

**LOAD CURRENT SENSING IN SWITCHMODE
BRIDGE MOTOR DRIVING CIRCUITS**

by Herbert Sax

Switchmode drive circuits with pulse-width modulation control of the current are widely used in motor driving because they give the best performance. In such circuits it is important to sense the load current precisely. This note provides practical solutions to this problem.

When it comes to controlling or driving electromagnetic actuators precise sensing of the load current is one of the key functions of any system. A switchmode bridge, however, does not lend itself to direct measurement of the load current in series with the actuator because the high common-mode levels that result from pulse-width modulation are far from conducive to low-cost measuring circuits. Even so, however, these problems can be overcome without resorting to costly isolating amplifiers. Most of the functions needed can be integrated in smart power circuits; some have already been implemented.

CURRENT CONTROL OF A DC MOTOR

In the final analysis, the voltage reference determines the complexity of a circuit for sensing the

load current of a DC motor bridge. The simplest arrangement calls for a measuring shunt at the common source pin of the lower branch of a power MOSFET bridge (Fig.1A).

On virtually all the smart power bridges in widespread use this pin is accessible and is adequate for straightforward current limitation functions.

During the load inductor's charge phase, the current that also drives the motor has no alternative but to flow diagonally to the shunt through the two transistors T1 and T2 and can therefore be sensed. Once the load current reaches its nominal value, it should be stored by the most efficient possible means.

The best way of achieving this aim is to short circuit the terminals, in other words to turn on transistors T2 and T3.

Figure 1A: Switch Mode Current Control Circuit for Load Current Limitation.(DMOS Bridge Configuration)

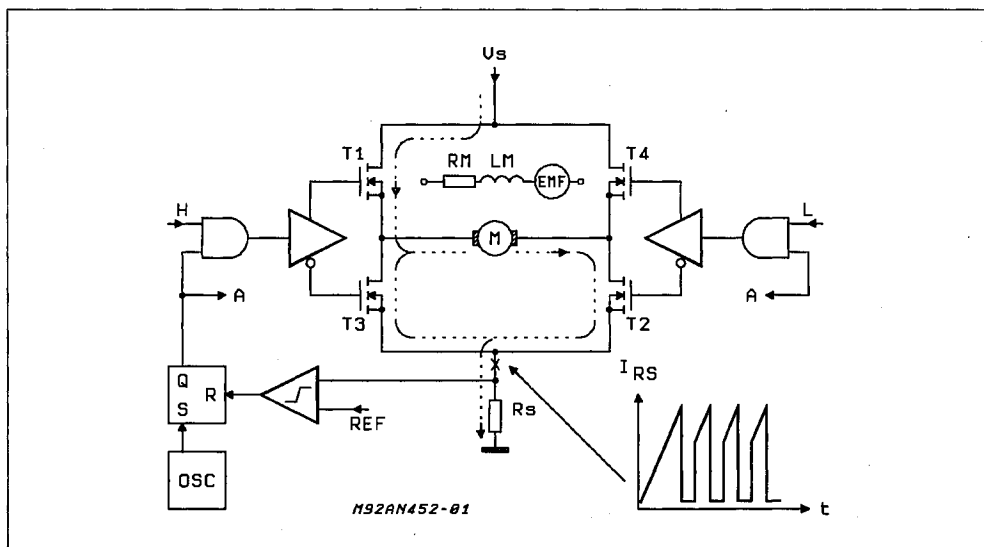
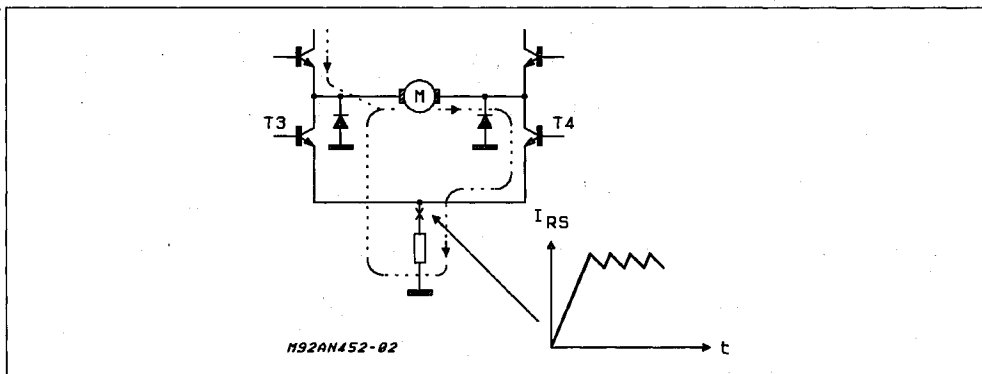


Figure 1B: Switch Mode Current Control Circuit for Load Current Limitation.(Bipolar Bridge Configuration)



A significant difference now becomes apparent between the new DMOS smart power bridges (Fig.1A) and the conventional bipolar configurations (Fig.1B). Since active MOSFET transistors and their body diode are reverse conductive, the load current circulates in the lower circuit and is no longer accessible at Rs. Neither the bridge nor the controller circuit is at risk — always supposing that the current in the short-circuited free-wheeling circuit drops — and the circuit illustrated in Fig. 1A represents the classic solution for simple clocked current limitation functions.

BRAKING

When a DC motor brakes, the counter EMF it generates feeds the motor inductor. When the two lower bridge transistors T2 and T3 are ON and forming what amounts to a terminal short circuit the current increases rapidly to a value equal to EMF/R_M .

Dangers arise if the short circuit current is allowed to exceed the maximum current rating of the bridge. Transistors having a large surface area can help avert damage, but they are costly irrespective of whether the board carries discrete components or smart power chips. It must also be borne in mind that merely short circuiting the terminals leads to a situation in which the motor's kinetic energy is largely converted into heat by the winding resistance, the time the motor needs to come to rest is uncontrolled.

SENSING THE BRAKING CURRENT

Consequently the aim must be to render the current measurable during braking. There are two approaches to this problem, both using current measuring shunts connected to ground on one side for the sake of simplicity.

The first arrangement is based on a bridge having interconnected source pins and will be described

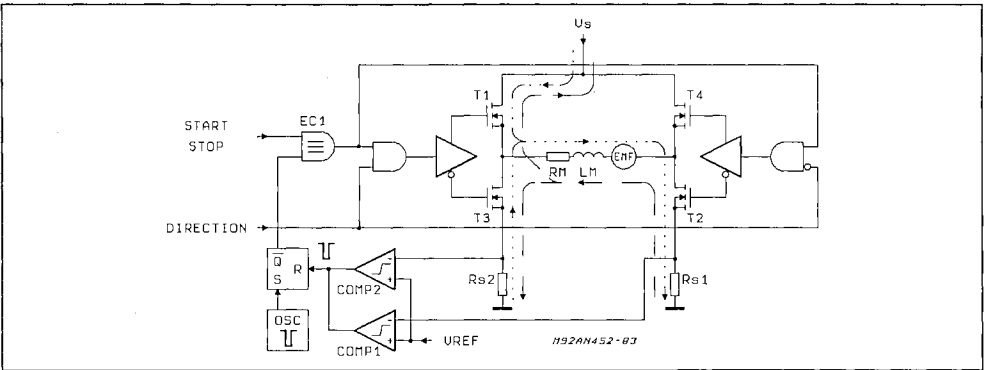
below. The alternative is a circuit with two separate shunts in the source pins of the lower bridge transistors, as shown in Fig 2.

During the charge phase of the load inductor, the current that causes the motor to turn in a given direction flows diagonally through T1, T2 and RS1. In the free-wheeling phase T2 and T3 are conductive and the situation is as shown in Fig 1A. Despite the fact that during this free-wheeling phase the current is sensed as a positive voltage at Rs1 and a negative voltage at Rs2, the information is ignored because the current is dropping. This no longer applies in the braking phase, when the start-stop input goes low.

At this point a higher current in the free-wheeling circuit activates comparator comp 2. Through the equivalence circuit EC1, the comparator disables T3 and makes T1 go conductive, thus inverting the left side of the bridge for a maximum of one oscillator period. The kinetically generated energy of the counter-EMF stored in the motor inductor is returned to the power input (Vs). This process is repeated periodically until the EMF divided by the motor resistance R_M yields a braking current that is less than V_{REF}/R_{S1} . This controlled return of energy has one major advantage in that the braking current and thus the braking time can be influenced, while on the other hand, a large proportion of the motive energy is recovered and the winding resistance has to dissipate much less heat.

Sadly, however, the configuration shown in Fig. 2 is not feasible with all smart power bridges with DMOS power transistors. Not infrequently the source pins of the lower half of the bridge are interconnected on the chip, either because a limited number of pins are available or because the metal resistance would be too high. In cases of this nature the only resort is to connect two ICs in parallel and form a bridge from two half bridges. Of course this entails an additional advantage in that since conductive losses are lower, too.

Figure 2: Same As Figure 1a but Including Braking Energy Recovery.



SOLUTIONS FOR SERVO SYSTEMS

Circuits such as those shown in figs 1 and 2 are used primarily to protect the motor and semiconductor bridge from overload. Torque limitation is often another major concern in stepper motor drive systems and with DC motors. Although the current can be varied within adequate limits by varying the reference voltage, the tolerance factor becomes larger as the values become smaller because only one-sided peaks can be measured, instead of mean values. If the current fluctuates close to or across zero, another strategy affording greater precision is needed.

Servo systems, being closed-loop control systems with position and speed sensors, are heavily reliant on accurate current sensing in a form that is perfectly reliable in the current reversal range close to zero. This further entails adopting a different drive strategy.

Since a short-circuited free-wheeling circuit in which both lower transistors are conductive would produce severe non-linearities in the current

reversal range close to zero, it is to be avoided at all costs. Free-wheeling in this case means selectively inverting the bridge, thus causing the current to drop along a largely linear path, but no more than five to ten percent before the original status is readopted. In a configuration of this nature, a zero motor current means that the bridge remains active, but the sampling ratio is cut to 50%.

Since there are only two conductive states (either T1 and T2 or T3 and T4), the current always flows through R_s, irrespective of whether the circuit incorporates two separate shunts or one common shunt.

Fig. 3 illustrates the current curves and their effect on the sense resistors R_s. Reconstructing the load current requires only an operational amplifier that operates as a subtractor. Via resistor R₁, the capacitors suppress the peaks that occur during changeover. Since the common-mode interference level is high, fast operational amplifiers are the obvious first choice if high signal precision is required.

Figure 3: Current Sensing by Reconstructor.

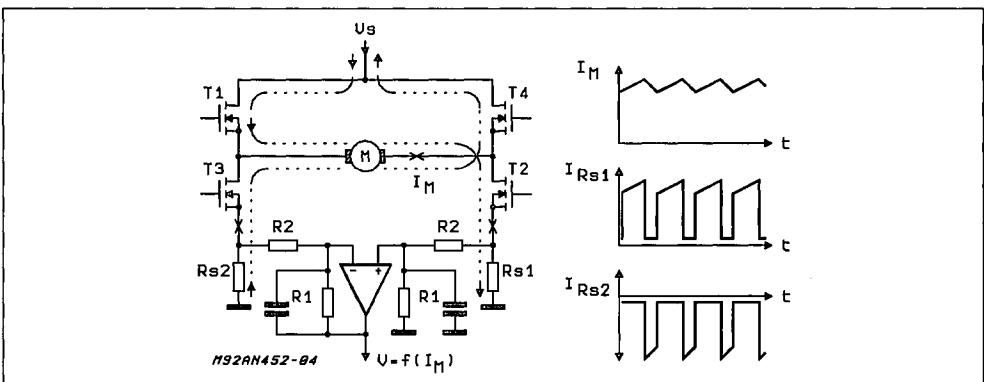


Figure 4: Current Sensing in the Load Circuit.

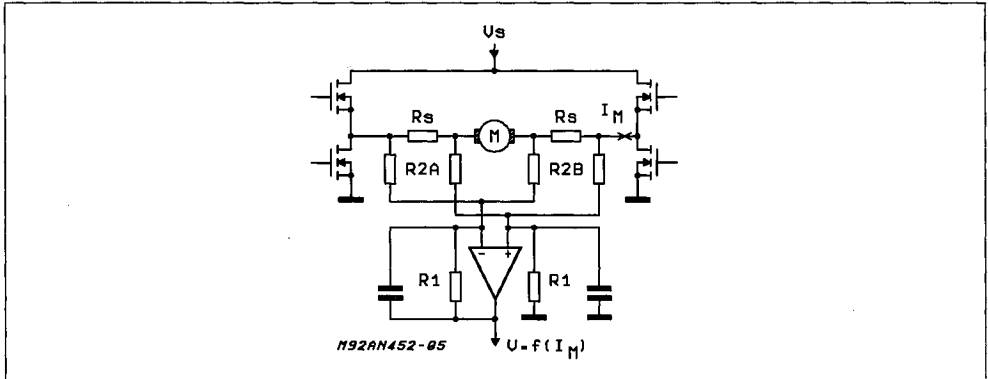


Fig. 4 shows another circuit that is feasible for all situations in which, since they cannot be inserted in the source circuit, the shunts have to be connected directly in series with the load, with all the disadvantages that this entails.

Although a single resistor suffices in theory, an operational amplifier provides the speed and common-mode suppression characteristics that make it virtually the ideal choice. Nonetheless, the results can be improved considerably by sensing the current on both sides of the load. Since measurement is symmetrical, the useful signals and the sense resistors are added together, while the counter-phase edges are subtracted, thus significantly reducing the common-mode load on the operational amplifier. This is true in so far as the matrix resistors are capable of satisfying the very high requirements.

CURRENT RECONSTRUCTION

Bridges with a common source output show an interesting current pattern. The load current is a positive signal during the charge phase of the coil, while it is negative in the inverted state, in other words during the free-wheeling phase. The only way to reconstruct this current is to periodically invert the sense voltage V_{RS} .

Two of the many solutions to this problem are shown in Fig. 5. The V_{RS} signal is applied to the output alternately as a direct or inverted signal (Fig. 5A), or the operational amplifier can work in the inverting or non-inverting mode, depending on the position of the switch. In both cases lateral MOS transistors or even simple small-signal bipolar transistors are perfectly adequate as switches. The RC filter at the output smooths switching peaks without distorting the time constant of the current control loop.

Figure 5A: Recovery of the Load Current Map.(Direct/Inverted Solution)

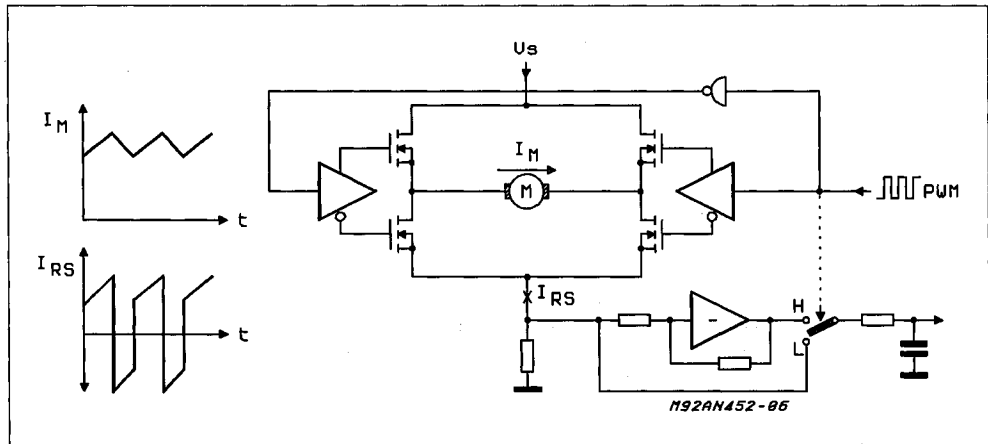
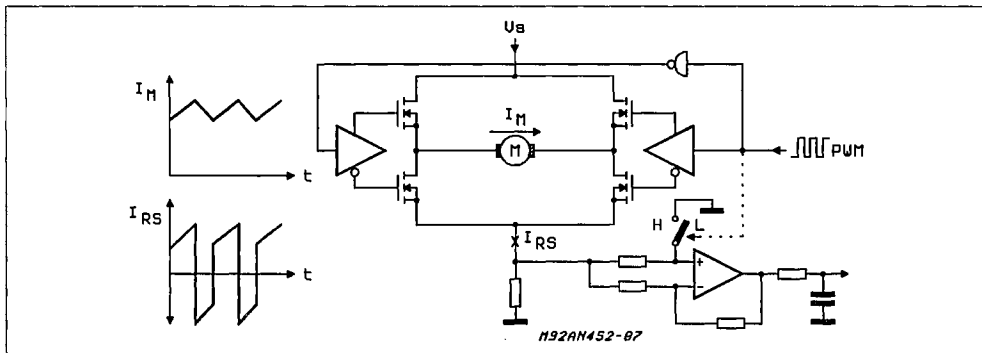


Figure 5B: Accovery of the Load Current Map. (Inverting/non Inverting Solution)



PRACTICAL EXAMPLE

Fig. 6 shows part of the circuit for a DC motor positioning system as use in a typewriter to control four movements. It consists of a controller circuit driving a smart power DMOS bridge with a single current sensing output.

Motor current can reach a maximum of 1A and is influenced by two control loops. The inner loop limits the current by positive or negative peak sampling of the reconstructed current information. An exclusive OR gate inverts the bridge phase for a maximum of one oscillator period, thus causing the current to change its direction. This loop is not delayed and therefore reacts very quickly. The second loop operates in a conventional circuit as a transconductance amplifier and converts an input error signal into a proportional current. If the difference between the measured value and the set point is large enough to force the error amplifier into saturation, the inner circuit limits the acceleration of braking current to the permissible

maximum.

POTENTIAL APPLICATIONS

The example circuits for sensing current and processing the signals shown in Figs. 1 to 6 are easily adaptable to other electromagnetic actuators that receive a bidirectional feed. Microstepping motors are a case in point, one in which inexpensive but nonetheless precise current control is very much desired by every user. As power MOSFETS in the guise of discrete components or smart power ICs become more popular, the techniques of sensing current in the source circuit either directly by means of shunts or in directly as sense FETs become correspondingly more important. The unavoidable errors caused by the base current of the bipolar transistors used to date thus become a thing of the past. Although the gate source capacitance remains a potential source of interference, its effect can be suppressed by analog or digital filters.

Figure 6:Part of a DC Motor Positioning Control Circuit.

