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Real Time Ripple Analysis of Buck DC-DC Converter

Inderpreet Kour*, Navdeep Kaur**
* (Department of Electrical Engg., BBSBEC, Fatehgarh Sahib, INDIA)
** (Department of Electrical Engg.,BBSBEC, Fatehgarh Sahib, INDIA)

ABSTRACT
Ripple filters can affect substantial reductions in power converter input and output ripple components, allowing considerable reduction in passive component size. This paper investigates a passive filter topology that achieves ripple reduction by increasing switching frequency and selection of inductor and capacitor values. Both current ripples and voltage ripples are analysed. The design of buck converter circuit for current ripples and voltage ripples are investigated. The experimental results demonstrate the feasibility and high performance of the buck dc-dc converter. It is demonstrated that the proposed approach is most effective in cases where it is desirable to minimize the amount of capacitance in the filter. The analysis is verified experimentally using LVDAC - EMS.

Keywords— **buck converter, data acquisition and control interface, LVDAC- EMS software.**

I. INTRODUCTION
The demand for high efficiency DC-DC converters is increasing dramatically, especially for use in battery operated devices such as cellular phones and laptop computers. In these devices, it is intrinsic to extend battery life. By employing DC-DC converter power-saving techniques, power efficiency can be significantly increased, thereby extending battery life [1]. Switching power converters inherently generate ripple, and typically require output filtration to meet ripple and EMI specifications. The buck type switched dc to dc converter is well known in power electronics. Due to the fact that the converter contains two energy storing elements, a coil and a capacitor, smooth dc output voltages and currents with very small current ripple can be generated [6]. Passive LC low-pass filters have been employed to achieve the necessary degree of ripple attenuation. The passive filter components often account for a large portion of converter size, weight, and cost [2].

II. THEORETICAL ANALYSIS
We have analysed a general buck converter circuit with the following assumptions.

- Ideal switching devices
- No filter capacitor ESR.
- Linear magnetic circuit.

A basic Buck DC-DC converter is shown in Fig. 1.

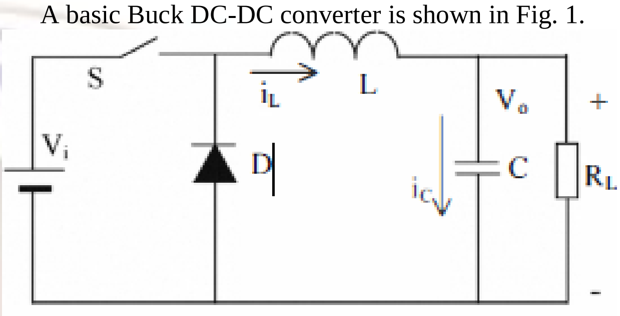

Figure 1. a typical buck dc-dc converter.

If the buck converter operates in Continuous Conduction Mode (CCM), the relationship between the input voltage (Vi) and the output voltage (V_o) is:

$$D = V_O / V_i \tag{1}$$

where, D is the conducting ratio or duty ratio or duty cycle and $D = \frac{T_{ON}}{T_S}$, T_S is the switching period and T_{ON} is conducting time of the switch.

$$\frac{V_o}{V_i} = \frac{T_{ON}}{T_S} = D \tag{2}$$

Since, $v_L = Ldi/dt$, during on period the change in inductor current is given as :

$$\Delta I_L = \frac{V_i - V_o}{L} T_{ON} \tag{3}$$

During off period , the inductor current is given as:

$$-\Delta I_L = \frac{-V_o}{L} T_{Off} \tag{4}$$

Also, from (3) and (4) the switching frequency f is expressed as:

$$f = \frac{1}{T} = \frac{1}{T_{ON} + T_{Off}} = \frac{V_o(V_i - V_o)}{V_i L \Delta I_L} \tag{5}$$

The peak to peak ripple current can be found as :

$$\Delta I_L = \frac{V_o(V_i - V_o)}{L V_i f} = \frac{V_i D(1-D)}{fL} \tag{6}$$

It shows that the current ripples can be reduced by increasing f and L . The peak to peak ripple voltage of the capacitor is :

$$\Delta V_C = \frac{\Delta I_L}{8 f C} \qquad (7)$$

Put the value of ΔI_L from (6) in (7) yields:

$$\Delta V_C = \frac{V_o(V_i - V_o)}{8 V_i L C f^2} = \frac{V_i D(1-D)}{8 L C f^2} \qquad (8)$$

It shows that voltage ripple can be reduced by increasing switching frequency f and C. In a buck converter with a load current step, the output capacitor supplies or sinks the immediate difference in current while the inductor current is ramped up or down to match the new load current. A small inductor allows ramping the current quickly to minimize the output capacitor requirement. However, small inductor values also lead to large ripple current requiring a large output capacitor [4]. However, the full ripple current flows through the inductor itself, resulting in higher losses and higher peak current requirements for the phase switches. One strategy to reduce the ripple current throughout, is to operate at very high switching frequencies.

III. Circuits Used in LVDAC-EMS

The buck converter circuit with a resistive load and a filtering inductor as shown in Fig. 2.

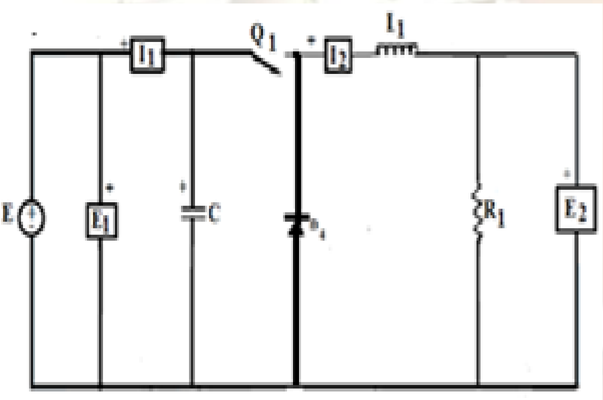

Figure 2. buck converter circuit with a resistive load and a filtering inductor in LVDAC-EMS.

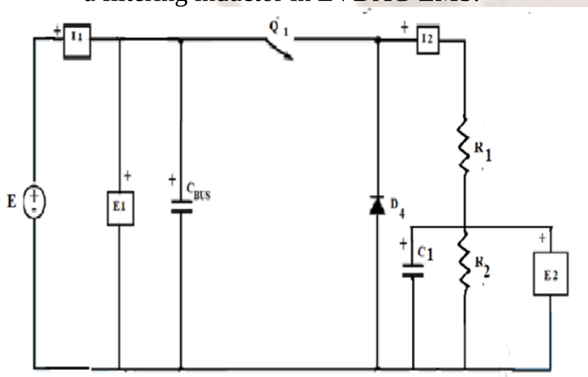

Figure 3. buck converter circuit with resistive load and filtering capacitor in LVDAC-EMS.

The input voltage is E and the output voltage is E 2 at a duty cycle D of 0.5 or 50%, the switching frequency varying from 400 to 10,000Hz and the inductance value of inductor taken 50 milli henry (mH) and 2 milli henry (mH) and the capacitance value of the capacitor taken 210 micro farad (uF) and 5 micro farad (uF).The eectronic switch is represented by Q. The buck converter circuit with resistive load and filtering capacitor as shown in Fig. 3.

IV. Experimental Results

Theoretical analysis presented so far has been verified by experiment of a buck converter using LVDAC-EMS. The specification of the buck converter is as follows: Input voltage = 25 V, Output voltage = 12.5 V, Duty ratio D = 0.5 from (2), Switching frequency f = 2000Hz, Filter inductance (L) = 50mH, Filter capacitance (C) =210uF, Load resistance (R) = 57 ohm.

We have analysed the buck converter circuit experimentally for different values of switching frequency f varying from 400Hz to 10,000Hz as the value of switching frequency cannot exceed 20,000Hz in LVDAC EMS. The range of switching frequency in LVDAC-EMS is from 400Hz to 20,000Hz. The current ripples waveform of inductor L at 50mH and 2mH for different values of switching frequency as shown in Fig. 4 to 13. The voltage ripples waveform of capacitor C at 5uF and 210uF for different values of switching frequency as shown in Fig. 14 to 23. The measured values of current ripple and voltage ripple are shown in Table I and Table II respectively. These measured values are plotted between switching frequency and peak to peak current ripples and between switching frequency and peak to peak value of voltage ripples as shown in Fig. 24 & Fig. 25 respectively. It shows that higher the switching frequency ,the current ripples and voltage ripples are reduced. And also larger the value of inductor and capacitor, the ripples are decreased. With the increase in duty cycle at fixed switching frequency of 2000Hz with the load resistance 57ohm, the efficiency of the buck converter is increased as shown in Fig. 26 and the measured values are shown in Table III.

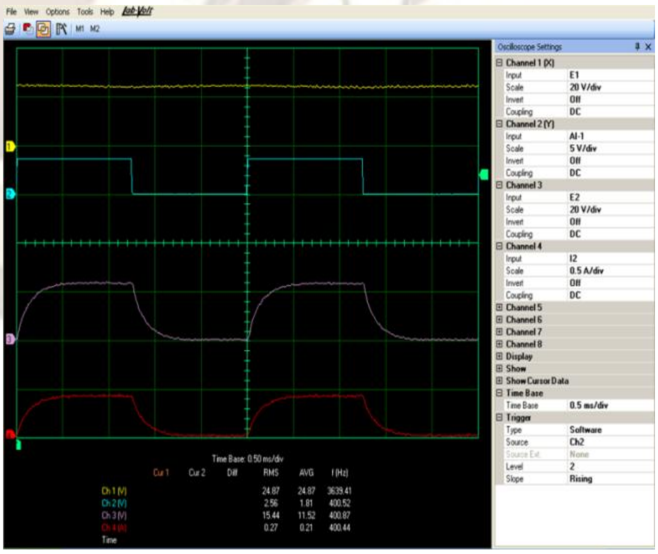

Figure 4. waveforms of output voltage and output current at inductance value of inductor 2mH with switching frequency 400Hz.

Figure 5. waveforms of output voltage and output current at inductance value of inductor 2mH with switching frequency 1000Hz.

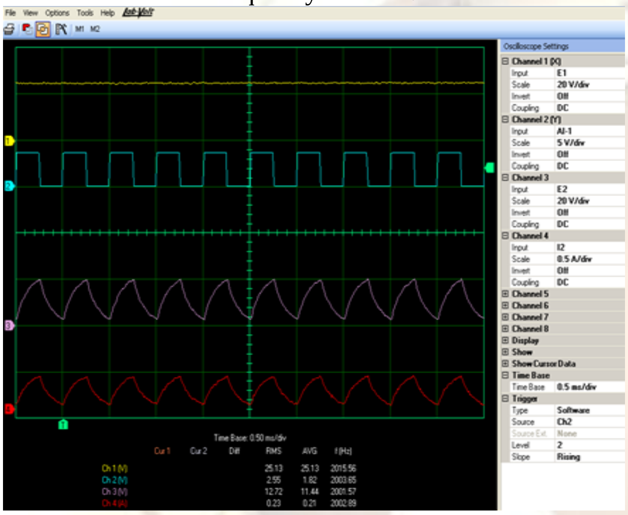

Figure 6. waveforms of output voltage and output current at inductance value of inductor 2mH with switching frequency 2000Hz.

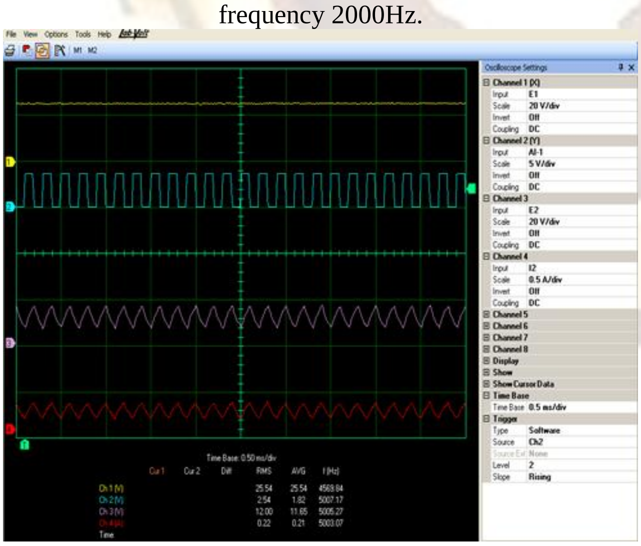

Figure 7. waveforms of output voltage and output current at inductance value of inductor 2mH with switching frequency 5000Hz.

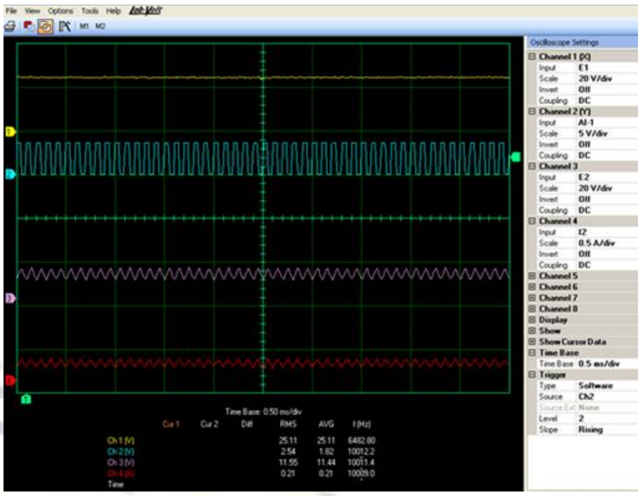

Figure 8. waveforms of output voltage and output current at inductance value of inductor 2mH with switching frequency 10,000Hz.

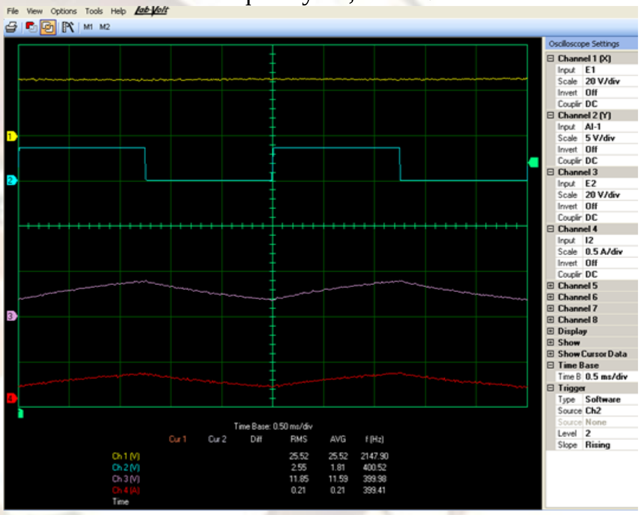

Figure 9. waveforms of output voltage and output current at inductance value of inductor 50mH with switching frequency 400Hz.

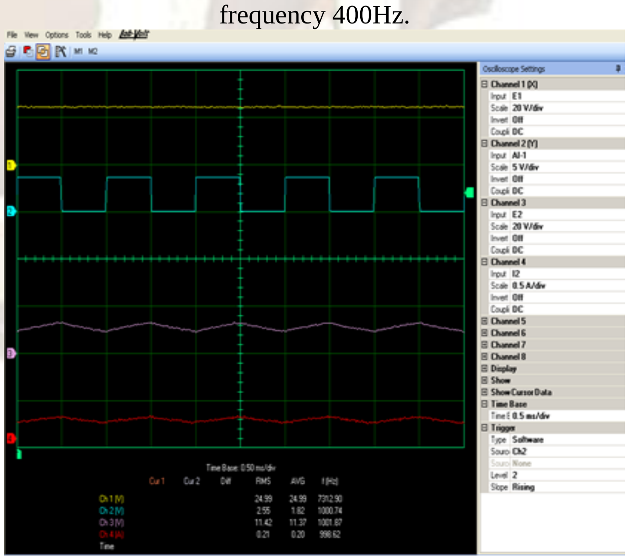

Figure 10. waveforms of output voltage and output current at inductance value of inductor 50mH with switching frequency 1000Hz.

Figure 11. waveforms of output voltage and output current at inductance value of inductor 50mH with switching frequency 2000Hz.

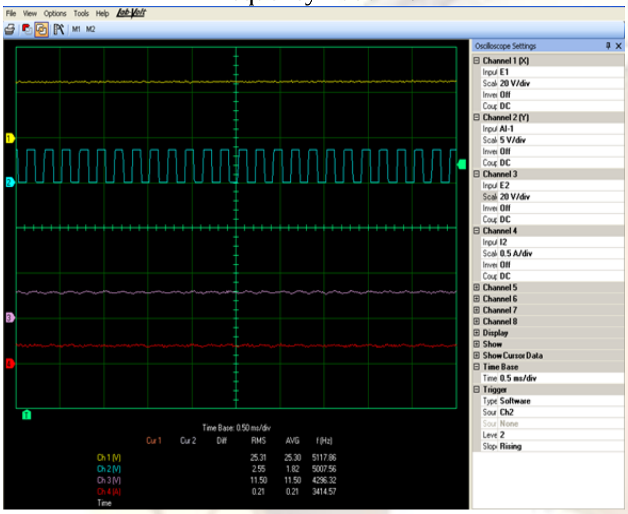

Figure 12. waveforms of output voltage and output current at inductance value of inductor 50mH with switching frequency 5000Hz.

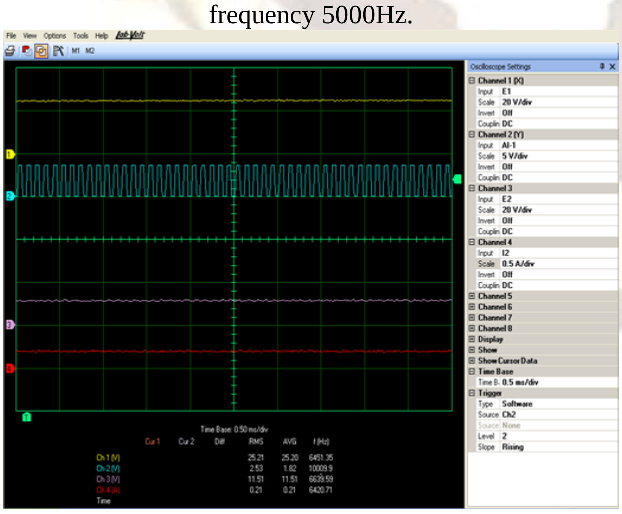

Figure 13. waveforms of output voltage and output current at inductance value of inductor 50mH with switching frequency 10,000Hz.

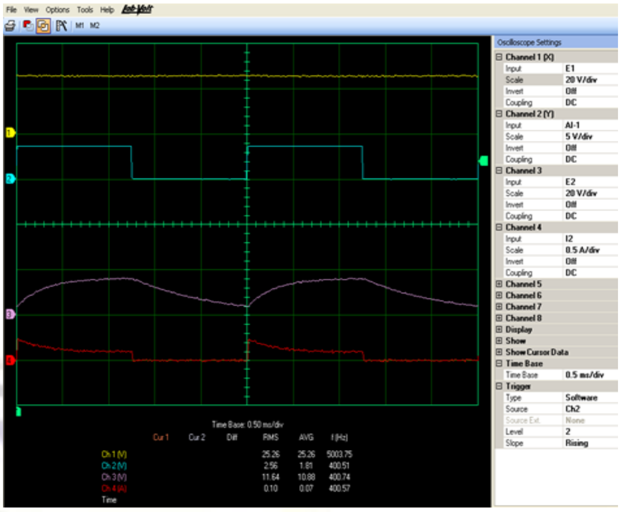

Figure 14. waveforms of output voltage and output current at capacitance value of capacitor 5uF with switching frequency 400Hz.

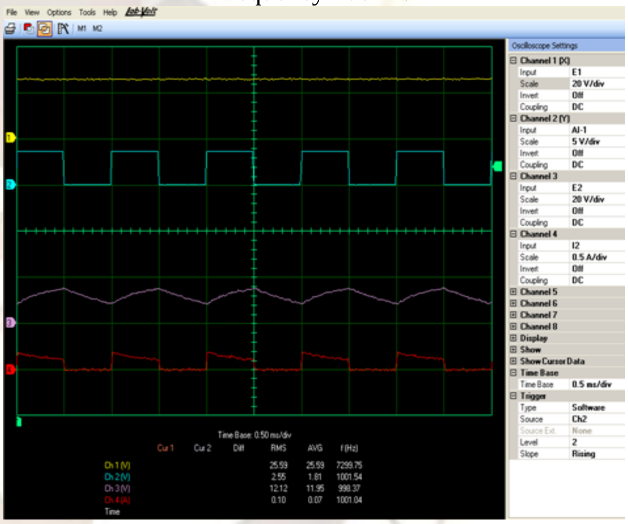

Figure 15. waveforms of output voltage and output current at capacitance value of capacitor 5uF with switching frequency 1000Hz.

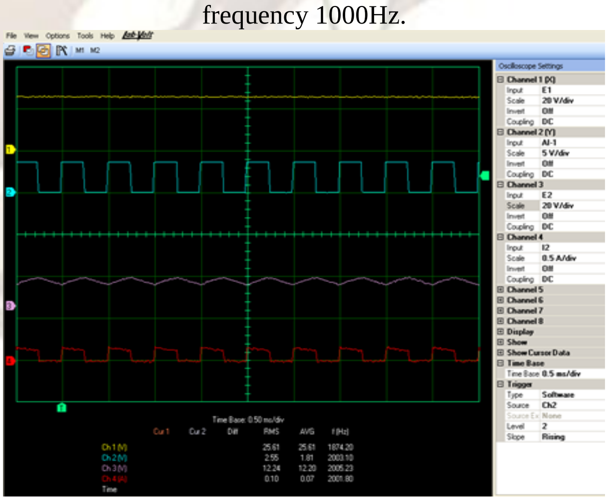

Figure 16. waveforms of output voltage and output current at capacitance value of capacitor 5uF with switching frequency 2000Hz.

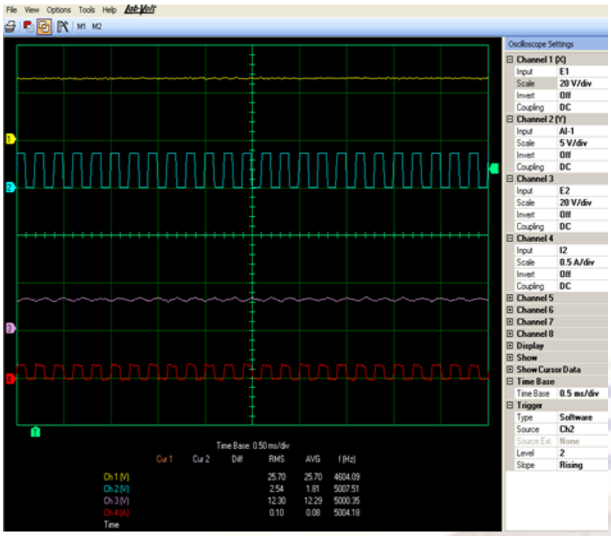

Figure 17. waveforms of output voltage and output current at capacitance value of capacitor 5uF with switching frequency 5000Hz.

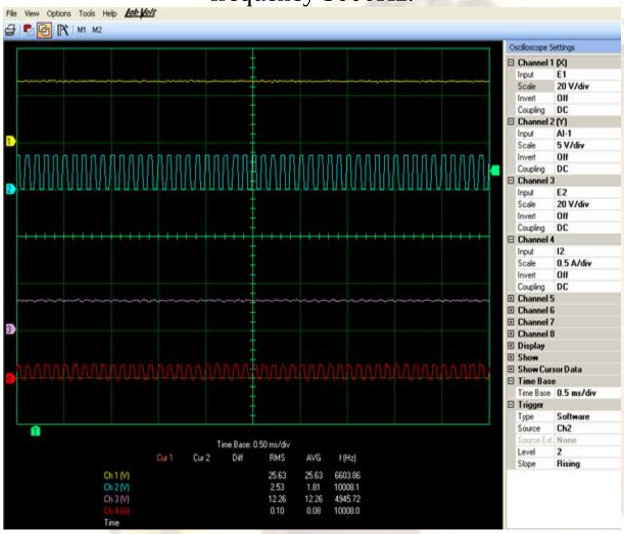

Figure 18. waveforms of output voltage and output current at capacitance value of capacitor 5uF with switching frequency 10,000Hz.

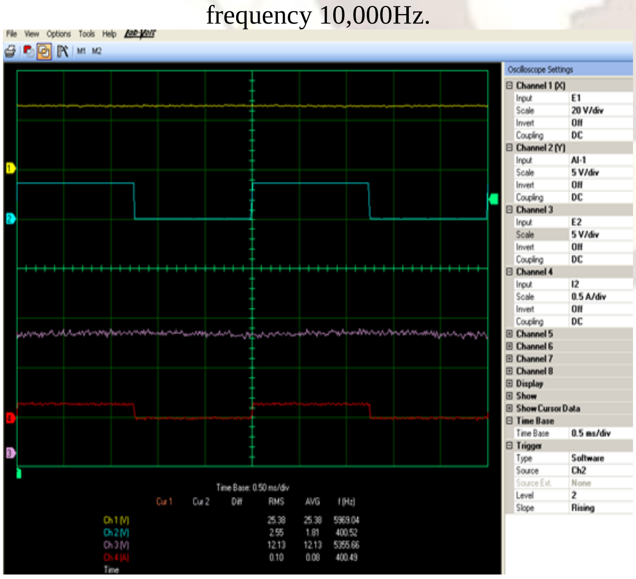

Figure 19. waveforms of output voltage and output current at capacitance value of capacitor 210uF with switching frequency 400Hz.

Figure 20. waveforms of output voltage and output current at capacitance value of capacitor 210uF with switching frequency 1000Hz.

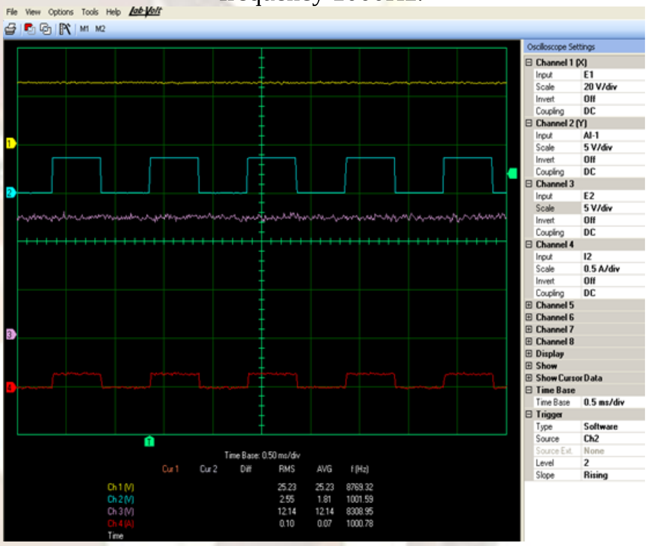

Figure 21. waveforms of output voltage and output current at capacitance value of capacitor 210uF with switching frequency 2000Hz.

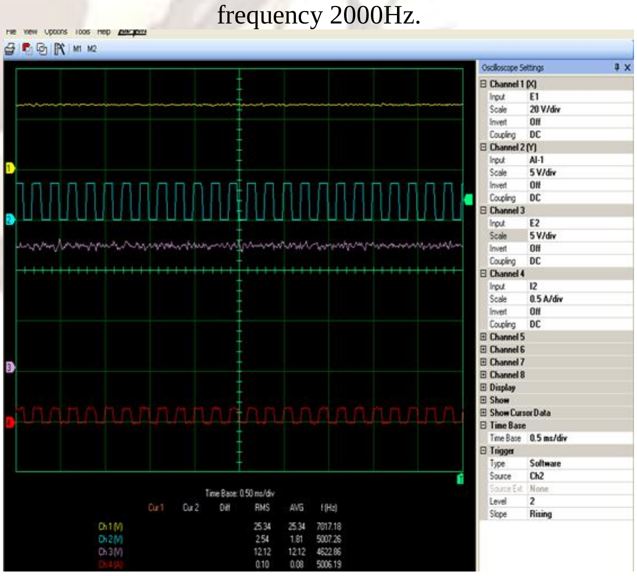

Figure 22. waveforms of output voltage and output current at capacitance value of capacitor 210uF with switching frequency 5000Hz.

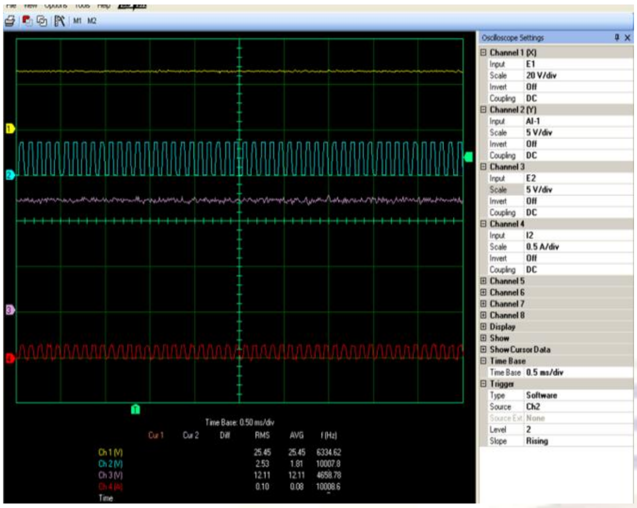

Figure 23. waveforms of output voltage and output current at capacitance value of capacitor 210uF with switching frequency 10,000Hz.

Table I.
Current Ripples at 50mH and 2mH for different values of Switching Frequency.

Switching Frequency	Current Ripples at 50mH	Current Ripples at 2mH
400	0.2	0.405
1000	0.1	0.4
2000	0.05	0.3
5000	0.04	0.2
10000	0.022	0.1

Table II.
Voltage Ripples at 5uF and 210uF for different values of Switching Frequency.

Switching Frequency	Voltage Ripples at 5uF	Voltage Ripples at 210uF
400	12	0.5
1000	8	1
2000	4	0.75
5000	2	0.5
10000	0.8	0.5

Table III.
Duty Cycle versus Efficiency at Load Resistance of 57 ohm.

Duty Cycle	Efficiency % at R = 57 ohm
0.2	91.17
0.4	92.03
0.6	93.57
0.8	97.82

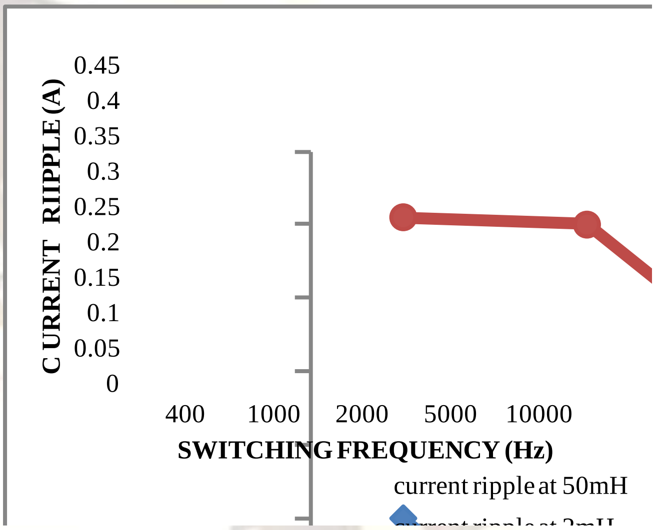

Figure 24. switching frequency versus current ripples at inductance value of inductor 50mH and 2mH.

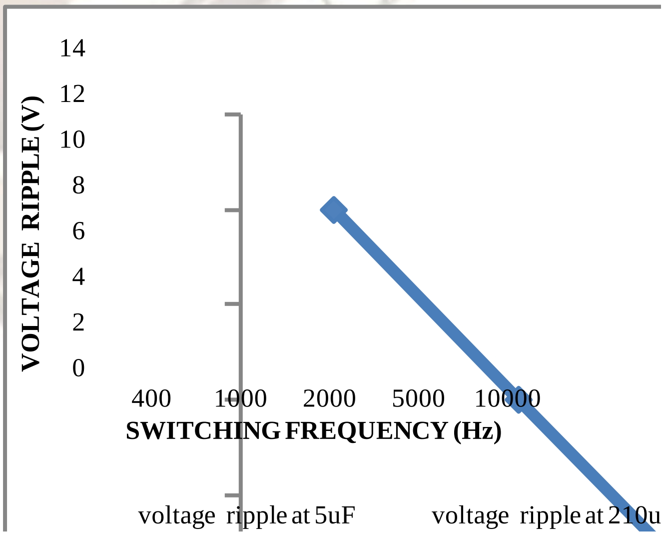

Figure 25. switching frequency versus voltage ripples at capacitance value of capacitor 5uF and 210uF.

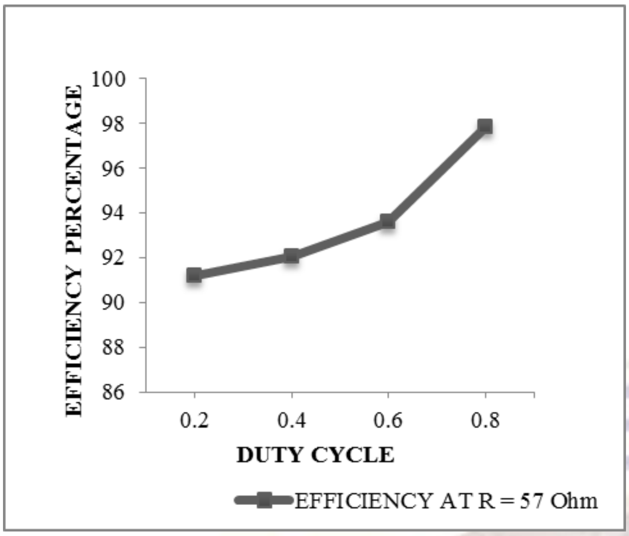

Figure 26. duty cycle versus efficiency at load resistance of 57 ohm.

V. Conclusion

The proposed passive filter technique has been applied to the design of an output filter for a buck converter operating at 12.5 V output from a 25 V input. The switching frequency ranges from 400Hz to 10,000Hz.The buck converter power stage utilizes a 50mH, 2mH inductors and 210 uF ,5uF primary output capacitors and operates in discontinuous conduction mode. The current through the inductor is used as the metric for output current ripple performance. Tests on the system were conducted using LVDAC-EMS software. Tests described here were performed using a resistive load. The voltage across the resistor is used as the metric for output voltage ripple performance. By experimental results, it is concluded that the current ripples and voltage ripples are reduced by increasing f , L and C . Experimental results have been provided to verify the analysis presented.

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