Application Note

Implementing a Brushless DC Motor Controller on an IGLOO FPGA

1.0 Introduction

The main objective of the design is to commutate a Three-Phase BLDC Motor which has Hall sensor feedback. The control inputs are available through hardware (I/Os) or a 2-wire serial interface.

2.0 General Implementation Overview

A BLDC Motor is a synchronous motor with no damping or starting windings. Three logic signals are decoded to determine the next winding sequence. A three-phase motor requires three push-pull stages. In each of the six possible states, two outputs are active at a given time (current flows in only two windings of the stator). Each state translates to electrical sectors.

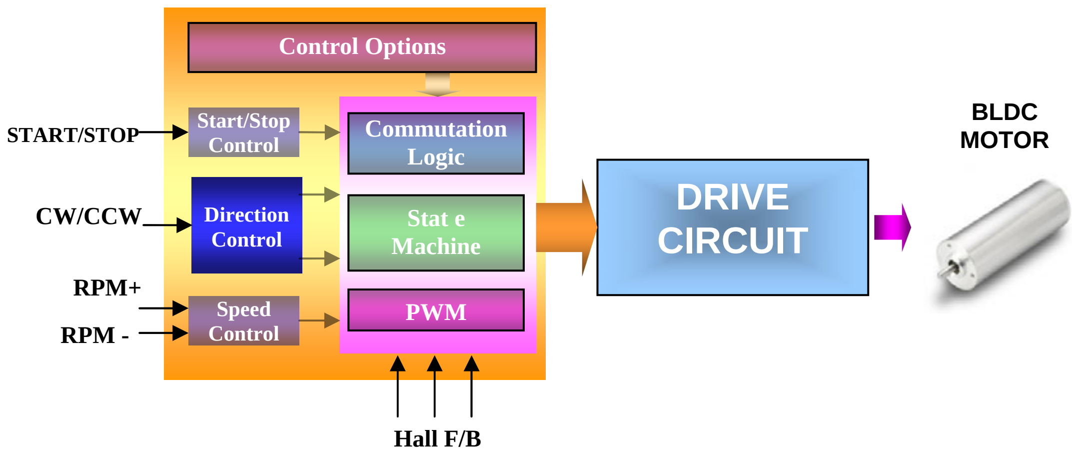

Figure 1. BLDC Motor Control on IGLOO® Device

3.0 Reference Design Implementation

Simple Control Technique would be to sense the change in the state of the position of the rotor and apply the next step/state for commutation. In case sensors are provided, the position is known by reading the Hall sensors to determine the next state. An 8-bit pulse width modulation (PWM) controller is used for speed control by varying the average voltage across the windings. The PWM frequencies can be made variable based on motor specifications.

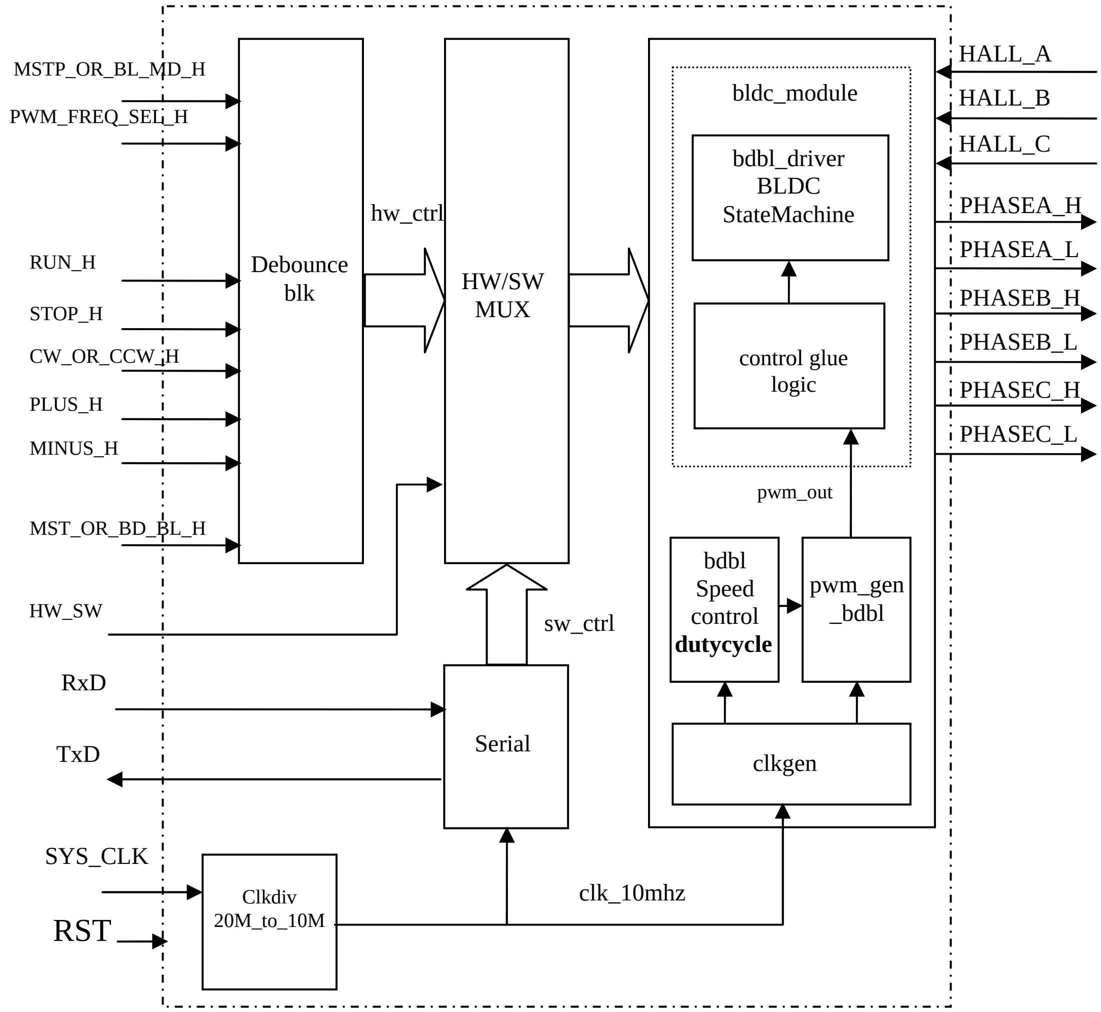

Figure 2. BLDC Motor Control – Logic Block Diagram

The motor is commutated based on the signals given by the Hall Sensors mounted at various positions inside the motor. Hall outputs change every 60 electrical degrees. The state of the control switches and the Hall sensor signals are scanned continuously. A new voltage vector / control trajectory is applied to the BLDC motor based on the Hall sensor signal conditions. This mechanism is known as commutation.

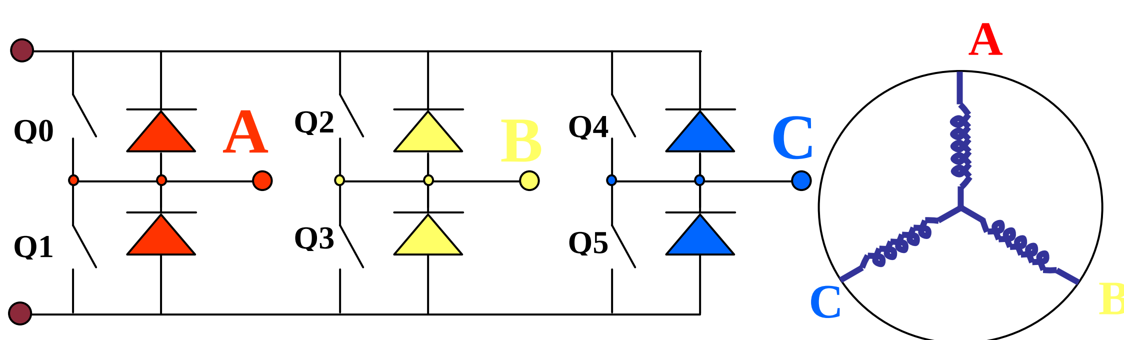

Figure 3 Push-Pull Stages of a 3-Phase BLDC Drive

3.1 Sensored Drive – Hall Effect Sensors

The Hall position sensors sense the actual rotor position. The Hall outputs are monitored by the controller and appropriate commutation sequence is applied to assist in commutating the motor. The speed of the motor is varied by making use of PWM outputs on the output voltages. Typically there are three Hall effect sensors provided inside the motor. The three sensors comprise six states: 001, 010, 011, 100, 101, and 110. Six steps are required to perform one complete electrical cycle. The electrical-to-mechanical ratio is based on the pole pairs inside the motor. Each state corresponds to the actual rotor position inside the motor. This determines the required direction of voltage vector based on the direction in which the rotor needs to be moved. A vector table is generated for the sensor state and the next commutation sequence.

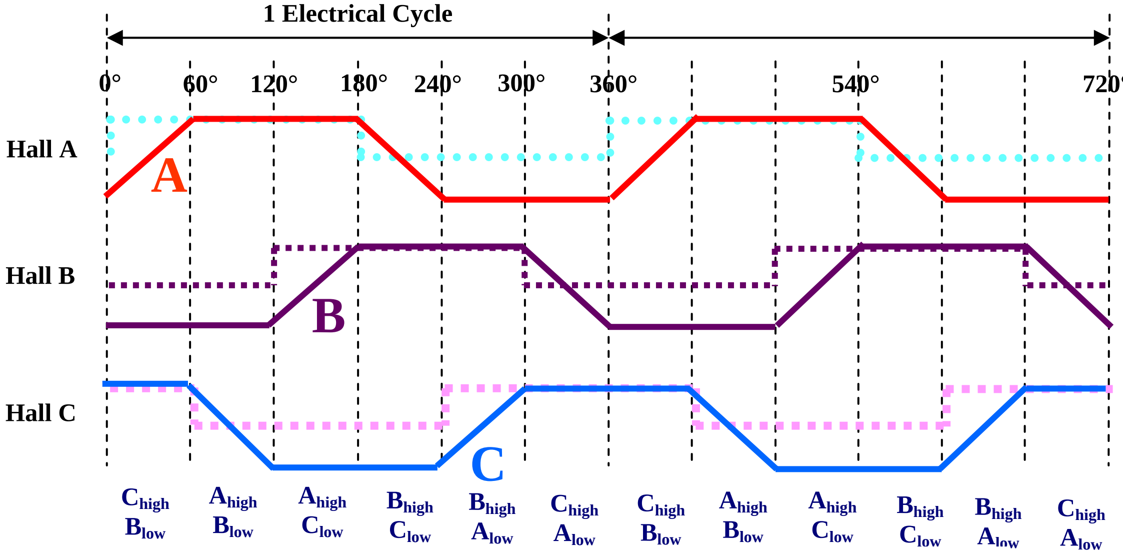

Figure 4. Commutation Using Hall Sensors

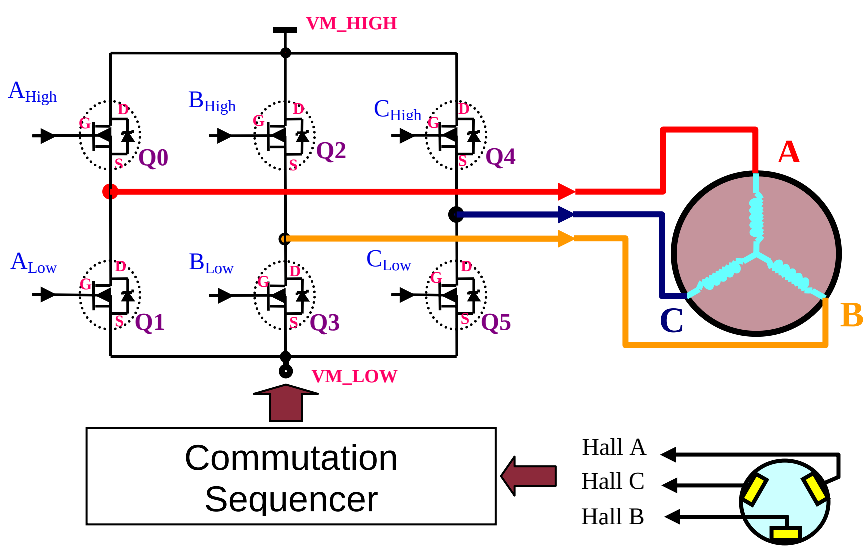

Figure 5. External MOSFET Bridge Circuit for Commutation

3.2 Speed Control

The speed of the motor is directly proportional to the applied voltage. By varying the average voltage across the windings, the RPM can be altered. This is achieved by altering the duty cycle of the base PWM signal. Maximum speed is achieved when PWM is OFF. In that case, the MOSFETs are ON for 100% of the commutation period. When PWM is turned ON, the speed is proportional to the duty cycle setting.

Digital Control of RPM

A fixed internal 8-bit register is incremented or decremented upon receiving the RPM+ or RPM- commands from the switches onboard or through the software interface. This alters the duty cycle and hence the speed of the motor.

3.3 Commutation

Typical 3-Phase Current Waveforms:

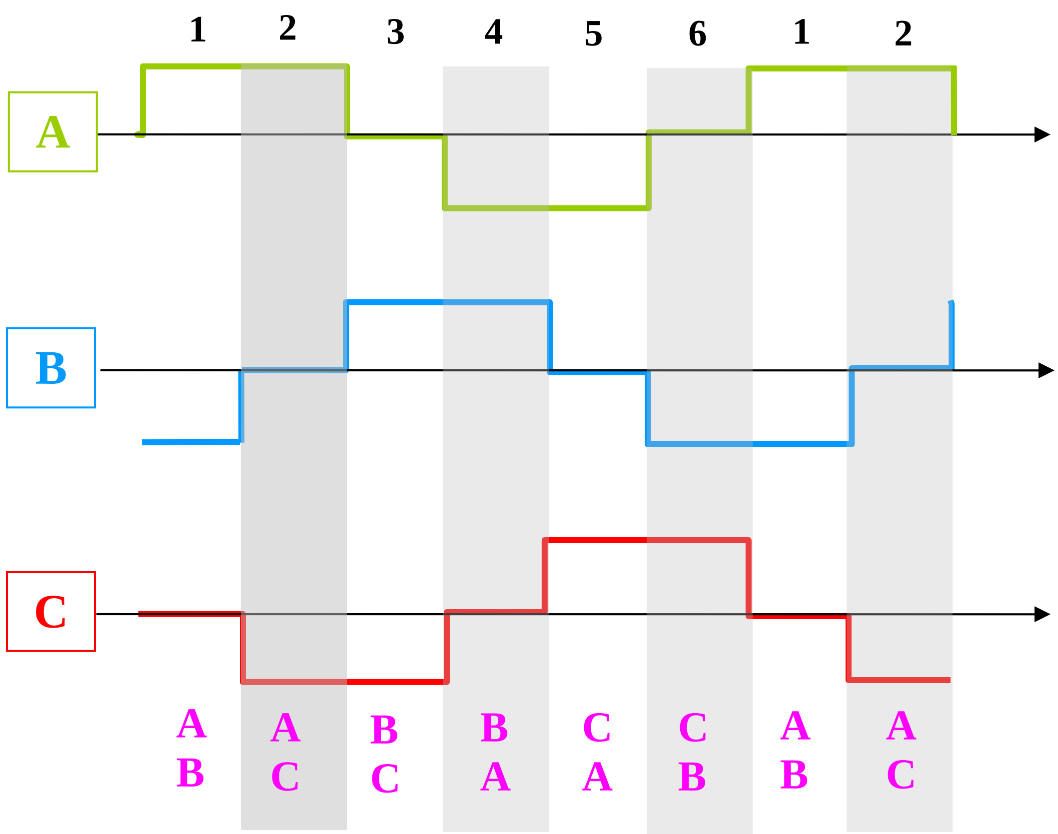

Figure 6. Six-Step Commutation Waveform

Figure 6 shows the commutation sequence for a typical 3-Phase BLDC Motor. Each phase is active for 120 electrical degrees. At any given time/step interval, notice that only two phases are active. The third phase is inactive or floating. This mechanism has built-in dead time and assures that the two MOSFETs in the same bridge are not active at the same time.

The commutation sequence as shown above will be AB-AC-BC-BA-CA-CB-AB-AC… and repeats from there on. Notice that during AB sequence, the upper side of the A bridge is active while the lower side of B bridge is active. So current flows from DC+ through the A high side to the motor winding across A and B, passes through the low side of the B bridge and to DC-. The commutation timing is determined based on the position of the rotor. In the case of a sensored drive, the Hall effect sensor digital outputs determine the position of the rotor, which can be used to move to the next logical sequence.

3.4 BLDC Control State Machine

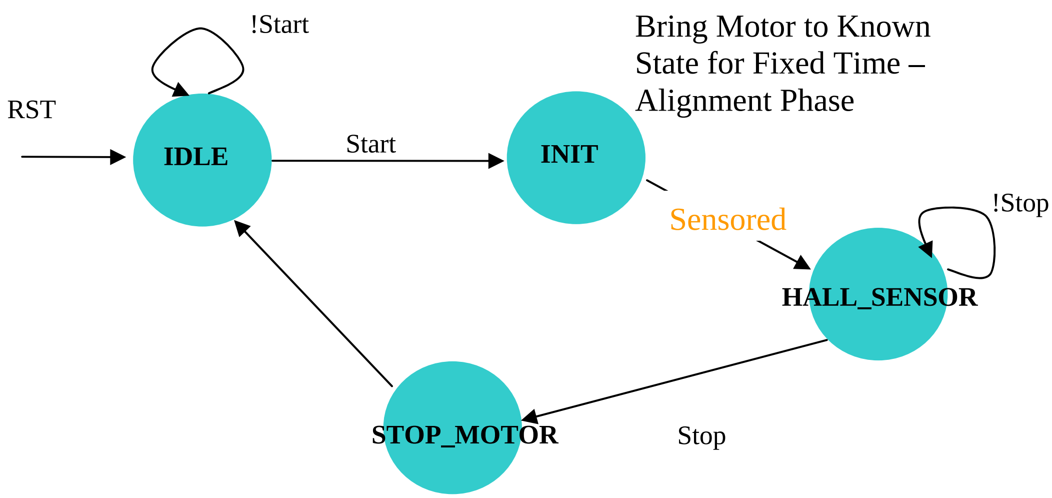

Figure 7. BLDC Control State Machine

4.0 Waveforms

PWM to High Side

In this case the PWM signal is applied only to the high side of the MOSFET pair, while the low side is driven for 100% of the commutation period.

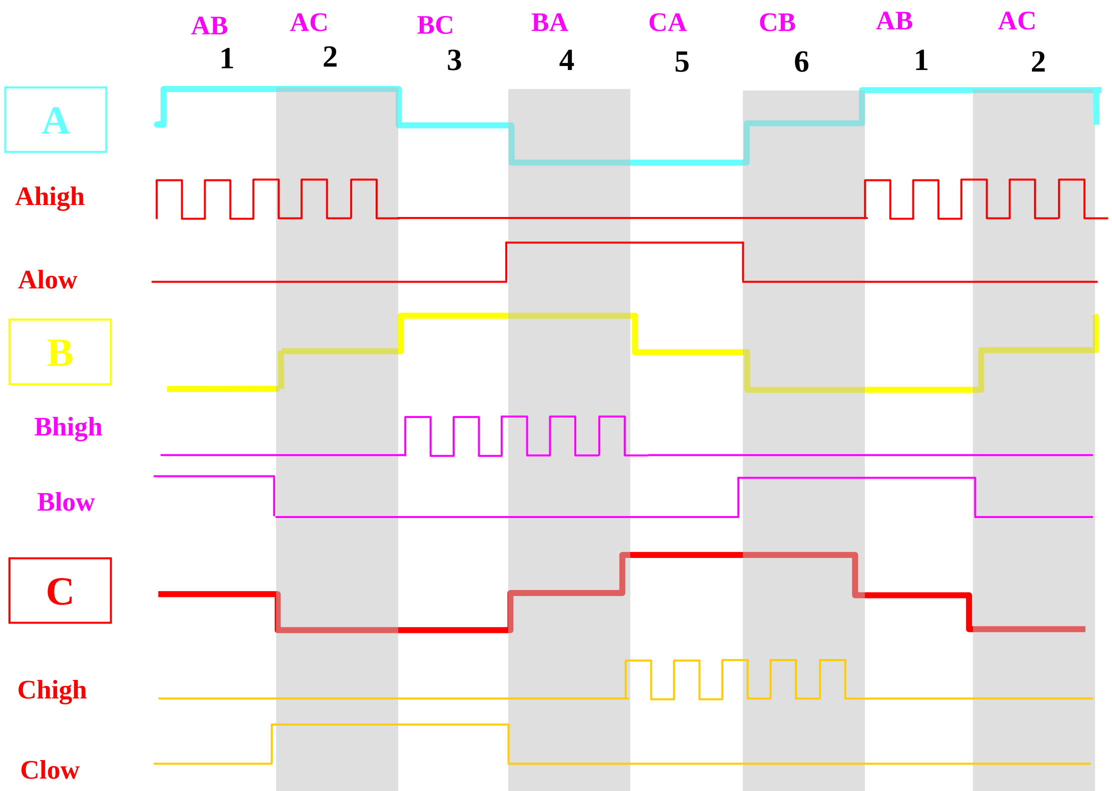

Figure 8. PWM to High Side

Phase	PhaseA_H	PhaseA_L	PhaseB_H	PhaseB_L	PhaseC_H	PhaseC_L
Phase1	PWM	0	0	1	0	0
Phase2	0	0	0	1	PWM	0
Phase3	0	1	0	0	PWM	0
Phase4	0	1	PWM	0	0	0
Phase5	0	0	PWM	0	0	1
Phase6	PWM	0	0	0	0	1

Table 1. Phase Sequence When PWM to High Side

5.0 I/Os

The following table describes the Main I/Os in the design.

Signal Name	Input/ Output	Description	Fusion Pin
RxD	Input	RS232 Receive	C31
TxD	Output	RS232 Transmit	B34
CW_OR_CCW_H	Input	Motor Direction Control 1 – Clockwise 0 – Counterclockwise	A31
MSTP_OR_BL_MD_H	Input	For BLDC motor, PWM Mode 1 – High Side PWM 0 – Low Side PWM	A21
STOP_H	Input	Motor Stop	A7
MST_OR_BD_BL_H	Input	For Brushed/Brushless motor 1 – Brushed motor, 0 – Brushless motor	B2
RUN_H	Input	Motor Start/Run	C4
SYS_RESET	Input	System Reset (Pulse through Switch SW6)	C1
PHASEA_H	Output	PhaseA – High Side Signal	C26
PHASEA_L	Output	Phase A – Low Side Signal	B30
PHASEB_H	Output	PhaseB – High Side Signal	A36
PHASEB_L	Output	PhaseB – Low Side Signal	C32
PHASEC_H	Output	PhaseC – High Side Signal	C2
PHASEC_L	Output	PhaseB – Low Side Signal	A16
HALL_A	Input	Hall Sensor A from Motor	C6
HALL_B	Input	Hall Sensor B from Motor	B10
HALL_C	Input	Hall Sensor C from Motor	B24
HW_SW	Input	Hardware or Software Control ON – Hardware, OFF – Software	A35
PLUS_H	Input	Increment Speed	A23
MINUS_H	Input	Decrement Speed	A26
PWM_FREQ_SEL_H	Input	PWM Frequency Select 0 – 39 KHz, 1 – 78 KHz	C14
SD	Output	Shutdown for MOSFET Driver	C5
SYS_CLK	Input	Sys Clock	A5

6.0 Conclusion

This design example allows the user to run a Three-Phase BLDC motor using the low-power IGLOO device. The design has been specifically developed with the drive circuit in mind. Please refer to the Icicle Motor control documentation for detailed usage of the IP and the features available through hardware and software.

Appendix A – BLDC Motor Controller Design Example

Design Files Summary

Files	Functionality
baud_clk_gen.v	This block generates the desired baud clock for Serial Comm
clk_by_2.v	Divides input clock by 2 – Toggle F/F
clk_gen.v	Clock Generator Block
debounce.v	Debounce Logic
debounce_blk.v	Interconnects all debounce blocks.
div_by_16.v	Divide by 16 block for serial communication – baud clock
divideby5.v	Derived Clock for internal use
clkdiv_20M_to_10M.v	Generate 10 MHz from 20 MHz Input
global.v	Defines/Parameters for the design
recv_control.v	This block receives data serially on RxD.
serial.v	This block generates software controls for bldc motor
mux_hw_sw.v	This block multiplexes between hardware and software controls
xmit_control.v	This block transmits data serially on TxD.
bd_bl_speedcontrol.v	Speed control block for BLDC driver
pwm_gen_bdbl.v	BLDC clock – PWM generator
bdbl_driver.v	BLDC driver module
top_serial.v	This block connects xmit_control, recv_control, serial, baud_clk_gen and div_by_16
top_bldc.v	This block connects bldc_driver, pwm_generator, and bd_bl_speedcontrol block
bldc_ip.v	This block interconnects top_bldc and clk_gen
top_bldc_ip.v	This block interconnects mux_hw_sw,debounce_blk and bldc_ip
top_tb.v	Testbench for bldc_ip

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