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RESEARCH ARTICLE

Design and optimization of a power supply unit for low profile LCD/LED TVs

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ABSTRACT

The ongoing demand for smaller and lighter power supplies is driving the motivation to increase power density while maintaining a robust design compatible with international harmonic standards. Transformer design is a major challenge for low profile and high power density TV power cards. In addition to these, for electromagnetic interference standard and for providing efficient thermal management for heat emission, it is required to minimize EMI noise. In this study, by taking these stated criteria into consideration, a TV power card has been designed, which has 220W output power and can be used in low profile televisions. Proposed power card will meet desired critical parameters such as surface area and output power of the referenced card which has 13.5mm height, the heat, and power consumption at standby mode. Moreover, it is designed with 10mm height limit without any engraving on PCB in a way that it will meet International Electrotechnical Commission (IEC) current harmonic standard to which TVs are subjected. Experimental results demonstrate that the proposed power supply with 10mm height has 34% higher power density with respect to its counterpart having 13.5 mm height.

NOMENCLATURE

V_g	Switching component trigger voltage
V_{DS}	Voltage stress on switching component
V_o	Voltage on output capacitor
V_{SN}	Snubber circuit voltage
I_{PRI}	Primary current
I_{SEC}	Secondary current
I_{ripple}	Ripple current
PDP	Plasma Display Panel
LCD	Liquid Crystal Display
LED	Light Emitting Diode
ZVT	Zero Voltage Transmission
ZVS	Zero Voltage Switching
SMPS	Switch Mode Power Supply
PFC	Power Factor Correction
PCCM	Pseudo Continuous Conduction Mode
CrM	Critical Conduction Mode
ESR	Equivalent Series Resistance
CSD	Current Source Driver
PSU	Power Supply Unit
EMI	Electromagnetic Interference
PCM	Printed Circuit Board
DCM	Discontinuous Conduction Mode
IC	Integrated Circuit
FHA	Fundamental Harmonic Approximation
DC	Direct Current
AC	Alternative Current

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1. Introduction

Emergence of plasma display panel (PDP), liquid crystal display (LCD) and light emitting diode (LED) technologies created important decrease in the dimension and weight of TVs. Orientation of customers to thinner and lighter TVs has led to the height limitation of power card design, which is one of the main constituents of low profile TVs. Different voltage levels are obtained as outputs in the power card of this kind of TVs. Power consumption standards which the developing technology reveals have made the usage of topologies having maximum efficiency obligatory in TV power cards [1-5].

For middle level power applications, among various DC-DC converters developed so far, LLC resonant converters, has the advantages as the simplicity of circuit configurations and the acquisition of big voltage gains in narrow frequency interval when compared to the serial/parallel resonant converters. Due to the limitations of high current effects, output regulation and power density of traditional resonant converters, novel topologies and switching modes for the design of LLC resonant converters have been proposed in the literature [6-9].

The most challenging part of thin power card design with high power density is the transformer design. Design of converter using flat magnetic component is difficult because of the increase in the temperature of flat transformer at high switching frequencies. In [10], for decreasing the temperature of this transformer, a power module composed of two flat transformers is designed. In [11], to give high output power, a new LLC resonant converter with two transformers is presented. In this structure, to decrease imbalance in primary current, two transformers are applied to LLC converter with their primaries serially connected and secondaries parallelly connected to each other. In [12], a new frequency controlled soft-switching resonant converter is proposed which has high power density, high efficiency, low switching losses and circuit components whose profile depth is decreased. In [13] a flyback converter with partial resonance was developed. In this type of converter, semi conductive power component's transmission with zero voltage transmission (ZVT) and cut-off with zero voltage switching (ZVS) is provided. Two output LLC converter circuit [14] having 10mm profile depth consists of two transformers, which are serially connected in the primary side and parallelly connected in the secondary side. Serial primary-parallel secondary connection type provides high power density; moreover, secondary leakage inductance reduction is achievable.

Since a switch mode power supply (SMPS) behaves as a nonlinear load, power factor has to be corrected. Power factor's being close to ideal provides the increase of system efficiency, the prevention of overloading of the line and the production transmission devices and the decrease in harmonics and losses [15, 16]. In TV power card design, power factor correction (PFC) circuits are used to provide the adjustment of low harmonic impairments and the necessary harmonic standards. A Boost type PFC converter turns standard network voltage into regulated DC output voltage, thus feeds power converter layer. In addition, it enhances power factor and current harmonics. In [17], a pseudo continuous conduction mode (PCCM) boost type PFC converter and control methods related to this structure were presented. In low and middle power class TV applications, boost type converters which are activated in critical conduction mode (CrM) are used. High efficiency can be achieved with this CrM, however it brings disadvantages such as increase in the component amount and ripples in output current. In order to overcome these ripples, integrated circuits (IC) having interleaved topology are designed in [18]. These ICs employ ZVS and have features such as wide input voltage gap and wide output load gap. Suggested CrM PFC controller is suitable for flat devices, where wide bulky components such as inductor and capacitor are divided and scattered thus decreasing profile thinness. In [19], frequency clenched CrM controlled PFC converter design associated with interleaved topology enabled the usage of small size passive components. In [20], a digital adaptive current source driver (CSD) is proposed for the interleaved Boost PFC converter under CrM to reduce the high turn-off loss and gate drive loss.

Topology and selection of material are important criteria to provide high efficiency and high power density in the design of power modules. In [21], a method is proposed for the improvement of high-current density PCB design while maintaining power supply unit (PSU) load balance. For medium power solid state lighting applications, a new topology along with the use of film technology capacitors which has a longer lifetime than standard electrolytics is presented for effective power factor correction to comply with the harmonic injection and energy saving standards [22]. Methods proposed in [7-12, 18-19] are used to optimize the efficiency of power sources used in LCD TVs. By using LLC resonance converters, 89.43% efficiency for 40 inch LCD TV in [7], high efficiency (full loading 96.5%) and low cost for power sources used in 42 inch PDP TVs in [8] are achieved. In [10, 11] LLC resonant converters designed for PDP TV are presented, in [10] design of 14 mm transformer is done and total efficiency is calculated as 96.6 %. Serial converter with two transformers proposed in [11] is used in 50 inch PDP TV system. In [12] half bridge resonant converter, with its LCD TV power source having 46/47 inch active PFC circuit and standby converter, is designed. Permanent conduction mode PFC controller proposed in [18] is suitable for flat devices, where profile depth is decreased by dividing and scattering bulky inductors and capacitors. Flyback converter design, having 12.5mm height high efficiency which enables the design of decreased depth LCD TV, is given in detail in [19]. Moreover, electromagnetic interference (EMI) noise has to be minimized to provide efficient thermal management for heat emission.

Considering the abovementioned criteria, the aim of this study, is to design a PSU with high efficiency and optimized power density which can be used in low profile TVs. For this purpose, a PSU having 13,5mm height and 220W output power has been redesigned as having 10mm height and the same output power with the referenced card. In the second part of the study, flyback converter, LLC resonant converter and PFC converter typologies used in PSU design are explained. When power levels of TV power source of today's technology is analyzed, a power need for 75-240W that can change according to screen dimension is determined. Outputs of designed power supply in this study are 5.2V/4.2A, 24V/6A and 12V/4.5A. Flyback topology is preferred for 100W and less power levels because of its features such as simple structure, low cost and its enabling input and output isolation. 24V/6A and 12V/4.5A output LLC converter topology, with its serial primary and parallel secondary connection type, provides high power density. In this topology [14], secondary windings have asymmetrical connection and leakage inductances resulting from current imbalances are decreased. For power levels below 300W, because of high power factor correction, low cost and simple control structure; Boost type PFC converter, which operates in CrM, is used. Third section includes circuit based studies related to the optimization of power density, operating in high switching frequencies, design of magnetic components, soft-switching technique and component selection. In the fourth section, experimental results related to the physical realization of power card are presented. Final section presents the concluding remarks and a discussion of optimization results.

2. Design of low profile PSU

In this study a power card, which meets the specifications of a regular TV power card and whose height is reduced in order to be suitable for low profile televisions, having 10 mm height and 220W output, is designed without any engraving process on printed circuit board (PCB). Proposed design meets the critical parameters such as referenced card's surface area, heat, power consumption in standby mode and the international security standards. Sub blocks used in the design of TV power card are given in Fig.1.

For power levels in 100W and below it, flyback converter topology is preferred for low cost, simple structure and its enabling input and output isolation. Above 100W level, LLC resonant converters are preferred in the design of power card due to its functions such as density of power and power efficiency they provide, control ease of output regulation over a wide load range and usage of soft-switching techniques that reduce high frequency switching losses [14]. Below 300W level power value, due to its high power factor correction, low cost, simple control structure, boost type PFC converter that operates on CrM is used. In Figure 1, proposed PSU design is given as a block diagram and optimization techniques are explained in sub-chapters.

2.1. Design of flyback converter

Circuit components are selected as flyback converter's output voltage being 5.2V and output current being 4.2A. Because of the limitations in the dimensions of magnetic component, inductance value is determined having switching in discontinuous conduction mode (DCM). DCM operating allows smaller size transformer to be used in circuit design. Since the average power dissipation is less, it is possible to decrease the loss of power consumption with less coiling. Figure 2 shows the flyback converter topology. Controller IC of MOSFET switch is not shown in the figure but it is used in the exact design of Flyback Converter.

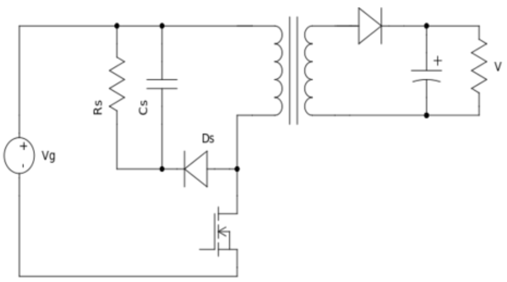

Figure 2. Flyback converter topology

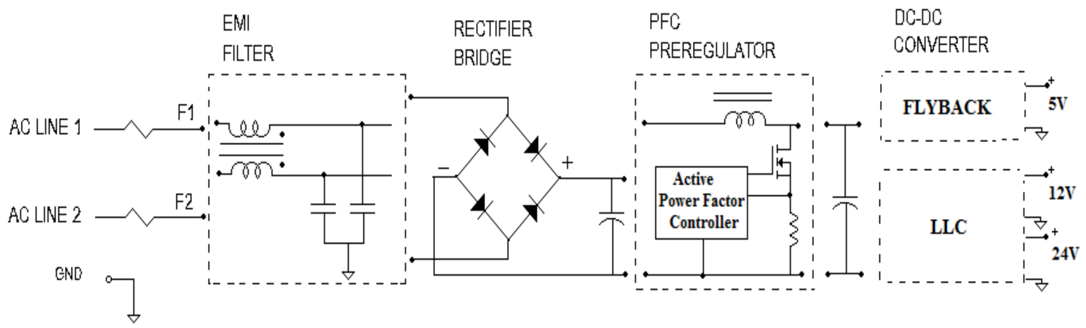

Figure 1. Sub-blocks of the PSU design

2.2. Design of LLC resonance converter

Output values (12V/4.5A, 24V/6A) of two output LLC converter circuits of which topology is presented in [14] is determined in accordance with the needs of optimized 40-42" TVs. Switching losses are decreased using soft-switching technique in high frequencies. Acquisition and input-output function are obtained using Fundamental Harmonic Approximation (FHA) analysis. With the aim of decreasing the current imbalance caused by leakage inductances, asymmetrical connection design is analyzed in [14]. LLC Converter topology is provided in Figure 3.

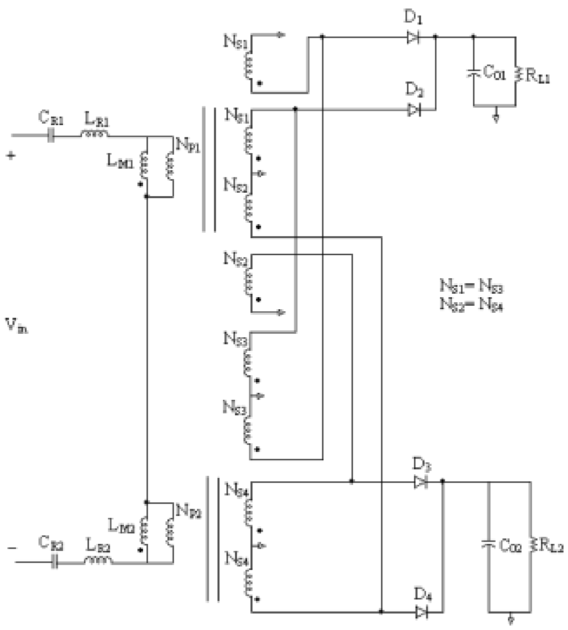

Figure 3. LLC resonant converter topology [14]

2.3. Design of boost type PFC converter

Common reasons for the usage of Boost PFC converter topology [23,24] are mainly input current shaping, isolation, and fast output voltage regulation that are performed in one single stage [23]. In control unit, a filtered DC output voltage is compared with reference voltage by using an error amplifier output of which is applied to the multiplier circuit. Output waveform of multiplier circuit follows the shape of AC input voltage and the shape of AC line voltage, the bobbin current of which was corrected. Gate drive pin controls the amplitude of bobbin current and thus output voltage is fixed. Boost type PFC converter topology is given in Figure 4.

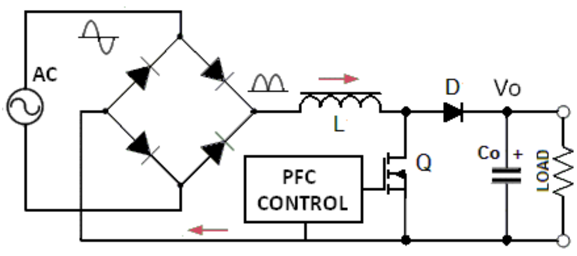

Figure 4. Boost type PFC converter topology

3. Power density optimization for LCD/LED TVs

The concept of power density in TVs defines the relationship between the power gained from the power card and dimensions of the power card. Circuit based studies related to the optimization of power density include operating in high switching frequencies, design of magnetic components, soft-switching techniques and component selection.

3.1. Selection of passive components and cooler

In case height limit of a TV power source is reduced, the most important limiting component is the dimension of passive components. Capacitor, bobbin and transformer are the group of passive components which compel the height limit. The bulk capacitor used in PFC converter output is a primary component which compels the height limit. This capacitor decreases the ripple of input voltage of other converters.

In addition to this, regulated source continues to provide regulated output voltage while ensuring hold up time in the absence of alternative input voltage which occurs in a sudden power failure. Equivalent series resistance (ESR) of output filter capacitor used in converters has to be as low as possible. ESR in high switching frequency applications has a great effect on the peak and active values of ripples in output voltages. Changes in the peak value of output voltage by a change in the load in the shape of a digit depend on ESR value of the capacitor [15]. Active current values of lower capacitors decreases in direct proportion with the dimensions. In case of increasing load in low profile structures, solution to increased stress on output capacitor is gathered by adding more than one capacitor to it.

When thin design is aimed, the necessity of providing input-output isolation is inevitable and the design of transformer compatible with reliability standards becomes more challenging. Decreasing the size of magnetic core reduces plastic cover options suitable for this material. Switching frequency can be increased to decrease magnetic core size, but this leads to the increase of losses on magnetic component and thus heating problems. Interleaving the windings of transformer can be a solution to the height limit of passive component. In order to gather the necessary power, two transformers are designed, having primaries serially connected and secondaries parallelly connected [14].

Selection of cooler is as important as the selection of passive components, since keeping the temperature values during power density optimization in the limits provided by the manufacturers is essential. Switching components used in primary side and corrective diodes used in secondary side are main components that require cooler. The surface area of coolers is determined by aiming a temperature value that does not exceed maximum junction temperature. In behalf of providing the heat flux of power source, materials that are predicted to warm are placed separately in a position that it doesn't block air flow and there is no gap between it and PCB surface. Cooling surface areas are calculated to meet the temperature standards of the company with which this study is carried out.

3.2. Selection of topology and conduction modes

When traditional power supply needs are taken into consideration, the most important factor that determines topology is the power level. When the power levels of today's technology's TV power sources are examined, a power need between 75-240W that changes according to TV screen dimensions is determined. Flyback converter topology is preferred for 100W and power levels below it due to some features such as simple structure, low cost and its enabling of input and output isolation. In this topology, dynamic fast-answering DCM is used for the magnetic induction of transformer [25].

PFC converter structures, which operate in CrM because of the low cost of power factor correction and its simple control structure, are used in power values below 300W.By using high voltage obtained by PFC converter in resonant topology, high efficiency and high output power can be obtained.

Switching losses can be majorly decreased by the soft switching method used in LLC resonant topology. Decreasing this loss also provides an increase in the efficiency and the usage of smaller cooling material. Moreover, when the height limit is decreased, the power that magnetic component can provide is also limited and thermal problems arise. As a solution, more than one magnetic components need to be connected serial-parallely to reach a high power level.

4. Low profile PSU implementation and experimental results

In this study, a TV power card is designed which has 10 mm height and multi-output, 220W in total that can be used in televisions which have a panel size changing between 40- 47". Optimization progress related to the reduction of height by protecting the surface area of 13.5mm power cards is done compatible with international TV standards. For PFC converter and DC-DC converters used in power card, three transformer designs that doesn't exceed height limit are carried out. Switching components are placed in a way to prevent temperature problems that can occur because of the reduction in height limit and special coolers for output capacitors are designed.

Surface view of the designed card is given in Fig. 5. To provide height limit of power card designed for low profile television, components which vertically exceed height limit on PCB are placed by tilting. Detailed view related to the height of the card is given in Fig 6.

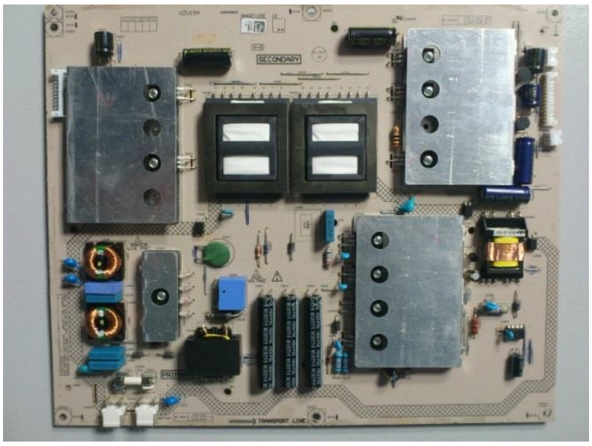

Figure 5. Surface view of the designed card

A TV power card having 13,5mm height and 220W output power is redesigned as having 10mm height and 220W output power by selecting optimal topology and material. In this study which focuses on the reduction of card height, the power density is enhanced at the rate of 34%. The card designed with 291mmx240mmx10mm dimensions operates at nominal load condition with 84% efficiency. The most calescent module on the card is transformer and thermal analysis result is given in Fig. 7.

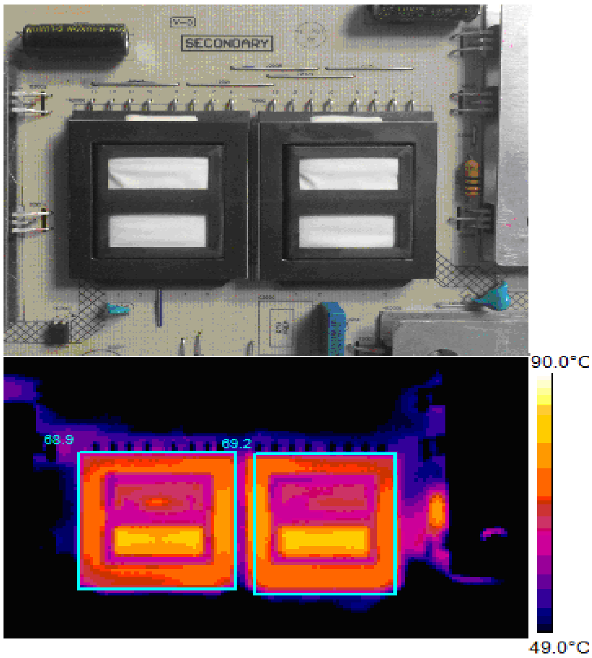

Figure 7. Thermal analysis under 25°C ambient temperature [14]

Figure 6. Detailed view of the height of the designed card

4.1. LLC resonant converter design converter

LLC resonance converter topology is used to gain 200W output power in the range of 330V-400V. Voltage acquired from PFC converter output is provided as an input to LLC topology and topology gives 12V/4.5A and 24V/6A outputs. Components used in LLC resonant converter is given in Table 1. Detailed simulation results of the LLC resonant converter are provided in [14].

Table 1. Components of LLC resonant converter [14]

Circuit Component	Definition	Value
LLC MOSFET	Magnachip	MDF5N50 (x2)
Resonant capacitor	C_R	22nF
Magnetic inductance	L_M	693uH
Resonant inductance	L_R	171.2uH
LLC IC	Fairchild	Fan7621
Output Diodes	D	SBR30A100

4.2. Flyback converter design results

A flyback converter, which operates for 5V output layer and standby mode in DCM is designed with its components are tabulated in Table 2. Voltage and current measurements are given in Fig. 8-10. Fig. 8 and Fig. 9 shows the switching behavior of flyback converter. From these figures, one can observe that energy is stored with the current flowing through primary winding when switch is on. When switch is off, this energy is transferred to secondary winding dependent on ratio of turns. High voltage and switching losses arise when switch is off. In order to protect the switch, a snubber circuit is used. In Fig. 10, voltage stress on switching component and snubber circuit voltage is given.

Table 2. Components of flyback converter

Circuit Component	Definition	Value
Snubber Resistor	R_S	47kΩ
Snubber Capacitor	C_S	1nF
Integrated Circuit (IC)	U2	FSB147H
Transformer Inductance	L_M	600uH
Output Diode	D	30A 60V
Output Capacitors	C_O	2,2mF(x2)

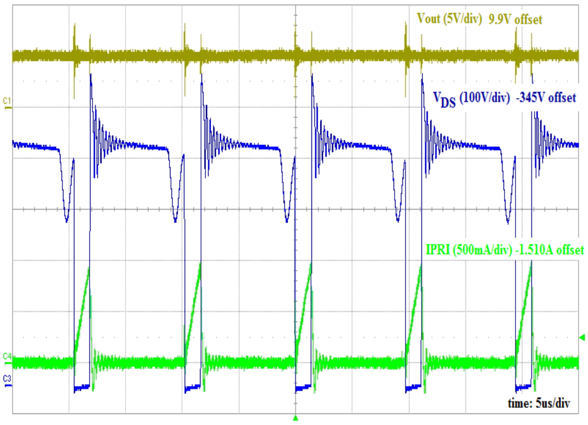

Figure 8. Flyback converter output voltage (V_{OUT}), voltage stress on switching component (V_{DS}) and primary current (I_{PRI})

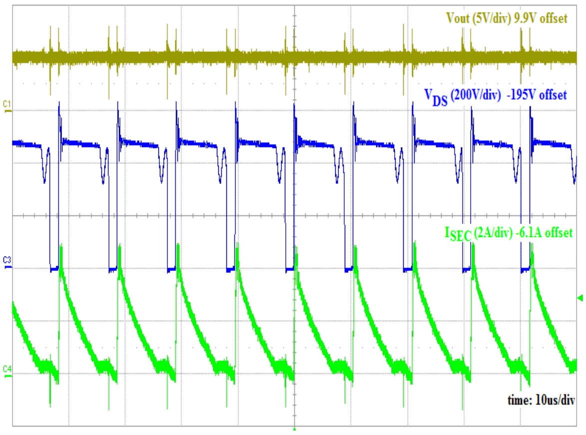

Figure 9. Flyback converter output voltage (V_{OUT}), voltage stress on switching component (V_{DS}) and secondary current (I_{SEC})

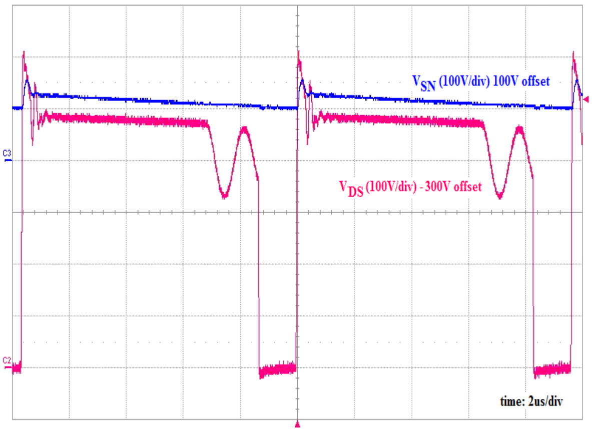

Figure 10. Voltage stress on switching component (V_{DS}) and snubber circuit voltage (V_{SN}).

4.3. Boost type PFC converter design results

Output voltage of PFC converter layer is selected as 400V to feed other layers. In Fig. 11, CrM PFC converter bobbin current (I_L), voltage on current measurement node (V_{CS}) and switching component trigger voltage (Vg) are shown. When V_{CS} reaches to the stated threshold point, trigger voltage Vg is cut, in addition to corrected network voltage, inducted current creates a voltage on bobbin and then it is transferred on output capacitor via output diodes. Thus, a higher voltage than the network voltage which is corrected with boost type PFC converter is acquired. In Fig. 12, voltage stress on switching component, switching component trigger voltage and current on PFC converter diode waveforms are given. Voltage on output capacitor and ripple current for over two periods are given in Fig. 13. Components used in PFC converter are tabulated in Table 3.

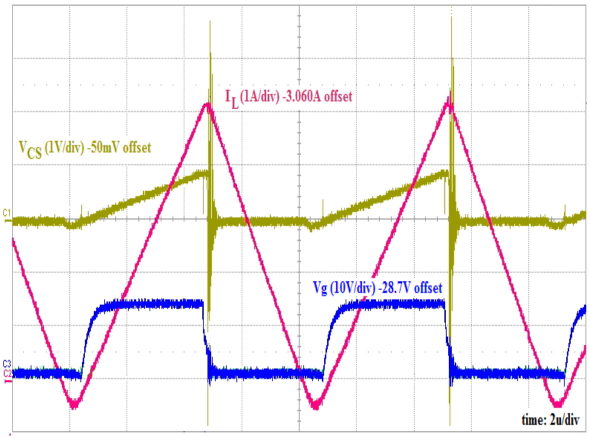

Figure 11. CrM PFC converter bobbin current (I_L), voltage on current measurement node (V_{CS}) and switching component trigger voltage (V_g)

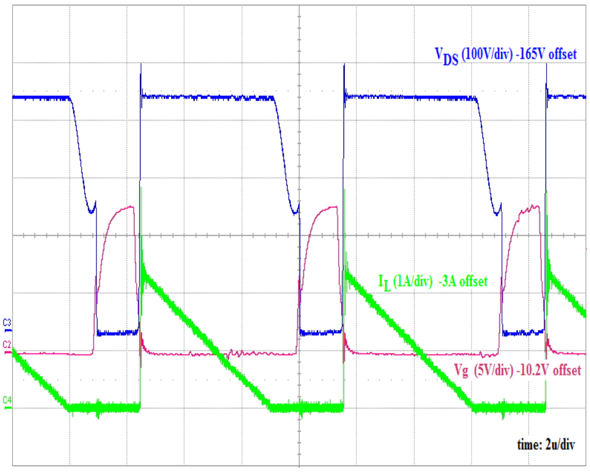

Figure 12. Voltage stress on switching component (V_{DS}), switching component trigger voltage (V_g) and current on PFC converter diode (I_g)

5. Conclusion

Considering the slim TV trend that today's TV technology reveals, orientation of customers to thinner and lighter TVs has led to the limitation of the design of the power card, which is one of the main constituents of low profile TVs. In this study, a TV power card having 13,5mm height and 220W output power has been redesigned as having 10mm height and the same output power with the referenced card. Topology and conduction modes of the converters are selected in order to provide 10 mm criterion for low profile TVs. Optimization of the power density of the card is targeted during the design procedure. Smaller cooling materials are used in order to reduce switching losses and thermal problems related height limit are minimized. TV power card with optimized power density is constructed with 200W LLC converter, 20W Flyback DC/DC converter, Boost PFC and EMI filter. In this study, power density of low profile TVs, which have various panel dimensions in a range of 40-47", is enhanced at the rate of 34%. The results are compatible with the International Electrotechnical Commission (IEC) 61000-3-2 current harmonic standard.

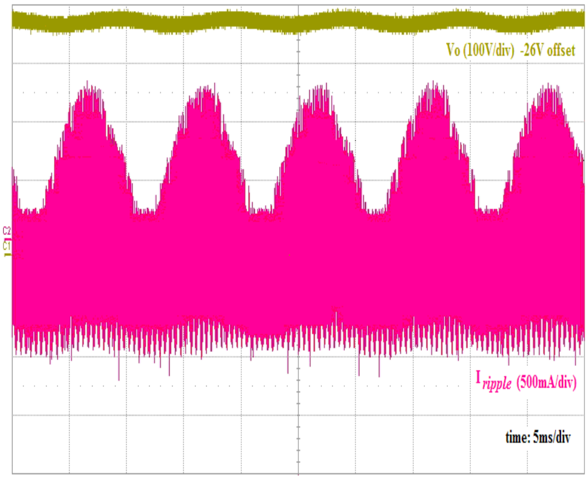

Figure 13. Voltage on output capacitor (V_O) and ripple current (I_{ripple})

Table 3. Components of PFC converter

Circuit Component	Definition	Value
PFC bobbin	L_M	200uH
PFC IC	Fairchild	Fan7930c
PFC MOSFET	Magnachip	MDF11N60
PFC Diode	NXP	BYV29X
Output Capacitors	C_O	39uF (x3)

Acknowledgements

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