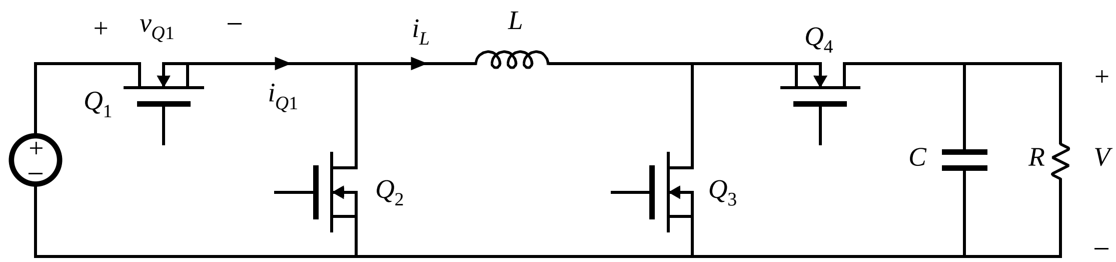
Non-inverting buck-boost converter

Figure below shows a converter consisting of buck switches Q_1 and Q_2, and boost switches Q_3 and Q_4. MOSFETs Q_2 and Q_4 are the synchronous rectifiers for the buck and boost stages, respectively. In all cases considered in this problem you can assume that switches are controlled such that Q_1 and Q_2 are operated in a complementary manner, and are never ON at the same time. Similarly, Q_3 and Q_4 are operated in a complementary manner, and are never ON at the same time. Switching frequency is $f_s = 1/T_s$.



The switches can be operated in two different ways:

(1) **Buck-boost mode**:

Q_1 and Q_3 are simultaneously ON during DT_s, Q_2 and Q_4 are simultaneously ON during $D'T_s$.

(2) **Buck or boost modes**:

(2.1) **Buck mode**: Q_1 duty cycle is D_{buck}, while Q_3 is OFF always and Q_4 is ON always.

(2.2) **Boost mode**: Q_3 duty cycle is D_{boost}, while Q_1 is ON always, Q_2 is OFF always.

(a) All MOSFETs have the same on-resistance R_{on}, and inductor winding resistance is R_L. Derive and sketch equivalent circuit models of the converter valid for (1) the buck-boost mode, and (2) the buck or boost modes. Solve the models to find analytical expressions for the dc conversion ratio $M = V/V_g$, and for the average inductor current I_L. Switching losses can be neglected in this part of the problem.

(b) A switching transition between Q_2 and Q_1 can be described as follows: Q_2 is initially ON, conducting inductor current i_L, while Q_1 is OFF; once Q_2 is turned OFF, the body diode of Q_2 conducts i_L. Then, Q_1 is turned ON, initiating reverse recovery of the Q_2 body diode; upon completion of the Q_2 body diode reverse recovery, Q_1 is ON, conducting inductor current i_L, while Q_2 is OFF. Assuming snappy, abrupt-recovery diode, having reverse-recovery time t_r and reverse recovery charge Q_r, sketch the waveforms i_{Q1} and v_{Q1} during the switching transition described above.

(c) Following the description in part (b), similarly describe (in words) a transition between Q_3 and Q_4, which involves reverse recovery of a MOSFET body diode. Sketch the corresponding waveforms.

(d) Derive and sketch equivalent circuit models for the converter operating in each of the buck, boost, and buck-boost modes of operation, including the loss mechanisms from part (a) as well as the reverse recovery behaviors.

(e) The converter is constructed using IRLH5036 MOSFETs having R_{on} = 6 mΩ, with body diode parameters t_r = 42 ns, Q_r = 201 nC, which can be considered constant values. The inductor winding resistance is R_L = 5 mΩ. Inductor current ripple can be neglected. The converter is designed to produce output voltage V = 24 V across the load R = 2.3 Ω. The input voltage is between V_{gmin} = 18 V and V_{gmax} = 30 V. The switching frequency is f_s = 100 kHz.

Solve the models you derived in part (d) to find the converter efficiencies for the two ways of operating the switches, and for the two input voltages. Show your efficiency results in a table, as shown below

	$V_g = V_{gmin}$ = 18 V	$V_g = V_{gmax}$ = 30 V
(1) Buck-boost mode		
(2) Buck or boost modes		

Briefly comment on the results: compare the two ways of operating the switches; compare switching and conduction losses.

(f) Examine the IRLH5036 MOSFET datasheet and explain how the values for R_{on}, t_r and Q_r were determined. Brief comments are sufficient. Search for alternative MOSFETs (e.g. on digikey.com), and suggest a replacement MOSFET that would result in improved efficiency results.