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A PROJECT REPORT ON A NOVEL MAGNETIC FIELD MEASUREMENT TECHNIQUE FOR EMI-EMC APPLICATIONS Submitted in ful?llment of the requirement for the award of degree of Bachelor of Technology in Electronics and Communication Engineering. 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 op- portunity 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 be- stowed upon us.

Prithvi Shankar 2016UEC1440 Vineet Bawal 2016UEC1138 Siddharth Gautam 2016UEC1645 Dushyant Raghav 2016UEC1685 Contents 

 3 1 Abstract The advancement of modern electronic communication technology has no where dimin- ished 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 pre- scribed limit on the values of the electromagnetic ?elds that can be radiated by these devices within the ?xed distance. The electric and magnetic ?elds are usually measured using costly electric and magnetic probes connected to a spectrum analyzer.Till now in order to measure both electric and magnetic ?elds radiated by a device, it requires to repeat the same experiment twice

using di?erent probes.

This could be ?ne 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 broadband helical spiral antennas to mea- sure the electric ?eld.

This electric ?eld data is then given to an advanced computational electromagnetic solver based on inverse scattering algorithm. This module basically transforms the electric ?eld in the near ?eld region to the magnetic ?eld. This approach makes the usage of magnetic probes redundant and the magnetic ?eld is measured for a broadband range of frequencies.

4 2 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 electromag- netically compatible with its environment if it satis?es 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 electro- magnetic 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 electromag- netic 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; un- desired behaviour of the receptor constitutes interference.

So in order to ?nd 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 di?cult 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 classi?ed 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 emit- ter 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 unin- tended (actually the emission is still intended but the coupling path isn’t). There are 5 some emitters whose emissions can serve no useful purpose. An example of that is the (invisible) electromagnetic emission from a ?uorescent light.

This implies that there are 3 ways to forestall interference: • Suppress the emission at its source. • Make the coupling path as ine?cient as possible. • Make the receptor less vulnerable to the emission. 3 Objectives • To provide low cost hybridized measurement procedure for EMI/EMC applica- tions. • To develop a in-house prototype of the proposed measurement procedure. • To validate the developed prototype against the state of the art techniques. 3.1

Relevance to local Problem The EMC-EMI setups are costly and therefore are found only in state of the art defence organizations and highly funded government labs. The proposed approach in this project has the objective to solve this by providing low cost computational approaches to EMI- EMC problems with higher accuracies. This will possibly penetrate EMI-EMC apparatus even at institutes with lower funding.

4 Literature Review The EMI-EMC problems related to the electronic systems has existed since the second world war era. However, with the advancement of the technology and the requirement of high speed digital circuits has brought these problems to even higher complexity level. The ?rst step in this regard is to obtain the near ?eld measurements to know whether the designed electronic system is following all the guidelines laid by the current EMI standards. The near ?eld measurements, also applied in the area of antennas, require very huge investment in terms of anechoic chambers.

However, such high cost techniques are not needed for the EMI-EMC tests as the objective here is not to ?nd the accurate 6 radiation ?eld patterns (as in case of characterizing antennas ) but to ?nd the maxi- mum value of the ?eld at a ?xed distance from the DUT. The near ?eld measurement is done using electric and magnetic probes to measure the radiated electric and magnetic ?eld from the DUT.

The size and the design of probes speci?cally dictates the sensi- tivity and the spatial resolution which can be obtained in the ?eld measurements. In order to improve the accuracy of the probes a good calibration techniques are needed. These calibration techniques are further categorized into spatial and frequency domain methods.

The near ?eld obtained after calibration can be used to obtain the near ?eld to near ?eld conversions using the source reconstruction algorithms using inverse scat- tering techniques. The source reconstruction techniques have been highly successfully applied in the antenna engineering community but are still not applied to EMI-EMC problems.

The e?ectiveness of near ?eld measurements done on the DUT are dictated by the electric and magnetic probes. It is usually simple to construct an electric probe but when it comes to magnetic probes it is plagued with plethora of design challenges. The sensitivity of the magnetic probe is a major issue which can be still solved using the resonant probes.

However, the resonant e?ects make them ine?ective in terms of apply- ing them to wideband near ?eld measurements. They need high pass and notch ?lters for explicitly suppressing the interference from the electric ?elds. The magnetic probe with very high sensitivity, wideband operating frequency range and ability to suppress unwanted electric ?elds is possible but then it increases its cost tremendously. 5 Block diagram of proposed prototype The overall block diagram of the proposed approach is illustrated in Figure 1.

The electronic device whose electromagnetic ?elds are to be measured is represented with block Device Under Test (DUT). Since we need to measure the electromagnetic ?eld in a uniformly sampled spherical surface we need a low cost pan and tilt system which will rotate the DUT in the three dimensional space using a position control system. The electric ?eld probe is ?xed in position.

Every step of rotation of the stepper motors will register one sample of the electric ?eld in the three dimensional space at the electric ?eld probe. The signal received by the probe is ampli?ed and fed to spectrum analyzer which sends the electric ?eld data to the computational electromagnetic solver which based on these data computes the magnetic ?eld data at the sampled points of the three 7 dimensional space. Figure 1: Overall block diagram of proposed model 5.1

Position Control- Pan and Tilt Head In this project in order to measure the electric ?eld, 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. 6 Stepper Vs Servo Motor The main reason for using the stepper motor instead of servo motor has been discussed in this part. The stepper motor has more number of poles when compared to a servo motor.

In a stepper motor, when it is given power it takes more rotations per windings hence increasing its resolution. The torque decreases at higher speed in servo motors 8 Figure 2: 3D modelling of Pan and Tilt head [8] and this decrease is called torque degradation e?ect. So to decrease this e?ect we use high driving bus voltage. Stepper motor has a torque advantage as it has greater number of pole count compared to servo motor.

Apart from above reason controlling of motor type is another one. There are various positioning applications available in market which require the help of encoder to drive the application but Stepper motor does not need any encoder to drive the motor.

But if we see the construction of servo motor then we ?nd that when they derive power then they create heat in bearing parts so this heat should be decreased and this is done by addition of an encoder. Thus they will need an encoder which will make them costly. Now from cost point of view we see that Stepper motor is also not very costly and they can be maintained simply.

They will not lose steps and for operating within their design limits they will require encoders. Steppers can be operated with dynamic loads and are ?xed at rest and they maintain their position with good control and without any variation. When motor starts operating its torque is higher as compared to servo motors.

From ?gure we can see that when motor starts operating its torque is higher as compared to servo motors. Servo produces two torques, one is intermittent peak torque and another one is peak and continuous torque. Thus in low speed stepper provides continuous while servo intermittent peak torques and if speed is increased further than range servo motor provides peak and continuous torque. 9 Figure 3: Pan and Tilt head[8] 7 Stepper Motor A stepper motor is that motor which rotates in a step and for this reason it is also referred as step motor.

It does not contain any brushes and is a DC motor. The motor makes a full rotation which is divided into little equal steps. It does not contain any position sensor which is required for feedback so we can manually command the motor position to move and hold at any of the position in which it steps towards. If we see the construction of stepper motor it has a gear at centre which is made of iron and around it has arranged multiple toothed electromagnets.

It is also needed to give energy to the electromagnets so we need a micro-controller or external driver circuit which will give electromagnet the current to get energized. Now it contains motor shaft and to turn them, one of the electromagnet is given power by which it attracts the gear's teeth and attraction process will be magnetically done and now when it's one of electromagnet gets aligned to gear's teeth then it will be slightly o?set from the subsequent electromagnet.

This means that when we give power to subsequent electromagnet ?rst electromagnet which was turned on has to be turned o? due to which the gear will now rotate lightly to align with subsequent one. From there the method is repeated. Each of these rotations is named a step and the steps which it makes is an integer number and which makes a full rotation, therein way, the motor are often turned by a accurate angle. . 10 Figure 4: Performance Curve Comparison with approximately same volume[13] Figure 5: Construction of Stepper Motor[14] 7.1

Working of Stepper Motor The working of stepper motor is described here. As we know that the Stepper motor is a DC motor which rotates in steps and also it does not contain any brushes. Like other motor it does not need any feedback sensor, this helps a lot because it can be positioned manually which will be representing the open loop controller.

This stepper motor consists of a rotor which is standard one and that rotor is a permanent magnet and it will be surrounded by windings of stator. Now we activate the windings which means that to give the power to the electromagnet step by step in a certain order and then the current start to ?ow through the winding then we can say that it will magnetized the stator and now these magnetization will make all the electromagnetic poles which is 11 Figure 6: Working of Stepper Motor[14] north and south poles to be in the sequence that will result in propulsion to the motor. 7.2 Driving Modes There are various ways to drive a stepper motor.

The ?rst is single-Coil Excitation and diagram of these is depicted below. From ?gure we ?nd that it has a four coil A,B, A,B and at one time one coil is active which means one electromagnet pair is formed so in these mode only one coil operates at a time and it will completes its full cycle rotation in four steps.

The following is Full step drive mode and from ?gure we ?nd that again it has a four coil A,B, A,B and at one time two coil is active but again it will completes its full cycle rotation in four steps. However this is not improving resolution and therefore Figure 7: Wave Drive or Single-coil Excitation mode[9] if we want to increase the resolution we will be using Half Step Drive mode. This mode 12 it is actually a combination of the two previous approaches.

If we talk about these modes it had one active coil accompanied by two active coils and then again one coil accompanied by two active coils and so on. So with this mode it will complete its full cycle rotation in eight steps. Figure 8: Full Step Drive mode[9] Figure 9: Half Step Drive mode[9] 8 Circuit Connections The circuit for controlling the Pan and tilt head consist of components like stepper motor, power switch , set button ,reset button, a couple of potentiometers, power jack and power switch.

There are two stepper motors in the circuit (NEMA-17) as shown in ?gure 10 . First stepper motor is used to control the pan while the second one is 13 Figure 10: Circuit Connections of Arduino Board to control Pan and Tilt head used to control the tilt. These stepper motors are connected to Arduino board (A4988) which is also termed as stepper driver. So in total there are two such boards too.

These boards in turn are connected to Arduino Mega 2560. The stepper driver which controls pan part is connected to the D4 and D5 pin of the Arduino Mega. Pins D2 and D3 which are also the digital pins are directly connected to the second stepper driver which controls the tilt part of the setup. There is a set button which is connected to D12 pin of the board.

A joystick is also used to control the setup of this pan and tilt and it is connected to analog pins (A0 and A1) of the Arduino Mega board. A potentiometer is connected with analog pin A3 which helps in speed setting. The power jack is used to supply power to the entire setup through a power switch. The reset button is connected to ground while its other terminal is connected to RST pin of Arduino Mega board. 14 9 Algorithm for Arduino Coding 9.1

Setup section In this section, we set the initial speed of stepper motor. We also de?ne 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 satis?ed. If the condition is false, the slider moves until the limit switch is pressed. 9.2

Loop section In the loop section, ?rst we take help of the result that we obtain from while loop. A while loop was inserted in the setup part of the algorithm. Hence from the results of while loop we verify if slider has got to its end point also called the limit. After this, we use the if statement in order to increment the speed of our movable part the pan and tilt.

This is done by using the joystick that is connected in the Arduino board at analog pins of it as discussed in the earlier part. After that, in order to set IN and OUT postions, we observe and check if the set button is pushed. After that, the initial position of the motor is stored. This is done with the help of initial pushing of the SET key. Once the intitial position of the motor has been recorded, we need to get the value of auto speed potentiometer.

This value serves the purpose of maximizing the motor speed. Now we make an array and store the positions of the motor in it. This data is used in the calculation of speed of the two stepper motors. 10 100 Series EMC Probes The 100 series EMC probes are well designed for recognizing and to settle most of the electromagnetic conduction problems.

There are these probes which are very responsive towards magnetic ?elds like 100a,100b,100c and a 100d stub probe which is sensitive to electric ?elds, these probes can detect EM radiations from device under test which is our motive behind making of such apparatus . The loop probes are already integrated with electrostatic shielding which provides stops the common mode signals which can distort the readings.And as they have such property,these probes can be repeated several times provides superb repeatability which is way more cheaper.They come with various sizes which makes it easier for user to use the optimum sought of these probes which 15 Figure 11: The Electric and Magnetic Probes[4] provides optimum sensitivity and spatial resolution.There is a probe with very narrow tip known as 100D stub probe,the purpose of that narrow tip is to provide best and highest spatial resolution which eventually helps in getting more amount of speci?ed data from the device under test.As this probe is directly connected to individual pins of an IC,which is ideally preferred to track down EMC sources to these pins.And because the construction of probes is planar,the maximum loop size which can be produced is only 0.279 centimetre thick.That small loop size is very convenient in getting readings as well as can be placed in narrow gaps.

11 Features of the probe • The common mode pickup is eliminated by an integrated electrostatic shield within the loop probe. • Various loop sizes helps to o?er optimum sensitivity and spatial resolution at various frequencies. • Probe dimensions are such that,they can be optimized for access to tight spaces. • Calibrated responsiveness is

usable beyond six gigahertz.It can go up to three gigahertz,looking on model. • Can be driven by a signal source to generate ?elds for electromagnetic susceptibility testing.

16 Frequency (MHz) Output Power(dBm) 1 29.33 10 29.02 30 29.25 50 28.82 80 28.76 100 28.37 Table 1: Table for frequency[MHz] vs.output power[dBm] for 100B probe Frequency (MHz) Output Power(dBm) 1 29.33 10 29.02 30 29.25 50 28.82 80 28.76 100 28.37 Table 2: Table for frequency[MHz] vs.output power[dBm] for 100B probe 12 Speci?cations of the probes The electric and magnetic probes have an equal length which is equal to 6.35 inches.

This length is considered without including the connector part of the probes.The thickness of the probes is 0.11 inch. The scale factor X which is used in calculation output power is di?erent for di?erent probes. The scale factor for 100D probe is -113.2. This parameter for other probes are also mentioned in table 4. Model Number Tip Diameter(in) Loop Diameter(in) 100C (large probe) 1.0 0.85 100A (medium loop) 0.5

0.4 100B (small loop) 0.25 0.15 100D (stub) 0.08 N/A Table 3: Dimensions of various probes 13 Sensitivity of Probes The output power of the probe at the 50 ohm load and its relationship with frequency and electric ?eld is described by the equation given below: Pout = X + 20*log(E) + 20*log(F), or alternatively, 20*log(E) = Pout + X - 20*log(F) where, E is the electric ?eld strength ( V/m). 17 Model Number X(Scale factor) 3 dB Frequency (MHz) First Resonance (MHz) 100C (large probe) 85.1 50 500 100A (medium loop) 65.2

1000 2600 100B (small loop) 42.2 3100 greater than 6000 Table 4: Frequency related parameters of various probes Frequency (MHz) Output Power(dBm) 1 29.22 10 28.92 50 28.72 80 28.75 100 28.4 Table 5: Table for frequency[MHz] vs.output power[dBm] for 100A probe F is the frequency of the received signal ( MHz). Pout is the probe output power into 50 ohms (dBm). X is the scale factor.

14 Calibration Of Probes The electric and magnetic probes are ?rst calibrated before taking actual readings for the electric and magnetic ?elds. 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 ?eld 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 ?eld in which the probe was placed.

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 18 Figure 12: Graph for loop output vs. Frequency for 100A probe Frequency (MHz) Output Power(dBm) 1 29.33 10 29.02 30 29.25 50 28.82 80 28.76 100 28.37 Table 6: Table for frequency[MHz] vs.output power[dBm] for 100B probe are usually calibrated in lower magnetic ?elds.

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 di?erent frequencies ranging from 1 MHz to 100 MHz. The experimental setup for the calibration 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) Frequency (MHz) Output Power(dBm) 1 29.05 10 28.83 50 28.78 80 28.68 100 28.60 Table 7: Table for frequency[MHz] vs.output power[dBm] for 100C probe 19 Figure 13: Graph for loop output vs. Frequency for 100B probe is ?rst 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 ?gure 11 and ?gure 12. For magnetic probe 100B, the output power decreases from 1 MHz to 10 MHz fre- quency range and then increases till 30 MHz frequency and then again starts to decline as shown in Figure 14. 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 di?erent from the magnetic probes.The electric probe does not has a closed geometry as a magnetic probes but has a ?at ending slightly narrow than the rest of the probe. For the 100D stub probe the output power initially with a small slope till approxi- mately 20 MHz frequency.

After that the output power decreases till 80 MHz and then again becomes almost constant as shown in Figure 18. 20 Figure 14: Graph for loop output vs. Frequency for 100C probe Frequency (MHz) Output Power(dBm) 1 30.01 10 29.93 50 29.19 80 28.70 100 28.73 Table 8: Table for frequency[MHz] vs.output power[dBm] for 100D stub probe 15 Computational EM solver The computational solver is based on the surface equivalence theorem of Electromagnet- ics ?ctitious source can be reconstructed around the DUT which will act as the source of equivalent surface currents.

These surface currents will then be given to the input as the Magnetic Field Integral Operator (MFIO) which will ?nally give the computed magnetic ?eld data. This step is core of the overall proposed approach as it mitigates the necessity of the magnetic ?eld probes and repeating of the experimental procedures for obtaining the magnetic ?eld data for the DUT whose electric ?eld data is already avail- able.

The electric ?eld data ?rst 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 ?eld integral operator.This magnetic ?eld integral operator ?nally provides us with the 21 Figure 15: Graph for loop output vs.

Frequency for 100D stub probe magnetic ?eld data which is the main motive for the entire computation. The ?ow diagram of the computational EM solver is shown in ?gure 16. 22 Figure 16: Block diagram of computational solver 16 Conclusion It is a fully comprehensive solution which provides both electric and magnetic ?elds 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 ?elds 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 ?eld. The accuracy of the overall procedure is bounded by the sensitivity of the electric probes.

The proposed procedure provides a cost e?ective way to obtain the near ?eld values in lesser time compared to existing state of the art techniques. 23 17 References 1. Zhang, Ji, Keong W. Kam, Jin Min, Victor V. Khilkevich, David Pommerenke, and Jun Fan. ”An e?ective method of probe calibration in phase-resolved near- ?eld scanning for EMI application.” IEEE transactions on instrumentation and measurement 62, no.

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IEEE Transactions on Antennas and Propagation 46, no. 5 (1998): 730-735. 12. Balanis, Constantine A. Advanced engineering electromagnetics. John Wiley Sons,1999. 13. https://www.kollmorgen.com/en-us/service-and-support/knowledge-center/white-papers/stepper-motor-or-servo-motor-which-should-it-be/ 14. https://www.electricaltechnology.org/2016/12/stepper-motor-construction-types-and-modes-of-operation.html

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