Sudan University of Science and Technology
Collage of Engineering
School of Electronics Engineering

DESIGN OF SMALL SATELLITE TESTING BED FOR THERMAL CONTROL SUBSYSTEM AND INTERFERENCE IMMUNITY

A Research Submitted in Partial fulfillment for the Requirements of the Degree of B.Sc. (Honors) in Electronics Engineering

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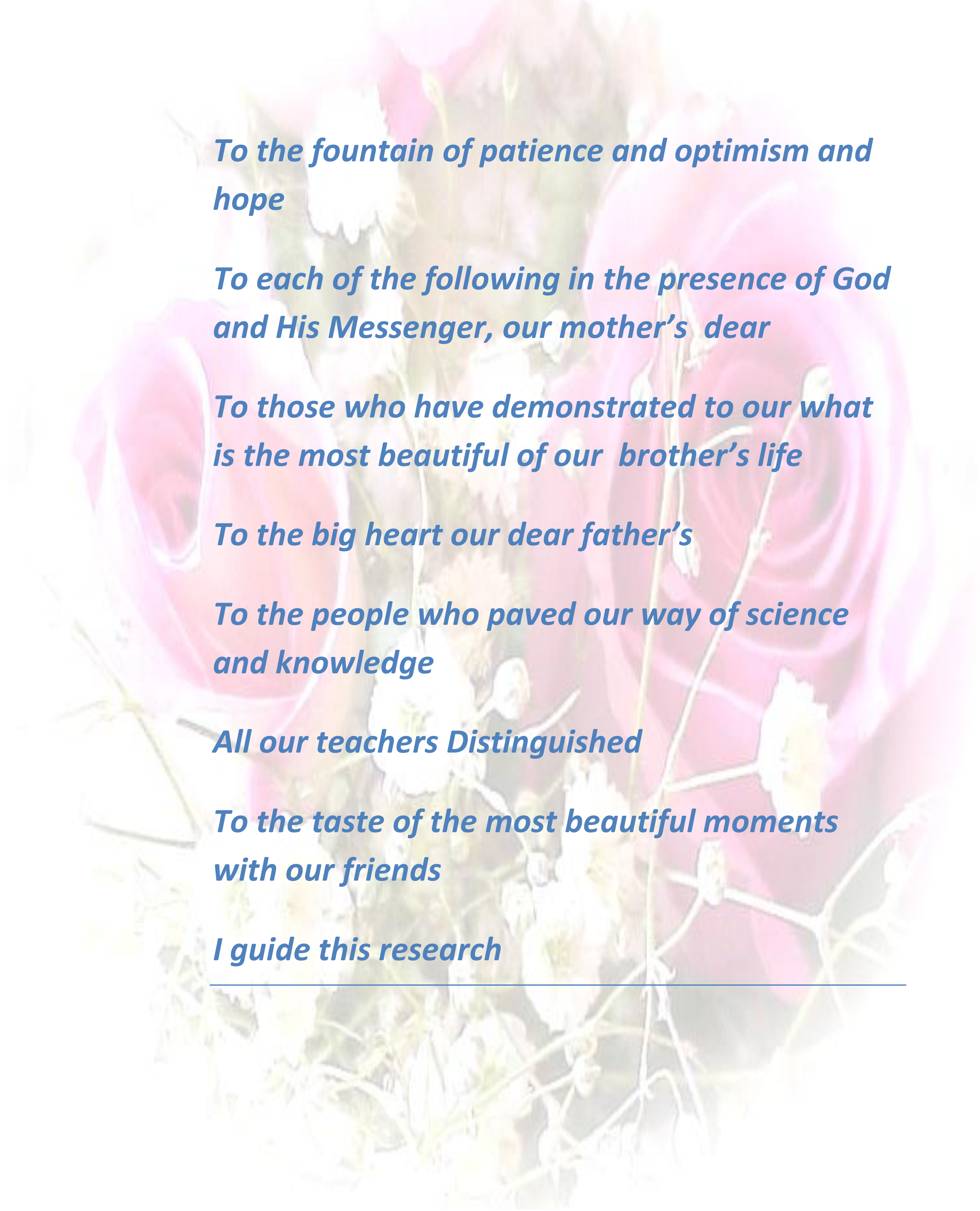
الآيـة

قال تعالى:

{ قُل لَّوْ كَانَ الْبَحْرُ مِدَادًا لِّكَلِمَاتِ رَبِّي لَنَفِدَ الْبَحْرُ
قَبْلَ أَن تَنفَدَ كَلِمَاتُ رَبِّي وَلَوْ جِئْنَا بِمِثْلِهِ مَدَدًا }

صدق الله العظيم
سورة الكهف الآية (١٠٩)

DEDICATION



To the fountain of patience and optimism and hope

To each of the following in the presence of God and His Messenger, our mother’s dear

To those who have demonstrated to our what is the most beautiful of our brother’s life

To the big heart our dear father’s

To the people who paved our way of science and knowledge

All our teachers Distinguished

To the taste of the most beautiful moments with our friends

I guide this research

ACKNOWLEDGMENT

Today, thank God, turn the tiring days and salvation journey between the covers of this work humble.

A beacon of science master of creation to the Holy Prophet Muhammad (peace be upon him).

To the fountain, which does not get tired tender to our mother's that mimicked our happiness woven threads of her heart

To the softest sought to comfort and contentment which he gave something for the batch in the way of success, who taught our that elevated him life wisdom and patience, to our dear father's.

To those who love being in our veins and meditates Newbie their memory, to our brothers and sisters

To every one who taught our letters of gold, and the words of the diamond and they have made their knowledge beacon light the path to success to our teachers honored

We offer sincere thanks and appreciation and respect to Dr. Ashraf Gasim Elsid.

And also thanks go to Dr. Moatman and teacher Ahmad Tag Elser at the Center Esra for Research and Space

ABSTRACT

In this project, we have designed a test environment for the small satellite include some of the factors faced by satellite in outer space , we have focused on two types of tests :the first test is thermal effect test, it was done by using PROTEUS ISIS program, to design the thermal control system we Connect the thermal sensor (LM35) with micro controller And the source of heat and last for cooler and LCD screen In order to test the heat source of the satellite occupy the source of cold and when testing the cooling source of the satellite occupy the heat source, we used two types of micro controller : ARDUINO UNO which programmed by ARDUINO IDE and re-test using ATMEGA 16 programmed by Micro C language because this language compatible with all micro controllers. The second test is interference immunity test, it was done by measuring the shield effectiveness because when shield effectiveness of some devise has a high value that mean this devise has a high immunity from electromagnetic interference, we used MATLAB program because it has excellent feature for plotting that determines the exact value of shield effectiveness of Metal that was used in the Shield manufacturing , and also helps the designer to choose a new shield because it is plotting and compares between the values of the shield effectiveness for a number of metals to choose the best among them.

المستخلص

في هذا البحث قمنا بتصميم بيئة اختبار لقمر صناعي صغير تشمل بعض العوامل التي يواجهها القمر الصناعي في الفضاء الخارجي ، وقد ركزنا على نوعين من الاختبارات :هما اختبار التأثير الحراري وتم ذلك باستخدام برنامج PROTEUS ISIS وذلك لتصميم نظام التحكم الحراري بتوصيل حساس حراري من نوع LM٣٥ مع متحكم دقيق و مصدر للحرارة واخر للبرودة وشاشة عرض ، ولكي نختبر مصدر الحرارة للقمر الصناعي نشغل مصدر البرودة وعند اختبار مصدر التبريد للقمر الصناعي نشغل مصدر الحرارة استخدمنا نوعين من المتحكمات وهما ARDUINO UNO المبرمج بواسطة ARDUINO IDE وتم اعادة الاختبار باستخدام ATMEGA١٦ المبرمج بلغة MICRO C لان هذه اللغة تتوافق مع كل المتحكمات الدقيقة و تعطي خيارات اوسع . الاختبار الثاني هو اختبار منع التداخلات الكهرومغناطيسية وتم ذلك بقياس تاثير الدرع وذلك لان قيمة تاثير الدرع للاجهزة عندما يكون كبير ذلك يعني ان لها حماية عالية ضد التداخلات الكهرومغناطيسية ، استخدمنا برنامج ماتلاب الذي يوفر خصائص ممتازة في عملية الرسم الذي يحدد بشكل دقيق قيمة تاثير الدرع للمعدن المعين المستخدم في صناعة الدرع ، وايضا يساعد المصمم في اختيار درع جديد وذلك لانه يرسم ويقارن بين قيمة تاثير الدرع لعدد من المعادن لاختيار الأفضل من بينهم .

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ABBREVIATIONS

TCS	thermal control system
ADCS	attitude determination and control system
IEEE	institute of electrical and electronic engineer
EMI	Electromagnetic interference
GEO	geostationary earth orbit
TTC&R	Tracking, telemetry, command and ranging
RFI	radio-frequency interference
Smallsats	small satellites
Nanosats	nano satellites
Cubesats	cube satellites
MLB	Motorized Light Band
UNP	University Nanosatellite Program
FM	frequency modulation
AM	amplitude modulation
CCDs	charged-coupled devices
SCOE	Special Check-Out Equipment
CCS	Check-Out System

OCOE	Over all Check-Out Equipment
GPS	global position system
IDE	integrated development environment
LCD	liquid crystal display
PC	personal computer
MGT	money grabbing trolls
ACS	attitude and orbit determination and control system
MOST	Micro variability and Oscillation of Stars
MLI	Multi-layered Insulation
ESA	employment and support allowance
ESTEC	European space research and technology
VHDL	vhsic hardware description language

LIST OF SYMBOLS

SE = Shielding Effectiveness
A = AbsorptionLoss
R = Reflection Loss
C = Re - Reflection Correction Factor

Γ = two - boundary reflection coefficient

r = distance from electroomegnatic sourse to shield

l = shield thickness
f = frequency
μ_r = permeability
g_r = conductivity

CHAPTER ONE

INTRODUCTION

1.1 Introduction:

Long-range electronic communications adopted in the sixties of the last century either on cable or on the reflection of radio signals from the atmosphere. Know that these cables contain a specific number of wires, while the reflected signals were extinguished quickly. This makes a very bad communication so that scientists have proposed the idea of using satellites in order to increase the effectiveness of electronic communications Satellite is complex object launched into space to perform specific tasks, the satellite spins around the earth by specific speed that inversely proportional with the distance between the satellite and the earth. It’s provided by precision electronic devices and it is supports by the solar cells to provide him by electrical power necessary for the operation. Satellite put in his orbit by rocked.

The first satellite launched by soviet on 1957, called sputnik1 it burred after 92 day, in 1958 the first satellite lunched. The first satellite for communicating lunched in 1960 called ech1. Unlike the past satellite technology where bigger size meant more functionality, technology Development since 1990 has been greatly affected by miniaturization and nano-technology that resulted in performance increase while the space components continued to decrease in size. Accordingly, many countries are focusing their efforts on smaller satellites under the motto of “Faster, Cheaper, Better" that can perform missions traditionally assigned to medium/large satellites in the past.1 In particular ultra-small satellites have the advantages of being able to perform as a test bed for new systems and core space technologies to be applied to space programs, for much lower cost, shorter schedule, and less risk. For this reason, the world leaders in space technology, including the U.S. and Europe, are focusing much effort in research and development of ultra-small satellites. Satellite have many benefits, they are used in meteorological, communication between the human, TV broadcasts, air navigation and military espionage.

1.2 Problem statement:

The cost is the main problem to design satellite that perform the required mission successfully. The consist of electronic devices which require test for efficiency evaluation accurately.

1.3 Objective:

The aim of this project is to simulate of small satellite testbed.

The objectives from this project are:

To Simulate thermal control system. To develop Arduino code for controlling thermal sensor. To develop MATLAB code to simulate metal shield for electromagnetic interference immunity.

1.4 Methodology:

In this project, the space environment of the test bed should be emulated under the condition of the high terminal radiation and zero gravity. The test bed should be controlled by PC and proper interface is required for data analysis.

The main tests are:

1) Thermal effects on the satellite structure "Mainly on the transmitting and receiving antennas".

2) Electromagnetic interference immunity. For thermal effect a hard sensor with an interface circuit is required, and for the interference reduction a metal shield should be designed for isolating the satellite structure for RF signals.

After making these tests the efficiency of transmitting and receiving of the satellite should be measured to decide if the satellite is acceptable or not to be lunched to the real space

1.5 Thesis out line:

This research includes five chapters as illustrated in the following:

First chapter includes a brief introduction about the satellite (importance, developing and objective). Second chapter includes more details about satellite components and development of it and how operating third chapter includes the methods of testing for satellite with making the space environment emulated under the condition of the high terminal radiation and zero gravity , testing should be making to the thermal effect on the satellite structure and electromagnetic interference immunity . Chapter four includes the practical result for designing and testing also includes figure and calculation. Chapter fifth includes on the summary conclusion for research, also include recommendation for some aspects discovered later that is not possible to add to the research that may be added in others development for this research

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction:

The use of small and microsatellites for Earth observation, communication, navigation and Science missions are increasing. It is generally accepted that small satellites have a mass less than 1000 kg; anything below 250 kg is considered a microsatellite and anything less than 10kg, a nanosatellite. Advancing technology in domains such as electronics, computer systems, and material science have made small satellites a viable option for space based solutions. The smaller platforms offer advantages such as shorter design periods and lower mass to reach orbit, leading to, in many situations, significantly lower costs [1]. There are several programmers in flight and many planned that have utilized small satellite designs to complete their mission objectives. The European Galileo Programme, for example, will be implementing a global navigation system, similar to the American GPS, which will use a constellation of thirty small satellites (mass of approximately 670 kg).

Orstead is a satellite with launch mass of 62 kg that was put into orbit February 23, 1999.This small satellite carried a payload that precisely mapped the magnetic held of the Earth, Measured the charged particle environment and collected Global Positioning System (GPS) occultation data [2]. These relatively small satellites require unique miniaturized onboard systems, such as propulsion, electric and computer systems that have reduced mass, reduced volume and demand minimal power consumption when compared to their predecessors. The attitude and orbit determination and control system (ACS) is of particular interest as it can be the limiting factor to the applicability of small satellites to certain missions. Small satellites tend to use passive attitude control devices to minimize mass and power consumption as well as increase simplicity of design which lowers cost. Rigid booms, for example, are used to achieve gravity gradient stabilization [3]. Passive attitude control often lacks the pointing accuracy required for many project objectives. The development of reliable miniaturized electronics and low cost computational capabilities has led to the movement towards using active stabilization onboard microsatellites. This allows for higher pointing accuracy which in turn increases the range of missions that can be fulfilled using small satellites.

Active control can be achieved by using magnetic torques which interacts with the Earth’s magnetic field to create and control torque. These actuators have low mass, require low power consumption and are reliable due to their simplicity of design. Active magnetic control has been proposed for satellites ranging in mass from 40 to 200 kg in low Earth orbits with minimum inclinations of 28.5° [3]. Although active magnetic control is possible on its own, generally magnetic torque are used in combination with reaction or momentum wheels to increase reliability and pointing accuracy.

The momentum wheel and magnetic torque configuration was used onboard the Canadian satellite, MOST (Micro variability and Oscillation of Stars), which was launched in June, ' 2003 and has now completed over a year of its mission successfully. MOST was designed to monitor tiny light variations that are undetectable from Earth in stars and extra-solar planets. A similar actuator configuration was also used on Odin, a Swedish satellite which was launched February 20, 2001 for observations of the Earth’s atmosphere and astronomy. As of early 2003, Odin had completed its two year design-goal lifetime successfully [4]. Another example is ChipSat, the Cosmic Hot Interstellar Plasma Spectrometer, which was launched January 13, 2003 and utilized four momentum wheels and three coils torques to maintain its desired orientation. Accurate satellite pointing can only be carried out if the orientation of the satellite and any error that may be present are known. A variety of sensors have been developed for use on satellites to enable the determination of satellite orientation. Satellites can be equipped ' with sun sensors, which determine the satellites position by measuring the angle at which the sunlight hits their photosensitive surfaces, Earth horizon sensors that use the thermal differences between the Earth (hot) and space (cold) to determine the orientation of the satellite, as well as magnetometers that measure the magnetic field and compare it to an' onboard model to determine orientation and orbit.

The magnetometer is lightweight, compact, reliable and robust, making it an ideal choice for microsatellites. It has been shown that satellites equipped with magnetic control algorithms can converge to a stable state with initial errors of hundreds of kilometers and unknown attitude as quickly as a couple of orbits [5]. The magnetometer is dependent on an accurate model of the Earth's magnetic field and measurements can be affected by magnetic storm sand surrounding electronic and metallic equipment.

Even so, there are studies that have shown accuracies in positioning within 1-2 km and 0.25 degrees using only magnetometer data [5].Many satellites have taken advantage of the Earth's magnetic field for attitude determination. Two Czech missions, APEX and Active, had components (or sub satellites) Magion-2 and Magion-3 respectively that used magnetometers as the sole source of attitude information.

These satellites showed an orientation determination accuracy of 5° [6]. To increase and ensure accuracy, satellites are generally equipped with a variety of sensors. The increased amount of input data to the systems flight code can prove to be a challenge to process. Multiple sensors are often reading the same information with variable degrees of accuracy and the flight code must be able to compute an estimate that is based on all the information. Moreover, sensors can be susceptible to external perturbations, such as abnormal fluctuations in the electrical equipment or solar flares, and certain sensors Cannot output information throughout the entire mission; for example, sun sensors cannot provide measurements during eclipse periods. Hence, the flight code must be able to handle redundant, possibly erroneous, missing and noisy data while still providing an accurate estimate of the spacecraft attitude and orbit.

One algorithm that is used regularly among satellite control system designers to estimate the system properties is the Kalman filter. The Kalman filter was first developed in 1960 by R.E. Kalman as a way to handle problems that involve the separation of random signals from random noise and the detection of signals of known form in the presence of random signals [7].This filter uses a dynamical model for the time development of the system and a model of the sensor measurements to obtain the most accurate estimate possible of the system states using a linear estimation based on present and past measurements [7]. The Kalman filter was initially used in linear estimation, but was soon adapted for nonlinear orbital guidance and navigation problems, showing impressive results as early as 1967 [8].

2.2 Background:

Important Satellite’s Equipments:

2.2.1 Transponder:

A transponder is the series of interconnected units which forms a single communications channel between the receive and transmit antennas in a communications satellite.

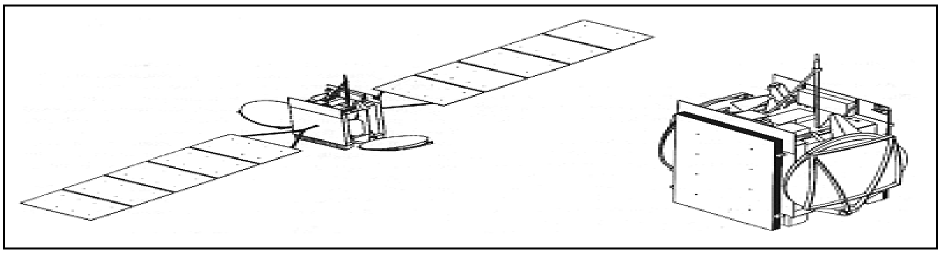


FIGURE 2.1: The transponder

In telecommunication, a transponder is one of two types of devices. In air navigation or radio frequency identification, a flight transponder is a device that emits an identifying signal in response to an interrogating received signal. In a communications satellite, a transponder gathers signals over a range of uplink frequencies and re-transmits them on a different set of downlink frequencies to receivers on Earth, often without changing the content of the received signal or signals.

A communications satellite's transponder is the series of interconnected units that form a communications channel between the receiving and the transmitting antennas. It is mainly used in satellite communication to transfer the received signals.[9]

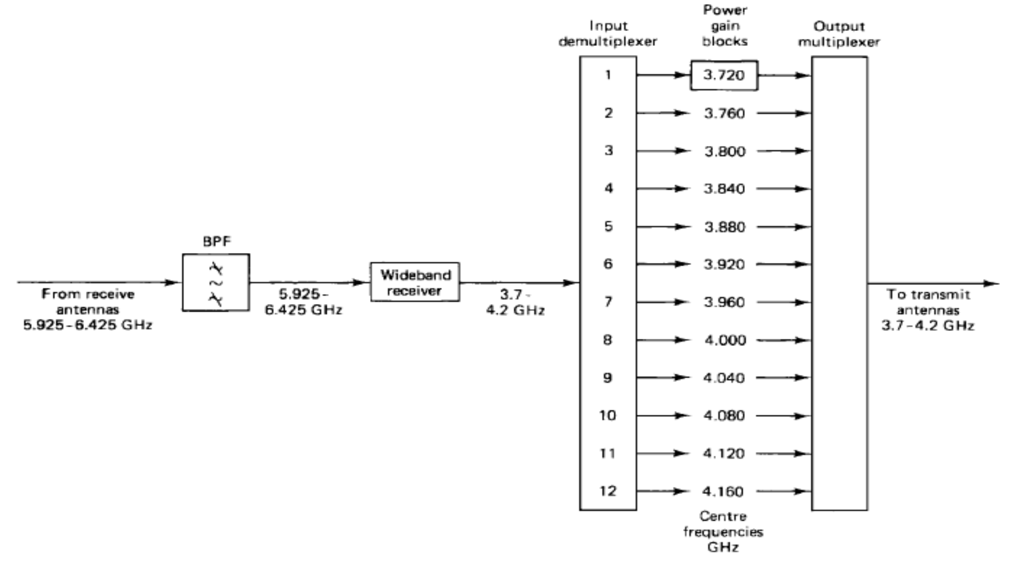


FIGURE 2.2: Transponder's channels

2.2.2 The Power Supply

The primary electrical power for operating the electronic equipment is obtained from solar cells. Individual cells can generate only small amounts of power, and therefore, arrays of cells in series-parallel connection are required. Higher powers can be achieved with solar panels arranged in the form of rectangular solar sails. Solar sails must be folded during the launch phase and extended when in geostationary orbit [9].

2.2.3 Thermal Control

Satellites are subject to large thermal gradients, receiving the sun's radiation on one side while the other side faces into space. In addition, thermal radiation from the earth and the earth's Albedo, which is the fraction of the radiation falling on earth which is reflected, can be significant for low-altitude earth-orbiting satellites, although it is negligible for geostationary satellites. Equipment in the satellite also generates heat which has to be removed. The most important consideration is that the satellite's equipment should operate as nearly as possible in a stable temperature environment. Various steps are taken to achieve this. Thermal blankets and shields may be used to provide insulation. Radiation mirrors are often used to remove heat from the communications payload.

2.3 Important Effects on Satellites:

2.3.1 Electromagnetic Interference:

Electromagnetic interference (EMI), also called radio-frequency interference (RFI) when in the radio frequency spectrum, is a disturbance generated by an external source that affects an electrical circuit by electromagnetic induction, electrostatic coupling, or conduction. The disturbance may degrade the performance of the circuit or even stop it from functioning. In the case of a data path, these effects can range from an increase in error rate to a total loss of the data. Both man-made and natural sources generate changing electrical currents and voltages that can cause EMI: automobile ignition systems, cell phones, thunder storms, the Sun, and the Northern Lights. EMI frequently affects AM radios. It can also affect cell phones, FM radios, and televisions. Satellite interference is a major problem that all satellite operators and users face with all the time. Interference is a big challenge avoiding uninterrupted transmission environment and harming both the operators and users.

Harms caused by interference include the tremendous drain on company resources including man power, Degradation of available satellite capacity, and financial impact.

Interference can be categorized into:

•Uplink personnel mistakes human error

• Cross-pole interference caused by misaligned uplink signal in opposite transponders.

- Unknown carriers (Interference source is not identified, rogue carrier)
- Hardware problems
- Adjacent satellite interference
- Terrestrial service interference

2.3.1.1 Cross pole Effect:

Before the transmission, every user must set their antennas to correct polarization alignment. This setting can minimize cross-pole effect however sometimes uplink personnel doesn’t obey the uplink procedures and try to carry its content to the head end immediately causing such interferences.

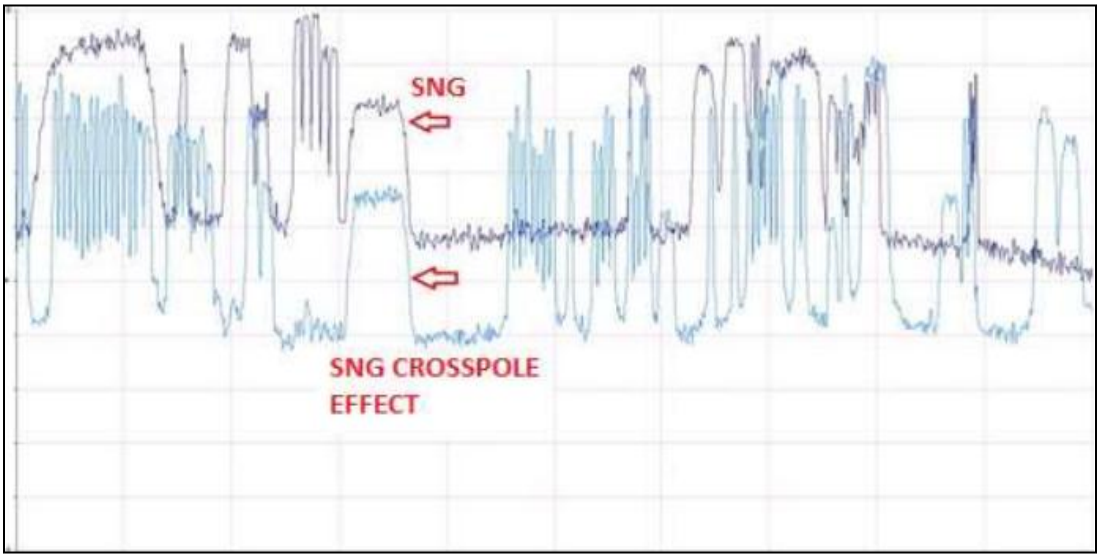


FIGURE 2.3: Cross pole effect

2.3.1.2 Human Error

Uplink personnel may enter incorrect parameters such as center frequency or symbol rate resulting in interference to other carriers.

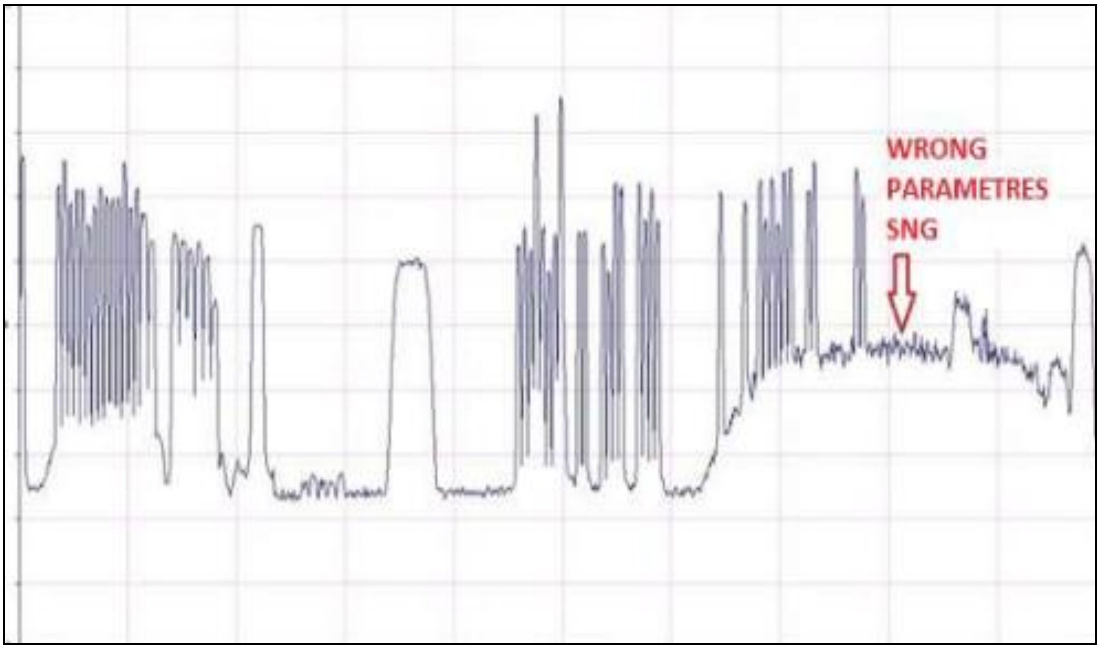


FIGURE 2.4: Human error

2.3.1.3 Equipment Error:

Equipment faults such as malfunctioning of Uplink Power Control systems could cause the carrier to increase its power level dramatically impacting other carriers.

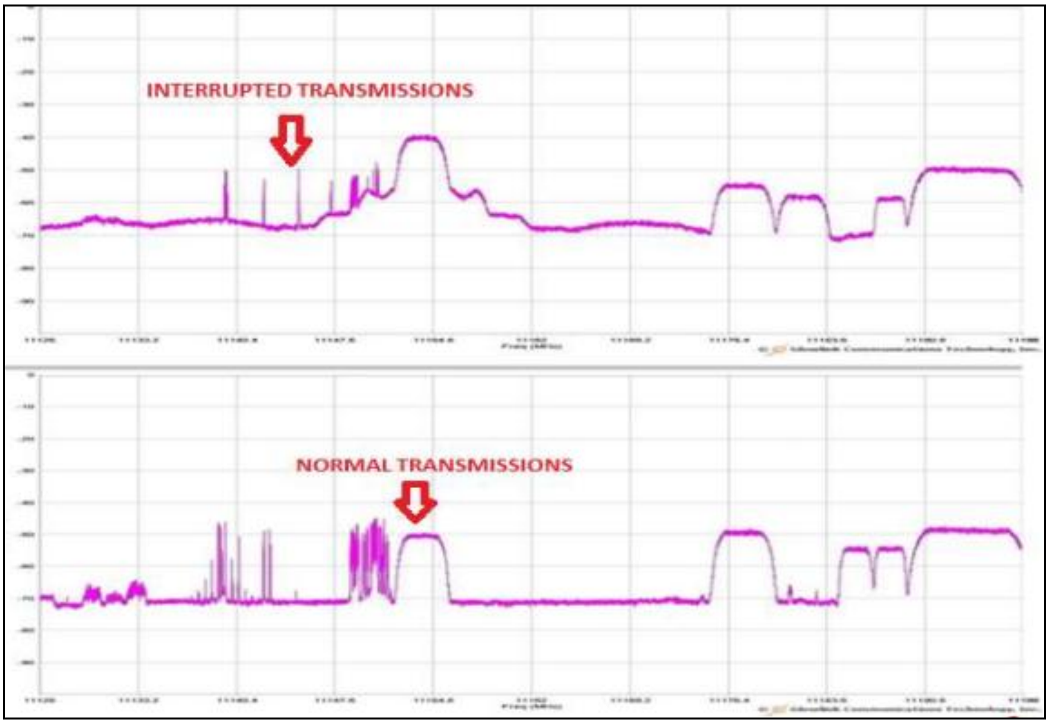


FIGURE 2.5: Equipment error

2.3.1.4 Adjacent Satellite –Antenna Alignment Error:

Uplink systems trying to uplink to a close by satellite may cause interference if the antenna is not aligned correctly to the intended satellite[13].

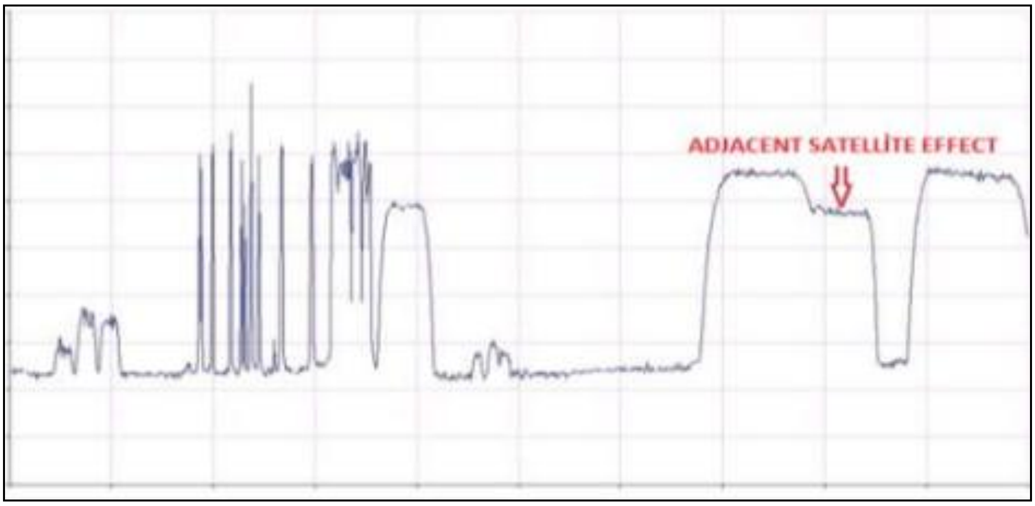


FIGURE 2.6: Adjacent satellite error

2.3.2 Thermal effect:

Designing and modeling an effective spacecraft Thermal Control System (TCS) requires an understanding of the top-level mission objectives as well as the physical interactions between components and their operational environment. The mission objectives translate into the system, assembly and component-level thermal control requirements.

Thermal control is accomplished through a variety of methods both passive and active that are used to maintain component temperatures within their operational or survival range.

Most small and nano-class satellites strive to use passive thermal control. Passive control can be achieved through the use of special surface finishes and proper orientation of heat producing and heat rejecting components. Some spacecraft components their thermal environment an may require additional active control mechanisms to meet their thermal requirements. Active control may be achieved by maintaining a spacecraft's attitude orientation with respect to external heat sources or by using heating and cooling devices to maintain component temperature ranges.

2.3.2.1 Heat Transfer in the Space Thermal Environment:

The thermal environment in space directly impacts a spacecraft's performance on-orbit by controlling how energy, in the form of heat, is transferred to and from a spacecraft. operating in the thermal-vacuum environment of space negates convection making conduction and radiation the dominant modes of heat transfer in space. Conduction and radiation heat transfer obey both the first and second laws of thermo-dynamics. The first law requires that the rate of energy transferred into a system be equal to the rate of energy leaving the system such that there is a conservation of energy. The second law states that energy will be transferred in the direction of decreasing temperature [10].

These laws are implemented through the general heat-transfer equation which includes both the internal and external sources of heat.[11]

2.3.2.2 Thermal Margin

A thermal engineer's primary responsibility is to ensure that component temperature requirements are met throughout all stages of the satellite's operational lifecycle to include:

Launch separation, commissioning, normal operations, safe modes, and decommissioning. To accomplish this task the thermal engineer must accurately project the worst case hot and cold temperature range for the spacecraft. All spacecraft components have a survivable and operational temperature range and exceeding either at the wrong time can be detrimental to the mission. Modeling a spacecraft's on-orbit thermal response is a critical risk-reduction step in the design phase. With all of the simplifying assumptions used in thermal modeling and the uncertainties associated with thermal analysis in general, it is nearly impossible to fully characterize

a satellite's on-orbit thermal response. Adding margin to the TCS design is an essential means of risk-reduction [11].

2.3.2.3 Material Properties

Spacecraft thermal control relies heavily on the material properties of each component on the vehicle. Two general categories to consider are the material's thermal and optical properties. The thermal properties primarily affect how the material conducts heat while the optical properties affect how the material radiates heat. Both are extremely important and should be considered throughout all levels (component through vehicle) of the satellite design. While conduction only accounts for _ 30% of heat transfer in space, selecting a material with the right set of thermal properties can be extremely beneficial for distributing, storing, or isolating heat. Radiation accounts for the other _ 70% of heat transfer which means that the material's optical properties play a significant role in the spacecraft's thermal performance.

2.3.2.4 Thermal Properties

Most satellite missions strive to achieve thermal control through passive techniques. Aside from component placement and mounting configurations, passive thermal control is usually attained through proper material selection [11]. Some components such as batteries and electronics prefer cooler temperature ranges but have a tendency to get hot during normal operations. Highly conductive heat sinks or radiators are used to distribute the heat to other parts of the satellite or to conduct the heat toward a radiating surface. At the other extreme are components such as ion engines that are required to operate at high temperatures. Insulating materials would be used to maintain the operational temperature range and to protect neighboring components from the effects of such high temperatures. In both of these cases conduction is the primary mode of heat transfer. Cooling a component such as the batteries or electronics requires an increase in the rate of heat transfer Q_{cond} away from the component. This can be accomplished by either selecting a material with a high thermal conductivity such as aluminum, beryllium, or copper or by increasing the cross-sectional area of the heat sink or radiator. These conductive materials generally have lower specific heat and higher densities than their insulating counterparts5. Insulators are chosen for their low thermal conductivity which will minimize the amount of heat conducted through the material.

It is often difficult to gauge the exact thermal property values for aerospace materials. Fortunately, the Aerospace Corporation has compiled a fairly comprehensive list of aerospace material thermal properties in the Spacecraft Thermal Control Handbook [11].

2.3.2.5 Optical Properties

Radiation to and from a component is highly dependent on the optical properties of the surface finish. Some surface finishes are highly emissive and are used to radiate heat away from a component while others are highly absorbent and are used to draw energy into a component. Utilizing a surface finish's optical properties is the best way to achieve passive thermal control. Components such as the solar arrays are designed to face the Sun for power generation. Inevitably excess heat will be stored on the arrays raising their temperature and degrading their performance. Cooling the arrays is often done by applying a highly emissive coating such as Z93 white paint to the back side of the array. Other components such as the charged-coupled devices (CCDs) used for imaging sensors, are required to operate in a very narrow temperature range. Wrapping the CCD in a Multi-layered Insulation (MLI) blanket will provide insulation by dampening the rate of heat transfer to and from the device. These examples depend on the emissivity (£) and absorptivity (α) of the surface finish. Unfortunately the emissivity and absorptivity are very difficult to determine because they depend heavily on dynamic factors such as the surface texture and temperature of the material as well as the direction and intensity of the incident light. Several key assumptions are used in determining the spectral emissivity and absorptivity for most aerospace surface finishes [12].

2.3.2.6 Small and Nanosat Thermal Control Systems

The primary objective of the TCS is to keep the spacecraft's components within their required temperature range throughout their lifecycle. Most components are given two temperature ranges; operational and survival. The operational temperature range is the most stringent range that must be maintained while the component is operating to achieve its intended performance. The survival range is the temperature range associated with the non-operating phase of a component's lifetime and provides the maximum and minimum temperatures the component can withstand without being rendered inoperable. Most components are designed to operate nominally at room temperature 273 plus or minus 30 Kelvin. Mission constraints may require a particular to component to remain either extremely cold or extremely hot, or even to maintain a very narrow temperature range in order to minimize shock due to thermal cycling.

2.3.3 Earth Gravity:

The Zero Gravity Research Facility at the NASA Glenn Research Center in Cleveland, Ohio is a unique facility designed to perform tests in a reduced gravity environment. It has successfully supported research for the United States manned spacecraft programs and numerous unmanned projects. The facility uses vertical drop tests in a vacuum chamber to investigate the behavior of components, systems, liquids, gases, and combustion in such circumstances. The facility consists of a concrete-lined shaft, 28 feet (8.5 m) in diameter, that extends 510 feet (160 m) below ground level. A steel vacuum chamber, 20 feet (6.1 m) in diameter and 470 feet (140 m) high, is contained within the concrete shaft. The pressure in this vacuum chamber is reduced to 13.3 Newton per square meter (1.3×10−4atm) before use. The service building at the top of the shaft contains a shop area, control room, and a clean room. Assembly, servicing, and balancing of the experiment vehicle are accomplished in the shop area. Tests are conducted from the control room, which contains controls for the "pump down" of the vacuum chamber, the experiment vehicle pre-drop checkout, release and the data retrieval system.

2.4 Satellite Test Systems:

A spacecraft and its payload must be able to withstand the extreme stress which occurs during the launch phase, and, once in orbit, the rigours of space environment. To make sure that the spacecraft works as planned, every single element of the vehicle as well as the completely assembled spacecraft itself must be tested on the ground under conditions simulating those it will face in space. This type of testing is carried out at test centre facilities either at ESA / ESTEC or at the satellite manufacturer's. Testing is very extensive and calls for automated test equipment that helps to shorten test durations. This so-called Special Check-Out Equipment (SCOE) is usually provided for each subsystem of a satellite and must be operable under remote control from a Central Check-Out System (CCS) or Overall Check-Out Equipment (OCOE) controller as well as in standalone mode via a local user interface.

2.4.1 SMALLSAT TEST OVERVIEW:

- **Small satellite testing demand:**

Presently, the smallsat design tends to use standardized, modular, serialized concept, formed the satellite observation, posture/orbit control, communication, management/signal processing, energy and so on many modules. Their relative independence, becoming subsystem, and through field bus connection, constitutes the network on the star, forms entire star synthesis automated system of the operational guidance, the autonomous controlling and the information processing.

Smallsat's composition principle and development method set the following request to the satellite testing:

1) The smallsat system is one whole that forms by many constituent unions which has the specific function. They are interact, interdependent, mutual influence and coexist, inalienable with each other. Various part of characteristics as well as coordinated mutually and divert, have formed the whole characteristic. Therefore, the test not only needs to inspect the function, the performance of each constituent, must inspect the mutual connection and restrains between various parts whether to satisfy requests.

2) The smallsat system's testing is a gradually refining process, is one amend process unceasingly. In this process, needs to adjust, changes original good parameter and function. Therefore, the test should establish the testing platform of the ‘flexibility’ interface based on analysis, induction and summary. Satisfies the testing command to the request for increasing, deletion and modification in the test procedure, satisfies the request for parameter change and revision in the test procedure on the star to the order frame and the telemetering downward data frame.

3) The smallsat system's testing is the process which is from ‘part’ to ‘whole’, is the process that both coordinates and diverts mutually. Therefore, the test must have the ‘simulation’ function, coordinates through software and hardware to realize simulation function on the star subsystem. At the same time, can interconnect with the subsystem equipment, realize pays equipment's preapproval; On the other hand, when the independent subsystem in the satellite system cannot normal work (or equipment is not equipped completely fully), when have the influence to the systematic testing, can substitute this subsystem, constructing closed loop run-time system, completes producing and transmitting the star network command, inspecting the running time and matching the logical relation, enables satellite system's development to be in parallel with carrying on.

4) Smallsat's test not only need be suit for the combined test in the laboratory situation, but also must satisfy the stable test under other experimental environment. Therefore, the test must have ‘the configuration’ function, can carry on ‘detach’ and ‘assembly’ to the test module, carries on working by the single computer way or networking way, satisfies the different application situation.

5) smallsat's test is the process which debugs unceasingly, is process which consummates gradually. Therefore, the test must have the function of the ‘data storage’ and ‘historical playbacking’, not only need be able to realize the complete record of the test data, moreover must be able to realize the repeated reproduction of the history test data. It is advantageous with the debugging inspection in

the test procedure, is advantageous with the generalized analysis in the test result.

In brief, the smallsat test must be able to be adapt to request the researching smallsat signal and parameter change and so on; Must be able to inspect and discover various parts' mistake on the star in the subsystem; When the subsystem presents breakdown, can remove the mutual diversion of each constituent, guaranteed that the test continues.

- **Synthetic Test Environment Building Method:**

The commonly used building testing environment's method has three kinds: Software prototype method, hardware prototype method and mixing method.

1) Software prototype method: Constructs the testing environment completely using the software method. The construction testing environment's language has many kinds, for example: C, VHDL, Matlab and so on. The software prototype's method characteristic is the environment construction and revision is quite flexible.

But constructing and the system same prototype using the software needs to spend the very long time.

2) Hardware prototype method: Establishes a set the hardware prototype which equates completely with the system to carry on the test to the software. Hardware prototype construction testing environment is equivalent with system function completely, therefore tests is quite real; But the hardware prototype's simulation is not very convenient, sometimes cannot simulate system's behavior in true environment, for example, GPS correspondence and needs to be able to output the orbital data in the satellite flight process, the static state is unable to obtain the orbital data, therefore it is very difficult in the ground testing procedure to use the hardware prototype to simulate GPS correspondence and the flight behavior.

3) The mixing prototype method: Using method of the combination of the software and hardware to simulate system behavior. Using the multi-purpose gathering card to simulate data interface, using the software to the single plane system behavior to model This methods design is simple, the revision is flexible, may add the function which needs to the system one by one, may also delete the function which do not need. The mix prototype method is the current widespread use construction method.

Figure (2.7) below explain the mixing method of satellite testing.

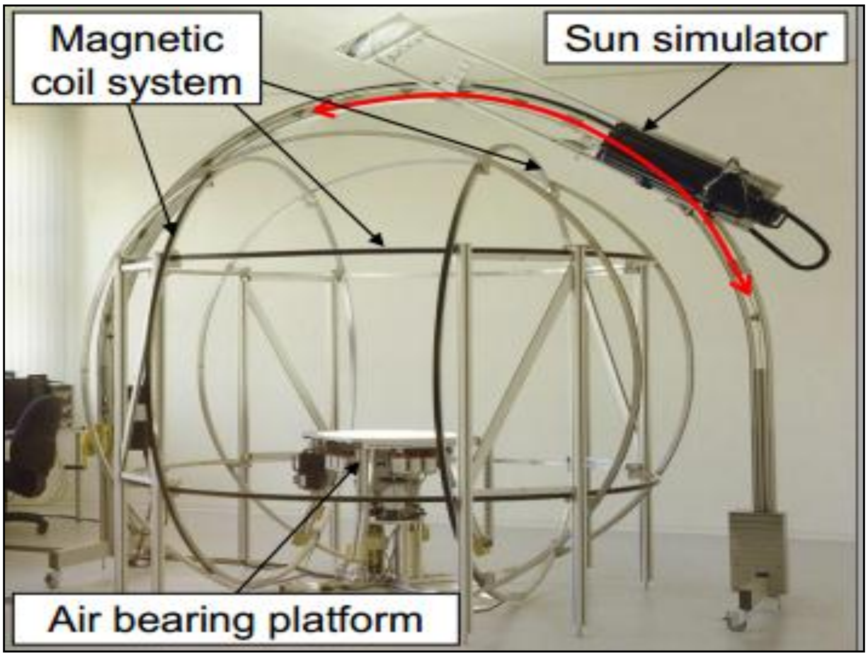


FIGURE 2.7: Small satellite testing bed

2.5 Summary:

The previous discussion can be divided into two main sections, section one explain briefly the communication system, satellite’s types and equipments, and main factors (RF interference, heat, and gravity) that affect on satellite’s performance. Section two shows a general overview of satellite’s testing, including the importance and types of tests.

CHAPTER THREE

METHODOLOGY

This project depend basically on hardware work, but unfortunately here in Sudan there is no attitude determination and control system (ADCS) in all existence satellites, in order that all tests was done by software programs as way as possible.

3.1 Thermal Effects Test:

The function of Thermal Control System (TCS) is to make a particular satellite's equipment "Power supply for example" working in pre-determinate range of temperature. In fact, major of risks came from temperature degrees higher\lower than pre-determinate range which can **damage** satellite's equipments, in order that, main goal of this test is to know if **TCS** has ability to decreasing heat before reaching the maximum upper value of the pre-determinate range, or increasing heat before reaching the minimum lower value of the pre-determinate range.

3.1.1 Test Requirements:

Preparing for test includes software and hardware equipments, as will described below:

Software:

1. Arduino IDE.
2. Atmel Studio.
3. Proteus ISIS.

Hardware:

1. LM35 temperature sensor.
2. Micro controller (here **Arduino uno** and **Atmega16** was used).
3. LCD screen.
4. Thermal source.

5. Cooling system.

3.1.2 Test Setup:

The theory of work depends mainly on **LM35** transistor, which has ability to convert heat to voltage signal, as heat increase as the voltage signal increase.

The LM35 should be connected with micro controller and LCD screen as follow:

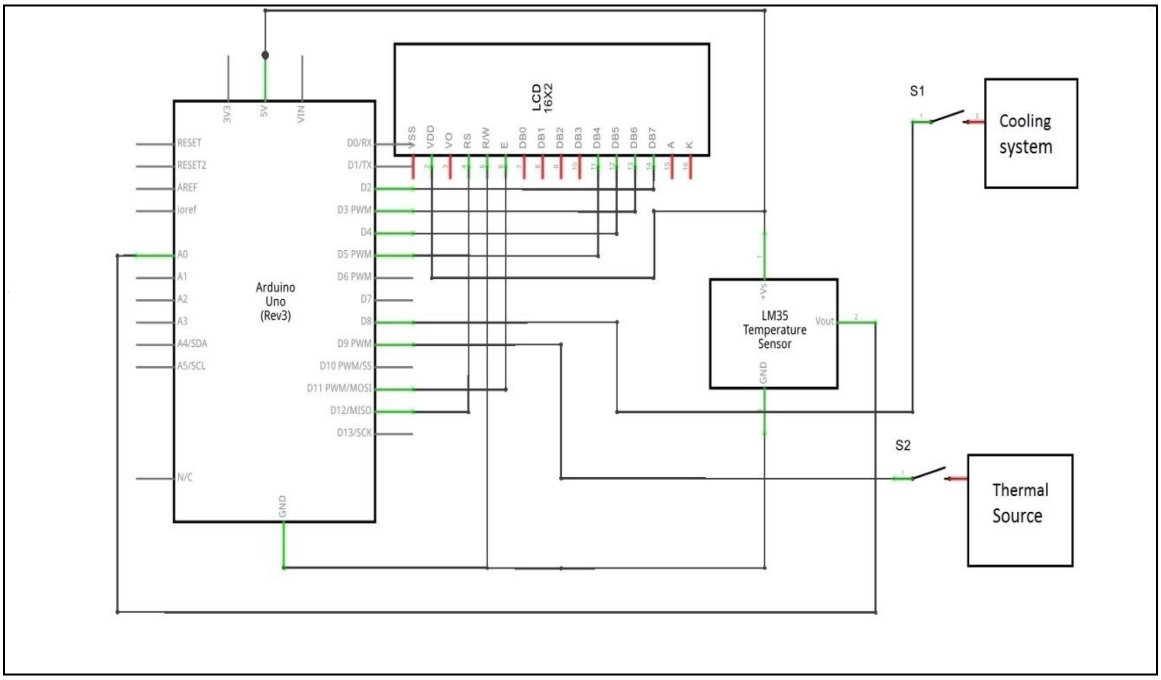
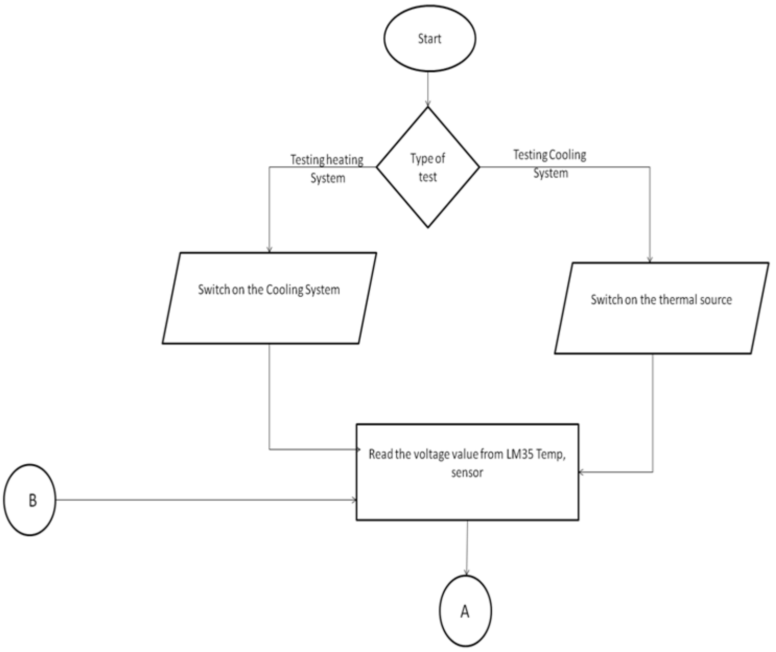


Figure 3.1: Thermal sensor circuit

To establish test, firstly thermal source or cooling source should be switched-on to testing internal cooling\ heating systems respectively.

Signal generated by LM35 would be received by Micro controller where it will be treated by embedded software program to convert voltage signal to temperature degree, and show the results on LCD screen and PC “if it connected to micro controller”. When temperature inside satellite out of range of the reference temperature values, the micro controller take decision to switched-off thermal\Cooling source in order to save components of satellite from damage, and that means as result the Thermal Control system (TCS) of satellite failed. The flow chart of this process described in figure (3.2) below.


Start
Type of test
Testing heating System
Testing Cooling System
Switch on the Cooling System
Switch on the thermal source
Read the voltage value from LM35 Temp, sensor
B
A

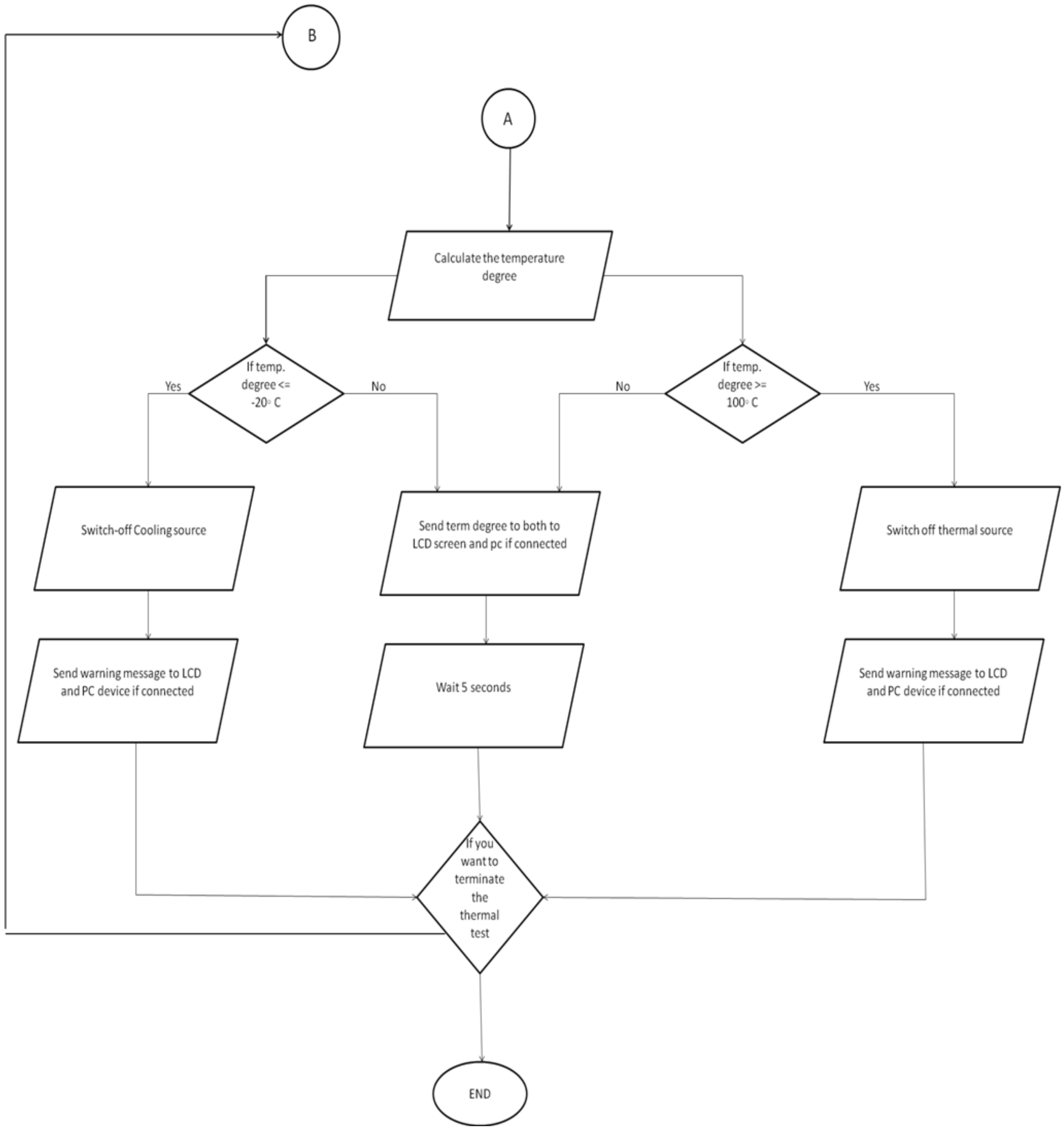


Figure 3.2: flow chart of thermal control system test

The LM35 sensor should be putted inside satellite touching “or few millimeters closest” to target equipment, and wire connect LM35 with micro controller must be tolerate high temperature degrees up to 400° C “for example MGT-1000 wire”.

Notice: this test should be done when satellite fixed, so if Testbed prepared with Helmholtz cage and Air bearing, both of them should be switched-off before set position of LM35 and running micro controller.

See **“Appendix A & B”** for codes of programs to both Arduino uno and Atmega16 respectively.

3.2 Interference Immunity Test:

Measuring shield effectiveness is the best way to make a good test for Interference immunity characteristic, because when shield effectiveness of some devise has a high value, that mean this devise has a high immunity from electromagnetic interference.

In satellites a shield can be used for several tasks:

- To cover antenna.
- Covering initial equipments individually.
- Outer shield for overall satellite, which must has ability to resist the thermal effects.

Shield Effectiveness:

Calculating shield effectiveness depends mainly on metal characteristics because any metal has different response to electric, magnetic, and plane wave fields.

These calculations are only a means to predict the shielding effectiveness of the metal, and should not be considered absolute

3.2.1 Mathematical model:

Measuring shield effectiveness can be done by following equations:

$$SE_{Magnetic} = A + R_{Magnetic} - C_{Magnetic} \qquad (3.1)$$

$$SE_{Electric} = A + R_{Electric} - C_{Electric} \qquad (3.2)$$

$$SE_{PlaneWave} = A + R_{PlaneWave} - C_{PlaneWave} \qquad (3.3)$$

$$\begin{aligned}&\text{SE} = \text{Shielding Effectiveness}\\&\text{A} = \text{AbsorptionLoss}\\&\text{R} = \text{Reflection Loss}\\&\text{C} = \text{Re - Reflection Correction Factor}\end{aligned}$$

Any of these factors can be calculated as follow:

1. **Absorption Loss:**

$$A = K1l\sqrt{(f\mu_r\ g_r)} \quad \text{(in dB)} \qquad (3.4)$$

$$\begin{aligned}K1 &= 131.4 \text{ if (l) is in meters}\\ &= 3.34 \text{ if (l) is in inches}\end{aligned}$$

l = shield thickness

f = frequency

μ_r = permeability

g_r = conductivity

1. **Reflection Loss:**

$$R_M = 20\log\left(\frac{c_1}{r\sqrt{\frac{fg_r}{\mu_r}}} + c_2 r\sqrt{\frac{fg_r}{\mu_r}} + 0.354\right) \qquad (3.5)$$

$where:$

$c_1 = 0.0117 \quad if \quad r \quad is \quad in \quad meters$

$\quad = 0.462 \quad if \quad r \quad is \quad ininches$

$c_2 = 5.35 \quad if \quad r \quad is \quad in \quad meters$

$\quad = 0.136 \quad if \quad r \quad is \quad ininches$

r = distance from electromegnatic sourse to shield

f = frequency

μ_r = permeability

g_r = conductivity

For electric field, the equation is:

$$R_E = c_3 - 10\lg \frac{\mu_r f^3 r^2}{g_r} \qquad (3.6)$$

$where:$

$c_3 = 322 \quad if \quad r \quad is \quad in \quad meters$

$\quad = 354 \quad if \quad r \quad is \quad ininches$

r = distance from electromegnatic sourse to shield

f = frequency

μ_r = permeability

g_r = conductivity

For the plane wave, the equation is:

$$R_p = 180 - 20\log r \sqrt{\frac{fu_r}{g_r}} \qquad (3.7)$$

f = frequency

μ_r = permeability

g_r = conductivity

1.Re-Reflection Correction Factor:

The equation for the re-reflection correction factor, *C*, is:

$$c = 20\log\left[1-\Gamma 10^{\frac{-A}{10}}\left(\cos 0.23A - j\sin 0.23A\right)\right] \qquad (3.8)$$

Where :

Γ = two-boundary reflection coefficient

A = AbsorptionLoss

For magnetic field, the equations are:

$$\Gamma = 4\frac{\left(1-m^2\right)^2 - 2m^2 + j2\sqrt{2m}\left(1-m^2\right)}{\left[\left(1+\sqrt{2}m+1\right)\right]^2} \qquad (3.9)$$

$$m = \frac{4.7*10^{-2}}{r}\sqrt{\frac{\mu_r}{fg_r}} \qquad (3.10)$$

r = distance from electromegnatic sourse to shield

f = frequency

μ_r = permeability

g_r = conductivity

For the electric field, the equations are:

$$\Gamma = 4\frac{\left(1-m^2\right)^2 - 2m^2 + j2\sqrt{2m}\left(1-m^2\right)}{\left[\left(1+\sqrt{2}m+1\right)\right]^2} \qquad (3.11)$$

$$m = 0.205*10^{-16}r\sqrt{\frac{\mu_r f^3}{g^2}} \qquad (3.12)$$

r = distance from electromegnatic sourse to shield

f = frequency

μ_r = permeability

g_r = conductivity

For the plane wave, the equations are:

$$\Gamma = 4\frac{\left(1-m^2\right)^2 - 2m^2 + j2\sqrt{2m}\left(1-m^2\right)}{\left[\left(1+\sqrt{2}m+1\right)\right]^2} \cong 1 \qquad (3.13)$$

$$m = 9.77*10-10\sqrt{\frac{f\mu_r}{g_r}} \qquad (3.14)$$

r = distance from electromegnatic sourse to shield

f = frequency

μ_r = permeability

g_r = conductivity

3.2.2 Test Setup:

Every satellite can send and receive signals with earth station in specific frequency of microwave range. The test was done in all microwave range of frequencies because shield effectiveness of a particular metal is varied with frequency of incident wave and the thickness of material.

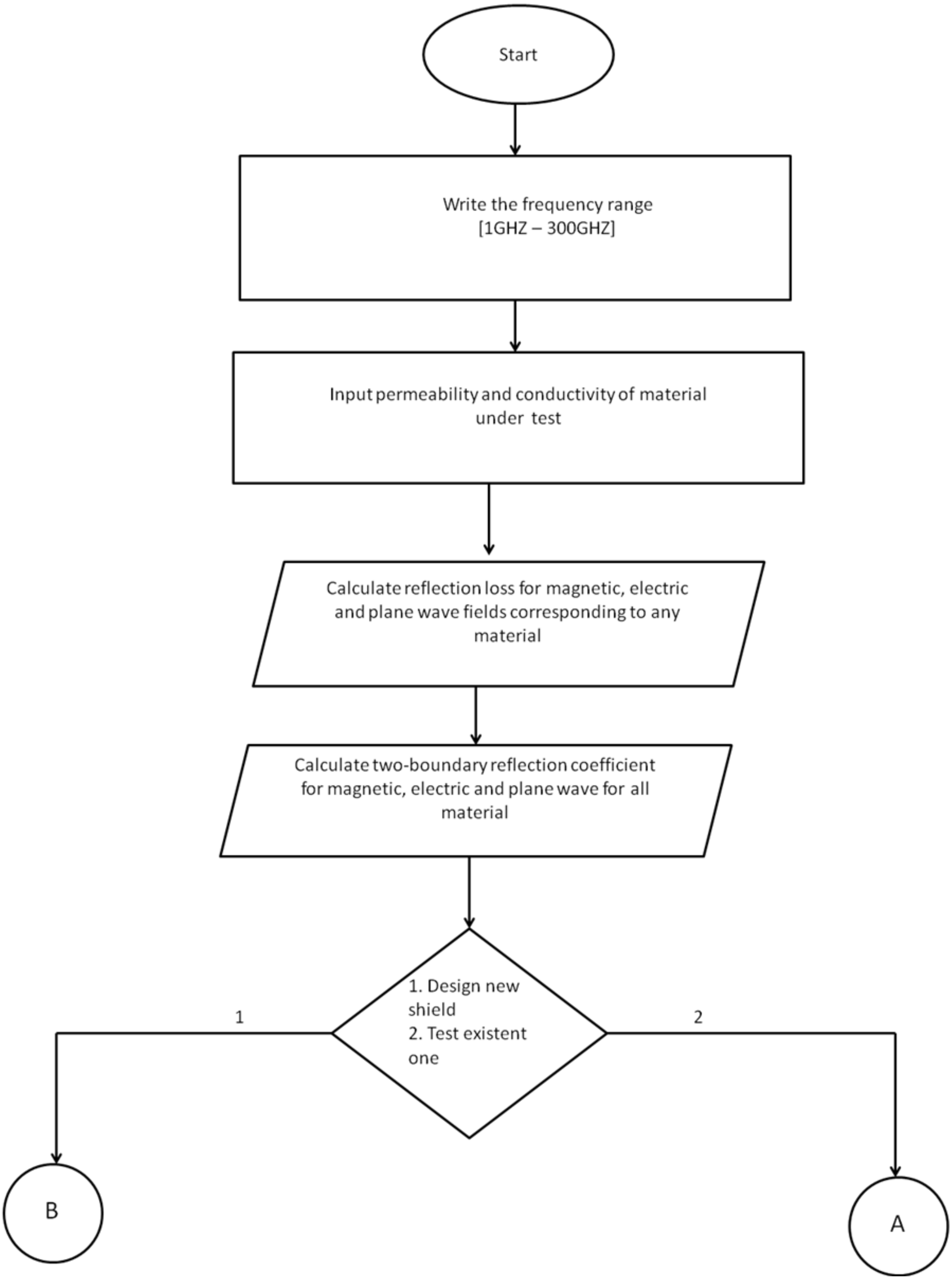
This test environment constructed completely using software method (Software prototype) assuming the materials of shield matching the standard characteristics of IEEE schedule of EMI shielding characteristics **[Appendix (C)].** Also because it is irrational to design this huge number of shields corresponding to any frequency in additional to range of thicknesses for all materials and frequencies.

The software program flow chart described in **figure (3.3)** below. It divided into two parts.

The first part help full in design new shield because it calculate shielding effectiveness for five different metals chosen from IEEE schedule of EMI shielding characteristics. All of that done to purposes of comparisons between materials in specified frequency to choose at the end the most suitable shield’s material and its thickness for satellite under test.

The second part of program help full in testing existent shield by calculating and plot shielding effectiveness of it, then if value of shielding effectiveness is not acceptable to Designer, he can run the program again in first part mode to redesign the shield depending on particular operating frequency and available budget.

The flow chart of Interference immunity test is shown below:


Start
Write the frequency range
[1GHZ – 300GHZ]
Input permeability and conductivity of material under test
Calculate reflection loss for magnetic, electric and plane wave fields corresponding to any material
Calculate two-boundary reflection coefficient for magnetic, electric and plane wave for all material
1. Design new shield
2. Test existent one
1
2
B
A

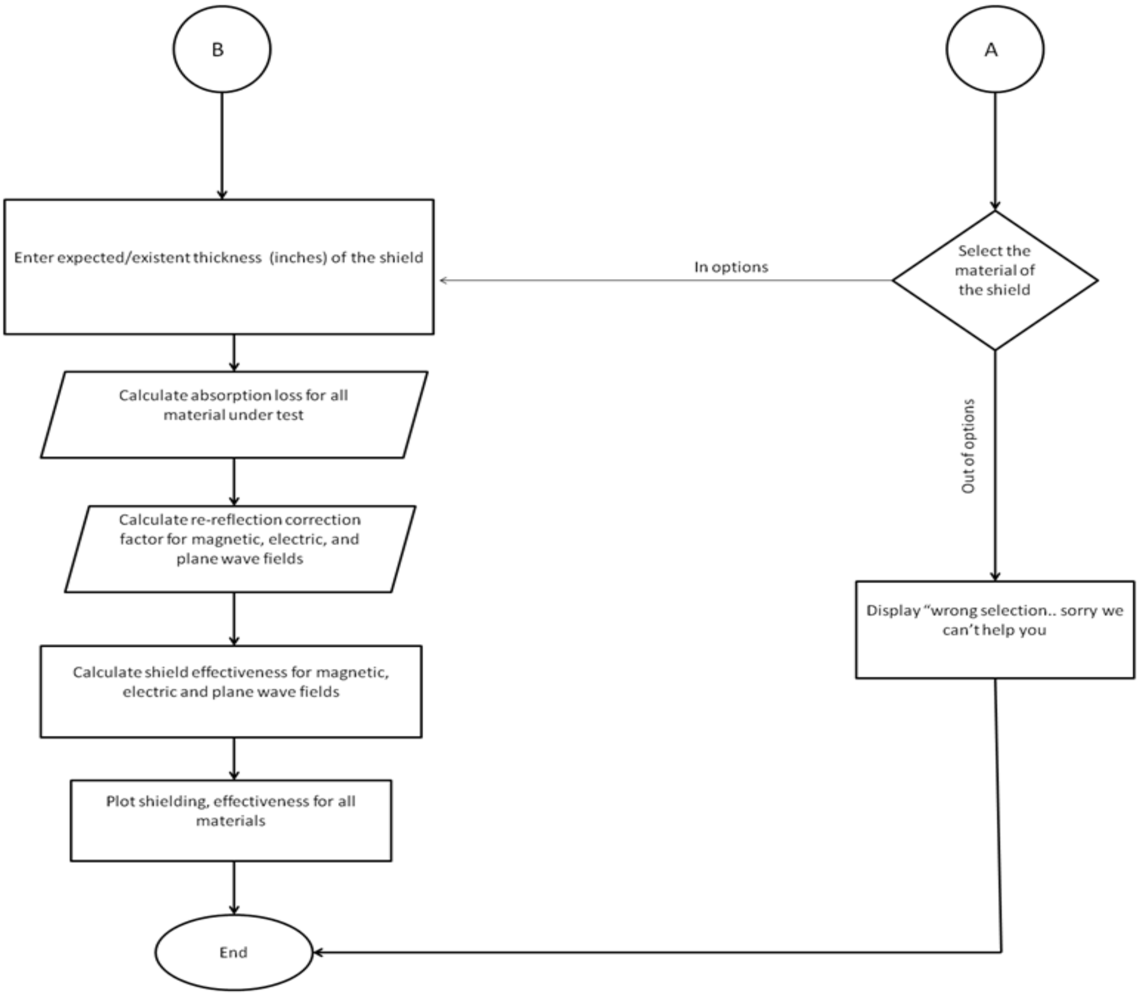


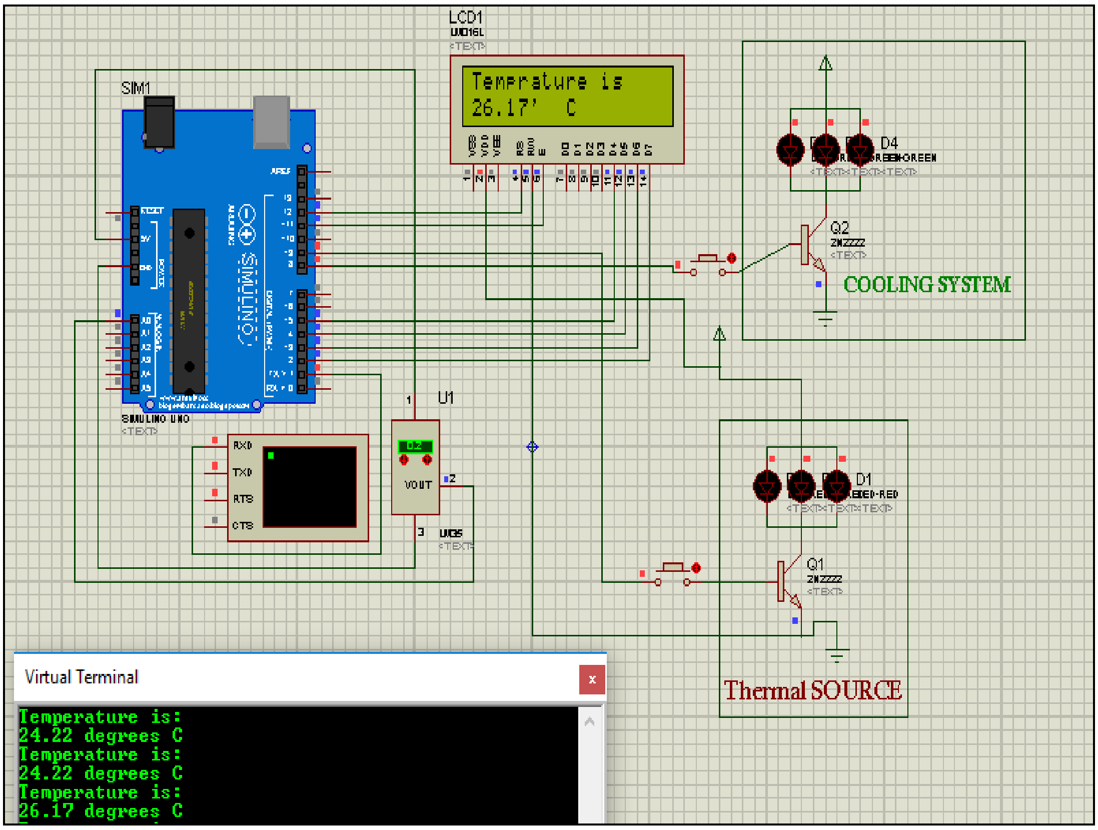
Figure 3.3: flow chart of interference immunity test

CHAPTER FOUR

RESULTS

4.1 Results of Thermal sensor Simulation:

The simulation of thermal sensor circuit described in previous chapter was done by **Proteus ISIS** program, the Arduino Uno and LM35 transistor was connected to LCD and thermal/cooling systems as follow:



```
Temprature is
26.17'  C
```

```
Temperature is:
24.22 degrees C
Temperature is:
24.22 degrees C
Temperature is:
26.17 degrees C
```

Figure 4.1: Thermal Sensor circuit with virtual terminal [in room's temperature]

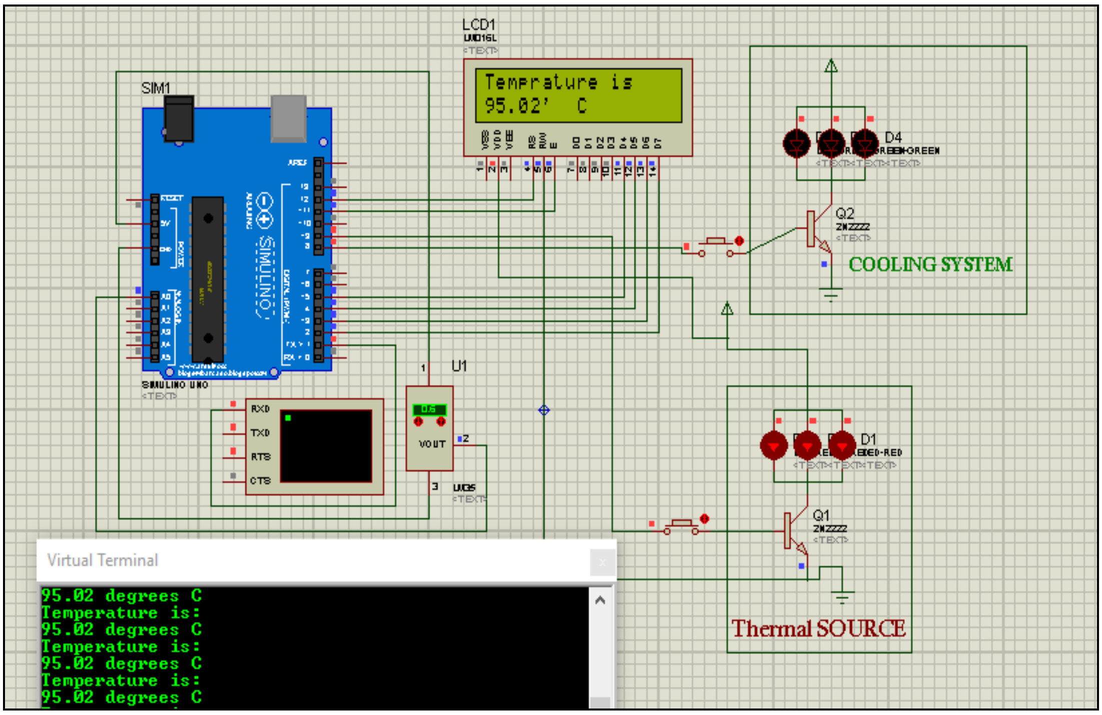
Notice: The task of virtual terminal, shown in lower section in above figure, is to display results that would be sending to PC if a hard Arduino used.

After running the simulation, **Proteus ISIS** has ability to increase\decrease output voltage of LM35 transistor, and of course that changing the temperature degree displayed in virtual terminal and LCD.

4.1.1 Results when thermal source switched-on:

The two figures below shows results of simulation when thermal source switched-on, then temperature degree should be increased.

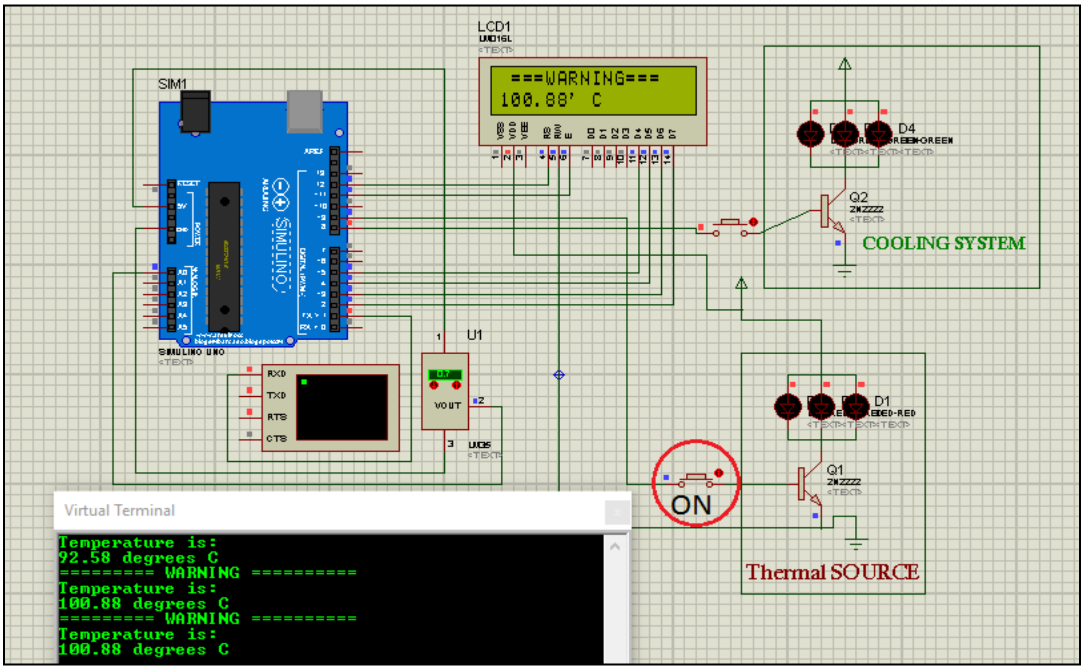
The system have ability to displaying the temperature degree every second in the LCD and virtual terminal, when temperature is higher than\equal to maximum degree "***hear range assumed -20_100° C***" warning message was displayed, and simultaneously, **Arduino** take decision to switch-off thermal source to guarantee that satellite's components would not damage, and stop the test. That indicates to a failure in internal cooling system of thermal control system (TCS) and this simply show why a **Testbed** is so important to check the satellite before launch it to space orbits.



```
Temprature is
95.02'  C
```

```
95.02 degrees C
Temperature is:
95.02 degrees C
Temperature is:
95.02 degrees C
Temperature is:
95.02 degrees C
```

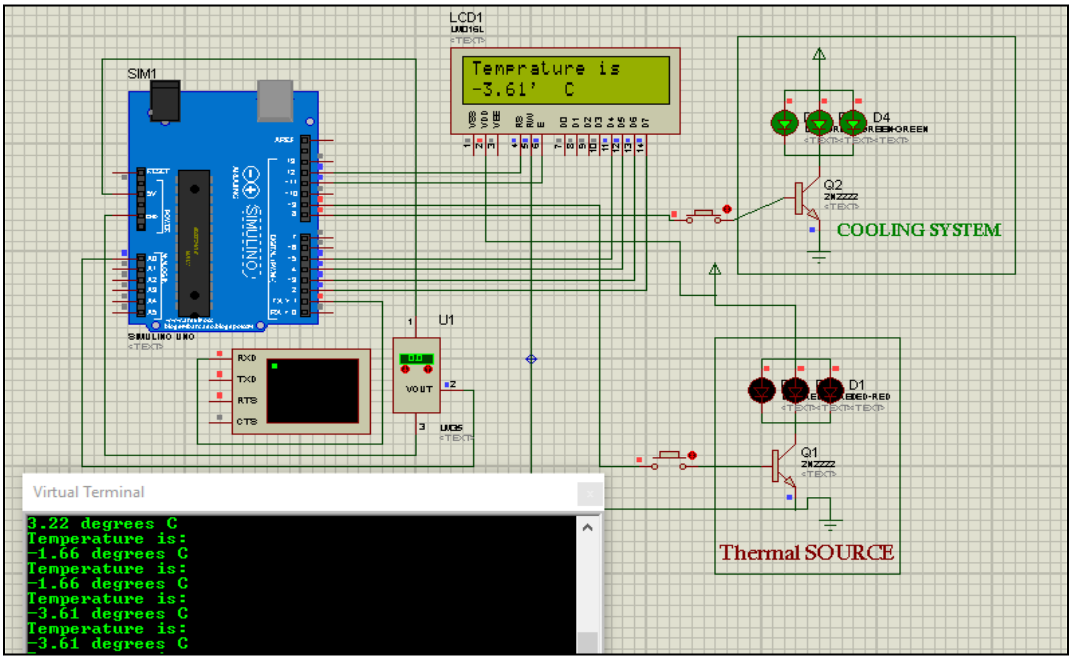
Figure 4.2: Thermal Sensor circuit after thermal source switched-on "Results when temperature is lower than maximum degree"



```
Temperature is:
92.58 degrees C
========= WARNING =========
Temperature is:
100.88 degrees C
========= WARNING =========
Temperature is:
100.88 degrees C
```

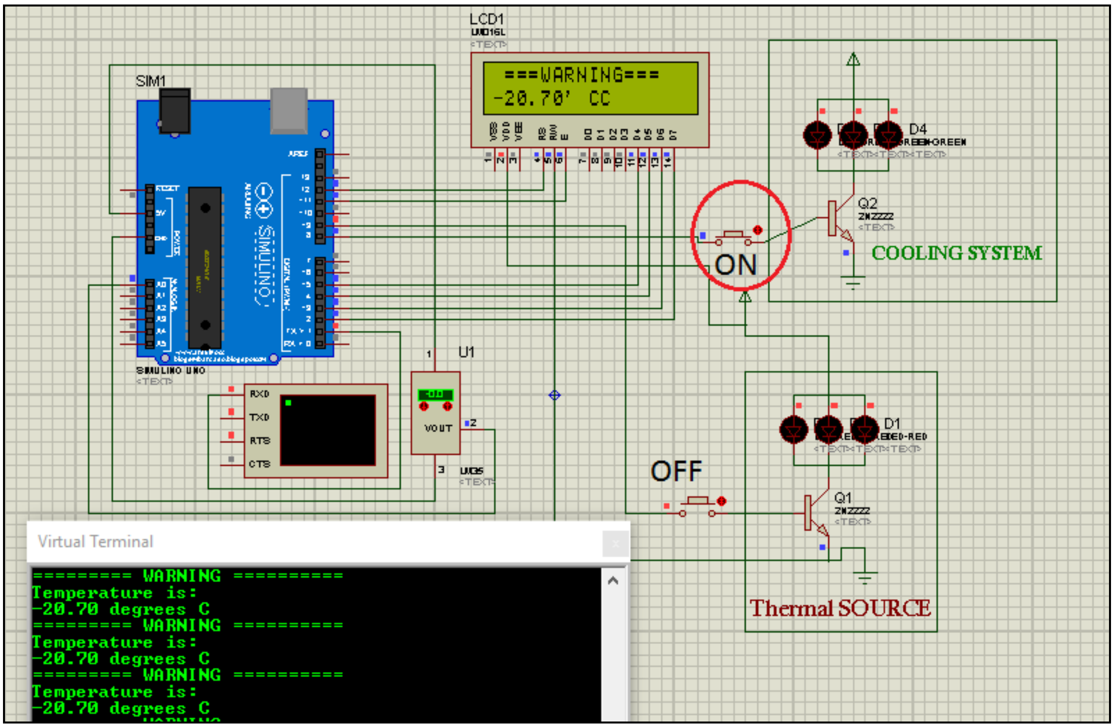
Figure 4.3: Thermal Sensor circuit when thermal source switched-on “Results when temperature is higher than maximum degree [notice thermal source cutoff energy although it still switched-on]

4.1.2 Results when Cooling System switched-on:



```
3.22 degrees C
Temperature is:
-1.66 degrees C
Temperature is:
-1.66 degrees C
Temperature is:
-3.61 degrees C
Temperature is:
-3.61 degrees C
```

Figure 4.4: Thermal test circuit when Cooling System switched-on



```
========= WARNING ==========
Temperature is:
-20.70 degrees C
========= WARNING ==========
Temperature is:
-20.70 degrees C
========= WARNING ==========
Temperature is:
-20.70 degrees C
```

Figure 4.4: Thermal test circuit when Cooling System switched-on and temperature reach minimum lower value [Notice: Cooling System cutoff energy although it is still switched-on]

When Cooling System switched-on the temperature degree should be decreased, *as shown in figure 4.3*, but when temperature degree reaching minimum lower of pre-determinate range ,**here -20° C**, the **Arduino** take decision to switch-off Cooling System to guarantee that satellite's components would not damage, and stop the test. That indicates to a failure in **internal** heating system of satellite thermal control system (TCS)

The above circuits are programmed by **Arduino IDE** which limited to operate with Arduino micro controllers, so Micro C code programmed by Atmel Studio Software to expanding options of using micro controllers chips like AVR, ARM and PLC.

Above circuits are redesigned by **Atmega16** micro controller as described by following figures:

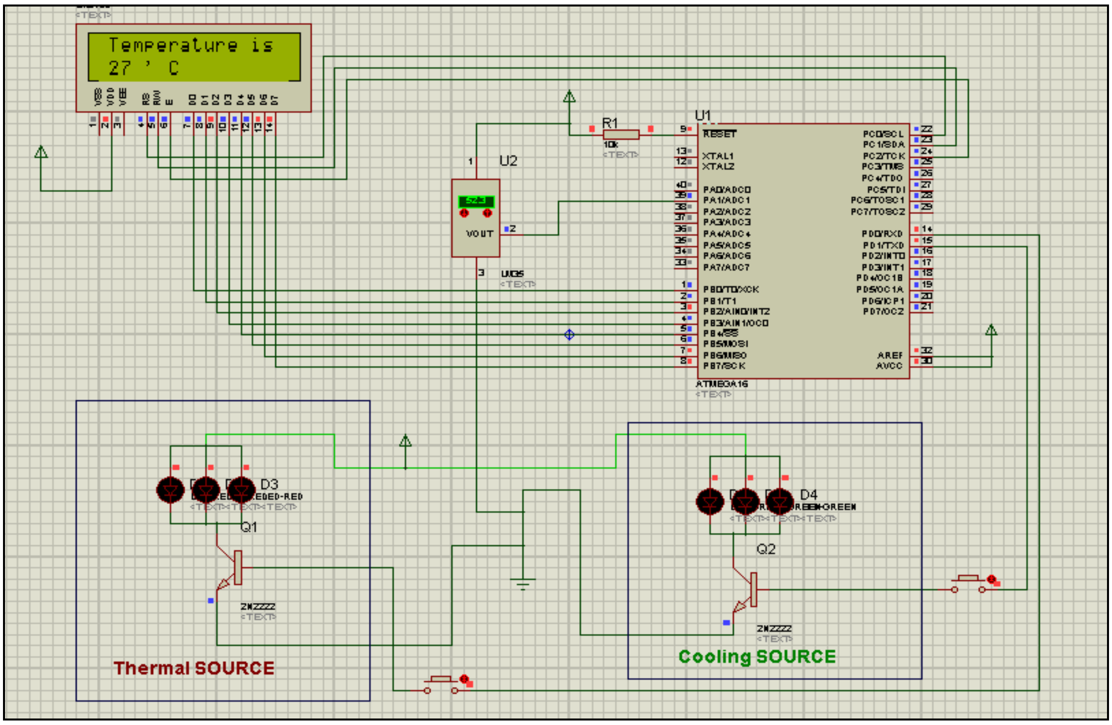


Figure 4.5: thermal sensor circuit with Atmega16 [in room's temperature]

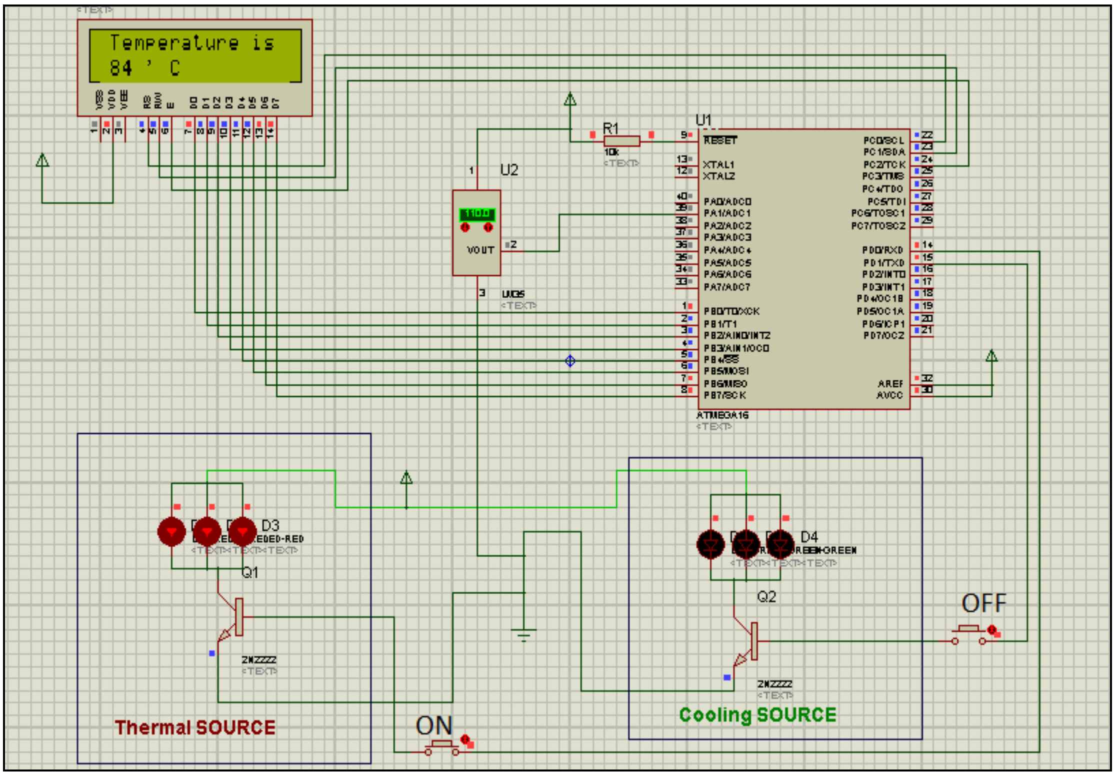


Figure 4.6: Atmega16 circuit when thermal source switch-on

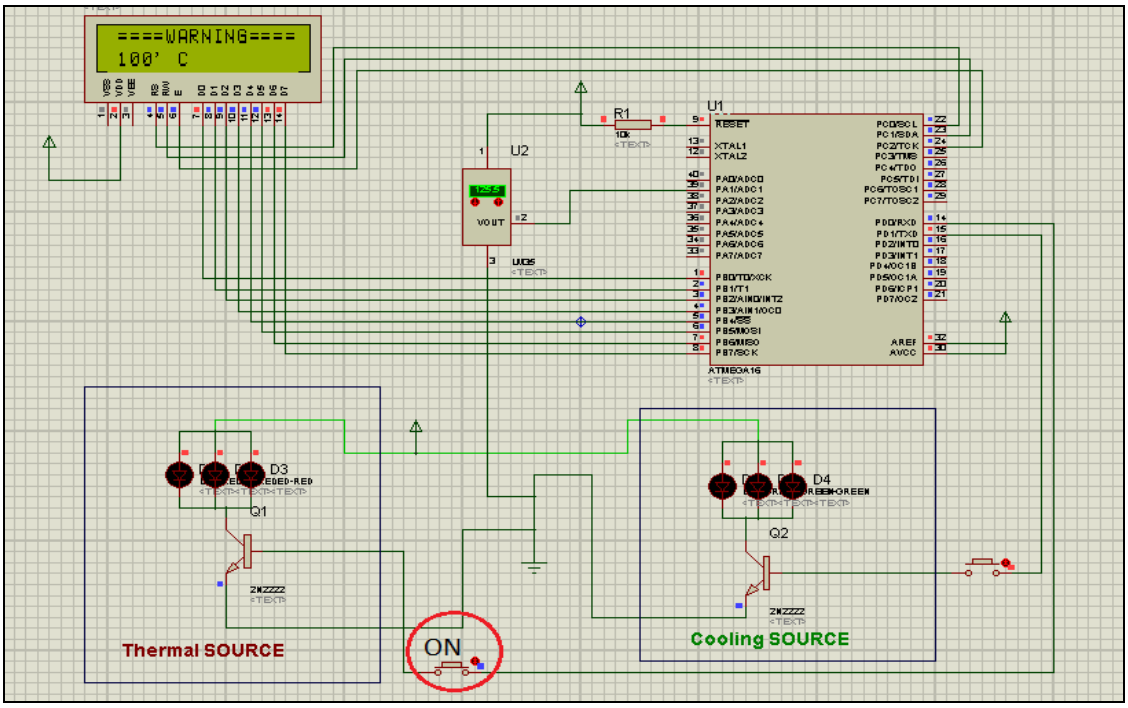


Figure 4.7: Atmega16 circuit when temperature degree reaching maximum upper value [notice thermal source cutoff energy although it still switched-on]

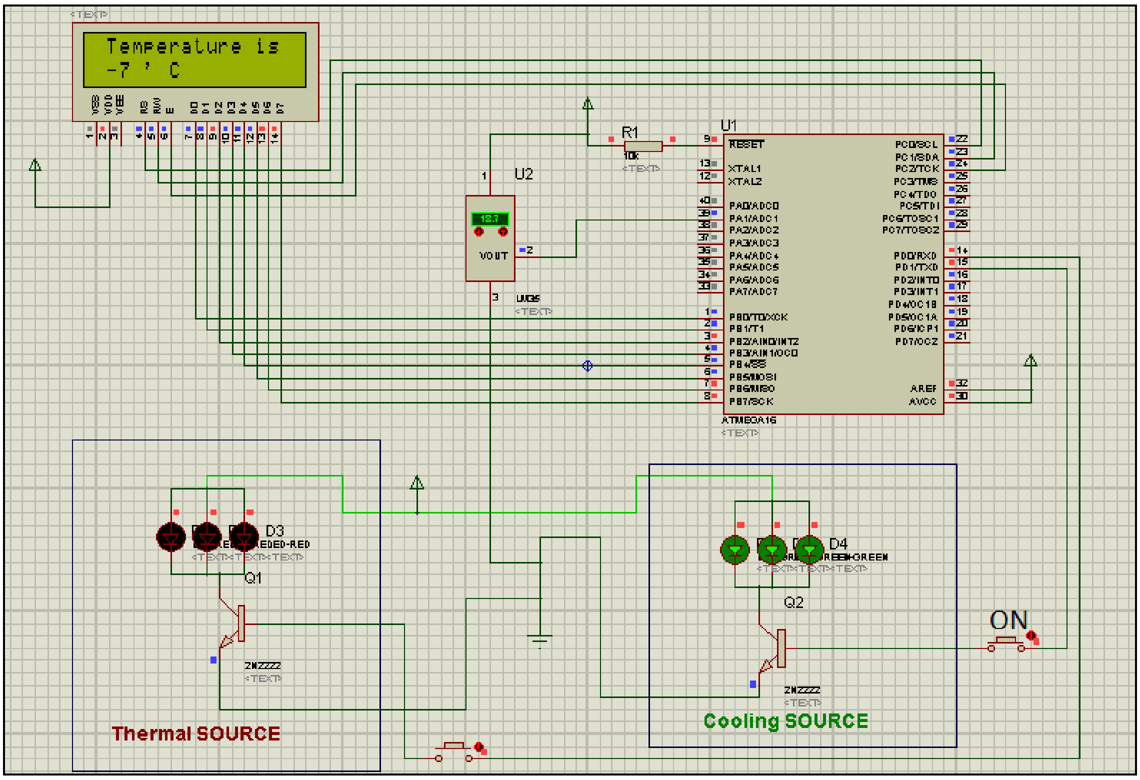


Figure 4.8: Atmega16 circuit when thermal source switch-on

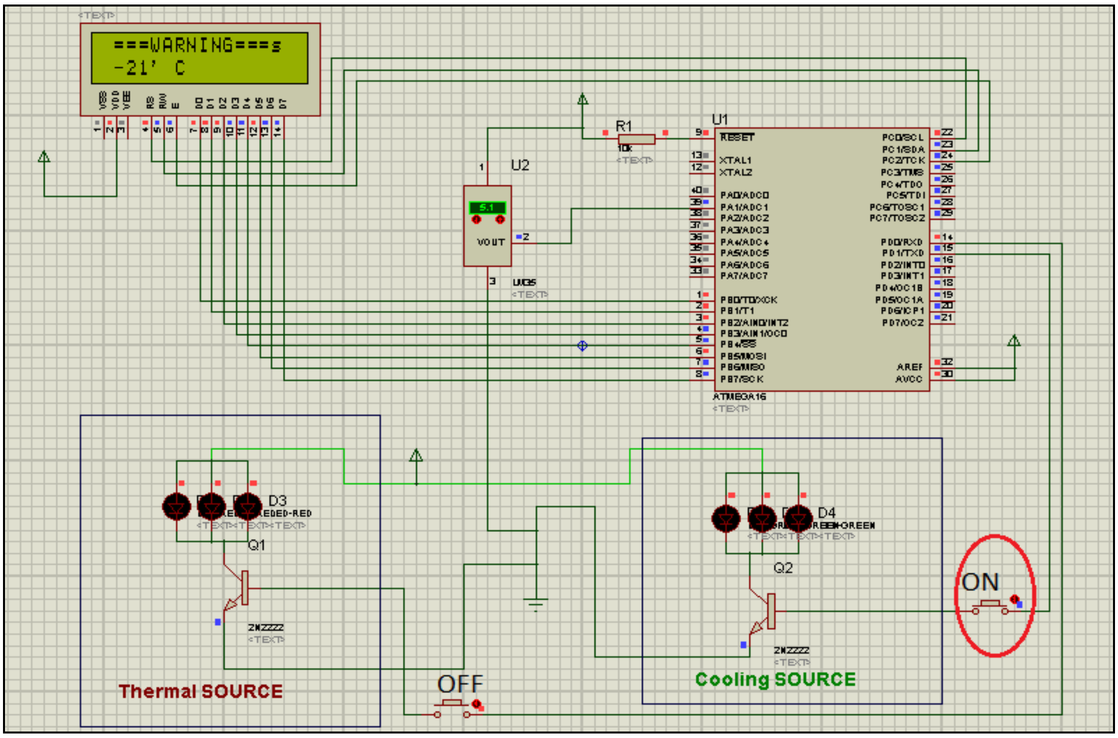


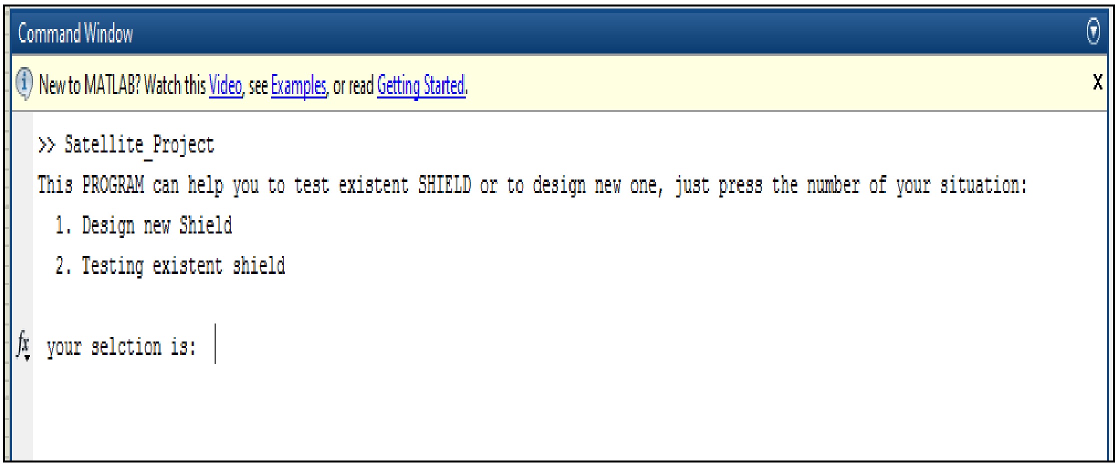
Figure 4.9: Atmega16 circuit when temperature reach minimum lower value [Notice: Cooling System cutoff energy although it is still switched-on]

4.2 Results of Interference Immunity Test:

The simulation of this test was done by **MATLAB** program because it has an excellent feature for plotting, and that is very useful to comparison between different materials performance corresponding to a particular frequency and particular shield's thickness.

The main idea of program is testing existence shield effectiveness to decide if it acceptable for satellite designers or not, with additional ability to calculate shield effectiveness for multiple materials in order to comparison between them to help designer to select suitable material for the shield if the test of existence shield results with not agreed value.

After executing program [**Appendix D**] in MATLAB, the program firstly need to know if it would be used to test existent shield or to redesign new one. As shown in figure below:



New to MATLAB? Watch this Video, see Examples, or read Getting Started.

```
>> Satellite_Project
This PROGRAM can help you to test existent SHIELD or to design new one, just press the number of your situation:
  1. Design new Shield
  2. Testing existent shield

 your selction is: 
```

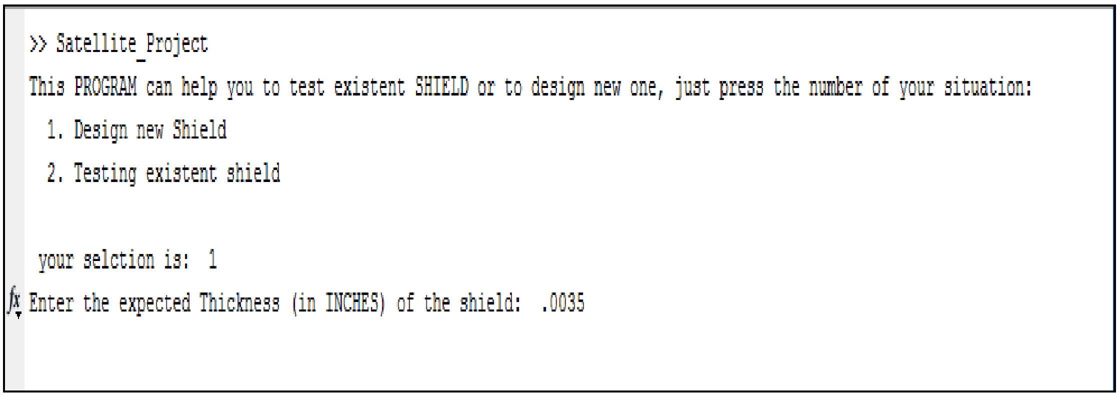
Figure 4.10: MATLAB user interface

The output figures of interference immunity test program for both situations above are shown below:

Notice: all thickness values included to MATLAB code assumed to be .0035 inches.

4.2.1 Results of first situation [Design new shield]:

After inserting number of situation, the program asks to know the expected thickness value, then plot shielding effectiveness diagrams for magnetic field, electric field, and plain wave as shown below.



```
>> Satellite_Project
This PROGRAM can help you to test existent SHIELD or to design new one, just press the number of your situation:
  1. Design new Shield
  2. Testing existent shield

 your selction is:  1
Enter the expected Thickness (in INCHES) of the shield:  .0035
```

Figure 4.11: interference immunity program’s first situation

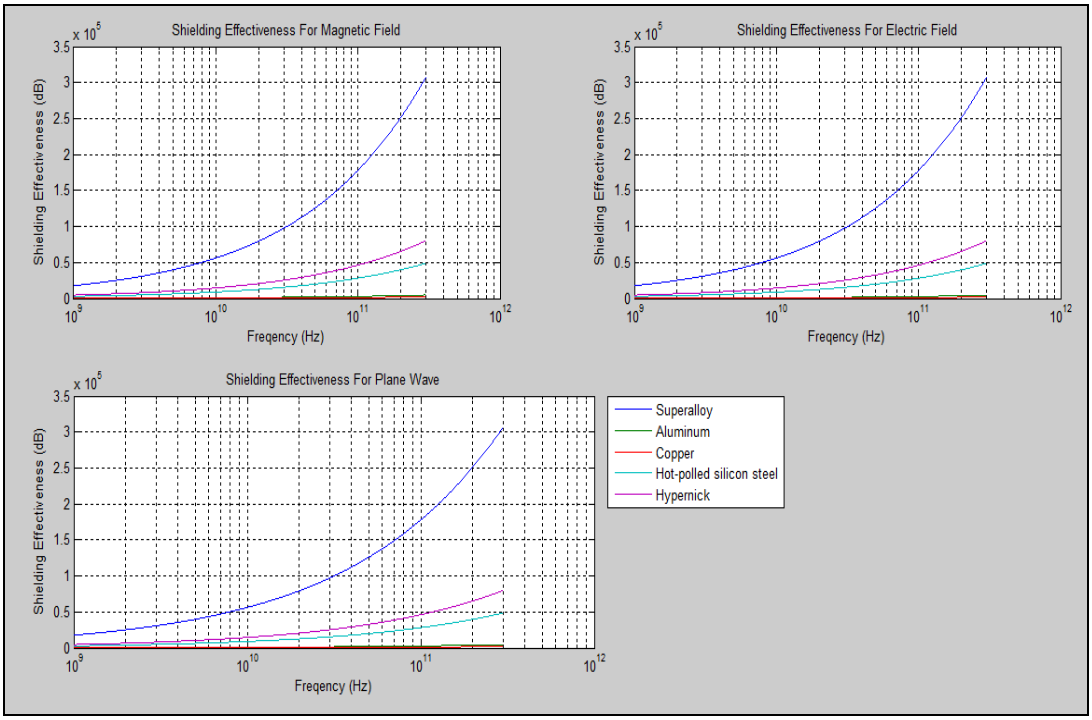
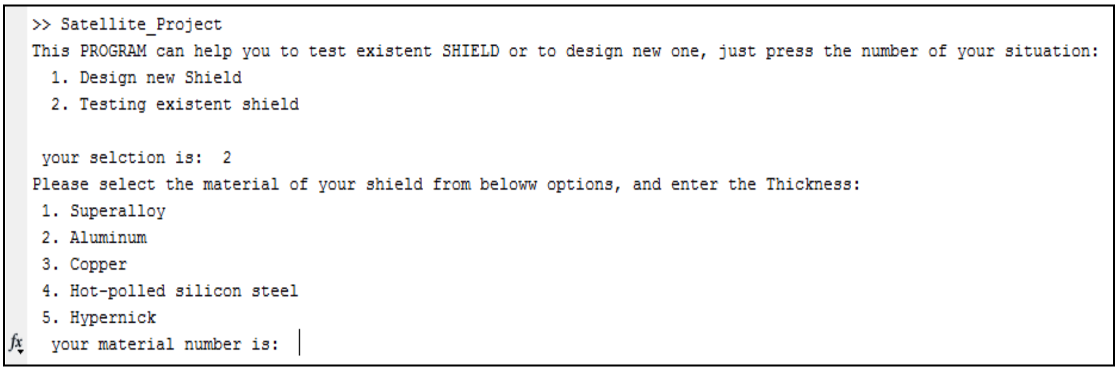


Figure 4.12: Shielding effectiveness plots of all material under tests

It is clear from above figure, in the microwave range of frequencies there is no notable differences in shield effectiveness values between magnetic field, electric field, and plain wave.

4.2.2 Results of second situation [Testing existence shield]:

If second situation was selected, the program needs to know type of material and thickness of the shield in order to calculate and plot shield effectiveness. [Notice: five materials was programmed with its conductivity and permeability from IEEE EMI shielding characteristics table [**Appendix C**] as shown in figure below:



```
>> Satellite_Project
This PROGRAM can help you to test existent SHIELD or to design new one, just press the number of your situation:
  1. Design new Shield
  2. Testing existent shield

 your selction is:  2
Please select the material of your shield from beloww options, and enter the Thickness:
 1. Superalloy
 2. Aluminum
 3. Copper
 4. Hot-polled silicon steel
 5. Hypernick
  your material number is:
```

Figure 4.13: options of materials available if second situation was selected

The output shield effectiveness figures for all these materials are shown below, sequentially:

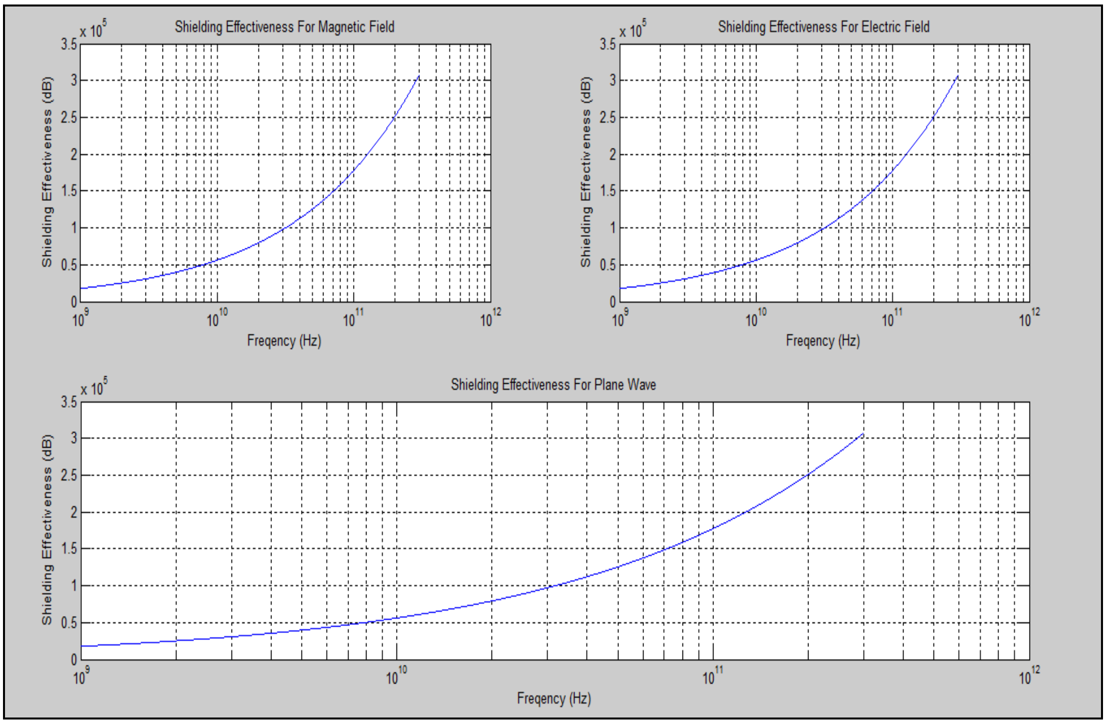


Figure 4.14: Shielding effectiveness plots of Superalloy material

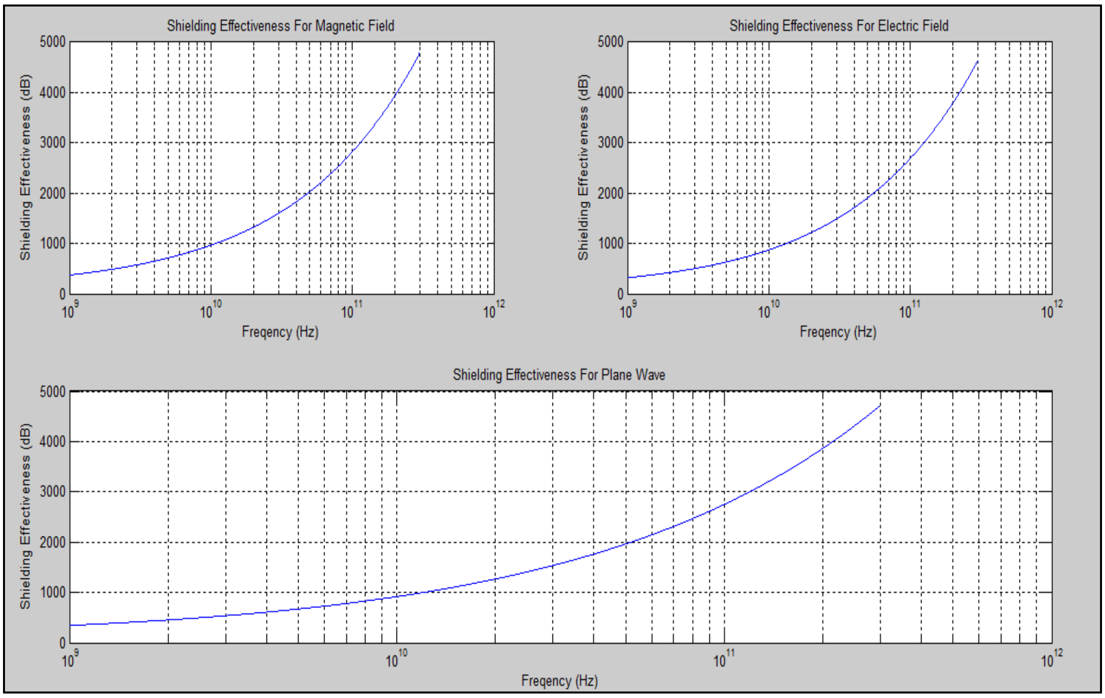


Figure 4.15: Shielding effectiveness plots of Aluminum material

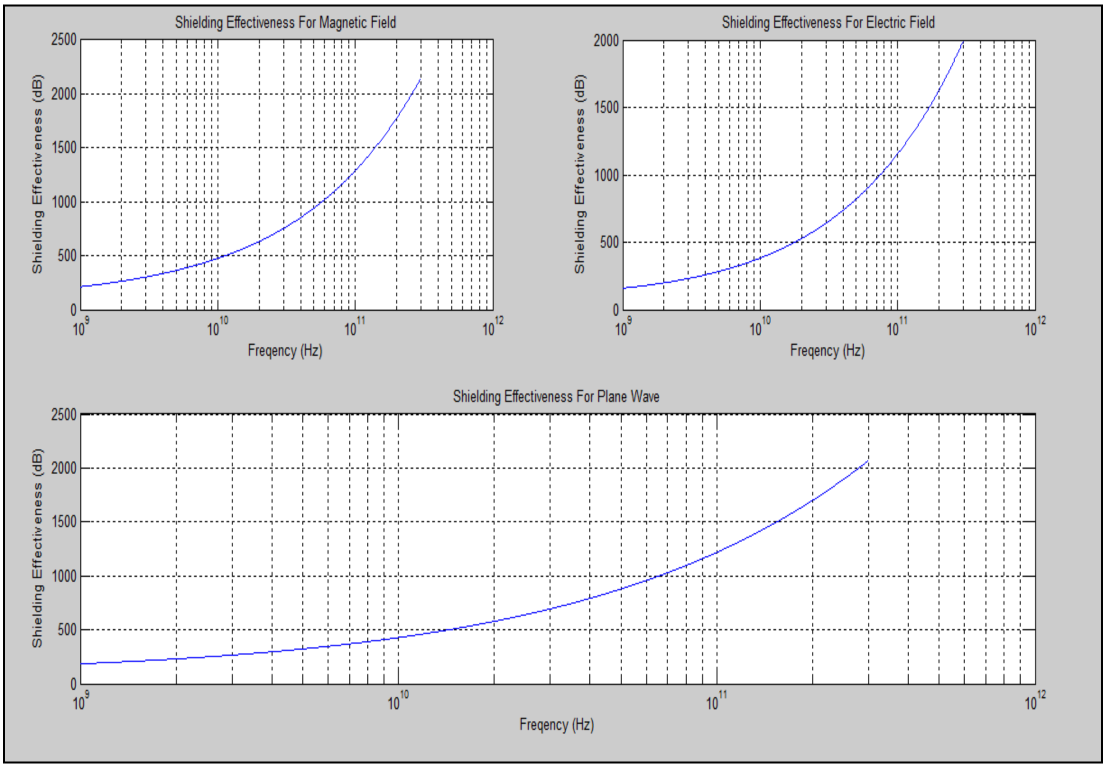


Figure 4.16: Shielding effectiveness plots of Copper material

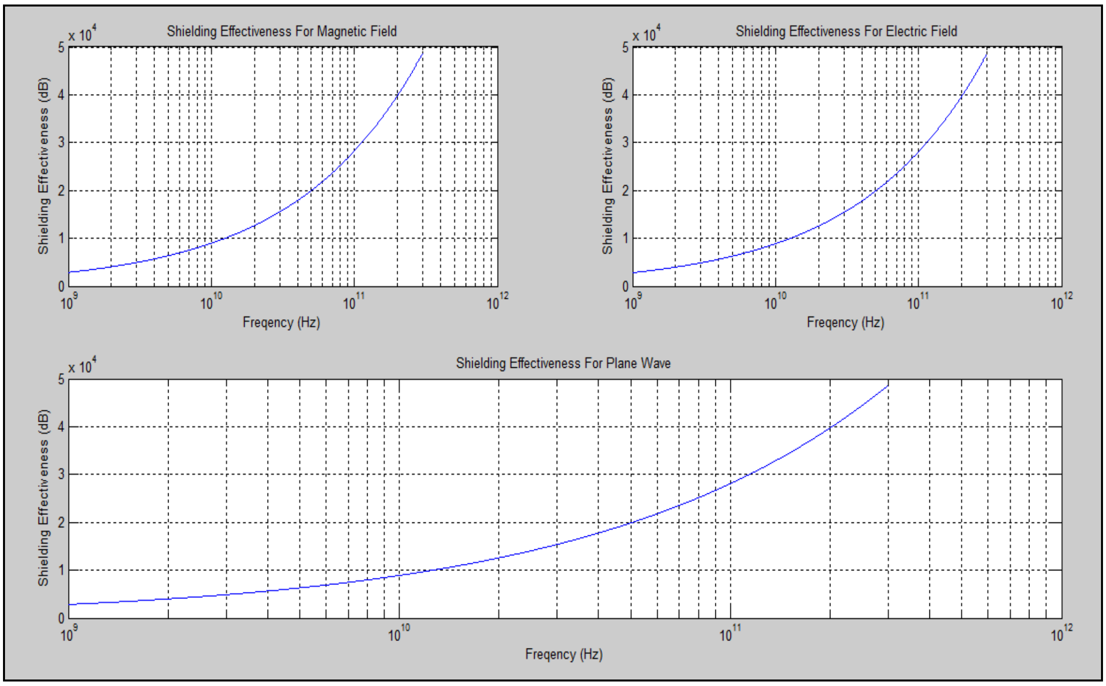


Figure 4.17: Shielding effectiveness plots of Hot-polled Silicon Steel material

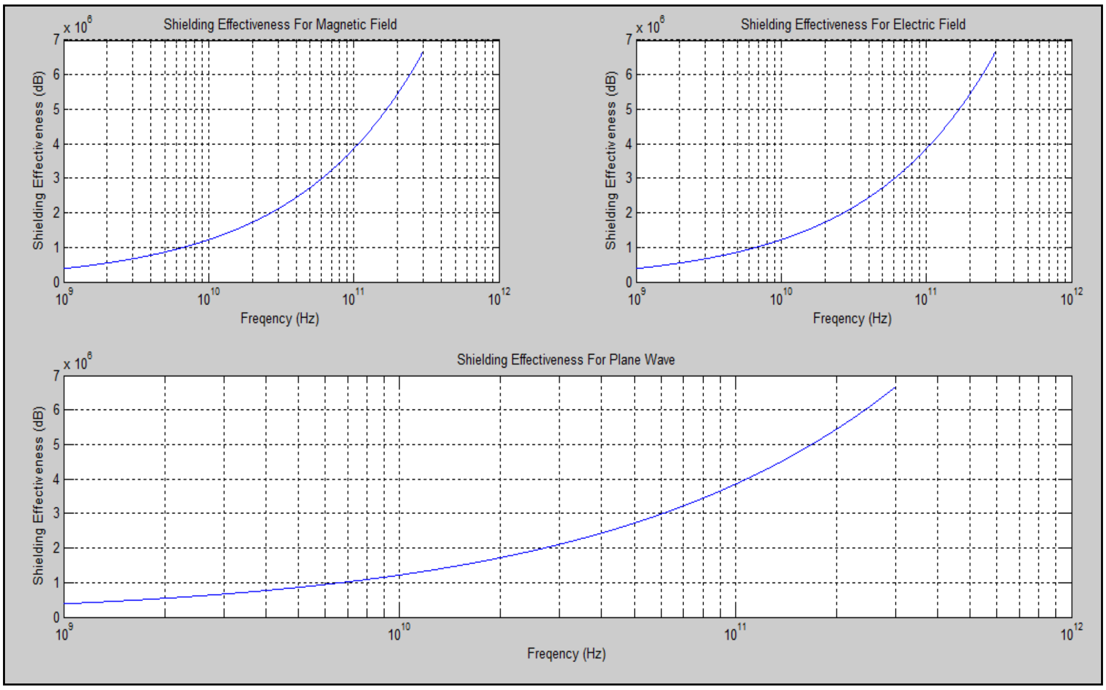


Figure 4.18: Shielding effectiveness plots of Hypernick material

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 conclusions:

A study of available simulation has been done. A shield has been designed and constructed. The shield is a capable of preventing EMI experienced by the external source of radiation. The performance of the shield has been measured by simulation depending on what type of materials used to design the shield. The test bed is used to calibrate the thermal sensor and the shield effectiveness. The cooling system were designed and used to maintain the temperature in acceptable range. For shield design the materials were chosen from IEEE table in appendix. The shield effectiveness was measured for electric field, magnetic field and plain microwave frequencies range.

The thickness of the material is important factor that proportional with the shield effectiveness. For the thermal control test a thermal sensor was used, that is done here by software and for hardware the required devices were described. For software the Arduino IDE and Atmel studio have been used. For hardware the LM35 temperature sensor, Micro controller (here Arduino UNO and Atmega16 were used), also LCD screen and thermal source and cooling system for emergency should be used. The connection process between this equipments were done by specific way to measure temperature displayed it in the LCD.

5.2 Recommendations:

The following models recommended to achieve integrated test and aided in future test.

- Design Helmholtz cage: it can produced controllable magnetic field, used to simulate the magnetic field experienced by the satellite in space. The Helmholtz consists of a pair of identical coils with equal number of turns placed in parallel at distance apart. The magnetic field is generated by the current owing through the coils. The strength of the magnetic field is directly proportional to the current owning through it and the number of turns.
- COTS turn table: which can simulate the movement of the satellite in two directions.
- COTS sun simulator: to produce a light source equivalent of one solar constant the fluorescent lamp can be use.
- Test of antenna to reading antenna spectrum and to read maximum gain and other details of antenna connected with external circuit PC (DUT).

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