

Extending Dimming Range of TPS92210 Over Universal AC Range by Applying Frequency Modulation Scheme

Abhijeet Godbole

ABSTRACT

The TPS92210 is a natural power-factor correction LED driver with advanced energy features to provide high efficiency and performance characteristics. Many LED driver applications demand two-stage dimming or full dimming features. This application note specifically addresses techniques used to increase the dimming range of the TPS92210. At high line input voltages, the TPS92210 dimming range gets restricted, due to limitations on minimum on time and transformer turns ratio. This document explains techniques which involve frequency modulation to increase dimming over the universal AC range, specifically at higher input voltages.

Contents

1	TPS92210 as LED driver in Constant ON Time (COT) Mode	2
2	Dimming Techniques for Off Line LED Drivers	2
3	Limitations with Dimming TPS92210-Based LED Driver in Fixed Frequency COT Mode at High Line Voltages	4
4	Frequency Modulation Scheme for Enabling Extended Dimming at Higher Line Voltages	5
	4.1 TPS92210 Frequency Setting and Mode of Operation	5
	4.2 Frequency Modulation Scheme to Achieve Full PWM Dimming	5
5	Experimental Results and Switch Node Waveforms	7
	5.1 Dimming Performance	7
	5.2 Switch Node Waveforms	8
	5.3 Frequency Modulation With Respect to Percentage Dimming	9
6	Conclusion	9

List of Figures

1	TPS92210 used in Fixed Frequency Constant ON Time Mode	2
2	LED Current Dimming By Changing VREF	3
3	TPS92210 Operating Modes Based on Feedback Current	5
4	Frequency Modulation Scheme Based on PWM Duty Cycle Used for Dimming	5
5	TPS92210 Oscillator Frequency versus Feedback Current	6
6	Switch Node Waveform, Normal Operating Condition, 0% Dimming (Frequency of Operation = 90 kHz)	8
7	Switch Node Waveform, Normal Operating Condition, 30% Dimming (Frequency of Operation = 86 kHz)	8
8	Switch Node Waveform, Normal Operating Condition, 70% Dimming (Frequency of Operation = 50 kHz)	9
9	Frequency Modulation With Respect to Percentage Dimming	9

1 TPS92210 as LED driver in Constant ON Time (COT) Mode

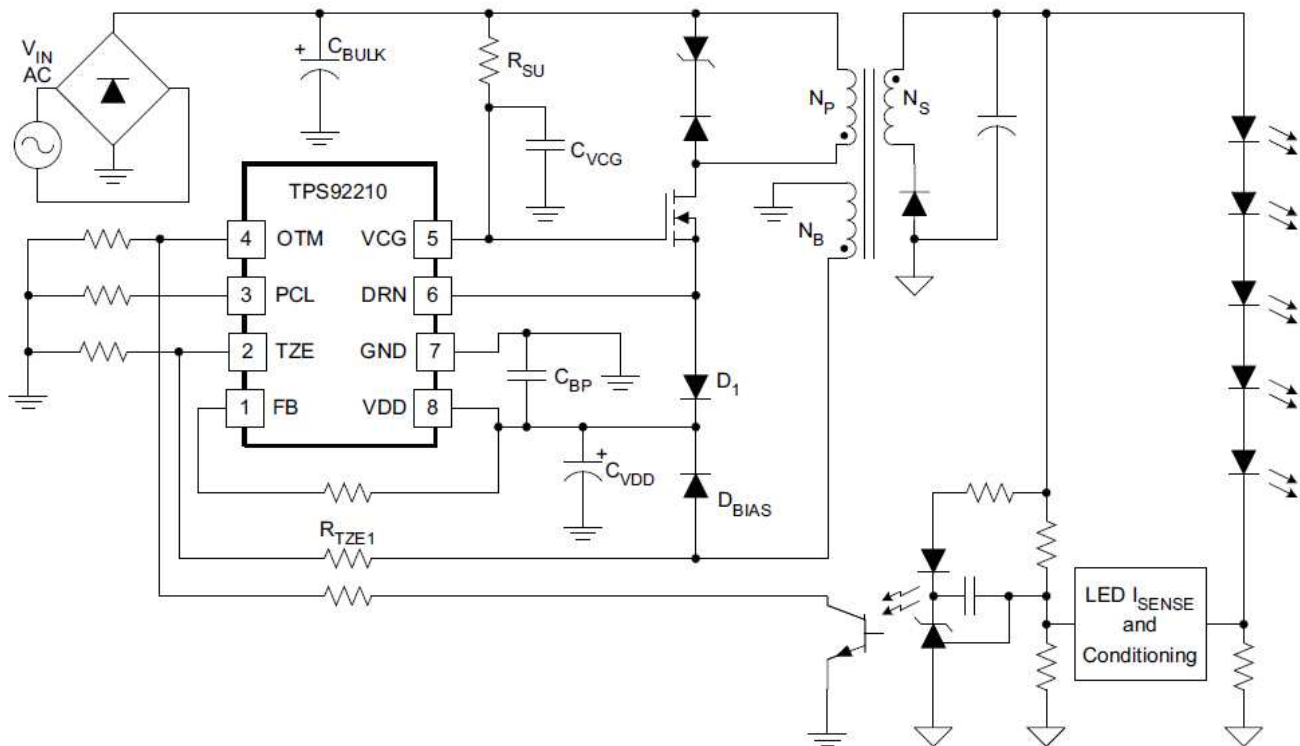


Figure 1. TPS92210 used in Fixed Frequency Constant ON Time Mode

A standard TPS92210 circuit operating in COT mode is shown in Figure 1. The TPS92210 controller can be programmed to operate at a fixed frequency with a COT for the internal switch which drives the primary power FET. The value of Bulk cap, CBULK, is kept small so that capacitor voltage follows full wave-rectified AC sine wave. The TPS92210 has an internal peak current control mechanism and thus eliminates any need for an external current-sense resistor. As the on time of the cascade switch and primary inductance of the transformer is kept constant, peak current through primary MOSFET is directly proportional to the input voltage. Peak primary current can be formulated as:

$$I_{\text{PRIM(peak)}} = \frac{V_{\text{BULK}} \times t_{\text{ON}}}{L_{\text{PRIM}}} = \frac{V_{\text{BULK}}}{k} \quad \text{where } k = \frac{L_{\text{PRIM}}}{t_{\text{ON}}} \quad (1)$$

The equation looks like the standard Ohm's equation with the proportionality constant 'k' analogous to resistance. Also, 'k' has Henrys/second as unit, which is equivalent to Ohms. Since the average (and RMS) current is directly proportional to peak current in discontinuous mode, the input current will also maintain the relationship to input voltage which eventually leads to better power factor.

2 Dimming Techniques for Off Line LED Drivers

There has been an exponential growth in the LED market over last few years. Many applications including household LED bulbs, such as GU10 and A19, to high wattage street lights ask for precise control of LED current. This section briefly describes different techniques used for dimming. Broadly there are three techniques used to dim LED drivers:

1. TRIAC Dimming
2. Analog Dimming
3. PWM Dimming

TRIAC dimming is a traditional way of dimming with fluorescent and incandescent lights. LEDs are a viable light source that can replace these traditional sources with increased lumens per watt and enhanced characteristics such as power factor and efficiency. So, there is a need for LED drivers which are compatible with traditional TRIAC dimmers. TI has a wide offering of TRIAC dimmable LED drivers. More information regarding this is found in TI's [power management](#) section.

In analog dimming, light intensity variation is achieved by changing LED current. This can be done by changing a reference voltage used to set LED current either by means of simple potentiometer or by chopping the reference voltage with PWM and using an averaged value as voltage reference. This technique is more simple than PWM dimming as far as the dimming circuit and overall cost is concerned.

In PWM dimming, light intensity variation is achieved by turning LEDs on and off but keeping LED current constant. The frequency of the on-off cycle must be greater than 200 Hz to avoid any flickering effects. As the driver stage is turned off and on at a particular rate there is an issue with inrush currents at every start cycle. This issue can be addressed by using a shunt device across LEDs instead of turning the driver on and off. This shunt device, preferably a fast-switching MOSFET, will reduce start up delay time and inrush currents. Though PWM dimming is a more sophisticated way of doing LED dimming, it will add up to extra component cost and a somewhat complex dimming circuit to LED driver.

Figure 2 explains the dimming scheme used for this particular design. In this case, the PWM signal is used to chop the analog voltage reference which is used to set LED current. The duty cycle of the PWM signal sets the reference voltage that eventually monitors LED current.

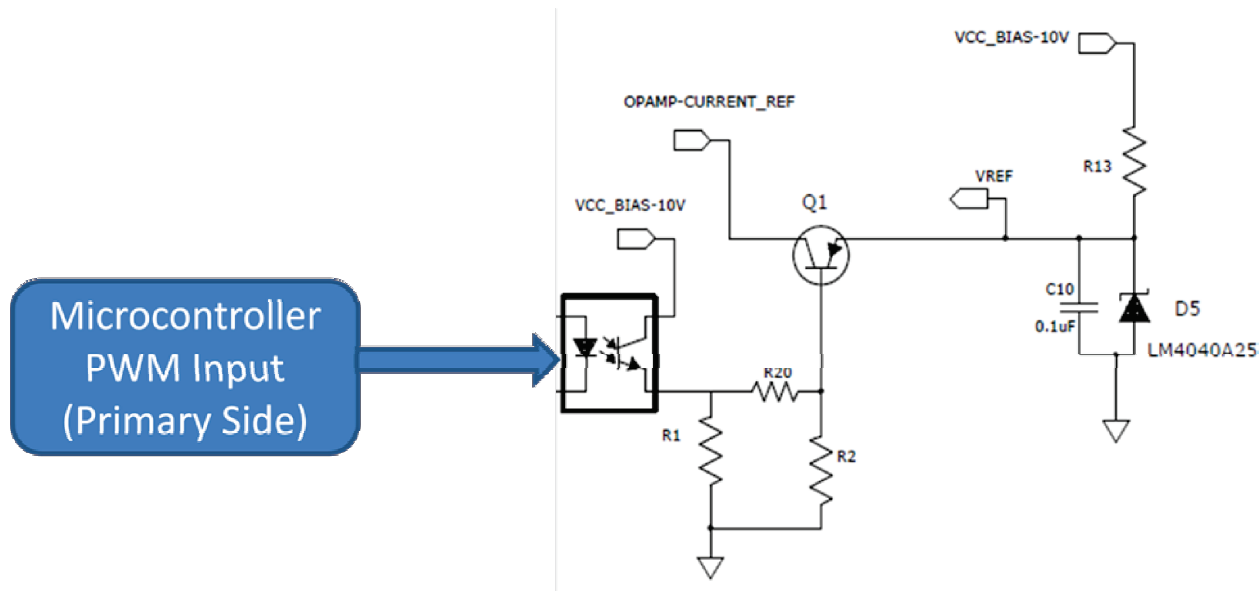


Figure 2. LED Current Dimming By Changing VREF

3 Limitations with Dimming TPS92210-Based LED Driver in Fixed Frequency COT Mode at High Line Voltages

As discussed earlier, the TPS92210 is operated in fixed-frequency COT mode when used as an LED driver. In this mode, the frequency of the TPS92210 is set by feeding a certain amount of current in the feedback pin (Pin 1) through a regulated DC source. For this particular design the following parameters are fixed:

- Operating frequency of SMPS
- Transformer primary inductance
- Transformer turns ratio

Dimming is generally achieved by reducing the voltage reference used to set output LED current. With high input line voltages; the on time of the switch reduces in accordance with the increase in percentage dimming. The TPS92210, when used in fixed frequency COT mode, has limitations on the MOSFET's minimum and maximum on time.

- Minimum on time (Typically 0.85 μ s)
- Maximum on time (Typically 5 μ s)

At higher line voltages and with increased dimming internal MOSFETs on time reduces. With a fixed turns ratio and operating frequency, the TPS92210 is unable to go beyond a certain dimming percentage, typically when the design has higher LED output voltage, that restricts the turns ratio to lower values for a lower reflected voltage. This confines dimming to a particular range typically at higher line voltages based on design parameters.

4 Frequency Modulation Scheme for Enabling Extended Dimming at Higher Line Voltages

4.1 TPS92210 Frequency Setting and Mode of Operation

The TPS92210 frequency in COT mode can be set by sourcing current in the feedback pin (Pin 1). An appropriate value resistor is connected from V_{DD} to the feedback pin to set the desired operating frequency. Please refer to TPS92210 datasheet ([SLUS989](#)) for further working details.

Based on the amount of current sourced in the feedback pin, the TPS92210 operates in three different modes as shown in Figure 3. Thus, by modulating current sourced in the feedback pin according to the dimming source, (in this case PWM scheme) the TPS92210 can work at lower frequencies when a higher degree of dimming is required. As other performance parameters such as turns ratio and primary inductance are fixed and set by design, modulating operating frequency allows you to achieve full dimming over the entire range.

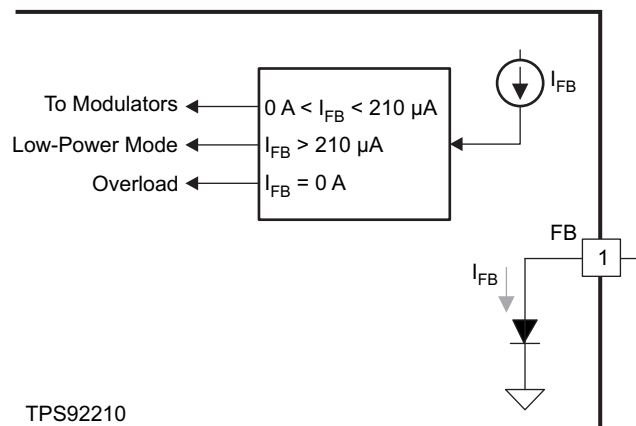


Figure 3. TPS92210 Operating Modes Based on Feedback Current

4.2 Frequency Modulation Scheme to Achieve Full PWM Dimming

Case 1. When percentage dimming achieved is directly proportional to PWM duty cycle:

As discussed in the previous section, the TPS92210 operating frequency can be modulated with respect to PWM applied for the dimming. When percentage dimming achieved is directly proportional to the PWM duty cycle used for dimming, an averaged PWM output can be used as additional DC source at the feedback pin (Pin 1) to modulate frequency. The arrangement in Figure 4 can be done to force extra current in the feedback pin, depending on your dimming percentage.

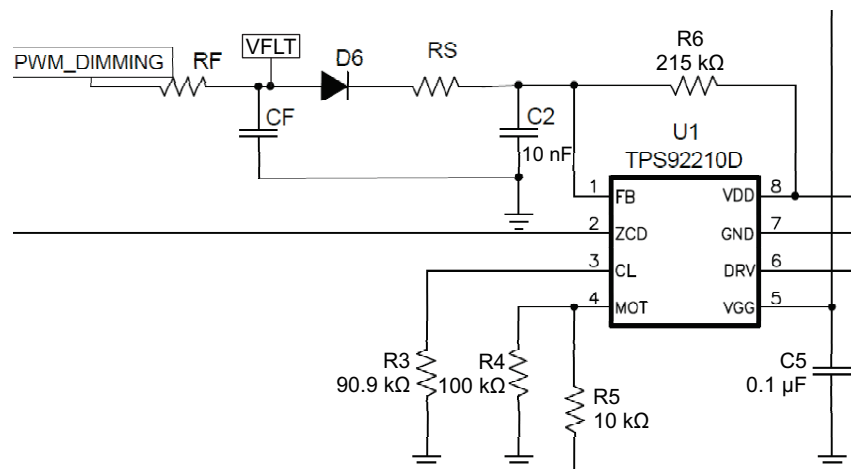


Figure 4. Frequency Modulation Scheme Based on PWM Duty Cycle Used for Dimming

An average value of PWM can be achieved by filtering it through a simple low-pass RC filter made by RF and CF. This averaged value of PWM is then fed through a series resistor, RS, to the feedback pin. This arrangement introduces additional current in the FB pin which is given by:

$$I_{FB-modulation} = V_{FLT} / R_S \tag{2}$$

As feedback current increases, the TPS92210 operates at lower switching frequencies. The RS value decides the amount of extra current fed to the feedback pin, therefore, decides the range of frequency modulation. The RS value should be calculated accurately based on the design parameters and the percentage of dimming required.

The TPS92210 gives satisfactory results with the dimming feature at lower line voltages. So this circuit should not affect the function of the TPS92210 under normal conditions. Thus; CF, RF, and RS values should be carefully selected so that this circuit becomes active after certain thresholds of dimming percentage.

Consider the following design example which explains how to select RF, CF, and RS component values:

VAC range: 90 V to 280 V, frequency of operation under normal condition: 85 kHz

Desired frequency variation: 85 kHz to 30 kHz

Assume frequency modulation is required after 50% dimming

To set an operating frequency of 85 kHz, feed a current of around 75 μA in the feedback pin. Based on VDD value, an appropriate resistor needs to be connected from VDD to the feedback pin.

Referring to Figure 4, suppose PWM has peak voltage of VPEAK. With 50% duty cycle and assuming filter attenuation about 10%, an averaged filter value VFLT can be stated as:

$$V_{FLT} = \text{Duty Cycle} \times V_{PEAK} \times 0.1 = 0.5 \times V_{PEAK} \times 0.1 \tag{3}$$

Diode D6 is added to isolate this circuit from VDD supply. Referring to Figure 4, the amount of extra current fed in to the feedback pin can be calculated as:

$$I_{FB-modulation} = (V_{FLT} - V_{FWD6} - V_{FB}) / R_S \tag{4}$$

Figure 5 shows frequency variation with feedback current.

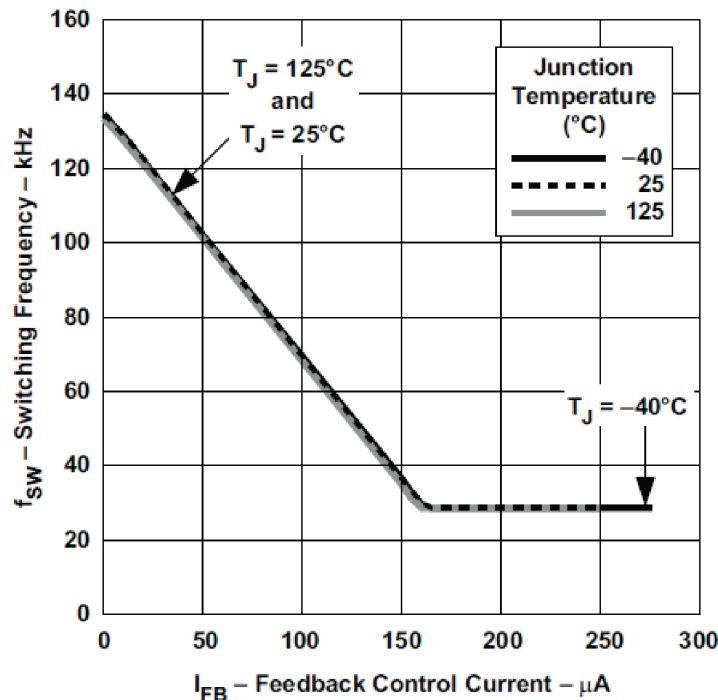


Figure 5. TPS92210 Oscillator Frequency versus Feedback Current

Figure 5 illustrates that to achieve frequency modulation from 85 kHz to 30 kHz, a feedback current variation of around 100 μA is required.

Based on [Equation 4](#), the value of **RS** can be calculated to achieve the desired frequency modulation.

Case 2. When percentage dimming is inversely proportional to PWM duty cycle:

When the percentage dimming achieved is inversely proportional to the PWM duty cycle used for dimming, then this PWM has to be inverted to get 180° out-of-phase waveform. This can be done by using a simple NPN transistor as an inverter. The inverted PWM then can be fed to the circuit described above, to achieve frequency modulation.

5 Experimental Results and Switch Node Waveforms

5.1 Dimming Performance

Table 1. Performance Characteristics of TPS92210 at 275 VAC over Entire Dimming Range⁽¹⁾

Percentage Dimming (%)	I _{LED} (mA)	V _{FLT} (Volts)
0	730	0.00
10	660	0.28
20	590	0.60
30	520	0.90
40	450	1.20
50	370	1.57
60	300	1.85
70	230	2.15
80	160	2.39
90	80	2.60
100	00	2.90

⁽¹⁾ V_{IN} = 275 V_{AC}, V_{OUT} = 42 V, I_{LEDMAX} = 730 mA

5.2 Switch Node Waveforms

The waveforms illustrated in Figure 6 through Figure 8 are all operating under normal conditions ($V_{IN} = 275 V_{AC}$, $V_{OUT} = 42 V$, $I_{LEDMAX} = 730 mA$).



Figure 6. Switch Node Waveform, Normal Operating Condition, 0% Dimming (Frequency of Operation = 90 kHz)

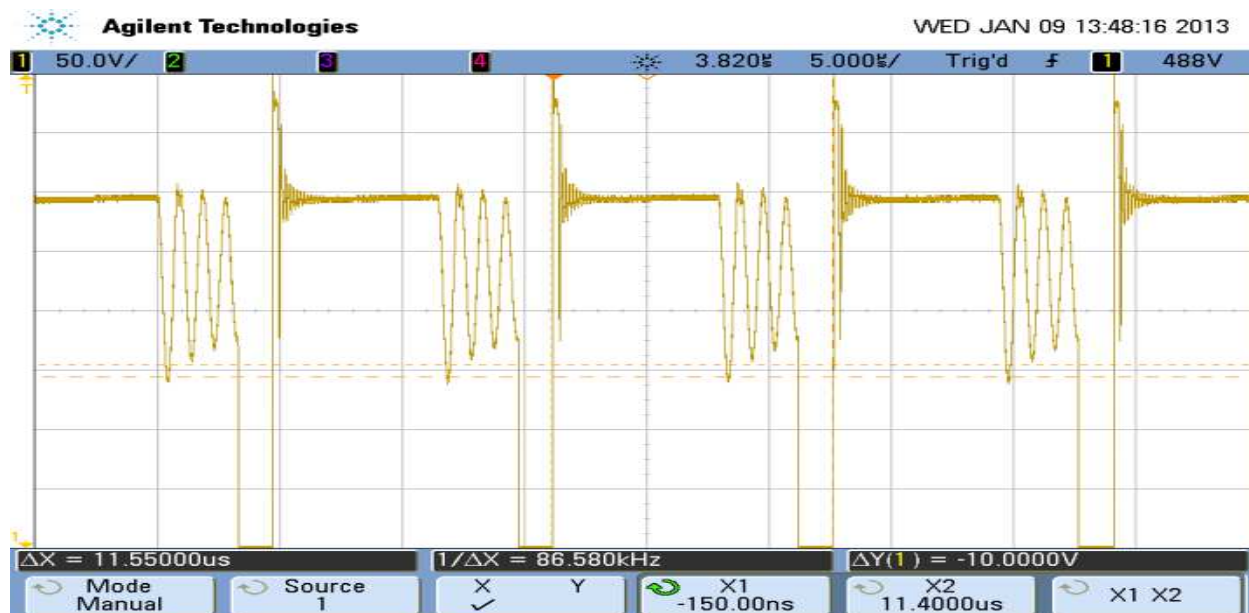


Figure 7. Switch Node Waveform, Normal Operating Condition, 30% Dimming (Frequency of Operation = 86 kHz)

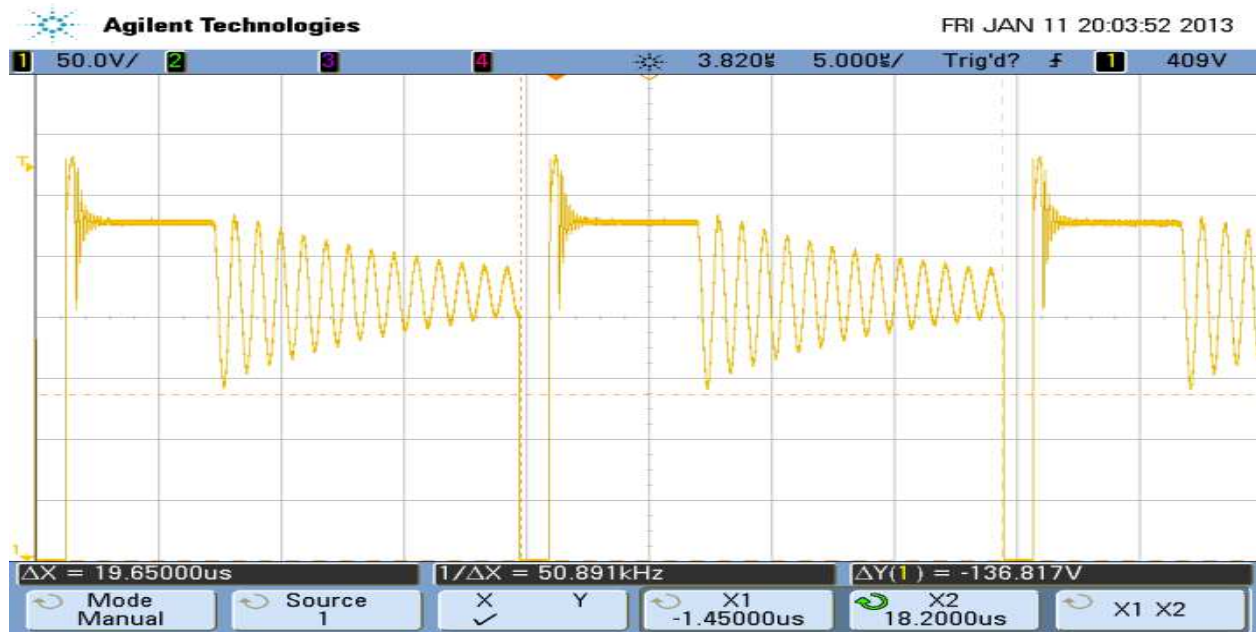


Figure 8. Switch Node Waveform, Normal Operating Condition, 70% Dimming (Frequency of Operation = 50 kHz)

5.3 Frequency Modulation With Respect to Percentage Dimming

Figure 9 illustrates the frequency modulation with respect to percentage dimming.

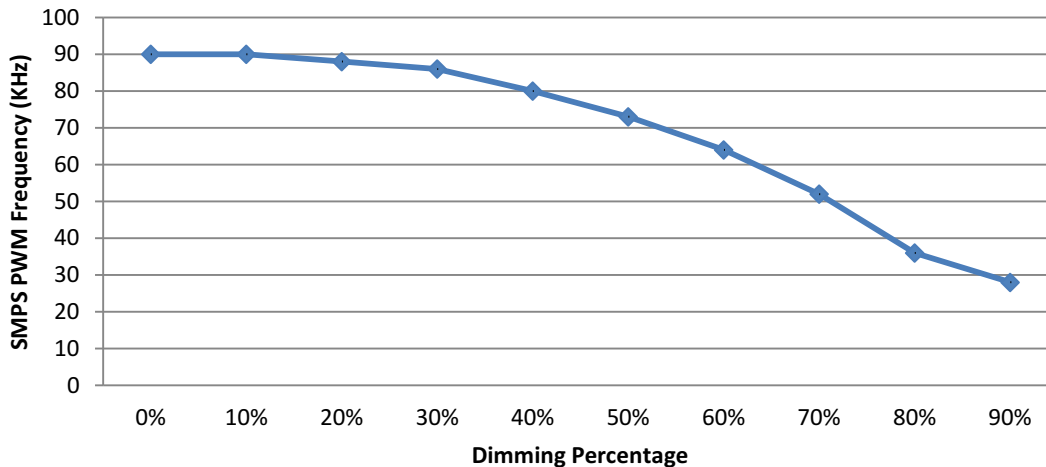


Figure 9. Frequency Modulation With Respect to Percentage Dimming

6 Conclusion

The TPS92210, when used in COT mode, has certain limitations for dimming at higher input line voltages. The dimming range of the TPS92210 can be extended by doing accurate frequency modulation with respect to dimming percentage. The same can be achieved by modulating current sourced in the feedback pin. Experimental results and waveforms are given to show the effectiveness of the frequency modulation scheme. Designers need to do specific changes and choose frequency modulation circuit components accurately depending on design parameters, performance characteristics, and the extent of dimming required.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com