

Microstrip Moisture Sensor Based on Microstrip Patch Antenna

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Abstract—A miniaturized U-shape patch sensor (15 mm × 15 mm) was designed at dual resonating frequencies (f_r) 5.2 GHz and 6.8 GHz. The proposed design printed on FR4 material with a thickness of 1.676 mm and relative permittivity 4.4. To simulate the performances of the proposed design, the CST Microwave Studio (CST MWS) was used. The reflection coefficient of U-shape patch sensor was measured. Basmati rice was investigated, and bulk density was increased with increase of moisture content, hence varied from 554.3 to 591 kg/m³. It has the longest average rice length (L) 7.2 mm, average width (W) 1.61 mm, and L/W ratio 4.47. The percentage of moisture was varied from 10.71% to 21.87% calculated on a wet weight basis. The lowest mean relative error (MRE) determined between predicted moisture content (PMC) and actual moisture content (AMC) was 0.55% at dual frequencies.

1. INTRODUCTION

Microstrip resonators have been widely used for the measurement of dispersion, phase velocity [1–4], dielectric constant [5], and discontinuities [6, 7]. The two configurations that are most used are linear and ring resonators. For a linear resonator, the fringing fields on both open ends will cause a foreshortening effect [8–10], along with surface- and space-wave radiation losses [11–13], whereas ring resonator (Figure 1) has two advantages: It is free of open-ended effects, and its curvature effects can be made negligible if its diameter is large enough, with respect to the line width [14].

Rice is the most important cereal food crop of India, occupying one-fourth of the gross cropped area of the country. As a basic food crop, rice is cultivated comfortably in hot and humid climate, but the main concern arises when matter rises related to its storage, transportation and delivery to beneficiaries. As India has both tropical and subtropical climates, if transportation is done from north to south or vice versa either for consumption or for exports, then proper storage becomes a main subject. For the storage of rice, its moisture content needs to maintain that will ensure safety of rice from destroy or insects. Also to fulfil needs of population [India consumes about 100 million metric tonnes (approx.) per year] government maintains its buffer stock. It is possible to maintain food in buffer stock fresh, and moisture content of rice also needs to be maintained. To achieve this, it is aimed to construct microstrip moisture sensors which can detect moisture quickly through which it becomes easy to decide regarding dispatch grain or storage related matters. A lot of procedures have been found to measure moisture content in rice. A traditional drying method has been described to measure moisture. An open-ended coaxial probe has been used to measure the dielectric concentration of starch. These time-consuming processes are complex, and the system development cost is high. Being comparatively simple and cost-effective system, microstrip technology is now widely used in various applications like agriculture, medical, communications, etc. [15, 16]. Dielectric based sensors depend on the dielectric properties, as well as the physical properties of the material. These sensors have

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been used in sensing the moisture content, temperature, bulk density, salinity, fuel adulteration, etc. A microstrip patch antenna has been reported in [15] which can be used in agricultural field with a relatively larger size of $7.9 \text{ cm} \times 5.4 \text{ cm}$. The effects of moisture on the dielectric properties of rice have been reported. The microstrip patch antenna has been used in the measurement of dielectric properties of materials. The technique of medical diagnostics using waveguide probes and reflection methods has been rendered in [16]. The rectangular dielectric waveguide (RDWG) technique has been described for the determination of moisture in oil palm fruits [17]. To measure moisture in hevea rubber latex, a U-shaped antenna has been described [18]. A moisture sensor has been rendered based on the microstrip antenna which is operated on dual frequencies [19–26].

In this article, the main focus was to design a patch sensor with compact size ($15 \text{ mm} \times 15 \text{ mm} \times 1.676 \text{ mm}$) and to reduce MRE between the PMC and AMC for detected the moisture content of rice through the sensor.

2. SENSOR DESIGN

The U-shape patch sensor design and fabricated sensor are shown in Figure 1 and Figure 2. The optimized dimensions of the sensor geometry are listed in Table 1. The area of the substrate was $15 \times 15 \text{ mm}^2$. The U-shape radiator was printed on top layer of the substrate. The CST optimized common element sensor fabricated on an FR4 substrate and energized using a 50 ohm SMA connector. An (SMA) 50Ω connector allowed the sensor to be connected to the port of an Agilent N9925A (VNA) Vector Network Analyzer, while discrete ports are mainly used to simulate lumped element sources inside the calculation domain. These ports are a good approximation for the source in the feeding point of antennas when calculating farfields. In some cases, these ports may also be used to terminate coaxial cables or microstrip lines. The parameters of the sensor are: $P_L = 8 \text{ mm}$, $P_W = 10 \text{ mm}$, $Q_L = 8 \text{ mm}$, $Q_W = 10 \text{ mm}$, $L = 15 \text{ mm}$, $W = 15 \text{ mm}$, $R_X = 10 \text{ mm}$. The U-shape patch sensor was designed to reduce the overall size of MPA structure for dual frequency. The sensor geometry is derived in 6 steps as shown in Figure 3.

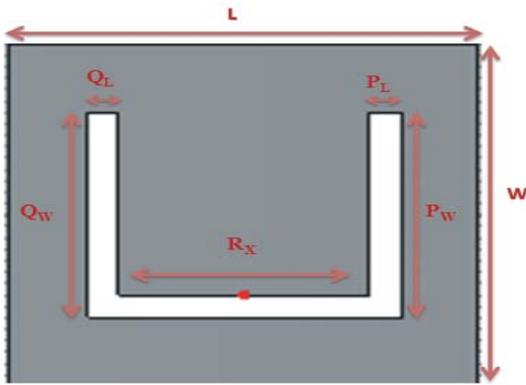


Figure 1. Schematic view of U-shape patch sensor.

Figure 2. Fabricated of U-shape patch sensor.

3. RESULT AND DISCUSSIONS

The variation between the reflection coefficient and frequency of the proposed sensor is shown in Figure 4. The simulation is with the help of CST software and measurement of sensor by vector network analyzer (VNA) N9925A, Unprecedented amplitude accuracy $\pm 0.5 \text{ dB}$. In the simulation, the reflection coefficients were found -30 dB at 5.2 GHz and -18 dB at 6.8 GHz , and the bandwidth of proposed design varies from 5.1 GHz to 5.7 GHz at 5.2 GHz and 6.5 GHz to 6.7 GHz at 6.8 GHz . On the other hand, by measurement, the reflection coefficients were found -28 dB at 5.2 GHz and -16 dB at 6.8 GHz , and the bandwidth of proposed design varies from 5.1 GHz to 6.0 GHz at 5.2 GHz and 6.3 GHz

Table 1. CST optimized U-shape patch sensor parameters (mm).

Parameter	Value
Length of the ground (L)	15 mm
Width of the ground (W)	15 mm
Length of the substrate	15 mm
Width of the substrate	4 mm
Thickness (h)	1.676
Relative Permittivity (ϵ_r)	4.4
Loss Tangent ($\tan \delta$)	0.001

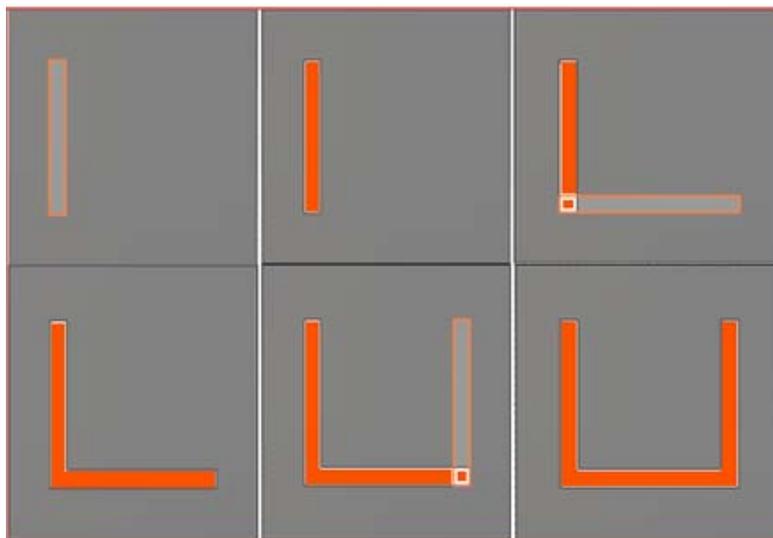


Figure 3. Design steps of proposed U-shape patch sensor.

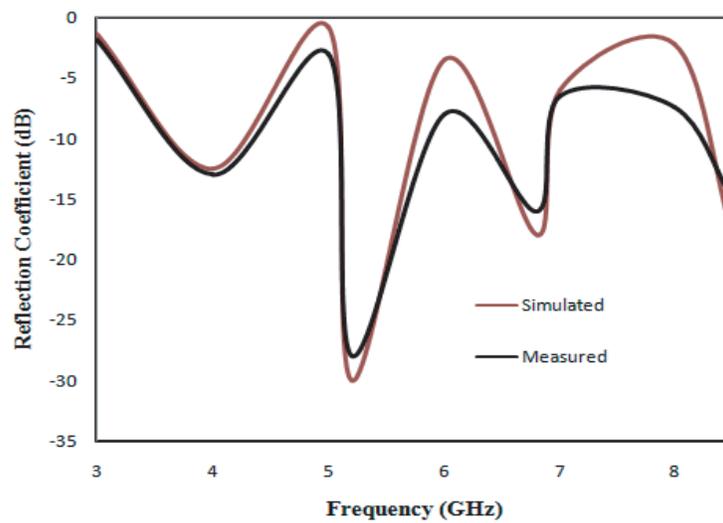


Figure 4. Reflection coefficient of U-shape patch sensor.



Figure 5. Reflection coefficient measurement of the different MC of rice.

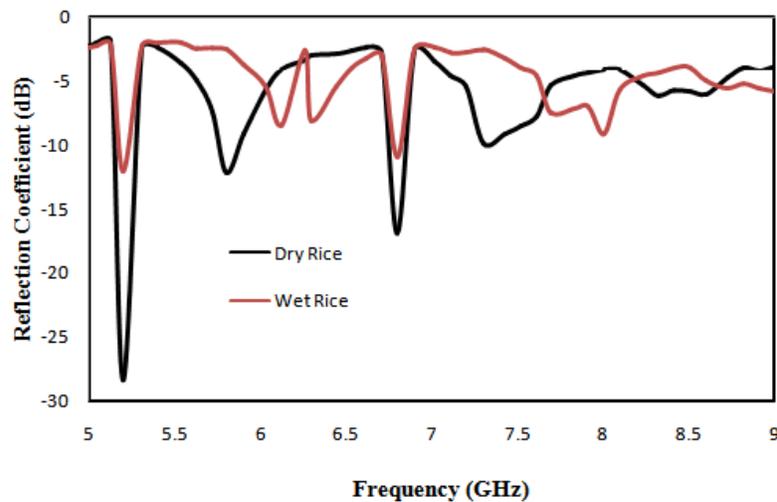


Figure 6. Reflection coefficient of dry and wet rice of U-shape patch sensor.

to 6.7 GHz at 6.8 GHz. It can be said that the resonant frequencies of simulation and measurement criteria are almost same at 5.2 GHz and 6.8 GHz. The VSWRs were found 1.13 at 5.2 GHz and 1.28 at 6.8 GHz maintaining the VSWR ($VSWR \leq 2$).

The MC of samples was measured by the U-shape patch sensor with the help of VNA (measurement setup) as shown in Figure 5. The relationship between the reflection coefficient and frequency is established to determine MC of rice. Figure 6 shows relation between reflection coefficient and state of rice (dry or wet) at 5.2 GHz and 6.8 GHz frequencies. The figure explains that at dry state reflection coefficient was very low in comparison with wet state. For example, at 5.2 GHz, in dry state reflection coefficient was very low (~ -28 dB), but it suddenly becomes high, when rice is wet, as shown in the figure, and such a variation can also be seen for 6.8 GHz. From Table 2, the derived equation for predicted moisture content shows that moisture content is directly proportional to reflection coefficient, which means that reflection coefficient increase results in moisture content increase, and the same can also be observed in Figure 7, which shows that with decrease in reflection coefficient moisture content is low. It will also provide more accuracy to the sensor because if there is dry rice then reflection coefficient suddenly goes to very low values, and when there is some moisture in the rice its reflection coefficient value suddenly becomes high such as in Figures 6 and 7; at frequencies 5.2 GHz and 6.8 GHz such a scenario can be observed. Initially, variation in reflection coefficient, given by VNA, was observed. It was found that reflection coefficients obtained for dry rice at 5.2 GHz and 6.8 GHz were -28.41 dB

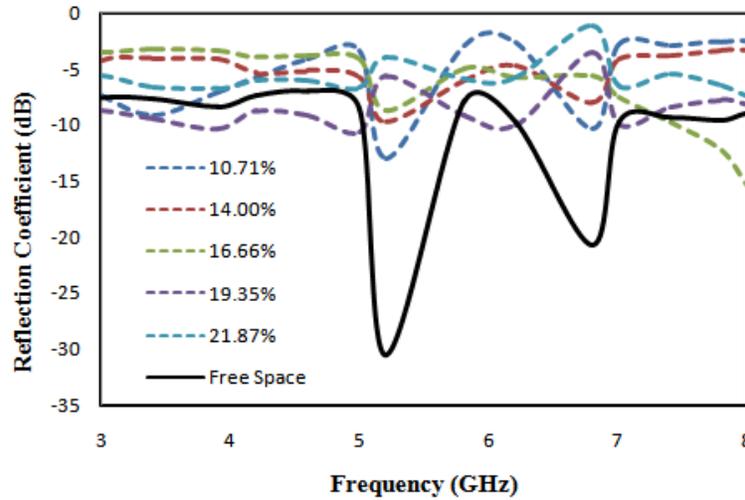


Figure 7. Relationship between the reflection coefficient with frequency for different percentages MC of U-shape patch sensor.

Table 2. Development of calibration equation for determination of MC at 3 GHz to 8 GHz.

Frequency	Calibration Equation	Regression coefficient	Sensitivity $(\frac{\Delta m.c.}{\Gamma})$
3 GHz	MC. = $-0.675\Gamma - 3.804$	0.052	0.575
4 GHz	MC. = $0.051\Gamma - 4.574$	0.013	0.051
5.2 GHz	MC. = $2.294\Gamma + 2.164$	0.411	2.294
6.8 GHz	MC. = $-0.628\Gamma - 5.372$	0.379	0.628
7 GHz	MC. = $-0.034\Gamma - 6.175$	0.021	0.034
8 GHz	MC = $-0.631\Gamma - 6.384$	0.146	0.531

Where Γ = Reflection coefficient.

and -16.86 dB, respectively, while for wet rice, reflection coefficients were -12.07 dB at 5.2 GHz and -10.88 dB at 6.8 GHz. Hence, it can be said that reflection coefficient decreased or had the least value for dry rice, but when rice was wet its value was increased, shown in Figure 6. The significance of Figures 6 and 7 is that if there is any little moisture present, then reflection coefficient varies significantly. Hence, there will be low probability of error (as at 5.2 GHz for dry it was -28 dB, but reflection coefficient value becomes high even at 10.71% moisture content).

It is expected to design the sensor with more accuracy. Regression coefficient was found highest at 5.2 GHz and 6.8 GHz (Table 2). So, the sensor was designed for these two frequencies, but regression coefficient was also obtained for two more frequencies, each below 5.2 GHz and above 6.8 GHz. The motive behind this was that to ensure whether regression coefficient was really higher for 5.2 GHz and 6.8 GHz, and it was found that regression coefficient was lower for 3 GHz, 4 GHz, 7 GHz, and 8 GHz than 5.2 GHz and 6.8 GHz. Moisture contents are between 10.71% and 21.87% wet basis (w.b) at room temperature. The results showed that both dielectric constant (ϵ') and loss factor (ϵ'') were dependent on frequency, moisture content, and temperature. Hence, ϵ' decreased with increasing frequency at a given moisture content or temperature. The calibration equations are established at selected frequencies (3 GHz to 8 GHz) for determining the predicted moisture content (PMC) as shown in Table 2. Simulation and measurement were done by CST software and VNA respectively for proposed sensor, which was designed for dual frequencies. Calibration equation was formed in terms of reflection coefficient, which was noted at selected frequencies (Table 2), in which regression coefficient (R^2) with sensitivity was

also taken into account. The regression coefficient and sensitivity were obtained as 0.052 and 0.575 at 3 GHz, 0.013 and 0.051 at 4 GHz, 0.411 and 2.294 at 5.2 GHz, 0.379 and 0.628 at 6.8 GHz, 0.021 and 0.034 at 7 GHz, 0.146 and 0.531 at 8 GHz, respectively. The highest regression coefficient and sensitivity were 0.411 and 2.294 at 5.2 GHz, and 0.379 and 0.628 at 6.8 GHz. Hence, PMC can be determined at dual frequencies (5.2 GHz and 6.8 GHz). The five samples considered to determine the PMC with the help of VNA are shown in Figure 7. The relationship between reflection coefficient and frequency was established to measure different samples for MC of rice (in percentages), then the reflection coefficients are -12.94 dB, -9.76 dB, -8.77 dB, -5.64 dB, -3.93 dB at 5.2 GHz and -10.34 dB, -7.95 dB, -5.65 dB, -3.53 dB, -1.14 dB at 6.8 GHz, when MC was 10.71%, 14%, 16.66%, 19.35%, 21.87%, respectively. When measurement of samples was done in free space, reflection coefficient was formed as -30.52 dB at 5.2 GHz and -20.75 at 6.8 GHz. It is clear that when the MC is increased, the reflection coefficient also increases and vice versa.

The dual frequencies are operated by the U-shape patch sensor, to find the predicted moisture content with the help of average method prediction. This method is easy and improves accuracy at dual, triple or more frequencies. Here, MC_1 is used for 5.2 GHz and MC_2 used for 6.8 GHz. From Table 2, the two equations are found for 5.2 GHz and 6.8 GHz as given below

$$MC = \frac{MC_1 + MC_2}{2}$$

$$MC_1 = 2.294\Gamma + 2.164 \quad (\text{for } 5.2 \text{ GHz})$$

$$MC_2 = -0.628\Gamma - 5.372 \quad (\text{for } 6.8 \text{ GHz})$$

An actual MC was determined with the help of standard oven drying technique (ODT). An actual moisture content (AMC) of grains was calculated in percentage using the relevant relationship,

$$MC(\%) = \frac{m_{\text{wet}} - m_{\text{dry}}}{m_{\text{wet}}}$$

where m_{wet} and m_{dry} are the masses of grains before and after being dried, respectively.

Only five values of moisture content were obtained because generally in government departments the samples of grains taken for checking moisture content vary from 3 to 5. Table 3 shows the calculated values of moisture content and MRE for 5 samples. Generally, grains affect when moisture content presence in grains is more than 8%. So by study and observation, we start by adding 30 ml water.

Table 3. Calculation of MRE.

S.No.	Dry weight of rice (m_{dry})	Water added (ml)	Saturated weight of rice (m_{wet})	Actual moisture content (%)	Predicted Moisture content (%)	MRE (%)
1	250 gram	30	280 gram	10.71	10.65	0.55
2	250 gram	40	290 gram	14	13.94	0.42
3	250 gram	50	300 gram	16.66	16.62	0.24
4	250 gram	60	310 gram	19.35	19.45	0.51
5	250 gram	70	320 gram	21.87	21.99	0.54
						Lowest MRE = 0.55% (Among 5 samples)

Each sample was dried in microwave oven dried weight (MODW) at 10°C for 3–5 minutes. Weight of samples (dry and wet rice) was taken from digital weighing machine, in grams, whose value was used to calculate actual moisture content (AMC).

$$MC(\%) = \frac{m_{\text{wet}} - m_{\text{dry}}}{m_{\text{wet}}}$$

where m_{wet} and m_{dry} are the mass of grains before dried and after dried, respectively. The lowest mean relative error (MRE) is determined between PMC and AMC by the given formula,

$$MRE = \left| \frac{MC_{\text{Actual}} - MC_{\text{Predicted}}}{MC_{\text{Actual}}} \right|$$

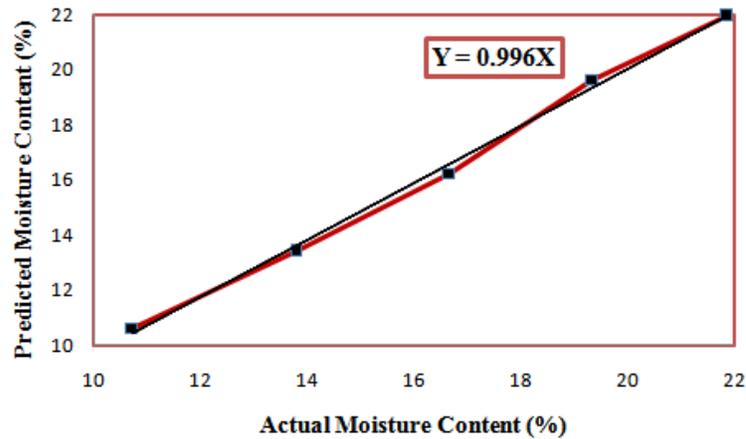


Figure 8. Predicted MC against actual MC of U-shape patch sensor.

The lowest mean relative error was 0.0055, and it is clear that the value of MRE 0.55% error was obtained between PMC and AMC. The variation between AMC and PMC, shown in figure 8, was found to be linear, and the formed equation is given below

$$Y = 0.996X$$

where Y = predicted value of MC. X = actual value of MC.

The comparison of existing moisture sensor with the proposed design is shown in Table 4. The proposed design produces better regression coefficient, moisture content, sensitivity, lower cost, less time consuming, better accuracy and compactness than the considered references. Ref. [26] proposed a microstrip ring sensor at dual frequencies (4.36 MHz and 10.69 MHz) with outer radius 17.96 mm and inner radius 8.92 mm. The sensor was fabricated on RT-Duroid 5880 (expensive). It developed the calibration equation to measure the MC of samples and found the MC range from 10%–28%. The MRE was found 0.85 at operated microwave frequency. In this design, a novel U-shape moisture sensor was fabricated on FR-4 (low cost) with compact size ($15 \times 15 \text{ mm}^2$) at operated microwave frequencies 5.2 GHz and 6.8 GHz. The MC range varies from 10.71% to 21.87% for detecting the MC of samples, reducing the MRE value compared to previously proposed design and was found 0.55%. It can be said that the proposed design is better than other designs at dual frequencies because of its easy technique, low cost and small size of the sensor.

Table 4. Comparison of proposed work with previously designed sensors.

References	Size of sensor	Operating frequency	Material	Cost of sensor	R^2	Moisture Content (%)	MRE (%)
26	$R_o \times R_I$ = 17.96 mm \times 8.92 mm	4.36 MHz & 10.69 MHz	RT-Duroid 5880	Expensive	0.9705 & 0.9383	10%–28%	0.85
Proposed sensor	$15 \times 15 \text{ mm}^2$	5.2 GHz & 6.8 GHz	FR4	Low	0.411 & 0.379	10.71%–21.87%	0.55

Ref. [26] designed the sensor at operated frequency 4.36 GHz and 10.69 GHz, fabricated on RT Duroid 5880 (expensive) with the outer radius and inner radius ($R_o \times R_I = 17.96 \text{ mm} \times 8.92 \text{ mm}$). The regression coefficient was obtained as 0.9705 and 0.9383 at frequency (4.36 GHz and 10.69 GHz). The moisture content was found varied from 10% to 28% with MRE 0.85.

In this paper, compared to earlier designs (Table 4) the proposed U-shaped sensor has compact size ($15 \times 15 \text{ mm}^2$) at operated frequency 5.2 GHz and 6.8 GHz, and is fabricated on an FR-4 substrate (low cost). The regression coefficient was obtained as 0.411 and 0.379. The moisture content was found 10.71% to 21.87% with MRE 0.55.

It is clear that the proposed design is better than other designs (see Table 4) because of compact size, low cost and reduced MRE 0.55%.

4. CONCLUSION

A U-shape moisture sensor is proposed based on MPA (microstrip patch antenna) for detecting the moisture content of rice. The sensor has a small size of $15 \times 15 \text{ mm}^2$. The calibration equations were developed at dual frequencies (5.2 GHz and 6.8 GHz) with regression coefficients and sensitivity 0.411 and 2.294 at 5.2 GHz and 0.379 and 0.628 at 6.8 GHz, respectively. The MC range varies from 10.71% to 21.87% at operated dual frequencies, The MRE was 0.55% between PMC and AMC, which clearly shows that this MRE is much lower than existing sensors' MRE (Ref. [26]). The experiment measurements show that the reflection coefficients increase with the increment of MC of samples. The proposed microstrip moisture sensor (MMS) with dual frequencies can have applications in various fields such as agriculture, geotech engineering and industries such as textile.

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