EMI Problems associated with DC-DC Converters

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Abstract: - This work presents the analysis of radiated EMI problems associated with DC-DC buck converters and the solutions for minimize the reverse recovery of the Drain-Bulk diode of the synchronous switching MOSFET. The DC-DC buck converter topology is used in computers and telecom applications because of its high power efficiency and multiple DC levels. For reducing the reverse recovery and its related EMI radiation is used a technique with monolithically integrated Schottky diodes.

Key-Words: - Electromagnetic Compatibility EMC, Conducted Radiated EMI, DC-DC Converter, Numerical Modeling, High Frequency, Electromagnetic Waves, Conducted and Radiated Perturbances, IC Controller.

1 Introduction

With the increase of switching frequency of electronic switches, power converters have raised more and more electromagnetic energy pollution to the local environment. Electromagnetic compatibility (EMC) and electromagnetic interference (EMI) norms applied to power converters have objective to reduce conducted and radiated perturbances. Radiated EMI appears in the form of electromagnetic waves directly from the circuitry. The circuitry and its interface can influence themselves or the transmitting antenna for this radiated EMI emission. This emission is generally measured at much higher frequencies than their conducted counterparts, namely beyond 30 MHz up to several GHz [2]. The new generations of microprocessors are powered by local low voltages but high currents power supplies. Due to connector and power loss issues, power cannot be delivered by a remote power supply at the desired DC voltage. In addition, the fast transient current demand requires the power source being located close to the microprocessors. The most commonly used voltage regulator design is based on the synchronous buck topology. The input power supply voltage is stepped down to the operating voltage needed by the microprocessor. DC-DC converters operate at switching frequencies up to a few MHz. The potential EMI problem has been well covered in the literatures [3], [4]. By operating a DC-DC converter with the soft switching scheme without disturbing its averaged duty cycle, it is possible to eliminate predominant harmonics present in the input current to reduce overall peak amplitude of the frequency spectrum. The spreading spectrum concept has been applied successfully for the mitigation of conducted harmonic interference of the DC-DC buck converters [5]. Using of high switching frequencies in DC-DC converters allows magnetic components to be minimized but also enhanced the spectrum of EMI caused by interaction of the active components.

2 Problem Formulation

The simulations on radiated emissions of the synchronous buck converters designed to investigate the wideband and transient events, uses the conventional temporal analysis, the spectral analysis and the Joint Time Frequency Analysis techniques (JTFA), extracting the time-varying information on the emissions from different switching activities of DC-DC buck converters. The Figure 1 shows the circuit diagram of a typical synchronous DC-DC buck converter [1]. The circuit includes the main control MOSFET switch Q_1, the synchronous MOSFET switch Q_2, free wheeling Schottky diode D_1, step down inductor L_1 and filtering capacitor C_1.

The two MOSFETs switch on and off in the synchronized pattern: 1) After the main control MOSFET switches on, current builds up in the inductor;

2) After the main control MOSFET switches off, the inductor current freewheels through Diode and 3) Is taken over from the diode as the MOSFET offers a lower impedance path.

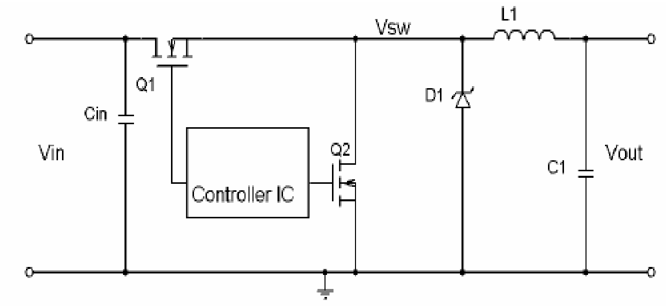

Fig. 1. Typical synchronous DC-DC buck converter.

The simulations are based on a multi-chip power module that includes the two MOSFET transistors, Schottky diodes, on-chip decoupling capacitors and the high-speed gate drive controller IC. The PWM controls 4 phase interleaved synchronous buck converters that operate up to 1 MHz per phase. The average power provided by the synchronous buck regulators to the microprocessor is over 120 W. The simulated switching outputs of the power IC are shown in Figure 2. The ringing is determined by the combination of the switch node capacitance and the total inductance of the current path [6]. Its resonance frequency is at about 185 MHz.

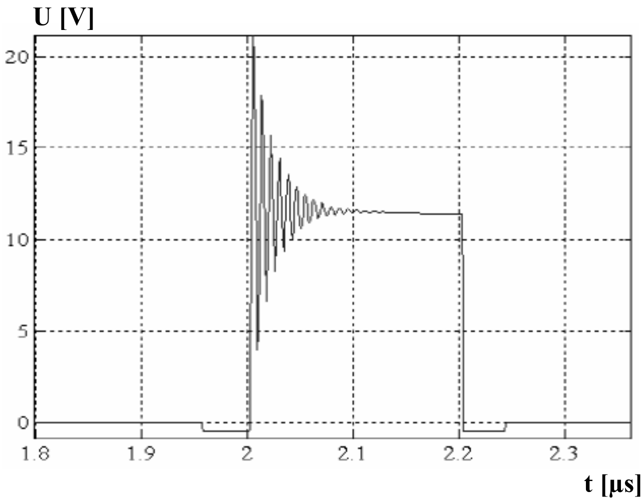

Fig. 2. The simulated switching output voltage from the power controller IC module.

The 850 MHz emissions are of special importance, although their level is less than the level of the emissions at lower frequencies. The data resulted from Figure 3 have been taken without enclosure, the enclosure would shield the lower frequencies significantly better than the 850 MHz, and thus the 850 MHz will be the dominating emission in the fully assembled system.

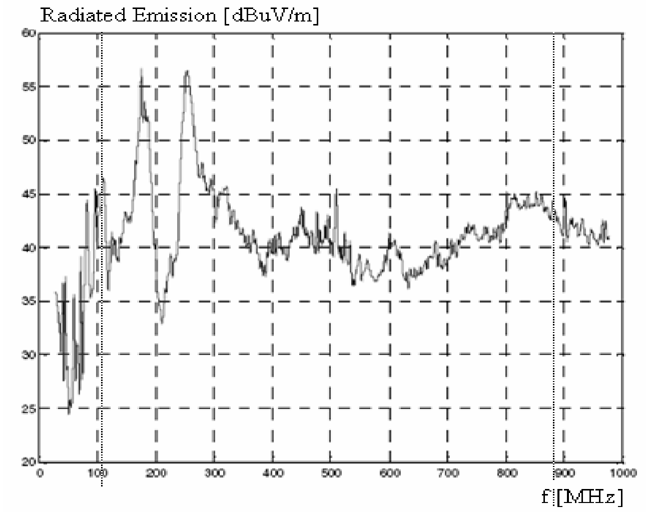

Fig. 3. The field spectrum of the system from 30 MHz to 1 GHz.

The field measurement on the Power IC is used to identify noise currents within the power IC. The Figure 4 shows the results of the near field spectrum captured with a small magnetic loop. The small loop scans on top of the IC and feeds the signal into the spectrum analyzer.

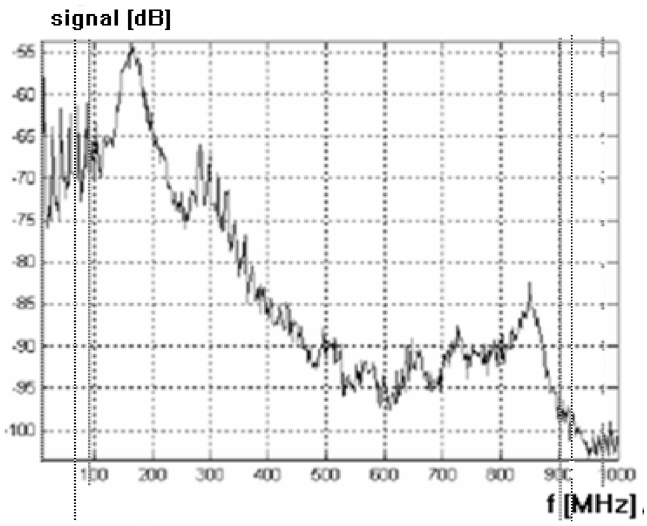

Fig. 4. The near field spectrum of the power IC.

The broadband components at 185 MHz and 850 MHz can be identified in both the near and the far field measurement. The location of strongest near field corresponds to the location of the associated switching semiconductor within the IC. These algorithms have suffered a significant increase in the amount of data to compute and store in the real time analysis.

The STFFT [6] works same as conventional Fourier transformation with short block length, sliding along with full or partial overlap. By taking the Fourier Transformation of the windowed data as the window is moved in time, a two-dimensional time-frequency image, or time-dependent spectrogram, is generated. This spectrogram provides information on the frequency components of the signals evolving with time. The long record of time domain data was taken and processed by STFFT implemented using Matlab - Simulink. The result is shown in Figure 5.

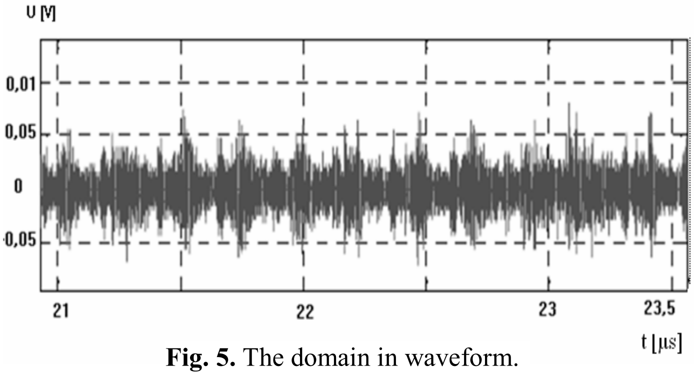

Fig. 5. The domain in waveform.

JTFA results show that the emission level from the system bursts at a particular time instance which is correlated then to every switching-on event of the buck converter. The 185 MHz and 850 MHz occur at the same time when control MOSFET starts to switch on. This correlation between converter switching event and its emission spectrum is clearly revealed when using the JTFA. For presents the advantages of this method, the STFFT analysis of the switching output waveform is shown in Figure 6. The switch-on event of the control MOSFET occurs every 1 μs and excites ringing in the power IC at frequencies of 185 MHz and 850 MHz. The 185MHz component is caused by the MOSFET drain-source capacitance and parasitic loop inductances. The observation of the emission profile and switching output waveform of the buck converters shows that the 850 MHz causing event is a result of the reverse recovery of the body diode associated with the synchronous MOSFET [7].

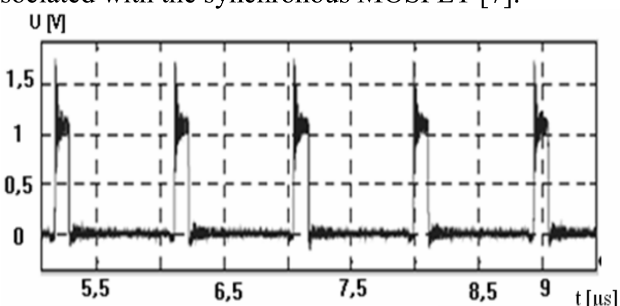

Fig. 6. Switching output with integrated Schottky contact.

3 Problem Solution

The reduced size Schottky diodes may not be able to carry a fully rated inductor current. At current levels above the Schottky diode rating, the current in the synchronous buck regulator starts to conduct through the MOSFET body diode and leads to a stronger reverse recovery [8]. The reverse recovery of the body diode will cause the high frequency noise by rapidly injecting minority carriers into an LC structure formed by parasitic elements. An experimental setup proves that the MOSFET body diode is causing the 850 MHz emissions. In this experiment, a secondary path is created such that the inductor current is diverted from the IC. Due to a DC-biasing method, it is possible to adjust the current sharing between the external path and the path internally to the IC. The circuit diagram is shown in Figure 7.

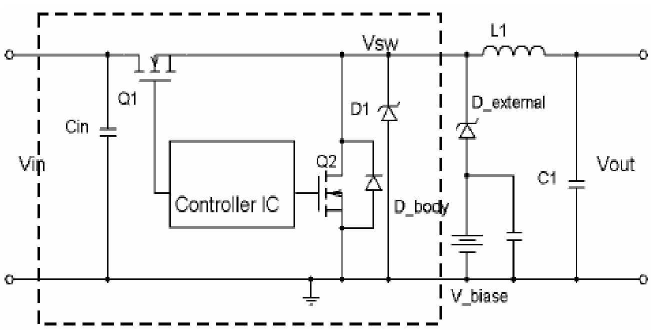

Fig. 7. The Schematic of the power IC with external Schotky.

The DC biased voltage is applied to enforce the current to go through the external Schottky diode D_l. The emission spectrum of the DC-DC converter circuits is shown in Figure 8. The higher the DC biased voltage, the lower the emission at 850 MHz.

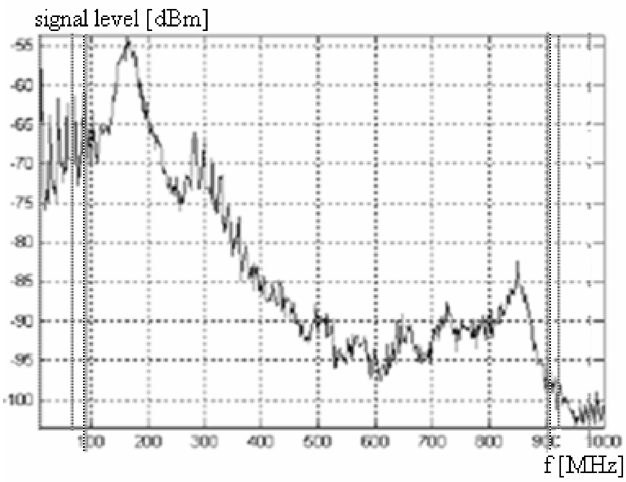

Fig. 8. Far field emissions under different biase voltages.

Reverse recover current has multiple negative effects: It is a source of radiated emission; further, it reduces the efficiency of the DC-DC buck converter. Designers have been trying to implement new techniques to mitigate the effects of the reverse recovery.

The radiated emission spectrum of a similar converter with the new power IC is shown in Figure 9. The 850 MHz emissions are drastically reduced.

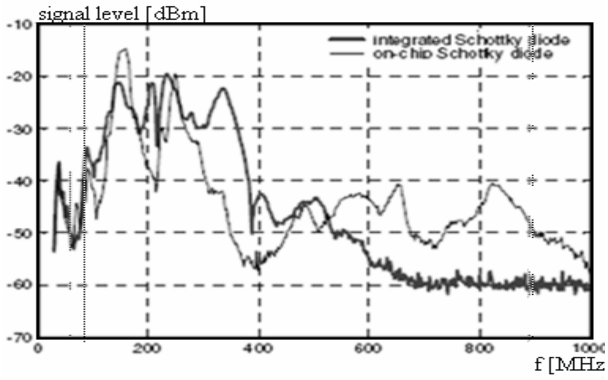

Fig. 9. Far field emissions with integrated Schottky contact.

The Figure 9 displays the MOSFET of the switching output waveform. The 850 MHz event used to be present after the rising edge of the control MOSFET turn-on is obviously removed.

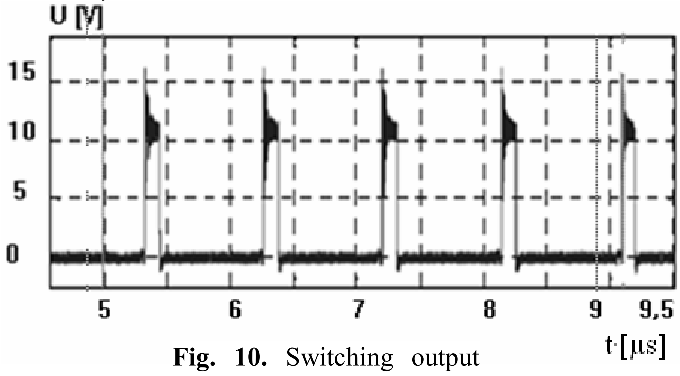

Fig. 10. Switching output integrated Schottky contact.

The Figure 10 shows the STFFT of the switching output waveform. The 850 MHz event used to be present after the rising edge of the control MOSFET turn-on is obviously removed.

4 Conclusions

To adequately characterize the interference potential of a synchronous DC-DC buck converter it is necessary to correlate the time-domain behavior and emission spectrum components. JTFA enables significant extra information to be gained over the conventional method. Reverse recovery not only reduces the power efficiency of the buck converter, but also releases the energy in the form of the electromagnetic field and increase the noise level of the synchronous DC-DC buck converters. The technique with monolithically integrated Schottky diodes is introduced for reducing the reverse recovery and its related EMI radiation.

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