NEW MONOLITHIC HIGH VOLTAGE CURRENT SENSING IC SIMPLIFIES AC DRIVE INTEGRATION

As power electronic technology evolves, the AC PWM inverter drive becomes more efficient, more compact, more advanced in performance, and less expensive. This tendency has been further accelerated in the small horsepower AC drives, particularly in the area of less than five horsepower range application. High Voltage Integrated Circuit (HVIC) technology has been one of the major contributing factor to achieve these objectives.

The motor current sensing device is an important element in the AC motor drive, which provides IGBT protection information as well as linear current feedback information for control purposes. Traditionally, the Hall Effect current sensing device has been widely used in the past. In some applications, shunt resistors with the optically isolated linear current sensing device have been used as well. However, these devices have often been limiting further size reduction and simplification of the AC inverter drives due to the mechanically large construction and the number of additional peripheral components.

International Rectifier has recently introduced the 600V monolithic motor current sensing IC based on the proprietary high voltage technology, which is the first in the industry. This will enable further integration and simplification of the AC drive and accelerate functional advancement of the Intelligent Power Module.

INTRODUCTION

Today's AC PWM inverters, the so-called "micro AC inverters", are typically equipped with the high voltage gate drive IC (HVIC) to accomplish significant space and cost reduction by a simplified ground isolation scheme. Due to the non-galvanic isolated direct control of the IGBTs, all control functions, except user interface I/Os, have the ground potential fixed to the negative DC bus voltage potential.

As the drive performance advances towards the sensor-less vector drive operation, the following features have been requested in the linear current sensing device to achieve a certain performance goal:

- Low secondary power to share the bootstrap power supply with HVIC gate drive IC
- Low PSRR (power supply variation rejection ratio) with a wide range of power supply voltage
- High accuracy, low temperature drift, reasonable bandwidth
- High dv/dt common noise immunity by PWM motor drive
- Simple and easily manufacturable construction

- Monolithic and low cost

Traditional devices - either Hall Effect or the optically coupled current sensing device - lack some of the above criteria. In order to meet the criteria above, the IR2171 has been newly developed. This paper discusses the key implementation issue of IC (i.e. high voltage IC technology), the latest test results, applications, and future direction of the high voltage linear current sensor technology.

MONOLITHIC CURRENT SENSING IC

The IR2171 is a linear current sensing device, which is based on the monolithic integrated circuit, fabricated with a high voltage junction isolation. Figure 1 shows the functional block diagram of the IR2171.

The internal circuit is mainly divided into two segments: the high side circuit and the low side circuit. High voltage level shifters isolate these circuits and allow two independent reference ground potentials within the monolithic integrated circuit. The high side circuit, floats up and down from 0 to 600V with respect to the low side ground potential (COM). This high side circuit contains most of the important functions such as the high precision operational amplifier, the analog-to-digital conversion unit, and the pulse generator. There are two P-channel level shifters, which transfer the digital PWM information in the high side circuit to the low side circuit by trailing edge pulses. The low side circuit contains simple circuits such as the PWM pulse reconstruction circuit, dv/dt filter and the output buffer.

The key innovation and achievement resides in the high side circuit. Today, although the 600V as well as the 1200V high voltage junction isolation technologies are available, it requires several key technological hurdle and innovation in order to accomplish precision measurement of small analog signal under harsh environment. Monolithic integration, low power consumption on the secondary floating power supply, wide range of the secondary voltage supply, and low temperature drift are the key design issues of this high precision linear current sensing device.

Figure 2 shows cross sectional view of three main devices, which form the monolithic integration. The P-channel level shifter transfers information across the high voltage barrier between the low side grounded CMOS circuit and the high side floating CMOS circuit. This device, located in the high side well, is designed to be able to send data from the high side well to the low side circuit under any voltage differential (600Vmax) including high dv/dt transient condition up to 50V/nsec. CMOS devices both in the low and the high side have well structures based on the P-type substrate and designed to sustain up to 25V breakdown voltage providing enough margin over 15V power supply for the motor drive environment.

High side CMOS floating circuit contains key technical innovation for high precision analog circuit. One is the low temperature drift P-channel MOS differential input stage which is designed to cancel out the temperature coefficient difference. The other is the stable current source to provide reference to the analog circuit, which can operate without degradation of accuracy under wide range of power supply ranging from 7V to 20V.

MOTOR CURRENT SENSING APPLICATIONS

Motor phase current feedback is quite often required in the motor drive application. In order to sense the Motor phase current, the location of sensing devices is ideally in series with the motor phase lead output as shown in Figure 3, since it provides the current waveform of the motor fundamental frequency. (If the current sensing devices are located in the other places within the PWM inverter power structure, then they need to reconstruct the measuring waveform to the fundamental waveform).

Application of the motor phase current is mainly divided into two purposes - the control purpose and the monitoring purpose. For the control purpose, it becomes a vital part when used for the closed loop current control in the vector control environment in terms of linearity, accuracy, offset temperature drift, and bandwidth. When used for the monitoring purpose, requirement becomes less stringent.

Historically Hall Effect current sensing device or more recently an optically isolated linear current sensing device has been used to meet the requirement. High voltage isolation is done by galvanic isolation in these devices. Although these devices have been widely used, it sometimes becomes a bottleneck for more advanced integration and simplicity in the AC PWM inverter drive application. Construction of Hall Effect sensor is mechanically large and does not compatible with any conventional integrated circuit packages due to electro-magnetic device structure. This in turns creates unwanted manual assembly process for the inverter drive manufacturing. It is also inherently expensive. Linear optical device is also a hybrid device consisting of three pieces of silicon devices; high side amplifier circuit, light emitting diode, and receiving circuit. Drawback of this device is large current requirement in the high side circuit (typically 7mA or more) and limited range of the high side voltage supply. Therefore it typically requires dedicated power supplied by individual transformer winding and its associated circuit.

IR2171 solves these cumbersome and open the door to more advanced PWM AC inverter integration. In particular, if the AC drive is based on Power Processing Architecture where the regulator hardware common is referenced to the negative DC bus potential, design of motor current feedback becomes very simple and a part of plug-in building block. Figure 3 shows typical block diagram of this type of AC inverter drive where all hardware pieces of the regulator function – uP, high voltage gate drive IC, high voltage linear current sensing IC- are directly coupled together and sit on the DC bus. In this architecture, whole regulator functions only require 5V and 15V with one common. The power supply is greatly simplified.

Figure 4 shows more detailed application circuit. IR2171 shares the bootstrap power supply in its high side secondary circuit with IR2137, which is the high voltage 3-phase gate driver IC with IGBT protection. Linear current sensing combined with the gate drive and IGBT protection function can be realized only by three pieces of silicon chips with simple 15V supply.

Output of IR2171 is a 35kHz digital PWM signal and is able to interface directly to the micro-controller's capture compare/timer unit. If other form of digital circuit is used such as a digital ASIC/gate array, then a simple timer to measure the PWM duty period can be easily implemented. Since it is an open drain output with 20mA driving capability, it can easily interface to the optically isolated device to achieve a galvanic isolation if needed.
In order to eliminate temperature drift more thoroughly, additional carrier frequency period measurement is recommended. If two measurement of duty and carrier period is concurrently performed, then temperature drift of gain and linearity can be wisely canceled. This due to the fact that temperature drift between two measurements tracks each other. For example, if a duty divided by a carrier period is performed, then resulting value can be used for temperature drift free variable inside of the AC drive function.

Since the input front-end circuit measures the small voltage across a shunt resistor in the IGBT driven PWM inverter circuit, it should be operational under any condition including short circuit condition. In particular, the input pin, VIN-, is designed to sustain up to negative 5V with respect to VS common pin. When input exceeds beyond +/-300mV, internal circuit naturally limits the final PWM waveform output to either 5% or 95% duty depending on the polarity of the input signal. Therefore, when used in the closed loop current control, it does not create abrupt discontinuity in the regulation.

TEST RESULTS

The first fabricated silicon device was tested and key parameters are obtained. Table 1 summarizes the key parameter performance data.

Linearity	0.4%
Linearity temperature drift	0.0003%
Total offset	1.5mV
Total offset temperature drift	30uV/°C
Gain error	1%
Gain error temperature drift	37ppm/°C
Power Supply Ripple Rejection	.06%@6kHz,1Vpp

Table 1: Key Parameters Performance Data

All temperature drift was derived over the range of [0 - 150°C]. Total offset was measured by shorting inputs and measuring PWM output duty at 25°C. Power supply ripple rejection was also measured by shorting inputs and measuring PWM output duty fluctuation while a 1Vpp triangular ripple voltage (6kHz) was applied onto the 15V VB power supply. In realistic situation, the bootstrap power supply can be easily designed less than 1Vpp voltage fluctuation.

Further system test was conducted to verify more practical performance data by using the leading manufacturer's AC servo motor drive product. Comparison was made against the Hall Effect sensor, which is used to sense the 750W permanent magnet motor phase current for the closed loop vector control. This AC drive has a 1.3kHz current loop bandwidth with an 8kHz IGBT PWM carrier frequency. The current rating is 5A normal condition and 15A for overload condition.

For comparison purpose, the simple analog output circuit was constructed to convert IR2171 PWM output signal to analog voltage with a galvanic isolation by an opto-coupler device. Figure 5 shows the circuit basic schematic. Two bootstrap capacitor values are 4700PF.

Actual test waveforms are shown in Figure 6 and Figure 7. Although the original servo drive uses the Hall Effect sensor inside, it was removed and used as monitoring and comparison purpose. Instead, IR2171 was used for the closed loop control. The motor has more than two times of inertia load on its rotational shaft so that it creates substantial amount of current amplitude during acceleration and deceleration. Top traces are velocity waveform, which shows 40 msec acceleration and deceleration from 0 to 5000rpm. In Figure 7, the bottom trace actually contains two traces on top of each other. In Figure 8, two traces are separated and shown in different amplitude range.

FUTURE DIRECTION

Design and application of the new HVIC current sensing device have been discussed. Practical test result shows that it has a wide range of application for the motor drive covering from the standard AC drive to the servo drive application. 1200V version of same current sensing IC is also under development to serve the 460V AC drive application.

Further monolithic integration is also possible. Since the technology basis is essentially compatible with one that used in the HVIC gate driver, it is logical to integrate this current sensing function into the existing HVIC and combine these functions. Eventually it will be not so long that one chip intelligent IC to perform gate drive, IGBT protection, and linear current sensing altogether.

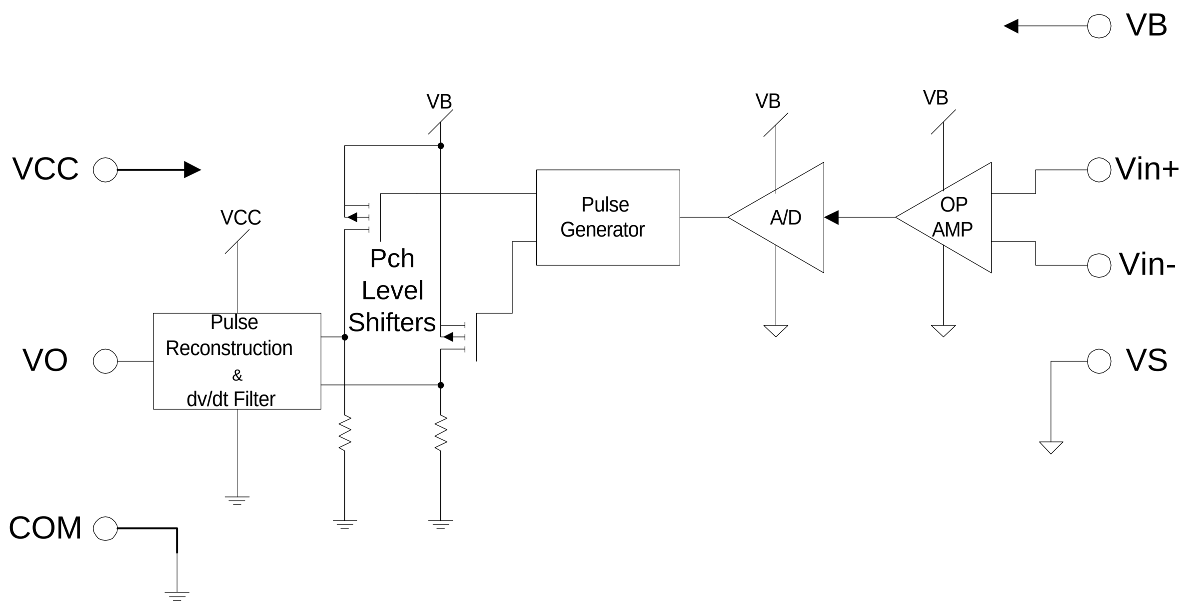

Figure 1: IR2171 Functional Block Diagram

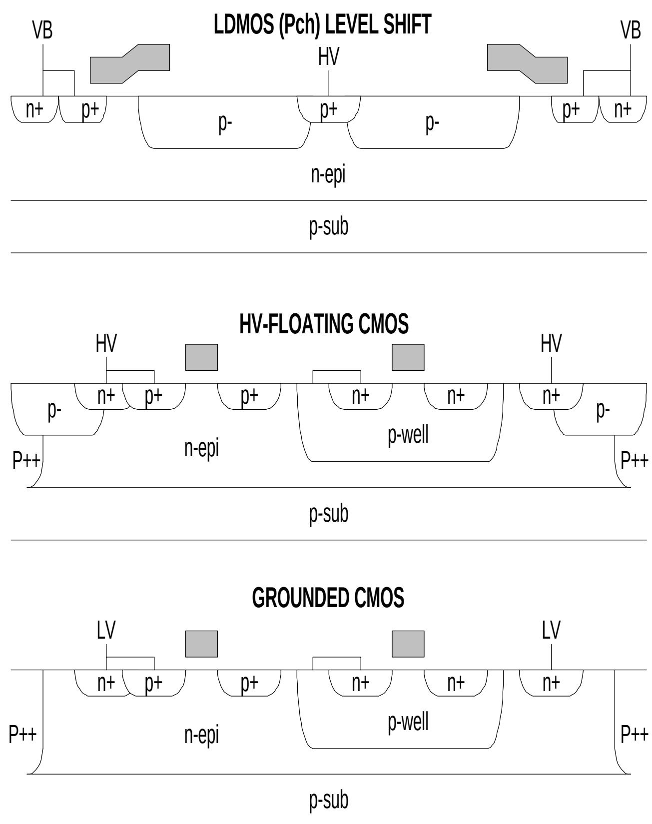

Figure 2: IR2171 Device Cross Sections

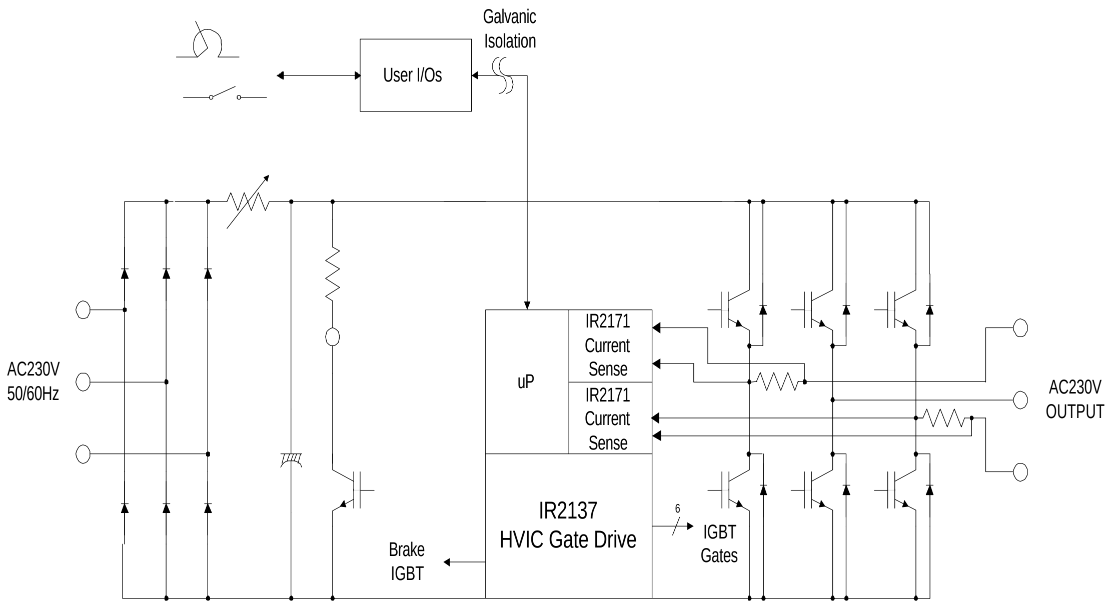

Figure 3: IR Power Conversion Processor ™ Architecture

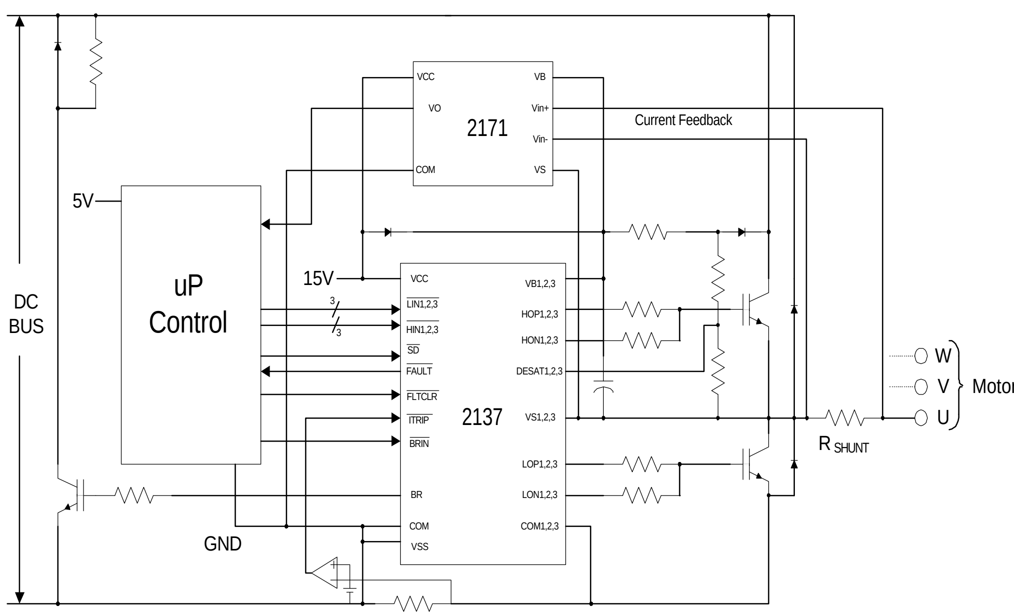

Figure 4: Companion Interface to HVIC Gate Drive

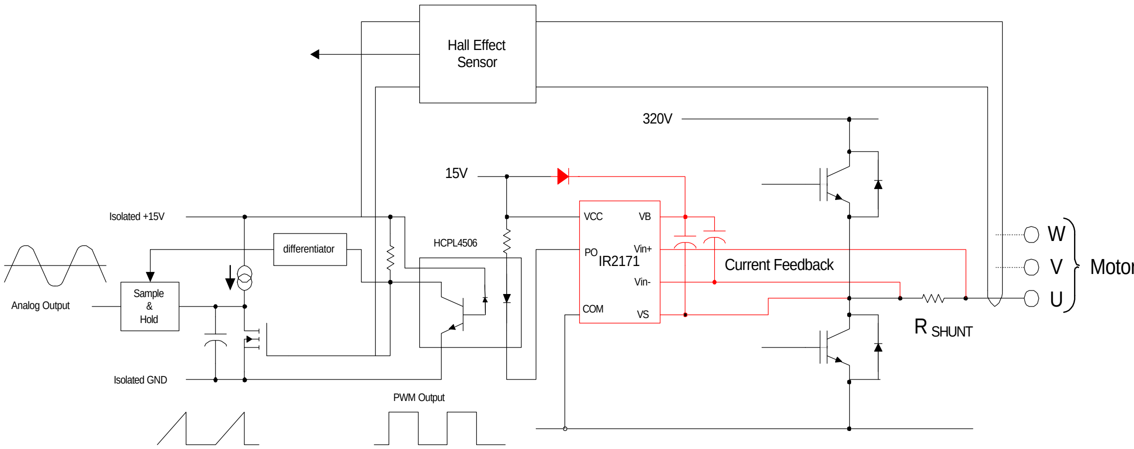

Figure 5: Servo Drive Closed Loop Current Control Test Circuit

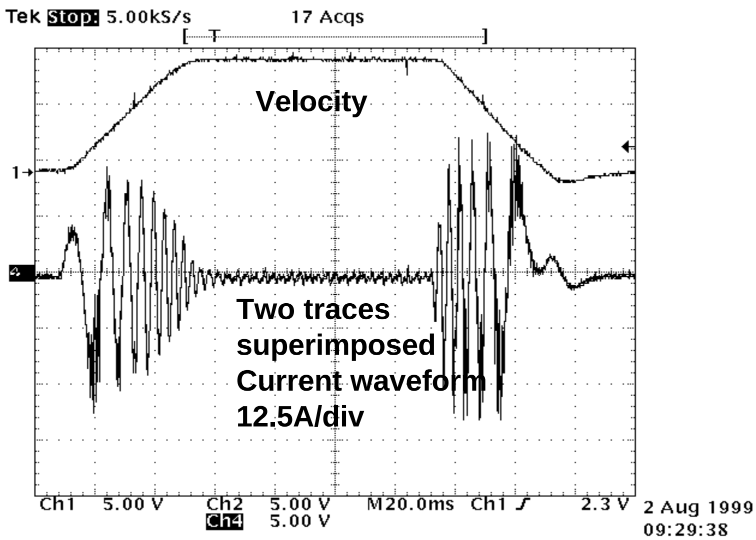

Figure 6: Fast Acceleration/Deceleration Current Waveform (superimposed)

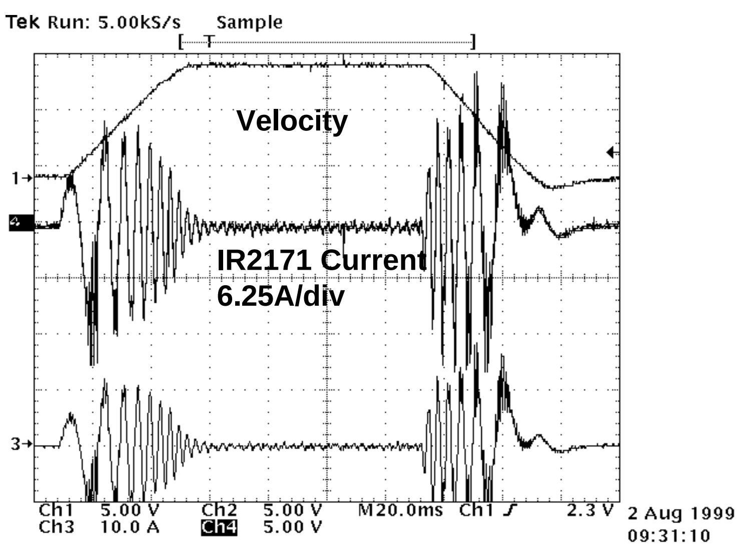

Figure 7: Fast Acceleration/Deceleration Current Waveform (separated)