Department of Electronics and Electrical Engineering

School of Engineering

Power Electronics

Experiment Set 2: Half- and Full-wave Diode Rectifier Circuits without and with Capacitive Filtering

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Matriculation Number : 2016200103020 2288941F

Acknowledgements

This laboratory has been planned with the assistance and continuous support of Ian Young & Peter Miller, our power electronics technicians. Many Thanks! I would also like to acknowledge the work carried out by my predecessors, Vassilios Agelidis, Calum Cossar, Prof. Andrew Knox and Dr. Ravinder Dahiya in originating and developing the Power Electronics 2 course.

Dr. Keliang Zhou Glasgow,

Feb 2015

Objectives

The objectives of this laboratory session are as follows:

- To study experimentally the operation of the half-wave diode rectifier circuit with a resistive load.
- To extend the study to a full-wave diode rectifier circuit, also with a resistive load.
- To investigate the effects of capacitive filtering on the performance of both circuits with respect to the input (AC side, i.e. source) and output (DC side, i.e. load).
- To investigate the regulation performance of the power supply circuits.

At the end of this laboratory session you should be able to:

- Explain how half-wave and full-wave diode rectifier circuit work, including the circuit operating steady-state waveforms.
- Determine the output voltage average and RMS values of both circuits without filtering.

- Discuss the effect of the DC output filter capacitor value on the rectifier's output voltage ripple, the average (DC) value of its output voltage and the RMS value of the line current.
- Explain why the use of a voltage regulator is needed to stabilise the output voltage.
- Compare the two topologies and elaborate on their respective merits and drawbacks.

You must bring a laboratory notebook for recording your result and hand in the completed notebooks at the end of semester.

1. Introduction

There are many cases where the load requires DC power but the available source of energy is AC. Simple examples include computer power supplies and mobile phone chargers. Rectification is used in most conventional cars to charge the battery (DC) from the alternator (AC). In aircraft electrical systems AC power is generated from the engines but the numerous loads require DC in order to function properly. There are many different rectifier circuits with varied performance and characteristics. In this experiment the simple half-wave diode rectifier with a resistive load will be used to illustrate the basic concepts of rectification and capacitive filtering. A full-wave diode rectifier will then be studied and compared with the half-wave version to confirm theoretical analysis and performance characteristics from both the output (DC) and input (AC) point of view. Finally, the DC performance of the power supply will be examined, both with and without the use of a voltage regulator circuit.

2. Background Information

In this experiment you are required to use provided components to construct a half-wave rectifier and full-wave rectifier respectively, and use an oscilloscope and DMM to view and measure voltage, current and power at various points in the circuits.

Theoretical Background

2.1 Half-wave rectification with resistive load and filtering

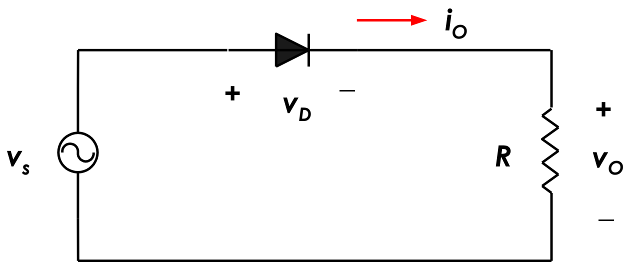


Figure 1: Half-wave diode rectifier circuit with resistive load.

The half-wave diode rectifier circuit schematic with a resistive load and the same circuit with capacitive filtering are shown in Figure 1 and Figure 2 respectively.

When no capacitive filtering is used, the amplitude of the DC (average) value of the half-wave rectified voltage wave-form is: $V_{DC}=V_P/$. The RMS value of the output half-rectified voltage waveform is given by $V_{RMS}=V_P/2$. In both cases, when a capacitor is added the average and RMS voltage is simply V_P (when no current is drawn).

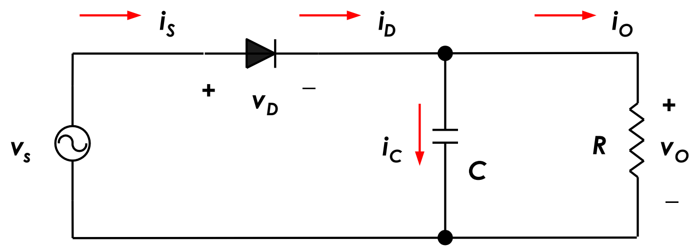


Figure 2: Half-wave diode rectifier circuit with resistive load and capacitive filtering.

2.2 Full-wave rectification with resistive load and filtering

The full-wave diode rectifier circuit schematic with a resistive load and the same circuit with capacitive filtering are shown in Figure 3 and Figure 4 respectively.

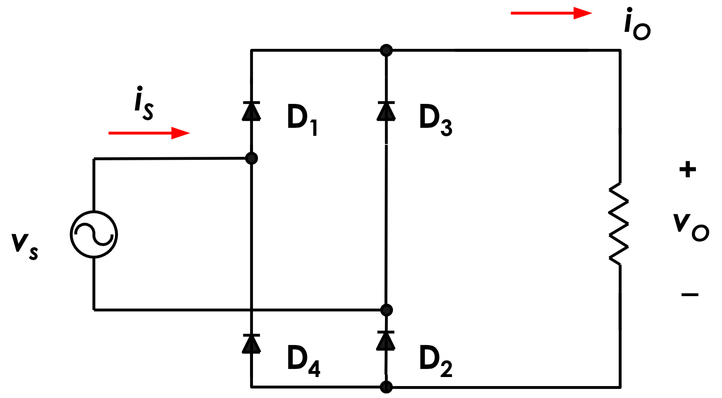


Figure 3: Full-wave diode rectifier circuit with resistive load.

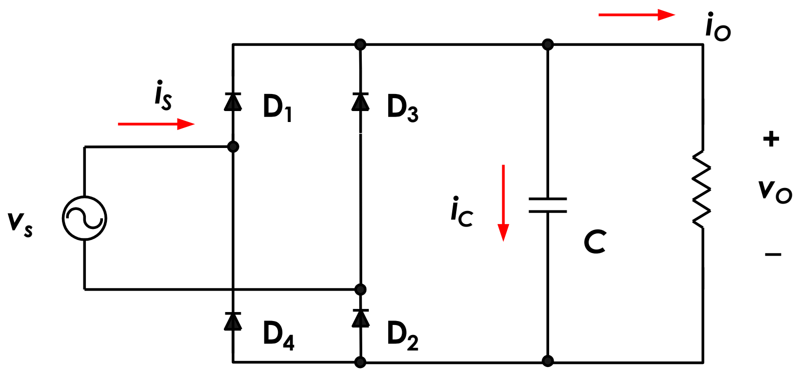


Figure 4: Full-wave diode rectifier circuit with resistive load and capacitive filtering.

When no filtering is used, the amplitude value of the DC (average) value of the full-wave rectified voltage waveform is: $V_{DC}=2V_P/$ and the value of the output full-wave rectified unfiltered voltage waveform is given by $V_{RMS}=V_P/\sqrt{2}$.

Pre-Laboratory Questions

2.3 Half-wave and full-wave diode rectifiers with resistive load

- Assume a 5V AC sinusoidal voltage waveform applied to the input of a diode rectifier with resistive load and no filtering. Calculate the average value and the RMS value of the half-wave and full-wave rectified (output) voltage waveform. You should record the 4 values in a table in your lab book.

For the half-wave rectified:

$V_{DC}=V_P/\pi=5/\pi$

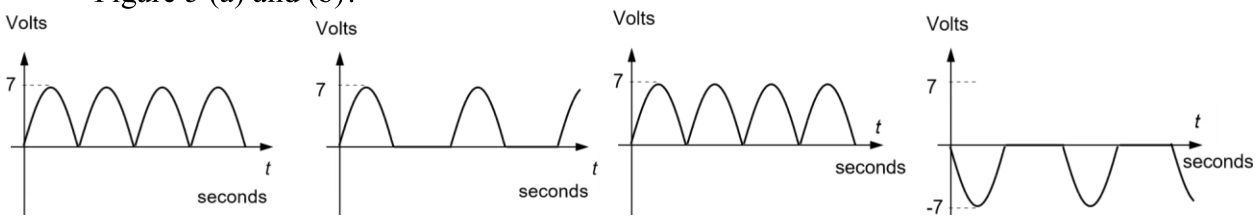
$V_{RMS}=V_P/\ 2=5/2$

For the full-wave rectified:

$V_{DC}=2V_P/\pi=2\times5/\pi$

$V_{RMS}=V_P/\sqrt{2}=5/\sqrt{2}$

- What is the relationship between the mean values of the two sets of signals depicted in Figure 5 (a) and (b)?



- a b
- Figure 5: Voltage Waveforms

In a)

$V_{DC}=1/2\times V'_{DC}$

In b)

$V_{DC}=-1/2\times V'_{DC}$

Please answer the following questions, with reasons, in your lab book.

Question	True	False
1. The average value of the output voltage waveform in half-wave diode rectifier circuits increases when a capacitive filter is added.	√	
2. The higher the capacitor values in diode rectifier circuits the higher the AC ripple of the output voltage waveform for a given load current. lower		√
3. The mean DC voltage of the half-wave diode rectifier without filtering is $V_P/$.	√	
4. The maximum theoretical value of average value of the half-wave diode rectifier when a very large (infinite value) capacitor filter is included is V_P.	√	

5. The frequency of the AC ripple in the case of a half-wave diode rectifier with or without a capacitor is twice the input frequency.		√
6. The period of the output rectified voltage waveform in the case of the full-wave diode rectifier is half the period of the input voltage waveform.	√	
7. The unfiltered mean value of the full-wave rectified voltage waveform is $V_P/$. $V_{DC}=2V_P/\Pi$		√
8. The average value of the output voltage of the half-wave rectifier without filter is equal to the average value of the output voltage of the full-wave rectifier.		√
9. When a capacitor filter is used on the DC side of diode rectifier circuits, the AC side power factor is reduced (worsens) when compared with the unfiltered case.		√
10. The full-wave diode rectifier is better than the half-wave diode rectifier with or without a filter capacitor for all practical purposes.		√
11. When a filter capacitor is used on the rectified output a higher input frequency gives a lower average output voltage when a load is being drawn.	√	
12. A full-wave rectifier always needs 4 diodes.	√	

3. Experimental work.

3.1 Half-wave and full-wave diode rectifier with resistive load

☞ **Before you apply power to the circuit, ask a laboratory demonstrator to check your connections.**

☞ **Electrolytic capacitors are polarised. They have two different leads, plus (+) and minus (-). Often the negative (-) lead is marked. If the capacitor is subjected to overvoltage, or if it is connected with incorrect polarity, it may burst. Make absolutely no mistakes.**

- Connect the half-wave rectifier circuit as shown in Figure 6 on the breadboard.
- Connect the oscilloscope to take the frequency and voltage measurements on each side (both AC and DC sides) of the rectifier.
- Once your circuit has been checked by a demonstrator, turn on the power supply unit.
- Use DMM to take the voltage measurements on each side of the rectifier.

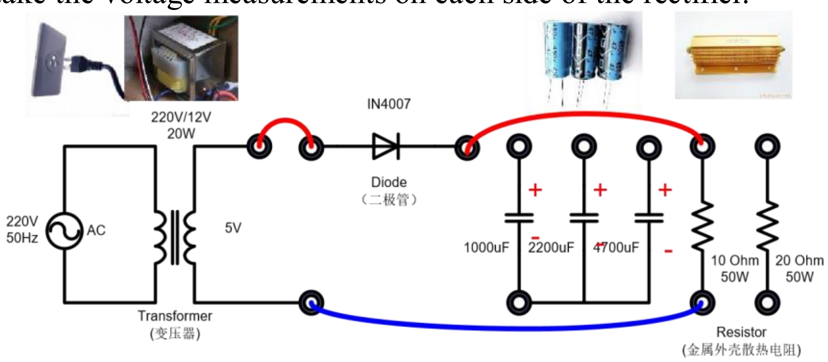
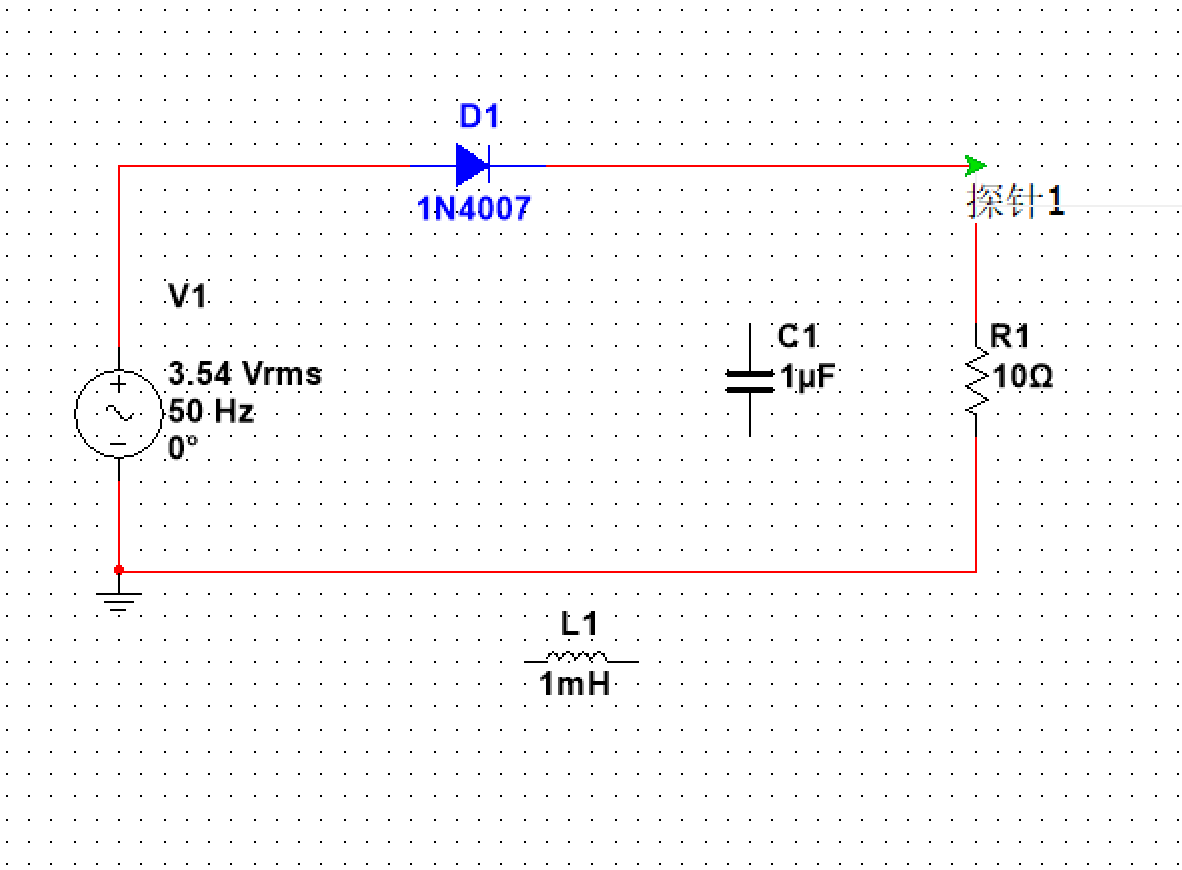
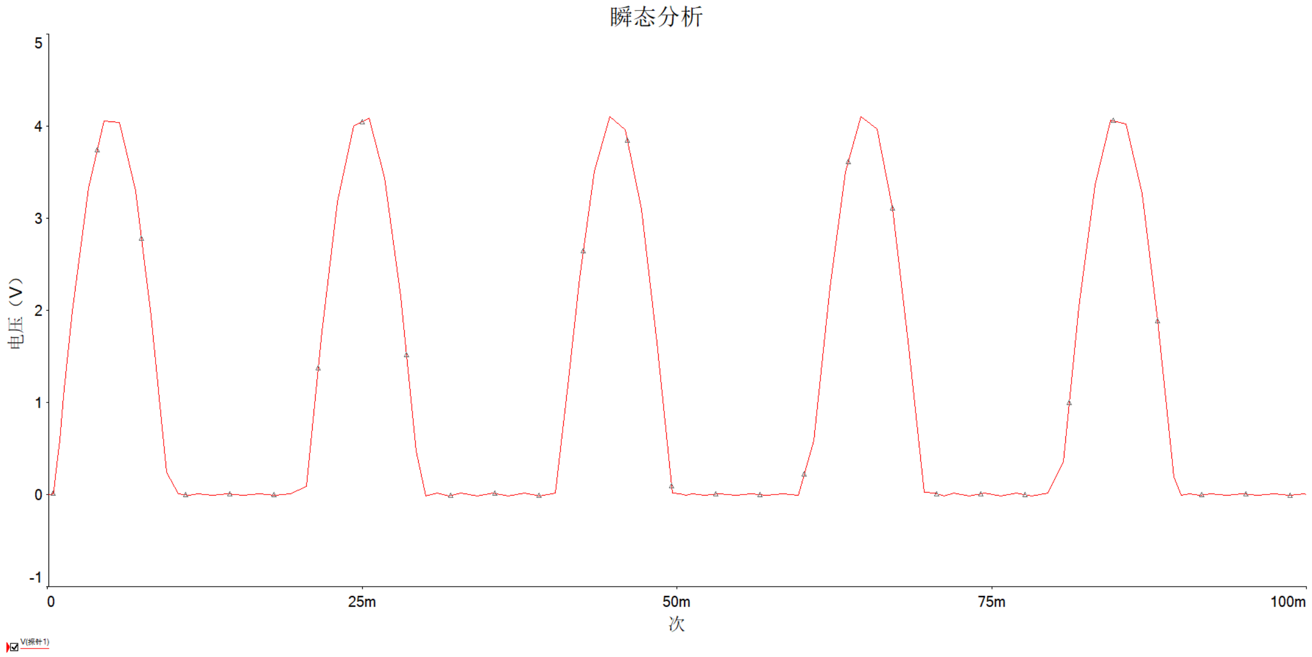


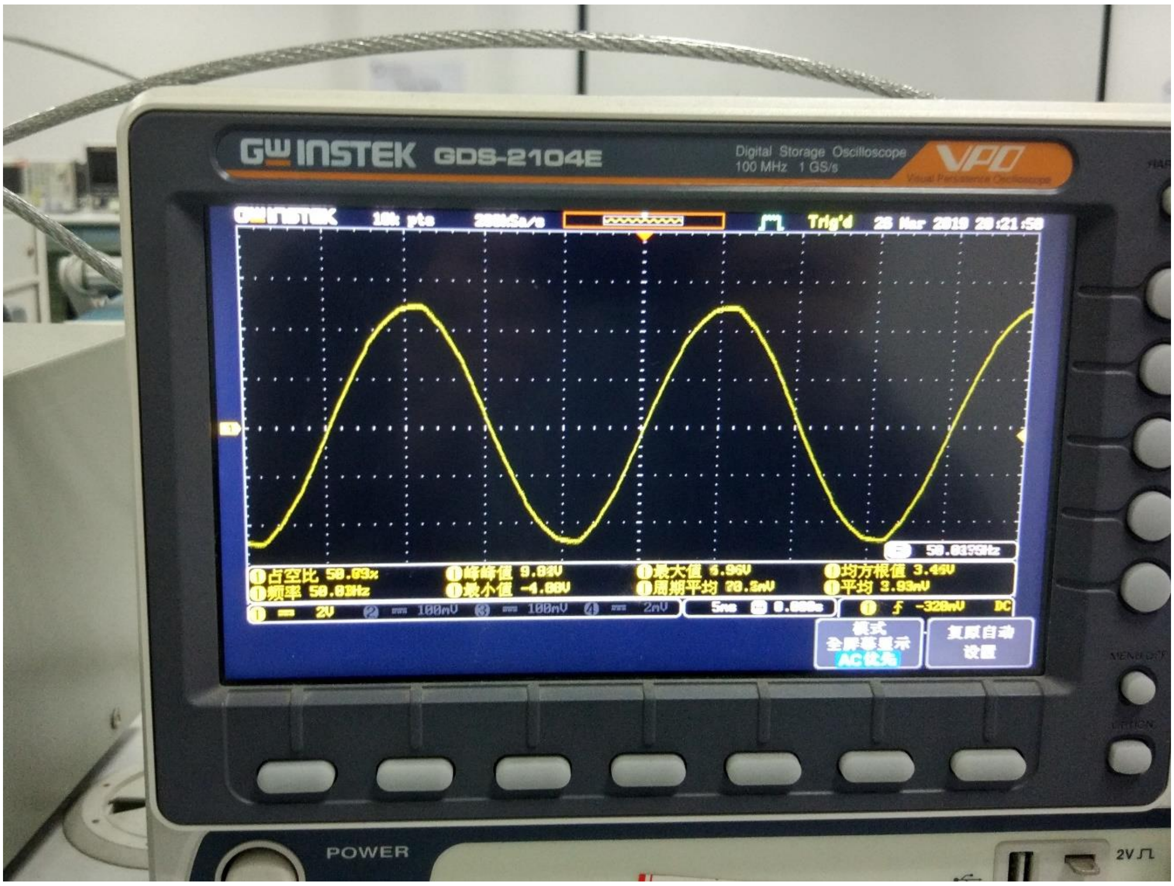
Figure 6: Half-wave rectifier with resistor load



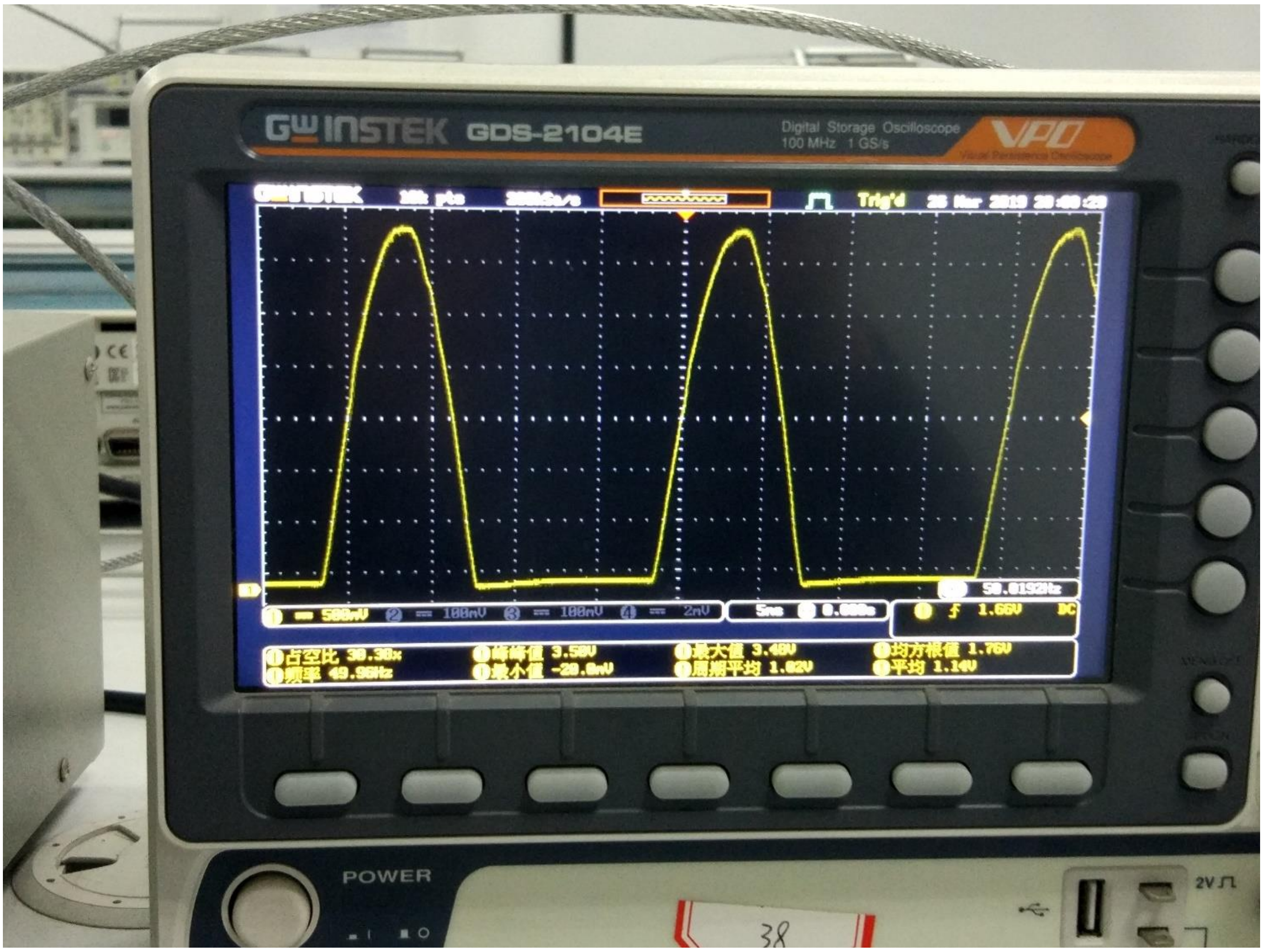

设计1
直流工作点

	直流工作点	
1	V(探针1)	0.00000





The ac terminal will always be the same throughout this experiment, and the difference happens solely in the dc terminal.



Obtain a copy of voltage waveforms on both AC side and DC side of the rectifier using the scope and printer and attach them to your lab book and label their peak values, and calculate their RMS or average value and compare them with the measured results from DMM.

The ac terminal will always be the same throughout this experiment, and the difference happens solely in the dc terminal.

ac:

Vpk=9.84/2=4.92V

Vdc=0V

Vrms=Vpk/ $\sqrt{2}$ =3.48V

Dc terminal in half-wave rectified circuit without capacitor:

Vpk=3.58V

Vdc=Vpk/ π= 3.58/ π=1.14V

Vrms=Vpk/ 2=3.58/2=1.79V

☞ **Do not use two channels of the Scope to measure AC side and DC side at the same time since all probes share the common ground of all channels.**

- Connect the full-wave rectifier circuit as shown in Figure 7 on the breadboard.
- Connect the oscilloscope to take the frequency and voltage measurements on each side (both AC and DC sides) of the rectifier.
- Once your circuit has been checked by a demonstrator, turn on the power supply unit.
- Use DMM to take the voltage measurements on each side of the rectifier.

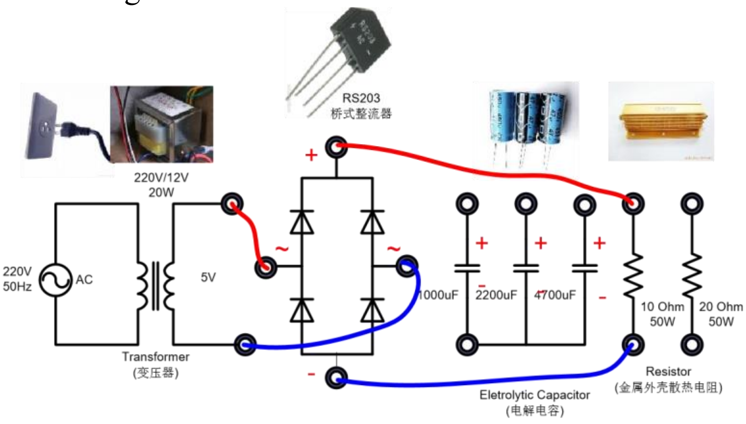
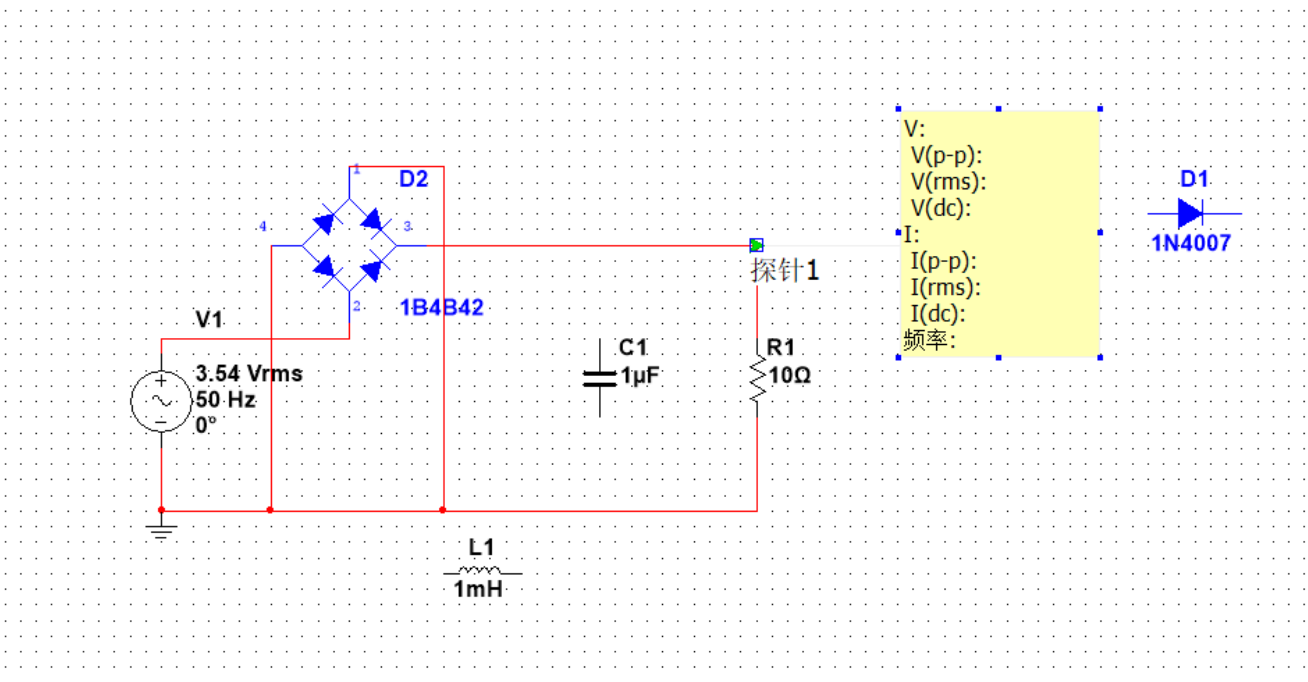
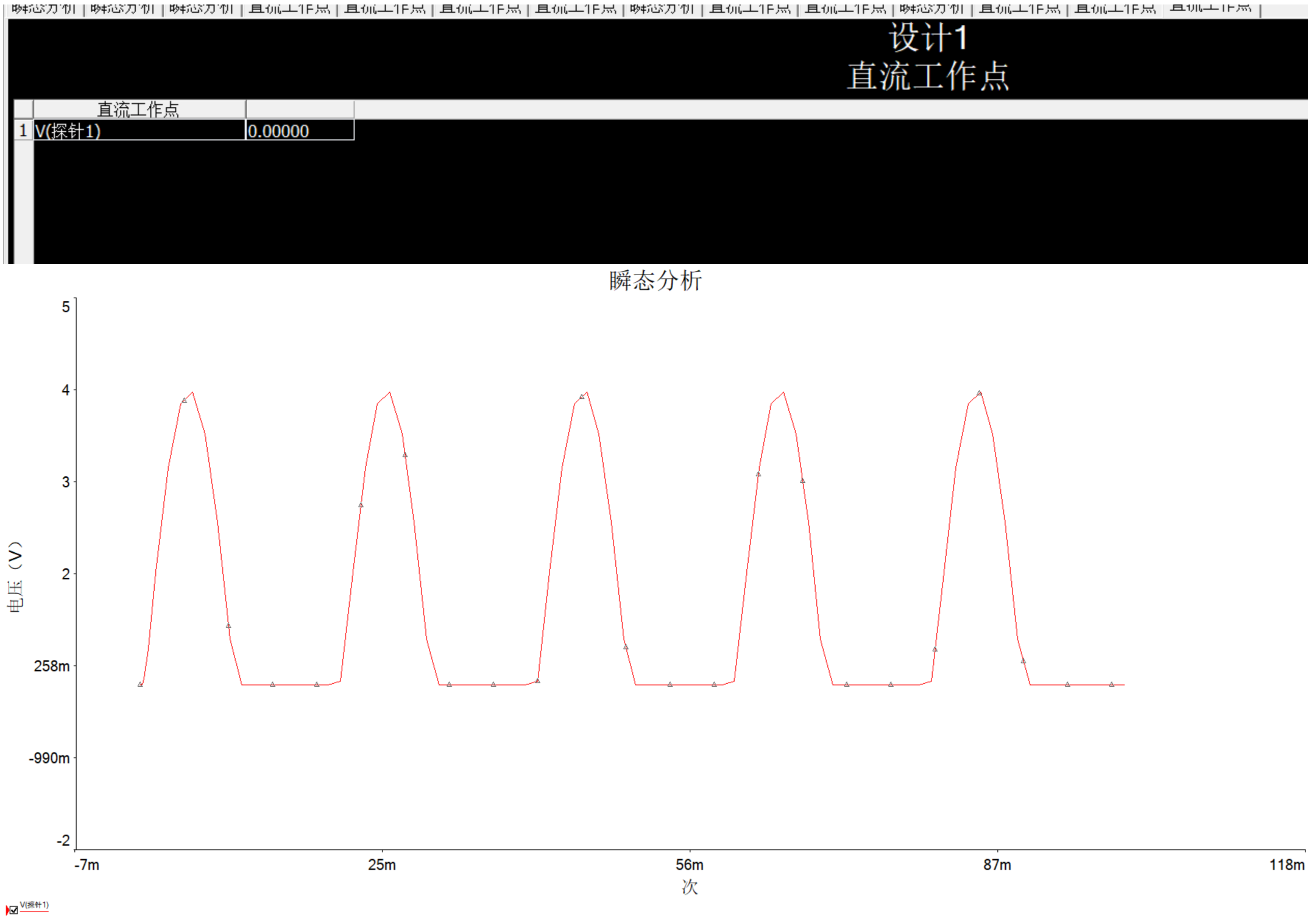
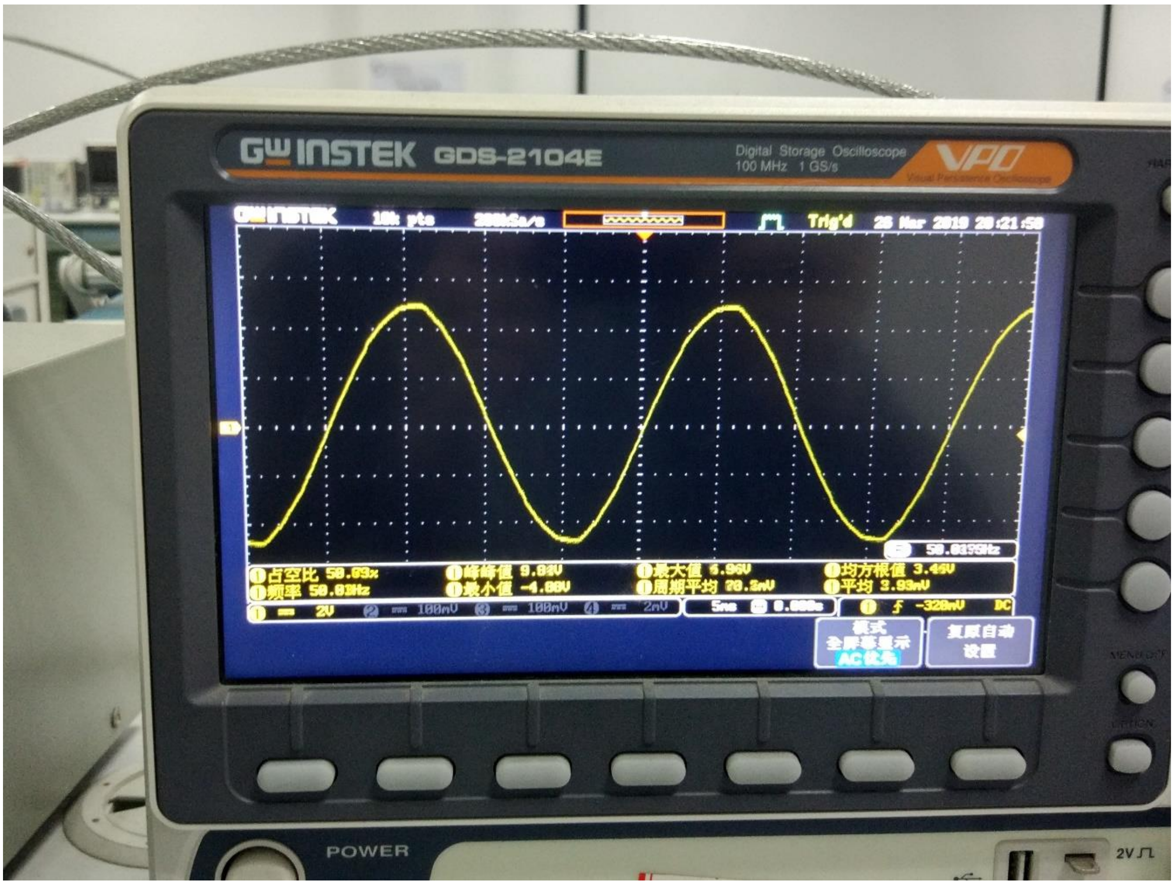


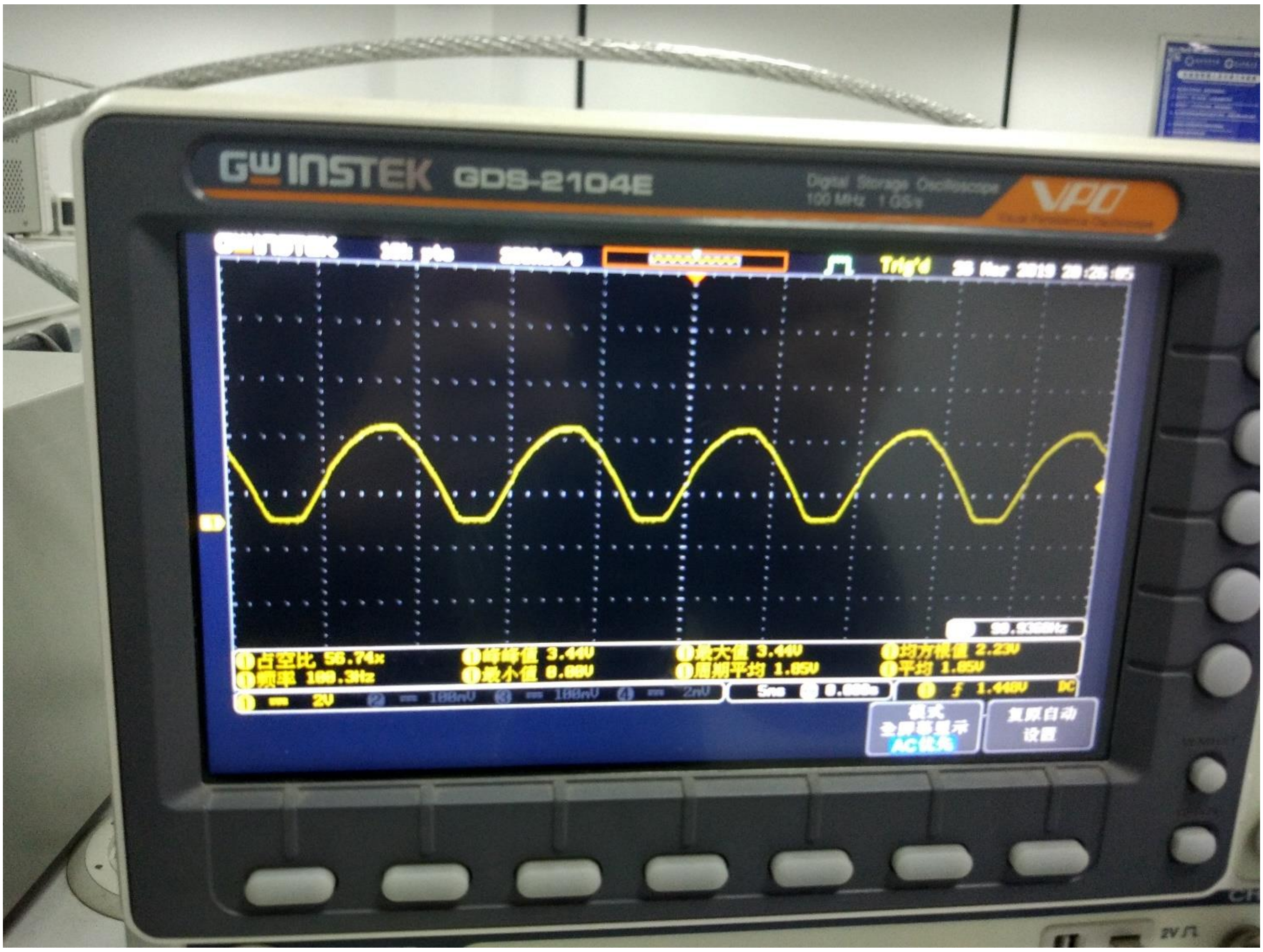
Figure 7: Full-wave rectifier with resistor load




设计1
直流工作点
直流工作点
1 V(探针1) 0.00000
瞬态分析
5
4
3
2
258m
-990m
-2
电压（V）
-7m
25m
56m
87m
118m
次
V(探针1)



The ac terminal will always be the same throughout this experiment, and the difference happens solely in the dc terminal.



Obtain a copy of voltage waveforms on both AC side and DC diode of the rectifier using the scope and printer and attach them to your lab book and label their peak values, and calculate their RMS or average value and compare them with the measured results from DMM.

The ac terminal will always be the same throughout this experiment, and the difference happens solely in the dc terminal.

ac:

$V_{pk}=9.84/2=4.92V$

$V_{dc}=0V$

$V_{rms}=V_{pk}/\sqrt{2}=3.48V$

Dc terminal in full-wave rectified circuit without capacitor:

$V_{pk}=3.44V$

$V_{dc}=2V_{pk}/\pi=2\times3.44/\pi=2.19V$

$V_{rms}=V_{pk}/\sqrt{2}=3.44/\sqrt{2}=2.43V$

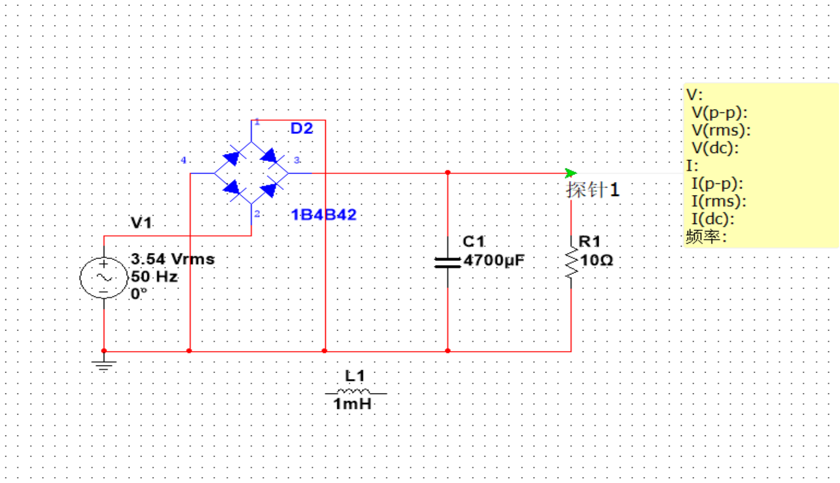
- Are the readings what you expected? Why?
  Yes, they are almost the same with small error.

3.2 Full-wave diode rectifier with a capacitive filter

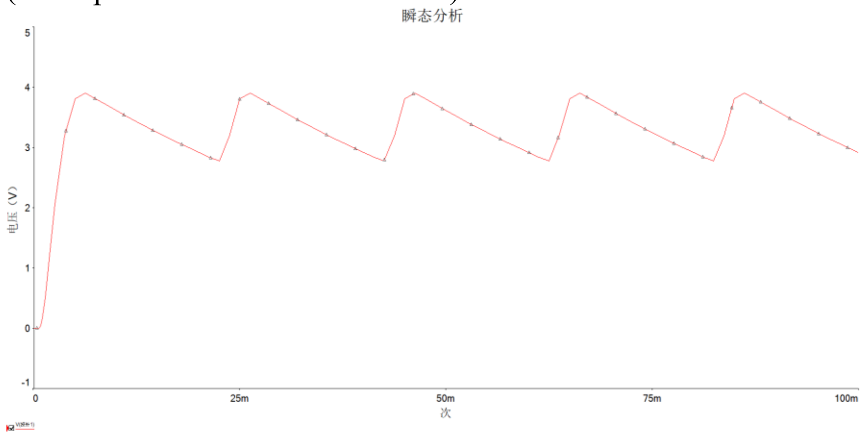
- Turn off the power supply unit.
- Configure the power supply unit for full-wave rectification as shown in Figure 8. Use the 2.2mF capacitor for smoothing.

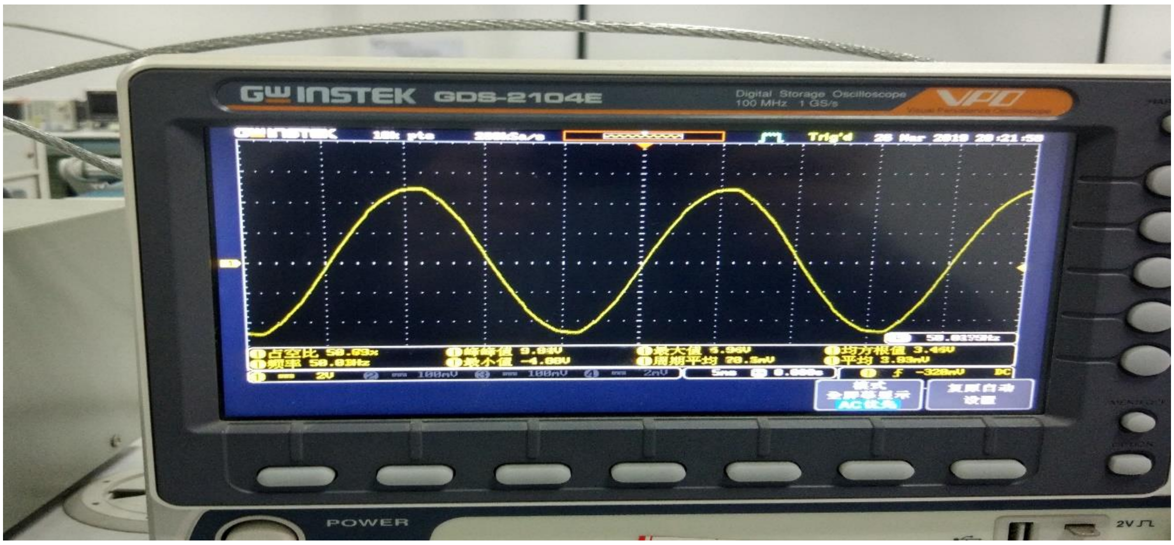
Before you apply power to the circuit, ask a laboratory demonstrator to check your connections.

- Using scope and DMM, measure the peak to peak ripple voltage, the minimum and average voltages and the RMS current on DC side of the rectifier.

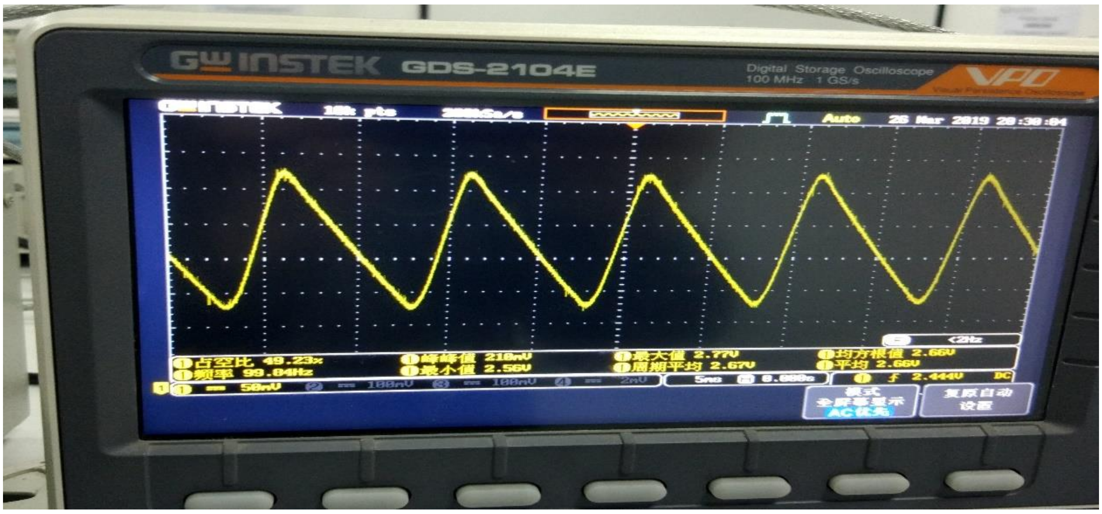


(the capacitor should be 2200uF!!!)





The ac terminal will always be the same throughout this experiment, and the difference happens solely in the dc terminal.



The ac terminal will always be the same throughout this experiment, and the difference happens solely in the dc terminal.

ac:

Vpk=9.84/2=4.92V

Vdc=0V

Vrms=Vpk/ $\sqrt{2}$ =3.48V

Dc terminal in full-wave rectified circuit with 2200uF capacitor:

Vpk=218/2=109mV

Vdc=2.66V

Vrms=2.66V

- From the displayed waveforms, estimate how long is the rectifier is conducting?
  - ? Using I = C dv/dt, calculate the expected ripple voltage. How does it compare to the experimentally determined value and what could the difference be caused by?

dv/dt=I/C=0.266A/2200uF=26.5
discharge time=10ms for full-wave rectified circuit
Vpp=discharge time×dv/dt=0.265V=265mV

265mV, compared to 218mV, seems to be accurate to some extent. The difference could be varying parameter, since the data used is transient.

Obtain a copy of the voltage DC side of the rectifier using the scope and printer and attach it to your lab book.

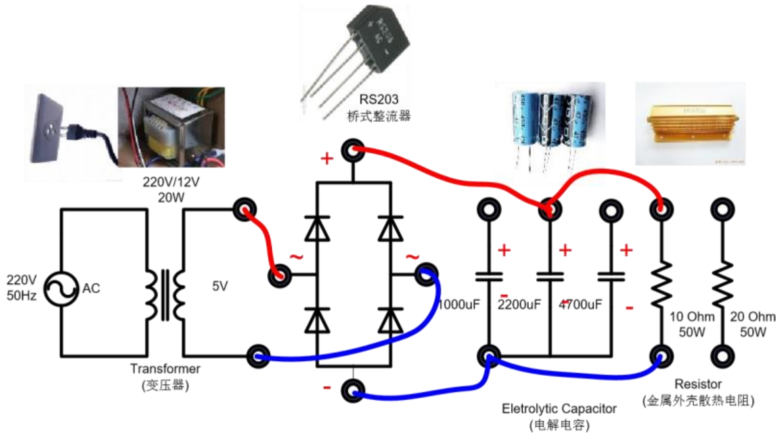


Figure 8: Full-wave rectifier with capacitive filter of 4700 F

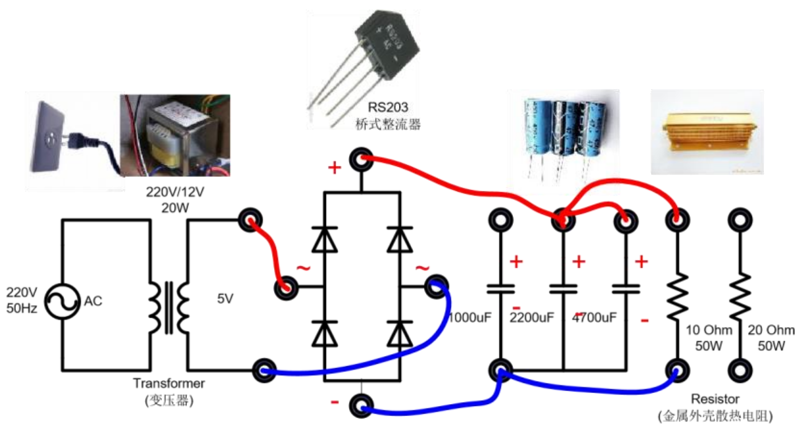
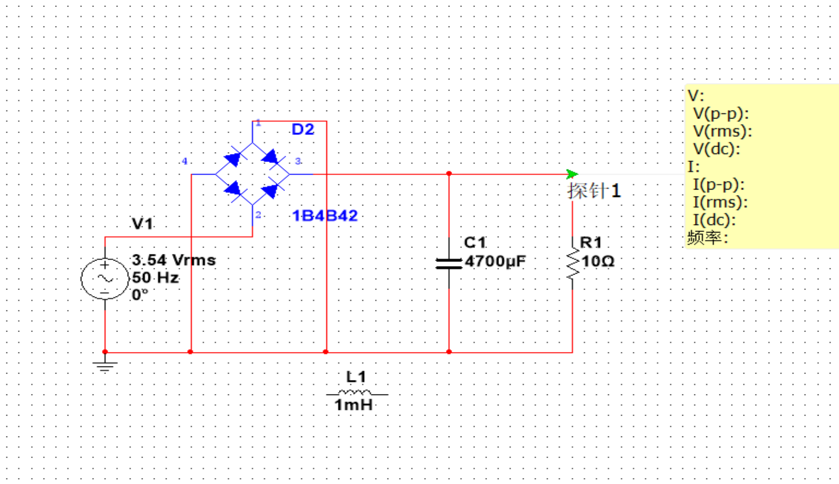
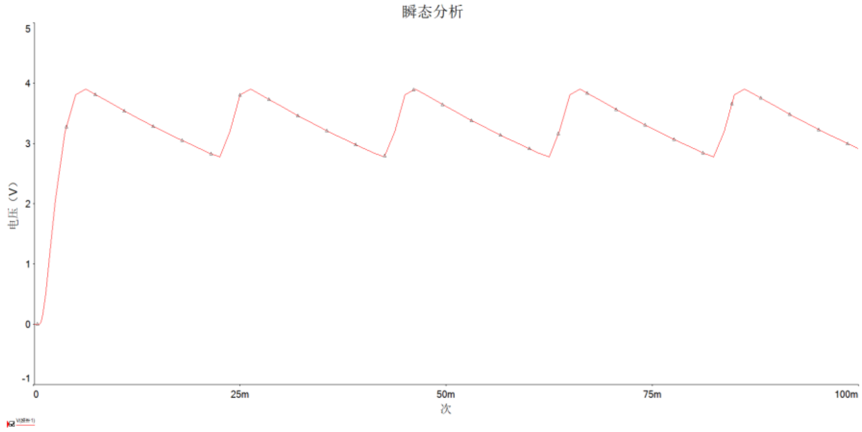
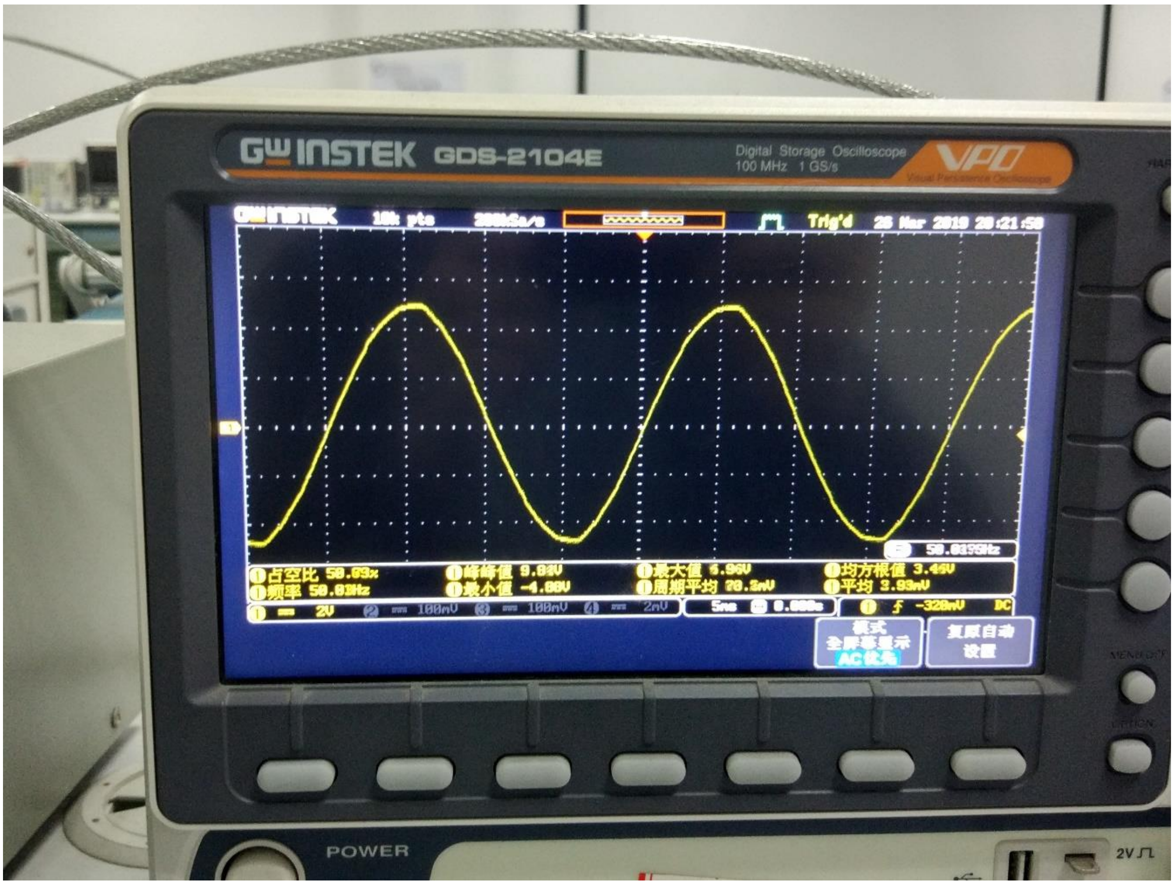


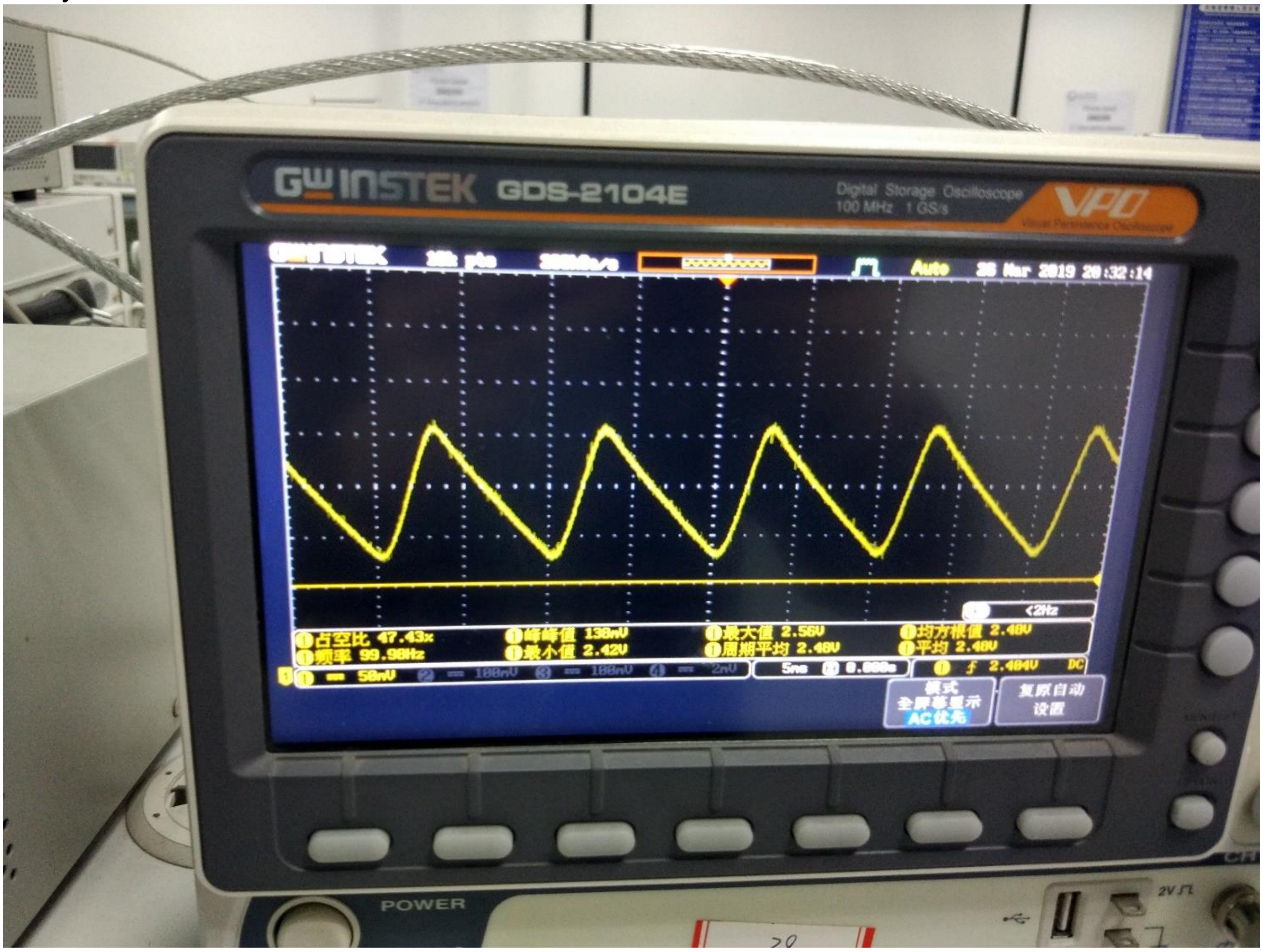
Figure 9: Full-wave rectifier with capacitive filter of 6900 F


D2
1B4B42
V1
3.54 Vrms
50 Hz
0°
C1
4700µF
R1
10Ω
L1
1mH
探针1
V:
V(p-p):
V(rms):
V(dc):
I:
I(p-p):
I(rms):
I(dc):
频率:


瞬态分析
电压 (V)
5
4
3
2
1
0
-1
0
25m
50m
75m
100m
次


GW INSTEK GDS-2104E
Digital Storage Oscilloscope
100 MHz 1 GS/s
POWER

The ac terminal will always be the same throughout this experiment, and the difference happens solely in the dc terminal.



- Turn off the power supply unit and add 4.7mF capacitor to the filter as shown in Figure 9.
- Turn on the supply and use scope and DMM to measure the peak to peak ripple voltage, the minimum and average voltages and the RMS current on DC side of the rectifier..

The ac terminal will always be the same throughout this experiment, and the difference happens solely in the dc terminal.

ac:

Vpk=9.84/2=4.92V

Vdc=0V

Vrms=Vpk/ $\sqrt{2}$ =3.48V

Dc terminal in full-wave rectified circuit with 4700uF capacitor:

Vpk=138/2=69mV

Vdc=2.48V

Vrms=2.48V

? How do the peak to peak, minimum and average voltages differ from the values obtained using the 2.2mF capacitor?

Compared with the 2200uF circuit, the Vpp was halved, and both Vrms and Vdc are reduced slightly.

? Explain briefly why a difference is observed, noting whether the effect of a larger capacitor is beneficial (or not) on the AC and DC sides of the rectifier.

The larger smoothing capacitor parallel to the load resistor, the smaller the ripple voltage it would be. So, with the increase of capacitor, the peak to peak value reduced.

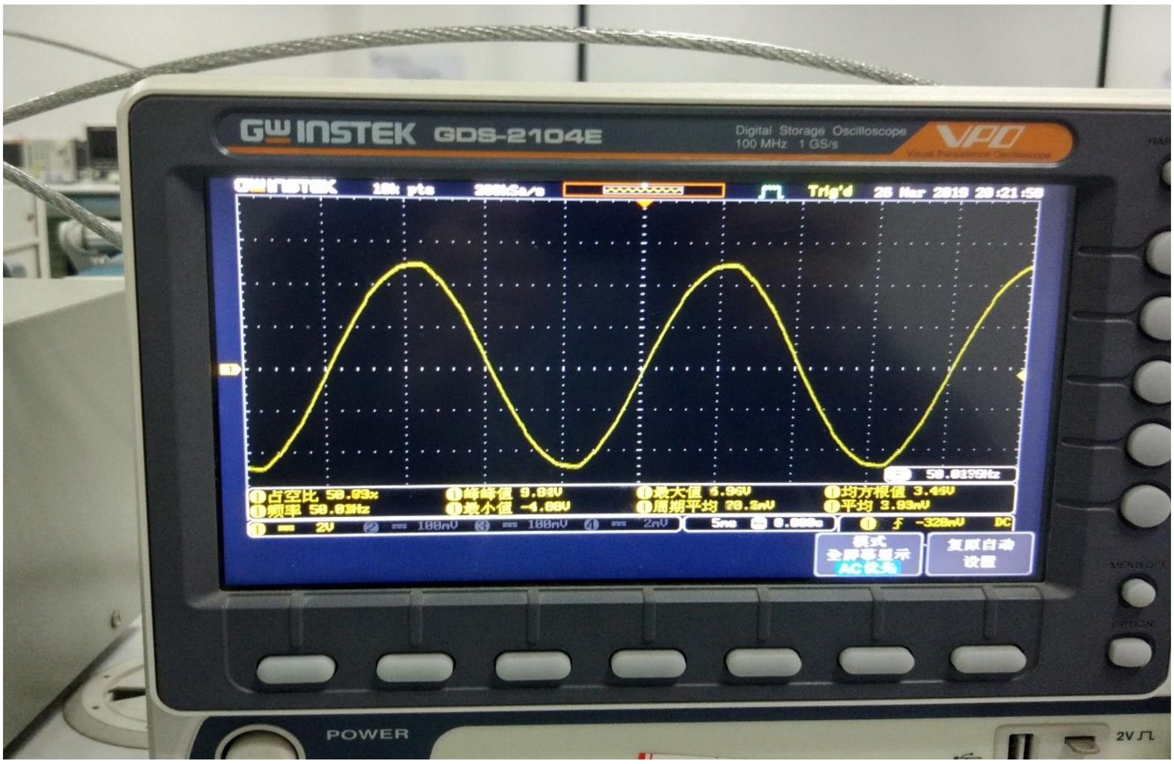
However, the varying smoothing capacitor does little effect on the value of the dc side of the rectifier.

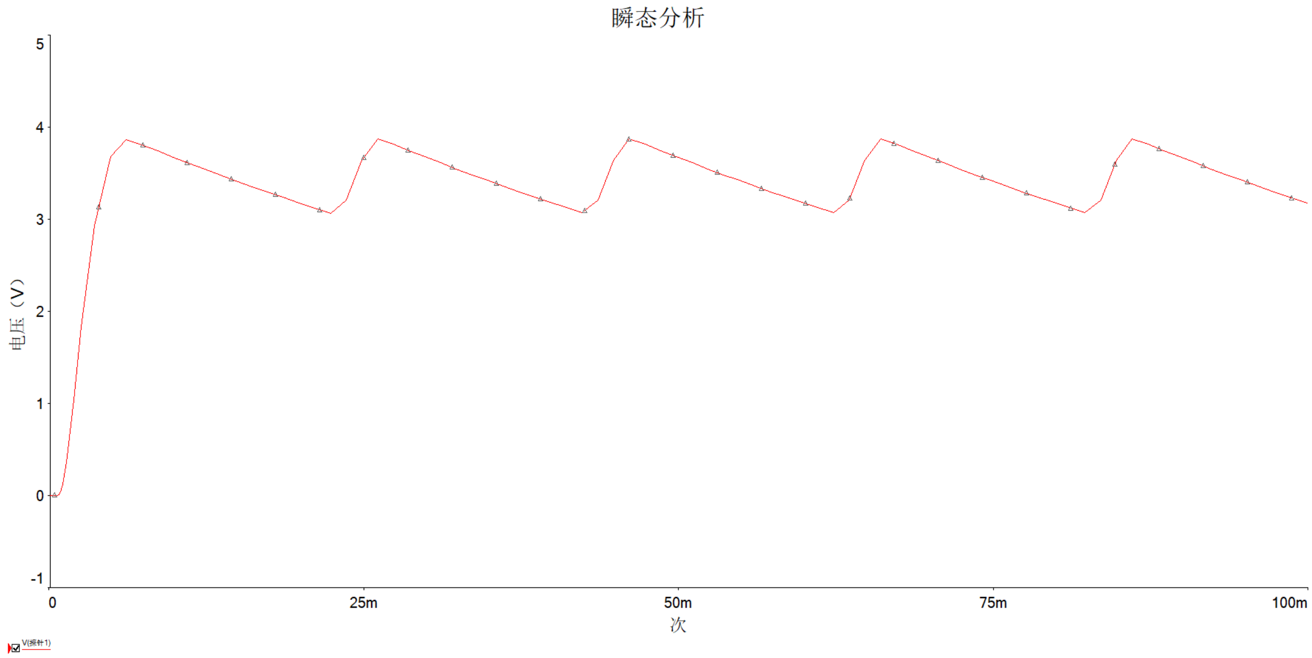
3.3 Unregulated power supply performance.

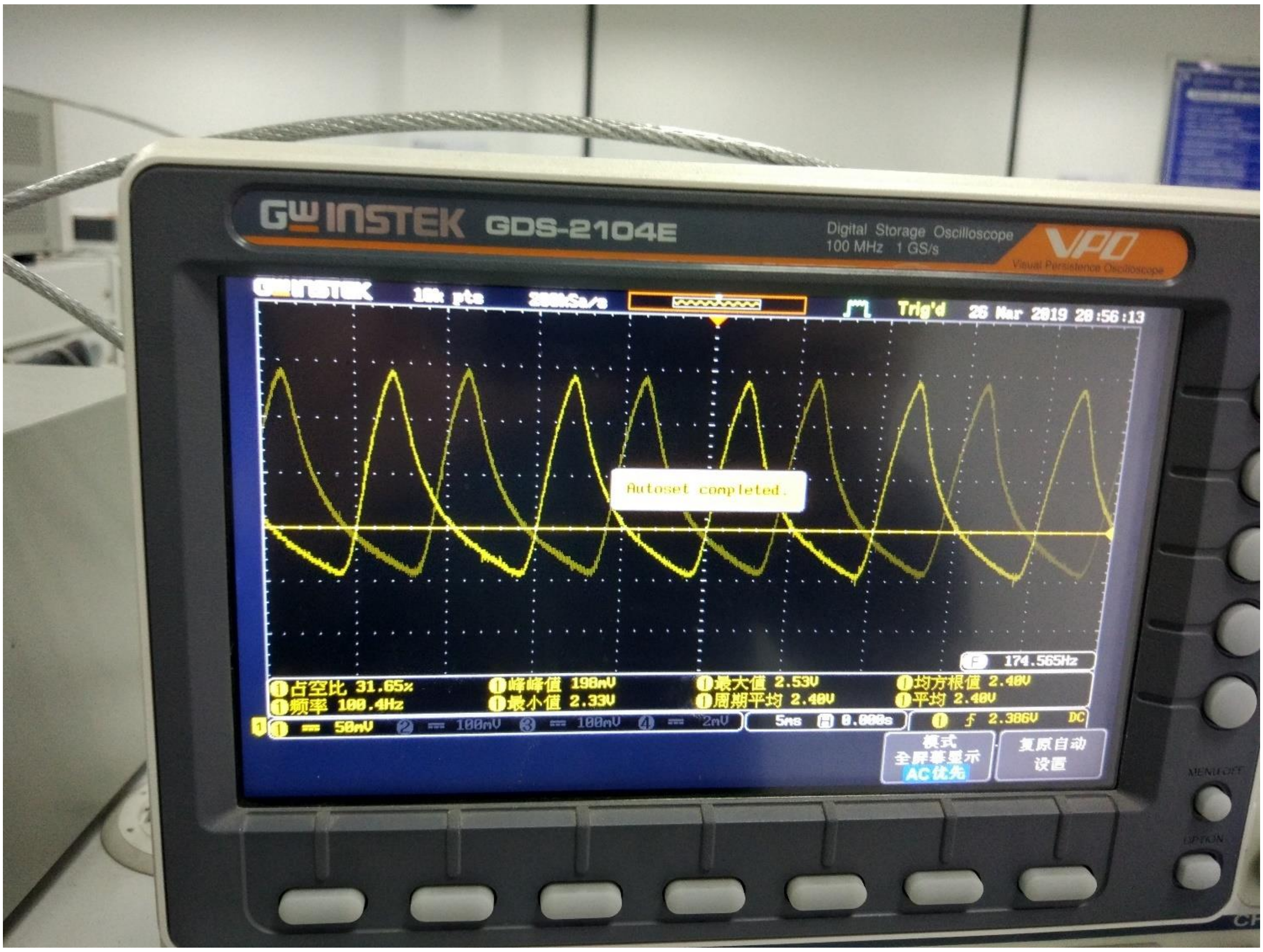
$$\%Volage\ Regulation = \frac{V_{No\ load-} - V_{Full\ load-}}{V_{No\ load-}}\ 100$$

- Configure the full-wave rectifier circuit as shown in Figure 9.
- Use Scope and DMM to measure load voltage and load current with resistor load = (no load), 10 and 20Ω respectively, and calculate the corresponding voltage regulation value.

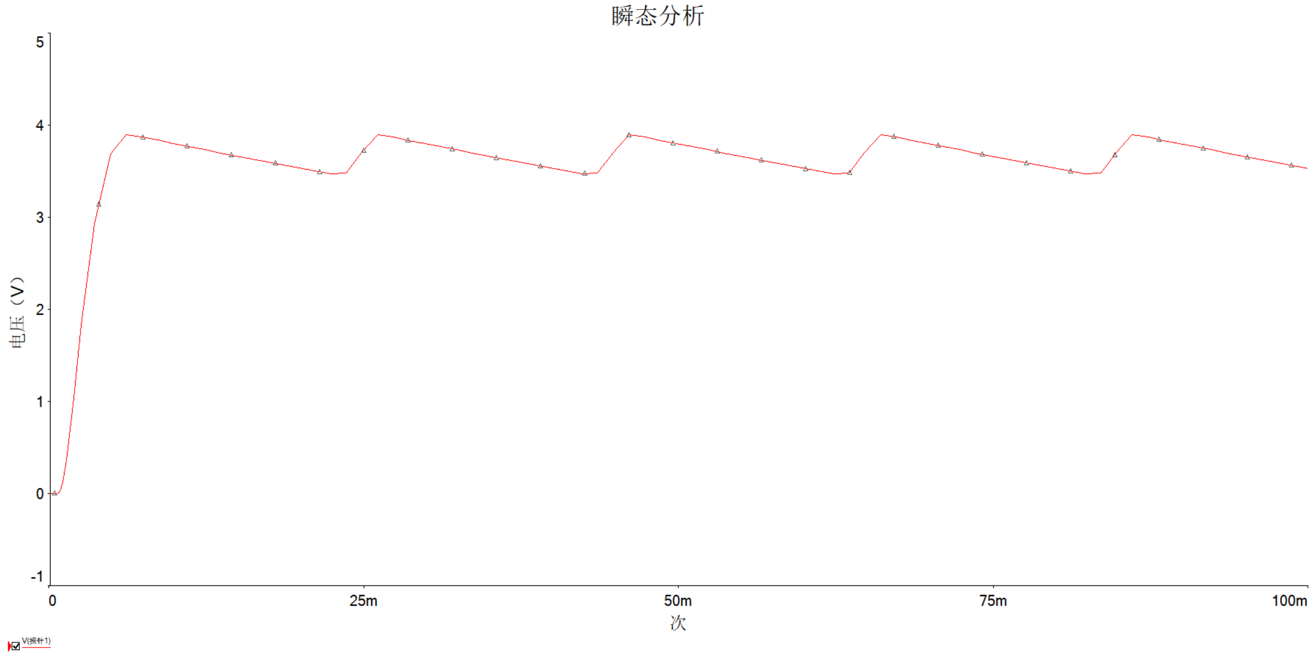
Obtain a copy of the load voltage with resistor load = (no load), 10 and 20Ω using the scope and printer and attach it to your lab book.



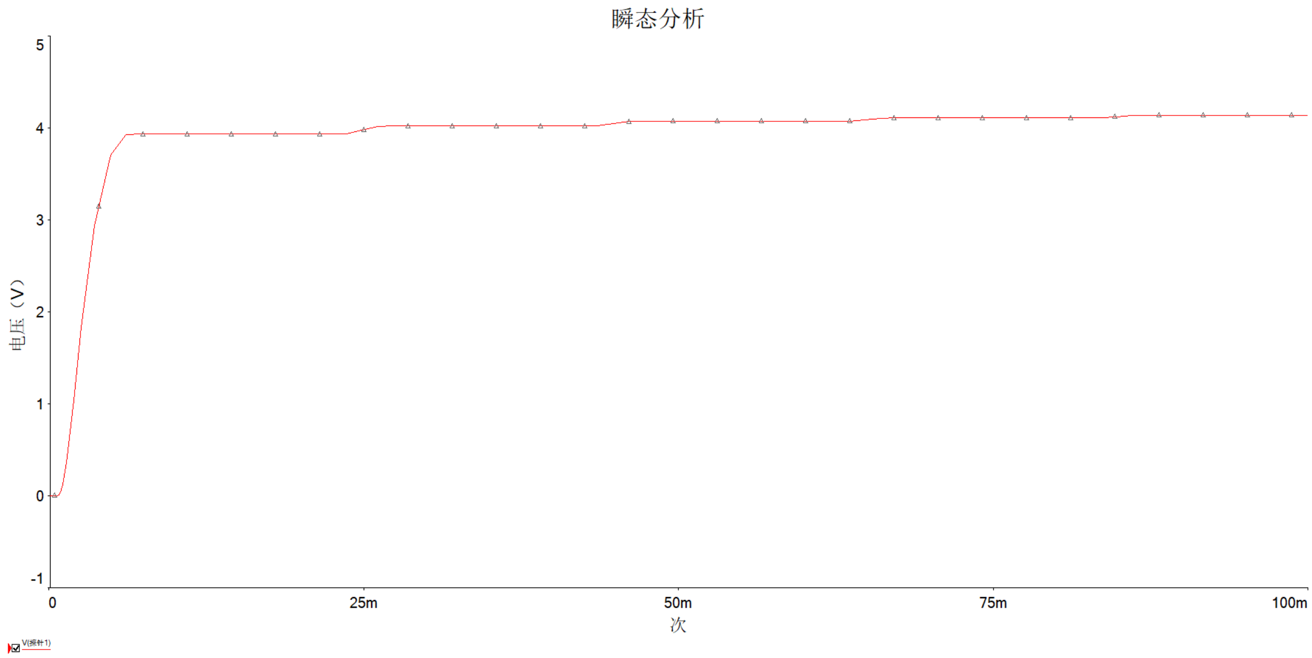

瞬态分析
电压（V）
5
4
3
2
1
0
-1
0
25m
50m
75m
100m
次

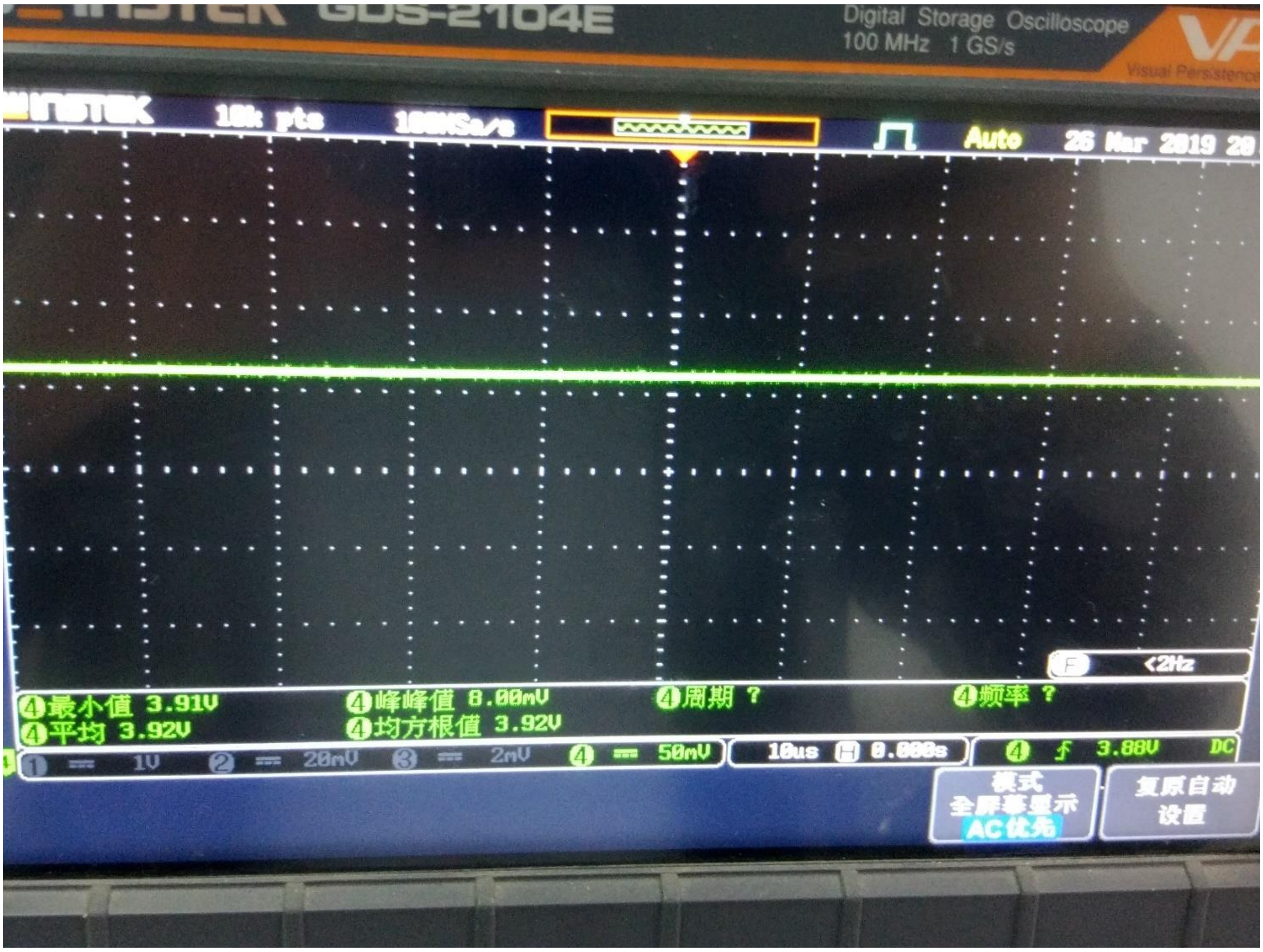

GW INSTEK GDS-2104E
Digital Storage Oscilloscope
100 MHz 1 GS/s
Trig'd
26 Mar 2019 20:56:13
Autoset completed.
174.565Hz
占空比 31.65%
频率 100.4Hz
峰峰值 198mV
最小值 2.33V
最大值 2.53V
周期平均 2.40V
均方根值 2.40V
平均 2.40V
50mV
5ms
2.386V
DC
模式
全屏幕显示
AC优先
复原自动
设置

Regulation=(Vno load-Vfull load)/Vno load=(3.45-2.48)/3.45=28.11% for R=10



Regulation=(Vno load-Vfull load)/Vno load=(3.45-2.63)/3.45=23.77% for R=20





Regulation=(Vno load-Vfull load)/Vno load=(3.45-3.92)/3.45=-13.62% for

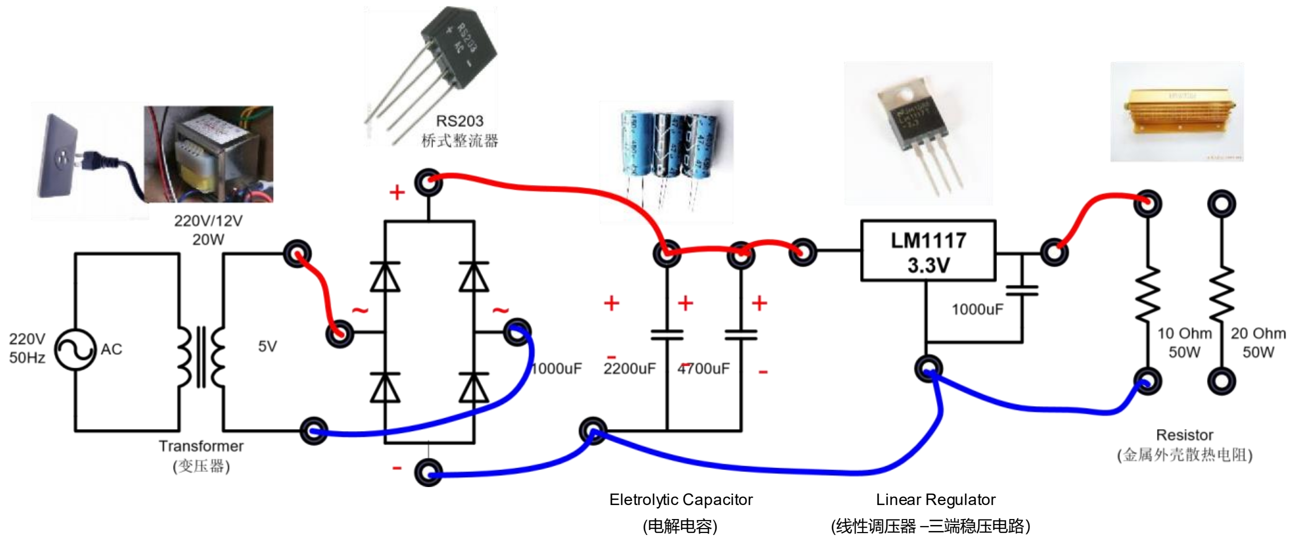
R=infinity (assume it is finite-20G- to some extent in multisim, in reality, the path will be cut off.)

☞ **Before you apply power to the circuit, ask a laboratory demonstrator to check your connections.**

3.4 Regulated power supply performance.

- In this experiment you will repeat the regulation test, but this time a 3-terminal voltage regulator will be included in the circuit.
- Turn off the power supply unit and add the voltage regulator to the circuit as shown in Figure 10.
- Measure load voltage and load current with resistor load = (no load), 10 and 20Ω respectively, and calculate the corresponding voltage regulation value.

Obtain a copy of the load voltage with resistor load = (no load), 10 and 20Ω using the scope and printer and attach it to your lab book.

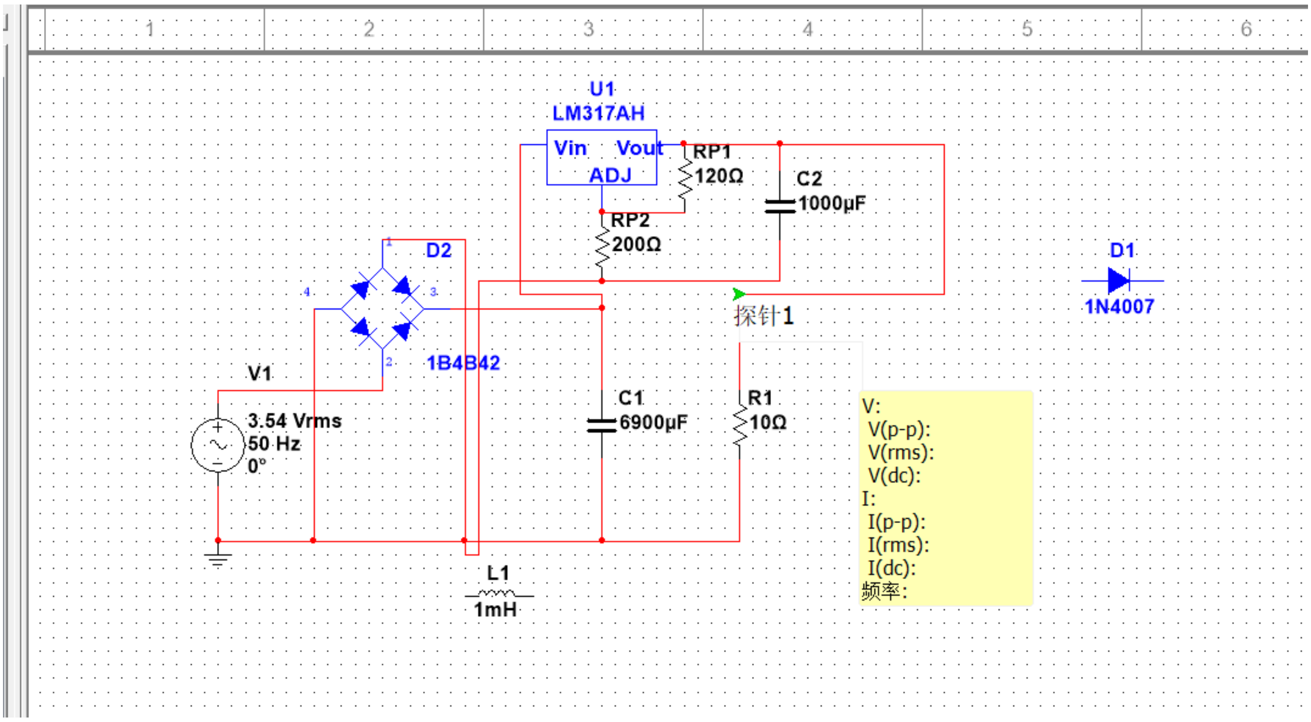


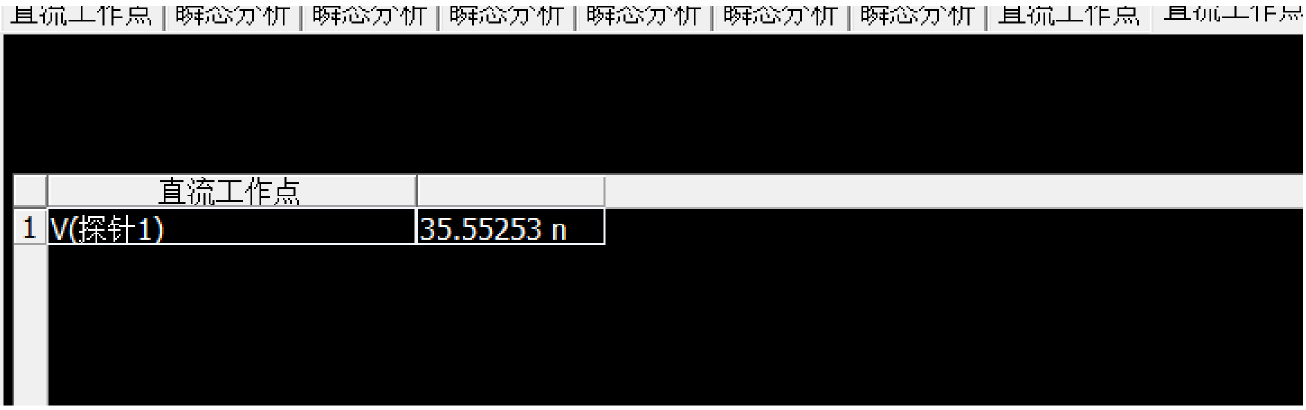
☞ **Before you apply power to the circuit, ask a laboratory demonstrator to check your connections.**

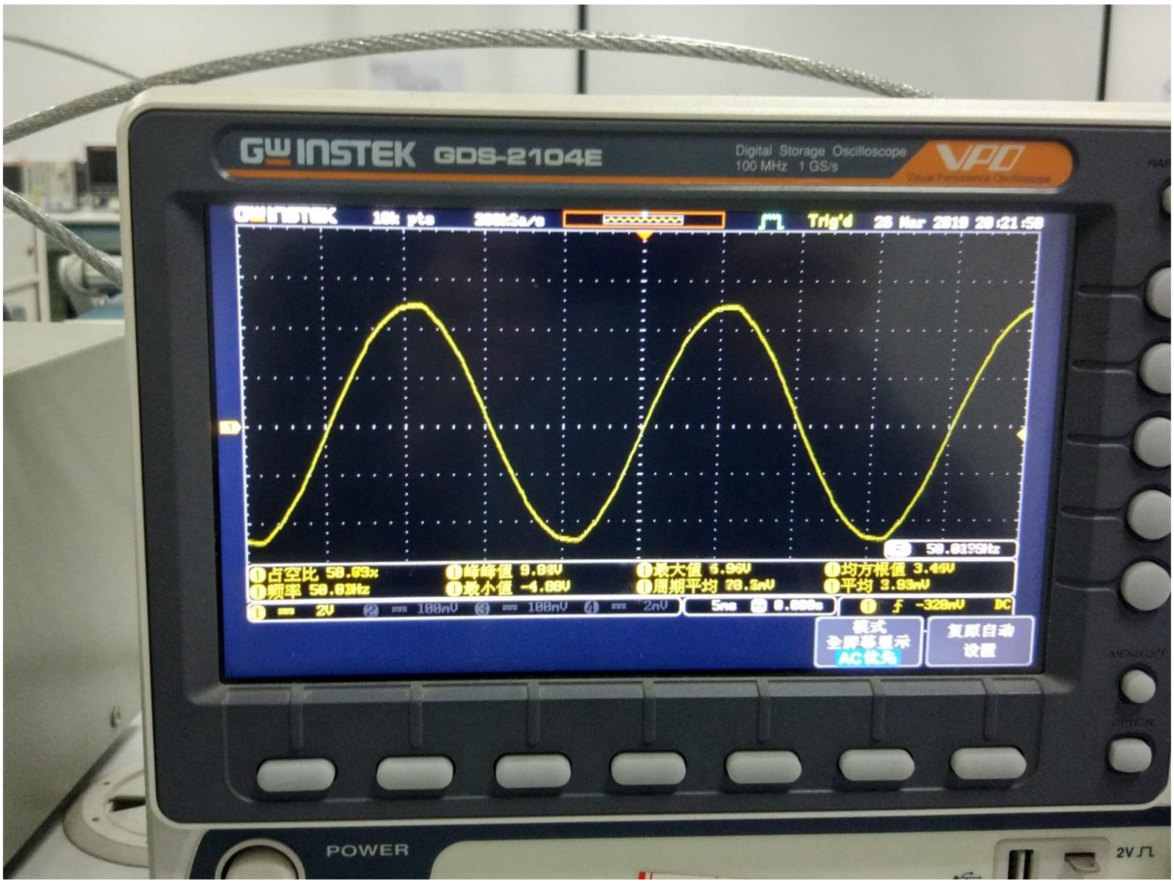
Note:

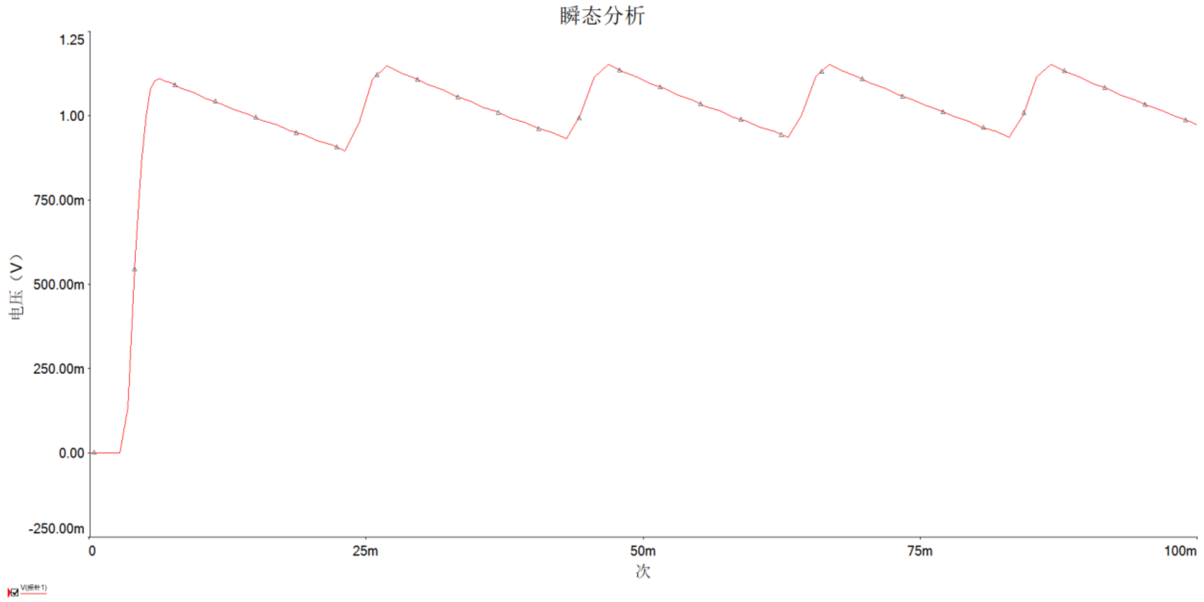
- **The voltage difference between the input and output voltages on the three-terminal regulator should be larger than a minimum value for the regulator to function correctly.**
- **This load resistor can get hot, so please be careful.**
- **Before you apply power to any circuit, ask a laboratory demonstrator to check your connections**

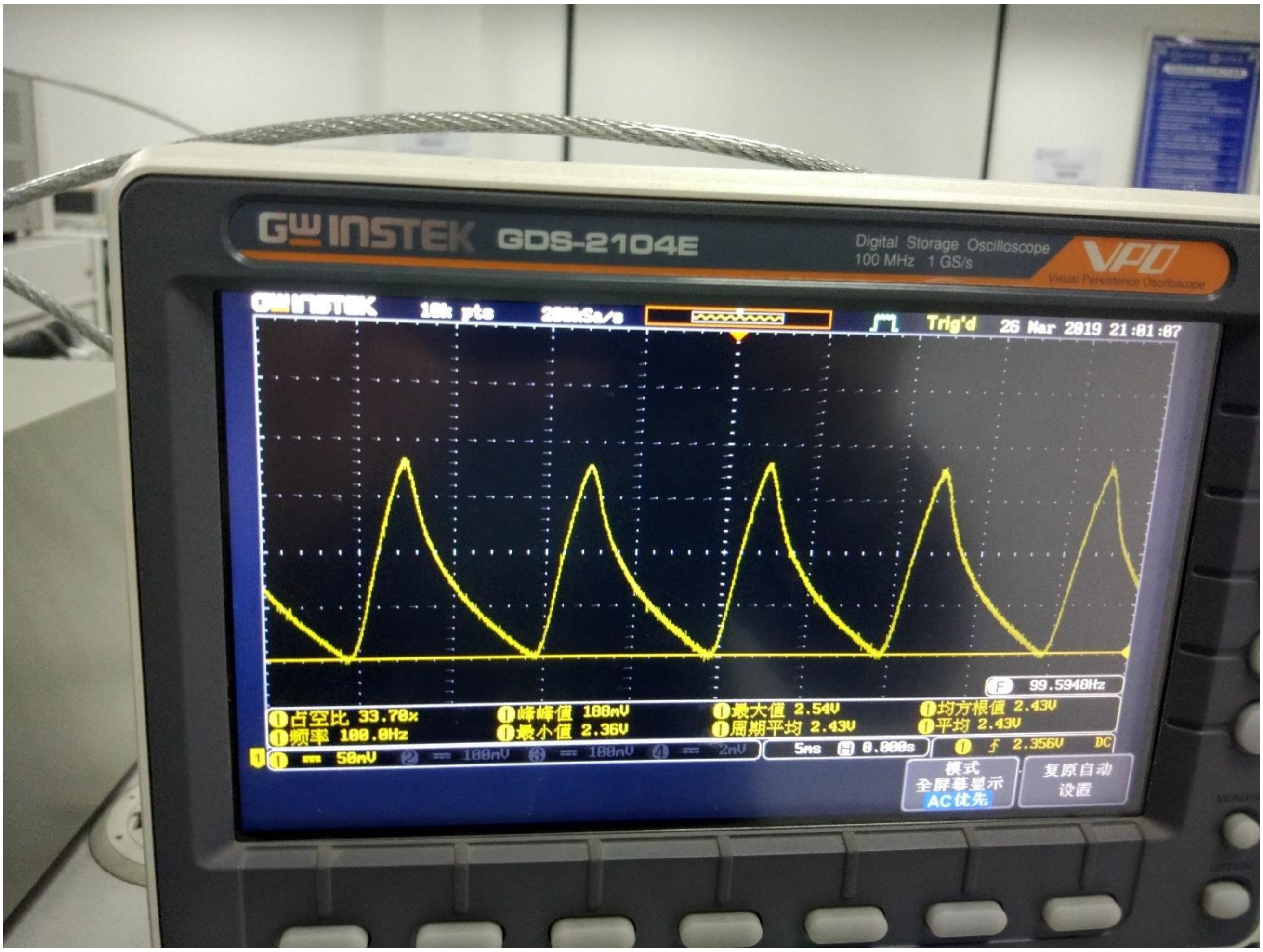
Regulation=(Vno load-Vfull load)/Vno load=(3.45-2.43)/3.45=29.57% for ***R=10***



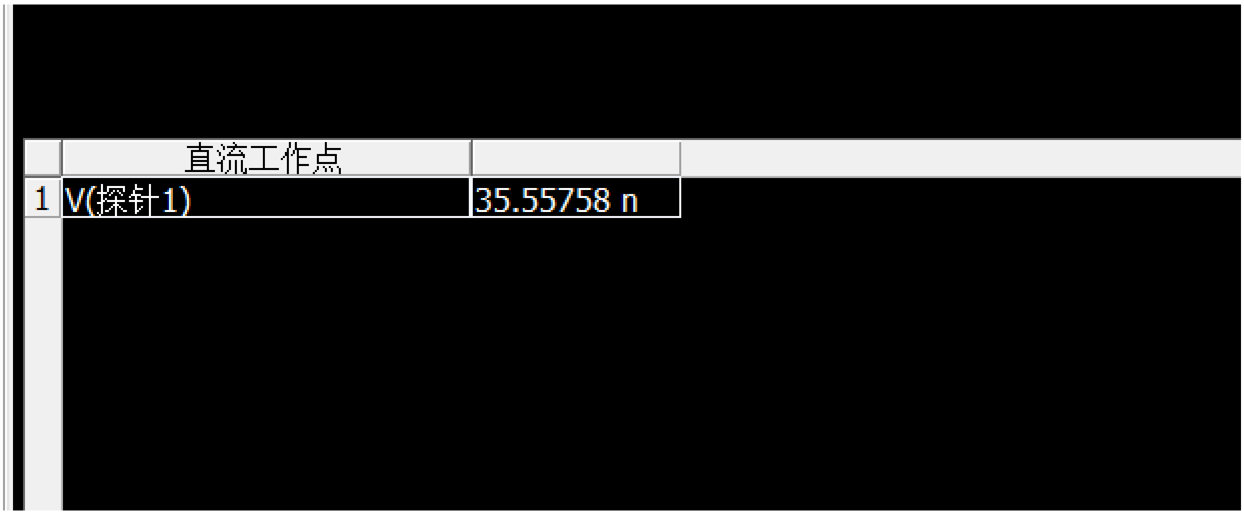

直流工作点
1 V(探针1) 35.55253 n

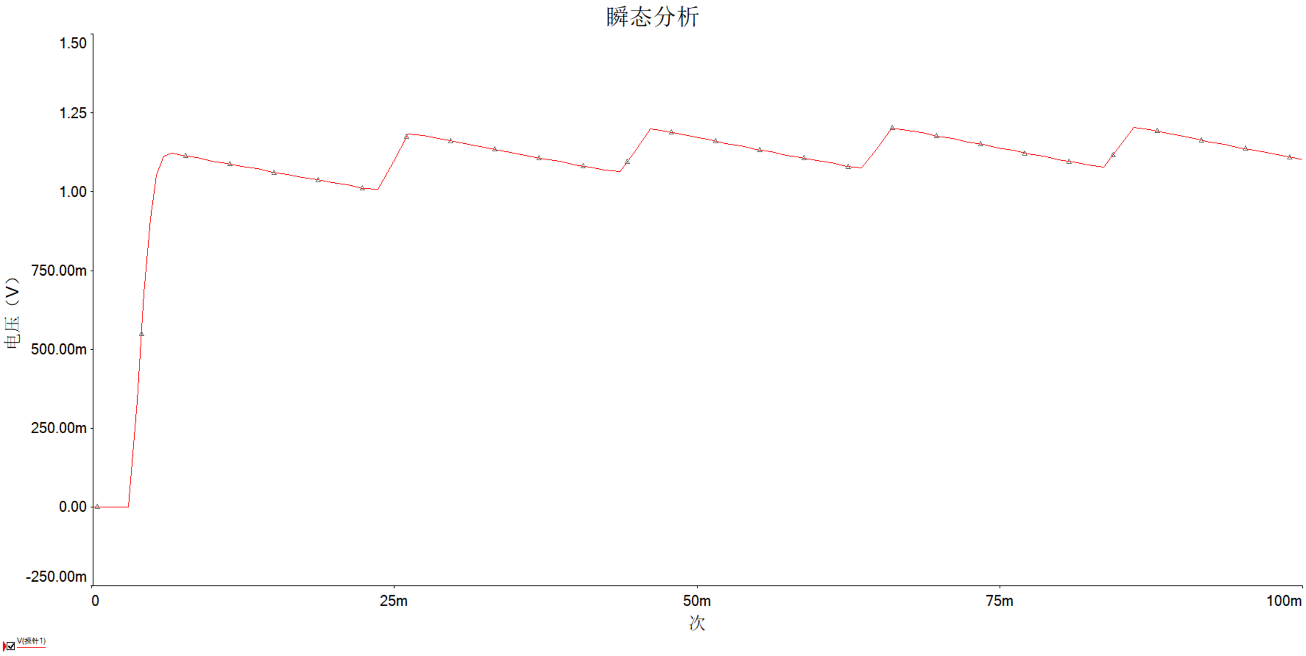

GW INSTEK GDS-2104E
Digital Storage Oscilloscope
100 MHz 1 GS/s
POWER

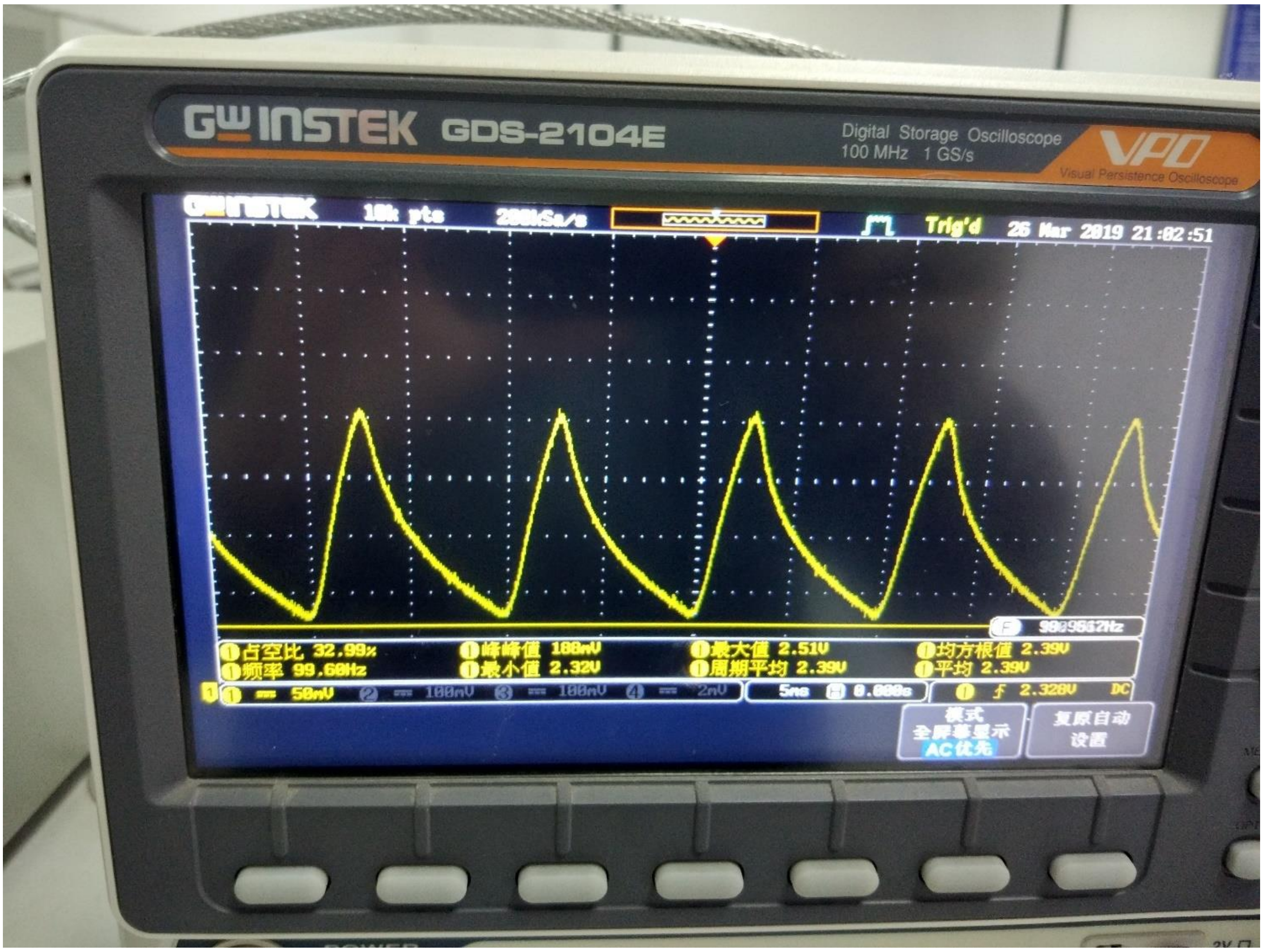




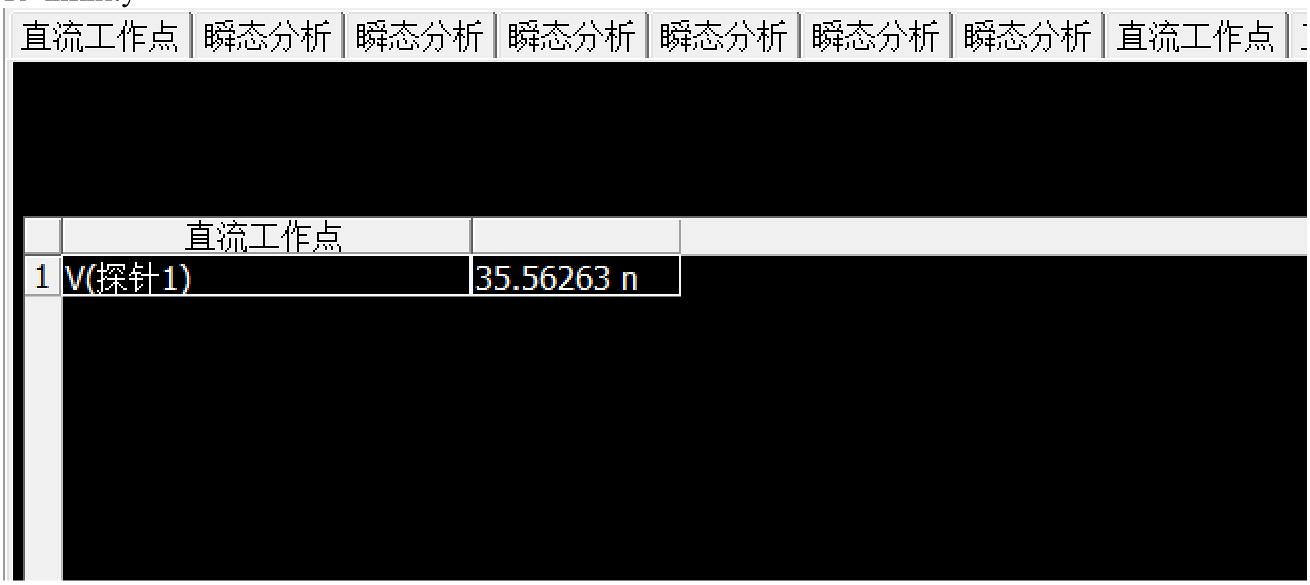
Regulation=(Vno load-Vfull load)/Vno load=(3.45-2.39)/3.45=30.72% for R=20

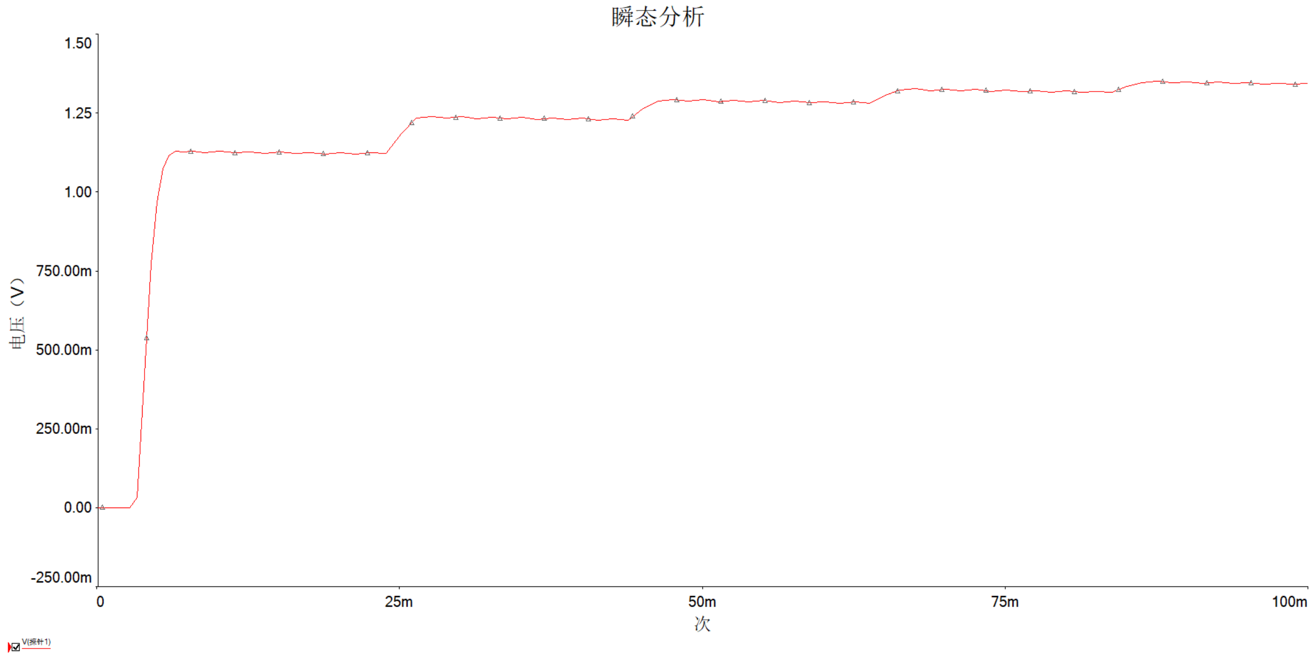

直流工作点
1 V(探针1) 35.55758 n

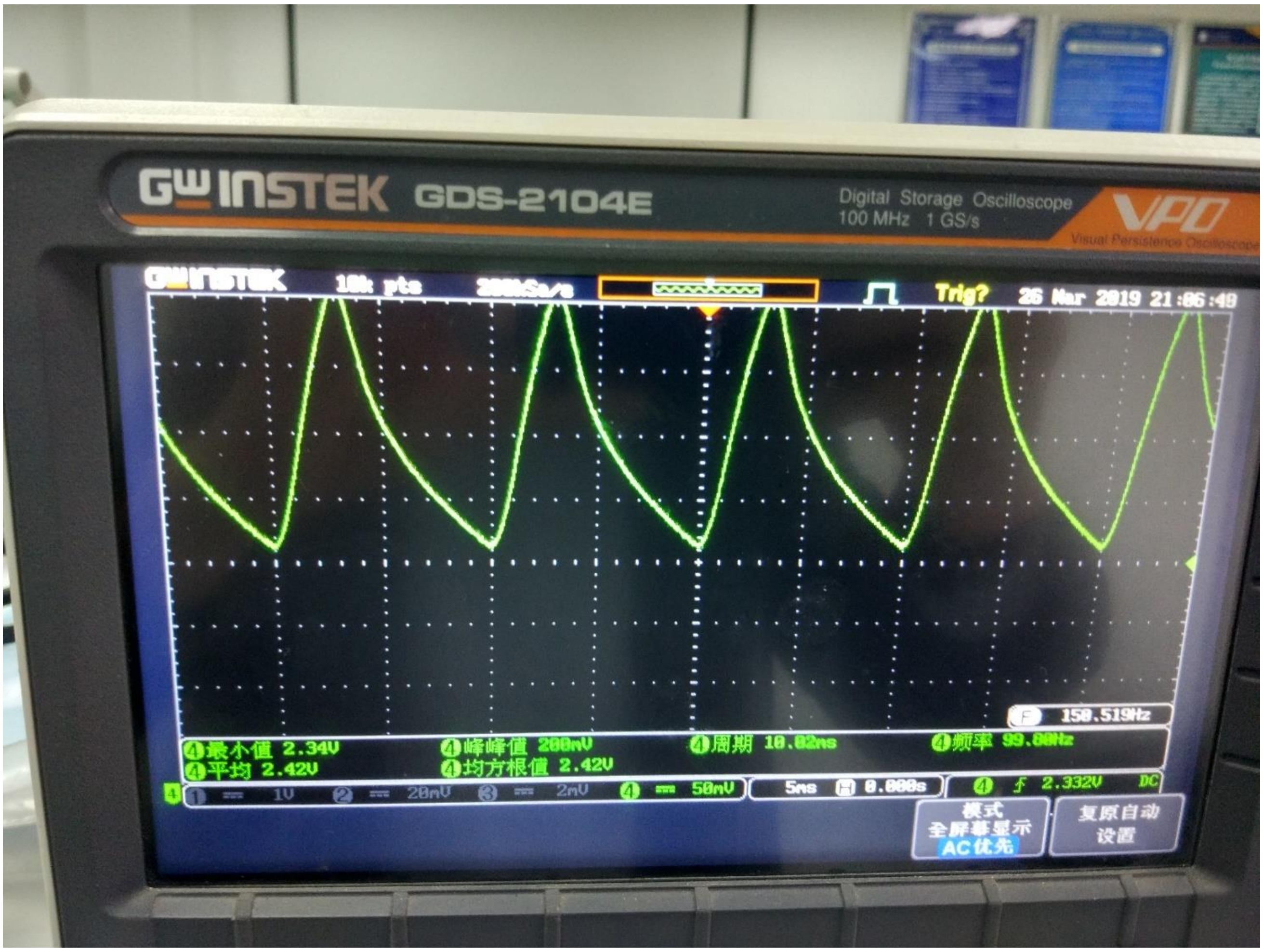

瞬态分析
1.50
1.25
1.00
750.00m
500.00m
250.00m
0.00
-250.00m
电压（V）
0
25m
50m
75m
100m
次
V(探针1)



Regulation=(Vno load-Vfull load)/Vno load=(3.45-2.42)/3.45=29.86% for R=infinity




瞬态分析
1.50
1.25
1.00
750.00m
500.00m
250.00m
0.00
-250.00m
电压（V）
0
25m
50m
75m
100m
次


GW INSTEK GDS-2104E
Digital Storage Oscilloscope
100 MHz 1 GS/s
最小值 2.34V
平均 2.42V
峰峰值 200mV
均方根值 2.42V
频率 99.80Hz
150.519Hz
5ms
2.332V
DC
模式
全屏幕显示
AC优先
复原自动
设置

4. Post-Laboratory Questions

Questions	Yes	No
Does the average DC voltage of a rectifier change between a half-wave topology and a full-wave circuit?		√
Does capacitive filtering improve the performance of a rectifier with respect to the AC ripple and the average value voltage (DC side)?	√	
Do larger capacitor values adversely affect the rectifier performance on its AC side?		√
Does the design of a rectifier involve resolving conflicting interests between the load and the source? (i.e. when improving the output performance is the input performance compromised?)	√	
Does a larger smoothing capacitor improve the supply regulation?		√