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Current Sensing Power MOSFETs

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Application note

Document information

Info	Content
Keywords	Current Sensing, PowerMOS, SenseFET, Sense Ratio, Sense Resistor, Virtual Earth
Abstract	Current Sensing power MOSFETs provide an effective means of protecting automotive electronic circuits from over current conditions. This application note shows the principle of operation using Virtual Earth current sensing and Sense Resistor current sensing techniques.

PHILIPS

Revision history

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1. Introduction

Current sensing power MOSFETs provide an effective means of protecting automotive electronic circuits from over current conditions. They offer an almost lossless method of measuring the load current that eliminates the need for a current shunt resistor.

Philips has developed a range of current senseFET products to address the automotive market as shown in Table 1. All are based on our low Rdson TrenchMOS^{TM} PowerMOS technology.

Table 1: Philips SenseFET range

Device	Rdson max (mΩ)	Sense Ratio
BUK7105-40AIE	5	500:1
BUK7905-40AI	5	500:1
BUK7C06-40AITE	6	560:1
BUK7108-40AIE	8	500:1
BUK7107-55AIE	7	500:1
BUK7C08-55AITE	8	500:1
BUK7109-75AIE	9	500:1
BUK7C10-75AITE	10	500:1

2. Principle of Operation

Current SenseFET technology is dependent on the close matching of transistor cells within the powerMOS. TrenchMOS^{TM} are made up of many thousands of transistor cells in parallel. Elements within the device are identical, and the drain current is shared equally between them. The more cells that are in parallel for a given chip area the lower the on-state resistance of the MOSFET will be. This principle has been the key driving force for automotive powerMOS for many years is well understood by both suppliers and customers alike.

Furthermore, it is possible to isolate the source connections of several cells from those of the majority, and bring them out onto a separate sense pin. The powerMOS can now be thought of as two transistors in parallel with a common gate and drain but separate sources (Figure 1). When the devices are turned on the load current will be shared in ratio of their on-resistances.

The sense cells pass only a small fraction of the total load current in proportion to the ratio of their areas. This ratio is typically 500:1.

The ratio of the current though the MainFET to the SenseFET is known as the ‘sense ratio’, n. This ratio is defined for the condition where the source and sense terminals are held at the same potential. An additional Kelvin connection to the source metallisation enables accurate determination of the source potential.

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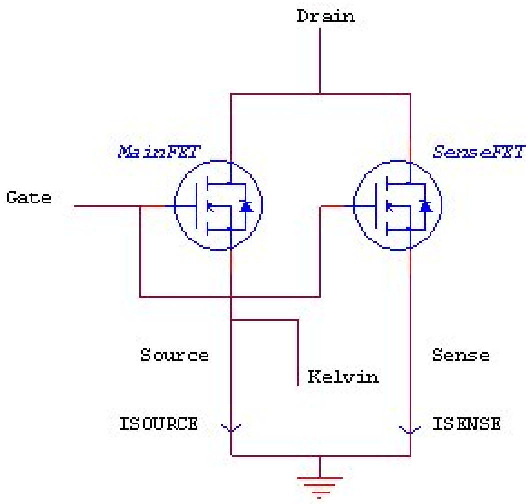

Fig 1. SenseFET equivalent circuit

3. Virtual Earth current Sensing

The virtual earth technique gives the best performance in terms of accuracy and noise immunity over the full temperature range of the device. This method is illustrated in Figure 2.

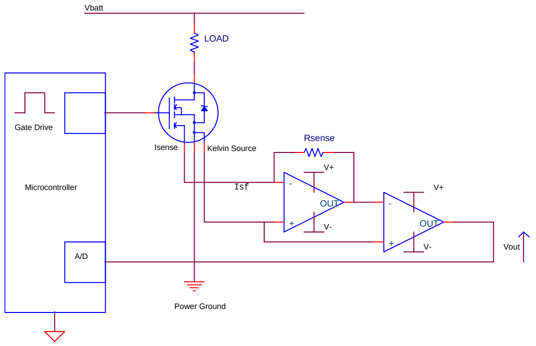

Fig 2. Virtual Earth method

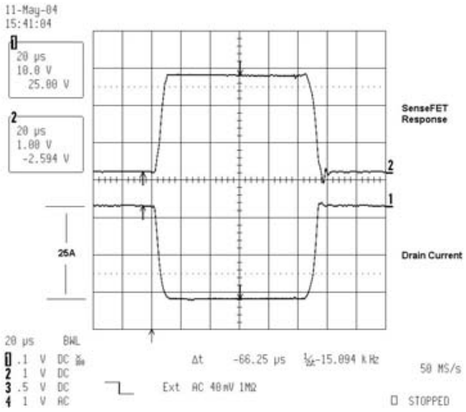

Fig 3. SenseFET response

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Current feedback to the virtual earth of the op-amp ensures that the sense and Kelvin terminals are held at the same potential so that the geometric ratio is measured.

$$Vsense = {}^{-I_D R_{sense}}\!/_{n}$$

Equation 1

A typical response is shown in Figure 3. The sense signal closely mirrors the drain current throughout the whole pulse duration.

Tolerances of ±5% can be achieved with this circuit over temperature. The main advantage of this method is that the sense signal is independent of temperature and linearly proportional to load current. A negative supply is needed for the op-amp when the MOSFET is used in the low side.

4. Sense Resistor current Sensing

The use of an external sense resistor in series with the sense pin offers a simpler technique for monitoring the current through the device (Figure 4 & Figure 5).

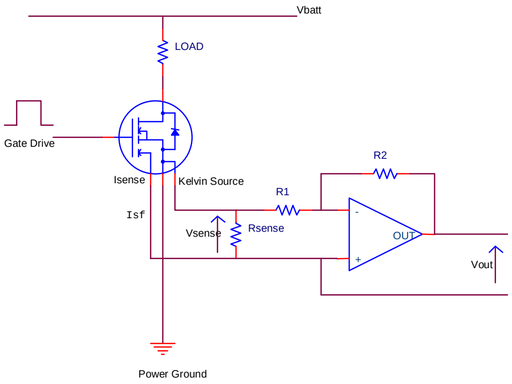

Fig 4.   Sense Resistor Circuit

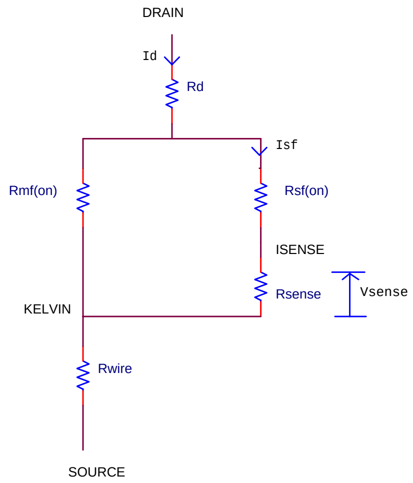

Fig 5.   Equivalent Model in the on state

In figure 4 above, an external op-amp circuit is used to amplify the sense signal.

In Figure 5, the resistance of the FET is separated in to active and passive components, again with a common drain resistance. The active channels are modelled by $R_{mf(on)}$ for the MainFET carrying the majority of the current and $R_{sf(on)}$ for the senseFET. The passive contribution from the wire resistance is denoted R_{wire}.

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The circuit operates as a potential divider with the following design equations.

$$Vout = (\frac{R_2}{R_1})R_{sense}I_{sf}$$

Equation 2

$$V_{sense} = I_D R_{mf\,(on)} \frac{R_{sense}}{R_{sense} + R_{sf\,(on)}}$$

Equation 3

The inclusion of R_{sense} increases the resistance of the mirror leg and the sense ratio now becomes

$$n' = n \cdot \left(1 + \frac{R_{sense}}{R_{sf\,(on)}} \right)$$

Equation 4

The maximum voltage seen on the Isense terminal occurs when the sense resistor is infinite i.e. open circuit condition. Known as the compliance voltage this equals $V_{DS\,(on)} \times R_{mf\,(on)} / \left(R_{mf\,(on)} + R_d \right)$.

Therefore the mirror terminal only samples a proportion of the full drain-source voltage. Fortunately for low voltage PowerMOS the contribution from the drain resistance is a small proportion of the total Rds(on) and so the compliance ratio is high. This will deteriorate in higher voltage devices.

As an example the BUK7905-40AIE has Rmf(on) = 3mOhm , Rsf(on) = 1.1Ohm and nominal sense ratio of 500:1 . If R_{sense} = 1Ω when 10A load current flows through the load this will generate Vsense ≈ 14mV. In the low side a single rail amplifier can be used to amplify this signal up to a more useful level.

The Kelvin connection to source is essential for accurate current sensing. Otherwise voltage drops over the wire resistance that are caused by load current will add to the sense voltage and introduce a source of error. In the past this was less of an issue as a wire resistance of 2mΩ was only a small fraction of a 200mΩ mainFET. But modern PowerMOS products can have on-resistances as low as 1mΩ, comparable with the parasitic resistances. Referencing to the Kelvin pin eliminates the wire contribution.

The main disadvantage of the sense resistor technique is that the inclusion of Rsense introduces a temperature dependence.

Imagine the case where Rsense→ 0Ω. The on-resistance of both the mainFET and senseFET track together over temperature and the ratio of the two remains constant. In this case the current sense ratio will also remain constant over temperature.

Conversely, if Rsense approaches infinity, the sense voltage now becomes $V_{sense} = I_D R_{mf\,(on)}(T)$ (Equation 3), and will follow Rmf(on) over temperature. The mainFET on-resistance almost doubles between 25C and 175C thus eroding the tolerance of the measurement. For values between the two a balance must be struck between signal magnitude and accuracy. We normally recommend maintaining $R_{sense} << R_{sf\,(on)}$ and amplifying the Vsense signal accordingly.

A typical response is shown in Figure 6.

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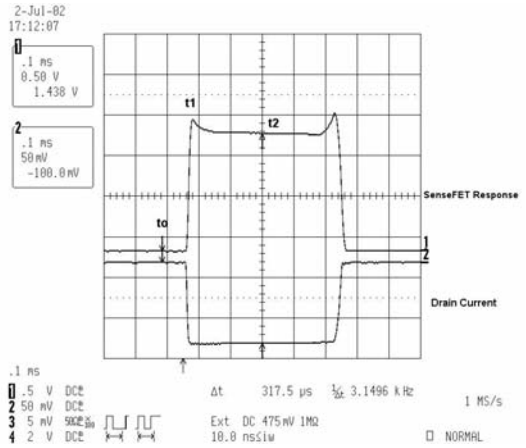

Fig 6. SenseFET response in resistor circuit

Looking at the trace above it appears that the senseFET reacts instantaneously to changes in the drain current, and the sense signal contains false peaks at turn-on and turn-off. These are due to a difference in current ratio between the linear and fully enhanced operating regions and are circuit related.

This becomes clearer if we evaluate the response in terms of an effective sense ratio, n', which is dependent on the ratio of $R_{sense}/R_{sf(on)}$ (Equation 4). Lets assume that Rsense = 1Ω.

At t0 the gate-source voltage is zero and no current flows. Once a gate voltage is applied a channel forms and current begins to flow through the device, although the on-resistance is still very high. At this point $R_{sf(on)} >> R_{sense}$ and the geometric sense ratio, n is measured. This will yield the maximum sense signal at time t1. As the gate is overdriven the on-resistance of the senseFET falls and the $R_{sense}/R_{sf(on)}$ factor becomes more significant (Figure 7). This continues until the final Vgs level and sense ratio are reached (t2). During turn-off the process is reversed. Note that if Rsense = 0Ω no false peaks are observed and the sense signal is akin to the virtual earth response (Figure 3).

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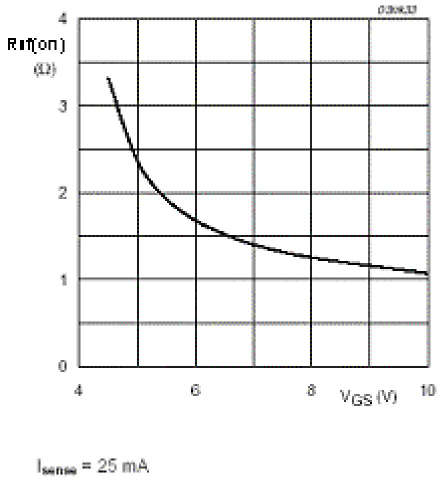

Fig 7. On-state resistance of senseFET as function of Vgs

Normally designers choose to blank out the false peaks and sense the current once the device is fully enhanced.

5. Conclusion

SenseFET devices are an effective means of protecting automotive applications. They are a loss less and cost effective alternative to traditional current shunts whilst retaining realistic tolerances.

6. References

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