A

PROJECT REPORT

ON

A NOVEL MAGNETIC FIELD MEASUREMENT TECHNIQUE FOR EMI-EMC APPLICATIONS

Submitted in partial fulfillment of the requirement for the award of degree of Bachelor of Technology in Electronics and Communication Engineering.

SUBMITTED TO:

DR. TARUN VARMA

SUPERVISED BY:

DR. RAJENDRA MITHARWAL

SUBMITTED BY:

PRITHVI SHANKAR (2016UEC1440)

VINEET BAWAL (2016UEC1138)

SIDDHARTH GAUTAM (2016UEC1645)

DUSHYANT RAGHAV (2016UEC1685)

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY, JAIPUR

ELECTRONICS AND COMMUNICATION ENGINEERING

ACADEMIC SESSION 2019-20

ACKNOWLEDGEMENTS

We are overwhelmed in all humbleness and gratefulness to acknowledge our depth to all those who have helped us to put these ideas, well above the level of simplicity and into concrete something.

We are very thankful to **Dr. Rajendra Mitharwal** for giving us opportunity to work on this project and for his valuable help. His valuable suggestions, encouragement, support and keen interest throughout the supervision greatly eased our task of implementing this project.We thank him for freedom of thought, expression and trust, which was greatly bestowed upon us.

We would also like to thank our project coordinator **Dr.Tarun Varma** and other professors of the department for their valuable guidance and constructive suggestions in various forms.

ABSTRACT

The advancement of modern electronic communication technology has no where diminished the importance of electromagnetic characterization of the concerned electronic system devices. This brings new design challenges for the engineers who work on such electronic systems which need to cope up with the new electromagnetic interference/ electromagnetic compatibility (EMI-EMC) standards. These standards dictates the prescribed limit on the values of the electromagnetic fields that can be radiated by these devices within the fixed distance. The electric and magnetic fields are usually measured using costly electric and magnetic probes connected to a spectrum analyzer. In order to measure both electric and magnetic fields radiated by a device till now it requires to repeat the same experiment twice using different probes. This could be fine if the focus is on one single frequency. This is not the case in real scenarios where a range of frequencies should be swept in order for the device to be a truly compliant with the standards.

In the current project, we propose to use a broadband helical spiral antennas to measure the electric field. This electric field data is then given to an advanced computational electromagnetic solver based on inverse scattering algorithm. This module basically transforms the electric field in the near field region to the magnetic field. This approach makes the usage of magnetic probes redundant and the magnetic field is measured for a broadband range of frequencies.

Contents

1 Introduction **2**

2 Block diagram of proposed prototype **3**

2.1 Position Control- Pan and Tilt Head 3

3 Stepper Vs Servo Motor **4**

4 Stepper Motor **5**

4.1 Working of Stepper Motor 6

4.2 Driving Modes 7

5 Circuit Connections **8**

6 Algorithm for Arduino Coding **9**

6.1 Setup section 9

6.2 Loop section 9

6.3 Pan and Tilt Control 10

7 100 Series EMC Probes **10**

8 Features and Applications **11**

9 Sensitivity of Probes **12**

10 Calibration Of Probes **12**

11 Computational EM solver **16**

12 Conclusion **17**

13 References **18**

1 Introduction

With the onset of recent technologies and gadgets there has been an increasing demand of such gadgets which don't interfere with the working of other tools. In other words, new technologies must be compatible with the prevailing ones. A system is electromagnetically compatible with its environment if it satisfies three criteria:

- It doesn't cause interference with other systems.
- It is not vulnerable to emissions from other systems.
- It doesn't cause interference with itself.

EMC is mainly concerned with the generation, transmission, and reception of electromagnetic energy. These three aspects of the EMC problem form the essential framework of any EMC design. A source (also said as an emitter) produces the emission, and a transfer or coupling path transfers the emission energy to a receptor (receiver), where it is processed, resulting in either desired or undesired behaviour. Interference is seen if the energy that is received causes the receptor to act in an undesired way. Frequent and unintended coupling modes are the main reason behind the transfer of electromagnetic energy. The unintentional transfer of energy becomes the cause for interference only when the energy received is above a given magnitude and spectral content at the receptor input makes the receptor to behave in an undesired fashion. Unintentional transmission or reception of electromagnetic energy is not necessarily detrimental; undesired behaviour of the receptor constitutes interference. So in order to find whether interference will take place or not, the processing of the received energy by the receptor is very important. In most of the cases it is difficult to say, in advance whether a signal that is incident on a receptor will cause interference in this receptor. It's also important to know that a source or receptor is also classified as intended or unintended. In fact, a source or receptor may act in intended as well as unintended modes. Whether the source or the receptor is intended or unintended depends on the coupling path further because of the sort of source or receptor. The carrier frequency forms an intended emitter when an AM station transmitter is picked by a receiver that is tuned to it. On the opposite hand, if the identical AM radio transmission is processed by another receiver that's not tuned to the carrier frequency of the transmitter, then the emission is unintended (actually the emission is still intended but the coupling path isn't). There are some emitters whose emissions can serve no useful purpose. An example of that is the (invisible) electromagnetic emission from a fluorescent light. This implies that there are 3 ways to forestall interference:

- Suppress the emission at its source.
- Make the coupling path as inefficient as possible.
- Make the receptor less vulnerable to the emission.

2 Block diagram of proposed prototype

Following are the main blocks for the implementation of our proposed prototype:

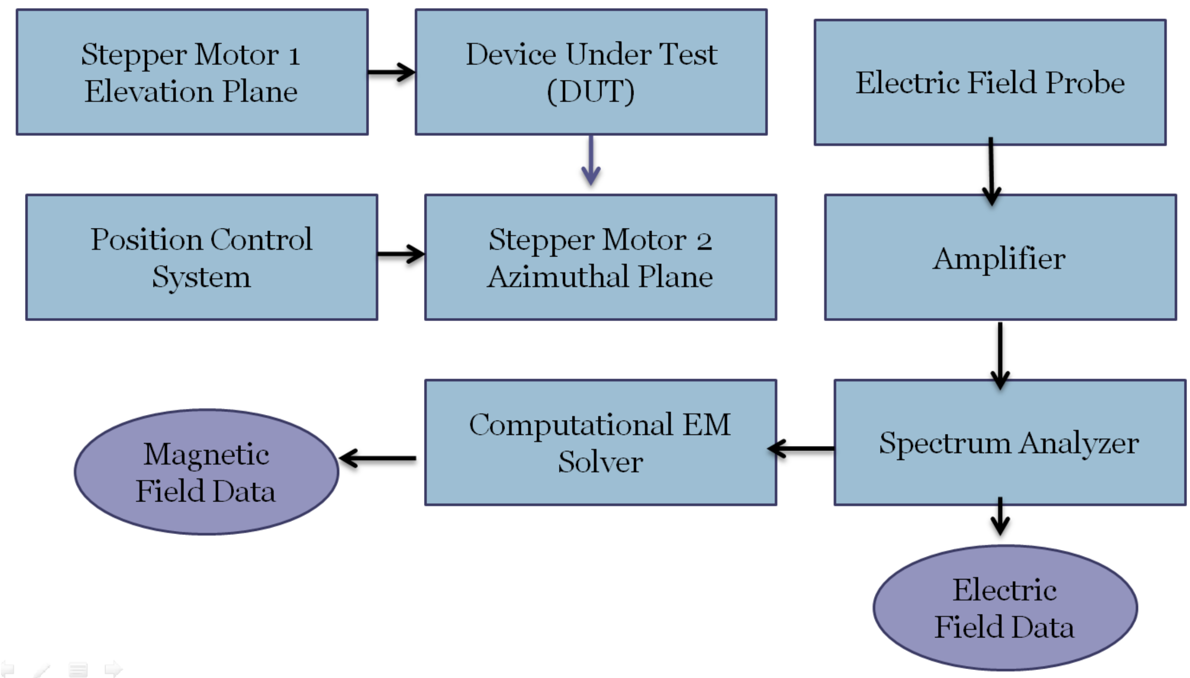

Figure 1: Overall block diagram of proposed model

2.1 Position Control- Pan and Tilt Head

In this project in order to measure the electric field, instead of moving the receiver (electric probes) again and again, we propose to move the device under test (source) covering all the possible orientations. We modelled a 'Pan and Tilt System' for the same. In order to reduce the Electromagnetic Interference (EMI) from the position control system, we propose to prepare the entire setup using wooden frames and minimizing the use of metals as far as possible. Movements both in elevation and azimuthal planes are ensured using two stepper motors. This position control system is controlled through Arduino.

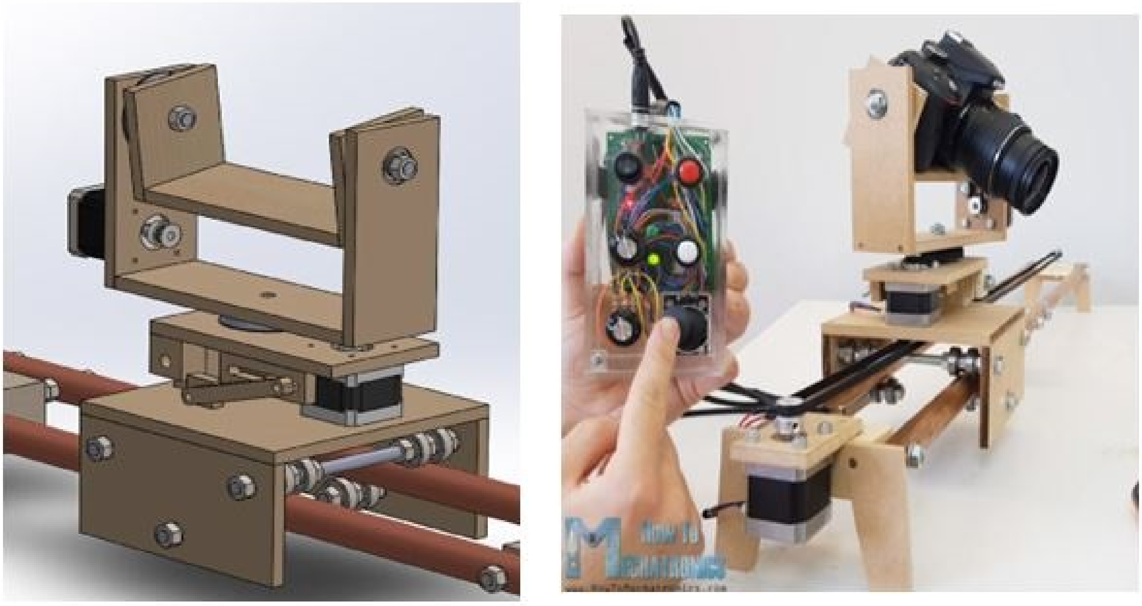

Figure 2: (a) 3D modelling (b) actual implementation of Pan and Tilt head

3 Stepper Vs Servo Motor

The main reason for using the stepper motor instead of servo motor has been discussed here. The poles in case of stepper motor are more as compared to that of servo motor. In stepper motor rotation through one winding will undergo many more current exchanges as compared to servo motor. The stepper motor design is in such a way that the torque degrades at higher speed in case of stepper motor. By using a high driving bus voltage, torque degradation effect reduces as it will mitigate the electrical time constant of windings. Stepper motor has a high pole count so at a lower speed it will have beneficial effect by giving stepper motor a torque advantage over servo motor.

Another difference is how motor type will be controlled. Stepper motor can operate in open loop constant current mode and also it is cost saving since no encoder is needed for most positioning application. Stepper motor operates in open loop constant current mode which creates heat in both motor and drive which is necessary for some applications. Servo motor resolves this by providing motor current which is required to move or hold the load. The torque which it produces is several times greater than the maximum continuous motor torque for acceleration. For controlling stepper motor in full servo closed loop mode, addition of encoder is required.

Steppers are simpler to maintain than servos and also they are less expensive especially in small motor applications. They will not lose steps and for operating within their design limits they will require encoders. Steppers especially with dynamic loads are stable at rest and hold their position without any fluctuation.

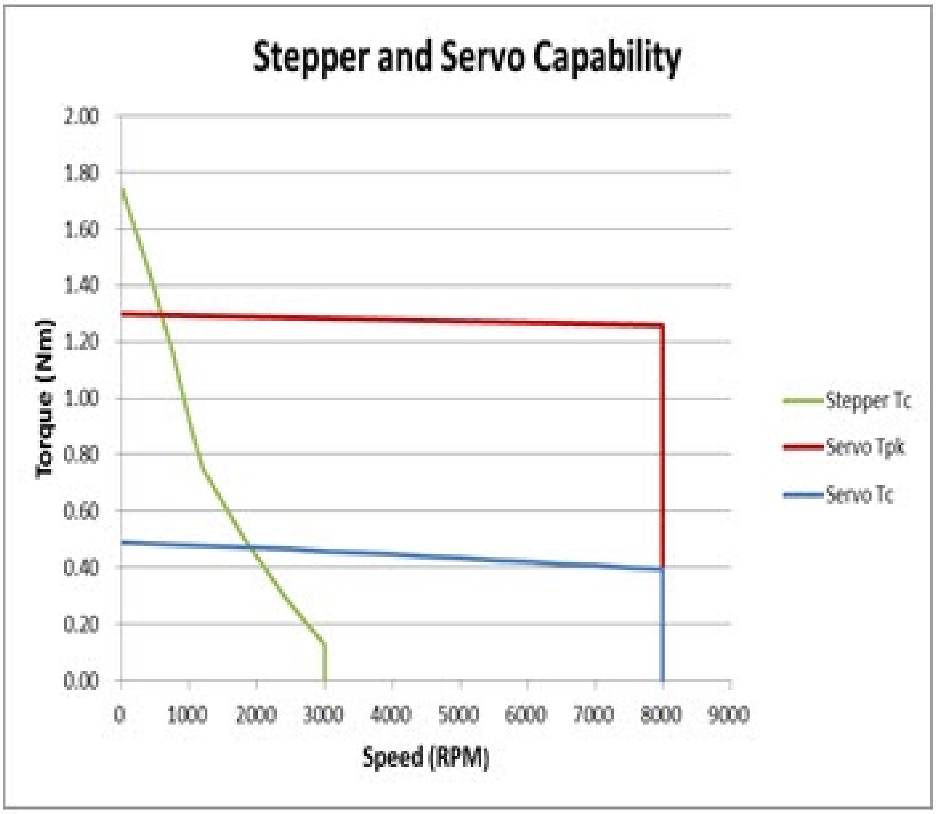

Figure 3: Performance Curve Comparison with approximately same volume

Steppers generate higher continuous torque at lower speed as compared to servo motors. In this same low-speed range in which steppers produce continuous torque, servo motors produce intermittent peak torques. Over a much wider-higher speed range servo motors provide peak and continuous torque.

4 Stepper Motor

A stepper motor is also referred as step or stepping motor. It is a brushless DC motor. It divides one full rotation into a few equal steps. The motor's position can then be commanded to maneuver and hold at one among these steps without any position sensor for feedback. If we see the construction of stepper motor it has multiple toothed electromagnets arranged around a central gear shaped piece of iron. The electromagnets can be energized by micro controller or external driver circuit.

To make the motor shaft turn, one of the electromagnets is given power which magnetically attracts the gear's teeth and now when it's one of electromagnet gets aligned to gear's teeth then it will be slightly offset from the subsequent electromagnet. This means that when subsequent electromagnet is turned on and therefore first is turned off, the gear rotates slightly to align with subsequent one. From there, this method is repeated. Each of these rotation is named a step with an integer number of steps making a full rotation,hence in this way, the motor is often turned by a particular angle.

.

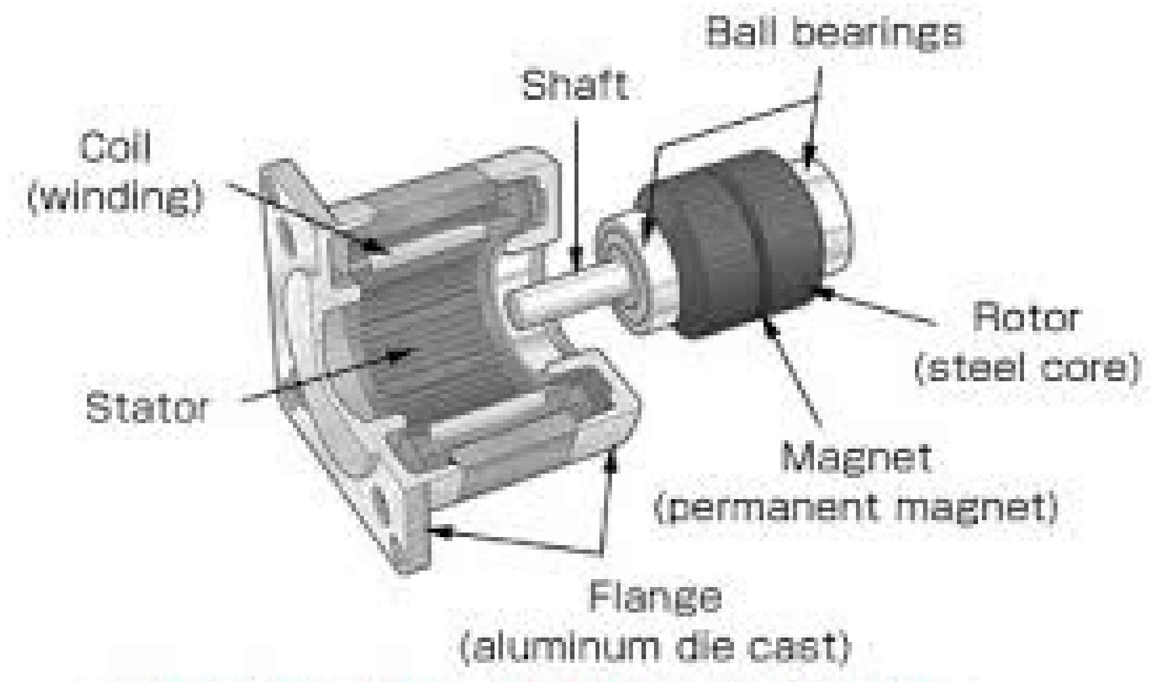

Figure 4: Construction of Stepper Motor

4.1 Working of Stepper Motor

The basic principle of working of stepper motor is described here. The stepper motor is a brushless DC rotary motor. This helps us a lot because it can be positioned directly without a reaction sensor, representing the open loop controller. This stepper motor consists of a standard rotor which is a permanent magnet and is surrounded by stator windings. As we activate the windings step by step in a certain order and let the current flow through them, we can say that it will magnetize the stator and make the electrical poles in the sequence which will result in pushing forward of the motor and we call it

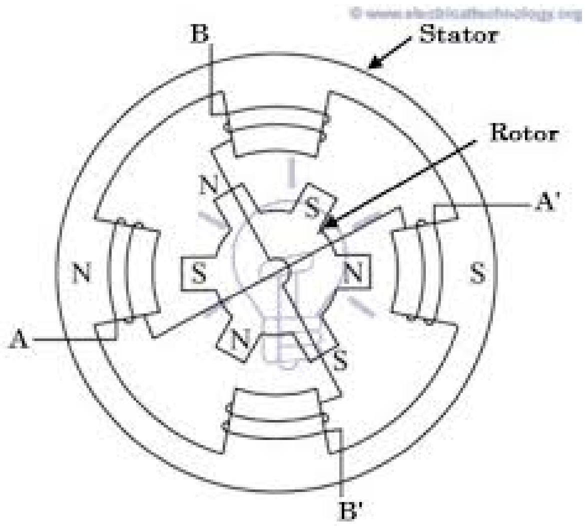

Figure 5: Working of Stepper Motor

propulsion to the motor.

4.2 Driving Modes

There are various ways to drive a stepper motor. The first is wave drive or single-coil excitation. In this mode we operate one coil at a time which means that in this example of a 4-coil motor, the rotor will make a full cycle in 4 steps.

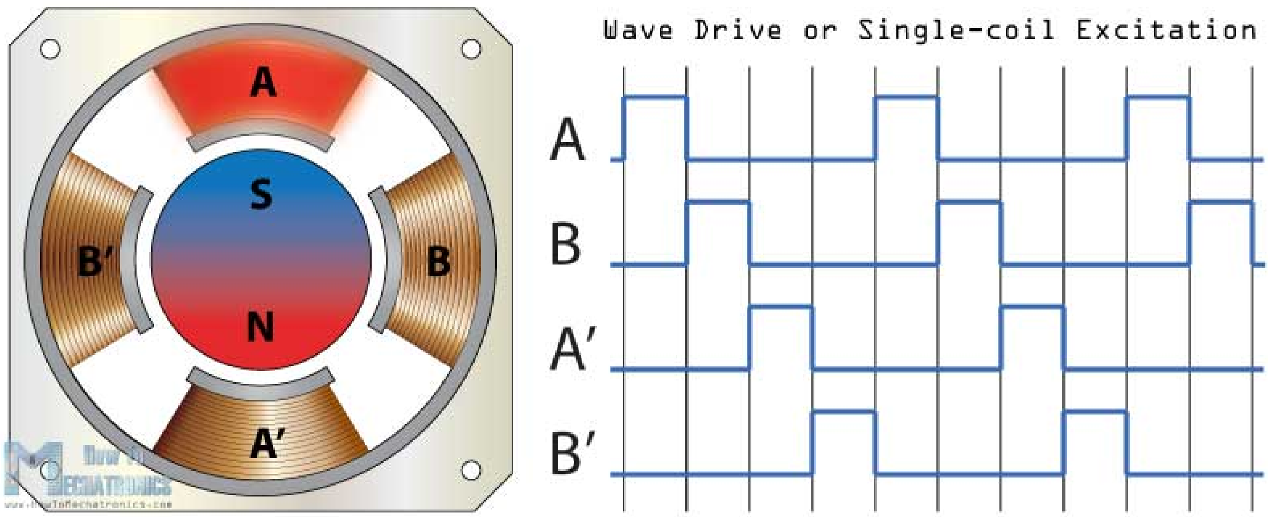

Figure 6: Wave Drive or Single-coil Excitation mode

The following is full step drive mode which provides maximum output torque because we always have 2 coils operating at a given time. However this is not improving the resolution and the rotor will make a full cycle in 4 steps. If we want to increase the resolution we use 'half step drive mode'.

This mode it is actually a combination of the two previous approaches. If we talk

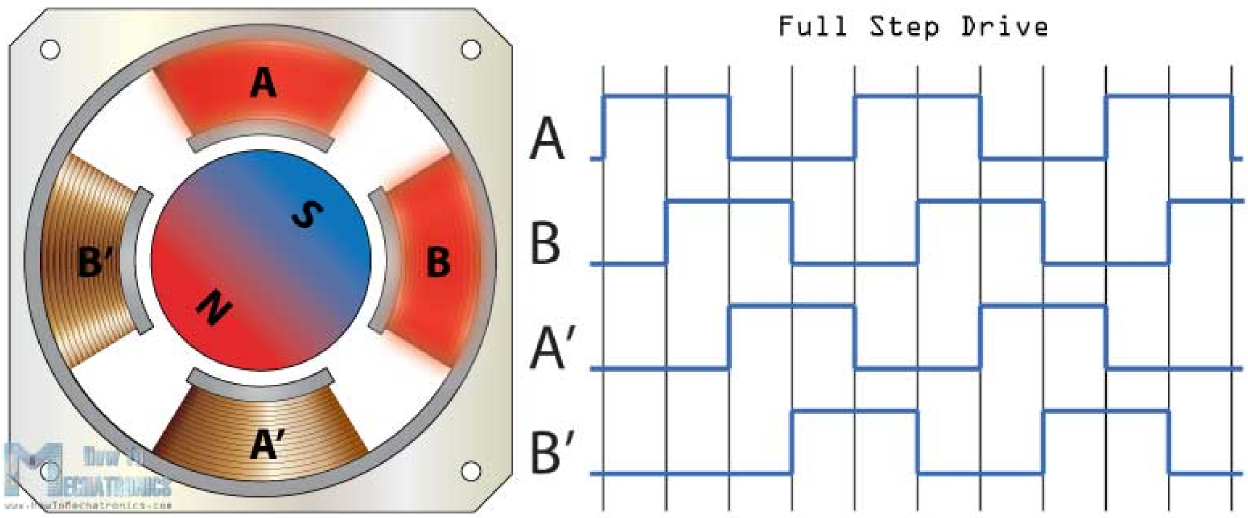

Figure 7: Full Step Drive mode

about these mode it has one active coil accompanied by 2 active coils and then again one coil accompanied by 2 active coils and so on. So with this mode we get double the correction with the same build. Now the rotor will do a full cycle in 8 steps.

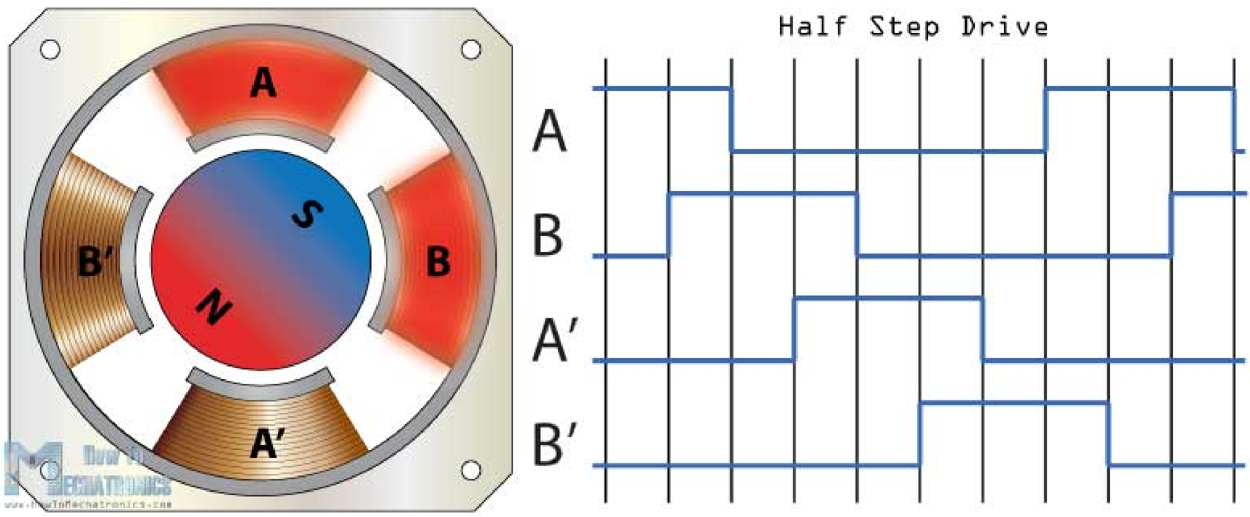

Figure 8: Half Step Drive mode

5 Circuit Connections

Two NEMA-17 stepper motors are controlled via the two A4988 stepper drivers. For controlling the slider movement we use a potentiometer connected to an analog input of the Arduino, and in order to control the pan and tilt head we use a joystick module which incorporates two potentiometers, so it's connected to two analog inputs. There's also another potentiometer used for setting the speed of the automated movement from

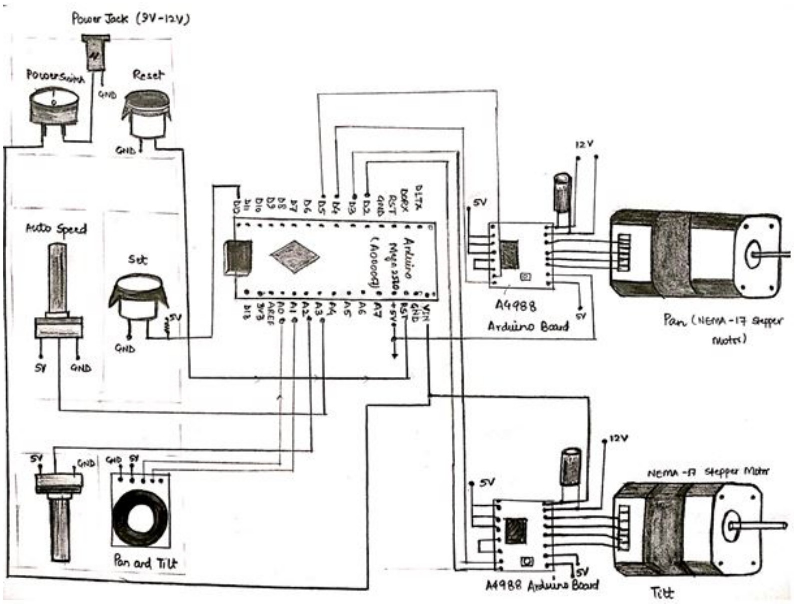

Figure 9: Circuit Connections of Arduino Board to control Pan and Tilt head

the in and out positions. These in and out positions are set with the assistance of push button. This push button incorporates a pull up resistor and it's connected to the digital pin of the Arduino board. There is a reset push button, a power jack and a power switch along with a limit switch for slider and two LEDs for indicating the in and out status. We can power this setup with either 9V or 12V.

6 Algorithm for Arduino Coding

6.1 Setup section

In this section, we set the initial speed of stepper motor. We also define the pin modes like JoySwitch, InOutSet, limitSwitch in this section. With the help of while loop, the slider is moved to the initial position if the condition (pos=initial position) is satisfied. If the condition is false, the slider moves until the limit switch is pressed.

6.2 Loop section

In this section we check whether slider has reached the limit position through the while loop described in setup section or not. Next with the help of if statement the pan and tilt speed is incremented with each press of the joystick switch. After that, it is checked whether we have pushed the set button, which serves the purpose of setting the IN and OUT positions.

Through the first push of the button, the IN positions of stepper motors are stored an the IN LED is lit too. Then with the next push of the button, we read the value of the auto speed potentiometer which is used to set the maximum speed of the motors. Also we store the IN positions into the gotoposition() array which is used in the moveTo( ) function that calculates separately the required speed for all steppers. Then using the runSpeedToPosition( ) function the slider automatically moves to IN position. In exactly the same way, with another push of the button, we move the slider to the OUT position.

6.3 Pan and Tilt Control

The analog value that we fetch from the slider is from 0 to 1024, or when it rests within the middle, this value is around 500. So if we move the slider to left and therefore the analog value is greater than 600, we set the speed of the actual motor to positive, and opposite to that if we move the slider right, we set the speed of the motor to negative, which implies it will rotate the other way.

Just in case it stays in the middle, the value of speed goes to 0. This method is employed for both axis of the joystick and the slider potentiometer. Actually, in the case of the potentiometer we use its analog value to increase the speed of the motor as we further turn the potentiometer. At last, we call the runSpeed() function for both stepper motors and to rotate the motors appropriately.

7 100 Series EMC Probes

The 100 series EMC beehive probes are designed for identifying and fixing EMC problems. The 100A, 100B, and 100C are such loop probes, and are responsive to magnetic fields. The 100D is a stub probe, and is responsive to electric fields. The loop probes have desegregated electrostatic shields, providing insulation from common mode signals. As a outcome of this, these probes convey excellent repeatability. The various loop sizes allow the user to pick the optimum sought of probe for a given frequency, providing the optimum sensitivity and spatial resolution. The 100D stub probe, with its narrow tip, offers the highest and very best spatial resolution. It is ideally suited to tasks like tracking EMC sources right down to the individual pins of an IC. Because of the planar construction of the probes, even the big loops are only 0.11 thick, permitting the probe

Figure 10: The Electric and Magnetic Probes

to be inserted into narrow seams and gaps.

8 Features and Applications

- An integrated electrostatic shield within the loop probe eliminates common-mode pickup.
- Various loop sizes offer optimum sensitivity and spatial resolution at different frequencies.
- Probe dimensions optimized for access to tight spaces.
- Calibrated responsiveness up to three gigahertz, looking on model. Usable to beyond six gigahertz.
- Can be driven by a signal source to generate fields for electromagnetic susceptibility testing.

APPLICATIONS:

- Finding sources of EMC emissions problems.
- Injecting fields into circuits to identify those which are EMC-susceptible.

- Noninvasive probing of RF circuits. The probes can be used to measure the signals present on an operational PC board. For example, using a pre amplifier, the probes can measure the characteristics of an oscillator, such as frequency, side bands, and phase noise.

9 Sensitivity of Probes

The probe output power into a load and therefore the force field strength are related by the following equation:

Pout = -113.2 + 20*log(E) + 20*log(F), or alternatively,

20*log(E) = Pout + 113.2 - 20*log(F)

where,

E is that the force field/electric field strength, in volts/meter.

F is that the frequency of the received signal, in Megahertz.

Pout is that the probe output power into 50 ohms, in dBm.

Stub probes tend to be less repeatable than shielded loop probes, thanks to the presence of common mode currents flowing to the outer surface of the probe or attached cable. As signals are measured, it's common to work out some dB of variation in output power because the user changes their grip on the probe or the attached cable. Thanks to this, the sensitivity of the 100D isn't assured. Typical sensitivity of the probe is shown.

10 Calibration Of Probes

The electric and magnetic probes are first calibrated before taking actual readings for the electric and magnetic fields. The magnetic probe is also calibrated to serve the purpose of verifying our results at a later stage. This calibration is important to make sure that readings from these probes are consistent with standard measurements. This process of calibration also ensures the accuracy of the probe readings. It is also a method to check whether our electric and magnetic probes are reliable and can be trusted for measurements or not. Magnetic probes include a long segment of wire which ends in a closed geometry mostly a circle. In our case, all the magnetic probes consist of a circular geometry at its end. When this probe is kept in the presence of time-varying magnetic field then according to the Faraday law of electromagnetics, electric potential gets induced in the closed circular loop of the probe. This electric potential is proportional to the time-varying magnetic field in which the probe was placed.

Frequency(MHz)	Output Power (dBm)
1	29.22
10	28.92
50	28.72
80	28.75
100	28.4

Figure 11: Table for frequency[MHz] vs.output power[dBm] for 100A probe

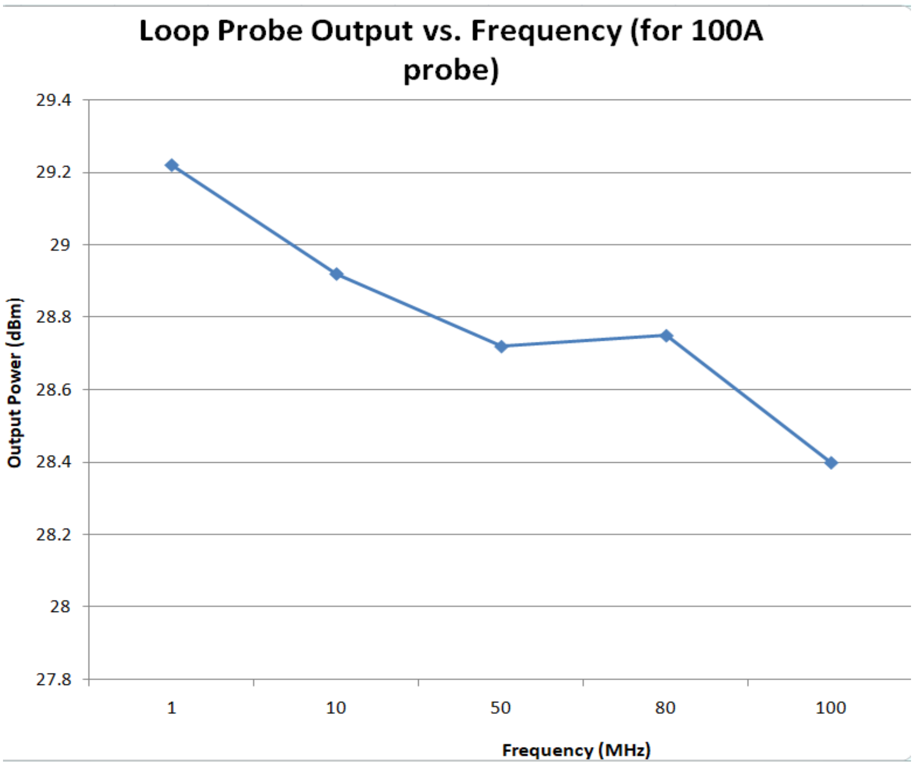

Figure 12: Graph for loop output vs. Frequency for 100A probe

The calibration of magnetic probes come with certain challenges too. First of them is that the sensitivity of the probe depends on the frequency. This happens because of the fact that at higher frequencies the output voltage tend to attenuate because of the increment in the reactance of the probe head which is basically an inductor. Another challenge comes when this process of calibration is carried out using a Helmholtz coil as source of calibration. In order to cope up with these challenges the magnetic probes are usually calibrated in lower magnetic fields. In order to calibrate our probe we used a 50 ohm load and a vector network analyzer to get the output power in dB at different frequencies ranging from 1 MHz to 100 MHz. The experimental setup for the calibration

Frequency(MHz)	Output Power(dBm)
1	29.33
10	29.02
30	29.25
50	28.82
80	28.76
100	28.37

Figure 13: Table for frequency[MHz] vs.output power[dBm] for 100B probe

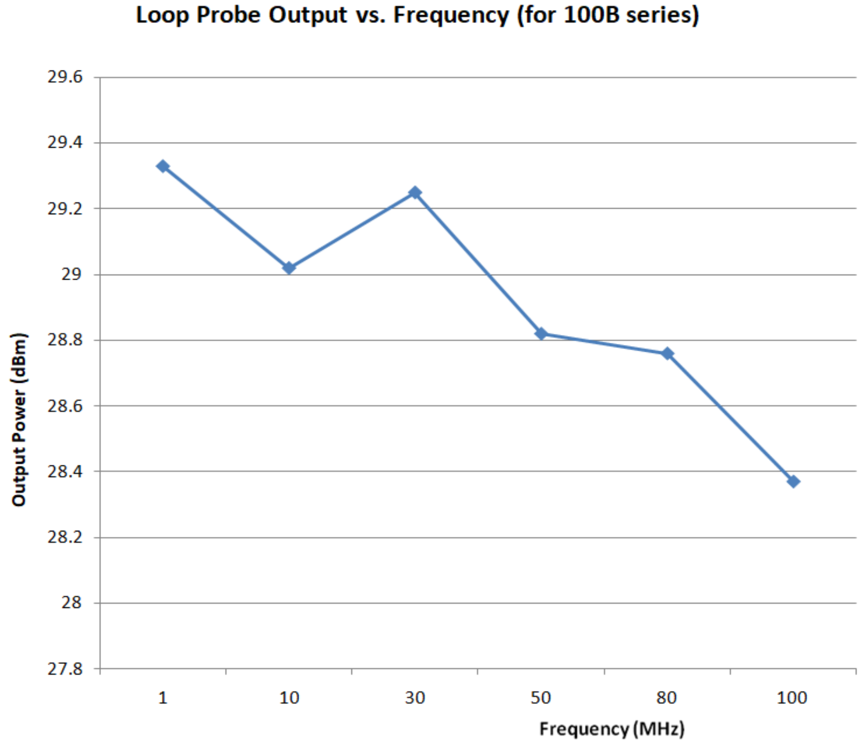

Figure 14: Graph for loop output vs. Frequency for 100B probe

also included a 112A N type cable which was connected to the vector network analyzer and 50 ohm load and the probe under test.

The calibration process is carried out for 100A, 100B, 100C magnetic probes and 100D electric probe. The output power obtained from the network analyzer (in dB) is first converted in dBm and graphs are plotted individually for the four probes. For the 100A probe which is a magnetic probe, with increase in frequency the output power tends to decrease till 50 MHz frequency then become almost constant for frequency range 50 MHz to 80 MHz and a then again decreases with a steep curve as shown in figure 11 and figure 12.

For magnetic probe 100B, the output power decreases from 1 MHz to 10 MHz frequency range and then increases till 30 MHz frequency and then again starts to decline as shown in Figure 14.

Frequency(MHz)	Output Power(dBm)
1	29.05
10	28.83
50	28.78
80	28.68
100	28.6

Figure 15: Table for frequency[MHz] vs.output power[dBm] for 100C probe

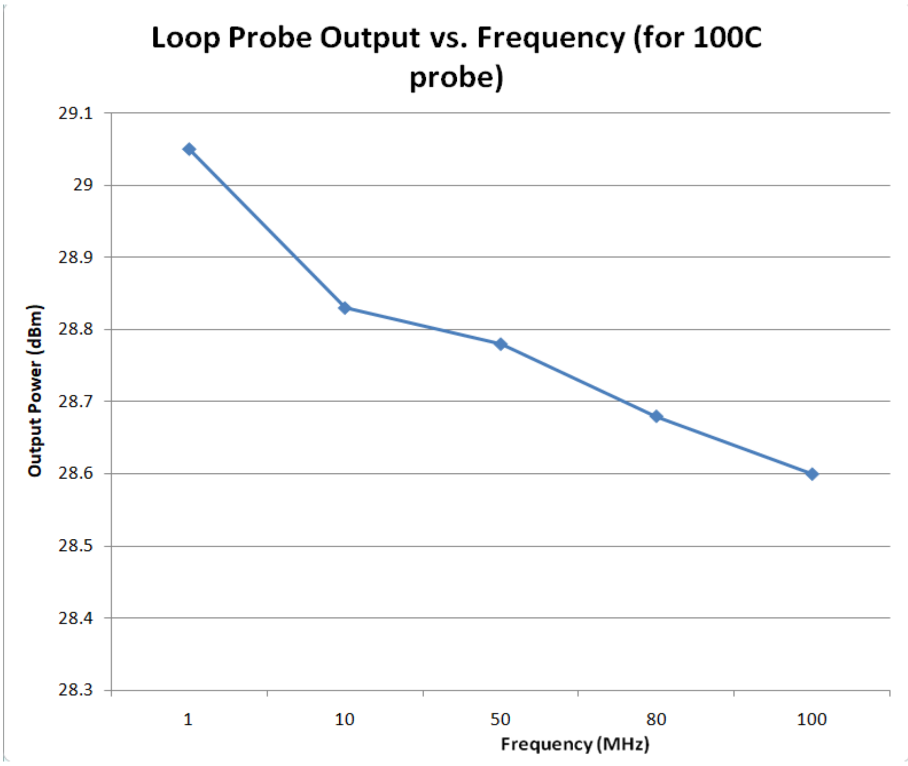

Figure 16: Graph for loop output vs. Frequency for 100C probe

For 100C magnetic probe, the output power decreases with changing slopes as in entire frequency range from 1 MHz to 100 MHz.The table for frequency and output voltages are shown in Figure 15. The curve for the loop output and frequency is shown in Figure 16.

The electric probe has a construction different from the magnetic probes.The electric probe does not has a closed geometry as a magnetic probes but has a flat ending slightly narrow than the rest of the probe.

For the 100D stub probe the output power initially with a small slope till approximately 20 MHz frequency. After that the output power decreases till 80 MHz and then again becomes almost constant as shown in Figure 18.

Frequency(MHz)	Output Power(dBm)
1	30.01
10	29.93
50	29.19
80	28.7
100	28.73

Figure 17: Table for frequency[MHz] vs.output power[dBm] for 100D stub probe

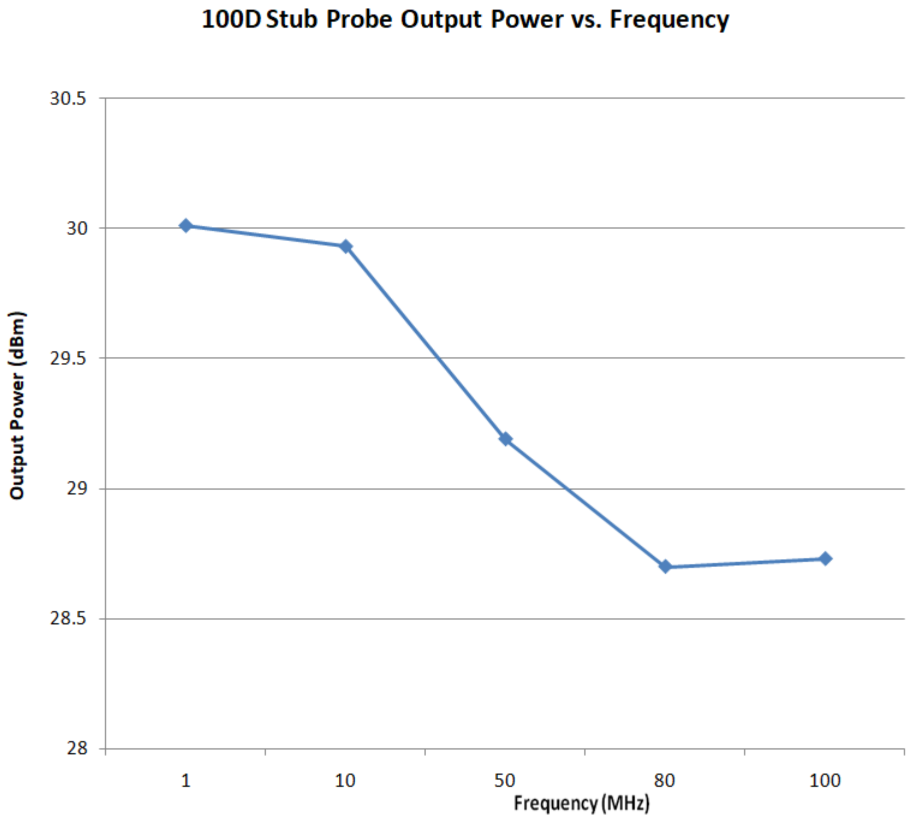

Figure 18: Graph for loop output vs. Frequency for 100D stub probe

11 Computational EM solver

The electric field data first goes through source reconstruction algorithm which will fetch us electric surface current.This algorithm takes help of the Maxwell's equations of electromagnetics. Once the electric surface current is obtained, it is fed into magnetic field integral operator.This magnetic field integral operator finally provides us with the magnetic field data which is the main motive for the entire computation.

The flow diagram of the computational EM solver is given below:

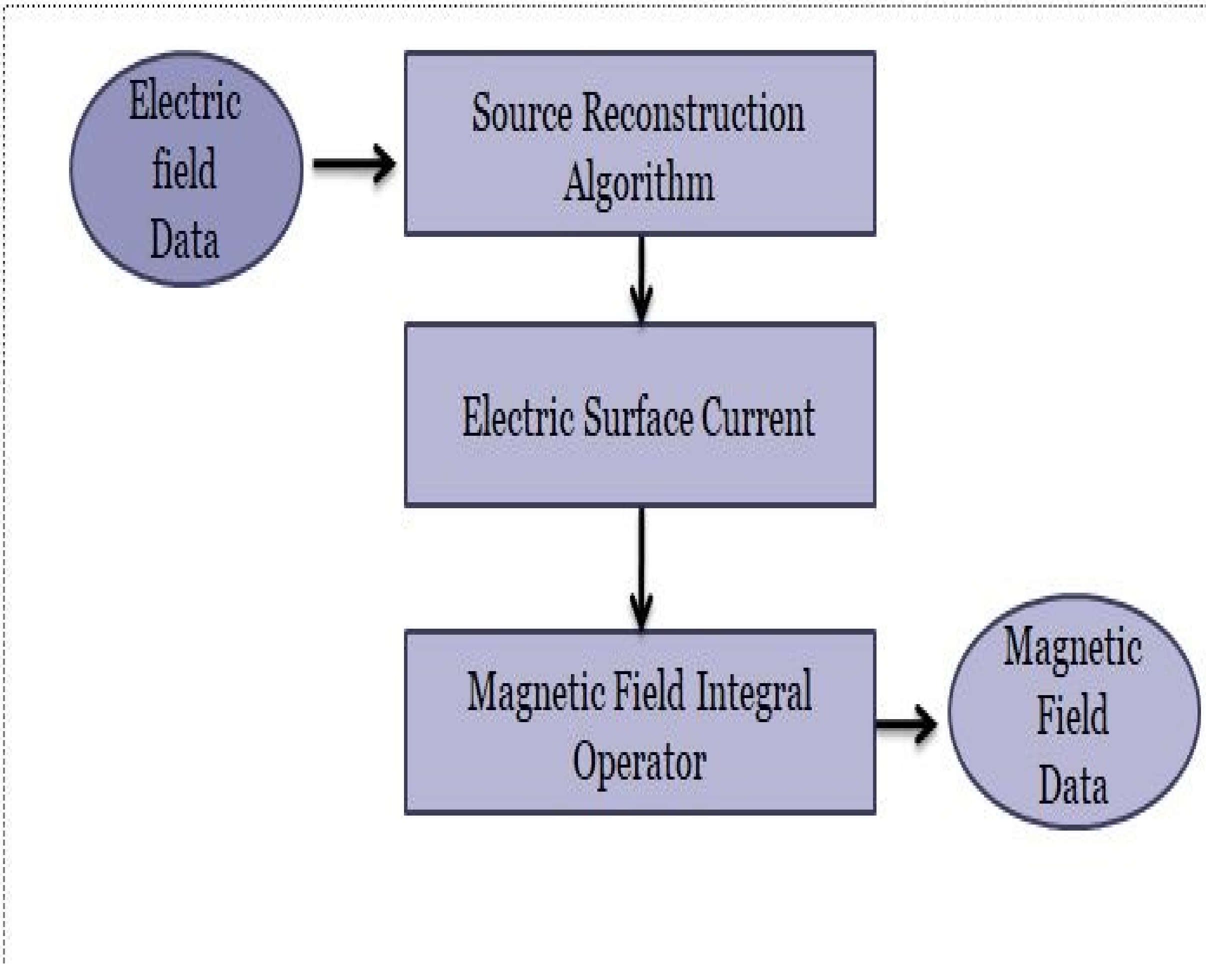

Figure 19: Block diagram of computational solver

12 Conclusion

It is a fully comprehensive solution which provides both electric and magnetic fields in one measurement using a single electric probe which do not exist in the current literature. It is relatively easy to construct a wideband electric probe compared to a magnetic probe. The project does not need a magnetic probe for providing the magnetic fields instead it uses a computational solver to do so. It is also easy to repeat the experiment as one step of measurement provides both electric and magnetic field. The accuracy of the overall procedure is bounded by the sensitivity of the electric probes. The proposed procedure provides a cost effective way to obtain the near field values in lesser time compared to existing state of the art techniques.

13 References

1. Zhang, Ji, Keong W. Kam, Jin Min, Victor V. Khilkevich, David Pommerenke, and Jun Fan. "An effective method of probe calibration in phase-resolved near-field scanning for EMI application." IEEE transactions on instrumentation and measurement 62, no. 3 (2012): 648-658.

2. Shi, Jin, Michael A. Cracraft, Kevin P. Slattery, Masahiro Yamaguchi, and Richard E. DuBroff. "Calibration and compensation of near-field scan measurements." IEEE Transactions on Electromagnetic Compatibility 47, no. 3 (2005): 642-650.

3. Judd, M. D. "Transient calibration of electric field sensors." IEEE Proceedings-Science, Measurement and Technology 146, no. 3 (1999): 113-116.

4. Datasheet: Beehive Electronics 100 Series Electric Probe.

5. Skibinski, Gary L., Russel J. Kerkman, Dave Schlegel, and Rockwell Automation. "EMI emissions." IEEE Industry Applications Magazine 5, no. 6 (1999): 47-81.

6. Micheli, Davide, Roberto Pastore, Carmelo Apollo, Mario Marchetti, Gabriele Gradoni, Valter Mariani Primiani, and Franco Moglie. "Broadband electromagnetic absorbers using carbon nanostructure-based composites." IEEE Transactions on Microwave Theory and Techniques 59, no. 10 (2011): 2633-2646.

7. Chuang, Hao-Hsiang, Guang-Hua Li, Eakhwan Song, Hyun-Ho Park, Hyun-Tae Jang, Hark-Byeong Park, Yao-Jiang Zhang, David Pommerenke, Tzong-Lin Wu, and Jun Fan. "A magnetic-field resonant probe with enhanced sensitivity for RF interference applications." IEEE Transactions on Electromagnetic Compatibility 55, no. 6 (2013): 991- 998.

8. https://howtomechatronics.com/tutorials/arduino/diy-motorized-camera-slider-pan-tilt-head-project.

9. https://howtomechatronics.com/how-it-works/electrical-engineering/stepper-motor/