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DC/DC Buck Converter

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Overview:

The objective of this experiment is to study different characteristics of a buck converter. The step-down capability of the converter will be observed under continuous conduction mode (CCM) where the inductor current is non-zero. Open-loop operation with a manually-set duty ratio will be used. An approximation of the input-output relationship will be observed.

Principles:

While it is simple to step up or down AC voltages and currents using transformers, stepping up or down DC voltages and currents in an efficient and regulated manner requires switching power converters. A buck converter is characterized by the ability to chop an input DC voltage and then filer out the harmonics from that converter to find the average output voltage. The output voltage is this less than or equal to the input voltage. Linear regulators (series and shunt) can provide step down capability, but are highly inefficient when the output-to-input voltage ratio is very low. Voltage dividers can also step down DC voltage, however, there is no regulation involved with variable loads. Buck converters thus present efficient and robust DC voltage step-down capabilities.

Procedure:

This experiment will utilize the DC-DC converter board provided by HiRel Systems.
http://www.hirelsystems.com/shop/Power-Pole-Board.html
Information about the board components, schematics, and operation are available here:
http://www.ece.umn.edu/groups/power/labs/pe/pe_manual.pdf
The procedure followed here applies to any simple buck converter circuit that can be built on proto boards, bread boards, or printed circuit boards.

1. Board setup:
   - 1.1 Connect the ±12 signal supply at the DIN connector but keep S90 OFF.
   - 1.2 Make sure that the PWM control selector is in the open-loop position.
   - 1.3 Set your DC power supply at 24V. Keep the output disconnected from your board.
   - 1.4 Before connecting your load resistor, adjusted it to 12Ω.
   - 1.5 Build the circuit shown in Fig. 1 by using the upper MOSFET, lower diode, and BB magnetic board. Note down the inductance value shown in the board.
     - 1.5.1 Connect R_L across V2+ and COM.
     - 1.5.2 Make sure the switch array for MOSFET selection, PWM selection, and other settings are as shown in Fig. 1.

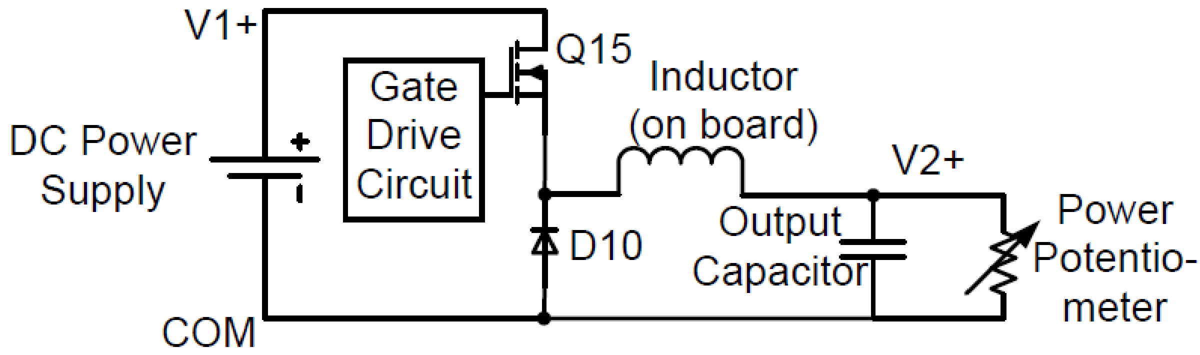

Fig. 1. Buck converter circuit

2. Adjusting the Duty Ratio and Switching Frequency
   - 2.1 Connect the differential probe across the gate to source of the upper MOSFET.
   - 2.2 Turn ON S90. A switching signal should appear on the scope screen.
     - 2.2.1 Adjust the signal time axis to see two or three periods.
     - 2.2.2 Adjust the frequency potentiometer to achieve a frequency of 100 kHz (period of 10μs).
     - 2.2.3 Adjust the duty ratio potentiometer to achieve a 50% duty ratio.

3. Buck Converter Testing for Variable Input
   - 3.1 Connect your input DC power supply which you already set at 24V to V1+ and COM.
   - 3.2 Connect your differential probe across the gate to source of the upper MOSFET.
     - 3.2.1 Connect the other probe across the load. Make sure the ground connector is connected to COM.
   - 3.3 Capture the waveforms and measure the output voltage mean and on-time of the gate-to-source voltage (also the duty ratio).
     - 3.3.1 Record the input current and voltage readings on the DC power supply.
   - 3.4 Adjust your input voltage to 21V, 18V and 15V, and repeat the above steps for each of these voltages.
   - 3.5 Disconnect your input DC supply and adjust its output to 24V.

4. Buck Converter Testing for Variable Duty Ratio
   - 4.1 Connect your differential probe across the gate to source of the upper MOSFET.
     - 4.1.1 Connect the other probe across the load. Make sure the ground connector is connected to COM.
   - 4.2 Connect the input DC supply that is set to 24V between V1+ and COM.
   - 4.3 Capture the waveforms and measure the output voltage mean and on-time of the gate-to-source voltage (also the duty ratio).
     - 4.3.1 Record the input current and voltage readings on the DC power supply.

4.3.2 Adjust your duty ratio for three steps of your choice between 30% and 70%. Repeat the above steps for each of these three duty ratios.

4.4 Reset your duty ratio to 50%.

4.5 Disconnect your input DC supply.

5. Buck Converter Testing for Variable Switching Frequency
   - 5.1 Connect your differential probe across the gate to source of the upper MOSFET.
   - 5.2 Connect the other probe across the load. Make sure the ground connector is connected to COM.
   - 5.3 Connect the input DC supply to V1+ and COM.
   - 5.4 Capture the waveforms and measure the output voltage mean and on-time of the gate-to-source voltage (also the duty ratio).
     - 5.4.1 Record the input current and voltage reading on the DC power supply.
     - 5.4.2 Adjust your switching frequency for three steps of your choice between 5 kHz and 40 kHz. Repeat the above steps for each of these three duty ratios.
   - 5.5 Turn OFF the input DC supply and S90, and then disassemble your circuit.

Representative Results:
It is expected the output-input voltage relationship of an ideal buck converter to be related to the duty cycle or duty ratio D. If the input voltage is V_{in} and the output voltage is V_{out}, $V_{out}/V_{in}=D$, where $0 \leq D \leq 100\%$. Therefore, for an input voltage of 24V, $V_{out} \approx 12$ V for D=50%, $V_{out} \approx 7.2$ V for D=30%, and $V_{out} \approx 16.8$ V for D=70%. Nevertheless, the output voltage will be lower than expected from the ideal relationship which is linear with the duty ratio, and the main reason is that the ideal buck converter model does not account for non-idealities and voltage drops in the converter.

Applications:
Buck converters are very common in electronic device chargers where they provide excellent voltage regulation required for battery charging. They are commonly used in power supplies that power computers, integrated circuits and electronic boards, as well as in renewable energy applications and battery fed systems.