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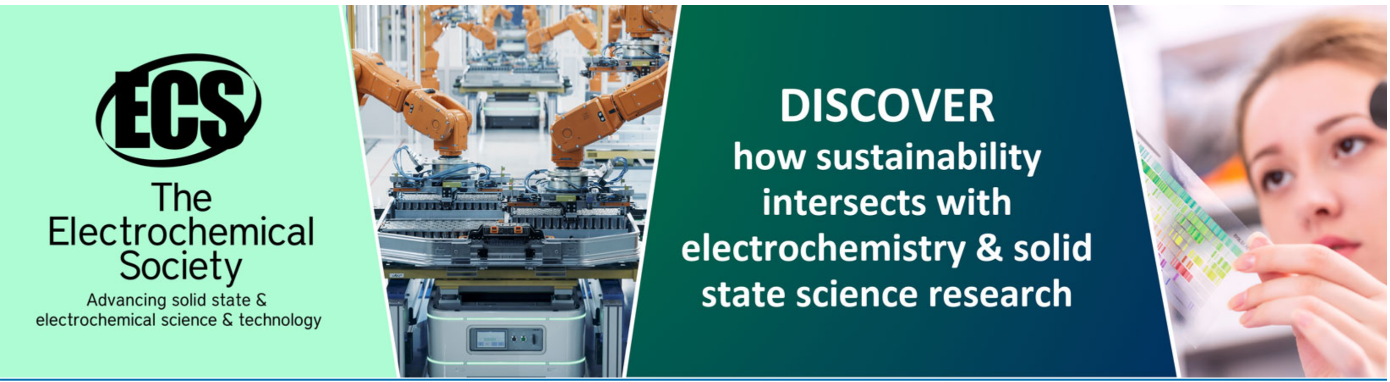

Microstrip patch antenna as a paper moisture sensor

P S Bansode*[1], H A Tanti[2], A C Joshi[1], Y J Gaikwad[3], R C Aiyer[4] and S.A. Gangal[1]

[1]Department of Electronic and Instrumentation Science, Savitribai Phule Pune University, Pune, India.

[2]Department of Astronomy, Astrophysics & Space Engineering (DAASE),Indian institute of Technology Indore, Indore, India

[3]School of Polytechinc and Skill development, MIT-WPU, Pune, India.

[4]Department of Physics, Savitribai Phule Pune University, Pune, India.

E-mail: *pranotisbansodeoffice@gmail.com

Abstract. This paper reports the use of non destructive, microstrip patch antenna as paper moisture sensor. Microstrip patch antenna is designed to resonate at 2.4GHz. This design is simulated and fabricated on copper clad type FR4 (εr= 4.4) having thickness of 1.6mm. Patch dimension are 27mm × 30mm and substrate dimension is 63mm × 60mm. The microstrip transmission line is used to provide excitation for the antenna. This design for microstrip patch antenna after fabrication showed a resonance at 2.38 GHz on vector network analyzer at S11=-19.38dB with impedance =49Ω. The variations in frequency in relation with water content in the paper is measured using Vector Network Analyzer by placing wet paper on the patch antenna. Moisture content in the paper was found out by taking wet weight and dry weight of the paper. The model of the wet paper is recommended primarily on the basis of water–dry paper reactions, along with the thickness and surface roughness explaining tendencies of the sensitivity graphs. Paper samples of 13 different types, with different GSM values and thicknesses, havingdimensions same as that of the substrate were tested. From the results it is observed that as the moisture content in the paper increases the frequency decreases. The change in frequency with respect to the moisture content is seen to have quadratic relation with moisture. The variations in the frequency are fitted in the form of equations. The calculated %Mwet indicates an error around ±0-4% in the calculated value as compared to the actual value. The response of sensor is almost linear with respect to the references but the coefficients depend non-linearly with the paper dimension.

1. Introduction

In biomaterial applications moisture determination is very important. Moisture can be detected in paper, leaves, rice, grain etc. For the quality of the paper moisture is important because excessive moisture content in the paper may have the prospect of fungus growth issues. Contarary to this lesser water content may lead to delicate papers. The microstrip patch antenna is used as a paper moisture sensor to improve the quality of the paper, avoiding damage and for improved commercial value. Therefore, by knowing the moisture one can control the quality of paper by adjusting moisture content.

Vessen Vassilev et al [1] developed a simple sensor for measurement of moisture content in the thin paper. The sensor is capable of resolving 0.005 dB loss achieving a moisture resolution of 0.1% for moisture content higher than 15%. Two horn antennas are kept in an angle for transmission and reception with respect to paper.so that signal transmitted through the paper gets attenuated in proportion to the water content. Uncertainty in the measurement is due to standing waves in the signal which can be calculated by using equation 2 in the referred in the paper. Kaida Khalid et al [2] Paper gives a review of the several moisture sensors using planar structures such as microstrip, conductor- backed coplanar waveguide (CBCPW) and micro-strip antenna. They developed a prototype known as microwave reflection type latexometer which is further used to measure the moisture content of hevea latex. Authors had mainly tested and reported about U-shaped micro-strip sensor and CBCPW sensor for measurement of moisture. Authors noticed that the sensitivity is drastically affected by the thickness of the protective layer. The deviation of the test result of the moisture parameter is less than 1%compared to that obtained by Standard Gravimetric method. R.A.Yogi et al [3] described the application of microstrip ring resonator for paper moisture sensor application. The paper samples of seven different types were tested with grammage and thickness ranging between 21- 70 gm^{-2} and 24- 80 µm respectively. A single equation for f_r variation is modelled corresponding to grammage and normalized percentage moisture (M_{ww}). A model indicating wet paper is recommended primarily on the basis of water–dry paper interaction, along with consideration of thickness and surface roughness, to explain nature of the response curves. The estimated $\%M_{ww}$ gives an error of ±0.9% in the calculated value as compared to the actual value. Tatsuo Toba et al [4]. A wireless moisture sensor has been developed on the basis of the backscatter characteristic of the microstrip antenna, which works in the far field without a battery. The moisture of the sensor surface is monitored by measuring the backscattered power ratio at two appropriate frequencies. 0.954 GHz and 2.45GHz were used to measure the backscattered power. Proposed sensor consists of microstrip antenna and a load resistance. The load resistance 50 ohm was soldered in the center of the PCB. The sensitivity of the water detection depends on the shape of the microstrip antenna. As per the paper author will further study the highly sensitive shape of antenna.

2. Antenna Design

Microstrip patch antenna is made up of dielectric substrate material. On which one of the substrate surface contains radiating patch element while other surface consists of ground plane. Usually, conducting material such as copper or gold is employed for fabricating patch antenna element and ground planes. Standard FR4 substrate (dielectric constant of 4.4) was used for designing the antenna and simulations were performed using HFSS software. The resonant frequency value for this design is at 2.4 GHz. figure 1 shows the fundamental design dimensions for the patch antenna.

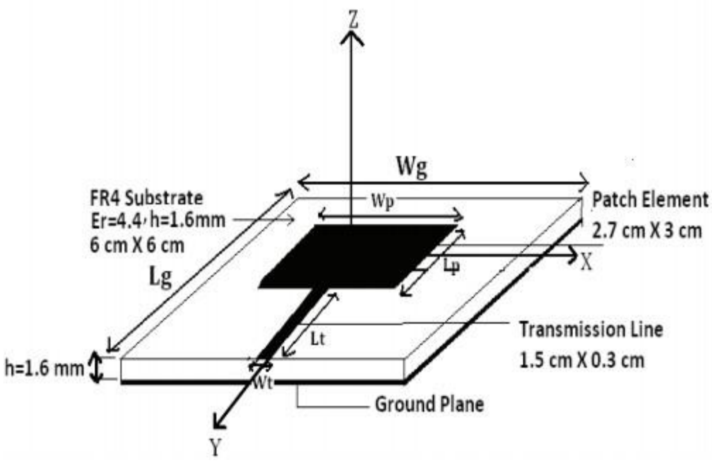

Figure.1 Microstrip patch antenna design dimensions

3. Experimental Procedures

The design of patch antenna is simulated using HFSS software. Photolithography technique was adopted further to print the previously designed microstrip patch antenna on FR4 substrate. The fringing fields between patch edge and ground plane are responsible primarily for radiation of microstrip antenna. Vector Network Analyzer (Agilent E5062A) was used for recording the resonant frequency and return loss (lS11l) of the fabricated antenna. Overlay technique is used for testing fabricated microstrip patch antenna as a paper moisture sensor.

3.1 Samples prepared for measurement.

Thirteen varieties of papers having variable thicknesses without laminations possessing different grams per square meter (here onwards GSM) values were used (refer to table 1). The dimensions of paper specimen were 6.3 cm X 6.3 cm, consequently casing the whole area where the patch antenna is defined. There were thirteen variations in paper thickness that were studied for sensing studies. The moisture concentrations were varied for thirteen values and each paper specimen having variable thickness was exposed to all moisture concentrations. In this experiment almost 1000 total observations were taken.

Table 1 – Sample paper descriptions

Paper Sample no.	Thickness (in µm)	GSM (gm^{-2})
A2	195	110.79
A3	209	130.12
A1	205	134.67
C3	47	31.85
C1	50	32.45
B2	172	131.97
K1	222	139.77
G1	541	348.83
H2	304	214.05
B4	183	129.34
WN1	489	282.33
D4	203	122.22
GR1	102	75.54
S1	277	246.52
GP1	52	30.63
GP2	57	29.59
E3	141	94.01

3.2 Method used for sample testing

The variation of resonant frequency F_r was recorded on Vector network analyzer (E5062A) by following the standard operating procedure from Agilent guide. Microstrip patch antenna was covered by a adhesive tape (50 micron thick) to circumvent electrical contact of patch antenna owing to an superimpose of moist paper sample. Firstly this paper sample was kept in water for possible absorption followed by mounting onto microstrip patch antenna along with addition of weight provided by a Polystyrene block ($\varepsilon_r \approx 1$) to maintain a pressure on it. So, at the time of measurement when paper soak then air will not go between the substrate and paper i.e. for better material contact with the microstrip patch antenna. There is a minute variation in resonant frequency due to adhesive tape and pressure block. The characterization of soaked paper was performed using a vector network analyzer. The weight of soaked paper was measured by a single pan electronic balance (Citizen CX165) and the weight value was denoted as wet weight W_{wet}. Further the paper was subjected to drying procedures and same measurement process was repeated until the moisture level in the paper is almost near to 0%. The final weight value corresponding to dry paper is noted as W_{dry}. After placing the wet paper on patch antenna till it becomes dry the corresponding changed microstrip patch antenna parameters established the former paper weight without water (W_{dry}). The absolute wetness (M_{ab}) in the sample specimen is calculated by employing the expression given below[4],

$$M_{ab} = W_{wet} - W_{dry} \quad (1)$$

4. Results and Discussions

Microstrip patch antenna senses the moisture in the paper which is placed on patch antenna as shown in figure 2. As we place the wet paper the variations in the frequency is observed with respective to moisture percentage (M_{wet}%). Following graph shows the variations.

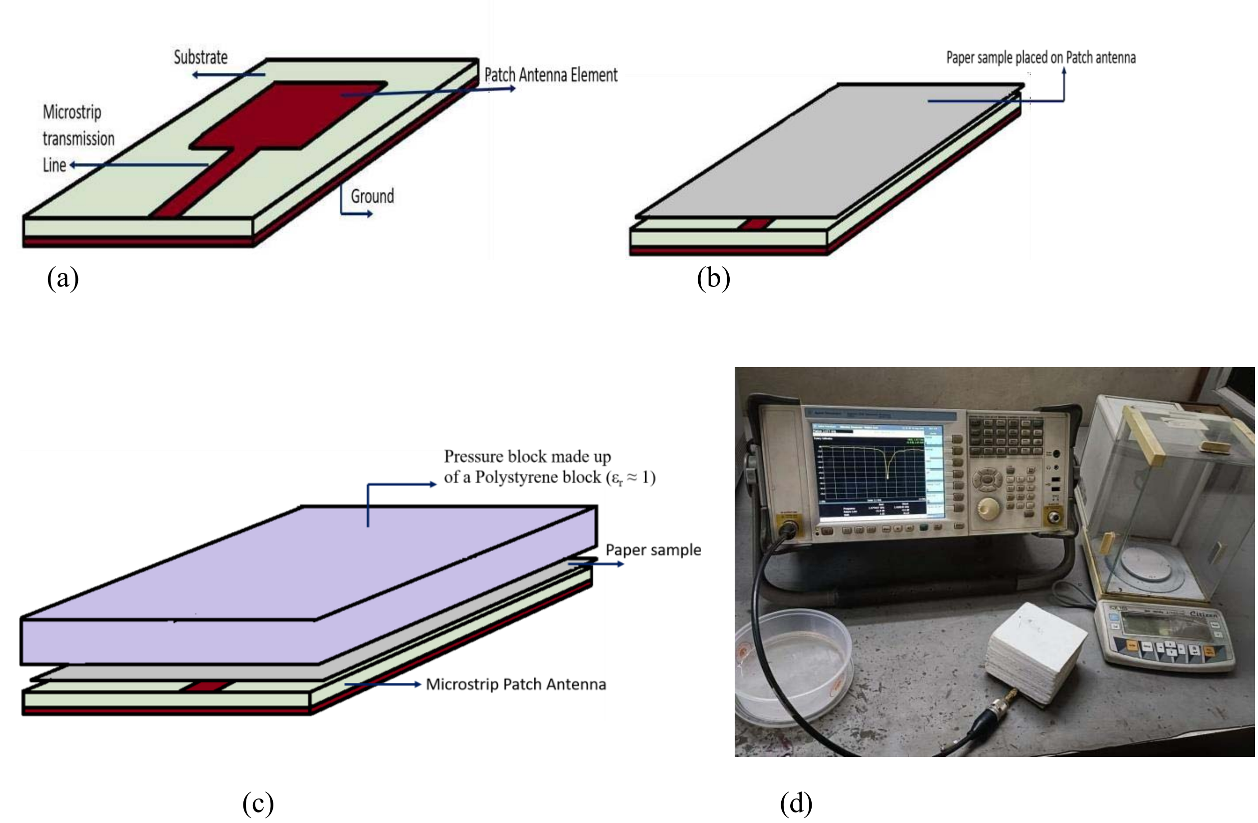

Figure.2 Paper arrangement on microstrip patch antenna. (a) Microstrip patch antenna structure. (b) Patch antenna with Paper sample placed.(c) Patch antenna with paper sample and pressure block. (d) Experimental Setup.

To eliminate the scatter, M_{ab} is standardized with reference of instant soaked overlaid paper weight (W_w) [3],

$$\%M_{wet} = (M_{ab}/W_{wet})\ 100 \quad (2)$$

The standardization procedure is proportional to density so variations in density will give similarity with results related to moisture content variations, consequently producing erroneous outputs. [3] In the paper industry for analyze the normalized data consider thickness as an important parameter. The following graph in Figure 3 is plotted for the variations in the frequency and moisture percentage.

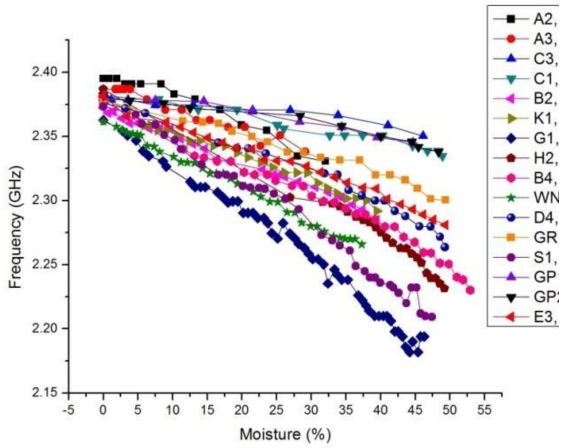

Figure.3 Frequency vs. Moisture content

From the Figure 3, it is observed that variations in the frequency with moisture percentage is dependent on the thickness of the paper. For each paper data was fitted with quadratic equation and coefficients values (A, B, C) were correlated with thickness of respective sample papers. A specific quadratic equation was established from these experimental data of variable thickness values indicating the correlation of frequency(F_r in gigahertz (f)), moisture content(% M_{wet}(m)) and thickness (t)of the paper,

$$F = F_0 + S_1M_{wet} + S_2M_{wet}^2 \quad (3)$$

$$F_0 = F_r + -0.03729t \quad (4)$$

F_r= Resonant frequency of patch in free space

$$S_1 = 2.60608 \times 10^{-4} + -0.01332\, t + 0.01508\, t^2 \quad (5)$$

$$S_2 = -2.49888 \times 10^{-6} - 7.75292 \times 10^{-5}\, t + 6.51835 \times 10^{-5}\, t^2 \quad (6)$$

The data will be generated according to the dry thickness of the paper. According to experimentation, frequency and thickness of the paper is available so, to calculate the moisture content in the paper can be calculated with help of following formulae. The data is shown in Figure 4.

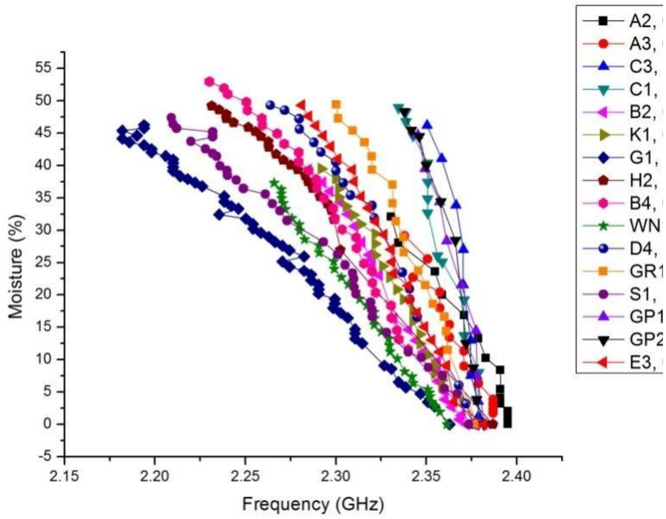

Figure 4 Moisture content vs. Frequency

$$M_{wet}=P + QF \quad (7)$$

Where, F is the resonant frequency after placing the sample.
P and Q are the thickness dependant coefficient which is formulated by curve fitting for each sample and reverse calculations. The formulae are as follows,

$$P = 770.65078 + 3916.30618 \exp(-t/0.07103) + 6.36175*10^{22} \exp(-t/0.00104) \quad (8)$$

$$Q = -324.11228 -1644.52661 \exp(-t/0.07083) -2.97912*10^{22} \exp(-t/0.00103) \quad (9)$$

5. Conclusion

The Microstrip patch antenna is use as a moisture sensor having variable thickness ranging between 47µm- 541 µm along with GSM variations between 29.59 gm^{-2} to 383.83 gm^{-2} .From the data of moisture percentage and variations in the frequency reveals that sensitivity of the curve is thickness dependent. An equation was established highlighting the sensitivity with normalized moisture content(% M_{wet}(m)) along with thickness(t) for all types of paper. Moisture content in specimen papers is calculated with the thickness of the paper and respected variation in the frequency after placing the sample over the patch antenna. The moisture content can be calculated by two way : Finding out the roots of the equation (3) and from equation (7) and calculating P and Q values. The error while calculating the moisture content is ±0-4% where as if one can calculate the value of F by using equation (3) the error will be ± 0-0.9 %.

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