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A FAST AND ACCURATE TECHNIQUE FOR DETERMINATION OF MOISTURE CONTENT IN HEVEA RUBBER LATEX USING AN INSULATED MONOPOLE SENSOR

Farizah Ansarudin*[1,2], Zulkifly Abbas*[1], Mohammad Aliff Ismail[1]

[1]Department of Physics, Faculty of Science, Universiti Putra Malaysia, 43000 Serdang, Selangor, Malaysia.
[2]Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
*Email: izah@vlsi.eng.ukm.my ; za@science.upm.edu.my

ABSTRACT

This paper presents a new insulated monopole sensor technique to determine the amount of moisture content in hevea rubber latex. The conventional oven drying method to determine moisture content in hevea rubber latex is too time consuming and laborious. Using insulated monopole sensor technique, calibration equations have been established relating magnitude and phase of reflection coefficient, conductance and susceptance to moisture content. These equations were in turn used to predict moisture content in rubber latex from microwave measurements. Correlation between the magnitude and phase shift of reflection coefficient, conductance and susceptance with frequency were analyzed for latex moisture content in the range from 36.95% to 82.92%. Comparison results were made between predicted and actual moisture content obtained using conventional oven drying method. Calibration equations based on the magnitude and phase of reflection coefficient, conductance and susceptance were found to be the most accurate within ±5% when compared to conventional oven drying method.

Keywords: *reflection coefficient, conductance, susceptance, relative error*
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INTRODUCTION

Many types of microwave sensors have been developed for determination of moisture content in materials. Applications of microwave sensors cover various industries such medicine, environment and tremendously in agricultural industry for quality assessment. Due to its importance in modern life especially in agricultural products, microwaves have a tremendous number of existing and possible applications techniques and instrumentation in improving agriculture. Application of microwaves in determining quality assessment of agricultural products has been reported by many researchers [1-3].

In the rubber industry, moisture content of freshly tapped natural rubber latex is usually between 40 and 65% in normal case and it is lower than total solid content [4]. This is also affect the different amount of moisture content (*m.c*) because this composition varies widely according to season, tree ages, weather, soil condition, clone, tapping system, etc [5]. Approximately half of the total world production of latex comes from rubber smallholdings. Latex collected by smallholders is sold to a collector who pays according to the dry rubber content (DRC) or *m.c*. It is important that the true *DRC* or *m.c.* of the latex is determined correctly to ensure a fair price is paid to the tapper. However, factors like the climatic conditions and tapping system will affect the concentration of rubber latex or scientifically called *Hevea Brasiliensis*. Bad practices such as addition of too much water for dilution could result in a dispute between the buyer and seller. Unfortunately existing methods to determine the amount of DRC or *m.c* such as titration, buoyancy and hydrometer method including the conventional oven drying method for determination of latex concentration are either laborious, inefficient, difficult, time consuming or inaccurate. Comparison of the determination of total solid content between conventional convection oven method and the microwave oven heating method reported by [6] shows that the microwave method is more economical, and faster. Hence, oven drying method suffers from the demerit of time consuming as well as not being able to completely remove the allergy causing proteins from the natural rubber.

Recent years, microwave measurement methods are used to to determine the quality of fresh hevea latex. [7] developed a microwave-based method to determine the DRC of natural latex while [8] presented that the DRC could be determined with a capacitive transducer. An experimental study carried out by [9] on dielectric properties of the DRC based on microwave measurement technique. Even the DRC have been widely investigated by previous researchers, the correct determination of *m.c.* is also important of the rubber latex to ensure fair price is paid to the tapper. A dual frequency sensor developed by [10]to measure moisture content of hevea rubber latex namely *Latexometer* at two frequencies in the X-band, 8.48 GHz and 10.69 GHz. The principle of the sensor is depending on an incident microwave signal from a transmitter situated at the bottom of the sample and the output of reflections and transmissions from and through the interfaces of a multi-layer system. However, the four layer system (air-perspex-sample-air) will produce an air gap between sample and sensor instead it does not involve proper sampling preparation while pouring it into container. The demerits of these measurements are high price and maintenance cost of the equipment that usually involve in high frequency devices, hence, most of these methods are hard to apply in practice. An open ended coaxial sensor [11] was also used to determine moisture content in hevea latex. However the technique is only suitable for subsurface measurement due to its low electromagnetic field penetration depth, thus only suitable for sensing moisture of a thin layer of latex. However, the penetration depth could be resolved probably by using a more dedicated instrument such as TROTEC T600 material moisture meter [12]. This paper presents the potential application of a commercially available stub contact panel as an insulated monopole sensor for the determination of moisture content in hevea latex based on reflection method.

MATERIALS AND METHODS

The insulated monopole sensor was a modification of a commercial standard SMA stub contact panel with a square flange serving as the ground plane in this work. The input port was a SMA female type with insulation material made of polytetrafluroethylene (PTFE). The protruding inner conductor of the stub was cut so that it has similar length h_a with the insulated material, i.e 15 mm. The radius of the inner conductor *a* and insulated material *b* were 0.65 mm and 2.05 mm, respectively. The research procedure of reflection measurement is shown in Figure 1. Measurements of the reflection coefficient of the insulated monopole sensor were accomplished by using a computer controlled Agilent Professional Network Analyser (PNA) model N5230A connected to a coaxial semi-rigid cable with characteristic impedance (Z_o=50 Ω) as shown in Figure 2.The frequency range of measurement was set from 100 MHz to 5 GHz. The measured reflection coefficient of the sensor were displayed in terms of the S-parameter S_{11} or reflection coefficient comprises of magnitude, $|\Gamma|$ and phase, φ of reflection coefficient. Prior to measurement, a full one-port calibration procedure was performed at the end of the coaxial cable using Agilent Calibration Kit 85052D. Three standard were measured, namely Short, Open and Load (S-O-L) to remove systematic error of the PNA according to manufacturer recommendation*s*. The sensor was then connected to the coaxial cable and the reflection coefficient of the unloaded sensor (in air) was recorded, followed by measurements on distilled water and rubber latex samples of different percentages of *m.c.* For each measurement, the sensor was wiped dry to ensure no traces were left on the insulated monopole sensor.

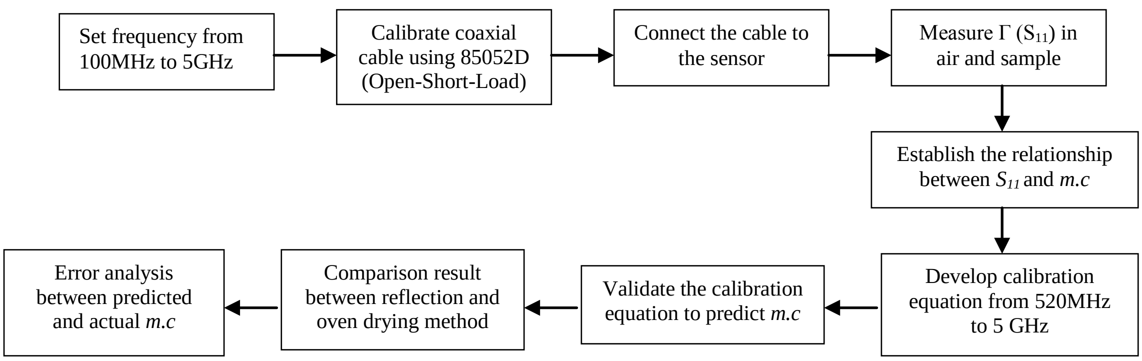

Fig. 1: The procedure of reflection measurement (S_{11})

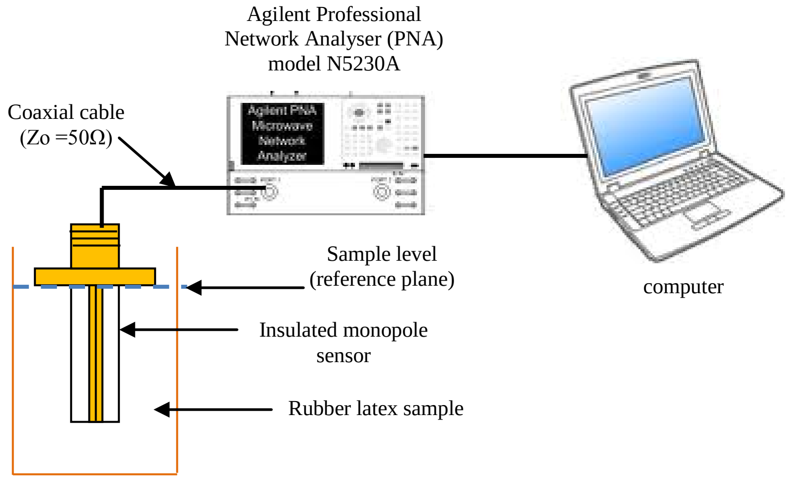

Fig. 2: The measurement set-up

The sample used in this study was hevea rubber which freshly tapped from rubber trees at Universiti Putra Malaysia Research Park. The freshly tapped latex samples in this work were found to be 42.47% *m.c.* which was considerably lower than typical values about 55% *m.c.* reported in [13]. Water in hevea latex can easily evaporate or condense leaving behind the dry rubber. A series of solution was prepared from the freshly tapped latex. These solutions were diluted with different volumes of deionised water to obtain different percentages of moisture content in latex. A total of 87 latex samples of different percentages of *m.c* were measured where 50 samples were used to establish the relationship between microwave parameters and moisture content. The accuracy of the calibration equations compared to the standard oven drying method was tested using another set of 37 samples. Ammonia was added to preserve the latex content from coagulation. The mass of ammonia is negligible always less than 0.39% of the mass of the fresh latex and the percentage was much lower for diluted samples. The actual moisture content of rubber latex in percentage was obtained using the conventional oven drying method and it was calculated specifically as:

$$m.c\ (\%) = \frac{m_w - m_d}{m_w} \times 100 \qquad (1)$$

RESULTS AND DISCUSSIONS

The relationships between magnitude, $|\Gamma|$, phase shift, $\Delta\varphi$, conductance, G, susceptance, B and moisture content with frequency have been obtained using regression analysis. An equation with high regression coefficient does not necessarily produced high accuracy prediction results. Accurate results can only be validated by comparing the predicted *m.c.* results obtained indirectly from the reflection measurements with the actual *m.c.* found using standard oven drying method. The distribution of calibration equations for $|\Gamma|$, φ, G B and moisture content from 0.52 GHz to 5 GHz were shown in Table 1. The performance of the sensor based on these different parameters with the objective to determine *m.c.* from reflection measurement using a simple insulated monopole sensor. The predicted *m.c* using the regression equations based on the relationship between magnitude, phase shift, conductance, susceptance and moisture content are compared with the actual *m.c* obtained for 37 new samples using standard oven drying method. The relative error in the predicted moisture content with respect to the actual moisture content obtained using standard oven drying method was based on the following equation:

$$\text{Relative Error} = \left| \frac{mc_{\text{actual}} - mc_{\text{predicted}}}{mc_{\text{actual}}} \right| \qquad (2)$$

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Table 1: Calibration equation and mean relative error from 0.5 GHz to 5 GHz for (a) magnitude, |Γ| (b) phase shift, Δφ (c) conductance,G (d) susceptance, B

Frequency (GHz)	Regression Coefficient (R^2)	Equation	Mean Relative Error
0.52	0.9492	$MC = 1.59*10^4|\Gamma|^2 - 29576|\Gamma| + 13814$	0.052
1.0	0.0471	$MC = -4.96*10^3|\Gamma|^2 - 8809|\Gamma| + 3966.9$	0.234
1.5	0.1136	$MC = 2.0*10^3|\Gamma|^2 - 2947.9|\Gamma| + 1113$	0.243
2.0	0.4880	$MC=3.93*10^2|\Gamma|^2 - 542.51|\Gamma| + 227.92$	0.189
2.4	0.2502	$MC=-4.33*10^2|\Gamma|^2+2819.7|\Gamma| - 388.82$	0.258
3.0	0.3121	$MC=3.63*10^4|\Gamma|^2 - 1645.6|\Gamma| + 244.26$	0.257
3.5	0.0218	$MC=3.25*10^3|\Gamma|^2 - 1529.6|\Gamma| + 241.68$	0.241
4.0	0.2975	$MC=-1.96*10^4|\Gamma|^2+ 10002|\Gamma| - 1196.3$	0.277
4.5	0.1651	$MC= -9.99|\Gamma|^2 - 144.59|\Gamma| + 105.12$	0.165
5.0	0.2385	$MC = 5.67*10^3|\Gamma|^2 - 3680|\Gamma| + 651.39$	0.253

(a)

Frequency (GHz)	Regression Coefficient (R^2)	Equation	Mean Relative Error
0.52	0.8955	$MC = -779.94\Delta\phi - 231.51$	0.013
1.0	0.8804	$MC = -192.97\ \Delta\phi - 99.047$	0.714
1.5	0.5658	$MC=-153.19\Delta\phi -150.29$	0.182
2.0	0.0003	$MC = -1.59\ \Delta\phi + 60.451$	0.261
2.4	0.3057	$MC = 46.97\Delta\phi + 188.8$	0.193
3.0	0.6168	$MC = 37.18\Delta\phi + 186.38$	0.113
3.5	0.8616	$MC = 64.32\Delta\phi + 283.47$	0.158
4.0	0.8657	$MC = 70.18\Delta\phi + 297.73$	0.167
4.5	0.8660	$MC = 80.89\Delta\phi + 411.26$	0.147
5.0	0.7662	$MC = 95.97\Delta\phi + 434.96$	0.624

(b)

Frequency (GHz)	Regression Coefficient(R^2)	Equation	Mean Relative Error
0.52	0.9264	$MC=9.00*10^7G^2 - 157849G + 105.99$	0.061
1.0	0.1548	$MC = -4.0*10^7G^2 + 164525G - 99.623$	0.170
1.5	0.5311	$MC = 8.19*10^3G^2 - 577.85G + 66.006$	0.171
2.0	0.1533	$MC = -6.03*10\ G^2 + 2986.9G + 29.282$	0.174
2.4	0.1075	$MC = -7.06*10\ G^2 + 24309G - 142.24$	0.133
3.0	0.2791	$MC = 7.0*10^6G^2 - 174044G + 1168.5$	0.327
3.5	0.5145	$MC = 3.0*10^6G^2 - 93364G + 768.89$	0.421
4.0	0.9638	$MC = -1.0*10^6G^2 + 39720G - 265.74$	0.345
4.5	0.3817	$MC = -5.65*10^5G^2 + 29511G - 308.11$	0.130
5.0	0.1373	$MC = -2.29*10^5G^2 + 14474G - 160.53$	0.269

(c)

Frequency (GHz)	Regression Coefficient (R^2)	Equation	Relative Error
0.52	0.8174	$MC = -1*10^{14}B^4 + 3*10^{12}B^3 - 5*^{10}B^2 + 3*10^8B - 624779$	0.5549
1.0	0.6682	$MC = 4*10^7B^3 - 3*10^6B^2+57397B-371.6$	0.3372
1.5	0.0162	$MC = 178.98B + 54.603$	0.2151
2.0	0.5446	$MC = 2217.7B + 112.88$	1.7498
2.4	0.4419	$MC = -8024.9B - 15.61$	0.4220
3.0	0.6478	$MC = -9101.7B + 54.878$	0.2354
3.5	0.6152	$MC = -8157.1B + 100.89$	0.4199
4.0	0.3251	$MC = -9552.2B + 160.1$	1.0023
4.5	0.4087	$MC = 4*107B^3 - 2*10^6B^2 + 19264B + 7.4459$	0.3880
5.0	0.3317	$MC = 3*10^7B^3 - 28418B^2 - 5421.7B + 47.371$	1.8120

(d)

The regression equations with the lowest mean relative error are listed in Table 2. The closer the predicted *m.c* to the actual *m.c*, the lower shall be the mean relative error and thus the more accurate the prediction of *m.c*. It can be concluded from Table 2 that the most accurate equation to predict moisture content in hevea latex is based on the measurement of the phase shift of the reflection coefficient at 0.52 GHz, i.e,

$$MC = -779.94\Delta\phi - 231.51 \quad (3)$$

The mean relative error percentage when using equation (3) was approximately 1.37%. Figure 3 compares directly the predicted and actual *m.c*. The very high sensitivity value 0.9933 indicates almost perfect on-to-one correspondence between predicted and actual *m.c*. Careful analysis of the tabulated results shown in Table 2 suggests at the same optimum frequency 0.52 GHz, prediction of *m.c* based on magnitude (|Γ|) and conductance G could also produce relative errors as low as 5.21% and 6.11%, respectively. However, susceptance was found low mean relative error as 21.51% at 1.5GHz.

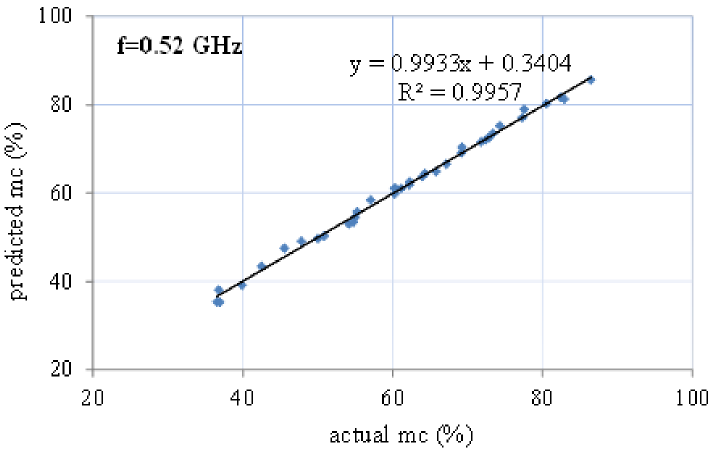

Fig. 3: Comparison between predicted *m.c* using equation (3) and actual *m.c*. using oven drying method.

Table 2: Accuracy in prediction of *m.c* using insulated monopole sensor calibration equations.

Parameter	Calibration Equation	Regression Coefficient (R^2)	Optimum Frequency (GHz)	Mean Relative Error
Magnitude of reflection coefficient (|Γ|)	$MC = 15873\|\Gamma\|^2 - 29576\|\Gamma\| + 13814$	0.9492	0.52	0.0521
Phase shifts (Δϕ)	$MC = -779.94\Delta\phi - 231.51$	0.8955	0.52	0.0137
Conductance (G)	$MC = 9x10^7 G^2 – 157849G + 105.99$	0.9264	0.52	0.0611
Susceptance (B)	$MC = 178.98B + 54.603$	0.0162	1.50	0.2151

CONCLUSIONS

Calibration equations relating moisture content to magnitude, phase shift, conductance and susceptance at different frequencies have been established. The accuracy of the proposed technique was tested on more than 37 samples of different percentages of moisture content. The best operating frequency for all the calibration equations based on magnitude, phase shift and conductance equation was 0.52 GHz. The phase shift technique was found be to be most accurate in the determination of moisture content within 1.37% when compared to actual moisture content obtained using standard oven drying method.

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