Troubleshooting Techniques of Complex Multi-Layered PCBs

Mirza Salman Baig[1,2,*] and Ambreen Insaf[1,2,#]

[1]*Department of Applied Physics, University of Karachi, Karachi, Pakistan*

[2]*Institute of Space and Planetary Astrophysics, University of Karachi, Karachi, Pakistan*

Abstract: In this modern era where technology is rapidly changing and is being advanced day by day, Pakistan is dependent on foreign OEM (Original Equipment Manufacturer) for the functional supportability of the systems because most of the commercial and non-commercial systems are foreign OEM based. In the case of any defect of the systems and to reduce the dependency on OEM, the simplest way is to troubleshoot the PCBs (Printed Circuit boards) of the system locally instead of purchasing new PCB or sending it back to OEM for repair until we are able to design our own systems. Thus, it won't be wrong saying "time, tide and technology wait for none". The purpose of this research is to achieve self-reliance in PCB troubleshooting, thereby reducing dependability on foreign OEMs, equipment downtime and high costs being acquired in PCB repairs, secondly to highlight the importance of this field so that universities may adopt it as a subject. This research paper is based on some troubleshooting techniques for repair of complex multilayered PCBs.

Keywords: Technology, functional supportability, foreign Original Equipment Manufacturer, commercial systems, repair of Printed Circuit Board.

INTRODUCTION

In electronic systems, printed circuit boards, or PCBs, are used to mechanically support and electrically connect electronic components like resistors, capacitors, transistors and ICs using conductive pathways, or traces, etched from copper sheets laminated onto a non-conductive substrate. Just a few years ago, PCBs were much simpler, easy to diagnose and repair as compared to today's modern PCBs. Modern days PCBs are complex multilayered and contain Microprocessors, RAMs, ROM, Ball Grid Arrays (BGAs), Field-Programmable Gate Array (FPGA) and un-identified ICs. These ICs are unique due to their high pin count and fine pitch. Unlike normal ICs, these devices cannot be tested manually or using IC testers for functional testing, but despite how severely damaged PCBs are, they can be diagnosed and repaired. The research would focus on exploring diagnosis techniques that could be used to identify defects in such kind of complex PCBs. Figures below show the difference between earlier days and modern days PCBs.

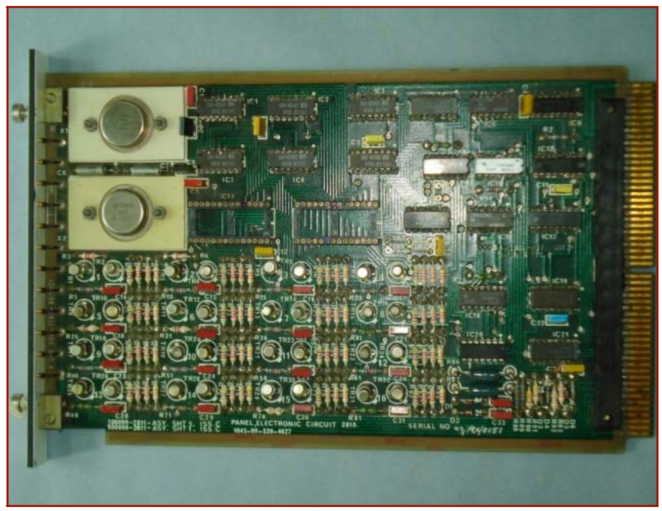

Figure 1: Earlier day's single layer PCB, design on through-hole technology.

Figure 2: Modern day multi-layered PCB, design on SMD technology containing BGAs and software ICs.

Electronic Systems

Electronic systems are combination of electronic circuits and components which are mounted on PCBs, designed to perform one or more complex functions e.g. radar systems, sonar systems, telecommunication systems, computer systems, and many others. Figure **3**

*Address corresponding to this author at the Institute of Space and Planetary Astrophysics, University of Karachi, Karachi, Pakistan; Tel: +92345-2847048; E-mail: mirza_salmanbaig@hotmail.com
[#]Co-Author: Email: ainsaf@uok.edu.pk

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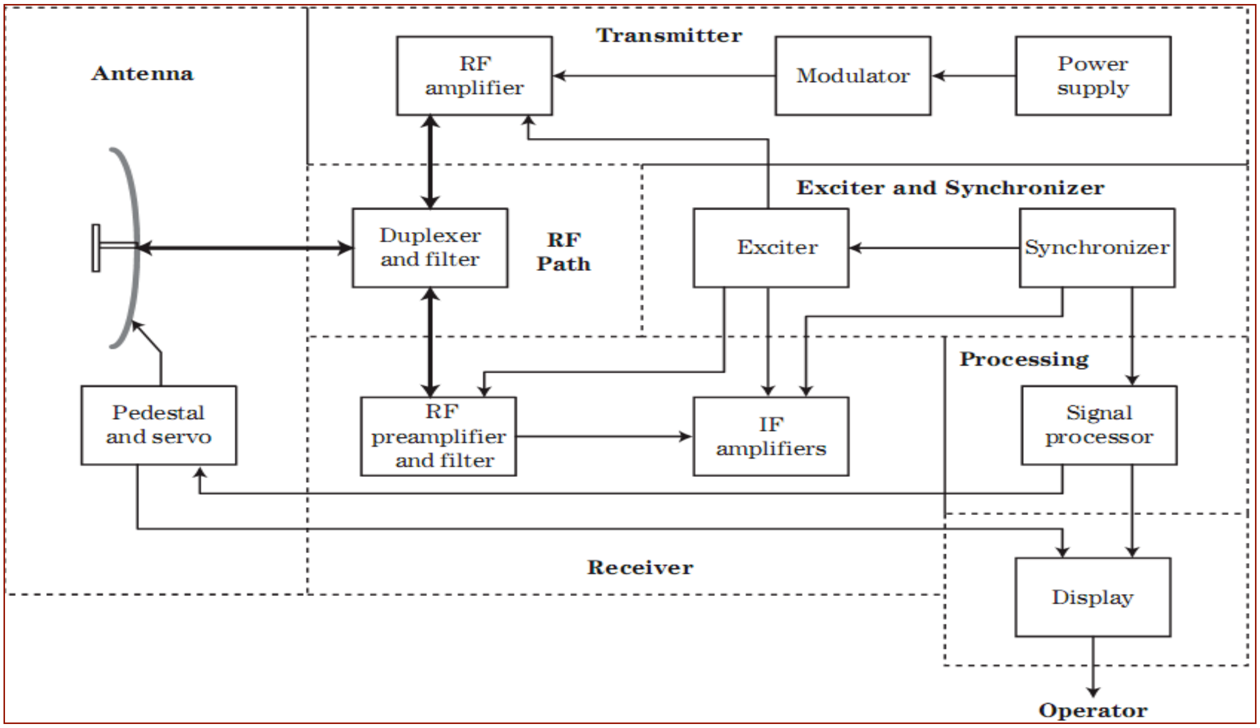

Figure 3: Block diagram of typical pulsed radar, (Figure source [1]).

shows Block diagram of typical pulsed radar [1] in which each block performs a specific function and represents a PCB.

To successfully troubleshoot the defective PCB it is suggested that the person repairing it first understand the system and specific function of defective PCB with the help of technical documentation (circuit diagrams and functional description) if available.

If a repair person knows the function of a PCB in the system then it would be easy for him/her to troubleshoot it successfully and it would only happen if technical documentation is present, but in our research we find that most of the systems are purchased without any technical documentations like circuit diagrams, embedded software's etc. or may be lost at the time when systems are defaulted.

Tools & Test Equipments

Following tools and test equipments are required for trouble shooting the complex PCBs

1. Power supplies, used to provide accurate variable power supplies to PCB
2. Oscilloscope, used for analysis of respective time & frequency domain signals emanating from test points of electronic components
3. Signal Generators, used to provide standard sources of AC energy, both audio frequency (AF) and radio frequency (RF), and are often used in the maintenance of electronic equipment.
4. Frequency counter, used for analysis of respective frequency domain signals emanating from test points of electronic components
5. Multi Meters, most extensively used tool for diagnosis of defective PCBs
6. LCR Meter, used for testing inductor, capacitor and resistor at different frequencies
7. IC Tester, used for functionally testing of ICs
8. VI Tester, used for testing the components and compare the impedance of two PCBs
9. Thermo graphic Camera, used to compare thermal images of two PCBs
10. Digital soldering station, it is a temperature control soldering station used to sold and de - sold the components
11. UV-ROM Eraser, used to erase the corrupted program
12. IC Programmer, used to erase and re-programmed the EEPROM, PAL, GAL and Microcontrollers

Six Keys of Success

There are six very important prioritized keys for successful troubleshooting of PCBs

1. Highly skilled persons
2. System understanding
3. Patience and dedication
4. Modern equipment for troubleshooting
5. Continuous training for interaction with the latest technology
6. Documentation for previous defects history

PCB troubleshooting is like treating a patient. Besides the support of sophisticated and costly equipment, the Doctor's ability to diagnose is a vital factor for the ultimate success [2] therefore in above mentioned keys if only the first point is neglected the entire trouble shooting process will collapse like a beautiful building with weak pillars will downfall. Unlike in automation industry where process is less dependent on person since people are only required for monitoring the process, whereas PCB troubleshooting process is completely dependent on person’s skills because only a highly skilled person can maximum utilised modern technology equipment’s and provide better results in the case of training.

Troubleshooting Techniques

Troubleshooting and fault analysis requires a good theoretical knowledge and analytical thinking. It is not something which can be studied from books, but has to be acquired through constant troubleshooting and experimenting. Basically, troubleshooting depends on the circuit complexity, on symptoms, and on the personal experience [3]. The most common troubleshooting techniques are listed below:

- Look and touch (visual inspection)
- Hot and cold check (physical check)
- Discrete Component testing
- ICs testing
- Embedded software check
- Comparison method

Look and Touch (Visual Inspection)

This inspection is part of the so-called sensory checks [3]. Sensory checks rely on the human senses to detect a possible fault [3]. The visual inspection of the PCB is the simplest troubleshooting technique (which is very effective in many of the cases) [3], without energizing the PCB. But be careful don’t touch the PCB without taking ESD (Electrostatic discharge) protection especially if the signs shown in figure are indicate on PCB. The PCB has to be inspected visually for blown fuse, burnt components, jumper settings, broken tracks, missing components, loose connections and carbon on ICs sockets and connectors. Sometimes, components that overheat leave a brown mark on the board [3]. They can be used as ‘starting points’ in the troubleshooting process and the reasons why they overheat have to be determined [3]. It is bad practice simply to replace such components, without trying to find out what actually caused the component to overheat [3]. In many cases, the reason is a faulty component near the failed component. It also has to be replaced [3]. In case of blown fuse replace it with appropriate current and voltage rating fuse instead of using jumper wire to bypass safety. Use contact cleaner on sockets of ICs and connector of the PCBs to remove the carbon.

Figure 4: ESD indication marks on PCBs.

Hot and Cold Check (Physical Check)

Like a visual inspection this check is also a sensory check which relies on human sense of touch but this check is conducted on powered PCB. This troubleshooting technique is very useful in two cases, first where everything seems to work properly for a while, and then the circuit fails, due to overheating of a certain component or IC [3], secondly when circuit impedance is low. After powered a PCB with correct polarity, overheated components or ICs can be detected by simply touching them. Sometimes the defective components or ICs overheated quickly and give the sense of smoke. Identifying such components or ICs helps to detect the possible cause of the fault [3]. Special freezing sprays are available, which allow instant freezing of components or ICs [3]. If the circuit begins to operate properly immediately after the heated component or IC is sprayed, this is an indication that this component or IC is causing the circuit failure [3].However, this check has to be performed with extreme caution, the circuit has to be turned off, and some time allowed for the large capacitors to discharge [3]. Always touch the component or IC with the right hand only [3]. This is important because in the case of electric shock it is less likely that the current will pass through the heart [3]. If possible, wear insulated shoes [3].Before replacing the component or IC, further investigation is needed to determine what caused the overheating in the first place [3].Also check the components or ICs which are cold because all components or ICs dissipate slight heat due to flow of current, if the component or IC is cold then check the supply connection for broken tracks with the help of multi-metre.

Discrete Component Testing

The most common and effective technique adopted by usually all persons after the visual inspection and which is the real test of person's skills and patience is Discrete Component testing. This technique includes testing of resistor, capacitor, inductor, diode, transistor, MOSFET and thyristor. Following are the techniques for testing the discrete components:

1. Check the resistors in-circuit by using multi-meter or LCR meter. If the meter reads the resistance value equal or less than the actual value according to the colour coding in case of through-hole technology or digit coding in case of surface mount technology consider it as a good one. In case of open resistor, first refresh the solder joints for checking the possibility of dry sold and check it again, if resistor remains open then declared it as faulty and replace it with a good one.

2. Check the capacitor in-circuit by using multi-meter or LCR meter. If the meter reads the capacitance value equal or greater than the actual value consider it a good one, here we recommend that for checking the possibility of leakage remove it from PCB or open the one lead and charge it with appropriate voltages and observe the discharging pattern by using multi-meter, if the voltage drops rapidly and capacitor discharges completely then declared it as faulty and replace it with a good one.

3. Check the inductance of inductor in-circuit by using LCR meter which is normally in the range of milli-hennery.

4. Check the diode in-circuit by selecting diode check function in multi-meter and measuring the voltage drop between the two test leads. The forward voltage is typically in between 0.5 to 0.7 volts for silicon and 0.2 to 0.3 volts for germanium (which is rarely used in PCBs).

5. Check the transistor in-circuit by selecting diode check function in multi-meter and measuring the voltage drop between the two test leads. The base-emitter (BE) and base-collector (BC) junction should behave like a diode and conduct in one direction only. The emitter-base junction reads a slightly greater forward voltage drop than the collector-base junction because the emitter is heavily doped as compare to collector. The collector-emitter (CE) should not conduct in both directions, here we recommend that for checking the possibility of leakage current, remove transistor from PCB and check it with transistor tester, if found leakage replace with a good one.

After adopting all the above techniques, it is recommended that conduct the PCB trials on known good system, if PCB works satisfactory then well done! Go to the next job. In the case of un-satisfactory don't be regret or give up and remember six keys of success. Observe the change in PCB behaviour (if any) before and after the repair and try to isolate the problem and go to next step which is ICs testing.

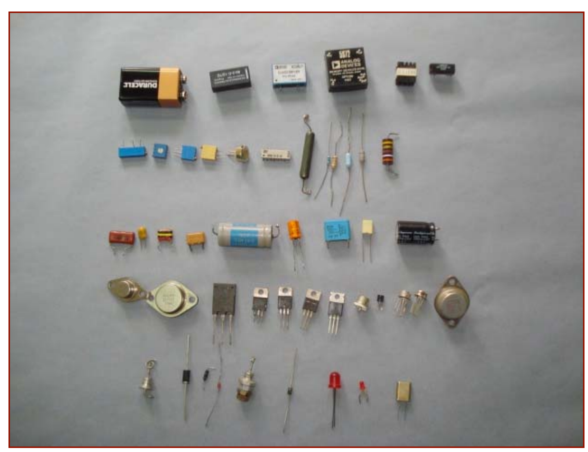

Figure 5: Showing some discrete components.

ICs Testing

Now it's time to interact with modern technology and modern equipment's for testing ICs. Normally most of the ICs on PCBs are identified and tested easily. ICs can be tested manually as well as by using in-circuit IC tester, but there are few ICs which can be tested manually like op-amp, 555-timer, opto-coupler, logic gates and multiplexer, therefore we recommended that use the IC tester for all testable ICs. Here we would like to remind that our research is limited on complex multi-layered PCBs and there is no such single equipment which can functionally test all types of ICs like Microprocessors, RAMs, ROM, Ball Grid Arrays (BGAs), complex programmable logic device (CPLD), Field-Programmable Gate Array (FPGA) and un-identified ICs.Sometimes these ICs are joint test action group (JTAG) compliant which can be tested in-circuit through JTAG device.

If find any defective IC, be-careful while replacing it because the excessive heat of soldering station or hot air can break internal layer track or can break the pad,then it could be difficult to recover such type of PCBs, especially if circuit diagram is not available.

Embedded Firm-Ware Check

Programmable ICs are very commonly used in modern day PCB design and with the advancement in technology; several variants of these ICs are being manufactured. Programmable ICs include ROMs, Microcontrollers, CPLD, PAL, GAL, etc. These ICs are designed to be configured by the user or designer after manufacturing. In many cases, the firm-wares of these ICs are corrupted. Sometime this can be indicated during system self-test or by fault indication LED, but mostly it can be verified by technical person by using IC Programmer if the known good program is available. Read the IC program, if program check sum is different consider it corrupted and reprogrammed it with the IC programmer but in some cases the known good program is not available for verification. In this situations read the IC's program multiple times if check sum is not change at each time consider it correct and if check sum changes every time then this really hampers the troubleshooting process and the only way is to copy a program from known good PCB, which includes a little risk.

Comparison Method

The one of the most useful techniques for quickly troubleshooting complex multi-layered PCBs is comparison method. It is mostly used in situations where PCBs contain un-identified or house coded ICs, non-testable components, circuit diagram not available, all the above techniques are failed to recover a PCB and the most important situation is when a known good PCB is available for comparison with a defective PCB.

There are two ways in which PCBs can be compared.

1. Using VI Instrument

2. Using thermograph camera

VI Instrument

The VI instrument is a very effective tool for troubleshooting the PCBs. It displays the VI (Voltage-Current) characteristics of component, whether alone or connected in any configuration in circuit by applying the V_{AC} stimulus signal across it and observing the displayed result. This qualitative test will reveal short–circuits, open-circuits, bad connections and leakage faults.

Figure **6** shows the VI instrument which represents how the defective PCB can be compared with known good PCB. There are two probes one is A (red) and other is B (green) are used to compare the two PCBs, the common test lead is used to ground the two PCBs with the instrument. Touch the pins of the ICs or other components on the PCBs with the test probes and observe the signature. If the signatures of the same pins are identical like shown in Figure **7** then there is no problem at that point but if the signatures of the same pins are different like shown in Figure **8** then technical person should start identifying the problem and following steps should be taken:

1. First of all refresh that particular pin with soldering iron to remove the possibility of dry sold and check the signature again

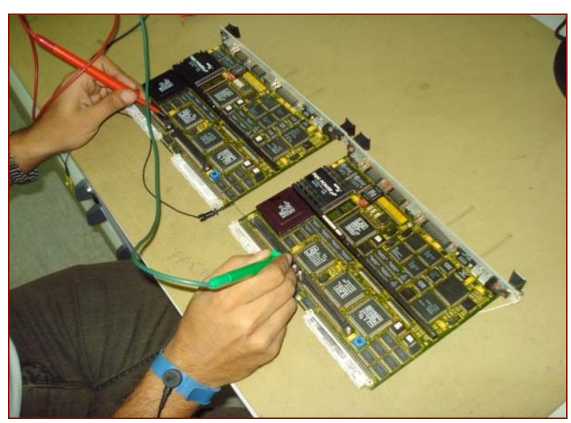

Figure 6: VI instrument showing how defective PCB can be compared with known good PCB.

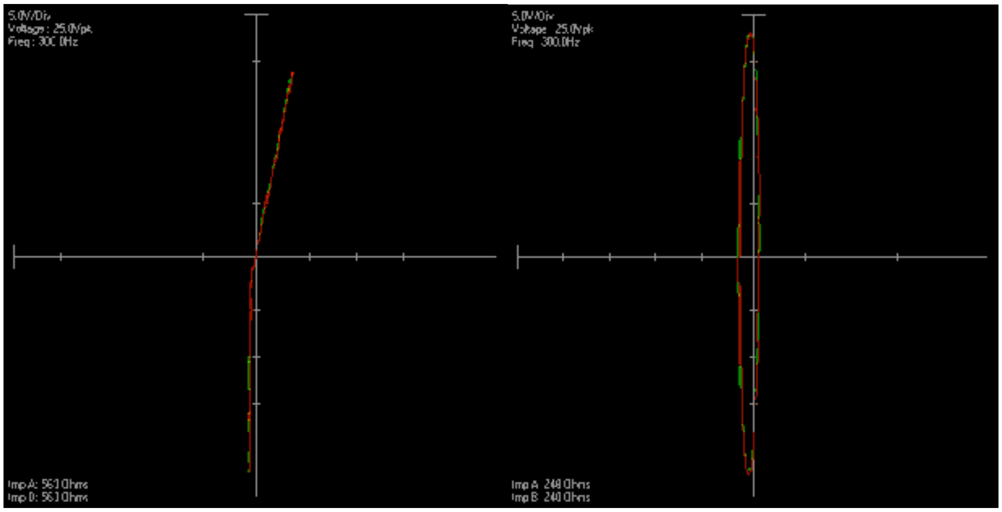

Figure 7: Identical signatures of same pins.

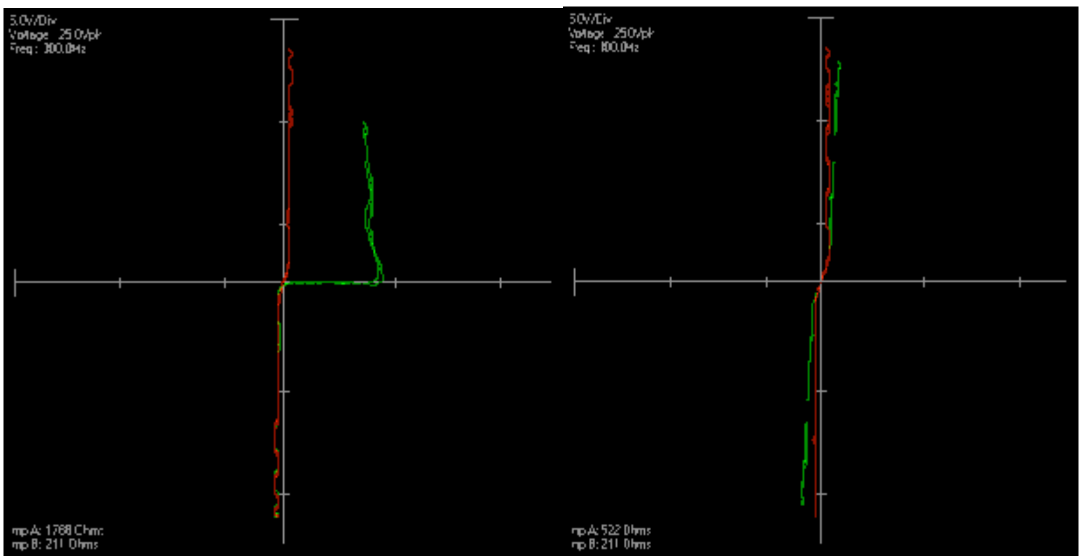

Figure 8: Different signatures of same pins.

2. With the help of the multi-meter and circuit diagram (if available) or known good PCB verify the tracks which are connected to that pin. In many cases tracks are opened which are re-make through jumper wire and check the signature again

3. Remove the IC or other component and check it out of the circuit

Thermograph Camera

Thermal Imaging has become well established as an invaluable tool for diagnostic [4]. Thermal imaging is often able to pinpoint problems or identify incorrect or unsuitable components [4]. Thermal imagers also known as infrared (IR) imagers or IR cameras, capture two-dimensional representations of the surface temperatures of electronics, electrical components and other objects. Since over- heating may signal that a trace, a solder joint, or a component (chip, capacitor, resistor, etc.) is malfunctioning [5]. Like in a VI instrument, a known good PCB is required to compare the temperature characteristics with a faulty PCB.

DISCUSSION

These troubleshooting techniques are very useful and give fruitful results many times but sometimes we faced very unique problems like un-identified ICs where the part number on the ICs has been removed or changed (house coded). This is often done by in an attempt to prevent pirating or copying of propriety information. However, when repairing these types of PCBs, IC's part numbers are essential, which may be identified by using IC identifier equipment but it is not

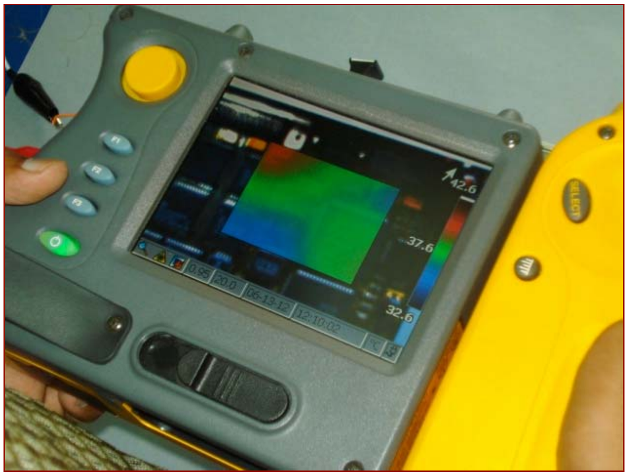

Figure 9: IR camera use to capture surface temperatures of electronics and electrical components.

necessary that it can identity all ICs secondly these are very expensive. If IC identifier is unavailable or unable to identify the IC, it has to be identified manually by counting the number of IC pins or by observing connection with the other components like resistor capacitor network or with other ICs. For this purpose good circuit knowledge is required.

In our research we observe that every scientist, engineer and technician working in this field has their own priority steps for troubleshooting the PCB adopted from the techniques as mentioned above, which varies according to their experience and skills. It may be useful in many cases but in few cases it becomes use less. As in the case when ICs impedance degraded and it draws excessive current and dissipated heat but functionally works correctly for a few moments as passed by IC tester, so if a person by-pass our recommended order of techniques, it means hot and cold check is skipped, which is very useful in this case.

In some cases PCB repair is not a viable option due to the difficulty that firmware of programmable ICs are secured or locked and could not be read or tested, also PCB contains obsolete components, un-identified ICs and non-testable ICs. In this situation functional replacement is good option by understanding the function of the PCB in the system.

CONCLUSION

In this research paper we conclude that by applying all above recommended troubleshooting techniques we will be able to achieve self-reliance in the field of PCB troubleshooting, thereby reducing dependability on foreign OEMs, equipment downtime and high costs being acquired in PCB repairs. It is also recommend that if the organisations which are working in this field involve the relevant universities and assign a task to the students like developing circuit diagram, functional test for non-testable ICs, exploring possibilities and techniques to retrieve embedded firmware from programmable ICs and functional replacement of the PCBs then it will be beneficial in many ways, not only enable us to solve the above mentioned problems which really hampers the troubleshooting process but also enhances the student's skills and will provide a good opportunity to interact with the latest technology and to prove their professional skills.

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