ECE 469
Lab Report - 0

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***Abstract*—In this introductory lab, two types of power converters are introduced–a rectifier and a DC-DC converter. The purpose of this lab was to test these two circuits in order to become familiar with lab equipment and procedures. Measurements were made using current probes, isolated voltage probes, and a power meter.**

I. Introduction

THIS lab primarily aims to familiarize students with lab equipment and general safety procedures. Towards this end, two circuits are tested: a rectifier and DC-DC converter. A rectifier is used whenever an AC waveform must be converted to DC, e.g., to power a desktop computer from a wall outlet. Furthermore, a DC-DC converter steps up or steps down a DC voltage. In II, two rectifier circuits are discussed-a passive diode rectifier and active SCR-based rectifier. Finally, in III the DC-DC converter is discussed and measured results are presented.

II. Discussion of Part-1

In this experiment, we are making a full wave passive rectifier with diodes only and then a full wave active rectifier with SCRs only.

We used the following equipments for our experiment :

1) Voltage source: Three-phase transformer set 120 V/25.2 V, using only two phases.
2) Scope: Tektronix Model MS04304B scope, 350 MHz 2.5 GS/s, 4 CH Analog and 16 CH Digital
3) Power meter: Yokogawa WT310 Power Meter
4) Current and voltage probes: Tektronix probes (current, voltage, and isolated voltage)
5) Diode: 1N4004
6) Polyphase SCR control unit
7) 50Ω load resistor
8) banana leads
9) breadboard with jumper wires

A. Theory

As it is a two-phase balanced voltage supply, we can say that Phase-A and Phase-B are 180° out phase from each other. So, in case of the passive recitifiers, we can connect the diode legs in parallel with each other as shown in Fig. 1.

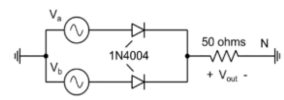

Fig. 1: Circuit Diagram for the passive full wave rectifier, from lab manual [1].

The basic principle of this is that each leg operates for 180°. This way we get the following waveform at the output, shown in Fig. 2.

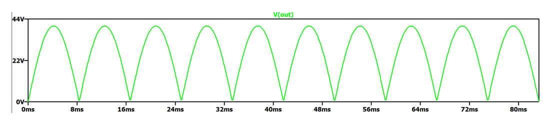

Fig. 2: V_{out} waveform for the passive rectifier, simulated in LTspice.

We see that in the ideal case V_{rms} of one phase of the supply must be the same as that of the V_{rms} at the load. Then we understand the working of the active full wave rectifier. For this we understand the working of the SCR control unit and its working.

Here, α is the "master delay" and β is the "phase delay" between the control signals of each of the two SCRs. For full-wave rectification, the two SCRs should switch with an electrical phase difference of 180° (like passive diodes). However, because SCRs require a switching signal to turn on, their switching signals must correspond to this phase shift. As we are using a 60 Hz source, the time period (T) is $\frac{1}{60}$. Thus, we use a phase delay equal to $\frac{1}{2}T$ if we want behavior similar to a full-wave rectifier.[1]

$$\begin{aligned}\beta &= \frac{\frac{1}{60}}{2} \\ &= \frac{1}{120} \\ &= 8.333ms\end{aligned}$$

α affects the RMS output voltage across the load according to the relationship below:

[1]Answer to study question 2.

$$(V_0)_{rms} = \sqrt{\frac{V_m^2}{\pi}\int_{\alpha}^{\pi+\alpha} \sin\theta^2 d\theta}$$
$$= \sqrt{\frac{V_m^2}{2\pi}\int_{\alpha}^{\pi} (1-\cos 2\theta) d\theta}$$
$$= V_m\sqrt{\frac{(\pi-\alpha)}{2\pi}}$$

So, in this part of the experiment we find the average output voltage for different values of α and keep β equal to 8.333 ms (180°). Fig. 3 shows a sketch of the current waveform in the SCR, demonstrating the qualitative effect of adjusting α.

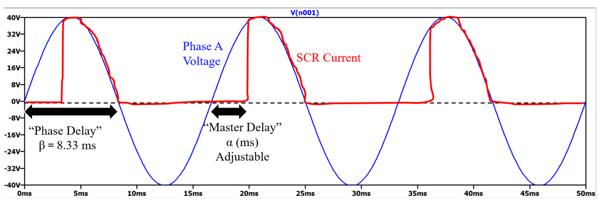

Fig. 3: Sketch of current waveform in SCR.

B. Results

1) Passive Full Wave Rectifier: We have made the circuit connection as shown in Fig. 4.

Furthermore, the measurements are shown in Table I.

TABLE I: Measurements with passive diode rectifier.

AC Source	Load				
V_{rms} (V)	V_{rms} (V)	V_{DC} (V)	$< V >$ (V)	I_{rms} (A)	P (W)
28.53	27.24	24.31	27.00	0.537	14.6

Note that, in general, $V_{rms} \neq < V >$. This distinction arises because power is proportional to voltage squared $P \propto V^2$. RMS quantities often are used to communicate power. For an arbitrary voltage waveform, V_{rms} is the voltage of an equivalent DC source that would supply the same power to a restive load. Average voltage $< V >$ is useful for quantifying the voltage component with no ripple. When filtering the output voltage of a converter, it is desirable to make the ripple as small as possible (approaching a DC source). [2]

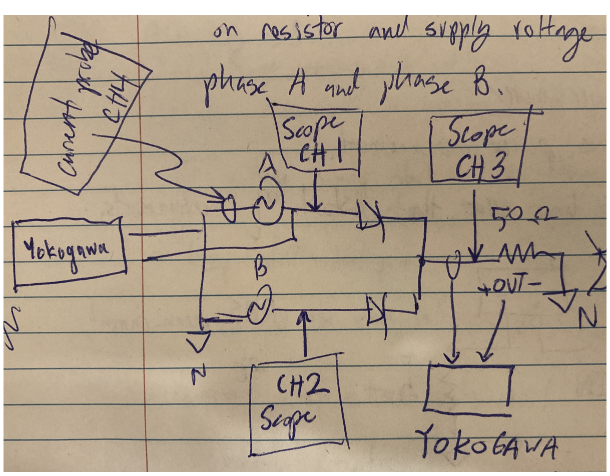

Fig. 4: Circuit connection for the passive rectifier

As can be seen from Table I, the V$_{rms}$ at the load is less than that of the supply V$_{rms}$. This is because there is a finite voltage drop across the diode. To know the amount of voltage drop across each diode in their turn-on state (V$_d$), we can do the following.

$$V_d = \sqrt{2}(V_{rms-supply} - V_{rms-load})$$
$$= 1.8V$$

Also, I$_{rms}$ can be calculated from V$_{rms}$ by the following equation.

$$I_{rms-load} = \frac{V_{rms-load}}{R}$$
$$= \frac{27.24}{50}$$
$$= 0.544A$$

Which is close to the reading of the current probe. Then the power lost in the 50 Ω resistor is as shown.

$$P_{load} = V_{rms-load} I_{rms-load}$$
$$= 27.24 \times 0.537$$
$$= 14.6W$$

This is as obtained in the reading of the Watt mater. Finally, the waveform measurements are shown in Fig. 5.

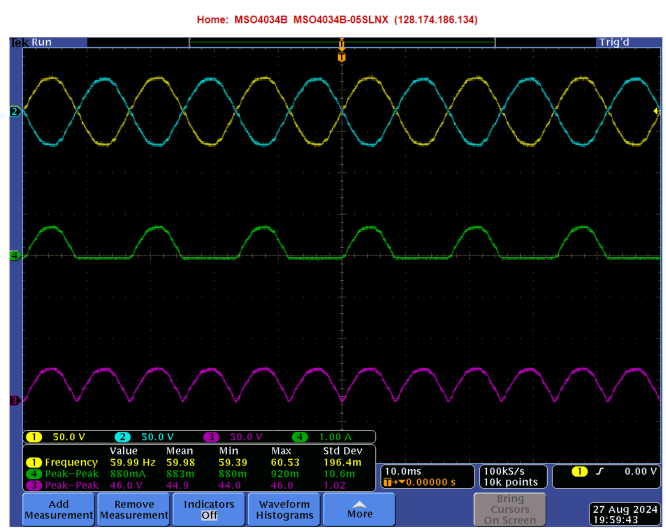

Fig. 5: Scope measurements with passive rectifier.

2) Active Full Wave Rectifier: We have made the circuit connections as shown in the Figure 6.

As can be seen from the TABLE II, the RMS voltage across the load resistor changes with change in firing angle or master

[2]Answer to study question 1.

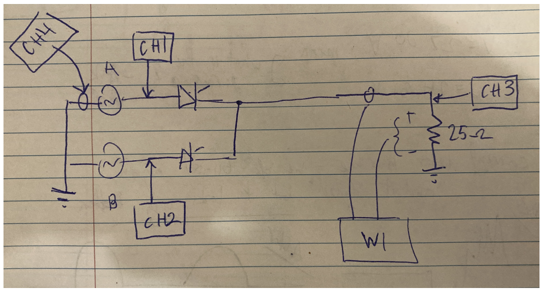

Fig. 6: Circuit connection for SCR-based full wave rectifier.

TABLE II: Measurements with SCR box and variable master delay.

Master delay (ms)	V_{rms} (V)	I_{rms} (A)	P (W)	V_{DC} (V)
0.005	26.5	1.05	27.9	23.79
3.005	23.4	0.928	21.73	17.08
6.005	9.69	0.384	3.71	4.1

delay (α). To convert from master delay to α, we can do the following.

$$\begin{aligned} \alpha &= \frac{T_{master-delay}}{2\pi} \times \frac{1}{60} \;\; rad \\ &= T_{master-delay} \times 2.652 \;\; rad \end{aligned}$$

Lastly, the waveforms measured on the scope are shown for two cases in Figures 7 and 8. These figures correspond to a master delay of 0.005ms and 3.005ms respectively.

III. Discussion of Part-2

A. Theory

In part-2, a new circuit was constructed as shown in Fig. 9 using the Isolated FET control unit (FET box). The purpose of this experiment was to become familiar with using the FET box and view how adjusting the duty cycle of the FET switching signal $q(t)$ affects the DC output voltage. In this case, the average output voltage $< V_{out} >$ is directly proportional to duty cycle D, according to the following equation: [3]

$$< V_{out} >= DV_{in}$$

Assuming ideal switches and a resistive load, the average output voltage should be independent of the switching frequency. This is essentially a buck converter, except that LC filtering elements are omitted for simplicity. Thus, it is expected that the output waveform will exhibit a square-wave shape.

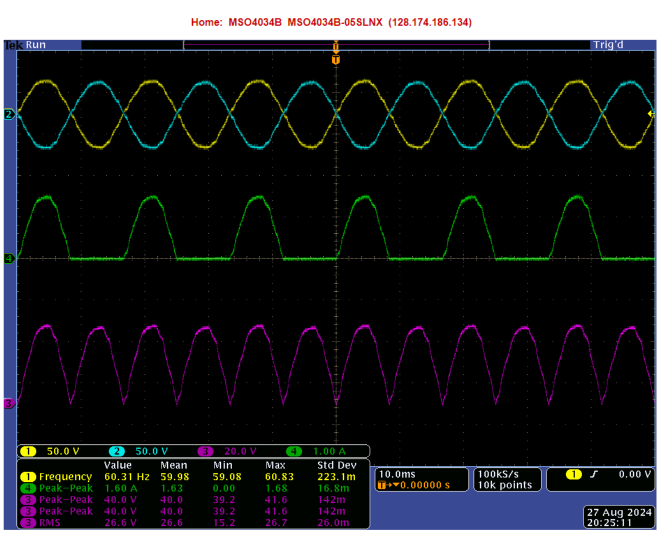

Fig. 7: Scope measurements with SCR at $\alpha = 0.005$ms.

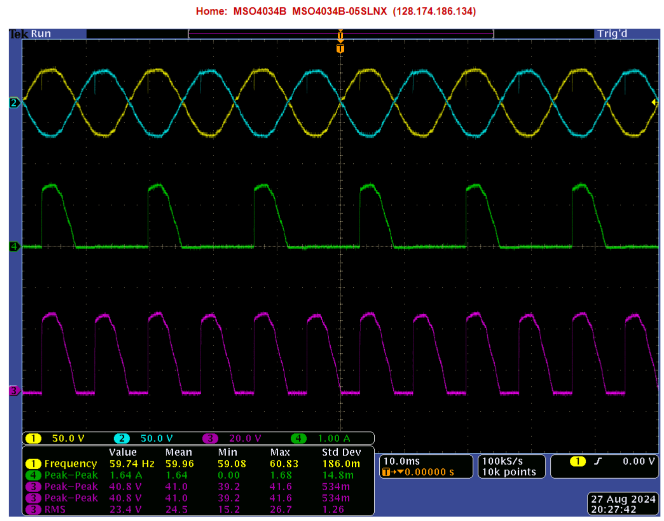

Fig. 8: Scope measurements with SCR at $\alpha = 3.005$ms.

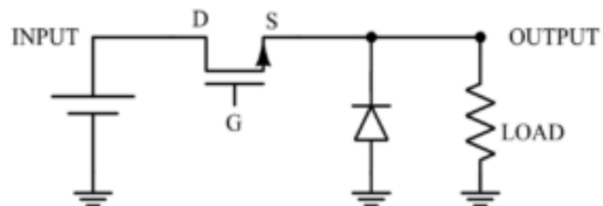

Fig. 9: Circuit of the FET-based DC-DC converter, from lab manual [1].

Equipment used:

1) Isolated FET control unit
2) Scope
3) Power meter
4) 25Ω load resistor
5) voltage source: Keithley DC power supply (started at low voltage then increased to 25V. Set the current limit to 1.5A)

B. Results

The circuit was assembled and probed according to the circuit schematic shown in Fig. 10 below. Measurements were

[3] Answer to study question 3.

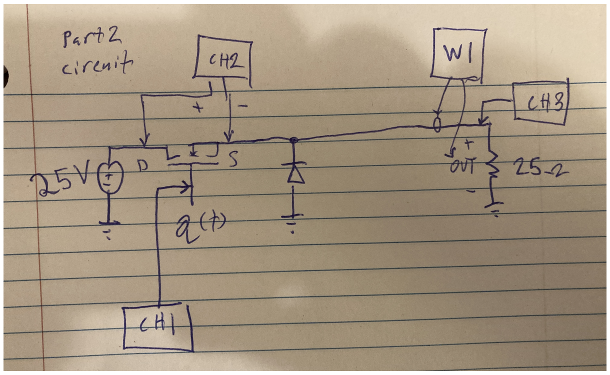

Fig. 10: Circuit connection for FET Box DC-DC converter.

TABLE III: Measurements for part-2

Frequency (kHz)	Duty Cycle	V_{out}^{DC} (V)
60	90%	21.59
50	50%	11.36
60	50%	11.78
70	50%	11.61
50	25%	5.69
60	25%	5.59
70	25%	5.5
60	10%	2.053

taken using voltage probes (for waveforms) and the Watt meter to record DC output voltage.

Figures 11 and 12 show the waveform results for the DC-DC converter in the two cases of 50kHz at 25% duty and 60kHz at 90% duty.

IV. Conclusion

In summary, in this lab we learned how to use the SCR box, the FET box, and how to take measurements with the power meter and oscilloscope using voltage, current, and isolated probes. Two simple circuits were assembled and tested, a full-wave rectifier and simple DC-DC step down converter.

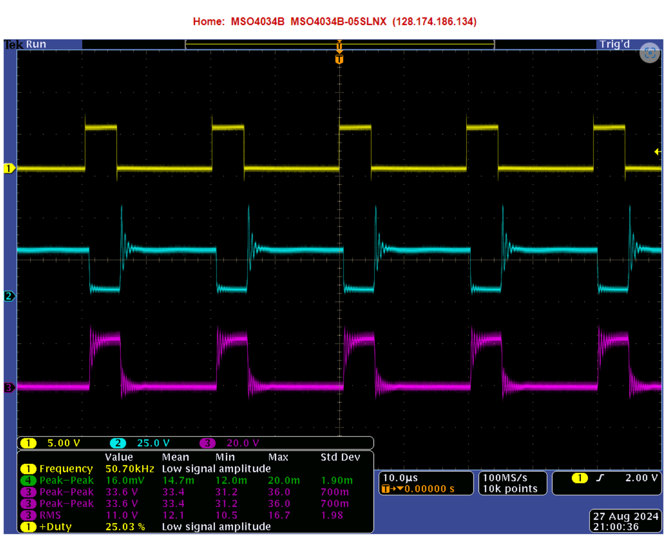

Fig. 11: Scope measurements with FET box at $f_{sw} = 50\text{kHz}$, $D = 25\%$.

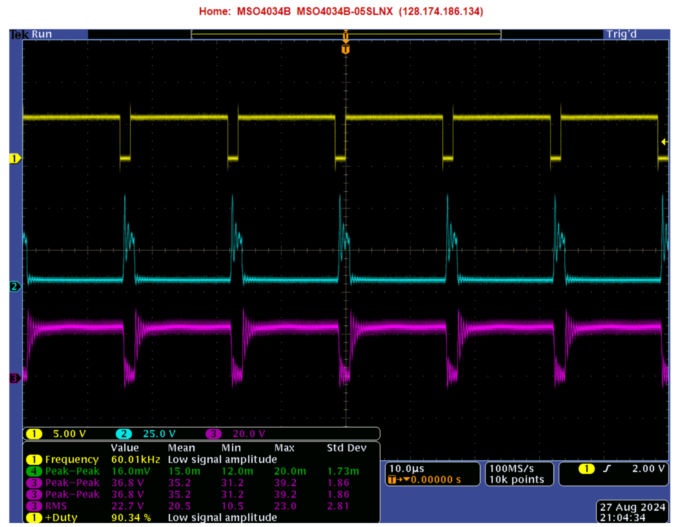

Fig. 12: Scope measurements with FET box at $f_{sw} = 60\text{kHz}$, $D = 90\%$.

References

[1] ECE 469 lab manual