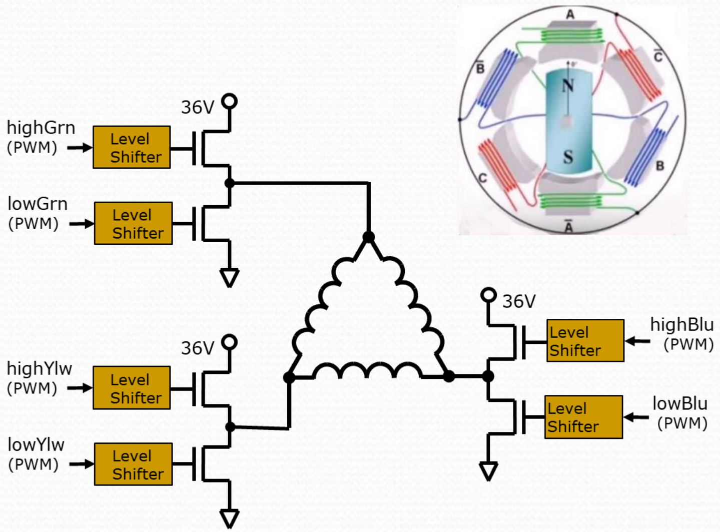
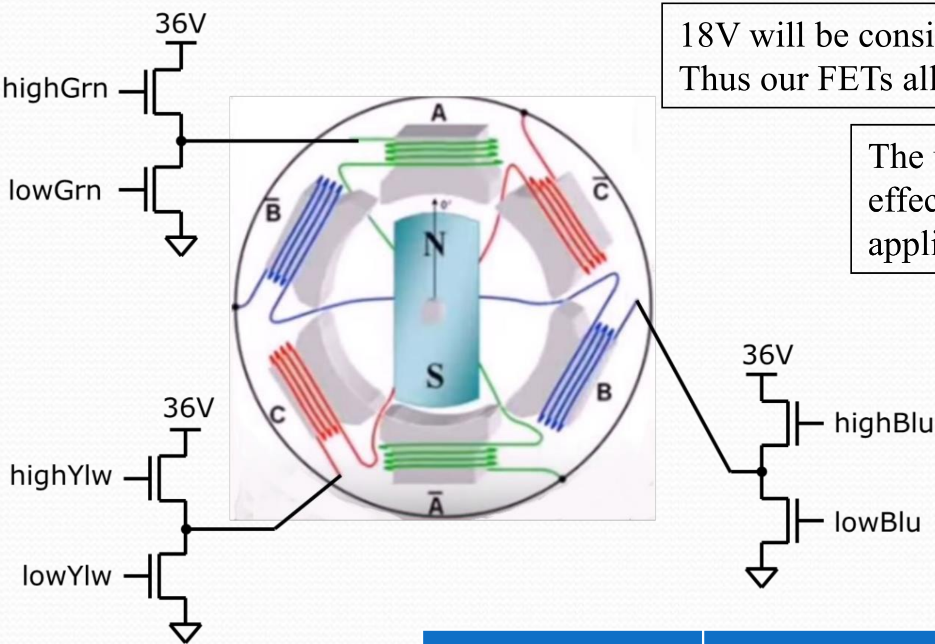
Exercise 12: brushless.sv and Test Bench

- Do you remember anything of what you learned back in HW1 about how a brushless DC motor is driven?
- We have 3 coil connections that we have to drive. We call them green, yellow, and blue. For any given coil we drive current in one direction, the opposite direction, or not at all.
- How do we know the proper coil drive at any given time? That is determined by the position of the rotor. We know the rotor position from the hall sensor inputs.



- **brushless.sv** will be the block that inspects the hall sensor signals and determines how to drive each coil. Each coil can be driven 1 of 4 ways: not driven (both high/low FETs off); driven "forward"; driven "reverse"; driven for dynamic braking (high FET off, low FET PWMed)
- Are the hall effect sensors synchronous to our clock domain? What does that mean?
- If you are curious why PWMing the lower FETs creates dynamic braking I think I can stumble through an explanation, but I suspect most of you lemmings will be content to just implement it as specified.

Exercise 12: brushless.sv and Test Bench



18V will be considered "virtual ground" for the coils. Thus our FETs allow us to drive positive or negative.

The use of PWM allows us to control the effective magnitude of the voltage applied across the coil. (hence speed/torque)

A PWM setting of 0x400 would be 50% and would represent driving a coil with 18V (virtual ground).

There are 4 possible states a coil can be driven in. Regenerative braking is a special case indicated by **brake_n** signal being low.

Coil Drive State:	FET gate controls:
Not driven (High Z)	Both high and low side low (both off)
Forward Current	High side driven with PWM, low side driven with ~PWM
Reverse Current	High side driven with ~PWM, low side driven with PWM
Regen Braking	High side low (off), low side driven with PWM

Exercise 12: brushless.sv and Test Bench

Determining next drive conditions from hall effect sensor readings: largely combinational

- The hall effect sensors tell us the current position of the rotor always_comb
- The hall effect sensor wires are also green, yellow, and blue. w/ big case statement
- Form a 3-bit vector: **rotation_state = {hallGrn,hallYlw,hallBlu};**
- The following table outlines how we drive our coils need default case drive all FETs to high impedance (z)

rotation_state	3'b101	3'b100	3'b110	3'b010	3'b011	3'b001
coilGrn	for_curr	for_curr	High Z	rev_curr	rev_curr	High Z
coilYlw	rev_curr	High Z	for_curr	for_curr	High Z	rev_cur
coilBlu	High Z	rev_curr	rev_curr	High Z	for_curr	for_curr

- In the case of **brake_n == 1'b0** (braking) all coils are driven in the regenerative braking state with the high side FET off and the low side FET PWMing. override (asynchronous)

Exercise 12: brushless.sv and Test Bench

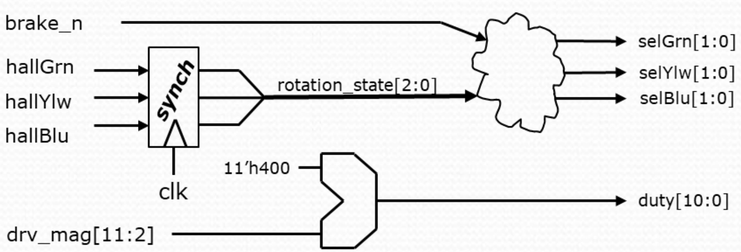
Signal:	Dir:	Description:
clk	in	50MHz clock
drv_mag[11:0]	in	From PID control. How much motor assists (unsigned)
hallGrn,hallYlw, hallBlu	in	Raw hall effect sensors (asynch)
brake_n	in	If low activate regenerative braking at 75% duty cycle
duty[10:0]	out	Duty cycle to be used for PWM inside ***mtr_drv***. Should be 0x400+drv_mag[11:2] in normal operation and 0x600 if braking.
selGrn[1:0], selYlw[1:0], selBlu[1:0]	out	2-bit vectors directing how ***mtr_drv*** should drive the FETs. 00=>HIGH_Z, 01=>rev_curr, 10=>frwd_curr, 11=>regen braking

Code and test ***brushless.sv*** with the interface specified in this table.

Synchronize incoming hall effect sensors

Submit: **brushless.sv** and **brushless_tb.sv**.

See hint/idea on next page for **brushless_tb.sv**



Exercise 12: Testing brushless.sv

- If you are done coding **brushless.sv** and are thinking about how to test it consider this:
  - The outputs of **brushless.sv** feed the inputs to **mtr_drv.sv**.
  - We develop **mtr_drv.sv** in the next exercise (Exercise 13).
  - Get started on Exercise 13 now.
  - When you are done with **mtr_drv.sv** implementation you can create a combined testbench **brushless_mtr_drv_tb.sv** that tests both units in combination.