Using HEXSense™ Current-Sense HEXFETs® in Current-Mode Control Power Supplies

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Introduction

Current-mode control has become a popular means of controlling Switched-Mode Power Supplies and there are now a variety of integrated circuits available to perform this function. The advantages usually cited for current-mode control are improved stability, automatic feed-forward compensation for input voltage variations, pulse-by-pulse current limiting and ease of parallelling of supplies. An economic and workable means of current sensing is central to the successful application of current-mode control.

Current-Sensing Methods

A major disadvantage of current-mode control is the necessity to monitor the instantaneous value of the current in the switching device. Traditionally this sensing function has been performed using either a resistor or a current transformer in series with the device. However, there are serious disadvantages with both methods. The series resistor gets hot, wastes energy and reduces reliability. Choosing a resistor involves a difficult compromise between keeping the dissipation low and generating a signal that is large enough to swamp any electrical noise. Finally, there remains the problem of locating a low value, non-inductive, high wattage resistor that is readily available. The disadvantages of the current transformer mainly derive from the fact that it is a magnetic component, not readily compatible with automated assembly.

Current-Sensing with HEXSense

A Current Sense HEXFET using HEXSense technology allows current sensing to be achieved at very low cost and with negligible losses. The Current Sense devices are identical to International Rectifiers normal range of HEXFET power MOSFET devices except that in the case of the HEXSense devices the current from a few of the HEXFET cells is diverted to a separate source pin. Since the ratio of sense current to drain current is known, the magnitude of the drain current can be determined by monitoring only the sense current which is typically of the order of a few milliamps.

Another pin, known as the Kelvin Source, is connected to a point on the main source metallization whose voltage is largely unaffected by the magnitude of the main source current. The Kelvin connection is used as the return point for the sense current to avoid the errors in current sense accuracy that would result if the voltage drop in the parasitic source pin resistance was included in the sense voltage. Figure 1 shows the device in a five-pin TO220 package. Figure 2 shows the symbol that has been adopted to represent the device.

Most applications require the current sense signal to be in the form of a voltage proportional to the current. There are two principal ways in which this can be obtained in the case of HEXSense devices. The simplest way, as shown in Figure 3, is by putting a resistor in the path of the sense current. This method is simple and economic and is adequate for many applications. Alternatively, the sense current can be measured using a virtual-earth operational amplifier as shown in Figure 4. The advantage of this arrangement is that the sense current can be detected while keeping the current sense terminal at source potential, thereby avoiding the change in sense ratio that occurs when a voltage is introduced into the current sense path.

These two methods of current sensing are more fully discussed in Reference 1. Both methods are appropriate for use in current-mode SMPS applications.

Figure 1. Five-Pin TO-220 Packages

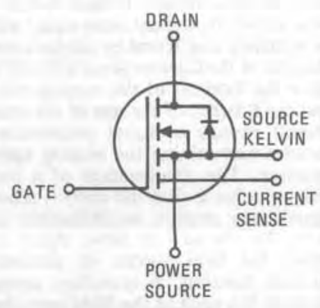

Figure 2. Device Symbol

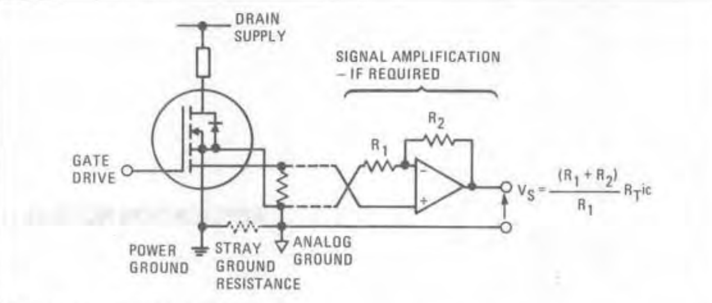

Figure 3. Resistor sensing circuit.

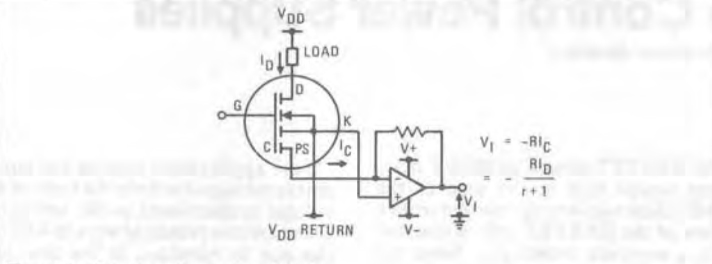

Figure 4. Virtual-earth sensing circuit.

Choosing The Sense Resistor

In current mode control, the sense resistor value is chosen to give a feedback voltage of an appropriate magnitude. Most control ICs such as the popular 3842 can operate with a feedback voltage in the range of about 50 mV to 1V.

For normal operation it is not important for the relationship between drain current and the current sense signal to remain constant as long as changes occur slowly compared to the response time of the voltage feedback loop. Therefore a change in the ratio between drain current and sense current due to a change in the temperature of the HEXSense device will not affect normal performance. However if accurate current limiting is required it is necessary to consider the accuracy of the current sense signal. If a low value of sense resistor is used then the accuracy of the current sense signal will be relatively unaffected by temperature changes of the Current Sense HEXFET since the Rds(on) of the sensing cells and the Rds(on) of the rest of the cells should change in equal proportion, thereby maintaining the sensing ratio constant. The disadvantage of a low resistor value is that the current sense signal may require amplification in order for the current sense signal to attain the level needed to produce current limiting. Fortunately some control ICs such as the 3846 provide internal amplification of the current sense signal.

Alternatively a high value of sense resistor may be chosen that gives a signal capable of producing current limiting without further amplification. However, this will change the sense ratio, r, from that published in the datasheet. In this case it will be necessary to allow for the change in the ratio of drain current to sense current produced by temperature changes of the HEXSense device. The drain current divides between the sense cells and the main body of cells in the ratio of the resistances of the two paths. In the case of a high value sensing resistor, a large proportion of the current sense path resistance is due to the external sensing resistor. Since the value of the external resistor is unaffected by changes in the temperature of the HEXFET, the ratio in which the drain current divides will alter somewhat with temperature. Whether an acceptable degree of accuracy in current limiting can be achieved depends on the application.

Virtual-Earth Sensing

Virtual-earth sensing provides a signal whose accuracy is least affected by temperature variations in the HEXFET. Clearly this method involves greater circuit complexity than does resistor sensing. The main drawback is the need to provide a negative supply for the operational amplifier. However in applications where a negative supply is available, and operational amplifiers are already incorporated in the design, virtual-earth sensing may be achievable at little extra cost.

Demonstration of Use of HEXSense in an SMPS

Current mode control of an SMPS is a well established technique. Therefore the focus of this application note is that part of the circuit which is affected by the advent of the Current Sense HEXFET — namely, the current sensing. The use of the Current Sense HEXFET in this application is illustrated by the demonstration circuit shown in Figure 5.

The circuit shown in Figure 5 is a 50 Watt forward converter using the popular 3846 SMPS control IC and operating at a frequency of 85 kHz. Manufacturer's data sheets and application literature provide abundant information on the use of the 3846 in this kind of circuit so that a detailed description of the operation of the circuit is not given here. Optional design features such as the means of deriving the 12V supply for the 3846 and the method used to achieve isolation between the primary and secondary sides of the circuit are also not dealt with here. Rather, this application note focuses on the derivation of the current sense signal necessary for satisfactory operation of the control circuit. The novel feature of the circuit shown in Figure 5 is the use of a Current Sense HEXFET to provide the current feedback signal.

The Current-Sense Waveforms

The current is sensed by a 300 ohm resistor with a 1000 pF capacitor in parallel with the resistor. The purpose of the capacitor is to suppress current signal spikes produced by parasitic capacitance charging currents. These spikes are produced when the HEXFET is in the off condition by rapid changes in drain-source voltage causing a charging current to flow through the parasitic drain-source capacitance of the sense cells. Spikes may also be produced as the HEXFET turns on and turns off, again due to parasitic capacitance charging and diode recovery currents. The presence of the capacitor reduces the bandwidth of the current sense signal but the reduction is inconsequential in this application.

The waveforms associated with the HEXFET are shown in Figure 6. The top trace shows the drain voltage, the middle trace the drain current measured with a current probe, and the bottom trace shows the current sense signal.

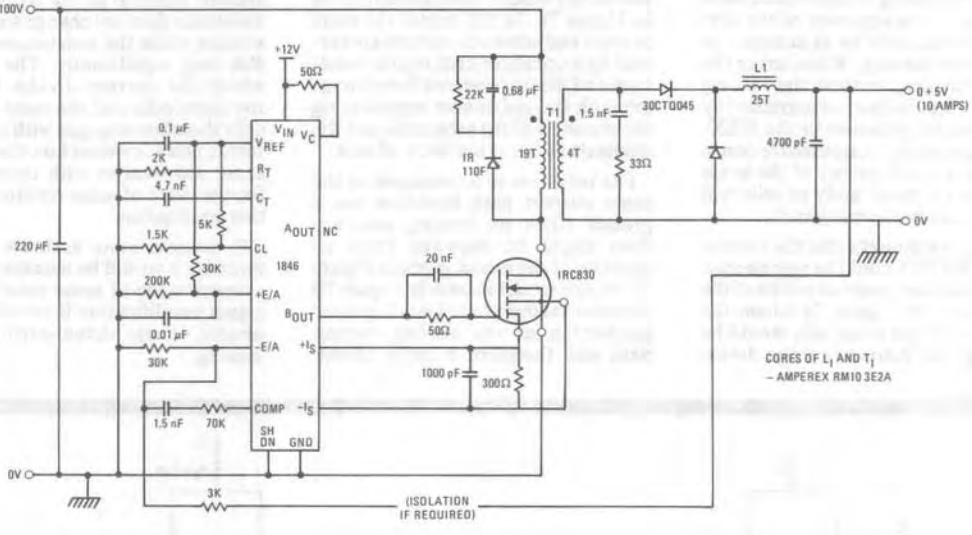

Figure 5. Circuit diagram of supply.

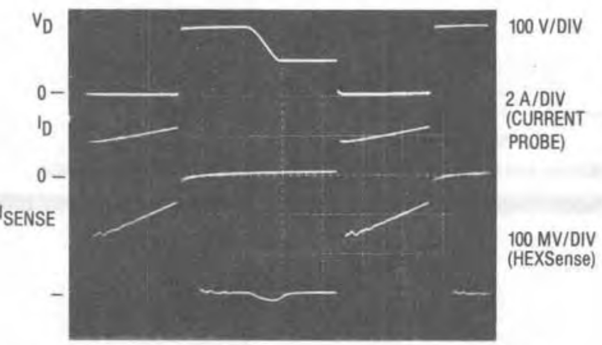

Figure 6. HEXSense signal for 50 Watts (10 Amp) output.

Several features of the current sense signal are noteworthy. During the period when the HEXFET is off there is a negative transition of the drain voltage. The resulting charging current of the drain-source capacitance of the sensing cells causes the sense voltage to dip transiently below zero. At turn-on the sense signal lags the drain current due to the time constant associated with the Rds(on) of the sense cells and the 1000 pF spike suppression capacitor across the sense resistor. At turn-off, although it is not clearly revealed in the waveform photographs, there is a positive-going spike in the sense signal as a result of the charging current flowing through the parasitic capacitance of the sense cells as the drain voltage rises. This does not affect the operation of the 3846 since the spike is produced after the comparator has detected that the appropriate level of current has been reached and has initiated turn-off of the HEXFET. After turn-off, the sense signal does not instantly fall to zero due to the hold-up effect of the spike suppression capacitor. The fall in signal voltage is governed by the time constant of the parallel combination of the capacitor and the sensing resistor. Other irregularities in the current sense waveform are largely due to parasitic coupling between the oscilloscope probe and the power supply circuit.

Current-Limiting

Most current-mode control ICs incorporate limiting of the current pulse amplitude. The accuracy of the current limit can only be as accurate as the current sensing. When using the resistor sensing method the sensing accuracy is principally determined by the expected variation in the HEXFET operating temperature since changes in the Rds(on) of the sense cells and the main body of cells will alter the current sensing ratio.

It might be thought that the current sense HEXFET could be represented by an equivalent resistor model of the kind shown in Figure 7a where the resistance of the sense cells would be equal to the Rds(on) of the device multiplied by the sense ratio. In fact the device is more accurately represented by the equivalent circuit shown in Figure 7b. In this circuit the main current and sense cell current are carried by a common drift region resistance and the two currents then diverge through the resistances representing the channels of the sense cells and the channels of the main body of cells.

The insertion of a resistance in the sense current path therefore has a greater effect on sensing accuracy than might be expected from an analysis of the model given in Figure 7a. In the model shown in Figure 7b the external resistor is a much greater proportion of the sensing current path and therefore is more instrumental in determining how the current divides. Also, because Rs is a resistor external to the HEXFET its resistance does not change with temperature while the resistances Rc and Rm vary significantly. The ratio in which the current divides between the sense cells and the main body of cells therefore changes with temperature. Figure 7c shows how the current sense ratio varies with temperature for the value of sense resistor used in this application.

To achieve more accurate current limiting, it would be necessary to use a lower value of sense resistor, with signal amplification if necessary, or, ideally, to use virtual-earth current sensing.

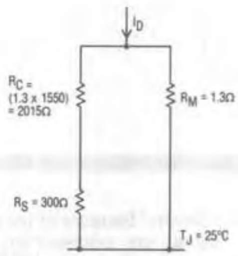

Figure 7a. Incorrect equivalent network of IRC830 with 300Ω sense resistor.

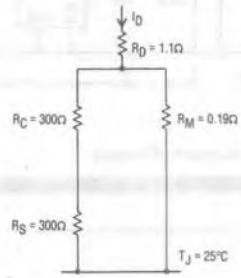

Figure 7b. More accurate equivalent network of IRC830 with 300Ω sense resistor.

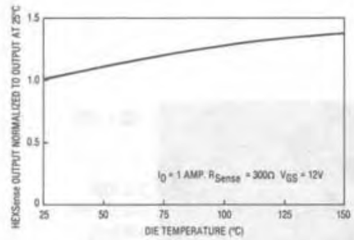

Figure 7c. Relationship between temperature and sensing accuracy for IRC830 with 300Ω sensing resistor.

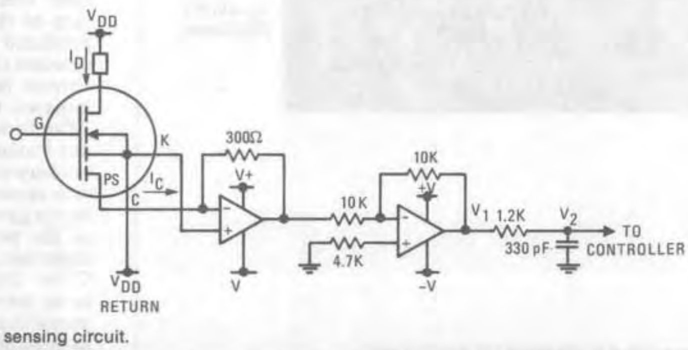

Figure 8. Virtual-earth current sensing circuit.

Virtual-Earth Current Sensing

The temperature dependence of the sensing ratio can be almost entirely eliminated by the use of virtual-earth sensing. (See individual device data sheets for temperature dependence of the sensing ratio under these conditions). Figure 8 shows how this may be implemented in practice.

Figure 9 shows the waveforms obtained with this circuit. The top trace shows the output of the second amplifier. The function of the second amplifier is to provide gain and to invert the signal. The spike at the leading edge of the current pulse is due to the discharge of the drain-source capacitance. This spike could activate the comparator of the control IC if not suppressed. Therefore a filter stage comprising a 1.2 kΩ resistor and a 330 pF capacitor is added to the output of the second stage. The cut-off frequency of this filter must be low enough to produce adequate attentuation of the spike without affecting the performance of the power supply. The slew rate limitations of the operational amplifiers may also attentuate the spike.

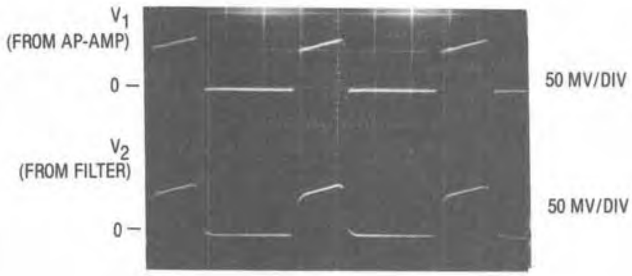

Figure 9. Typical output waveforms when using virtual-earth sensing

Conclusion

The Current Sense HEXFET provides the designer of current-mode control power supplies with a method of current sensing that has significant advantages over other methods. The Current Sense HEXFET can provide a signal of the required quality with negligible power loss and without the need for magnetic components.

The method chosen to derive the current signal from the HEXSense output will depend on the accuracy of current limiting that is required and the convenience of providing amplification. Whichever method is employed, circuit design is simple and the Current Sense HEXFET is eminently suitable for use in current-mode control SMPS applications.

References

(1) International Rectifier Application Note AN-959, "An Introduction to the HEXSense Current-Sensing Device." □