

BLDC Ceiling Fan Controller with Sensor-less Sinusoidal Current Control, TIDA-00386

This reference design provides complete solution for 3-phase BLDC, ceiling fan applications. The solution consists of three sections:

1. AC-DC section: designed to work with universal main AC input range i.e. 90Vac-265Vac. It uses fly back ac/dc topology, to generate 24V DC input power from main AC. It is based on UCC28630 primary side PWM regulator.
2. Motor control section: It based on DRV10983, single chip IC operates at 24Vdc. This IC integrates all basic building blocks of 3-phase BLDC motor control i.e. sinusoidal sensor-less motion control engine + 3-phase H-bridge inverter including pre-drivers. It also provides 3.3V regulated output to support external loads up-to 100mA.
3. IR remote based Speed control section: based on value-line MSP430G2201, which decodes the remote inputs and generate PWM duty cycle command for fan speed control.

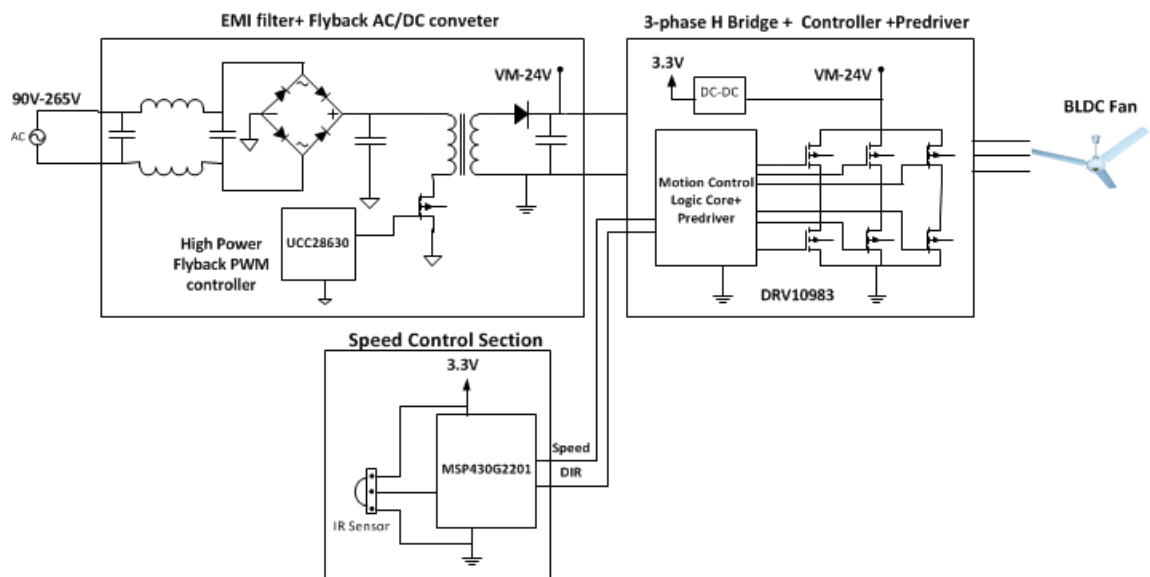


Figure 1: Functional block diagram of BLDC ceiling fan controller

Measuring Equipment used for Testing:

1. Voltech single phase power analyzer PM100 for AC power measurement at input
2. Fluke digital Multi-meters for DC power measurement at 24Volt
3. Tektronix Digital Oscilloscope DPO4034 for waveform capture

Loading Equipment: 24V/16-pole 3-phase BLDC ceiling fan motor is utilize for testing. Motor is able to reach 310 rpm at 90% duty at 24Vdc input with power consumption of 40Watt at DC.

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Motor Speed Control Firmware: A remote based on NEC IR transmission protocol runs at carrier frequency of 38 kHz is used for speed control. Firmware is developed for MSP430G2201 to provide 5-step PWM duty cycle commands to DRV10983 with following features:

- PWM duty cycle command is generated at 1.5 kHz and provides 10% step change in duty cycle.
- Each time increment key is pressed duty-cycle is increased by 10%, similarly for decrement key duty-cycle is reduced by 10%. Maximum duty cycle is 90% and minimum duty cycle is kept at 50%.
- The firmware can be used with any IR remote that supports NEC IR transmission protocol, by changing key-codes in software. Please refer to appendix-A for more details.

Test Results:

- AC-DC characterization test:** Test is performed to characterize AC/DC converter at different load (motor speed) and input AC line condition. Table below shows the data for AC/DC input power, output power at 24V and most importantly efficiency and output voltage regulation, as shown in figure 2, 3 and 4 respectively. From these figures it can be concluded that AC/DC efficiency is above 88% and output voltage remains with limits of 23.75V to 24.25 at all load and line conditions to achieve speed regulation within $\pm 1\%$.

AC Voltage (Volt)	Ac current (Amp)	AC Power (Watt)	DC Voltage (Volt)	DC Current (amp)	DC Power (Watt)	AC/DC efficiency (%)	Motor Speed (rpm)
90	0.24	09.87	23.80	0.37	08.81	89.21	1 st step ~190 rpm
	0.36	15.72	23.86	0.59	14.08	89.55	2 nd step ~220 rpm
	0.52	23.85	23.89	0.90	21.50	90.15	3 rd step ~250 rpm
	0.71	33.40	23.90	1.25	29.87	89.44	4 th step ~280 rpm
	0.95	45.90	23.91	1.71	40.88	88.55	5 th Step ~310 rpm
115	0.19	09.85	23.80	0.37	08.81	89.41	1 st step ~190 rpm
	0.29	15.65	23.86	0.59	14.08	89.55	2 nd step ~220 rpm
	0.42	23.71	23.89	0.90	21.50	90.68	3 rd step ~250 rpm
	0.57	33.2	23.90	1.25	29.87	89.98	4 th step ~280 rpm
	0.74	45.3	23.93	1.70	40.68	89.80	5 th Step ~310 rpm
230	0.13	09.73	23.77	0.37	08.67	89.13	1 st step ~190 rpm
	0.20	15.50	23.83	0.58	13.82	89.17	2 nd step ~220 rpm
	0.28	23.65	23.89	0.90	21.50	90.91	3 rd step ~250 rpm
	0.38	32.80	23.90	1.25	29.87	91.00	4 th step ~280 rpm
	0.48	44.90	23.91	1.70	40.65	90.52	5 th Step ~310 rpm
265	0.11	09.77	23.77	0.37	08.67	88.76	1 st step ~190 rpm
	0.17	15.52	23.81	0.58	13.81	88.98	2 nd step ~220 rpm
	0.25	23.70	23.88	0.90	21.50	90.68	3 rd step ~250 rpm
	0.33	32.85	23.90	1.25	29.87	90.94	4 th step ~280 rpm
	0.43	44.95	23.90	1.70	40.63	90.38	5 th Step ~310 rpm

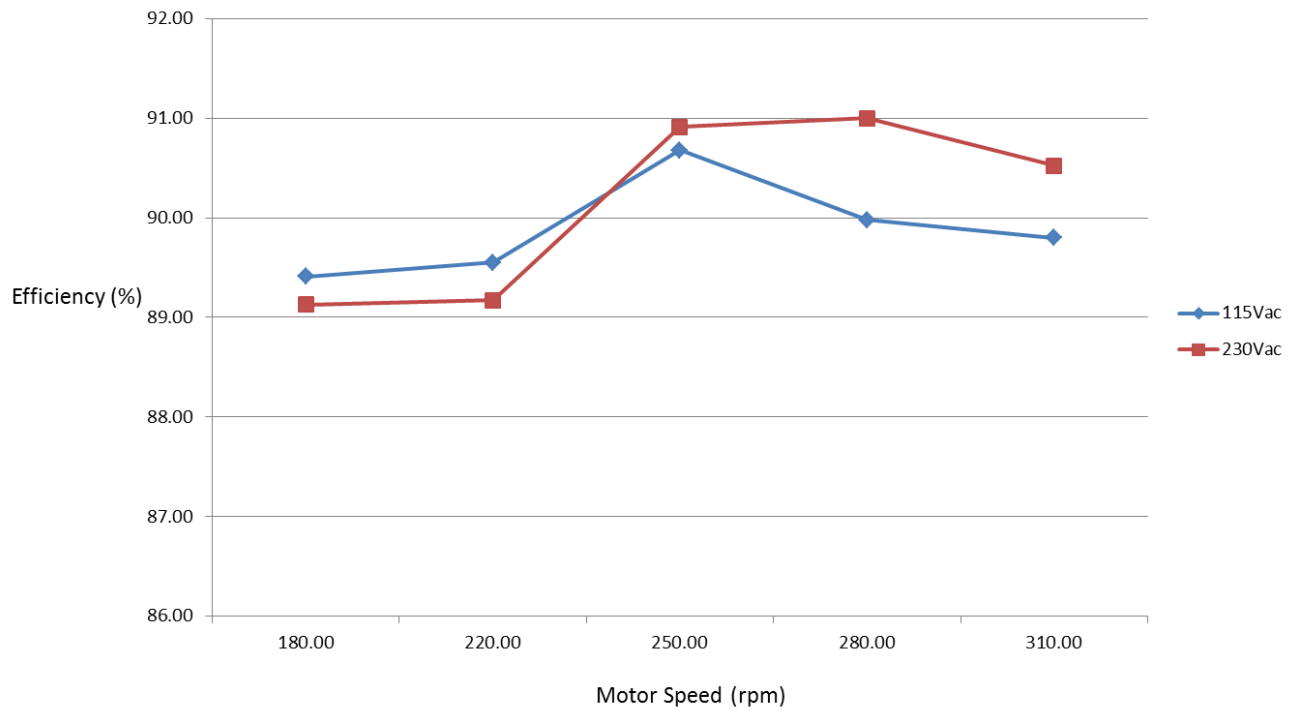


Figure2: AC/DC efficiency with respect to motor load at nominal voltages

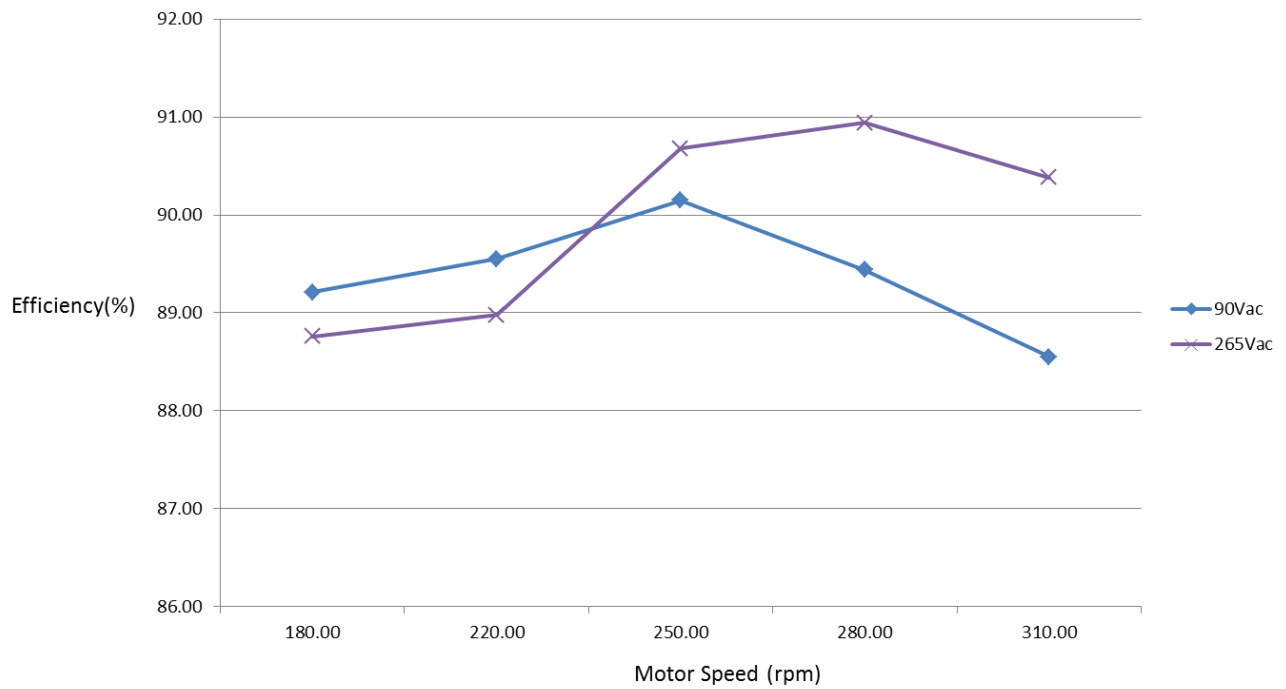


Figure3: AC/DC efficiency with respect to motor load at Min& Max voltage

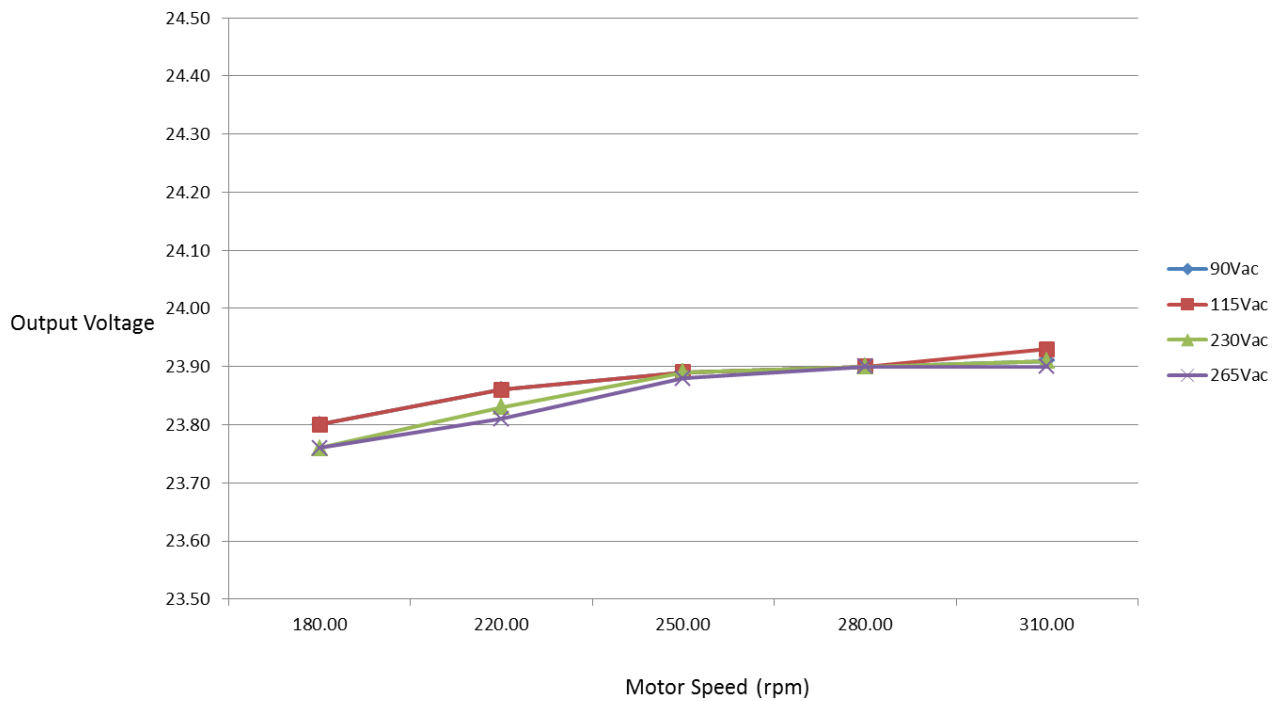


Figure4: 24VDC output regulation with respect to motor load

- 2. Motor phase voltage and current waveforms:** Figure 5 and 6 shows the three-phase voltages applied voltages with respect to GND and current flowing through one phase of motor at full speed, 310 rpm. Figure 5 shows the actual PWM voltages waveform applied to motor whereas figure 6 shows the filtered voltage waveforms. Figure 6 demonstrate sinusoidal PWM with third-harmonic addition, as explained in DRV10983 data-sheet. The third harmonic content in phase to ground voltage get cancelled across phase to phase voltage and produce sinusoidal current in motor phase, as evident in both figure 5 and 6.

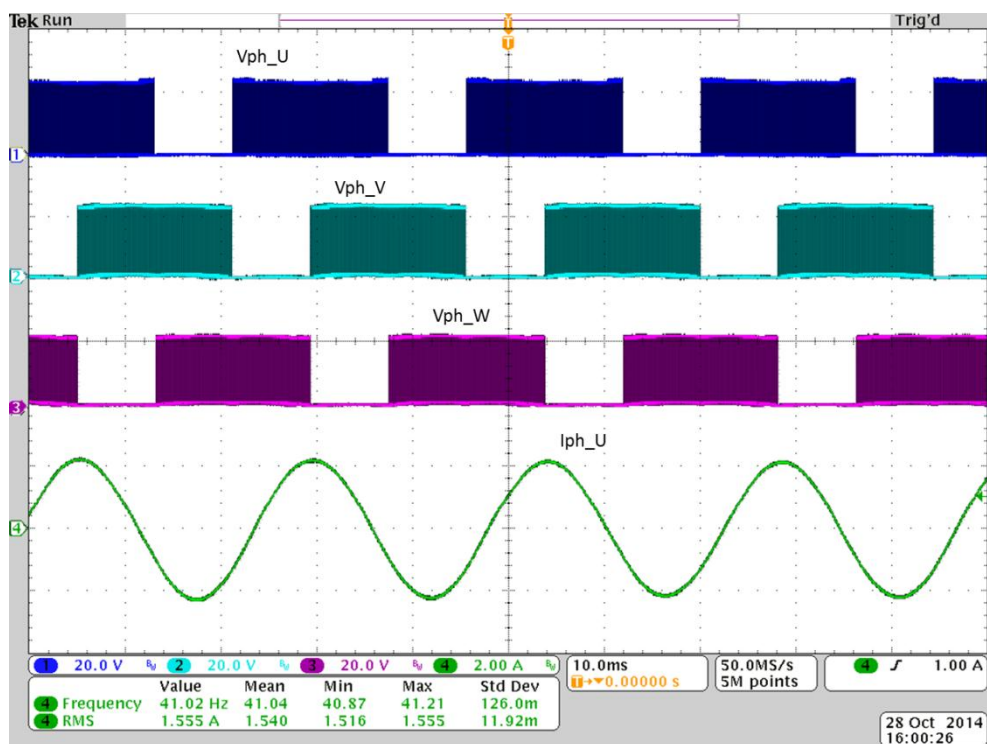


Figure5: Motor phase voltages & current at 310 rpm¹

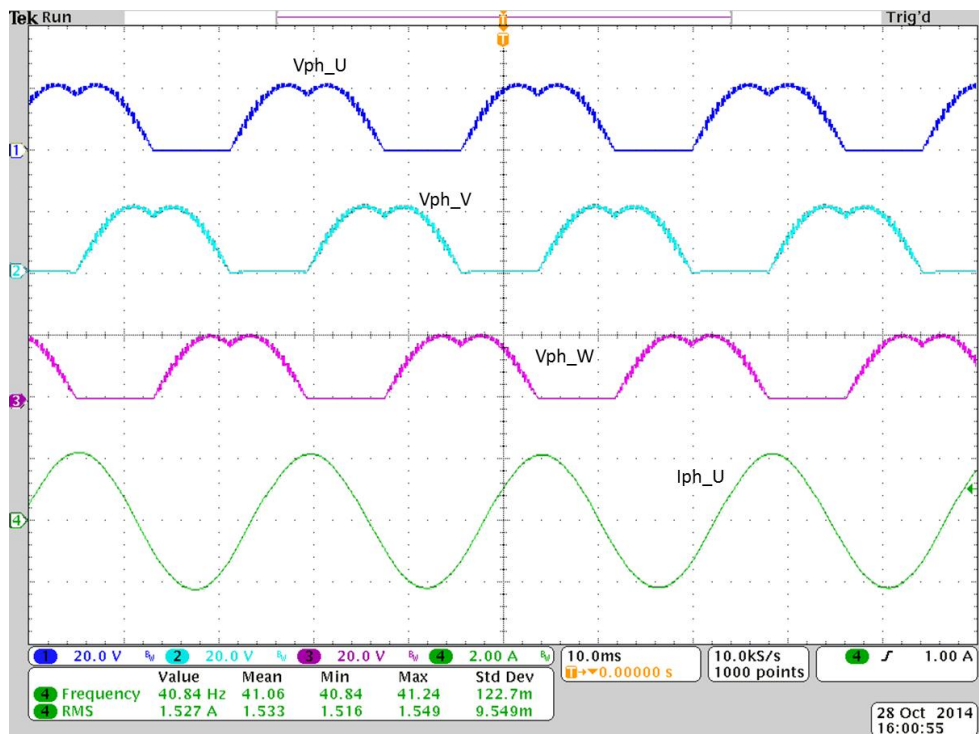


Figure6: Filtered Motor phase voltages & current at 310 rpm

¹ Motor rpm = 120 * 41.2 Hz / 16 ~ 310 rpm

3. **Start-up time:** Figure 7 and 8 below shows the motor start-up time at different line condition. The maximum start-up time occurs at low line condition i.e. at 90Vac and it is in range of 1.3 seconds, whereas at 230Vac it is in range of 700msec.

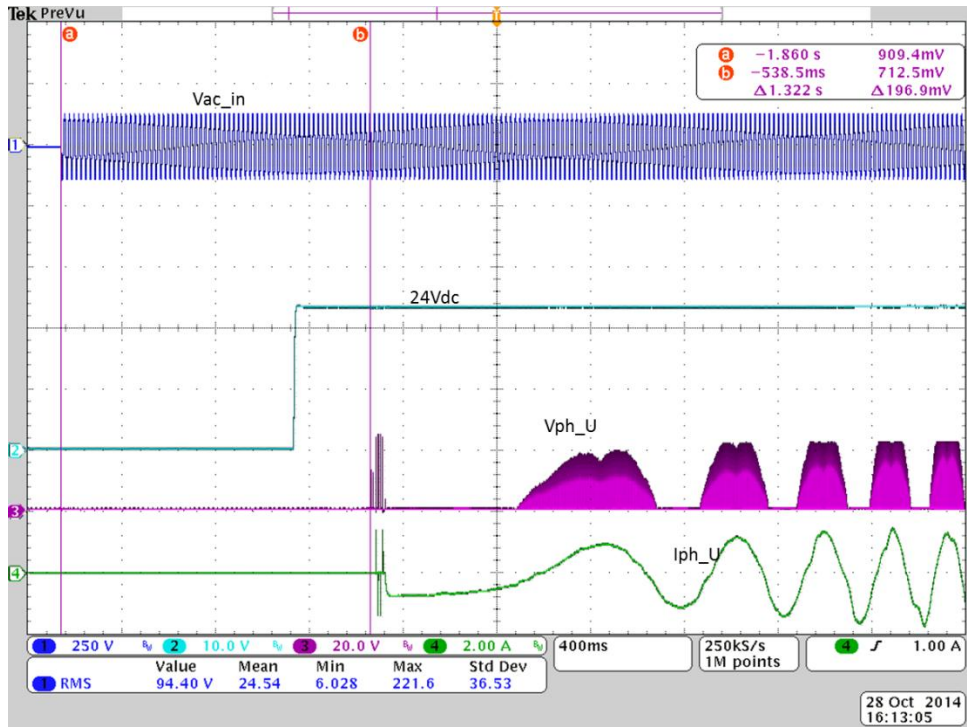


Figure7: Motor Start-up time at 90Vac

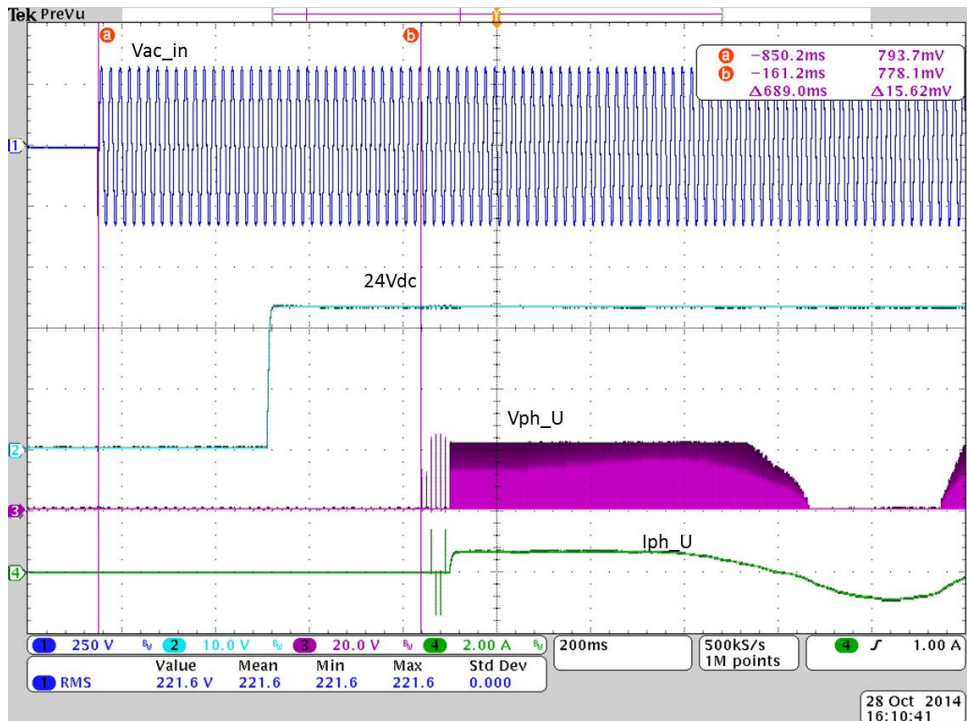


Figure8: Motor Start-up time at 220Vac

4. **Ripple voltage at 24Vdc:** One of primary goal of this reference design is to minimize power frequency ripple (100 Hz or 120Hz) in 24Vdc. This provides efficient utilization of sinusoidal control of DRV10983 to avoid low frequency noise and achieves best in class acoustic performance. The figures 9 and 10 capture ripple voltage and max ripple voltage is in range of 160mVpk-pk i.e. 0.6% of 24Vdc.

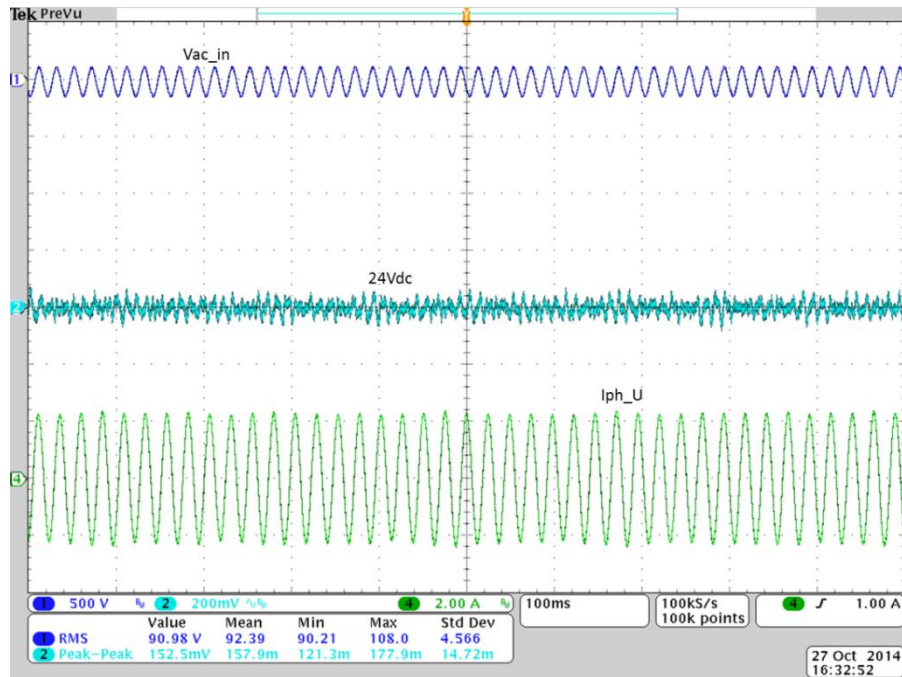


Figure9: 24Vdc ripple voltage at 90Vac & 310 rpm

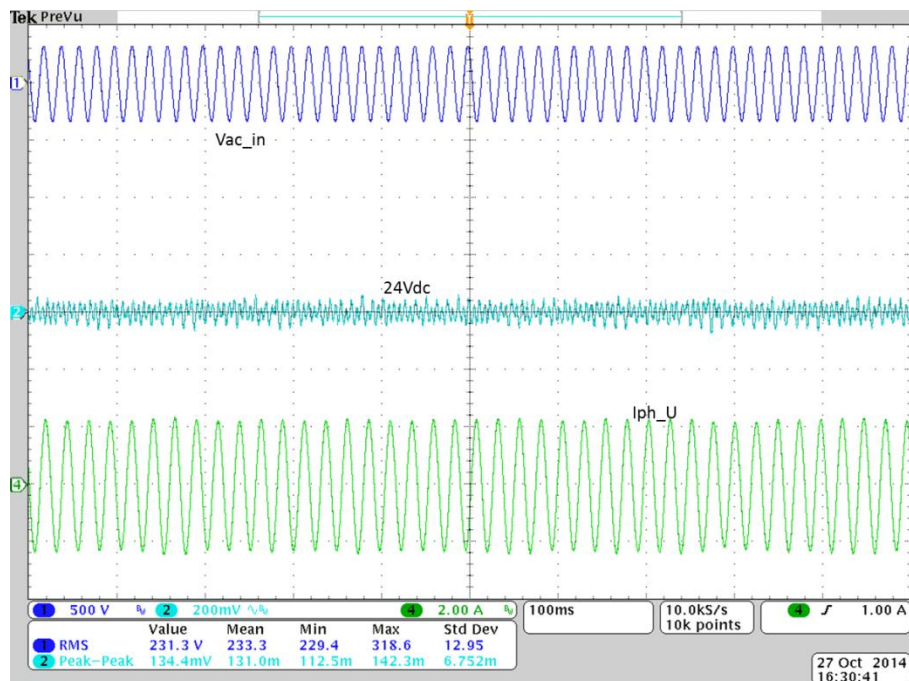


Figure10: 24Vdc ripple voltage at 230Vac & 310 rpm

5. **Thermal Image of test board:** Figures 11 and 12 shows thermal image of top and bottom of test board at 25⁰ Celsius ambient during 45watt input power. The maximum temperature rise of ~55⁰ Celsius is observed at DRV10983 case and snubber-diodes (D8/D9).

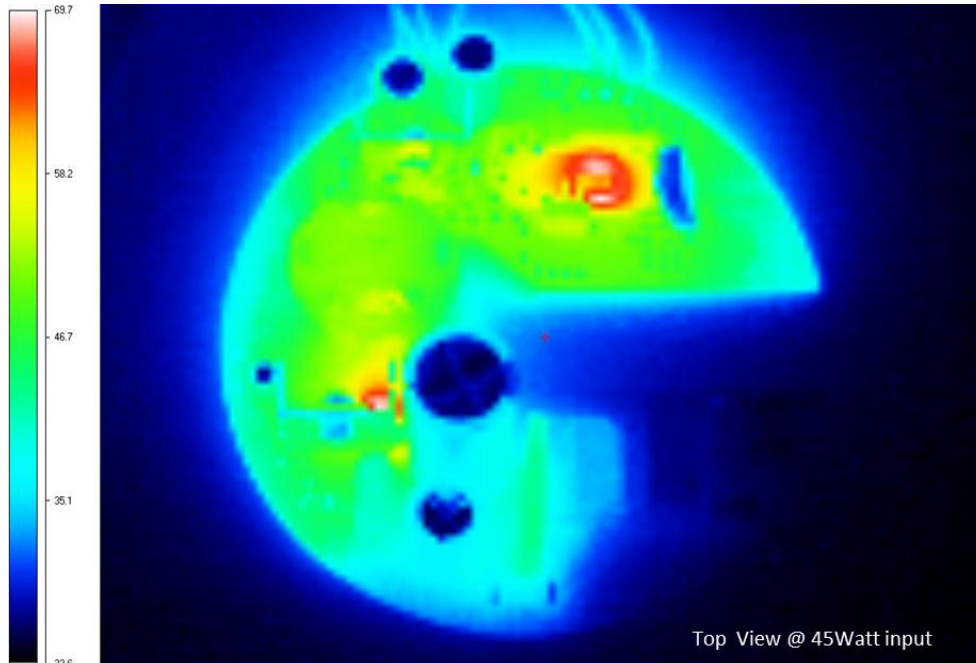


Figure11: PCB top side thermal image at 230Vac/ 45Watt input power

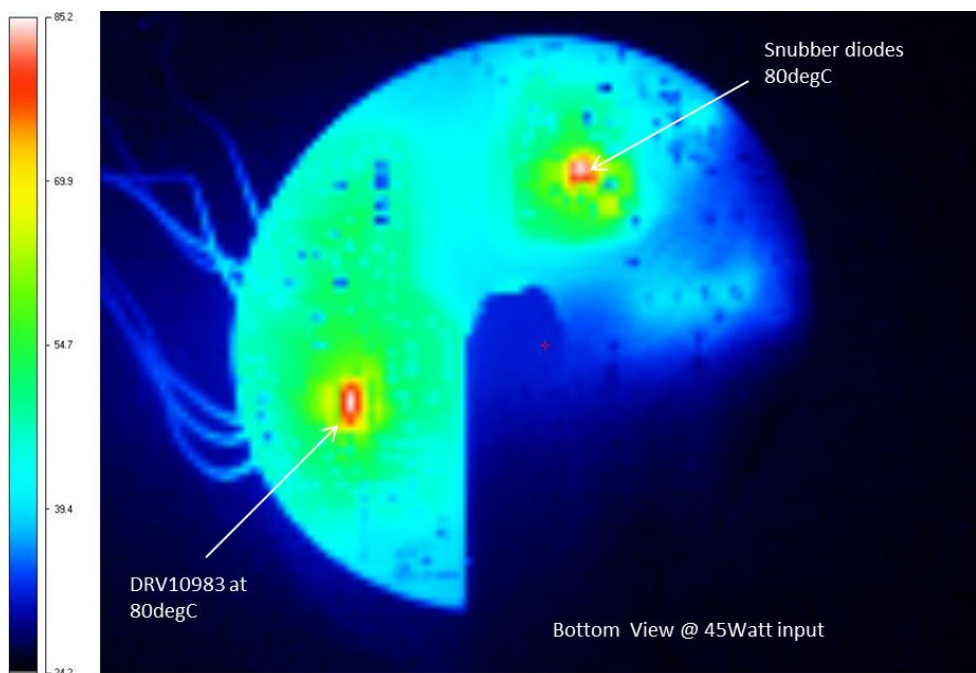


Figure12: PCB bottom thermal image at 230Vac/ 45Watt input power

Appendix-A

Instruction to change the IR (infra-red) remote key codes for speed control

Important Downloads:

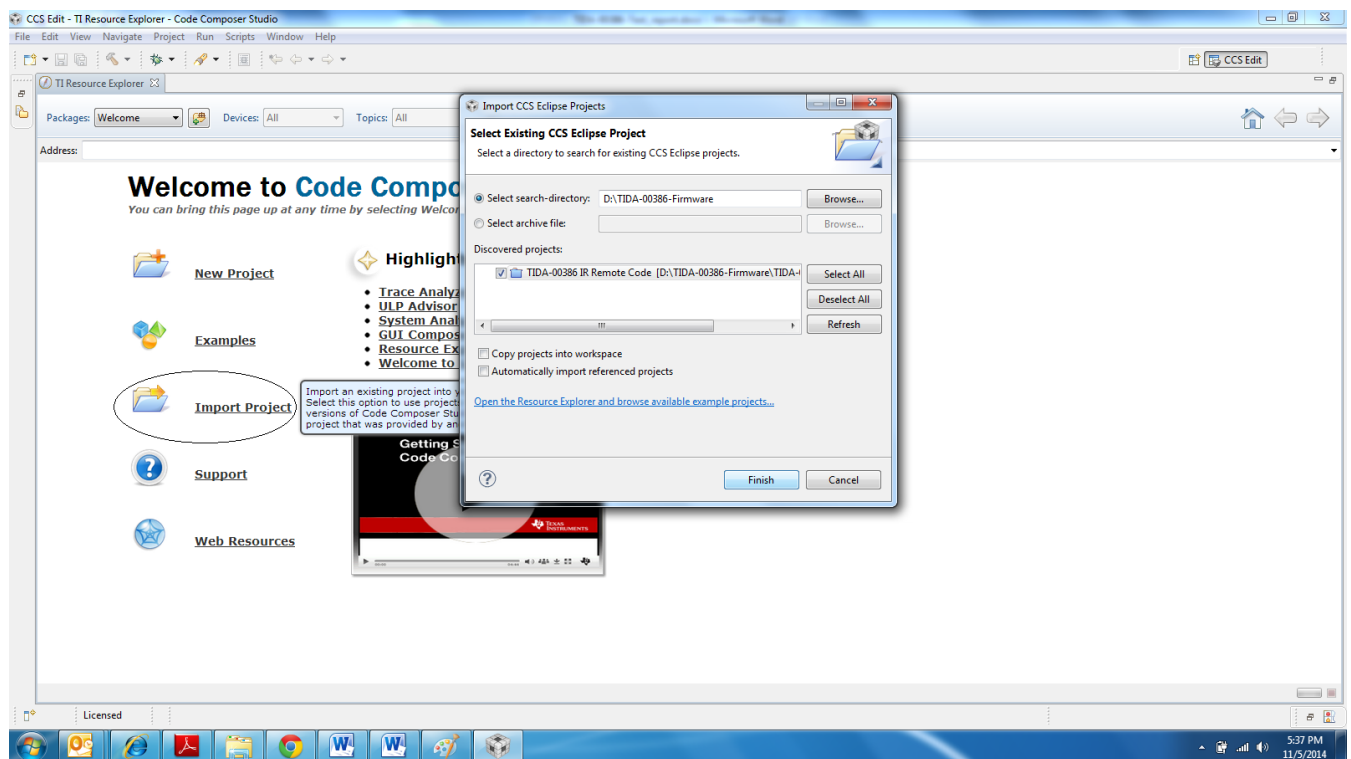
1. The firmware for this design is developed for MSP430G2201 using Texas's Instrument IDE- Code composer Studio version 5.5.0 (CCS), therefore as first step user must have CCS version 5.5.0 or any other latest version after 5.5.0. For details to download CCS refer to <http://www.ti.com/tool/ccstudio-msp430>.
2. Download TIDA-00386Firmware Project files from reference design webpage.

Hardware Set-up:

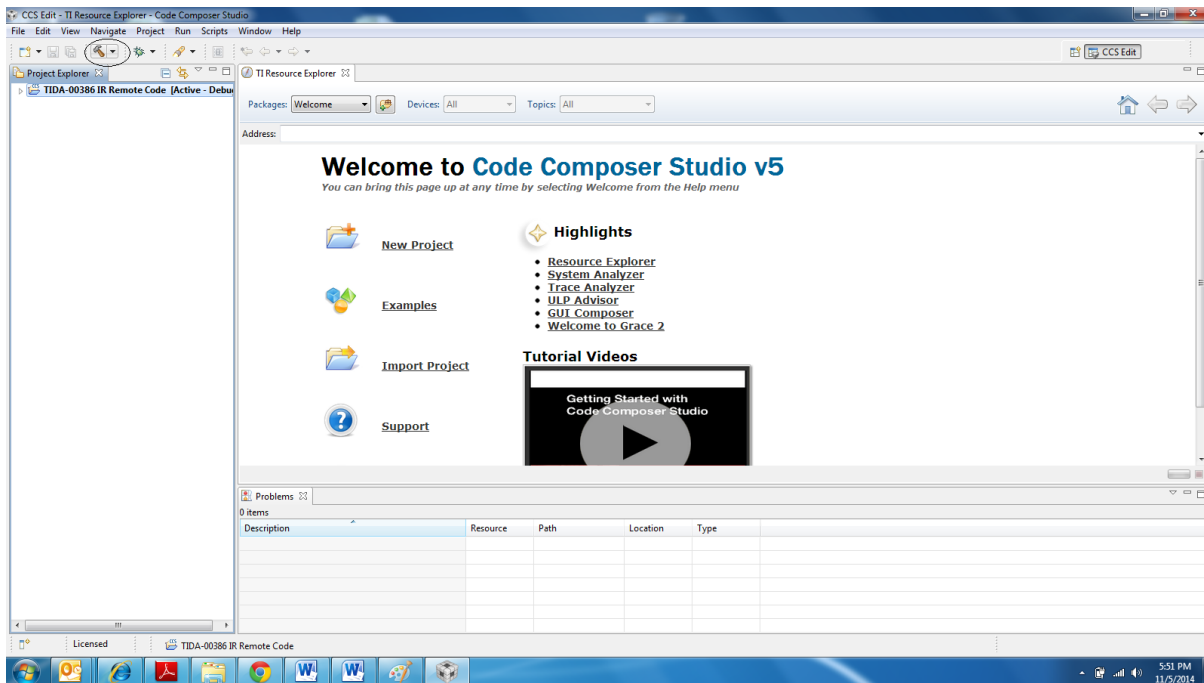
- To get the remote key-codes, do not apply main ac power to the board. Connector J2 on board provides 4-pin JTAG interface for SPI-BY-WIRE Programming. It has pin for 3.3V and any utility which provides SPI-Programming support, should be able to provide 3.3V to on-board devices, MSP430G2201 and IR sensor TSOP31338.

Steps to change remote key codes:

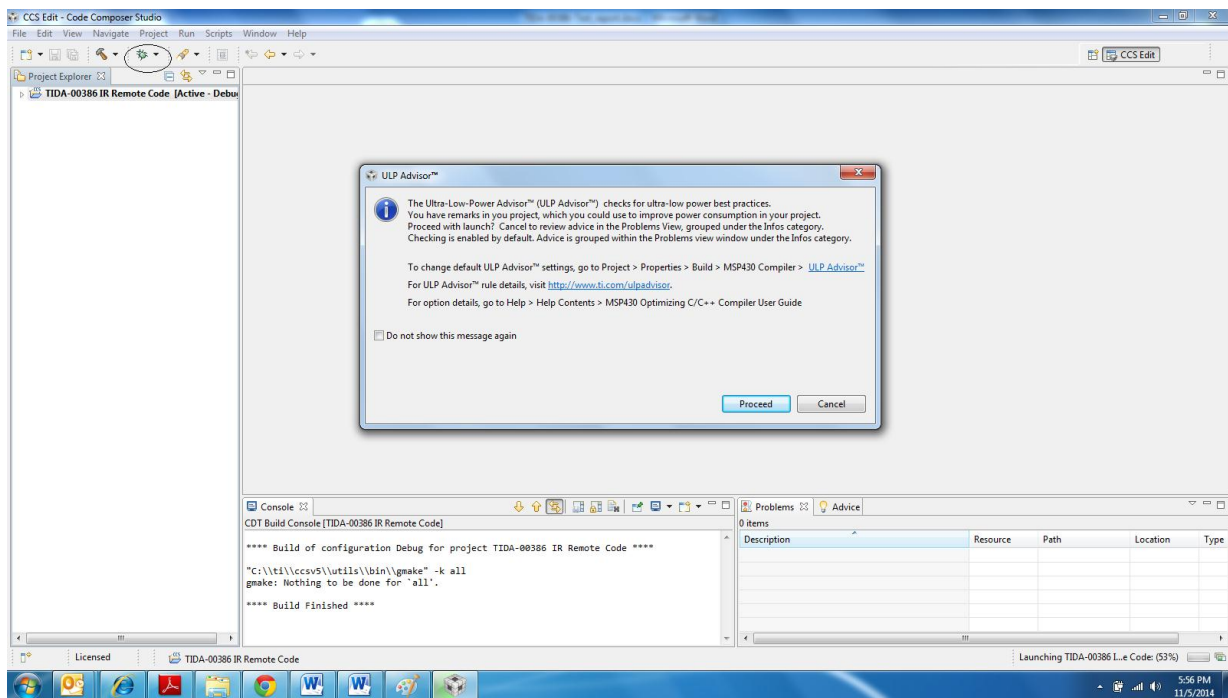
1. Launch code-composer studio. Select Import Project, Browse to the directory containing the firmware on pop-up window. Check the CCS project found and click on Finish button. You may choose to copy the project into workspace.



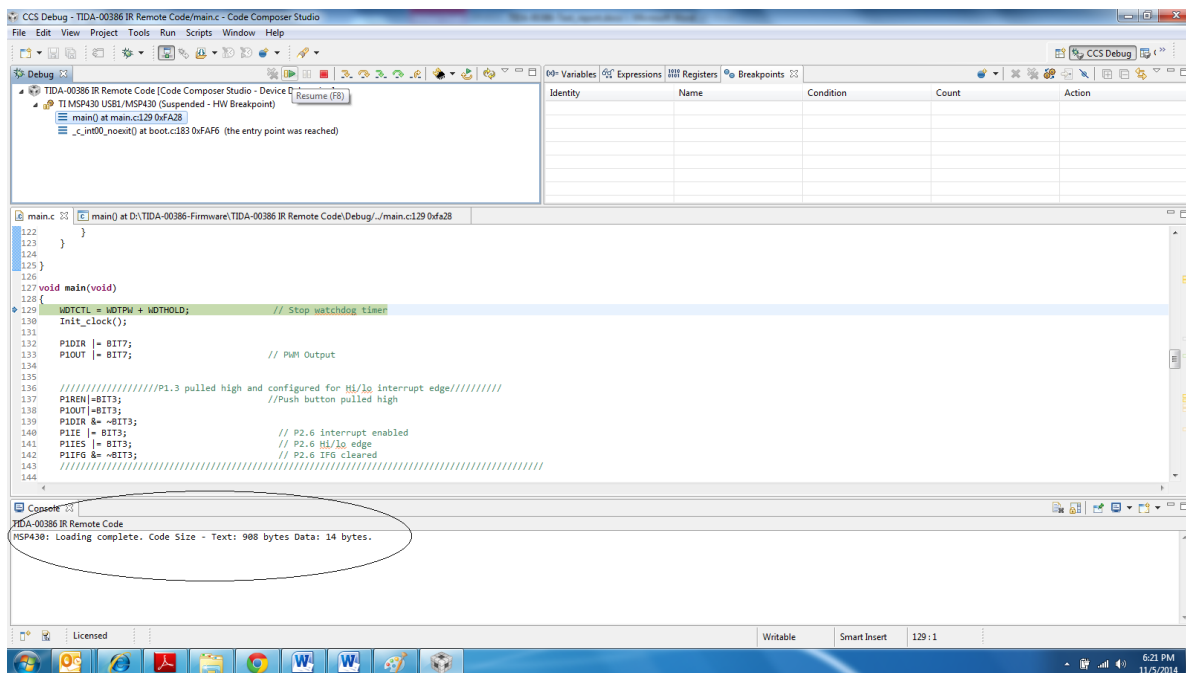
- Build the project, by first left clicking the project Title and then clicking the build button as shown below. Close TI resource explorer window.



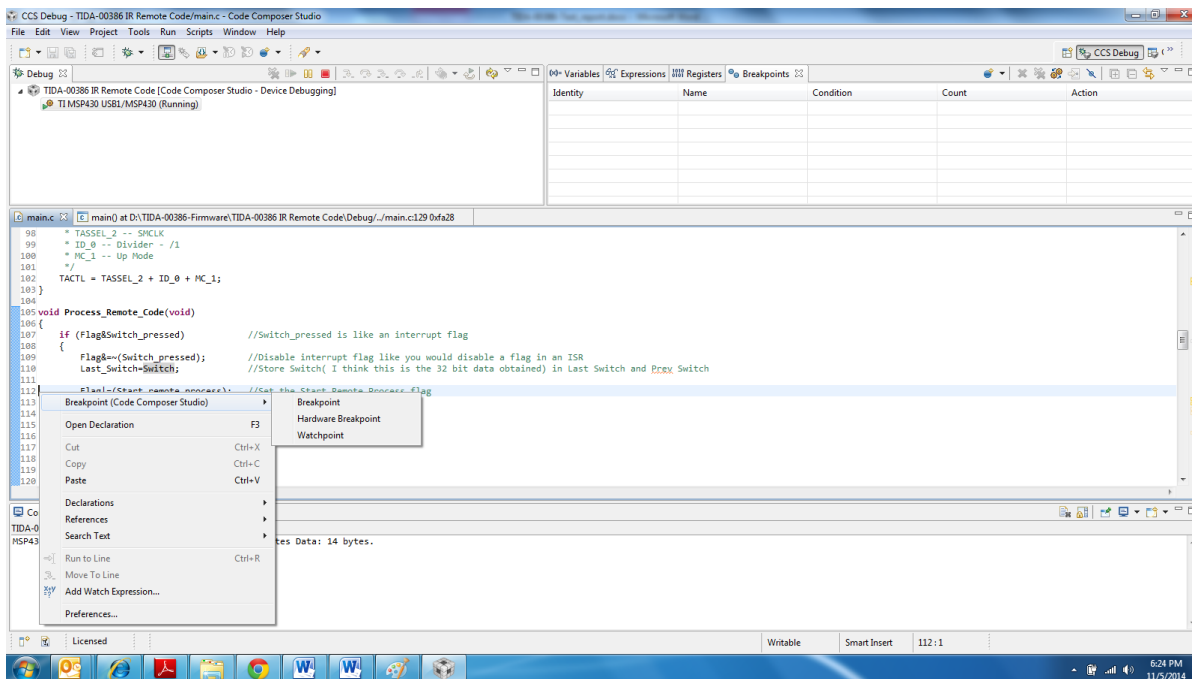
- Download the code by clicking Debug button. In case ULP advisor window appears, click Proceed. You may choose to select do not show again message option to avoid its appearance for future launches.



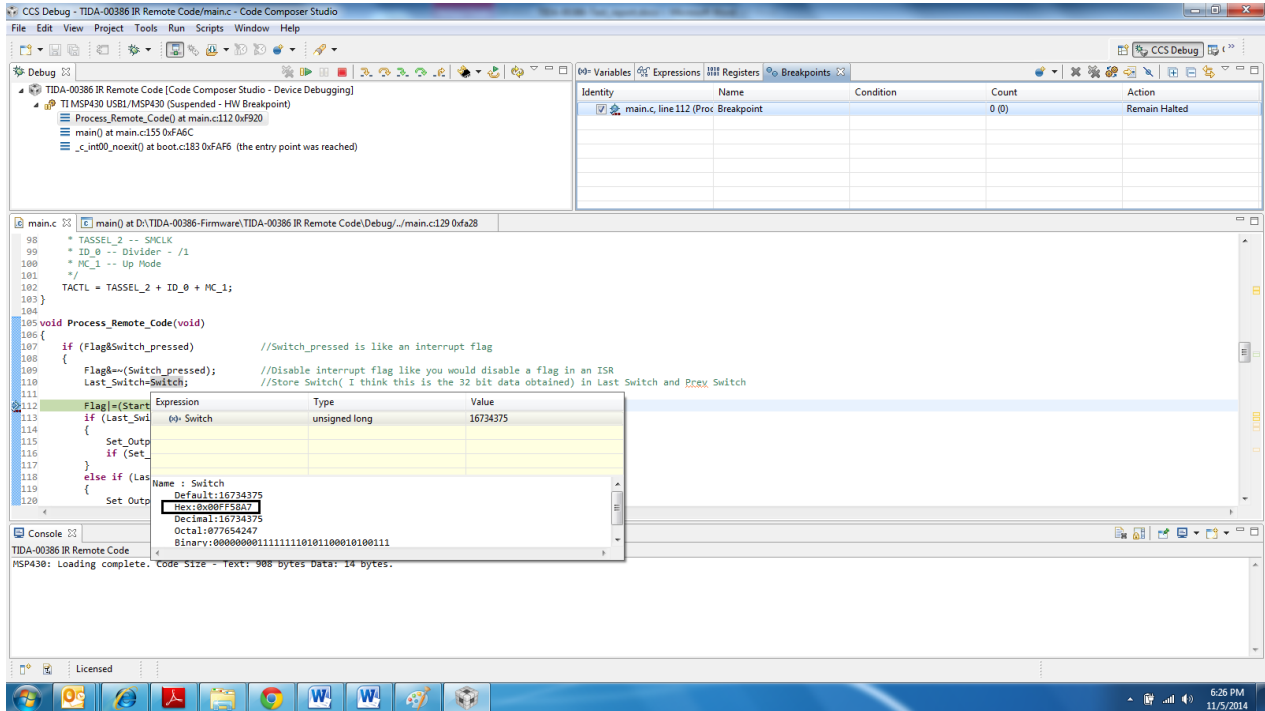
- Upon successful downloading the code, following window appears. Match the console message and click resume.



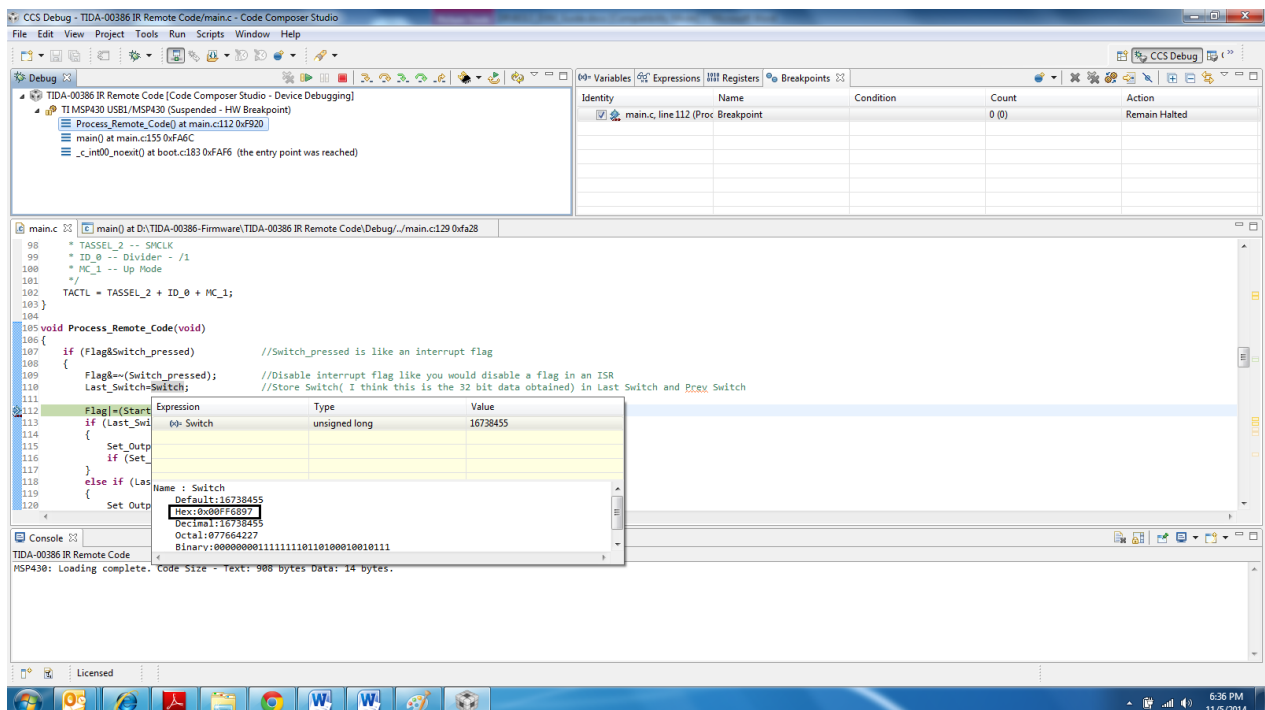
- Insert breakpoint by right clicking at line 112, (right side of 112) and then selecting breakpoint option from pop-up window.



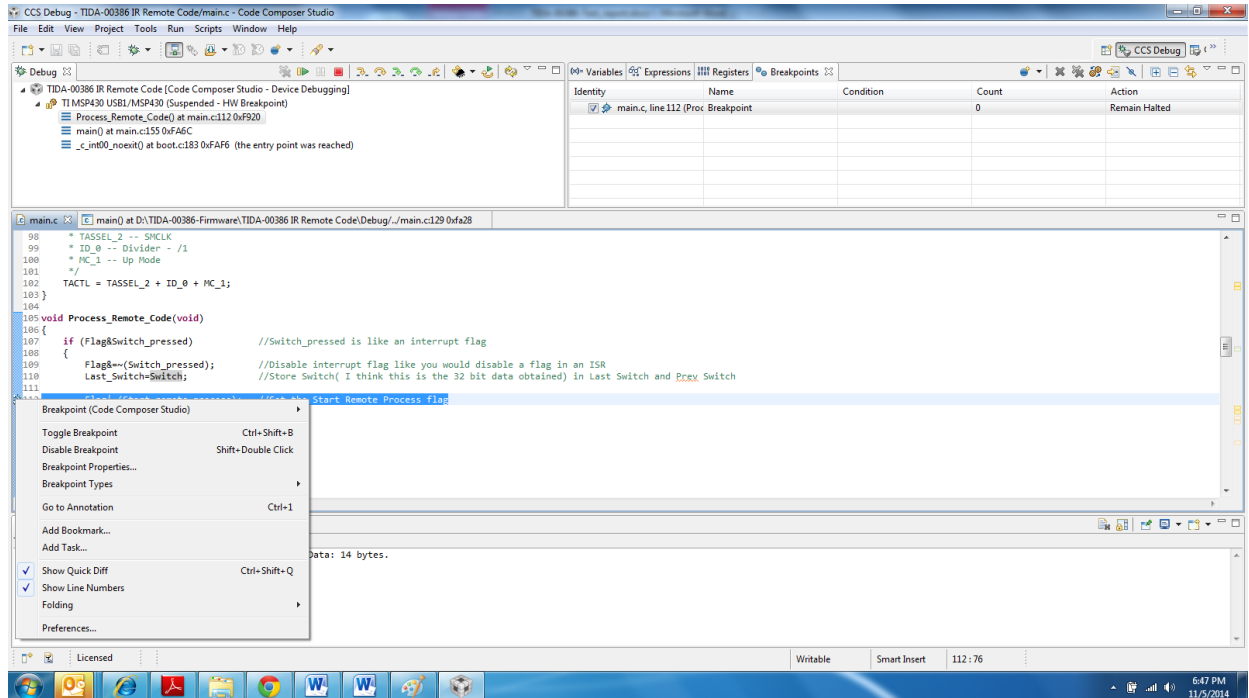
- Point your remote to IR sensor and press increment key. The code should come to halt at line 112. Move the cursor to variable "Switch" on line 110, a pop window will appear as shown below. Note down the Hex code, this is code for increment key of your remote.



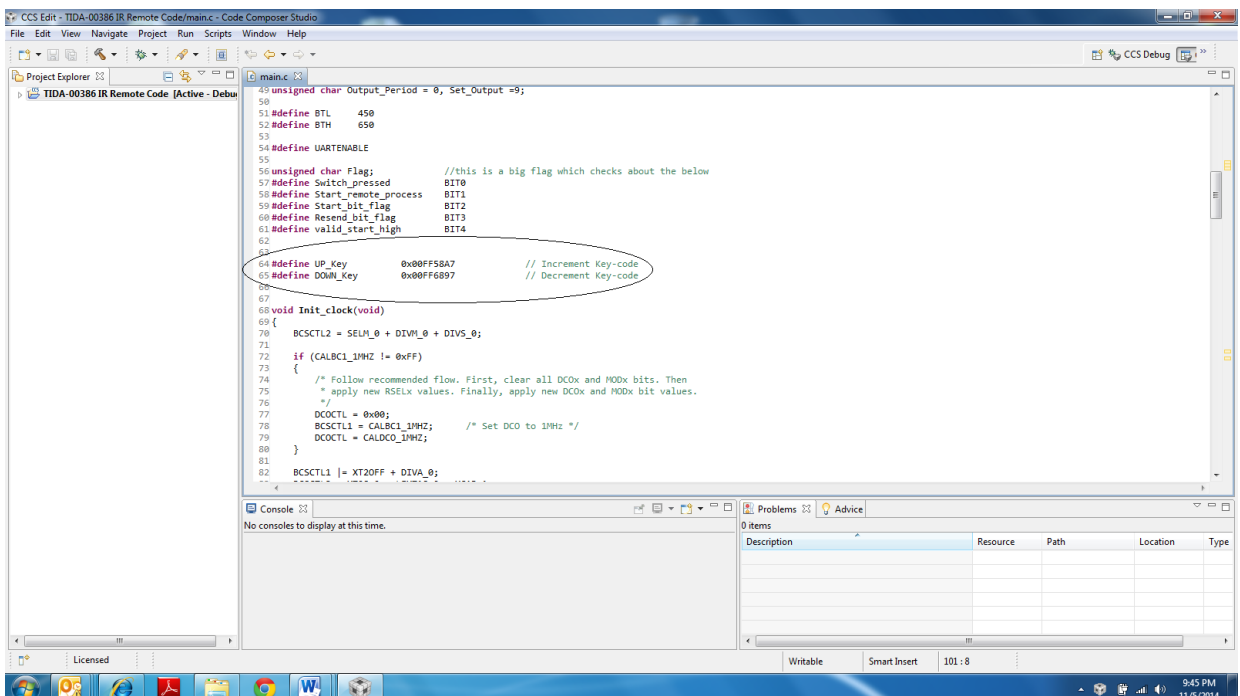
- Again resume the code as mentioned in step 4. Point the remote to IR sensor and press decrement key. Repeat the process as explained in previous step.



8. Repeat the step 6 and 7 two to three times, and make sure every time both key codes are same. Upon successful repetition, go to line 112 and disable the break-point by right-click exactly at break-point (left side of 112) and selecting "toggle breakpoint" option from pop-up window and terminate the debug launch by clicking red button next to resume.



9. Go to main.C and change the key-codes at line 64 and 65. Re-flash the new code as explained in step 3 & 4. New code is ready to use for speed control with your remote.



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