SGS-THOMSON
MICROELECTRONICS

APPLICATION NOTE

TWIN-LOOP CONTROL CHIP CUTS COST OF DC MOTOR POSITIONING

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Using a novel control IC that works with a simple photoelectric sensor, DC motors can now compare with stepper motors in positioning applications where cost is critical. The chip contains two complete control circuits, so that two motors can be controlled with one IC.

Since the introduction of integrated power drive stages, stepper motors have been the most popular choice for positioning drives in cost-critical applications like printer carriage control. Though DC motors are cheaper, require less power and provide more holding torque, they were rejected because they needed a costly shaft angle encoder to achieve comparable performance.

Today, however, it is possible to build a cheap, fast and efficient DC motor positioning drive that uses a simple optical encoder. What makes this possible is an integrated circuit -- the SGS-THOMSON type L6515 -- that embodies a twin-loop control system and uses a novel tacho conversion scheme which works effectively without high precision sensors.

The new IC is designed to work in a system shown schematically in figure 1. Actually the device contains two complete control circuits because most applications involve two motors. For simplicity only one half is shown. The system is controlled by a micro and uses a high-power bridge IC as the output stage to drive the motor. On the motor shaft is an optical encoder that provides two sinusoidal or triangular outputs 90° out of phase.

Two closed-loop operating modes are used: speed control and position control. At the beginning of a positioning action the system operates in speed control mode. The microcontroller applies a speed demand word to the L6515's DAC, normally calling for maximum speed. The motor current rises rapidly, accelerating the motor to the desired speed, which is maintained by a tacho feedback voltage derived from the sensor signals.

A counter in the micro monitors the squared sensor outputs, counting pulses to determine the distance travelled. As the target position is reached the micro reduces the speed demand word step-by-step, thus decelerating the motor. Eventually, when the speed demand word is zero and the final position very close, the micro closes the posi-

Figure 1: A highly integrated control circuit using novel circuit techniques makes it possible to design a dc motor positioning system that competes with stepper motors. This device is used with a bridge power stage and optical encoder.

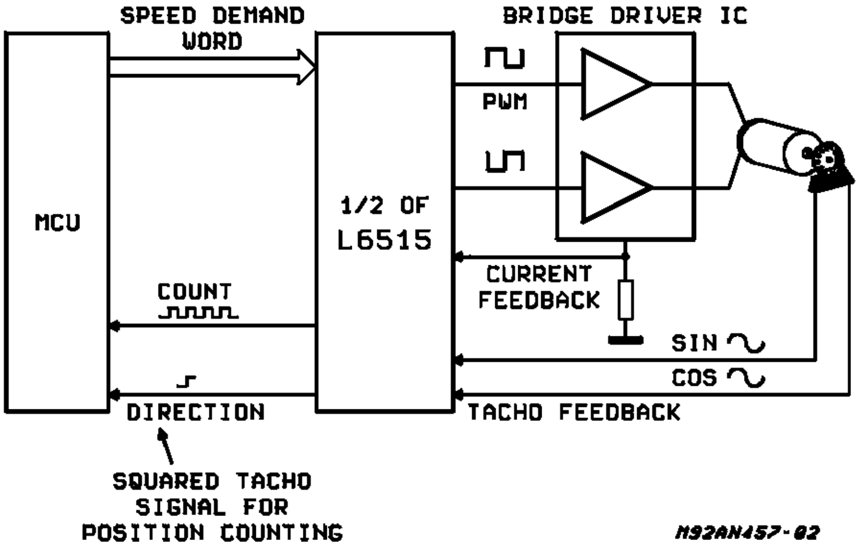
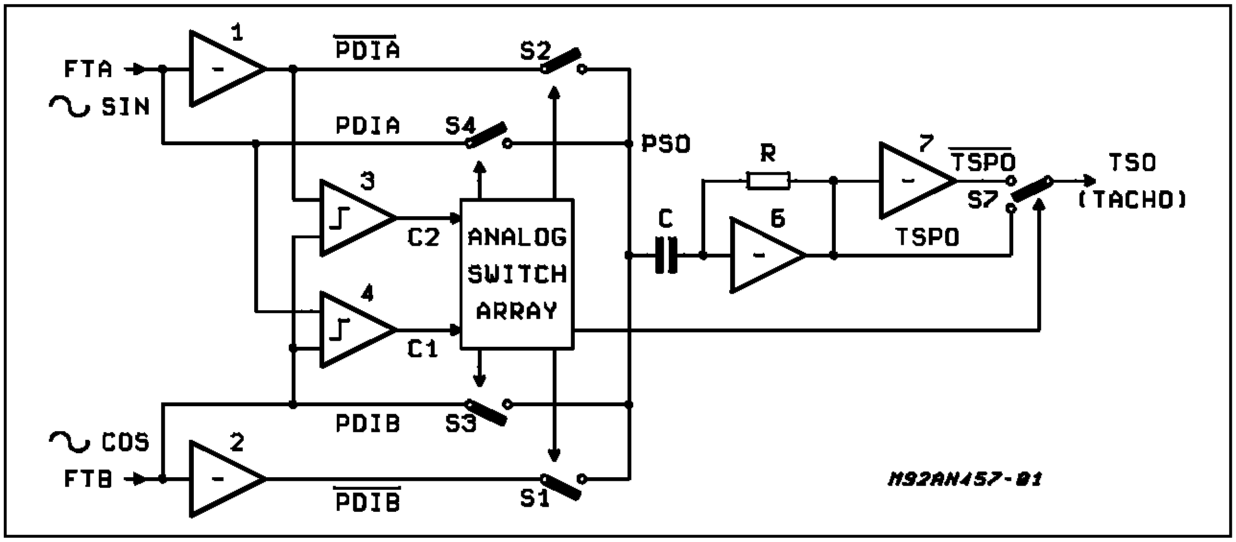


Figure 2: Unlike conventional tacho converters the L6515 uses this circuit which does not depend on a high-precision mechanism because it exploits the crossover points between the sine and cosine signals from the encoder.



tion loop -- where one of the sensor outputs is connected directly to the error amplifier -- forcing the motor to stop and hold in a position corresponding to a zero crossing of the sensor signal.

This combination of closed loop speed control, pulse counting and closed loop position control gives very fast and precise positioning.

GENERATING THE TACHO SIGNAL

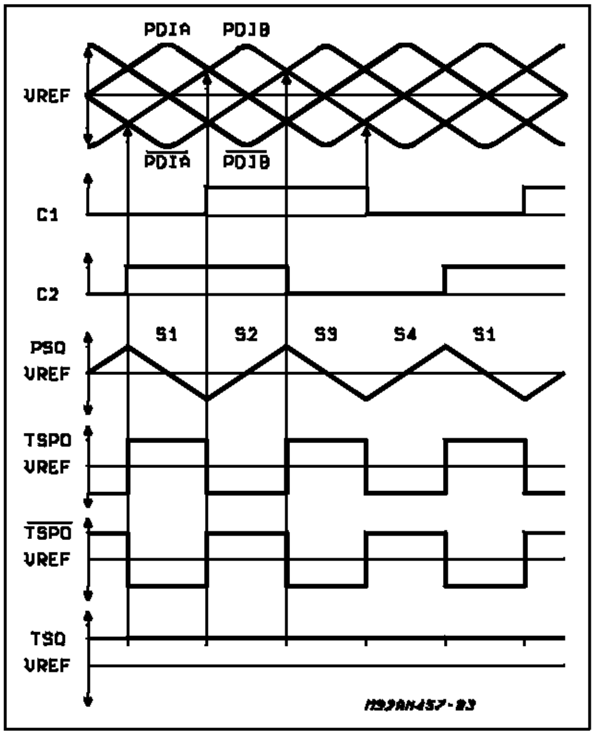
Systems working on this basic principle have been used before, but they used a conventional tacho conversion scheme where the encoder outputs are converted to a voltage proportional to speed by differentiation and synchronous rectification. To make this scheme work the encoder signals must be exactly sinusoidal or the tacho output will not be sufficiently precise. This in turn calls for great mechanical precision in the encoder construction and electronic brightness control for the light source. Such encoders are intrinsically expensive.

One alternative is to design a purely digital system, where the controller simply processes pulses from a simple encoder. However, this would require an encoder with a large number of steps/rotation to keep the loop stable at low speeds and guarantee the necessary precision. Also, at high speeds the pulse rate would overload low cost microcontrollers.

A completely new approach has been chosen for the L6515 which solves this problem. Rather than depend on the magnitude of the signals, this method relies on sensing the $\Delta V/\Delta t$ between crossovers in the encoder signals (figure 2).

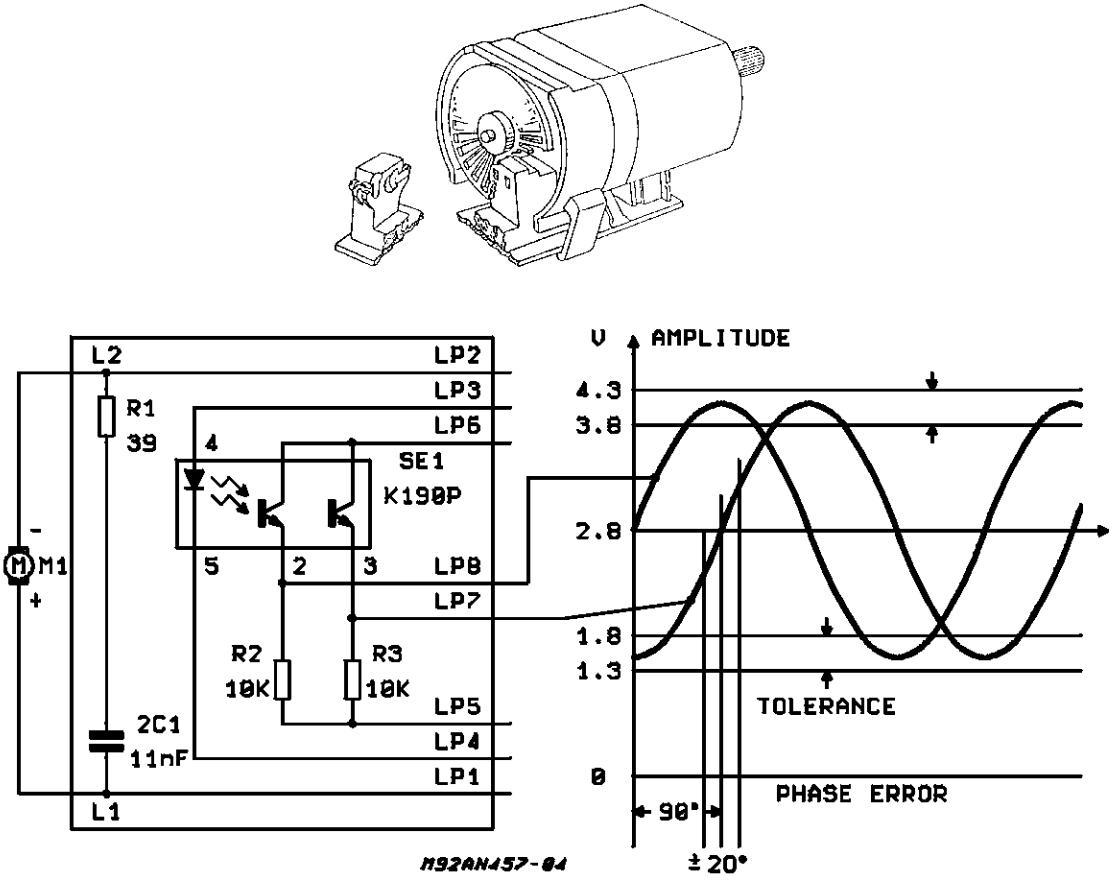
How this works can be seen in the waveforms of figure 3. First the two encoder signals are in-

Figure 3: Waveforms and truth table for the tacho conversion circuit in figure 2.



TRUTH TABLE, S1 - S7			
C1	C2	CLOSED	S7 IN POSITION
L	H	S1	TSPO
H	H	S2	$\overline{TSPO}$
H	L	S3	TSPO
L	L	S4	$\overline{TSPO}$

Figure 4: The system operates with a simple, inexpensive optical encoder which has only one adjustment, which ensures that the maxima of the sine and cosine waveforms are within a certain tolerance. All other tolerances are guaranteed by the construction of the encoder.



verted, giving a total of four signals. One of these is selected by the switches S1 to S4 depending on the outputs of the two comparators which cross-compare the sine and cosine signals. The selected encoder signal is then differentiated and the output inverted or not depending on the two comparator outputs.

The beauty of this approach is that it is independent of the encoder waveforms -- they can even be triangular. The only requirement for precision is that the maxima of the sine and cosine waveforms must be within a certain tolerance, ensuring sufficient precision in the crossover points. This can be achieved in practice with a simple mechanical adjustment.

Figure 4 shows an encoder used in this system and how it is attached to the motor. For an encoder of this type and a resolution of less than 100 steps/revolution no other adjustments are necessary because the mechanical construction guarantees all of the other tolerances.

CLOSING THE POSITION LOOP

As we have seen above, the tacho loop is augmented by a position loop for the final precise positioning and holding. How the two loops are connected in shown in figure 6.

The eight bits from the microcontroller consist of five bits for the magnitude of the speed demanded, one bit for its sign (and hence the motor direction) and two bits which select which half of the IC is addressed. If a speed demand word of 00000 is loaded one of the two switches S5 or S6 is closed, depending on the direction selected. Thus one of the encoder signals is connected directly to the summing point of the error amplifier input and the motor will be brought to a halt at the zero crossover of the encoder signal. It will remain in this position until a new position operation is initiated.

At the output of the error amplifier is the pulse-width-modulation circuit which drives an external power stage (figure 8).

In basic outline this circuit is very simple: the error

Figure 5: Application Circuit

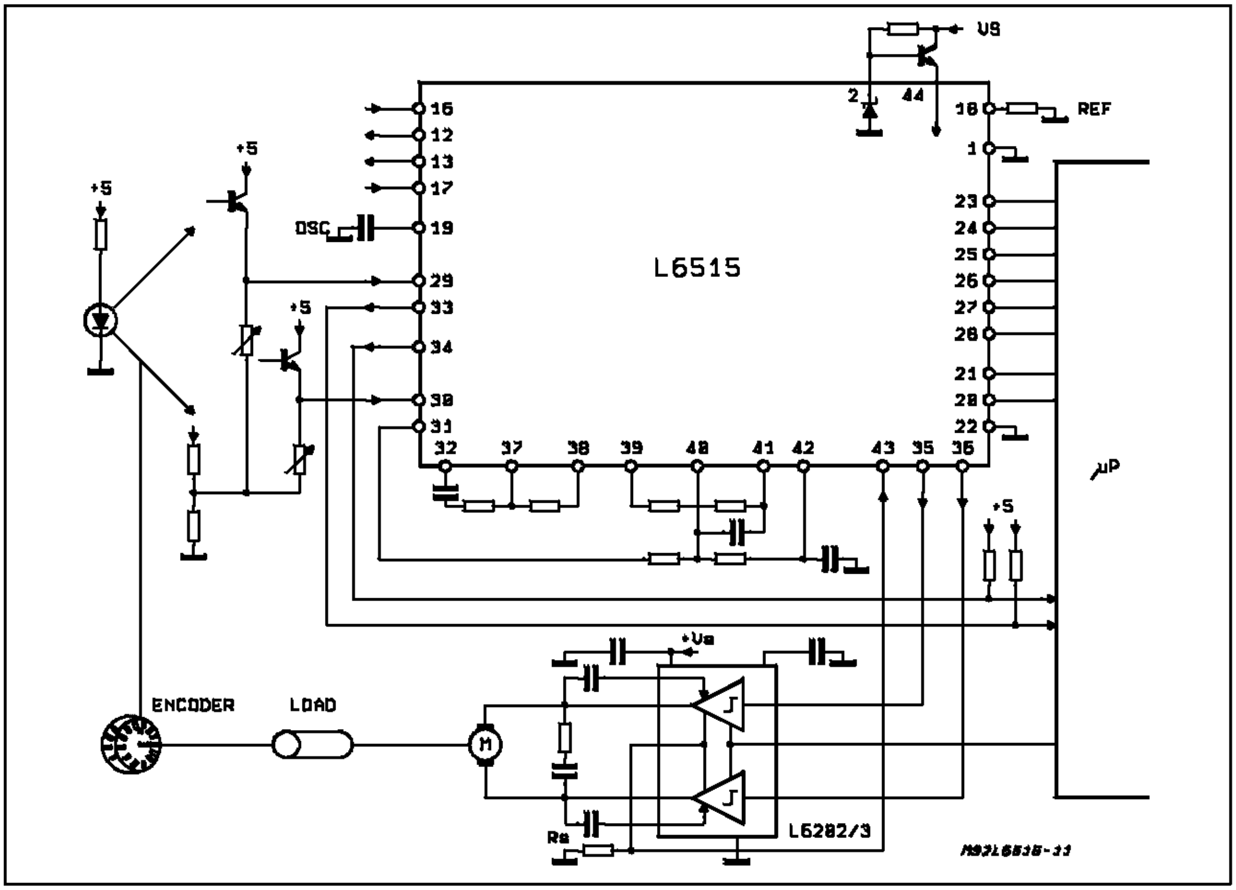


Figure 6: Shown schematically, the complete system has a main, velocity loop where the tacho signal and the output of a DAC are compared in an error amplifier which drives a PWM output stage. For final positioning S5 or S6 is closed, forming a position loop.

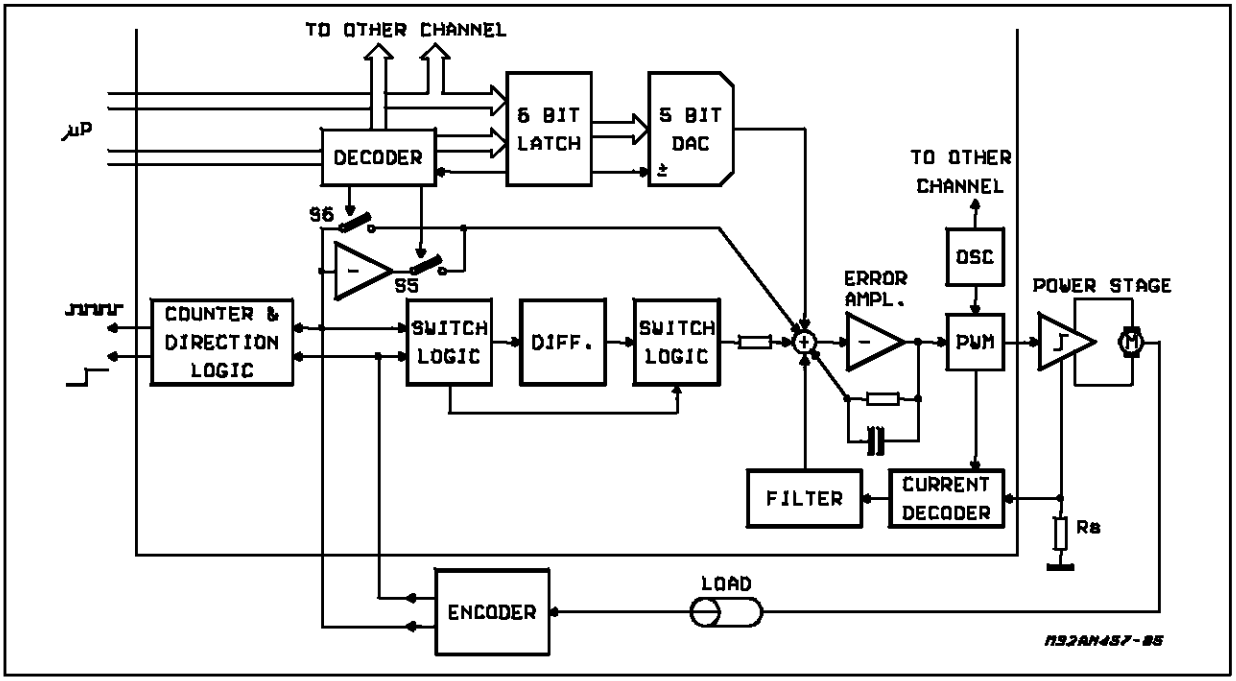


Figure 7: Because there is a single sense resistor connected to the lower legs of the bridge the current feedback voltage does not reflect the polarity of the motor current. Before the feedback signal can be added to the error signal its polarity must be restored.

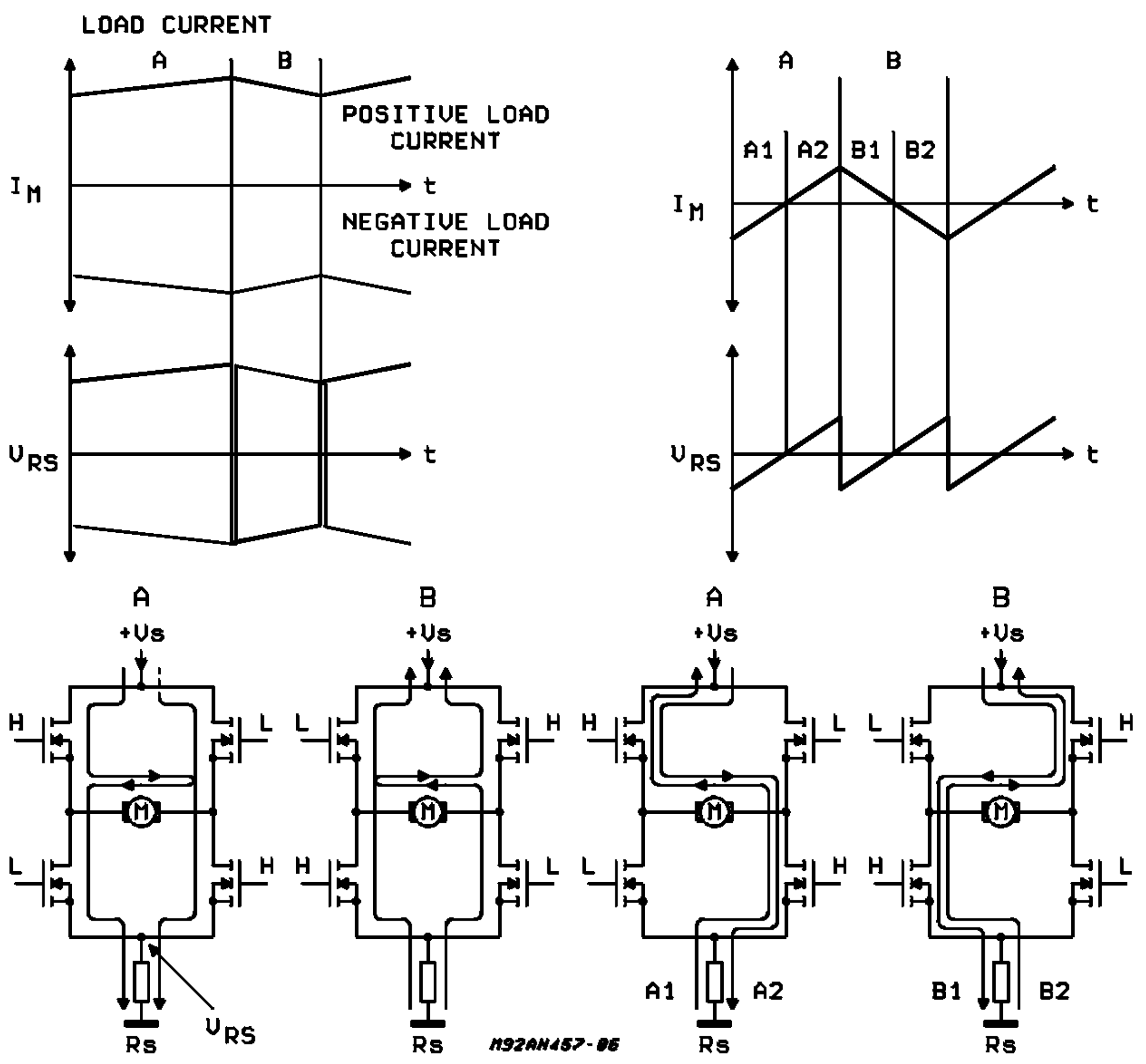
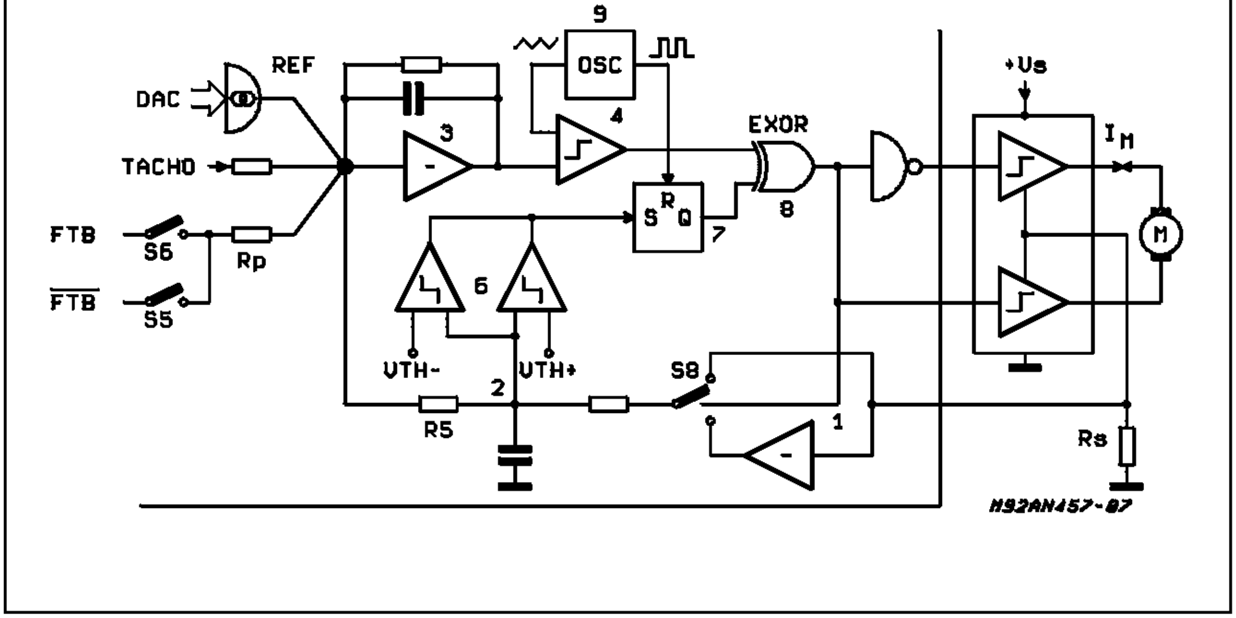


Figure 8: The pulse width modulator is formed by an oscillator (9) and a comparator (4). Switch S8 and (1) restore the correct polarity to the voltage from the current sense resistor.



amplifier output sets the threshold of the comparator 4, thus transforming the triangular wave from the oscillator into a rectangular signal whose duty cycle depends on the error amplifier output amplitude.

Feedback is provided by the sensing resistor Rs, which provides a voltage proportional to I_M.

The whole loop works in current mode which controls the torque of the motor.

Figure 9: The gain of the current loop is set by R5, while the maximum current can be set independently by the sense resistor, R_S.

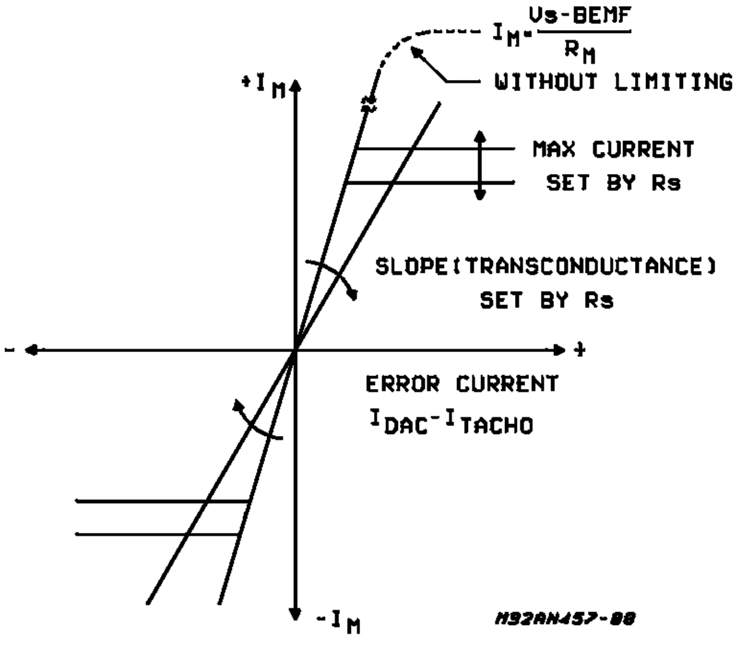
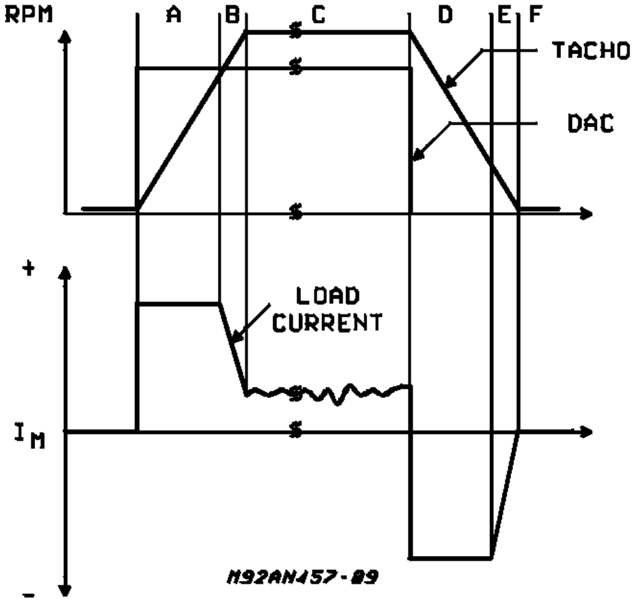


Figure 10: There are six distinct phases in an elementary positioning operation. These waveforms show the corresponding speed demand word, actual motor speed and motor current.



However, in practice it is necessary to reconstruct the polarity of the feedback voltage because the voltage across R_S is always of the same polarity, regardless of the direction of the drive current. This is performed by the inverter in the feedback path which is switched by S8 depending on the direction of the drive signal, which controls the current direction.

When the motor is accelerating rapidly to the set speed the current control loop saturates so the load current could increase to the point where the power stage or motor may be damaged.

To prevent this a limiting circuit formed by stages 6, 7 and 8 has been included. Normally the flip flop is reset periodically by the R_S oscillator and remains in the reset state; consequently the EXOR gate is ”transparent”, having no effect on the PWM output. When, however, the current exceeds a positive or negative threshold the flip flop will be set, thus the EXOR gate will invert the PWM output thus reversing the bridge drive, causing the current to drop rapidly.

Figure 8 shows the loop characteristics of the system and how they are controlled.

The loop gain is set by the resistor R5, while the maximum current is set independently by the sensing resistor R_S. These components can be set to accommodate a wide variety of motors and conditions.

Now that the circuit functions have been explained it is possible to follow in detail the functioning of the device. A basic positioning operation would consist of six steps (figure 10):

A. Acceleration, where the current is at a maximum limited by stages 6/7/8 (indicated in figure 8)

B. End-of-acceleration, where the current is reduced under control of stages 3/4

C. Constant speed, where tacho feedback controls the current at a low value

D. Deceleration, where the current is limited by stages 6/7/8

E. End-of-deceleration, where the current is controlled by 3/4

F. Positioning, where either S5 or S6 is closed.

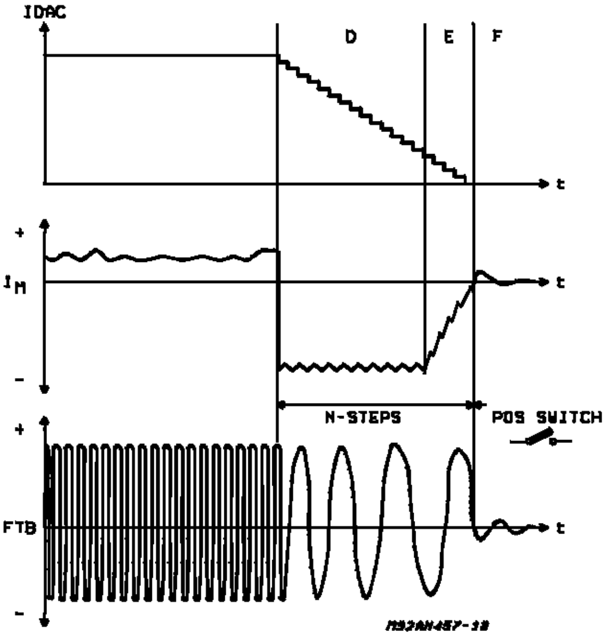
In practice phase D will be replaced by a series of decelerations to bring the motor speed down smoothly to zero at the destination point. Figure 10 shows the corresponding waveforms.

HIGH POWER BRIDGE ICs

The L6515 control IC is designed to be used with monolithic high power bridge driver ICs which are widely used today for DC and stepper motor driving. These devices are very simple to use because they are controlled by logic level inputs and include basic protection circuits to prevent damage in case of a fault in the controller or software.

Suitable types for output currents from 500mA to 4A are listed in Table 1. Note that bridge drivers

Figure 11: In a real positioning operation the deceleration of the motor is controlled smoothly by a progressive reduction of the speed demand word.



using DMOS power stages make it possible to obtain 1.5A output current using a DIP package, which is very compact and convenient for assembly. Also, single power ICs containing two bridges are available, so it is possible to make a positioning system for two motors with just two ICs.

The same BCD technology used to make smart power bridges like the L6202 and L6204 is also employed in the L6515, even though there are no power stages in the device. This technology is, in fact, highly suitable for this IC because it combines high density logic with the precision of bipolar circuits. Moreover, it also allows the inclusion of very low resistance MOS transistors which are needed in the tacho conversion switching circuits.

SOFTWARE

Software to control the L6515 must initialize the system at each reset then manage each positioning operation.The initialization routine is very simple; bringing the two latch control inputs R & S high together resets both of the latches at the DAC inputs. (see Figure 5).

At the same time the position counters in the micro will be zeroed. If the mechanical subsystem is in an unknown position the motor will have to be driven at a moderate speed to a known position during this phase. In a printer, for example, it can be driven towards an endstop.

For each positioning operation the micro will have to determine a suitable profile -- in particular when to begin deceleration. Then, once the first speed demand word has been latched into a DAC it will have to count the squared encoder pulses, usually with an interrupt routine. At specific distances from the end point reduced speed demand words will be loaded and then when the final position has been reached a zero speed demand word will be loaded; this automatically activates the position loop.

Table 1: High Power Bridge Driver ICs

HIGH-POWER BRIDGE DRIVER ICs				
TYPE	**FUNCTION**	**TECHNOLOGY**	**DC CURRENT**	**PACKAGE**
L6204	DUAL BRIDGE	DMOS	0.5 A	20 - PIN POWERDIP
L6201	BRIDGE	DMOS	1 A	20 - PIN SO
L6202	BRIDGE	DMOS	1.5 A	20 - PIN POWERDIP
L298N	DUAL BRIDGE	BIPOLAR	2 A	15 - PIN MULTIWATT
L6203	BRIDGE	DMOS	4 A	11 - PIN MULTIWATT

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