PBL 3717
Stepper Motor Drive Circuit

Description

PBL 3717 is a bipolar monolithic circuit intended to control and drive the current in one winding of a stepper motor.

The circuit consists of a LS-TTL compatible logic input stage, a current sensor, a monostable multivibrator and a high power H-bridge output stage with built-in protection diodes.

Two PBL 3717 and a small number of external components form a complete control and drive unit for LS-TTL or microprocessor-controlled stepper motor systems.

Key Features

- Half-step and full-step modes.
- Switched mode bipolar constant current drive
- Wide range of current control 5 – 1000 mA.
- Wide voltage range 10 – 45 V.
- Designed for unstabilized motor supply voltage.
- Current levels can be selected in steps or varied continuously.
- Thermal overload protection.
- Built-in recirculation diodes.

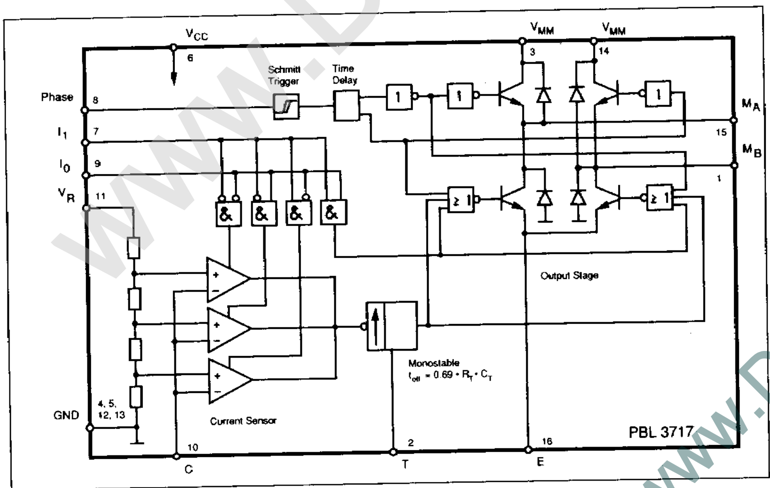
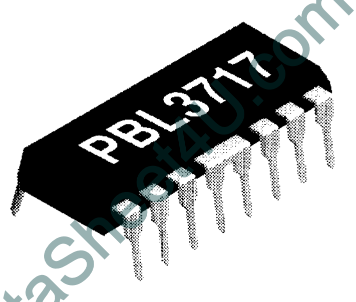


Figure 1. Block diagram.



16-pin plastic batwing DIP

Maximum Ratings

Parameter	Pin no.	Symbol	Min	Max	Unit
Voltage					
Logic supply	6	V_{CC}	0	7	V
Motor supply	3, 14	V_{MM}	0	45	V
Logic inputs	7, 8, 9	V_I	-0.3	6	V
Comparator input	10	V_C	-0.3	V_{CC}	V
Reference input	11	V_R	-0.3	15	V
Current					
Motor output current	1, 15	I_M	-1.0	+1.0	A
Logic inputs	7, 8, 9	I_I	-10		mA
Analog inputs	10, 11	I_A	-10		mA
Temperature					
Junction temperature		T_j		+150	°C
Operating ambient temperature		T_a	0	+70	°C
Storage temperature		T_s	-55	+150	°C

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Logic supply voltage	V_{CC}	4.75	5	5.25	V
Motor supply voltage	V_{MM}	10		40	V
Motor output current	I_M	-800		800	mA
Ambient temperature	T_a	0		+70	°C
Rise time logic inputs	t_r			2	µs
Fall time logic inputs	t_f			2	µs

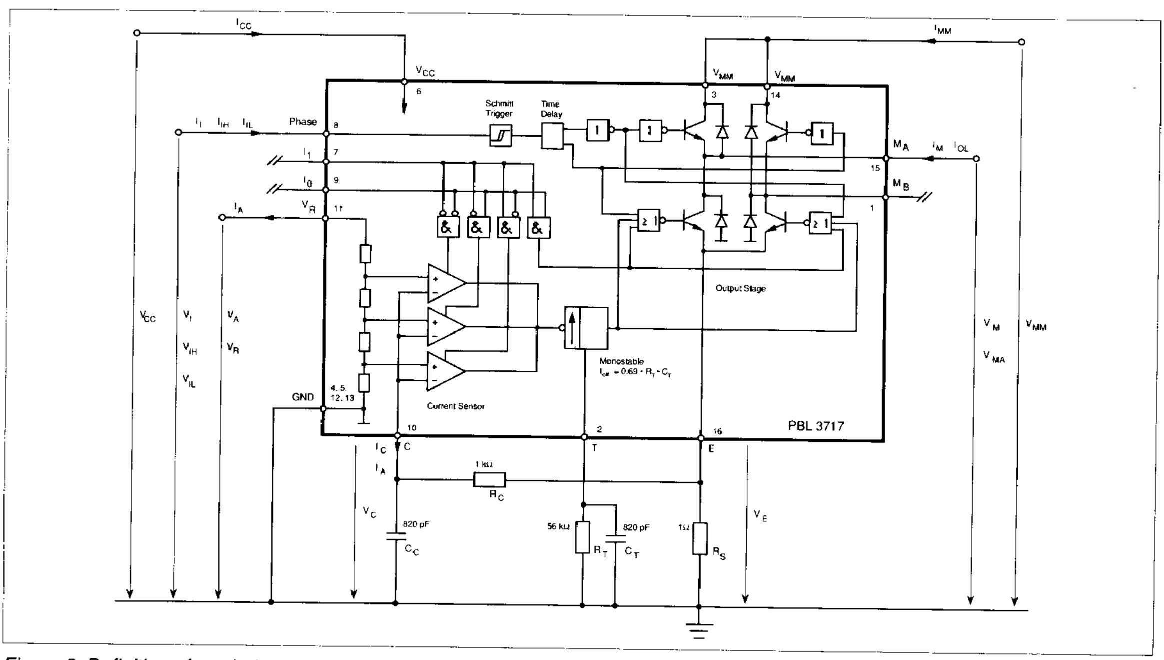


Figure 2. Definition of symbols.

Electrical Characteristics

Electrical characteristics over recommended operating conditions. C_T = 820 pF, R_T = 56 kohm .

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
General							
Supply current	I_{CC}	3				25	mA
Total power dissipation	P_D		f_s = 30 kHz, I_M = 500 mA. T_a = +25°C. Note 2, 4.		1.8	2.3	W
			f_s = 30 kHz, I_M = 800 mA. T_a = +25°C. Note 3, 4.		3.7		W
Thermal shutdown junction temperature					170		°C
Turn-off delay	t_d	2	T_a = +25°C, $dV_C/dt \geq$ 50 mV/µs.		0.9	1.5	µs
Logic Inputs							
Logic HIGH input voltage	V_{IH}	3		2.0			V
Logic LOW input voltage	V_{IL}	3				0.8	V
Logic HIGH input current	I_{IH}	3	V_I = 0.4 V	-0.4			mA
Logic LOW input current	I_{IL}	3	V_I = 2.4 V			20	µA
Comparator Input							
Threshold voltage	V_{CH}	3	V_R = 5.0 V, $I_0 = I_1$ = LOW	390	420	440	mV
	V_{CM}		V_R = 5.0 V, I_0 = HIGH, I_1 = LOW	230	250	270	mV
	V_{CL}		V_R = 5.0 V, I_0 = LOW, I_1 = HIGH	65	80	90	mV
Input current	I_C	3		-20			µA
Reference Input							
Input resistance	R_R		T_a = +25°C		6.8		kohm
Motor Outputs							
Total saturation voltage drop			I_M = 500 mA			4.0	V
Output leakage current			$I_0 = I_1$ = HIGH, T_a = +25°C			100	µA
Monostable							
Cut off time	t_{off}	2	V_{MM} = 10 V, $t_{on} \geq$ 5 µs	27	31	35	µs

Thermal Characteristics

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
Thermal resistance	Rth_{j-c}				11		°C/W
	Rth_{j-a}	14	Note 2.		40		°C/W

Notes

1. All voltages are with respect to ground. Currents are positive into, negative out of specified terminal.
2. All ground pins soldered onto a 20 cm² PCB copper area with free air convection. T_a = +25°C.
3. DIP package with external heatsink (Staver V7) and minimal copper area. Typical Rth_{j-a} = 27.5°C/W.
4. Not covered by final test program.

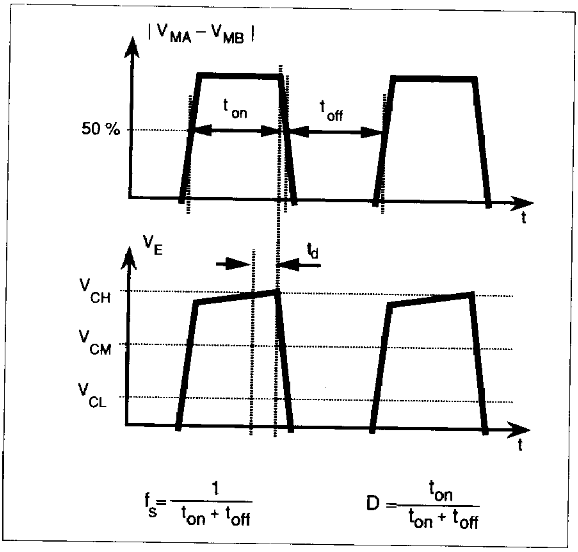


Figure 3. Definition of terms.

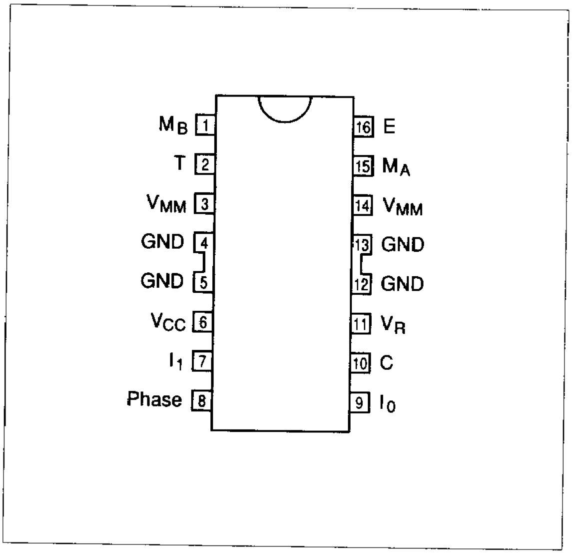


Figure 4. Pin configuration.

Functional Description

The PBL 3717/2 is intended to drive a bipolar constant current through one motor winding of a 2-phase stepper motor.

Current control is achieved through switched-mode regulation, see figure 5 and 6.

Three different current levels and zero current can be selected by the input logic.

The circuit contains the following functional blocks:

- Input logic
- Current sense
- Single-pulse generator
- Output stage

Input logic

Phase input. The phase input determines the direction of the current in the motor winding. High input forces the current from terminal M_A to M_B and low input from terminal M_B to M_A. A Schmidt trigger provides noise immunity and a delay circuit eliminates the risk of cross conduction in the output stage during a phase shift.

Half- and full-step operation is possible.

Current level selection. The status of I_0 and I_1 inputs determines the current level in the motor winding. Three fixed current levels can be selected according to the table below.

Motor current		I_0	I_1
High level	100%	L	L
Medium level	60%	H	L
Low level	20%	L	H
Zero current	0%	H	H

The specific values of the different current levels are determined by the reference voltage V_R together with the value of the sensing resistor R_S.

The peak motor current can be calculated as follows:

$i_m = (V_R \cdot 0.084) / R_S$ [A], at 100% level

$i_m = (V_R \cdot 0.050) / R_S$ [A], at 60% level

$i_m = (V_R \cdot 0.016) / R_S$ [A], at 20% level

The motor current can also be continuously varied by modulating the voltage reference input.

Current sensor

The current sensor contains a reference voltage divider and three comparators for measuring each of the selectable current levels. The motor current is sensed as a voltage drop across the current sensing resistor, R_S, and compared with one of the voltage references from the divider. When the two voltages are equal, the comparator triggers the single-pulse generator. Only one comparator at a time is activated by the input logic.

Single-pulse generator

The pulse generator is a monostable multivibrator triggered on the positive edge of the comparator output. The multivibrator output is high during the pulse time, t_{off}, which is determined by the timing components R_T and C_T.

$t_{off} = 0.69 \cdot R_T \cdot C_T$

The single pulse switches off the power feed to the motor winding, causing the current to decrease during t_{off}.

If a new trigger signal should occur during t_{off}, it is ignored.

Output stage

The output stage contains four darlington transistors and four diodes, connected in an H-bridge. The two sinking transistors are used to switch the power supplied to the motor winding, thus driving a constant current through the winding. See figures 5 and 6.

Overload protection

The circuit is equipped with a thermal shut-down function, which will limit the junction temperature. The output current will be reduced if the maximum permissible junction temperature is exceeded. It should be noted, however, that it is not permitted to short circuit the outputs.

Operation

When a voltage V_{MM} is applied across the motor winding, the current rise follows the equation:

$i_m = (V_{MM} / R) \bullet (1 - e^{-(R \cdot t)/L})$

R = Winding resistance

L = Winding inductance

t = time

(see figure 6, arrow 1)

The motor current appears across the external sensing resistor, R_S, as an analog voltage. This voltage is fed through a low-pass filter, $R_C C_C$, to the voltage comparator input (pin 10). At the moment the sensed voltage rises above the comparator threshold voltage, the monostable is triggered and its output turns off the conducting sink transistor. The polarity across the motor winding reverses and the current is forced to circulate through the appropriate upper recirculation diode back through the source transistor (see figure 6, arrow 2).

After the monostable has timed out, the current has decayed and the analog voltage across the sensing resistor is below the comparator threshold level. The sinking transistor then closes and the motor current starts to increase again, The cycle is repeated until the current is turned off via the logic inputs.

By reversing the logic level of the phase input (pin 8), both active transistors are turned off and the opposite pair turned on after a slight delay. When this happens, the current must first decay to zero before it can reverse. This current decay is steeper because the motor current is now forced to circulate back through the power supply and the appropriate sinking transistor recirculation diode. This causes higher reverse voltage build-up across the winding which results in a faster current decay (see figures 6 and 7).

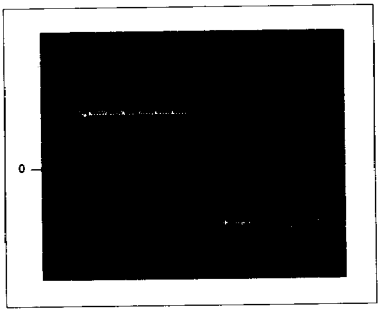


Figure 5. Motor current (I_M), Vertical : 200 mA/div, Horizontal: 1 ms/div, expanded part 100 µs/div.

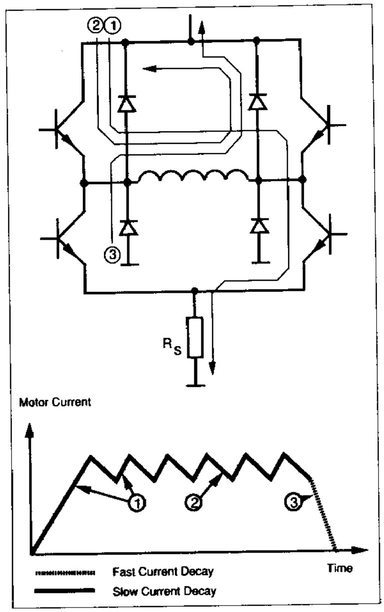


Figure 6. Output stage with current paths for fast and slow current decay.

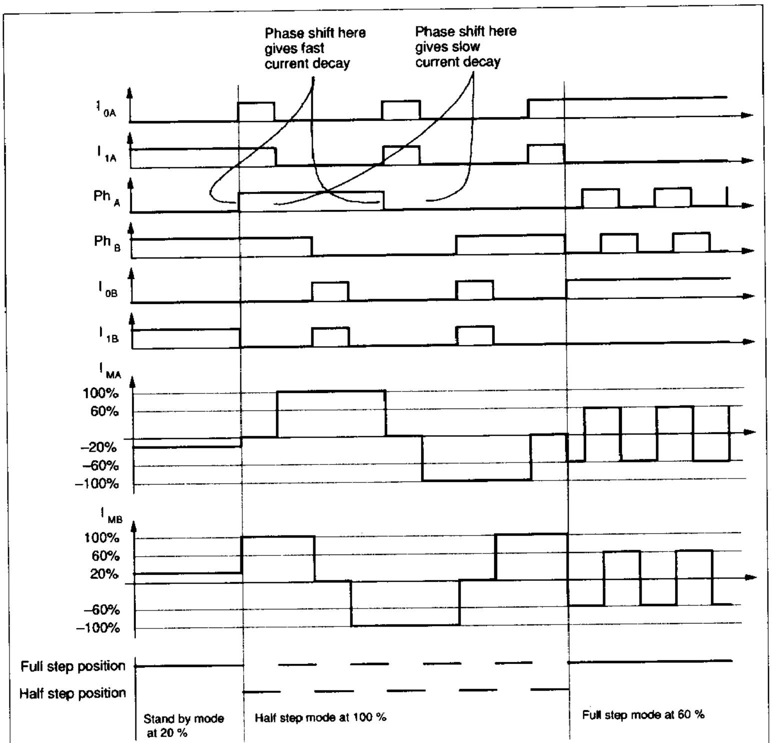


Figure 7. Principal operating sequence.

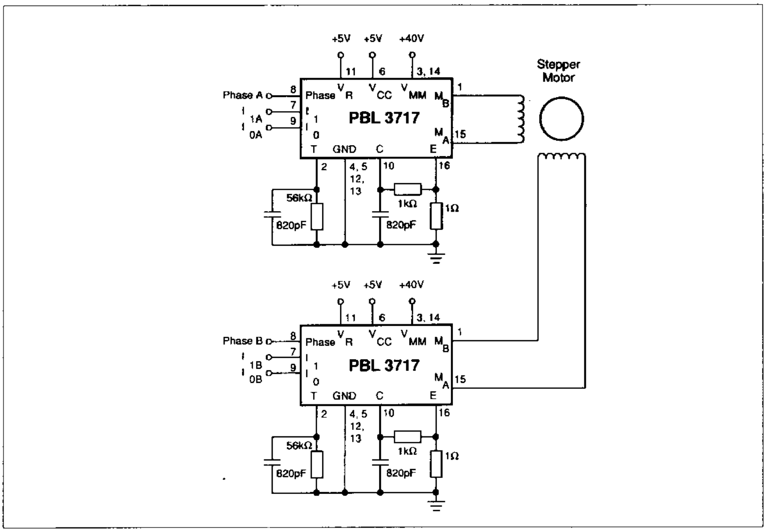


Figure 8. Typical stepper motor driver application with PBL 3717.

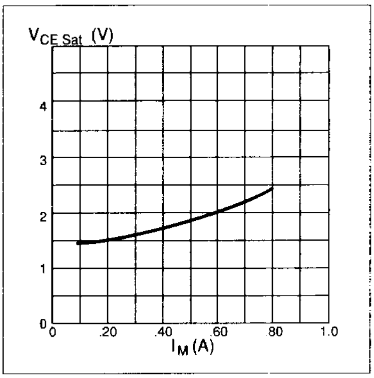


Figure 9. Typical source saturation vs. output current.

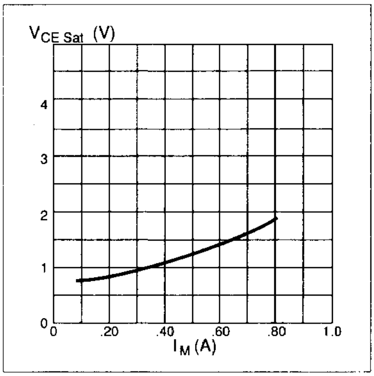


Figure 10. Typical sink saturation vs. output current.

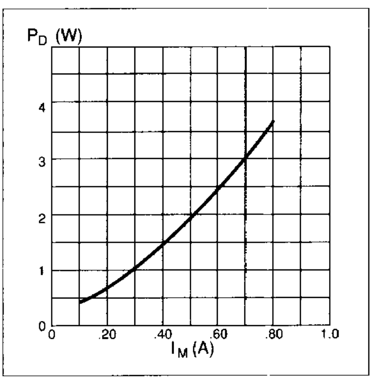


Figure 11. Typical power dissipation vs. motor current.

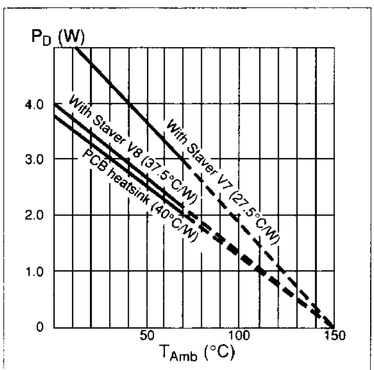


Figure 12. Allowable power dissipation vs. ambient temperature.

For best speed performance of the stepper motor at half-step mode operation, the phase logic level should be changed at the same time the current-inhibiting signal is applied (see figure 2).

Heatsinking

The junction temperature of the chip highly effects the lifetime of the circuit. In high-current applications, the heatsinking must be carefully considered.

The Rth_{ja} of the PBL 3717 can be reduced by soldering the ground pins to a suitable copper ground plane on the printed circuit board (see figure 14) or by applying an external heatsink type V7 or V8, see figure 13.

The diagram in figure 12 shows the maximum permissible power dissipation versus the ambient temperature in °C, for heatsinks of the type V7, V8, or a 20 cm^2 copper area respectively. Any external heatsink or printed circuit board copper must be connected to electrical ground.

For motor currents higher than 500 mA, heatsinking is recommended to assure optimal reliability.

The diagrams in figures 11 and 12 can be used to determine the required heatsinking of the circuit. In some systems, forced-air cooling may be available to reduce the temperature rise of the circuit.

Applications Information

Motor selection

Some stepper motors are not designed for continuous operation at maximum current. As the circuit drives a constant current through the motor, its temperature can increase, both at low- and high-speed operation.

Some stepper motors have such high core losses that they are not suited for switched-mode operation.

Interference

As the circuit operates with switched-mode current regulation, interference-generation problems can arise in some applications. A good measure is then to decouple the circuit with a 0.1 µF ceramic capacitor, located near the package across the power line V_{MM} and ground.

Also make sure that the V_R input is sufficiently decoupled. An electrolytic capacitor should be used in the +5 V rail, close to the circuit.

The ground leads between R_S, C_C and circuit GND should be kept as short as possible. This applies also to the leads connecting R_S and R_C to pin 16 and pin 10 respectively.

In order to minimize electromagnetic interference, it is recommended to route M_A and M_B leads in parallel on the printed circuit board directly to the terminal connector. The motor wires should be twisted in pairs, each phase separately, when installing the motor system.

Unused inputs

Unused inputs should be connected to proper voltage levels in order to obtain the highest possible noise immunity.

Ramping

A stepper motor is a synchronous motor and does not change its speed due to load variations. This means that the torque of the motor must be large enough to match the combined inertia of the motor and load for all operation modes. At speed changes, the requires torque increases by the square, and the required power by the cube of the speed change. Ramping, i.e., controlled acceleration or deceleration must then be considered to avoid motor pull-out.

V_{CC}, V_{MM}

The supply voltages, V_{CC} and V_{MM}, can be turned on or off in any order. Normal dv/dt values are assumed.

Before a driver circuit board is removed from its system, all supply voltages must be turned off to avoid destructive transients being generated by the motor.

Analog control

As the current levels can be continuously controlled by modulating the V_R input, limited microstepping can be achieved.

Switching frequency

The motor inductance, together with the pulse time, t_{off}, determines the switching frequency of the current regulator. The choice of motor may then require other values on the R_T, C_T components than those recommended in figure 7, to obtain a switching frequency above the audible range. Switching frequencies above 40 kHz are not recommended because the current regulation can be affected.

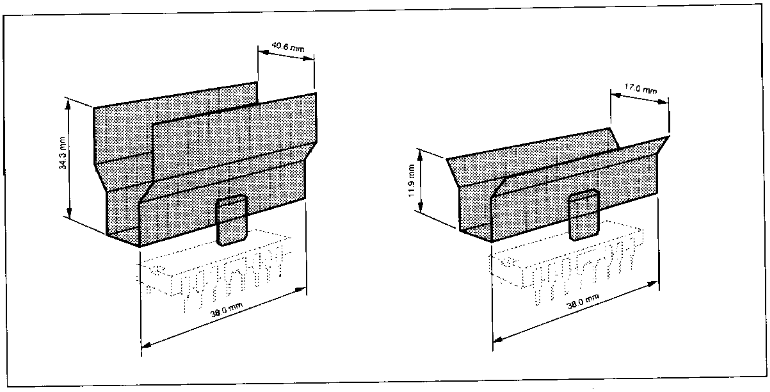


Figure 13. Heatsinks, Staver, type V7 and V8 by Columbia-Staver UK.

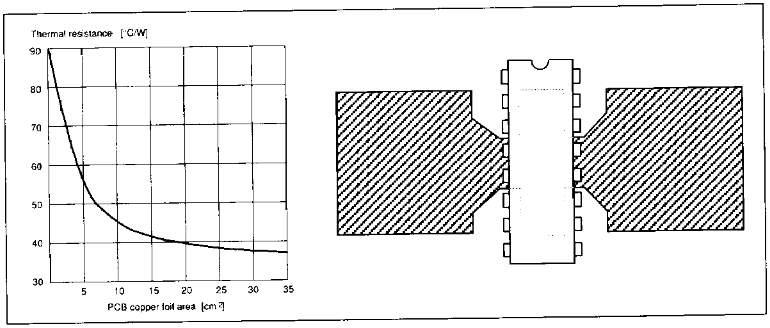


Figure 14. Copper foil used as a heatsink.

Description	Condition	Typ value
Rth_{j-c}, Junction to Case	Case = the four ground pins	11°C/W
Rth_{j-a}, Junction to Ambient	The four ground pins soldered to a 20 cm² ground plane according to figure14.	40°C/W

Table 1. Thermal resistance . Thermal resistance values are heavily dependant on location and shape of heatsink.

Sensor Resistor

The R_S resistor should be of a non-inductive type power resistor. A 1.0 ohm resistor, tolerance ≤ 1%, is a good choice for 420 mA max motor current at V_R = 5V.

The maximum motor current, i_m, can be calculated by using the formula:

$i_m = (V_R \cdot 0.084) / R_S$ [A], at 100% level

$i_m = (V_R \cdot 0.050) / R_S$ [A], at 60% level

$i_m = (V_R \cdot 0.016) / R_S$ [A], at 20% level.

Ordering Information

Package	Temp. Range	Part No.
Plastic DIP	0 to 70°C	PBL 3717N