

# **POWER CONVERSION PROCESSOR™ ARCHITECTURE AND HVIC PRODUCTS FOR MOTOR DRIVE**

*IR's Motor Drive IC family supports the emerging Power Conversion Processor™ Architecture and delivers new level of ruggedness, compact size and lower EMI. Monolithic integration of high voltage circuits for gate driving with protection, soft start charging of DC bus and linear current sensing of motor phase current enable best in class power conversion platforms. Each new generation of products drives down the price points for high performance control techniques and evolves cost effective motor drive designs from V/Hz to sensor-less vector or servo control.*

## **INTRODUCTION**

International Rectifier (IR) has recently expanded their family of 600V and 1200V ICs specifically designed to be used in 115Vac, 230Vac and 460Vac motor drives for industrial and appliance applications. The common theme at the heart of the new products is the Power Conversion Processor™ Architecture that IR is setting the standard and paving the way for implementation by the industrial and appliance drive companies.

New products in the Industrial Motor Drive IC family include the latest generation of the industry standard three phase gate drivers, the 600V IR2137 and 1200V IR2237, that add integrated protection and soft shutdown for the IGBT inverter stage. Expanding the family, new product category is created for current sensing ICs, 600V IR2171 and 1200V IR2271, that sense motor phase current and convert to digital format to be used in the algorithm for closed loop current control. Another new product category, the soft start converter controller IC, IR1110, is designed to soft charge the DC bus capacitor and provide a bulletproof input converter stage.

New products in the Home Appliance and Light Industrial Drive IC family include the 600V half-bridge gate drivers IR2106/07/08/09, IR21064/74/84/94 and the three-phase gate driver IR2136 and IR21362. These series of new products are simple and low cost. They are especially designed to be used in refrigerator compressor, air-conditioner compressor and direct drive washing machine.

## **DRIVE FUNCTIONS AND ARCHITECTURES**

The power conversion sub-system in AC or BLDC motor drive is commonly partitioned into different functions (Figure 1). Each function serves its unique requirements but also has to couple with each other in order for the complete system to work as a whole. For example the IGBT gate drive and protection functions have to be synchronized and the feedback sensing and the regulator control and PWM have to be matched.

Older types of drive use an architecture that can be called two levels power conversion processing (Figure 2). All the motion profile and power conversion signal processing functions are implemented within an isolated low voltage supply level that is remote from the power level. The power conversion actuation devices, diodes and IGBTs, are contained within the high voltage supply level directly connected to the AC main. Then different types of technologies are used to connect the two levels. Gate drives are supplied through opto-couplers, feedback functions are implemented through combination of linear opto-couplers and hall-effect sensors, and soft start function is implemented through relay. A bulky multiple winding transformer is also needed to supply the various isolated supplies for the different functions.

In more modern drives a new type of architecture is becoming popular that uses single level power conversion processing (Figure 3). Here all the gate drive, protection, feedback sensing and control functions are implemented within the same level of the high voltage supply rail and all the functions are coupled with each other in the same electrically connected level. Now higher performance control loop is implemented easier, protection is localized and more effective, the board layout is more compact contributing to lower EMI and the total system cost is lower. This type of architecture is most effective for “dedicated purpose” drive such as for home appliance and the new class of small industrial drive less than 5hp or 3.75kW, called Micro-Inverter or Micro-Drive.

A more advanced type of architecture is emerging that uses mixed mode power conversion processing (Figure 4). Primarily the power conversion processing is done at the high voltage supply level. A second level of signal processing is added for motion profiling and communication. This second level helps facilitate network and option cards connection for “general purpose” drives. Also it simplifies the encoder connection for position sensing in servo drives. The two levels of processing are connected through isolated serial bus such as the SPI interface. The bus speed and performance are not very demanding because the information bandwidth is not so severe at this connection layer with all the high speed signal processing already done locally at the power conversion processing level. A comparison between the different power conversion architectures is shown in Table 1.

## **HIGH VOLTAGE INTEGRATED CIRCUIT TECHNOLOGY**

One of the key features of the single level and mixed mode Power Conversion Processing Architecture is the integration of the gate drive, protection and sensing functions. The integration is implemented in a high voltage integrated circuit (HVIC) technology (Figure 5). This structure supports a versatile set of devices and circuits plus the unique capability of integrating high voltage level shifting and floating CMOS in a single piece of silicon.

The 600V or 1200V N-channel and P-channel LDMOS are used for level shifting functions from low voltage to high voltage and vice versa. The CMOS circuits can be referenced to a high voltage floating supply level (VB-VS) for high-side gate drive and

signal processing circuits. This floating capability allows differential mode signal processing on top of 600V or 1200V common mode voltage. Other uses for the high voltage devices include start-up bias supply and synchronous bootstrapping supply.

Gate drive circuits are implemented in enhanced voltage CMOS with supply rail up to 25V and provides necessary gate drive voltage to the IGBT. Analog and digital circuit blocks are implemented in BiCMOS. Circuit library includes Pulse Width Modulator (PWM), Voltage Control Oscillator (VCO), Precision Sense Amplifier, Fast Fault Comparator and other power conversion control functions.

## **GATE DRIVER AND PROTECTION FUNCTIONS**

The gate drive and protection functions are divided into three types of circuits. The first one is the output buffer that is needed to provide sufficient gate charge to the IGBT. The second is the level shifters that are needed to interface between the control signals to the high side and low side output buffers. The third is the sensing of overload conditions in the IGBT and the appropriate countermeasure taken in the output buffer as well as fault status feedback.

IR pioneered the first single phase and three phases gate driver ICs and is now leading the evolution of the products. These devices set the standard for appliance drives and industrial micro-drives. Each new generation of devices are evolved to obtain higher performance and more features at lower cost. Table 2 shows the available types, ratings and main features for three generations of products.

First generation devices were the first of their types and spurred the development of the Single Level Power Conversion Processing Architecture. They provide simple high and low side gate drive functions. The monolithic integration delivers compact size and the tight layout lowers EMI. Separate series were offered to match the price/performance requirements for appliance and for industrial drives.

Second generation devices were introduced to improve the transient immunity capability as well as the introduction of 1200V rating. Higher level of immunity to  $-V_s$  voltage spike allows simpler layout and handles safely larger excessive voltage swing at the IGBT stage during transient over-load conditions. The series for industrial drives feature 1200V rating for 460Vac input while the 600V devices are used for 230Vac applications. The series for appliance drives feature 110/220Vac operation, improved noise immunity, more functions and lower cost.

**Table 2: Three Generations of HVIC Products**

Types	Topology & Ratings	Features	Applications
<i>First Generation</i>			
IR2101 IR2102 IR2103 IR2104	1-Phase Gate Drive 600V, 0.5A	Simple HS and LS Drivers 8-pin Package	110-220Vac Appliance 0.1-0.5kW
IR2110 IR2113	1-Phase Gate Drive 600V, 2A	High Current HS/LS Drivers 14-pin Package	230Vac Industrial 3-10kW
IR2125 IR2127 IR2128	High Side Gate Drive 600V, 1A	HS Shutdown HS Fault Status	230Vac Industrial 3-10kW
IR2130 IR2132	3-Phases Gate Drive 600V, 0.5A	Control all 3-phases LS Current Comp and Amp	230Vac Industrial 0.3-3kW
<i>Second Generation</i>			
IR2106 IR2107 IR2108 IR2109	1-Phase Gate Drive 600V, 0.3A	High Side UVLO Soft Gate Drive 8-pin package	110-220Vac Appliance 0.1-0.5kW
IR21064 IR21074 IR21084 IR21094	1-Phase Gate Drive 600V, 0.3A	Logic + Power Ground Dead time adjust 14-pin package	110-220Vac Appliance 230Vac Industrial 0.1-3kW
IR2181 IR2182 IR2183 IR2184	1-Phase Gate Drive 600V, 1A	High Current HS/LS Drivers High -Vs Immunity 8-pin package	230Vac Industrial 3-10kW
IR21814 IR21824 IR21834 IR21844	1-Phase Gate Drive 600V, 1A	High Current HS/LS Drivers Logic + Power Ground High -Vs Immunity 14-pin package	230Vac Industrial 3-10kW
IR2213	1-Phase Gate Drive 1200V, 2A	High Current HS/LS Drivers High -Vs Immunity	460Vac Industrial 3-10kW
IR2136 IR21362	3-Phases Gate Drive 600V, 0.3A	Low Cost 3-Phase LS Current Trip Comparator	110-220Vac Appliance 230Vac Industrial 0.1-3kW
IR2133 IR2135	3-Phases Gate Drive 600V, 0.5A	High -Vs Immunity LS Current Trip Comparator	230Vac Industrial 0.3-5kW
IR2233 IR2235	3-Phases Gate Drive 1200V, 0.5A	High -Vs Immunity LS Current Trip Comparator	460Vac Industrial 0.3-5kW
<i>Third Generation</i>			
IR2137	3-Phases Gate Drive 600V, 0.5A	HS De-Saturation Detection Synchronous Soft Shutdown	230Vac Industrial 0.3-5kW
IR2237	3-Phases Gate Drive 1200V, 0.5A	HS De-Saturation Detection Synchronous Soft Shutdown	460Vac Industrial 0.3-5kW
IR2171	High Side Current Sense 600V	Differential +/-300mVin PWM output, +/-0.5%	230Vac Industrial 0.3-5kW
IR2271	High Side Current Sense 1200V	Differential +/-300mVin PWM output, +/-0.5%	460Vac Industrial 0.3-5kW
IR1110	3-Phases SCR Drive 230/460Vac	Soft Charge Control DC Bus Regulation Power Dip Ride-Through	460Vac Industrial >10kW

Third generation devices are now being introduced to address robust protection of the IGBT inverter stage. Over-current conditions are fatal faults to the drives. Three types of over-current faults -- line to line short, ground fault or shoot-through -- are commonly encountered as shown in Table 3 and Figure 6. Protection circuit implementation and type of over-current sensing device vary depending on which mode of the over-current condition to be protected due to different path and flow of the current in each mode. And protection schemes also depend on the drive architecture.

<b>Over-current mode</b>	<b>Potential causes</b>
line-to-line short	Miss-wiring, motor leads short, motor phase-to-phase insulation breakdown
Ground fault	Motor insulation breakdown to ground
Shoot through	False IGBT turn-on

**Table 3: Over-current modes and causes**

Main feature of the new third generation gate driver products, 600V IR2137 and 1200V IR2237, is the integration of IGBT protection functions with high side de-saturation detection and synchronous soft shutdown for all six IGBTs. The high side output buffer schematic is shown in Figure 7. Here the pull-up and pull-down output drivers are separated to allow simpler optimization of IGBT turn-on and turn-off characteristics. In the event of an over-current condition that triggers the de-saturation threshold, a soft shutdown sequence is initiated. The soft shutdown scheme prevents large voltage overshoot at the IGBT due to too fast current turn-off transient. The synchronization allows all six IGBTs to be turned off together to avoid potential false IGBT turn-on.

The integrated protection scheme in the IR2137/2237 offers many advantages. Table 4 shows a comparison against the traditional protection method in the Two Levels Power Conversion Processing Architecture.

	<b>Two Levels Architecture</b>	<b>Single Level Architecture IR2137/2237</b>
Gate Drive	Six Fast Optical Isolators	Single chip
IGBT Protection	Two Hall Effect sensors and two comparators	Integrated high side de-saturation protection
	Snubber circuit or discrete soft shutdown circuits	Integrated soft shutdown function
Additional Circuits	Brake IGBT drive circuit with a optical isolator	Integrated brake IGBT driver circuit
	Four floating power supplies	Use bootstrap power

**Table 4: Protection methods - single and two levels power conversion architectures**

Figure 8 shows the oscillogram of the current and voltage turn-off waveforms of the IGBT in short circuit condition using the IR2137 solution. No snubber circuit was used for this test. Thanks to soft shutdown feature, there is virtually no overshoot voltage across the collector and the emitter when it turns softly off.

## CURRENT SENSING FUNCTION

Perhaps the most difficult function in the drive design is sensing the inverter stage and motor phase currents. The current signals are used for current mode control, which requires high precision and linearity, as well as for over-current protection, which requires fast response. Different circuit techniques have to be used to process the current signals depending on which parts of the inverter stage that the current signals are sampled. Precision, low ohmic value, sensing resistors are typically used in the current path to generate a sensing voltage signal with maximum range of +/-300mV to minimize power dissipation. Alternatively hall-effect sensors are used. They are generally bulkier and more expensive than sense resistors but they have the advantages of loss-less sensing.

Practically the current signals can be sampled in series with +DC bus, -DC bus, individual IGBT phase leg or motor phase lead (Figure 9). Current signals sampled in the + DC or - DC bus are the vector sum of all the IGBT phase leg currents. Also the signal content is the pulse width modulated envelop, at fixed carrier frequency, of the fundamental variable frequency motor current. Therefore rather complicated sample and hold plus digital signal processing circuits have to be used to extract useful current information with good linearity and accuracy. Individual IGBT phase leg current is somewhat easier to process but cannot escape from dealing with carrier frequency sampling. By far the simplest current signal available is from the motor phase lead. The signal content is only the fundamental variable frequency motor current. However the one significant complication is that the small differential signal in the mV range is floating on top of 600V to 1200V common mode voltage. In addition the common mode voltage is swinging from -DC to +DC at a dv/dt rate of up to 10V/ns.

IR now offers a new type of monolithic HVIC product that solves the difficult problem of sampling motor phase current. The IR2171 is a 600V product and the IR2271 is the 1200V counterpart. Figure 10 shows the block diagram of the HVIC. Basically the current signal as sampled across ( $V_{in+}$ ,  $V_{in-}$ ) is processed by a precision differential amplifier. After the amplified signal is converted to digital format by an analog to digital converter, the signal is translated from the floating high voltage channel ( $V_B$ - $V_S$ ) to the ground referenced supply rail ( $V_{CC}$ - $COM$ ) through high voltage level shifters. Then the signal is re-constructed and sent to the VO pin as 35kHz digital PWM output. Note that the  $V_B$  floating channel has common mode voltage range up to 600V for IR2171 and 1200V for IR2271 plus immunity to dv/dt transient up to 50V/ns. Another advantage is the low current drawn from the  $V_B$  circuit such that a bootstrap power supply can be used instead of complicated isolated supply.

The typical performance data of the 600V IR2171 are shown in Table 5. Note that the extremely low temperature drift that enables the device to operate linearly in wide industrial temperature range. And the high power supply ripple rejection ratio counteracts the effects of noises on the bootstrap supply.

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 5: Performance Data of the IR2171**

Actual system performance data using the IR2171 in an industry leading closed loop Servo Drive is shown in Figure 11. The Servo Drive has a 1.3kHz current loop bandwidth on top of 8kHz PWM frequency. The top trace is velocity monitor signal that indicates a fast acceleration and deceleration from 0 to 5000rpm in 40msec. The motor has two times the inertia load such that it requires substantial current amplitude up to 12.5A. The bottom trace is a superimposed composite of the IR2171 output re-constructed as analog signal on top of a hall-effect sensor output of the same motor phase current output. The two signals are practically indistinguishable.

Figure 12 shows an application circuit of using the IR2171 together with the IR2137 to provide linear current feedback as well as IGBT protection. IR2171 shares the bootstrap power supply in its high side secondary circuit with IR2137. Output of IR2171 is a 35kHz digital PWM signal and is able to interface directly to the micro-controller's capture compare/timer unit. IR2137 provides the fast de-sat protection as well as synchronous soft shutdown. Together these two chips provide another step toward the IR Power Conversion Processor™ Architecture.

## SOFT START FUNCTION

The DC bus capacitor is charged by the AC line through the input diode bridge. Common practice is to use a series resistor that limits the charging current when the AC line is switched on. Since the series resistor is dissipative, some sort of bypass is required after the bus is charged up. Conventional methods use temperature sensitive (NTC) resistor, electromechanical contactor bypass, or auxiliary SCR bridge (Figure 13). All of these methods suffer from bulkiness, slow charge up time due to the exponential tail in the charging profile, long recovery time after AC line disturbance, too slow protection against DC bus short circuit and little or no control of the DC bus voltage.

A new IC, IR1110, from the IR Power Conversion Processor™ product family, solves these problems and offers additional value added features. This new IC is designed to phase control a SCR bridge as shown in Figure 14. The phase angle of the SCR firing pulses is advanced step by step, increasing the bus voltage in controlled series of steps, as illustrated in Figure 15. Total ramp-time is programmable and typically set at 150 to 350ms with linear charging profile.

IR1110 is unique in its ability to minimize the effect of line interruption. The power dip ride through capability of motor drive is defined as the time it takes to re-establish load power after input line dips or outages. Figure 16 shows the fundamental difference between series resistor charging versus IR1110 SCR phase control method. Load power can be re-established even during the ramp-back time in the phase control method whereas the resistor method dictates a long waiting period until the bus capacitor is fully charged and the series resistor is bypassed.

Other value-added benefits of the IR1110 include increase of inverter output current at low speed using bus regulation as well as protection against bus over-voltage, bus short circuit and phase loss (Table 6).

<b>IR1110 Features</b>	<b>System Benefits</b>
Phase control DC bus voltage linear ramp-up	Controlled and faster system start up time
Phase control re-charging after line interruption or outage	Fast power dip ride-through reduces system down-time
Dynamic control of DC bus voltage	Enable higher inverter output current at low speed by decreasing IGBT losses
Phase angle retardation due to DC bus short circuit	Protect against input bridge failures from high fault current
Phase loss detection and feedback	Protect against high capacitor ripple current from single phase

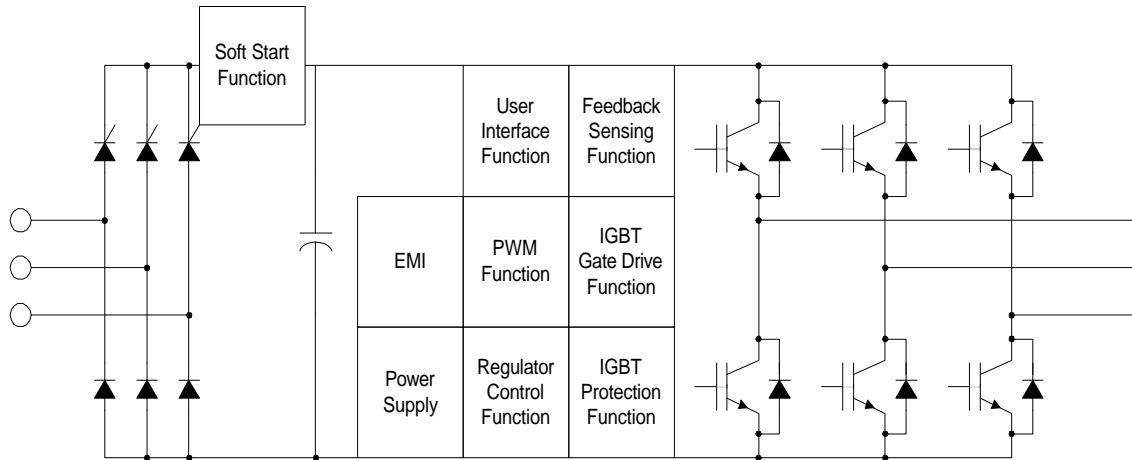
**Table 6: Value-Add Features and Benefits of the IR1110 Soft Start Solution**

## **ARCHITECTURAL EVOLUTION AND ROAD MAP**

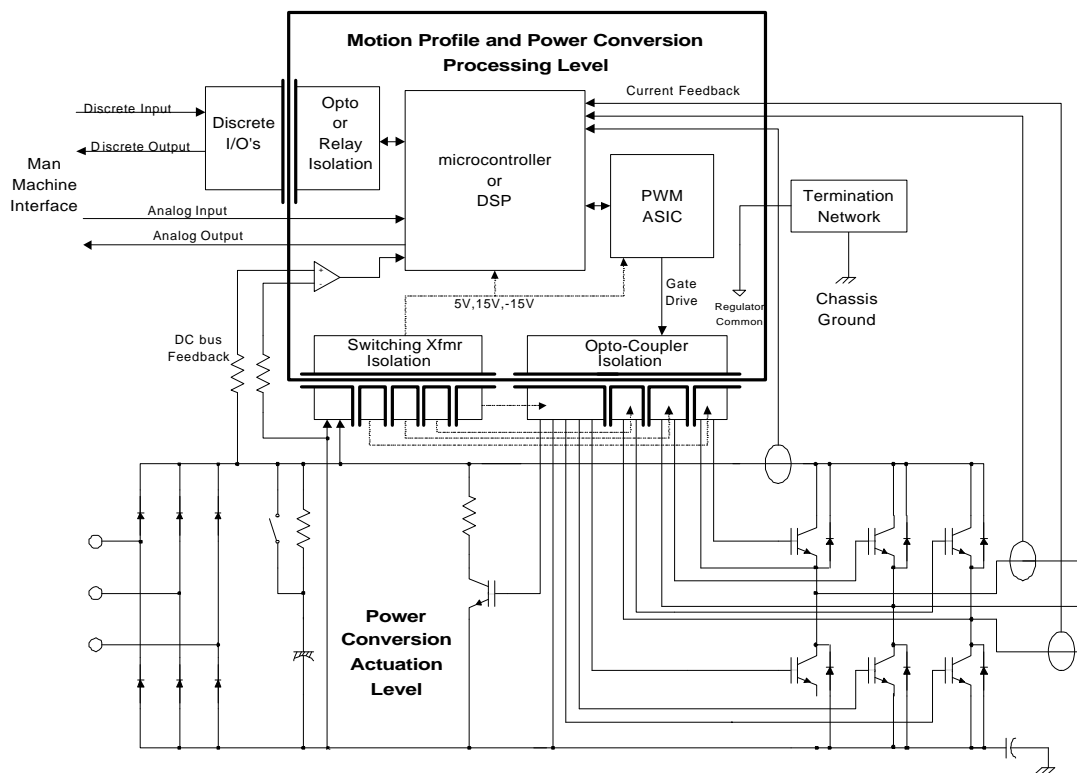
The IR Power Conversion Processor™ Architecture, for the first time in the industry, provides an integration of product and system designs for the power conversion processing functions of AC or BLDC motor drive. Designers no longer have to wrestle with incompatible components that are designed with little or no system knowledge on how they are supposed to work together. Now the system problems are addressed with a set of integrated product solution (Figure 17). Furthermore the architecture is modular and expandable while evolving with advancement in the technologies of power and control elements.

Evolution in IGBT/FRED and associated HVIC gate drive technologies will allow high carrier frequencies with lower losses and lower EMI. That in turns will reduce the heat sink and noise filtering requirements such that the overall size of the drive will also be decreased in lockstep. Monolithic integration of the gate drive, protection and linear current sensing functions in a single piece of silicon using HVIC technology will be the next step. Going still further out and taking advantages of the compatibility of integration with the single level power conversion processing architecture, more functions will be either monolithic or multi-chip integrated in the IR Power Conversion Processor (Figure 18). Potentially the sensing function will integrate phase current, phase voltage and IGBT junction temperature feedback signals that can be used to enable algorithms for sensor-less vector control. Additionally the IGBT devices will be integrated with on-chip current and temperature sensors that are compatible with the sensing IC. And since integration of these control elements together with the micro-controller or DSP controller are small enough to be easily mounted on PCB alongside the IMS or DBC Substrate containing the shunt resistors and power elements, new type of Power Conversion Processor Module can be defined.

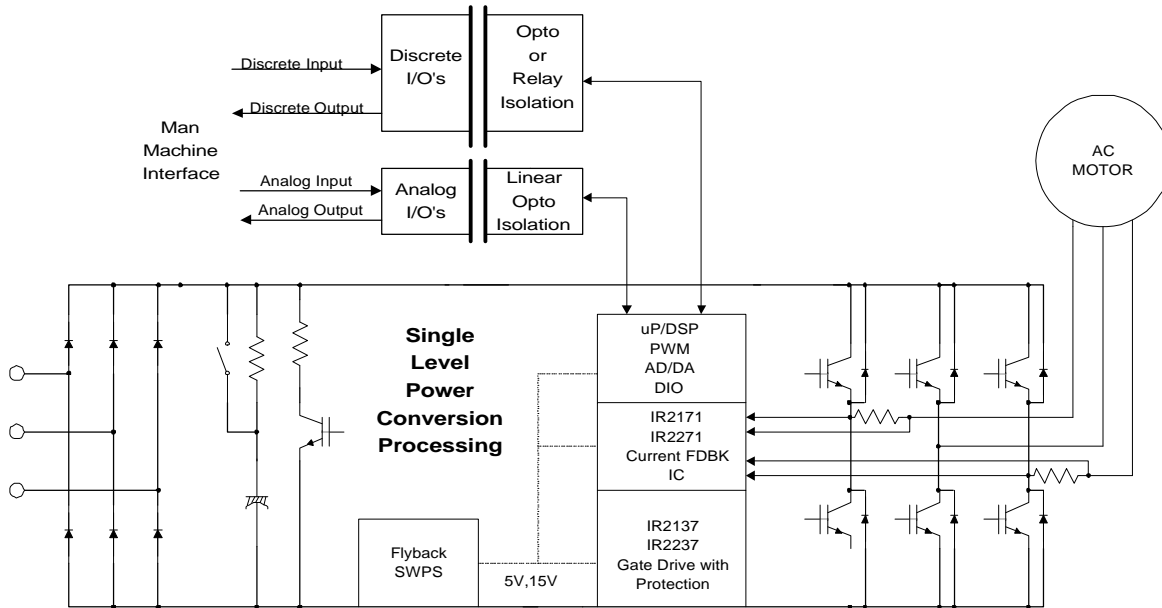
In the system design side, the open loop V/Hz control with current limit function had completely been integrated within the Single Level Power Conversion Processor™ Architecture and it is now the standard for the Micro-Drive. Adding the linear current sensing function expands the architecture to sensor-less vector control. And in the future multi-functions sensing chips integrating current and voltage feedback with both amplitude and phase information will simplify the designs of sensor-less field oriented vector control. For designs that require an encoder feedback such as the permanent magnet servo control and sensor based field oriented vector control, a Mixed Mode Power Conversion Processor Architecture can be used. The high bandwidth current regulator will be completely configured in the power conversion processing level while the speed and flux regulations are handled separately in another motion profile processor operating at an isolated supply level. In all cases, the complete power conversion functions for the AC or BLDC motor drive will be integrated in modular fashion with appropriately defined serial communication protocol. The net effect is that the price points for advanced control are reduced and economic implementation of high performance drives are brought into the realm of high volume industrial and appliance applications. Figure 19 illustrates the nominal price points for drives with different control methods reducing with the IR Power Conversion Processor™ road map.



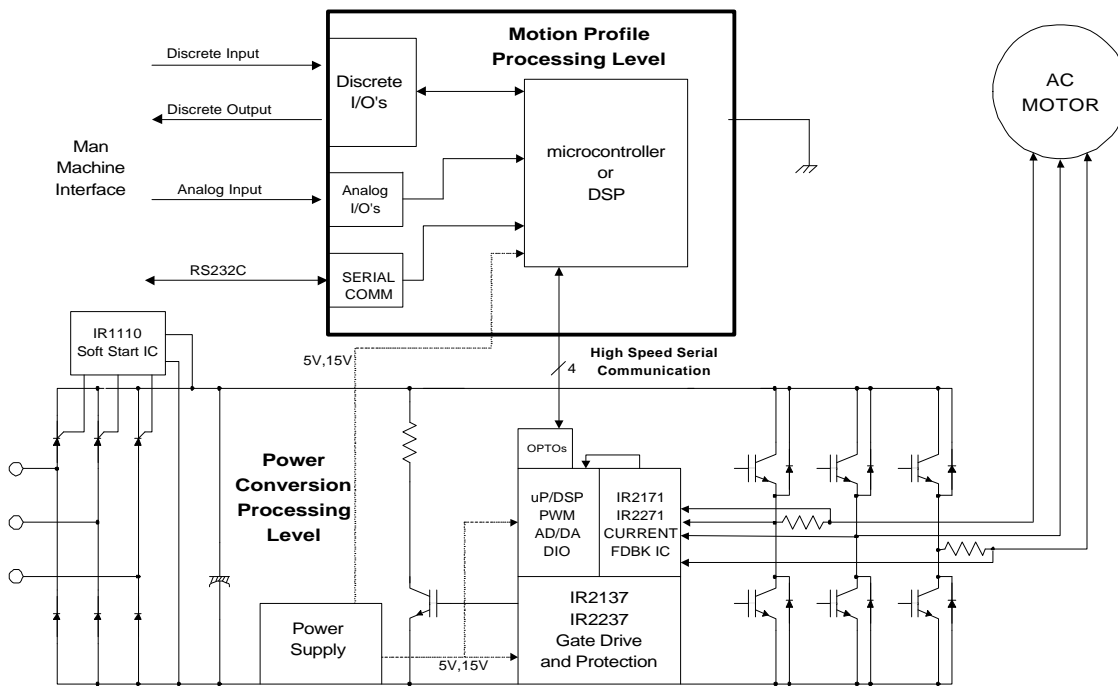
**Figure 1: AC or BLDC Motor Drive Power Conversion Processing Functions**



**Figure 2: Two Levels Power Conversion Processing Architecture**



**Figure 3: Single Level Power Conversion Processing Architecture**



**Figure 4: Mixed Mode Power Conversion Processing Architecture**

<b><u>Two Levels Architecture</u></b>	<b><u>Single Level Architecture</u></b>
Motion and Power Conversion Processed Together	Motion and Power Conversion Processed Separately
Isolation at Opto Drivers (sensitive high speed signals)	Isolation at Digital Interface (high noise-margin signals)
Large Deadtime	Small Deadtime
Complex Switching Supply	Simple Flyback Supply
Large Hall Current Sensors	Small HVIC Current Sensors
Protection at Signal Level	Protection at Power Level
Larger Size and More EMI	Smaller Size and Less EMI

**Table 1: Comparing Two Levels vs. Single Level Power Conversion Architecture**

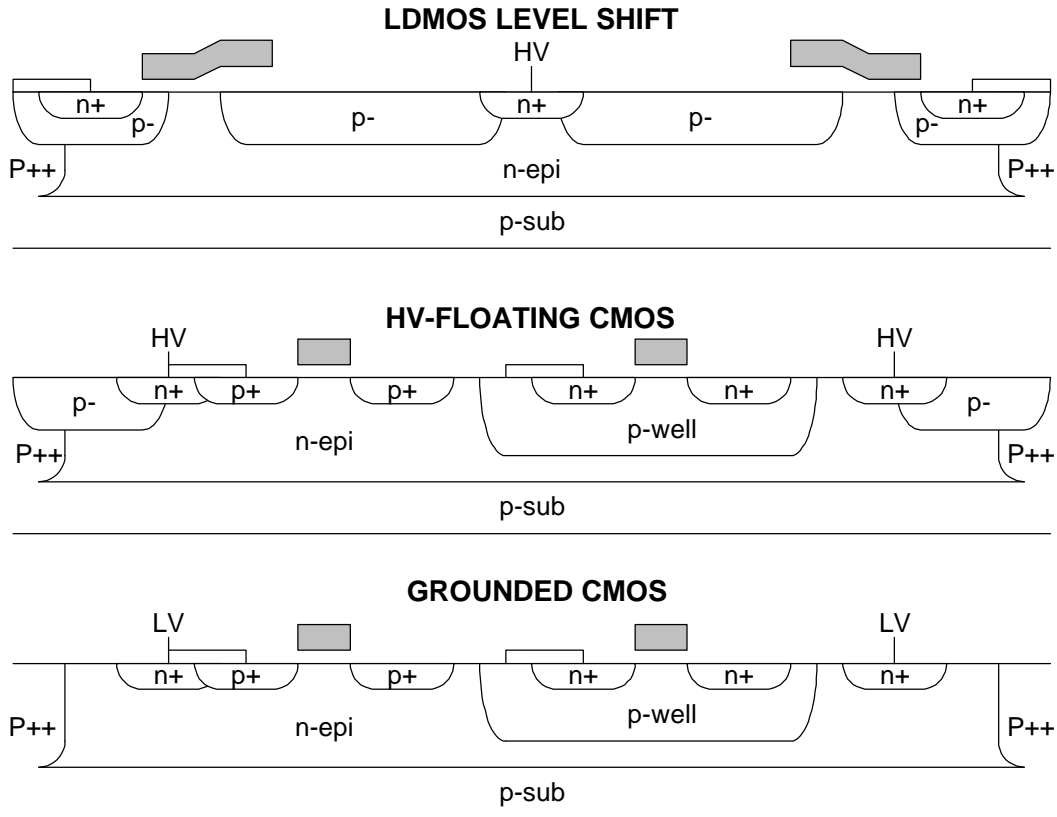


Figure 5a: Device Cross Section of HVIC

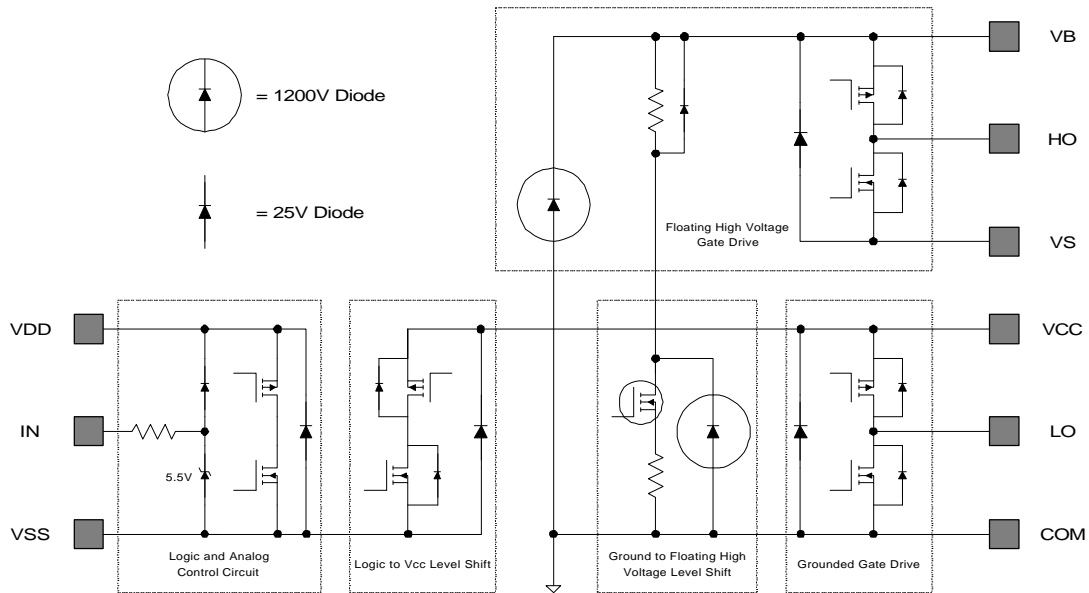
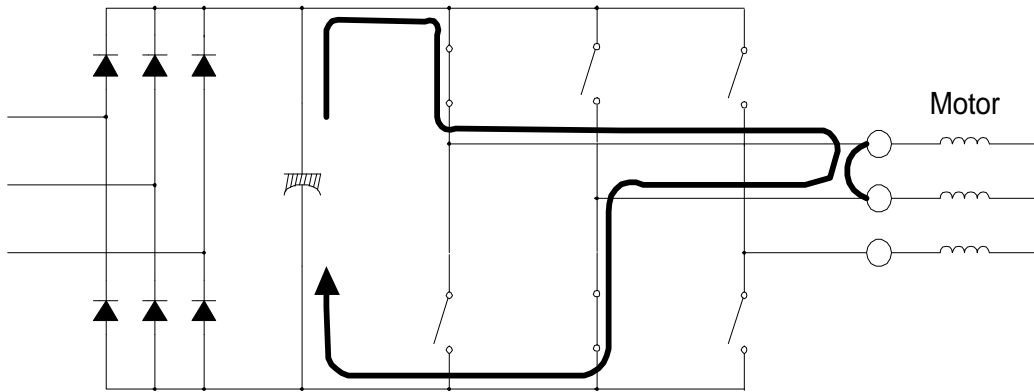
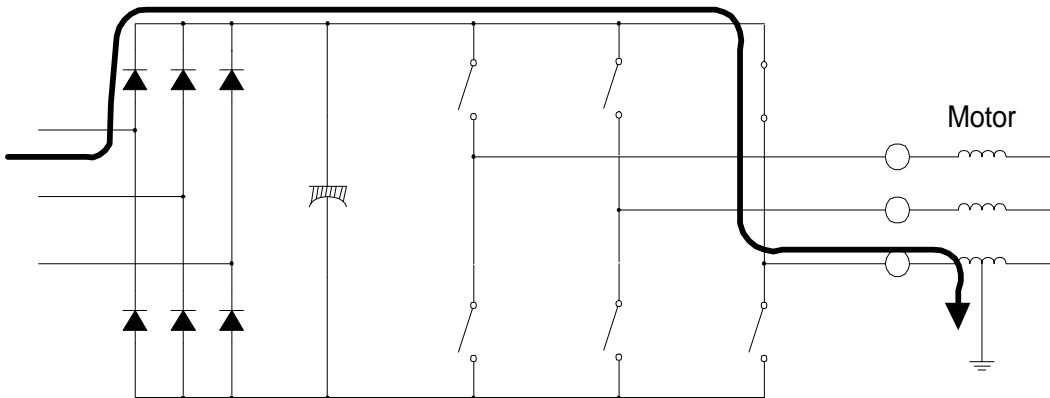


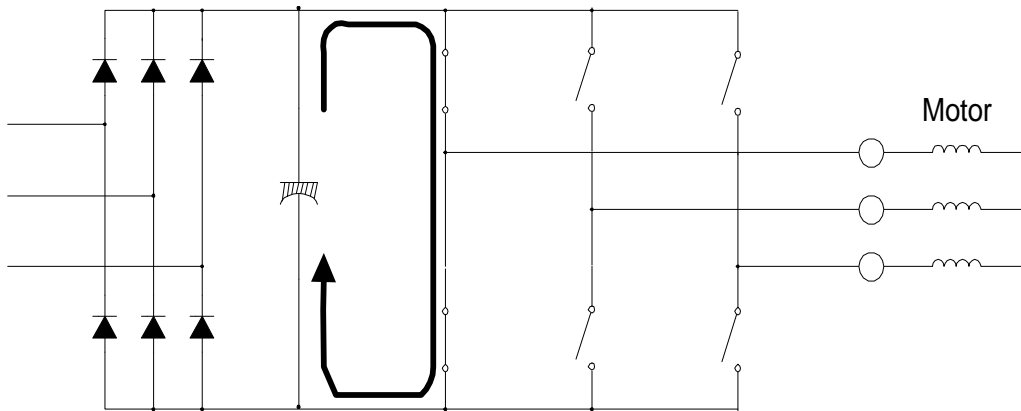
Figure 5b: Common Circuit Blocks of HVIC



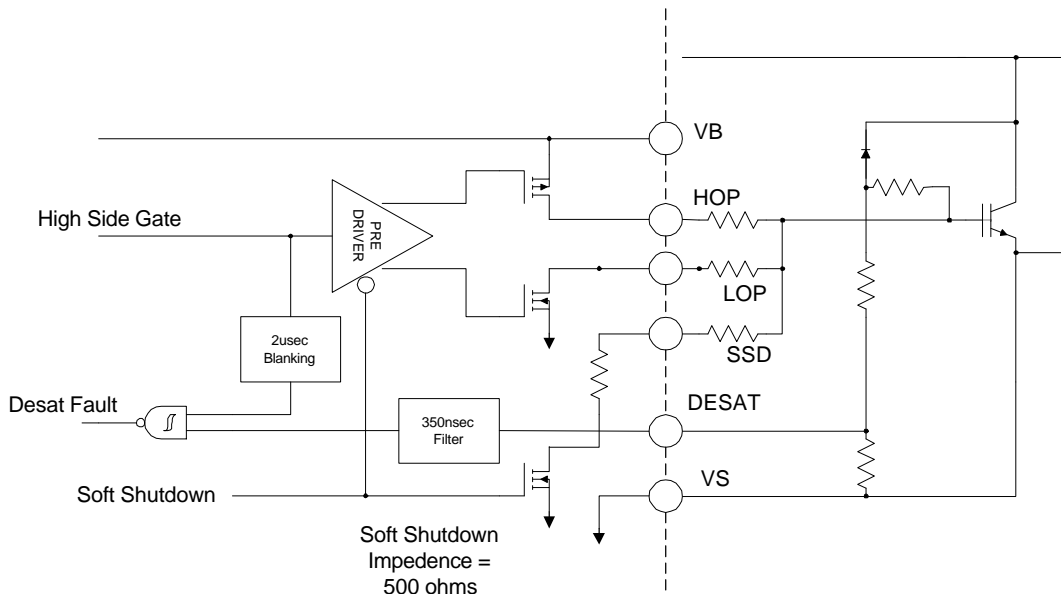
**Figure 6a: Line to Line Short**



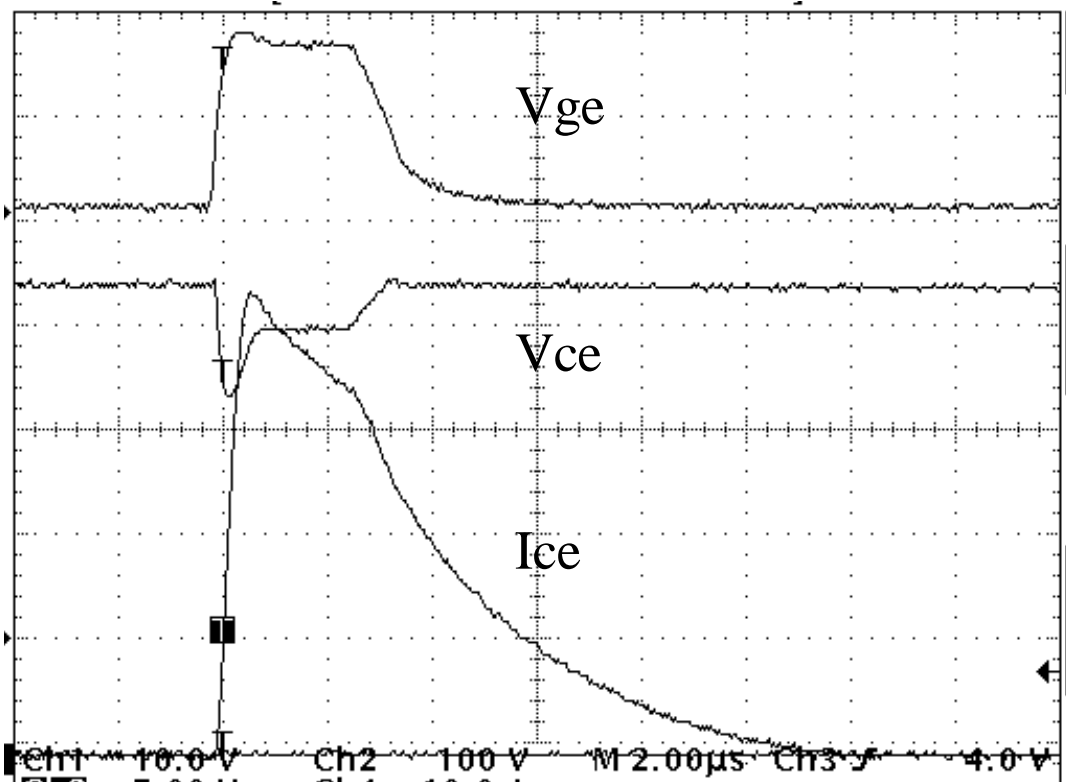
**Figure 6b: Ground Fault**



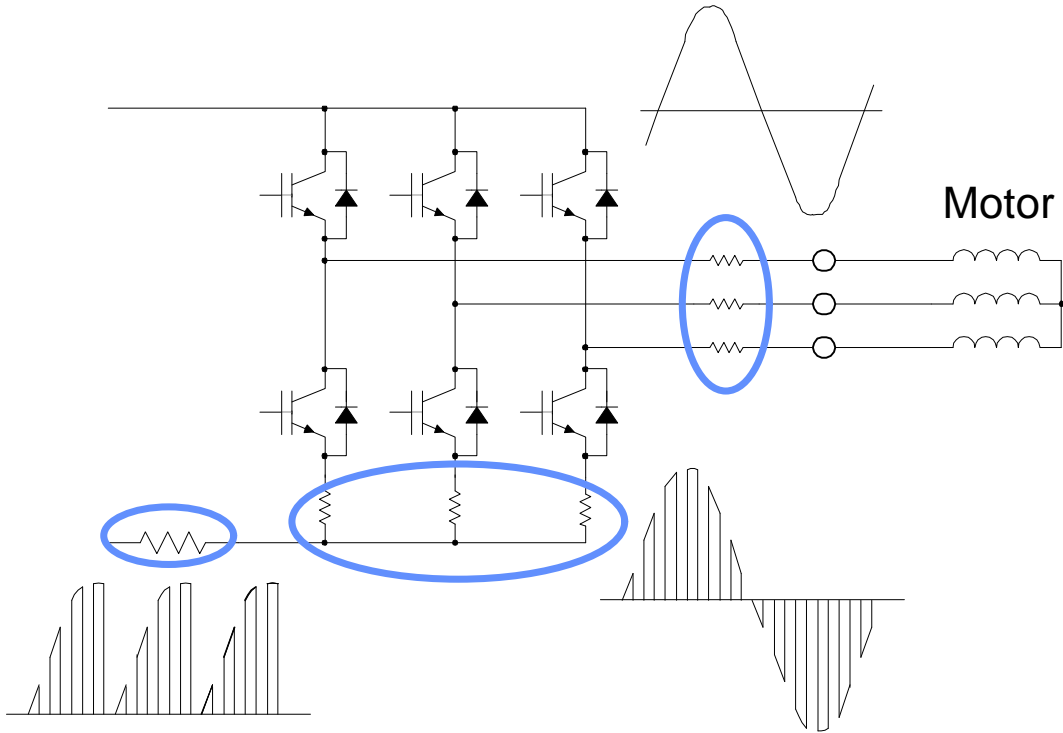
**Figure 6c: Shoot-through**



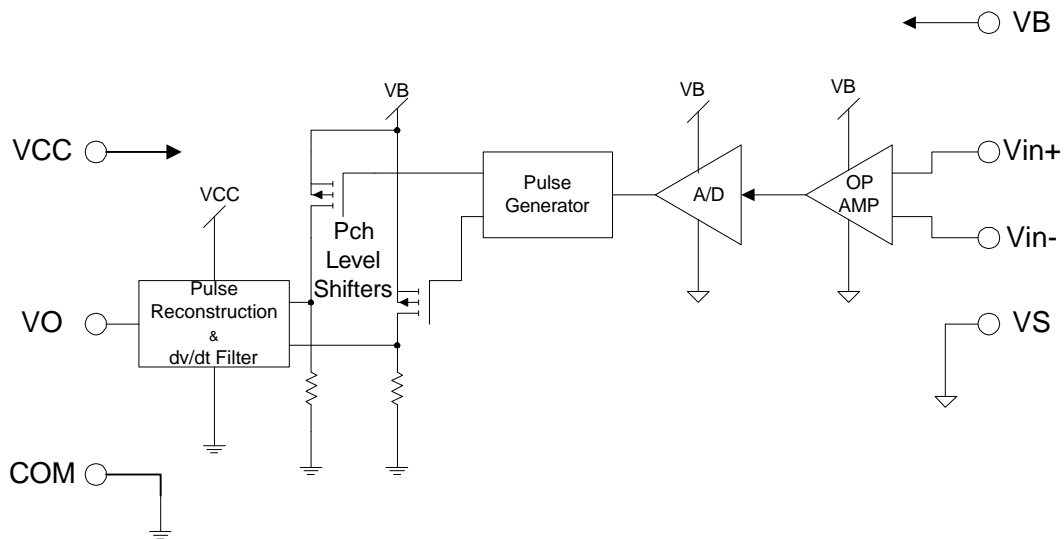
**Figure 7: High side Output Buffer Circuit Schematic for IR2137/2237**



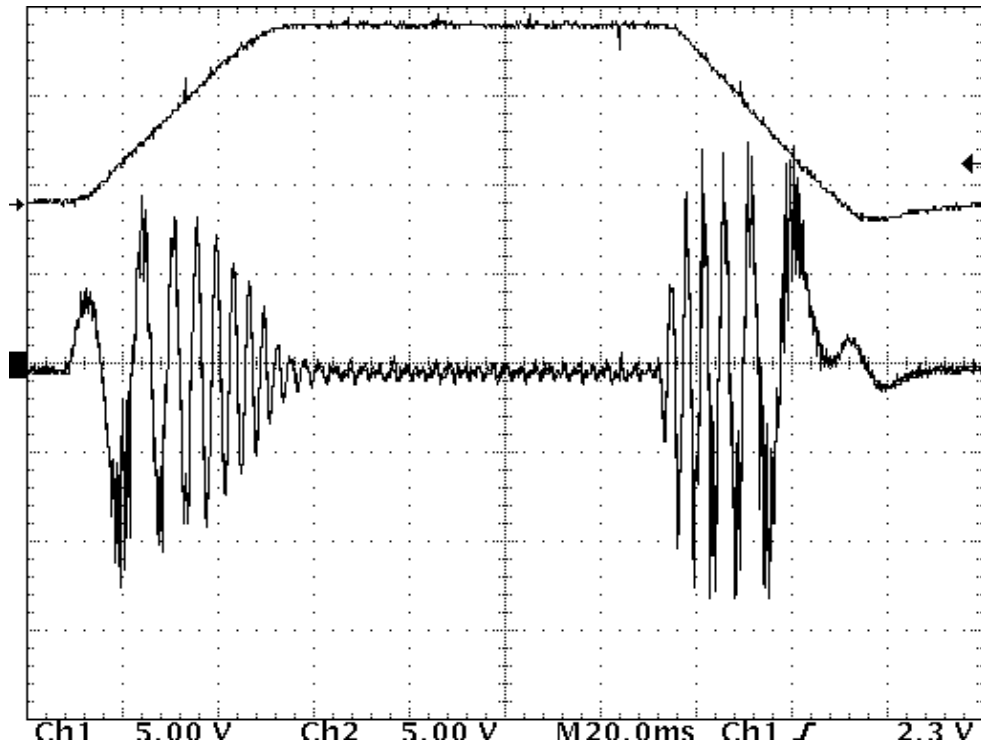
**Figure 8: IGBT Soft Shutdown using IR2137**



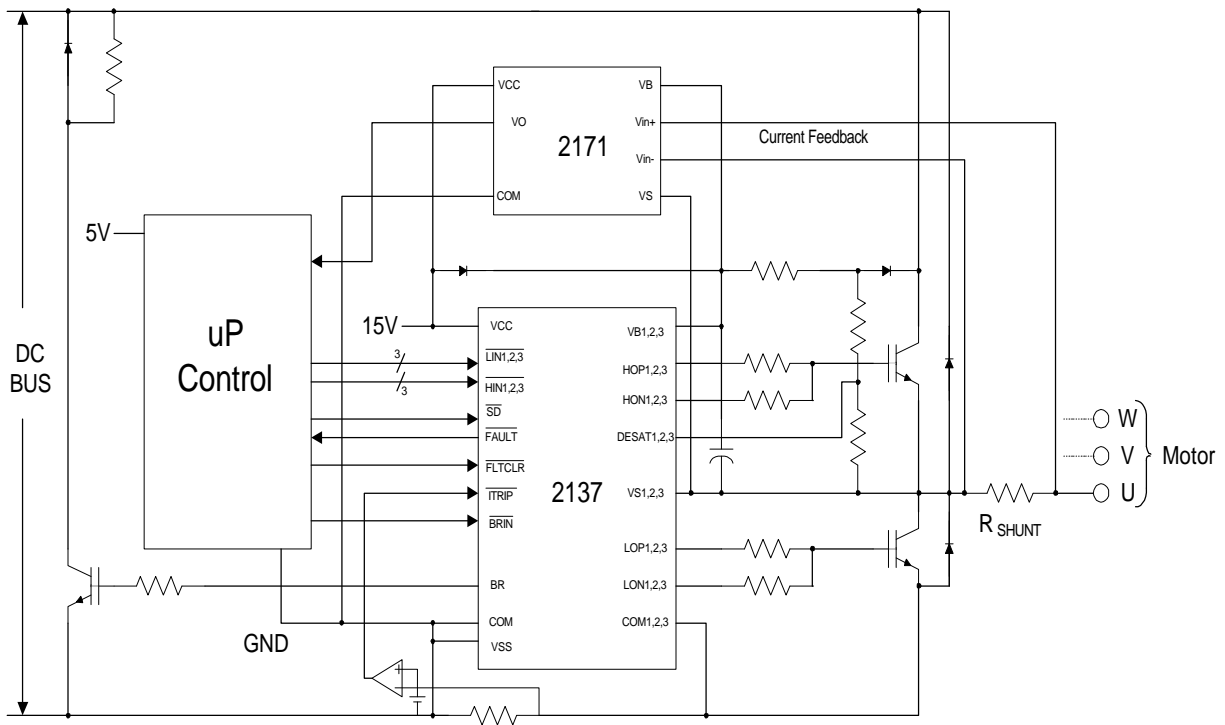
**Figure 9: Current Signal from DC Bus, IGBT Phase Leg or Motor Phase Output**



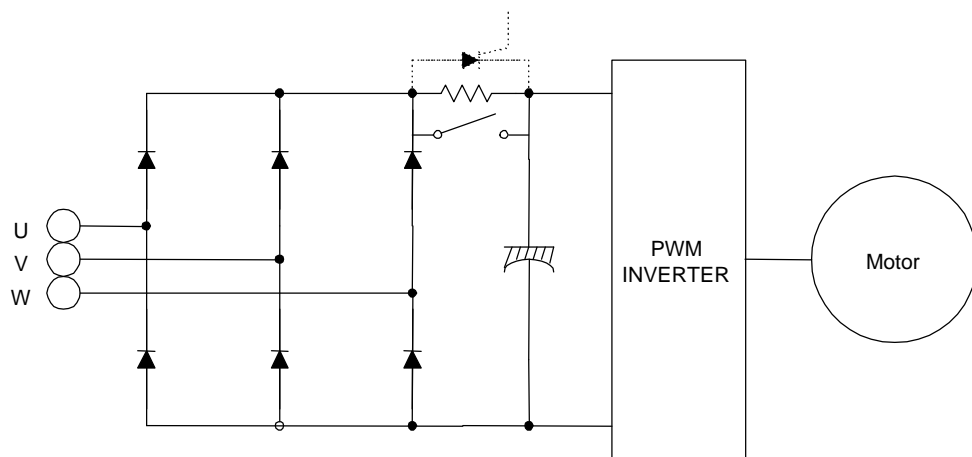
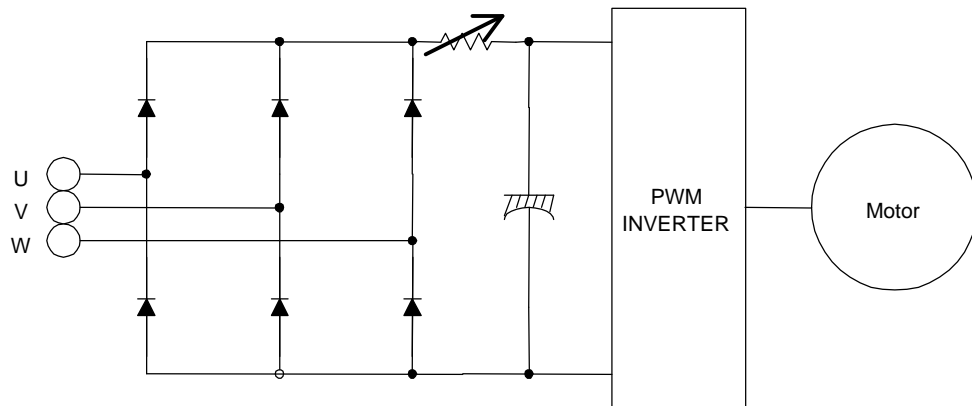
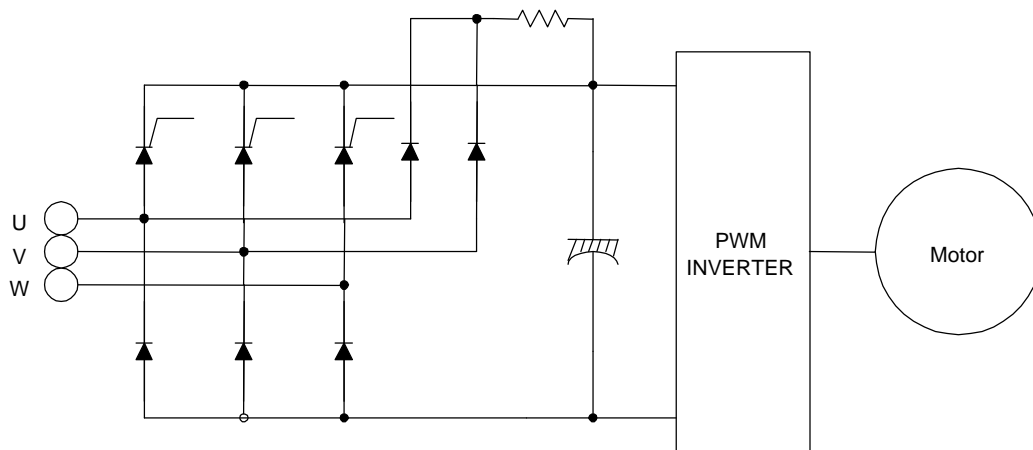
**Figure 10: Current Sensing IC Block Diagram**



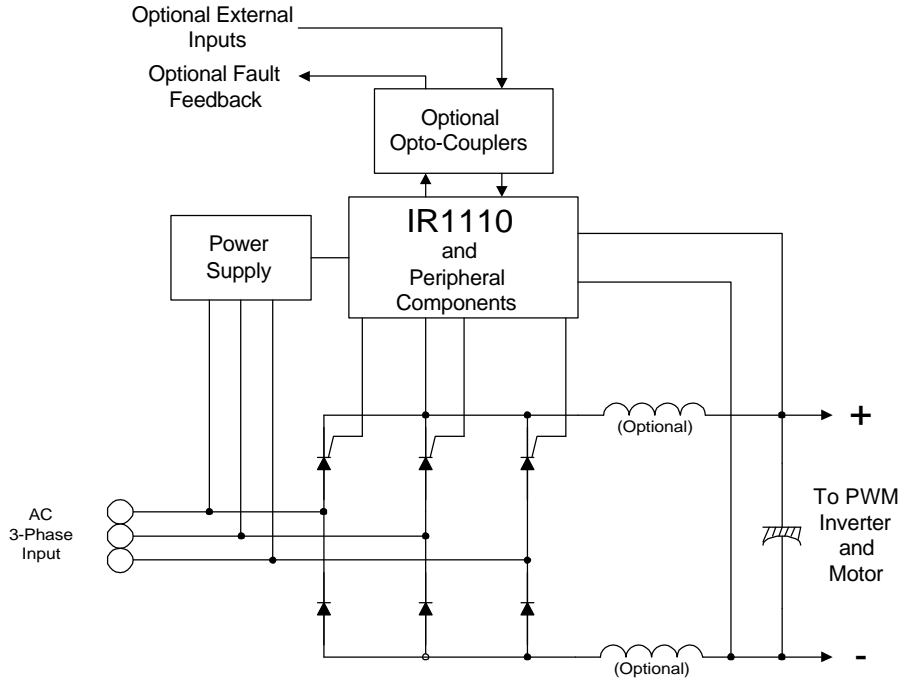
**Figure 11: Current Waveforms Using the IR2171 in a Closed Loop Servo System during Fast Acceleration and Deceleration**



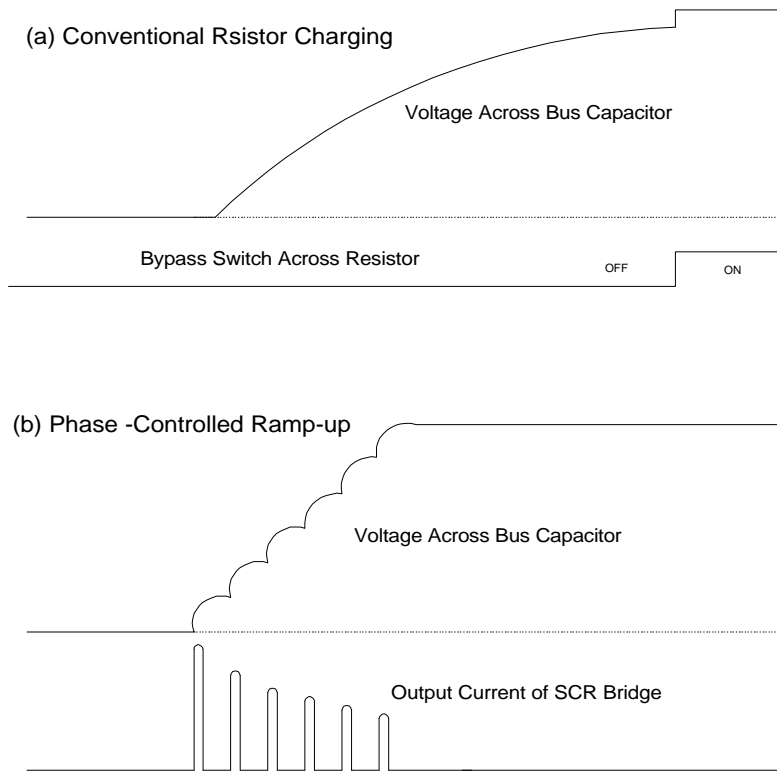
**Figure 12: IR2171 & IR2137 in the IR Power Conversion Processor™ Architecture**



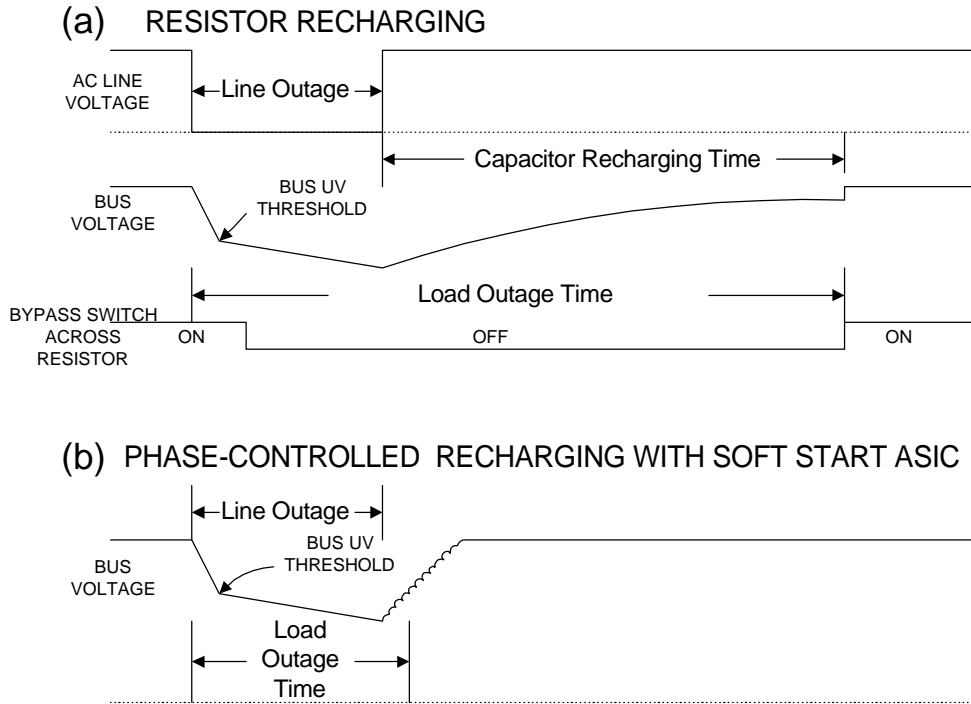
**Figure 13: Series Resistor Connected Soft Charging Circuits**



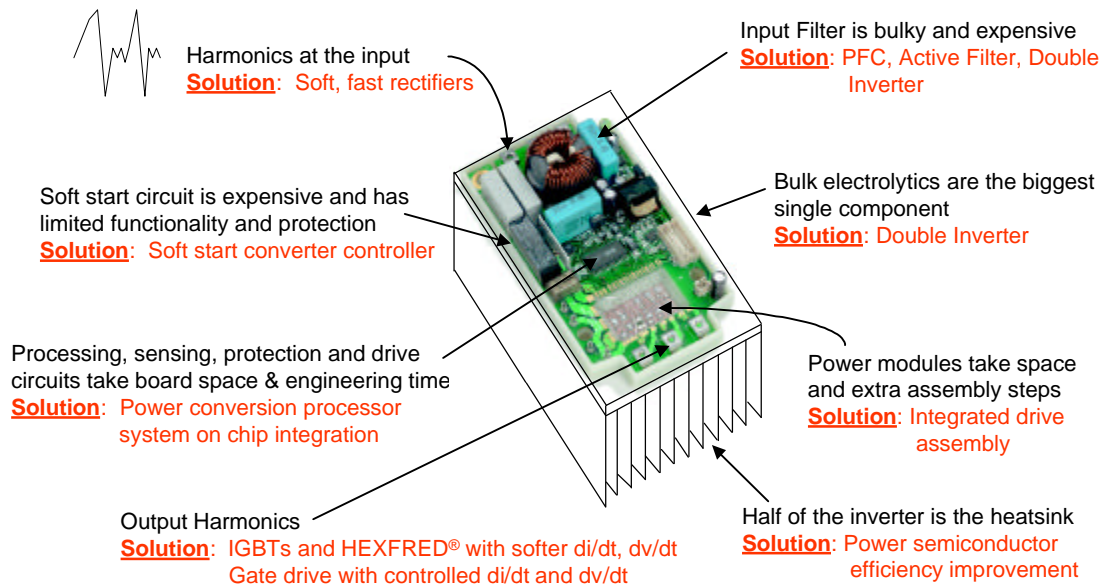
**Figure 14: IR1110 Phase Control SCR Soft Charging Method**



**Figure 15: Series Resistor vs. Phase Control DC Bus Voltage Ramp-Up Waveforms**



**Figure 16: Power Dip Ride Through**



**Figure 17: Drive System Problems and Integrated Product Solutions**

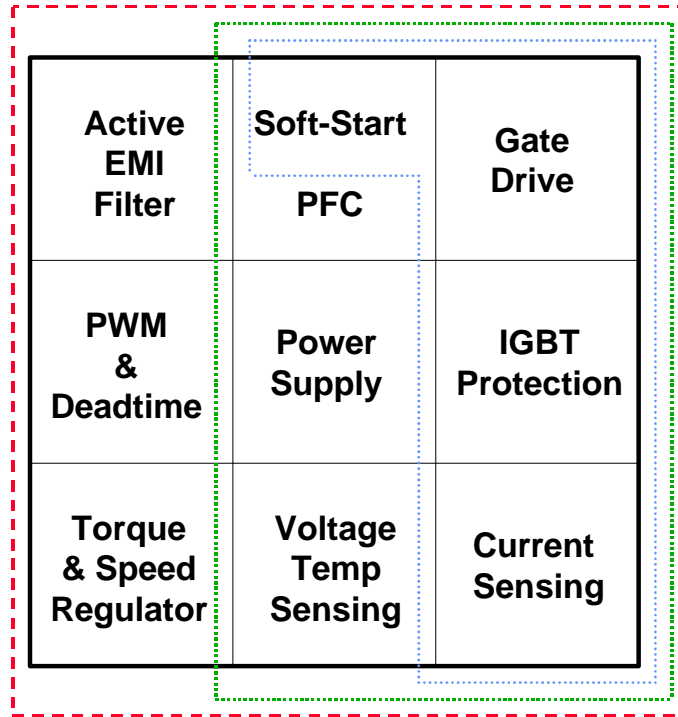


Figure 18: Product Function Evolution in IR Power Conversion Processor

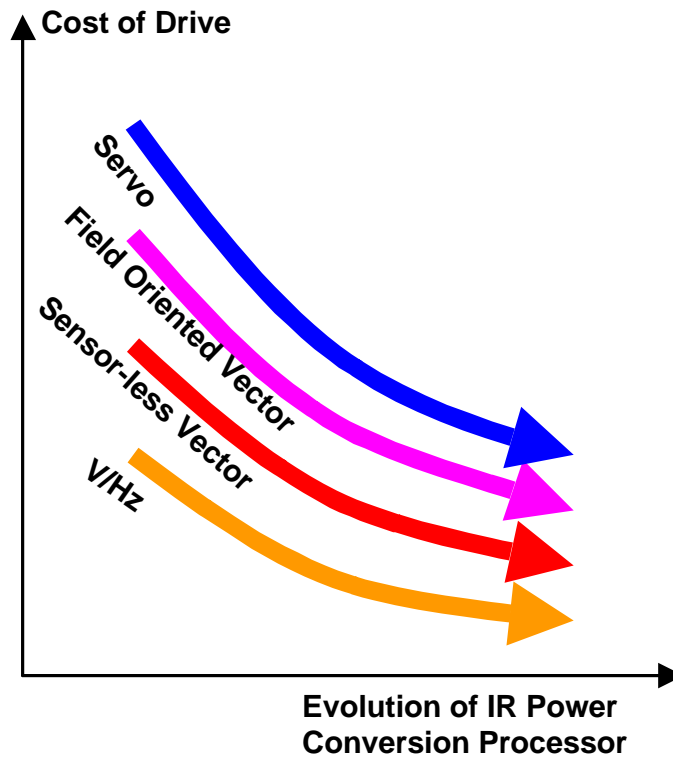


Figure 19: Nominal Cost of Drive vs. Evolution of IR Power Conversion Processor