Characterization of Pulsed Direct Current (PDC) as Driving Circuit for Fringing Electric Field (FEF) Sensor

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Abstract – **This paper presents a study of Pulsed Direct Current (PDC) as driving circuit for Fringing Electric Field (FEF) sensor. This study is to implement the PDC concept on drive circuit of FEF as the PDC circuit has been designed, simulated and tested while connecting to FEF sensor. The voltage of PDC waveform is variable as it rises up and down along the wave and it maintains a single positive or negative polarity. The study is to investigate the characterization of using Pulsed Direct Current to drive the FEF sensor. Since the FEF sensors are widely used for non-invasive measurements, Pulsed Direct Current used as to make it more reliable and cost effective. This paper also presents both simulation and experimental data to characterize the circuit on FEF sensor. The results show that the trend pattern of both simulation and experiment are similar as the capacitance is increasing, the peak-to-peak voltage increased.**

Keywords–Pulsed Direct Current, Pulsed DC, Fringing Electric Field, FEF

I. INTRODUCTION

Nowadays, pulsed direct current is useful in many modern DC equipment operations after it has been smoothed using capacitor that was charged to a specific voltage and then the voltage release as regular DC current to the circuit [2].

Pulsed direct current is a current that flows at a certain point in a circuit. During a first period of time, the PDC has a first significant constant magnitude then has at least one additional significant constant magnitude that is different from the first during at least one additional next period of time and may repeat [1].

As we know, pulsed direct current has characteristics of both direct current (DC) and alternating current (AC). The PDC power supply delivers a current of a single polarity with a variable voltage which is obtained using either a full-wave or half-wave rectifier. Pulsed direct current shares a characteristic with traditional AC current which the voltage is variable as it rises up and down along the wave but the difference is the polarity of the current does not change, the current maintains a single positive or negative polarity just like traditional DC current [2].

The most common application of pulsed direct current is in the production of thin film synthesis for magnetron sputtering and as well as for plasma generation purpose [1]-[4]. In generating plasmas, the pulsed direct current voltage sources used to overcome the disadvantages of using high frequency voltage sources which are expensive to develop and maintain. In addition, uses of high frequency voltage sources also risky and dangerous to operate [1].

The pulsed direct current also used in welding equipment and many clinical applications for example previous researcher used it in medical diagnosis of human skin [2], [5]-[7].

For recent years, fringing electric field sensor is one of the popular methods to measure material properties such as moisture content, porosity, viscosity, temperature, hardness and degree of cure and it has advantages of one-side access, control of signal strength and imaging capability [8]-[10]. In previous paper [8], fringing electric field sensor connected to a voltage sensing circuit with AC voltage applied between the driven electrodes and ground like shown in figure below.

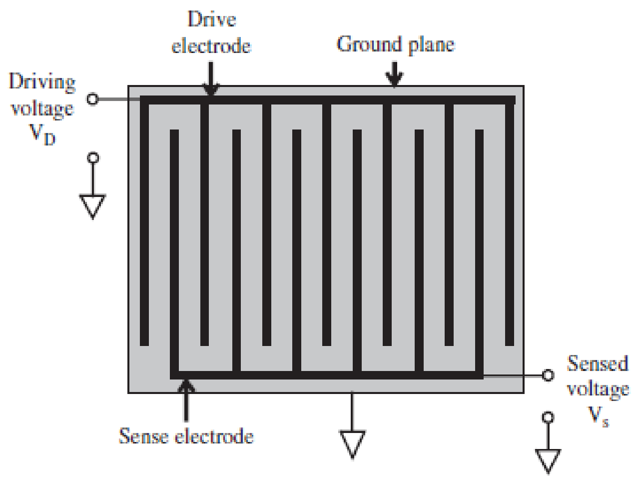

Figure 1. Schematic of fringing electric field sensor connected in voltage sensing configuration with its back plane grounded.

The disadvantages of using this sensing method are there is potential difference across the substrate and some charge is lost in parasitic coupling [8]. Thus, pulsed direct current circuit proposed to drive the fringing electric field sensor because it more reliable and cost effective [2]-[4].

II. METHODOLOGY

This project consists of two parts which are simulation and experiment using actual circuit. For simulation, NI Multisim software is used to see the output results. The second part is to test and characterize the FEF sensor on actual circuit.

A. Simulation

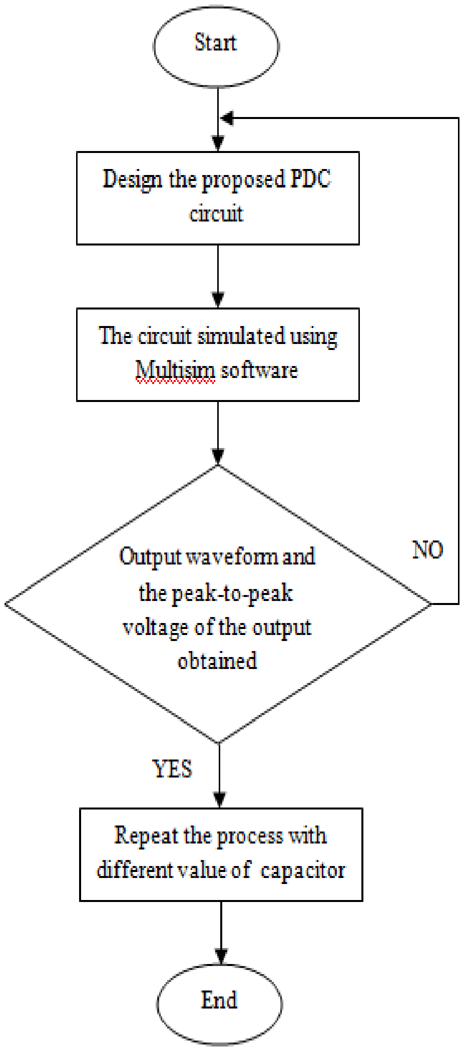

Figure 2. Flow chart of the simulation process.

There are three circuits proposed but only two circuits have been simulated and tested with fringing electric field sensors.

1) Circuit 1: Direct C/V converter. The C/V converter circuit has been designed with AC/DC converter so that the AC voltage can converted into DC voltage [11]. The schematic of the completed circuit is shown in Fig. 3.

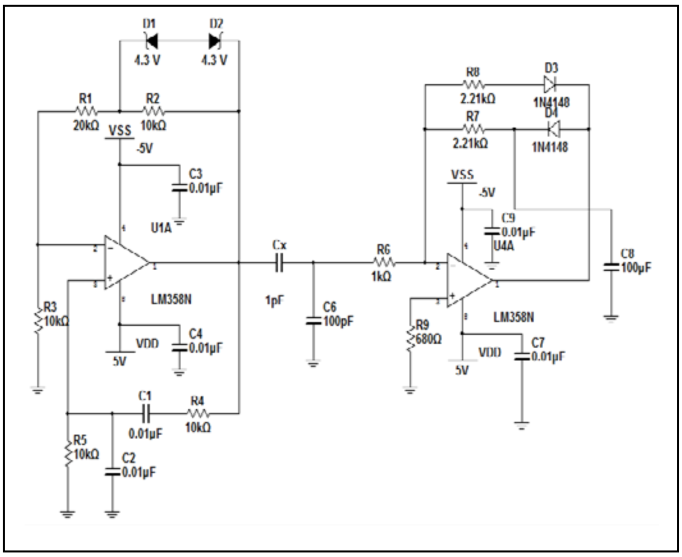

Figure 3. Schematic diagram of C/V Converter.

2) Circuit 2: Precision fullwave rectifier. Fullwave or halfwave rectifier can produce pulsed direct current [12]. The fullwave rectifier converts an AC signal into pulsing DC which can provide average of the input voltage by filtered it [13].

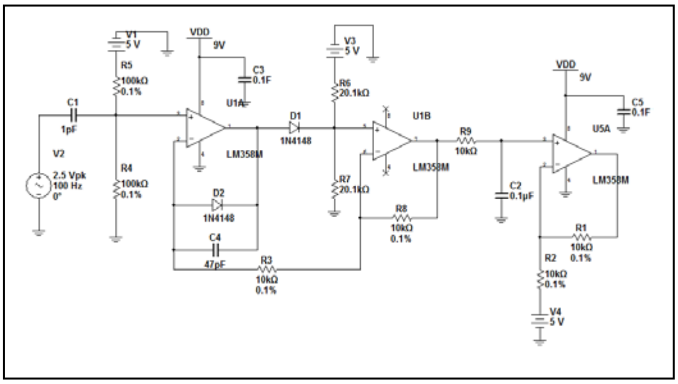

Figure 4. Schematic diagram of Precision Fullwave Rectifier.

The circuit shown in figure above have been simulated and tested to characterize different value of the fringing electric sensor.

3) Circuit 3: Pulsed DC CS Generator. The output of this circuit which its schematic diagram is shown in Fig. 5 is a pulsed DC square wave but the function of this circuit is to make Colloidal Silver where it can lead to argyria [14, 15]. This kind of circuit is not suitable and relevant to test the FEF sensor.

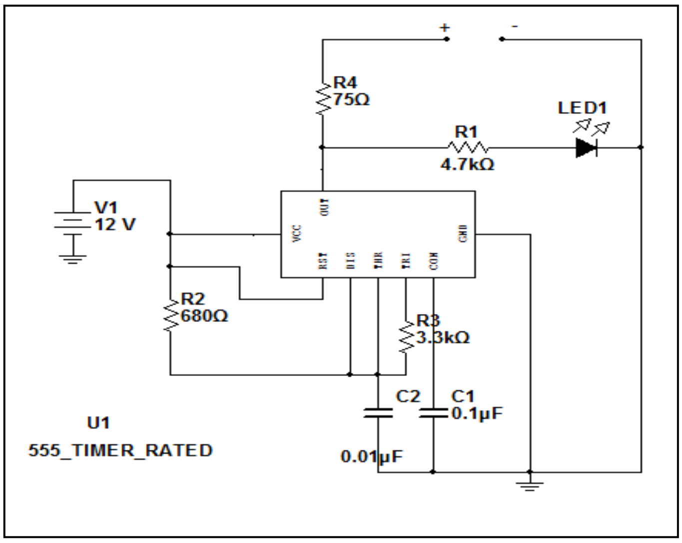

Figure 5. Schematic diagram of Pulsed DC CS Generator.

B. *Experimental*

In this part, the fringing electric field sensors have been tested on actual circuits which are precision fullwave rectifier and C/V converter.

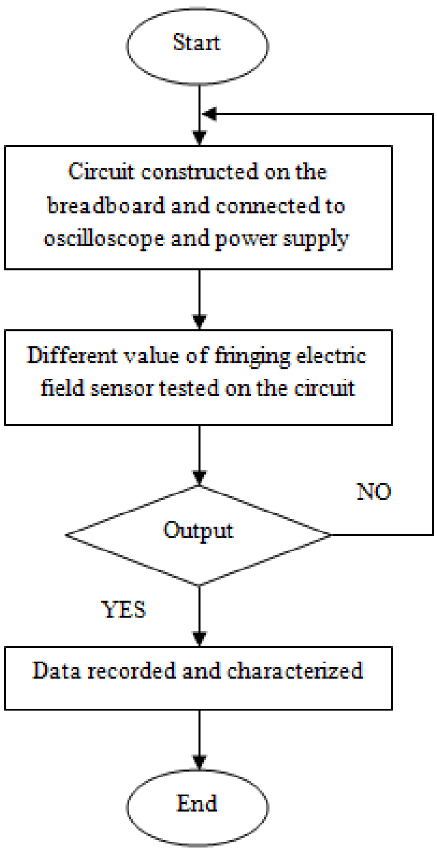

Figure 6. Flow chart of the experimental process.

The actual circuit has been tested with different value of fringing electric field sensors connected to it. For circuit 2, the FEF sensor placed on C1 point in the schematic while for circuit 1, the FEF sensor placed on Cx point in the schematic.

There is two outputs obtained which are the waveforms and peak-to-peak voltage that will discussed more in result and discussion part. The data obtained then recorded and plotted into graph.

III. RESULTS AND DISCUSSION

This study is to investigate the characterization of peak-to-peak voltage of PDC circuit when driving on FEF sensor which the values are in capacitance. This section divided into two parts which are simulation and experimental part. Simulation and experiment are using precision fullwave rectifier and direct C/V converter circuits but in experiment, precision fullwave rectifier circuit is focusing more.

A. *Simulation*

In the simulation, values of capacitances tested are 1, 5, 10, 50, 100 and 1000 pF. Fig. 7 shows the simulation of circuit 1 which direct C/V converter circuit is connecting to oscilloscope to obtain signal and a peak-to-peak voltage. In this circuit, all capacitances are testing on Cx point.

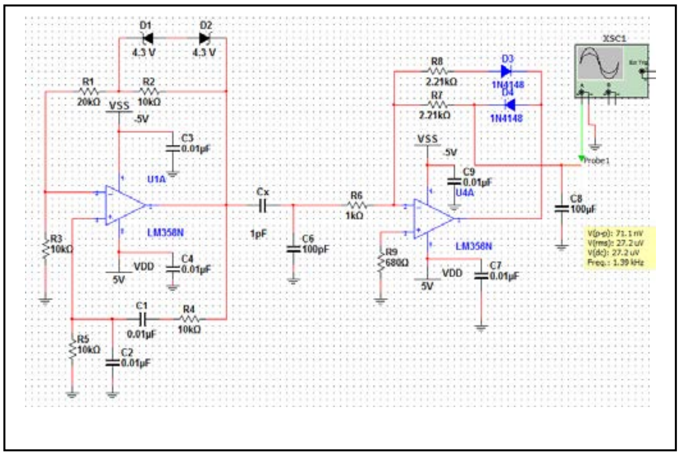

Figure 7. Simulation of Direct C/V converter circuit.

The input stage of the circuit in Fig. 7 is a sine wave oscillator with 2.5 V amplitude and 1.6 kHz oscillation frequency which can be calculated when C1=C2 and R4=R5 using equation (1) while the second stage of this circuit is AC/DC converter.

$$f = \frac{1}{2\pi RC} \tag{1}$$

The capacitor C8 is a rectifier filter while D3 and D4 form a half-wave rectifier. The AC/DC converter gives a DC output equals to the Vout(rms) of the capacitive voltage divider like shown in figure above which the value of V(rms) and V(dc) are same [11] .

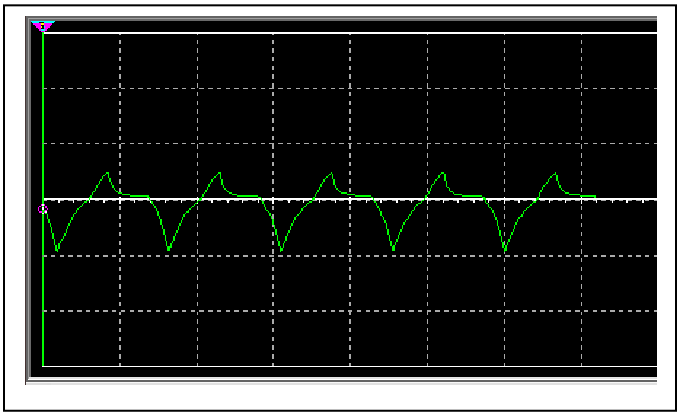

Figure 8. Output waveform when Cx = 1 pF.

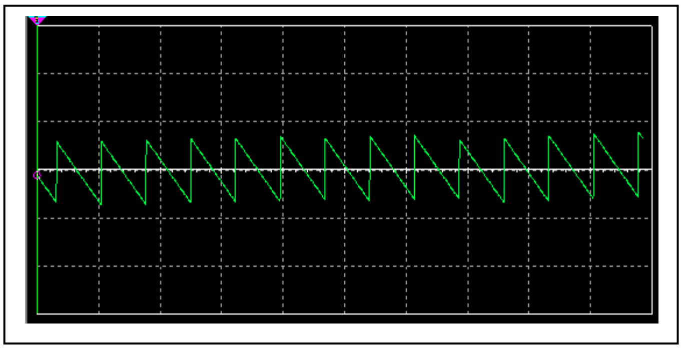

Figure 9. Output waveform when Cx = 1000 pF.

Fig. 8 and 9 show the output waveforms of the circuit 1 when testing with capacitance value of 1 pF and 1000 pF. The output waveform when testing with capacitance of 1000 pF shows better pattern than the output waveform when testing with capacitance of 1 pF.

In simulation, the circuit in Fig. 7 tested for different range of Cx which in the range of 1 to 1000 pF. The output results obtained are shown in table below.

TABLE I. SIMULATION RESULTS FOR CIRCUIT 1

Capacitance (pF)	**Peak-to-peak voltage, Vp-p (μV)**
1	0.07
5	0.40
10	1.24
50	23.70
100	55.80
1000	354.00

Based on the Table I and Fig. 10, the trend shows that this C/V converter has a linear capacitance-voltage characteristic. It can say that as the capacitance value is increase, the peak-to-peak voltage also increases [11].

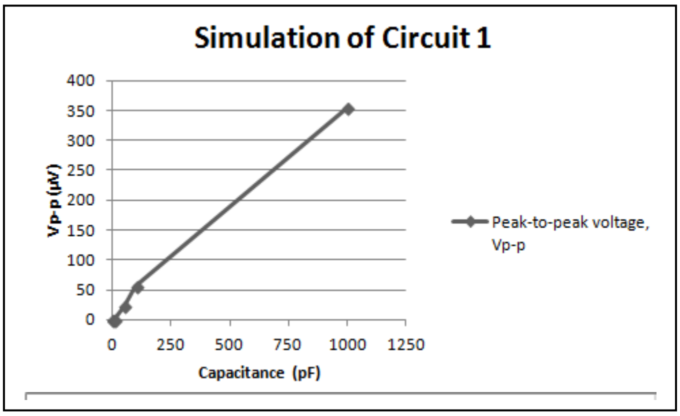

Figure 10. Graph of simulation results from circuit 1.

Fig. 11 shows the simulation of circuit 2 which precision fullwave rectifier circuit is connecting to oscilloscope to obtain signal and a peak-to-peak voltage. In this circuit, all capacitances are testing on C1 point.

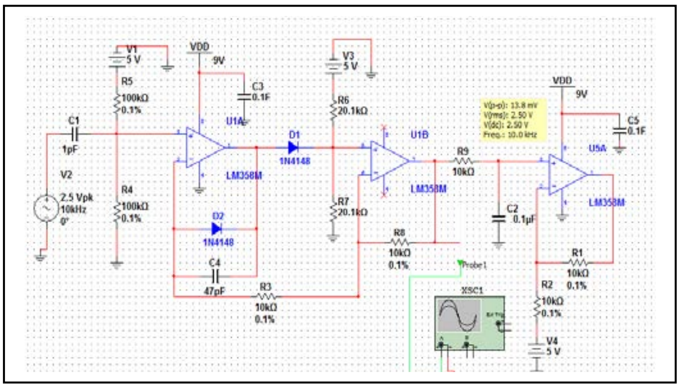

Figure 11. Simulation of Precision Full wave Rectifier circuit.

This circuit converts an AC signal into pulsing DC. In this circuit, AC voltage with 5 Vpp and frequency of 10 kHz is supplying to the input of the circuit.

Figure 12. Output waveform when C1 = 1 pF.

Fig. 12 and 13 show the output waveform of the circuit 2 when testing with 1 and 100 pF respectively. As the capacitance increase, the ouput waveform shows better pattern.

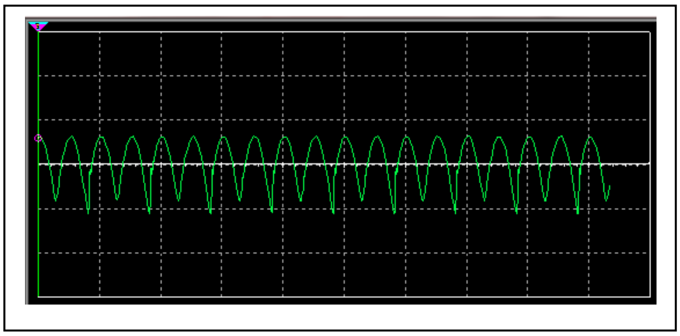

Figure 13. Output waveform when C1 = 100 pF

The circuit 2 also simulated with the capacitance value in the range of 1 to 1000 pF and the results obtained are shown in Table II.

TABLE II. SIMULATION RESULTS FOR CIRCUIT 2

Capacitance (pF)	Peak-to-peak voltage, Vp-p (mV)
1	13.8
5	35.9
10	71.3
50	372.0
100	724.0
1000	2340.0

From Table II, the results show a same trend like in circuit 1 which as the value of capacitance increase, the peak-to-peak voltage also increases. Thus, it can say that this circuit also has linear characteristic. The values of Vp-p obtained from simulation of circuit 2 are much higher than circuit 1 which in mV.

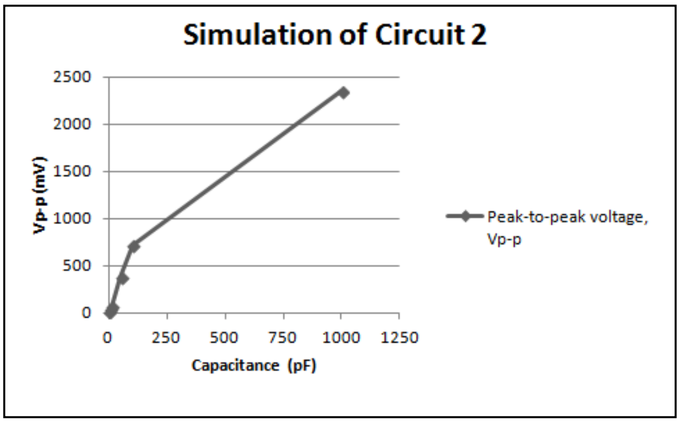

Figure 14. Graph of simulation results from circuit 2.

B. *Experimental*

In this part, only circuit 2 is tested. Firstly, the actual circuit is testing by using ceramic capacitor in the range of 1 to 100 pF. The setup is like shown in Fig. 15.

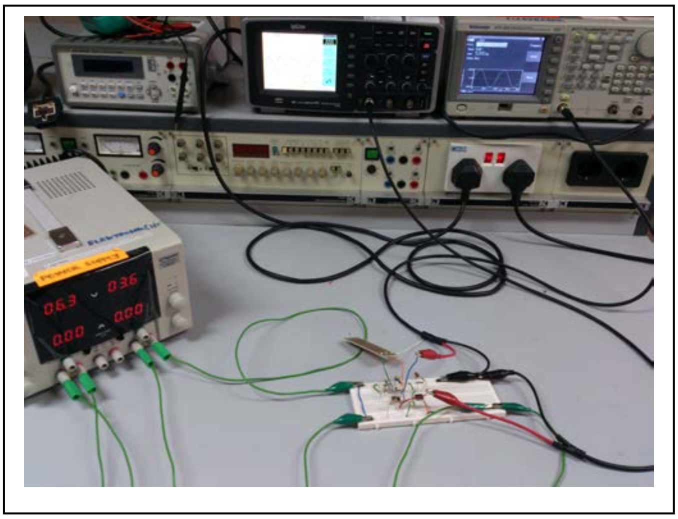

Figure 15. Experiment setup using Power Supply, Function Generator and Oscilloscope.

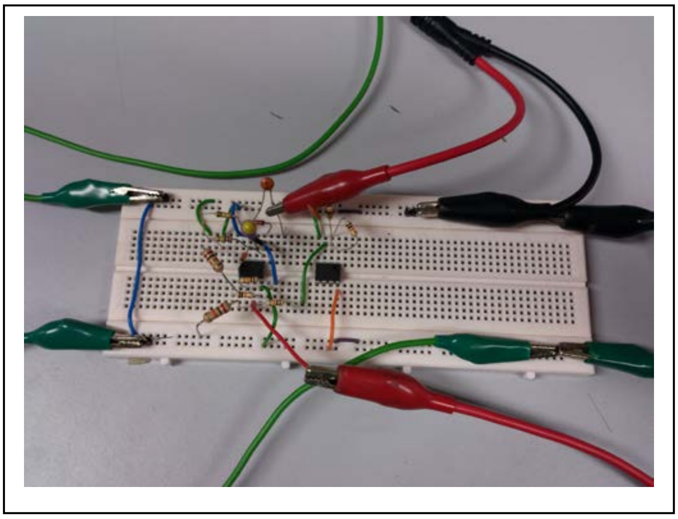

Figure 16. Connection of circuit 2 on breadboard.

The circuit is connecting to power supply, oscilloscope and function generator with frequency of 10 kHz and amplitude of 5 Vp-p using breadboard and the output waveform generated are like shown in figure below.

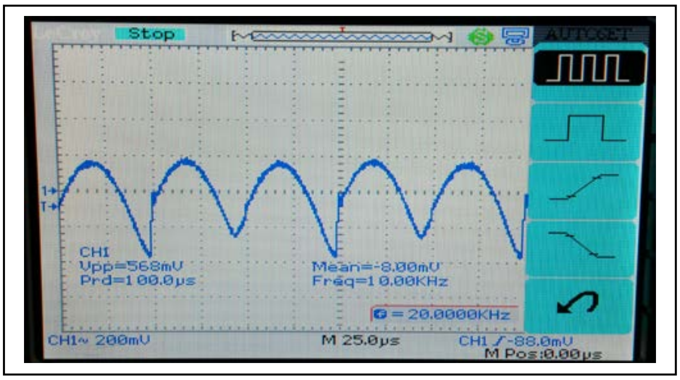

Figure 17. Output waveform when testing with capacitor of 27 pF.

TABLE III. EXPERIMENTAL RESULTS WHEN TESTING WITH CAPACITORS

Capacitance (pF)	Peak-to-peak voltage, Vp-p (mV)			
	Reading 1	*Reading 2*	*Reading 3*	*Average*
1	54.4	53.6	56.8	54.9
5	142.0	138.0	140.0	140.0
10	220.0	236.0	224.0	226.7
12	256.0	256.0	260.0	257.3
18	392.0	384.0	392.0	389.3
27	576.0	584.0	568.0	576.0
39	740.0	760.0	740.0	746.7
68	1440.0	1460.0	1460.0	1453.3
82	2020.0	2020.0	2040.0	2026.7
100	2560.0	2560.0	2560.0	2560.0

Table III and Fig. 18 show the results of circuit 2 when testing with ceramic capacitors. As the capacitance value increase, the peak-to-peak voltage also increases. It easy to see that from the graph illustrated in figure below that the results show linear characteristic.

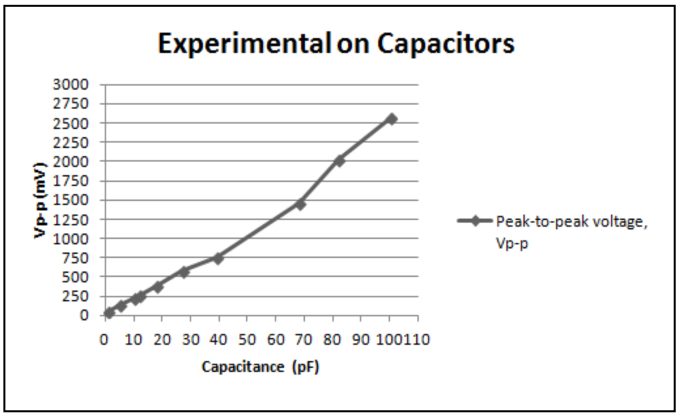

Figure 18. Graph of experimental results when using ceramic capacitors.

Next, the circuit is testing with different range capacitance values of FEF sensor. The FEF sensor has many patterns which are different number of finger, different width of finger, horizontal or vertical finger. But in this experimental, it only focusing on capacitance value not the pattern of fringing electric field fingers.

Fig. 19 shows the FEF sensor is connecting with the circuit and Fig. 20 shows the output waveform when the FEF sensor which has capacitance value of 15.6 pF is connecting to the circuit.

As mention in introduction, the voltage of a PDC wave continually varies like an AC wave but the sign of the voltage is constant like a DC wave [2].

The reason why only circuit 2 been tested in the experiment is because in the simulation, the output results of circuit 2 is more relevant compared to the output results of circuit 1 which the values are too small.

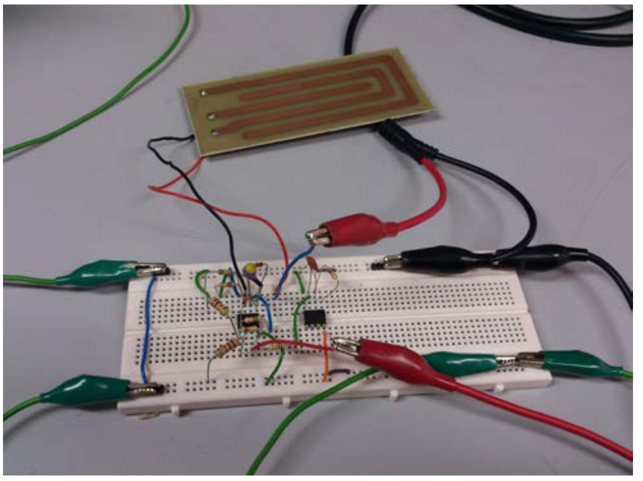

Figure 19. The FEF sensor is connecting to the circuit.

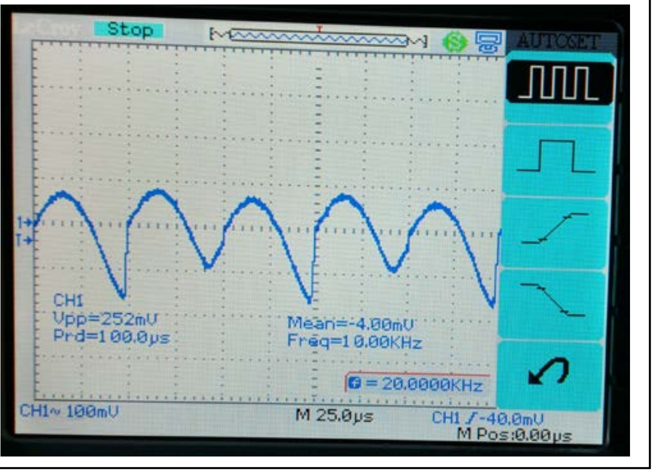

Figure 20. Output waveform when testing with FEF sensor of 15.6 pF.

TABLE IV. EXPERIMENTAL RESULTS WHEN TESTING WITH FEF FINGERS

Capacitance (pF)	Peak-to-peak voltage, Vp-p (mV)			
	Reading 1	*Reading 2*	*Reading 3*	*Average*
15.18	252	252	248	250.7
15.60	256	248	252	252.0
17.05	268	272	272	270.7
18.05	288	304	304	298.7
18.27	308	312	316	312.0
63.21	1120	1120	1100	1113.3
64.20	1120	1140	1140	1133.3
78.45	1620	1600	1560	1593.3
79.03	1560	1600	1620	1593.3
104.00	2400	2400	2440	2413.3
115.80	2480	2560	2520	2520.0

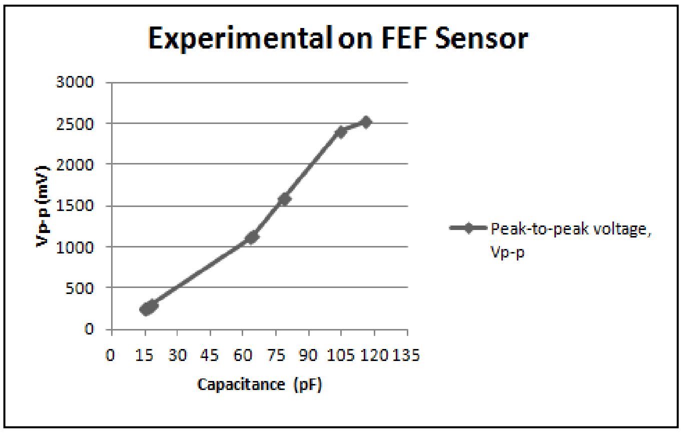

Figure 21. Graph of experimental results when using FEF sensor.

Table IV shows the value of peak-to-peak voltage obtained when testing with different capacitance values of FEF sensors connecting to the circuit. It also has capacitance-voltage linear characteristic. The output results when connecting the FEF sensor to the circuit are about the same with the output results when connecting the ceramic capacitor to the circuit.

The output results from experimental and simulation are quite different but both show the same trend which is linear characteristic. The differences may be caused by the environment effects during experimental, components and instrument for measurement itself.

IV. CONCLUSION

The characterization of pulsed direct current as driving circuit for fringing electric field sensor is reported. In simulation, direct C/V converter and precision fullwave rectifier circuit are tested. From the results obtained it can be concluded that the precision fullwave rectifier circuit is more reliable and suitable to test with the FEF sensors. Both simulation and experimental show the linear characteristic from the results obtained. Because of fringing electric field sensors are widely used nowadays for measure material, hence pulsed direct current can be used as driving circuit on fringing electric field fingers to make it more reliable and cost effective. In future, it is recommended to do the experiment in right environment and handle FEF sensor properly because air and water do give effects to the FEF sensor. In addition, perhaps pulsed direct current can be tested with different patterns of FEF sensors in next research.

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