) with the first overlapping plate component even without soldering above the PCB (c) component zoom.

After this process, the plate is brought to a low cost reflow oven, specially designed and constructed in this design to accomplish the welding of SMD components on the board. For the heating furnace developed can choose one of two possible different temperature patterns, as suggested in [5]. Using this technique by reflow soldering furnace, all parts are welded at once. This technique takes advantage of the welding technique with hot air station also used for mounting SMD components, in which components are welded one at a time. For this reason, the hot-air technique is used for maintenance, i.e. in cases where they need to weld component isolated over an existing plate. The RF module already completed all welded components and including the built-in antenna is shown in Figure 8 (b).

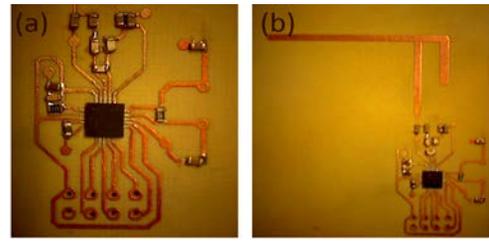


FIGURE 8. (a) RF module with the components fixed only with solder paste (b) RF module to the built-in antenna and welded components.

C. TECHNICAL WELDING

Figure 9 shows the block diagram oven for soldering the SMD electronic components developed in the laboratory.

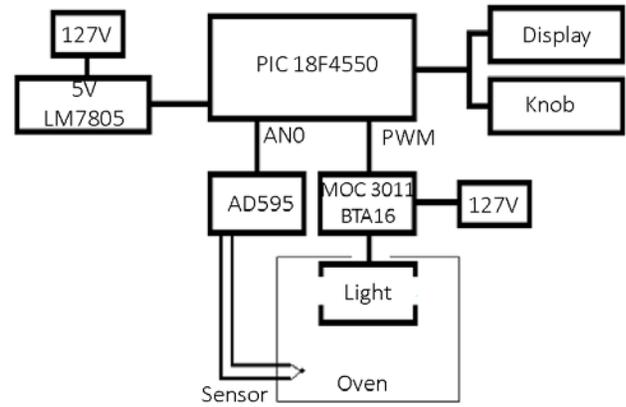


FIGURE 9. Diagram welding oven block.

In the oven are used two halogen lamps for heating, installed in a metal box. The temperature is checked by a K-type thermocouple, and converted through an AD595 circuit [5] which is connected to the microcontroller PIC18F4550 [6] by analog reading pin. The microcontroller is responsible for processing information received from the sensor (thermocouple) and control the PWM (Pulse Width Modulation). The power system consists of the transistor BTA16 [7] and the integrated circuit MOC3011 [8], which was directly linked to the oven lights. A user interface was designed to display on a display welding process from the preheating furnace to the completed weld. The buttons allow you to choose the pattern of temperature with the oven will operate.

The theoretical standard temperature chosen in this design for the welding of SMD components, following standard published in [9], is shown in blue in Figure 10 (theoretical curve). The red curve shows the true behavior of the furnace operation temperature. This curve is lifted from the measurements taken in real time that are displayed on the device display. It is observed that in about 260

seconds one obtains the highest heating furnace. From that moment halogen lamps are switched off and the oven begins to cool slowly without accompanying theoretical curve of cooling. It is important to note that even if the actual curve does not follow the theoretical curve of cooling, the furnace is developed within the range specified in [9] establishing a cooling rate of at most 6 °C/s. A faster cooling can lead to cracking of the welds.

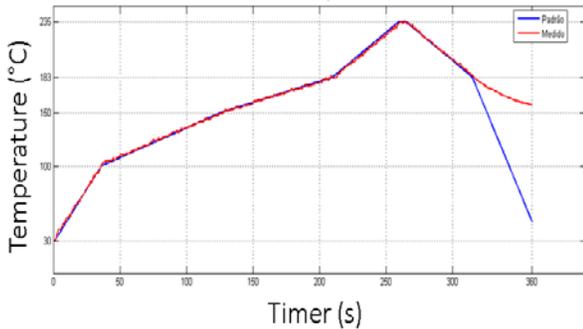


FIGURE 10. Welding curve based on standards.

Figure 11 shows the furnace built in operation.



FIGURE 11. Oven operation.

Visual inspection of welds performed on the card in question was satisfactory, and the integrity of the components was verified with functional tests.

V. RESULTS

In order to validate the mounting, soldering and operation of the RF module made and still show its capability in achieving learning experiments were implemented three different applications. Three types of microcontrollers are the key components that make this distinction between applications. Importantly, the projected module is intended to be a management device and it has no additional feature. Therefore, it is evident the need to use the microcontroller receiving the sensor readings and send via SPI (to set up as

a receiver or transmitter) of the nRF24L01 integrated circuit component. The microcontroller has the function to access the modes of operation, it has the characteristic FIFO (First In First Out) and may access the register maps by 1 byte commands.

For this function and tests, the different microcontrollers used were: PIC16F628A [10] Arduino Uno [11] and a board FRDMKL25Z Freedom [12].

A. TEST 1 - PIC16F628A

Using the RF module developed with a microcontroller coupled to indoor object monitoring applications, connected to the project on a scheduled PIC16F628A to send an object identification code every 15 seconds. In Figure 12 there is the block diagram of the operation of the experiment.

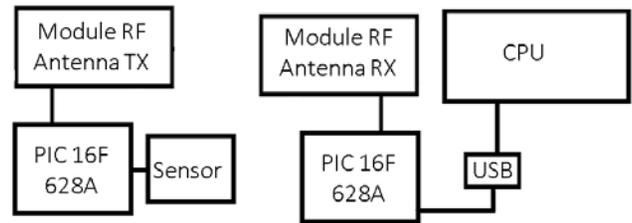


FIGURE 12. Block diagram of operation to monitor indoor objects.

The PIC16F628A not have the peripheral (physical layer) SPI. However, in the software by means of a simple configuration, the SPI protocol is emulated using functions in the firmware.

The microcontroller is connected to the transmitter / receiver module, as shown in Table III.

TABLE III. List of pin connections PIC16F628.

Pin	Name	Funtion	PIC
1	GND	Terra	GND
2	VCC	Power Supply	3.3V
3	CE	Chip Enable RX/TX	Pin 1
4	CSN	SPI Chip Clock	Pin 17
5	SCK	SPI Clock	Pin 18
6	MOSI	SPI Slave Data Input	Pin 2
7	MISO	SPI Slave Data Output	Pin 15
8	IRQ	Interruption	Pin 16

The microcontroller sends the information to the RF module via the SPI, the module is responsible to take the data and send radio frequency through the antenna. In the receiver, the information is received, processed, and with a serial cable converter for USB (Universal Serial Bus), then are stored in a real-time database. Figure 13 shows monitoring in real time graphic objects.

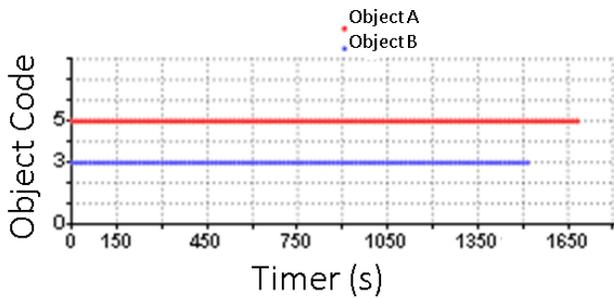


FIGURE 13. Graphic monitoring of two objects in indoor room.

A. TEST 2 - Arduino UNO

The main idea is to test two monitoring the temperature of a site as a supervisory system. For real-time monitoring temperature used the LM35 sensor with a UNO Arduino the transmitter / receiver. The module connections are shown in Table IV.

Table IV. Pin connections list Arduino UNO.

Pin	Name	Function	Arduino
1	GND	Terra	GND
2	VCC	Power Supply	3.3V
3	CE	Chip Enable RX/TX	Pin 9
4	CSN	SPI Chip Clock	Pin 10
5	SCK	SPI Clock	Pin 13
6	MOSI	SPI Slave Data Input	Pin 11
7	MISO	SPI Slave Data Output	Pin 12
8	IRQ	Interruption	-NC-

The LM35 sensor sending information over the analog input of the Arduino, which in turn treats this information, converts the voltage sensor to degrees celsius, stores the maximum and minimum values, and sends this information by SPI through the RF module. The receiving module receives the information and stores on a database. In Figure 14 there is the diagram of complete design. In Figure 15 the graph monitoring real time temperature is shown.

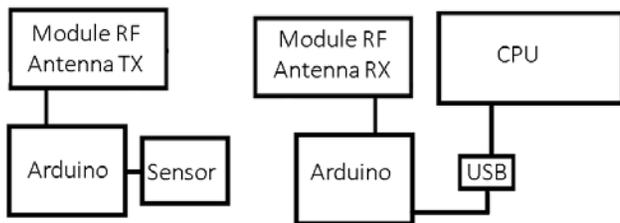


FIGURE 14. Diagram of the functioning blocks to monitor temperature.

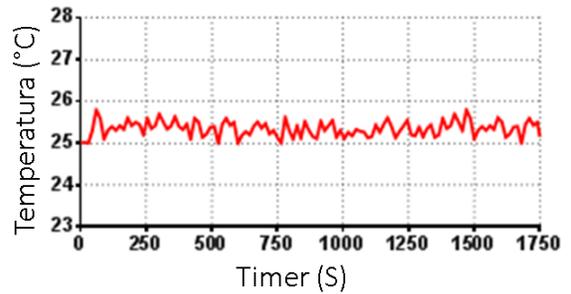


FIGURE 15. Temperature monitoring chart in an air-conditioned environment.

A. TEST 3 - Freedom KL25Z

Another application was held the real-time monitoring of the accelerometer. Connected to a development board Freedom board, which already has the accelerometer sensor coupled MMA8451Q [13].

The accelerometer has the function of recognizing the projection gravity vector in each axis (x, y, z). In Figure 16 there is the circuit block diagram mounted surrounding the transmitter and receiver modules.

In experiment was monitored in a short period of time at 90° rotation around some axis. Figures 17 and 18 show the rotations of 90° about the X axis and around the Y axis, respectively.

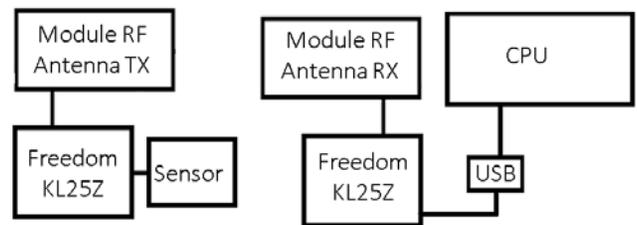


FIGURE 16. Block diagram of operation to monitoring accelerometer.

VI. CONCLUSION

The results showed that the technique used was sufficient for the construction of the RF module is not necessary to improve the technique used. The successful assembly of the RF module SMD components developed was evident with its operation, as is known, the assembly of high-frequency circuits have very stringent requirements and special care. In addition, the developed plate provided sometimes applications in teaching practices within easy reach.

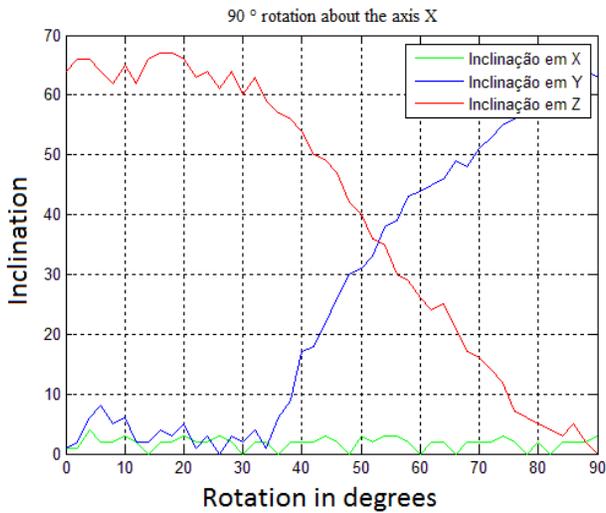


FIGURE 17. 90 ° rotation about the axis X.

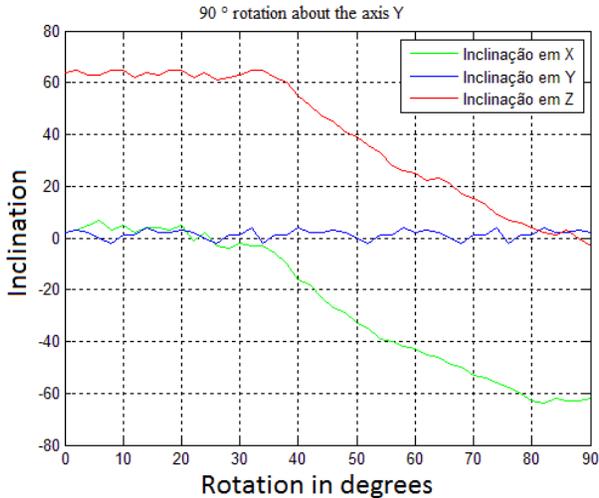


FIGURE 18. 90 ° rotation about axis Y.

REFERENCES

[1] Fratassi, S. R., Reparos em placas com Componentes SMD (Antena Edições Técnicas, São Paulo, 2007).
 [2] Panasonic, Thick Film Chip Resistors, <<http://industrial.panasonic.com/www-data/pdf/AOA0000/AOA0000CE1.pdf>>, visited on August 5, 2015.

[3] Sparkfun, Single Chip 2.4GHz Transceiver nRF24L01 <<https://www.sparkfun.com/datasheets/Components/SMD/nRF24L01Plus Preliminary Product Specification v1.0.pdf>>, visited on August 5, 2015.
 [4] Fazendo suas placas de circuito impresso Técnica de corrosão, <<http://www.ppgel.ufsj.edu.br/uaisoccer/downloads/1272061971.pdf>>, visited on August 5, 2015.
 [5] Analog Devices. Monolithic Thermocouple Amplifiers with Cold Junction Compensation, AD594/AD59, <<http://html.alldatasheet.com/html-pdf/48077/AD/AD595/19/1/AD595.html>>, visited on August 5, 2015.
 [6] Microchip. High-Performance, Enhanced Flash, USB Microcontrollers with nanoWatt Technology-18f4550, <<http://ww1.microchip.com/downloads/en/DeviceDoc/39632e.pdf>>, visited on August 5, 2015.
 [7] On Semiconductor. Triacs Silicon Bidirectional Thyristors -BTA16-600BW3G, <http://www.onsemi.com/pub_link/Collateral/BTA16-600BW3-D.PDF>, visited on August 5, 2015.
 [8] Texas Instruments. OPTOCOUPLERS / OPTOISOLATORS – MOC3011, <<http://www.ti.com/lit/ds/symlink/moc3011.pdf>>, visited on August 5, 2015.
 [9] Joint Industry Standard (USA). Norma IPC/JEDEC J-STD-020D. 1 de agosto de 2007 com revisão março 2008, (JEDEC, Arlington VA, 2008).
 [10] Microchip. Flash-Based, 8-Bit CMOS Microcontrollers with nanoWatt Technology-16f628a. Available in: <<http://ww1.microchip.com/downloads/en/DeviceDoc/40044F.pdf>>, visited on August 5, 2015.
 [11] Atmel. Flash-Based, 8-Bit CMOS Microcontrollers with nanoWatt Technology-arduino UNO, <<http://www.atmel.com/Images/doc8161.pdf>>, visited on August 5, 2015.
 [12] Microchip. 48 MHz Cortex-M0+ Based Microcontroller with USB-Freedom k125Z. Available in: <<http://ww1.microchip.com/downloads/en/DeviceDoc/40044F.pdf>>, visited on August 5, 2015.
 [13] Freescale Semiconductor MMA8451Q, 3-Axis, 14-bit/8-bit Digital Accelerometer, <http://cache.freescale.com/files/sensors/doc/data_sheet/MMA8451Q.pdf?fp=1&WT_TYPE=Data%20Sheets&WT_VENDOR=FREESCALE&WT_FILE_FORMAT=pdf&WT_ASSET=Documentation&fileExt=.pdf>, visited on August 5, 2015.