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IoT based dielectric constant measurement system for solid or semi-liquid materials using Arduino WeMos D1R1

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ABSTRACT

The measurement-system mainly consists of sensing-element, signal conditioning circuit and signal-processing unit. The sensing-element of a measuring system is directly affected by materials carrying quantity to be measured. This system supports solid or semi-liquid material. This paper signifies the designed system for dielectric constant measurement using Arduino with Wi-Fi and capacitive sensing element which sends/shows information continuously on android app or cloud to build IoT based system.

With the help of Polarization, Dielectric properties, Cole-Cole diagram, Microwave Measurement Methods and Arduino with IC-555, many techniques with limitations and complications are available to calculate dielectric constant. But this advanced system consists only Arduino without any other bulky circuit. In this system, measurement of dielectric constant depends on parameters of capacitive sensing element and property time constant of capacitor. Capacitor with larger capacitance takes more time to charge as well as discharge. The charging and discharging voltage of the capacitor is applied to Arduino (WeMos D1-R1) with signal conditioning. Here, from capacitance, dielectric constant of material is calculated and verified with standard values. WeMos D1-R1 Arduino has Wi-Fi facility to transmit data continuously on cloud. Designed system gives the capacitance, dielectric constant of substance, and displays it on android app and cloud or website with accuracy about approximately 99.46%.

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1. Introduction

The elements are insulators or dielectric materials, conductors, and semiconductors. Insulators or dielectrics play vital role in our day-to-day life appliances as well as all electrical and electronic equipments. The applications of dielectric constant measurement system are in quality testing of various fruits and vegetables [1]. Also useful in transformer manufacturing, for dielectric properties measurements of paper, pressboard and transformer oil, with effect of the ageing and moisture [2,3].

Electronic circuits having high frequency applications uses dielectric-material and the working principle of all high-frequency circuits depends on the dielectric properties of the material. In designing of high frequency circuits, it is necessary to have proper acquaintance of the properties of the dielectric materials particularly the dielectric constant (real-part of complex permittivity) and loss tangent at the working conditions [4]. Dielectric property is also a key parameter of plant and fruits mainly due to the large amount of water content and the structure of the biomaterials. Dielectric materials are electrically insulating materials which will be polarized under an electric field, such a phenomenon is called as dielectric polarization. The dielectric properties of material give considerable data about the dissipation and storage of magnetic and electric fields in materials [5]. The permittivity expresses the polarizability of the material. The permittivity is always in the form of complex number and its real part

Abbreviations: IoT, Internet of Things; RF, Radio Frequency; TDR, Time domain spectroscopy.

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is generally known as dielectric constant. Though the perfect dielectric material has electrical conductivity zero, every insulator is not a dielectric-material [6].

2. Dielectric property measurement techniques

Ninety-three years ago, polar dielectrics and modelling studies were used to determine grain moisture content and permittivity measurement techniques were based on dc electrical resistance [7]. A non-linear rise in the resistance of grains, as the temperature decreased provides useful readings [8]. The ac measurement techniques used to measure the variations in capacitance and suitable sample holding capacitors were industrialized [9]. Based on the dielectric properties, grain moisture measurement data turn out to be the most projecting agricultural applications. Novel instruments with their calibration led to the advance of a standard oven technique that more contributed to several applications of RF dielectric heating and added the pursuit for more quantitative values. In past 25 years, techniques of the permittivity measurement have been extended and used to various bio-resource, food and agricultural problems.

The dielectric properties of the food or agricultural materials in the microwave region can be resolute by numerous methods using different micro-wave measuring sensors [10]. The use of specific method be subject to the expected frequency range and the type of the material to be tested. Selection of the equipment for measurement and sample holder design depends upon the dielectric materials to be examined, available equipment, resources for the studies and the extent of the research [11]. For measuring the dielectric-properties of homogeneous food materials, the cavity perturbation technique is often used because of its simplicity, easy data reduction, accuracy, and high temperature capability [12]. The transmission line technique is inconvenient because the sample to be available in annular geometry or a slab. Only the coaxial line technique is practical because of the requirement of larger size of the waveguide [13]. A microwave resonator completely filled or partly with a material can be used in the measurement of the permittivity. The resonator or perturbation technique is generally standardized with materials having known dielectric properties, typically with organic solvents like ethanol, methanol, etc. The frequency range for measurement is from 50 MHz to 100 GHz. If the transmission line is enclosed (waveguide), it is possible to measure the permittivity of a material without the resonator by keeping it inside the waveguide directly. The method is applicable to all solid and liquid materials, but not for the gases because of lower permittivity of gas [14]. TDR (Time domain spectroscopy) or reflectometry methods were developed in the 1980 s and applied in studies related to dielectric properties of the food materials. Basically, to compute dielectric properties, the reflection characteristic of the material is utilized. This measurement method is rapid and gives high accuracy, within very small percent error [15]. Free space transmission technique is grouped under nondestructive and contactless measuring methods. It does not require particular sample preparation. So, it is mostly suitable for inhomogeneous dielectric and for material at the high temperature. Moreover, it may be simply implemented in industrial applications for control and continuous monitoring. e.g., density measurement and moisture content determination [16]. In microstrip transmission line method, microstrip has been used as microwave component, it shows numerous properties which overcome some limitations, hence makes it suitable for dielectric permittivity measurement. The effective permittivity of a microstrip transmission line highly depends on the permittivity of region above line. This is used in designing of the microwave circuits and to smaller amount examination of dielectric permittivity [17]. The Colloid Dielectric Probe is implemented in permittivity evaluation of the colloidal liquid material in pharmaceutical, chemical, biochemical, and food industries. It works from 200 kHz – 20 MHz with the precision LCR meter [11].

3. Methodology

The IoT based dielectric constant measurement system is designed using Arduino WeMos D1R1. Here, non-polar capacitor is built by using two parallel copper plates with dimensions 0.05 m × 0.015 m as shown in Fig. 1, with gap of 0.10 mm and air as a dielectric material between them. On LCR meter, it gives capacitance 64.1pF with small variations as shown in Fig. 2.

The parallel plate capacitor is interfaced with Arduino WeMos D1R1at pins D13 and A0 as shown in Fig. 3.

Fig. 1. Photograph of parallel plates of designed capacitor.

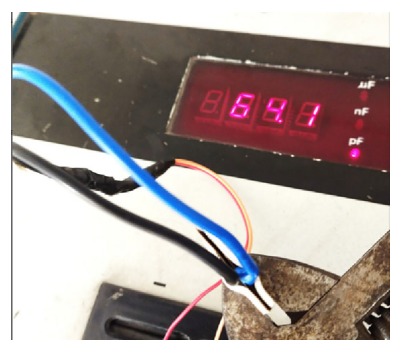


Fig. 2. Photograph of designed capacitor with air as dielectric medium for capacitance measurement using LCR meter.

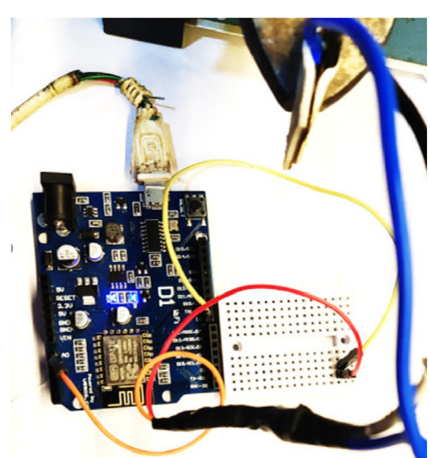


Fig. 3. Photograph of dielectric constant measurement system using Arduino WeMos D1R1 for parallel plate capacitor with air as dielectric medium.

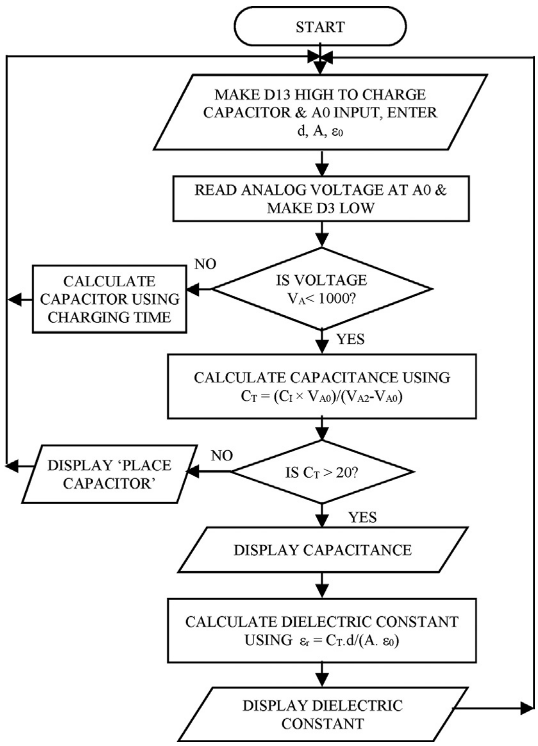


Fig. 4. Flowchart for capacitance measurement using WeMos D1R1 for nonpolar capacitors with the range 20 pF–1000 nF.

This system is useful for the capacitance measurement from 20pF to 1000nF. Arduino C program is written to measure capacitance and dielectric constant with logic shown in Fig. 4.

The unknown capacitor is connected between D13 and A0. Here, pin D13 is used as the charging pin and pin A0 used as the discharging pin. Initially, the unknown capacitor is charged by setting D13 as HIGH and measure the voltage at A0 from the following formula.

$$V_{A0} = (V_{A2} \times C_T)/(C_T + C_I)$$

where

V_{A0} = voltage at pin A_0,
V_{A2} = voltage at pin A_2,
C_T = capacitor under test and.
C_I = internal capacitor.

But voltage at A_0 is measured with the help of analog read function. Hence, using that value in the above equation, the unknown capacitance is obtained.

$C_T = (C_I \times V_{A0})/(V_{A2} - V_{A0})$ [18].

Substituting distance between parallel plates (d), area of rectangular plates (A) and $\varepsilon_0 = 8.84 \times 10^{-12}$ in standard equation $\varepsilon_r = C_T \cdot d/(A \cdot \varepsilon_0)$ [19], dielectric constant of the material placed between two copper plates is calculated. Figs. 5 and 6 shows readings of

Fig. 5. Screenshot of designed Android app showing readings of dielectric constant measurement system.

Dielectric constant measurement system on designed Android app and webpage respectively.

Specifications of LCR Meter:

- Brand Name: Aplab.
- Type of Product: Digital LCR Q - Meter.
- Model No: Aplab 4910.
- Measurement Frequency: User selectable 100 Hz or 1KHz.
- Display: 3½ Digit.
- Operating Temp. Range: 0° to 40 °C.
- Measurement Ranges.
  - Inductance Range: 0.1µH to 9999H.
  - Capacitance Range: 0.1pF to 9999µF.
  - Resistance Range (Ohm): 0.001 to 100 M.
  - Quality Factor: 0.1 to 99.
- Resolution.
  - Inductance: 0.1µH.
  - Capacitance: 0.1pF.
  - Resistance: 0.001 O.
  - Quality Factor: 0.01.
- Accuracy: ±0.25%.

Features of WeMos D1R1:

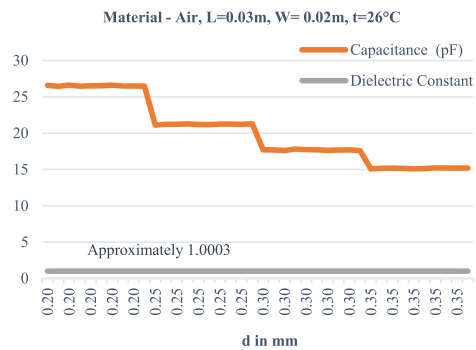
- 11 × I/O × pin.
- 1 × ADC × pin (input range 0–3.3 V).
- Support OTA wireless upload.
- Integrated 5 V 1A switching power supply (maximum voltage 24 V).
- Based on ESP-8266EX.
- Arduino compatible, using IDE Arduino to program.
- CPU 80 MHz [20].

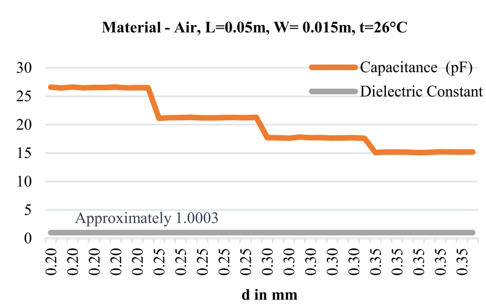
Following tables and graphs show measured capacitance and dielectric constants of air, mica, glass and talcum powder at different temperatures with accuracy about approximately 99.46%.

Accuracy is calculated by using formula: Accuracy = (1 – (Observed value – Actual value)/Actual value) × 100.

Dielectric Medium - Air $\varepsilon_0 = 8.84 \times 10^{-12}$ Temperature = 26°C

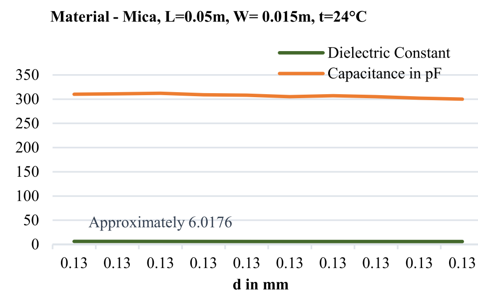
Sr. No.	Dimension of C				Capacitance by Arduino in pF	Dielectric Constant
	L in m	W in m	Area (A) in m^2	d in m		$\varepsilon_r = C.d/(A.\ \varepsilon_0)$
1	0.03	0.02	0.0006	0.00020	26.59	1.0026
2	0.03	0.02	0.0006	0.00020	26.46	0.9977
3	0.03	0.02	0.0006	0.00020	26.62	1.0038
4	0.03	0.02	0.0006	0.00020	26.48	0.9985
5	0.03	0.02	0.0006	0.00020	26.52	1.0000
6	0.03	0.02	0.0006	0.00020	26.53	1.0004
7	0.03	0.02	0.0006	0.00020	26.61	1.0034
8	0.03	0.02	0.0006	0.00020	26.49	0.9989
9	0.03	0.02	0.0006	0.00020	26.50	0.9992
10	0.03	0.02	0.0006	0.00020	26.47	0.9981
11	0.03	0.02	0.0006	0.00025	21.11	0.9950
12	0.03	0.02	0.0006	0.00025	21.23	1.0007
13	0.03	0.02	0.0006	0.00025	21.22	1.0002
14	0.03	0.02	0.0006	0.00025	21.27	1.0025
15	0.03	0.02	0.0006	0.00025	21.19	0.9988
16	0.03	0.02	0.0006	0.00025	21.18	0.9983
17	0.03	0.02	0.0006	0.00025	21.24	1.0011
18	0.03	0.02	0.0006	0.00025	21.25	1.0016
19	0.03	0.02	0.0006	0.00025	21.21	0.9997
20	0.03	0.02	0.0006	0.00025	21.29	1.0035
21	0.03	0.02	0.0006	0.00030	17.70	1.0011
22	0.03	0.02	0.0006	0.00030	17.68	1.0000
23	0.03	0.02	0.0006	0.00030	17.62	0.9966
24	0.03	0.02	0.0006	0.00030	17.82	1.0079
25	0.03	0.02	0.0006	0.00030	17.72	1.0023
26	0.03	0.02	0.0006	0.00030	17.71	1.0017
27	0.03	0.02	0.0006	0.00030	17.64	0.9977
28	0.03	0.02	0.0006	0.00030	17.66	0.9989
29	0.03	0.02	0.0006	0.00030	17.69	1.0006
30	0.03	0.02	0.0006	0.00030	17.59	0.9949
31	0.03	0.02	0.0006	0.00035	15.09	0.9958
32	0.03	0.02	0.0006	0.00035	15.16	1.0004
33	0.03	0.02	0.0006	0.00035	15.17	1.0010
34	0.03	0.02	0.0006	0.00035	15.14	0.9991
35	0.03	0.02	0.0006	0.00035	15.08	0.9951
36	0.03	0.02	0.0006	0.00035	15.12	0.9977
37	0.03	0.02	0.0006	0.00035	15.21	1.0037
38	0.03	0.02	0.0006	0.00035	15.20	1.0030
39	0.03	0.02	0.0006	0.00035	15.18	1.0017
40	0.03	0.02	0.0006	0.00035	15.19	1.0024
Average						**1.0003**
1	0.05	0.015	0.00075	0.00010	66.30	1.0000
2	0.05	0.015	0.00075	0.00010	66.29	0.9998
3	0.05	0.015	0.00075	0.00010	66.32	1.0003
4	0.05	0.015	0.00075	0.00015	44.19	0.9998
5	0.05	0.015	0.00075	0.00015	44.21	1.0002
6	0.05	0.015	0.00075	0.00020	33.14	0.9997
7	0.05	0.015	0.00075	0.00020	33.18	1.0009
8	0.05	0.015	0.00075	0.00025	26.51	0.9996
9	0.05	0.015	0.00075	0.00025	26.53	1.0004
10	0.05	0.015	0.00075	0.00025	26.54	1.0008
Average						**1.0002**
Accuracy						**99.82**

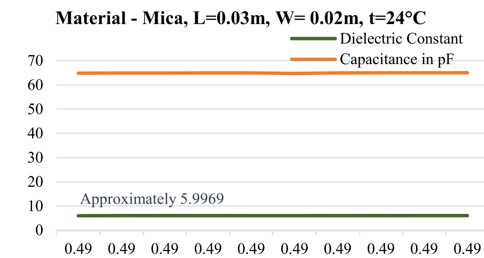


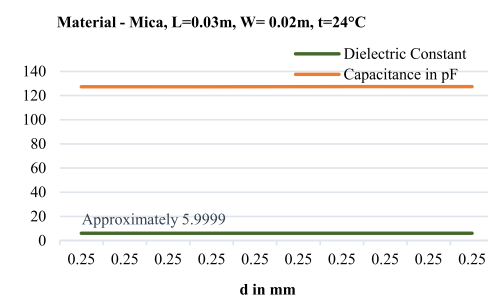


Dielectric Medium - Mica $\varepsilon_0 = 8.84 \times 10^{-12}$ **Temperature = 24°C**

Sr. No.	Dimension of C				Capacitance by Arduino in pF	Dielectric Constant
	L in m	W in m	Area (A) in m^2	d in m		$\kappa = C.d/(A.\ \varepsilon_0)$
1	0.05	0.015	0.00075	0.00013	310.00	6.0784
2	0.05	0.015	0.00075	0.00013	311.00	6.0980
3	0.05	0.015	0.00075	0.00013	312.00	6.1176
4	0.05	0.015	0.00075	0.00013	309.00	6.0588
5	0.05	0.015	0.00075	0.00013	308.00	6.0392
6	0.05	0.015	0.00075	0.00013	305.00	5.9804
7	0.05	0.015	0.00075	0.00013	307.00	6.0196
8	0.05	0.015	0.00075	0.00013	305.00	5.9804
9	0.05	0.015	0.00075	0.00013	302.00	5.9216
10	0.05	0.015	0.00075	0.00013	300.00	5.8824
11	0.03	0.02	0.0006	0.00049	64.84	5.9901
12	0.03	0.02	0.0006	0.00049	64.87	5.9929
13	0.03	0.02	0.0006	0.00049	64.91	5.9966
14	0.03	0.02	0.0006	0.00049	64.94	5.9994
15	0.03	0.02	0.0006	0.00049	64.95	6.0003
16	0.03	0.02	0.0006	0.00049	64.70	5.9769
17	0.03	0.02	0.0006	0.00049	64.96	6.0012
18	0.03	0.02	0.0006	0.00049	64.99	6.0040
19	0.03	0.02	0.0006	0.00049	64.98	6.0031
20	0.03	0.02	0.0006	0.00049	65.00	6.0049
21	0.03	0.02	0.0006	0.00025	127.21	5.9959
22	0.03	0.02	0.0006	0.00025	127.23	5.9969
23	0.03	0.02	0.0006	0.00025	127.27	5.9988
24	0.03	0.02	0.0006	0.00025	127.28	5.9992
25	0.03	0.02	0.0006	0.00025	127.29	5.9997
26	0.03	0.02	0.0006	0.00025	127.30	6.0002
27	0.03	0.02	0.0006	0.00025	127.31	6.0007
28	0.03	0.02	0.0006	0.00025	127.33	6.0016
29	0.03	0.02	0.0006	0.00025	127.35	6.0025
30	0.03	0.02	0.0006	0.00025	127.37	6.0035
Average						**6.0048**
Accuracy						**99.60**

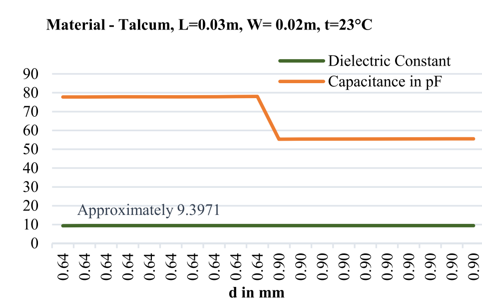






Dielectric Medium - Talcum $\varepsilon_0 = 8.84 \times 10^{-12}$ **Temperature = 23°C**

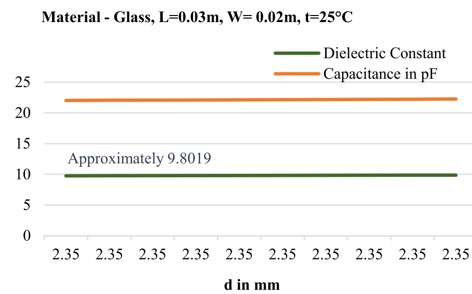
Sr. No.	Dimension of C				Capacitance by Arduino in pF	Dielectric Constant
	L in m	W in m	Area (A) in m^2	d in m		$\kappa = C.d/(A.\ \varepsilon_0)$
1	0.03	0.02	0.0006	0.00064	77.72	9.3780
2	0.03	0.02	0.0006	0.00064	77.74	9.3804
3	0.03	0.02	0.0006	0.00064	77.81	9.3888
4	0.03	0.02	0.0006	0.00064	77.89	9.3985
5	0.03	0.02	0.0006	0.00064	77.70	9.3756
6	0.03	0.02	0.0006	0.00064	77.78	9.3852
7	0.03	0.02	0.0006	0.00064	77.82	9.3900
8	0.03	0.02	0.0006	0.00064	77.86	9.3949
9	0.03	0.02	0.0006	0.00064	77.92	9.4021
10	0.03	0.02	0.0006	0.00064	77.98	9.4094
11	0.03	0.02	0.0006	0.00090	55.32	9.3869
12	0.03	0.02	0.0006	0.00090	55.35	9.3920
13	0.03	0.02	0.0006	0.00090	55.37	9.3954
14	0.03	0.02	0.0006	0.00090	55.39	9.3988

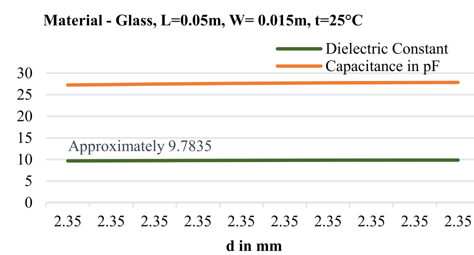


15	0.03	0.02	0.0006	0.00090	55.40	9.4005
16	0.03	0.02	0.0006	0.00090	55.41	9.4021
17	0.03	0.02	0.0006	0.00090	55.44	9.4072
18	0.03	0.02	0.0006	0.00090	55.48	9.4140
19	0.03	0.02	0.0006	0.00090	55.51	9.4191
20	0.03	0.02	0.0006	0.00090	55.53	9.4225
Average						**9.3971**
Accuracy						**98.96**

Dielectric Medium - Glass $\varepsilon_0 = 8.84 \times 10^{-12}$ **Temperature = 25°C**

Sr. No.	Dimension of C				Capacitance by Arduino in pF	Dielectric Constant
	L in m	W in m	Area (A) in m^2	d in m		$\kappa = C.d/(A.\varepsilon_0)$
1	0.03	0.02	0.0006	0.00235	22.00	9.7474
2	0.03	0.02	0.0006	0.00235	22.05	9.7695
3	0.03	0.02	0.0006	0.00235	22.07	9.7784
4	0.03	0.02	0.0006	0.00235	22.08	9.7828
5	0.03	0.02	0.0006	0.00235	22.09	9.7872
6	0.03	0.02	0.0006	0.00235	22.14	10.1904
7	0.03	0.02	0.0006	0.00235	22.16	10.1993
8	0.03	0.02	0.0006	0.00235	22.18	10.2037
9	0.03	0.02	0.0006	0.00235	22.21	10.2126
10	0.03	0.02	0.0006	0.00235	22.25	10.2259
1	0.05	0.015	0.00075	0.00235	27.23	9.6517
2	0.05	0.015	0.00075	0.00235	27.32	9.6836
3	0.05	0.015	0.00075	0.00235	27.45	9.7296
4	0.05	0.015	0.00075	0.00235	27.54	9.7615
5	0.05	0.015	0.00075	0.00235	27.63	9.7934
6	0.05	0.015	0.00075	0.00235	27.68	9.8112
7	0.05	0.015	0.00075	0.00235	27.74	9.8324
8	0.05	0.015	0.00075	0.00235	27.78	9.8466
9	0.05	0.015	0.00075	0.00235	27.82	9.8608
10	0.05	0.015	0.00075	0.00235	27.83	9.8643
Average						**9.7927**
Accuracy						**99.82**





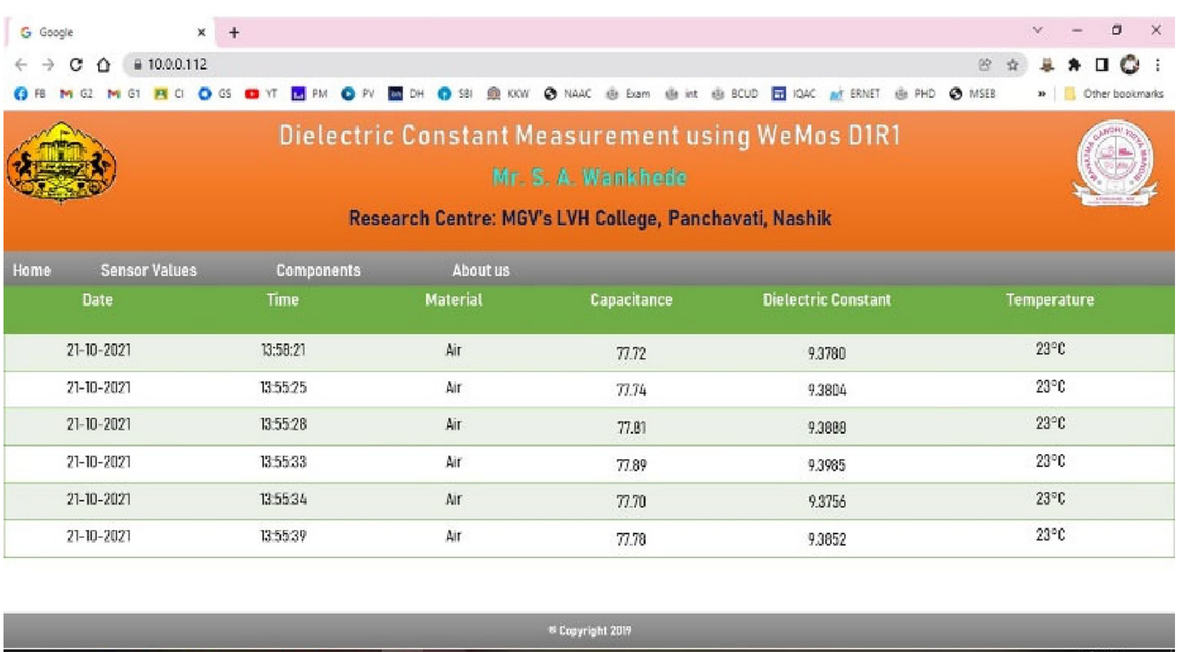


Fig. 6. Screenshot of designed webpage showing readings of dielectric constant measurement system.

4. Conclusion

The IoT based dielectric and capacitance measurement system using Arduino WeMos D1R1 is designed and developed for non-polar capacitor. The non-polar capacitance measurement range 20 pF to 1000 nF is tested. Accuracy of capacitance varies depending on the value of capacitance. Designed capacitor provides approximately 99% accuracy for the range 20 pF to 600 pF. Major application of this system will be in various industries where not only capacitance and dielectric property measurement is required but also that storage is possible and available anywhere, anytime as it is IoT based. For different size and shape of material, modification in program and capacitor like area of plates and distance between plates is required. Dielectric constant of material placed between two plates can be easily measured. This increases application of this system in quality testing of various fruits and vegetables. Also useful in transformer manufacturing, for dielectric properties measurements of paper, pressboard and transformer oil, with effect of the ageing and moisture.

CRediT authorship contribution statement

Somnath A. Wankhede: Methodology, Software, Data curation, Writing – original draft, Visualization, Investigation. **Vijay S. Kale:** Conceptualization. **A.D. Shaligram:** Supervision. **Arun Patil:** Validation. **Dharma K Halwar:** Writing – review & editing.

Data availability

The data that has been used is confidential.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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