

Analysis and experiment of capacitor charging characteristics

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Abstract. This paper analyses capacitor charging characteristics which affects the delay time of DC output of Switch Mode Power Supply(SMPS). By charging experiments of three different capacitors, quantitative analysis of different situations influence and algorithm of the delay time due to ohmic leakage is made. Through theoretical calculation, software simulation and physical circuit experiment, finds a reasonable solution under different charging conditions.

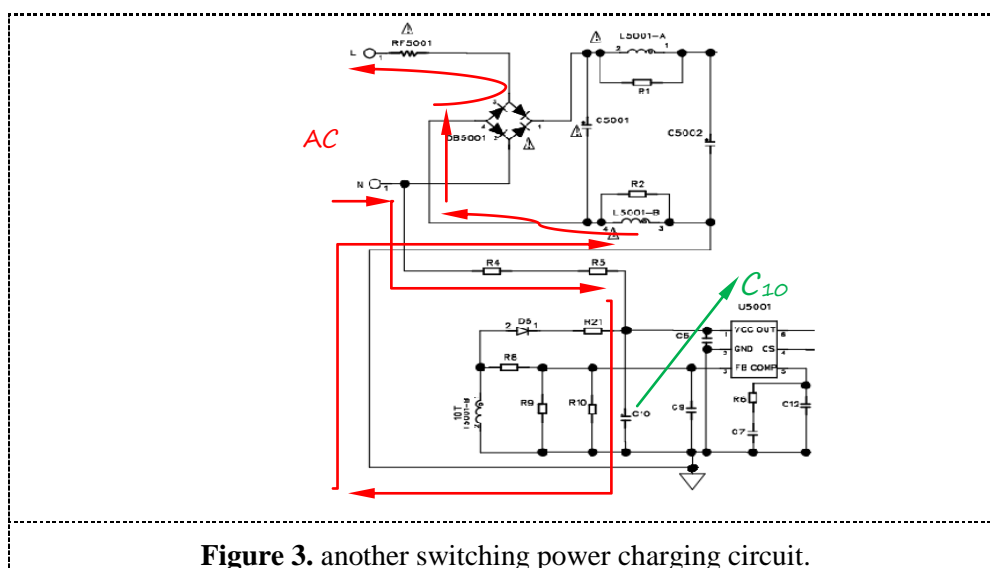
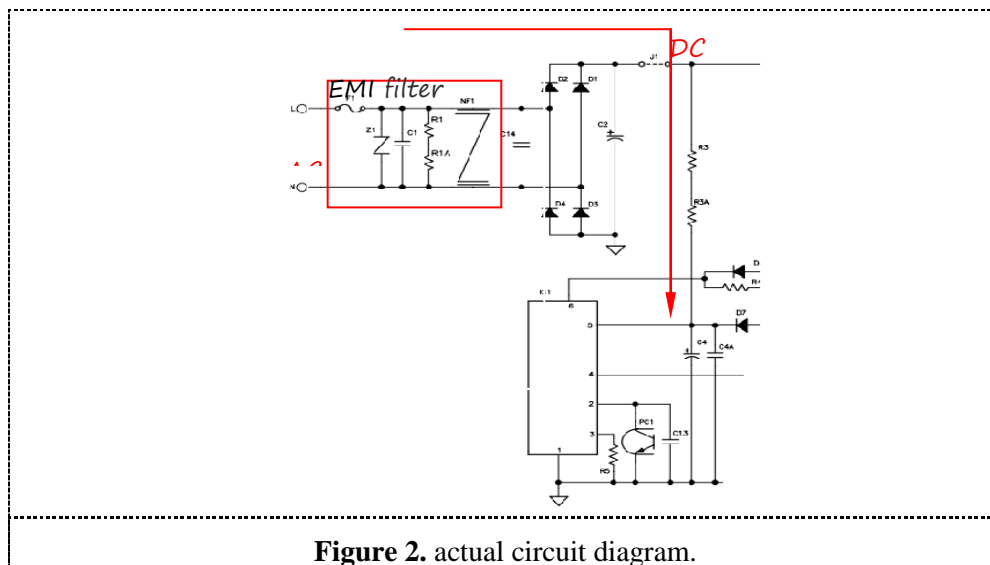
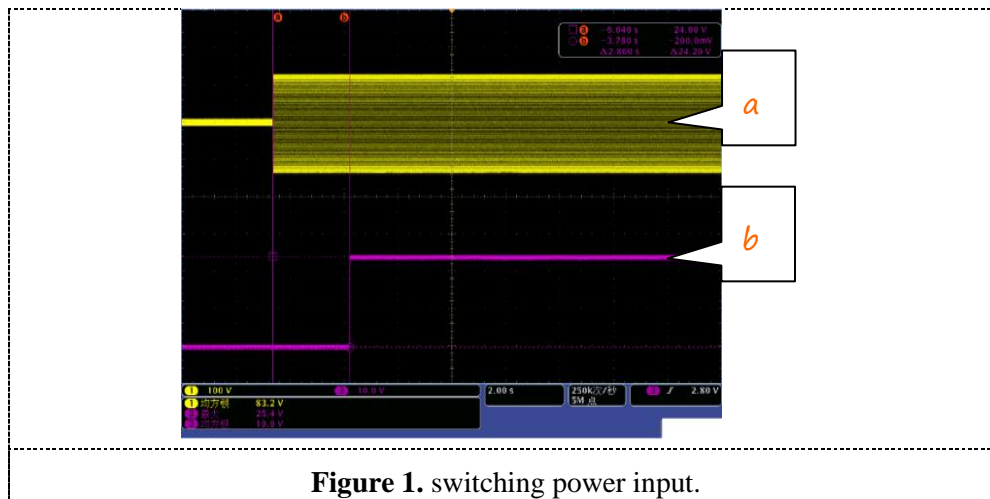
Keyword. Switch Mode Power Supply, capacitor, charging characteristics, ohmic leakage

1. Charge characteristic analysis of capacitor

Common switching power supply after input AC, DC output is not immediately available, usually there is a certain delay time. As shown in figure 1, a is an AC voltage input for a switching power supply, b is the DC voltage output. From the data read-out of the graph, there is a 2.86s delay between the inputs and outputs. Figure 2 is the actual circuit diagram of this switching power supply. The input is sinusoidal AC voltage, through the diode full bridge rectifier and filter, the chip IC1 5 feet connected capacitor C4 is charged. When the charging voltage reached U_{set} , Chip IC1 starts external direct current power supply. Figure 3 is a switching power supply of another type, In the case of pulsating DC current after half wave rectification, the capacitor C10 is charged to start the chip. The red arrow is the direction of the voltage signal[1].

Aluminum electrolytic capacitors are usually used to charge for starting a chip. If capacitance leakage resistance is different, the charging time will be affected, thus affecting the delay time of the DC output of the Switching Power Supply. In this paper, three experiments are conducted to analyse quantitatively the influence of leakage resistance in different cases on delay time.





2. Experimental verification

The first experiment is the DC charging of the ideal capacitor without leakage. Experiment two is the direct current charging of the capacitor with leakage resistance. Experiment three is the charging of a resistive capacitor with half wave sinusoidal voltage input. By theoretical calculation, software simulation and physical circuit experiment, algorithms and solutions for different charging scenarios is found.

2.1. Experiment 1: Measurement of the leakage of the capacitor under DC voltage conditions

Experimental objective: Theoretical calculation method, simulation method and actual measurement method are adopted to measure the relationship between the DC voltage and the time on the capacitor C1.

Experimental illustrations: The experimental circuit is shown in figure 4. The actual power supply V1 uses 50Hz amplitude 100V sinusoidal AC voltage source. After full bridge rectification, filtered by 3.3uF capacitor, the voltage waveform is shown in figure 5. The measured capacity of film capacitor C1 is 0.95uF, the measured leakage current is 0. That is to say, the leakage resistance tends to infinity. Measured impedance of oscillograph used in actual measurement is $R3=10M\Omega$, parallel with C1. When the voltage on the capacitor C1 is $U_{set}=10V$, measures the time took to recharge.

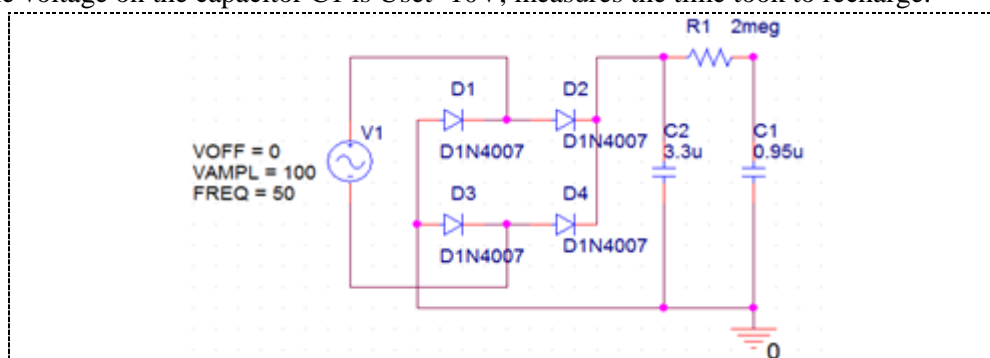


Figure 4. no leakage Capacitor DC charging circuit.

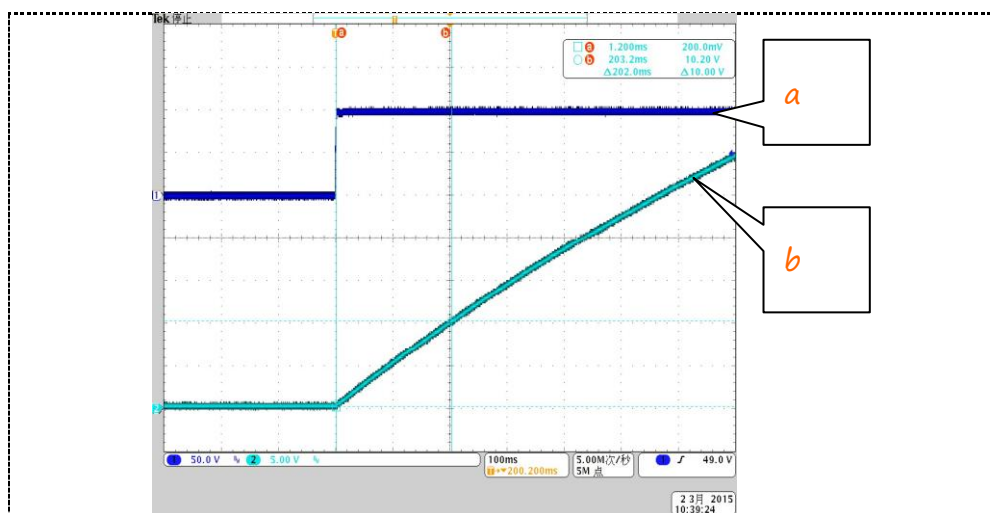


Figure 5. oscillograph waveform.

2.1.1. Theoretical arithmetic. The theoretical calculation circuit is shown in figure 6, DC Voltage Source Vdc=100V, ignoring the influence of capacitor leakage resistance and oscilloscope probe on the circuit.

According to the three element method: $u_c(t) = U_{c(\infty)} \times (1 - e^{-\frac{t}{R_1 C_1}}) = U_{set}$,

that is

$$t = -R_1 C_1 \ln \left[1 - \frac{U_{set}}{U_{c(\infty)}} \right]$$

(1)

thereinto $U_{c(\infty)} = 100V$, $R_1 = 2M\Omega$, $C_1 = 0.95\mu F$, $U_{set} = 10V$. Substitution formula $t = 200.2ms$.

2.1.2. Software emulation. The simulation circuit is shown in figure 7. In order to reduce the influence of the rising edge of the voltage source and the leakage resistance, the DC voltage source V1 uses ideal voltage source, parameter for initial value is 0, step high level is 100V, time-delay is 0s, rising edge is 0s, trailing edge is 0s, high level time is 1000s, pulse period is 1001s, $R_1 = 2M\Omega$, $C_1 = 0.95\mu F$. Using Orcad9.2 version of simulation, the result is shown in figure 8 of the A coordinate. When charging 202.6ms, voltage on C1 is 10.006V.

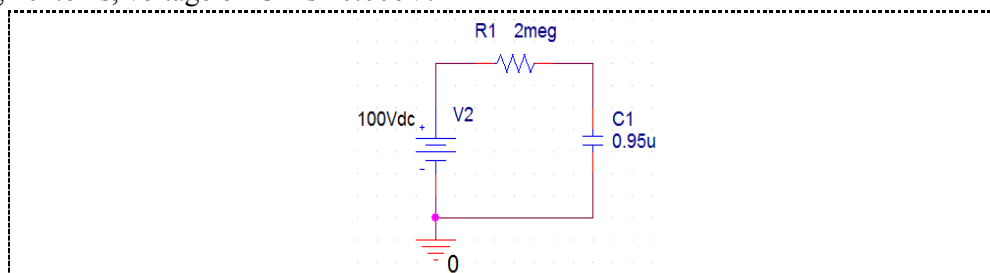


Figure 6. Experiment 1.

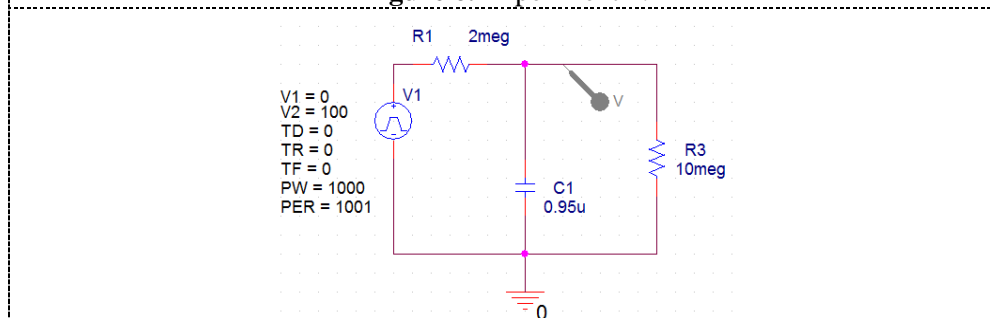


Figure 7. no leakage simulation circuit.

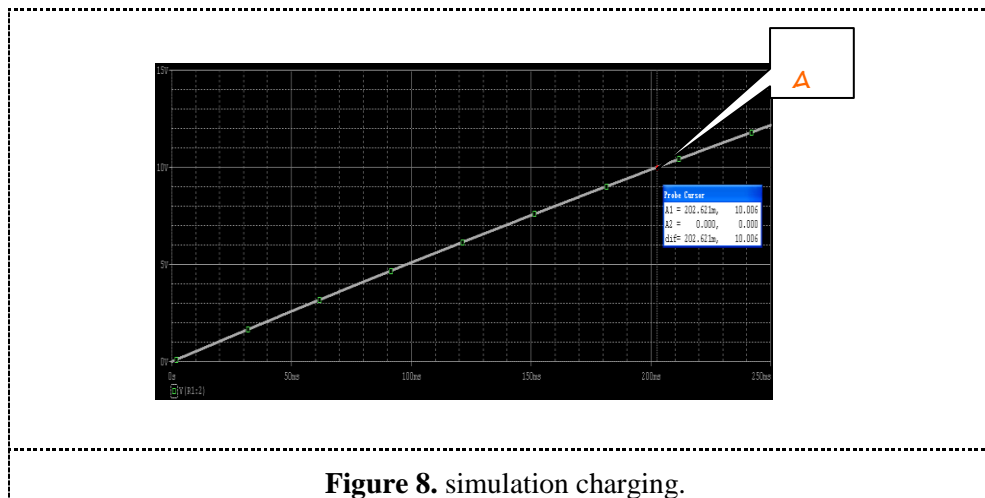


Figure 8. simulation charging.

2.1.3. Physical circuit experiment. Oscilloscope settings trigger, observed waveform is shown in figure 5. Where a is the DC supply voltage, b is the capacitor (capacitor cannot leak electricity; there is a residual charge) charging voltage. Starts clocking from 200mV, read from the chart: when $\Delta V = 10V$, $\Delta t = 202ms$.

Experiment 1 Conclusion: when capacitive DC voltage is $U_{set}=10V$, formula calculator $t=200.2ms$, simulation result $t=202.6ms$, experimental measuring $t=202ms$, the time difference between the three

is very small. Formula (1) $t = -R_1 C_1 \ln \left[1 - \frac{U_{set}}{U_{c(\infty)}} \right]$ can be used in actual circuit calculations, moreover,

the simulation results can accurately predict the measured values.

Error analysis: In the calculation method, the influence of 10M ohm resistance leakage on oscilloscope probe is not considered, caused about 1% error. In order to be close to the actual conditions, the experimental 2 is improved.

2.2. Experiment 2

Considering the influence of capacitance leakage resistance and oscillograph probe, measures the charging of capacitor under DC voltage.

Experimental objective: Theoretical calculation method, simulation method and actual measurement method are adopted to measure the relationship between the DC voltage and the time on the capacitor C1 in case of leakage of electricity.

Experimental illustrations: The experimental circuit is shown in Figure 9. To reduce the impact of other factors, use figure 10 equivalent. $R_2=1M\Omega$ equivalent leakage resistance of capacitance C1, measured impedance of oscilloscope probe is $R_3=10M\Omega$, the other experimental conditions are the same as those of Experiment 1. When the voltage on the capacitor C1 is $U_{set}=10V$, measures the time took to recharge.

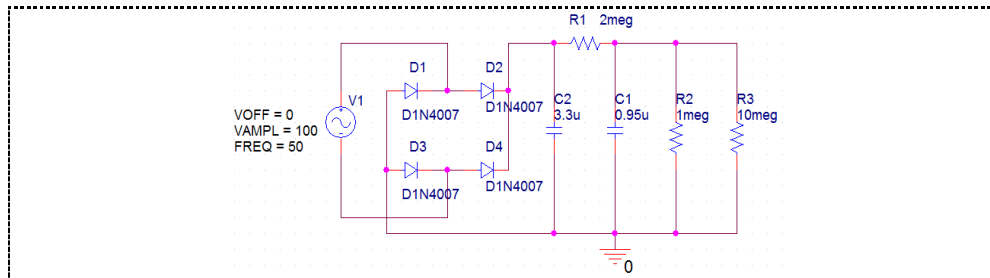


Figure 9. Experiment 2 circuit.

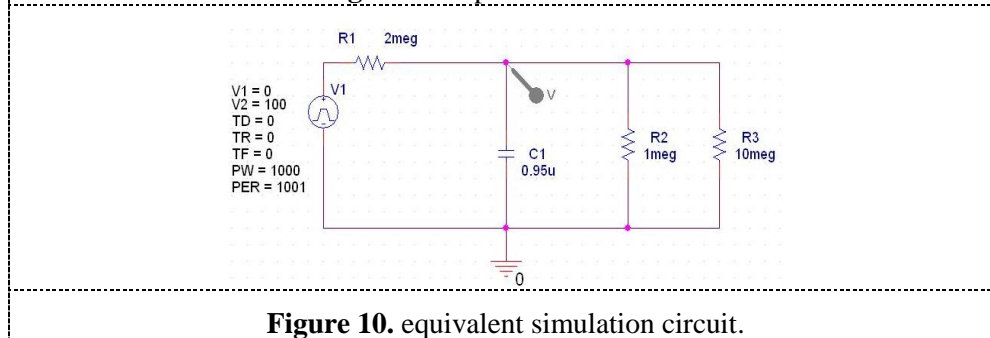


Figure 10. equivalent simulation circuit.

2.2.1. Theoretical arithmetic. The circuit is shown in Figure 11, considers capacitor C1 as an external circuit, the rest is the internal circuit. By Thevenin's theorem, the equivalent circuit is shown in Figure

12. Output resistance $R_o = R_1 // R_2 // R_3$, thereinto $R_1 = 2M\Omega$, $R_2 = 1M\Omega$, $R_3 = 10M\Omega$. So

$$R_o = 0.625M\Omega, \text{ orders } R' = R_2 // R_3 = 0.909M\Omega, \text{ open circuit voltage } U_{OC} = U_{C(\infty)} = V_1 \frac{R'}{R' + R_o}.$$

Using three factor method, brings the above conditions into the formula (1)

$$\text{gets: } t = -\frac{R_1 \times R'}{R_1 + R'} \times C_1 \times \ln \left[1 - \frac{U_{set} \times (R_1 + R')}{R' \times V_1} \right] \quad (2)$$

brings data into formula (2): $t = 229\text{ms}$.

2.2.2. Software emulation. The simulation circuit is shown in figure 11, among them, V1, R1 and C1 are the same as the experiment 1.

Drain resistance and resistance of film capacitor $R_2 = 1M\Omega$, and parallel with oscilloscope probe $R_3 = 10M\Omega$. The simulation results are shown in figure 11 in the A point coordinates, when charging 229.2ms, voltage on C1 is 10.0V.

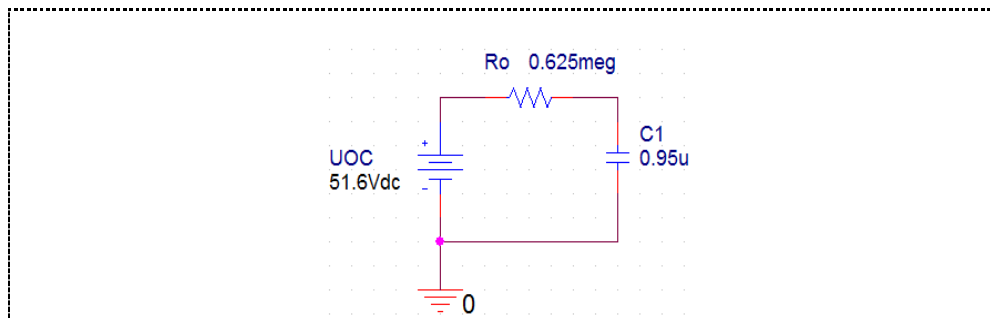


Figure 11. Thevenin equivalent circuit.

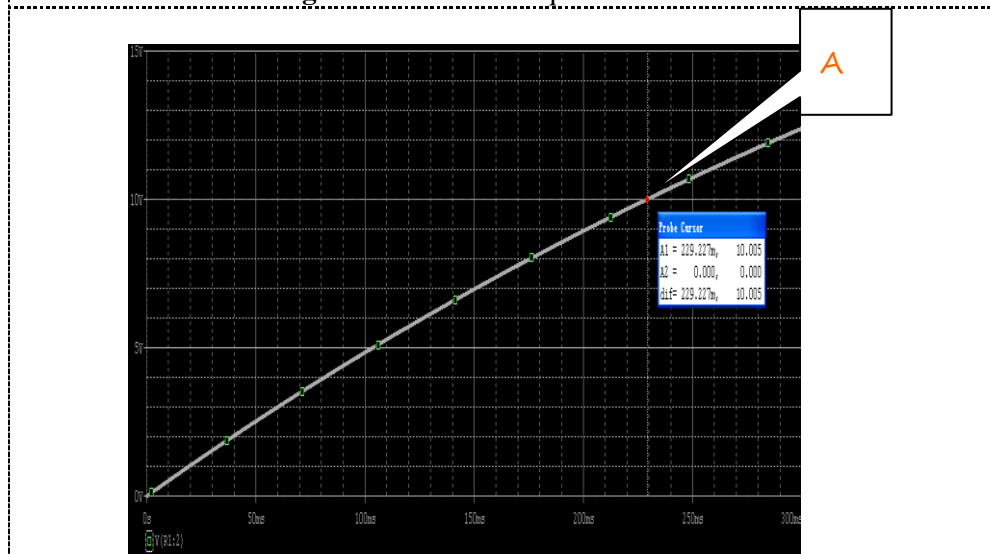


Figure 12. simulation result.

2.2.3. Physical circuit experiment. Oscilloscope settings trigger, observed waveform is shown in figure 12. Where a is the DC supply voltage, b is the capacitor (capacitor can leak electricity; there is no residual charge) charging voltage. Starts clocking from 0V, read from the chart: when $\Delta V = 10.00V$, $\Delta t = 229.0ms$.

Experiment 2 Conclusion: when capacitive DC voltage is $U_{set}=10V$, formula calculator $t=229ms$, simulation result $t=229.2ms$, experimental measuring $t=229ms$, the time difference between the three

is very small. Formula (2) $t = -\frac{R_1 \times R'}{R_1 + R'} \times C_1 \times \ln \left[1 - \frac{U_{set} \times (R_1 + R')}{R' \times V_{CC}} \right]$ can be used in actual circuit

calculations, moreover, the simulation results can accurately predict the measured values[2], thereinto $R' = R_2 // R_3$.

2.3. Experiment 3

Considering the influence of capacitance leakage resistance and oscillograph probe, measures the charging of capacitor under the condition of half wave sinusoidal voltage.

Experimental objective: Simulation method and actual measurement method are adopted to measure the relationship between the voltage and the time on the capacitor C1.

Experimental illustrations: The experimental circuit is the same as the simulation circuit, shown in figure 13. Actual voltage source is 50Hz, $V_m=100V$ AC Voltage Source. After half wave rectification, the capacitor C1 is charged by the resistance R1.

2.3.1. Software emulation. The simulation circuit is shown in figure 14 among them, thereinto V1, C1, R1, R2 and R3 are the same as those of Experiment 2. D1 is diode 1N4007, takes half wave rectification of sinusoidal alternating current. The simulation results are shown in figure 15 in the A point coordinates, when charging 1326.5ms, voltage on C1 is 10.03V.

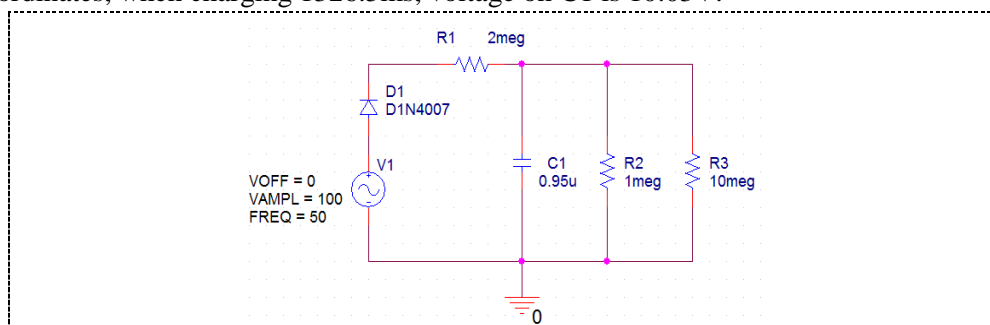


Figure 13. Experiment 3 circuit.

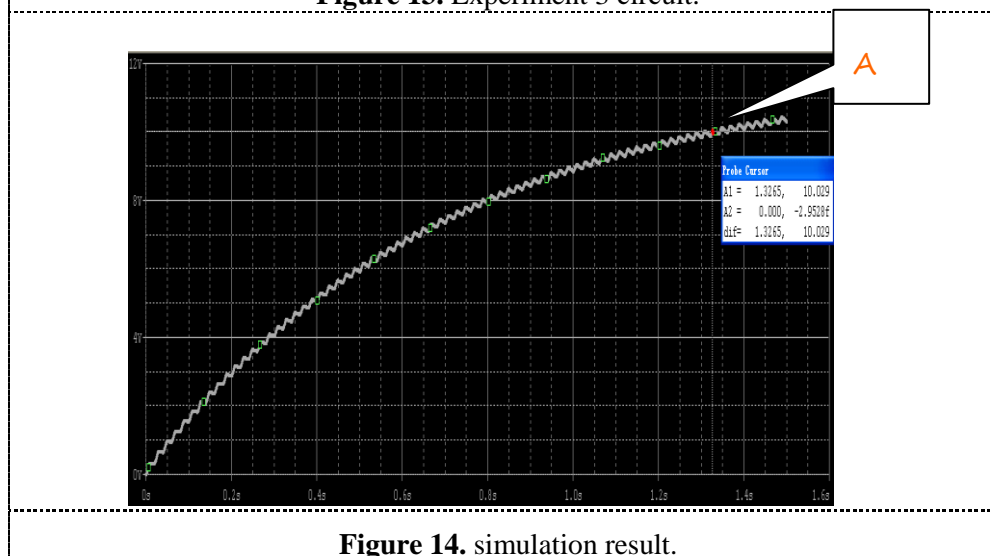


Figure 14. simulation result.

2.3.2. Physical circuit experiment. Oscilloscope settings trigger, observed waveform is shown in figure 15. Where a is the AC voltage source voltage, b is the capacitor (capacitor can leak electricity; there is no residual charge) charging voltage. Starts clocking from 0V, read from the chart: when $\Delta V = 10V$, $\Delta t = 1324ms$.

Experiment 3 Conclusion: In half wave sinusoidal charging, when capacitive DC voltage $U_{set}=10V$, simulation result $t=1326.5ms$, experimental measuring $t=1324ms$, the time difference between the three is very small (less than 0.2%). The simulation results can accurately predict the measured values[3].

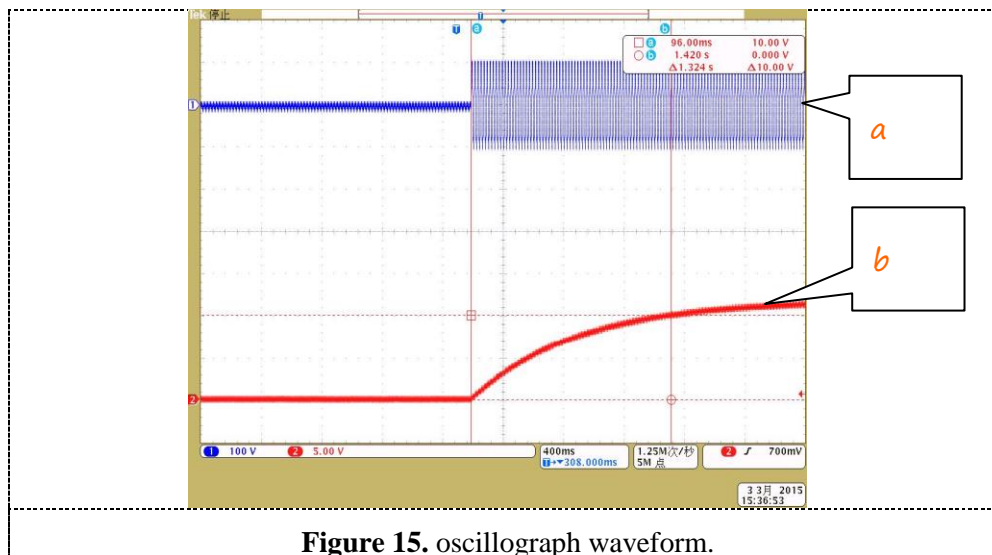


Figure 15. oscillograph waveform.

3. Interpretation of result

Comprehensive conclusions and Solutions: In the case of the above three capacitors charging, you can use formulas (1) and (2) or simulations to get results quickly in experiment 1 and 2; simulation results can be used as an important basis and conclusion for similar experiments in experiment 3. Different algorithms and solutions should be chosen under different charging conditions.

4. References

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