Development of Methodology and Instrument for Measuring Dry Rubber Content in Latex Using Microwave Techniques

Piti Sunheem

A Thesis Submitted in Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Physics
Prince of Songkla University
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I hereby certify that this work has not already been accepted in substance for any degree, and is not being concurrently submitted in candidature for any degree.

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ชื่อวิทยานิพนธ์ การพัฒนาวิธีการและเครื่องมือในการวัดเนื้อยางแห้งในน้ำยางโดยใช้เทคนิคทางไมโครเวฟ

ผู้เขียน นายปิติ สันหีม

สาขา ฟิสิกส์

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บทคัดย่อ

งานวิจัยชิ้นนี้มีวัตถุประสงค์เพื่อศึกษาวิธีการวัดค่าเนื้อยางแห้ง (DRC) ในน้ำยางธรรมชาติที่ได้ผลอย่างรวดเร็วและมีความแม่นยำ โดยใช้หลักการการส่งผ่านของคลื่นไมโครเวฟและอาศัยหลักการดูดกลืนคลื่นไมโครเวฟจากโมเลกุลของน้ำที่อยู่ในน้ำยางเพื่อหาค่า DRC ในน้ำยางได้ ในการศึกษาครั้งนี้จะใช้สายอากาศแบบท่อนำคลื่นสี่เหลี่ยมในการส่องผ่านคลื่นไมโครเวฟเข้าไปในน้ำยางที่วางอยู่ระหว่างสายอากาศภาครับและภาคส่ง และจะวัดความเข้มของคลื่นไมโครเวฟที่ทะลุผ่านน้ำยางออกมาด้วยตัววัดสัญญาณ จากการทดลองเพื่อสร้างสมการถดถอยโดยใช้น้ำยางที่มีค่า DRC ในช่วง 10.26% - 60.63% พบว่าสมการถดถอยที่แสดงความสัมพันธ์ระหว่างค่าการลดทอนของคลื่นไมโครเวฟกับค่า DRC ของน้ำยางนั้นจะมีค่าสหสัมพันธ์ดีที่สุด คือ 0.9996 เมื่อใช้คลื่นไมโครเวฟที่ความถี่ 2.36 GHz โดยนำสมการที่ได้ไปคำนวณโดยใช้ไมโครคอนโทรลเลอร์เป็นตัวอ่านค่าประมวลผลเพื่อวัดค่า DRC จากการนำเครื่องวัด DRC ต้นแบบที่สร้างขึ้นไปทดลองวัดค่า DRC จากน้ำยางจำนวน 26 ตัวอย่างและเปรียบเทียบผลที่ได้กับการวัดด้วยวิธีมาตรฐานแบบอบแห้ง พบว่าค่าเฉลี่ยความคลาดเคลื่อนสัมพัทธ์ในช่วง DRC 30%-40% และ 60% มีค่า 0.016 และ 0.001ตามลำดับ และค่าสหสัมพันธ์ระหว่าง DRC ที่ได้จากเครื่องวัดที่สร้างขึ้นกับวิธีมาตรฐานมีค่า 0.9983 ซึ่งจากผลการทดลองแสดงให้เห็นว่าเครื่องวัด DRC ต้นแบบที่สร้างขึ้นมีประสิทธิภาพที่ดีและสามารถวัดค่า DRC ได้อย่างแม่นยำ

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ABSTRACT

An accurate, quick and practical method for measuring the dry rubber content (DRC) in natural rubber latex is proposed and investigated experimentally, based on microwaves transmission technique. The concept exploits the microwave absorption of water molecules to infer the DRC. However, various design aspects had to be experimentally investigated. In this study, rectangular waveguide antennae were used for microwave transmission. The latex was placed between two antennae, and the signal was measured by power detector. A calibration curve was fit with least squares regression for sample DRCs ranging from 10.26% to 60.63%. The best linearity with 0.9996 correlation between attenuation and DRC was obtained at 2.36 GHz. The power detection of microwave and the fitting equation are executed by the microcontroller for the calibration and calculation. To validate the prototype of DRC meter, 26 local rubber latex samples were measured both with the slow reference gravimetric determination of DRC that involves oven drying, and with the rapid microwave transmission technique. It was found that the mean relative errors in latex from 30% to 40% and the 60% concentrated latex are 0.016 and 0.001 respectively, and an 0.9983 correlation to the gravimetric DRC. The experiment results are shown that the prototype of DRC meter results is a good accuracy performance.

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Piti Sunheem

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CHAPTER 1

INTRODUCTION

1.1 Introduction of Dry Rubber Content Determination

Para rubber is a significantly industrial drop of Thailand with making a large number of incomes to the agriculturists. At present planting Para rubber trees has not been considered as only an occupation in the southern part and the eastern part but also the north-eastern part, where about hundred thousand of areas represent their stability, covering its expanding to the northern part as well. In the past the majority of rubber tappers preferred to transform latex into rubber sheets before selling them to the rubber merchants. But nowadays selling rubber latex is an alternative for them. Additionally they sell not only in rubber sheets but also waste tire rubber cups including the increasing number of needs of Para rubber in industrial factories. With its advantages, the reasons why the rubber tappers prefer selling it from rubber latex to rubber sheets are that they do not have to pay for the materials and equipments in making rubber sheets, such as coagulation troughs, acetic acid, woven wire filter, a smooth roller and groove roller machine, etc., and they do not waste time in making rubber sheets since they can receive the money from selling latex within 24 hours after trading, which is different from selling in rubber sheets that needs to take around 5-10 days for drying up before selling. Trading latex depends on the quantity of dry rubber content (DRC) in latex. To measure the quantity of DRC is to measure the percent of DRC in rubber latex by calculating from the proportion of 100 rubber latex and comparing DRC value in it. This always causes the delay of displayed results and imprecise or highly inaccurate values from its measurement. The reason is that the results depend on testers who are the rubber buyers and determine the quality and price of rubber latex. The rubber tappers cannot participate in examining the DRC measurement because they lack of knowledge and a simply-used instrument in the measurement of DRC of themselves to compare with the one is measured by the rubber merchant. It is highly possible that they are taken advantages and cheated by the rubber merchants.

Natural rubber latex (NRL) is a natural product that comes from the fluid contained in the tissue under the bark of *Hevea Brasilienesis* rubber trees. The characteristics of NRL are white liquid, milk-like substance, its density is approximately 0.98 g/cm^3. The component of NRL consists of rubber particles 30-40%, 55-65% water, and non-rubber substances approximately 5-9% (Poh, 1989). The rubber particles and water are the main composition in NRL comparing with other content. For market trading, the amount of rubber particles in NRL has to be known, and it can usually be shown by DRC. The definition of DRC is the ratio of the mass in grams of dry rubber substance and the mass in 100 grams of rubber latex (Zhao *et al.*, 2010). The DRC of fresh rubber latex are different according to the season, tapping system, weather, soil conditions, strain of the trees and chemical stimulation. It is important not only for market value but also the manufacturing process of rubber products. The price of rubber latex is strongly related with the DRC. Therefore, it should be measured the DRC before trading.

DRC measurement methods can be obtained from direct and indirect technique. The direct one is a standard drying method (ISO 126-2005) that is to coagulate a known mass of sample latex with 2% acetic acid. The coagulated sample is then changed into a sheet and dried in a hot air oven at 70° C ± 5° C for about 10-12 hours; determines DRC of the sample latex as a ratio between the mass of rubber sheet after drying and the mass of sample latex. This is the most accurate method. However, this method is not suitable for the field's use because of the following reasons. First, the oven drying process is time consuming that requires a considerably over night. Second, according to the first reason, payments cannot be refunded to the tappers on one day. Last but not least, the experiment setting has to be done in only the laboratory.

The indirect one is the measurement of physical properties of rubber latex, and it is a rapid technique, for instances density measurement (Metrolac) (Tillekeratne *et al.*, 1988; Schulz *et al.*, 1984), a titration technique (Alex *et al.*, 2003), microwave resonant frequency (Somwong *et al.*, 2008), capacitive transducer (Kumar *et al.*, 2007), ultrasonic pulse (Kerdtongmee, 2014), NMR pulsing (Kumar, 2009), light refraction (Zhao *et al.*, 2010), microwave reflection (Khalid, 1992; Khalid, 1995; Mohammadi, 2012) and microwave transmission (Khalid, 1982; Chung, 2007; Abbas *et al.*, 2001; Jayanthy, 2005). The mentioned methods have pros and cons but we are focusing only on microwave techniques. Microwave resonant frequency technique was ignored in this study because of its requirement for a complex microwave system in order to fine the resonant frequency. The Microwave reflection technique is; however, simpler. It is based on the measurement of the dielectric permittivity of rubber latex because the DRC depends directly on the dielectric permittivity. The Vector Network Analyzer (VNA) is used to connect to an open-ended coaxial probe, which is a transmitter for launching the microwave signal to the rubber latex and detecting the reflected signal back at the same probe. The reflection coefficient, which relates to the dielectric permittivity of the rubber latex, is then calculated using the ratio between the reflected and incident signals. The problem with this method is that the rubber latex must be sufficiently thick and the surface contact of the probe and the sample has to be flat and free from bubbles or air gaps. The probe durability is also an issue, as the probe has to be dipped into the sample causing the probe to be easily damaged. The transmission technique, on the other hand, requires no dipping, sample touching nor the precise probe angle; hence, avoiding the problem of the reflection technique. For these reasons, the transmission technique was selected.

Microwave transmission technique is based on the dielectric constant of water which influences much higher than the non-water substances in the rubber latex. Khalid (1982) has studied in the determination of dry rubber content of *Hevea* latex by microwave technique. This study has developed portable Latexometer by using microwave technique for determining the DRC of rubber latex. This technique is based on the same principle used for determination of moisture content. Instead of measuring the water content, he measured the solid content of the material. The meter consists of a Gunn diode oscillator, transmitting, receiving horns, and a detector. A microwave signal at 10.7 GHz, 10 mW is generated by the Gunn diode which is located in a rectangular waveguide cavity. The detector is made up of a receiver horn, coaxial adapter, detector diode, and an amplifier. In order to measure the attenuation the transmitter horn and receiver horn are set facing each other in a horizontal plane.

The latex is filled in a Perspex cell and placed in a horizontal position in the gap between these horns. The cell is placed in a horizontal position to ensure uniform density of the latex. The microwave power is measured by a detector and displayed on the voltmeter. The correlation coefficient between the DRC determined using this instrument and the reliability of standard laboratory method is 0.998 and the standard deviation is less than 0.7%. Although the results of this equipment are accurate which the total error is approximately 1% compared to the standard method, it is expensive for Gunn diode oscillator and cannot show the real time resulting in DRC digital output. Mohammadi (2012) has developed the microwave reflection system to measure solid content of rubber latex composing of microcontroller, open-ended coaxial probe, and dual directional coupler. An open-ended coaxial probe and low-cost stripline dual directional coupler are simulated, designed and connected to microwave sources and detectors. TSC parameter is determined from the relationship between moisture content in the rubber latex and the reflection coefficient value from coaxial probe. The system of this study was tested by the sample latex with various TSC and a comparison between the results of standard method and this microwave reflection system was shown a good agreement in accuracy at the level of less than 1%. However, the probe has to contact with the surface and sample dipping causing the probe to be damaged easily. In contrast, transmission microwave techniques do not require to contact the sample and the information collected obtained from the whole sample volume. The advantages of microcontroller such as small size, high speed in analyzing data, the real time result in digital output, and multi-task capability, are appropriate for a portable measurement system of DRC in rubber latex. The research focuses on a low-cost and infield DRC determination solution. For these reasons, transmission microwave techniques and microcontroller were selected.

The purposes of this research are: to design a DRC meter for rapid DRC determination in rubber latex which consist of rectangular waveguide, power detector, and microcontroller; to determine the optimal frequency for the device; and to compare DRC results between a DRC meter and standard method.

1.2 Objectives of the Study

1. To design the microwave transmitting and receiving antenna system.
2. To study a relationship between DRC and microwave transmission.
3. To design and invent a DRC meter for rapid DRC determination in rubber latex by using a microcontroller.
4. To compare DRC results between a DRC meter and standard method.

CHAPTER 2

LITERATURE REVIEWS

2.1 Dry Rubber Content Determination

Hevea latex is a natural biological liquid consisting of the complicated compositions. Rubber hydrocarbons comprises of non-rubber substances, such as lutoids, carbohydrates, proteins, lipids, and inorganic salts, and others (Nair *et al*., 1993). The DRC of latex is different according to season, tapping system, weather, soil conditions, clone, age of the tree etc (Chin, 1979). The DRC or Total Solid Content (TSC) of the latex must be tested to guarantee fair prices for latex commercial exchange. DRC is measured in grams of rubber presenting in 100 g of latex (Kuriakose, 1992). Generally, the rubber industries are familiar with this latex DRC. This is due to the industries will firstly consider the latex properties in processing the rubber- made products , trading, and even in selling- buying rubber trees. It is a valuable parameter in production process of rubber where the DRC of rubber latex and the amount of chemical additives needed for the production of rubber and latex products are determined and a quick evaluation of yield for academic purposes. The significance of DRC is not only when it comes to industries based on latex/rubber processing, but also the DRC or TSC measurement is the automatic process control in latex based on industries. A DRC sensor is an essential device for direct interfacing to the computer system for automation of the industrial process (Khalid, 1982). The most accurate method for the determination of DRC is by the standard laboratory drying. However, this method is time consuming and not suitable for fieldwork. Numerous methods have been cited in literature for the measurement of the DRC of latex, of which the hydrometer is probably the most rapid one, even though its accuracy is limited by a wide range of conditions encountered in practice, which include biodeterioration, adulteration, dilution, aeration and warming. For latex, the average error of the measurement is about 4% of the value estimated by the standard procedure, which compares with the oven dry weight of a sample of rubber coagulated from the 10g sample of latex. The Spot Method is favorite one to determine DRC in many laboratories which uses an accurate weighing balance to weigh a 0.3 g latex sample and acidified with acetic acid. Then the coagulated rubber is processed in different forms such as a sheet and dried steam oven which presented a percentage of the original mass. The measurement time is about 30 minutes, with an error of about 1% (British Standard, 1972).

Other methods that have been reported for DRC determination include indirect method. This indirect method is a quick and simple process which is used in measuring the natural properties of rubber latex. In other words, the indirect method is a density measurement called Metrolac (Tillekeratne *et al*., 1988), light refection (Zhao *et al*., 2010), a titration technique (Alex *et al*., 2003), capacitance technique (Kumar *et al*., 2007), microwave resonant frequency (Somwong *et al*., 2008), microwave reflection (Khalid, 1992; Mohammadi, 2012) and microwave transmission (Khalid, 1982; Chung, 2007; Abbas *et al*., 2001). The method of DRC determination both direct and indirect ones are shown as below.

2.1.1 The standard laboratory method

The standard test procedure to obtain DRC is based on British standard. The procedure is based on the Malaysian Standard MS 3:35:1975 entitled Methods of Sampling and Testing Concentrated Natural Rubber Latices, the British Standard BS 1672:1972 entitled Methods for Testing Natural Rubber Latices, the American Society for Testing and Materials (Khalid *et al*., 1989). The general procedure in the laboratory is to coagulate a known weight of representative sample of the latex with dilute acetic acid, sheet the coagulum, and dry the sheet at a temperature of 70° C ± 5 °C until it has no white patches. If the sheet is dried on a watch glass, carefully turn it over two or three times during the first few hours of drying. Allow to cool it in desiccators for 30 min and weigh. Repeat the operations of drying, cooling and weighing until the loss in mass is less than 1 mg after heating for 30 min (Bureau of Indian Standards, 2003). The DRC of the latex is, therefore, the percentage by weight of the dry sheet over the weight of latex tested from equation.

$$DRC = \frac{m_1}{m_0} \times 100 \qquad (2.1)$$

Where m_0 is the mass, in grams, of the test portion;

m_1 is the mass, in grams, of the dry sheet.

This method, however, has its limitations and is not suitable for field use owing to the following reasons.

(1) The fieldwork with no electricity is impossible to operate this method. This is because the operation requires a laboratory with an analytical balance, electrical oven and water bath.

(2) A heavy capital is required in investment to establish an electricity and equipment. In addition, it is far from the capacity of small holders and many small establishments.

(3) The drawback of this method is that it requires an operator who are skillful to operate and maintain the laboratory equipment.

(4) The results of this method test cannot be suddenly obtained because it for overnight for test sample to get dry.

(5) Payments are very high for the tappers due to the reason cited as (4) above.

(6) It takes more than 16 hours for the whole method operation that is beyond the ability of the trapper to process. The tappers need not accept the test method adopted. (Rubber Research Institute of Malaysia, 1973)

2.1.2 The hydrometer method

The hydrometer usually known at rubber plantations by name, Metrolac, Latexometer or Simplexometer, are commonly used as the easiest method of obtaining an approximate estimate of the DRC of latex and this has been reviewed by many researchers. Metrolac is essentially a hydrometer which measures the density of rubber latex. The density varies according to the amount of rubber present. The Metrolac instrument presents a reading scale of the valid content of the rubber in grams per litre (Kumara, 2006). One part of the field latex is mixed with two parts of water. Then the diluted latex is filled in a tall cyclindical jar normally with a 7.5 cm diameter. The air bubbles and froth floating on the surface of the latex are removed and blown. The metrolac is freely submerged in the latex and allowed it to come to be motionless without moving any interior of the vessel. The reading on stem is shown. The DRC of the latex is measured by multiplying the reading by three (due to two parts of water are added) and dividing by ten. Even though this method is simple and rapid, it is not really much accurate. The error from the method processing could be found around 5 to 10 percent. Therefore, to minimize the error, a correction factor is used in assessing the DRC of the latex in actual laboratory.

The measurement errors are due to the following reasons. First, the density of the rubber particles in latex is not precisely known, it varies with what we choose to define rubber. Available evidence indicates that the density of purified rubber at 29°C is about 0.902 to 0.9035. It should be recognized that this is to be taken only as an empirical value for this purpose in hand, and not as an unbiased estimate of the true density of rubber. Second, the serum in latex is not a single substance like water, but is a solution of mixed ingredients, proteins and salts; and unfortunately there is no satisfactory evidence to show how its density varies between different estates, clones, season etc. However, available evidence suggests that serum density is not directly correlated to DRC of latex (Rhodes, 1939)

2.1.3 The light technique

Recently laser technique and spectral measurement technique have been widely used in the component content measurement of a sample. For example, Zhao *et al*. (2008) used spectral analysis technique to measure the component content of the blood. Guo *et al*. (2005) presented the light-cured material based on laser technique. Togersen *et al*. (2003) studied the chemical composition of semi-frozen ground beef using near infrared spectroscopy technique. Zhang *et al*. (2008) investigated the composition analysis of food using near infrared spectroscopy with double detector. Simultaneously, some self-made measurement instruments relative to spectroscopy measurement are also used in component analysis, for examples, the portable spectroscopy measurement instrument based on AOFT is put forward by Bi *et al*. (2005). As the photoelectric technology is developed, the cheap LED can make a beam of the light with high precision even without the light source. Besides, the price of high- performed amplifier for amplifying weak photocurrent signals reduces gradually.

Zhao *et al.* (2010) designs a new system for measuring dry rubber content in the concentrated rubber latex. According to the principle Lambert, the reflectivity of samples will be different when the dry rubber contents of samples are different. Chemical stances of samples composing C-H, N-H and O-H functional groups will make characteristic absorption. The concentration of tested composition goes in line with the logarithm of the reciprocal of transmittance in the characteristic absorption wavelength according to Lambert- Beer law.

$$\log\left(\frac{1}{T}\right) = Kbc \qquad (2.2)$$

c is the concentration of composition tested in the sample. K is the absorptivity related to the wavelength of the incident light and the temperature of the sample. b is the length of the colorimetric dish. T is the transmittance- the ratio of transmitted light intensity to incident intensity, and the following is its definition,

$$T = \frac{I_t}{I_o} \qquad (2.3)$$

Where; I_0 is the incident intensity of monochromatic light, while I_t is the intensity of emergent monochromatic light. The measurement system consists of annular photoelectric sensor, laser diode, distance detector, two-stage amplifier module of weak photocurrent signal, signal conversion module, microprocessor, data storage, data display module and key module. The dry rubber content in the sample affects the scattering and reflection of the incident light, and the output photocurrent of the sensitive module increases as the dry rubber content increases at constant sample temperature. According to this principle, the light source of the system is composed of multi-LED with emergent light obliquely incident to the surface of the sample. The lifting stage and distance detector are used to fix the distance between sensitive module and the surface of the sample because the surfaces of samples in the vessel are different when changing samples. Finally, the weak signal is amplified by the two-stage amplifier module and then it is sent to the microprocessor. An indirect measurement method is used in the system, that is, it needs to establish the standard equation in advance and the microprocessor calculates the equation with the real-time data in order to obtain the dry rubber content.

2.1.4 The capacitance technique

The simplest capacitor consists of two sheets of metal foil separated by a thin film of dielectric such as air, oil, plastic, mica, paper, ceramic, or metal oxide. An advantage of a capacitor is its ability to store electrical power for a period of time and then to release the stored charge when needed. Its capacity is defined by the amount of electrical power that a capacitor is able to store in each unit between metal plates. The capacity of a condenser can be increased by placing between the plates a dielectric material.

An elementary parallel plate capacitor consists of two conducting plates, electrically isolated from one another by an insulating medium. The capacitance (C) of this elementary capacitor is proportional to the cross - sectional area A of the plates, the permittivity (or dielectric constant K) of the insulating medium and the reciprocal of the separation, t, between the plates. The relation is given by

$$C = K\left(\frac{A}{t}\right) \tag{2.4}$$

If the area of the plates and the separation between them are kept constant, the capacitor's capacitance is directly proportional to the dielectric constant or the medium permittivity. If there is a direct relation between the DRC and dielectric constant of latex, then the same relationship holds good for the capacitance and ORC of rubber latex, if used as the dielectric. Hence it is possible to calculate the DRC of latex by measuring the capacitance of latex using capacitance techniques (Kumar *et al.*, 2009).

2.1.5 The microwave technique

The factor of related to nonmagnetic materials which explains their interaction with an electromagnetic field, is the relative complex permittivity $\varepsilon = \varepsilon' - j\varepsilon''$, where ε' is the dielectric constant and ε'' is the imaginary part known as the loss factor. The concept of permittivity is closed to the electrical conductivity in which it associates with charge separation rather than current to applied electric field. Ions or electrons are the sample materials that have no free charge carriers, and they still pass current when a voltage is applied. In other words, moving charge is the result of energy from the voltage source that has been drawn. The permittivity is ability of a material to polarize in an applied electromagnetic field. As the frequency of the applied field increases, the molecules cannot re-orient completely before the electromagnetic field reverses. The orientation of permanent dipoles no longer contributes to the dielectric constant and it is dissipated as heat. Physically, the dielectric constant shows the capacity of a material to store electric energy whereas dielectric loss shows the loss of electric field energy in the material. Furthermore, the material dielectric constant not only depends on the concentration and activity of permanent electric dipole molecules but also on the dipole alignment degree with the varying time electric field applied. The latex dielectric constants are strongly affected by the water quantity in rubber. This is due to that dipole molecules contained in water will have a very strong orientation of polarization. When the microwave transmits in the wet material, the microwave electric field will affect water molecules (Hongliang, 1992).

The principle of microwave technique is in fact based on the water permittivity is much higher than that of solid substances in the latex. The value of water permittivity is defined about $\varepsilon_W = 60 - j0.34$, while the permittivity of solid material is about $\varepsilon_S = 2.3 - j0.02$ at room temperature and at microwave frequency 10.7 GHz. This means that the absorption coefficient of microwaves due to water is higher than that due to solid substances. Therefore, the higher is the water content, the higher is the attenuation of microwaves. So microwave absorption technique can be used to determine TSC and DRC of latex. However, non-rubber substances in latex samples vary with clone, soil condition, season, weather etc. Therefore, the accuracy of low power microwave technique is affected by variations in non-rubber substances

(Kumar *et al.*, 2009).

2.2 Dielectric Properties of Rubber Latex

Hevea latex, a polar molecule, contains water as its main component. When the Hevea latex is in electric field, both positive and negative charges occur. That is charge from polar molecule will transpose across to one another. As a result, the molecules of water tend to rotate their selves, and this causes of aligning the dipoles into the field. This phenomenon of polarization of dipoles is known as the dielectric constant of the medium, where ε' is the circumstance storing the electromagnetic charge. In terms of the dielectric loss, ε'', it is defined as the circumstances dissolving and converting the electromagnet energy into heat. Furthermore, the water content and geometrical shape of water extensively affect the dielectrically properties of liquid.The water molecules are basically assumed that they are in forms of ellipsoid.

In dielectric materials, basically the charge carriers are bound without the electrical conduction. Nonetheless, when external electric field is applied, those bound charge carriers might be withdrawn. This circumstances rises a dipole filed opposing the applied field and the material is polarized. In a linear isotropic medium, the polarization of volume density is directly associated with the applied electric field intensity. Electric field intensity D is associated the polarization density and the electric field intensity as follows.

In dielectric materials,

$$D = \varepsilon_0 E + P = \varepsilon E = \varepsilon_0 \varepsilon_r E \qquad (2.5)$$

Permittivity of materials is called ε and known as the dielectric constant of the materials. When electric field is varied, in a material medium two kinds of currents are produced. Conduction current is generated when free charges flow and the bound charges induce a displacement current. Those all conduction and displacement density currents are called total current density. Thus

$$J_T = \sigma E + j\omega\varepsilon E = j\omega\varepsilon^* E \qquad (2.6)$$

where $\varepsilon^* = (\varepsilon - j\sigma/\omega)$ is known complex dielectric constant

$$\varepsilon^*/\varepsilon_0 = (\varepsilon/\varepsilon_0 - j\sigma/\omega\varepsilon_0) = \varepsilon' - j\varepsilon'' \qquad (2.7)$$

$$\varepsilon^* = \varepsilon'(1 - j\tan\theta) \qquad (2.8)$$

$\tan\theta$ is the electrical power that lost in dielectric processes stored per cycle and called as loss tangent. (Jayanthy *et al*, 2005).

Dielectric properties of materials are generally generated from measurements of reflection known as transmission coefficients and in some instances from both (Baker *et al*., 1990). Free-space transmission techniques have been widely used for dielectric characterization, particularly since recent advances in microwave components and instrumentation have made them more convenient. These techniques are in various forms. They are nondestructive and contactless. Also, the sample preparation is not much required. Not only is that, at high temperature, the measurement easy to make.

The basis of latex dielectric properties at various temperatures is required to determine the different absorption of microwave energies in latex during microwave heating. Such properties are also essential in modeling the electromagnetic wave propagation and interaction in latex, especially in estimating the effect of temperature on the microwave latexometer (Khalid 1994). Furthermore, Julrat *et al.* (2012) studied the DRC determination by microwave reflection technique which considered the effects of temperature on a sample and can be developed into a simple. Several kinds of latex properties were measured with a full range of in-field temperatures. The results of this study show that the dielectric constant of latex decreased as temperature is on increase and the dielectric constant is mainly related to the DRC, with a small variation with temperature. In other words, it is the fact that the dielectric constant is dominated throughout the processes of dipolar. When temperature increases, the factors causing dielectric loss are on decrease at low DRC. Besides, when the content of rubber latex continually is on increase, the dielectric loss factor is free from temperature. Thus, it can be said that the DRC is the related causes of dielectric constant and dielectric loss factor.

2.3 Wave Propagation in Dielectric Materials

Waves are the processes transferring information or energy. Electromagnetic waves transport energy through a vacuum in outer space with 2.99×10^{8} ms^{-1} speed. The waves are the results of vibration of an electric charge which induced both electric field and magnetic field. The electromagnetic waves include radio waves, TV signals, microwave, infrared, light rays, and radar beams. When electromagnetic is propagated through dielectric materials, the energy will lose. This is the cause of the poor conduction. Thus the speed of energy is less than 2.99×10^{8} ms^{-1}.

Wave propagation in dielectric materials can be derived from Maxwell's equations by assuming and suppressing the time factor e^{jwt}.

$$\nabla \cdot E_s = 0 \tag{2.9}$$

$$\nabla \cdot H_s = 0 \tag{2.10}$$

$$\nabla \times E_s = -j\omega\mu H_s \tag{2.11}$$

$$\nabla \times H_s = (\sigma + j\omega\varepsilon) E_s \tag{2.12}$$

taking the curl of both sides of Eq.(2.11) gives

$$\nabla \times \nabla \times E_s = -j\omega\mu \nabla \times H_s \tag{2.14}$$

applying the vector identity

$$\nabla \times \nabla \times A = \nabla(\nabla \cdot A) - \nabla^2 A \tag{2.15}$$

to the left-hand side of Eq.(2.14) and invoking Eq.(2.9) and Eq.(2.12), we obtain

$$\nabla^2 E_s - \gamma^2 E_s = 0 \tag{2.16}$$

where

$$\gamma^2 = j\omega\mu\left(\sigma + j\omega\varepsilon\right) \tag{2.17}$$

and γ is called the propagation constant (in per meter) of the medium. By a similar procedure, it can be shown that for the *H* field,

$$\nabla^2 H_s - \gamma^2 H_s = 0 \tag{2.18}$$

Eq.(2.16) and Eq.(2.18) are known as simply vector wave equation. Since γ in Eq.(2.16) to Eq.(2.18) is a complex quantity, we may let

$$\gamma = \alpha + j\beta \tag{2.19}$$

and we obtain α and β from Eq.(2.17) and (2.19)

$$\alpha = \omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1+\left[\frac{\sigma}{\omega\varepsilon}\right]^2} - 1\right]} \tag{2.20}$$

$$\beta = \omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1+\left[\frac{\sigma}{\omega\varepsilon}\right]^2} + 1\right]} \tag{2.21}$$

where α is the attenuation constant or attenuation factor of the medium, it is a measure of the spatial rate of decay of the wave in the medium, measured in nepers per meter (Np/m) or in decibels per meter (dB/m). The quantity β is phase constant or wave number (Sadiku, 1995). From Eq.(2.20) give the general expression for the loss tangent, $\tan\theta = \dfrac{\sigma}{\omega\varepsilon}$, in dB/m

$$\alpha = \frac{17.37\pi}{\lambda}\sqrt{\frac{\varepsilon}{2}\sqrt{1+\tan^2\theta} - 1} \tag{2.22}$$

when $\tan^2\theta << 1$, Eq.(2.22) becomes

$$\alpha = \frac{8.686\pi}{\lambda}\sqrt{\varepsilon}\tan\theta \qquad (2.23)$$

from Eq.(2.23), it shows that α is related to ε. Therefore, dielectric constant can be determined by measuring the attenuation of electromagnetic waves propagating in dielectric materials medium (Ahmad *et al.*, 2012).

2.4 Attenuation

2.4.1 Attenuation Phenomena

Attenuation or extension (called in some other contexts) is a process that flux gradually loss its intensity through a medium. For example, dark glasses can attenuate sunlight, lead attenuates X-rays, and water attenuates light and sound. In the fields of electrical engineering and telecommunication, attenuation occurs in the processes of waves and signals preparation in optical fiber and in radio waves.

Ultrasound can also be attenuated its ultrasound beam in which to be reduced its signal amplitude. This affects the quality of images produced by ultrasound. Therefore, in order to gain the ultrasound quality images, factors causing ultrasound attenuation should be considered. That is to adjust the input signal amplitude so that to reduce any loss of energy (Stewart *et al.*, 1991).

- Similar to emulsion and colloids, ultrasound attenuation is a complex system that gives in information on particle size distribution. ISO standard is also required on this technique.
- In extensional rheology measurement, ultrasound attenuation can be used by employing Stokes' law for measuring the viscosity of extensional and volume.

In water where light attenuation occurs, shortwave radiation produced from the sun has the visible spectrum of light wavelengths from 360 nm (violet) to 750 nm (red). When the sun radiation approaches the water-surface, the wavelengths will be attenuated by the water. This makes the light intensity is on decrease rapidly depending on the depth of water. Beer- Lambart Law is used in calculating the light intensity in depth. The longest wavelengths will be absorbed first. As a result, in clear open water, the visible light, red, orange, and yellow wavelengths are absorbed at higher water depths. Blue and violet wavelengths approach the deepest in the water column because these wavelengths are last absorbed comparing with others. Therefore, open and clear water is shown in deep- blue to the eyes. Different from water near coastal shore, the water contains much phytoplankton that can absorb the light. The plants themselves spread the light, and this is the result of the water near shore less clear. Chlorophyll-a can absorb light most strongly in the shortest blue and violet wavelengths of the visible spectrum. Thus, in the water near coastal where much phytoplankton, at the deepest water column the green wavelengths approach and this cause the water appeared in green- blue or green.

In addition, attenuation can also occur because some specific wavelengths are selectively absorbed as the color appearance. Both electron and molecules are the main material factors as follows:

- At the electronic level, the electron orbitals can cause of the rise of colors. That is, it depends on whether the electron orbitals are spaced or not. If such that they are able to absorb a quantum of light of a specific wavelengths in the ultraviolet (UV).
- At the molecule level, the frequencies of molecule vibration or chemical bounds, the close- pack of molecules, and its exhibition in long- range order will affect the capacity of wavelengths to transmit the long wavelengths like the infrared (IR), far IR, radio, and microwave ranges.

The absorption of infrared (IR) selectively occurs on a particular material due to the light frequencies that matches with some particles of materials vibrated. Because different molecules have different natural vibration frequencies, those molecules specifically absorb different frequencies of spectrum of IR (Archibald *et al*, 1978).

All in all, the microwaves are the electromagnetic wave for frequencies ranging from 300 MHz to 300 GHz or the wavelengths from 1mm to 1m. When the microwave transmits in the hydrated material, the dipole of the water molecule having a strong polar is influenced by the electric field from microwave. The polarization of water molecules will be strongly orientated. The loss of microwave energy causes from polarization loss and the magnitude of energy loss depending upon the amount of water (Hongliang, 1992). When the microwave is sent into the latex, the attenuation resulted significantly from water rather than dry rubber molecules. As a result, the total solid content has less impact on the attenuation of the microwave power. By assuming the proportional relationship between the total solid content and DRC, a correlation between the DRC and the attenuated microwave power can be derived. When the microwave comes into the loss medium, the input power of microwave shows an exponential decay effect with the decay constant (Pengfei, 2010), as show by equation:

$$P_2 = P_1 e^{-\alpha x} \tag{2.24}$$

In this equation, P_1 is the input microwave power (mW). P_2 is the microwave power after decay (mW). α is the decay constant, and x is the thickness of the medium (mm).

The extent of attenuation (A) is usually represented in units called decibels (dB). If P_s is the signal power at the transmitting end (source) and P_d is the signal power at the receiving end (destination), then $P_s > P_d$. The power attenuation A_p in decibels is given by the formula:

$$A_p = 10\log_{10}\left(\frac{P_s}{P_d}\right) \tag{2.25}$$

Attenuation can also be represented in terms of voltage. If A_v is the voltage attenuation in decibels, V_s is the source signal voltage, and V_d is the destination signal voltage (Margaret, 2006), then:

$$A_v = 10\log_{10}\left(\frac{V_s}{V_d}\right) \qquad (2.26)$$

2.4.2 The Attenuation Measurement Systems

Many different and ingenious ways of measuring attenuation have been developed over the years, and most methods in use today embody the following principles:

(1) Power ratio

(2) Voltage ratio

2.4.2.1 Power ratio method

The power ratio method of measuring attenuation is perhaps one of the easiest to configure. Fig. 2.1 represents a simple power ratio configuration. First, the power sensor is connected directly to the matching attenuator and the power meter indication noted P_1. Next, the device under test is inserted between the matching pad and power sensor and the power meter indication again noted P_2. Insertion loss is then calculated using

$$L(dB) = 10\log_{10}\left(\frac{P_1}{P_2}\right) \qquad (2.27)$$

Note that unless the reflection coefficient of the generator and load at the insertion point is known to be zero, or that the mismatch factor has been calculated and taken into consideration, measured insertion loss and not attenuation is quoted. This simple method has some limitations:

(1) Amplitude stability and drift of the signal generator

(2) Power linearity of the power sensor

(3) Zero carry over

(4) Range switching and resolution

Amplitude drift of the signal generator. Measurement accuracy is directly proportional to the signal generator output amplitude drift.

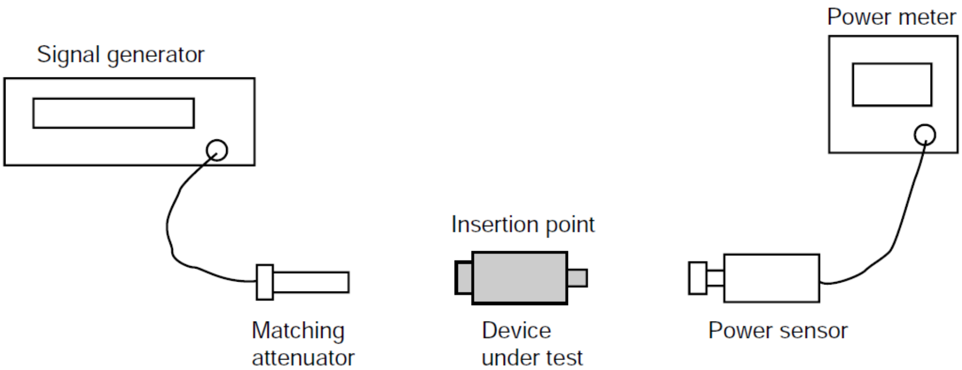

Fig. 2.1 Power ratio measurement system (Richard *et al.*, 2007)

2.4.2.2 Voltage ratio method

Fig. 2.2 represents a simple voltage attenuation measurement system, where a digital voltmeter (DVM) is used to measure the potential difference across a feed through termination, first when it is connected directly to a matching attenuator (V_1), and then when the device under test has been inserted (V_2). Insertion loss may be calculated from:

$$L(dB) = 20\log_{10}\left(\frac{V_1}{V_2}\right) \quad (2.28)$$

This simple system is limited by the frequency response and resolution of the DVM as well as variations in the output of the signal generator. The voltage coefficient of the device under test and resolution of the DVM will determine the range, typically 40–50 dB from dc to 100 kHz. A major contribution to the measurement uncertainty is the linearity of the DVM used, which may be typically 0.01 dB/10 dB for a good quality eight digit DVM. This may be measured using an inductive voltage divider, and corrections made (Richard *et al.*, 2007).

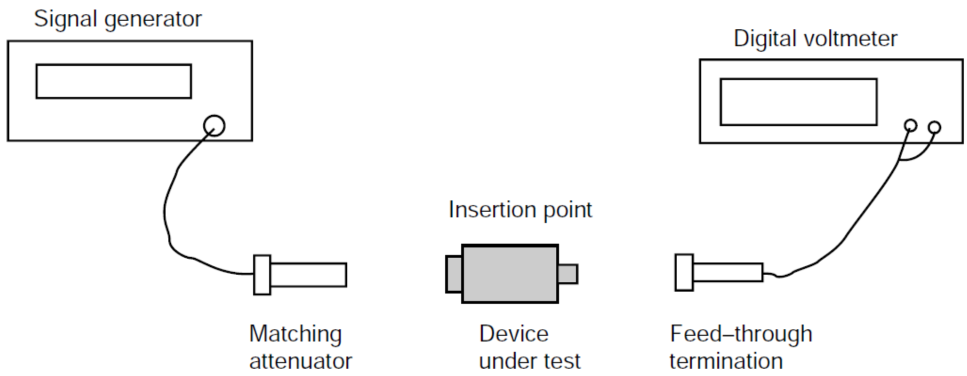

Fig. 2.2 Voltage ratio measurement system (Richard *et al.*, 2007)

2.5 Antenna

An antenna is a device that can convert electrical energy into electromagnetic waves. It is an important part of a radio system. An ideal transmitting antenna receives power from a source and radiates the received power into space. That is, electromagnetic (EM) energy escapes from the antenna and, unless reflected or scattered, does not return. A practical antenna, however, generates both radiating and non-radiating EM field components. An example of a non-radiating EM field component would be the portion of the accepted power that is returned to the source, or otherwise dissipated in a resistive load (McLean *et al.*, 2007).

Antennas are essential part for radio receiving and transmitting system such as cell phone, satellite communication, radar, communication receiver, two-way radio, broadcast television, radio broadcasting, as well as other devices used in daily life, for example, wireless computer network, baby monitor and radio-frequency identification (RFID) tags found on merchandise. An antenna typically consists of metallic arrangement conductor called element in order to transform electricity to electric magnetic wave or, in reverse, from electronic magnetic wave to electricity from transmitter to receiver. Magnetic field around antenna will be created by an oscillating current of electrons that forced through antenna by transmitter, and in the same time, an oscillating electric field along the element also will be created by the charge of electron. Then, the signal radiated away from antenna into space and created electromagnetic wave. In converse, when it receives the wave, the oscillating electric and magnetic field of an incoming radio wave exert force on the electrons in the antenna element, resulting them to move back and forth and create oscillating currents in the antenna.

According to its functional design, there are two types of antennas. The first one is antenna designed to transmit radio wave in horizontal direction (Omni-direction antenna) and, second one, antenna designed to transmit radio wave in a specific direction (directional or high gain antennas). For the specific direction antenna, it may require additional parts or surface without any electrical connection to transmitter and receiver such as parasitic elements, parabolic reflectors or horns that serve to direct the wave into a beam or other desired radiation pattern.

2.5.1. Dipole antenna

This kind of antenna, sometimes called hertz antenna, has been widely used since the early days of radio. Simplicity and effectiveness for a wide range of communications needs are the reasons for this. The dipole antenna has its name from its two halves-one on each side of its center. The poles of the antenna are symmetrical and make it a balanced antenna. The poles have equal length and they extend to opposite direction from their feeding point. In short, a dipole antenna is a type of antenna that made of wire and fed at its center as shown in Fig. 2.3.

In term of resonance, a dipole antenna must have electrically a half wavelength long at the operating frequency. Its resonance will happen at the lengths at which its impedance has no reactance only resistance at the certain wave frequency. As it turns out, that resonant impedance range is compatible with many common coaxial feed lines. Within limits, however, resonance isn't necessary for a dipole to be effective. Resonant half-way dipole range in size from about 16 feet for the 10 meter band (28-29.7 MHz) to 260 feet for the 160 meter band (1.8-2 MHz) (jame, 1991)

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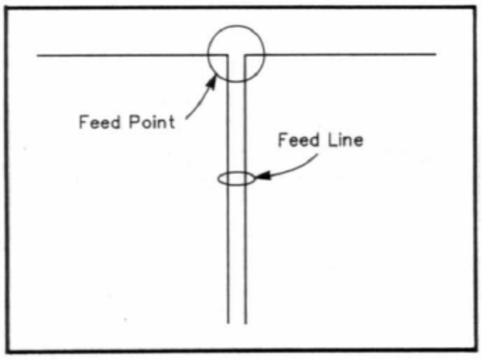


Fig. 2.3 A dipole is wire fed at its center (Jame, 1991)

A dipole has two straight wires or rods which they orient end to end on the same axis and having the feed line connected to adjacent ends. These two wires or rods which approximately have 1/4 wave length are the most common form of a dipole. According to theoretical point of view, dipole is simplest type of antenna. The half-wave dipole is the most common form of this kind of antenna. As it is a resonant antenna, the tool functions as resonator allowing standing radio wave current flowing back and forth between their ends. The length of the radio wave used determines the length of dipole (Winder *et al*., 2002).

Although the a dipole has half wave format, but there are other half wave antenna as follow (Ian, 2011);

- Half wave dipole antenna: This kind of half wave length dipole is the most widely used. It serves as resonant antenna.
- Multiple half wave dipole antennas: Dipole antenna can be utilized by an odd multiple of half wave length long.
- Fold dipole antenna: This kind of half wave antenna has its rod folded back and connected to each other. It retains the length between the ends of half wavelength.
- Short dipole antenna: This antenna is popular because it is much shorter than half wave length and provides many advantages. It has triangular distribution that feed impedance

starts to rise and respond less dependent upon frequency change.

- Non-resonant dipole antenna: A dipole can also be operated without resonant frequency and fed by high impedance feeder. With this characteristic, it is enabled to operate over much wider band width.

2.5.2. Yagi Uda antenna

This antenna is simply know as a Yagi antenna or Yagi. It is a directional antenna composed a dipole array and additional parasitic elements which usually has a reflector and one or more directors.

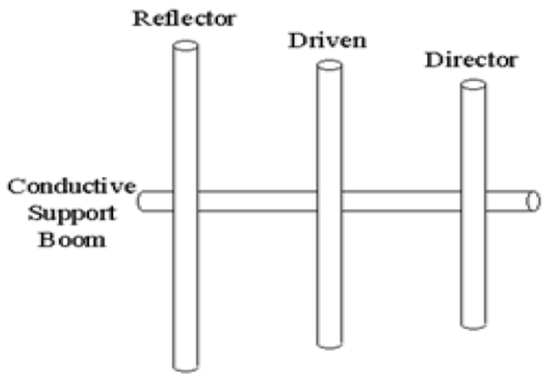


Fig. 2.4 Yagi-Uda Antenna Element (Ankit et al., 2013)

The Yagi Uda antenna with second dipole in array is the only key element to drive for input-output feeding source. The interaction of other element is conducted through mutual coupling and by sending and receiving electromagnetic energy. These elements work as parasitic element by induced current. Moreover, it is a device that passively works that can be used either for sending or receiving electromagnetic energy. It can also be applied with Yagi Uda antenna.

A directional antenna has high capacity in radiate power in one direction or more. This kind of antenna which is also called beam antenna performs high performance. It increase in transmission and reception and in contrast decrease performance from the sources unwanted. Same to directional antenna, Yagi-Uda also gives better performance comparing to dipole antenna in term of when radiation in a certain direction has high intensity. Radiation pattern is called lobes. These lobes can be found as major lobes, minor lobes, side lobes and back lobes (Ankit et al., 2013)

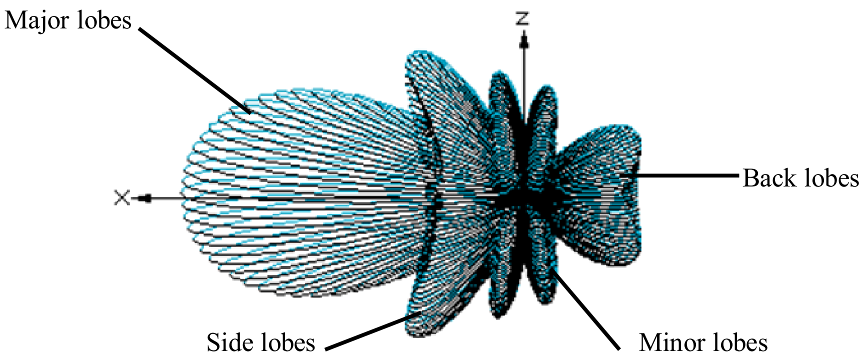


Fig. 2.5 Parts of Radiation Pattern (Peter, 2011)

The simple Yagi Uda has basic working principle which requires two parasitic elements attached behind Driven Element (DE). However there is also the antenna with only one parasitic element which happen in the case that electrical length is greater than the DE as shown in Fig 2.6.

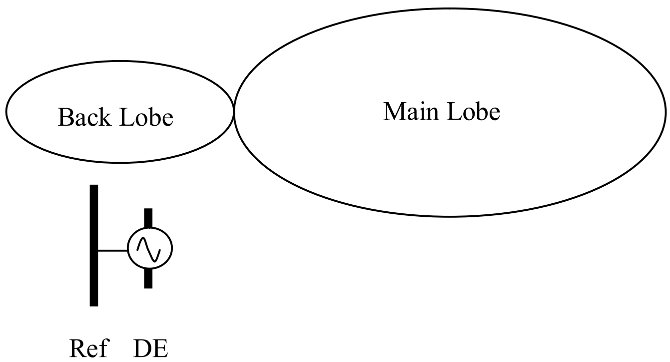


Fig. 2.6 Element Yagi (Reflector+Driven Element) (Ankit *et al*., 2013)

In the case that the driven element is longer than electrical length of parasitic element, its radiation pattern can be revered. The parasitic element will become a Director (D) which is always found in the two elements of Yagi Uda antenna as illustrated in Fig 2.7.

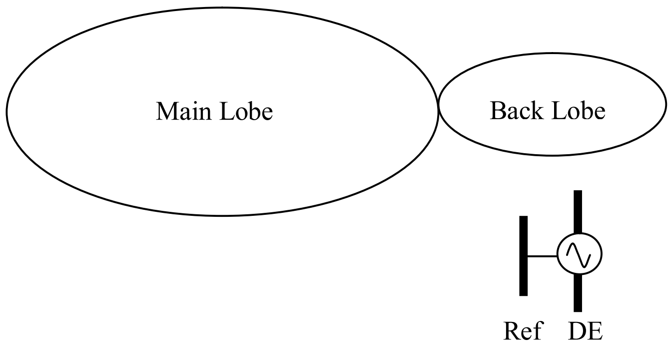


Fig. 2.7 Element Yagi (Director+Driven Element) (Ankit *et al.*, 2013)

Like the basic antenna, Yagi Uda antenna consists of driven element with director and reflector, and attached with beam gain (Fig. 2.8). Both director and reflector of Yagi Uda are attached to parasitic mode and they adjust the radiation parameter of driven element and array. From physical experimental it founds that to have an increasing gain can be done by narrowing the beam width of the dipole in a cheap manner and by the way of using simple metallic rod and made focus on electromagnetic energy in the desired direction.

Driven element requires one or more parasitic element to be attached axially in the front of it. These parasitic elements function as director. Like reflector, the directors (D1…Dn) have no direct wire to the feed point. More number of directors there increases the directivity because its beam receives the Yagi-Uda system array. However, with new technology and design, to increase the increase the impedance of banwidth more than one dipole can be done by applying the parasitic elements.

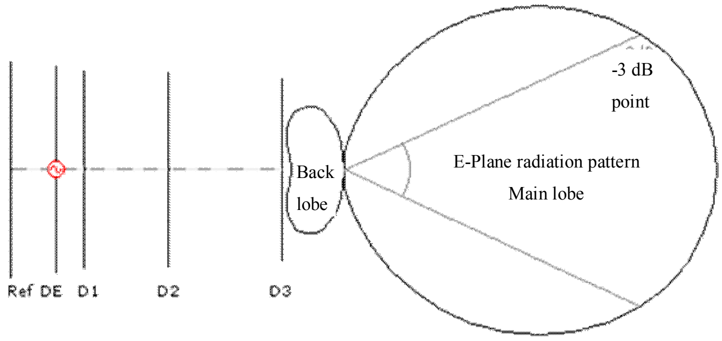


Fig. 2.8 Element Yagi (Reflector+Driven Element+Director)
(http://yagi-uda.com/yagi-uda_basics.php)

2.5.3 Parabolic antenna

A parabolic antenna is antenna with a parabolic shape applied as a reflector. This type of antenna is also called satellite dish antenna. The parabolic reflector is designed to send radio wave in certain direction. The antenna has high directivity. Like searchlight reflector, the reflector of a parabolic antenna functions to direct radio wave in narrow beam. It also functions as radio wave receiver from a particular direction. It can produce the narrowest beam widths and to achieve this, its parabolic reflector must be larger than the wavelength of the radio wave used. In the radio spectrum, the parabolic reflector antenna is used in high frequency at UHF and SHF frequency (Straw, 2000).

The parabolic antennas are designed to function as high gain antennas which are used in a wide range of point-to-point communication. They are taken to apply as microwave relay links which carry television or telephone signals between nearby area or cities. Communication through wireless WAN/LAN, satellite communication as well as spacecraft communication also use parabolic antennas. Moreover, the parabolic reflector antennas are used for radar antennas that require transmitting narrow beam of radio wave to identify the location of object like airplanes, ships as well we guided missile. As the result the spreading of satellite television, parabolic antennas are commonly seen as radio receivers.

Fig. 2.9 A parabolic satellite communications antenna
(http://en.wikipedia.org/wiki/Parabolic_antenna)

The parabolic antennas operate by the principle that a point source of radio wave will be reflected into collimated plane wave beam along the axis of the reflector. The radio wave is focalized at the focal point in front of parabolic reflector of the antennas. In converse, the incoming plane wave which parallel to the axis is focused to the focal point.

A parabolic antenna consists of parabolic shape reflector having a small feed antenna installed in front of the reflector and pointed back to the reflector. This reflector is made of metal that truncated in a circular rim which creates the diameter of the antenna. For a transmitting antenna, the radio frequency generated from transmitter is transmitted trough transmission cable to feed the antenna and converted it into radio wave. The radio wave then is sent back to parabolic reflector and reflects off into a parallel beam. In a receiving antenna, the radio wave bounced off parabolic reflector and went to a point at the feed antenna. The wave will be converted to electric current to radio receiver (Stutzman *et al*., 2012)

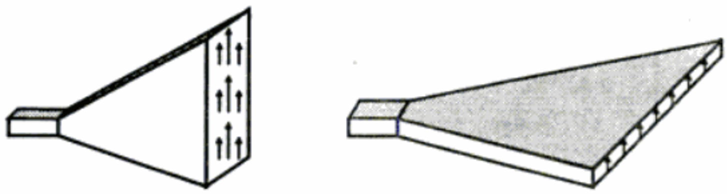
2.5.4 Horn antenna

A horn antenna which is also known as a microwave horn antenna consists of a horn shape flared metal with waveguide. The waveguide functions to direct the radio wave in a beam. The horn shape flared metal and waveguide are designed to work as feeders for larger antenna structure. For example, in the case of parabolic antenna, they are used as standard calibration antenna in order to measure the gain of other antennas. They are also used as radar guns for directive antenna. Moreover, the horn antenna is applied for door opener and microwave radiometer. The remarkable advantages of this type of antennas are they provide directivity gain and low standing wave ratio (SWR). They offer broad bandwidth and construction and adjustment .They are popular and widely used at above 300 MHz of microwave frequencies and UHF (Narayan, 2007).

The horn antenna is designed to transfer radio wave from its waveguide out to space, and in contrast, it also works as receptor of the radio wave and passes it back to the waveguide. In the reception process, the radio wave is brought to waveguide by coaxial cable line installed on its outer side. The quarter wave monopole is formed after the central conductor projects the waveguide. The radio wave sent out from this kind of antenna has its end in a narrow beam. In some devices, the waves are produced between antenna and conductors or receivers by the waveguide. However, in this case, the horn is required to be attached to the end of the waveguide. For the feed horns of satellite dishes and other horns used in outdoor, a transparent plastic sheet is attached to cover the mouth of the horn preventing from moisture (Graf, 1999).

The horn antenna is nothing but a flared out or opened out waveguide. The main function of this kind of antenna is to make a uniform phase with a metallic horn shape aperture to create higher directivity. Basically the horn antennas are classified as rectangular horn antennas and circular horn antennas. The rectangular horn antennas are fed with rectangular waveguide, while the circular horn antennas are fed with circular waveguide. Depending upon the direction of flaring, the rectangular horns are classified as sectoral horn and pyramidal horn.

A sectoral horn is obtained if the flaring (tapering) is done in one direction only. A sectoral horn is further classified as E-plane and H plane sectoral horn. The E-plane sectoral horn is used in the case that the flaring is done to direct the magnetic field vector. The flaring is done along the signal wall of the rectangular waveguide in one direction in both E-plane sectoral horn and H-plane sectoral horn. They both are shown in the Fig. 2.10 (a) and (b) respectively (Bakshi *et al.,* 2009)



(a) (b)

Fig. 2.10 Rectangular sectoral horns (a) E-plane sectoral horn (b) H-plane sectoral Horn (Bakshi *et al.*, 2009)

A pyramidal horn when the flaring is done along both the walls of rectangular waveguide in direction of both the magnetic and electric field vectors. The obtained horn is called pyramidal horn as shown in the Fig. 2.11.

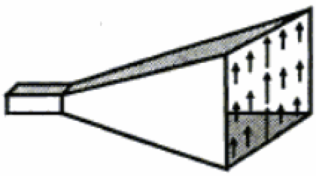
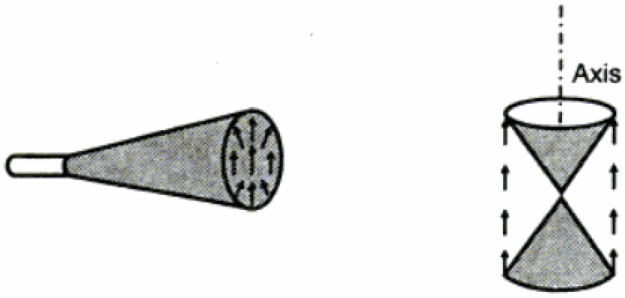


Fig. 2.11 Pyramidal horn (Bakshi *et al.*, 2009)

Similar to the rectangular horns, the circular horn antenna can be attained by flaring the walls of the circular wave guide. The circular horn antennas are to two types namely conical horn antenna and biconical horn antenna as shown in the Fig. 2.12 (a) and (b).



(a) (b)

Fig. 2.12 Circular horn antennas (a) Conocal horn (b) Biconicalhorn (Bakshi *et al.*, 2009)

A waveguide antenna in principle is a device designed to transfer electromagnetic energy from one area to another area. It requires waveguide which is metallic tube normally formed in circular in cross section or rectangular. The antenna is able to transmit the direct power to the direction where needed. It can also to manipulate big amount of power. However, the disadvantage of waveguide is it only propagate signals above a certain frequency or cutoff frequency. Below shown equation is the formula for the cutoff frequency of a rectangular cross-sectioned waveguide,

$$f_c = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left[\frac{m\pi}{a}\right]^2 + \left[\frac{n\pi}{b}\right]^2} \qquad (2.29)$$

where $\frac{1}{\sqrt{\mu\varepsilon}}$ is velocity of plane wave, μ'. The cutoff frequency for the TE_{10} mode is obtained from (2.30) as $(m = 1, n = 0)$

$$f_c = \frac{\mu'}{2a} \qquad (2.30)$$

where a is the larger width of the waveguide (m) (Sadiku, 1995).

Requiring directional or beam antenna, this rectangular waveguide antenna is suitable for microwave transmission technique. It transfer or receive electromagnetic wave in a specific direction on in directional pattern in order to force the microwave going through the sample. A study by Khalid (1982) examined the determination of DRC in latex by microwave transmission technique using rectangular waveguide antenna. The system consists of a Gunn diode oscillator transmitting and receiving wave guide antenna and detector. Attenuation of microwave used in this technique by latex is calculated at 10.7 GHz. The microwave then is calibrated according to the standard laboratory method. By comparing with the standard method, this study revealed that this device has capability to reduce the measuring time from 8-16 hours to only 3 minutes. There is co-relation between DRC controlled by using this tool. The standard laboratory test is 0.998 with the 0.7% of test deviation result, therefore, it provides a satisfactory result when compare to that obtained by standard method.

2. 6 Measurement of dielectric material properties

Many fields of research and study increasingly pay attention to the importance of the measurement material's complex dielectric properties at the frequency of radio, for example, biological research, absorber development, material science research, microwave circuit design. Dielectric measurement received attention because it has importance in term of providing electrical or magnetic characteristics of certain materials. The dielectric measurement therefore is useful in the field of research and development.

There are many methods that have been designed to measure the complex properties of materials. All methods have limitation and constraints on specific frequencies, materials and applications. Frequency domain or time domain method, for example, is one of them. However, as technology gets advanced, new methods can be applied with some software programs to measure the complex reflection and transmission coefficients. The software program then converts the received data into the complex dielectric property parameter.

The dielectric properties measurement commits the complex relative permittivity measurement (ε_r) and material complex relative permeability (μ_r). The complex dielectric permittivity has both real part and imaginary part. Its real part which is also known as dielectric constant aims the measure of energy amount from internal electrical field which is stored in the material. For the imaginary permittivity, it makes zero for lossless materials and known as lose factor. The loss factor which is best known as loss tangent and represented in term *tan* (δ) is the amount of energy loss from a material as the result of external electrical field. According to the real part of the complex permeability, it demonstrates the energy amount from an external magnetic field which is stored in a material. However this measurement on the complex permeability can be used only with magnetic materials. For non-magnetic material, its permeability is close to free space permeability. Example of some dielectric material on their characteristics shown in Table 2.1 provides data on dielectric constant and loss tangent at normal room temperature.

Numbers of methods are designed and developed to measure the complex permittivity and permeability. However, these methods still have some limitations on specific frequency, applications, materials and etc. Following methods will be discussed;

- Transmission/reflection line method,
- Open ended coaxial probe method,
- Free space method and
- Resonant method.

Table. 2.1 Example of some selected dielectric material characteristics at frequency 2.45 GHz in a room with normal temperature, (Kuek, 2012).

Material	Dielectric constant	Loss-tangent
Alumina	9.0	0.0006
Smoked bacon	2.50	0.05
Frozen beef	4.4	0.12
Raw beef	52.4	0.3302
Blood*	58	0.27
Salted butter	4.6	0.1304
Unsalted butter	2.9	0.1552
Borceillicate glass	4.30	0.047
Dry concrete	4.5	0.0111
Corn oil	2.6	0.0077
Cotton seed oil	2.64	0.0682
Sandy soil	2.55	0.0062
White egg	35.0	0.5
Fused quartz	4.0	0.0001
Fat*	5.5	0.21
Ceramic glass	6.0	0.0050
Lard	2.5	0.0360
Lung*	32.0	0.3
Muscle*	49	0.33
Olive oil	2.46	0.0610
Paper	3-4	0.0125-0.0333
Soda lime glass	6.0	0.002
Teflon	2.1	0.0003
Water	78	0.15
Wood	1.2-5	0.0040-0.4167
*at 37 ° C		

2.6.1 Transmission/Reflection Line Method

Transmission/Reflection Line method can be applied by placing a sample that we need to test in a section of waveguide or coaxial line. A two ports complex parameter and a vector network analyzer (VNA) are used for measurement. However, calibration must be completed before carrying on the measurement. This measurement requires the reflected measurement and transmitted signal measurement. The relevant scattering parameter closely associates to the complex permittivity and permeability of material by equation. The parameter conversion to complex dielectric is calculated by solving equation by using a computer program. In several cases, this method needs sample preparation in order to make sure the sample is fitted tightly to coaxial line and waveguide. In the transmission line measurement calibration, various terminations are required to create different resonant behavior in the transmission line. To make efficient measurement, it requires maximum electric field by open capacity termination and circuit. The coaxial line measurement calibration can be done by using either open circuited, short circuited or match load termination. This measurement method allows the permittivity measurement and permeability of the dielectric material.

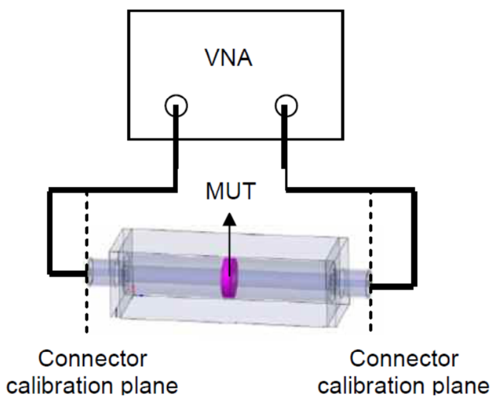


Fig. 2.13 Measurement using TR method with a waveguide (Kuek, 2012)

The vector network analyzer needs to be calibrated at connector calibration plane and place the material undertest in the sample holder. In order to reduce measurement uncertainty that may caused by air gap, make sure the sample is tightly fit in the holder. However the extension of calibration plane to the surface of the sample can be done by two methods i.e. feeding the phase factor manually and de-embedding function of vector network analyzer. The first method can be done by manually feed the phase factor that equivalent to the distance between the connector calibration plane and the sample surface. It is easy to include the phase factor in the measurement with the feather in the vector network analyzer. The calibration plane will shift the analyzer from connector to the surface of undertest material. The second method can be done by de-embedding function of vector network analyzer. This method can e applied only after the calibration was completely done by measuring s-parameter of sample holder. After that, put the s-parameter into the network analyzer. The influence of empty sample holder on the material can be removed by using the de-embedding function in the vector network analyzer. However, these two methods normal give the same results. The s-parameter then is applied to find out the complex dielectric properties by using a computer program. Conversion method can be done by various ways to calculate dielectric parameters from measured s-parameters. These conversion methods will be discussed on their details in the application note.

Transmission/Reflection line method advantages

This method has advantages as follow;

- The coaxial lines and waveguide generally are used to measure sample with medium and high loss,
- This method can be used to find the result of permittivity and permeability of the under-test material.

Transmission/Reflection line method disadvantages

This method has disadvantages as follow;

- There is limitation on measurement accuracy caused by air-gap effects,
- There is limitation on giving low accuracy in the case that the length of the sample is multiple of one-half wavelength in the material.

2.6.2. Open-ended coaxial probe method

The open-ended coaxial probe method is a non-destructive testing method used to measure the electric field normal component. The probe used in the method is pressed against specimen or immersed into the liquids. The reflection coefficient is calculated and then it is used to determine the permittivity.

In some measurements, to cut out the material sample might be Impossible especially the in case of biological specimen to be tested in-vivo measurement. It is because the material characteristics might change. The sample tested by this method must be placed and closely contacted with probe and avoid any change in the characteristics of the materials.

The reflection coefficient can be measured by using the vector network analyzer. The analyzer with a probe firstly needs to be calibrated in order that the measurements of reflection coefficient are referenced to the probe aperture plane. There are two methods that can be used. The first one is to use reference liquids for the direct calibration at the open end of the probe. This measurement method is simple, but however, there might be some uncertainties which normally caused by two uncertainties i.e. the uncertainty in the characterization of reference liquid and the uncertainty of reference liquid selection as calibration standard. Measurements used in this method are performed by placing the standards at the end of the probe. The liquid which is used as calibration standard must be one that has dielectric properties. Normally methanol, saline and water are selected to be the reference.

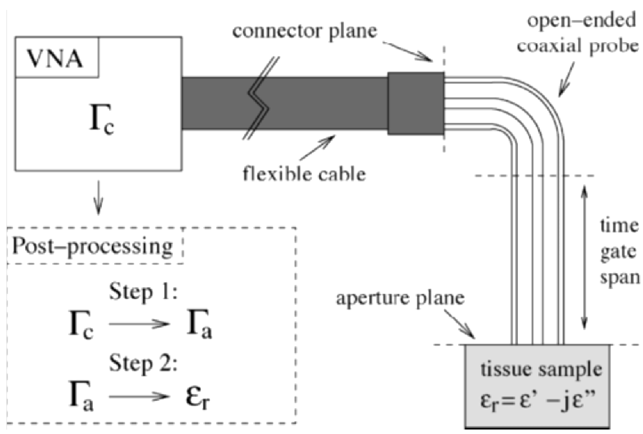


Fig. 2.14 Measurement of tissue sample using open coaxial probe (Kuek, 2012)

Fig. 2.14 illustrates measurement procedure of second method. The method requires combination of standard calibration in calibrating connector plane and the stimulated model of the probe which translates the calibration plane to probe aperture. The permittivity can be calculated from the reflection coefficient at the aperture of the probe.

In the calibration process, calibrating the vector network analyzer (VNA) at the connector plane by using a calibration standard is required. The probe the must be connected to the connector plane. In order to reduce the reflections from connector to minimum level, gating function of time domain feather is used.

Open-ended coaxial probe method advantages

- The method does not require the sample machining, it makes sample preparation easy.
- The method allows repeatedly measuring large number of samples on their dielectric properties in short time after calibration.
- The method allows performing the measurement in the environment of controlled temperature.

Open-ended coaxial probe method disadvantages

- The method is available with reflection measurement.
- The method can be affected by air gaps especially for the specimen measurement.

2.6.3 Free space method

Free space method can be performed the measurement on material under test under high temperature and even in a hostile environment condition. The method normally operates in the wide band frequency. The material under test used in the measurement must be large and flat. Two antennas normally are used to utilize by placing them facing each other and connect the antennas to network analyzer. It is important to calibrate the vector network analyzer before starting measurement. Numbers of calibration method can be used in calibration such as the reflect line method (TRL), the through-reflect-match method (TRM) and the line-reflect-line method (LRL). Among these three methods, LRL method is commonly use due to giving highest calibration quality. The reflected standard calibration method applied in this calibration can be done by placing a metal plate on sample holder between antennas. The line standard calibration method can be done by removing the focal plane to the two antennas a quarter of wavelength approximately. After calibration is completely done, the s-parameter of sample holder can be measured by placing the sample holder at the middle in between of the two antennas, then place the material under test on the sample holder and perform s-parameter measurement again. By using the de-embedding function of the vector network analyzer, the sample holder influence can be cancelled out and determine only the s-parameter of material under test. It is suggested to use time domain gating to ensure no multiple reflection in the sample and thickness of the sample should be appropriated. The diffraction of energy is also eliminated from the edge of the antennas. By using the a program, the dielectric properties will be shown after the post processing the measured reflection and transmission coefficient.

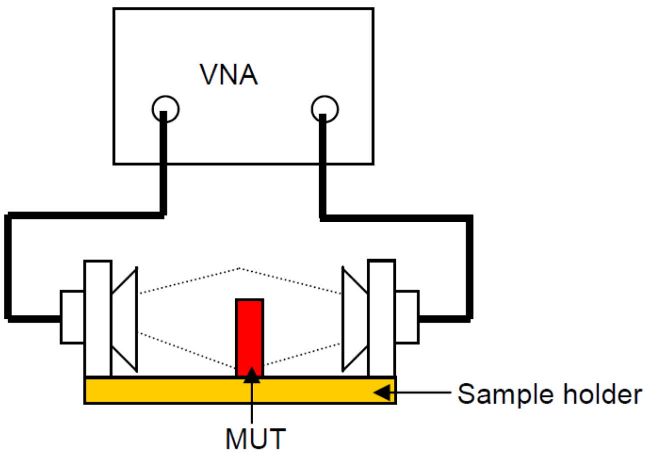


Fig. 2.15 Measurement of sample using free space method (Kuek, 2012)

Free space method advantages

- The method can be used for measurement that having high frequency.

- The method can be used for non-destructive measurement.
- The method is able to measure the material under test in hostile environment.
- The method is able to evaluate both magnetic and electric properties.

Free space method disadvantages

- The material under test of this method must be large and flat.
- The method may give multiple reflections between sample surface and antenna.
- The method causes diffraction effects on the edge of sample.

2.6.4 Resonant method

Resonant measurement method is the most reliable and accurate in measuring permittivity and permeability comparing to all methods. Even it provides most accurate results, the method also has limitations on frequencies and loss characteristics of the material under test. The resonant method has many types that available such as Fabry-Perot resonator, cavity resonator, split cylinder resonator, reentrant cavity etc. Only cavity resonator method is discussed on it general procedure of application. There two types of resonant method that are commonly used i.e. perturbation method and low loss measurement method. The perturbation method is suitable for permittivity measurement, materials having magnetic characteristic and medium to high loss material measurement. Low loss method is used to measure low loss materials. The sample used in the low loss measurement must be large sample. The perturbation method is used in a TM cavity geometry. Determined by resonant characteristics of the material under test in a cavity, quality factor and resonance frequency can be monitored in order to determine the dielectric parameter. The first step of dielectric properties measurement using this method is measuring the resonant frequency and quality factor of an empty cavity. The next step is repeating the measurement after filling the cavity with material under test. The material permittivity and permeability can be calculated by using frequency, volume and q-factor. This measurement method does not require the calibration of the network analyzer.

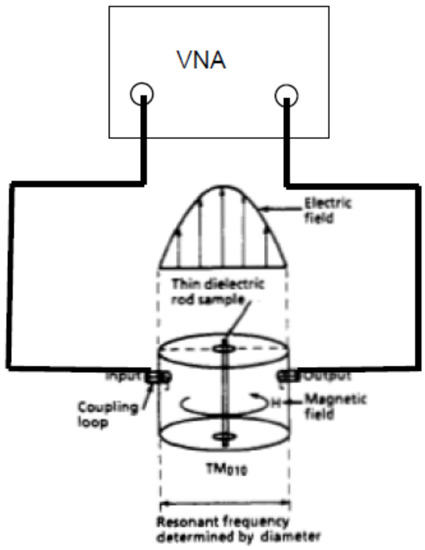


Fig. 2.16 Measurement of thin film using cavity resonator (Kuek, 2012)

The above figure shows that the rod shape solid sample has been placed at the center of the cavity. The change in resonant frequency and Q-factor determine the properties of the sample. This resonant cavity method requires network analyzer having high frequency resolution up to 1Hz.

The cavity resonant method advantages

- This method can be used to measure small materials
- This method can be used to approximate the expression for field in sample and cavity.

Cavity resonant method disadvantages

- This method requires the vector network analyzer having high frequency.
- This method is limited to narrow band of frequencies.

CHAPTER 3

MATERIALS AND METHODS

3.1 Material and Equipment

3.1.1 Sample preparation

The sample latex in this research includes freshly latex, concentrated latex, and diluted concentrated latex. The DRC samples was varied from 10.26%-60.63% with dilution the concentrated latex by adding distilled water. The diluted samples were prepared to find the relationship between DRC and the output voltage of detectors over the frequency range from 2.0-2.4 GHz. The freshly latex from various local areas was provided for verifying the accuracy of novel devices.

3.1.2 Power supply

Power supply in this research was divided into two parts. First, fixed DC power supply 5V, it supported for all electric devices in this instrument, such as a microwave generator, a detector, and microcontroller. The fixed DC power supplies mainly use AC electricity current as a power source. Such power supplies will sometimes employ a transformer to convert the input voltage to a lower or higher AC voltage. A rectifier converter is applied to convert the transformer's output voltage to a variable DC voltage, which in turn is sent to an electronic filter for conversing it to an unregulated DC voltage. The filter removes most, but not all of the AC voltage variations and regulator using by IC 7805 +5V, 1A. Second, variable DC power supply, it supported to tune voltage of voltage controlled oscillator for frequency variation. It can be created with a single IC LM317 series of voltage regulators. The LM317T is an integrated circuit which is very useful in many renewable energy applications. It is used to provide a stable fixed output voltage ranging from about 1.25 to 30 volts. The LM317T variable voltage regulator also has built in current limiting, and thermal shut down abilities which makes it short-circuit proof and ideal for any low voltage or homemade bench power supply.

3.1.3 Microwave generator

The voltage controlled oscillator (ZX95-2400A+) has been used for microwave generators. It is an electronic oscillator whose frequency is controlled by a voltage input. The applied input voltage determines the instantaneous oscillation frequency. The voltage controlled oscillator is a broad range of voltage controlled oscillators using lumped element and coaxial resonator based on designs. The voltage controlled oscillators contribute a combination of very low phase noise, low pushing and low pulling. Linear tuning, wideband capability as well as 5V tuning for a phase locked loop integrated circuits (PLLICs) are proposed in miniature surface mount. The specifications of ZX95-2400A+ are shown as table 3.1

Table 3.1 The specifications of ZX95-2400A+ (Minicircuits, 2014)

Mfr Package Description	ROHS COMPLIANT, CASE GB956
Status	ACTIVE
Operating Temperature-Max	85° C
Operating Temperature-Min	-55° C
Mounting Feature	CHASSIS MOUNT
Physical Dimension	L30.48XB19.05XH11.68 (mm)/L1.2XB0.75XH0.46 (inch)
Supply Voltage-Nom	5 V
Operating Frequency-Max	2400 MHz
Operating Frequency-Min	2000 MHz
Control Voltage-Max	24 V
Control Voltage-Min	0.5000 V
Modulation Sensitivity	37 MHz/V
Offset Frequency	1 kHz
Oscillator Type	VOLTAGE CONTROLLED OSCILLATOR
Output Power	3.6 dBm
Phase Noise	-73 dBc/Hz
Supply Current-Max	40 mA

3.1.4 Detector

A system detector is coaxial power detector (ZX47-50+) for frequency range from 10-8000 MHz which is characterized low noise DC output, VSWR (1.3:1), high dynamic range (-50 to +22 dBm), and operating power 5V. The detector has been used to detect the transmitted microwave from the waveguide antenna. The specifications of ZX47-50+ is shown as table 3.2

Table 3.2 The specifications of ZX47-50+ (Datasheet360, 2014)

Mfr Package Description	ROHS COMPLIANT, CASE HN1173
EU RoHS Compliant	Yes
Status	ACTIVE
VSWR-Max	1.3
Construction	COAXIAL
Terminal Finish	NICKEL
Characteristic Impedance	50 ohm
Operating Temperature-Max	85° C
Operating Temperature-Min	-40° C
Input Power-Max (CW)	22 dBm
Input Power-Min (CW)	-50 dBm
Operating Frequency-Max	8000 MHz
Operating Frequency-Min	10 MHz
RF/Microwave Device Type	LINEAR DETECTOR

3.1.5 Waveguide antenna

There are two waveguide antennae in the system: the transmitting waveguide antennae; and the receiving waveguide antennae. The rectangular waveguide antennae used 70mm×70mm×70mm rectangular aluminum box with 3mm thick. The probe in waveguide is about 36 mm length with a 2 mm diameter copper wire soldered into an N-Socket (1/4 of wavelength in free space, including the protruding bit of the N-Socket), it is connected to the microwave generator and detector through the RG58 coaxial cables and N-Type male connector adaptors.

3.1.6 Microcontroller

Microcontroller is a main part in the system which performs as a computer for data collection, calculation, system calibration, data analysis between attenuation of microwave from the detector and DRC of latex sample under test. Additionally it shows the result on the LCD. The AVR EASY88 board using ATmega88 microcontroller from ATMEL Company which is low-power, Atmel 8-bit AVR RISC-based microcontroller combines, has been adopted in this study. The characteristics of ATmega88 are, namely 8KB ISP flash memory, 1KB SRAM, 512B EEPROM, an 8-channel/10-bit A/D converter (TQFP and QFN/MLF), and debug WIRE for on-chip debugging. The device supports a throughput of 20 MIPS at 20 MHz and operates between 2.7-5.5 volts. The features of AVR EASY88 board are shown as follows:

- Support MCU AVR ATMEGA88 (Flash 8KB), ATMEGA168 (Flash 16KB) ATMEGA328 (Flash 32KB).
- SRAM 1KB, EEPROM 512 Byte, Clock 19.6608 MHz.
- 20 Bits I/O Port (PB 6 Bits, PC 6 Bits, PD 8 Bits) as RS232, SPI, I2C, Timer/Counter, A/D 10 Bits 6 Channels.
- 3 Slots of ET-10PIN.
- Output 74HC595 for 10PIN IDE (LCD application).
- RESET and BOOTLOADER Switch (PD2).
- RS232 4 PIN Port for applications and programming download.
- 10 PIN IDE for AVR ISP standard programming download.
- Support ET-MINI I/O Board (4.4 x 5.6 cm).
- Power Supply 7-10 VDC (LM2940 – low drop out on Board).
- PCB Size: 8 x 6 cm.
- Included: ET-RS232 DB 9 Pins.

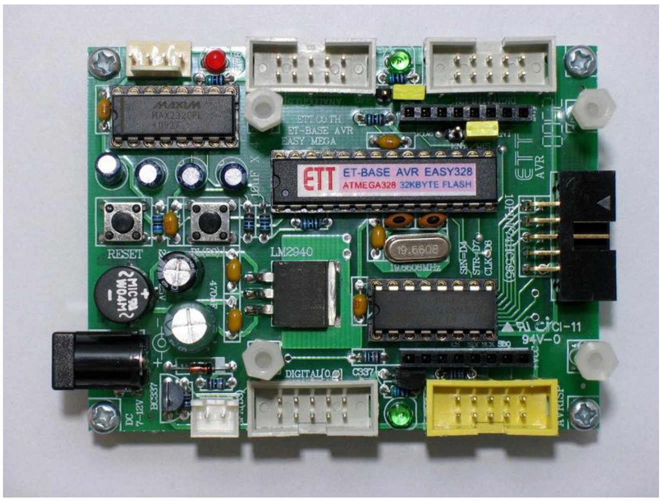


Fig. 3.1 AVR EASY88 board

3.2 Method

3.2.1 Study device for a microwave source

Water molecules contain three atoms which its biggest atom is oxygen and the two little attached ones are hydrogen. It has a positively and a negatively charged side so it can be vibrated in a number of different ways. When microwaves pass through water, the water molecules absorb some of the microwave energy which lead to their rotation and turn, writhing around, as the radiation passes by. The rotational transitions are responsible for absorption in the microwave. This study is based on the propagation of microwave in the latex, which contains water the most. These waves pass through the latex between two antennae, i.e. a transmitter and a receiver. The water in latex absorbs parts of this energy transmitted between the antennae. Therefore, microwaves in frequency range from 2.0–3.0 GHz are implemented to estimate the DRC in latex sample. A microwave source in this study is the voltage controlled oscillator (ZX95-2400A+) which its frequency is controlled by a voltage input. It is an easy employment, a low phase noise, low pushing and low pulling. So the microwave source is suitable to this study. The voltage controlled oscillator was tested by spectrum analyzer for studying the relationship between the tuning voltage and the frequency and comparing to the data sheet.

3.2.2 Design of the transmitting and receiving antennae

The principle used in this study is transmission of microwave into the latex and then measurement of the microwave absorption in the latex. Therefore, it is necessary to study and design the high gain antennae that are used to radiate the microwave into the latex, allowing for increased performance on transmit and receive and reduced interference from unwanted sources. The types of antennae were selected in this study as follows:

3.2.2.1 Dipole Antenna

The wireless antennas have been used for a receiver and a transmitter antenna which are connected to the microwave generator and detector via RG58 coaxial cables and SMA male connector adaptors. The output signal which is detected by power detector (ZX47-50+) was -21.6 dBm at distance between the pair antennae 16 cm as Fig. 3.2. The result shows that the dipole antenna is not suitable for this study because the detected output power is still low.

Fig. 3.2 The receiving and transmitting system using dipole antennae

3.2.2.2 Cylindrical Waveguide Antenna

The cylindrical waveguide antenna has a diameter of 10 cm. It opens at one end that is made of metal with its length of 16 cm. The probe in waveguide is about 36 mm in length with a 2-mm diameter copper wire soldered into an N-Socket (1/4 of wavelength in free space, including the protruding bit of the N-Socket). The output signal which is detected by power detector (ZX47-50+) was -8.6 dBm and it shows that the cylindrical waveguide antenna has a good performance.

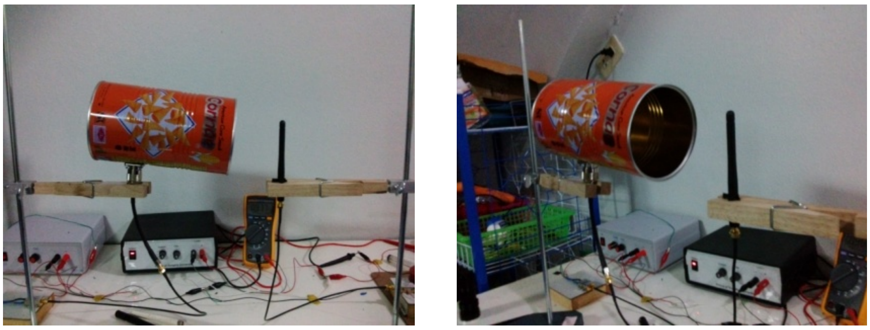


Fig. 3.3 The receiving and transmitting system using cylindrical waveguide antenna

3.2.2.3 Rectangular Waveguide Antenna

The formula for the cutoff frequency of a rectangular cross-sectioned waveguide is given by Sadiku's equation as in:

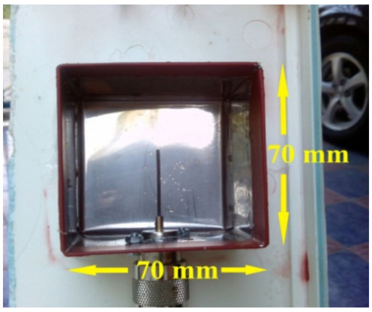
$$f_c = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left[\frac{m\pi}{a}\right]^2 + \left[\frac{n\pi}{b}\right]^2} \qquad (3.1)$$

where ε is permittivity of the medium (F/m), μ is permeability of the medium (H/m), a and b are side length of the rectangular cross section (m), m and n are the numbers of half-cycle variations in the x-y cross section of the waveguide. The cutoff frequency for the TE_{10} mode is obtained with $m = 1$ and $n = 0$:

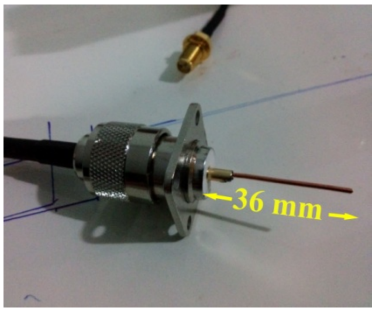
$$f_c = \frac{v}{2a} \qquad (3.2)$$

where v is the velocity of plane wave in the medium (m/s),a is the larger side length of the rectangular cross section (m). (Sadiku, 1995).

The frequencies ranging from 2.0 to 3.0 GHz is what we chose because of its good linear relationship between the microwave attenuation. The larger width of the waveguide (a) for these frequencies is obtained from equation (3.2), and the value is approximately 70 mm. Therefore, the rectangular waveguide in this research used 70mm×70mm×70mm rectangular hollow box section with 3 mm thick aluminum. The probe in waveguide is about 36 mm length with a 2-mm diameter copper wire soldered into an N-Socket (1/4 of wavelength in free space, including the protruding bit of the N-Socket), it is connected to the microwave generator and detector by N-Type male connector adaptors and RG58 coaxial cables .



(a)



(b)

Fig. 3.4. (a) The rectangular waveguide antenna
(b) The probe of antenna.

The detected output signal was -6.5 dBm and it can be seen that the rectangular waveguide antenna has the best performance. In this study the rectangular waveguide antenna was, therefore, applied to DRC meter design.

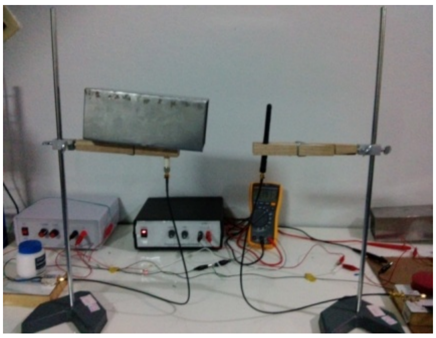


Fig. 3.5 The receiving and transmitting system using rectangular waveguide antennae

3.2.3 Design a microwave transmission method using rectangular waveguide antennae

The rectangular waveguide antenna is a directional antenna which is used to transmit microwaves from a waveguide (a metal pipe used to carry microwaves) out into space, or collect microwave into a waveguide for reception. It achieves a very substantially increased antenna's directionality gain compared to a simple dipole. The rectangular waveguide antenna can direct the microwaves in a narrow beam which pass into the sample. There are, however, still some of waves not moving through into the sample. This study also designs rectangular waveguide antenna consisting of the metal wall because it does not allow any of the microwaves pass without being through into the sample. There are 3 types of the rectangular waveguide antenna. To study the relationship between the microwave attenuation and DRC in latex, the output signals which pass into the latex with different DRC of 25%, 30%, 35%, and 40% by using 3 types of rectangular waveguide antenna were detected by a power detector. The optimal rectangular waveguide antenna was selected by the best correlation among them.

3.2.3.1 Waveguide splice without sidewall

The latex was filled in a sample holder and placed in a horizon orientation between the transmitting and receiving waveguide antennae by without the sidewall around the sample holder. A rectangular container made of polystyrene with 2 mm wall thickness, 85mm×85mm×97.5mm in size. The rectangular waveguide used 80mm×65mm×148mm rectangular hollow box section Aluminum with 3 mm thick walls. The intensity of the transmitted microwave was measured by the detector which was also connected to the digital multimeter.

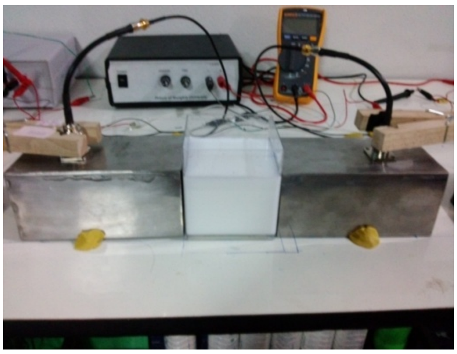


Fig. 3.6 Waveguide splice without wall

3.2.3.2 Waveguide splice with sidewall

To minimize diffraction of microwave, the sample holder (85mm×85mm×97.5mm) was embedded in the rectangular waveguide with a rectangular box made of Aluminium with 3 mm thick walls by cutting into the middle slot to put a sample holder. The microwave diffraction between the transmitting and receiving waveguide antennae which does not pass into the latex in the sample holder is unable to travel to the probe because the Aluminium sidewalls can well protect radiation of the microwave diffraction.

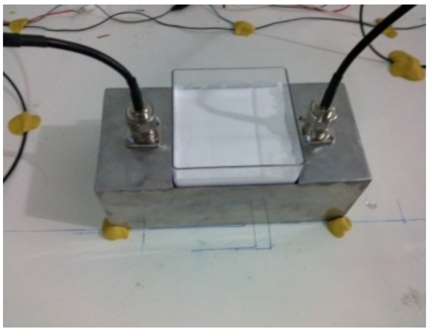


Fig. 3.7 Waveguide splice with Aluminium sidewall

3.2.3.3 Dipped waveguide in latex

The transmitting waveguide was dipped into the sample latex which was placed between a vertical orientation between the transmitting and receiving waveguide antennae. The width of the sample holder must be large enough to avoid diffraction of the microwaves between the antennae and the thickness of sample considered the skin depth or penetration depth of the medium. The dimensions of the sample holder used in this experiment are 80mm×80mm.

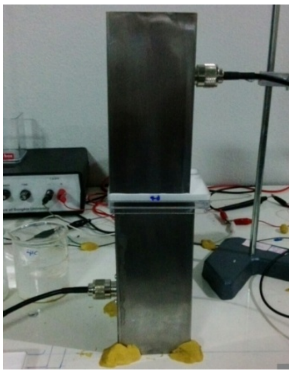


Fig. 3.8 Dipped waveguide in latex

3.2.4 Design of experiment system

As shown in Fig. 3.9, the experiment system consists of the power supply, Voltage Controlled Oscillator, rectangular waveguide antennae, sample holder, detector, and digital voltmeter. The system started with the power supply to supply electricity to the Voltage Controlled Oscillator which is the source of the microwave. The microwave signal would be transmitted along the coaxial cable from a transmitter to a receiver antenna. The latex in sample holder was placed in the middle between the transmitter and receiver antenna. When the microwave passed into the latex, the part of energy was absorbed by latex sample. The signal of attenuation microwave was received by the receiving antenna, and then the detector detected microwave signal and converted it into a voltage signal. The procedures of this experiment system for DRC determination in latex are as the three following steps.

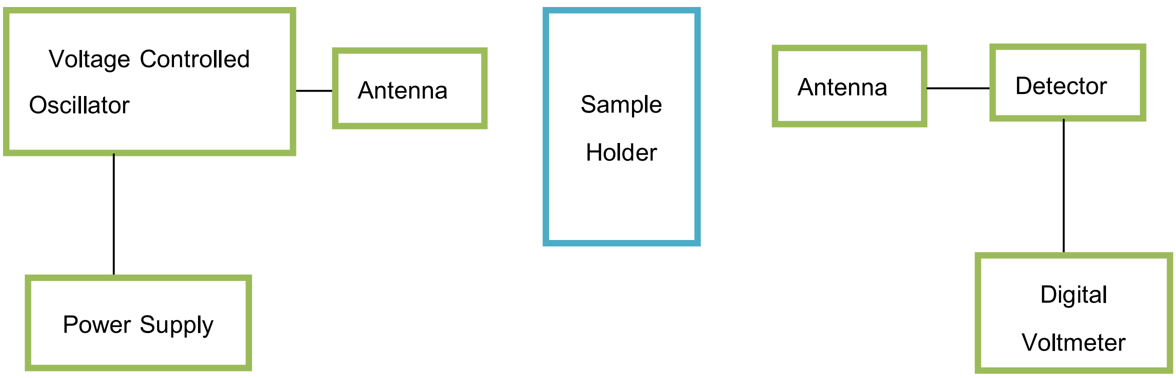


Fig. 3.9 The diagram of experiment system

3.2.4.1 Study of latex volume influence the microwave transmission for latex with difference of DRC

The experiments measured the intensity of the microwave radiation that passed through the latex using a rectangular waveguide antenna and coaxial power detector (ZX47-50 +). The sample holder was made of a plastic container size of 8.25cm x8.25 cm. The latex samples for rang of DRC 20%-45% are tested for variation volume of 15ml, 20ml, 25ml, 30ml, and 35ml. The difference of output voltage (ΔV) of the detector was measured from the system both with and without the sample latex placed between the transmitting and receiving antennae.

3.2.4.2 Measurement of antenna efficiency

The antenna efficiency can be determined by Standing Wave Ratio (SWR) that is the proportion of the amplitude of standing wave at the highest position (maximum) to the amplitude at the lowest position (minimum). SWR is usually used for determining the antenna efficiency in transmission lines used for connecting radio transmitters and receivers with the antennae. The problem of transmission lines is the impedance mismatch in the cable that can reflect the radio waves back toward the source causing the source damage. In conclusion, SWR describes the power getting reflected from the antenna. An ideal transmission line would have all the power reaching the destination with no reflected power or SWR of 1:1. The SWR of a transmission line can be tested with the instrument called an SWR meter, or is derived from reflection coefficient $|\Gamma|$ that is derived from as (Beatty, 1959).

$$SWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{3.3}$$

where $|\Gamma|$ is the magnitude of reflection coefficient.

In this setup, a pair of rectangular waveguide antennae was mounted on polystyrene sample holder in a horizontal plane. The waveguide antennae were connected to the two ports of the 8510B Vector Network Analyzer via RG58 coaxial cables and N-Type male connector adaptors. The latex was filled in a sample holder and placed in a vertical orientation between the transmitting and receiving waveguide antennae. The sample holder was a rectangular container made of a 2-mm wall thickness of polystyrene . The network analyzer was set in the transmission mode with the through connection of receiving and transmitting antennae. The value of reflection coefficient can be obtained by S_{11} from Vector Network Analyzer.

3.2.4.3 Determination of optimal frequency

This experimental measurement were tested on latex for a range of DRC between 10.26% and 60.63% by diluting concentrated rubber latex, over the frequency range of 1.0–4.0 GHz using two rectangular waveguide antennae and HP8510B vector network analyzer. The optimum frequency was obtained by plotting graphs for variation in attenuation with DRC for all frequencies. The attenuation due to the water in latex samples is obtained from the measurement of S_{21} value. The attenuation is derived from the magnitude of S_{21} as shown as:

$$S_{21} = |S_{21}|e^{j\Phi} \tag{3.4}$$

$$A = -20\log|S_{21}| \tag{3.5}$$

$$\Phi = 2\pi n + \phi \tag{3.6}$$

where A is the attenuation in dB. Φ is a total phase, ϕ is phase shift and n is an integer.

3.2.5 Performance testing of rectangular waveguide antennae

The performance of the rectangular waveguide antenna is obtained from the variation of the microwave attenuation with the DRC of latex sample for a range of DRC 10.26%-60.63%. The aim of this section is to measure the microwave attenuation at 2.36 GHz with the Vector Network Analyzer (VNA) and compare the measured microwave attenuation by using coaxial power detector for different DRC of latex sample. The microwave attenuation of the Vector Network Analyzer (VNA) is calculated from the magnitude of the transmission coefficient (S_{21}) from as

$$A = -20\log|S_{21}| \tag{3.7}$$

where A is the microwave attenuation in dB. S_{21} is the transmission coefficient.

The microwave attenuation equation of coaxial power detector is shown as follow:

$$A = 10\log\left(\frac{P_1}{P_2}\right) \tag{3.8}$$

where P_1 is the input microwave power (mW); P_2 is the microwave power after decay (mW)

3.2.6 Invention of a prototype of DRC meter

3.2.6.1 Study of the Microcontroller

A microcontroller (sometimes abbreviated µC, uC or MCU) is a compact microcomputer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals which designed to govern the operation of embedded systems in machines. Either Program memory in the form of NOR flash or OTP ROM is also often included on chip as well as a typically small amount of RAM.

Microcontrollers are applied in automatically controlled products and devices, such as automotive engine control systems, appliances, implantable medical devices, remote controls, robot, motor vehicles, power tools, toys and other embedded systems. By reducing the size and cost compared to a design using separate microprocessor, input/output devices, and memory, microcontrollers can make it economical to digitally control even more devices and processes. Mixed signal microcontrollers are common, integrating analog components needed to control non-digital electronic systems.

This study requires the microcontroller which represents as a computer to input data, save data, and analyze data between output voltage of the sensor and DRC of sample under the test. Finally, it can run the LCD and shows the results. The AVR EASY88 board using ATmega88 microcontroller from ATMEL Company which is low-power, Atmel 8-bit AVR RISC-based microcontroller combines, has been used in this research. The properties of ATmega88 are 8KB ISP flash memory, 1KB SRAM, 512B EEPROM, 20 Bits I/O Port (PB 6 Bits , PC 6 Bits , PD 8 Bits) as RS232 , SPI , I2C , Timer/Counter , A/D converter 10 Bits 6 Channels and Output

74HC595 for 10PIN IDE (LCD application) that would be sufficient for this sensor system.

There are three steps for the sensor system. First, the detector sends the voltage output signal to the microcontroller by coaxial line. Second, the microcontroller converts the voltage output signal to digital values by 10-bit A/D converter and the DRC determination is obtained from the linear fitting equation between detected power and DRC by using waveguide antennae and coaxial power detector. Finally, the result of DRC shows on the LCD.

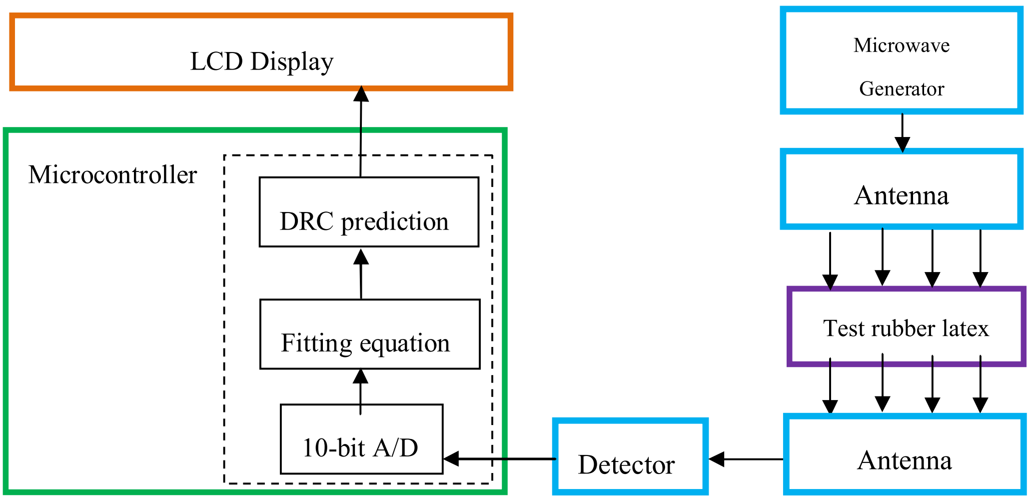


Fig. 3.10 Block diagram of the DRC measurement system

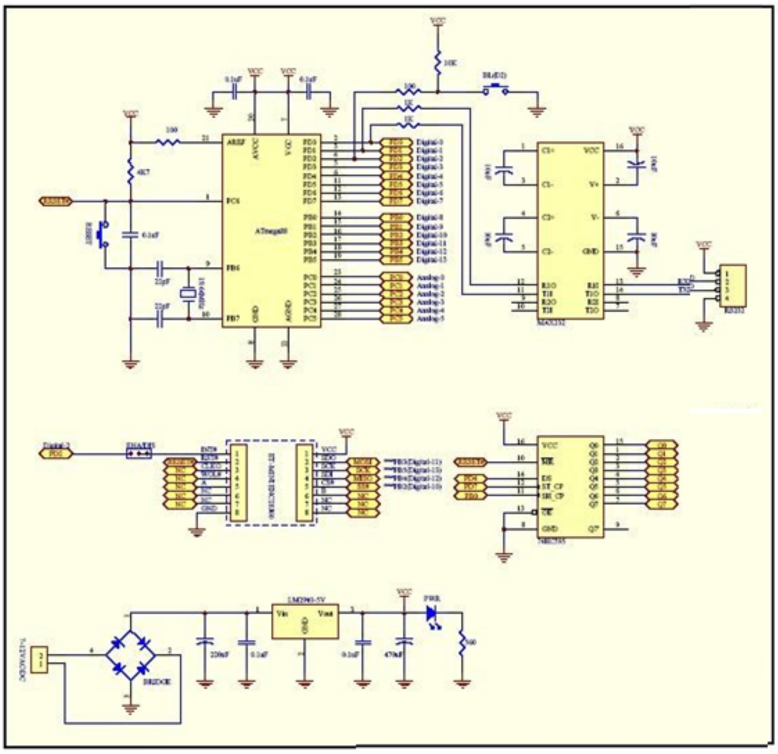


Fig. 3.11 The configuration of ATmega88 microcontroller in the electronic board (Makan, 2011)

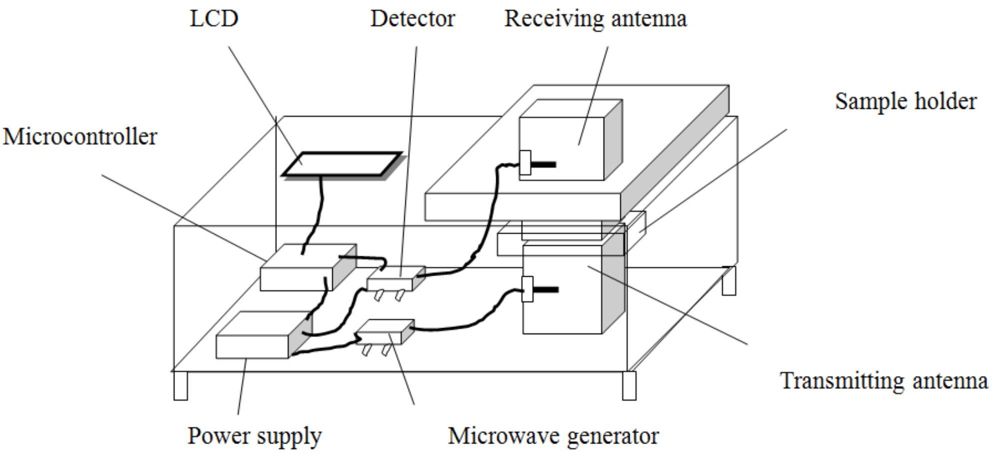


Fig. 3.12 The schematic design of the DRC measurement system

3.2.6.2 Empirical relationship between digital values and output voltage

An analog-to-digital converter (ADC, A/D, or A to D) is a electrical device that is used for converting a continuous voltage quantity to a digital number that represents the quantity's amplitude. The conversion involves quantization of the input so it necessarily introduces a small amount of errors. A/D converter in this research is designed for voltages from 0 to 2.0 V. The output data of the A/D converter is a binary signal, and that binary signal is converted from the analog input voltage. As a result, the output is some kind of digital number. The performance of A/D converter is based on the variation of input voltage ranging from 0 – 2.0V and converted to the digital output value for studying the relationship between the digital output values and the analog input voltage.

3.2.6.3 Fitting equation between detected power in 10 bit and DRC

To fitting equation, the diluted solution sample of rubber latex with DRC ranging from 10.26% to 60.63% were provided to find the empirical relationship between measured digital output of detector and DRC of sample. Initially, the 25 ml sample latex in holder was placed in the gap between the transmitting and receiving waveguide antennae. Then, the transmitting waveguide was dipped into the sample latex. Finally, the detected power in 10 bit which were converted from the output voltage of coaxial power detector (ZX47-50+) by ADC was recorded. For the measurement there should be no gas bubbles in the sample holder and the outer part of the sample holder should be dried off.

3.2.7 Performance testing of a prototype of DRC meter

A prototype of DRC meter is composed of two power supplies. First, fixed DC power supply 5V, it supported for all electric devices in this instrument. Second, variable DC power supply, it supported to tune voltage of voltage controlled oscillator to generate the microwave in frequency range of 2.0–2.4 GHz. Moreover, it is composed of a microwave generator, waveguide antennae, a detector, sample holder, microcontroller and LCD display.

The performance testing of a prototype of DRC meter is obtained from the 26 latex samples of various local areas in Songkhla province. The 25 ml latex sample is filled in a sample holder and put between the transmission of connection to the microwave generator and reception of waveguide antennae which is connected to the detector. Then, the detector detects microwave signal and converts it into a voltage signal and through the signal to the microcontroller. After that, the microcontroller is provided to measure the detected power and converted to digital values by 10-bit A/D converter. The system software is designed to interface the whole hardware (Detector, A/D, LCD, etc). The DRC determination software consists of two algorithms which are evaluating the microwave attenuation by using detected power, and the fitting equation is interfaced into the microcontroller for data analysis and DRC determination of latex sample. The comparison between DRC's results from DRC meter and the standard method are investigated.

Fig. 3.13 The prototype of DRC meter

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 The relationship between the tuning voltage and the frequency of the voltage controlled oscillator

The voltage controlled oscillator (ZX95-2400A+) was adjusted to the tuning voltage for studying the output frequency by the variable DC power supply with an output voltage ranging from about 1.25 to 30 volts. The output frequencies were measured by the GSP-830 3GHz Spectrum Analyzer which is the latest evolution from GWInstek. The measurement results are shown in Fig. 4.1.

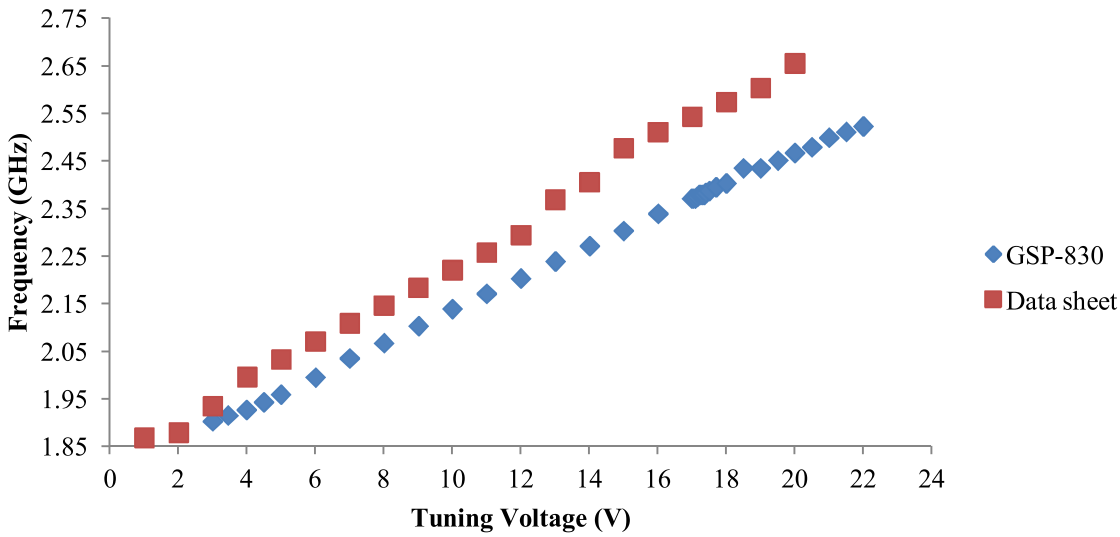


Fig. 4.1 Relationship between tuning voltage and output frequencies

The Fig. 4.1 shows that the measurement results by spectrum analyzer are almost linear with frequencies increases as tuning voltage increases. For the comparison between the measurement results and the data sheet is a good agreement. Therefore, the voltage controlled oscillator (ZX95-2400A+) is suitable for a microwave source with the frequency range of 2.0-2.4 GHz**.**

4.2 The relationship between the microwave attenuation and DRC in latex using 3 types of the rectangular waveguide antennae

4.2.1 Waveguide splice without sidewall

Fig. 4.2 shows the output voltage of detector when the microwave pass into the latex with different DRC of 20%, 25%, 30%, 35%, and 40% using waveguide splice without sidewall. The results show that the relationship between output voltage and DRC is R^2 = 0.219 which is a very low correlation because the microwave cannot directly pass into the latex having thickness more than the skin depth. Moreover, some of the microwave can propagate to the detector without passing into the latex because there is not the sidewall to protect the diffraction of microwave. As a result, this waveguide is not suitable to apply to the DRC meter.

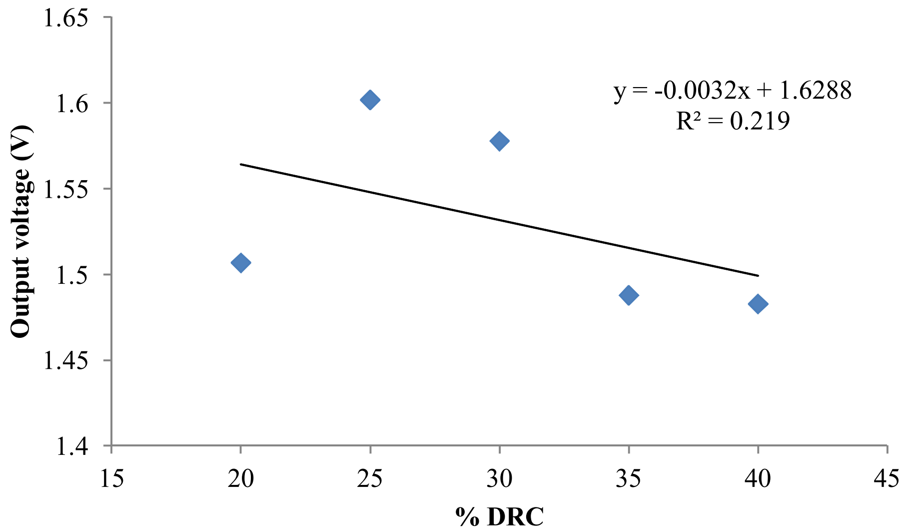


Fig. 4.2 The relationship between output voltage and DRC without sidewall

4.2.2 Waveguide splice with sidewall

Fig. 4.3 shows the output voltage of detector when the microwave pass into the latex with different DRC of 25%, 30%, 35%, and 40% using waveguide splice with sidewall. The correlation of the relationship between output voltage and DRC is R^2 = 0.513 which is more linear than the result of waveguide splice without sidewall because the sidewall can well protect the diffraction of microwave between the transmitting and receiving waveguide antennae. However, the relationship between output voltage and DRC still has a low correlation. Due to the thickness of the sample more than the skin depth, a few of the microwaves can pass through the latex to the detector. Hence, the detected microwave has a low relationship with DRC in the latex sample.

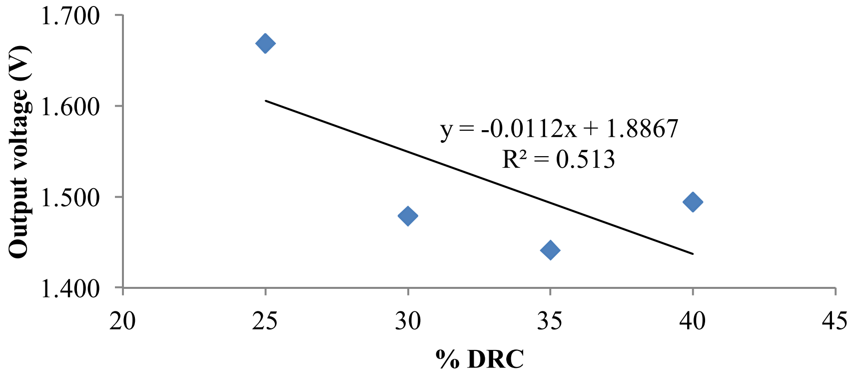


Fig. 4.3 The relationship between output voltage and DRC with sidewall

4.2.3 Dipped waveguide in latex

Fig. 4.4 shows the relation between the output voltages obtained by waveguide with being dipped into latex and the DRC ranging from 25% to 40%. The correlation between the results of this method is 0.983. It is presented that this method can be obtained a high correlation because the microwave from the transmitting waveguide dipping into the sample latex must pass into the latex only. For radiation to the detector in the receiving waveguide antennae it is complete. Consequently, this method makes the microwave and the latex has a direct reaction, which is a suitable method to apply to a DRC meter.

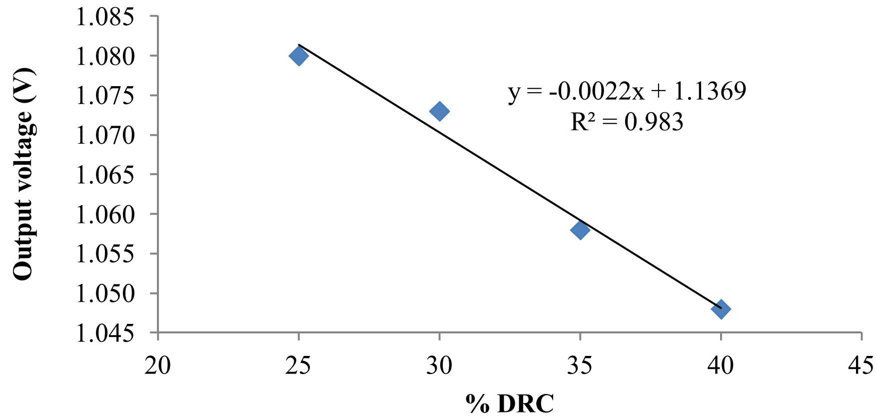


Fig. 4.4 The relationship between output voltage and DRC with dipped waveguide in latex

4.3 The relationship between the latex volume and the difference output voltage (ΔV) with variation of DRC

The result of relationship between the microwave attenuation and DRC in latex using 3 types of the rectangular waveguide antennae displays that the dipped waveguide in latex method is a suitable application to a DRC meter. Therefore, the dipped waveguide is used in this study. In this step, the relationship between the latex volume and the different output voltage (ΔV) with variation of DRC is investigated.

The latex sample with DRC ranging 20%-45% is tested for variation volumes of 15ml, 20ml, 25ml, 30ml, and 35ml. The different output voltage (ΔV) of the detector was measured from system by with and without the sample latex placed between the transmitting and receiving antennae. The results show that the relationships between DRC and the different output voltage are good correlation for all volumes, and the best correlation is 0.999 with 25 ml. Thus, the optimal volume for this research is 25 ml.

Table 4.1 The correlation of different output voltage (ΔV) and the latex volume

volume (ml)	ΔV						R^2
	20%	25%	30%	35%	40%	45%	
15	0.201	0.182	0.155	0.148	0.115	0.110	0.972
20	0.250	0.226	0.211	0.193	0.172	0.155	0.997
25	0.280	0.264	0.246	0.232	0.216	0.200	0.999
30	0.294	0.279	0.262	0.248	0.234	0.220	0.998
35	0.287	0.281	0.265	0.254	0.241	0.229	0.992

4.4 The rectangular waveguide antennae efficiency

The ratio between the radiated power and the total power from the terminals is shown as antenna efficiency. The power loss in antenna terminals is changed into heat and this result from the loss resistance in the antenna's conductors, dielectric and magnetic core losses in the antennae. The value of reflection coefficient can be obtained by S_{11} from VNA. The SWR of rectangular waveguide antenna with various frequencies of the microwave in water and latex for DRC values of 21.12%, 42.20% and 60.63% is shown in Fig. 4.5

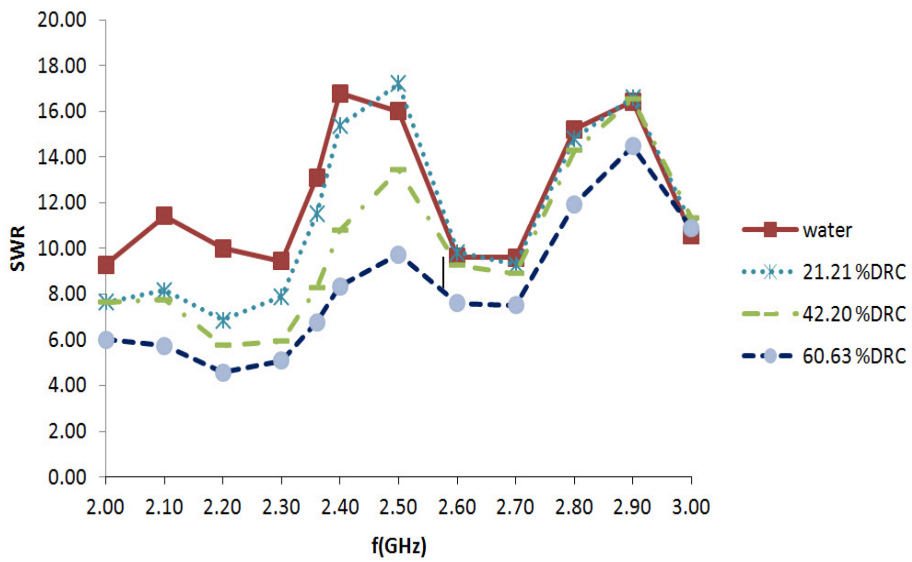


Fig. 4.5 The SWR of rectangular waveguide antenna from 2.0 GHz to 3.0 GHz

Fig. 4.5 shows the results of SWR obtained for each frequency of microwave in water and latex for DRC values of 21.12%, 42.20% and 60.63%. It can be seen that the good results are between the frequency of 2.0 and 2.4 GHz and the best SWR is 4.56 in latex for DRC 60.63% at the frequency of 2.2 GHz. Thus, the rectangular waveguide antennae are good efficiency antennae and the microwave can be efficiently transmitted into the latex by this antennae.

4.5 Determination of the optimal frequency

The results of attenuation due to the water in latex samples which were obtained from HP8510B vector network analyzer over the frequency range of 1.0 – 4.0 GHz using two rectangular waveguide antennae are presented in Fig. 4.6. It is seen that the relationship between attenuation and DRC indicates a good over the frequency range of 2.0 – 3.0 GHz only. The optimal frequency was selected from the best correlation of the graphs that show the relationship between attenuation and DRC in latex.

The summary of graph's slope interception and correlation values at each particular frequency is given in Table 4.2. A linear regression between attenuation and DRC is used to fit the data

$$A = k_1 D + k_0$$

where A is attenuation, D is DRC(%), k_1 is slope, k_0 is the interception at 0% DRC.

The results in table 4.2 demonstrate as follows: at 2.00 GHz the correlation value was 0.965; at 2.10 GHz the correlation value was 0.967; at 2.20 GHz the correlation value was 0.979; at 2.30 GHz the correlation value was 0.997; at 2.36 GHz the correlation value was 0.999; at 2.40 GHz the correlation value was 0.998; at 2.50 GHz the correlation value was 0.989; at 2.60 GHz the correlation value was 0.972; at 2.70 GHz the correlation value was 0.962; at 2.80 GHz the correlation value was 0.946; at 2.90 GHz the correlation value was 0.963; and finally at 3.00 GHz the correlation value was 0.941. Therefore, the high regression values of 0.999 was found at 2.36 GHz, indicating that 2.36 GHz is the optimum operating frequency because of its high regression values when compared to other frequencies. In addition, the frequency of 2.36 GHz is the appropriate operating frequency for DRC meter including rectangular waveguide antenna because the frequency has a minimum effect of ionic phases as well as the loss is influenced by the dipole orientation of water molecules in Hevea latex.

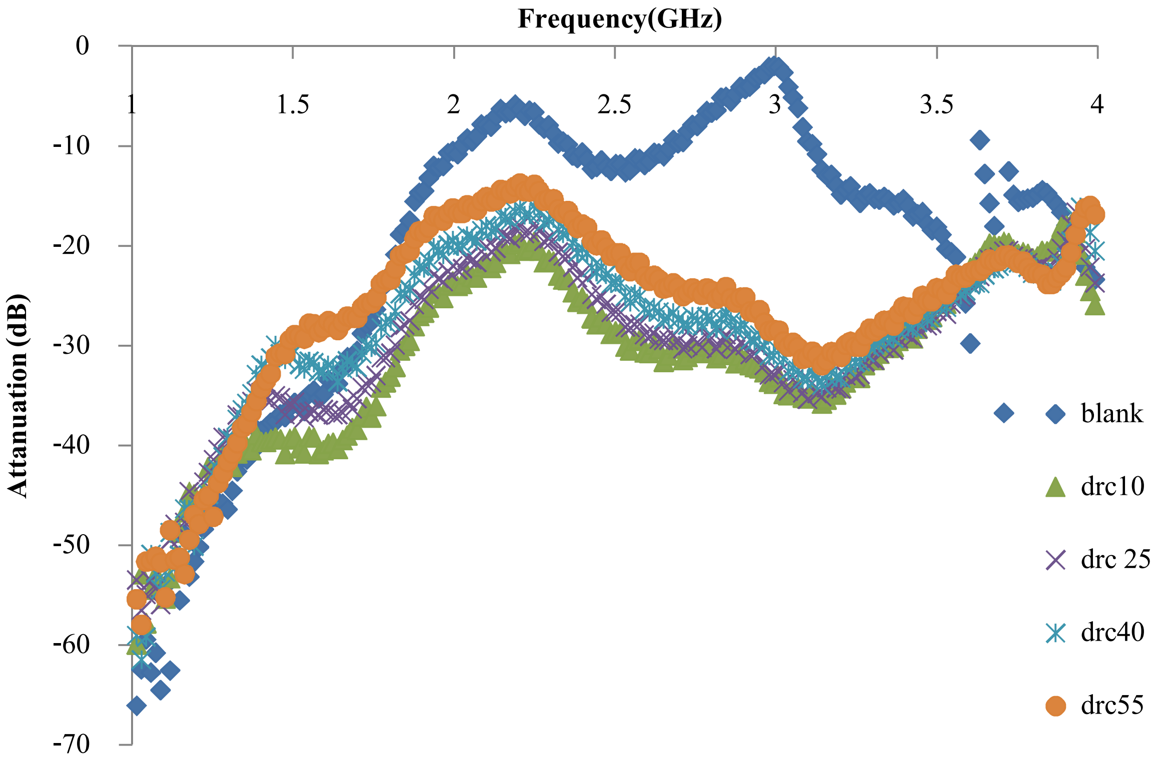


Fig. 4.7 The relationships between attenuation and DRC in latex from 1.0 GHz to 4.0 GHz

Table 4.2 Summary of the preliminary measurements

Frequency	Correlation		
(GHz)	k_0	k_1	R^2
2.00	15.595	-0.1630	0.965
2.10	16.183	-0.1456	0.967
2.20	14.902	-0.1271	0.979
2.30	14.231	-0.1366	0.997
2.36	15.334	-0.1571	0.999
2.40	16.250	-0.1647	0.998
2.50	19.248	-0.1785	0.989
2.60	21.539	-0.1620	0.972
2.70	24.277	0.1491	0.962
2.80	26.992	-0.1342	0.946
2.90	28.853	-0.1328	0.963
3.00	33.143	-0.1146	0.941

4.6 Performance testing of rectangular waveguide antennae

A comparison of the measured microwave attenuation in latex sample for the DRC's range of 10%-60% with the rectangular waveguide antenna by using both coaxial power detector and the commercial VNA (HP8510B) is exhibited in Fig. 4.8

Fig. 4.8 shows that the result of the comparison between coaxial power detector and the commercial VNA is a good agreement with the mean error of 2.25%. Therefore, the attenuation measurement system of the instrument by using rectangular waveguide antennae and coaxial power detector is effective.

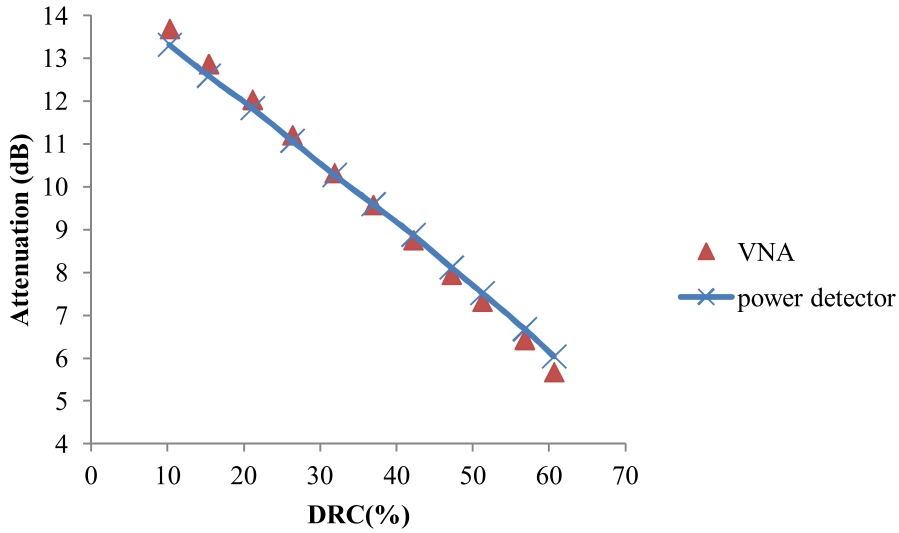


Fig. 4.8 Comparison of attenuation between coaxial power detector and the commercial VNA

4.7 The relationship between digital values and output voltage

The performance of ADC mainly depends on their resolution. The resolution of the ADC is expressed in the number of Bit. For an ADC, the resolution states the number of intervals or levels which can be divided from a certain analog input range. An n-bit ADC has the resolution of $1/2^n$. In this research, the resolution of a 10-bit ADC is 1/1024 because 2^{10} are equal to 1024. Since the measuring voltage range is 2.0 V, this input range can be resolved into 2.0 V /1024 = 1.95 mV precision.

The correlation of the relationship between digital output and analog input voltage is the main value for ADC performance testing. The analog input voltage ranging from 0 – 2.0 V is converted with 10-bit ADC to digital output. As shown in Fig. 4.9, these data values are closely fitted with a linear function model for R^2 = 0.999. Therefore, the 10-bit ADC in ATmega88 microcontroller is the good analog to digital converter, and it is a proper device for determining the measured output voltage from coaxial power detector that can be processed by a microcontroller.

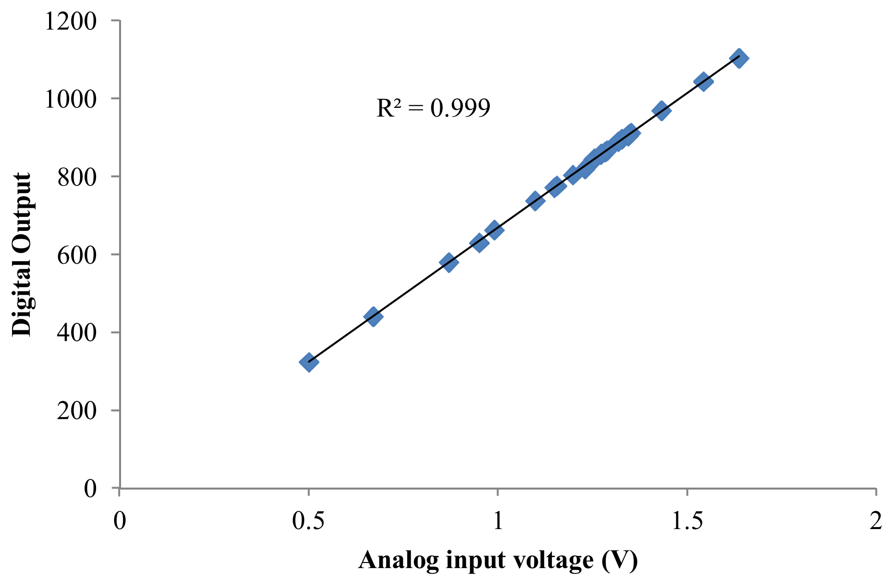


Fig. 4.9 The relationship between digital output and analog input voltage

4.8 A fitting equation between detected power in 10 bit and DRC

A fitting equation of the detected power in 10 bit against the DRC is then plotted as shown in Fig. 4.10. Taking Y to be the detected power measured using this instrument (in 10- bit) and X to be DRC value measured by the standard method, the linear fitting equation between detected power in 10 bit and DRC by using rectangular waveguide antennae is :

$$MC = -2.4791D + 919.07$$

where MC is detected power in 10 bit from microcontroller conversion, D is DRC(%) in rubber latex. As shown in Fig. 4.10, the measured detected power decreases from 892.60 to 768.00 with the increase of DRC from 10.26% to 60.63%. The R^2 value from this fitting equation is 0.999, which is acceptable. This fitting equation can subsequently be used with the instrument to ascertain the DRC of the latex.

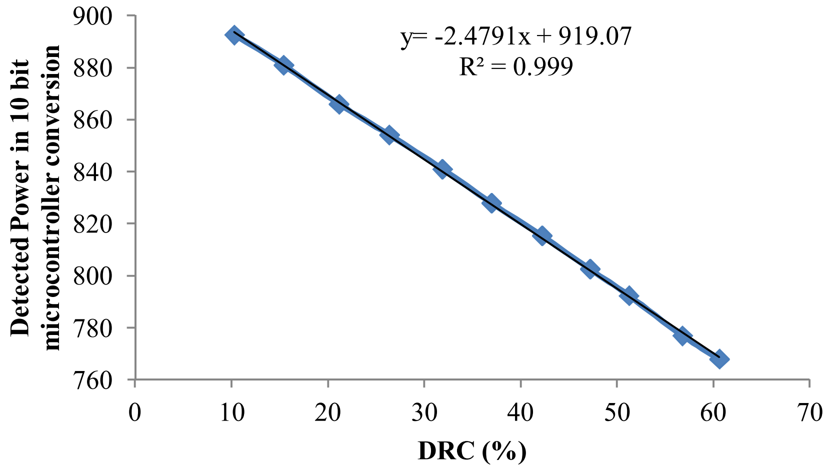


Fig. 4.10 The relationship between DRC and detector power

4.9 The comparison between DRC results from DRC meter and standard method

To demonstrate the DRC meter, the 17 latex samples with different DRC for the range of 30%-40% from natural rubber latex in the various local areas in Songkhla province and the 9 latex samples from the 60% concentrated latex were measured. The comparison between the DRC results of a DRC meter and standard oven-drying method is shown in Fig. 4.11. It can be observed that the determination of DRC meter results are very relatively to the standard oven drying method with R^2 = 0.998.

The relative errors between standard method and DRC meter were calculated by using

$$\text{Relative error} = \left| \frac{\text{standard DRC} - \text{DRC meter}}{\text{Standard DRC}} \right|$$

Fig. 4.12 and Fig. 4.13 show the relative errors for DRC meter using microwave transmission technique. It was found that the mean relative errors in latex from 30% to 40% and the 60% concentrated latex are 0.016 and 0.001 respectively.

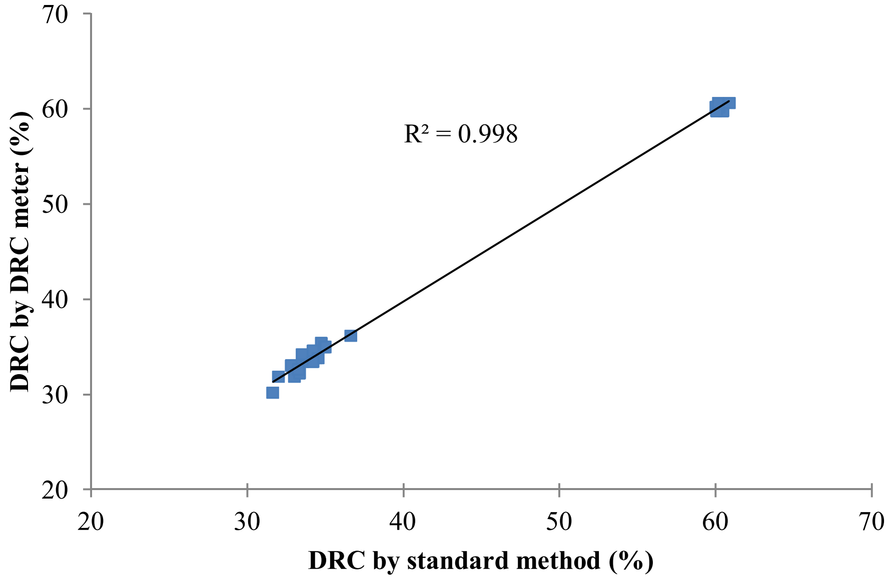


Fig. 4.11 The relationship between DRC of a DRC meter and standard method

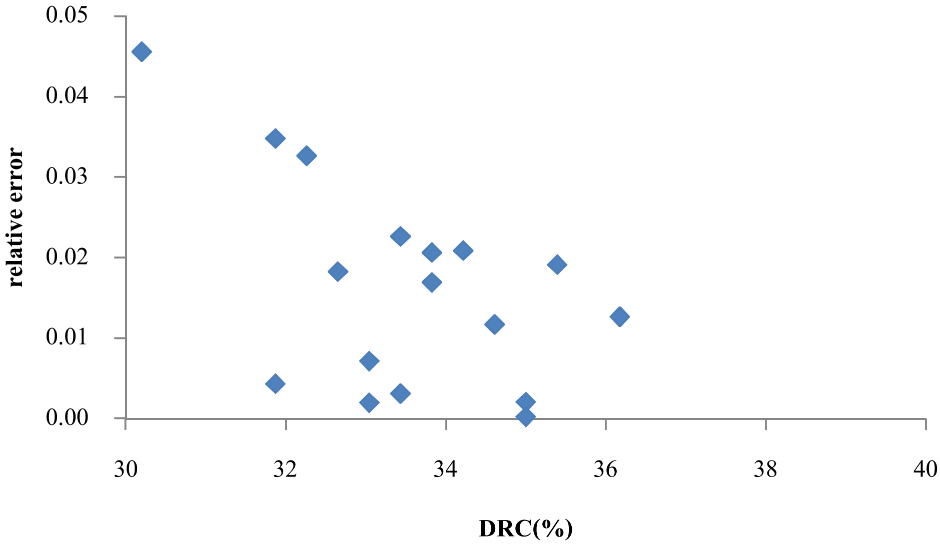


Fig. 4.12 Variation of relative errors distribution versus DRC (%) in latex from 30% to 40%

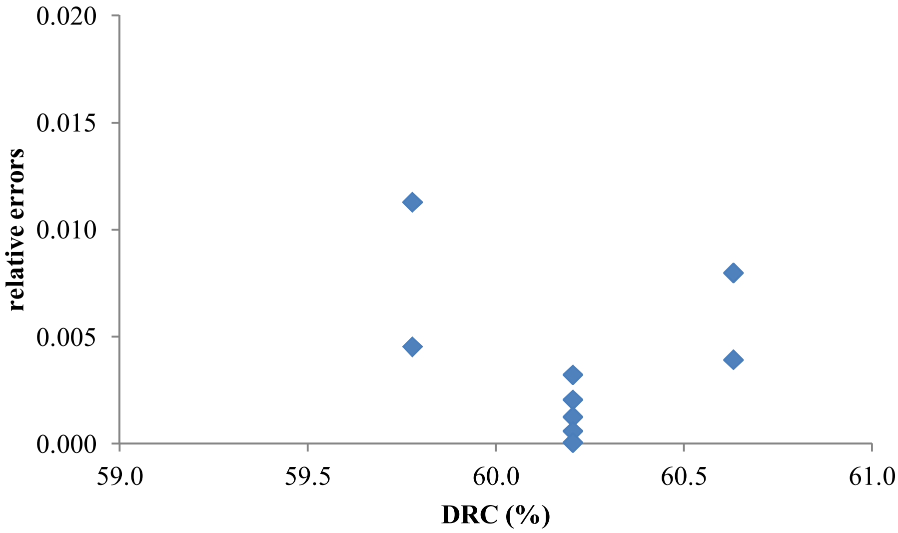


Fig. 4.13 Variation of relative errors distribution in 60% concentrated latex

This deviation may be due to instabilities of the microwave power, detector sensitivity, and moisture of the air, room temperature and the dryness of the outer part of the sample holder, especially the difference in the chemical compounds of the natural rubber latex. Consequently, we can observe, from Fig.4.12, the relative errors is more than the results from Fig. 4.13 which were obtained from the 60% concentrated latex. This is because the natural rubber latex is a biological product of a complex composition and it also varies according to the clone, weather, soil condition and area etc; whereas, the concentrated latex is pure and is one of the cleanest raw materials in term of rubber. The concentrated latex obtained from the natural rubber latex that is placed into a centrifuge, stabilizers are added. As the latex is centrifuged to remove some of the water and non-rubber constituents, the concentrated latex sample has the similar properties and components. For these reasons, the mean relative error of the concentrated latex is less than of the natural rubber latex.

Probability density function (PDF) is a function that describes the relative likelihood for this random variable to occur at a given point in the observation space. The graph of normal probability density function reveals that where the higher probability density of error occurs in measurement. A normal probability density function can be calculated using

$$p(x)=\frac{1}{\sigma\sqrt{2\pi}}e^{\left[-\frac{(x-\bar{x})^2}{2\sigma^2}\right]} \quad (4.1)$$

Where σ represents a standard derivation, x and $\bar{x}$ represents error and mean error of DRC, respectively.

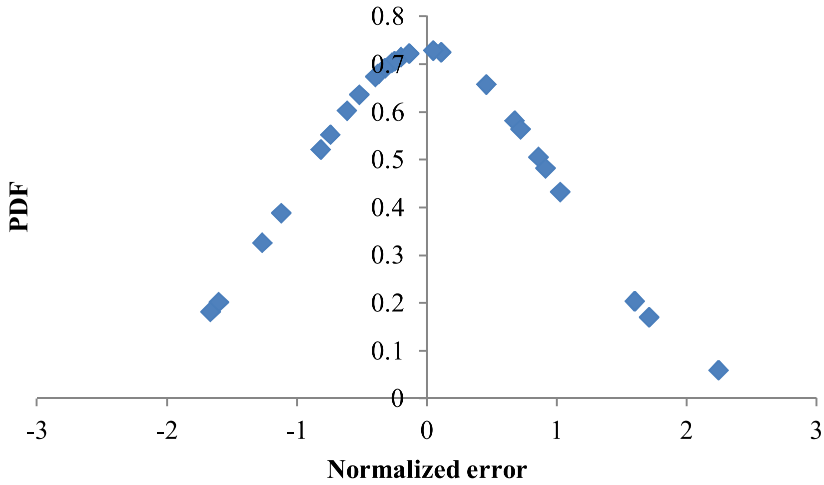


Fig. 4.14 Probability Density Function versus normalized error of DRC for DRC meter

Fig. 4.14 shows the probability density function versus normalized error of DRC in Hevea rubber latex for DRC meter. This study used it to detect an existence of systematic errors during measurement. A good result can be obtained if the probability density of error is normally distributed. The mean error of DRC measured by using DRC meter is 0.21 .The mean error was obtained and calculated by using

$$\text{Mean Error} = \frac{\sum\left|DRC_{s\tan dard} - DRC_{meter}\right|}{number\ of\ error} \quad (4.2)$$

where $DRC_{s\tan dard}$ is actual DRC which is obtained using standard oven method. The error was normalized in the Fig. 4.14 using

$$\text{Normalized Error} = \frac{x - \bar{x}}{\sigma} \tag{4.3}$$

Where σ represents a standard deviation, x and $\bar{x}$ is represented an error and mean error of DRC, respectively.

However, this technique is very appropriate to implement a high-performance and a low-cost DRC measurement device. Furthermore, this method is rapid and the whole operation takes time less than three minutes.

Table 4.3 Timing Chart

Operation	Pouring the latex in holder	Putting the holder in the gap	Reading the data	Removing the holder	Washing the holder and device	Total time
The time required (seconds)	10	5	20	10	60	105

Table 4.3 shows the timing chart of whole operations. The method is also simple to operate and does not require skillful operators. The Hydrometric method is easier because the chemical preparation does not need for the test. The instrument is portable. The data reading is not hard because it can show the result on the LCD screen. The tapper can be witnessed the whole operation of the test on their lattices and the result can be obtained after three minutes. As a result, this research has successfully developed a low cost DRC meter for rapid, accurate determination, and the simple use of DRC determination of rubber latex.

CHAPTER 5

CONCLUSIONS

This chapter includes the summary of our study, and presents research contribution of the thesis. At the end of the chapter, a list of suggestions for future research is provided.

5.1 Summary

The standard oven drying method determination of dry rubber content (DRC) in collected natural rubber latex is too slow for practical field use at latex collection points. It requires a considerably long time normally over night, and the experiment set up has to be manipulated in the laboratory. However, this is the most accurate method. The Metrolac, Latexometer, or Simplexometer are commonly used as the easiest method of obtaining an approximate estimate of the DRC of latex and it is an essential hydrometer which is used to measure the density of rubber latex. It is though quick, simple and easy, but is not very accurate. The error is in the range of 5 to 10 percent. However, this method is still in use in rubber estates for assessing the DRC of latex in order to produce sheets on a large scale and also calculate the quantity of rubber brought in by a tapper. Accordingly, alternatively rapid and sufficiently accurate methods would be welcome.

In this study we designed and implemented microwave transmission experiments using rectangular waveguide antennae made of aluminum which are intended to transmit or intercept the electromagnetic waves in a particular direction, or with a directional pattern that focuses the microwaves to the sample, and sandwiching a sample holder in a vertical stack. Additionally, a novel instrument consists of the power supply, Voltage Controlled Oscillator, detector, microwave generator, power detector, and microcontroller. The microwave energy is guided to pass through the latex samples, and the design prevents electromagnetic interference from outside the waveguides. The temperature increment of the sample is neglected because of the low power and short exposure of the microwave radiation. The microwave is transmitted and received by rectangular waveguide antennae, the power loss of microwave when comes into the latex was detected by the power detector and calculated by ATmega88 microcontroller from ATMEL company which is low-power microcontroller, 10-bit A/D converter. It performs as a computer in data collection, calculation, system calibration, data analysis between attenuation of microwave from the detector and DRC of latex sample under the test, and it shows the result on the LCD. The optimum frequency for this study was 2.36 GHz. The fitting equation was developed from the digital values of microwave attenuation by water diluting concentrated rubber latex so the value of DRC is from 10.26% to 60.63%. The R^2 value from this fitting is 0.9996, which is acceptable. This fitting equation can be subsequently used with the instrument to ascertain the DRC of the latex. The different DRC of latex samples were measured DRC by a novel instrument, and compared the results from standard oven-drying method. The novel instrument results show that it has good accuracy performance with the mean relative errors in latex from 30% to 40%, and the 60% concentrated latex are 0.016 and 0.001, respectively, and R^2 = 0.9983 in latex from 30% to 60%. The results demonstrate microwave attenuation as a promising approach to quickly estimate the DRC of natural rubber latex, and could support the development of novel commercial instruments for such measurements.

5.2 Contribution

The major contribution of this thesis is to propose a DRC determination prototype based on the microwave transmission technique using rectangular waveguide antennae. The prototype shows the excellent accuracy performance and provides a real-time DRC measurement solution. It does not require a skilled operator to operate and maintain the laboratory equipments, and it is easy to use for non-technical personnel in the field. Furthermore, this method is rapid and the whole operation such as pouring the latex in holder, reading the data and washing the holder takes time less than three minutes. The prototype is very suitable for laboratory, industry and in-field applications because it is a fast and highly accurate DRC determination system. The cost of DRC determination prototype is immensely reduced because circuit complexity is handled by software embedded in a microcontroller having high speed in analyzing data, multi-programming capability, and it can also show a real-time result on LCD display. With the price of this DRC determination prototype, it is accessible by the rubber orchard man. Finally, we strongly believe that if the DRC determination prototype is used in a latex trading market, it will create a fair-trade latex system in Thailand and the other rubber producing countries. The system designed here can be applied to measure the moisture content for crops, or agriculture products by re-calibrating, or adjusting the antennae system. Furthermore, it can also be applied to measure the content of other compounds with changing of the frequency of microwave generator, for example, measuring the fat content or protein content in milk.

Besides the DRC meter that has been created support the rubber tappers in measuring DRC by themselves simply without a high skill to use it, using chemicals for preparing rubber latex sample to be measured, and being practically adoptable to the fieldwork. This enables the rubber tappers to measure DRC of rubber latex by themselves and leads to not being taken advantages and defrauded by the dishonest rubber merchants. Additionally the created instrument can be commercially developed and expanded with the reasons that it is not high cost in production process. The rubber tappers can buy and use it at home. From the survey of marketing needs, it was explored that most of the rubber tappers want to but DRC meter helping to measure the DRC value quickly and precisely in order to compare their DRC measurement to the one measured by the rubber merchants. Also, the rubber merchants desire to possess it for assuring the values obtained from the other measurements. If the measurement of DRC has mistakes, it will impact on benefits decreased or capital lost. Moreover, in factories of industrial rubber latex, particularly in some process such as centrifuge that separates water and non rubber from rubber particle to get 60 % concentration of rubber latex, are considerably required the quick and accurate DRC meter to enable the process of producing thick rubber latex in accordance with the suitable process without too much time-wasting of DRC measurement. As a result, the researchers think that this DRC meter that is created can resolve the corruption problem on purchasing rubber latex and also promotes the development of thick rubber latex production that takes decreased time of analyzing

DRC values. This brings about developing the country on Para rubber production with more highly competitive potential in the global market level.

5.3 Suggestions for Future Research

A microwave transmission method using rectangular waveguide antennae for DRC determination has opened up many issues in the research area needed improvement. The exploration of the new issues will lead to a complete design of DRC determination system. These issues are as follows:

5.3.1 Development of the stability power supply

There are two parts of power supply in a DRC determination prototype. First, fixed DC power supply 5V, it supported all electrical devices in this instrument, such as a microwave generator, a detector, and a microcontroller. Second, variable DC power supply, it supported tuning the voltage of voltage controlled oscillator for frequency variation. The stability and accurate power supply is the most important parts for electrical devices because it is a crucial component that ensures proper functions of the electrical devices. The inefficient power supply can lead to problems like system malfunctions and accuracy of measurement system. Thus, a high-quality power supply is required.

5.3.2 Two fitting equation of DRC determination for fresh and concentrated rubber latex

The constituents and DRC range of fresh and concentrated rubber latex are different. To increase the efficiency of DRC determination, the fitting equation should be divided into two modes: fresh; and concentrated. If this two-mode operation is implemented, the accuracy of the measurement is more effective.

5.3.3 Increasing the resolution of ADC bit

The resolution of ADC impacts on the accuracy of measurement system. This research uses the AVR EASY88 board with ATmega88 microcontroller which is 10 bit ADC. An n-bit ADC has the resolution of $1/2^n$. In this research, the resolution of a 10-bit ADC is 1/1024 since 2^{10} = 1024. The measurement of voltage range is 2.0 V so this input range can be resolved into 2.0 V /1024 = 1.95 mV precision. However, due to the sensibility of power detector at 1 mV, if users require a better resolution, ADC can be upgraded to 12-bit which gives a better precision than the power detector. The 12-bit resolution will be 2.0 V /4049 = 0.49 mV.

Solving these issues could potentially lead to a better DRC determination prototype based on microwave transmission technique using rectangular waveguide antennae.

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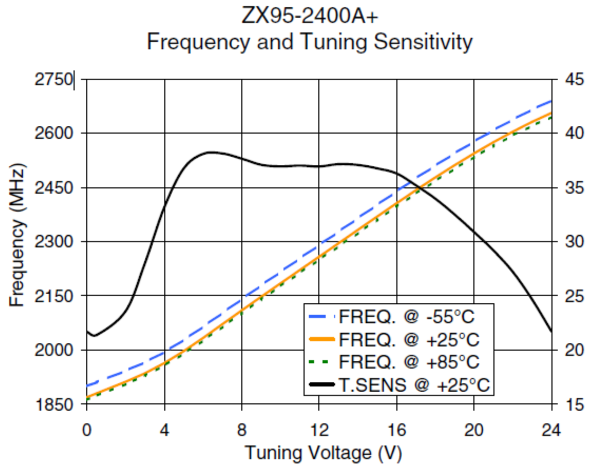
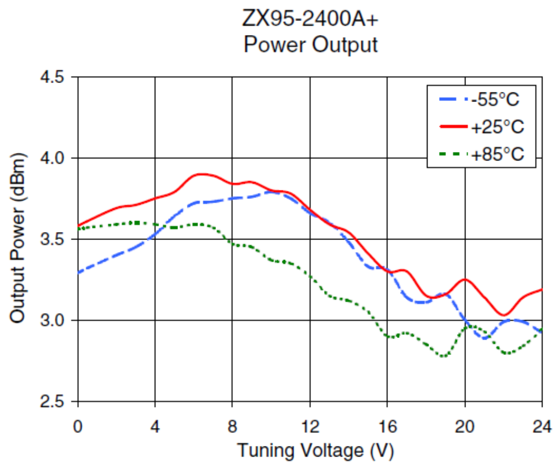
APPENDIX A. DATA SHEET OF THE VOLTAGE CONTROLLED OSCILLATOR AND POWER DETECTOR

Appendix A1 Performance Data of the voltage controlled oscillator (ZX95-2400A+)

V TUNE	TUNE SENS (MHz/V)	FREQUENCY (MHz)			POWER OUTPUT (dBm)			Icc (mA)	HARMONICS (dBc)			FREQ. PUSH (MHz/V)	FREQ. PULL (MHz)	PHASE NOISE (dBc/Hz) at offsets			
		-55°C	+25°C	+85°C	-55°C	+25°C	+85°C		F2	F3	F4			1kHz	10kHz	100kHz	1MHz
0.00	21.68	1900.1	1869.3	1862.4	3.29	3.58	3.56	34.41	-18.4	-36.5	-55.7	4.96	0.81	-74.5	-95.7	-115.5	-135.8
0.50	21.39	1910.9	1880.2	1873.5	3.32	3.61	3.57	34.39	-18.8	-36.8	-55.5	4.95	1.03	-74.5	-95.5	-115.5	-135.7
3.00	28.03	1966.3	1935.7	1929.1	3.45	3.71	3.60	34.34	-19.9	-38.8	-56.1	4.76	0.38	-73.0	-96.6	-115.8	-136.7
5.00	36.75	2028.0	1996.9	1989.9	3.64	3.79	3.57	34.32	-21.4	-41.5	-54.9	4.59	0.35	-72.4	-96.4	-117.0	-136.9
6.00	38.09	2064.8	2033.7	2026.5	3.72	3.89	3.59	34.33	-22.4	-43.6	-56.0	4.50	0.87	-73.6	-94.9	-117.3	-137.4
7.00	38.13	2102.9	2071.8	2064.6	3.73	3.89	3.57	34.33	-23.6	-46.5	-59.5	4.37	0.42	-75.1	-97.7	-117.8	-137.9
8.00	37.65	2141.2	2109.9	2102.6	3.75	3.84	3.47	34.34	-23.4	-47.8	-69.6	4.32	0.77	-76.7	-98.5	-118.1	-138.4
9.00	37.09	2179.1	2147.5	2140.1	3.76	3.85	3.45	34.37	-26.7	-49.6	-65.9	4.29	0.38	-74.9	-98.4	-118.6	-138.8
10.00	36.94	2216.4	2184.6	2177.0	3.79	3.80	3.37	34.40	-26.2	-52.6	-59.7	4.36	0.65	-73.8	-98.0	-118.7	-138.8
11.00	37.02	2253.8	2221.6	2213.7	3.75	3.78	3.35	34.45	-27.3	-51.1	-51.6	4.42	0.40	-73.1	-98.9	-119.0	-138.9
12.00	36.94	2290.5	2258.6	2250.4	3.66	3.68	3.27	34.52	-29.6	-51.2	-51.2	4.47	0.68	-74.4	-97.7	-119.1	-139.5
13.00	37.15	2327.5	2295.5	2287.2	3.60	3.59	3.15	34.60	-30.0	-51.3	-44.6	4.56	0.39	-72.3	-98.2	-119.3	-139.6
15.00	36.76	2402.0	2369.7	2360.9	3.33	3.41	3.05	34.82	-29.9	-48.2	-44.0	4.65	0.32	-74.0	-99.7	-119.9	-139.7
16.00	36.28	2439.1	2406.5	2397.4	3.31	3.30	2.90	34.96	-30.2	-48.2	-46.0	4.73	0.56	-75.5	-100.4	-120.0	-140.4
18.00	33.95	2510.6	2478.0	2468.3	3.11	3.15	2.85	35.36	-29.8	-46.7	-41.8	4.93	0.73	-73.6	-98.8	-120.9	-140.3
19.00	32.48	2544.6	2511.9	2502.1	3.16	3.16	2.78	35.61	-30.0	-45.0	-39.2	5.07	0.49	-73.0	-99.2	-120.8	-140.9
20.00	30.88	2577.2	2544.4	2534.5	3.00	3.25	2.95	35.90	-30.2	-45.6	-37.8	5.16	0.42	-74.0	-99.8	-121.0	-141.3
21.00	29.18	2608.4	2575.3	2565.2	2.89	3.14	2.93	36.21	-30.0	-45.0	-36.8	5.16	0.60	-72.5	-99.8	-121.6	-141.8
22.00	27.20	2638.0	2604.5	2594.0	2.99	3.03	2.80	36.53	-29.1	-44.5	-37.2	5.17	0.25	-73.5	-100.7	-120.9	-141.8
24.00	21.69	2690.8	2656.3	2645.0	2.92	3.19	2.95	37.18	-30.1	-44.4	-38.7	4.76	0.39	-74.4	-99.8	-121.6	-141.8





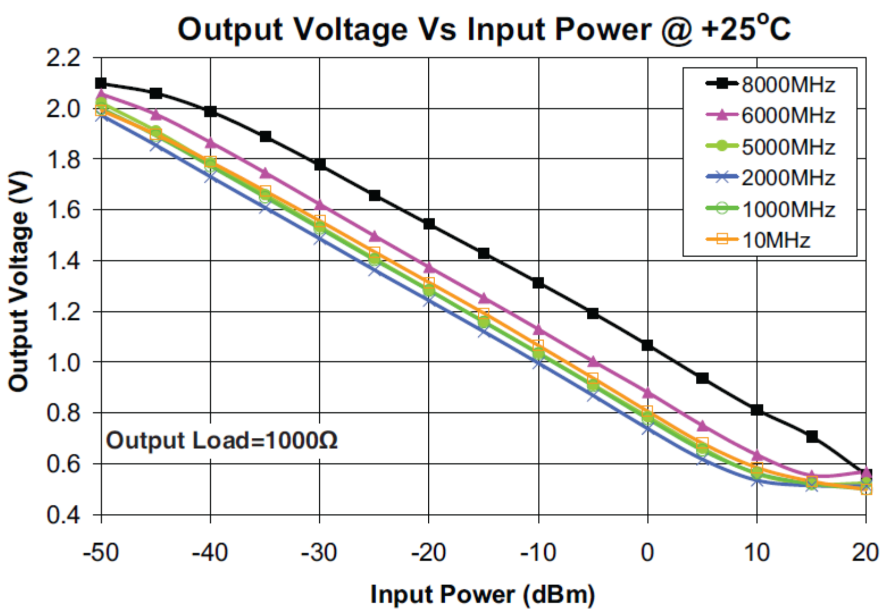
Appendix A2 Performance Data of Power Detector

Electrical Specifications (T_{AMB}= 25°C)

FREQ. (MHz)		DYNAMIC RANGE AT ±1dB ERROR (dBm)	OUTPUT VOLT. RANGE (V)	SLOPE (mV/dB) (Note 1)	VSWR (:1)	PULSE RESPONSE TIME (nSec) Typ.				TEMP. SENSOR OUTPUT SLOPE (mV/°C) (Note 2)	DC OPERATING POWER			
						ZX47-50+		ZX47-50LN+			Vcc (Volts)			Note 3 Current (mA)
Min.	Max.	Typ.	Typ.	Typ.	Typ.	Rise	Fall	Rise	Fall	Typ.	Min.	Typ.	Max.	Typ.
10	1000	-45 to +10	0.50 - 2.10	-25	1.05	400	10	800	400	2.00	4.5	5.0	5.5	100
1000	5000	-50 to +5			1.20									
5000	6000	-45 to +10			1.30									
6000	8000	-40 to +15			1.20									

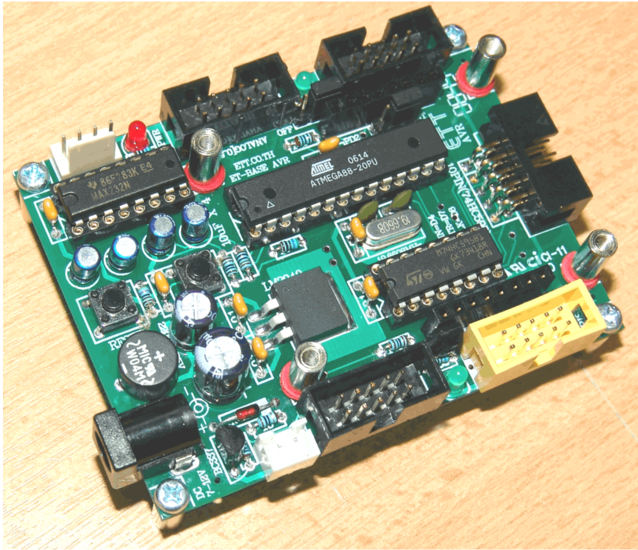
Notes:

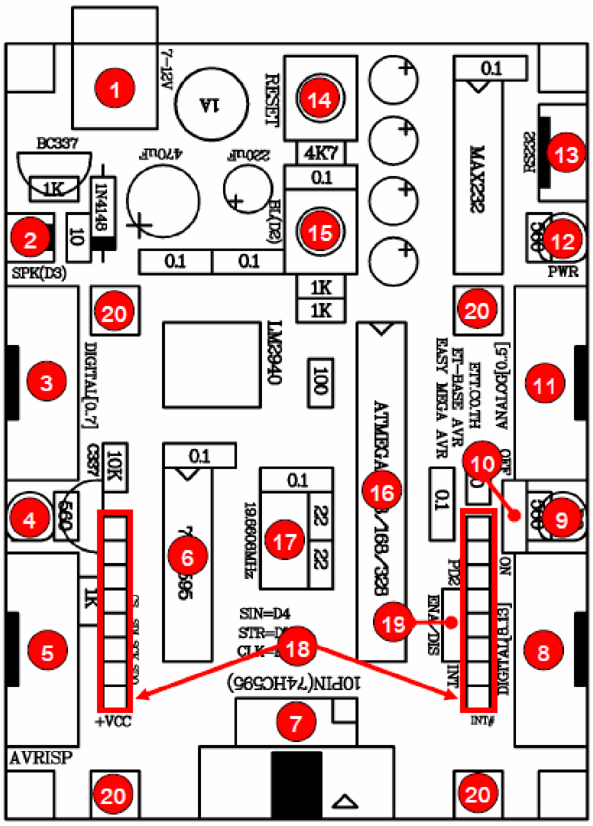
1. The negative slope indicates that Output Voltage decreases as Input Power increases. See "Output Voltage vs Input Power" graph below.
2. Temperature sensor output provides a DC Output Voltage which increases linearly with temperature rise. Recommended minimum load for this port is 2 kΩ.
3. Recommended minimum load at DC out port is 100 Ω. See maximum ratings for no damage.



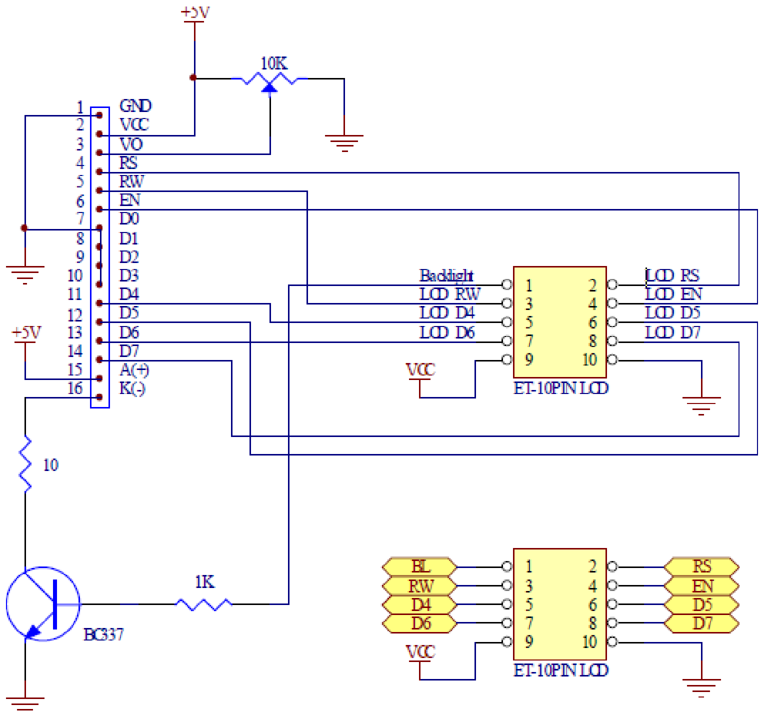
APPENDIX B. AVR EASY88 BOARD AND ET-EASY AVR LCD

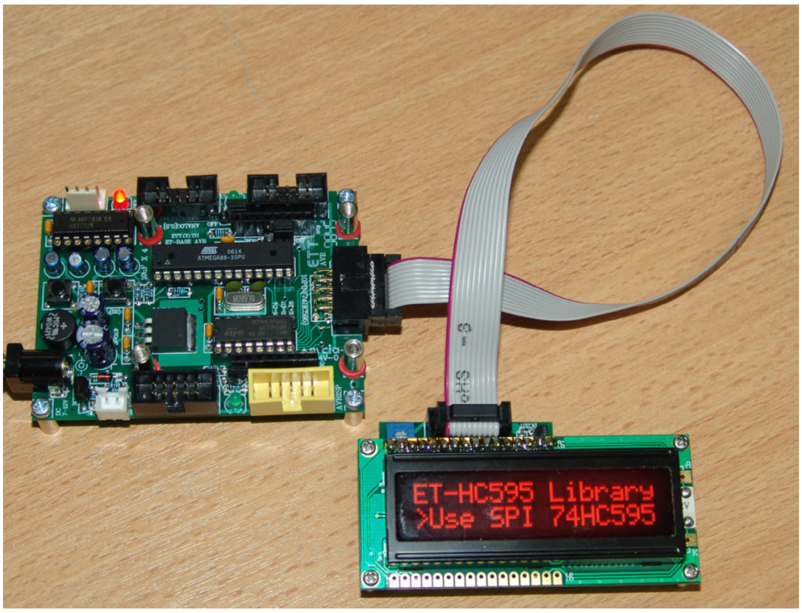
Appendix B1 Circuit layout of AVR EASY88 BOARD



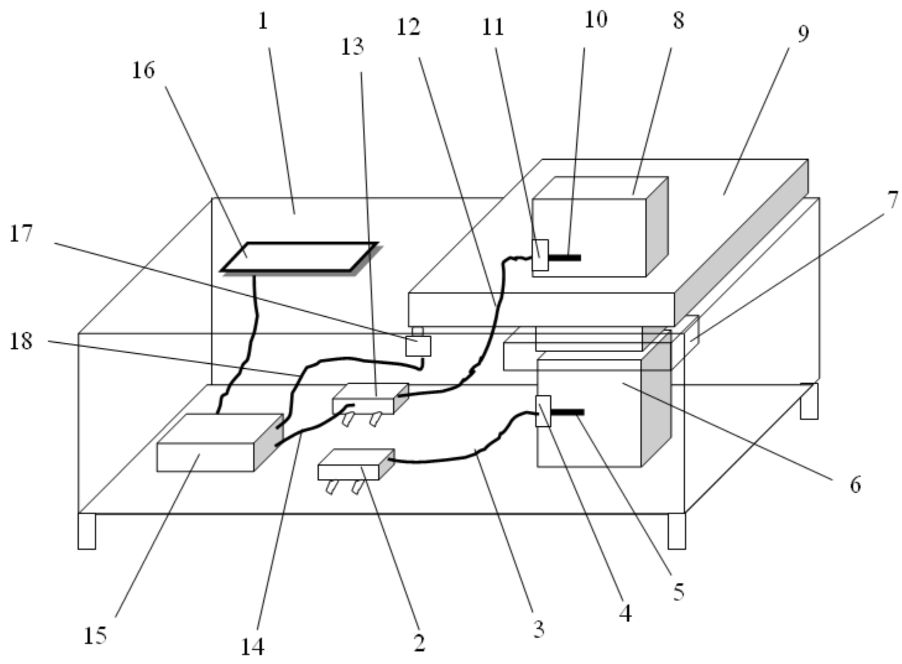


Appendix B2 Circuit layout of ET-EASY AVR LCD





APPENDIX C THE SCHEMATIC OF THE DRC MEASUREMENT INSTRUMENT



Instrument Components:

1. Frame made of plastic box size 330mm×160mm×100mm
2. Microwave generator
3. RG58 coaxial cables
4. N-Type male connector adaptor
5. The probe in waveguide is a 2 mm diameter copper wire, length about 36 mm
6. The transmitting waveguide antenna with 70mm×70mm×70mm in size, made of rectangular hollow box section with 3 mm thick aluminum
7. Sample holder, a rectangular container made of polystyrene with 2 mm wall thickness, 85mm×85mm×97.5mm in size
8. The receiving waveguide antenna with 70mm×70mm×70mm in size, made of rectangular hollow box section with 3 mm thick aluminum
9. The cover, it can be opened and closed for take the latex in the sample holder

10. The probe in waveguide is a 2 mm diameter copper wire, length about 36 mm

11. N-Type male connector adaptor

12. RG58 coaxial cables

13. Coaxial power detector

14. Electric wire

15. ATmega88 microcontroller

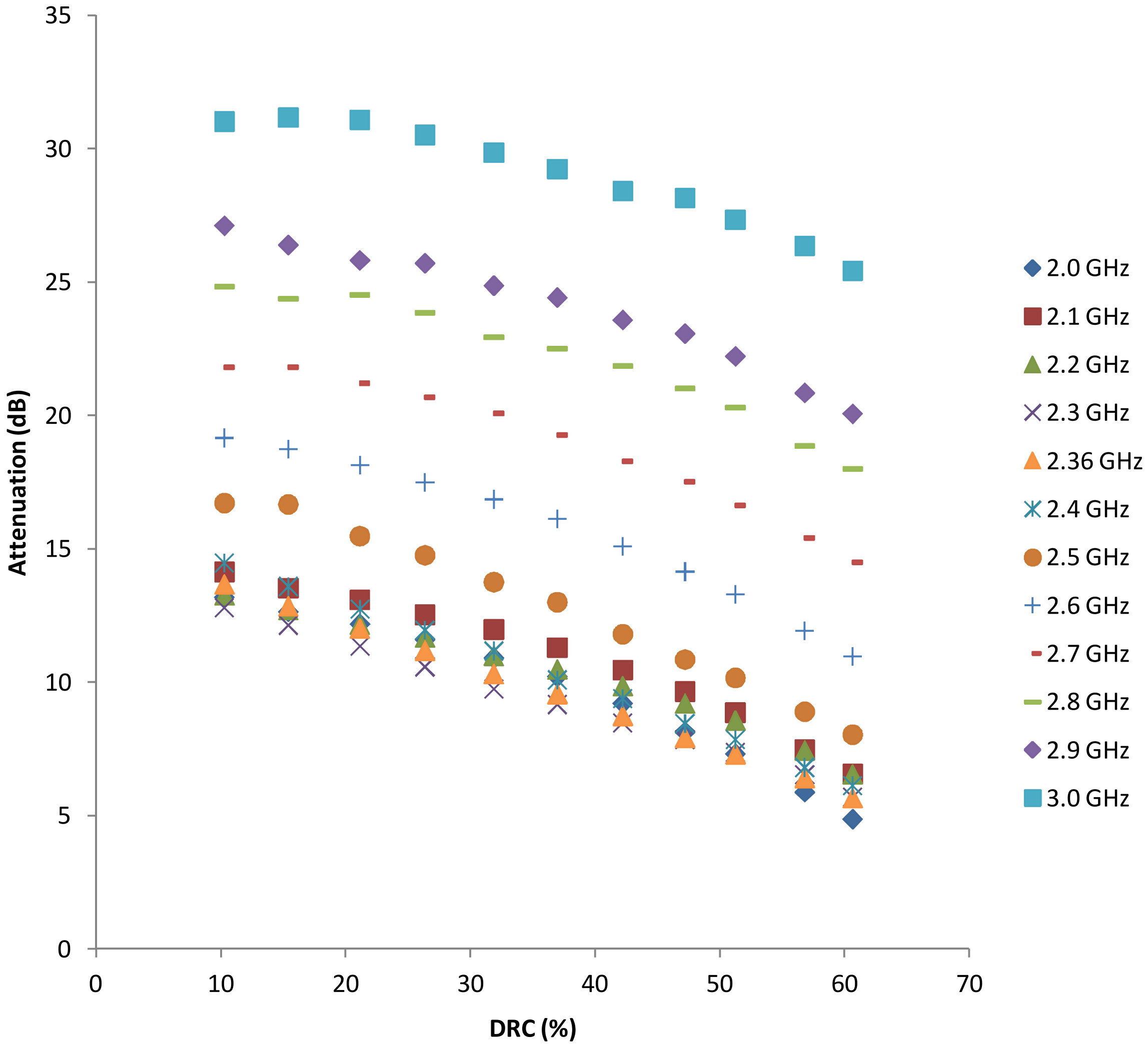
16. AVR LCD

17. Cover Switch

18. Electric wire

APPENDIX D THE RELATIONSHIPS BETWEEN ATTENUATION AND DRC

Appendix D the relationships between attenuation and DRC in latex at frequency range 2.0–3.0 GHz



APPENDIX E THE PROGRAMMING CODE IN ATMEGA88 MICROCONTROLLER

```
int CS = 8;
int SCK = 9;
int SDI = 10;
int LDAC = 11;
int SHDN = 12;
int inPin = 6;
int botton;
int i = 0;
int val1;
int aver=0;
unsigned int sum;
unsigned int val2;
int fulldrc;
int drc;
int dotdrc;
float realdrc;
#include <LCDHC595.h>
#define SIN_PIN 4
#define STR_PIN 7
#define CLK_PIN 8
LCDHC595 lcd = LCDHC595(SIN_PIN,STR_PIN,CLK_PIN);

void Write_MCP4922(unsigned char DAC_Channel,unsigned int DAC_Data)
{
 digitalWrite(CS,LOW);                  //Enable MCP4922
 switch          (DAC_Channel)                  //Select Ch(0=A,1=B)
 {
        case 0x00: DAC_Data|=0x3000;          // Write DAC-A
               break;
        case 0x01: DAC_Data |=0xB000;          // Write DAC-B
                break;
```

```
 }
 shiftOut(SDI,SCK,MSBFIRST,(DAC_Data >>8)&0xFF);  //MSB Data(High Byte)
 shiftOut(SDI,SCK,MSBFIRST,DAC_Data &0xFF);      //LSB Data(Low Byte)

  digitalWrite(CS,HIGH);                 //Disable MCP4922
  digitalWrite(LDAC,LOW);                 //Enabla Pulse Latch
}
void setup()
{
 pinMode(CS,OUTPUT);
 pinMode(SCK,OUTPUT);
 pinMode(SDI,OUTPUT);
 pinMode(LDAC,OUTPUT);
 pinMode(SHDN,OUTPUT);
 digitalWrite(CS,HIGH);                  //Standby CS Signal
 digitalWrite(SCK,LOW);
 digitalWrite(SDI,LOW);
 digitalWrite(LDAC,HIGH);                //Standby LDAC Signal
 digitalWrite(SHDN,HIGH);                //Standby SHDN Signal
 lcd.Initial();
 lcd.Backlight(1);
 }
void loop()
{
   botton = digitalRead(inPin);
   if (botton==1)
   {
    if(val2<=10000)
     {
               Write_MCP4922(0,1229);               //DAC-A = 0.3 Scale of REF-A
(1.5V)
```

```
            Write_MCP4922(1,4095);              //DAC-B = Full Scale of REF-B
(5V)
        analogReference(EXTERNAL);
        int analogPin = 0;
        delay(500);
        val1 = analogRead(analogPin);    //read analogpin 0
        i=i+1;
        sum = val1+val2;        //calculation sum
        val2 = sum;
        aver = sum/i;           //cal aver
        realdrc =(919.07-aver)/2.4791;
        drc = realdrc;
        fulldrc =realdrc*100;
        dotdrc=fulldrc%100;
       lcd.ClearScreen();
       lcd.Print("val=");                  //show val
       lcd.SetCursor(0x04);
       lcd.Print(val1);                    //show val1
       lcd.SetCursor(0x0d);
       lcd.Print(i);
       lcd.SetCursor(0x40);
       lcd.Print("av=");
       lcd.SetCursor(0x43);
       lcd.Print(aver);                    //show aver

       if(aver>690)
        {
          lcd.SetCursor(0x08);
          lcd.Print(fulldrc);                    //show fulldrc
          lcd.SetCursor(0x47);
          lcd.Print("drc=");                     //show sum
          lcd.SetCursor(0x4B);
```

```
            lcd.Print(drc);
            if(dotdrc>10)
            {
            lcd.SetCursor(0x4D);
            lcd.Print(".");
            lcd.SetCursor(0x4E);
            lcd.Print(dotdrc);
            }
           else
            {
            lcd.SetCursor(0x4D);
            lcd.Print(".0");
            lcd.SetCursor(0x4F);
            lcd.Print(dotdrc);
            }
          }
        else
          {
          lcd.SetCursor(0x08);
          lcd.Print(0000);                    //read fulldrc
          lcd.SetCursor(0x47);
          lcd.Print("drc=0");                  //show sum
          }
       }
     else
       {
       val2 =0;
       i=0;
       delay(500);
       }
  }
  else
```

```
  {
   lcd.ClearScreen();
   lcd.Print("close to start");
   i = 0;
   val2 = 0;
   delay(1000);
  }
}
```

VITAE

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Education Attainment

Degree	Name of Institution	Year of Graduation
B.Sc (Physics)	Prince of Songkla University	1998
M.Ed (Science Education)	Prince of Songkla University	2004

Scholarship Awards during Enrolment

Prince of Songkla University Graduate Studies Grant

List of Publication and Proceedings

Sunheem, P. and Aiyarak, P. 2014. Determination of dry rubber content based on phase shift by microwave transmission technique. International Congress on Natural Sciences and Engineering, Committee of ICNSE 2014 Yamagata University.

Work Experience

Lecturer : Yala Islamic University Year 2005-2011