SGS-THOMSON MICROELECTRONICS

APPLICATION NOTE

COMPACT HIGH PERFORMANCE BRUSH D.C. MOTOR SERVO DRIVES USING MOSFETS

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ABSTRACT

For medium power (200VA to 6kVA) brush D.C. motor servo drives, MOS field effect transistors (MOSFET) are ideally suited. A compact high performance (20 to 50kHz) 1.2kVA brush D.C. motor velocity servo drive, which has been developed and tested, is presented. SGSP477 and BYW8PI200 high efficiency fast recovery epitaxial diode (FRED) are used in the 1.2kVA power stage. A 6kVA motor drive design using ISOFETs is also presented.

TSD4M250 (ISOFET) and BYV54V200 FRED diodes are utilized in the 6kVA design in which FREDs are used as the MOSFET series blocking diode and the free-wheel diode. Different power H-bridge configurations are chosen and justified for the 1.2 and 6kVA drives. Particular emphasis is placed on short-circuit protection techniques and simple gate drives.

INTRODUCTION

Brush D.C. permanent magnet motors are extensively used as velocity servo drives for high performance applications such as robotics and machine-tools. The high voltage D.C. (HVDC) supply of the power stage for such motors rated up to 6kVA is generally limited to 200V D.C. because of sparking of the commutator and brush assembly.

The commutator has a maximum volts per segment rating at rated power above which there is excessive brush wear. MOSFETs are well adapted for medium power applications at voltages up to 500V. Consequently the ease of paralleling, high peak current capability and the ease with which MOSFETs can be controlled and protected make them ideal power semiconductor switching devices for such motor drives. Medium power brush D.C. motor voltage limitation of 200V D. C. enables fast recovery epitaxial diodes (FRED) to be used which have high efficiency due to very low conduction losses and negligible switching losses :

BYW81PI-200 : FRED :

$V_f < 0.85V$ ($I_F = 12A$; $T_j = 100°C$)
$t_{rr} < 35ns$

Block diagram schemes for brush D.C. permanent magnet velocity servo drives are discussed. Servo drive specifications shown in table 1 are considered and solutions for the 1.2kVA and 6kVA motor drives are presented. The 1.2kVA motor drive is developed and tested. Protection, efficiency and switching frequency requirements have strongly influenced the designs.

Other than the power ratings, the parameters listed in the specification are common for many high performance servo drives. The main component in the design of the hardware is the power H-bridge switching ideally above the audio-frequency range. High frequency switching permits a compact power output filter to be used to filter the switching frequency if so desired.

SWITCH-MODE MOTOR DRIVE CONCEPTS

Figure 1 illustrates a conventional pulse width moldulated (PWM) D.C. motor servo drive. The velocity demand and the tachogenerator feedback signals are compared and the resultant velocity error is amplified. This error is fed to the current servo amplifier where it is compared with the actual current flowing in the motor armature. The amplified current error is fed into a linear PWM generator. The control of the mark to space ratio of the PWM generator is achieved by comparing the input error signal with a constant frequency triangular waveform. This results in a fixed frequency PWM signal which is fed to the power stage.

A switch-mode drive designed to the specification in table 1 comprises of :

1/ Drive and protection for power devices
2/ Power supplies
3/ Regenerative energy clamp (4 quadrant control)
4/ Current loop
5/ Control and logic for PWM and velocity servo.

The block diagram of the drive which has been developed is outlined in figure 2. (The complete circuit diagram is provided in figure 14). The differences between the two schemes outlined in figures 1 and 2 are that the current control loop and the PWM integrated circuit are eliminated in the second scheme. In the second scheme the velocity error is fed directly into a velocity compensation and modulation circuit. The elimination of the current feedback loop limits this scheme in so much as it can not be used in torque control applications.

Table 1 : Typical Brush D.C. Servo Drive Specification.

Specification	1.2kVA	6.0kVA
Modulation Frequency	> 20kHz < 50kHz	
Continuous Power	1300VA	6000VA
Maximum Continuous Current	10A	50A
Bus Voltage Input	$120V_{DC}$	
Efficiency	> 90%	
Short to Ground	Shut down	
Short to Bus Voltage	Shut down	
Armature Short	Shut down	
Operating Temperature	0 to 50°C	
Velocity Demand	10V	
Regenerative Energy Dissipation	10% of Continuous Rating	

Figure 1 : PWM D.C. Servo Drive.

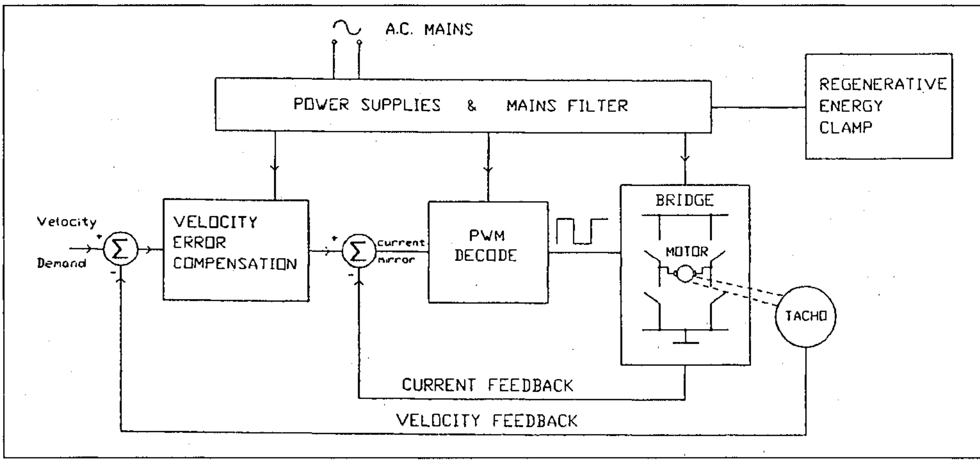
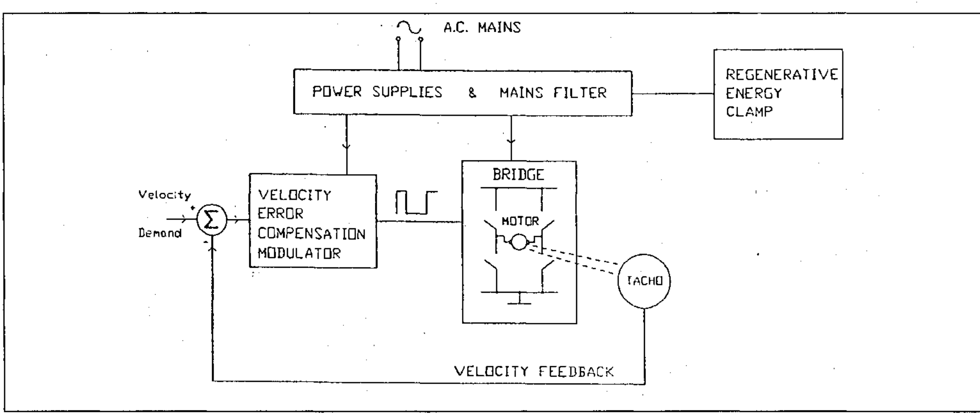


Figure 2 : Schematic Diagram of Brush D.C.P.M. Motor Drive.



BRIDGE CONFIGURATIONS & MODULATION TECHNIQUES

The bridge design must be capable of supplying bi-directional current to the motor for optimal four quadrant control. This can be achieved by using a "T-bridge" or an "H-bridge", as shown in figure 3. The H-bridge is generally chosen since it requires a single power supply. The voltage rating of the power semiconductor devices matches the motor voltage rating for the H-bridge alternative.

The H-bridge has eight operating modes when connected to a D.C. motor load. These modes can be seen in figure 4. Two of the modes increase current supplied to the motor winding in either direction. The other six operating modes reduce current in the motor winding and are commonly known as free-wheeling modes. Numerous switching modes are possible for PWM and current control. For example, it is possible to PWM both the top and bottom devices in the bridge or simply either the top or bottom device. It is possible to use the PWM mark to space ratio such that the mark provides a positive rate of change of current in the motor winding and the space provides a negative rate of change of current. The control of the pulse width thus establishes an adjustable average voltage across the motor load.

A modulation technique used in the developed servo drive is illustrated in figure 5. This modulator is based on "delta modulation" (reference 1). The mark to space ratio of the modulator output (0(t)), determines the conduction period of the MOSFETs in the H-bridge. The modulator comprises of the standard delta modulator (part A), the proportional term (part B) and the integral term (part C) of the PID controller.

Figure 3 : Bridge Configurations.

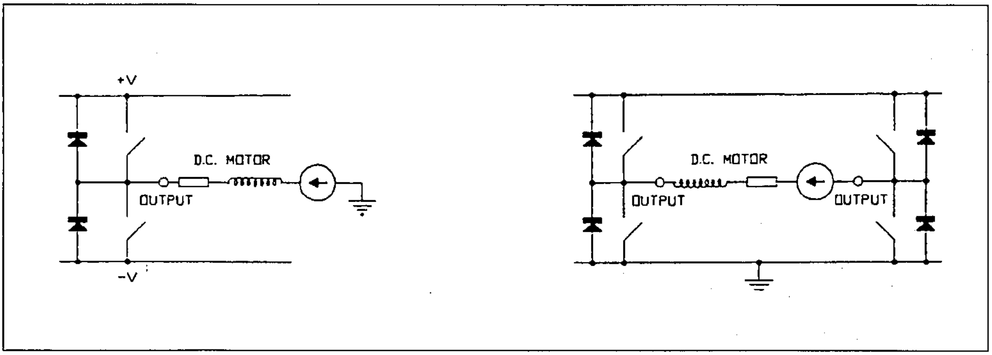


Figure 4 : Operating Modes of the H-bridge Showing Current Flow Paths.

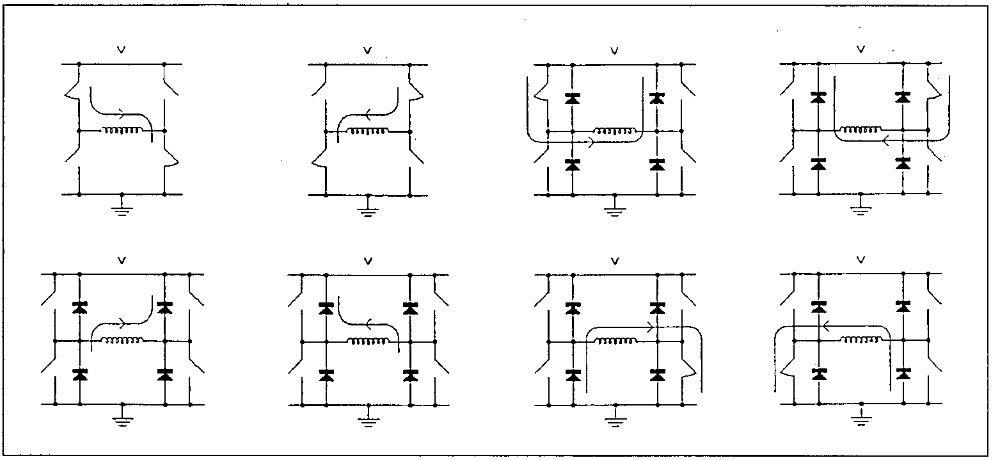
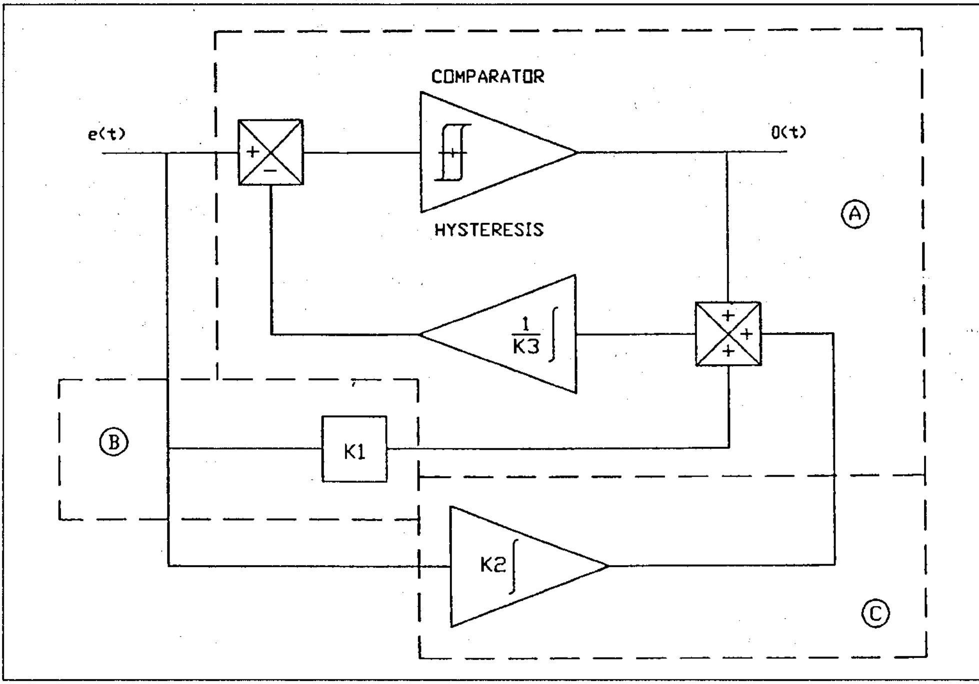


Figure 5 : A PID Controller with Binary Output.



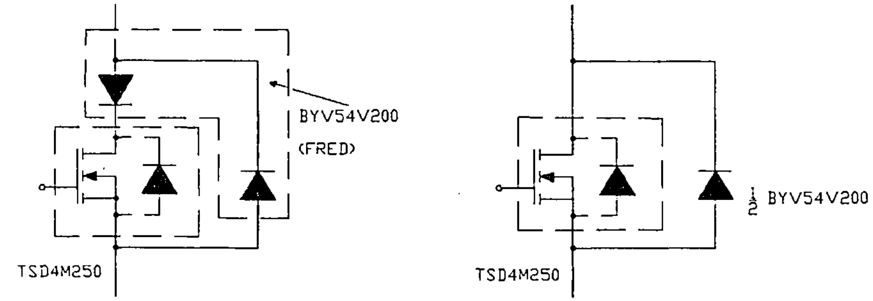
SWITCHING DEVICES FOR A RANGE OF D.C. MOTOR SERVO DRIVES

At medium power levels the MOSFET is ideally suited offering high switching speed, ease of paralleling and simple gate drive and protection. SGS-Thomson has introduced a range of MOSFET devices in plastic isolated packages. The 200V devices, summarised in table 2, can be used to design a servo drive range from 600VA to 6kVA without the need to parallel MOSFETs in separate plastic packages.

The MOSFET internal parasitic diode is too slow for applications requiring ultrasonic switching frequencies. Excessive switching losses in the MOSFET can result from the reverse recovery time of the internal parasitic diode (greater than 600ns). Noise is also induced on the supply rails when the conducting diodes reverse recover. Table 2 specifies high efficiency ultra fast recovery epitaxial diodes for freewheeling. These diodes, having a conduction voltage of less than 0.85V at rated nominal current, are ideally suited as MOSFET series blocking diodes used to prevent the conduction of the internal parasitic diode.

Figure 6 illustrates possible techniques for utilizing fast external diodes for the 6kVA brush D.C. motor design.

Figure 6 : 6kVA MOSFET Switch Configurations Using ISOFETs and FREDs.



Manufacture : SGS - THOMSON MICROELECTRONICS							Basic Brush D. C. Motor Drive Spec. Switching Freq. > 20kHz		
Part N° MOSFET	$R_{DS(ON)}$ $T_j = 25°C$ (Ω)	I_D $T_c = 100°C$ (A)	R_{TH} (°C/W)	Part N° Diode FRED	V_F at $T_j = 100°C$ (V)	I_F (A)	POWER (VA)	V_{nom} (V)	I_{nom} (A)
SGSP367[1]	0.45	10	1	BYW80PI200	0.85	7	600	120	5
SGSP477[1]	0.17	20	0.83	BYW81PI200	0.85	12	1200	120	10
TSD4M250[2]	0.021	68	0.25	BYV54V200	0.85	50	6000	120	50

Table 2 A range of brush D. C. motor velocity servo drives.

1 - without insulation.

2 - ISOFET : MOSFET chips in parallel in ISOTOP package.

1.2.KVA BRUSH D.C. SERVO DRIVE

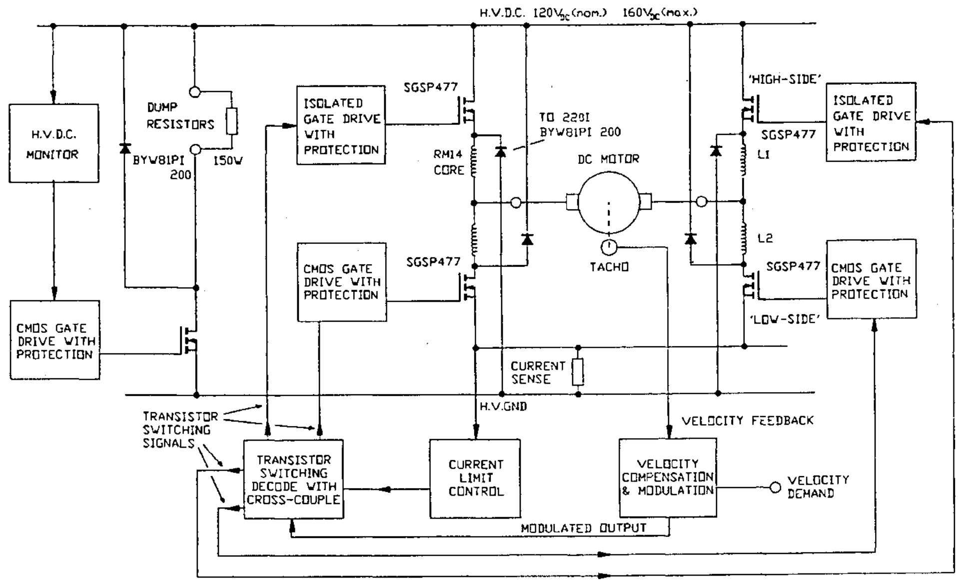
Figure 7 illustrates the block diagram of the developed 1.2kVA brush D.C. servo drive. The H-bridge operates at a nominal voltage of 120V_{DC}. The D.C. motor in certain applications is driven by its load and hence is a generator of energy. This regenerative energy causes the HVDC rail voltage to increase as energy is stored in the smoothing capacitors.

At a maximum voltage of 160V_{DC}, a resistive dump is turned-on to dissipate the regenerative energy and thus limit the HVDC to 160V_{DC}. The drive utilizes the velocity PID controller illustrated previously in figure 5. A current sense resistor is incorporated in the H-bridge to provide load current feedback necessary to limit this load current to the maximum continuous current rating of the drive.

MOSFET based bridge-leg configurations have previously been discussed (reference 2). The bridge-leg utilized comprises of "low-side" and "high-side" switches connected in series across the HVDC. In this asymetrical bridge-leg, (illustrated in figure 7), the rate of change of short-circuit current is limited by inductors (L1 and L2 : RM14 cores) which also limit freewheeling current from going through the parasitic diodes of the MOSFETs. At the 10A maximum continuous current rating of the drive, these inductors are still a managable size. This bridge-leg configuration is capable of withstanding simultaneous conduction of the two devices in the bridge-leg since there are series inductors which reduce the rate of change of drain current. This provides sufficient time for the short-circuit detection loop to operate. The power devices are thus turned-off without being stressed with high rates of change of pulse currents.

At a maximum continuous current rating of 10A, SGSP477 MOSFETs and BY81PI200 fast free-wheel diodes plastic packages are optimally rated for the 1.2kVA power stage.

Figure 7 : 1.2 Brush D.C. Motor Velocity Servo Drive (120V_{DC} ; 10A : nom.).

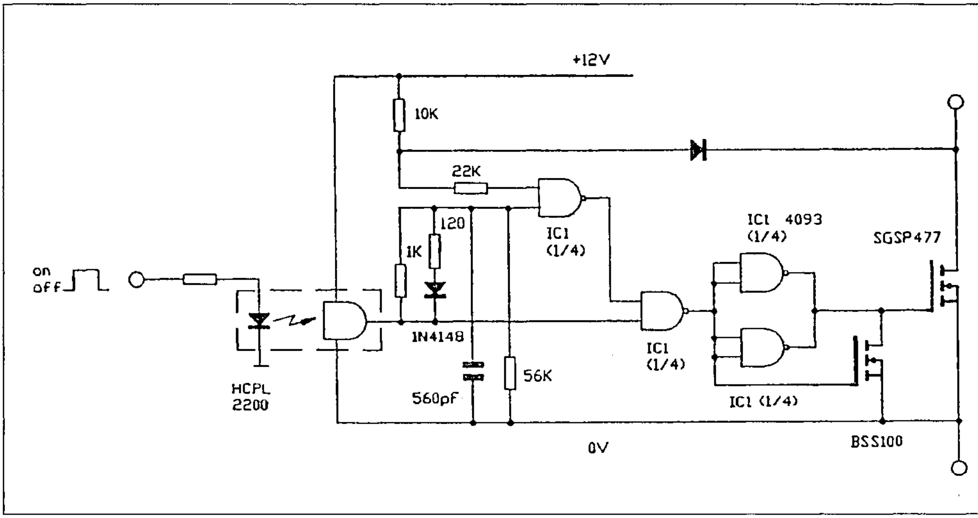


GATE DRIVES AND PROTECTION

Similar gate drives and protection circuits, (illustrated in figure 8), have been used for the "high-side" and "low-side" switches. This CMOS gate drive is well suited as switching speeds of 100 to 250 nanoseconds are sufficient in motor drive applications requiring a switching frequency of around 20 to 30kHz. Monitoring of the drain to source voltage while the device is conducting permits the detection of short-circuit conditions which lead to device failure. The device is turned-off before the drain current reaches a value in excess of the peak pulse current capability of the MOSFET. When the MOSFET is turned-on the on-state voltage of the device ($V_{DS(on)}$) is compared with a fixed reference voltage of approximately 8V. At the turn-on instant, $V_{DS(on)}$ monitoring is inhibited for a period of approximately 400 nanoseconds in order to allow the MOSFET to turn-on fully. After this period, if $V_{DS(on)}$ is detected to be greater than the fixed reference voltage, the device is latched-off until the control signal is turned-off and turned-on again.

The "high-side" gate drives have isolated low voltage supplies and isolated command signals using high speed opto-couplers.

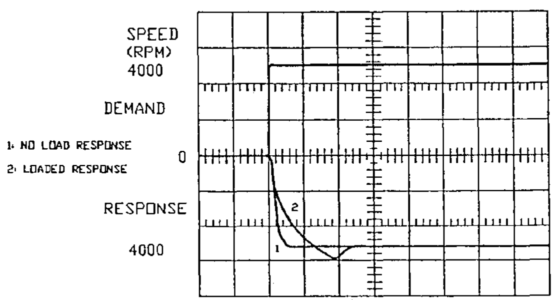
Figure 8 : An Isolated CMOS Gate Drive with Protection.



MOTOR DRIVE PERFORMANCE

Figure 9 illustrates the dynamic response of the motor drive to a step demand of 4000rpm. The response has been optimised for the no-load case (trace 1). Under heavy load inertia there is an overshoot in the velocity response (trace 2). The effects of changing the proportional gain and the integrator time constant of the PID controller can be seen in figures 10 and 11.

Figure 9 : Velocity Response of Motor Drive.



Time scale : 0.5s/div

Figure 10 : The Effect Upon the Dynamic Response of the Analogue Velocity Servo System, When the Gain of the Proportional Term in the PID Controller is Varied.

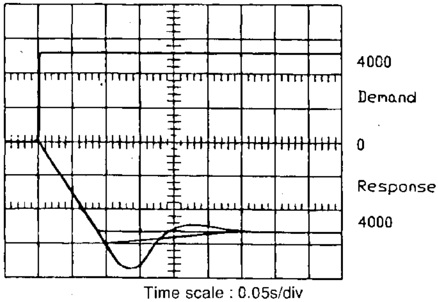
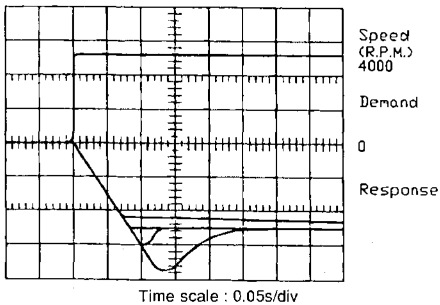


Figure 11 : The Effect Upon the Dynamic Response of the Analogue Velocity Servo System, when the Time Constant of the Integrator in the PID Controller is Varied.



6KVA BRUSH D.C. MOTOR SERVO DRIVE

Figure 12 illustrates the block diagram of the proposed 6kVA (120V_{DC} ; 50A) motor drive using ISOTOP packages for the MOSFETs in parallel (ISOFET) and the FRED diodes.

Blocking diodes in series with the MOSFETs are proposed to prevent the MOSFET internal parasitic diodes from conducting. The asymetrical bridge-leg configuration is not a cost-effective solution since inductors rated for 50A continuous operation are large and expensive. The series blocking diode has to be an ultra fast high voltage type. If the transistor F2 (shown in figure 12) is conducting, the drain to source capacitance of the transistor F1 is charged to the HVDC voltage. If F2 is turned-off, the load current transfers from F2 to the free-wheel diode, D1. Consequently the series blocking diode, D2, supports the drain to source capacitance voltage of F1 (equal to HVDC) provided this capacitance is not discharged by turning-on F1.

An isolated D.C. current measurement device, (such as an Hall-effect current sensor, LT80-P, manufactured by LEM), is recommended for the measurement of load current necessary for current limit control.

Pulse transformer based floating gate drives illustrated in figure 13 can be used for the TSD4M250 ISOFETs. The pulse transformer is used to transmit simultaneously the ISOFET logic command signal together with the gate to source capacitance charging current. The current mirror technique (reference 2) is used to provide short-circuit and over-load current protection. The pulse transformer operates at an oscillating frequency of 1MHz when a turn-on control signal is present. The secondary is rectified to provide gate source capacitance voltage. The current mirror provides a voltage "image" of the main drain current. This voltage is compared with a fixed reference voltage in order that the gate drive be latched-off whenever the drain current exceeds the specified overload current level.

Figure 12 : 6kVA Brush D.C. Motor Velocity Servo Drive (120V_{DC} ; 50A : nom.).

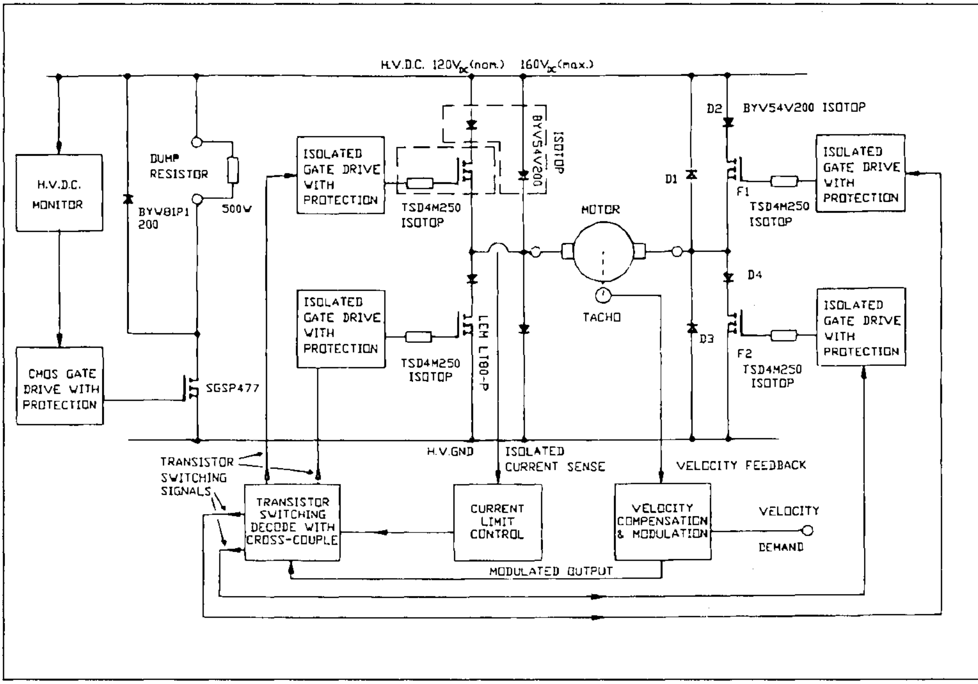
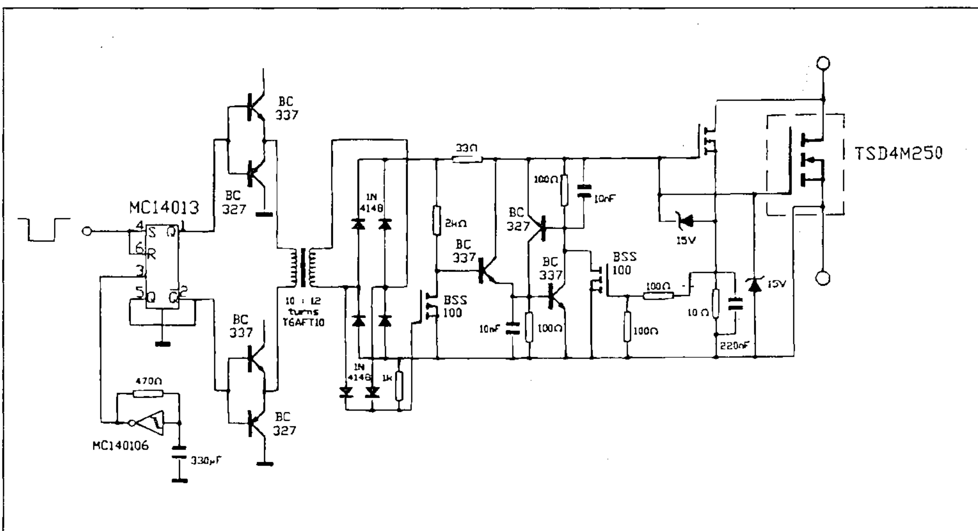


Figure 13 : Pulse Transformer Gate Drive with Current Mirror Protection for a TDS4M250.



CONCLUSION

MOSFET based brush D.C. motor velocity servo drives have been described, with particular emphasis placed on the bridge-leg configuration, the PID compensation and modulation, the gate drive and protection techniques. The PID compensation and modulation circuits require few components to achieve good velocity servo performance.

The development has led to a compact high performance 1.2kVA drive which is fully protected against output short-circuit conditions. A 6kVA motor drive is proposed using ISOFETs. MOSFET switching devices and their associated free-wheel and blocking diodes have been specified for a range of brush D.C. motor drives rated between 600VA to 6kVA without the need to parallel MOSFETs in separate plastic packages.

Figure 14 : 1.2kVA Switched-mode Motor Drive.