INHOUSE ELECTROSTATIC FIELD METER CALIBRATION FOR IMPROVED ESD PROTECTION

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IN HOUSE ELECTROSTATIC FIELD METER CALIBRATION FOR IMPROVED ESD PROTECTION

ABSTRACT

This research project presented an improved in house calibration procedure for electrostatic field meter. The proposed improved arrangement is by using copper parallel plates with the optimum separation distance of 6.01 mm between plates. The material properties test, repeatability test and reproducibility test have been conducted throughout the project. The material properties test shows that copper is the suitable material to be used as the calibration plate due to its behaviour that can withstand high voltage up to 8 kV. The repeatability test conducted shows that the arrangement produces consistent results in five cycles of measurements. As for the reproducibility test where taken into account that the arrangement has been dismantled before undergoes the reproducibility test shows that the arrangement is reproducible. This study is conducted for the improvement electrostatic discharge (ESD) protection monitoring in the production line. ESD protection can prevent from any hazard caused by ESD. Calibration of the electrostatic meter is required for the confidence in its measuring accuracy.

PENENTUUKURAN DALAMAN PENGUKUR MEDAN ELELTROSTATIK UNTUK PENAMBAHBAIKAN PERLINDUNGAN PELEPASAN CAS ELEKTROSTATIK (ESD)

ABSTRAK

Projek pnyelidikan ini membentangkan prosedur penentuukuran dalaman yang lebih baik untuk pengukur medan elektrostatik. Susunan alatan yang dicadangkan adalah dengan menggunakan plat selari tembaga dengan jarak pemisahan optimum antara plat sebanyak 6.01 mm. Ujian sifat bahan, ujian pengulangan dan ujian kebolehulangan telah dijalankan sepanjang projek ini. Ujian sifat bahan yang dijalankan menunjukkan bahawa tembaga adalah bahan yang sesuai untuk digunakan sebagai plat penentuukur kerana sifatnya yang boleh bertahan dengan voltan tinggi sehingga 8 kV. Ujian pengulangan yang dijalankan menunjukkan bahawa prosedur tersebut dapat memberi bacaan pengukuran yang konsisten dalam lima kitaran pengukuran. Manakala, untuk ujian kebolehulangan pula di mana susunan tersebut telah dibongkar dan dipasang semula menunjukkan bahawa prosedur yang telah ditambahbaik ini boleh direproduksi. Kajian ini dijalankan untuk menambahbaik pemantauan pelepas cas elektrostatik (ESD) di bahagian pengeluaran terutamanya di kilang. Perlindungan ESD boleh mencegah sebarang bahaya yang disebabkan oleh pelepasan cas elektrostatik. Penentuukuran pengukur elektrostatik diperlukan untuk keyakinan dalam ketepatan pengukurannya.

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In the name of Allah, The Most Loving and The Most Compassionate. In completing this research project, I have received so much help from important people around me. They have contributed greatly towards my understanding and thoughts. Firstly, I would like to convey my appreciation to my supervisor, Associate Prof. Dr Wan Nor Liza binti Wan Mahadi for the support and guidance throughout this research project. Utmost appreciation goes to my superior, Mr Shah Zulkifli Nor and colleagues in Sendi Mahir Sdn Bhd for helping me and giving ideas in order to complete this study. To my parents, Pn. Hjh. Noorida binti Abdul Majid and Ir. Hj. Abdul Rahim bin Ibrahim, thank you so much for the support and understanding and for being my ultimate supporter in completing my master degree journey. Special thanks to my siblings and friends for always believing in me.

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CHAPTER 1: INTRODUCTION

According to history, the word ‘electricity’ originates from 'electron' and it was Thales of Miletus who first watched this particular property identified with field of electrical and electronic items. It was titled as 'electrical' in 1600 by William Gilbert who is said to have started the scientific investigation of electric and magnetic field and its properties.

With the advancement of science and innovation and creation of new materials, electrical and electronic gadgets have developed rapidly. Scaling down of electrical and electronic segments offered ascend to new potential outcomes to build the exhibitions and diminish the sizes of electrical gadgets, and yet expanded their powerlessness to produce new problems.

Today, the development of the electronic business and the far reaching utilization of electronic hardware in communications, automations, computations, biomedicine, space, and different purposes have prompted numerous electrostatic discharge and electromagnetic field/radiation.

The issue of charge collection is intense in the instance of high voltage direct current (HVDC) transmission when the corona discharge is created along the conductor (Li, C., et al, 2017) . With the purpose of measuring the surface charge, there are a few approaches. The approach of using the electrostatic test is straightforward and practicable, and it has a wide scope of use (Zisman, 1932). Therefore it is the most standard method implemented in the measurement of surface charge.

Electrostatic meters are used as one of the ESD protection practice in production line. It is used for determining static charges in electrically shielded materials.

Static charges can be estimated and determined in objects using electrostatic meters by estimating the electric field at a standard separation distance. Electrostatic meters ought to dependably be utilized for ESD protection. This is, for instance, the case in the utilization or creation of development components with electrostatic hazard, or when working with effectively combustible materials. With electrostatic meters, it is conceivable to identify possibly hazardous sources in enough time to take appropriate measures.

An instrument needs to be calibrated in order to minimize the measurement uncertainty. Calibration quantifies and controls errors or uncertainties within measurement processes to an acceptable level. Calibration is important wherever measurements are important, it enables users and businesses to have confidence in the results that they monitor, record and subsequently control. To gain confidence in the calibration, a proper procedure and calculation of measurement uncertainty need to be generated first. It is a plus point for the laboratory if the calibration is accredited by the authorities. In Malaysia, all calibration laboratories are monitored by the Department of Standard Malaysia.

The motivation of this study is the concern on the ESD protection in the production line. Most engineering industry such as manufacturing is facing the static electricity hazard frequently. As an early step to minimize the hazard is by monitoring the static electricity presents at the workplace. The monitoring process is conducted by using a specific instrument that can measure the electrostatic field on the surface. An electrostatic field meter is used to measure the field. However, how the measurement of the meter can be confidently accepted? That is why the calibration of the electrostatic meter is required in order to gain confidence in the measurement.

The purpose of this study is to improve the in house calibration procedure of electrostatic field meter. Electrostatic field meter is widely used in the production line in the manufacturing field. Many practical electrostatic measurements do not need to be very accurate. There is need however for proper methods of measurement and for methods of calibration which ensure reliable and comparable information.

The objectives of this research projects are as listed below:

i. To design and develop suitable in house calibration arrangement of the electrostatic field meter.
ii. To evaluate suitable material for the selected range of measurement. In this study, the ranges are separated as 0kV to 2 kV as low voltage range and 2kV to 10kV as high voltage range.
iii. To measure and evaluate optimum distance between the parallel plates.
iv. To come out with proper and suitable calibration arrangement procedure for electrostatic discharge (ESD) in production line.

The main improvement made in this study firstly is to improve the plate used in the procedure. Previously, aluminium plate is used. Aluminium is one of the electric conductors. However, the material is easy to bend and scratch. This will affect the electrostatic measurement as in the procedure, the plate used ought to be flat, unbended and free from dust.

Secondly is the arrangement of the apparatus. Electrostatic field measurement used the same concept as the parallel plate capacitor. A range of voltage is sourced to the plate and the electric field strength present between the plates.

The electrostatic field meter is used to measure this field. The apparatus arrangement is referred to the international standard BS7506: Part 2: 1996.

Taking into account all of the factors that influenced the electrostatic measurement, in this study, instead of using aluminium plate, a pair of single sided copper plates are suitable to be implemented in the procedure. Copper is the best electrical conductor. The plates used are flat, free from dust and scratch.

Electric field is a vector quantity with magnitude and direction presented in unit Newton per Coulomb (N/C) or Volt per meter (V/m). Electric field is describe as when we move one coulomb of charge starting with one point then onto the next in an electric field, we are exerting work to that charge and that gives us the electric potential or voltage.

$$E = \frac{V}{d}\frac{Volt}{meter}$$.............. Equation (1)

E is the electric field or strength present as the work is done on the charge. V is the source of power applied to the charge and d is the distance of the charge travels.

A volt is the measure of work it takes to move one coulomb of charge a specific separation through an electric field. This is currently leads to capacitance. A capacitor is typically seen as any two conductors isolated by an insulator. The capacitance of a capacitor is the proportion of the amount of the charge Q on two bodies to the potential difference between the bodies. The capacitance is expressed as follows where C is the capacitance in unit Farad, Q is the charge in Coulomb and V is the potential difference in Volt.

$$C = \frac{Q}{V}$$..... Equation (2)

The calibration of electrostatic field meter practiced for in house generally, still has room for improvement. The main purpose of this study is to evaluate an improved outcome for the calibration of electrostatic field meter. In this research, it will include the principle of electrostatic measurement, the measurement setting, the equipment used and the comparison of the outcome from the previous procedure.

By improving the in house calibration procedure of the electrostatic field meter, it also can be encompassed as one of the early steps in monitoring the Electrostatic Discharge (ESD) protection in the production line. This means, by improving the procedure, confidence in the static measurement is gained and the ESD protection step will be more efficient.

This is a qualitative approach research. The improvement of the procedure will be conducted by using different type of material used and the arrangement of the apparatus compared to the previous procedure. The aim of the experiment is to prove that a stable measurement reading will be obtained.

In this report, it will consist of literature review that will mainly discuss on the principle of the electrostatic discharge, the working principle of electrostatic measuring device and the purpose of calibrating electrostatic measuring device. The methodology chapter will discuss on the apparatus, the arrangement and the material used in the procedure.

Results will be presented by comparing with the data collected from the previous procedure. Discussions will be made by analysing the aspects that involved in the improvement of the procedure. Suggestions for further study will also be included in this chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Electrostatic Discharged (ESD)

The generation and impact of static electricity, saw from ancient occasions, was early described in the 1500's. The underlying tribo-electric series, established in the 1757 by Wilche, was deciphered as the exchange of electrons between two surfaces that are in contact with one another. The tribo-series regardless of its 250-year presence is as yet factor; reliant on the literature and a robotic clarification of its starting points is as yet continuous research subject.

2.1.1 Static electricity

The term 'electrostatic' or 'Static Electricity' introduces to the phenomenon related with the development of electrical charges created, for instance, by contact/rubbing of two objects. Static electricity and electrostatic discharge (ESD) are naturally occurring phenomena. Hebeish AA et al. have characterized static electricity as electrical energy stationary on a surface. At its most straightforward, static electricity is an electrical charge that cannot move.

In the event that charges don't have a way to the ground, they become "static". In the event that static electricity is not quickly evacuated, the charge will assemble. It will in the long run grow enough energy to bounce as a spark to some adjacent grounded or less exceptionally charged item trying to balance the charge.

2.1.2 Charging objects

Charging that creates when two solids come into contact has been alluded to as frictional charging, contact charging, tribo-electric charging and tribo-electrification.

Most static electricity is created by tribocharging. Tribocharging happens when two materials contact with one another and are then isolated. One material surrenders electrons and turns out to be positively charged; the other takes on these electrons and turns out to be negatively charged. (Figure 2.1). Since an object has a large number of electrons, therefore the charge on objects develops to huge sums. This is the most widely recognized way static charge is amassed.

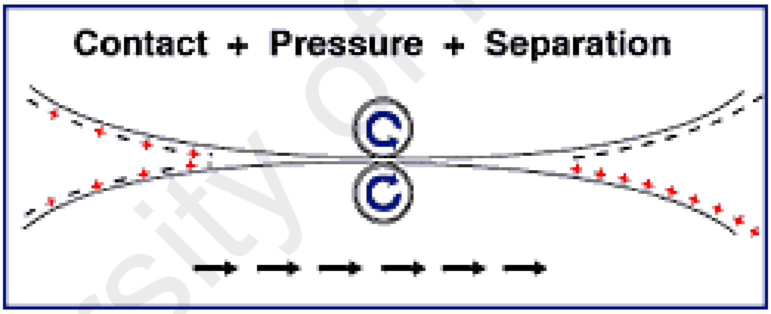

Figure 2.1 Triboelectric occurrence

Rubbing is not constantly important for charge production. It more often than not builds the measure of charge delivered. Experimental results have demonstrated that, when an insulating surface is rubbed either by a conductor or another insulator, charge transfer might be greater than simple contacting objects.

Gonzalez JA, Rizvi SA, Crown EM, et al. have discovered that objects have possibility to charge via any of these methods: triboelectrification, induction, polarization and conduction.

2.1.3 What is ESD?

ESD is the unexpected discharge of this electrostatic potential starting with one body then onto the next. A genuine model is the shock we get when contacting a metal door handle subsequent to walking over a carpeted floor. Electrostatic charge, or static potential, is generally measured in volts. Its magnitude and polarity are influenced by humidity, the sort and speed of movement, the degree of contact, and the kinds of materials included.

Event of electrostatic discharge (ESD) has been around since the very beginning. Be that as it may, this characteristic wonder has turned into a huge issue with the boundless utilization of electronics instrument.

Many years ago the issues resulting from static charges were comparatively low with natural fibres in elevated humidity settings, but when synthetic fibers of a hydrophobic nature were introduced, these issues has become more serious.

2.1.4 Electrostatic properties in conductors

Conductors have mobile charge carriers. In metallic conductors, these charge carriers are electrons. In a metal, the external (valence) electrons part away from their atoms and are allowed to move freely. These electrons are free inside the metal yet not allowed to leave the metal.

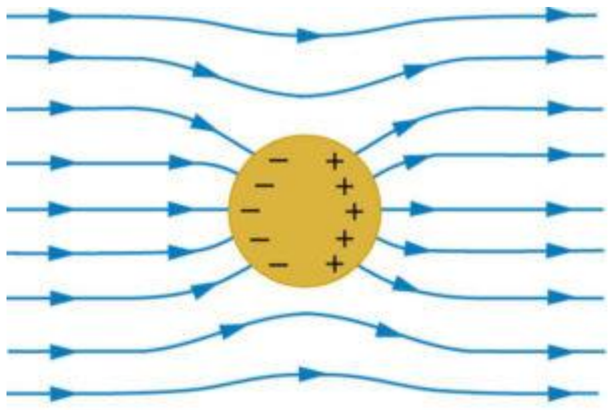

Figure 2.2: The electric field in a conductor

In an outer electric field, they drift against the path of the field. The positive particles made up of the nuclei and the bound electrons stay held in their fixed positions. In electrolytic conductors, the charge carriers are both positive and negative particles. A portion of the significant focuses about the electrostatic properties of a conductor are as per the following:

i. Zero electric field in a conductor

In the static condition, regardless of whether a conductor is neutral or charged, the electric field inside the conductor is zero all over the place. This is one of the characterizing properties of a conductor.

We realize that a conductor contains free electrons which, within the sight of an electric field, experience a drift or a power. Inside the conductor, the electrons appropriate themselves so that the last electric field at all focuses inside the conductor is zero.

ii. Electrostatic field line are perpendicular to the charged surface of a conductor

We can say, if the electric field lines were not perpendicular at the surface, a part of the electric field would have been available along the outside of a conductor in the static condition.

Therefore, free charges travelling onward the surface would likewise have encountered some forces prompting their movement. Yet, this does not occur. Since there are no tangential parts, the powers must be perpendicular to the surface.

iii. In static condition, no excess charge exist inside the conductor

Neutral conductor contains the same amount of negative and positive charged particles, at each point. This remains constant even in an imperceptibly little component of volume or surface zone. From the Gauss' law, we can say that on account of a charged conductor, the superfluous charges are available just on the surface. Consider a arbitrary volume component of the conductor, which is indicated as 'v' and for the closed surface leaping the volume component, the electrostatic field is zero. Accordingly, the electric flux through S is zero. In this way, from the Gauss law, it pursues that the net charge encased by the surface component is zero.

As the size of the volume and the surface component decreasing, at a point where the component is vanishingly little, it signifies any point in the conductor. So the net charge anytime inside the conductor is constantly zero and the excess charges resides at the surface.

2.1.5 Sources and implications of ESD

The era of electronics carried with it new issues related with static electricity produced and electrostatic discharge. As electronic gadgets, decreased in size and increased in their operation speed, their sensitivity to ESD expanded. Electrostatic discharge (ESD) is known as "the imperceptible danger".

The release can be brought about by an assortment of sources, most usually a direct discharge from an individual or instrument into a sensitive object. The types of ESD occurrence is by discharge to and from the device and also field-induced discharge.

The main implication or hazard of static electricity is the production of sparks in an explosive or combustible air. These sparks can set off a blast or fire. The danger is most notable when combustible fluids are being poured or moved. In numerous conditions, ESD issues go past the minor irritation of a mild shock on a dry winter day. It can harm or damage delicate electronic equipment, or set off blasts or flames in combustible area.

ESD impacts profitability and product dependability in apparently every purpose of the present electronics surrounding. ESD influences creation yields, fabricating costs, item quality, item unwavering quality, and gainfulness. Industry specialists have evaluated normal item misfortunes because of static range from 8-33%. Brown L and Burns D. have assessed genuine expense of ESD harm to the electronics business as running into the billions of dollars annually. Refer Figure 2.2 for some labels or indicator of ESD hazards.

Figure 2.3: Examples of ESD hazard labels

2.1.6 ESD control and protection

As a result of enlightening outcomes as of late in research on electrostatic events, there have been successful applications in industry in copiers, dust gatherers and so forth, however there has been no closure to the fiascos because of electricity produced via friction, for example, issues of harm because of electrostatic discharge in the electronics business where it is frequently called ESD and flames and blasts in the chemical industry as example. While there is particular learning for the avoidance of electrostatic hazards, it is most significant that the administrators and staff really captivating underway in production line get physically involved with the right information concerning electrostatic hazards, find the potential reasons for electrostatic risks and counsel specialists on security and debacle counteractive action (Ota, 2004).

Grounding is the most crucial parameter in the ESD precaution. Disobeying proper grounding could lead to ESD hazards. Grounding can be classified into two categories which are personnel grounding and equipment grounding. Wrist straps are basic in dissipating charge from personnel and guaranteeing safety of dealt with instruments. In any case, insignificant existence of the wrist straps is no affirmation of proper personnel grounding. For instance, the wrist strap could be worn over a sleeve in order to create no grounding impact at all; it may not be connected the grounding terminal; the grounding terminal itself can be disconnected from the ground, loose or partially contact. Figure 2.4 shows the wrist strap that is normally used in the production line for personnel grounding.

Figure 2.4: Wrist strap

In a dynamic assembling condition, the nature of equipment grounding can be similarly as powerful. Ground wires can be loosened up or, disengaged during maintenance and not re-connected, and grounding terminals themselves might be detached from ground. In production line where changes are made regularly, the likelihood of these events is very high. The negligible nearness of an establishing wire joined to an instrument amounts to nothing if this wire isn't connected on the opposite end to proper ground. A static dissipative mat without anyone else's input gives no way to ground and no dissemination of charges on the off chance that it is not grounded by itself. Realizing that all equipment is appropriately grounded consistently is basic for persistent affirmation of ESD precaution, just as for personnel safety. Figure 2.5 below shows one of the work station monitor tester that is installed in production line for the grounding purposes.

Figure2.5: ESD workstation monitor tester

Monitoring the ESD events is one of the protection methods that should be implemented in the production line. What comprises ESD presentation? For gadget damage, it implies the existence of ESD events, or discharges. For particle contamination resolves, it is static voltage. The magnitude and frequency of ESD events is a definitive measurement of the ESD-safety of the production condition. Despite the degree of ESD protection executed, in the event that regardless you have ESD events, something isn't working. ESD events last a very brief time, ordinarily on the case of nanoseconds. The main remaining data they leave is a damaged device. Real-time ESD events monitoring enables the identification of the devices, offering a continuous confirmation of ESD-safety, and alerting to any issues as they arise.

Other than proper grounding and shielding as well as the use of the real-time monitoring device, the personnel itself must have knowledge on the ESD management. The established ESD Standards ANSI/ESD S20.20 and IEC 61340-5-1 should be used to drive the ESD protection program. An ESD program manager or coordinator is recommended to be appointed so that there is a person that is particularly in-charge to monitor and manage the ESD related case.

2.2 Electric and Magnetic Field (EMF)

Since the mid-twentieth century, electricity has been a fundamental piece of our lives. Electricity supplies power to the appliances, office equipment, and incalculable different devices that we use to make life more secure, simpler, and more fascinating. Utilization of electric power is something we underestimate. However, some have pondered whether the electric and magnetic fields (EMF) delivered through the generation, transmission, and utilization of electric power (50 Hz to 60 Hz) may unfavorably influence to the workplace and our safety and health.

2.2.1 Basic of EMF

A field portrays the impact of an item on its encompassing space. Inside nature, various electric and attractive fields happen. The earth is itself an immense natural magnet with magnetic poles near the north and south poles.

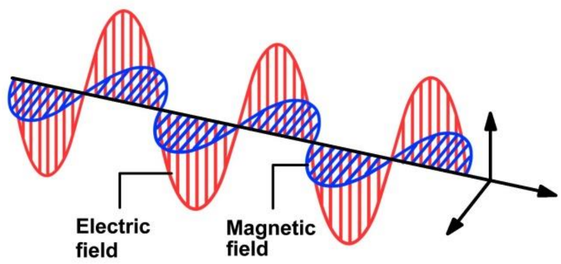

Figure 2.6: Electric and magnetic fields

EMF defines the two sorts of fields related with any sort of electricity—electric fields and magnetic fields. Electric and magnetic fields are created by both normal and man-made sources that encompass us in our day by day lives.

An electric field is delivered inside the encompassing zone when voltage is connected to a conductor (or wire). Similarly as the territory around a high temperature water pipe is influenced by the temperature of the pipe, the region encompassing an electrical conductor is impacted by the voltage of the conductor. The strength of an electric field at a given area relies upon two components — the level of voltage connected to the conductor and the distance from it. (Electric fields are identified with voltage. Voltage is similar to pressure in a water pipe. Higher voltages produce stronger electric fields.)

The piezo effect is identified with electrical fields. Piezo actuators don't deliver magnetic fields nor are they influenced by magnetic fields. They are extraordinarily appropriate for applications where magnetic fields can't go on without serious consequences.

Magnetic fields are created where electric current is available. The strength of a magnetic field at a given area relies upon the level of current flowing in the conductor or wire and the distance from it. (Magnetic fields are identified with the measure of current that is flowing. Current is similar to the rate of liquid stream in a water pipe. Higher currents produce stronger magnetic fields.) For instance, the magnetic field created just by a hair dryer is higher when the dryer is worked on its "high" heat setting than on the "low" setting in light of the fact that the high setting draws progressively current. Electric and magnetic fields (EMFs) are undetectable zones of energy that is often refers as radiation.

2.2.2 Characteristics of EMF

There are a few characteristics that explain the behavior of the EMF. The wavelength is the distance of a peak on the wave to the next peak of the same polarity. The frequency is the number of cycles that occur in a second. Amplitude is the strength or the level of the waveform.

The course of the field substitutes from one polarity to the inverse and back to the first polarity in a timeframe called one cycle. EMF in large sense - fields at amazingly low frequencies, for example, those related with the utilization of electricity. EMF in an a lot more extensive sense - fields with low or high frequencies. Refer Figure 2.7 below.

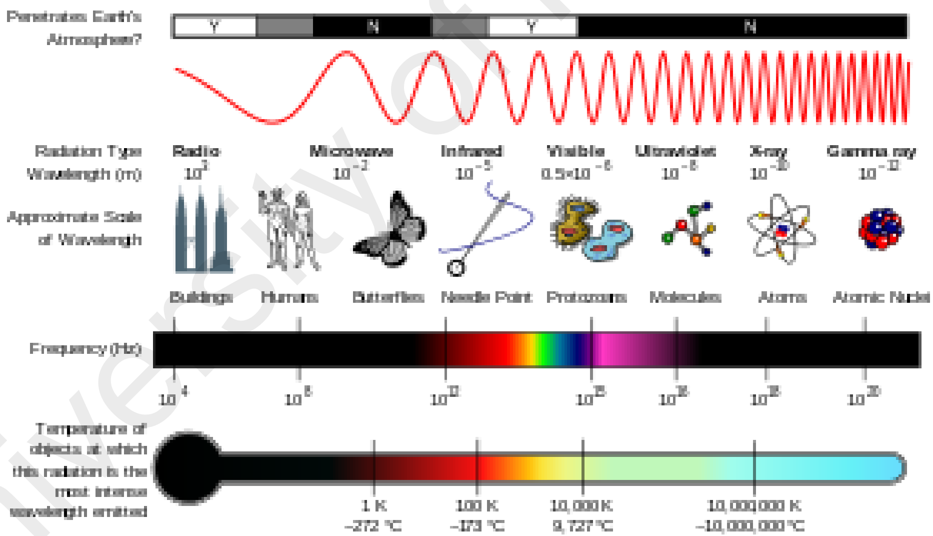

Figure 2.7: Electromagnetic spectrum

There are two categories of radiations that are characterized by the wavelength and frequency as shown in Figure 2.8. Ionizing radiation is generally perceived as harmless to human due to its low-level radiation. The non-ionizing radiation has a potential for cellular and DNA damage due to its high-level radiation.

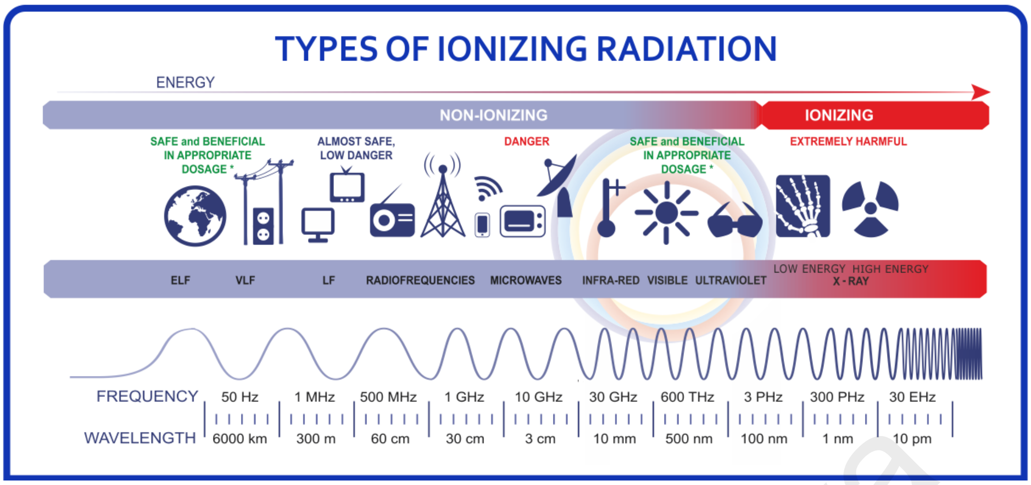

Figure 2.8: Ionizing & non-ionizing radiation and its penetration

2.2.3 Sources of EMF

Because of a wide range of electrical equipment and building wiring just because of close-by power lines, complex EMF exposures exist in the work environment.

EMF is found any place electricity is produced, delivered or utilized. Power lines, wiring in homes, working environment equipment, computers, and appliances all produce EMF. Our exposure to EMF differs for the duration of the day relying upon the causes of fields we experience and how close we are to the source (Fig. 2.9). The strength of the electric field relies upon the voltage, while the strength of the magnetic field relies upon the size of the current carried. The strengths of the fields diminish quickly with distance from the sources.

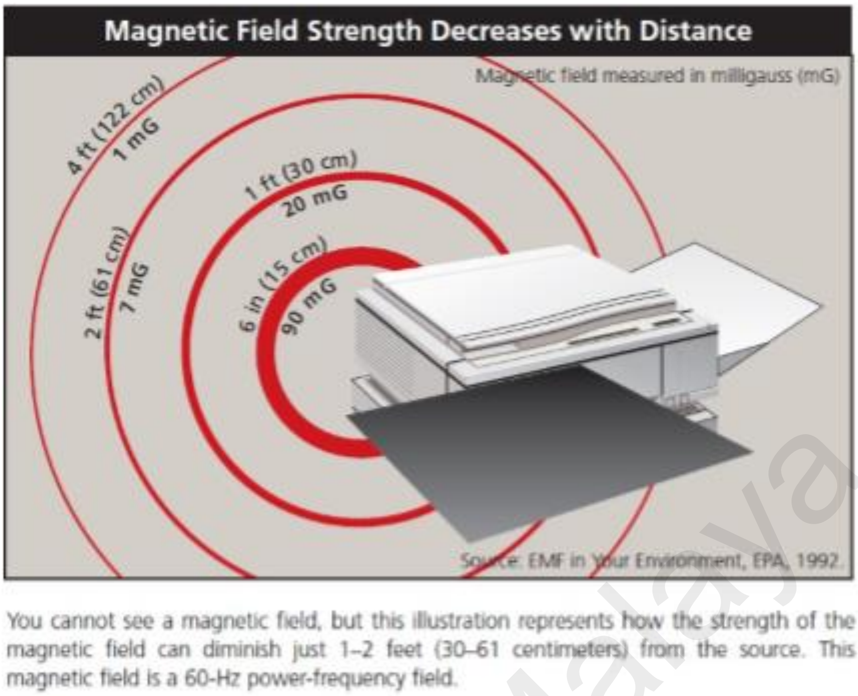

Figure 2.9: The magnetic field strength and the affected distance

The magnetic fields around the electrical source can impact delicate instrument, particularly those that utilization electron beams. Models are electron microscope and electron beam lithography instrument. The electron beams are controlled and centered with magnets. Undesirable and uncontrolled magnetic fields in nearness to the equipment effect in reduced performance of the instrumentation.

Another significant issue to be tended to with EM (Electromagnetic) waves is their conceivable health impacts on humans. The World Health Organization (WHO) proposes that a wide scope of environmental EM impacts cause natural impacts. There is additionally expanding worry that EMI unfavorably influences the task of biological devices, for example, pacemakers.

Semiconductor Industries :

Varieties of technologies are utilized in semiconductor assembling and testing. These innovations use a wide scope of radiation sources. Basic RF/Microwave radiation and penetration creating gadgets utilized by the semiconductor business and RF/Microwave penetration in muscle, skin and different tissues are appeared in Table 2.2 and Table 2.3.

Field Strength	Operating Frequency (MHz)	Assigned Range in US
0.3T	12.8	Maritime mobile
0.5T	21.3	Shortwave "ham" radio (15 m band)
1.0T	42.6	Land mobile
1.5T	63.9	Analog TV Channel 3 (USA)
3.0T	127.8	Civil aviation
7.0T	298.2	Mobile satellite

Table 2.1: The RF wave and frequency range of devices

Frequency (MHz)	Depth of Penetration (cm)
1	91
27	14
40	11
433	3.6
915	3.0
2450	1.7
5800	0.72
10,000	0.34

Table 2.2: RF wave penetration depth in muscle, skin and tissues

2.2.4 EMF Protection

Electromagnetic shielding is only the precaution step against electromagnetic radiations/waves (EMR) is likewise called as protection against EMI/RFI. Perumalraj et al. have proposed that shielding viability is a key parameter which frequently decides the extension for utilization of a given material (Perumalraj, Balasaravanan, Nalankilli, & Roshanraja, 2010). Wu F, Xu Z, et al. have proposed electromagnetic shielding shown in Figure 2.10 used to avert electromagnetic signals, for example, radio sign from leaving or entering a case or enclosure (Wu, Xu, Wang, & Wang, 2014). Previously, metals were the contender for EMI shielding since they could reflect or conduct the free electrons.

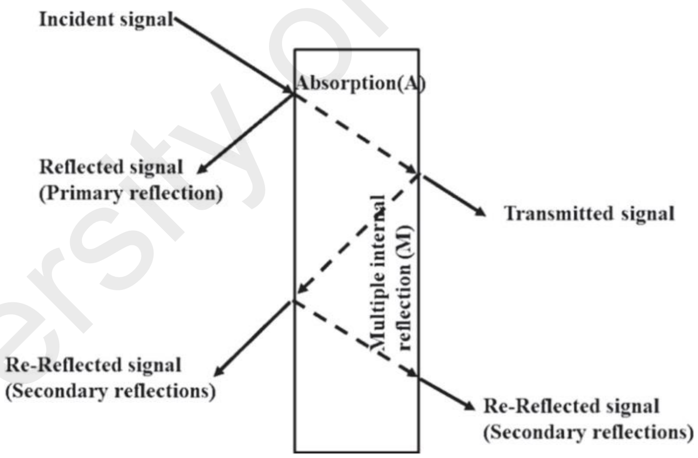

Figure 2.10: The transmission of electromagnetic waves

2.2.5 Electric Field Strength

The most precise approach to express WiFi field (signal) quality is with dBm, which represents decibels in respect to a milliwatt. Received signal strength indicator (RSSI) is a typical measurement too, yet most WiFi connectors handle it in an unexpected way, so it's basic for applications to change over it to dBm.

The significant thing to comprehend about dBm is that we're working in negatives. - 40 is higher - 70, due to - 70 is a much lower number.

As for the electric field strength, it defines as the existence of strength at a point in an electric field is the force following up on unit positive charge set by then. It is a vector quantity therefore it will have magnitude and direction. The formula of electric field, E is as follows:

$$E = \frac{F}{Q} \qquad E = \frac{V}{d}$$

The units are N/C or V/m - N/C is generally utilized for field strength around point charges (in spiral fields) and V/m for uniform fields (between capacitor plates and so on.)

The force of the electric field or the electric field strength can be thought of as the inclination of the field. The more extreme the angle of a slant the more prominent the power following up on an item moving down it - so the greater the acceleration of the object will be.

The equivalent is valid with the electric field. F = EQ, so for a given charge the more prominent the electric intensity (or electric field strength) the more noteworthy the force will be on that charged molecule

We frequently need to do calculations on the acceleration of charged particles inside an electric field. We hence need to utilize the above condition to decide the force acting and after that utilization F=ma to decide the acceleration that will result.

When finding the electric field strength between capacitor plates, one factor should be taken into account that there is uniform field strength, therefore there is a separation distance between the plates denotes as d and 'V' is the potential difference between those plates - the intensity is the equivalent at all focuses between those plates so any increasing speed delivered will be uniform - as the power created (and in this manner the acceleration) will be consistent .

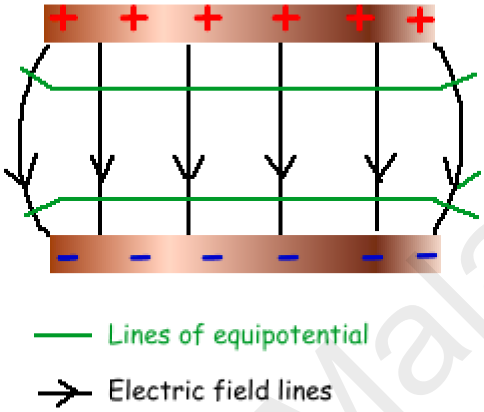

Figure 2.11: The uniform electric field lines

2.2.6 Parallel Plate Capacitor

Parallel-plate capacitors are utilized in a wide assortment of detecting applications, for instance proximity sensing, pressure measurement, switches, and interchanges, just as material property detecting of sustenance items, polymer pitches, and different insulating materials.

Parallel Plate Capacitors are the sort of capacitors which that have a course of action of cathodes and insulating material (dielectric). The two directing plates go about as anodes. There is a dielectric between them. This goes about as a separator for the plates.

The two plates of parallel plate capacitor are of equivalent measurements. They are associated with the power supply. The plate, associated with the positive terminal of the battery, gets a positive charge. Then again, the plate, associated with the negative terminal of battery gets a negative charge. Because of the fascination charges are in a manner caught inside the plates of the capacitor.

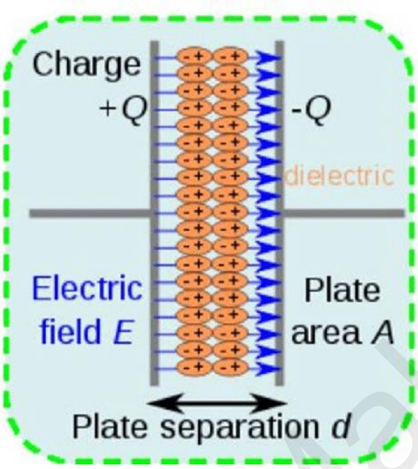

Figure 2.12: The parallel plate capacitor diagram

A specific measure of charge can be given to a plate. In the event that more charge is supplied, the potential increments and it could prompt a spillage in the charge. When another plate is placed next to a positively charged plate, the negative charge will flow towards the side of the plate which is closer to the positively charged plate.

As both the plates have charges, the negative charge on plate 2 will diminish the potential difference on plate 1. Then again, the positive charge on plate 2 will expand the potential difference on plate 1. In any case, the negative charge on plate 2 will have more effect. Along these lines, more charge can be given on plate 1. On account of the negative charges on plate 2 the potential distinction will be less. This is the rule of the parallel plate capacitor.

The amount of electric charge stored in the parallel plate capacitor is directly proportional to the potential difference between the two plates. The parallel plate capacitor is implementing the Gauss's Law. According to the Gauss's Law, the electric field can be expressed as:

$$E = \frac{V}{d} \qquad \text{Equation (1)}$$

Where E is electric field, V is the voltage applied and d is the separation distance between plates.

2.3 Electrostatic Measuring Instrument

Several methods of measuring electrostatic field in the air are implemented. One of the methods used is when an electric charge on a capacitance induced by a measured field.

2.3.1 Electrostatic Field Meter

An ideal electrostatic field meter should have a few of these characteristics. An ideal electrostatic meter is small in size and it is capable of orientation to determine the magnitude and direction of the electric field. It is also capable in assuming the potential in the dielectric to the point where the field intensity is wanted. It must also translate data to the ground as any interconnecting wire would totally falsify the field in the proximity of the probe.

In general, the ideal electrostatic field meter would have the capability of measuring the field without disrupting the electric field. The practical electrostatic meter used today is a ground referenced measuring device

When all is said in done the perfect field meter would have the capacity of measuring the field without mutilating that field in any capacity. The down to earth field meter utilized today is a ground referenced measuring instrument in which readings are relatively identified with the distance from the probe to the surface or item under test.

This attribute is one of the restricting components of all field meters and if exact readings are to be acquired, the distance from the field-meter test to the surface under test must be decisively known. Another normal for field meters is the field of perspective on the test.

2.3.2 Type of Field Meters

Field meters are accessible in three essential varieties. They are the electrometer type, the radioactive sensor type and the A.C. transporter kind of field meter.

The electrometer or the pocket size electrostatic locator sort of field meter will be checked on first. This is essentially a capacitively coupled D.C. intensifier with a shunt capacitor for calibration (Vosteen, 1984).

All amplifiers draw a limited measure of current, along these lines this current instrument's readings will float after some time at the rate of $dv/dt=I/C$ where I is the electrometer input current and C is the shunt capacitance. An increasingly extreme float can likewise be brought about by a minute ion imbalance if this kind of field-meter is utilized in an ionized air condition. To balance this issue the shunt capacitor must be occasionally released in a zero field condition or a known field condition that might be utilized as a source of reference.

The main points of interest of this sort of field meter are minimal cost, effortlessness, little size and the capacity to make incredibly fast measurements.

The inconveniences are the powerlessness to screen a region over an all-inclusive timeframe, the need to intermittently zero and, additionally in view of its D.C. coupled hardware, the failure to utilize these in an ionized air condition.

The second field meter type uses a radioactive sensor. This sensor will ionize the air in its prompt region. At the point when this is presented to an electric field, a flow will stream that is corresponding to the electric field. The flow is then estimated to acquire an electric field perusing.

This is a basic framework and it is D.C. stable. Its downsides are the feelings of trepidation related with radioactive materials, the likelihood of blunders in readings because of soil aggregation on the radioactive material influencing its ionization capacity and the half-existence of the radioactive material.

2.3.3 Usage of Electrostatic Field Meter

An electrostatic field meter, likewise called a static meter is an apparatus utilized in the static control industry. It is utilized for non-contact estimation of electric charge on an article. It quantifies the electrostatic field of an article in volts, measuring both the peak voltage and the rate at which it falls away.

As mentioned above, electrostatic field meter is used to measure static charge on any targeting surface. This is a very delicate instrument. It must be handled with care. Electrostatic field meter is widely used in production line where there is so many electrostatic charge exist on their equipment surfaces.

Figure 2.13: The electrostatic field meter

During the measurement of electrostatic, the ground clamp must be connected to the ground to avoid any disruption from the surrounding. The disruption will affect the measurements.

2.3.4 Calibration of Electrostatic Field Meter

Monetarily accessible electrostatic field meters, albeit receptive to electric field intensity, are frequently calibrated to peruse voltage when held at a fixed dispersing as for a plane surface at steady voltage. The more modern instruments are calibrated to peruse field force straightforwardly, as a rule in volts for each centimeter or volts per meter or volts per inch.

A typical calibration method is to set up a uniform electric field by utilizing two enormous parallel transmitters isolated by a littler fixed known dispersing crosswise over which is connected a known voltage. The electric field set up in the focal point of the plates is then just V/d, voltage divided by the distance.

One of these plates is grounded and a hole is given in this plate only sufficient to allow the field meter probe to be held flush with the grounded surface. The field meter probe is then exposed to a similar electrostatic field as its environment and can be effectively calibrated. Probe—To—Surface geometry is significant and ought to consistently be considered when endeavoring to decide charge or voltage from a field intensity measurement.

A procedure that is regularly elevated to get progressively exact field meter readings is to mount the probe glancing through a grounded metal plate. This standardizes the meter's readings by lessening the electric field combination on the test subsequently making a progressively uniform field condition at the probe.

2.4 Calibration of Measuring Instrument

All measuring instrument need to be checked for their accuracy and drift. This is where calibration and verification of an instrument is important has to be conducted periodically.

2.4.1 What is Calibration?

There are many meanings of calibration as there are methods. As indicated by ISA's The Automation, Systems, and Instrumentation Dictionary, the word calibration is characterized as "a test during which known estimations of measurand are connected to the transducer and comparing yield readings are recorded under determined conditions." The definition incorporates the ability to modify the instrument to zero and to set the ideal range. An elucidation of the definition would state that an alignment is an examination of estimating gear against a standard instrument of higher precision to identify, correspond, modify, correct and report the accuracy of the instrument being thought about.

Normally, calibration of an instrument is checked at a few points all through the calibration scope of the instrument. The calibration range is characterized as "the area between the points of confinement inside which an amount is estimated, gotten or transmitted, communicated by expressing the lower and upper range esteems." The breaking points are characterized by the zero and length esteems. The zero worth is the lower end of the range. Length is characterized as the mathematical distinction between the upper and lower range esteems. The adjustment range may contrast from the instrument extend, which alludes to the ability of the instrument.

2.4.2 Importance of Calibration

It bodes well that calibration is required for new instrument. We need to ensure the instrument is giving exact sign or yield signal when it is introduced. However, for what reason wouldn't we be able to simply disregard it as long as the instrument is working appropriately and keeps on giving the sign we anticipate?

Instrument error can happen because of an assortment of elements: drift, condition, electrical supply, expansion of segments to the yield circle, process changes, and so forth. Since a calibration is performed by contrasting or applying a known sign with the instrument under test, errors are identified by playing out a calibration. An error is the logarithmic contrast between the sign and the genuine estimation of the deliberate variable. Common errors that happen include span error, zero error, combined zero and span error and linearization error.

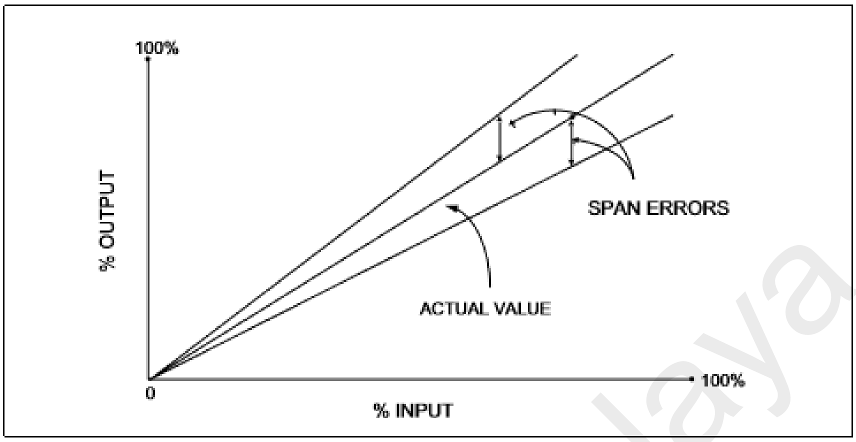

Figure 2.14: The span error

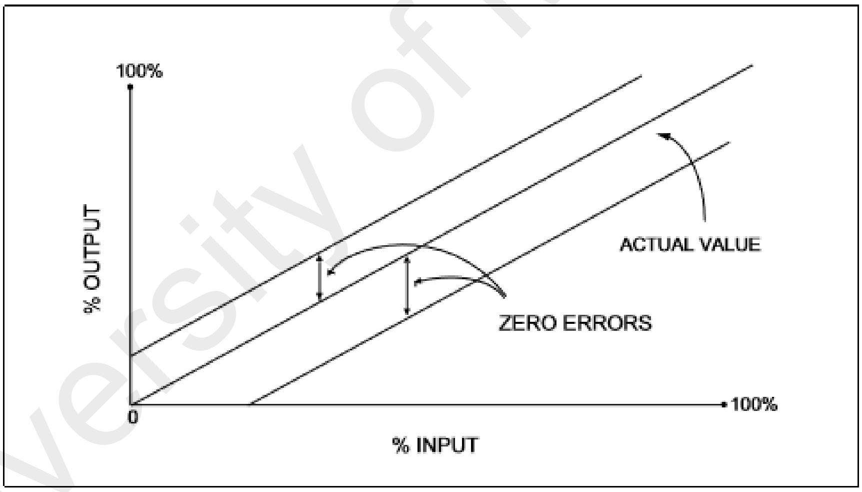

Figure 2.15: The zero error

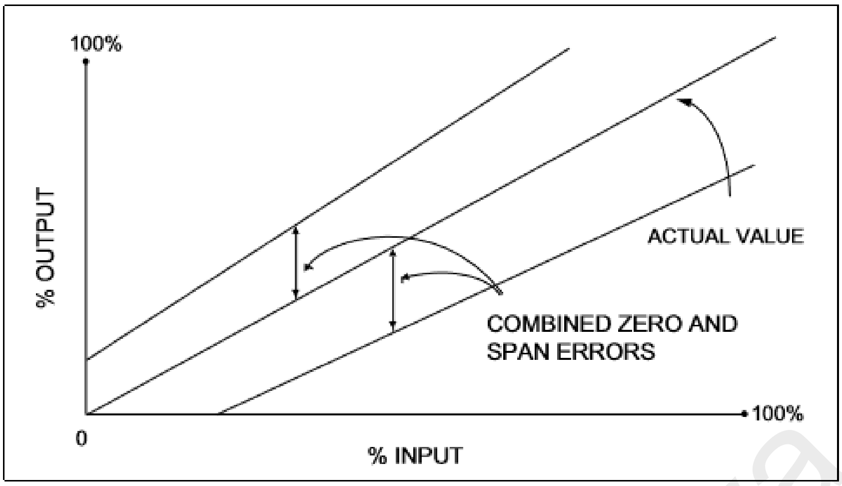

Figure 2.16: The combined zero and span error

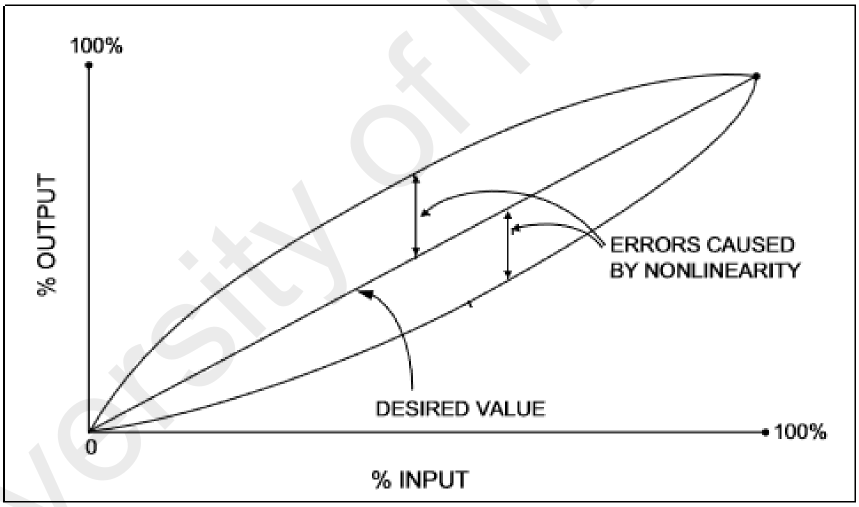

Figure 2.17: The linearization error

Zero and span errors are corrected by playing out a calibration. Most instruments are furnished with a method for modifying the zero and range of the instrument, alongside guidelines for playing out this modification. The zero change is utilized to create a parallel move of the info yield bend. The range alteration is utilized to change the slant of the info yield bend. Linearization error might be amended if the instrument has a linearization change. In the event that the magnitude of the nonlinear error is unsatisfactory and it can't be balanced, the instrument must be supplanted.

To distinguish and address instrument error, periodic calibrations are performed. Regardless of whether an intermittent alignment uncovers the instrument is impeccable and no alteration is required, we would not have realized that except if we played out the calibration. Also, regardless of whether changes are not required for a few back to back calibration, we will at present play out the calibration check at the following booked due date. Periodic calibrations to indicate resistances utilizing endorsed strategies are a significant component of any quality framework.

CHAPTER 3: METHODOLOGY

The apparatus arrangement and procedure are mainly refereed to the standard BS 7506: Part 2: 1996 Methods for Measurements in Electrostatics Part 2 : Test Methods.

3.1 The apparatus

The electric field for calibrating electrostatic field meters is set up by use of a stable continuous voltage between a pair of parallel metal plates. The field meter is mounted with its sensing aperture mounted through a hole at the center of one of the plates refer Figure 1. The hole should fit the surface around the sensing aperture with a gap that is within ±0.5% of the aperture diameter and with the sensing aperture coplanar with the encircling surface to within ±1% of the diameter. The calibration plates ought to be rigid, flat to better than ±2% of the plates spacing, smooth and free from contamination and free residue.

Calibration accomplished by comparing the field meter reading and the calculation of electric field which is by dividing a range of voltages applied by the plates separation distance. Since most of the electrostatic field meter used in the industry is within 5% accuracy, the spacing between the plates ought to be in any event 1.5 times the sensing aperture diameter during calibration.

The external edges of the plates ought to have radii of arch of 2 mm or more and be secured by a nearby layer of protection to evade corona discharges at the higher applied voltages.

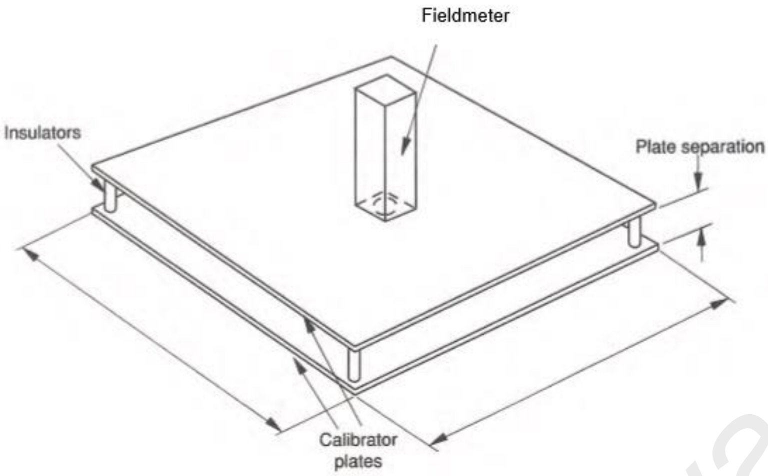

Figure 3.1: Arrangement for electrostatic measurement

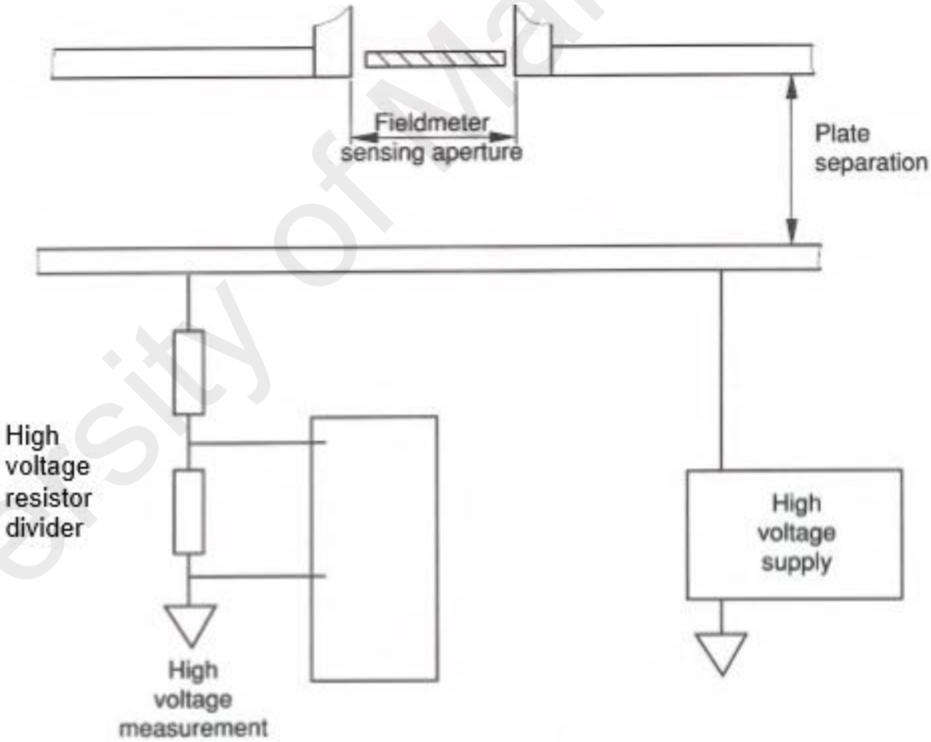

Figure 3.2: Mounting of field meter to the calibration plate

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3.2 The voltage source and measuring system

A source of steady, low swell voltage of the two polarities ought to be utilized to give a range of electric fields in the calibrator from less than 25% of the most sensitive full scale range of the field meter under thought to at least 25% of the least sensitive range.

Typically voltages required are between 50V to 30kV. In this study, we will be using ETS Model 812 as shown in Figure 3 as the DC High Voltage supply. And maximum output from this instrument is 10kV. The accuracy of this high voltage supply is ±1% which is more than 4 times better than most electrostatic field meter in the market. Further specifications on this instrument can be referred in Appendix.

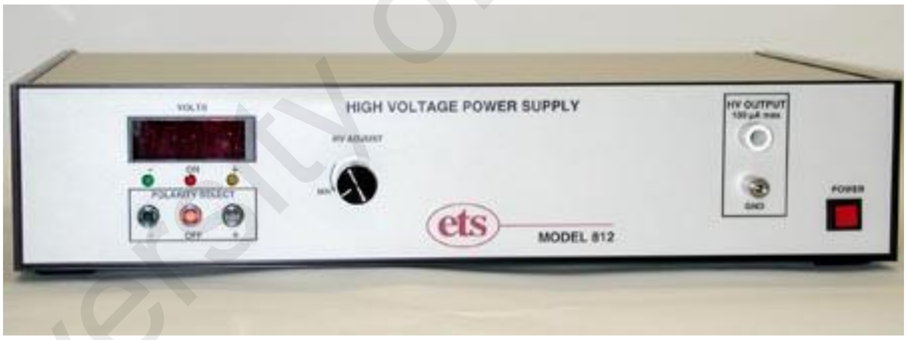

Figure 3.3: High Voltage Power Supply

The voltage measuring system should cover the estimation of the two polarities and be isolated from the voltage source with the aim that it might be calibrated independently. Voltage measurements ought to be made with direct independent connection with the calibrator plates and the accuracy ought to be within 1% for electrostatic with medium precision. Voltage up to 1000V might be measured with a digital multimeter. For higher voltage a high voltage meter is used. In this study, we are using the Kikusui 149-10A as shown in Figure 4 as a parallel measurement with the calibrator and plate. His instrument gives 0.5% accuracy of its reading and this satisfies the ratio 4:1 rule in calibration. Further specifications about this instrument can be referred in Appendix.

Figure 3.4: High Voltage Meter

Precaution ought to be taken to keep away from corona as corona discharge current could influence accuracy. The voltage values at which the voltage measuring instruments are calibrated ought to be those at which field meter calibration measurements are made to avoid any linearity errors at interpolation between calibration points.

3.3 Distance measurements

The spacing between the plates adjacent to the hole for mounting the field meter sensing aperture ought to be estimated using a gauge block or any precision measurement instrument such as a vernier caliper. The spacing distance is taken as the mean of measurement at four positions around the mounting hole with calculation of uncertainty.

The error in coordinating the plane of the sensing aperture to the mounting calibration plate is built up using gauge block determine the thickness of the mounting plate at four equispaced positions around the mounting hole and measuring the spacing distance of the field meter calibrated to the plate.

3.4 Procedures

Mount the field meter with the sensing aperture fit through the mounting hole of the parallel plates. In this study, we are using the SIMCO FMX 003 Electrostatic Field Meter with 10 % accuracy. The distance of the sensing aperture to the plate is within one inch (25.4 mm). The high voltage supply and the high voltage meter ought to be warmed up for at least 30 minutes for stabilization. Switch on the electrostatic field meter and allow for stabilization for five minutes. The temperature is controlled at 23˚C ± 5˚C and the humidity is controlled at 50% RH ± 10% RH. The zero reading of the field meter is recorded during no voltage applied to the calibration plate. Adjust the zero adjustment knob so that the reading on the field meter displays zero. The distance between the plate and sensing aperture of the field meter is measured using a caliper.

Records the field meter measurement reading for a few test points of applied voltages. The test points suggested are from 10% to 90% of full range of the field meter. Use the voltage values at which the voltage measuring system has been calibrated. Six cycles of measurement is conducted in order to obtain the consistent measurement reading of the electrostatic field meter.. The measurement is taken in increasing order. After that, record the measurement in decreasing order and check the zero reading at the end of the process.

The elements that are taken into account are the applied voltage, the display reading on the electrostatic field meter as the results and the calculated electric field as the nominal value. Table 1 shows the parameters that are involved in this procedure.

Parameter	Description
Material of calibration plate	Copper, Aluminium
Width of the copper plates	0.15 m
Length of the copper plates	0.10 m
Thickness of the copper plate	0.001m
Dielectric material	Air

Table 3.1: Parameters of electrostatic field meter calibration

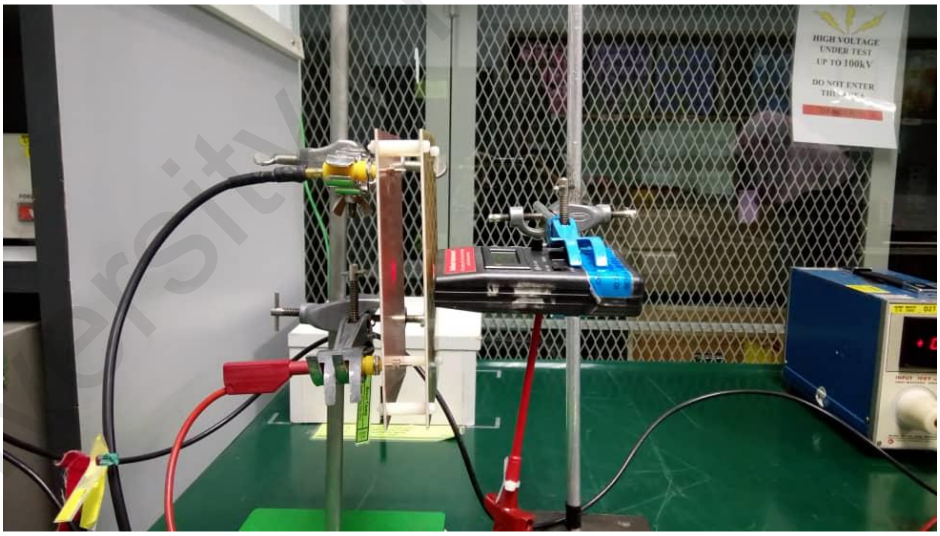

Figure 3.5: Arrangement of the electrostatic field meter and calibration plate

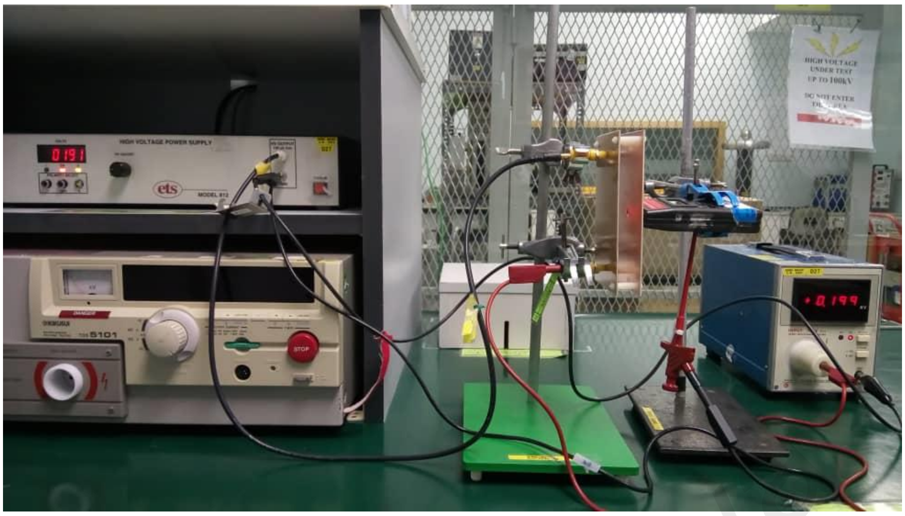

Figure 3.6: Arrangement of the apparatus

The calculated value is obtained from equation E=V/d where V is the voltage applied to the plate and d is the distance measured between the plate and the sensing aperture. The measurement unit for distance, d is depends on the model of electrostatic meter used. Most of the electrostatic meter used kV/in as the measurement unit for the electric strength measured. Therefore, to simplify the calculation, the distance measured by caliper in unit millimeter (mm) converted to inch (in).

The experiment will be conducted in a few approaches. These approaches are conducted to determine the reliability of the proposed procedure. Three types of metal plates are used in this method. The former single aluminium plate, a pair of parallel plate with 6.12 mm separation distance and a pair of parallel plate with 7 mm separation distance.

Then, the parallel plate will be dismantled and re-mantled and the same measurement procedure is conducted. This is for the reproducibility test where the system is retest to determine its reliability after reproduce.

One important aspect that ought to be taken into account during the measurement is the ground clamp of the electrostatic field meter. The ground clamp must be connected to one pole of measured voltage. The arrangement of the procedure is conducted on a non-conductive pad or the ESD mat and the electrostatic field meter is mounted on a retort stand clamp. The meter cannot be hold by hand to prevent a charging of measured electrode by a forged charge (Draxler & Styblikova, 2003).

CHAPTER 4: RESULTS

The tests conducted have the objective to determine the reliability of the new proposed procedure of the calibration of the electrostatic field meter. The constant parameter that need to be taken are the measuring instrument used that is the SIMCO FMX003 Electrostatic Field Meter and the measuring distance where the distance of the electrostatic field meter and the calibration plate is measured at 1.00 inch. The specifications of the electrostatic meter can be referred in Appendix.

The Source Value is the applied value set from the High Voltage Supply and monitored with the High Voltage Meter in parallel connection. The unit is in kilovolt (kV). The Calculated Value presented is the expected value of electric field measured by the electrostatic field meter. The calculation is based on Equation (1) where the voltage applied is divided by the distance. The unit should be in volt per meter (V/m) according to SI unit. However, in this case, most of electrostatic field meter in the market is measuring in volt per inch (V/in) unit. Therefore the Calculated Value presented is the Source Value divided by 1.00 inch.

4.1 Material properties and separation distance test

		Copper (6.12 mm)		Copper (10.26 mm)		Aluminium	
Source Value (kV)	Calculated Value (kV/in)	Results (kV/in)	Error (%)	Results (kV/in)	Error (%)	Results (kV/in)	Error (%)
0.0	0.00	0.00	0.0	0.00	0.0	0.00	0.0
0.2	0.20	0.20	-1.0	0.26	30.0	0.20	0.0
0.4	0.40	0.40	-0.5	0.52	29.0	0.40	0.0
0.6	0.60	0.60	-0.7	0.77	28.7	0.60	0.0
0.8	0.80	0.80	0.2	1.05	31.8	0.80	0.0

1.0	1.00	1.00	-0.4	1.29	29.4	1.00	-0.2
1.2	1.20	1.19	-0.5	1.62	35.0	1.20	-0.2
1.4	1.40	1.39	-0.4	1.92	37.1	1.34	-4.4
1.6	1.60	1.60	0.0	2.16	35.0	1.50	-6.3
1.8	1.80	1.80	0.0	2.42	34.4	1.70	-5.6
2.0	2.00	2.00	0.0	2.80	40.0	1.90	-5.0
2.5	2.50	2.50	0.0	3.44	37.6	2.32	-7.2
3.0	3.00	3.00	0.0	4.14	38.0	2.82	-6.0
3.5	3.50	3.50	0.0	4.74	35.4	3.26	-6.9
4.0	4.00	4.00	0.0	5.48	37.0	3.68	-8.0
4.5	4.50	4.50	0.0	6.14	36.4	4.14	-8.0
5.0	5.00	5.00	0.0	6.84	36.8	4.54	-9.2
5.5	5.50	5.50	0.0	7.48	36.0	4.94	-10.2
6.0	6.00	6.00	0.0	8.18	36.3	5.28	-12.0
6.5	6.50	6.50	0.0	8.96	37.8	5.64	-13.2
7.0	7.00	7.00	0.0	9.62	37.4	6.02	-14.0
7.5	7.50	7.52	0.3	10.16	35.5	6.36	-15.2
8.0	8.00	8.08	1.0	10.94	36.8	6.62	-17.3

Table 4.1: The measurement results of three different setups of apparatus

The first test conducted is to compare the measurement error executed by three different setups of apparatus where the separation distance of the parallel plate is varied.

From Table 4.1, the three different setups are described as the first measurement is by using a pair of parallel copper plates at 6.12 mm separation distance. The next setup is the measurement by using a pair of copper plates with 10.26 mm separation distance. The third measurement is by using a single aluminium plate.

From Table 4.1, we can compare the error obtained by all measurements. From the error obtained, we can see that copper parallel plates with minimum separation distance shows smaller error margin compared to the other two plate arrangement. It can be discussed on the suitability of the calibration plate material and separation distance that can be implemented in the improved procedure of the electrostatic field meter calibration. Further discussion will be discussed in Chapter 5.

4.2 Repeatability test

The next test conducted is to obtain the repeatability results for the measurement. The test is conducted by taking the measurement for five measuring cycles.

Source Value (kV)	Calculated Value (kV/in)	Test 1 (kV)	Test 2 (kV)	Test 3 (kV)	Test 4 (kV)	Test 5 (kV)
0.0	0.0	0.00	0.00	0.00	0.00	0.00
0.2	0.23	0.20	0.20	0.20	0.19	0.20
0.4	0.45	0.39	0.41	0.39	0.41	0.39
0.6	0.68	0.58	0.61	0.59	0.61	0.59
0.8	0.90	0.80	0.81	0.79	0.82	0.79
1.0	1.13	0.99	1.00	0.99	1.00	1.00
1.2	1.36	1.19	1.20	1.19	1.20	1.19
1.4	1.58	1.39	1.40	1.39	1.40	1.39
1.6	1.81	1.60	1.60	1.60	1.60	1.60
1.8	2.04	1.80	1.80	1.80	1.80	1.80
2.0	2.26	2.00	2.00	2.00	2.00	2.00
2.5	2.83	2.50	2.50	2.50	2.50	2.50
3.0	3.39	3.00	3.00	3.00	3.00	3.00
3.5	3.96	3.50	3.50	3.50	3.50	3.50
4.0	4.52	4.00	4.00	4.00	4.00	4.00
4.5	5.09	4.50	4.50	4.50	4.50	4.50
5.0	5.65	5.00	5.00	5.00	5.00	5.00
5.5	6.22	5.50	5.50	5.50	5.50	5.50
6.0	6.79	6.00	6.00	6.00	6.00	6.00
6.5	7.35	6.50	6.50	6.50	6.50	6.50
7.0	7.92	7.00	7.00	7.00	7.00	7.00
7.5	8.48	7.60	7.50	7.40	7.50	7.60
8.0	9.05	8.10	8.20	7.90	8.10	8.10

Table 4.2: The results of five measuring cycles of using parallel copper plates

Source Value (kV)	Calculated Value (kV/in)	Test 1 (kV)	Test 2 (kV)	Test 3 (kV)	Test 4 (kV)	Test 5 (kV)
0.0	0.00	0.00	0.00	0.00	0.00	0.00
0.2	0.23	0.20	0.20	0.20	0.20	0.20
0.4	0.45	0.40	0.40	0.40	0.40	0.40
0.6	0.68	0.60	0.60	0.60	0.60	0.60
0.8	0.90	0.80	0.80	0.80	0.80	0.80
1.0	1.13	1.00	0.99	1.00	1.00	1.00
1.2	1.36	1.20	1.20	1.19	1.20	1.20
1.4	1.58	1.30	1.30	1.39	1.30	1.40
1.6	1.81	1.50	1.50	1.50	1.50	1.50
1.8	2.04	1.70	1.70	1.70	1.70	1.70
2.0	2.26	1.90	1.90	1.90	1.90	1.90
2.5	2.83	2.30	2.30	2.30	2.30	2.40
3.0	3.39	2.80	2.80	2.80	2.80	2.90
3.5	3.96	3.20	3.20	3.30	3.30	3.30
4.0	4.52	3.60	3.60	3.70	3.70	3.80
4.5	5.09	4.00	4.10	4.20	4.20	4.20
5.0	5.65	4.40	4.40	4.60	4.60	4.70
5.5	6.22	4.80	4.80	5.00	5.00	5.10
6.0	6.79	5.10	5.10	5.30	5.30	5.60
6.5	7.35	5.40	5.40	5.70	5.70	6.00
7.0	7.92	5.70	5.80	6.10	6.10	6.40
7.5	8.48	6.00	5.90	6.60	6.60	6.70
8.0	9.05	6.10	6.20	6.90	6.90	7.00

Table 4.3: The results of five measuring cycles of using single aluminium plate

Table 4.2 and Table 4.3 show is the repeatability test that is conducted by measuring the electric field using the same electrostatic field meter SIMCO FMX003 using a pair of parallel copper plates with 6.12 mm separation distance and a single aluminium plate. This test is conducted to compare the consistency of the electrostatic field measurement for copper and aluminium.

From the table shown, it can be diagnose that the copper material gives more consistent reading compared to aluminium.

4.3 Reproducibility test

In order to convince the reliability of the new proposed procedure of the calibration of electrostatic meter, a test called the reproducibility test is conducted. This test is done by dismantling the apparatus arrangement. This includes dismantling the parallel plates as well. In this test, we are using the parallel copper plates with 6.12 mm separation distance. The measurement results before the dismantling process can be referred in Table 4.1. Table 4.4 below will show the measurement results after the apparatus arrangement undergo the dismantling process. The analysis of the results will be further discussed in Chapter 5.

Source Value (kV)	Calculated Value (kV/in)	Results (kV/in)	Error (%)
0	0.00	0.00	0.0
0.2	0.20	0.20	-1.0
0.4	0.40	0.40	-0.5
0.6	0.60	0.60	0.0
0.8	0.80	0.80	0.3
1	1.00	1.00	0.0
1.2	1.20	1.20	-0.2
1.4	1.40	1.40	0.0
1.6	1.60	1.60	0.0
1.8	1.80	1.80	0.0
2	2.00	2.0	0.0
2.5	2.50	2.5	0.0
3	3.00	3.0	0.0
3.5	3.50	3.5	0.0
4	4.00	4.0	0.5
4.5	4.50	4.5	0.4
5	5.00	5.0	0.4
5.5	5.50	5.5	0.4
6	6.00	6.0	0.3
6.5	6.50	6.5	0.3
7	7.00	7.1	0.9

7.5	7.50	7.6	0.8
8	8.00	8.1	1.5

Table 4.4: The measurement results taken after the dismantling process

CHAPTER 5: DISCUSSIONS

In this chapter, the tests conducted will be discussed according to the objectives of this study. To refresh, there are three parameters to be discussed in this chapter. The aim of these parameter tested is to determine the reliability of the new proposed in house procedure for the calibration of the electrostatic field meter.

The parameters are the behavior or properties of the materials used, the optimum separation distance of the parallel plates, the consistency of the repeatability of the measurement and the reproducibility test. The reproducibility test is where the system has been dismantled and then rearrange to its initial arrangement and measurement is taken.

5.1 Material properties

In this study, there are two types of conductive material used. They are aluminium and copper. Both materials can conduct electricity and static charges on it react uniformly. However, according to Chubb J. and Pavey I., a surface with uniformly separated charge will migrate most rapidly through a higher conductivity material (Chubb, 2007).

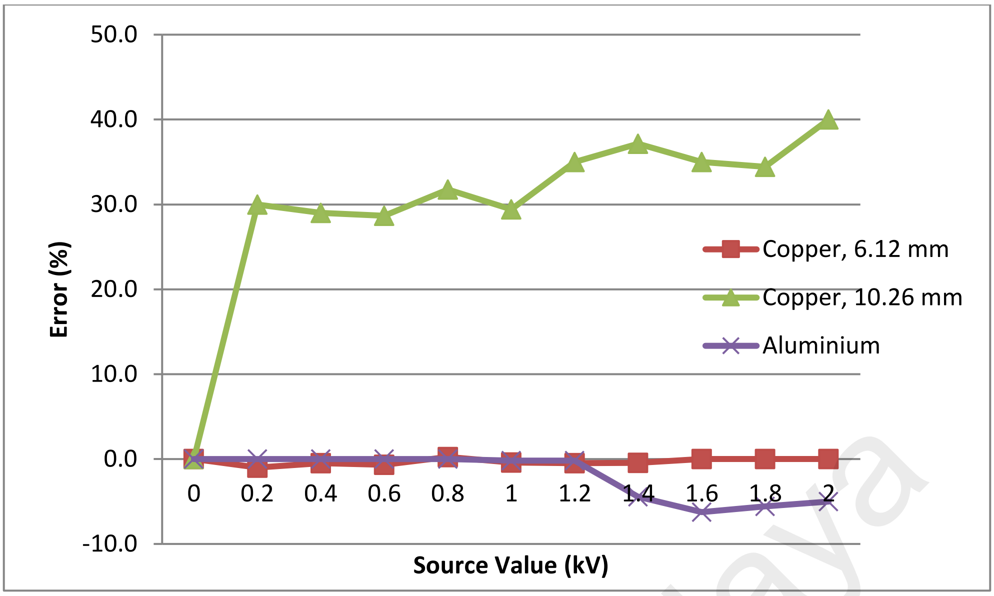

Figure 5.1: The graph of Error obtained against the Applied Value from 0 kV to 2 kV

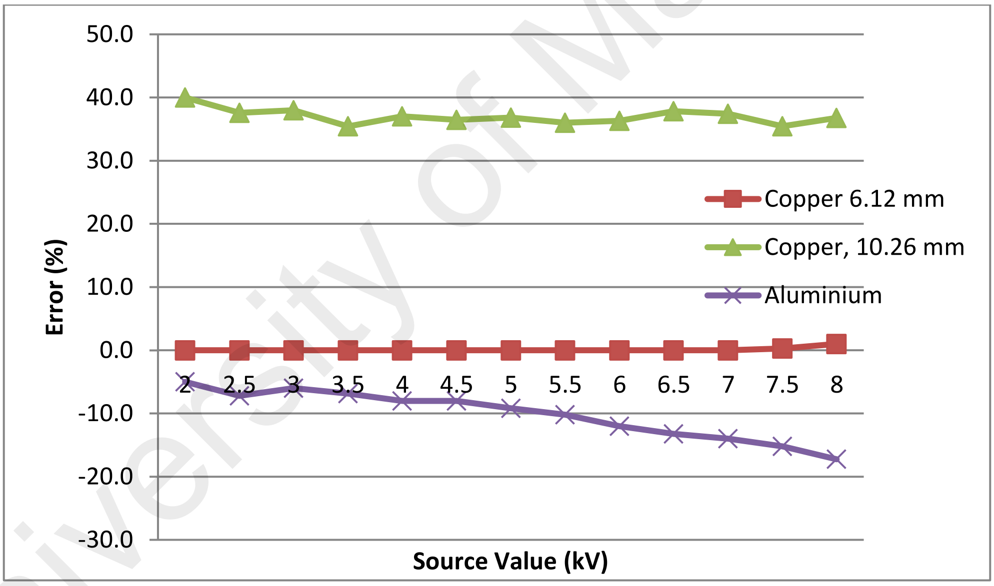

Figure 5.2: The graph of Error obtained against the Source Value from 2 kV to 8 kV

For this test, there are three different plates undergo the measurement. The parallel copper plates with separation distance of 6.01 mm 10.26 mm as well as a single aluminium plate. The analysis discussions of the measurement results can be referred to a tabulated measurement results presented as in Table 4.1

from Chapter 4. Based on Figure 5.1 and Figure 5.2 above, it can be observed that there are three different trends appear in the graph.

The parallel copper plates with 6.01 mm separation distance show a consistent error where the percentage of error is less than 10% for both ranges. The error obtained for parallel copper plates with 10.26 mm separation distance is quite high but consistent. The percentage of the measurement error is between 30% and 40% for both ranges.

For the single aluminium plate, the percentage of error is observed to be gradually greater to negative percentage error as the source value increasing. The error is consistent at less than 10% from 0 kV to 1.2 kV. The error starts to get larger at higher voltage. This shows that the aluminium plate can be used for low voltage measurements. This analysis proves that the breakdown voltage of aluminium is lower than copper (Yang, Jin, Sima, & Liu, 2016). As observed from Figure 5.1 and Figure 5.2 above, the aluminium plate cannot withstand voltage higher than 1.2 kV. This is because when the source value exceeds 1.2 kV, the measurement starts to drop.

From this test, it can be analyzed that copper gives better consistency on the movement of the static charge that is spread uniformly on the surface. This is because one of the properties of copper itself is it has higher conductivity value which is $5.96 \, x \, 10^7$ S/m compared to aluminium which has the conductivity value of $3.77 \, x \, 10^7$ S/m. Other properties are the flatness of the material. The degree of flatness of copper surface is better than aluminum where the surface is not wavy and difficult to dent (Madhusudan, Sarcar, & Rao, 2016).

5.2 Separation distance of copper parallel plates

The graph of measurement error against the source value shown in Figure 5.1 and Figure 5.2 above interpret that the separation distance of the parallel plates influenced the consistency of the measurement. The electric field between the plates becomes stronger and stable as the distance between charged plates decreases.

The parallel plates arrangement implemented in this study acts the same behavior as the parallel plate capacitor. The parallel plate capacitor are concerning on the capacitance obtained so that it can determine the capacity of the energy stored in the capacitor. The capacitance is influenced by the area of the plates and the separation distance of the plate. The electrostatic charge is concerned on the separation distance. As the distance between plates decrease, the capacitance increases. This is because the uniformly strong field appears at the center of the plate. Meanwhile, the weak fringing field exists outside the plates (Parker, 2001).

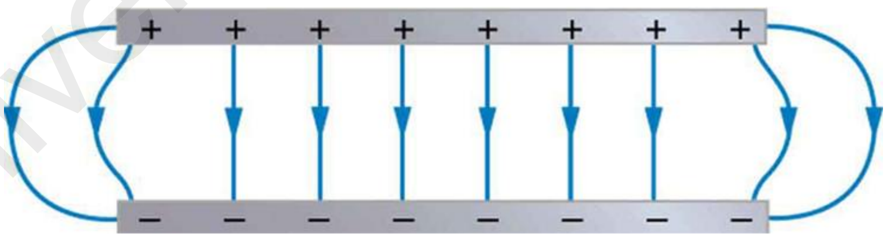

Figure 5.3: The electric field lines between plates

As the properties of a conductor in an equilibrium state of electrostatic, the electric field lines outside the conductor travel in perpendicular line to its surface. Thus, it creates the ending and beginning of charges on the surface of the conductor. This leads to the excess charge resides entirely on the conductor surface. The fringing field is negligible when the spacing of the conducting material is lesser than the width of the conductors' surfaces (Hegg & Mamishev, 2004). Therefore the excess field at the edge of the plates is not taken into account (Blecic, Diduck, & Baric, 2016).

5.3 Measurement consistency

In any testing that requires measurement to be made, it is advisable to take the measurement reading at least three samplings and obtain the average from the samplings. In this study, the measurement is taken for five cycles or five samplings. The first measurement cycles conducted is by recording the measurement reading in increasing order. After the maximum test point reading is recorded, the voltage applied is then decreases and the reading is recorded as the second cycle measurement. The same method applies for the third until fifth measurement.

This test is conducted to determine the consistency of the reading by comparing the measurement from using the parallel copper plate with separation distance of 6.01 mm and the aluminium plate as the calibration plates.

The analysis of this test is exerted from Table 4.2 and Table 4.3 shown in Chapter 4. The Results for all five cycles is then plotted in graphical form. The idea is to see the pattern of the measurement cycles. From this test, we can determine which material can provide a consistent measurement reading.

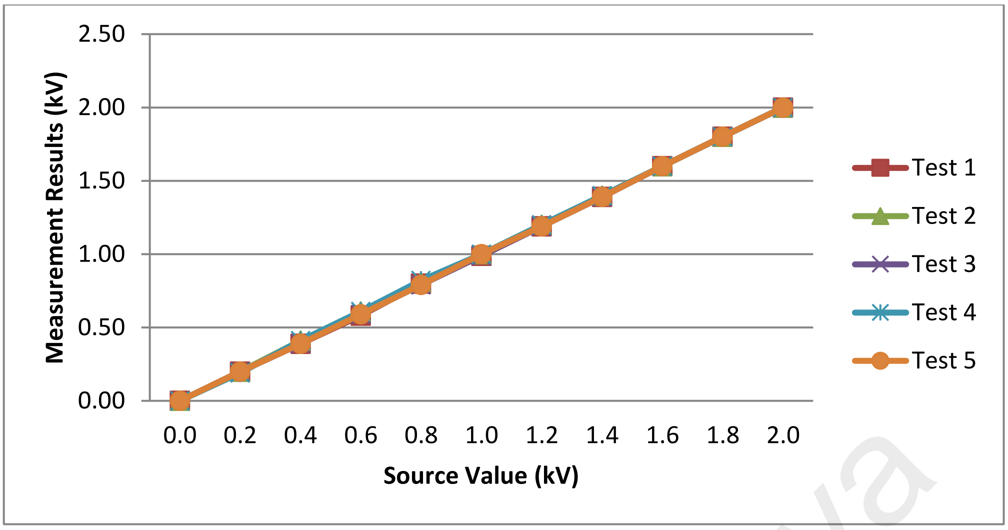

Figure 5.4: The graph of the measurement results for all five cycles against the source value from 0 kV to 2 kV by using parallel copper plates

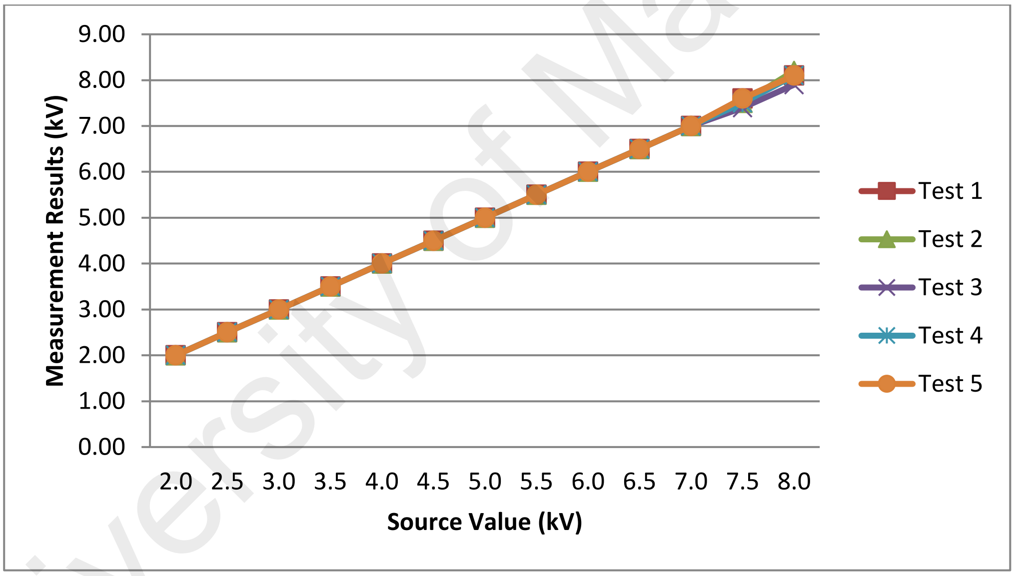

Figure 5.5: The graph of the measurement results for all five cycles against the source value from 2 kV to 8 kV by using parallel copper plates

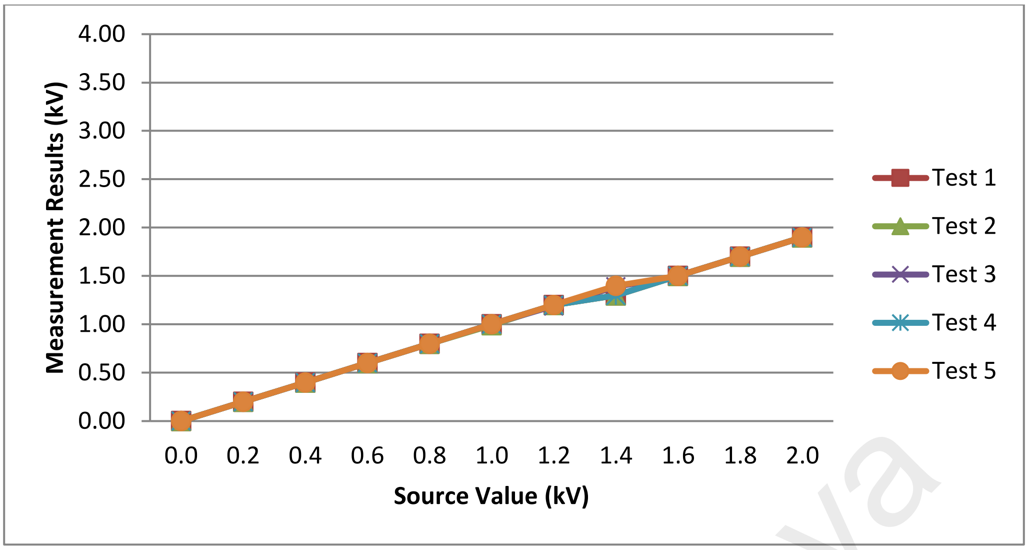

Figure 5.6: The graph of the measurement results for all five cycles against the source value from 0 kV to 2 kV by using single aluminium plate

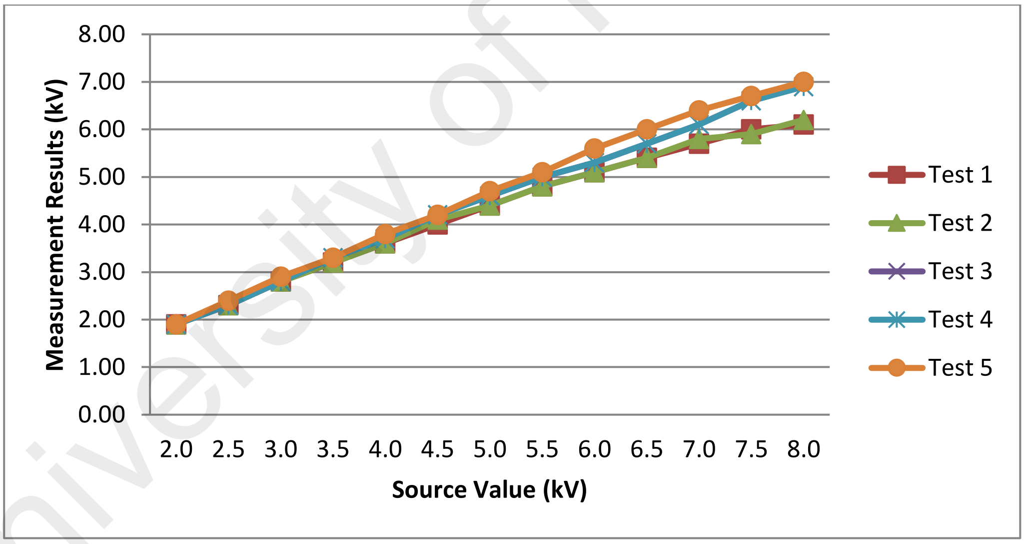

Figure 5.7: The graph of the measurement results for all five cycles against the source value from 2 kV to 8 kV by using single aluminum plate

Based on Figure 5.4 and Figure 5.5, it can be observed the electrostatic field measurement reading is consistent on parallel copper plates. Despites the method of the voltage being applied to the plate, the measurement of all cycles is almost the same as shown from the linear line from both graphs.

However, as the graph shown in Figure 5.6, the measurement reading is not consistent at 1.4 kV. And from the graph shown in Figure 5.7, the linear line starts to disperse at 2.5 kV. The measurement on the aluminium plate might be influenced by the method of the voltage being applied to the surface of the plate. This is the effect of the charge accumulation on the surface.

The observations from the graphs show that the parallel copper plates provide consistent measurement reading throughout the procedure.

5.4 Reproducibility analysis

The reproducibility test is conducted as one of the method to determine the reliability of the proposed in house calibration procedure of electrostatic meter. The procedure is conducted by using a pair of copper parallel plate where the plate can be dismantled. The need of this reproducibility test is to provide more consistency from the perspective of stable electrostatic measurement repeatability (Ishida, Xiao, Kami, Fujiwara, & Nitta, 2016).

The arrangement of the procedure is shown in Figure 3.5 in Chapter 3. The dismantling of the plates is shown in Figure 5.8. After dismantling process, the plates are left in a controlled room of 22ºC and 50% RH for one hour.

Figure 5.8: Dismantling of the copper parallel plate

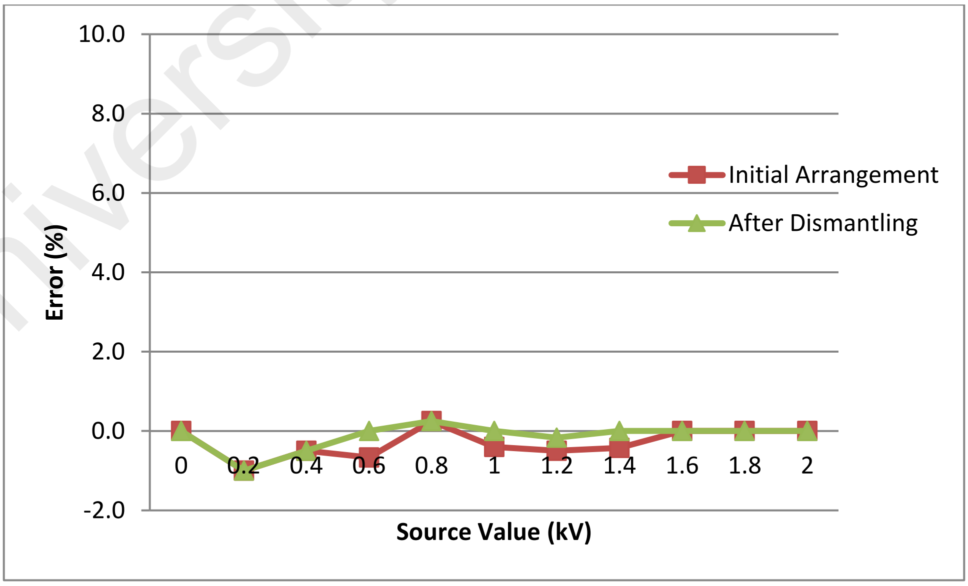

Figure 5.9: The graph of the error of the measurements against the source value from 0 kV to 2kV

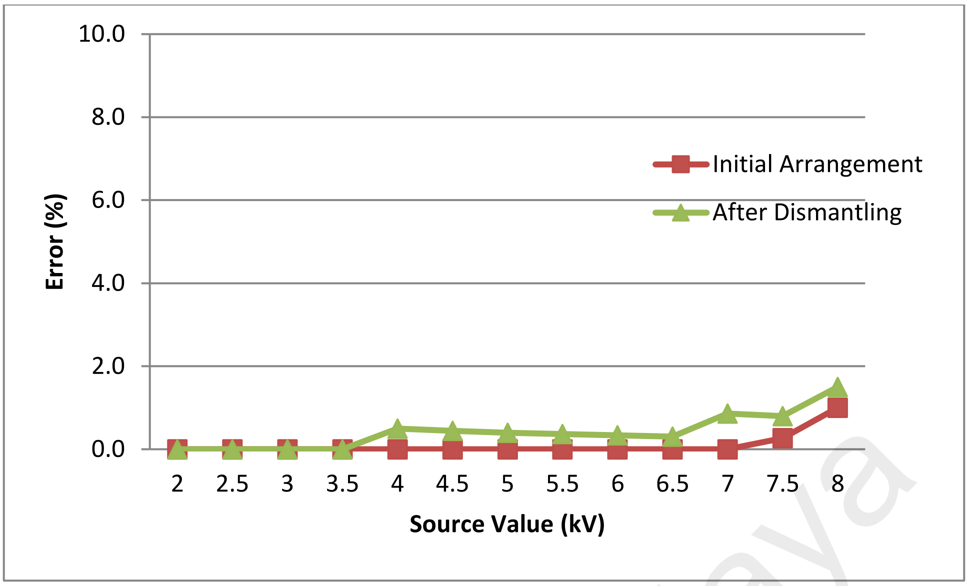

Figure 5.10: The graph of the error of the measurements against the source value from 2 kV to 8kV

From the Figure 5.10 shown above, it can be observed that the measurement error is almost the same as the initial arrangement. The percentage error is less than 2%. The pattern of the measurement error is almost the same. This event proves that the behavior of the copper plates remain the same. The response or behavior of the parallel copper plates is not influenced by the temperature and humidity.

5.5 Summary

Based on the tests conducted on the electrostatic field measurement, the most reliable system to be implemented for the improvement of in house electrostatic field meter calibration procedure is the parallel copper plates with 6.01 mm separation distance.

The tests conducted on the parallel copper plates show convincing results on its reliability. The plates provide the minimum measurement error as well as consistent measurement reading. The plates behave the same as its initial arrangement even though it has been dismantled and rearrange for the reproducibility test.

Therefore, from the test conducted, shown that the measurement of electrostatic charge using copper parallel plates of 6.01 mm optimum separation distance, is repeatable and reproducible.

CHAPTER 6: CONCLUSIONS

In this final chapter, conclusions of overall research project findings will be presented. Suggestion for future work or implementation of electrostatic field meter calibration will be specified as the improvement recommendations for further study.

5.1 Conclusions

In this research project, the proposed improvement of in house calibration procedure of electrostatic field meter is achievable. The objectives of this study as listed have been achieved successfully.

A suitable calibration arrangement for the electrostatic field meter has been designed and developed by installing the parallel plates system in order to achieve a stronger and more stable electrostatic charge.

The evaluation of the material to be used in the arrangement has shown that copper is capable in withstanding a wide range of charge or voltage applied. The measurement readings are stable throughout the procedure.

The optimum distance of the separation gap of the parallel plate has been measured and evaluated. The optimum separation distance is 6.01 mm where the distance is not too large so that the electric field exists between the plates is stronger and more stable.

A proper and suitable calibration arrangement procedure has been achieved where taken into account the repeatability and reproducibility tests conducted. The arrangement undergoes repeatability test to ensure the measurement consistency and has shown the measurement is repeatable. As for the reproducibility test to ensure the system can be operated in despites the dismantling process. The measurement result obtained after dismantling shows that the arrangement is reproducible.

5.2 Improvement recommendations for future work

Firstly, as stated earlier in this report, the distance between the electrostatic field meter and the calibration plates plays an important role in the measurement. Therefore, the gap must be precise. To make the arrangement easier, a gap gauge can be fabricate and utilize so that an accurate measurement can be obtained.

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