International Rectifier

Application Note AN-1052

Using the IR217x Linear Current Sensing ICs
By Jonathan Adams

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Topics Covered:

- Basic Functionality
- Bootstrap Circuit
- Retrieving Analog Current Signal at the Output
- Interfacing the Output With Digital Circuits
- Dealing With Negative Transients at the Vs Pin
- Layout Recommendations
- dV/dt and its effect on Duty Cycle
- Comparison of IR2170/1/2/5

1. BASIC FUNCTIONALITY

This section will cover the basic operation of the current sense IC.

These Linear Current Sensing ICs are designed to transfer current sense information from the high side part of a Motor drive circuit to the low side circuit, so that the information may be processed by the ground referenced control circuits.

The Analog input signal is actually a voltage which comes from the voltage drop across an external sensing resistor. The sensing resistor senses the motor phase current, and generates a small AC voltage signal input to the IR2175 Current sensing IC. The maximum input signal is +260mV so the sense resistor should be chosen such that the desired setting for overcurrent would generate 260mV across it (e.g. for a 10A overcurrent the sense resistor would be 26mΩ).

The AC input signal is converted to a PWM signal, in the high side circuitry of the IR2175, using a carrier frequency of 130kHz . The PWM signal is then level shifted down to the low side ground referenced circuit.

The PO output is an open drain PWM output, which means it can be easily interfaced with any control circuit with operating voltages of 3.3V to 15V. Due to the fact that the output is an open drain output, the PO pin will need to be connected to the low side control circuit power supply by means of a pull-up resistor (the size of this pull-up resistor is dependant on the input current requirement of the circuit that the PO output is being interfaced with, but typically 1-10KΩ would be a good value for this resistor.

There are two options for handling the output signal from the current sense IC:

1. Use a filter to filter out the carrier frequency and retrieve the analog current signal.
2. Directly interface the output with the low side digital control circuit (e.g. microcontroller or DSP) and use a software algorithm to calculate the current

Methods and circuits will be discussed later in sections 3 & 4.

The high side floating supply between Vb and Vs is generated by means of a bootstrap circuit, which is described in the next section. The circuit will operate down to a minimum Vbs supply of 8V, but it is recommended that the Vbs and

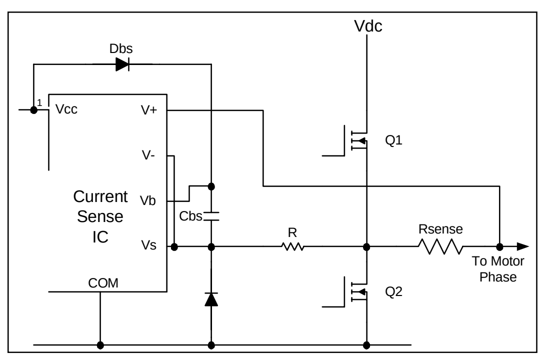

Figure 1 Typical Connection Diagram

Vcc voltage are kept above 10V.

2. BOOTSTRAP CIRCUIT

The Vbs supply voltage is a floating supply that sits on top of the Vs voltage (which in most cases will be a high frequency square wave). There are a number of ways in which the Vbs floating supply can be generated, one of these being the bootstrap method described here in this design tip. This method has the advantage of being simple and inexpensive but has

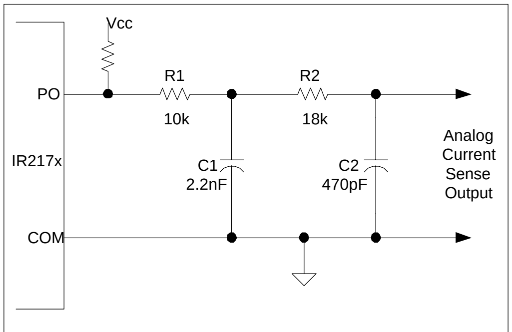

Figure 2 Two Stage RC Filter circuit

some limitations, duty cycle and on-time are limited by the requirement to refresh the charge in the bootstrap capacitor (long on-times and high duty cycles require a charge pump circuit - see application note an978 for information) . The bootstrap supply is formed by a diode and capacitor combination as shown in Figure 1).

The operation of the circuit is as follows. When Vs is pulled down to ground (either through the low side FET or the load, depending on the circuit configuration), the bootstrap capacitor (Cbs) charges through the bootstrap diode (Dbs) from the 15V Vcc supply. Thus providing a supply to Vbs. When Vs is pulled to a higher voltage by the high side switch the Vbs supply will float and the bootstrap diode will be reverse bias and block the rail voltage from the supply.

3. RETRIEVING THE ANALOG CURRENT SIGNAL AT THE OUTPUT

The simplest method of retrieving the analog current sense signal is to use a low pass filter to filter out the PWM carrier frequency. Obviously there are many types of low pass filters which can be used, both passive and active. Here we will concentrate on simplicity and low cost so we will look at two alternatives, a passive RC filter and a single stage active filter.

3.1 PASSIVE FILTERS

The simplest and lowest cost low pass filter is the basic RC low pass filter. This type of filter does not have a sharp cutoff the typical fall off is 6dB/octave, so the -3db point of the circuit should be designed to be close to the fundamental frequency of the current signal, which in motor drives is commonly in the range of 8-10kHz. A better solution is to use a 2 pole RC filter as shown in fig 2. In the implementation used in this example the first stage is designed to have a cutoff frequency of 7.2kHz which we use the standard formula of:

$$f_c = \frac{1}{2\pi RC}$$

makes R1 = 10k, and C1=2.2nF. For the second stage we use a higher cutoff frequency to further attenuate the switching frequency, but to have little effect on the 8-10kHz carrier frequency, so R2=18k, and C2=470pF,this gives a cutoff frequency of 19kHz for the second stage. It is always a good idea to make sure the resistance of the second stage is higher than that of the first stage to minimize the loading on the first stage.

Using the above filter on the PO output of an IR2175, we can check the linearity, for both a DC current input and an 8kHz AC current input. The typical use in an application circuit would involve the IC sensing an AC current so the AC linearity is a more important measure, and this is what we will focus on.

A typical situation and the one used here for example would be an 8kHz AC input signal, using the AC input signal and measuring the AC output from the filter, using a 150nF decoupling capacitor. Fig 3 shows the AC linearity characteristics of the IR2175 which has a PWM frequency of 130kHz. This results in the characteristic following the ideal with a linearity of better than 1% down to 25mV, at which point the difference is 3% from the ideal.

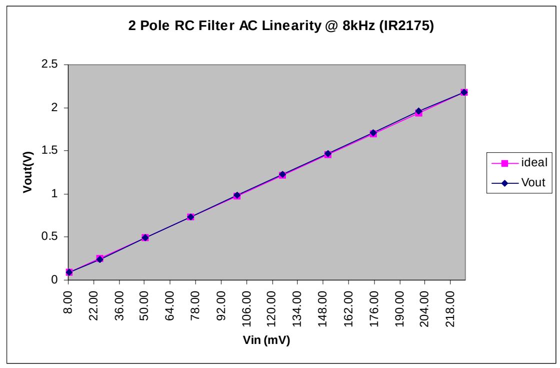

Figure 3 AC Characteristics of 2 Stage RC Filter IR2175

If we characterize the IR2175 again with an RC filter, but this time with a 16kHz input signal (some motor drive systems are moving to using this as the PWM switching frequency), and with R1 in fig 2 changed to 4.7k to change the cutoff frequency point to be in the order of 15.5kHz, we get the charcteristic shown in figure 4.

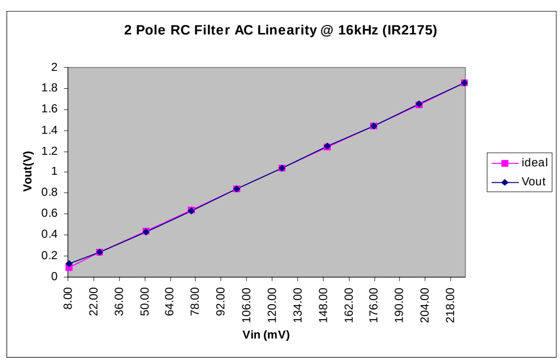

Figure 4 AC Characteristics of 2 Stage RC Filter IR2175

Again we get a linearity against the ideal of better than 1%, down to the minimum input resolution at 8mV, at which point we veer away from the ideal.

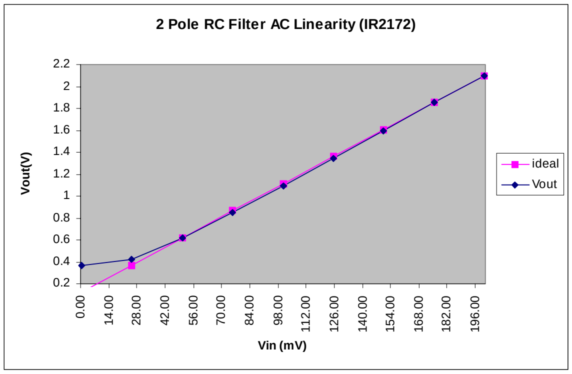

Figure 5 AC Characteristics of 2 Stage RC Filter IR2172

For comparison we will look at the AC linearity characteristics of the IR2172 with an 8kHz AC input signal. This IC has a PWM carrier frequency of 40kHz, so we will use the same filter circuit as used for the the tests of figure 3. The results can be seen in Figure 5. The measured characteristic follows the ideal line closely down to about 50mV with a linearity of approximately 2%, but below 50mV it starts to veer away sharply with a 14% difference from the expected ideal at 25mV input. The lower PWM carrier frequency results in lower resolution which leads to the lower performance in terms of linearity, particularly at low level input signals.

Active filters commonly have sharper cutoff points than do passive filters so we will see how they perform in the next section.

NOTE: Using passive LC filters is not recommended due to the loading on the PO pin.

3.2 ACTIVE FILTERS

Active filters typically have sharper cutoff characteristics than passive filters, and flatter passbands, so in a case where the desired pass frequency is 8kHz and the frequency to filter out is 40kHz an active filter would have a more desirable characteristic. In this example we are using the IR2172, but the circuit could also be easily be used with the IR2175.

For the application example used here a single stage 2 pole VCVS (voltage controlled voltage source) filter has been implemented. The circuit can be seen in figure 6. This implementation is basically a butterworth filter, with a gain of 19. We are using a higher gain than would normally be used for this type of filter, as the cutoff frequency is set to 9kHz which is very close to the actual desired output frequency.

Figure 7 shows the AC linearity characteristics under the same test conditions as for the RC filter, and it can be seen

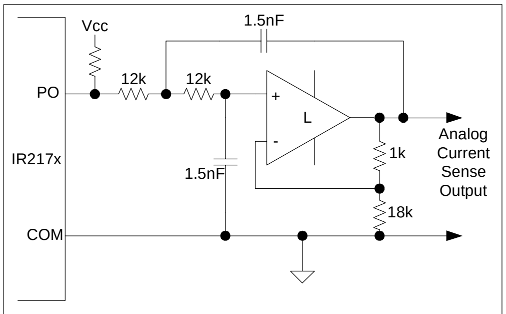

Figure 6 Two Pole VCVS Active Filter

that the performance is much improved over the passive filter, with a linearity better than 1% down to a 50mV input and about 9% at 25mV.

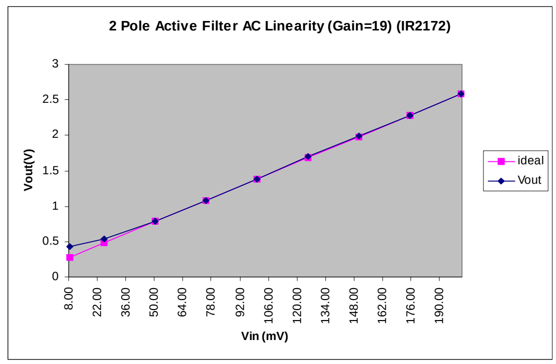

Figure 7 AC Characteristics of 2 Pole VCVS Active Filter

The filter could be futher improved, by adding another stage, but performance cost issues will dictate whether that is necessary.

4. INTERFACING THE OUTPUT WITH DIGITAL CIRCUITS

Interfacing the IR2175 with digital control circuits such as microcontrollers, or DSP processors is more simple in terms of the hardware aspect, however the software algoritm will involve more work. However it will limit any introduced error from the filtering circuits discussed in section 3. The IR217x devices were primarily designed with this application in mind.

4.1 HARDWARE INTERFACING

As the PO output of the IR2175, and the IR2171/2 have open drain outputs, interfacing with the digital control circuit will involve using a pull up resistor which is tied to the power supply of the control circuit, which will likely be a microcontroller or DSP device, with a Vdd of either 3.3V or

5V, so a connection would look something like the one shown in Figure 8.

4.1 SOFTWARE FOR DECODING THE PWM SIGNAL

An example of using the linear current sensing IC with a DSP can be found in Design Tip DT99-8, This provides the hardware and software solution for an IR2171/IR2172 with a TI TMS320C240 DSP.

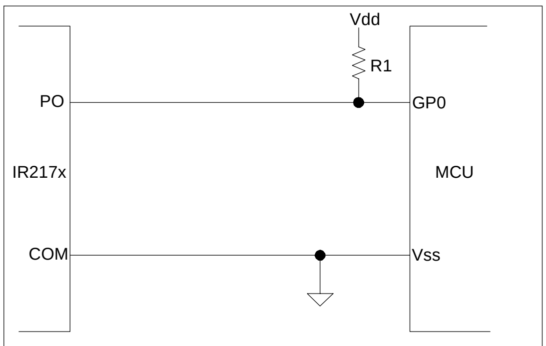

Figure 8 Interface between IR217x and Digital Controller

5. DEALING WITH NEGATIVE TRANSIENTS AT THE VS PIN

***IMPORTANT:* The current sensing ICs require their own separate negative transient protection circuit, due to the fact that they are not synchronized with the gate drivers**

The condition where the Vs pin goes negative with respect to the com pin is more critical for the current sensing ICs due to the fact that, unlike the gate drivers, the current sense IC will be continuing to operate during the transition, where the high side switch is turning off. For this reason it is very important to ensure that the current sense IC does not see a negative transient at the Vs pin. More details on the issue of negative transients at the Vs pin can be found in Design Tip DT97-3.

Notice in the typical connection diagram that there is a diode connected from com to Vs and a resistor between vs and the center of the half bridge. The combination of these two components clamps the Vs pin, so that it can only fall one diode drop below the com pin. The diode should be a fast recovery diode with a recovery of better than 100ns, and a 1A diode would be sufficient. The resistor between Vs pin and the center of the half bridge should be in the range of 10-20 Ohms.

Notice that although the resistor between the Vs pin and the ceneter of the half bridge is in the current sensing path (i.e. between V+ and V-, it will not contribute to the current sense signal unless there is current flow in that resistor, and that will only occur during a transition and would be short in duration (hence being ignored by the amplifier at the input of the IR2175 due to the limited Slew rate of this amplifier).

6. LAYOUT RECOMMENDATIONS

As with all power electronics care should be taken with the circuit layout to minimize parasitic elements. Figure 9 below shows a typical half bridge circuit and the stray inductances. Each of these stray inductances can be minimized by making the tracking on the circuit board as short and as wide as possible.

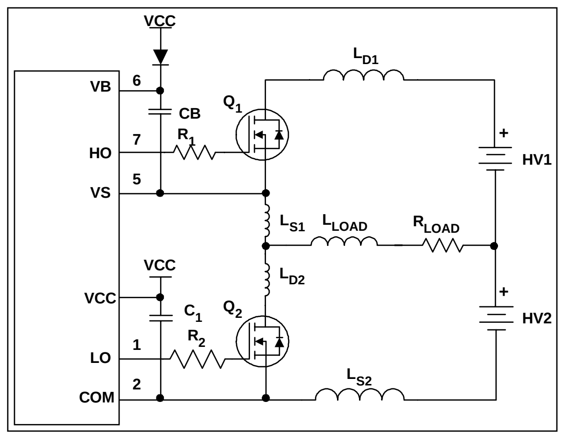

Figure 9. A typical half-bridge circuit with stray inductances.

For the IR2175 current sense IC, the layout guidelines are similar to those for gate drive ICs. As Shown in Figure 10 the decoupling capacitors for the Vcc and Vbs supply should be as close as possible to the IC. Also the connection between V- and Vs should be made very close to the IC, to minimize

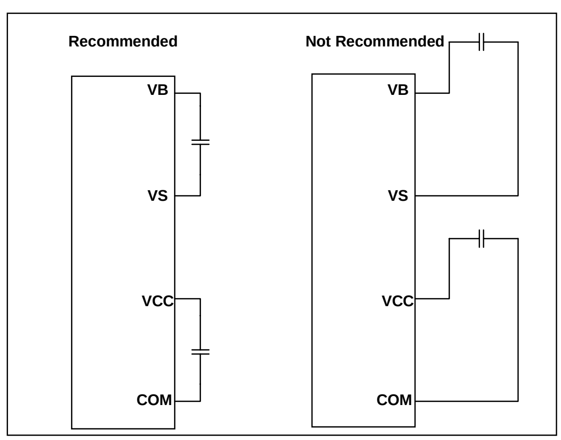

Figure 10. Decoupling Capacitor Layout.

the voltage difference between these pins. The connection between the sensing resistor and the V+ pin should be as short as possible to minimize noise pickup.

An example of a layout for the IR2175 can be seen in fig 11. This is a layout for the typical connection diagram shown in figure 1. Notice the short connections between the current sensing resistor and the IR2175, this will help to minimize noise coupling into the current sense signal. The high current tracks are kept wide to minimize inductance. The negative transient protection circuit formed by R2 and D2 is kept close to the IC to have maximum effect, and notice that the decoupling capacitors for Vcc and Vbs, are put as close to the IC pins as is physically possible.

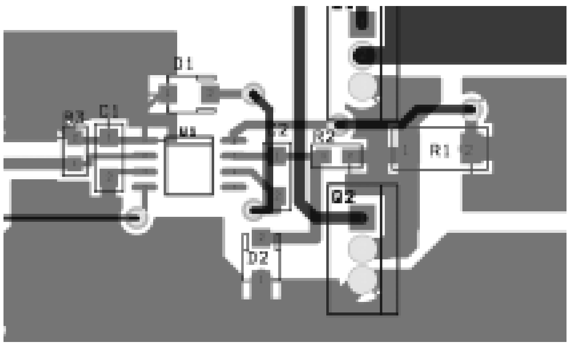

Figure 11. A typical IR2175S circuit layout

7. DV/DT AND ITS EFFECT ON DUTY CYCLE

This could also be described as the CMRR (Common Mode Rejection Ratio) of the current sense ICs. In a situation wher the high side is floating but not switching up and down (i.e. the Vs pin voltage is fixed), then there would be no duty cycle jitter.

However it is more likely that the IC would be used in a circuit similar to that shown in the typical circuit diagram of figure 1 in which the Vs pin is connected to the center point of a half-bridge, an example would be using two current sensing ICs to sense motor phase current in a thre phase half-bridge. In this application then the Vs pin and therefore the high side circuitry of the current sensing IC would switch between ground or near ground and the positive DC bus, so in each transition there would be a dV/dt, which the current sensing IC will have to contend with. during the Vs pin transition the dV/dt will cause some slight jitter in the output duty cycle at the PO pin. In the case of the IR2175 this is 2% for a DC bus voltage of 300V. Table 1 below shows some typical duty jitter for the IR2171/2 and IR2175 at various bus voltages for positive and negative dV/dt. The results in the table are taken from system testing on an IR Accelerator servo system.

In the example of a motor drive circuit this would translate to a torque ripple at the motor and should be taken into account.

	Jitter @100V (%)	Jitter@200-V (%)	Jitter @300V (%)
IR2171/2 +ve dV/dt	1.4	2.8	4.0
IR2171/2 -ve dV/dt	1.5	3.3	5.0
IR2175 +ve dV/dt	0.75	1.4	2.1
IR2175 -ve dV/dt	0.25	0.8	1.6

Table 1 Typcal Duty Jitter(CMRR) for IR217x ICs

8. COMPARISON OF THE IR2170/1/2/5

The table 2 below provides a comparison of the functionality differences between the differnt current sensing ICs.

	IR2170	IR2171	IR2172	IR2175
PWM Out	No	Yes	Yes	Yes
Overcurrent Signal	Yes	No	Yes	Yes
OC Trip Delay (µs)	1.5	1.5	1.5	2.0
I_{QBS} (mA)	1	1	1	2
F_O (kHz)	N/A	40	40	130
Dmin (%)	N/A	7	7	9
Dmax (%)	N/A	93	93	91

Table 2 Comparison of IR217x Current Sensing ICs

IMPORTANT NOTE: It should be noted that the IR2171/IR2172 are being obsoleted, so for new designs the IR2175 should be used.

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