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PCB Design for EMC Testing

Metropolia University of Applied Sciences

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With technology speeding up, electronic circuits are widely used in different applications, such as communication, computation, automation. Circuitry is getting smaller in physical size which increases the chance of EMI problems. Devices maybe compromised polluting nearby equipment and environment.

The goal of the thesis was to study and observe two versions of self-designed printed circuit board (PCB) by EMC testing. PCB No.1 was designed as the best by following EMC rules while PCB No.2 as the worst.

Two similar schematics were given by the senior lecturer. The project was divided into three parts to be carried out. The first part was familiarizing with theoretical background. The second part was implementation. When implementing, design was mainly accomplished using PADS provided by Mentor Graphics. PCB were manufactured using milling machine LPKF ProtoMat S62. In the second part, procedure was repeat multiple times because of components issue. The final part was to test and analyze. When analyzing, comparison graphs were created and studied.

The objective of the project was completed successfully. Two PCB were fully functional and tested. All relevant reports for PCB are attached into the thesis.

Keywords	EMC, EMI, coupling, PCB, layout

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Contents

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List of Abbreviations

BOM   Bill of Materials

CAE   Computer-Aided Engineering

CAM   Computer-Aided Manufacturing

dBµV   Voltage Ratio in Decibels (dB) of the Measured Absolute Voltage of the Signal Referenced to One Microvolt

E   Electric Field

ECO   Engineering Change Order

EMC   Electromagnetic Compatibility

EMI   Electromagnetic Interference

H   Magnetic Field

Hz   Hertz

I/O   Input /Output

IDE   Integrated Development Environment

PCB   Printed Circuit Board

PDF   Portable Document Format

RMS   Root Mean Square

Ω Ohms

1   Introduction

With technology speeding up, electronic circuits are widely used in different applications, such as communication, computation, automation. Circuits are affected by each other adversely. Therefore, it is necessary for circuits to operate without causing interference to each other. After the end of 19th century, electromagnetic interference (EMI) has become a significant problem for circuit designers, and it will be more severe in the future because of the use of integrated circuits. Companies such as Intel or Samsung are trying to reduce the size of electronic equipment, for instance, decreasing chips' size every year. As circuitry has become sophisticated and smaller, circuits are being compressed in less space, which increase possibility of EMI.

In 21th century, there are more additional requirements for designers to make sure their designed equipment operate properly. All electronics products must be designed to be proper functioning without interference or damaging other adjacent equipment. In addition, products must obey government electromagnetic compatibility (EMC) standards, which means that the equipment should be affected by external electromagnetic source and should not itself be a source of electromagnetic noise that can pollute the environment.

The goal of the project was to study the effects of PCB design to the radiated interference in the near field. This goal was achieved with a set of test results that can be used in future as a reference for PCB design in embedded systems.

2   EMC Theory

2.1   EMC Introduction

Electromagnetic Compatibility (EMC) refers to the ability of a device or system to operate in electromagnetic environment without causing unacceptable electromagnetic interference (EMI) or physical damage to any operational equipment [1].

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Therefore, EMC includes two requirements. On the one hand, the electromagnetic disturbance generated by apparatus or devices in normal operation process cannot exceed a certain limit. On the other hand, it means that the appliance has a certain level of intrinsic immunity to electromagnetic interference existing in environment.

2.2   Elements of an EMC Problem

In an EMC problem, there are always three essential elements as illustrated in figure 1.

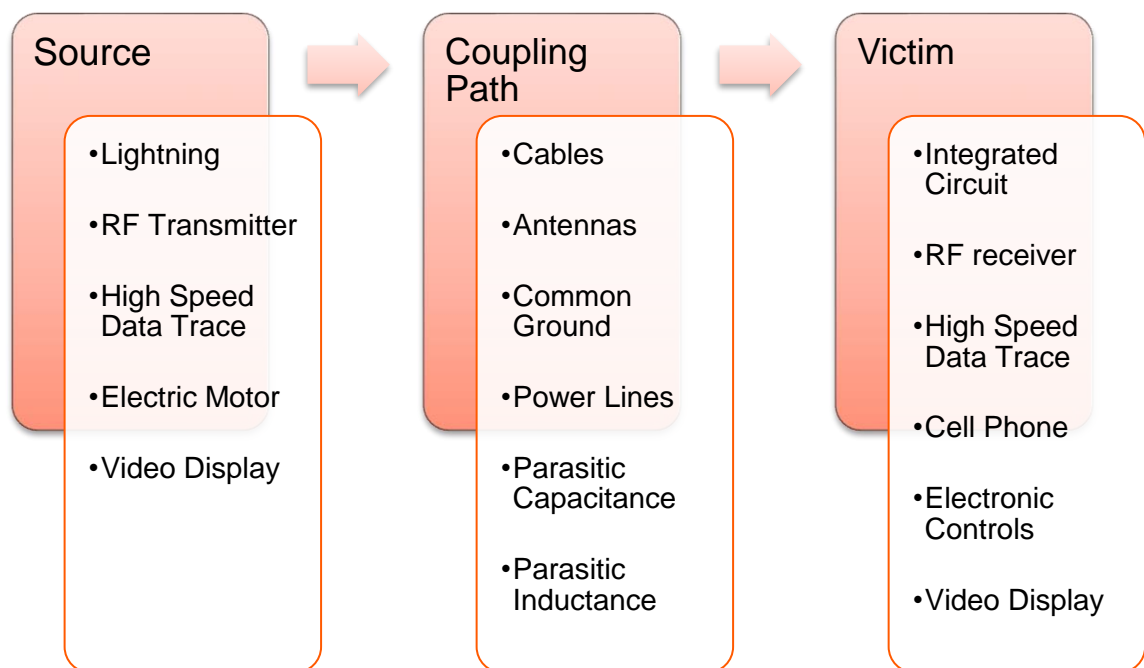| Source	Coupling Path	Victim
•Lightning	•Cables	•Integrated Circuit
•RF Transmitter	•Antennas	•RF receiver
•High Speed Data Trace	•Common Ground	•High Speed Data Trace
•Electric Motor	•Power Lines	•Cell Phone
•Video Display	•Parasitic Capacitance	•Electronic Controls
	•Parasitic Inductance	•Video Display

Figure 1.   The three essential elements of an EMC problem. Modified from [2].

Firstly, there is always a source of electromagnetic energy. Secondly, a victim is presented necessarily, which is a receptor that cannot function properly due to the electromagnetic energy. Finally, there is a path between them that couples the energy from the source to the victim (receptor). Not to mention each of these three elements must be performed, although they may not be quickly identified in every situation. In order to solve EMC problems, at least two of these elements must be identified and one of these elements must be eliminating or attenuating. [2.]

2.3   Capacitive (Electric Field) Coupling

In figure 2, a simple capacitive coupling between two conductors is shown on the left-hand.
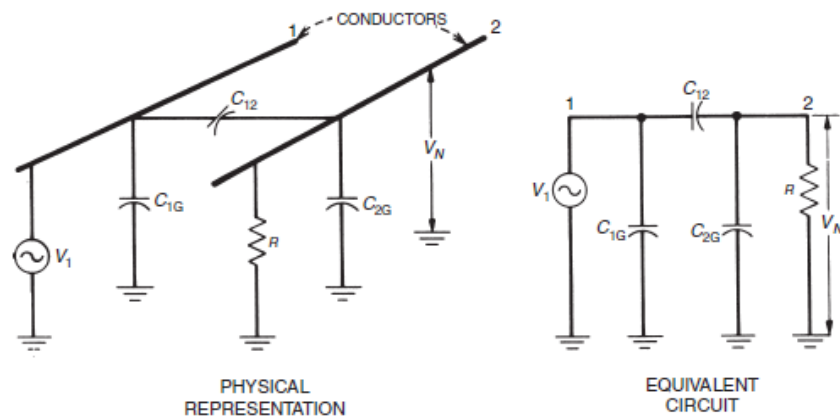

Figure 2.   Capacitive coupling between two conductors. Copied from [3, 45].

In here,

- C_{1G} - the capacitance between conductor 1 and ground

- C_{12} - the stray capacitance between conductor 1 and conductor 2

- C_{2G} - the capacitance between conductor 2 and ground

- R - the resistance of circuit 2 to ground

Note that the resistance R results from the circuitry connected to conductor 2 and is not a stray component. Capacitance C_{2G} consists of both the stray capacitance of conductor 2 to ground and the effect of any circuit connected to conductor 2. [3, 45.]

In figure. 2 the right-hand circuit is the equivalent circuit of the coupling.

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In here,

- V_1 - the source of interference on conductor 1.

- Conductor 2 - the affected circuit or receptor. Any capacitance connected directly across the source, such as C_{1G} can be neglected because there is no effect on the noise coupling.

- V_N - the noise voltage generated between conductor 2 and ground

V_N can be expressed as follow:

$$V_N = \frac{j\omega[C_{12}/(C_{12}+C_{2G})]}{j\omega+1/R(C_{12}+C_{2G})} V_1 \tag{1}$$

Eq.1 can be simplified when R is a lower impedance than the total impedance of C_{12} plus C_{2G}. And this is true in most practical cases. Therefore, for

$$R \ll \frac{1}{j\omega(C_{12} + C_{2G})},$$

Eq.1 can be reduced to the following:

$$V_N = j\omega R C_{12} V_1 \ , \tag{2}$$

Eq.2 is the most important equation to explain the capacitive coupling between two conductors. It demonstrates that the noise voltage is directly proportional to the frequency ($\omega = 2\pi f$) of the noise source, the mutual capacitance C_{12} between conductors 1 and 2, the resistance R of the affected circuit to ground, and the magnitude of the voltage V_1. [3, 52.]

2.4 Inductive (Magnetic Field) Coupling

As known, when current *I* flow through a conductor, it creates a magnetic flux $\emptyset$, which is proportional to the current. The inductance *L* is the constant of proportionality. Therefor

$$\emptyset_T = LI \ , \tag{3}$$

where

- $\emptyset_T$ is the total magnetic flux

- I is the current producing the flux.

According to Eq.3, the self-inductance of a conductor can be expressed as followed

$$L = \frac{\emptyset_T}{I},$$

(4)

When current flow in one circuit generates a flux in a second circuit, there is a mutual inductance shown in figure 3. [3, 52.]

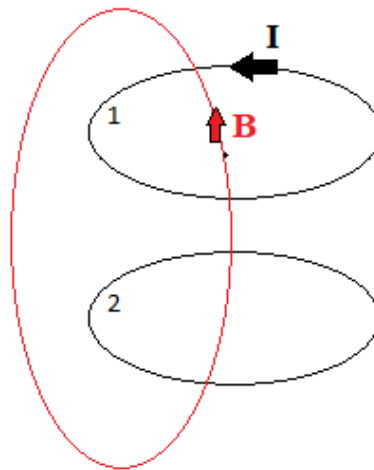Figure 3.   Mutual inductance

Mutual inductance M_{12} between circuits 1 and 2 is defined as

$$M_{12} = \frac{\emptyset_{12}}{I_1},$$

(5)

In here, $\emptyset_{12}$ stands for total flux in circuit 2.

The voltage V_N induced in a closed loop of area $\bar{A}$ resulting from a magnetic field of flux density $\bar{B}$ can be derived from Faraday's law [4] and is

$$V_N = -\frac{d}{dt}\int_A \bar{B} \cdot d\bar{A},$$ (6)

where $\bar{B}$ and $\bar{A}$ are vectors. If the closed loop is stationary and the flux density is sinusoidally varying with time but constant over the area of the loop, Eq.6 reduces to [3, 53.].
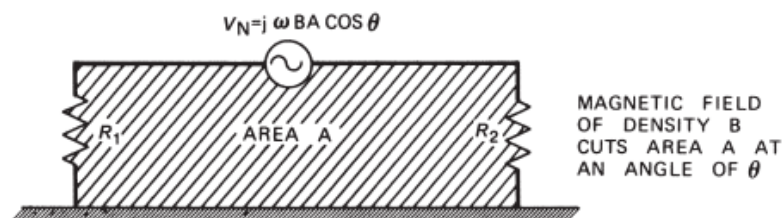
$$V_N = j\omega BA \cos\theta,$$ (7)

Figure 4.   Induced noise depends on the area enclosed by the disturbed circuit. Copied from [3, 53].

As shown in Figure 4

- A is the area if the closed loop

- B is the RMS value of the sinusoidally varying flux density of frequency ω radians per second

- V_N is the rms value of the induced voltage.

Since $BA \cos\theta$ stands for the total magnetic flux (ϕ_{12}) coupled to the receptor circuit, Eqs. 5 and 7 can be combined to express the induced voltage in terms of the mutual inductance M between two circuits, as follows:

$$V_N = j\omega MI_1 = M\frac{di_1}{dl}$$ (8)

[3, 53.]

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3   Grounding

Ground connection are essential for EMC in many ways. The function and performance of a ground system is influenced by connection types and concepts. Grounding should meet the following requirements:

- Between susceptible paths and paths with high emission at coupling should be decreased.

- From external radiated field at coupling should be decreased as long as emission from the equipment itself.

- Between several units, differences in potential should be avoided. [5, 24.]

For grounding, there are several rules which should be applied:

- An independent ground connection at each electrical circuit is necessary.

- For lower frequencies, single – point grounding method should be applied.

- For higher frequencies, multi – point grounding method should be applied.

- For circuits with low and high frequencies, the best solution is using triaxial cables, shown in figure 5. [5, 24.]

Figure 5.   Triaxial cables

4 Shielding

A shielding is a metallic partition placed between two regions of space. Shielding tech-nique is used to control EMC from on region to the other. Shielding may be used for many purposes. For example, shield could be used for containing electromagnetic fields. In figure 6 below, if a shield is applied to cover the noise source, it provides protection for all susceptible equipment outside the shield. [3, 238.]
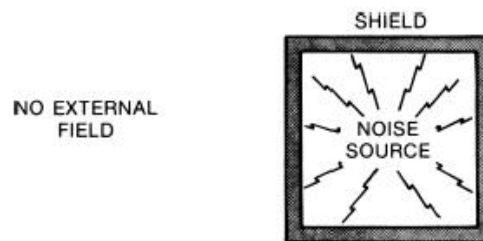

Figure 6.   Shield prevents noise coupling to equipment Copied from [3, 239].

Besides, shield could be used to keep out electromagnetic radiation from a region, as shown in figure 7.
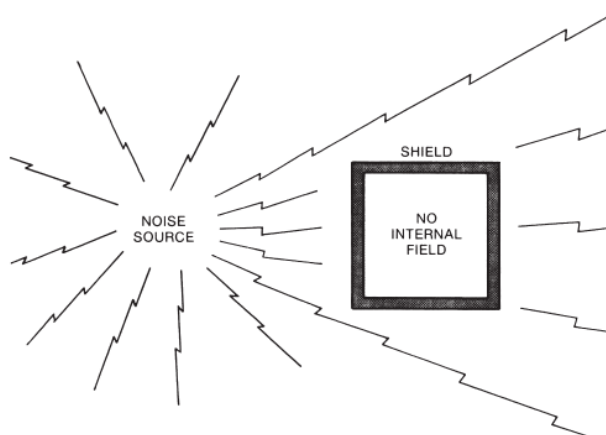

Figure 7.   Shield prevents noise from a region [3, 239].

For most cases, it is more efficient to shield the noise source than shielding the receptor. [3, 239.]

5   Inductor Saturation Current

Induction saturation current is the applied DC current at which the inductance value drops a specified amount below its measured value with no DC current [6]. More scientifically, it is the current at which all the magnetic domains in the core are aligned and there are no more available [7].

Before implementing any actual circuitry, it is required to check the inductor saturation current. Because if the saturation current does not meet the requirements of the circuit, consequently any additional DC current will not be stored as magnetic energy but wasted and turned as heat. As a result the inductor might burn. [7.]

An example can be seen in figure 8 below, which presents current in the inductor of a switching power supply. The current rises linearly until the red zone, where it increases significantly. The red zone is the saturation zone. [7.]
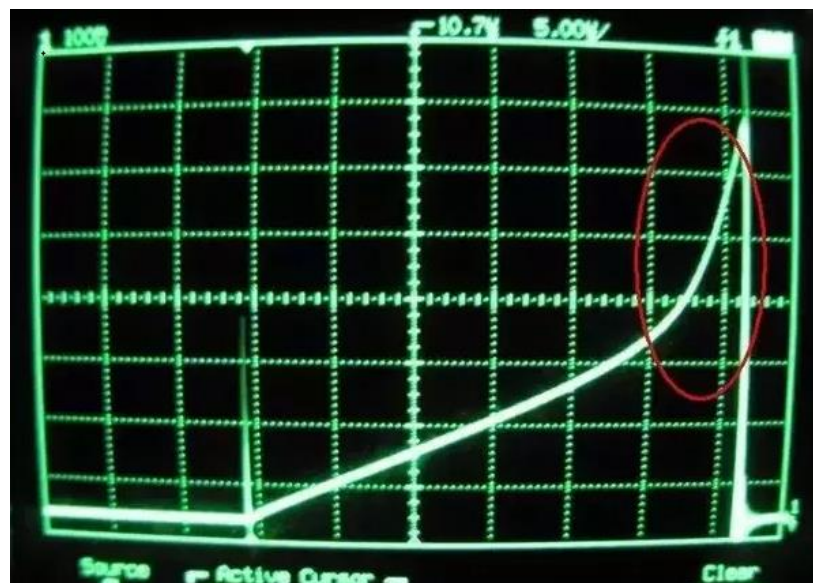

Figure 8.   Scope trace in the inductor of a switching power supply. Copied from [7].

6   PCB Layout Considerations

There are some EMC design guidelines for PCB:

- Before any PCB layout placement, grouping of components should always be carried out at first place.

- The length of traces carrying high-speed signals or clocks should be minimized. The reason behind that is because, usually high-speed digital signals and clocks are the strongest noise sources.

- The length of traces linked directly to connectors should be minimized, since they act as path for energy to be coupled on the board.

- All connectors should be placed on the edge of PCB. Because connector is functioning as antenna and provide a route for external noise and interference to the system.

- All voltage planes referenced to the same ground place should be routed on the same layer. For an instance, if a PCB requires 3 different voltages such as 1 V, 2 V, 2 V. To ensure there is no overlap, putting the voltage planes on the same layer is a certain choice.

- There should be no gaps or slots in the ground plane. [8.]

7   PCB Design

7.1   Mentor Graphic – PADS

This project is primarily designed and created based on PADS software family. PADS is an affordable and intuitive printed circuit board (PCB) design software created by Mentor Graphics company, which provides tools for schematic, layout, and rapid prototyping. There are two sub software mainly used, which are PADS Logic and PADS Layout. In order to build a finished PCB product, PADs software is necessary.

7.1.1 PADS Logic

PADS Logic is a powerful and user-friendly design software. Principally, by using PADS Logic, a schematic can be designed and created in a simple way. The essential functions are creating part types, generating netlists, generating reports (BOM), and interfacing with PADS Layout. More specifically, users are capable of:

- Customizing PADS Logic interface

- Creating 2D lines, texting objects

- Creating parts types, pin symbols, Computer-aided engineering (CAE) decals, connectors symbols and off page symbols

- Creating a schematic with parts, connections and busses

- Defining the PCB layer stack

- Defining design rules

- Creating netlists, report files, portable document format (PDF) and engineering change order (ECO) files

- Forwarding annotate with PADS Layout

7.1.2 PADS Layout

PADS Layout, mainly, is a routing software for PCB design. With PADS Layout, a schematic will be sent from PADS Logic. The essential functions are importing netlists, adding or updating parts, routing connections, generating reports and CAM files which are image file format files. More precisely, by using PADS Layout, there are more that can be done, which are

- Customizing PADS Layout interface

- Creating board outlines, keep-out zone, 2D line items

- Creating part types and PCB decals

- Placing parts manually

- Routing connections manually or automatically by PADS itself

- Generating computer aided manufacturing (CAM) files

- Editing in ECO mode

7.2 Circuit Board Plotter – LPKF ProtoMat S62

For electronics engineers, making a PCB prototype is an essential step in electronics development. In this project, the LPKF ProtoMat S62 circuit board plotter, shown in figure 9, is used for structuring, drilling, and milling of printed circuit board (PCB).

Figure 9.   LPKF ProtoMat S62

7.2.1 BoardMaster & LPKF CircuitCAM

BoardMaster, shown in figure 10 below, is a software associated with LPKF ProtoMat S62. It is a user-friendly software to manage and control LPKF ProtoMat S62.

LPKF CircuitCam, shown in figure 11 below, is a CAM software for PCB manufacture.

In the milling phase, PCB is manufactured by following the user manual step by step.
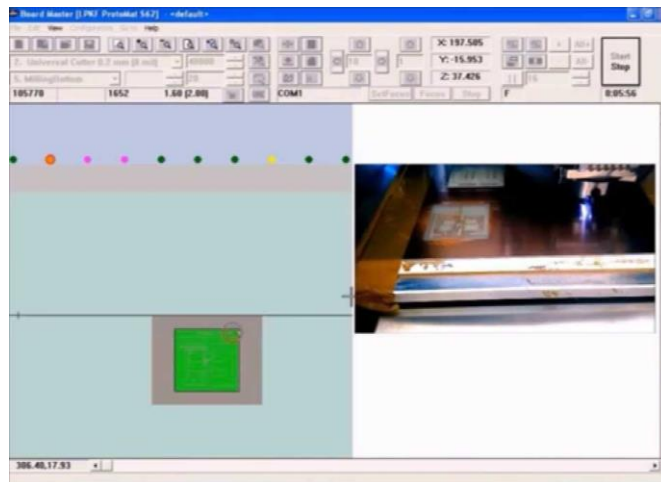

Figure 10.   User interface of BoardMaster

Figure 11.   User interface of CircuitCAM
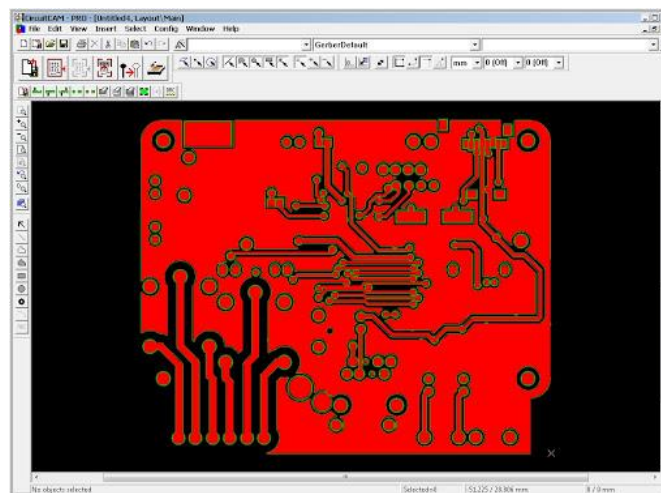
7.3   Particle Build IDE

In this project, an IDE called Particle Build was used to develop and compiled all user code. Particle Build IDE is an integrated development environment (IDE). It is an online browser- based platform where Photon code can be edited and saved. Furthermore, Photon code can be compiled, debugged and flashed to any Photon devices with an internet access.

An example of user interface of Particle Build IDE is shown in figure 12.
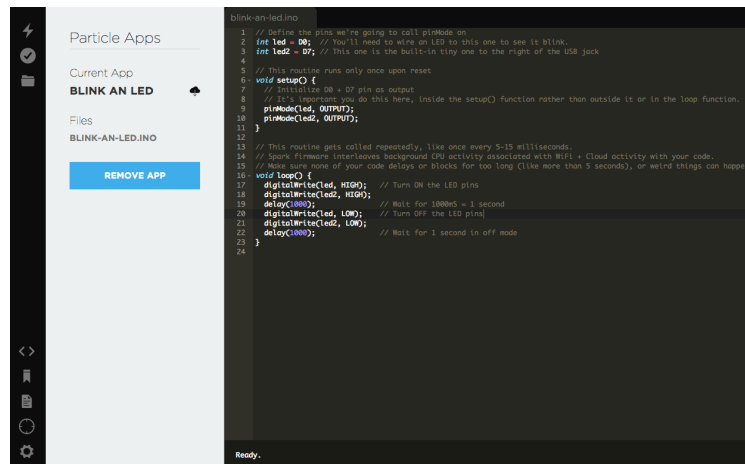
Figure 12.   User interface of Particle Build IDE

7.3.1   Particle IoT

Particle IoT is a mobile app which allows user to configure and manage Particle hardware and cloud deployments. Particle IoT application is required in this project. It allows users to check Photon device diagnostics, and tract whether setup devices are online or offline. An example of article IoT interface shown in figure 13.

Figure 13.   An example of Particle IoT shows Photon device is offline

7.4 Two Versions of PCB Design

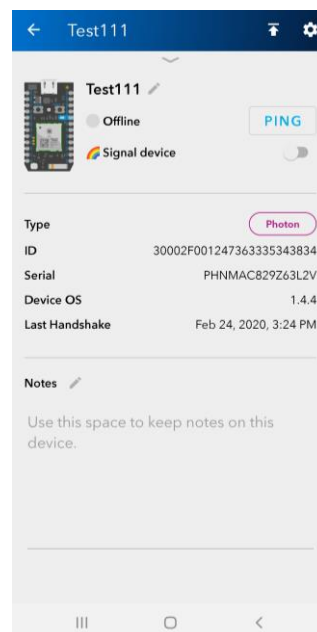In this project, the goal was to run EMC test on two different PCB with similar given schematics by project supervisor. Therefore, two different PCB layouts were designed. Therefore, two different PCB layouts were designed. One with an inadequate EMC layout design and another with an appropriate EMC layout design.

7.4.1 The First Version of PCB (PCB No.1)

7.4.1.1 Given Schematic of PCB No.1

Figure 14 below shows the given schematic of PCB No.1. J1 are connected to power supply with a range of 7 to 35 V. J2 are connector for serial port. In the project, connector J2 are not used. J3 are LED Strip connectors. J4 are the connector for an external load, which is 100Ω.

The component close to J1 is a switching regulator whose output is 5V. The 5V output acts as supply power for Particle Photon connected to Vin. BS107A is a PWM module and IRF510 controls the power to external load.

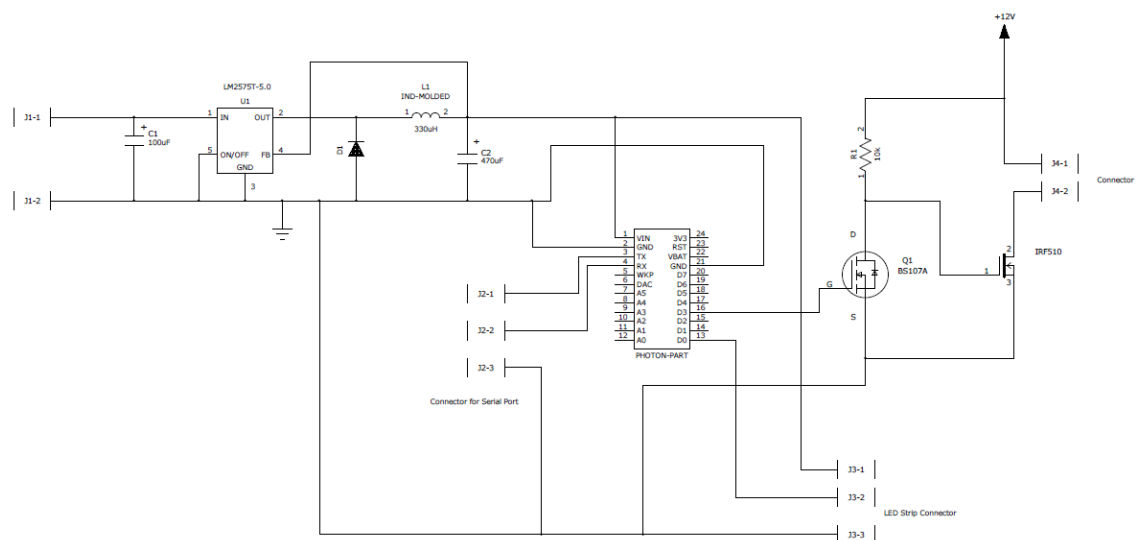

Figure 14.   Schematic of PCB No.1

7.4.1.2   Layout of PCB No.1

In figure 15, the layout of PCB No.1 is illustrated. Blue traces are connected on the bottom layer. On the contrary, red traces are connected on the top layer. Components with grey dots marked are ground pins. As can be seen, all components are placed randomly without a logical grouping. Some traces are connected not in 45°. Additionally, there is no ground layer.

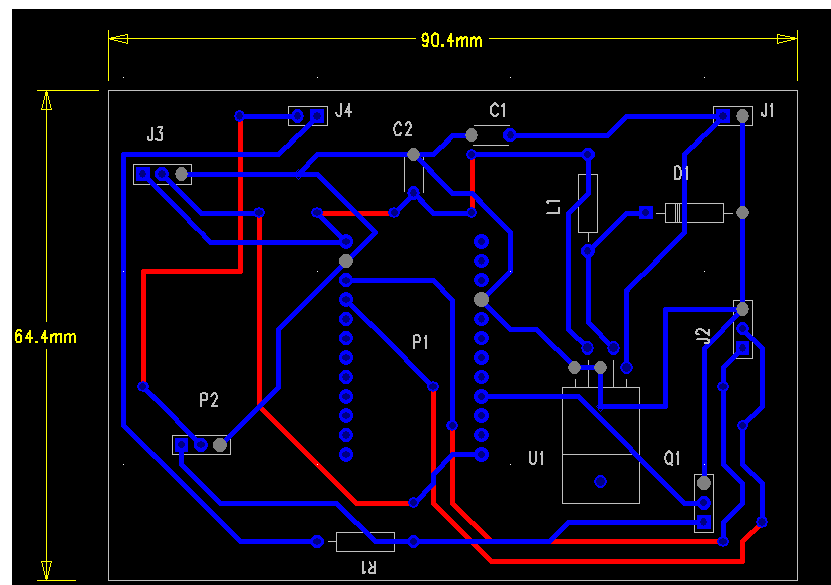Figure 15.   Layout of PCB No.1

7.4.2   The Second Version of PCB (PCB No.2)

7.4.2.1   Given Schematic of PCB No.2

The schematic of PCB No.2 is shown in figure 16. The schematic of PCB No.2 is similar compared with the schematic of PCB No.1. The only difference is that there is a polarized capacitor C3 connected parallel with connector J4 and IRF510. This capacitor acts as a decoupling capacitor [9].
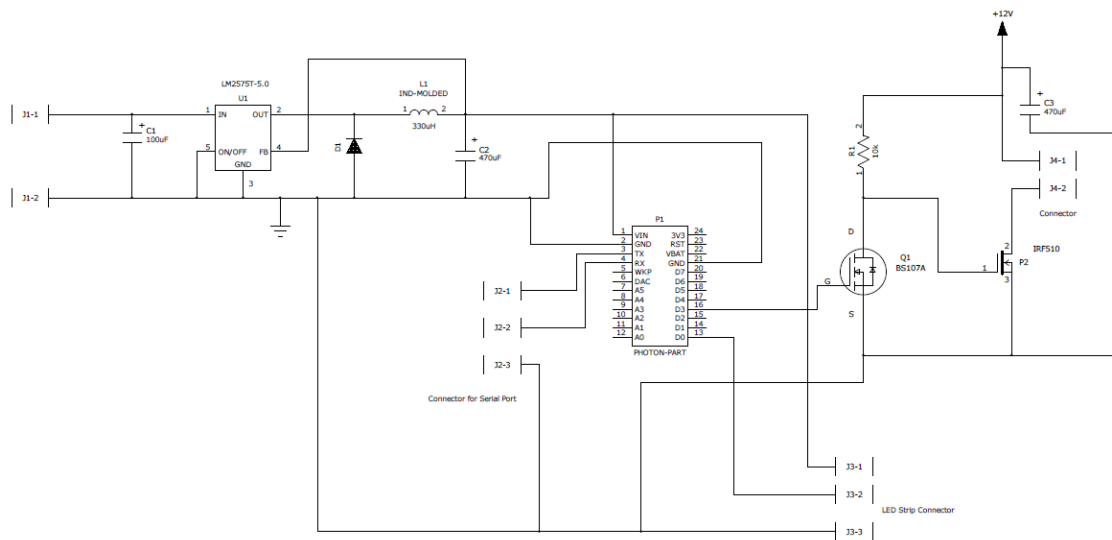
Figure 16. Schematic of PCB No.2

7.4.2.2 Layout of PCB No.2

The layout of PCB No.2 is shown below in figure 17. Same as the layout of PCB No.1, blue traces are on the bottom while red traces are on the top. All components are grouped and placed. The upper area is for connectors. Moreover, the left corner is for digital and the rest part is for analog.

The most difference is that there is a ground layer connected to all ground pins, which is the inner square board line. By creating the ground plane, EMI will be decreased significantly.
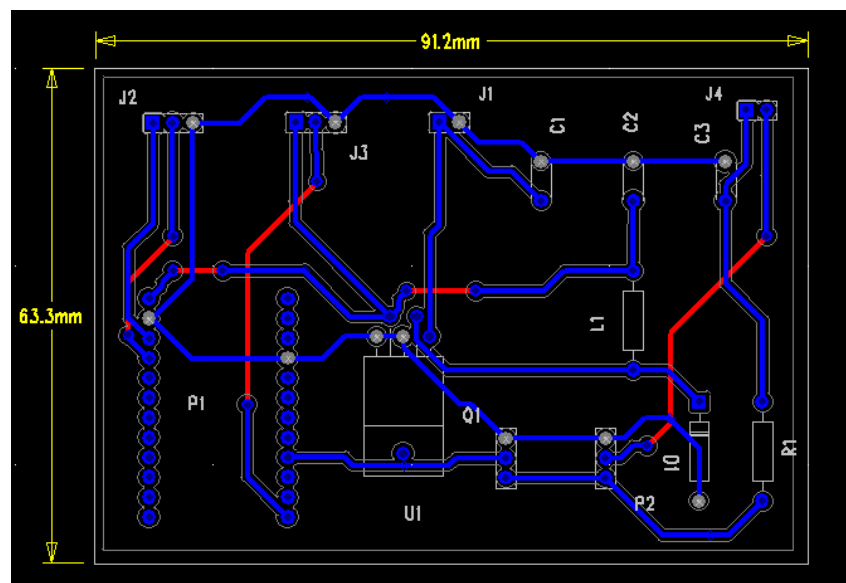
Figure 17. Layout of PCB No.2

8 Implementation

8.1 List of Components

The following list contains the components used in PCBs.

Polarized Capacitors:

- 100uF 35V x 2

- 470uF 50V x 3

Power Inductors:

- 330uH (saturation current = 1.8A) x 2

Diode:

- 1N4001 x 2

Switching Regulator

- LM2575-5.0 x 2

Photon Particle x 2

FET- switches:

- BS107A x 2

- IRF510 x 2

Resistors:

- 10kΩ x 2

LED Strip:

- Grove – WS2813 RGB LED Waterproof (30 LED/m – 1m) x 1

External load:

- 100Ω x 2

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Used components for the PCB's are listed above. In figure 14 and figure 16, as illustrated, supply voltage on switching regulator connected to connector J1-1 ranges from 7 – 40V. In this project, 12V are applied. Hence, for both polarized capacitors C1 in two schematics, 100uF with 35V voltage rating is sufficient. As for C2 and C3, any 470uF capacitor with voltage rating higher than 12V meets the requirement. The reason why 50V voltage rating for 470uF capacitors are used is simply because only they were available in laboratory.

Another key thing to remember is that power inductor saturation current is 1.8A. Any power inductor with less than 1.8A saturation current rating will only operate properly with minimum load current.

Saturation current of the power inductor is calculated in this way. From datasheet of LED strip in figure 18, the operating current is 0.06A per LED. In order to turn all LED to white, in other words, to brightness level 255, the total current is

$$I = 0.06 \times 30 = 1.8\ A$$

Technical Details

Dimensions	1000mm x 12mm x 4mm
Weight	G.W 44g
Battery	Exclude
Operating Voltage	DC 5V
Operating Current	3.6A per meter / 0.06A per LED

Figure 18.   LED Strip datasheet Copied from [11].

Additionally a PWM control for external load was designed with BS107A transistor. Particle Photon has several specific pins for PWM control as shown in datasheet in figure 19. In this project, output pin D3 is used for PWM control.
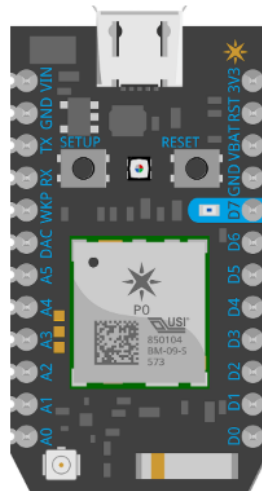
[3] PWM is available on D0, D1, D2, D3, A4, A5, WKP, RX, TX with a caveat: PWM timer peripheral is duplicated on two pins (A5/D2) and (A4/D3) for 7 total independent PWM outputs. For example: PWM may be used on A5 while D2 is used as a GPIO, or D2 as a PWM while A5 is used as an analog input. However A5 and D2 cannot be used as independently controlled PWM outputs at the same time.

Figure 19.   Particle Photon datasheet. Copied from [12].

8.2   Assembling

Firstly, two schematics, shown in figure 14 and figure 16, were created using PADS Logic. Parameters of all components should be checked before forwarding to PADS Layout, since it might cause errors.

Secondly, the schematics created by PADS Logic were transmitted to PADS Layout. Before connecting traces, drill sizes and pads sizes should be checked carefully, since the whole layout placement is affected by them. For example, if the drill sizes used are too small, the consequence is that components cannot be implemented physically, which leads to repeat PCB milling procedure many times. Time and money will be wasted.

Thirdly, all traces were connected from the bottom layer first, which are those blue connections presented in figure 15 and figure 17. After bottom layer, top layer connections can be connected. As mentioned in '7.4.2.2 Layout of PCB No.2', a ground layer should be created and flooded, shown in figure 20. After that, CAM files were created for the purpose of milling.
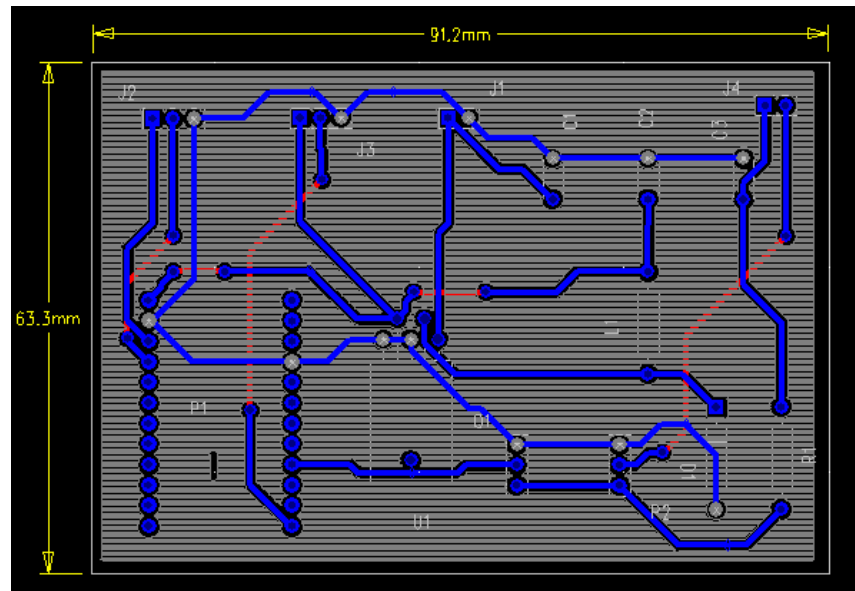
Figure 20.   Flood ground layer

Fourthly, by using milling machine LPKF ProtoMat S62, both PCB were manufactured. Figure 21 is a prototype PCB of this project. It is not the final PCB.
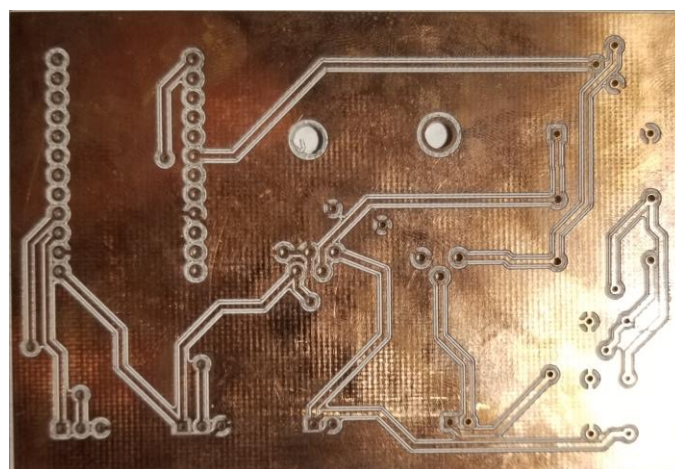
Figure 21.   A prototype of PCB

Fifthly, components were soldered to the PCB's. For Particle Photon pins, it is recommended to use 24 sockets instead of soldering Photon directly. In figure 22, a prototype of soldered PCB is presented.
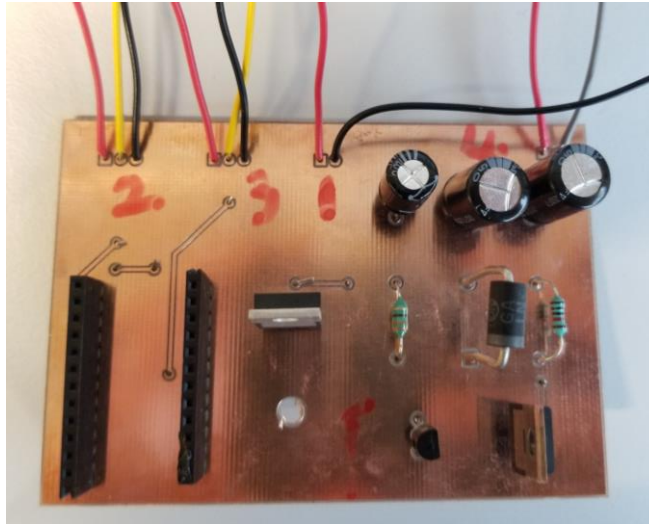
Figure 22.   A prototype of solder PCB

Sixthly, all 24 sockets were tested to check whether there were short circuit or leaked current. The correct voltage output from switching regulator should be 5V shown in figure 23.
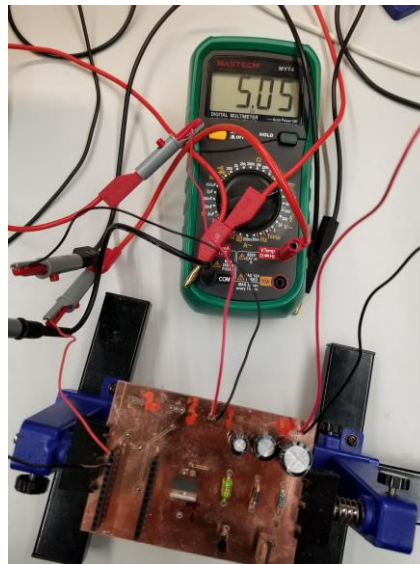
Figure 23.   5V output from switching regulator pins in a prototype PCB

Seventhly, PWM switch were tested to check whether it was working or not, shown in figure 24, by flashing example code shown in listing 1 on Particle IDE website.

```
int led1 = D3;
void setup() {
pinMode(led1, OUTPUT);
}
void loop() {
analogWrite(led1, 60);
}
```

Listing 1.   Example Code for PWM testing
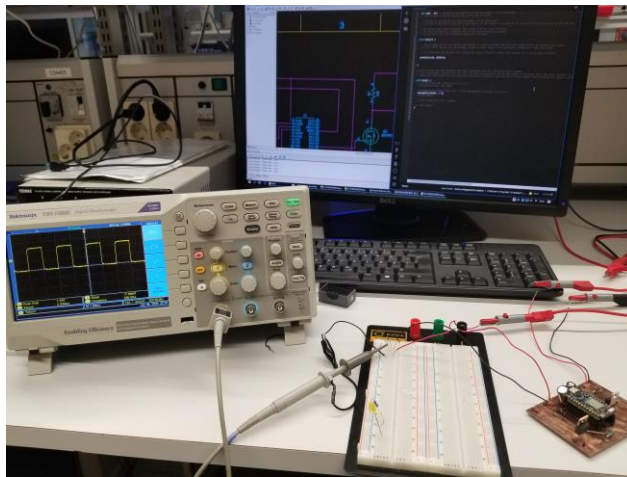
Figure 24.   PWM testing of a prototype

After correcting any found mistakes, two final PCB were assembled, shown in figure 25 and 26.
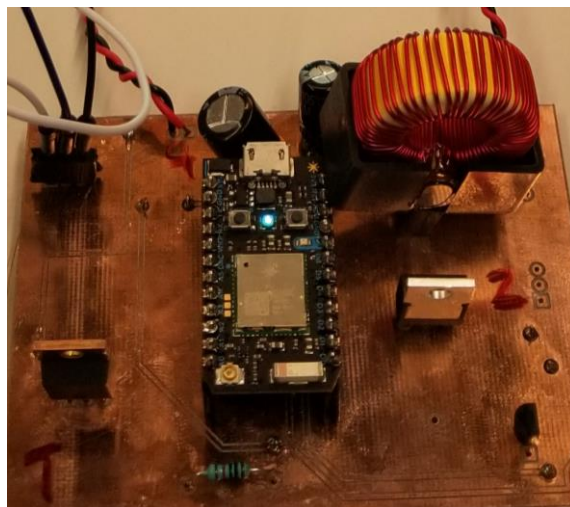
Figure 25.   Final version of PCB No.1
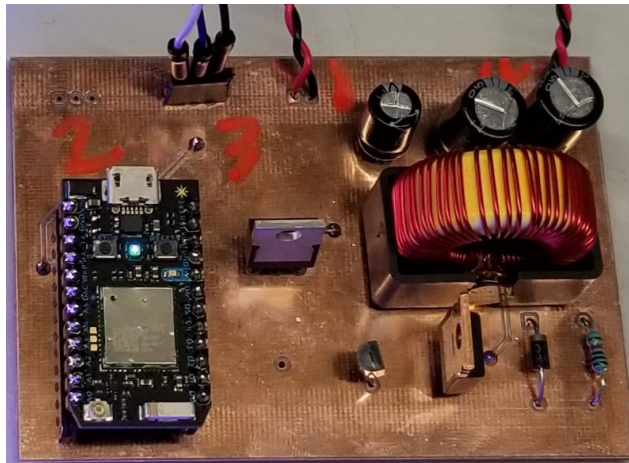
Figure 26.   Final version of PCB No.2

Finally, in order to turn on the LED strip, an example code called *a-rainbow.ino* shown in listing 2, presented below, from Particle IDE library was applied. By lighting on all LEDs, the result will be clear since LEDs increased current as well as emission intensity. Both PCB are shown as figure 27 and 28.

```
#include "Particle.h"
#include "neopixel.h"

SYSTEM_MODE(AUTOMATIC);

// IMPORTANT: Set pixel COUNT, PIN and TYPE
#define PIXEL_PIN D0
#define PIXEL_COUNT 30
#define PIXEL_TYPE WS2812B

Adafruit_NeoPixel strip(PIXEL_COUNT, PIXEL_PIN, PIXEL_TYPE);

// Prototypes for local build, ok to leave in for Build IDE
void rainbow(uint8_t wait);
uint32_t Wheel(byte WheelPos);

void setup()
{
  strip.begin();
  strip.show(); // Initialize all pixels to 'off'
}

void loop()
{
  rainbow(20);
}

void rainbow(uint8_t wait) {
  uint16_t i, j;

  for(j=0; j<256; j++) {
    for(i=0; i<strip.numPixels(); i++) {
```

```
        strip.setPixelColor(i, Wheel((i+j) & 255));
      }
      strip.show();
      delay(wait);
    }
}
// Input a value 0 to 255 to get a color value.
// The colours are a transition r - g - b - back to r.
uint32_t Wheel(byte WheelPos) {
  if(WheelPos < 85) {
   return strip.Color(WheelPos * 3, 255 - WheelPos * 3, 0);
  } else if(WheelPos < 170) {
   WheelPos -= 85;
   return strip.Color(255 - WheelPos * 3, 0, WheelPos * 3);
  } else {
   WheelPos -= 170;
   return strip.Color(0, WheelPos * 3, 255 - WheelPos * 3);
  }
}
```

Listing 2.   Example code: *a-rainbow.ino*
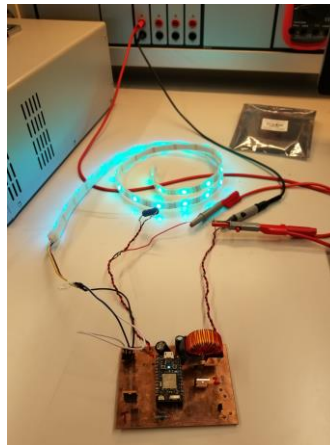
Figure 27.   PCB No.1 was under testing
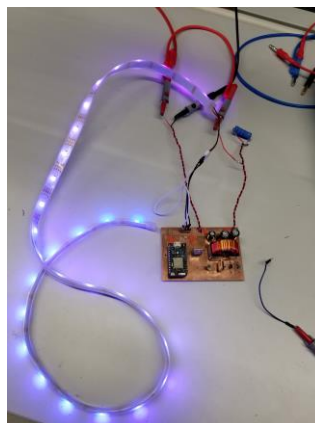
Figure 28.   PCB No.2 was under testing

9   EMC Testing

In this chapter the tools used in EMC tests are introduced as well as the actual EMC tests condcuted. Finally a summary of results is presented and analysed.

9. 1   Testing Tool - EMC Scanner – RSE 642

Model RSE 642, designed by Detectus AB, was used for EMC scanning. RSE 642 is shown in figure 29. There are five functions, which are

- Visual noise detection

- Objective comparative measurements

- MultiScan

- Import 3D surface models

- High resolution heat scanning

Figure 29.   EMC scanner RSE 642. Copied from [10].

In this project, Visual noise detection and MultiScan were mainly used to measure and compare two different models of PCB.

For Visual noise detection function, it measured the emission from PCB's, components, cables and products. The system was consisted of an X-Y-Z robot, a spectrum analyzer with near field probe, a GPIB or similar communication interface with the spectrum analyzer and a PC with installed custom software. By following the manual, all testing parameters were set before measurement. During measurement, the near field probe was moved to measuring point above the test PCB. At each measuring point, the location of the probe and the value of the emission intensity was stored instantly. After the measurement, results were stored in report files.

For MultiScan function, field plots were generated from any frequency within the measured wide band span.

9.2   Testing

As can be seen in figure 27 and 28, both PCBs were operating properly without EMC testing. The next step was to place both PCBs on EMC scanner table and test individually. Before that, there were some parameters' setting needed to be edited for EMC scanner.

In this project, spectrum analyzer setting ranges from 9 kHz to 30 Mhz. The probe named PROBE_RF_E_10 was used. Measured area was starting from 300 mm to 400 mm on X - axis and from 0 mm to 70 mm on Y- axis, on which PCB was placed. The step size was 10 mm. [See Appendix 1]

As mentioned in 10.1, the near field probe was moved to measuring point where X = 300 mm and Y = 0 mm above the test PCB and ended to the point where X = 400 mm and Y = 70 mm. At each measuring point, the location of the probe and the value of the emission intensity was stored instantly.

After both PCBs were measured, reports were created automatically. [See Appendix 1&2]

9.3   Results Analysis and Comparison

All comparison of PCB No.1 and PCB No.2 are presented from figure 30 to 33 below and from figure 36 to 42 [See Appendix 3].

As can be seen in figure 30, the blue line and red line represent the radiated interference of PCB No.1 and PCB No.2. separately. On the left table next to the line graph, detailed magnitudes were given. For example, on the second row, it means that the radiated interference measured for PCB No.1 was 131.321 dBμV where the probe was on position X = 300 mm, Y = 0 mm. When the probe moved from 0 to 10 on Y – axis, the radiated interference measured for PCB No.1 was 131.446 dBμV.

Besides, in figure 30 and figure 31, there are not much difference with the radiated interference which indicates that at this position there are no parts of the system which generate interference.

	PCB No.1	PCB No.2
0	131,432	107,973
10	131,446	107,973
20	131,468	124,344
30	131,453	122,031
40	131,474	124,242
50	131,469	127,506
60	131,459	128,397
70	131,474	128,562
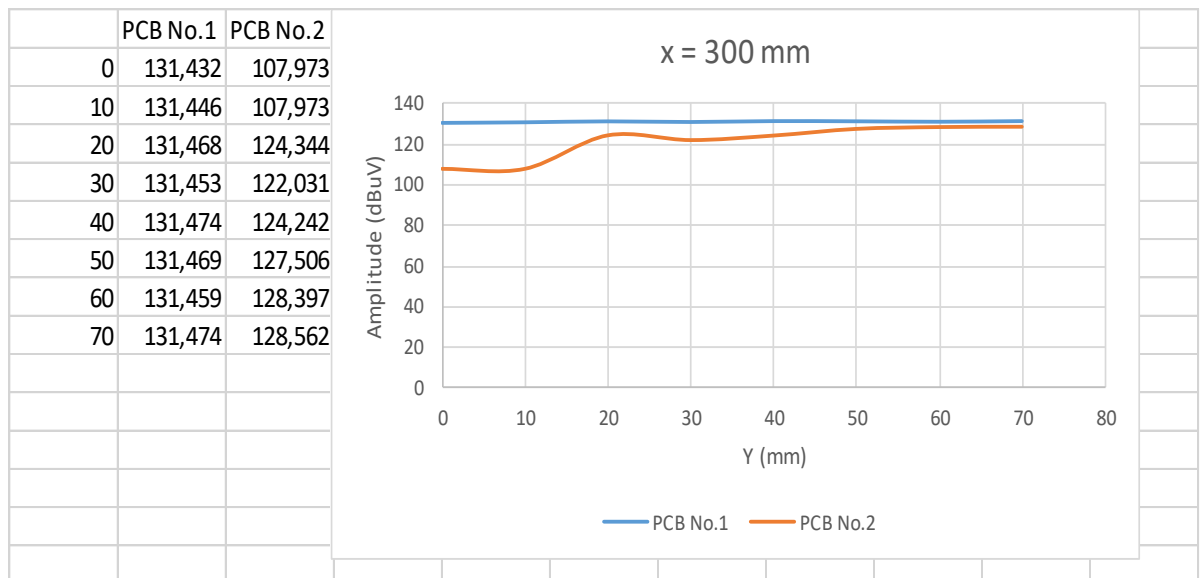
Figure 30.   Amplitude when probe position on x = 300, y = 0 to 70

	PCB No.1	PCB No.2
0	131,444	126,12
10	131,451	122,087
20	123,921	131,476
30	123,527	121,152
40	114,378	124,263
50	129,33	107,766
60	125,71	126,565
70	130,855	128,613

Figure 31.   Amplitude when probe position on x = 310, y = 0 to 70

On figure 32 and figure 33, as can be seen, the radiated interference of PCB No.2 is greatly reduced due proper PCB layout design.

	PCB No.1	PCB No.2
0	129,14	124,521
10	123,064	116,628
20	130,023	120,11
30	130,341	124,323
40	129,998	123,288
50	129,903	127,864
60	129,901	128,31
70	129,797	128,509
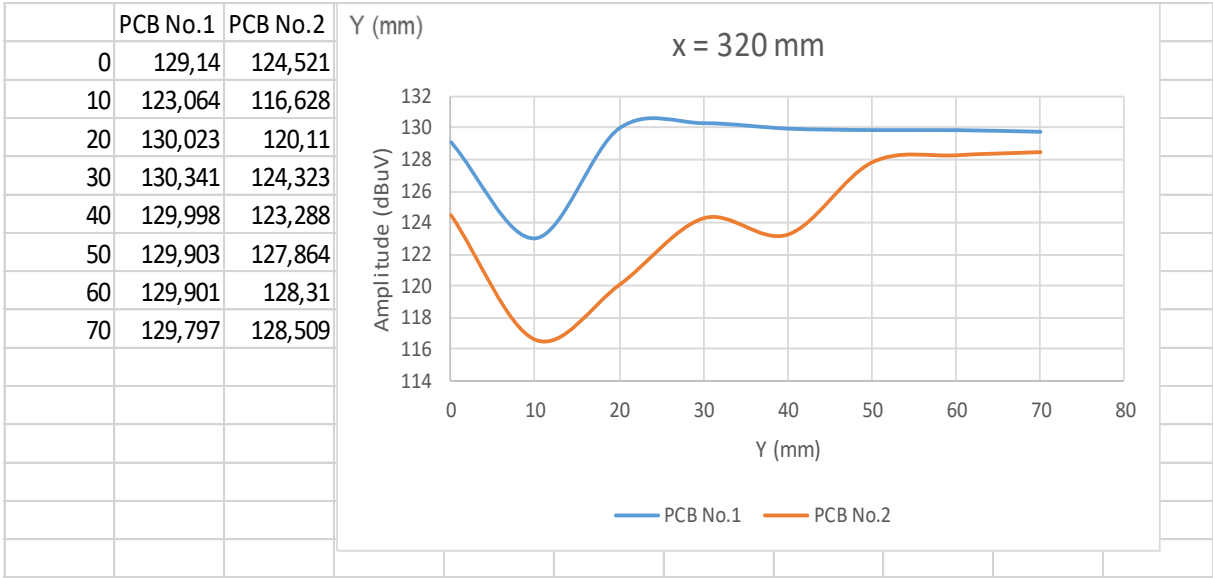
Figure 32.   Amplitude when probe position on x = 320, y = 0 to 70

	PCB No.1	PCB No.2
0	129,962	126,979
10	129,403	126,142
20	129,754	126,701
30	129,596	126,482
40	129,597	126,275
50	128,912	126,483
60	130,177	125,134
70	128,822	128,423

Figure 33.   Amplitude when probe position on x = 330, y = 0 to 70

Figure 34 and 35 displays the radiated interference of PCB No.1 and PCB No.2 individually in color mode. If the color is more red, it means more interference.
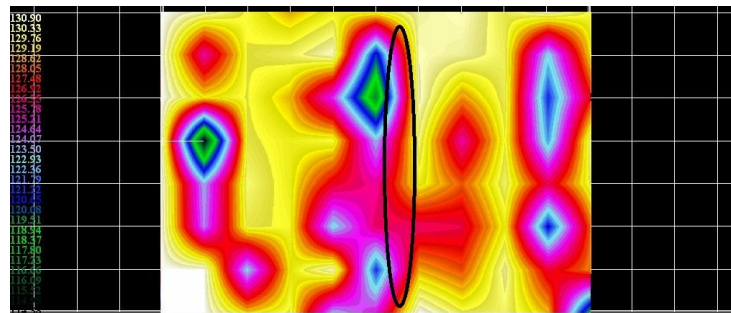
Figure 34.   MultiScan of PCB No.1
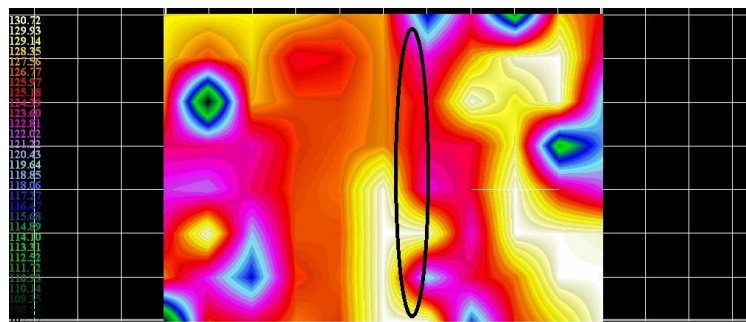
Figure 35.   MultiScan of PCB No.2

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10 Conclusion

The goal of the project was to study the effects of PCB design to the radiated interference in the near field. This goal was achieved with a set of test results that can be used in future as a reference for PCB design in embedded systems. Inappropriate PCB layout increases the chance of EMC problems. With the purpose of reducing and avoiding EMC problems, there are several techniques that can be concluded:

- Before PCB layout design, components should be grouped logically. In the project, on PCB No.1, all components were placed randomly increasing EMC.
- It is important to prepare shielding. In the project, for both PCB No.1 and No.2, all external wires were shielded by isolated cover and twisted to cancel EMI from eternal source.
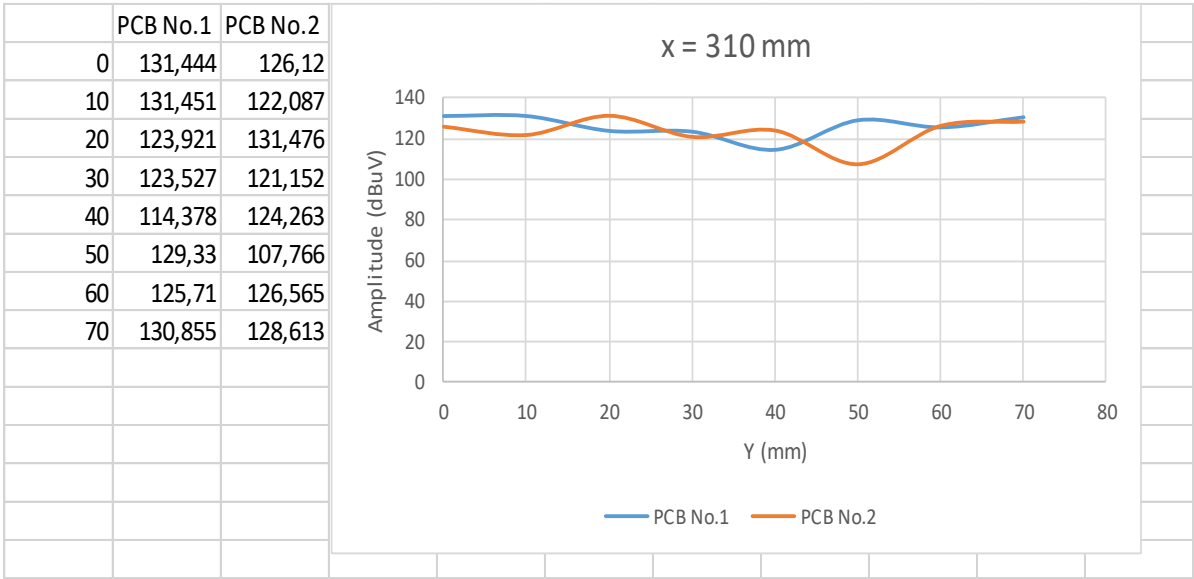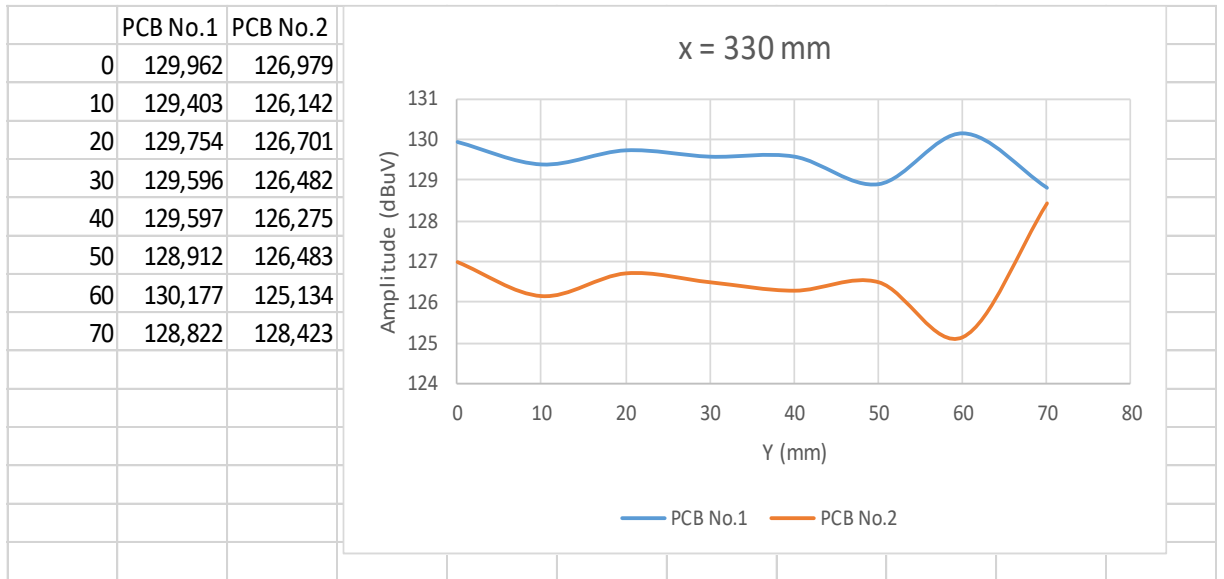- The grounding system is the main factor to attenuate the noise. In the project, PCB No.2 was design with a grounding plane, which decreased EMI.
- Decoupling capacitor should be used to decouple one part of an electrical network from another. In the project, capacitor C3, shown in figure 16, is a decoupling capacitor, which supress high-frequency noise in power supply signals.
- Avoid creating unintented antennas in PCB design. If the components pin legs are too long exposed to the outside of PCB, it will act as an antenna causing EMC issue. In the project, in figure 22, diode pins were implemented too far away from prototype PCB acting as antenna. Hence, prototype in figure 22 was not applied as final model.

Here is a list of some common design failures and mistake made during this project.

- Before PCB design, datasheet of all components was not checked carefully leading to reform PCB layout multiple times. Because there was not enough space for components on the PCB.
- Supported drill sizes by the milling machine were not checked.
- Pad sizes were not checked. As a result, soldering became a huge problem.
- Inductor saturation current was not leaned and checked.
- Connector J-3 should be created as 3 pins.

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Appendix 1

EMC Report of PCB No.1

Detectus EMC-Scanner report

Detectus AB

Measurement report

Ackumulated trace

Trace at position X300.00 Y40.00 Z0.00
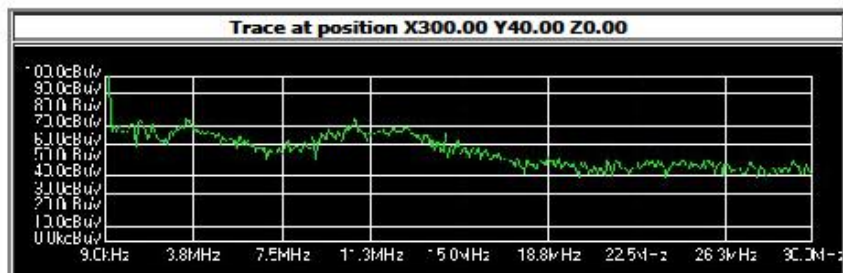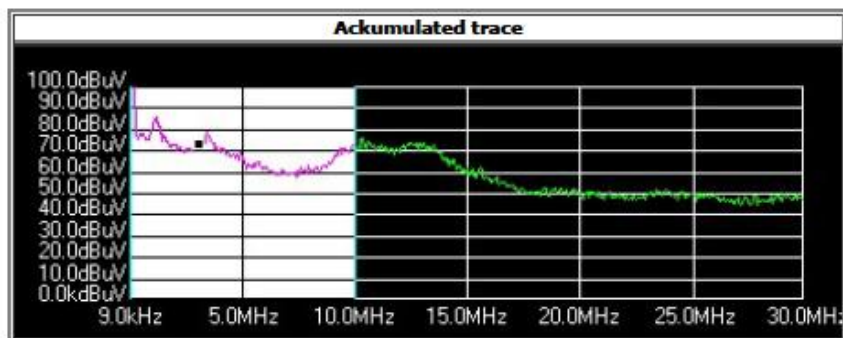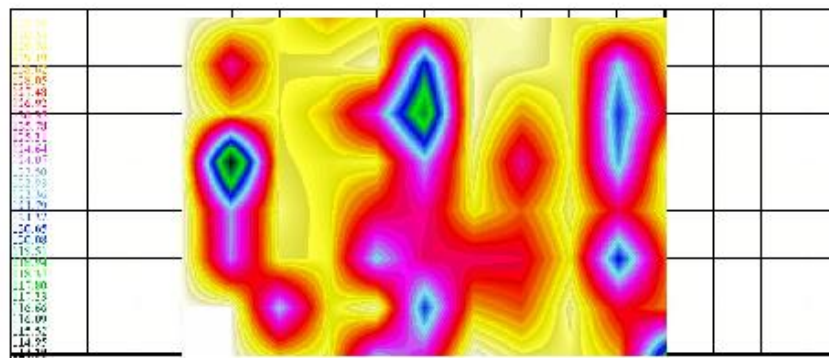
File name:	basic multiscan.ms2d
Date:	24.2.2020

Measured area:			
Start X:	300 mm	End X:	400 mm
Start Y:	0 mm	End Y:	70 mm

Detectus EMC-Scanner report

Step size:	10 mm
Base level Z:	0 mm

Min and Max:

Min amplitude:	114dBuV	Max amplitude:	131dBuV

Position of highest amplitude:

X(mm)	Y(mm)
300.000	40.000
Peak frequency:	9KHZ

Settings:

Spectrum analyzer setting:	9kHz - 30MHz
Probe:	PROBE_RF_E_10

Amplitude:

Reference level offset:	0dB
Reference level:	-20dBm
RF attenuation:	0dB
Pre-amplifier:	0dB
Unit:	dBuV

Bandwidth:

Resolution bandwidth:	100kHz
Video bandwidth:	300kHz

Frequency:

Base measurement center frequency:	15.0MHz
Base measurement frequency span:	30.0MHz
Selection center frequency:	5.00900MHz
Selection frequency span:	10MHz
No. of spectrum sweeps:	3

Probe:

Correction factors:	0Hz, 40dB, 5MHz, 28dB, 15MHz, 18dB, 25MHz, 14dB, 50MHz, 8dB, 300MHz, 3dB, 600MHz, 0dB, 2100MHz, 0dB, 2200MHz, 1dB, 2600MHz, 1dB, 2700MHz, 0dB, 3000MHz, 0d

Data list:

X(mm)	Y(mm)	Amplitude (dBuV)	Frequency (Hz)
300.000	0.000	131.432	9000
300.000	10.000	131.446	9000
300.000	20.000	131.468	9000
300.000	30.000	131.453	9000
300.000	40.000	131.474	9000

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Detectus EMC-Scanner report

300.000	50.000	131.469	9000
300.000	60.000	131.459	9000
300.000	70.000	131.474	9000
310.000	70.000	130.855	9000
310.000	60.000	125.710	9000
310.000	50.000	129.330	9000
310.000	40.000	114.378	9000
310.000	30.000	123.527	9000
310.000	20.000	123.921	9000
310.000	10.000	131.451	9000
310.000	0.000	131.444	9000
320.000	0.000	129.140	9000
320.000	10.000	123.064	9000
320.000	20.000	130.023	9000
320.000	30.000	130.341	9000
320.000	40.000	129.998	9000
320.000	50.000	129.903	9000
320.000	60.000	129.901	9000
320.000	70.000	129.797	9000
330.000	70.000	128.822	9000
330.000	60.000	130.177	9000
330.000	50.000	128.912	9000
330.000	40.000	129.597	9000
330.000	30.000	129.596	9000
330.000	20.000	129.754	9000
330.000	10.000	129.403	9000
330.000	0.000	129.962	9000
340.000	0.000	123.410	9000
340.000	10.000	130.960	9000
340.000	20.000	122.940	9000
340.000	30.000	126.926	9000
340.000	40.000	129.869	9000
340.000	50.000	124.727	9000
340.000	60.000	130.986	9000
340.000	70.000	129.602	9000
350.000	70.000	129.875	9000
350.000	60.000	120.336	9000
350.000	50.000	116.721	9000
350.000	40.000	123.447	9000
350.000	30.000	125.874	9000
350.000	20.000	126.386	9000
350.000	10.000	121.159	9000
350.000	0.000	125.037	9000
360.000	0.000	131.427	9000
360.000	10.000	128.745	9000
360.000	20.000	126.344	9000
360.000	30.000	129.587	9000

Detectus EMC-Scanner report

360.000	40.000	130.327	9000
360.000	50.000	131.049	9000
360.000	60.000	130.911	9000
360.000	70.000	130.749	9000
370.000	70.000	130.960	9000
370.000	60.000	130.719	9000
370.000	50.000	128.546	9000
370.000	40.000	125.755	9000
370.000	30.000	127.997	9000
370.000	20.000	126.643	9000
370.000	10.000	127.880	9000
370.000	0.000	129.972	9000
380.000	0.000	130.220	9000
380.000	10.000	130.635	9000
380.000	20.000	129.555	9000
380.000	30.000	130.250	9000
380.000	40.000	129.892	9000
380.000	50.000	130.148	9000
380.000	60.000	130.150	9000
380.000	70.000	130.038	9000
390.000	70.000	130.968	9000
390.000	60.000	123.000	9000
390.000	50.000	121.137	9000
390.000	40.000	122.148	9000
390.000	30.000	126.562	9000
390.000	20.000	120.682	9000
390.000	10.000	126.790	9000
390.000	0.000	128.888	9000
400.000	0.000	118.674	9000
400.000	10.000	128.392	9000
400.000	20.000	128.208	9000
400.000	30.000	130.049	9000
400.000	40.000	130.522	9000
400.000	50.000	127.342	9000
400.000	60.000	129.397	9000
400.000	70.000	129.761	9000

Measurement produced by **Detectus** EMC-Scanner.

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Appendix 2

EMC Report of PCB No.2
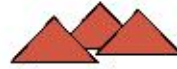
Detectus EMC-Scanner report

Measurement report
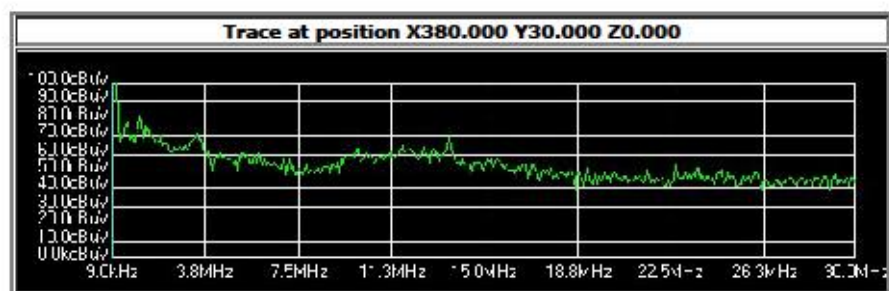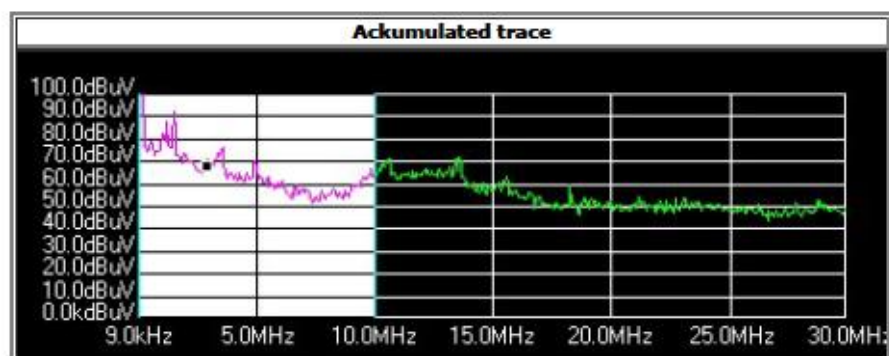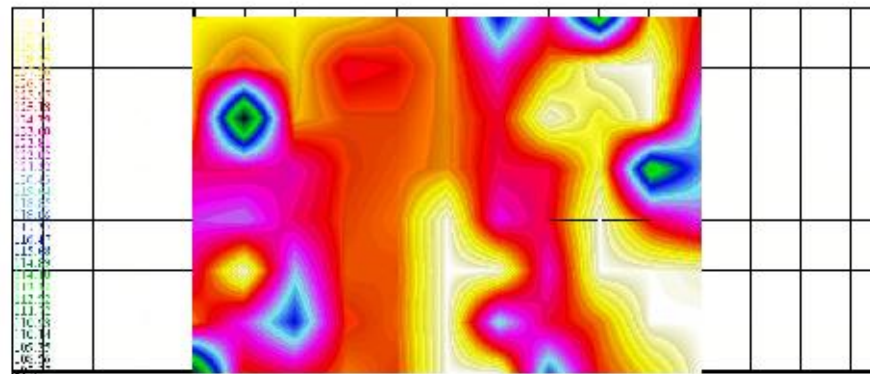
| File name: | improved multiscan.ms2d |
| Date: | 24.2.2020 |

Measured area:			
Start X:	300 mm	End X:	400 mm
Start Y:	0 mm	End Y:	70 mm

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Detectus EMC-Scanner report

Step size:	10 mm
Base level Z:	0 mm

Min and Max:

Min amplitude:	108dBuV		Max amplitude:	132dBuV

Position of highest amplitude:

X(mm)	Y(mm)
380.000	30.000
Peak frequency:	9KHZ

Settings:

Spectrum analyzer setting:	9kHz - 30MHz
Probe:	PROBE_RF_E_10

Amplitude:

Reference level offset:	0dB
Reference level:	-20dBm
RF attenuation:	0dB
Pre-amplifier:	0dB
Unit:	dBuV

Bandwidth:

Resolution bandwidth:	100kHz
Video bandwidth:	300kHz

Frequency:

Base measurement center frequency:	15.0MHz
Base measurement frequency span:	30.0MHz
Selection center frequency:	5.00900MHz
Selection frequency span:	10MHz
No. of spectrum sweeps:	3

Probe:

Correction factors:	0Hz, 40dB, 5MHz, 28dB, 15MHz, 18dB, 25MHz, 14dB, 50MHz, 8dB, 300MHz, 3dB, 600MHz, 0dB, 2100MHz, 0dB, 2200MHz, 1dB, 2600MHz, 1dB, 2700MHz, 0dB, 3000MHz, 0d

Data list:

X(mm)	Y(mm)	Amplitude (dBuV)	Frequency (Hz)
300.000	0.000	107.973	9000
300.000	10.000	127.241	9000
300.000	20.000	124.344	9000
300.000	30.000	122.031	9000
300.000	40.000	124.242	9000

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300.000	50.000	127.506	9000
300.000	60.000	128.397	9000
300.000	70.000	128.562	9000
310.000	70.000	128.613	9000
310.000	60.000	126.565	9000
310.000	50.000	107.766	9000
310.000	40.000	124.263	9000
310.000	30.000	121.152	9000
310.000	20.000	131.476	9000
310.000	10.000	122.087	9000
310.000	0.000	126.120	9000
320.000	0.000	124.521	9000
320.000	10.000	116.628	9000
320.000	20.000	120.110	9000
320.000	30.000	124.323	9000
320.000	40.000	123.288	9000
320.000	50.000	127.864	9000
320.000	60.000	128.310	9000
320.000	70.000	128.509	9000
330.000	70.000	128.423	9000
330.000	60.000	125.134	9000
330.000	50.000	126.483	9000
330.000	40.000	126.275	9000
330.000	30.000	126.482	9000
330.000	20.000	126.701	9000
330.000	10.000	126.142	9000
330.000	0.000	126.979	9000
340.000	0.000	126.375	9000
340.000	10.000	126.752	9000
340.000	20.000	126.590	9000
340.000	30.000	126.910	9000
340.000	40.000	126.676	9000
340.000	50.000	126.417	9000
340.000	60.000	125.633	9000
340.000	70.000	127.245	9000
350.000	70.000	127.646	9000
350.000	60.000	127.511	9000
350.000	50.000	127.319	9000
350.000	40.000	127.361	9000
350.000	30.000	131.485	9000
350.000	20.000	131.505	9000
350.000	10.000	131.486	9000
350.000	0.000	131.472	9000
360.000	0.000	131.514	9000
360.000	10.000	119.295	9000
360.000	20.000	131.490	9000
360.000	30.000	122.724	9000

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360.000	40.000	124.670	9000
360.000	50.000	125.069	9000
360.000	60.000	122.796	9000
360.000	70.000	115.977	9000
370.000	70.000	123.973	9000
370.000	60.000	127.507	9000
370.000	50.000	131.444	9000
370.000	40.000	124.740	9000
370.000	30.000	125.020	9000
370.000	20.000	122.796	9000
370.000	10.000	124.973	9000
370.000	0.000	117.434	9000
380.000	0.000	126.170	9000
380.000	10.000	127.040	9000
380.000	20.000	131.466	9000
380.000	30.000	131.516	9000
380.000	40.000	129.516	9000
380.000	50.000	128.835	9000
380.000	60.000	131.282	9000
380.000	70.000	111.187	9000
390.000	70.000	128.222	9000
390.000	60.000	131.480	9000
390.000	50.000	131.458	9000
390.000	40.000	112.147	9000
390.000	30.000	125.068	9000
390.000	20.000	131.444	9000
390.000	10.000	131.476	9000
390.000	0.000	128.654	9000
400.000	0.000	131.494	9000
400.000	10.000	131.498	9000
400.000	20.000	131.214	9000
400.000	30.000	121.814	9000
400.000	40.000	118.587	9000
400.000	50.000	118.928	9000
400.000	60.000	123.592	9000
400.000	70.000	125.603	9000

Measurement produced by **Detectus** EMC-Scanner.

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Appendix 3

Comparison Pictures

	PCB No.1	PCB No.2
0	123,41	126,375
10	130,96	126,752
20	122,94	126,59
30	126,926	126,91
40	129,869	126,676
50	124,727	126,417
60	130,986	125,633
70	129,602	127,245
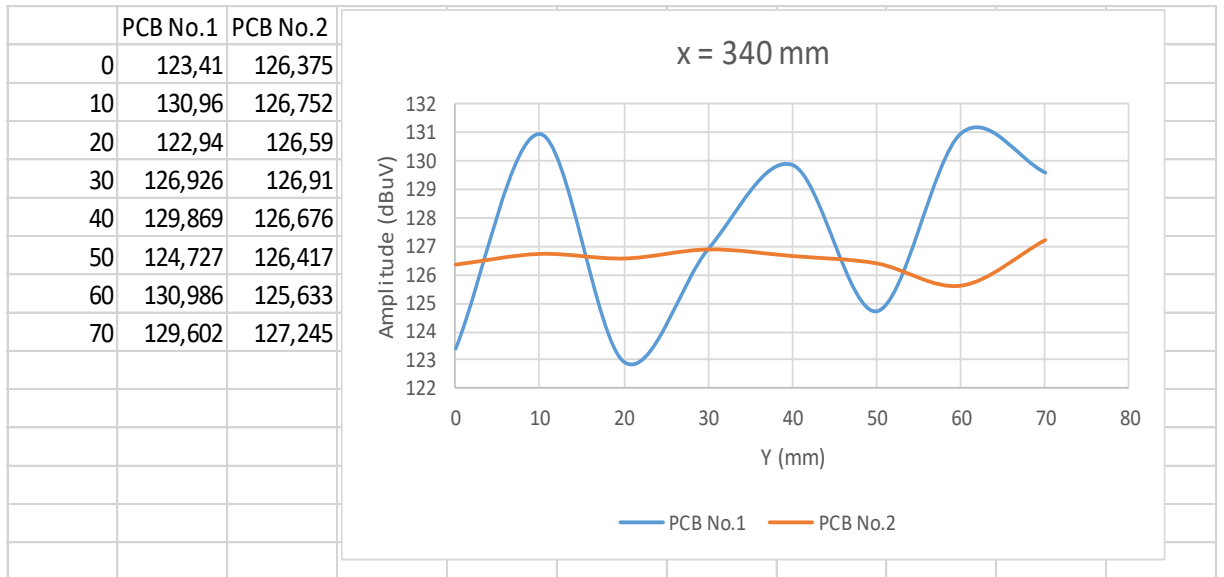
Figure 36.   Amplitude when probe position on x = 340, y = 0 to 70

	PCB No.1	PCB No.2
0	125,037	131,472
10	121,159	131,486
20	126,386	131,505
30	125,874	131,485
40	123,447	127,361
50	116,721	127,319
60	120,336	127,511
70	129,875	127,646
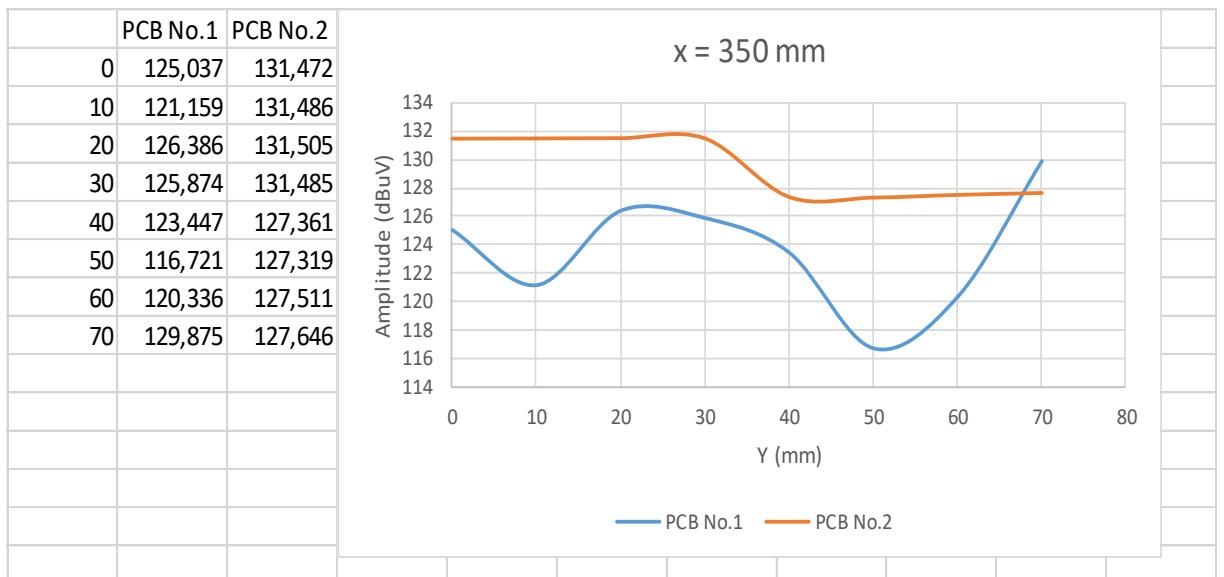
Figure 37.   Amplitude when probe position on x = 350, y = 0 to 70

	PCB No.1	PCB No.2
0	131,427	131,514
10	128,745	119,295
20	126,344	131,49
30	129,587	122,724
40	130,327	124,67
50	131,049	125,069
60	130,911	122,796
70	130,749	115,977

x = 360 mm
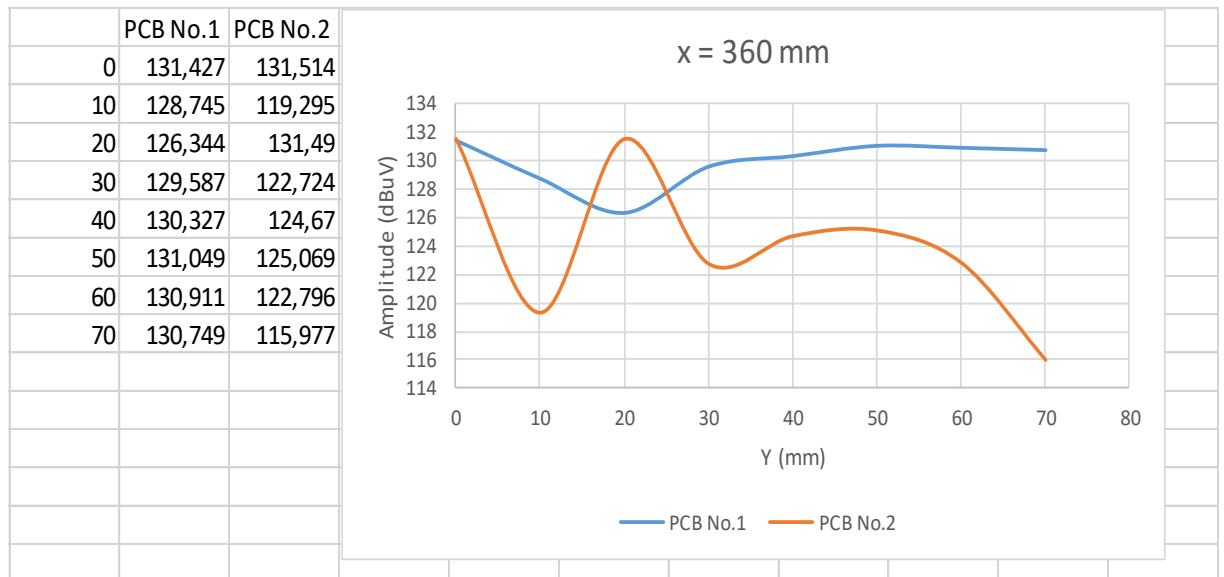
Figure 38.   Amplitude when probe position on x = 360, y = 0 to 70

	PCB No.1	PCB No.2
0	129,972	117,434
10	127,88	124,973
20	126,643	122,796
30	127,997	125,02
40	125,755	124,74
50	128,546	13,444
60	130,719	127,507
70	130,96	123,973

x = 370 mm
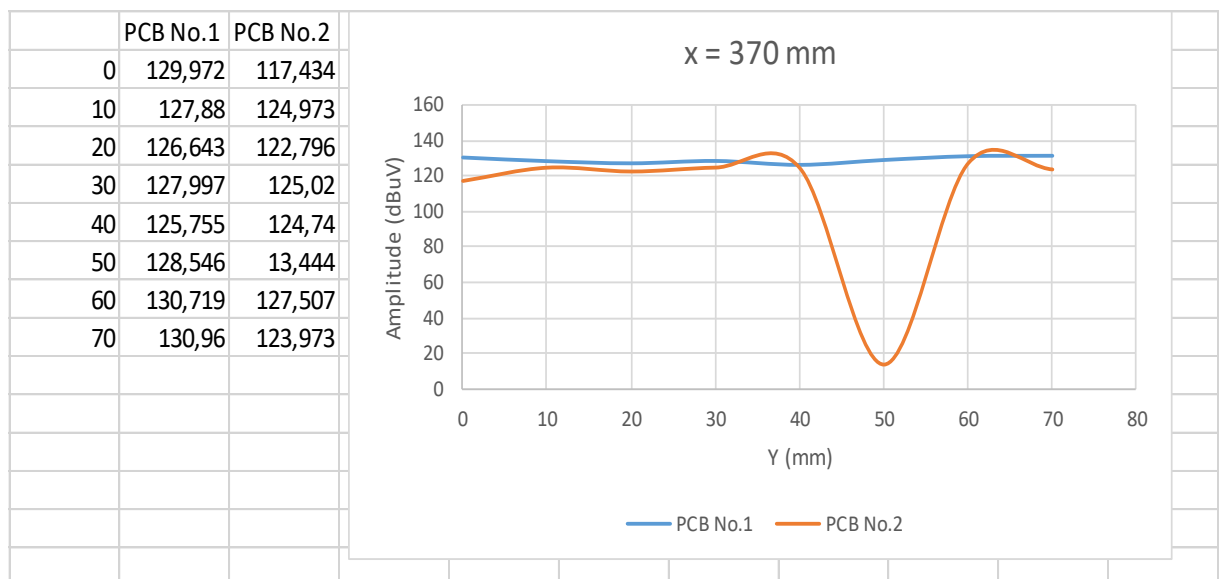
Figure 39.   Amplitude when probe position on x = 370, y = 0 to 70

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	PCB No.1	PCB No.2
0	130,22	126,17
10	130,635	127,04
20	129,555	131,466
30	130,25	131,516
40	129,892	129,516
50	130,148	128,835
60	130,15	131,282
70	130,038	111,187

x = 380 mm
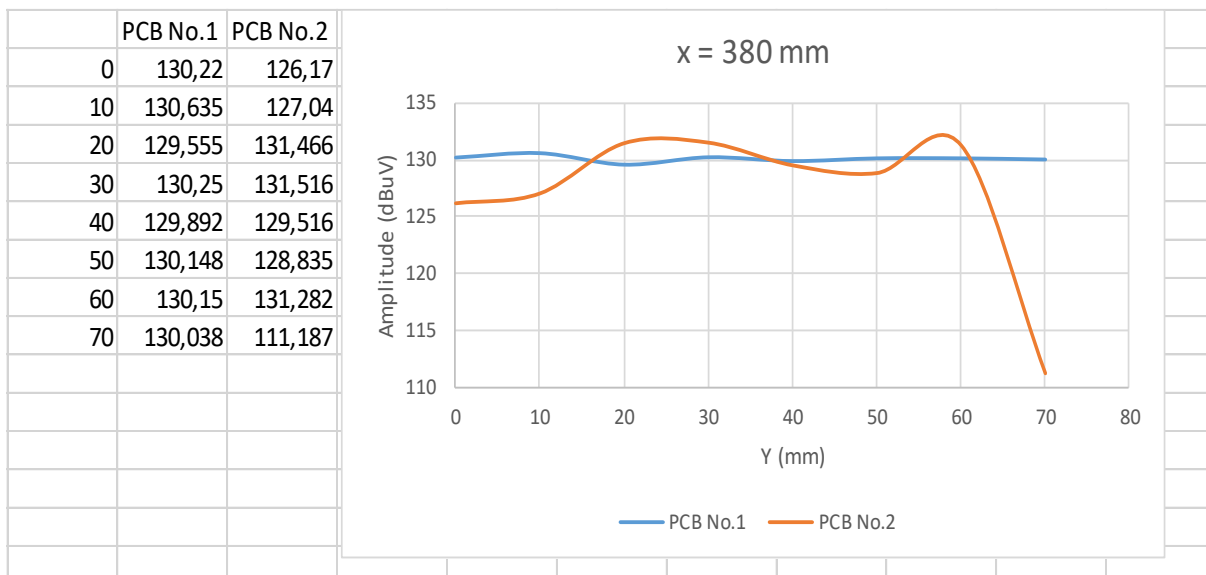
Figure 40.   Amplitude when probe position on x = 380, y = 0 to 70

	PCB No.1	PCB No.2
0	128,888	128,654
10	126,79	131,476
20	120,682	131,444
30	126,562	125,068
40	122,148	112,147
50	121,137	131,458
60	123	131,48
70	130,968	128,222

x = 390 mm
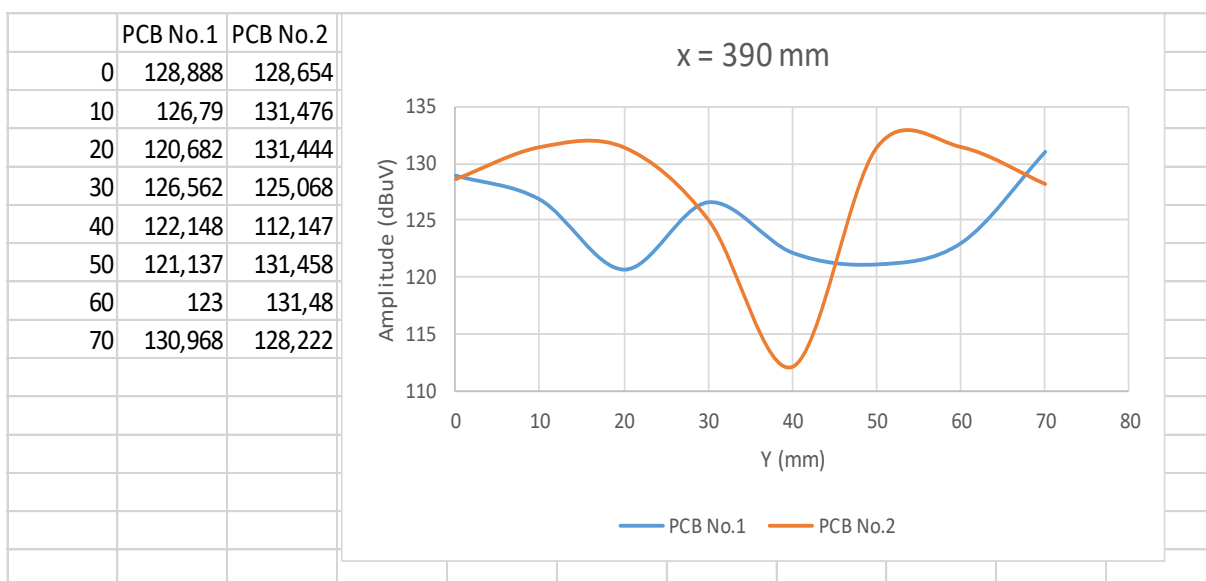
Figure 41.   Amplitude when probe position on x = 390, y = 0 to 70

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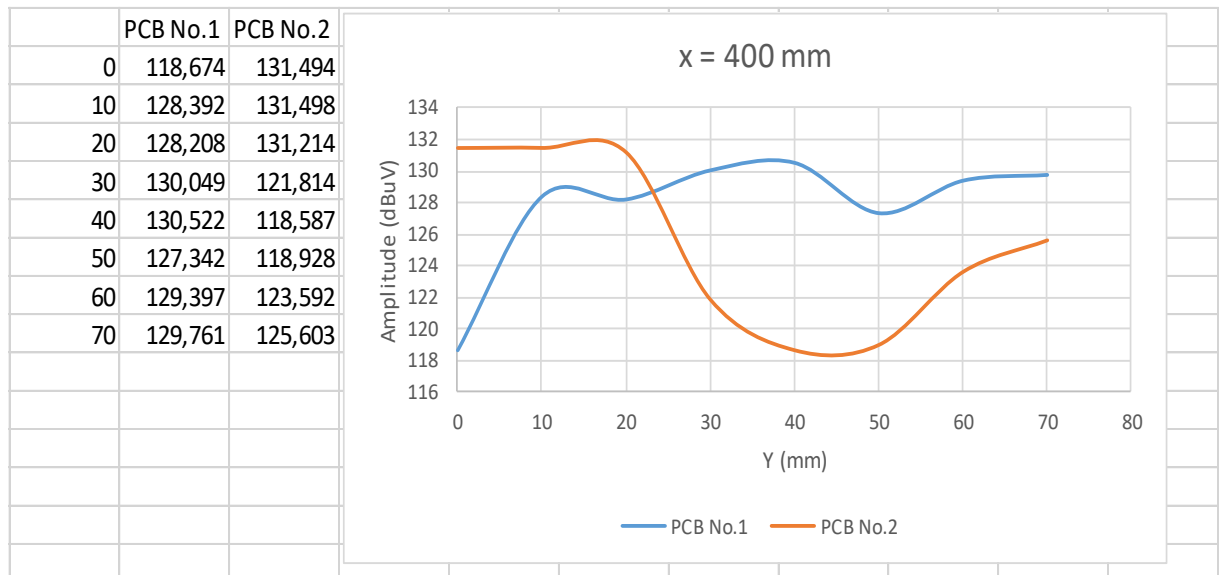|	PCB No.1	PCB No.2
0	118,674	131,494
10	128,392	131,498
20	128,208	131,214
30	130,049	121,814
40	130,522	118,587
50	127,342	118,928
60	129,397	123,592
70	129,761	125,603

Figure 42.   Amplitude when probe position on x = 400, y = 0 to 70