A new primary side regulation constant voltage (PSR-CV) two-stage solution is proposed in this paper to avoid low frequency current ripple and to maintain high power factor, low cost compared with currently single stage and conventional three-stage solution in analog LED dimming or non-dimming application. PSR-CV is employed in primary side to achieve high power factor, simple circuit combined with secondary DCDC stage to eliminate low frequency current ripple and implement dimming function. Furthermore, system cost is reduced due to no need secondary voltage or current-sense circuit, opto-coupler and low voltage stress component in secondary side. Moreover, PSR-CC (constant current) and PSR-CV two-stage solution are contrastive analyzed. Finally, one prototype is built based on PSR-CV and tested to verify the effectiveness of the presented LED driver.

Introduction
Nowadays, a growing trend in the LED lighting is no line frequency and low ripple current while maintains high PF. Japan market requires ripple ratio of the lamp current should be less than "1.3" and ripple frequency should be larger than 100Hz, Energy star has similar requirement, output operating frequency ≥120Hz [1].

Figure1 - Energy star requirements for integral LED lamps.
Meanwhile, the tendency in LED lighting driver is PSR constant current (PSR-CC) with Single-flyback topology due to its simple circuit and low cost. Nothing comes for free, the biggest drawback of PSR-CC solution is line frequency ripple current and it needs large output capacitor to suppress current ripple (Figure 2).

![Figure 2 Line frequency ripple current in 17W single stage](image)

In order to have high PF, single stage PFC PSR-CC doesn’t have bulk E-cap, therefore it can’t eliminate line frequency ripple current. In some high end lighting application, single stage PSR-CC can’t be used. Traditional solution is using three-stage: PFC stage, Flyback converter stage and secondary DCDC stage to solve this issue, as show in Figure 3.

![Figure 3 Three-stage solution](image)

Obviously, the circuit is too complex and it has more components, not cost effective, space saving, even though the performance is good. In this paper, two stage solution is derived by adopting PSR technology, it saves one stage cost while maintain high performance—no line frequency ripple current and high PF. The circuit performance analyses of PSR-CC and PSR-CV solution are listed in section 1; how to achieve two stage PSR-CV solution are given in section 2. The experimental results of two-stage PST-CV solution prototype are given in section 3; the last section summarized the conclusions drawn from the investigation.

1. Two-stage solution
In terms of PSR technique depends on your control target it has two control methods: constant voltage regulation and constant current regulation. Because LED current
determines luminous intensity, so single stage PFC PSR-CC is steady used in lighting application.

In order to remove line frequency ripple current and meet strictly standards we must use multi-stage solution. Since PSR technique doesn’t need secondary feedback loop, opto-coupler and its tight regulation make two-stage solution comes true. Based on three-stage solution, we can achieve two-stage solution with PSR technique through two different ways:

1.1 Two-stage PSR-CC
The first two-stage PSR solution is that combine Flyback converter stage and secondary DCDC stage to one stage to obtain isolation and driving, dimming LED function, the left one stage is PFC stage. As we can see in Figure 4, the LED current is controlled in primary side so the solution is also named two-stage PSR-CC.

Two-stage PSR-CC solution is well accepted in market, especially in phase cut dimming area----dimming signal comes from AC line. But in analog or PWM dimming, things are different. Since dimming function is done at primary side, considering safety, this solution needs transformer to isolate dimming signal. And it’s primary dimming, dimming control is a little complex and not easy to achieve. Another thing is relative poor CC regulation due to PSR-CC is weak point in high end lighting application. Also dimming range is another concern for this topology.

1.2 Two-stage PSR-CV
Based on single stage solution and two stage PSR-CC solution, a new two stage structure is coming out which is suitable for no line frequency current ripple application. The key point is that combine PFC stage and Flyback convert stage to single stage to achieve PFC and isolation functions as we all know [2]. The big difference compared to
PSR-CC is that this single stage only control secondary output voltage not output current, hence it’s called PSR-CV. The right stage is DCDC stage which is used to drive or dim LED. As show in Figure 5, two-stage PSR CV has very clear function stage: PFC function is achieved in primary side and LED driving is implemented in secondary side which will reduce circuit difficulty and easy to design.

![Figure 5 Two-stage PSR-CV solution](image)

Two-stage PSR-CV solution maintains two stage PSR-CC merits and besides it has some extra advantages. First, LED current control is simple and it has more accurate LED current due to secondary DCDC stage control LED current directly. Secondly, for dimming application, whatever 0~10V analog dimming or PWM dimming it can be easily implemented in secondary DCDC stage and without any isolation. Third, cost may lower than PSR-CC. Compared with PSR-CC, we can consider it moves PFC stage to secondary DCDC stage. As we all know, PFC stage contain high voltage components. But in secondary DCDC stage, these are low voltage components. Last, PSR-CV solution gives us more flexibility. For example, we can add standby power function in PSR-CV stage to get low standby power once LED is not connected. Or we can choose suitable DCDC for multi-strings application. Only drawback is PSR-CV output voltage regulation is not very tight, but we can choose wide input range secondary DCDC to overcome this problem.

2. PSR-CV operation principle
Currently, PSR-CV is implemented through controlling voltage on auxiliary winding. Once auxiliary winding voltage is controlled, the output voltage is set via transformer coupling. Therefore, in order to have accurate output voltage, we need to control auxiliary winding terminal voltage directly as we can see from Figure 6.

![Figure 6 Simplified accurate PSR-CV control](image)

During the rectifier diode conduction time, the sum of output voltage and diode forward-voltage drop is reflected to the auxiliary winding side as \((V_o + VF) \frac{N_{aux}}{N_s}\). Since the diode forward-voltage drop decreases as current decreases, the auxiliary winding
terminal voltage reflects the output voltage best at the end of diode conduction time, where the diode current diminishes to zero. By sampling the winding voltage at the end of the diode conduction time, the more accurate output voltage information can be obtained.

Because auxiliary winding terminal voltage will move up and down in one switching period, we need to find out sampling point first, then using sampling/holding circuit, after that compare sensing voltage to internal precise reference. Anyhow, the control logic is a little complex. Another easy and feasible way is we can control rectified auxiliary winding voltage through PFC controller error amplifier as figure 8 shows. The drawback is not accurate output voltage.
However, it’s tradeoff between simply control and accurate output voltage. In two-stage PSR-CV solution, first stage output voltage accuracy is not big issue, we can choose wide input voltage range secondary DCDC to overcome this.

3. Test results and waveform measurement
An evaluation board is made based on single PFC controller FL6961 which has OVP function can be changed to implement PSR-CV and high voltage buck controller FL7701[3] which has extremely wide input range.

![Figure 9 PSR-CV plus DCDC total solution](image)

Thanks to the PSR-CV solution, we also can easily generate a secondary CV supply to other accessories like MCU by applying another auxiliary winding at the secondary side.

With PSR-CV Vcc regulation, we can see the CV accuracy than can achieve ±4.25% CV tolerance in whole output load range. If eliminate the light load voltage drift (caused by the burst mode), the CV accuracy will be better up to ±1.1%.

![Figure 10 CV performance](image)

With FL7701 can easily help build up the BUCK DCDC with analog dimming function inside. Thus total solution comes out with extremely low ripple current.
Conclusion
This paper introduces and develops a new two-stage PSR-CV solution which offers no line frequency current ripple and high PF and maintains simple circuit, easy to design merits. Experimental results have proved the proposed two-stage PSR-CV solution is an excellent candidate for high-end LED analog dimming and PWM dimming application. In the future, we can add new features such as standby-power at primary side to achieve low standby-power in order to meet LED driver development tendency.

REFERENCE
[3] Fairchild Semiconductor, FL7701MX (Smart Non-isolated PFC Buck LED driver), 2012