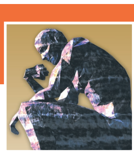

by A.I. Maswood and Zee Kum Yoong

Switching Loss Reduction Through Digital Burst Technique in TV Power Supply

Electronic appliances such as television sets are indispensable nowadays, and this gives rise to the need for them to be highly energy efficient. In general, standby mode is preferred as compared to "hard-off" (completely turning off) since it offers the user the convenience of turning on the set by using the remote control. As a result, it is essential to ensure that during standby mode, the loss in the circuit is kept at its minimum [2]. Besides, the standby-mode operation also helps to increase the reliability of power switch and offers the soft picture collapse function [2].

The complete circuit diagram of the proposed power supply is depicted in Figure 1. In the figure, terminals UB(L) and UA(L) are for output video/audio voltages, and terminal P(L) is for the control signal. Terminal BURST is for a microprocessor burst signal used only during burst operation. During the TV standby mode, a digital (software) controlled burst signal from a microprocessor is used for switching the power MOSFET. The control circuit, which is also called the secondary feedback loop and regulation, and the microprocessor burst generator are illustrated in the lower right-hand side of the diagram. (The detailed operations of these circuits are further shown in Figures 3–6, and their functions under these three possible conditions are described in full.)

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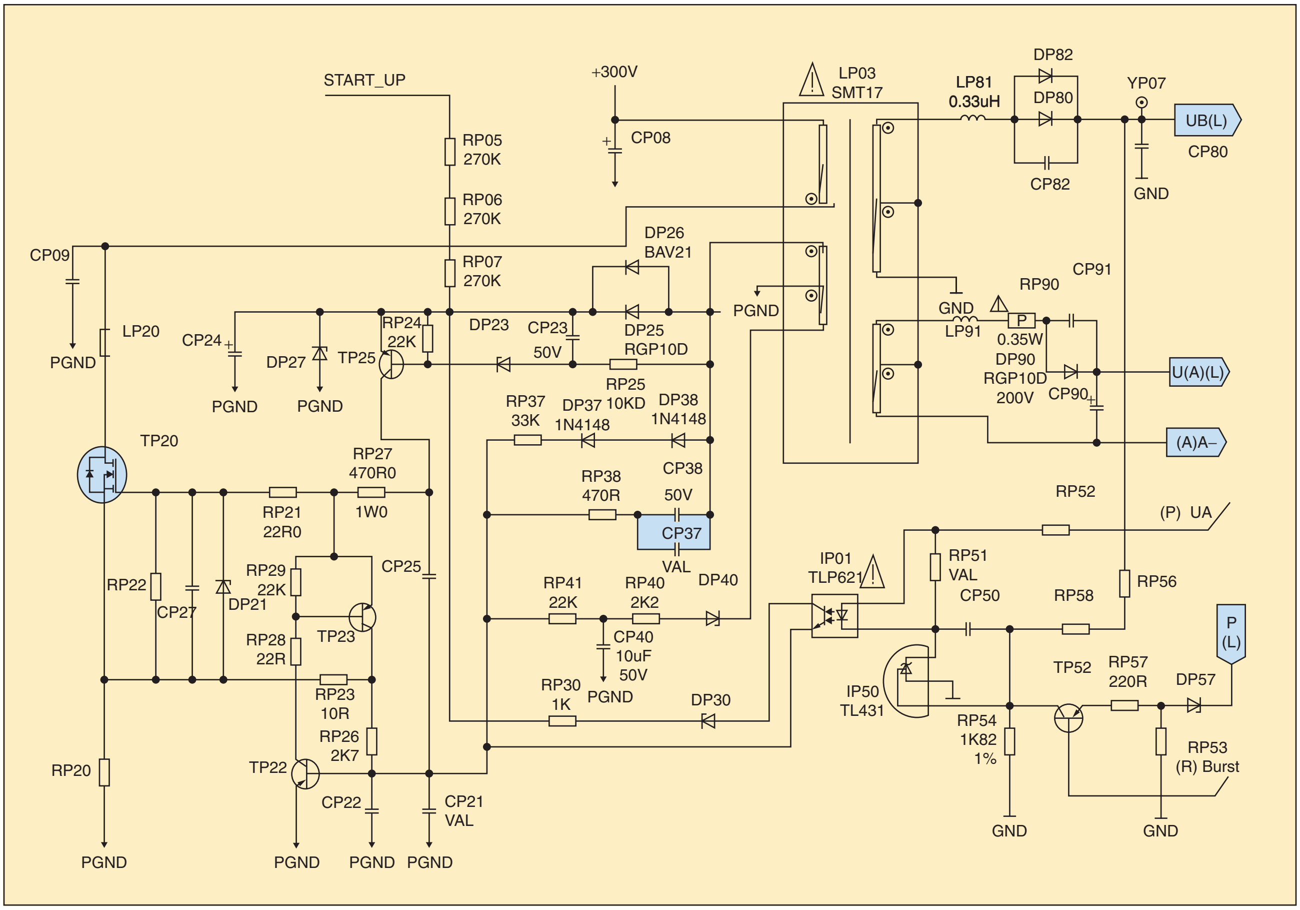

FIGURE 1 – Complete circuit diagram of the proposed power supply.

The novelty of this work lies in the implementation of the proposed burst technique using simple discrete electronic devices and components. Such an approach is economical and easy to troubleshoot. In the event of breakdown, individual components can be replaced, as opposed to replacing the entire IC chip, which sometimes can be hard to find. Moreover, it is impossible to model a circuit involving an IC chip, since the manufacturer seldom provides the IC's internal diagram. The switch mode transformer SMT17 is designed to be functional over wide input voltage ranges [1], as it is expected to be used in developing countries where the supply voltage can fluctuate.

In the proposed digital control of the switch mode power supply (SMPS) operation, a pulse-width modulated (PWM) signal called the burst from the system microprocessor is used to control its standby operation. As shown in the block diagram of Figure 2, this signal is sent from the microprocessor to the power supply secondary feedback circuit. The result of this burst control is that a noncontinuous switching occurs in the primary power MOSFET (TP20 in Figure 1).

Burst Switching Circuit

The burst switching circuit is a part of the SMPS feedback circuit as illustrated in the block diagram of Figure 2. This circuit is extracted from the main circuit of Figure 1 to explain the proposed digital burst control mode. The key switching device in the burst mode is the transistor TP52, as shown in Figure 3. The burst signal is transmitted through the CONTROL port. During burst mode, transistor TP52 operates in switching mode, which is controlled by the microprocessor burst signal (CONTROL signal). The result is that the switching of TP52 is alternately regulated by Ub and P. Hence, the burst operation can be further explained for three cases:

- regulation by signal Ub
- regulation by voltage P
- regulation by burst signal.

Case 1: Regulation by Ub

The circuit of Figure 4 shows how regulation by Ub can be achieved. The voltage divider as shown by the arrows determines the regulation and feedback loop to the primary switching control circuit such as the biasing of transistor TP22 of the main circuit of Figure 1. During this mode, the CONTROL signal from the microprocessor is low (off).

DIGITAL BURST MODE IS AN OPERATION THAT CAN BE USED TO CONTROL POWER TRANSISTOR SWITCHING BY THE MICROPROCESSOR SIGNAL.

Case 2: Regulation by Voltage P

During this mode, the power supply regulation is switched to voltage at P as shown in Figure 5. In this case, the CONTROL signal (also known as the burst) from microprocessor is high (on). TP52 is operated in the reverse direction as indicated by arrow 1. This loop current indicated by the arrow overwrites the current

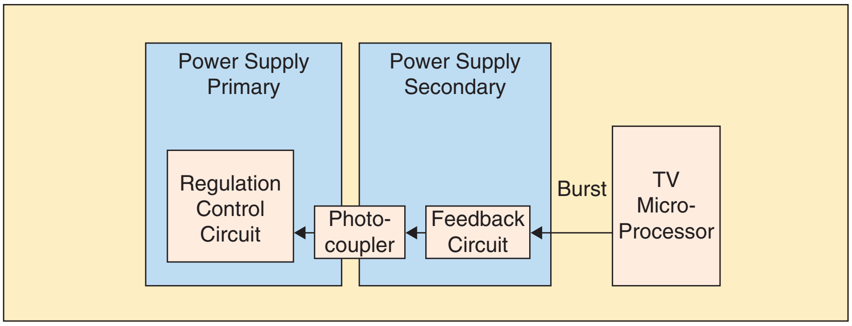

FIGURE 2 — Block diagram of TV standby operation.

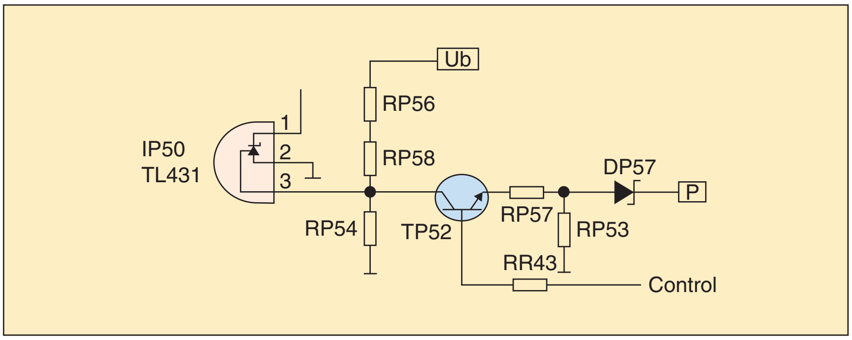

FIGURE 3 — Burst switching circuit (see lower right-hand side of the main circuit of Figure 1).

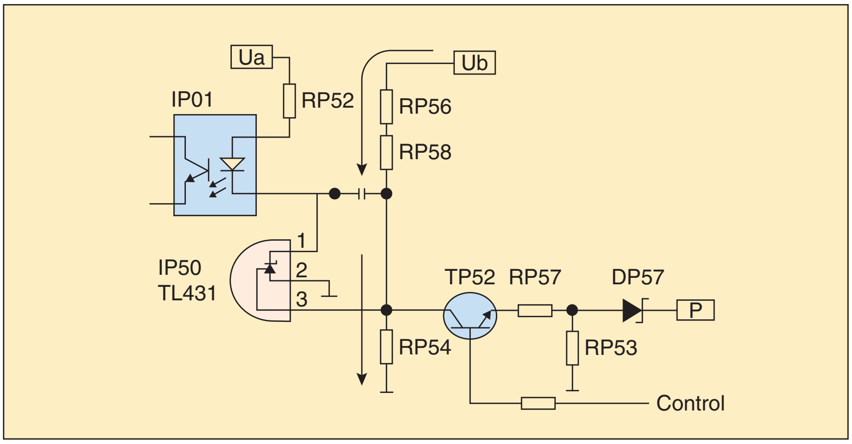

FIGURE 4 — Regulation by Ub.

from Ub into pin 3 of the programmable voltage reference TL431. Hence, regulation is solely dependent on voltage P. When the control signal is in logic "1′" (5 V), two possible operations will occur:

1) If P is higher than Vref+ at the Zener diode DP57, the conduction is as shown in current loop 1 of Figure 5. Transistor TP52 is operated in reverse mode. Since it is a bipolar transistor, it is possible to make it conduct in the reverse mode [1]. The transistor reverse beta (h_{FE}) becomes lower than the forward one. In this case current is injected into pin 3 of TL431. The error amplifier input thus reduces SMPS switching conduction time in order to reduce the voltage of P. Hence, the current loop 1 increases error amplifier input voltage to reduce voltage P.
2) If P reduces until a point where the Zener diode DP57 stops conduction, TP52 operates in normal (forward) mode. It functions like a switch to the parallel resistor RP54 with the series resistors of RP57 and RP53. This parallel effect is that the error amplifier input is being reduced to the voltage found below [4]:

$$V_i = \frac{\dfrac{RP54}{(RP57 + RP53)}}{\dfrac{RP56 + RP58 + Rp54}{(RP57 + Rp53)}}, \qquad (1)$$

where V_i is the error amplifier input voltage at pin 3 of TL431.

If V_i reduces, the error amplifier corrects the conduction time of the power transistor, and that increases the potential at P. On the other hand if P is too low and DP57 does not conduct, TP52 operates in the forward mode as shown by loop 2 in Figure 6. Hence, the parallel effect of RP57 + RP53 increases the voltage P [5].

Case 3: Regulation by Burst Signal

Burst mode efficiently combines cases 1 and 2. The power supply is regulated by Ub and P alternately. This is controlled by the burst (indicated as CONTROL in Figure 6) switching as a PWM signal. A signal CONTROL = 1 initiates a regulation by voltage P, and a signal CONTROL = 0 reverses that and produces a regulation by Ub. Due to the fact that P is regulated at a voltage that is lower than the normal condition, the switching is stopped when regulation by voltage P is boosted. This action results in a burst switching at the main switching power MOSFET TP20. The result of cases 1, 2, and 3 is a complete burst system as presented in the following sequences of circuit and waveform diagrams of Figure 7.

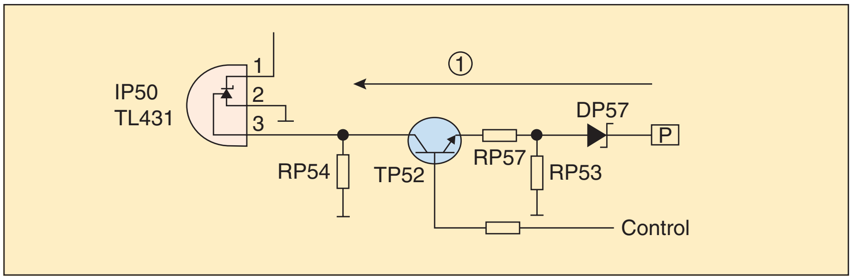

FIGURE 5 — Regulation by voltage P.

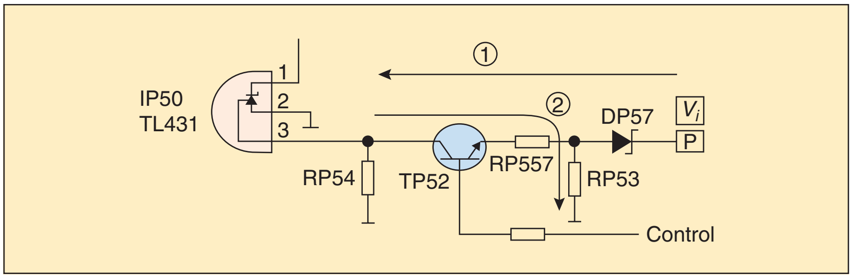

FIGURE 6 — Regulation by burst signal.

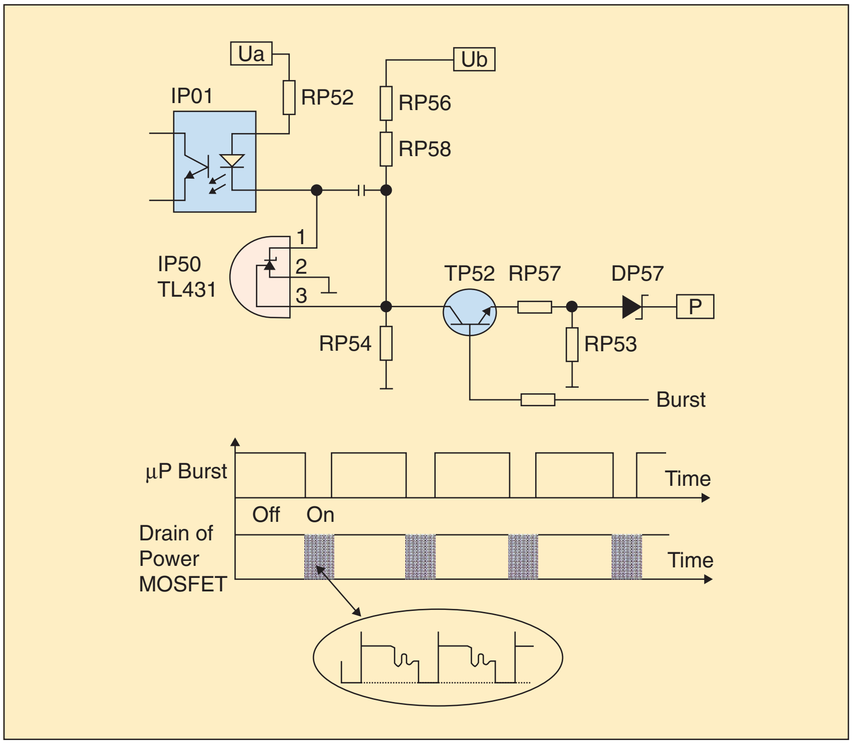

FIGURE 7 — Schematic of the burst standby operation.

Feedback of the Burst Signal to the Power Supply

The regulation techniques mentioned in the previous section translates into a feedback to the primary control circuit; i.e., the biasing of TP22. The burst result is the current from TP52 and is fed into the programmable voltage reference TL431. The current into the photodiode (TLP621) also follows the burst signal, where during regulation of P the photodiode current is increased. This provides more charging current to the primary biasing transistor TP22. Hence, the power transistor stops switching and Ub is slightly reduced.

When regulation is switched to Ub, the power MOSFET recovers its switching activity, since Ub is reduced by the previous action. Hence, the burst mode is generated. The feedback of burst-mode operation from the secondary to the primary circuit is via the photodiode. The programmable voltage reference is the link between the photodiode and burst-switching transistor TP52.

Operation in the Burst Mode

The role of the opto-coupler is to provide a feedback between the secondary and primary of the proposed SMPS. During normal TV "on" operation, the circuit is regulated by a signal from Ub only. Under such a condition, the burst signal is at a "low" level, where changes in Ub reflect the bias condition of IP50 via RP54-56-58. Thus, current in the photodiode is varied. As such, the current from the photo-transistor triggers and varies the power MOSFET conduction time, Ub can then be regulated to the appropriate dc voltage.

When the TV is in standby mode, a burst signal generated from the microprocessor switching at a fixed frequency and fixed duty cycle is used to drive the regulating circuit transistor TP52. When the microprocessor burst is "low," TP52 is biased OFF. Power supply is regulated by Ub (video output) and the power MOSFET is in switch mode. When the microprocessor burst is "high," TP52 is biased ON, which causes the regulation loop to be changed to voltage Ua (audio output) instead of Ub. The reflected voltage from Ua to Zener DP57 at the emitter of TP52 has the potential to bring up the voltage at input pin 3 of IP50 (programmable voltage reference TL431). This results in increased conduction of the photodiode IP01 and, hence, primary switching stops due to the current drive in the control circuit transistor TP22 being increased by the opto-coupler.

The burst switching for a 21-in.color TV experimental prototype is captured and is shown in Figure 8. Burst operation increase the reliability of the power transistor because of its discontinuous switching [6]. This allows more rest time (reduced stress) for the transistor during standby mode for a very long duration. In addition, this feature can be used to perform soft picture collapse under which the picture switches off slowly and smoothly. The sequence to generate soft picture collapse is shown in Figure 9. Without this feature, in which the microprocessor burst is generated and the system voltage

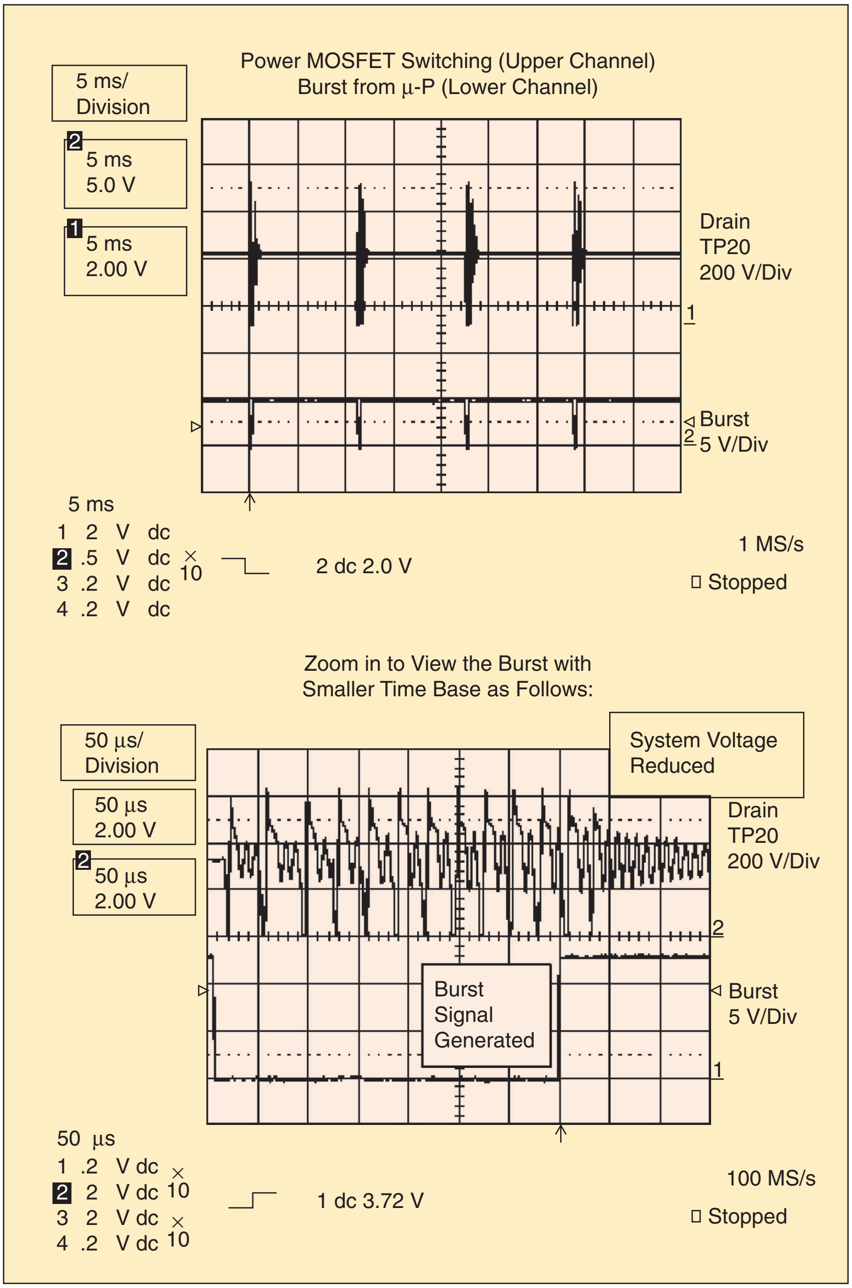

FIGURE 8 – Standby burst waveforms. Drain voltage of primary MOSFET switch TP20 (upper traces) and burst signal from the microprocessor (lower traces).

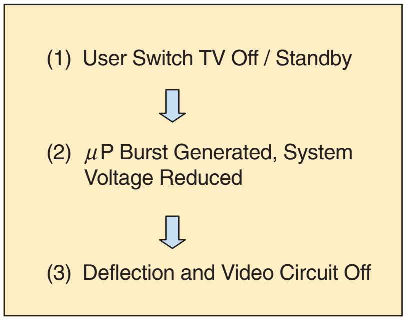

FIGURE 9 — TV ON-OFF sequence.

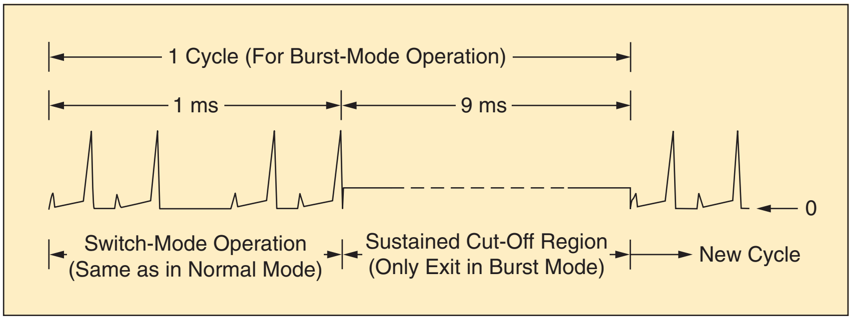

FIGURE 10 — The burst mode phenomenon in one period.

reduced, the TV screen will flush during the moment of switching OFF either to standby or TV off mode [6].

Switching Losses in the Burst Mode

During burst-mode operation, the primary MOSFET switch TP20 operates in two regions. First, it is the cut-off region where the MOSFET is locked in the off state when the burst signal is high. Alternatively, it is in the switch mode region when the MOSFET is switched rapidly at 50 kHz when the burst signal is low. The switching mode consists of 50 cycles (1 ms) of normal mode switching segments (20 μs). Figure 10 illustrates the modes of operations in one cycle:

From Figure 10, the area per cycle of normal mode operation is

$$\begin{aligned} \text{An} &= \text{Total power loss/fs} \\ &= 4.44\ \text{W}/50\ \text{kHz} \\ &= 88.8\text{E-06 unit} \end{aligned}$$

where 4.44 W is the switching loss in normal mode, and fs is the switching frequency.

The total area in the switch mode region is

$$\begin{aligned} \text{As} &= \text{An}^{*}50\ \text{cycles} \\ &= 4.44\ \text{E-03 unit.} \end{aligned}$$

The total area in the cut-off region is

$$\begin{aligned} \text{Ac} &= 232\ \text{E-03 W}^{*}\ 9\ \text{E-03 s} \\ &= 2.088\ \text{E-03 unit.} \end{aligned}$$

The total power loss in the burst mode cycle [3] is

$$\begin{aligned} \text{Pb} &= (\text{As} + \text{Ac})^{*}\text{fs(burst mode)} \\ &= 6.528\ \text{E-03}^{*}100\ \text{Hz} \\ &= 0.653\ \text{W.} \end{aligned}$$

The reduction in the switching power loss as compared to normal mode is

$$\begin{aligned} \Delta\text{P} &= [(\text{Pn-Pb})/\text{Pn}]^{*}100\% \\ &= 85.3\%. \end{aligned}$$

Conclusions

Digital burst mode is an operation that can be used to control power transistor switching by the microprocessor signal. This also allows burst mode to be extended to future applications, such as multiple regulation in TV and other audio/video products. This technique substantially reduces stress for the main switching transistor during standby mode since it is not a complete turn-off.

The frequency of the proposed burst signal is 100 Hz and has a duty cycle of 90%. This satisfies the demand of the infrared receiver module (remote) during standby mode. This "soft-switching" helps to perform soft picture switches slowly and smoothly. This is a feature without which a TV screen will flush during switching off either to standby or collapse. Implementation of this technique using discrete components yields benefits in cost, maintenance, and universality. The main transistor- and microprocessor-generated waveforms of Figure 8, obtained from the experimental hardware prototype, do fully support the stipulated characteristics of the proposed burst technique and also significantly reduce the main switching transistor transient power loss. This SMPS with the proposed burst soft switching technique is now commercially produced and fitted with 21-in color TVs.

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Biography

A.I. Maswood received his M. Eng. degree from the Moscow Power Engineering Institute and Ph.D. from Concordia University, Montreal, Canada. He joined Nanyang Technological University, Singapore, in 1991, where currently he is an associate professor. He is a Senior Member of the IEEE and chapter author for the *Power Electronics Handbook* (Academic Press). He is an editorial board member of *IET Power Electronics*.

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