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Prospective Review Sustainable

Highlights

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Discovering Thoughts, Inventing Future

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Prospective Review on the Sustainable Materials and Activities Applied to Brazilian Electrical Sector

By Douglas Aguiar do Nascimento ,Yuzo Iano, Hermes José Loschi ,Vlademir de Jesus Silva Oliveira, Matheus Montagner & Carlos Bertolassi

State University of Campinas

Abstract- All economic activities that affect the environment should be submitted to environmental licensing, being mandatory throughout the Brazilian territory. The National Environment Policy (PNMA) and National Solid Waste Policy (PNRS), established by Law No. 12,305/2010 and regulated by Decree No. 7,404/2010, establishes the need for compliance with socio-environmental principles through prevention and precaution, eco-efficiency, among others. Considering that most of the electrical equipment – e.g. power transformers, capacitor banks, circuit breakers, reactors, switches, Gasinsullated Switchgear- present in the plant of the electricity distribution companies use mineral oil insulating, Sulfur Hexafluoride (SF6) and non-biodegradable solid materials, and given the complexity and extension national electric grid, it is evident the concerning with the methods of protection to the environment. So the appropriate treatment and disposal of waste, generated by energetic companies, brings benefits such as the improvement of socio-environmental indicators of the company and provides control and monitoring of its assets.

Keywords: dielectrics, non-regenerative, high voltage, sustainable materials, emerging materials.

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PROSPECTIVEREVIEWONTHESUSTAINABLEMATERIALSANDACTIVITIESAPPLIEDTOBRAZILIANELECRICALSECOR

Strictly as per the compliance and regulations of:

Prospective Review on the Sustainable Materials and Activities Applied to Brazilian Electrical Sector

Douglas Aguiar do Nascimento [α], Yuzo Iano [σ], Hermes José Loschi [ρ],Vlademir de Jesus Silva Oliveira [ω], Matheus Montagner [¥] & Carlos Bertolassi [§]

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Keywords: *dielectrics, non-regenerative, high voltage, sustainable materials, emerging materials.*

I. Introduction

Electrical energy is essential for a country's economy to guarantee all support to social and cultural aspects(Siemens, 2014). In this context,
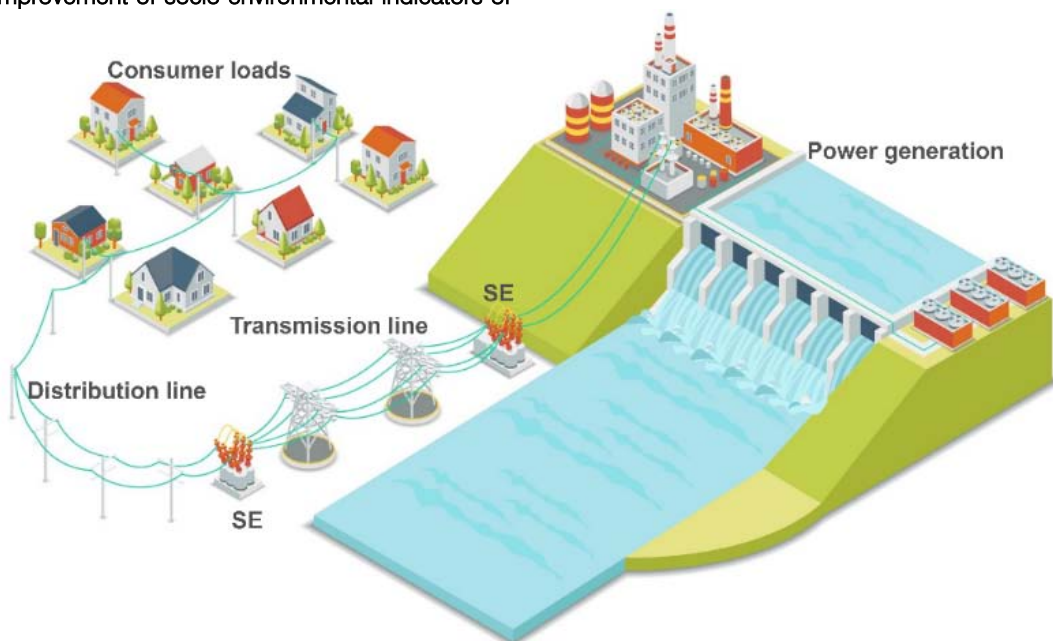
Figure 1: Generation, transmission, distribution and consuming of electrical power.

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electricity must be present in the urbanization of new areas and transported over large distances through electric power transmission lines, which have the function of connecting generating stations to distribution systems, while the distribution systems connect individual loads of a certain area to the transmission lines as shown in figure 1. Since the voltage amplitudes in the generation, transmission and distribution processes differ, it is necessary to adapt them to the consumption centers by lowering or raising the voltage levels when the energy is transmitted. In these situations, the substations (SE) are used to adjust the voltage values between the processes through transformers of specific ends and equipment that allow the maneuver, measurement and protection of the electric power system (Grigsby, 2006; Loschi et al., 2015).

Acording to (IBGE, 2018),Brazil has about 208 million inhabitants, with the population having access to the electricity grid and the Brazilian electricity sector encompassing electricity generation, transmission, distribution and commercialization services. For reaching each part of Brazil it employs the National Interconnected System (SIN), demonstrated in figure 2a, a transmission electrical grid integrated by 134.765 thousand km of extension at 230 kV or superior voltage level - a system composed of power plants, transmission lines and distribution assets covering all the country and shown in figure 2b(ONS, 2016). Altogether, the electricity supply is carried out by 75 electric power companies providing between transmission and distribution services (ANELL, 2018).
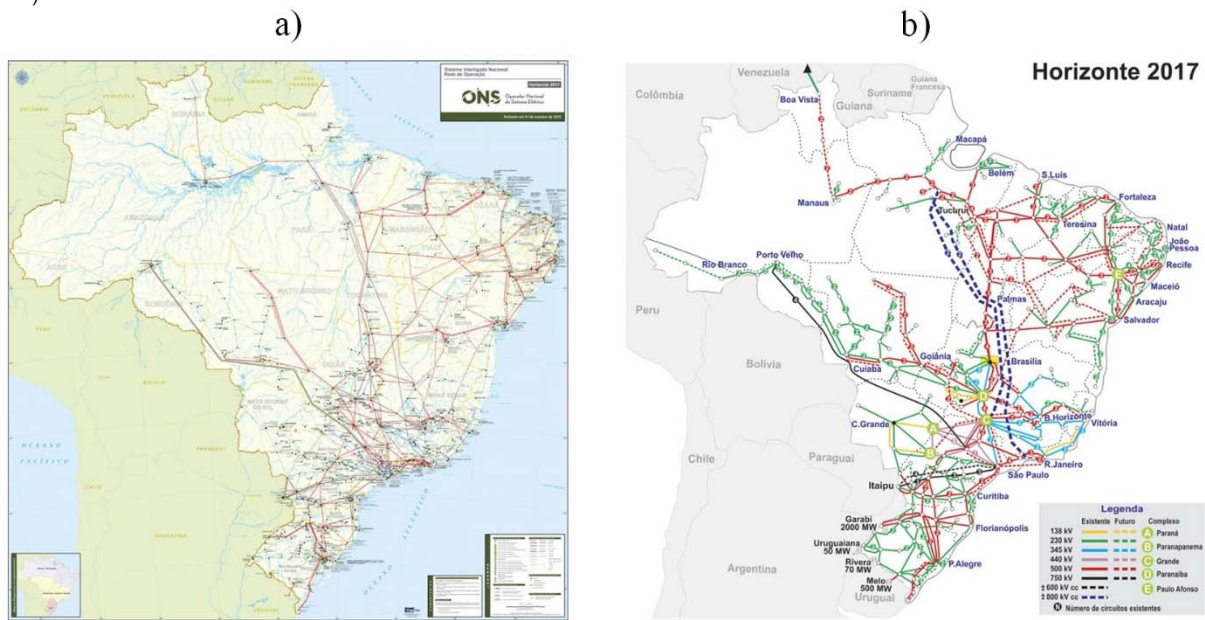
Figure 2: SIN's geographical information (ONS, 2018): a) Geoelectrical mapping; b) Brazilian electrical transmission grid mapping.

To demonstrate improvements in maintenance actions of electric energy assets and in compliance with national sustainability policies Section 2 shows concepts of dielectric, electrical characteristics and classification. In Section 3 sustainable dielectrics and advanced materials used in high voltage equipments are presented. In Section 4, a prospective analysis on the use of environmentally friendly materials by the electrical insulation ensures that the current flows only along the conductors and not between individual conductors or between the conductor and the ground and can also serve as a support for electrical conductors, from low to high voltage levels (order of up to hundreds of kilovolts) (Chudnovisk, 2017). Conduction of current through a

Brazilian electric utilities through sustainability reports, case study and use in the distribution system are presented. Finally, trends in the electricity market and future studies are described in Section 5.

II. High Voltage Equipment Dielectrics

Dielectric depends mainly on its relative permittivity number εr and the type and amplitude of the voltage signal. While conductors have resistance and coils have inductance, dielectrics can be electrically modeled as capacitances. So a typical parallel plate capacitor is demonstrated in Figure 3 (Arora & Mosch,2011).
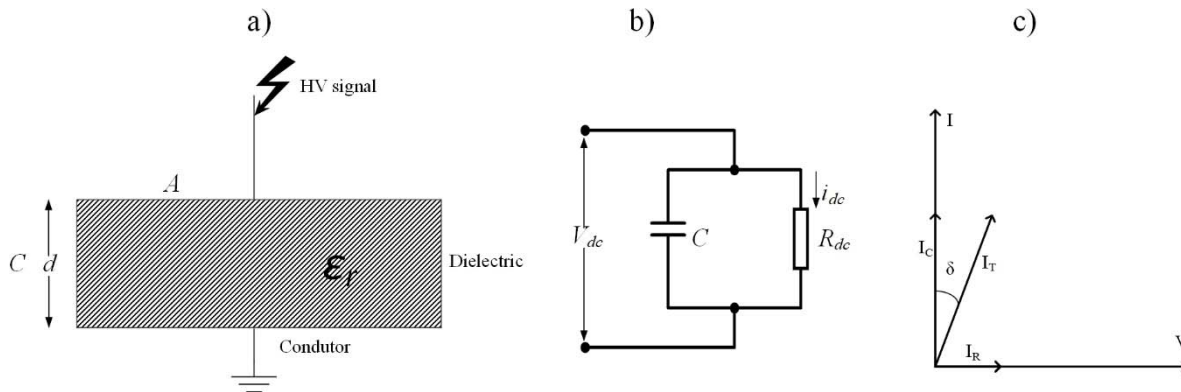
Figure 3: Representation of insulation: a) Dielectric modelling and b) equivalent circuit diagram of insulation material (Arora & Mosch, 2011); c) loss factor (Duplessis, 2017).

Knowing that $\varepsilon = \varepsilon_o \varepsilon_r$, the capacitance C is given by:

$$C = \frac{\varepsilon_o \varepsilon_r A}{d} [F] \qquad \text{Equation (1)}$$

Where: ε_o –absolute permittivity or dielectric constant is 8.854. 10^{-12} ou$[1/(36\pi)]$. 10^{-9} F/m; ε_r – number of relative permittivity; A – plate areas in m^2; d – distance between plates. The DC (direct current) resistance provided by an insulating material represents the insulation resistance concept of a dielectric and is generally described as P_{ins} specific insulation resistance, which is the reciprocal of the conductivity K_{dc}, expressed by(Arora & Mosch, 2011),

$$\rho_{ins} = \frac{1}{k_{dc}} [\Omega.m] \qquad \text{Equation (2)}$$

When the direct current i_{dc} is applied through the two uniform field electrodes separated by a block of insulating material having an area A and a length d (Figure 3a.) of the equivalent circuit diagram (Figure 3b.), constituting a capacitance C(Figure 3a.) and a DC resistance R_{dc} in parallel(Figura 3b.), the following relationship can be described,

$$R_{dc} = \rho_{ins} \cdot \frac{d}{A} [\Omega] \qquad \text{Equation (3)}$$

Considering Ohms's Law, the i_{dc} (figure 3b.) can be expressed:

$$i_{dc} = \frac{U}{R_{dc}} = \frac{U \cdot A}{\rho_{ins} \cdot d} [A] \qquad \text{Equation (4)}$$

For a uniform field (E = U/d), the following equation is valid,

$$i_{dc} = \frac{E.A.d}{\rho_{ins}.d} = \frac{E.A}{\rho_{ins}}$$
$$= k_{dc} .A .E [A] \qquad \text{Equation (5)}$$

As well as conductivity K_{dc}, the specific resistance of the insulation depends heavily on the temperature and is a function of time with respect to the applied voltage. When two conductors are insulated from each other, a layer of gas or insulating material fills the medium between them, forming the electrical insulation. The equivalent circuit of a practical capacitor is therefore an ideal capacitor in parallel with a resistance as shown in Fig. 3b. Considering figure 3c., where I_T is the total current and V is the voltage source applied with a frequency ω, the loss of power in the capacitor is given by(Holtzhausen & Vosloo, 2011),

$$P = VI_R = VI_c \tan \delta = V(\omega CV) \tan \delta$$
$$P = 2\pi f CV^2 \tan \delta \ [W] \qquad \text{Equation (6)}$$

Where, I_R and I_C are resistive the capacitive currents, respectively, and f is the signal frequency. The tangent delta term (tan δ) is known as loss factor or loss tangent and it can be expressed as (Arora & Mosch, 2011),

$$\tan \delta = \frac{ActivePower}{ReactivePower} = \frac{V.i_T.\cos \emptyset}{V.i_T.\sin \emptyset} = \frac{I_R}{I_C} \qquad \text{Equation (7)}$$

The tan δ indicates the quality of the insulation material and is important in the evaluation of insulating liquids e.g. liquid dielectric of transformers. In this way, the main characteristics of dielectrics to be analyzed in order to identify the state of the insulator are: the relative permittivity of the material (dielectric constant), polarization, dielectric strength, tangent delta properties and applications as expressly by(Arora & Mosch, 2011; Holtzhausen & Vosloo, 2011).

The liquid and solid insulation systems have polarization properties, resulting in a dielectric constant greater than unity and, therefore, are composed of dipoles as shown in Figure 4.
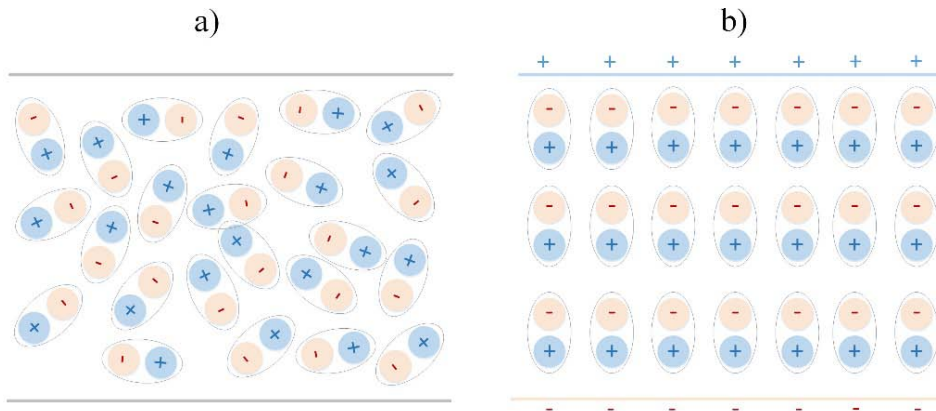
Figure 4: Dielectric polarization (Holtzhausen & Vosloo, 2011): a) no voltage applied; b)voltage applied.

The dipoles can occur due to positive and negative charge centers of the molecules do not match or due to the distribution in the crystalline structure of the material. When the dielectric is not energized, the dipoles are randomly arranged (Figure 4a) and when subjected to DC signal voltage, the dipoles are aligned (Figura 4b). In the case of an alternating voltage from AC (alternating current) signal, the dipoles vibrate according to the frequency of inversions of polarity, resulting in heating of the dielectric due to friction (these dielectric losses are also the principle of microwave oven operation). As no insulation material is a perfect insulator, there are also conduction losses (Holtzhausen & Vosloo, 2011).

The insulation systems comprises air spacings, solid insulation and immersion in insulating liquid and are classified, according to their intended purpose, as being of external use or internal use. In addition, they can still be classified as self-regenerative (they have the capacity to recover the electrical rigidity, after

occurrence of discharge caused by the application of the test voltage) and non-regenerative (Frontin, 2013).The present analysis takes into consideration only non-regenerative insulation systems since they form equipments those requires continuous dielectric state assessment as described by (Aguiar do Nascimento et al., 2018) in which demonstrates maintenance tests of instrument transformers' dielectrics. Furthermore, it was investigated the insulating replacement for sustainable procedures by energy concessionaires power.

a) Solid Insulating Materials

Solid dielectrics are classified according to their chemical compositions, being classified in inorganic, organic materials and composed of both materials. The main dielectric materials are described in Table 1.

In the diagram shown in Figure 5, as described by (Arora & Mosch, 2011), a summary of the main insulators.

Table 1: Solid insulation materials (Holtzhausen & Vosloo, 2011).

Material	εr	tan δ	Electric Strength	Properties	Applications
Mica	5.5 - 7	$30. 10^{-4}$	-	Stable at high temperatures	Insulation of rotating machine windings (up to 20 kV) together with epoxies.
Paper	-	$20 - 50. 10^{-4}$	-	-	Oil-impregnated in HV transformer winding insulation.
Glass	4.5 - 7	$10 - 100. 10^{-4}$	$10 - 50$	Brittle	Glass cap and pin insulators. Glass fibres together with epoxy resin.
Porcelain	6	$3 - 30. 10^{-4}$	$20 - 40$	-	Insulators, bushings.
Polythene	2.3	$1 - 10. 10^{-4}$	$30 - 40$	-	Cross-linked (XLPE) polythene used in hv cables up to 110 kV.
PVC	5.5	$>100. 10^{-4}$	$11 - 30$	-	LV cables.
PTFE	2	$2. 10^{-4}$	19	-	High temperature applications.
Epoxy resin (with sílica filler)	4	-	18	-	Encapsulation of MV Ct's and VT's Transformer bushings and insu-lators: cycloaliphatic resin.
EPDM rubber	2 - 3	-	-	-	Insulators, using a fibre glass core.
Silicone rubber	3 - 6	-	-	Hydrophobic surface properties	Insulators, using a fibre glass core.

Therefore, taking into consideration Table 1 and Figure 5, the main inorganic insulation materials are porcelain, glass and mica. As organic polymeric materials are in extensive use paper, PVC (Polyvinyl chloride) and PE (Polyethylene) and various rubbers e.g. silicone and EPDM (Ethylene propylene diene monomer) rubber. Among organic and inorganic compounds the epoxy resin and impregnated paper are used.
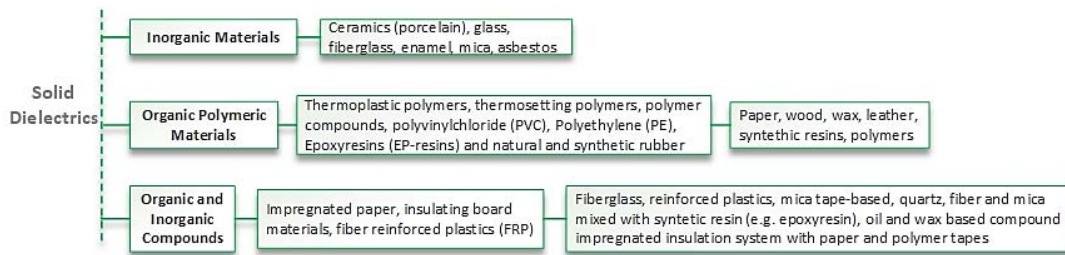
Figure 5: Classification of conventional dielectric materials.

b) Liquid Insulating Material

A liquid can be expressed as an extremely compressed gas as a molecular arrangement, the molecules being very close to each other - called the kinetic model of the liquid structure. Thus, the constituent molecules have free movement and without the tendency to separate. Some of the functions provided by liquid dielectrics are: insulation between energized parts, e.g. insulation between containers and grounded containers, as in transformers; insulation impregnation produced in thin layers of paper or other materials e.g. transformers, cables, capacitors; convective refrigerant action in transformers and oil-filled cables action in transformers and oil filled cables through circulation; filling voids, in order to make the dielectric integrally added; arc extinction in circuit breakers; higher capacitance (liquids of greater permissivity) in power capacitors. In this state of matter, the dielectrics can be synthetic or natural, with high dielectric strength and with varying viscosity and permissiveness over a wide range. In figure 6, we have the main materials that form the liquid dielectrics: Nitrogen (N_2), Helium (He), Sulfur Hexafluoride (SF_6), as describedby (Arora & Mosch, 2011).
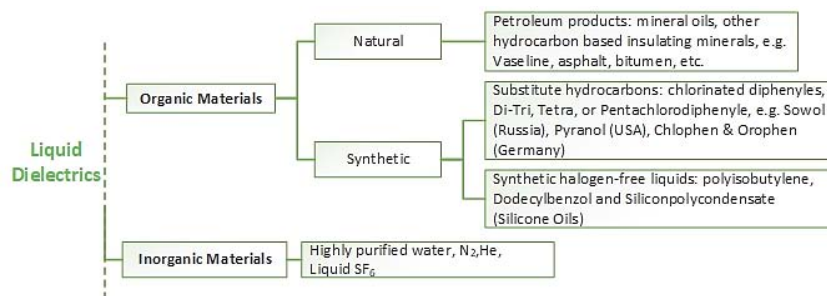
Figure 6: Liquid dielectric materials used in high voltage equipments.

The liquid dielectric materials can be divided into two major classifications: organic and inorganic. Organic dielectrics are basically chemical compounds that contain carbon. Among the main natural insulating materials of this type are petroleum products and mineral oils and the most important and widely used organic liquid dielectrics for electrical energy equipment are mineral oils. The other natural organic insulating materials are asphalt, vegetable oils, wax, natural resins, wood and fiber plants (fibrins). In this case, the permissiveness, tangent delta and dielectric strength were taken into account, as shown in Table 2, where properties of some materials used in electrical equipment are demonstrated. Inorganic materials have limited application due to the high cost and complexity handling in high voltage environment so it is not addressed here and can be found in (Arora & Mosch, 2011).

Table 2: Conventional liquid insulation materials (Arora & Mosch, 2011; Beyer, Boeck, Möller, & Zaengl, 1986; Bogorodizki, Pasynkow, & Tarejew, 1955; Brinkmann, 1975).

Material	εr*	tan δ*	Electric Strength	Applications
Mineral In sulating Oils	2.0	$20°C \leq 10^{-3}$ $90°C \leq 4.10^{-3}$	≥ 300(Transformers) ≥ 175(Circuit Breakers)	Power transformers, CTs, PTs, Circuit Breakers ,Bushings ,Cables and Condensers
Linseed oil	3.2	$>10^{-3}$	-	-
Castor oil	4.2 and 4.5	$<10^{-2}$	$175 - 250$	Condensers
Chlorinated Diphenyles	4 - 6	$10^{-4} - 10^{-3}$	$250 - 500$	Transformers, condensers
Silicone oils	2.6	$<10^{-4}$	$300 - 400$	Cables, condensers, bushings

Approximate values, at 20 °C and 50 Hz when not expressed.

Liquid insulation material is usually used in conjunction with solid insulation, such as paper in cables or transformers. In this way, the liquid impregnates the insulation material of paper or linen and displaces air or gas (Holtzhausen & Vosloo, 2011).

c) Gaseous Dielectrics

The SF$_6$ gas is the most recommended gaseous dielectric today in the power system after the air. There are a lot of other insulating gases, but they do not have the proper properties required for electrical insulation such as Oxigen (O$_2$), Hidrogen (H$_2$), Carbon dioxide (CO$_2$), Helium (He), Neon (Ne), Carbon tetrachloride (CCl4), Sodium (Na) or Dichlorofluor-methane (CCl$_2$F$_2$). However, air is the most important because it is freely available and the cheapest gaseous dielectric (Arora & Mosch, 2011).Figure 7 shows some of the main gaseous insulators used in the electrical industrial environment.
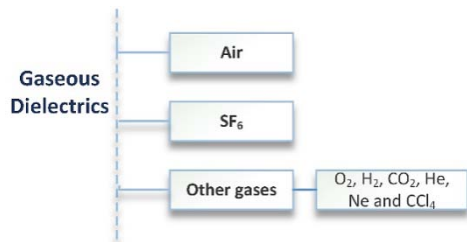
Figure 7: Gaseous dielectrics used in high voltage equipments.

Table 3: SF$_6$ dielectric properties (Arora & Wolfgang, 2011; Mosch & Hauschild, 1979).

Property	Physical Conditions	Symbol	Value
Relative Permittivity	0.1 MPa, 25 °C $-51°C$ (liquid)	εr	1.002 1.81 ± 0.02
Dielectric Loss Tangent	0.1 MPa $-51°C$ (liquid)	tanδ	$<5 \cdot 10^{-6}$ $<1 \cdot 10^{-3}$

The potential of SF6 as a greenhouse gas is extremely high, although the amount of SF6 in the atmosphere, as compared to concentrations of natural occurrence and other man-made greenhouse gases, is extremely low. This has led to growing concern about the possible long-term environmental impact of SF$_6$ (Arora & Wolfgang, 2011).

Even though atmospheric air is the cheapest and most common dielectric, it has very poor insulation properties. Thus, atmospheric air insulation systems have comparatively very large geometric dimensions. The electric field prevalent in these systems is an extremely non-uniform field. As transmission voltages increase, the size of transmission towers, lines and substations have increased to achieve the required requirements. In this case, the size can be reduced by changing the extremely non-uniform fields in atmospheric air insulation systems in weakly non-uniform fields in gas isolated systems (GIS). Better utilization of the dielectric properties is achieved in weakly non-uniform fields. Therefore, it reduces the dimensions of the equipment to a certain rated voltage. Atmospheric air, even under high pressure, has a relatively lower dielectric strength. The most suitable gas, widely used since 1960, as an alternative to air and nitrogen, is Sulfur Hexafluoride (SF6) (Arora & Mosch, 2011) and its properties are described in Table 3.

d) Conventional Insulating Materials

The electrical equipments present in the generation, transmission and distribution systems have the purpose of switching, transforming, protecting and regulating the electric voltage and, if necessary, compensating the reactive power and, for this purpose, use electric insulation systems to realize such

Table 4: High voltage equipment conventional materials.

Equipment	Description	Insulating Material
Power Transformer	Transmits electrical power or power from one circuit to another, transforming voltages and currents into an alternating current circuit, or modifying values of electrical circuit impedances	Insulating oil and cellulose (paper or presspan)
Shunt reactors	Neutralizes the effect of line reactance in order to compensate for the natural capacitive reactance of the transmission line	Insulating oil and cellulose (paper and presspan). The cooling system is specified as ONAN - natural oil and natural air or KNAN - natural ester and natural air
Bushing	Insulated electrical components that allow safe passage of electrical energy through a grounded barrier eg transformer tank, building wall or GIS	Insulation paper and, or, mineral oil and can be used insulating paper and either resin or SF_6 gas
Current Transformer	Provides insulation against high voltage of the circuit and converts the primary current to secondary to a level suitable for measuring instruments	Liquid - mineral oil; solid - insulation Kraft paper, crepe paper, pressed paper, cotton tapes, high adhesive polyester film tape, PVC tape, Bakelite, PVC insulated copper cable, quartz, silica porcelain, alumina porcelain, resin system epoxy
Potential Transformer	Electrical equipment used to isolate the primary circuit from the secondary by converting the voltage from the primary circuit to the secondary circuit in order to carry out the voltage measurement at appropriate levels of measuring instruments	Liquid - mineral oil; solid - Kraft insulation paper, crepe paper, pressed paper, cotton tapes, high adhesive polyester film tape, PVC tape, Bakelite, densified and non-impregnated laminated wood, enameled winding wire, PVC insulated copper cable, quartz , silica porcelain, alumina porcelain, epoxy resin system
Arresters	Also called voltage surge suppressors, they are devices that control part of the overvoltages in the SEP, in order to contribute to the reliability, economy and continuity of operation	Consisting of a set of nonlinear resistive network elements, or series-parallel, associated with a spark plug encapsulated in a porcelain or amorphous or crystalline polymer shell. The polymeric sheaths are systems composed of glass fiber reinforced element in epoxy resin and covered by polymer. The resistors can consist of zinc carbide (SiC) - resistors with scintillators and zinc oxide (ZnO) - resistors without scintillators
Switch Disconnect or	They have the function of ensuring a safe insulation distance after opening of main current blocking equipment, usually circuit breakers, in order to protect equipment from electrical discharges	Porcelain, glass or polymer
Circuit Breaker	Interrupts short-circuit currents at short intervals and shall be capable of establishing fault currents and establish and interrupt low-amplitude currents and isolate part of the systems when in the open position	Oil, compressed air, SF^6 or vacuum
Capacitors	They allow the realization of capacitive reactive compensation of electrical energy of the network, resulting in voltage control, power factor correction, network capacity increase, loss reduction, energy reduction and harmonic filtering when used as passive filters	Shunt Capacitors: In units with two bushings, the terminals and capacitive elements are isolated from the carton by means of paper impregnated with synthetic oil (family of aromatic hydrocarbons), free of chlorinated compounds and PCB (polychlorinated biphenyls); series capacitors: paper impregnated in oil.
Insulators	Provide proper connection of live conductors to grounded support structures. Therefore, they are used to guarantee the electrical integrity of the system under various climatic conditions and the mechanical integrity through the associated mechanical stress support	They are classified into two types: ceramic - made of glass and porcelain; and polymeric (non-ceramic) - made from composite insulation (glass fiber, EPDM rubber and silicon rubber) and cycloaliphatic epoxy resin

In the electrical sector, residues considered to be aggressive and dangerous to the environment are, mainly, lubricating and insulating oils and materials containing oils, which in case of equipment failure or leakage, the hydrocarbon compounds, given their relatively high solubility in water, can migrate, with

Infiltration of rainwater, f rom the surface to the first layer of the water table (Leme & Ribeiro, 2017). Therefore, the concern to use sustainable materials by the concessionaires of electrical energy in their equipment becomes evident due to the amount of non-biodegradable materials generated during maintenance and replacement of the electrical equipment.

III. Consideration On The Advanced Materials And Sustainable Dielectrics

Advanced materials can contribute to increase equipment life, improve operation under emergency conditions, reduce ohmic losses, assist in compacting substations, improve insulation, etc (Frontin, 2013). In this sense, the concerns are related to the development of different techniques of analysis and manufacture of the materials constituting the insulation paper to obtain them with higher quality in order to support the various requests to which they are subject. Figure 8 shows the types of emerging and sustainable materials for use as solid, liquid and gaseous dielectrics (Arora & Mosch, 2011).
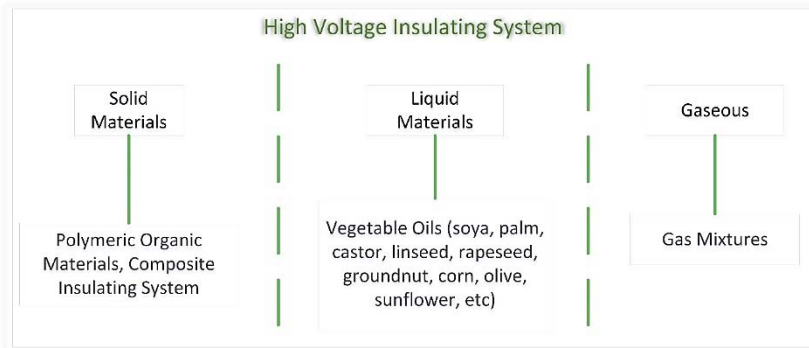
Figure 8: Sustainable high voltage insulation.

It has been found that the application of innovations is related to insulating papers, vegetable oils and gas mixture, as detailed below:

a) A way to improve the development of paper is the use of aramid, a special polymeric material with chemical properties and making it possible to make considerable progress in reforming and using power transformers. Aramid has characteristics much higher than those of cellulose, a material commonly used in the manufacture of solid insulation (Front in, 2013). Its dielectric rigidity is higher than that of cellulose, it resists significantly higher temperatures, does not absorb water, does not propagate flames and practically does not degrade under higher temperatures (Wykrota, 2004). The paper that uses this aramid is known as Nomex®, which can withstand temperatures in the range of 180 °C to 200 °C. The advantages of Nomex® papers include(DuPont, 2016): Inherent dielectric strength; Mechanical resistance; Thermal stability; Chemical compatibility; Flame resistance; Insensitivity to moisture; Cryogenic capacity; Radiation resistance; Non-toxic formulation. Considering that cellulose is the most fragile parameter of a power transformer, its substitution by aramid allows the transformer to operate, without major consequences, at a higher temperature, so that the power density in the transformer increases significantly (Frontin, 2013);

b) The search for an alternative to mineral oil results in the use of vegetable oil, which is based on natural esters, because it is biodegradable and provides safety for the equipment. Natural oils (vegetable oils) are seed-based oils containing edible grade materials suitable for various categories as high fire resistance; superior dielectric strength and viscosity close to that of the Mineral Insulating Oil (MIO), however with relatively high melting point(Oliveira, 2013). It was observed that the vegetable oil is decomposed in the environment in only 45 days, while the mineral takes 15 years to be totally degraded (junior, 2006). In addition, the literature reports that Vegetable Insulating Oil (VIO) oxidation products are not harmful to insulating Kraft paper and prevent their early degradation (McCone, Gauger, Rapp, Luksich, & Cork ran, 2001). Electrical equipment isolated from VIO presents no risk of failure due to corrosive sulfur, since this fluid is free of sulfur compounds (H. M. Wilhelm, Tulio, & Uhren, 2009). Due to its chemical nature, VIO has great affinity with water and this property contributes to the increase in the life of the solid insulation. The aging of Kraft paper in vegetable oil is much slower than in conventional mineral oil, because the main degradation factors of Kraft paper in transformers are: temperature (thermo-kinetic degradation) and amount of water (thermo hydrolytic degradation). In this case, natural esters can accommodate a greater amount of water than mineral oils, causing more water to be displaced from the paper into the fluid. This is one of the advantageous

characteristics of the natural esters used as insulators, since there is a significant increase in the useful life of the paper and therefore the increase in the useful life of the electrical equipment(Arora & Mosch, 2011);

c) SF$_6$ has extremely high global warming potential which requires its release into the environment to be minimized. One way to achieve this is to use other gases or mixtures of SF6 instead of pure SF6 gas. The other major gases considered so far are air, nitrogen, carbon dioxide and helium. Gases with very strong fixing properties, usually halogenated hydrocarbons, were also considered as mixed with SF6 to obtain higher dielectric properties than pure SF6. Various gas mixtures show considerable promise for use in new equipment. However, the equipment should be designed specifically for use with a gas mixture (Christophorou, Olthoff, & Green, 1997). It was observed that only about 25% of SF6 in the mixture entails more than 75% of the electrical resistance properties of the pure SF6 are achieved. Mixtures of almost equal quantities of SF6 and N2 exhibit dielectric properties suggesting that they could be used as "universal application" gas for both electrical insulation and arc end, or, current disruption. Mixtures of low concentrations (<15%) of SF6 in N2 show excellent potential for use in gas-insulated transmission lines. A mixture of SF6 and helium has shown promise when used in gas-insulated circuit-breakers and should be investigated. An important desirable property of gaseous insulation is that they should be environmentally friendly. Therefore, the use of SF6 mixtures with other gases requires investigation of decomposition of the new blend and the effects of newer byproducts on the electrical equipment (Arora & Mosch, 2011).

IV. Brazilian Electrical Companies Landscape

Considering that most of the electrical power equipment (e.g. power transformers, capacitor banks, circuit breakers, reactors, switches) present in the plant of the electricity distribution companies in Brazil use mineral insulating oil and that the extension of continental proportions of Brazil and its interconnected power system of great complexity, it is evident the concern with the methods to be used to protect the environment, since any economic activity that impacts the environment must be submitted to compulsory environmental licensing throughout the national territory, provided for in Federal Law 6938/81.

Therefore, the electric energy concessionaires must comply with the National Environment Policy (PNMA) - which establishes the environmental licensing system as one of the environmental management instruments - and with the National Solid Waste Policy (PNRS), established in Law 12305/2010 and regulated by Decree No. 7,404/2010, which establishes principles, objectives, instruments and guidelines related to the management and management of solid waste (including hazardous waste) applicable to generating companies, public authorities and economic instruments.

In view of this, it was observed that one of the first actions to use sustainable materials was the replacement of the mineral insulating oil by natural sterility, from vegetable oil(H. M. Wilhelm et al., 2009). The first commercial products of vegetable insulating oil (VIO) launched in the national market were: 1. Biotemp, with insulation medium, dielectric, advanced and developed by ABB. It has fluid based on sunflower oil, obtained through genetically selected or manipulated seeds. 2. Envirotemp FR3, marketed by Cooper Power System and manufactured by Cargill, based on soybean oil. And 3.BIOVOLT, which has dielectric fluids based on vegetable oils obtained with different oleaginous and formed by the isolates Biovolt HW (sunflower oil), Biovolt A (corn oil); Biovolt B (soybean oil)(Schmidt, 2016; TULIO, 2008; H. M. Wilhelm et al., 2009) and AGBIOELETRIC, divided into W3 - soybean-based insulation vegetable; W6 - canola base; W9 - high oleic sunflower base, which are in use in medium voltage level distribution transformers (FAG, 2011).Thus the Table 5 presents a physical-chemical summary comparison between the Lubrax Industrial AV-58 - a type of mineral oil insulating (MIO), from Petro bras company,), and the BIOTEMP and Biovolt B (VIO) isolators.

Table 5: Comparison between mineral and vegetal insulating oil's properties values adapted from (Oliveira, 2013; TULIO, 2008; H. M. et al Wilhelm, 2006).

Test		Mineral Oil	Vegetal Oil	
Property	Method	AV-58	BIOTEMP	Biovolt B
Visual Analysis		Clear, Limpid	Clear, Limpid	Clear, Limpid
Neutralization Index [mg KOH/g oil]	ABNT NBR 14248	0.01	0.01	0.03
WaterContent	ABNT NBR 10710/B	16	81	150
Color	ABNT NBR 14483	0.0	L0.5	0.5
Density at 20°C [g/mL]	ABNT NBR 7148	0.8880	0.9159	0.9184
Dielectric Loss Factor at 25 °C [%]	ABNT NBR 12133	0.01	0.05	0.15
Dielectric Loss Factor at 100 °C [%]	ABNT NBR 12133	0.17	1.6	2.5
Flash Point [°C]	ABNT NBR 11341	142	322	316
Combustion Point [°C]	ABNT NBR 11341	154	356	348
DielectricStrength [kV]	ABNT NBR 6869	53	45	51
Viscosityat 20 °C [cSt]	ABNT NBR 10441	Not performed	82	70.6
Viscosityat 40 °C [cSt]	ABNT NBR 10441	9.63	39.63	33.2
Viscosityat 100 °C [cSt]	ABNT NBR 10441	2.34	8.53	7.9
CorrosiveSulfur	ABNT NBR 10505	Non-corrosive	Non-corrosive	Non-corrosive
PCB Content	ABNT NBR 13882/B	Not detected	Not detected	Not detected
Pour Point [°C]	ABNT NBR 11349	< -30	-18	-

Due to their chemical composition, the natural sterols present greater water affinity compared to MIO, resulting in the dryness of the cellulose present in Kraft paper, although manufacturers report that use of VIO provides a life of 2 to 5 times longer than that provided by the MIO. (Martins, 2008), however, describes that the useful life occurs only in temperatures above 130 ºC and 140 ºC. Among these and other characteristics, natural sterols are increasing their market share as insulation fluid for high-power transformers. The characteristic of biodegradability, high flash point (> 300 ºC) and possibility of increasing insulation paper life are more relevant points that can be approached (Oliveira, 2013).

This review survey demonstrates the use of insulating system of alternative electrical equipment to conventional dielectrics through biodegradable materials and by means of management techniques used in large Brazilian electric power concessionaires, research centers and educational institutions. For that, the Proceedings of the National Seminar of Production and Transmission of Electric Energy - SNPTEE; case studies of Brazilian electric energy concessionaires; sustainability reports of energy companies; and evaluation of use in electric energy distribution systems.

In the articles of the SNPTEE the studies of the Study Group of Transformers, Reactors, Materials and Emerging Technologies (GTM) were evaluated. In XXIII SNPTEE, carried out in 2015, it was verified: in GTM 11, COPEL (Companhia Paranaense de Energia), tests

were carried out with VIO on elevating transformers at UHE Guaricana and it was verified that the lack of internal technical preparation in relation to the use of a new technology was surpassed by the experience of the Engineering and O&M team members with the assistance of the assembly company, the manufacturer and the supplier of the VIO (Nogarolli, 2015).

In the GTM 12, carried out by CARGILL and ELETRONORTE (Brazilian North Central Electrical Company SA), it describes the use of a three-phase 145 kV/11.1 MVar reactor with OVI that operated for 7 years with a defective sealing system, allowing the VIO oxidized during the field tests and occurrence presented in this article confirm the insulating vegetable oil (natural ester) as a robust and reliable solution, presenting a performance far superior to the life expectancy of the transformer, in both free and adverse conditions such as assembly deviations or eventual exposure to the environment (Sbravati, Arantes, Martins, & Rapp, 2015).In GTM 07, developed by Cargill and University of Stuttgart, conducted in XXIV in 2017, the level of field concentration was investigated which results in divergences between VIO and MIO insulation liquids.

Despite the great similarity between vegetable oil and mineral in relation to dielectric behavior, the liquids are chemically different, which can lead to different results. The identified difference in the tensile stress between mineral and vegetable oil is limited to extremely high field concentration levels, situated in the Schwaiger factor $0.01 < \eta < 0.1$. Despite these differences in dielectric behavior, no barriers were

identified for the application of vegetable oils in any voltage class, either AC or CC (Sbravati, Rapp, Haegele, & Tenbohlen, 2017).

As conclusion of the SNPTEE GTM study group, we have: Increased reliability in transformers with insulating vegetable oil. Increase the life of insulation paper in transformers with insulating vegetable oil. It was evidenced the need to improve the quality of the fences in equipment with insulating vegetable oil. It has been found that dissolved gas analysis methodologies for the insulating mineral oil can be used for the insulating vegetable oil, preferably the duval triangle. The analysis of results of monitoring and diagnostic systems for decision-making purposes should consider the application of different techniques: agd-dissolved gas analysis, partial discharge analysis-dp-acoustic method and electric method, power factor and response in frequency-SFRA. Trendency to establish maintenance centers with information integration and monitoring.

In the case study, sustainable actions were observed by Cemig, Light S.A and AES Eletropaulo: it was verified that Trench provides equipment with renewable dielectric materials, providing sustainability in power generation, transmission and distribution systems eg the Trench Blue instrument transformer, which consists of core-to-air insulation, instead of SF6 and oil, and operates up to 245 kV. The high voltage shunt reactors supplied by Trench are of the dry type and used in applications up to 500 kV, as shown in Figure 9.

Figure 9: CemigIrape Project (Trench, n.d.).

The main advantage with respect to oil immersed reactors is that there is no aggression to the environment because it does not need to perform the handling of insulating mineral oil, which is aggressive to the environment. In addition, there is no greater effort for maintenance, there is a fire risk, lower investment cost; there is no inrush current of excessive magnetization because it has no iron core; cold start capability (Trench, n.d.).

The Light S. Aenergetic Company performs research and development of sustainability indicators as a tool for LIGHT solid waste management and the development of alternative solutions for the disposal of various types of waste. Among the actions used, were discarded mineral oil and use of vegetable oil in electric transformers: In relation to the effect of moisture that acts on the MIO as a catalyst agent in the decomposition of cellulose, thus reducing the useful life of the electrical equipment, the VIO due to its chemical nature shows great affinity with water. In addition, in cases of accidents the remediation processes of the systems impacted by the VIO are simpler and with lower costs, since the VIO is easily degraded by the microorganisms present in the environment (Souza et al., 2011).

Opportunities for Improvement in Waste Management in Company were observed in AES Eletropaulo. In 2009, this company generated almost 4 thousand tons of non-hazardous waste, subdivided into 30 types (e.g. wooden crosshead, metals parts and others). In addition, it would be possible to internalize porcelain waste on substation floors and / or to build gabions to contain slopes. Still, discarded pieces of galvanized iron could be reused, from pickling and new galvanizing (Mancini et al., 2011).

In the sustainability reports of the Energisa, Equatorial and Cemig companies, sustainable actions were identified, such as the use of soybean-based insulating vegetable oil, the reuse of dielectric materials and the sale of solid waste. Energisa has proposed the R&D of a modular substation of a fragmented mobile SE, consisting of three products in one (mobile transformer, AT and mobile BT breakers), with transport by two truck horses, with 38 MVA. The distributor also carried out sustainable actions for the correct disposal of materials (lamps), recycling (cables, ferrous scraps and meters), co processing of oil-contaminated soil, regeneration of insulating oil from electrical equipment, reverse logistics of spray paints and tonner, among others initiatives (Energisa, 2016).

The Equatorial Group identified electrical equipments containing as carel oil and were removed from energy distribution systems, discarding mineral oil, selling scrap (wires, cables, equipment and fittings of the electrical system in general) for refineries and recyclers which have environmental licensing. Equatorial's distributors tracked the waste to its final destination, as required, reuse of materials (wood), reused as packaging or other purposes or donated (Equatorial, 2018). At Cemig, waste consisting of 45.5 thousand tons of cables and wires, scrap transformers, metal scrap, meter scrap, poles, crosses, trimmings and wood residues were sold, generating revenues that represented a reduction of approximately 13.4% over the previous year's revenue. In addition, 187.5 tons of contaminated waste and equipment containing PCBs were sent for thermal destruction in an environmentally licensed company. There was a 22.7% decrease in the generation of oil-impregnated waste in relation to the previous period, due to the greater control in the equipment maintenance activities (CEMIG, 2016).

With regard to the use of insulation systems in distribution of electric energy, at medium voltage levels (up to 69 kV), the distribution network transformer core is insulated by insulation oil, as shown in Figure 10a at a level of 13.8 kV. An example of application is the Green Distribution Transformer, from the CPFL (Companhia Paulista de Força e Luz) electricity company, which has biodegradable insulating vegetable oil as its insulator, shown in Figure 10a. As shown in Figure 10b, green transformers is already a reality and it can be seen by electric power distribute on poles within large urban centers since 2007 (e.g. São Paulo, Campinas, etc).

a)   b)

Figure 10: A. CPFL green transformer (CPFL, 2017); b. Itaipu distribution transformer 13.8 kV voltage level (Vasconcellos, Mak, & Jr, 2014).

The Green Transformer has the same electrical operating principles as a conventional transformer by insulation in mineral oil and is used as a substitute because the oil degradation time has been reduced from 15 years to 45 days. In addition, the transformer allows a 20% higher load of the nominal power in steady state (Junior, 2006). Therefore, it was observed that the main factors that led these distributors to adopt insulating vegetable oil were the concern with environmental preservation in their concession area, reduction of fire risks, reduction of maintenance costs and new works, since mineral oil does not attack exclusively the environment, but also the equipment that uses it, through corrosion.

Although the use of environmentally sustainable materials is advantageous from the point of view of environmental sustainability and gave its cost-benefit, some factors imply in the difficulty of insertion of them in the Brazilian electricity market. These are: a) Cost. The cost of vegetable oil is considered the biggest barrier to its entry into the market, around 70% higher than that of the MIO (Soares, 2015).b) New materials: materials still under development, as verified in SNPTEE; c) Brazilian oil attractiveness: despite the growth in oilseed production, oil as a raw material in the manufacture of MIO is still a lower cost solution in relation to the development of VIO. Despite this, some independent institutions continue to develop solutions such as the development of AGBIOELECTRIC by the Assis Gurgacz Faculty jointly with the concessionaire COPEL Distribuição; Lack of government incentive: during the development of this survey, it was not observed tendencies for incentives and government policies to occur in the production of VIO for use in electrical systems.

V. Conclusion

In this paper, it was presented the usage of emerging materials and sustainable actions carried out by Brazilian energetic companies through Proceedings of the National Seminar of Production and Transmission of Electric Energy (SNPTEE), company's sustainable reports and case studies. It was observed that insulating vegetable oil can be considered the oil of the future, because its cost of production combined with the consequences of mineral oils' sleakage or spillage and its facilitated biodegradability has become attractive to the electric sector. Although there were no reports pointing out the using SF6 with other gases, it was

observed the replacement of air-cored equipment rather than SF6 or mineral oil filling. The use of solid insulators observed was mainly due to the substitution of paper and kraft cellulose by the use of aramid (Nomex®), which, although not indicated by the electric power concessionaires was described by companies manufacturing electrical materials, e.g. for immersed liquid transformer e.g. Dupont Nomex 900 series papers and pressboards in liquid immersed applications used by power utilities. Thus Brazilian energetic companies could provide training courses about installation and maintenance of sustainable materials in order to improve environmental indicators and solutions to the using of environmentally aggressive material.

Finally, in spite of the integration between academic and industrial activities as described in case studies, the potential commodities production (such as vegetable oil) is not fully exploited due to the high cost associated with the generation of such products, lack of governmental incentive and lapse of companies specialized in the generation of OVI. One way to overcome this issue is provide continuous incentive the production of sustainable materials such as Normative Instruction N° 1,514 from November 20th, 2014, which exempts companies from PIS/Pasep (Programs of Social Integration and Formation of the Patrimony of the Public Servant) and Cofins (Contribution to Social Security Financing) taxes levied on revenues from the sale of raw material of vegetable origin intended for the production of biodiesel.

ACKNONWLEGMENTS

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Design and Performance Analysis of Digital Controllers in Discrete and Continuous Time Domains for a Robot Control System

By Dhiman Chowdhury

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Abstract- This paper presents design approach and performance analysis of different types of digital compensators for arobot arm joint control system which involves a sensor feedback. The design procedure incorporates discrete (z-plane) and continuous time (warped s-plane or w-plane) domain parameters. The design techniques of frequency response characteristics have been investigated and four basic types of controllers-phase-lag, phase-lead, proportional-integral (PI) and proportional-integral derivative (PID) have been designed and simulated on MATLAB. All the controllers have been implemented to achieve a phase margin of 40 deg. and open loop bode plots and closed loop step responses have been evaluated. Comparison among the controllers on the basis of step response characteristics has beenp resented in this paper.

Keywords: bode plot, compensators, continuous time, discrete domain, lag, lead, phase margin, PI, PID, robot control system, step response.

GJRE-F Classification: FOR Code: 29090

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Strictly as per the compliance and regulations of:

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Dhiman Chowdhury

Abstract- This paper presents design approach and performance analysis of different types of digital compensators for arobot arm joint control system which involves a sensor feedback. The design procedure incorporates discrete (z-plane) and continuous time (warped s-plane or w-plane) domain parameters. The design techniques of frequency response characteristics have been investigated and four basic types of controllers-phase-lag, phase-lead, proportional-integral (PI) and proportional-integral derivative (PID) have been designed and simulated on MATLAB. All the controllers have been implemented to achieve a phase margin of 40 deg. and open loop bode plots and closed loop step responses have been evaluated. Comparison among the controllers on the basis of step response characteristics has beenp resented in this paper.

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I. Introduction

Controllers are essential to determine the changes of system parameters and to attain desired characteristics with performance specifications which are related to steady-state accuracy, transient response, stability and disturbance reduction. Analog control systems are robust and do not incur inherent band width limits and system modifications. Analog control lersare hard to synthesize complicated logics, make dynamic interfaces among multiple subsystems and are prone to inaccurate designs and limitations due to the tolerances of the practical devices. In addition analog systems are highly susceptible to corruption by extraneous noise sources. Digital control Systems are reliable since no signal loss occurs in an along to-digital (A/D) and digital-to-analog (D/A) conversions and are more flexible and accurate in case of sophisticated logic implementation. Digital filters are not subject to external noises and are compatible for adaptive filtering applications. Memory interface and fast response are possible for digital systems.

A physical system or plant is accurately controlled through closed-loop or feedback operation where an output (system response) is adjusted as required by an error signal [1]. The error signal is Generated from the difference between there sponge as measured by the sensor feedback and the desired response. A controller or compensator processes the error quantity to meet certain performance criteria [1]. This paper documents design methodologies of four digital controllers for a real time robot control system. The compensating parameter in these design approaches is the phase margin, determined from the bode diagram of the plant. The design procedure employs frequency response techniques which account for the phase margin or cross-over frequency. Phase-lag, phase-lead, PI and PID (lag-lead) controllers have been designed according to the compensation theory and methodologies as described in [1].

The mathematical and conceptual pr emises articulated in this paper have been explained in [1]. The basic framework and illustrations of digital control systems have been reported in [2].For education purpose, theory, simulation and experimental approaches of digital control systems have been documented in [3]. A closed loop model for digital control systems and applications of digital controllers to speed drives have been presented in [4] and [5]. Several novel design and practical implementation of digital controllers have been proposed in [6]-[10].

The example robot control system illustrated in this paper consists of a sampler, digital controller block, D/A block which is a zero-order hold (ZOH), a power amplifier gain ,a servomotor represented by a s-domain transfer function, gears represented by a gain value and a feedback sensor block. The uncompensated plant is presented by a s-domain transfer function. The sampler initiates A/D conversion and zero-order hold implements D/A conversion. The control lersare required to compensate the plant phase margin and the desired outcome is considered as 40 deg. For performance evaluation, steady-state error, percent over's hoot; rise time and settling time are measured for each controller. The literature review of digital compensation, example uncompensated robot arm joint plant, discrete and continuous time equations with design procedure, MATLAB simulation results of lag, lead, PI and PID controllers and comparative analysis among these four are documented in this paper section-by-section.

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II. LITERATURE REVIEW

The plant configuration, compensation theory, mathematical derivations [equations (1)-(47)] of the design approaches and open loop and closed loop parameters of the controllers described in this paper completely follow the literature reported in [1]. For first-order compensation, the controller transfer function can be expressed as

$$D(z) = \frac{K_d(z - z_0)}{z - z}$$ (1)

Here z_0 and z_p are the respective zero and pole locations. The bilinear or trapezoidal transformation of the controller from the discrete z-plane to the continuous w-plane (warped s-plane) implies
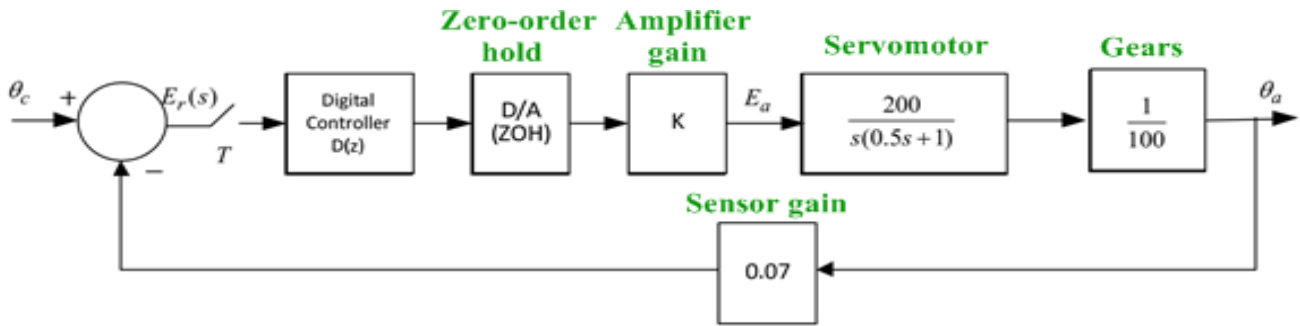
$$D(w) = D(z), z = \frac{1 + (T/2)w}{1 - (T/2)w}$$ (2)

Figure 1: Block diagram of a robot arm joint control system [1]

Table I: Applications of Mat lab Commands

Commands	Applications
tf	Constructs transfer function or converts to transfer function
c2d	Converts continuous-time dynamic system to discrete time
bode	Plots bode frequency response of dynamic systems
margin	Locates gain and phase margins and crossover frequencies
zpk	Creates continuous-time zero-pole-gain (zpk) model [used for lead controller]
d2c	Converts discrete time model to continuous time model
feedback	Evaluates the closed loop system
step	Evaluates the step response

and

$$D(w) = a_0 \frac{1 + (w/\omega_{w0})}{1 + (w/\omega_{wp})}$$ (3)

Here! w_{w0} and! WP is the respective zero and pole locations in the w-plane and a_0 is the compensator dc gain. According to the bilinear approximation,

$$w = \frac{2}{T} \frac{z - 1}{z + 1}$$ (4)

From the equations (1)-(4), in z-plane the controller can be realized as

$$D(z) = a_0 \frac{\omega_{wp}(\omega_{w0} + 2/T)}{\omega_{w0}(\omega_{wp} + 2/T)} \frac{z - (\frac{2/T - \omega_{w0}}{2/T + \omega_{w0}})}{z - (\frac{2/T - \omega_{wp}}{2/T + \omega_{wp}})}$$ (5)

The equation (1) yields to

$$K_d = a_0 \frac{\omega_{wp}(\omega_{w0} + 2/T)}{\omega_{w0}(\omega_{wp} + 2/T)}$$ (6)

$$z_0 = \frac{2/T - \omega_{w0}}{2/T + \omega_{w0}}$$ (7)

and

$$z_p = \frac{2/T - \omega_{wp}}{2/T + \omega_{wp}}$$ (8)

The presented digital control system has been implemented and simulated on MATLAB and certain built in command shave been applied for evaluating the design specifications. Table-I consists of some specific MATLAB commands and their applications.
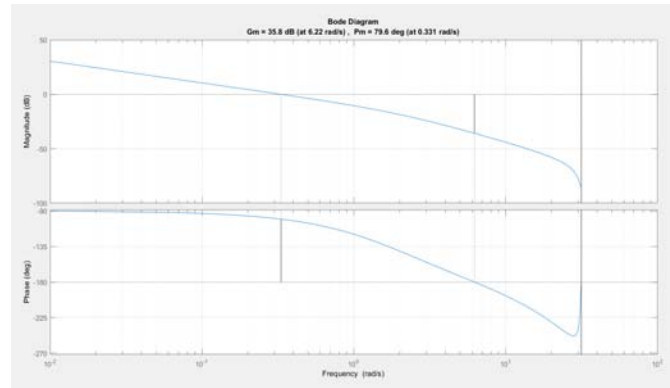
Figure 2: Bode plot of the uncompensated system

III. Plant

The robot arm control system has been presented in Fig. 1. In this example system, the sampling time, T = 0:1s, power amplifier gain, K = 2:4 and sensor feedback gain, H_k = 0:07.The sensor input is θ_a in degrees and the output is in volts. For the uncompensated plant, the controller, D (z) = 1. The zero-order hold transfer function can be defined as

$$G_{HO}(s) = \frac{1 - e^{-sT}}{s} \tag{9}$$

The continuous-time plant transfer function is

$$G_p(s) = \frac{9.6}{s2 + 2s} \tag{10}$$

The continuous-time plant with feedback sensor gain transfer function is

$$G_c(s) = G_p(s) \times H_k = \frac{0.672}{s^2 + 2s} \tag{11}$$

The discrete-time plant with feedback sensor gain transfer function is

$$G_d(z) = \frac{0.003147z + 0.002944}{z^2 - 1.819z + 0.8187} \tag{12}$$

Fig. 2 presents the bode diagram of the system with D (z) = 1. For the uncompensated system, the phase margin, Pm = 79:6deg. With a gain margin, G_m = 35:8 dB.

IV. Phase-Lag Controller Design

The dc gain of the lag controller design, a_0 = 10 and the high-frequency gain can be expressed as

$$G_{hf}(dB) = 20log\frac{a_0\omega_{wp}}{\omega_{w0}} \tag{13}$$

Figure 3: Bode plot of the phase-lag cont roller

Figure 4: Bode plot of the phase-lag controlled total open loop system

The maximum phase shift lies between 0 and -90 deg. Which depends on the ratio $w_0 = ! \ w_p$. In this paper, the controller is designed for 40 deg. phase margin and the cross-over or phase margin frequency for this design has been selected as

$$\omega_{w0} = 0.1\omega_{wc} \qquad (14)$$

and

$$\omega_{wp} = \frac{\omega_{w0}}{a_0 |G_d(j\omega_{wc})|} \qquad (15)$$
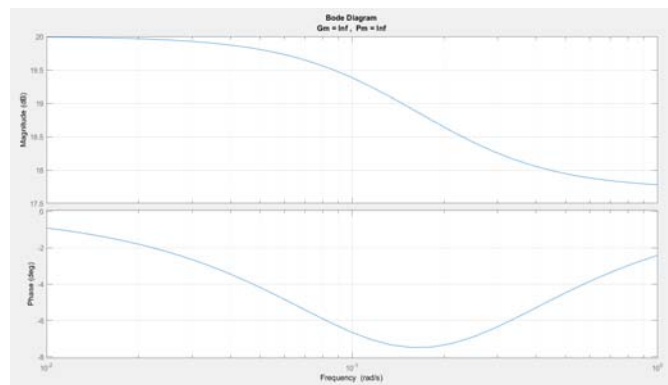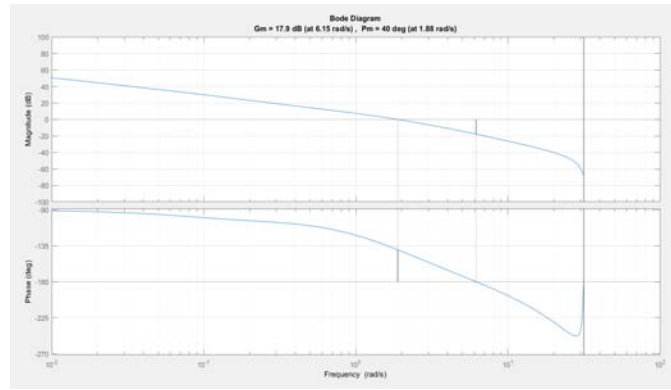
The design approximates that the controller introduces 5 deg. phase lag to the system and $jD(jww_c)Gd\ (jww_c)j = 1$. The lag controller implies that $w\ w_0 = 0{:}1880 > ww_0 = 0{:}1446$ and the compensating phase angle, $\phi_m = (-180 + 5 + 40) = -135$ deg.

$$D_{lag}(z) = \frac{7.707z - 7.564}{z - 0.9856} \qquad (16)$$

Fig. 3 and Fig. 4 present the bode plots of the phase-lag Controller and the compensated open loop system respectively. From the bode plot, it can be observed that the phase margin of the compensated plant, $P_m = 40$ deg. at 1.88 rads-1 and the gain margin, $G_m = 17.9$ dB. The phase-lag controller reduces the gain margin by $(35{:}8 - 17{:}9) = 17{:}9$ dB and the phase margin by $(79{:}6 - 40) = 39{:}6$ deg. From the marginalized bode plot of the controller, it can be observed that the gain and phase margin values are undefined and thereby these are found to be infinite. Bode plot of the controller, it can be observed that the gain and phase margin values are undefined and thereby these are found to be infinite.

Table II: Design Parameters Satisfying the Constraints

Parameters	Values
a1	7.6354
b1	0.4646
θr	372.4823 deg.
\Gd(j!wc)	-152.4823 deg.
jGd(j!wc)j	0.0695
jD(j!wc)j	14.4025
cos θr	0.9764

V. Phase-Lead Controller Design

The dc gain of the phase-lead controller, $a_0 = 10$ and the maximum phase shift, θ_m occurs at a frequency, $Wm = pww_0ww_P$. In this paper, the controller is designed for 40 deg. phase margin and the cross-over or phase margin frequency for this design has been selected as$!wc = 2{:}8$ rads-1. The lead controller design approach yields to.

$$D(j\omega_{wc})G_d(j\omega_{wc}) = 1\angle(180 + \phi_{pm}) \qquad (17)$$

Here ϕpm is the desired phase margin and

$$D(w) = a_0 \frac{1 + w/(a_0/a_1)}{1 + w/(b_1)^{-1}} \qquad (18)$$

Where $ww_0 = a_0 a1$ and $ww_P = 1b1$. The angle associated with the controller can be expressed as

$$\theta_r = \angle D(j\omega_{wc}) = 180 + \phi_{pm} - \angle G_d(j\omega_{wc}) \qquad (19)$$

The controller design requires

$$|D(j\omega_{wc})| = \frac{1}{|G_d(j\omega_{wc})|} \qquad (20)$$

From the equations (18)-(20), it can be evaluated that

$$a_1 = \frac{1 - a_0 |G_d(j\omega_{wc})| \cos\theta_r}{\omega_{wc} |G_d(j\omega_{wc})| \sin\theta_r} \qquad (21)$$

and

$$b_1 = \frac{\cos\theta_r - a_0 |G_d(j\omega_{wc})|}{\omega_{wc} \sin\theta_r} \qquad (22)$$

Because of the phase lead characteristic, $\theta_r > 0$ and in the design procedure, ww_c has been selected to satisfy the following constraints.

$$\angle G_d(j\omega_{wc}) < 180 + \phi_{pm}; |D(j\omega_{wc})| > a_0 \qquad (23)$$

$$|G_d(j\omega_{wc})| < \frac{1}{a_0}; b_1 > 0 \qquad (24)$$

$$\cos\theta_c > a_0 |G_d(j\omega_{wc})| \qquad (25)$$

The lead controller implies that $ww_0 = 1{:}3097 < ww_p = 2{:}1524$. The calculated design parameters are presented instable-II. The controller transfer function is

$$D_{lead}(z) = \frac{15.809(z - 0.8771)}{(z - 0.8057)} \qquad (26)$$

Fig. 5 and Fig. 6 present the bode plots of the phase-lead controller and the compensated open loop system respectively. From the bode plot, it can be observed that the phase margin of the compensated plant, $P_m = 39{:}9$ deg. at 2.8 rads-1 and the gain margin, $G_m = 14{:}6$ dB. The phase-lead controller reduces the gain margin by (35:8 - 14:6) = 21:2 dB and the phase margin by (79:6 - 39:9) = 39:7 deg. From the marginalized bode plot of the controller, it can be observed that the gain and phase margin values are undefined and thereby these are found to be infinite.
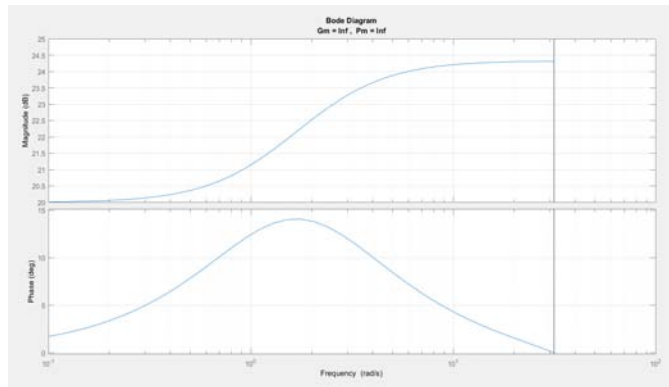

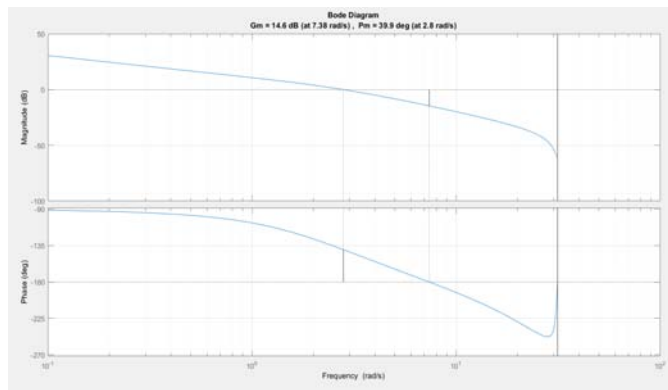Figure 5: Bode plot of the phase-lead controller

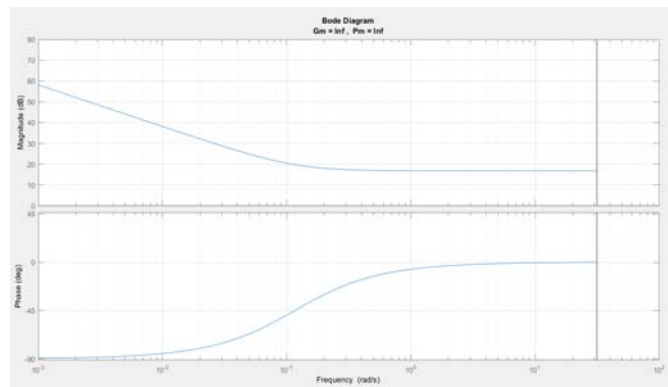Figure 6: Bode plot of the phase-lead controlled total open loop system

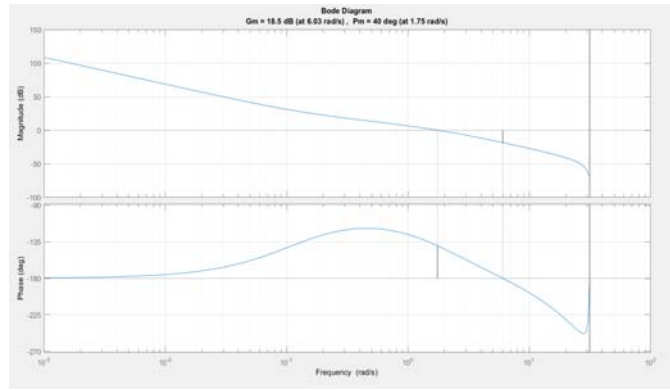Figure 7: Bode plot of the proportional-integral (PI) controller

Figure 8: Bode plot of the PI controlled total open loop system

VI. PROPORTIONAL-INTEGRAL (PI) CONTROLLER DESIGN

The controller transfer function can be expressed as

$$D(w) = K_P + \frac{K_I}{w} = K_I \frac{1 + w/\omega_{w0}}{w} \qquad (27)$$

Here $ww_0 = K_I = K_P$. Proportional-integral (PI) compensator acts like a phase-lag controller with the pole placed at $ww_p = 0$.

Using the equation (4), the discrete transfer function of a PI controller can be expressed as

$$D(z) = K_P + K_I \frac{T}{2} \frac{z+1}{z-1} \qquad (28)$$

and

$$D(j\omega_w) = K_P - j\frac{K_I}{\omega_w} = |D(j\omega_w)|e^{j\theta_r} \qquad (29)$$

The controller design approach yields that at the crossover Frequency

$$D(j\omega_{wc})G_d(j\omega_{wc}) = 1\angle(-180 + \phi_{pm}) \qquad (30)$$

At the cross-over frequency (1.75 rads-1 in this design example)

$$K_P - j\frac{I}{\omega_{wc}} = |D(j\omega_{wc})|(\cos\theta_r + j\sin\theta_r) \qquad (31)$$

The angle associated with the controller is

$$\theta_r = -180 + \phi_{pm} - \angle G_d(j\omega_{wc}) \qquad (32)$$

From the equations (30)-(32), it can be derived as

$$K_P = \frac{\cos\theta_r}{|G_d(j\omega_{wc}|} \qquad (33)$$

and

$$K_I = -\frac{\omega_{wc}\sin\theta_r}{|G_d(j\omega_{wc})|} \qquad (34)$$

The controller transfer function has been calculated as

$$D_{PI}(z) = \frac{6.954z - 6.874}{z - 1} \qquad (35)$$

The design parameters are: θ_r = 356:1990 deg., K_P = 6:9143 and K_I = 0:8039. Fig. 7 and Fig. 8 present the bode plots of the PI controller and the compensated open loop system respectively. From the bode plot, it can be observed that the phase margin of the compensated plant, P_m = 40 deg. At 1.75 rads-1 and the gain margin, G_m = 18:5 dB. The PI controller reduces the gain margin by (35:8 - 18:5) = 17:3 dB and the phase margin by (79:6-40) = 39:6 deg. From the marginalized bode plot of the controller, it can be observed that the gain and phase margin values are undefined and thereby these are found to be infinite.

VII. PROPORTIONAL-INTEGRAL-DERIVATIVE (PID)CONTROLLER DESIGN

The controller transfer function can be expressed as

$$D(w) = K_P + \frac{K_I}{w} + K_D w \qquad (36)$$

Using the equation (4), the discrete transfer function of a PID controller can be expressed as

$$D(z) = K_P + K_I \frac{T}{2} \frac{z+1}{z-1} + K_D \frac{z-1}{Tz} \qquad (37)$$

The controller frequency response is

$$D(j\omega_w) = K_P + j(K_D\omega_w - \frac{K}{\omega_w} \frac{I}{\omega_w}) = |D(j\omega_w)|e^{j\theta_r} \text{ (38)}$$
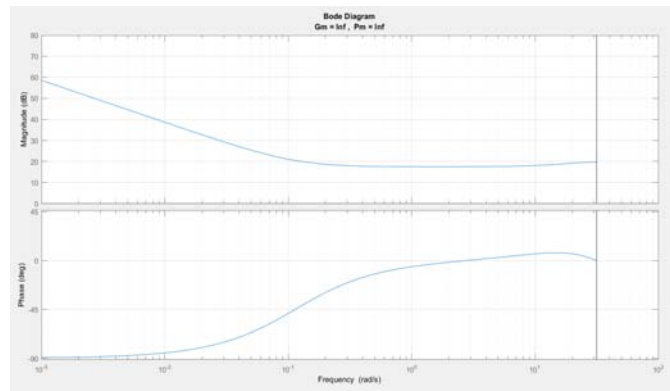
Figure 9: Bode plot of the proportional-integral-derivative (PID) controller

At the cross-over frequency (1.85 rads-1 in this design example)

$$K_P + j(K_D\omega_{wc} - \frac{K_I}{\omega_{wc}}) = |D(j\omega_{wc})|(\cos\theta_r + j\sin\theta_r) \tag{39}$$

From the equations (30) and (39), it can be derived as

$$K_P = \frac{\cos\theta_r}{|G_d(j\omega_{wc}|} \tag{40}$$

and

$$K_D\omega_{wc} - \frac{K_I}{\omega_{wc}} = \frac{\sin\theta_r}{|G_d(j\omega_{wc})|} \tag{41}$$

Which yields to?

$$[K_P + \frac{K_D\omega_{wc}^2(2/T)}{(2/T)^2 + \omega_{wc}^2}] + j[\frac{K_D\omega_{wc}(2/T)^2}{(2/T)^2 + \omega_{wc}^2} - \frac{K_I}{\omega_{wc}}] = \frac{\cos\theta_r + j\sin\theta_r}{|G_d(j\omega_{wc})|} \tag{44}$$

From the equation (44), it can be concluded that

$$K_P + \frac{K_D\omega_{wc}^2(2/T)}{(2/T)^2 + \omega_{wc}^2} = \frac{\cos\theta_r}{|G_d(j\omega_{wc})|} \tag{45}$$

and

$$\frac{K_D\omega_{wc}(2/T)^2}{(2/T)^2 + \omega_{wc}^2} - \frac{K_I}{\omega_{wc}} = \frac{\sin\theta_r}{|G_d(j\omega_{wc})|} \tag{46}$$

The controller transfer function has been calculated as

$$D_{PID}(z) = \frac{8.655z^2 - 9.694z + 1.125}{z^2 - z} \tag{47}$$

For design consideration, by adding a pole in the derivative term, the controller transfer function is modified as

Fig. 9 and Fig. 10 present the bode plots of the PID controller and the compensated open loop system

For design consideration, by adding a pole in the derivative term, the controller transfer function is modified as

$$D(w) = K_P + \frac{K_I}{w} + \frac{K_Dw}{1 + (T/2)w} \tag{42}$$

The modified frequency response is

$$D(j\omega_w) = K_P - j\frac{K_I}{\omega_w} + \frac{K_Dj\omega_w}{1 + j\omega_w(T/2)} \tag{43}$$

respectively. From the bode plot, it can be observed that the phase margin of the compensated plant, P_m = 40 deg. at 1.85 rads-1 and the gain margin, G_m = 20:2 dB. The PID controller reduces the gain margin by (35:8-20:2) = 15:6 dB and the phase margin by (79:6 - 40) = 39:6 deg. From the marginalized bode plot of the controller, it can be observed that the gain and phase margin values are undefined and thereby these are found to be infinite.
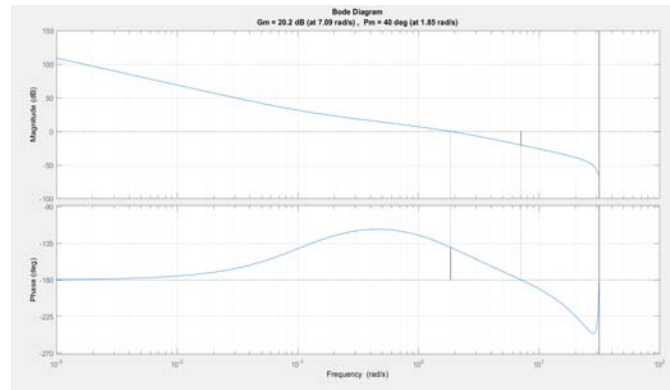
Figure 10: Bode plot of the PID controlled total open loop system
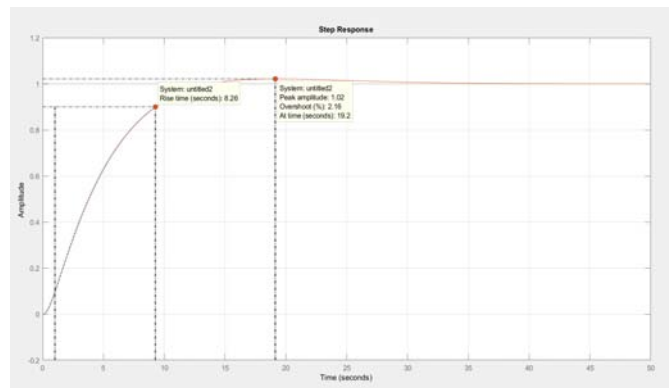
Figure 11: Step response of the closed loop system for the phase-lag controller
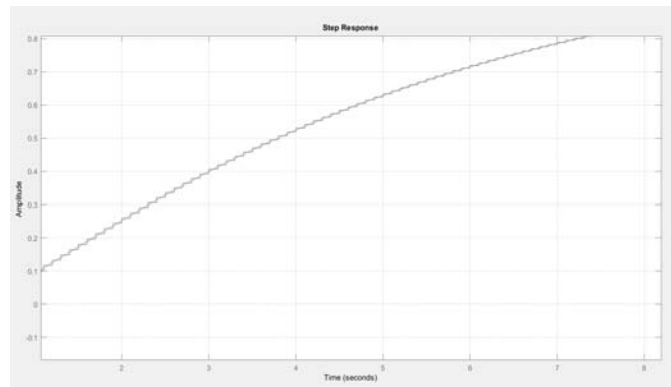
Figure 12: Enlarged version of Fig. 11 to show the continuous and discrete step responses

VIII. STEP RESPONSE CHARACTERISTICS

The design problem explained in this paper has assumed an input of $\theta_e = 0.07u(t)$; where u (t) is the unit step function. The scaled step response of the closed loop system for the designed phase-lag controller is presented in Fig. 11 and Fig. 12 shows the enlarged view.

From Fig. 11, the rise time is found to be 8.26s and percent overshoot is found to be 2.16% for the lag compensator. There are two plots concatenated in this figure. One is the continuous-time (w-plane) response and other is the actual digital controlled system response.
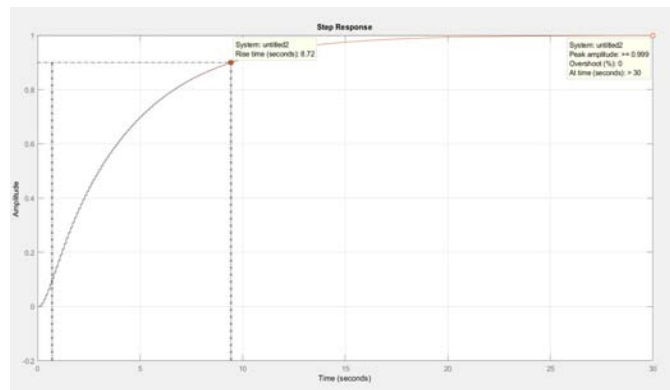
Figure 13: Step response of the closed loop system for the phase-lead controller
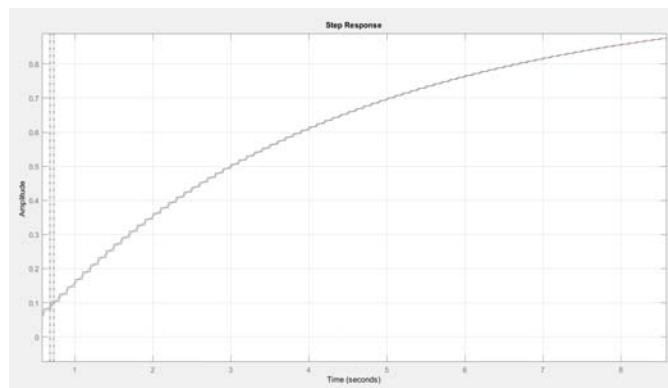
Figure 14: Enlarged version of Fig. 13 to show the continuous and discrete step responses
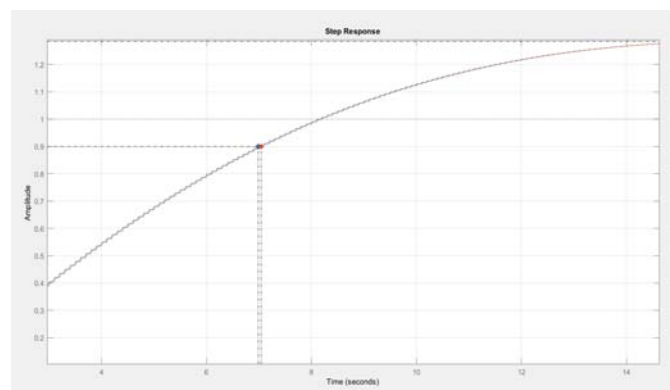
Figure 15: Step response of the closed loop system for the proportional-integral (PI) controller

The scaled step response of the closed loop system for the designed phase-lead controller is presented in Fig. 13 and Fig. 14 shows the enlarged view. From Fig. 13, the rise time is found to be 8.72s and percent overshoot is found to be 0% for the lead compensator. There are two plots concatenated in this figure. One is the continuous-time (w-plane) response and other is the actual digital controlled system response.

The scaled step response of the closed loop system for the designed PI controller is presented in Fig. 15 and Fig. 16 shows the enlarged view. From Fig. 15, the rise time is found to be 5.96s and percent overshoot is found to be 28.5% for the PI compensator. There are two plots concatenated in this figure. One is the continuous-time (w-plane) response and other is the actual digital controlled system response.
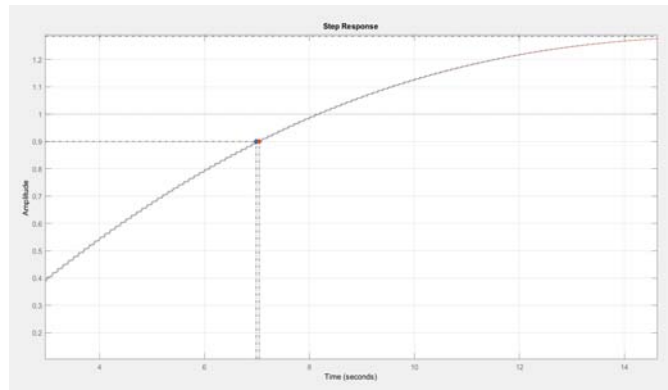
Figure 16: Enlarged version of Fig. 15 to show the continuous and discrete step responses
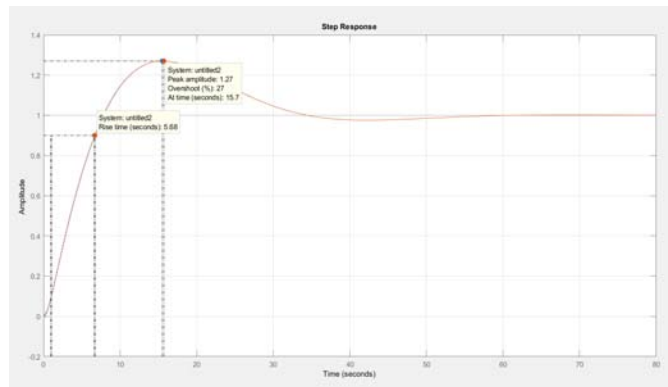
Figure17: Step response of the closed loop system for the proportional-integral derivative (PID) controller
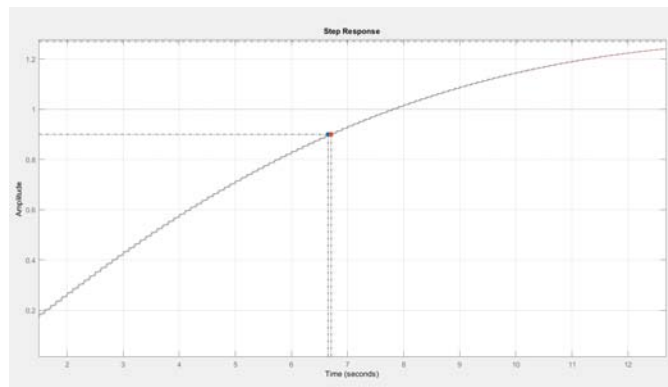
Figure 18: Enlarged version of Fig. 17 to show the continuous and discrete step responses

The scaled step response of the closed loop system for the designed PID controller is presented in Fig. 17 and Fig. 18 shows the enlarged view. From Fig. 17, the rise time is found to be 5.68s and percent overshoot is found to be 27% for the PID compensator. There are two plots concatenated in this figure. One is the continuous-time (w-plane) response and other is the actual digital controlled system response.

compensators in discrete (actual digital) domain and continuous (warped splane or w-plane) domain respectively. The step response characteristics of the designed controllers are enlisted in Table III for comparative analysis.

IX. COMPARISON

Fig. 19 and Fig. 20 present the step responses of the designed phase-lag, phase-lead, PI and PID

Table III: Step Response Characteristics of the Controllers

Characteristics	Phase-lag	Phase-lead	Proportional-integral (PI)	Proportional-integral derivative (PID)
Steady-state error	0	0	0	0
Percent overshoot (%)	2.16	0	28.5	27
Rise time (s)	8.26	8.72	5.96	5.68
Settling time (s)	21.4	15.9	50.3	46.7
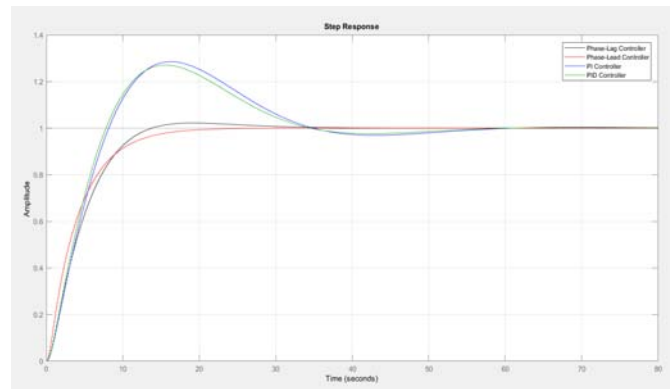
Figure 19: Step responses of the lag, lead, PI and PID controllers in discrete domain
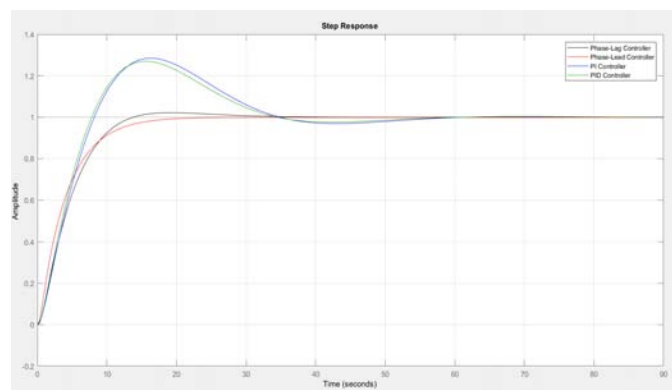
Figure 20: Step responses of the lag, lead, PI and PID controllers in continuous domain

Since the controllers are designed with optimum considerations, no steady-state error is observed. In case of the phase-lag controller, the low frequency response and stability margins get improved with a reduced bandwidth. In case of the phase-lead controller, high frequency response and stability margins get improved with an increased bandwidth. PI controller behaves like a phase-lag compensator since the integral term is the lag controller. From Table-III, it can be observed that in terms of percent overshoot, lead controller performs better than the other controllers and in terms of rise time, PID shows the best performance. PID controller is a lag-lead compensator in which PI block acts as the lag controller and PD block acts as the lead controller? In comparison of PI and PID controllers, PID results in reduced overshoot and settling time than the PI because of the additional derivative term. Rise time is the highest for the lead controller but in case of percent overshoot and settling time it

outperforms rest of the three. Rise time is the lowest for the PID controller. Phase-lead compensator yields to a complex design methodology for the system where PID controller is governed by tuning the control parameters. Therefore phase-lead or PID can be selected for compensation of the presented robot control system.

X. Conclusion

This paper presents design and performance assessment of four basic digital controllers: phase-lag, phase-lead, PI and PID for a physical system of robot arm joint plant. The design statement yields to a compensated phase margin of the system frequency response to 40 deg. Frequency response techniques have been applied and cross-over frequency is the prime design specification to compensate the plant. The Design methodologies have been investigated in both discrete (z-domain or actual digital) and continuous (warped s-domain or w-plane) time frames. The

controllers have been simulated on MATLAB and open loop bode plots and closed loop step responses have been analyzed for comparative premises. Such design specifications are applicable in different practical control systems.

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Equilateral Triangular Microstrip Patch Antenna using Different Substrates

By Abhishek Pandey

Abstract- The triangular geometry of micro strip antenna is one of the most common shapes having a wide range of wireless application ranging from circuit element to wireless antennas. The proposed equilateral triangular micro strip patch antenna is designed by using different substrates of different permittivity .Proposed paper gives an idea about bandwidth changes with change of substrate material. Proposed antenna operated in C-Band .This antenna designed on soft HFSS designer software, impedance bandwidth, VSWR, return losses & smith charts are observed and experimentally studied. Details of simulated results are presented and discussed.

GJRE-F Classification: FOR Code: 100599

EQUILATERALTRIANGULARMICROSTRIPPATCHANTENNAUSINGDIFFERENTSUBSTRATES

Strictly as per the compliance and regulations of:

Equilateral Triangular Microstrip Patch Antenna using Different Substrates

Abhishek Pandey

Abstract- The triangular geometry of micro strip antenna is one of the most common shapes having a wide range of wireless application ranging from circuit element to wireless antennas The proposed equilateral triangular micro strip patch antenna is designed by using different substrates of different permittivity. Proposed paper gives an idea about bandwidth changes with change of substrate material. Proposed antenna operated in C-Band. This antenna designed on soft HFSS designer software, impedance bandwidth, VSWR, return losses & smith charts are observed and experimentally studied. Details of simulated results are presented and discussed.

I. Introduction

Compact micro strip antennas have recently received much attention due to the increasing demand of small antennas for personal as well as commercial communication equipment. It has been demonstrated that equilateral triangular micro strip patch can effectively reduce the required patch size for a given operating frequency [1]. In mobile communication system such as satellite, RADAR, Global Position System (GPS) often require extremely small size, light weight. The 'C' band of frequency is used for the satellite communication and terrestrial application.

Single band & Dual band frequency operation of triangular micro strip antennas have been studied by Many researchers using coaxial probe feed [1]-[2]. This paper reports the simulation result using equilateral triangular patch antenna with co-axial feed. This paper therefore proposed a design of single & dual band operation of equilateral triangular micro strip antenna using HFSS (high frequency structure stimulator) which is commercially available in the market and the it depend on the FEM(finite element method) analysis.

II. Antenna Geometry

The geometry of the proposed triangular antenna using a co-axial probe feed is shown in fig.1. The proposed antenna is constructed on a dielectric substrate on different substrates such as:
1. Rogers RT/duriod 5880(TM) which has a dielectric constant 2.2, & loss tangent 0.0009.
2. FR-4 EPOXY which has a dielectric constant 4.4, & loss tangent 0.002

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3. Rogers TMM6 which has a dielectric constant 6, & loss tangent 0.0023.
4. Rogers RT/duroid 6010/6010 LM(TM) which has a dielectric constant 10.2, & loss tangent 0.0023.

The area of the equilateral triangular patch antenna is situated on the substrate with dimension $1/2(31.1*26.97779)$ mm^2.Height of substrate is 4mm.
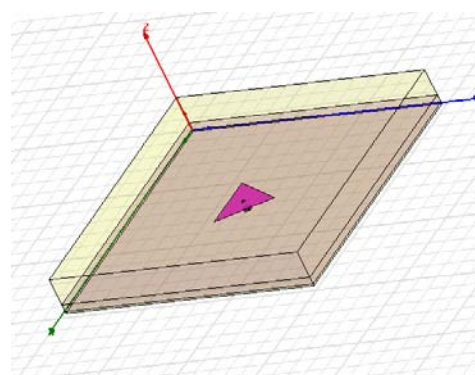
Figure 1: Antenna Geometry

III. Simulation Result

a) Rogers RT/duriod 5880(TM)

The impedance bandwidth of proposed antenna at the centre frequencies is shown in Fig. 2.1.This result shows single band width below to the –10dB so we can operate this antenna in the single bands and the return loss is-19.67dB. Proposed antenna can operate efficiently at frequency 3.42GHz. impedence Bandwidth achieved by this antenna is 34.23%.The VSWR is 1.26.

The impedance bandwidth and VSWR shows in fig. 2.1 & fig 2.2 and we can see here the antenna have resonance at 3.42GHz. The radiation pattern is shown in fig 2.3 which shows the antenna is unidirectional. By varying the position of coaxial probe for the input impedance matching of the feeding system can be characterized.

Furthermore, the radiation pattern of the proposed antenna is also measured with respect to gain. The radiation pattern of the antenna is shown in Fig. 2.3.Smith chart is shown in fig 2.4.

Figure 2.1: Measured impedance bandwidth
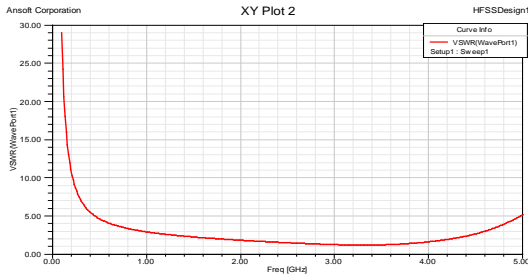
Figure 2.2: Measured VSWR
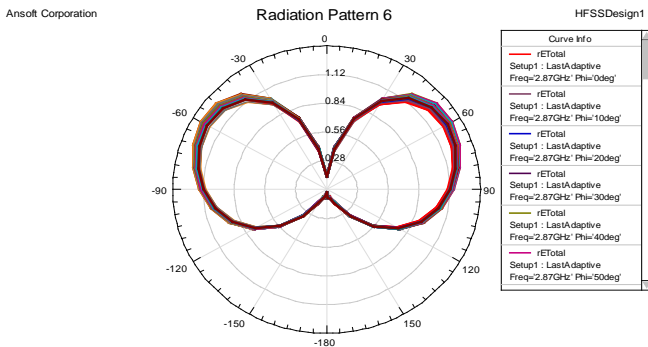
Figure 2.3: Radiation pattern 2D
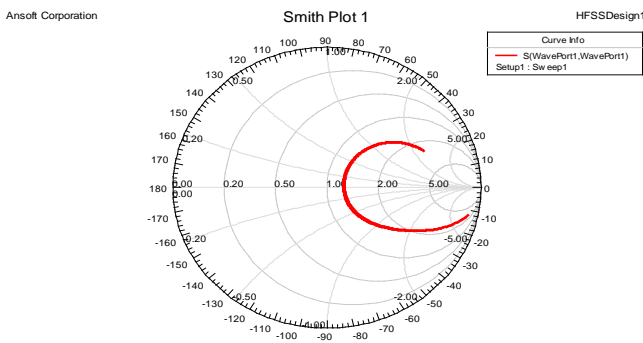
Figure 2.4: Input impedance loci using smith chart

b) FR-4 Epoxy

When we use FR-4 EPOXY as substrate the measured return loss is -18dB & impedence bandwidth is 32%. In this case measured VSWR is 1.24 & resonance frequency is 2.9 GHZ. Measured return loss,

VSWR, radiation pattern, and smith chart is shown in fig.3.1-fig 3.4.
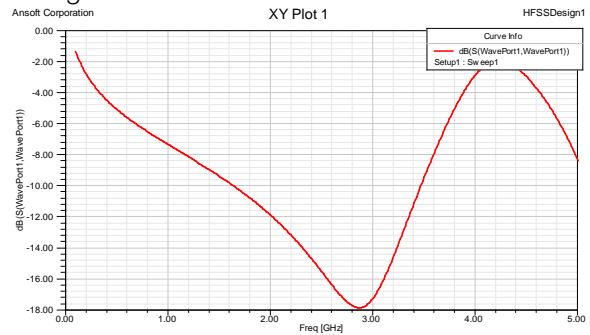
Figure 3.1: Measured impedence bandwidth
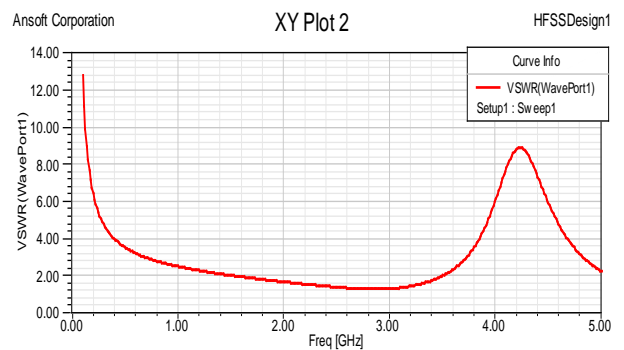
Figure 3.2: Measured VSWR
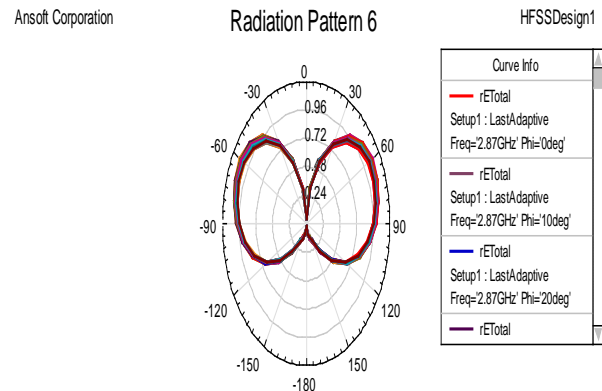
Figure 3.3: Radiation pattern
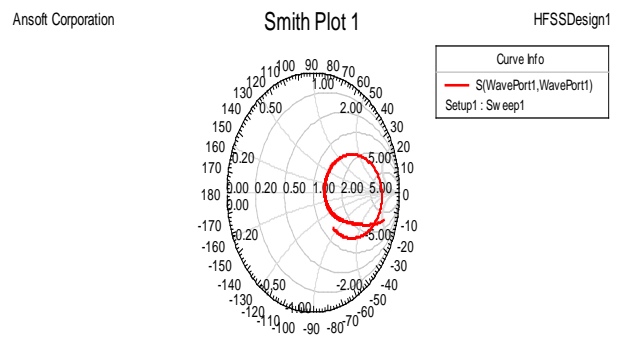
Figure 3.4: Input impedance loci using smith chart

30

c) Rogers TMM6

By using Roger TMM6 as substrare dual band has achieved which is resonant at 2.68 GHZ and 4.88GHZ .in this case the measured return loss is -17.43dB & -20.33dB respectively. impedence bandwidth is 30.85% & 6.25% resp.. In this case measured VSWR is 1.34 & 1.16 resp. Measured return loss, VSWR, radiation pattern, and smith chart is shown in fig.4.1-fig 4.4.
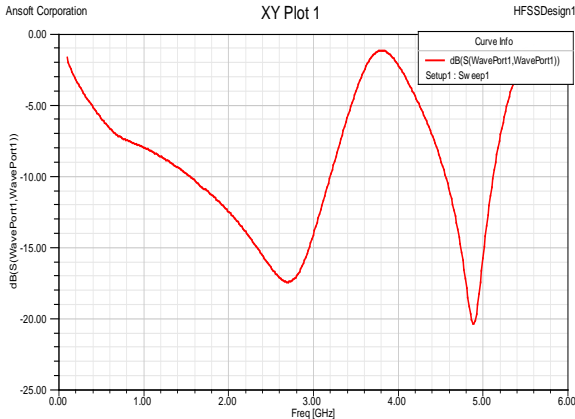
Figure 4.1: Measured impedance bandwidth
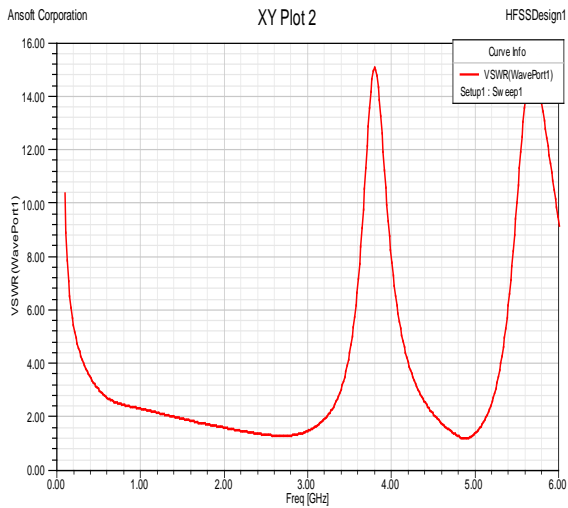
Figure 4.2: Measured VSWR
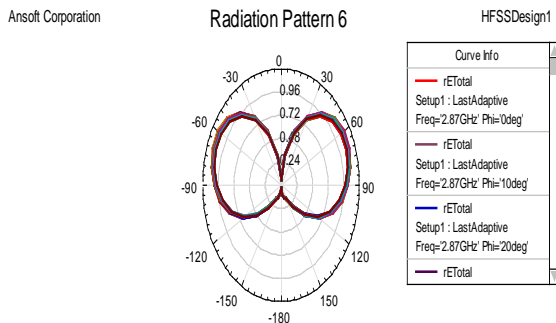
Figure 4.3: Radiation pattern
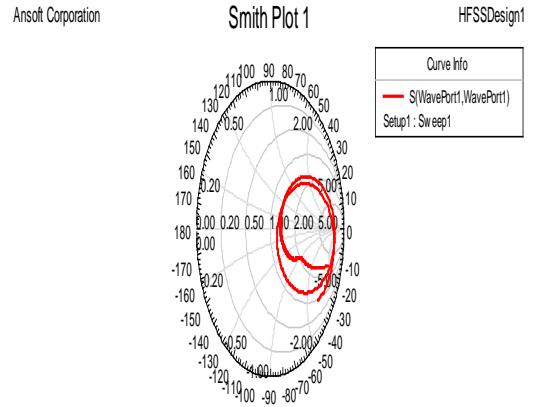
Figure 4.4: Input impedance loci using smith chart

d) Rogers RT/duroid 6010/6010 LM(TM)

Dual band operation can also be achieved by using Rogers RT/duroid 6010/6010LM(TM).

In this case resonant frequencies are 2.29GHZ & 3.87GHZ.measured return losses are -16.1dB & -20.33Db.

Impedence bandwidth 27% & 6.47%resp.VSWR measured are 1.37 & 1.13 resp. Measured return loss, VSWR, radiation pattern, and smith chart is shown in fig.5.1-fig 5.4.
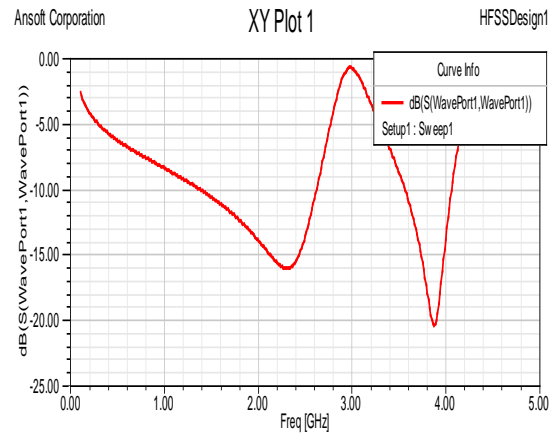
Figure 5.1: Measured impedence bandwidth

Figure 5.2: Measured VSWR

Table: Comparison table

	Resonant frequency	Return losses	Bandwidth	VSWR
$\varepsilon_{1=2.2}$	3.42GHz	-19.67 dB	34.23%	1.26
$\varepsilon_{2=4.4}$	2.90 GHz	-18 dB	32%	1.24
$\varepsilon_{3=6.0}$	2.68 GHz	-17.43 dB	30.85%	1.34
	4.88 GHz	-20.33 dB	6.25%	1.16
$\varepsilon_{4=10.2}$	2.29 GHz	-16.10 dB	27%	1.37
	3.87 GHz	-20.33 dB	6.47%	1.13

ε_1- Rogers RT/duriod 5880(TM)
ε_2- FR-4 EPOX
ε_3- Rogers TMM
ε_4- Rogers RT/duroid 6010/6010 LM(TM)

IV. CONCLUSION

From Comparison table we observe that as we increase the permittivity of substrate, resonance frequency & bandwidth are decreases, and return losses increases. From results we concluded that proposed equilateral triangular patch antenna with co-axial probe feed gives better performance with substrate whose permittivity is 2.2(Rogers RT/duriod 5880(TM)).Which can be used in C-band operation.

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Figure 5.3: Input impedance loci using smith chart
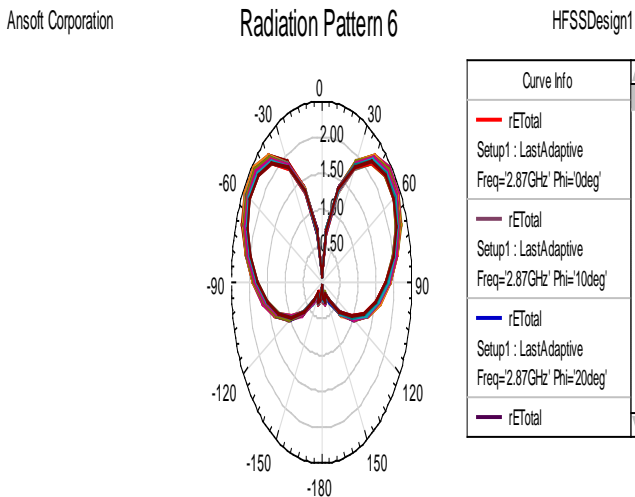
Figure 5.4: Radiation pattern

Integer Wavelet Transform based Dual Watermarking Technique using Tent Map and Local Binary Pattern

By Sumaya Rahman, Chandan Saha, Md. Foisal Hossain & Tanjil Alam Tamal

Khulna University of Engineering & Technology

Abstract- Watermarking ascribes to insert pattern of bits into an image that conserves copyright information from unauthorized users. In this paper, Integer Wavelet Transform based image watermarking technique using Tent map and Local Binary Pattern has been proposed. Tent Map is used to generate chaotic key sequence to scramble two watermark images. Integer Wavelet Transform (IWT) is applied on the host image to define approximation coefficient (LL) band and to achieve higher level of robustness as perfect reconstruction is guaranteed by the composition of Lifting method. Local Binary Pattern (LBP) is used to generate binary matrix from LL band. Two watermarks are embedded simultaneously to the even and odd coefficients of 5×5 mask of host image. To check robustness, several attacks has been added to watermarked images; their normalized correlation (NC) and peak signal to noise ratio (PSNR) values are quite inspiring, that exhibits superiority of our scheme than some existing schemes.

Keywords: dual watermarking, integer wavelet transform, local binary pattern, tent map.

GJRE-F Classification: FOR Code: 090699

INTEGERWAVELETTRANSFORMBASEDDUALWATERMARKINGTECHNIQUEUSINGTENTMAPANDLOCALBINARYPATTERN

Strictly as per the compliance and regulations of:

Integer Wavelet Transform based Dual Watermarking Technique using Tent Map and Local Binary Pattern

Sumaya Rahman [α], Chandan Saha [σ], Md. Foisal Hossain [ρ] & Tanjil Alam Tamal [ω]

Abstract- Watermarking ascribes to insert pattern of bits into an image that conserves copyright information from unauthorized users. In this paper, Integer Wavelet Transform based image watermarking technique using Tent map and Local Binary Pattern has been proposed. Tent Map is used to generate chaotic key sequence to scramble two watermark images. Integer Wavelet Transform (IWT) is applied on the host image to define approximation coefficient (LL) band and to achieve higher level of robustness as perfect reconstruction is guaranteed by the composition of Lifting method. Local Binary Pattern (LBP) is used to generate binary matrix from LL band. Two watermarks are embedded simultaneously to the even and odd coefficients of 5×5 mask of host image. To check robustness, several attacks has been added to watermarked images; their normalized correlation (NC) and peak signal to noise ratio (PSNR) values are quite inspiring, that exhibits superiority of our scheme than some existing schemes.

Keywords: dual watermarking, integer wavelet transform, local binary pattern, tent map.

I. Introduction

Watermarking is a marvelous technique in which number of bits another image or logo are inserted in another contents. Digital image watermarking supports image, audio or video file as watermark. At present data security, copyright protection, imperceptibility and authenticity have become indispensable issues in data hiding. Watermarking indemnifies all these issues in a strategic way. Watermarking technique can be implemented in two domains: spatial domain and frequency domain. In spatial domain, without using any transformation, the watermark can be embedded into host image which is of less complexity and simpler but it's not that much robust against attacks. Frequency domain needs some transformation [1-2] before embedding the watermark image into host. Though it is complex than spatial domain, it shows more robustness against attacks. According to type of document, watermarking is of text, image, audio or video types. Based on several applications it is of three types as fragile, semi-fragile and robust. Visible and invisible watermarks are types of fragile water marking. Tamper detection is a prime theme for fragile watermarking. Robust watermarking is an algorithm that is dynamic and rigid even after adding noise.

Many embedding techniques have been proposed earlier based on Local Binary Pattern, Integer Wavelet Transform or Tent Map. Bhardwaj et al. [1] has proposed a lifting wavelet transform based robust watermarking scheme that uses singular value decomposition for obtaining singular values of watermark image. Makbol et al. [2] has discussed a robust watermarking scheme that based on IWT and SVD that performs authentication and helps security issues. Lazarov et al. [3] proposed an algorithm that uses chaotic maps for embedding; Arnold's cat map and Tent map are applied to the host and watermark image respectively. Chang et al. [4] have proposed a LBP based recoverable fragile watermarking technique that uses 3×3 size blocks for LBP operator. Zhang et al. [5] proposed a blind fragile watermarking scheme based on LBP, Arnold transform and Logistic map.

An sari et al. [6] proposed a water marking technique in which IWT and singular value decomposition (SVD) based scheme was discussed to ensure security and robustness. On the host image, IWT was applied first and then, on this transformed image, SVD was applied because the properties of SVD and IWT gave higher level of robustness. Wenyin et al. [7] proposed a semi-fragile multi-level image watermarking scheme based on LBP operators that was performed in spatial domain. A digital dual watermarking using SVD and redundant discrete wavelet transform (RDWT) has been proposed by Gaur et al. [8] which has a primary watermark and a scrambled watermark using Arnold cat map. Saiyyad at el. [9] proposed a dual watermarking process with hash function and the security purpose of AES ciphered watermarking and also tampers detection. It uses unique identification code as first watermark and for second water mark; hash code is generated from host image. All these papers have proposed watermarking scheme using Local Binary Pattern, Integer Wavelet Transform or Tent Map individually. But we wanted to combine these three themes into one method to provide more robustness and stiffness of technique. Morteza et el. [10-11] proposed two watermarking schemes using SVD and DWT-SVD technique.

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In this paper, a robust and dual level watermarking scheme has been discussed that is the combination of Tent map, IWT and LBP. Chapter 2 describes the basic background of chaotic mapping and image transformation. Chapter 3 presents the procedure of the proposed watermarking scheme. Chapter 4 shows the experimental result analysis. Chapter 5 concludes the paper.

II. BACKGROUND

a) Tent Map

Tent map is an image scrambling or mapping system that generates a fixed number of chaotic bit sequences. Mathematically, Tent map is the real-valued function and the sequence x_n using this map is produced by iterating x [12]. In this scheme, the sequence that is produced by this map is rounded up to binary numbers and reshaped to a matrix of same size of watermark.

$$x_n = f_\mu(x_n) = \begin{cases} \mu\, x_n & \text{for } x_n < .5 \\ \mu(1 - x_n) & \text{for } .5 \le x_n \end{cases} \quad (1)$$

If the value is $\mu = 2$, the function f_μ will divide the unit interval into two, first stretching the interval to get again the interval [0,1].

b) Local Binary Pattern

Local Binary Pattern (LBP) is a very systematic texture operator that operates with the pixel of an image, sets a threshold level for each pixel and shows the result as binary numbers. For 3×3 mask, the binary numbers are generated by following formula [4]. In our scheme, instead of 3×3 mask, we applied 5×5 mask.

$$S_x = \begin{cases} 1, & P_x \ge P_c \\ 0, & P_x < P_c \end{cases} \quad (2)$$

c) Integer Wavelet Transform

Integer wavelet transform is an integer to integer wavelet transformation technique that is efficient for lossless data compression and also faster in comparison with continuous wavelet transform and discrete wavelet transform. IWT provides higher level of robustness because of the structure of Lifting scheme [6]. Like DWT, 4 bands are generated ($CA1, CV1, CD1, CH1$) in IWT.

In lifting method, there are three steps to implement IWT. These are-split, predict and update [13-14]. Split refers that, original signal is folded into odd (Co) and even (Ce) components. On predictor, the odd sequence is being predicted by even sequence. Neweven samples are produced that are based on updater.

III. PROPOSED SCHEME

a) Embedding Procedure

A gray-scale image of size ($M \times N$) is taken as the host image. Then IWT is applied on this image for find LL band ($CA1$ band). After this, local binary pattern [7] is applied for each (5×5) mask of $CA1$ band to form binary matrix .The whole embedding procedure is shown in Fig. 1 and is illustrated in algorithm as follows:

1. A grayscale image is considered as cover image

2. Two watermark images ($w1\ \&\ w2$) are taken to embed in the cover image, $w1$ is for odd pixel and $w2$ for even pixel; perform XOR operation with Tent map to generate scrambled watermarks ($s1\ \&\ s2$)

3. IWT is applied on host to obtain $CA1$ band

4. LBP is applied on $CA1$ band If neighbor pixel > centre pixel, assign neighbor pixel = 1 and If neighbor pixel ≤ centre pixel, assign neighbor pixel = 0 Thus, binary matrix (b) is generated.

5. For each 5×5 mask, perform XOR operation on even and odd pixels of the binary matrix (b).

6. Compare XOR outputs of odd (b1) and even (b2) pixels of the binary matrix (b) with the scrambled water mark images s1 & s2 respectively. If $b1\,(i,j) == s1\,(i,j)$or $b2\,(i,j) == s2\,(i,j)$; no change will occur to the original $CA1$ band. If $b1\,(i,j)\sim = s1\,(i,j)$or $b2\,(i,j)\sim = s2\,(i,j)$; any one of the 12 odd pixels or any one of the 12 even pixels of 5×5 mask except centre pixel, will be changed in the original $CA1$band.

7. For odd pixels, in the original $CA1$ band, If $CA1\,(i-1, j-1)$ > centre pixel, assign $CA1(i-1, j-1)$ =centre pixel+k and If $CA1\,(i-1, j-1)$ ≤ centre pixel, assign $CA1(i-1, j-1)$ = centre pixel- k

8. For even pixels, in the original $CA1$band, If $CA1(i-1, j)$ >centre pixel, assign $CA1(i-1, j)$ = centre pixel+ k and If $CA1(i-1, j)$ ≤ centre pixel, assign $CA1(i-1, j)$ = centre pixel- k

9. Watermarked $CA1$ band is obtained

10. Inverse IWT is applied to obtain watermarked image.

```
┌──────────────┐      ┌──────────┐      ┌──────────────┐
│  Original    │      │          │      │ Apply LBP on │
│  grayscale   │─────▶│ Apply IWT│─────▶│ LL band of   │
│  image       │      │          │      │ image for    │
│              │      │          │      │ 5 × 5 mask   │
└──────────────┘      └──────────┘      └──────────────┘
                                                │
                                                ▼
┌──────────────┐   ┌──────────────┐     ┌──────────────┐
│ Perform XOR  │   │ Splitting    │     │              │
│ on both even │   │ into even &  │     │   Binary     │
│ & odd pixels │◀──│ odd pixel    │◀────│   matrix     │
│ for each 5×5 │   │ positions    │     │              │
│ mask         │   │ for each 5×5 │     │              │
│              │   │ mask         │     │              │
└──────────────┘   └──────────────┘     └──────────────┘
       │
   ┌───┴────────────────────────────────┐
   ▼                                     ▼
┌──────────────┐                 ┌──────────────┐
│ Algorithm for│                 │ Algorithm for│
│ embedding w1 │                 │ embedding    │
│ on odd pixel │                 │ w2 on even   │
│ position     │                 │ pixel position│
└──────────────┘                 └──────────────┘
   ▲              ┌──────────┐         ▲
   │              │ Tent map │         │
┌──────────────┐  └──────────┘  ┌──────────────┐
│ Scrambled    │ Xor   ▲  ▲  Xor│ Scrambled    │
│ watermark    │◀──────┘  └─────│ watermark    │
│ s1           │   ┌────┐ ┌────┐│ s2           │
└──────────────┘   │Wmk │ │Wmk │└──────────────┘
                   │ w1 │ │ w2 │
                   └────┘ └────┘
```

Figure 3: Block diagram for embedding procedure

```
┌──────────────┐      ┌──────────┐      ┌──────────────┐
│ Watermarked  │      │          │      │ Apply LBP    │
│ image        │─────▶│ Apply IWT│─────▶│ on LL band   │
│              │      │          │      │ of image for │
│              │      │          │      │ 5 × 5 mask   │
└──────────────┘      └──────────┘      └──────────────┘
                                                │
                                                ▼
        ┌──────────────┐                ┌──────────────┐
        │ Perform XOR  │                │   Binary     │
        │ on both even │◀───────────────│   matrix     │
        │ & odd pixels │                │              │
        │ for each 5×5 │                └──────────────┘
        │ mask         │
     ┌──│              │
     │  └──────────────┘
     │   ┌──────────┐  Xor    ┌────────┐   ┌──────────┐
     └─▶ │Scrambled │────────▶│        │──▶│Watermark │
         │watermark │         │Tent map│   │   w1     │
         │ s1       │         │        │   └──────────┘
         └──────────┘    ┌───▶│        │   ┌──────────┐
     ┌─▶ ┌──────────┐    │    │        │──▶│Watermark │
     │   │Scrambled │────┘    └────────┘   │   w2     │
     │   │watermark │  Xor                 └──────────┘
     │   │ s2       │
     │   └──────────┘
```
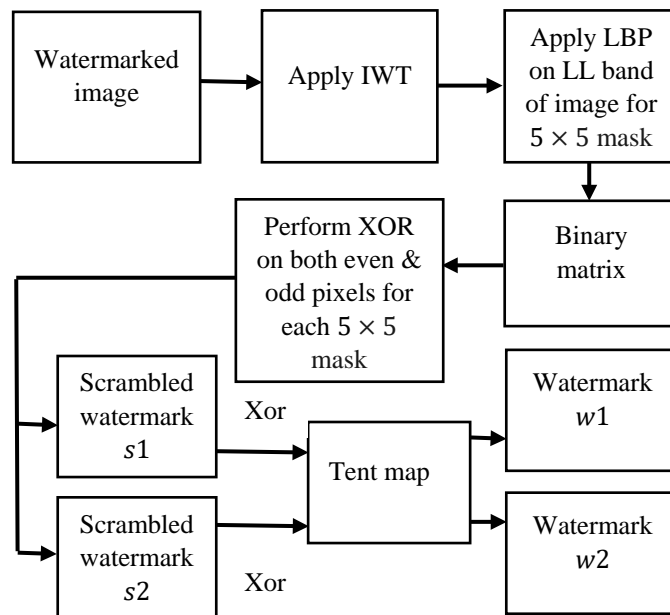
Figure 4: Block diagram for extracting procedure

b) Extraction Procedure

In this section, we will discuss about the extraction procedure of proposed method. In the extraction part, two watermark images are extracted from the watermarked image. First two scrambled watermarks $s1 \& s2$ are generated, then performing the XOR operation with tent map, the extracted watermarks $w1 \& w2$ are again generated. The whole procedure is shown in Fig. 2 and also illustrated in the following algorithm:

Whole procedure is shown in Fig. 4. and also illustrated in the following algorithm:

1. IWT is applied on the watermarked image to find approximation coefficient band
2. LBP is again applied on watermarked $CA1$ band
3. For each 5×5 mask, all even and odd pixels are found and apply XOR operation on them
4. For each 5×5 mask, for both even and odd XOR outputs,
   If XOR output is 1, store 1; otherwise store 0
   The outputs are the extracted scram bled
5. Tent map is XORed with both s1 & s2 to obtain extracted watermarks $w1 \& w2$ again

This procedure is repeated for different values of scaling factor.

IV. Experimental Result

In this section, the performance analysis of this proposed scheme has been discussed. We have implemented our proposed technique using MATLAB 2014 and used some test images and two watermarks for embedding. The host image is taken $(M \times N)$ dimension. After applying IWT, dimension of LL band has become half of host image, i.e. $(m \times n)$. So, the size of watermarks is taken as one-fifth of the LL band that means $(m/5 \times n/5)$ as the mask size is taken (5×5). Tent map is used in this technique to generate random numbers which are converted to binary numbers and then reshaped to a matrix of size $(m/5 \times n/5)$. This output is used to scramble the two watermarks. For performing the XOR condition between tent map and sample image, it is important to take their dimension equal. If their dimensions don't match, XOR operation will not take place. After performing XOR between the Tent map and sample image, a scrambled image is generated. For performing the XOR condition between tent map image and sample image, it is important to take their dimension equal. If their dimensions don't match, XOR operation will not take place.
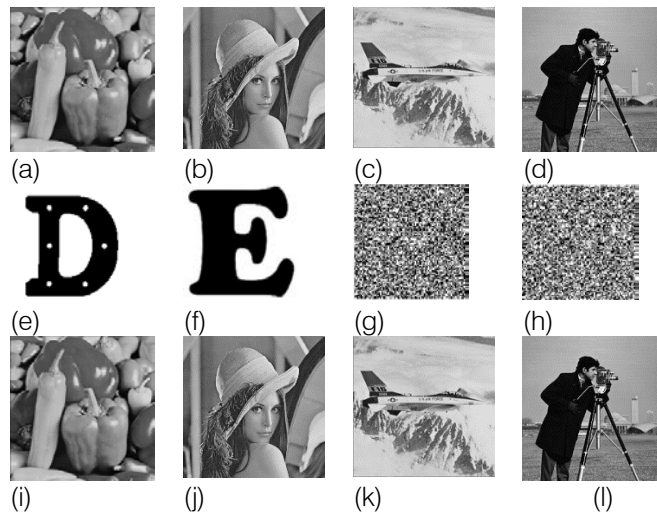
Fig. 3: (a-d) Test images; (e) Watermark $w1$; (f) Watermark $w2$; (g) Scrambled watermark $w1$; (h) Scrambled watermark $w2$; (i-l) Watermarked images: (i) Pepper (PSNR 46.74 dB), (j) Lena (PSNR 45.43 dB), (k) Jet plane (PSNR 44.74 dB), (l) Cameraman (PSNR 44.38 dB).

MSE means mean square error that can be defined as cumulative squared error between the watermarked image and original image. PSNR is the measure of peak to peak error of image that is measured in terms of logarithmic decibel scale. With the increase of MSE of an image, PSNR value decreases. For $M \times N$ image, they can be calculated as following:

$$\text{MSE} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} [x(i,j) - y(i,j)]^2 \qquad (3)$$

$$\text{PSNR} = 10\log_{10}\left[\frac{\max^2}{\text{MSE}}\right] \qquad (4)$$

Table 1: Performance parameters for test images $(k = 1)$

Image	PSNR(dB)	MSE	NC
Peppers	46.74	1.2571	1
Lena	45.43	1.7902	1
Jet plane	44.74	2.1812	1
Cameraman	44.38	2.3945	1

Table 2: PSNR (dB) values for different scaling factor

Scaling factor	Peppers	Lena	Jet plane	Cameraman
$k = 1$	46.74	45.43	44.74	44.38
$k = 2$	46.31	45.06	44.42	44.11
$k = 3$	45.87	44.68	44.07	43.83
$k = 4$	45.42	44.29	43.73	43.54
$k = 5$	44.97	43.90	43.37	43.23
$k = 6$	44.52	43.52	43.02	42.93
$k = 7$	44.09	43.14	42.69	42.62

Normalized correlation describes the congruity between two images. NC for any image is always 1 when no attack is added. When any attack is added to an image, this value decreases according to amount of noise. NC is calculated by:

$$NC = \frac{\sum_{x=1}^{M} \sum_{y=1}^{N} (W(x,y) \times W'(x,y))}{\sum_{x=1}^{M} \sum_{y=1}^{N} W(x,y)^2} \tag{5}$$

W and W' are original watermark and extracted watermark, respectively. M and N are rows and columns of the watermark image.

Table 3: NC values of two watermarks after adding noises

Noises	Peppers		Lena		Jet plane		Cameraman	
	W1	W2	W1	W2	W1	W2	W1	W2
Salt & pepper (var = 0.001)	0.9758	0.9743	0.9756	0.9765	0.9753	0.9765	0.9739	0.9768
Gaussian (var = 0.001)	0.9939	0.9940	0.9971	0.9965	0.9918	0.9889	0.9942	0.9945

Table 4: NC values of two watermarks after geometric attacks

Geometric attacks	Peppers		Lena		Jet plane		Cameraman	
	W1	W2	W1	W2	W1	W2	W1	W2
Cropping (middle)	0.9883	0.9978	0.9737	0.9931	0.9860	0.9968	0.9827	0.9971
Cropping (upper right)	0.9787	0.9767	0.9802	0.9800	0.9772	0.9978	0.9805	0.9808
Cropping (bottom left)	0.9937	0.9980	0.9928	0.9961	0.9943	0.9953	0.9938	0.9967

Table 5: NC values of two watermarks after image processing attacks

Image processin attacks	Peppers		Lena		Jet plane		Cameraman	
	W1	W2	W1	W2	W1	W2	W1	W2
Histogram equalization	0.9503	0.9498	0.9760	0.9768	0.9387	0.9409	0.9362	0.9356
Sharpening	0.9957	0.9964	0.9916	0.9916	0.9943	0.9944	0.9877	0.9909
Contrasting	0.9655	0.9654	0.9168	0.9256	0.9681	0.9669	0.9452	0.9484

Test images, watermarks, scrambled watermarks and watermarked images with corresponding PSNR values are shown in Fig. 3. The PSNR, MSE and NC values of four test images are demonstrated in Table 1. Varying the scaling factor k, different PSNR values are obtained which are listed in Table 2. From the both Table 1, it is observed that, peppers image gives the highest PSNR value for all the values of k. Changing the scaling factor from 1 to 7 indicates rigidness of our proposed method because PSNR values of this scheme is fluctuating very little. With increasing this value, PSNR decreases gradually. In Peppers image, maximum PSNR is 46.74 dB, obtained for $k = 1$. This value decreases at 45.87 dB for $k = 3$. and finally it is 44.09 dB when $k = 7$. same phenomena happen for all the test images.

Performance parameters as PSNR and NC are also observed after adding some noises as attack. Variation of the value of NC is noticed for different attacks because for adding noises, images become little distorted. That means, some pixel values may change in the extracted watermarks. To check the rigidness of this

technique, attacks as Salt & pepper noise, Gaussian noise, Cropping, histogram equalization, image sharpening and contrasting are added to the watermarked image and then watermarks are then extracted. Normalized correlation between the original watermark and extracted watermark for Salt & pepper noise (0.001) and Gaussian noise (0.001) are observed in Table 3. These values are fluctuating according to test images. Lena image gives the better NC values for both watermarks 0.9971 and 0.9965, for Gaussian noise. Here, watermark 1 gives better result than watermark 2. But in peppers image, watermark 1 gives smaller value 0.9939 than watermark 2, i.e. 0.9940. Lowest value is 0.9889 for second watermark of Jet plane image. For Salt & pepper noise, NC values are decreased. In this case, watermark 2 of all the images gives better NC than watermark 1 except Peppers image. Geometric attack is also added to the watermarked image. Three types of cropping as: middle, bottom left and upper right are applied and their corresponding NC values for the both watermarks are shown in Table 4. Among these attacks, bottom left gives better NC values for both the watermarks. Overall values of bottom left are better than other two attacks. Peppers and Cameraman images gives higher NC. Image processing attacks are also added as histogram equalization, image sharpening and contrasting in Table 5. In image sharpening, the NC value is better in watermark 2 than watermark 1for all the test images. For example, w1 gives0.9873 NC value in Lena image and w2 gives 0.9916. But in image contrasting, watermark 1 gives better values for most of the test images such as; for Jet plane image, w1 gives 0.9681 and w2 gives 0.9669. Lena image gives lowest NC values for both watermarks among all the images; 0.9168 and 0.9256. Cameraman image gives lowest NC values for histogram equalization; w1 gives 0.9362 and w2 gives 0.9356 among these three attacks, image sharpening shows better performance for all the test images.

Salt & pepper — Extracted w1 — Extracted w2

Gaussian — Extracted w1 — Extracted w2

Contrasting — Extracted w1 — Extracted w2

Cropping(middle) — Extracted w1 — Extracted w2

Sharpening — Extracted w1 — Extracted w2

Histogram equalization — Extracted w1 — Extracted w2
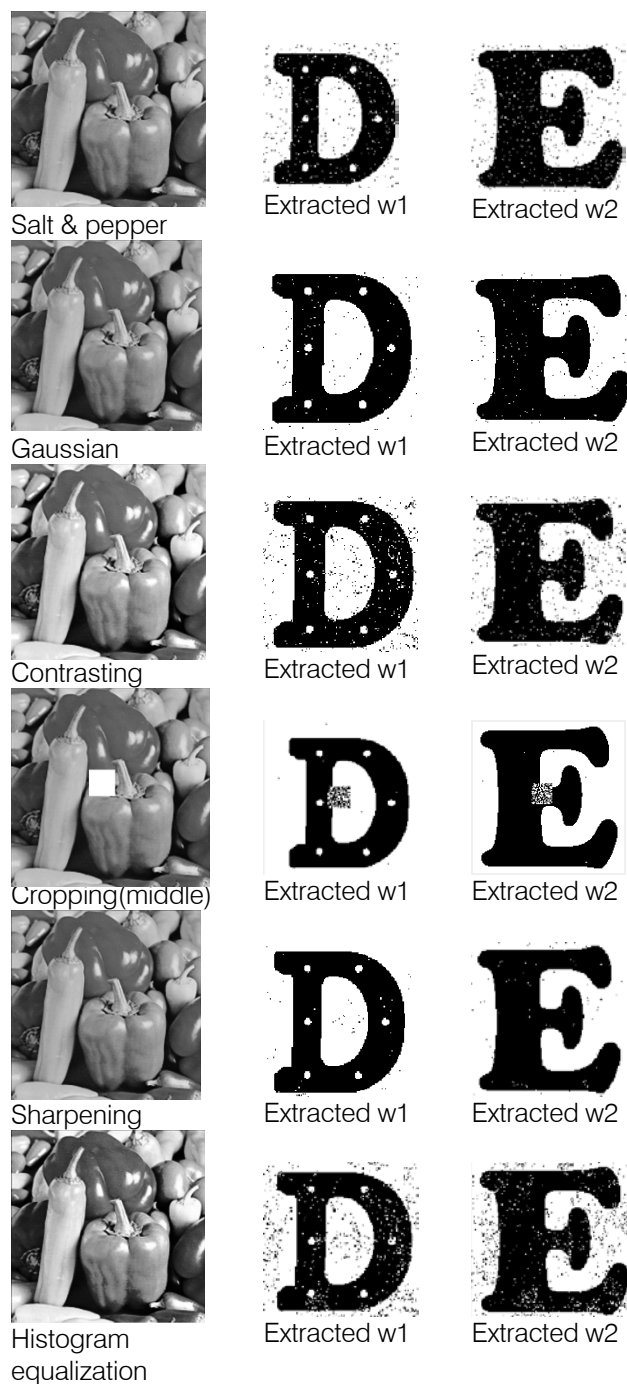
Figure 4: Peppers watermarked image and two extracted watermarks with various noise

Figure 5: Lena watermarked image and two extracted watermarks with various noise

Figure 6: Jet-plane watermarked image and two extracted watermarks with various noise

Salt & pepper — Extracted w1 — Extracted w2

Gaussian — Extracted w1 — Extracted w2

Contrasting — Extracted w1 — Extracted w2

Cropping(middle) — Extracted w1 — Extracted w2

Sharpening — Extracted w1 — Extracted w2

Histogram equalization — Extracted w1 — Extracted w2

Figure 7: Cameraman watermarked image and two extracted watermarks with various noise

Table 6: Comparison of the scheme with scheme [10] considering NC values

Attacks Types	Scheme [10]		Proposed Scheme (W2)	
	Lena	Peppers	Lena	Peppers
Gaussian noise (var=0.001)	0.6454	0.6483	0.9965	0.9971
Cropping (middle)	0.7018	0.7674	0.9931	0.9978
Contrasting	0.6782	0.6457	0.9256	0.9654

Table 7: Comparison of the scheme with scheme [11] considering NC values

Attacks Types	Scheme [11]		Proposed Scheme (W2)	
	Jet-plane	Peppers	Jet-plane	Peppers
Gaussian noise (var=0.001)	0.7174	0.8689	0.9889	0.9971
Cropping (middle)	0.8530	0.8844	0.9968	0.9978
Contrasting	0.7463	0.7127	0.9944	0.9654

Fig. 4 Shows the Peppers image with six different attacks and its corresponding extracted watermarks. For cropping (middle), extracted watermarks are very similar to the original image. For contrasting and histogram equalization, extracted watermarks are little bit distorted than other attacks. In Peppers image, watermark 2 seems to be better than watermark 1. Fig. 5.Shows the Lena image with attacks and its corresponding extracted watermarks. For contrasting and histogram equalization, both the watermarks are little distorted. In this figure, cropping (middle) gives better extracted watermarks again. Watermark 2 seems to be better than watermark 1 in this figure also. Same attacks are applied on jet-plane and cameraman images which are demonstrated in Fig. 6 and Fig. 7, respectively. Table 6 and Table 7 demonstrates the comparison of the scheme in terms of robustness test for Lena and Peppers images. NC values of watermark *W2*are used for comparison with schemes [10] and [11].

V. Conclusion

In this paper, a dual level robust watermarking scheme has been introduced with the combination of integer wavelet transform, local binary pattern and tent map. IWT has made this method more robust and faster computability than any others transformation. Embedding procedure is conformed to odd and even pixel positions of host image with two watermarks. PSNR of the test images are varied according to change of scaling factor. For checking the rigidness of this method, image sharpening, histogram equalization, cropping, salt & pepper noise, gaussian noise and image contrasting are added to watermarked image. The output normalized correlation values show robustness of the method. We have also compared PSNR values with an existing method that exhibits remarkable results.

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Thermal Stress Analysis of BGA Packaging Structure

By Tasneem Khan Shifa & Dr. Md. Faruque Hossain

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Abstract- In this paper the performance of the ball grid array (BGA) electronic packaging is investigated. The fields of temperature and stress are analyzed for the overall model &for solder balls by finite element method (FEM) usingCOMSOL Multiphysics 5.2a soft ware to analyze different aspects to improve the reliability & efficiency of integrated chip. The simulation result shows that the maximum value of temperature and thermal stress are 41 degree Celsius &199MParespectively.The maximum temperature is obtained on the chip surface and the maximum stress happens on the outside corner of the ball joints. The range analysis shows that the maximum stress increases with the increase of chip thickness, substrate width, ball pitch, CTE but the value of maximum stress decrease with the increase of ball diameter and Poisson's ratio.

Keywords: ball grid array (BGA), finite element method (FEM), thermal stress analysis, simulation.

GJRE-F Classification: FOR Code: 290903p

THERMALSTRESSANALYSISOFBGAPACKAGINGSTRUCTURE

Strictly as per the compliance and regulations of:

Thermal Stress Analysis of BGA Packaging Structure

Tasneem Khan Shifa[α] & Dr. Md. Faruque Hossain[σ]

Abstract- In this paper the performance of the ball grid array (BGA) electronic packaging is investigated. The fields of temperature and stress are analyzed for the overall model & for solder balls by finite element method (FEM) using COMSOL Multiphysics 5.2a soft ware to analyze different aspects to improve the reliability & efficiency of integrated chip. The simulation result shows that the maximum value of temperature and thermal stress are 41 degree Celsius &199MParespectively.The maximum temperature is obtained on the chip surface and the maximum stress happens on the outside corner of the ball joints. The range analysis shows that the maximum stress increases with the increase of chip thickness, substrate width, ball pitch, CTE but the value of maximum stress decrease with the increase of ball diameter and Poisson's ratio.

Keywords: *ball grid array (BGA), finite element method (FEM), thermal stress analysis, simulation.*

I. Introduction

In recent years, the volume of a new developed electronic device has reduced by more than three orders of magnitude compared with several years ago. Thus, it is very important to research an efficient electronic packaging form to improve the efficiency and reduce the cost [1]. The electronic packaging technologies have developed to control a large amount of heat that is generated through the integrated circuit (IC) and match the coefficient of thermal expansion (CTE) between different parts of packaging materials. Among various advanced forms of packaging, ball grid array (BGA) becomes one of the most promising packaging technologies due to its higher efficiency, smaller geometry size, lower cost [2]. However, among all the factors leading to the failure of the electronic device, such as vibration, humidity, loading& temperature affects mostly.

Furthermore, because electronic packaging consists of different CTE materials, the thermal stress emerges during the working cycle due to the expansion between adjacent materials which fails the products. Therefore, it is necessary to find appropriate materials combination to lower the thermal stress. To guarantee the stability of integrated chip, the packaging material should have characteristics like strength and stiffness to prevent stress deformation and other features such as high gas tightness, low density, radiation protection and low Cost [3].

A significant number of literatures are published about the BGA packaging. Luo [4] developed an analytical thermal resistance network model to calculate mean die temperature of a typical BOA packaging which is demonstrated to be accurate in predicting the temperature distribution. Z. Sauli, V. Retnasamy, R. Vairavan, K. Anwar, and N. Abdullah [5] analyzed the stress response of BGA solder with the different material during maximum vertical loading using the simulation method. The results showed that the Normal BGA demonstrated a higher stress response. Q.Gao, K.K. Wang [6] studied the thermal field and stress field distribution when chip worked on a given power. The results showed that the influence on the temperature and stress decreased with the increasing heat convection coefficient. K.K. Wang, L. Wang, L. Wang, Y.Z. Wang [7] studied the influence of different materials and boundary conditions on the temperature distribution. The results showed that the packaging temperature rose up faster at the beginning of the simulation than that at the end and high convection significantly reduced the maximum temperature. Also, adhesive thickness had an impediment on heat transfer due to the package temperature slightly rose as the thickness of adhesive increases. S.F. Popular [8] studied the reliability of flip chip BGA package based on the finite element method (FEM) parametric analysis. L.L. Mercado, V. Sarihan, Y.F. Guo, and Mawer [9] applied FEM parametric analysis to study the reliability of flip chip BGA, and the design parameters including solder bump layout, solder bump center to die edge, solder material/geometry, die size as well as substrate size/material. W. Chen [10] investigated the test methodology for assessing reliability performance of both single chip BGA& multiple chips flip-chip BGA on board assemblies. B. Rosner, J. Liu, and Z. Lai [11] developed a thermal cycle testing experiment for the flip chip BGA packaging &a daisy chained test IC was designed for the packaging reliability testing.

The fields of temperature and stress are analyzed for the overall model & for solder balls by finite element method (FEM) by COMSOL Multiphysics 5.2a software.

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II. BACKGROUND

a) Pin Grid Array

Pin grid array (PGA) is a package with one face covered with pins is in a grid pattern. It is placed in a printed circuit board (PCB) and carry out electrical signal between integrated circuit & printed circuit board (PCB).PGAs are often mounted on printed circuit boards using the through hole method or inserted into a socket [12].

b) Ball Grid Array (BGA)

A ball grid array (BGA) came from the Pin grid array (PGA) in which there are pads instead of pins on the bottom of the package and a tiny solder balls stuck to each of the pads. The device is placed on a PCB with copper pads in a pattern that matches the solder balls. The assembly is then heated which melts the balls & the melted solders hold the package with the circuit board. Then the solder cools down and solidifies& forms soldered connections between the device and the PCB [13].

III. EXPERIMENTAL PROCEDURE

a) Finite Element Method (FEM)

The finite element method (FEM) is the dominant discretization technique in structural mechanics. To deal with a large problem, it subdivides a large problem into smaller, simpler parts that are called finite elements. The simple equations are used to model these finite elements and they are then assembled into a larger system of equations that models the entire problem.

b) Geometry Model

A typical 3-D model BGA structure with 16 solder joints with the diameter 0.3 mm are placed on the substrate and connect the electronic chip & one-quarter model is imported into simulation software COMSOL Multiphysics 5.2a to reduce the calculating time. Figure 1 shows the model,

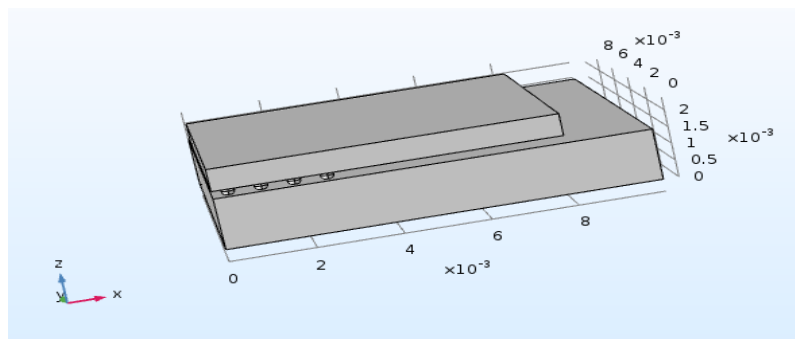*Figure 1:* Simplified quarter BGA model

Table 1 shows a comprehensive geometry size of BGA,

Table 1: BGA Dimension

Component	Size (mm)
Chip	8×8×0.65
Ball Grid	0.3
Substrate	10×10×1.5

c) Meshing

The BGA model meshed with 7318 number of domain elements shown below,
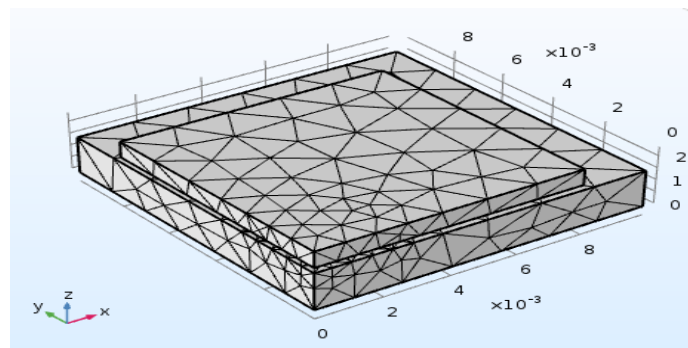
Figure 2: The mesh result of the BGA model

d) Chosen Material & Parameters

Materials used in the BGA mode were homogeneous and isotropic, they were adhesive to Each other & pre-stress between them was ignored. The following table 2 shows the material parameters.

Table 2: Material Parameters

Component	Chip	Ball grid	Substrate
Material	Si	Sn-Pb	Epoxy
Thermal Conductivity (W/m.K)	120	30	0.2
CTE	2.6	24.5	18
Poisson's ratio	0.28	0.35	0.38

The environment temperature is 25 °Cand the power of the chip is 0.2 Watt. The convective heat coefficient between the chip and substrate is 10W/(m^2.k) [14]. The thermal stress analysis is conducted on the base of the thermal results obtained above.

is on the surface of the chip and the minimum temperature is on the substrate. The heat generated by the chip transfers to the substrate via the solder joints. Also, the heat also dissipates to the surrounding environment. Finally, a steady state is found.

IV. Simulation & Result Analysis

a) Temperature Field

Figure 3 shows the temperature distribution of BGA model. It indicates that the maximum temperature
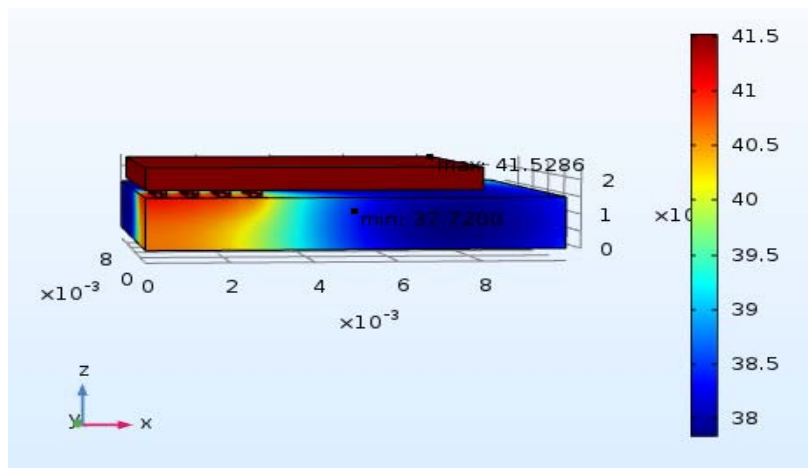
Figure 3: Temperature distribution in BGA
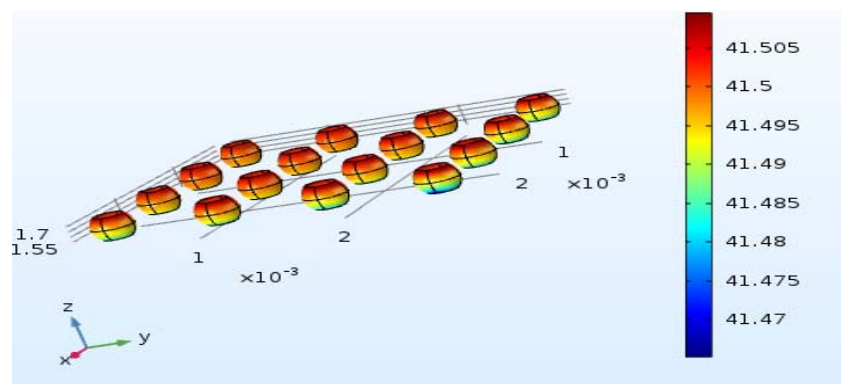
Figure 4: Temperature distribution of solder joints

In figure 4, it is seen that among all the sixteen ball grids, the ball grid farthest away from the center has the maximum temperature at the top surface and the minimum one at the bottom surface. So, this temperature difference makes it easier to produce defects like fatigue and cracks.

Figure 5 shows the temperature distribution of the substrate,
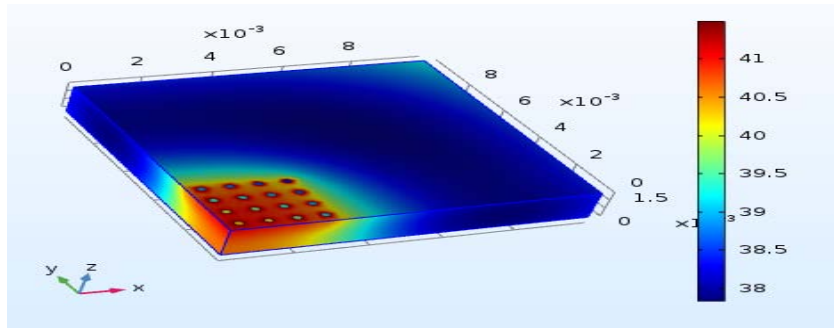
Figure 5: Temperature distribution of the substrate

From figure 4&5, it is seen that the maximum temperature of both ball grid array, chip & substrate reaches the maximum value at the corner far away from the center area because of the more heat dissipation via the solder joints, making the lower temperature at the center.

b) Thermal Stress Field

Figure 6 &7 shows the overall von misses stress distribution of BGA,
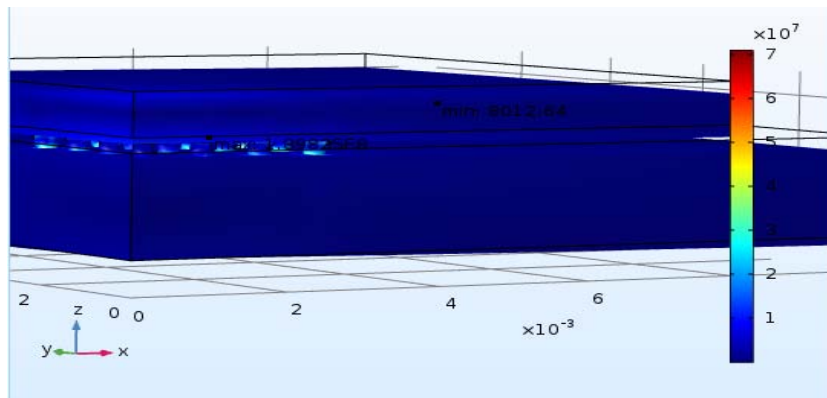
Figure 6: Von Mises stress field in BGA
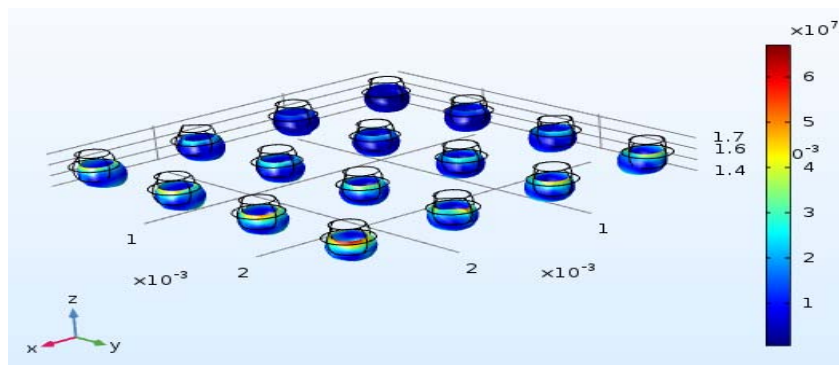
Figure 7: Von Mises field of solder balls

From figure 6, the maximum stress happens on the outside corner of the ball joints because of heat dissipation. From Figure 7, the solder joints have the highest stress value due to the higher thermal expansion coefficient than the substrate & the chip and the maximum & highest displacement of the solder joints happens in the same place with the maximum stress [14].

The maximum value of temperature and thermal stress are 41 degree Celsius & 199MPa respectively.

V. FACTORS INFLUENCING THERMAL STRESS

Maximum stress plays a significant role in affecting the reliability and efficiency of BGA packaging. Various factors were considered for optimization.

a) Influence of Ball Pitch
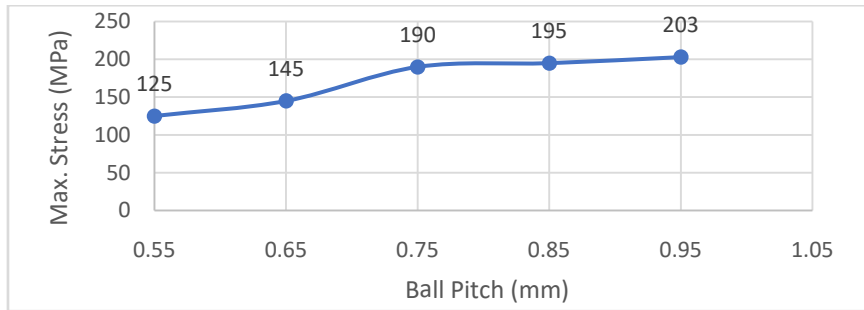
Figure 8: Influence of max. stress as a function of ball pitch

b) Influence of Chip Thickness
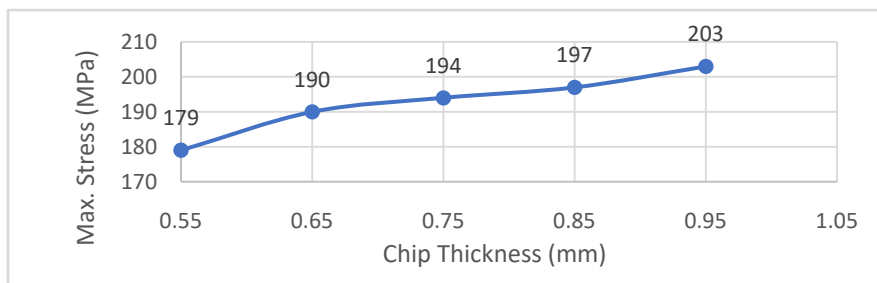
Figure 9: Influence of max. stress as a function of chip thickness

c) Influence of Substrate Width
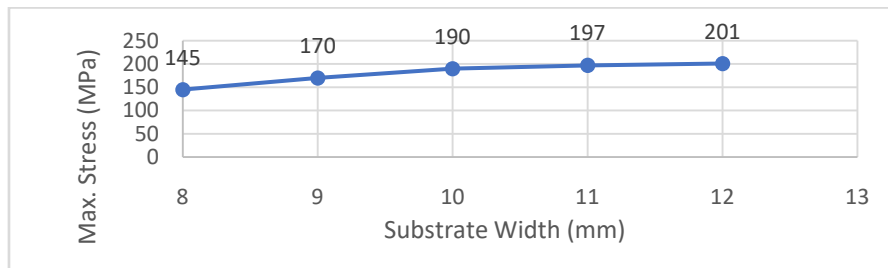
Figure 10: Influence of max. stress as a function of substrate width

In figure 8, 9 & 10, it is observed that with the increasing values of ball pitch, chip thickness& substrate width maximum stress increases because as value increases more heat is dissipated& heat transfers from chip to substrate via solder balls. Thus, temperature difference gets higher.

d) Influence of Ball Diameter
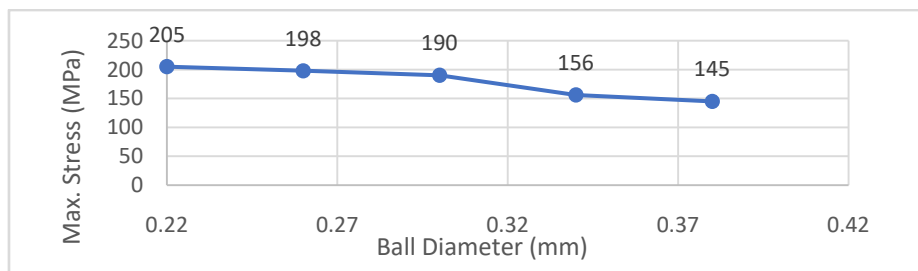
Figure 11: Influence of max. stress as a function of the ball diameter

Figure 11 shows that for higher values there is a notable decrease in maximum stress. With the ball diameter of solder balls getting larger, more heat is generated at chip & more heat is dissipated from chip to substrate through solder balls.

e) Influence of Poisson's Ratio
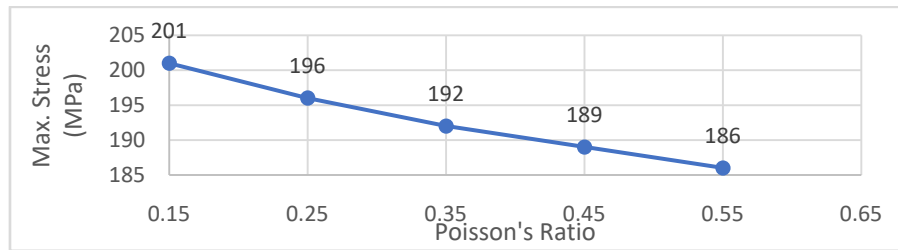
Figure 12: Influence of max. stress as a function of Poisson's ratio

Figure 12 shows that as the value of Poisson's ratio of solder balls increases, maximum stress decreases. Because for any given temperature distribution the thermal stresses are directly related to the Poisson's ratio.

f) Influence of Coefficient of Thermal Expansion
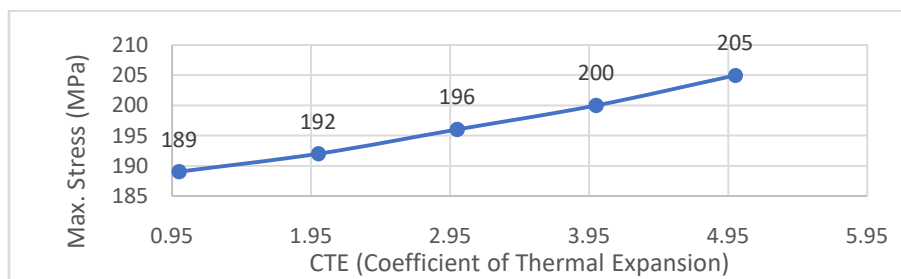
Figure 13: Influence of max. stress as a function of a coefficient of thermal expansion

From figure 13, it is observed that with the values of CTE increases, more heat is dissipated & maximum stress gets higher because heat dissipation increases exponentially with coefficient of thermal expansion.

The decreasing of the stress and temperature has a positive effect on the reliability & efficiency of BGA packaging. So, based on these values minimum stress can be obtained with a new series of parameters.

Several conclusions can be summarized as follows in the table:

Table 3: Results of factors range analysis

Ball pitch (mm)	0.55	0.65	0.75	0.85	0.95
Max. stress (MPa)	125	145	190	195	203
Ball diameter (mm)	0.22	0.26	0.3	0.34	0.38
Max. stress (MPa)	205	198	190	156	145
Chip thickness (mm)	0.55	0.65	0.75	0.85	0.95
Max. stress (MPa)	179	190	194	197	203
Substrate width (mm)	8	9	10	11	12
Max. stress (MPa)	145	170	190	197	201
Poisson's ratio	0.15	0.25	0.35	0.45	0.55
Max. stress (MPa)	201	196	192	189	186
CTE	0.96	1.96	2.96	3.96	4.96
Max. stress (MPa)	189	192	196	200	205

VI. CONCLUSION

In this paper, the typical BGA packaging is modeled and simulated using COMSOL 5.2a Multiphysics. Several conclusions are summarized as follows:

a) The maximum temperature is found on the chip surface. The maximum stress happens on the outside corner of the ball joints. The maximum value of temperature and thermal stress are 41 degree Celsius & 199MPa respectively.

b) The maximum stress increases with the increase of chip thickness, substrate width, ball pitch, CTE but the values of maximum stress decrease with the increase of ball diameter and Poisson's ratio.

c) Considering different values for different factors of BGA geometry structure, it is observed that the geometry size of the substrate & chip and different material parameters of solder balls plays a significant role in influencing the temperature and thermal stress.

In future work, by using these different factors, a standard BGA model can be designed where maximum stress can be lowered and also can be more reliable and efficient.

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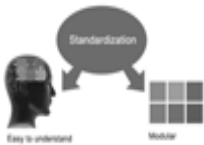
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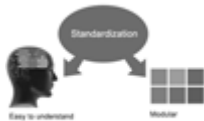
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Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

PREPARATION OF ELETRONIC FIGURES FOR PUBLICATION

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

TIPS FOR WRITING A GOOD QUALITY ENGINEERING RESEARCH PAPER

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

INFORMAL GUIDELINES OF RESEARCH PAPER WRITING

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

o Single section and succinct.
o An outline of the job done is always written in past tense.
o Concentrate on shortening results—limit background information to a verdict or two.
o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

o Explain the value (significance) of the study.
o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

o   Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
o   In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
o   Present a background, such as by describing the question that was addressed by creation of an exacting study.
o   Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
o   Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

o   Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
o   Do not include raw data or intermediate calculations in a research manuscript.
o   Do not present similar data more than once.
o   A manuscript should complement any figures or tables, not duplicate information.
o   Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

o   You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
o   Give details of all of your remarks as much as possible, focusing on mechanisms.
o   Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
o   One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
o   Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

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Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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