UNITRODE

# Stepper Motor Drive Circuit

## FEATURES

- Full-Step, Half-Step and Micro-Step Capability
- Bipolar Output Current up to 1A
- Wide Range of Motor Supply Voltage 10-46V
- Low Saturation Voltage with Integrated Bootstrap
- Built-In Fast Recovery Commutating Diodes
- Current Levels Selected in Steps or Varied Continuously
- Thermal Protection with Soft Intervention

## DESCRIPTION

The UC3717A is an improved version of the UC3717, used to switch drive the current in one winding of a bipolar stepper motor. The UC3717A has been modified to supply higher winding current, more reliable thermal protection, and improved efficiency by providing integrated bootstrap circuitry to lower recirculation saturation voltages. The diagram shown below presents the building blocks of the UC3717A. Included are an LS-TTL compatible logic input, a current sensor, a monostable, a thermal shutdown network, and an H-bridge output stage. The output stage features built-in fast recovery commutating diodes and integrated bootstrap pull up. Two UC3717As and a few external components form a complete control and drive unit for LS-TTL or micro-processor controlled stepper motor systems.

The UC3717A is characterized for operation over the temperature range of 0°C to +70°C.

## ABSOLUTE MAXIMUM RATINGS (Note 1)

Voltage
- Logic Supply, $V_{CC}$ . . . . . 7V
- Output Supply, $V_m$ . . . . . 50V

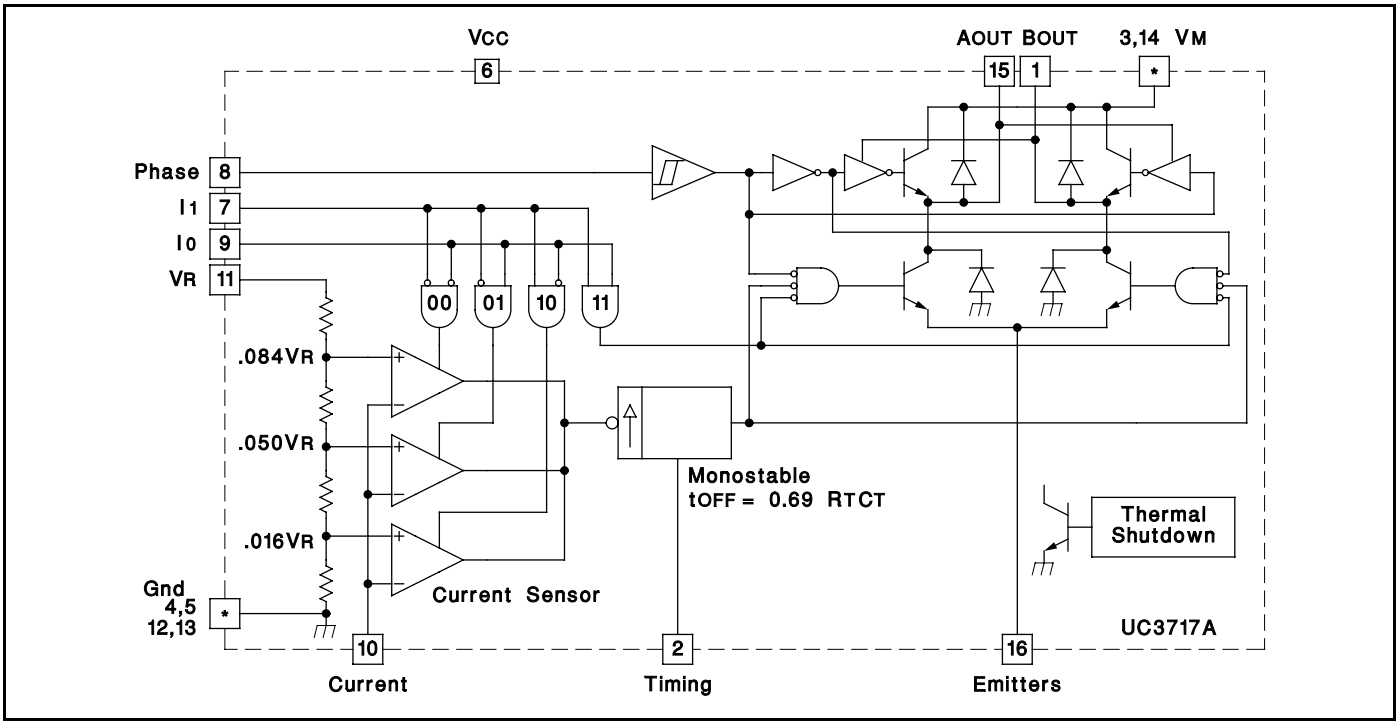
Input Voltage
- Logic Inputs (Pins 7, 8, 9) . . . . . 6V
- Analog Input (Pin 10) . . . . . $V_{CC}$
- Reference Input (Pin 11) . . . . . 15V

Input Current
- Logic Inputs (Pins 7, 8, 9) . . . . . -10mA
- Analog Inputs (Pins 10, 11) . . . . . -10mA

Output Current (Pins 1, 15) . . . . . ±1.2A
Junction Temperature, $T_J$ . . . . . +150°C
Storage Temperature Range, $T_S$ . . . . . -55°C to +150°C

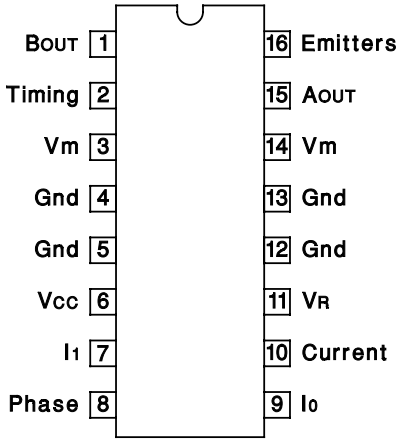
*Note 1: All voltages are with respect to ground, Pins 4, 5, 12, 13. Currents are positive into, negative out of the specified terminal. Pin numbers refer to DIL-16 package.*
*Consult Packaging Section of Databook for thermal limitations and considerations of package.*

## BLOCK DIAGRAM

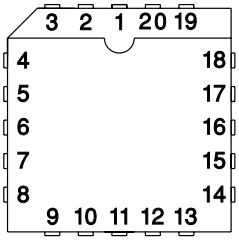


## CONNECTION DIAGRAMS

**DIL-16 (TOP VIEW)**
**J or N Package**




**PLCC-20 (TOP VIEW)**
**Q Package**




| PACKAGE PIN FUNCTION | |
|---|---|
| **FUNCTION** | **PIN** |
| N/C | 1 |
| BOUT | 2 |
| Timing | 3 |
| Vm | 4 |
| Gnd | 5 |
| N/C | 6 |
| Gnd | 7 |
| VCC | 8 |
| I1 | 9 |
| Phase | 10 |
| N/C | 11 |
| I0 | 12 |
| Current | 13 |
| VR | 14 |
| Gnd | 15 |
| N/C | 16 |
| Gnd | 17 |
| Vm | 18 |
| AOUT | 19 |
| Emitters | 20 |

## ELECTRICAL CHARACTERISTICS

(Refer to the test circuit, Figure 6. $V_m$ = 36V, $V_{CC}$ = 5V, $V_R$ = 5V, $T_A$ = 0°C to 70°C, unless otherwise stated, $T_A = T_J$.)

| PARAMETERS | TEST CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|
| Supply Voltage, $V_m$ (Pins 3, 14) | | 10 | | 46 | V |
| Logic Supply Voltage, $V_{CC}$ (Pin 6) | | 4.75 | | 5.25 | V |
| Logic Supply Current, $I_{CC}$ (Pin 6) | $I_O = I_1 = 0$ | | 7 | 15 | mA |
| Thermal Shutdown Temperature | | +160 | | +180 | °C |
| **Logic Inputs** | | | | | |
| Input Low Voltage, (Pins 7, 8, 9) | | | | 0.8 | V |
| Input High Voltage, (Pins 7, 8, 9) | | 2 | | $V_{CC}$ | V |
| Low Voltage Input Current, (Pins 7, 8, 9) | $V_I$ = 0.4V, Pin 8 | | | -100 | µA |
| | $V_I$ = 0.4V, Pins 7 and 9 | | | -400 | mA |
| High Voltage Input Current, (Pins 7, 8, 9) | $V_I$ = 2.4V | | | 10 | µA |
| **Comparators** | | | | | |
| Comparator Low, Threshold Voltage (Pin 10) | $V_R$ = 5V; $I_O$ = L; $I_1$ = H | 66 | 80 | 90 | mV |
| Comparator Medium, Threshold Voltage (Pin 10) | $V_R$ = 5V; $I_O$ = H; $I_1$ = L | 236 | 250 | 266 | mV |
| Comparator High, Threshold Voltage (Pin 10) | $V_R$ = 5V; $I_O$ = L; $I_1$ = L | 396 | 420 | 436 | mV |
| Comparator Input, Current (Pin 10) | | | | ±20 | µA |
| Cutoff Time, $t_{OFF}$ | $R_T$ = 56kΩ, $C_T$ = 820pF | 25 | | 35 | µs |
| Turn Off Delay, $t_D$ | (See Figure 5) | | | 2 | µs |
| **Source Diode-Transistor Pair** | | | | | |
| Saturation Voltage, $V_{SAT}$ (Pins 1, 15) | $I_m$ = -0.5A, Conduction Period | | 1.7 | 2.1 | V |
| (See Figure 5) | $I_m$ = -0.5A, Recirculation Period | | 1.1 | 1.35 | V |
| Saturation Voltage, $V_{SAT}$ (Pins 1, 15) | $I_m$ = -1A, Conduction Period | | 2.1 | 2.8 | V |
| (See Figure 5) | $I_m$ = -1A, Recirculation Period | | 1.7 | 2.5 | V |
| Leakage Current | $V_m$ = 40V | | | 300 | µA |
| Diode Forward Voltage, $V_F$ | $I_m$ = -0.5A | | 1 | 1.25 | V |
| | $I_m$ = -1A | | 1.3 | 1.7 | V |

**ELECTRICAL CHARACTERISTICS (cont.)** (Refer to the test circuit, Figure 6. $V_M$ = 36V, $V_{CC}$ = 5V, $V_R$ = 5V, $T_A$ = 0°C to 70°C, unless otherwise stated, $T_A$ = $T_J$.)

| PARAMETERS | TEST CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|
| **Sink Diode-Transistor Pair** | | | | | |
| Saturation Voltage, $V_{SAT}$ (Pins 1, 15) | $I_m$ = 0.5A | 0.8 | 1.1 | 1.35 | V |
| | $I_m$ = 1A | | 1.6 | 2.3 | V |
| Leakage Current | $V_m$ = 40V | | | 300 | µA |
| Diode Forward Voltage, $V_F$ | $I_m$ = 0.5A | | 1.1 | 1.5 | V |
| | $I_m$ = 1A | | 1.4 | 2 | V |

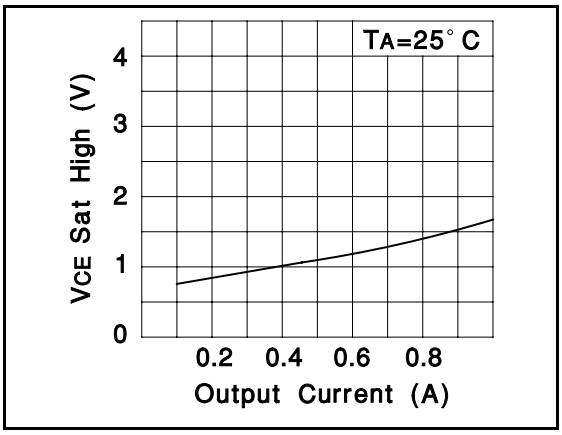



**Figure 1. Typical Source Saturation Voltage vs Output Current (Recirculation Period)**

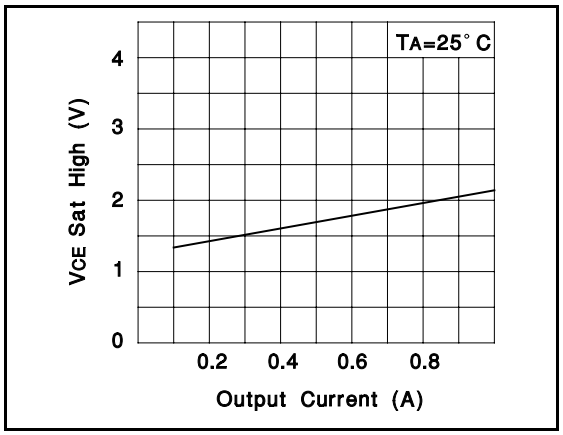



**Figure 2. Typical Source Saturation Voltage vs Output Current (Conduction Period)**

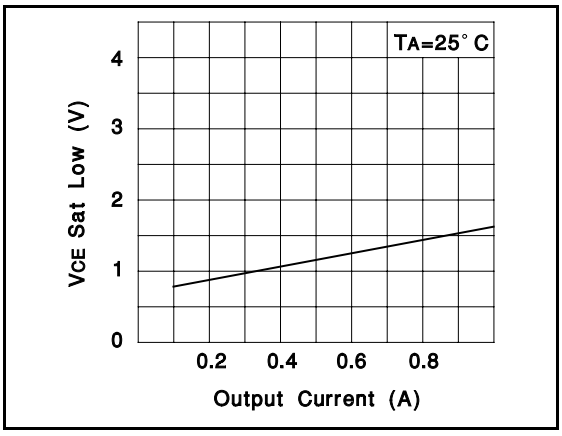



**Figure 3. Typical Sink Saturation Voltage vs Output Current**

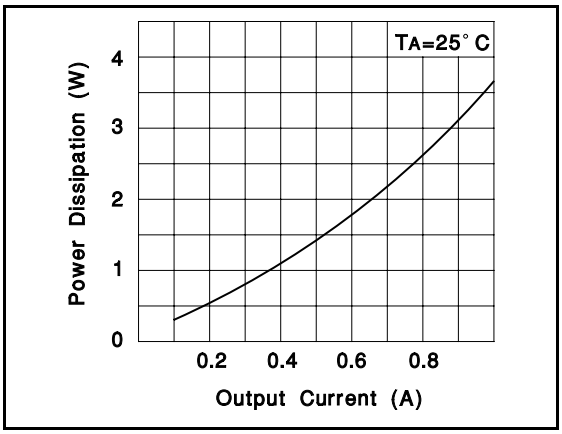



**Figure 4. Typical Power Dissipation vs Output Current**

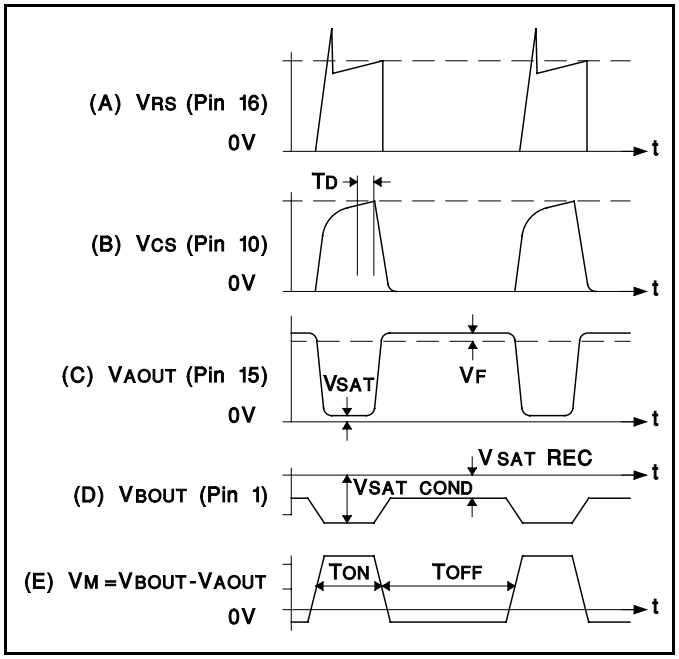



**Figure 5. Typical Waveforms with MA Regulating (phase = 0)**

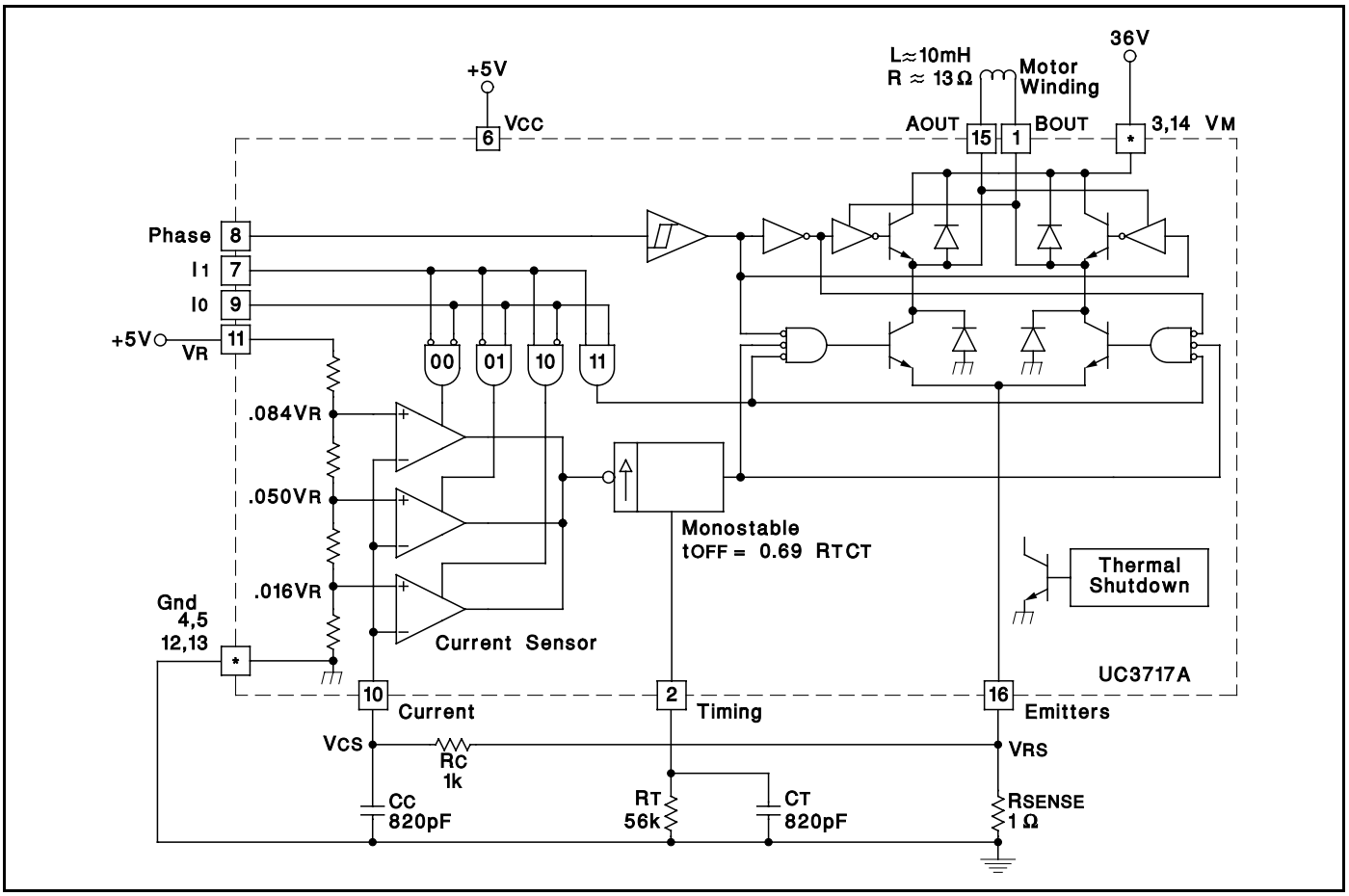



**Figure 6. UC3717A Test Circuit**

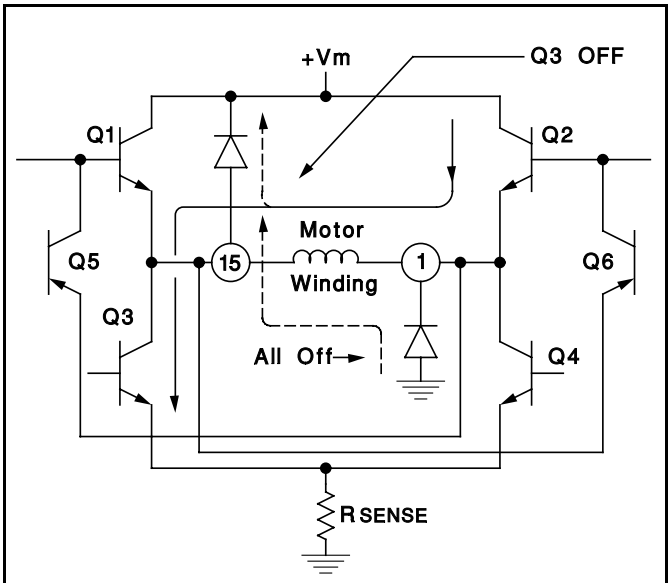
## FUNCTIONAL DESCRIPTION

The UC3717A's drive circuit shown in the block diagram includes the following components.

(1) H-bridge output stage
(2) Phase polarity logic
(3) Voltage divider coupled with current sensing comparators
(4) Two-bit D/A current level select
(5) Monostable generating fixed off-time
(6) Thermal protection

## OUTPUT STAGE

The UC3717A's output stage consists of four Darlington power transistors and associated recirculating power diodes in a full H-bridge configuration as shown in Figure 7. Also presented, is the new added feature of integrated bootstrap pull up, which improves device performance during switched mode operation. While in switched mode, with a low level phase polarity input, Q2 is on and Q3 is being switched. At the moment Q3 turns off, winding current begins to decay through the commutating diode pulling the collector of Q3 above the supply voltage. Meanwhile, Q6 turns on pulling the base of Q2 higher than its previous value. The net effect lowers the saturation voltage of source transistor Q2 during recirculation, thus improving efficiency by reducing power dissipation.




*Note: Dashed lines indicate current decay paths.*

**Figure 7. Simplified Schematic of Output Stage**

## FUNCTIONAL DESCRIPTION (cont.)

### PHASE POLARITY INPUT

The UC3717A phase polarity input controls current direction in the motor winding. Built-in hysteresis insures immunity to noise, something frequently present in switched drive environments. A low level phase polarity input enables Q2 and Q3 as shown in Figure 7. During phase reversal, the active transistors are both turned off while winding current delays through the commutating diodes shown. As winding current decays to zero, the inactive transistors Q1 and Q4 turn on and charge the winding with current of the reverse direction. This delay insures noise immunity and freedom from power supply current spikes caused by overlapping drive signals.

| PHASE INPUT | Q1, Q4 | Q2, Q3 |
|---|---|---|
| LOW | OFF | ON |
| HIGH | ON | OFF |

### CURRENT CONTROL

The voltage divider, comparators, monostable, and two-bit D/A provide a means to sense winding peak current, select winding peak current, and disable the winding sink transistors.

The UC3717A switched driver accomplishes current control using an algorithm referred to as "fixed off-time." When a voltage is applied across the motor winding, the current through the winding increases exponentially. The current can be sensed across an external resistor as an analog voltage proportional to instantaneous current. This voltage is normally filtered with a simple RC low-pass network to remove high frequency transients, and then compared to one of the three selectable thresholds. The two bit D/A input signal determines which one of the three thresholds is selected, corresponding to a desired winding peak current level. At the moment the sense voltage rises above the selected threshold, the UC3717A's monostable is triggered and disables both output sink drivers for a fixed off-time. The winding current then circulates through the source transistor and appropriate diode. The reference terminal of the UC3717A provides a means of continuously adjusting the current threshold to allow microstepping. Table 1 presents the relationship between the two-bit D/A input signal and selectable current level.

**TABLE 1**

| $I_0$ | $I_1$ | CURRENT LEVEL |
|---|---|---|
| 0 | 0 | 100% |
| 1 | 0 | 60% |
| 0 | 1 | 19% |
| 1 | 1 | Current Inhibit |

### OVERLOAD PROTECTION

The UC3717A is equipped with a new, more reliable thermal shutdown circuit which limits the junction temperature to a maximum of 180C by reducing the winding current.

### PERFORMANCE CONSIDERATIONS

In order to achieve optimum performance from the UC3717A careful attention should be given to the following items.

**External Components:** The UC3717A requires a minimal number of external components to form a complete control and switch drive unit. However, proper selection of external components is necessary for optimum performance. The timing pin, (pin 2) is normally connected to an RC network which sets the off-time for the sink power transistor during switched mode. As shown in Figure 8, prior to switched mode, the winding current increases exponentially to a peak value. Once peak current is attained the monostable is triggered which turns off the lower sink drivers for a fixed off-time. During off-time winding current decays through the appropriate diode and source transistor. The moment off-time times out, the motor current again rises exponentially producing the ripple waveform shown. The magnitude of winding ripple is a direct function of off-time. For a given off-time $T_{OFF}$, the values of $R_T$ and $C_T$ can be calculated from the expression:

$$T_{OFF} = 0.69 R_T C_T$$

with the restriction that $R_T$ should be in the range of 10-100k. As shown in Figure 5, the switch frequency $F_S$ is a function of $T_{OFF}$ and $T_{ON}$. Since $T_{ON}$ is a function of the reference voltage, sense resistor, motor supply, and winding electrical characteristics, it generally varies during different modes of operation. Thus, $F_S$ may be approximated nominally as:

$$F_S = \tfrac{1}{1.5}\,(T_{OFF}).$$

Normally, Switch Frequency Is Selected Greater than

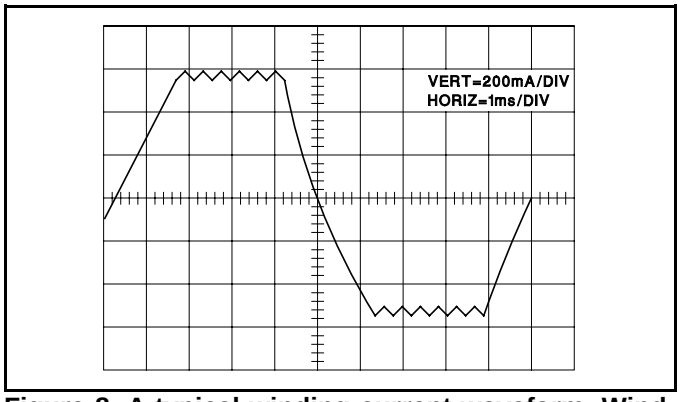



**Figure 8. A typical winding current waveform. Winding current rises exponentially to a selected peak value. The peak value is limited by switched mode operation producing a ripple in winding current. A phase polarity reversal command is given and winding current decays to zero, then increases exponentially.**

**FUNCTIONAL DESCRIPTION (cont.)**

Low-pass filter components $R_C$ $C_C$ should be selected so that all switching transients from the power transistors and commutating diodes are well smoothed, but the primary signal, which can be in the range of $1/T_{OFF}$ or higher must be passed. Figure 5A shows the waveform which must be smoothed, Figure 5B presents the desired waveform that just smoothes out overshoot without radical distortion.

The sense resistor should be chosen as small as practical to allow as much of the winding supply voltage to be used as overdrive to the motor winding. $V_{RS}$, the voltage across the sense resistor, should not exceed 1.5V.

**Voltage Overdrive:** In many applications, maximum speed or step rate is a desirable performance characteristic. Maximum step rate is a direct function of the time necessary to reverse winding current with each step. In response to a constant motor supply voltage, the winding current changes exponentially with time, whose shape is determined by the winding time constant and expressed as:

$$I_m = \frac{V_m}{R\,[1 - EXP\,(-R\tau/L)]}$$

as presented in Figure 9. With rated voltage applied, the time required to reach rated current is excessive when compared with the time required with over-voltage applied, even though the time constant L/R remains constant. With over-voltage however, the final value of current is excessive and must be prevented. This is accomplished with switch drive by repetitively switching the sink drivers on and off, so as to maintain an average value of current equal to the rated value. This results in a small amount of ripple in the controlled current, but the increase in step rate and performance may be considerable.

**Interference:** Electrical noise generated by the chopping action can cause interference problems, particularly in the vicinity of magnetic storage media. With this in mind, printed circuit layouts, wire runs and decoupling must be considered. 0.01 to 0.1µF ceramic capacitors for high frequency bypass located near the drive package across V+ and ground might be very helpful. The connection and ground leads of the current sensing components should be kept as short as possible.

**Half-Stepping:** In half step sequence the power input to the motor alternates between one or two phases being energized. In a two phase motor the electrical phase shift between the windings is 90°. The torque developed is the vector sum of the two windings energized. Therefore when only one winding is energized the torque of the motor is reduced by approximately 30%. This causes a torque ripple and if it is necessary to compensate for this, the $V_R$ input can be used to boost the current of the single energized winding.

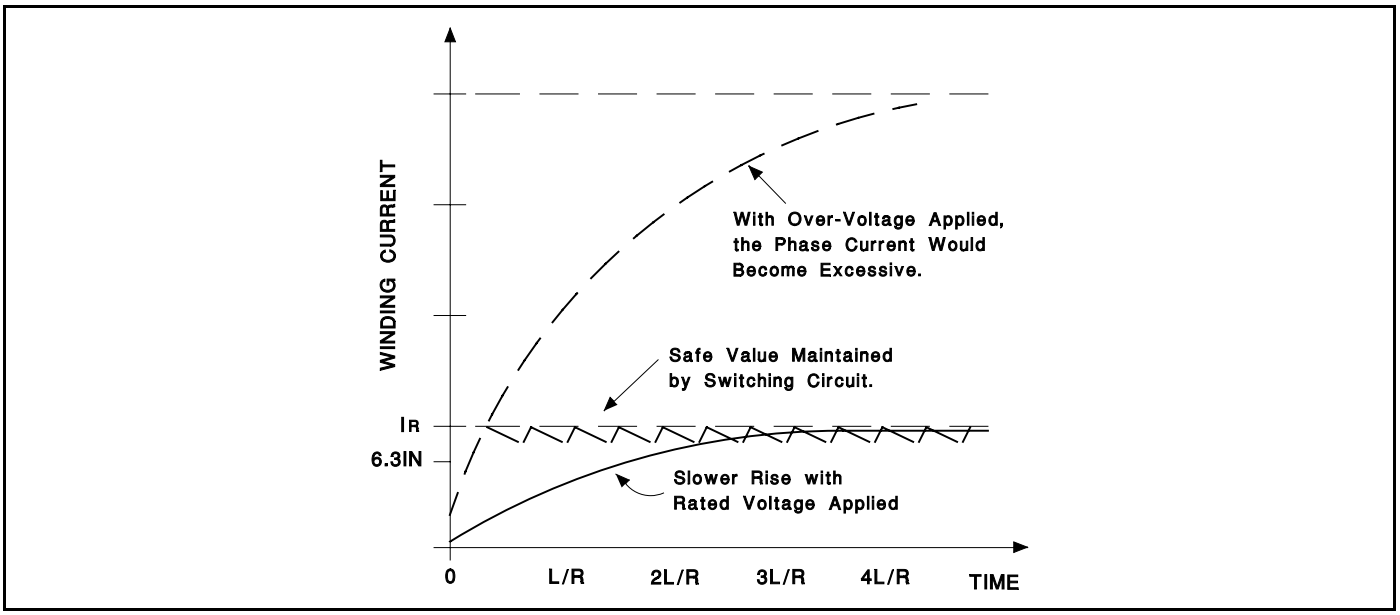



**Figure 9. With rated voltage applied, winding current does not exceed rated value, but takes L/R seconds to reach 63% of its final value - probably too long. Increased performance requires an increase in applied voltage, of overdrive, and therefore a means to limit current. The UC3717A motor driver performs this task efficiently.**

## MOUNTING INSTRUCTIONS

The $\theta_{JA}$ of the UC3717AN plastic package can be reduced by soldering the GND pins to a suitable copper area of the printed circuit board or to an external heat sink. Due to different lead frame design, $\theta_{JA}$ of the ceramic J package cannot be similarly reduced.

The diagram of Figure 11 shows the maximum package power $P_{TOT}$ and the $\theta_{JA}$ as a function of the side " l " of two equal square copper areas having a thickness of 35µ (see Figure 10).

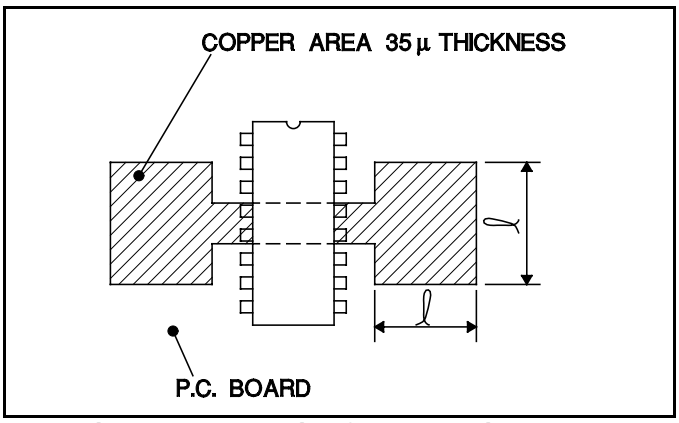



**Figure 10. Example of P.C. Board Copper Area which is used as Heatsink.**

During soldering the pins' temperature must not exceed 260°C and the soldering time must not be longer than 12 seconds.

The printed circuit copper area must be connected to electrical ground.

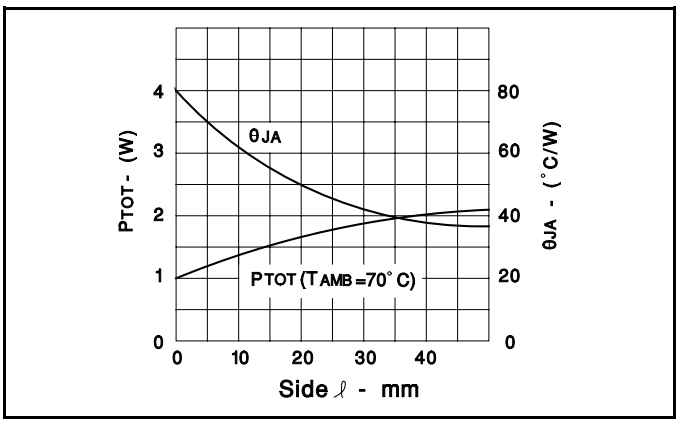



**Figure 11. Maximum Package Power and Junction to Ambient Thermal Resistance vs Side "l".**

## APPLICATIONS

A typical chopper drive for a two phase bipolar permanent magnet or hybrid stepping motor is shown in Figure 12. The input can be controlled by a microprocessor, TTL, LS, or CMOS logic.

The timing diagram in Figure 13 shows the required signal input for a two phase, full step stepping sequence. Figure 14 shows the required input signal for a one phase-two phase stepping sequence called half-stepping.

The circuit of Figure 15 provides the signal shown in Figure 13, and in conjunction with the circuit shown in Figure 12 will implement a pulse-to-step two phase, full step, bi-directional motor drive.

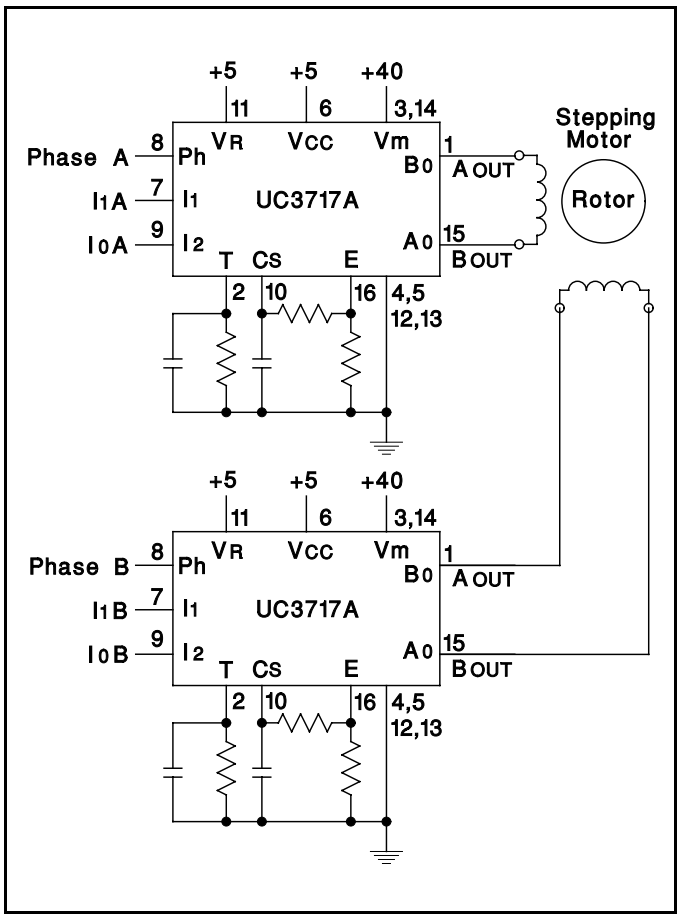



**Figure 12. Typical Chopper Drive for a Two Phase Permanent Magnet Motor.**

The schematic of Figure 16 shows a pulse to half step circuit generating the signal shown in Figure 14. Care has been taken to change the phase signal the same time the current inhibit is applied. This will allow the current to decay faster and therefore enhance the motor performance at high step rates.

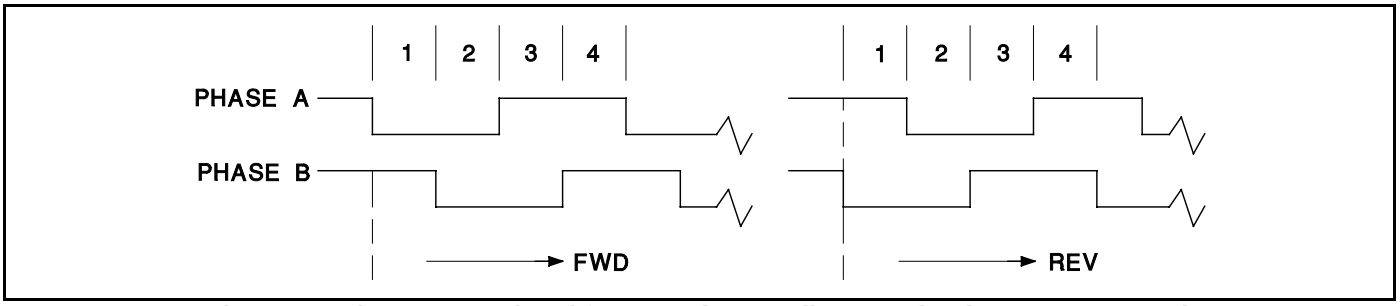



**Figure 13. Phase Input Signal for Two Phase Full Step Drive (4 Step Sequence)**

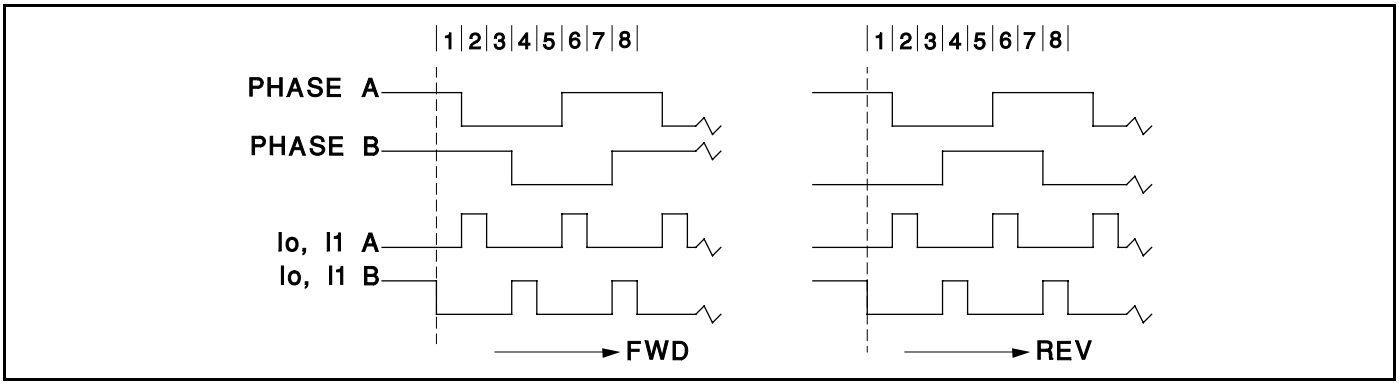



**Figure 14. Phase and Current-Inhibit Signal for Half-Stepping (8 Step Sequence)**

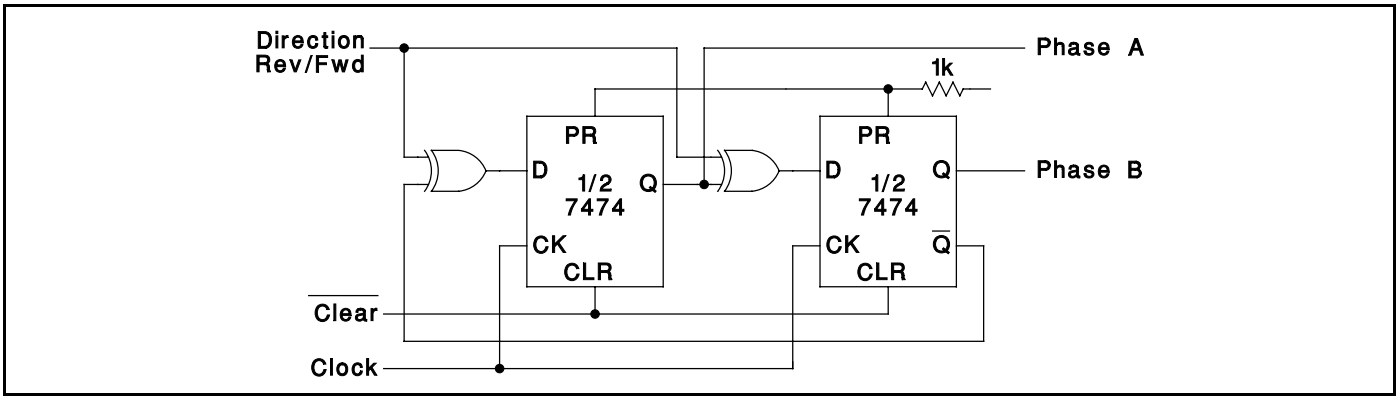



**Figure 15. Full Step, Bi-directional Two Phase Drive Logic**

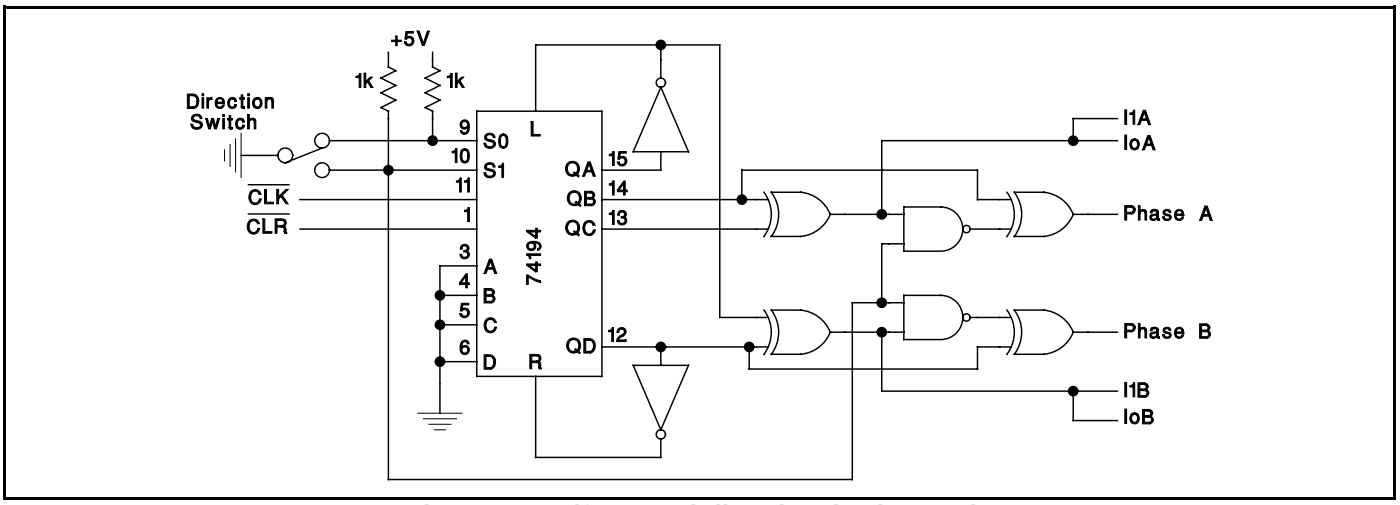



**Figure 16. Half-Step, Bi-directional Drive Logic**

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## PACKAGING INFORMATION

| Orderable part number | Status (1) | Material type (2) | Package \| Pins | Package qty \| Carrier | RoHS (3) | Lead finish/ Ball material (4) | MSL rating/ Peak reflow (5) | Op temp (°C) | Part marking (6) |
|---|---|---|---|---|---|---|---|---|---|
| UC3717AN | Active | Production | PDIP (N) \| 16 | 25 \| TUBE | Yes | NIPDAU | N/A for Pkg Type | 0 to 70 | UC3717AN |
| UC3717AN.A | Active | Production | PDIP (N) \| 16 | 25 \| TUBE | Yes | NIPDAU | N/A for Pkg Type | 0 to 70 | UC3717AN |
| UC3717ANG4 | Active | Production | PDIP (N) \| 16 | 25 \| TUBE | Yes | NIPDAU | N/A for Pkg Type | 0 to 70 | UC3717AN |

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

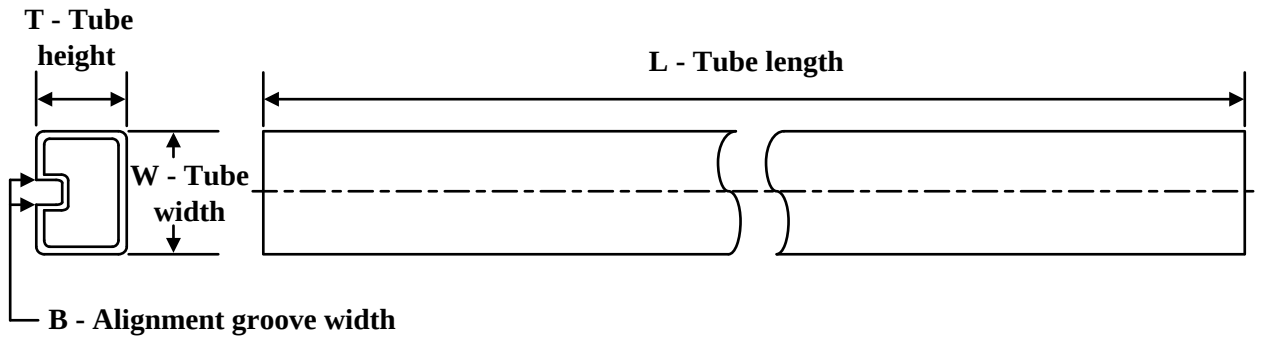
(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

## TUBE




*All dimensions are nominal

| Device | Package Name | Package Type | Pins | SPQ | L (mm) | W (mm) | T (µm) | B (mm) |
|---|---|---|---|---|---|---|---|---|
| UC3717AN | N | PDIP | 16 | 25 | 506 | 13.97 | 11230 | 4.32 |
| UC3717AN.A | N | PDIP | 16 | 25 | 506 | 13.97 | 11230 | 4.32 |
| UC3717ANG4 | N | PDIP | 16 | 25 | 506 | 13.97 | 11230 | 4.32 |

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