SGS-THOMSON MICROELECTRONICS

THE L297 STEPPER MOTOR CONTROLLER

The L297 integrates all the control circuitry required to control bipolar and unipolar stepper motors. Used with a dual bridge driver such as the L298N forms a complete microprocessor-to-bipolar stepper motor interface. Unipolar stepper motor can be driven with an L297 plus a quad darlington array. This note describes the operation of the circuit and shows how it is used.

The L297 Stepper Motor Controller is primarily intended for use with an L298N or L293E bridge driver in stepper motor driving applications.

It receives control signals from the system's controller, usually a microcomputer chip, and provides all the necessary drive signals for the power stage. Additionally, it includes two PWM chopper circuits to regulate the current in the motor windings.

With a suitable power actuator the L297 drives two phase bipolar permanent magnet motors, four phase unipolar permanent magnet motors and four phase variable reluctance motors. Moreover, it handles normal, wave drive and half step drive modes. (This is all explained in the section "Stepper Motor Basics").
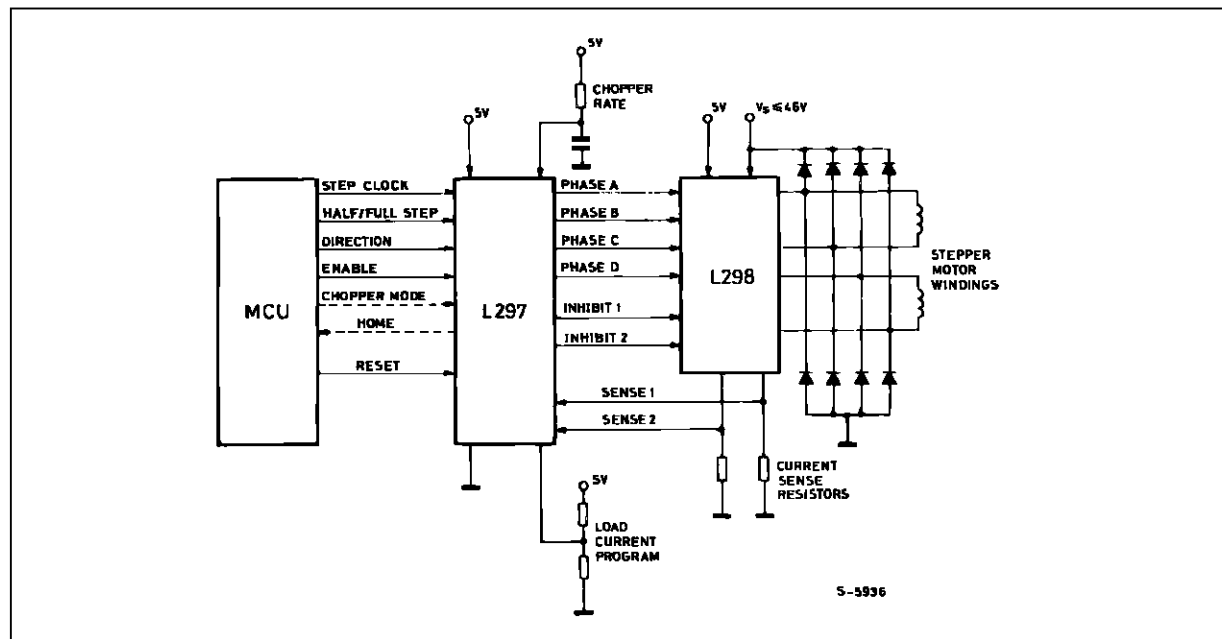
Two versions of the device are available : the regular L297 and a special version called L297A. The L297A incorporates a step pulse doubler and is designed specifically for floppy-disk head positioning applications.

ADVANTAGES

The L297 + driver combination has many advantages : very few components are required (so assembly costs are low, reliability high and little space required), software development is simplified and the burden on the micro is reduced. Further, the choice of a two-chip approach gives a high degree of flexibility-the L298N can be used on its own for DC motors and the L297 can be used with any power stage, including discrete power devices (it provides 20mA drive for this purpose).

Figure 1 : In this typical configuration an L297 stepper motor controller and L298 dual bridge driver combine to form a complete microprocessor to bipolar stepper motor interface.

For bipolar motors with winding currents up to 2A the L297 should be used with the L298N ; for winding currents up to 1A the L293E is recommended (the L293 will also be useful if the chopper isn't needed). Higher currents are obtained with power transistors or darlingtons and for unipolar motors a darlington array such as the ULN2075B is suggested. The block diagram, figure 1, shows a typical system.

Applications of the L297 can be found almost everywhere ... printers (carriage position, daisy position, paper feed, ribbon feed), typewriters, plotters, numerically controlled machines, robots, floppy disk drives, electronic sewing machines, cash registers, photocopiers, telex machines, electronic carburetos, telecopiers, photographic equipment, paper tape readers, optical character recognisers, electric valves and so on.

The L297 is made with SGS' analog/digital compatible I^2L technology (like Zodiac) and is assembled in a 20-pin plastic DIP. A 5V supply is used and all signal lines are TTL/CMOS compatible or open collector transistors. High density is one of the key features of the technology so the L297 die is very compact.

THE L298N AND L293E

Since the L297 is normally used with an L298N or L293E bridge driver a brief review of these devices will make the rest of this note easier to follow.

The L298N and L293E contain two bridge driver stages, each controlled by two TTL-level logic inputs and a TTL-level enable input. In addition, the emitter connections of the lower transistors are brought out to external terminals to allow the connection of current sensing resistors (figure 2).

For the L298N SGS' innovative ion-implanted high voltage/high current technology is used, allowing it to handle effective powers up to 160W (46V supply, 2A per bridge). A separate 5V logic supply input is provided to reduce dissipation and to allow direct connection to the L297 or other control logic.

In this note the pins of the L298N are labelled with the pin names of the corresponding L297 terminals to avoid unnecessary confusion.

The L298N is supplied in a 15-lead Multiwatt plastic power package. It's smaller brother, the functionally identical L293E, is packaged in a Powerdip – a copper frame DIP that uses the four center pins to conduct heat to the circuit board copper.

Figure 2 : The L298N contains two bridge drivers (four push pull stages) each controlled by two logic inputs and an enable input. External emitter connections are provided for current sense resistors. The L293E has external connections for all four emitters.
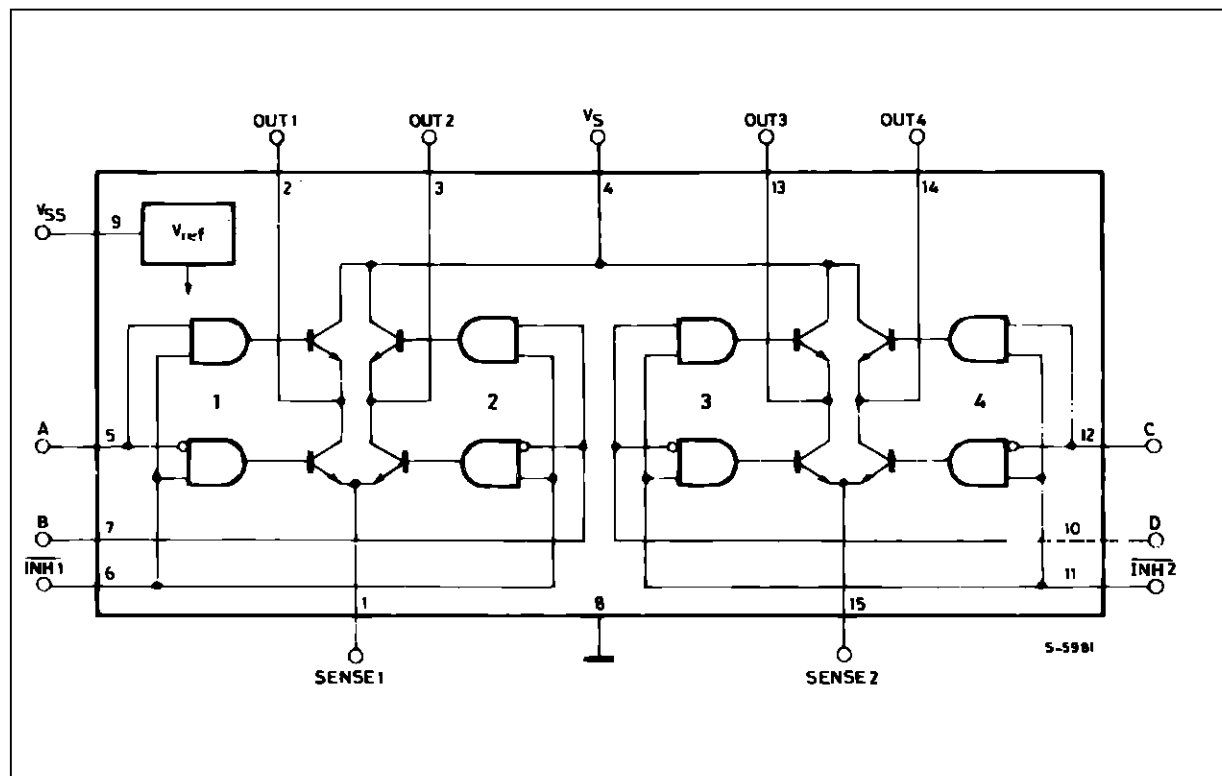
STEPPER MOTOR BASICS

There are two basic types of stepper motor in common use : permanent magnet and variable reluctance. Permanent magnet motors are divided into bipolar and unipolar types.

BIPOLAR MOTORS

Simplified to the bare essentials, a bipolar permanent magnet motor consists of a rotating permanent magnet surrounded by stator poles carrying the windings (figure 3). Bidirectional drive current is used and the motor is stepped by switching the windings in sequence.

For a motor of this type there are three possible drive sequences.

Figure 3 : Greatly simplified, a bipolar permanent magnet stepper motor consist of a rotaring magnet surrounded by stator poles as shown.
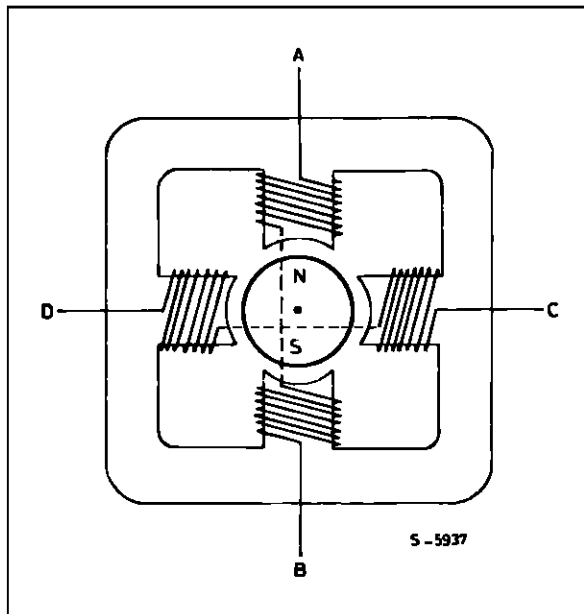
The first is to energize the windings in the sequence AB/CD/BA/DC (BA means that the winding AB is energized but in the opposite sense). This sequence is known as "one phase on" full step or wave drive mode. Only one phase is energized at any given moment (figure 4a).

The second possibility is to energize both phases together, so that the rotor always aligns itself between two pole positions. Called "two-phase-on" full step, this mode is the normal drive sequence for a bipolar motor and gives the highest torque (figure 4b).

The third option is to energize one phase, then two, then one, etc., so that the motor moves in half step increments. This sequence, known as half step mode, halves the effective step angle of the motor but gives a less regular torque (figure 4c).

For rotation in the opposite direction (counter-clockwise) the same three sequences are used, except of course that the order is reserved.

As shown in these diagrams the motor would have a step angle of $90°$. Real motors have multiple poles to reduce the step angle to a few degrees but the number of windings and the drive sequences are unchanged. A typical bipolar stepper motor is shown in figure 5.

UNIPOLAR MOTORS

A unipolar permanent magnet motor is identical to the bipolar machine described above except that bifilar windings are used to reverse the stator flux, rather than bidirectional drive (figure 6).

This motor is driven in exactly the same way as a bipolar motor except that the bridge drivers are replaced by simple unipolar stages - four darlingtons or a quad darlington array. Clearly, unipolar motors are more expensive because thay have twice as many windings. Moreover, unipolar motors give less torque for a given motor size because the windings are made with thinner wire. In the past unipolar motors were attractive to designers because they simplify the driver stage. Now that monolithic push pull drivers like the L298N are available bipolar motors are becoming more popular.

All permanent magnet motors suffer from the counter EMF generated by the rotor, which limits the rotation speed. When very high slewing speeds are necessary a variable reluctance motor is used.
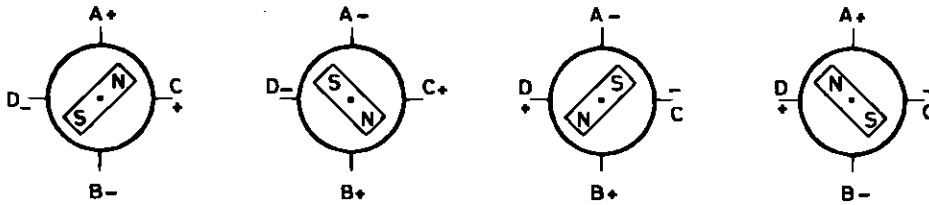
Figure 4 : The three drive sequences for a two phase bipolar stepper motor. Clockwise rotation is shown.
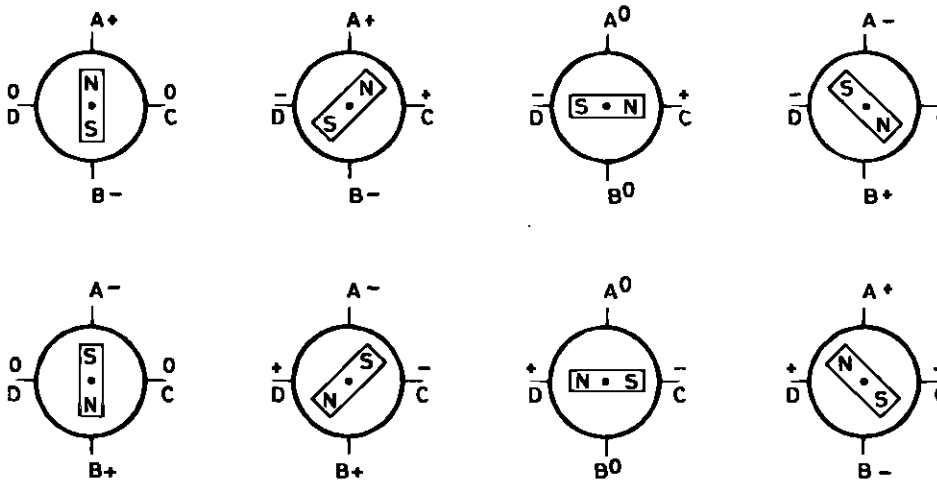**Figure 4a :** Wave drive (one phase on).
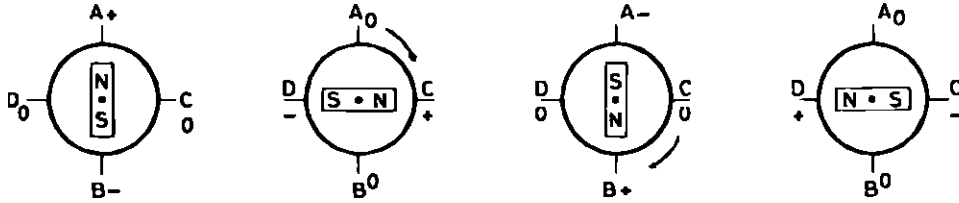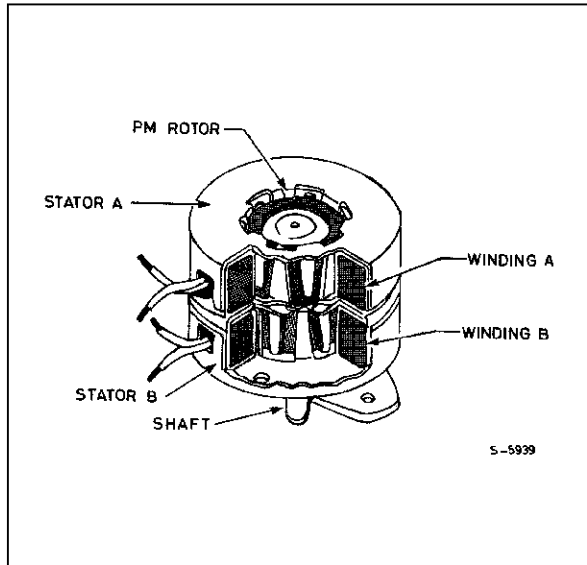

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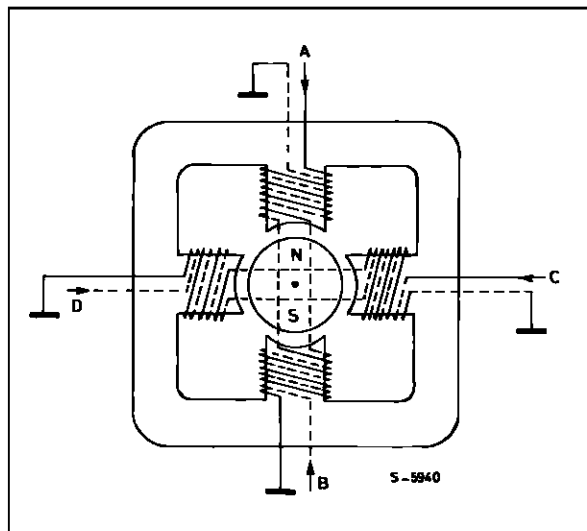**Figure 4b :** Two phase on drive.

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Figure 4c : Half step drive.

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Figure 5 : A real motor. Multiple poles are norma-
lly employed to reduce the step angle to
a practical value. The principle of opera-
tion and drive sequences remain the
same.

Figure 6 : A unipolar PM motor uses bifilar win-
dings to reverse the flux in each phase.


VARIABLE RELUCTANCE MOTORS

A variable reluctance motor has a non-magnetized
soft iron rotor with fewer poles than the stator (fig-
ure 7). Unipolar drive is used and the motor is step-
ped by energizing stator pole pairs to align the rotor
with the pole pieces of the energized winding.

Once again three different phase sequences can be
used. The wave drive sequence is A/C/B/D ; two-

phase-on is AC/CB/BD/DA and the half step se-
quence is A/AC/C/BC/B/BD/D/DA. Note that the
step angle for the motor shown above is 15 °, not 45 °.

As before, pratical motors normally employ multiple
poles to give a much smaller step angle. This does
not, however, affect the principle of operation of the
drive sequences.

Figure 7 : A variable reluctance motor has a soft
iron rotor with fewer poles than the sta-
tor. The step angle is 15 ° for this motor.
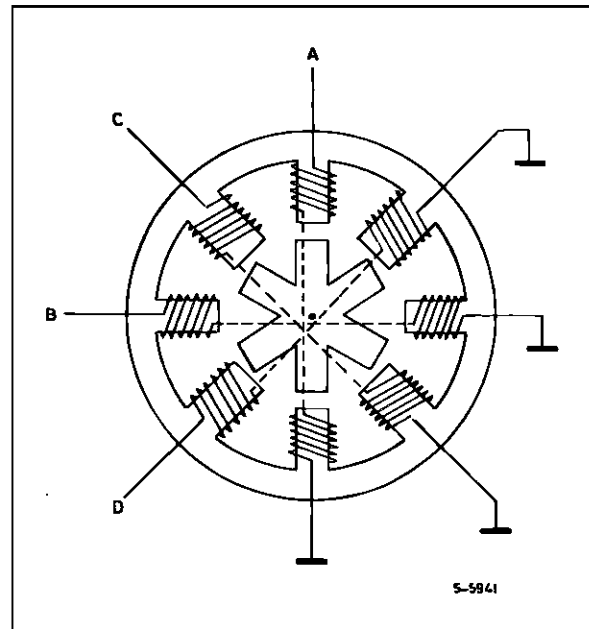
GENERATING THE PHASE SEQUENCES

The heart of the L297 block diagram, figure 8, is a
block called the translator which generates suitable
phase sequences for half step, one-phase-on full
step and two-phase-on full step operation. This
block is controlled by two mode inputs – direction
(CW/ CCW) and HALF/ FULL – and a step clock
which advances the translator from one step to the
next.

Four outputs are provided by the translator for sub-
sequent processing by the output logic block which
implements the inhibit and chopper functions.

Internally the translator consists of a 3-bit counter
plus some combinational logic which generates a
basic eight-step gray code sequence as shown in
figure 9. All three drive sequences can be generated
easily from this master sequence. This state se-
quence corresponds directly to half step mode, se-
lected by a high level on the HALF/ FULL input.

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The output waveforms for this sequence are shown in figure 10.

Note that two other signals, $\overline{INH1}$ and $\overline{INH2}$ are generated in this sequence. The purpose of these signals is explained a little further on.

The full step modes are both obtained by skipping alternate states in the eight-step sequence. What happens is that the step clock bypasses the first stage of the 3-bit counter in the translator. The least significant bit ot this counter is not affected therefore

the sequence generated depends on the state of the translator when full step mode is selected (the HALF/ $\overline{FULL}$ input brought low).

If full step mode is selected when the translator is at any odd-numbered state we get the two-phase-on full step sequence shown in figure 11.

By contrast, one-phase-on full step mode is obtained by selecting full step mode when the translator is at an even-numbered state (figure 12).

Figure 8 : The L297 contains translator (phase sequence generator), a dual PWM chopper and output control logic.
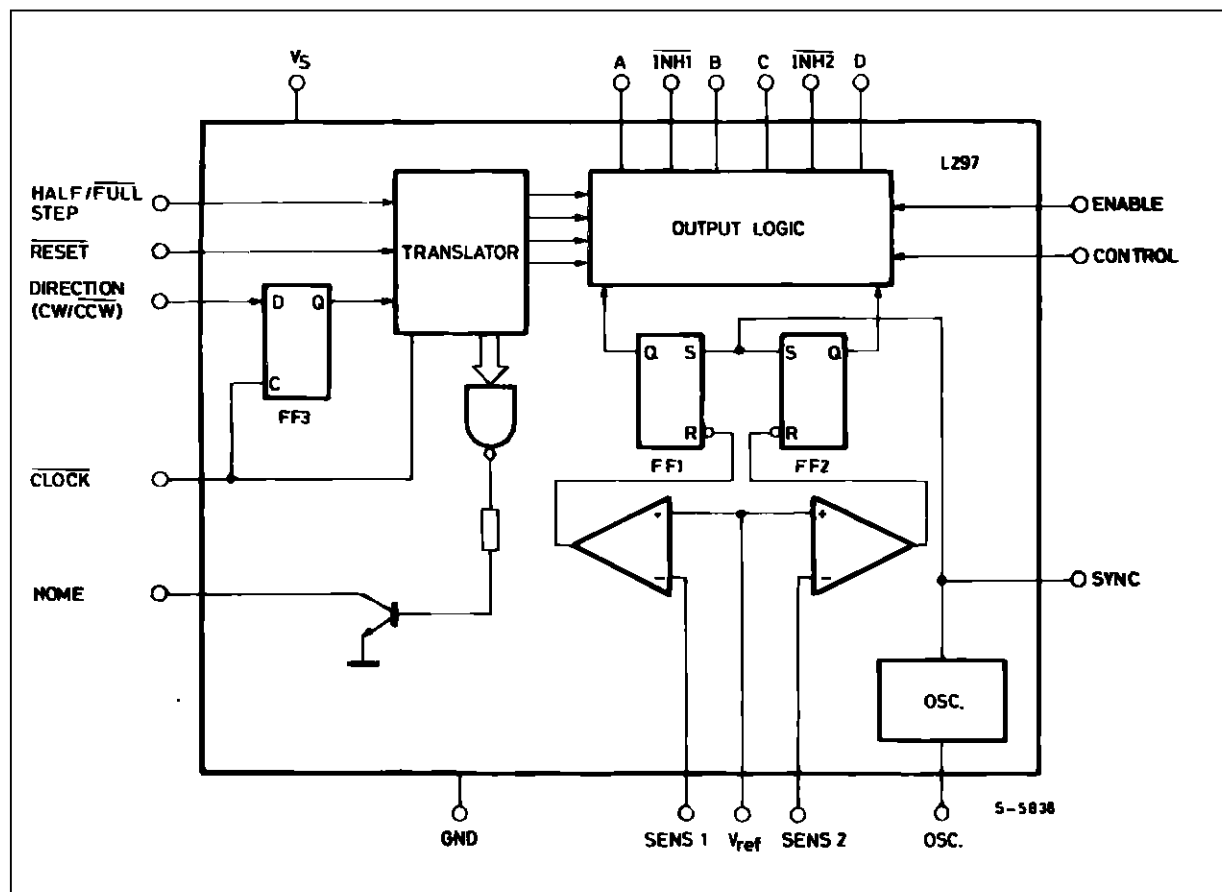

Figure 9 : The eight step master sequence of the translator. This corresponds to half step mode. Clockwise rotation is indicated.

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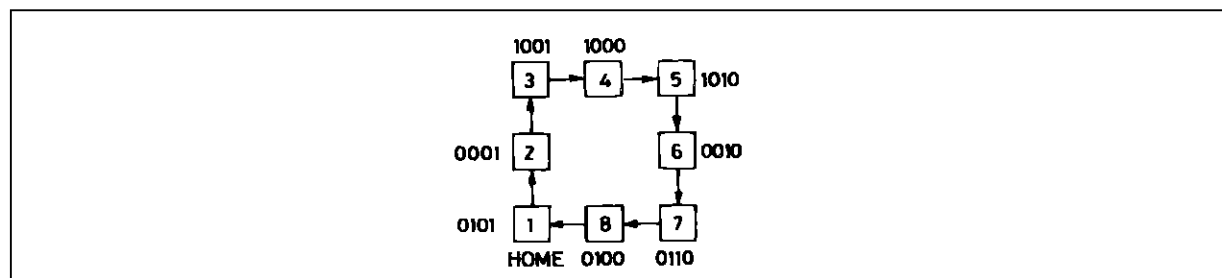
Figure 10 : The output waveforms corresponding to the half step sequence. The chopper action in not shown.

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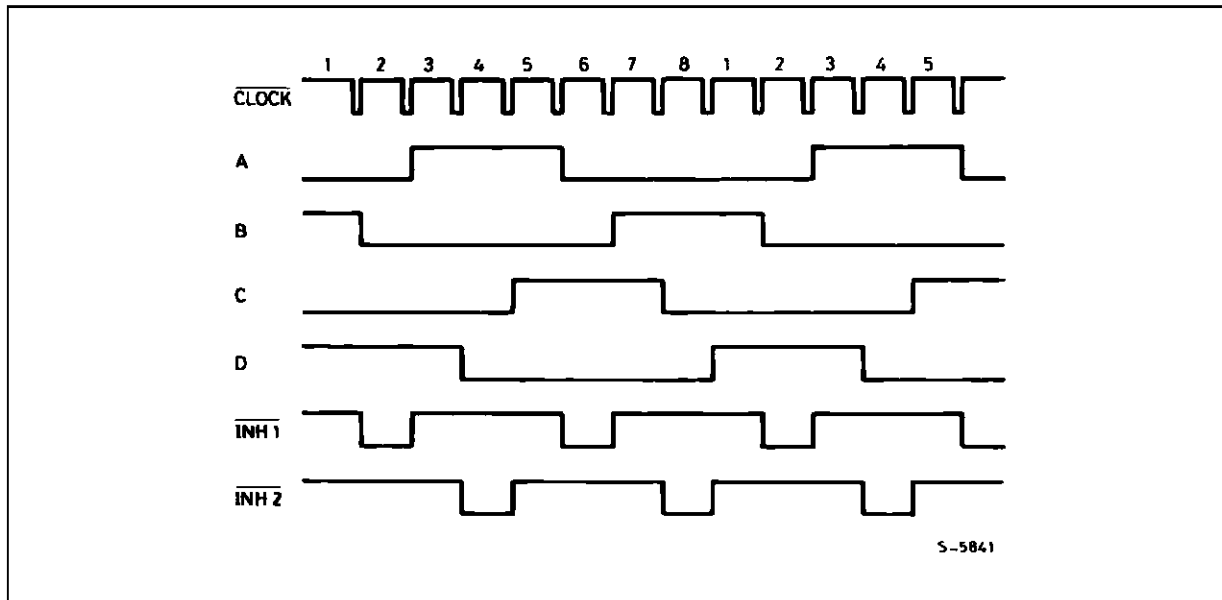
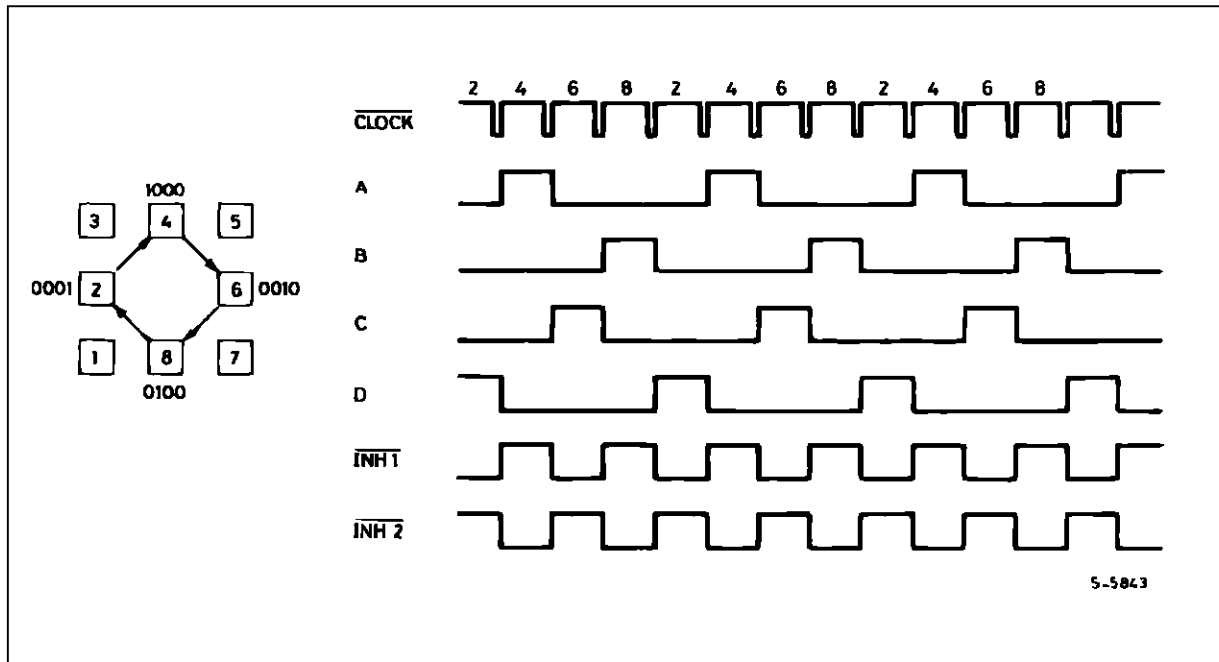**Figure 11 :** State sequence and output waveforms for the two phase on sequence. $\overline{INH1}$ and $\overline{INH2}$ remain high throughout.

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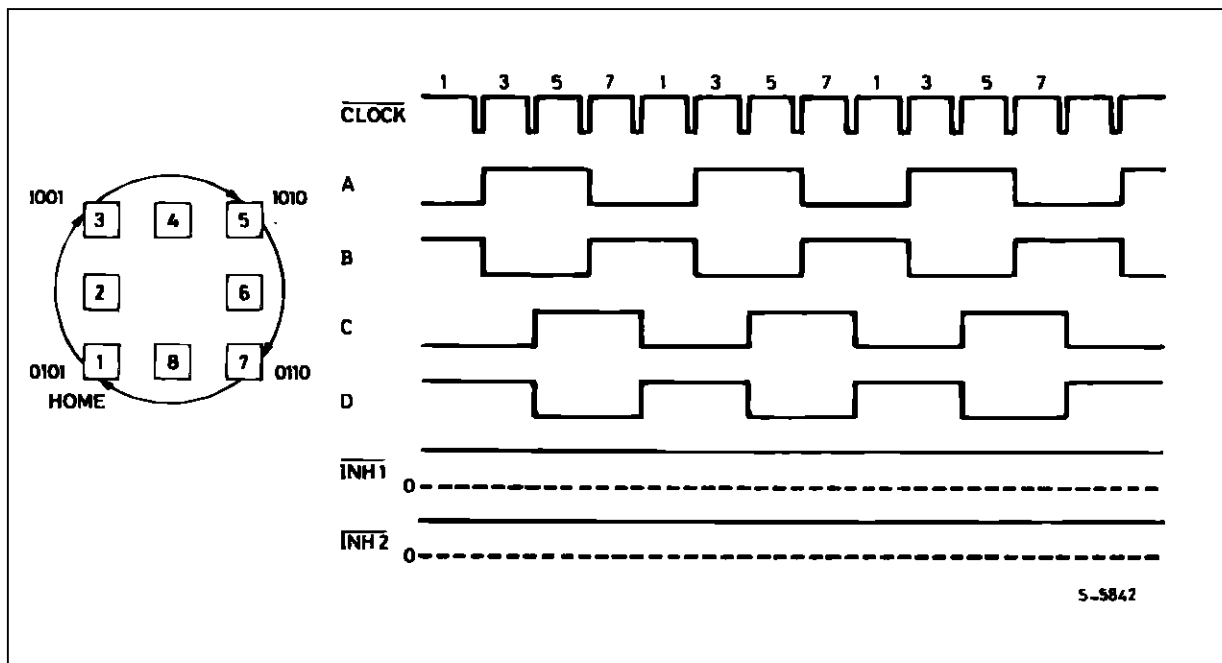
Figure 12 : State Sequence and Output Waveforms for Wave Drive (one phase on).

$\overline{\text{INH1}}$ AND $\overline{\text{INH2}}$

In half step and one-phase-on full step modes two other signals are generated: $\overline{\text{INH1}}$ and $\overline{\text{INH2}}$. These are inhibit signals which are coupled to the L298N's enable inputs and serve to speed the current decay when a winding is switched off.

Since both windings are energized continuously in two-phase-on full step mode no winding is ever switched off and these signals are not generated.

To see what these signals do let's look at one half of the L298N connected to the first phase of a two-phase bipolar motor (figure 13). Remember that the L298N's A and B inputs determine which transistor in each push pull pair will be on. $\overline{\text{INH1}}$, on the other hand, turns off all four transistors.

Assume that A is high, B low and current flowing through Q1, Q4 and the motor winding. If A is now brought low the current would recirculate through D2, Q4 and R_s, giving a slow decay and increased dissipation in R_s. If, on a other hand, A is brought low and $\overline{\text{INH1}}$ is activated, all four transistors are turned off. The current recirculates in this case from ground to V_s via D2 and D3, giving a faster decay thus allowing faster operation of the motor. Also, since the recirculation current does not flow through R_s, a less expensive resistor can be used.

Exactly the same thing happens with the second winding, the other half of the L298 and the signals C, D and $\overline{\text{INH2}}$.

The $\overline{\text{INH1}}$ and $\overline{\text{INH2}}$ signals are generated by OR functions :

$$A + B = \overline{\text{INH1}} \qquad C + D = \overline{\text{INH2}}$$

However, the output logic is more complex because inhibit lines are also used by the chopper, as we will see further on.

OTHER SIGNALS

Two other signals are connected to the translator block : the RESET input and the HOME output

RESET is an asynchronous reset input which restores the translator block to the home position (state 1, ABCD = 0101). The HOME output (open collector) signals this condition and is intended to be ANDed with the output of a mechanical home position sensor.

Finally, there is an ENABLE input connected to the output logic. A low level on this input brings INH1, INH2, A, B, C and D low. This input is useful to disable the motor driver when the system is initialized.

LOAD CURRENT REGULATION

Some form of load current control is essential to obtain good speed and torque characteristics. There are several ways in which this can be done – switching the supply between two voltages, pulse rate modulation chopping or pulse width modulation chopping.

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Figure 13 : When a winding is switched off the inhibit input is activated to speed current decay. If this were not done the current would recirculate through D2 and Q4 in this example. Dissipation in R_s is also reduced.
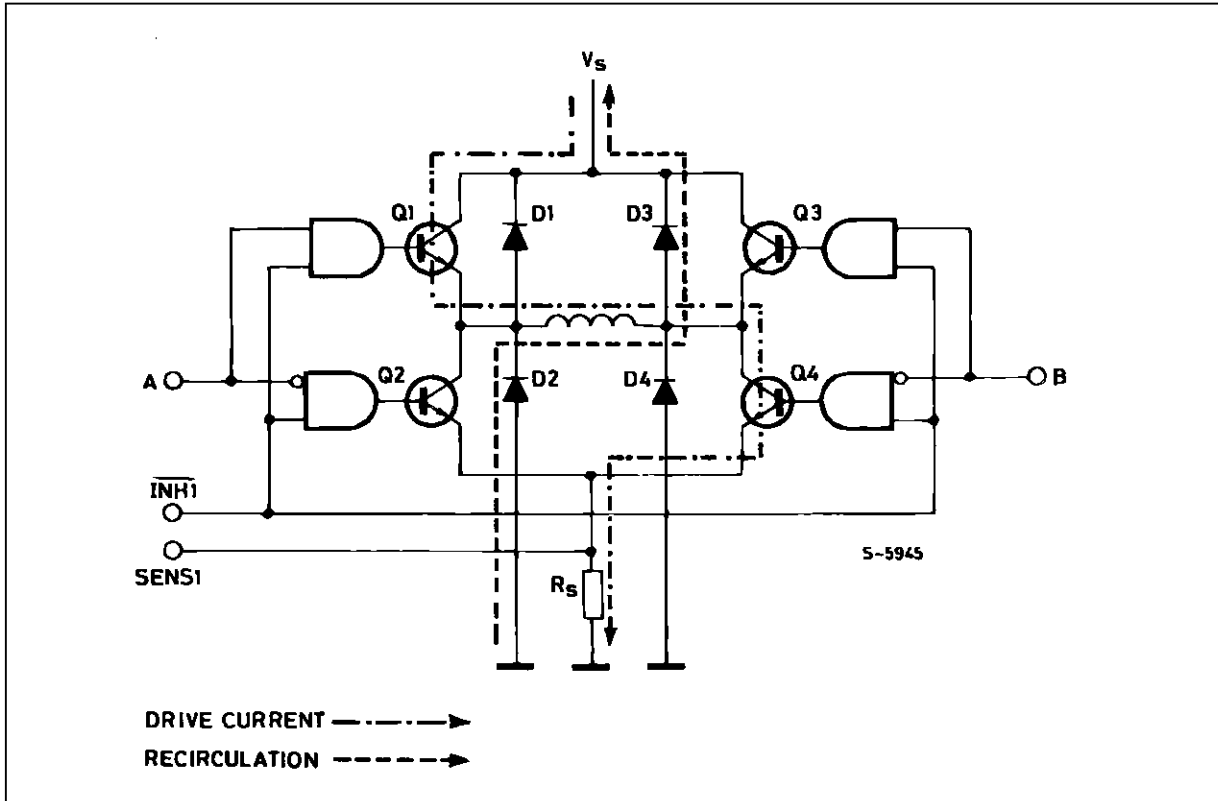

The L297 provides load current control in the form of two PWM choppers, one for each phase of a bi-polar motor or one for each pair of windings for a unipolar motor. (In a unipolar motor the A and B windings are never energized together so thay can share a chopper ; the same applies to C and D).

Each chopper consists of a comparator, a flip flop and an external sensing resistor. A common on chip oscillator supplies pulses at the chopper rate to both choppers.

In each chopper (figure 14) the flip flop is set by each pulse from the oscillator, enabling the output and allowing the load current to increase. As it increases the voltage across the sensing resistor increases, and when this voltage reaches V_{ref} the flip flop is reset, disabling the output until the next oscillator pulse arrives. The output of this circuit (the flip flop's Q output) is therefore a constant rate PWM signal. Note that V_{ref} determines the peak load current.

Figure 14 : Each chopper circuit consists of a comparator, flip flop and external sense resistor. A common oscillator clocks both circuits.

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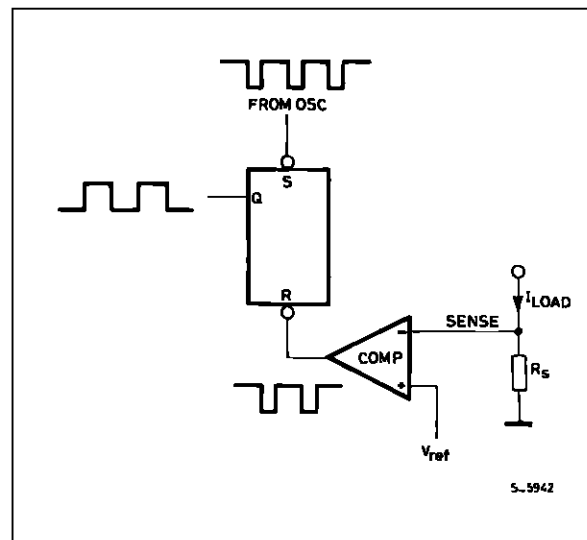
PHASE CHOPPING AND INHIBIT CHOPPING

The chopper can act on either the phase lines (ABCD) or on the inhibit lines INH1 and INH2. An input named CONTROL decides which. Inhibit chopping is used for unipolar motors but you can choose between phase chopping and inhibit chopping for bipolar motors. The reasons for this choice are best explained with another example.

First let's examine the situation when the phase lines are chopped.

As before, we are driving a two phase bipolar motor and A is high, B low (figure 15). Current therefore flows through Q1, winding, Q4 and R_s. When the voltage across R_s reaches V_{ref} the chopper brings B high to switch off the winding.

The energy stored in the winding is dissipated by current recirculating through Q1 and D3. Current decay through this path is rather slow because the volt-age on the winding is low ($V_{CEsat\ Q1} + V_{D3}$) (figure 16).

Why is B pulled high, why push A low ? The reason is to avoid the current decaying through R_s. Since the current recirculates in the upper half of the bridge, current only flows in the sensing resistor when the winding is driven. Less power is therefore dissipated in R_s and we can get away with a cheaper resistor.

This explain why phase chopping is not suitable for unipolar motors : when the A winding is driven the chopper acts on the B winding. Clearly, this is no use at all for a variable reluctance motor and would be slow and inefficient for a bifilar wound permanent magnet motor.

The alternative is to tie the CONTROL input to ground so that the chopper acts on INH1 and INH2. Looking at the same example, A is high and B low. Q1 and Q4 are therefore conducting and current flows through Q1, the winding, Q4 and R_s, (figure 17).

Figure 15 : Phase Chopping. In this example the current X is interrupted by activating B, giving the recirculation path Y. The alternative, de-activating A, would give the recirculation path Z, increasing dissipation in R_s.

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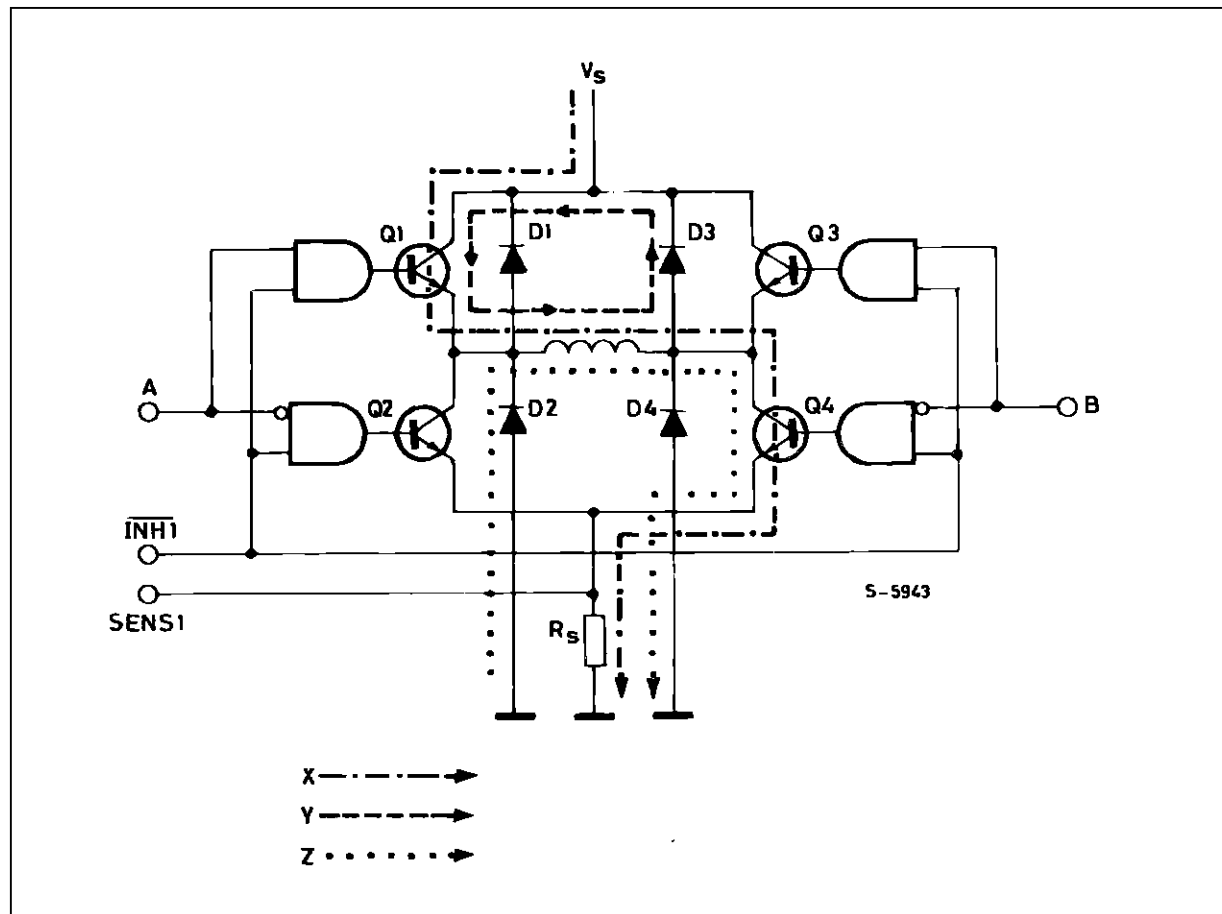
Figure 16 : Phase Chopping Waveforms. The example shows AB winding energized with A positive with respect to B. Control is high.
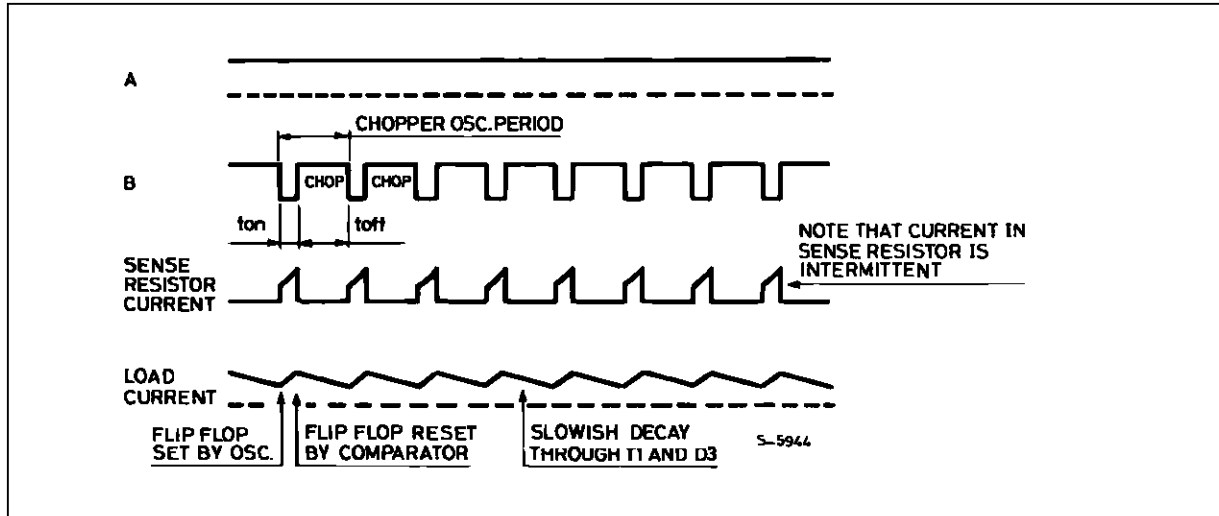
Figure 17 : Inhibit Chopping. The drive current (Q1, winding, Q4) in this case is interrupted by activating INH1. The decay path through D2 and D3 is faster than the path Y of Figure 15.

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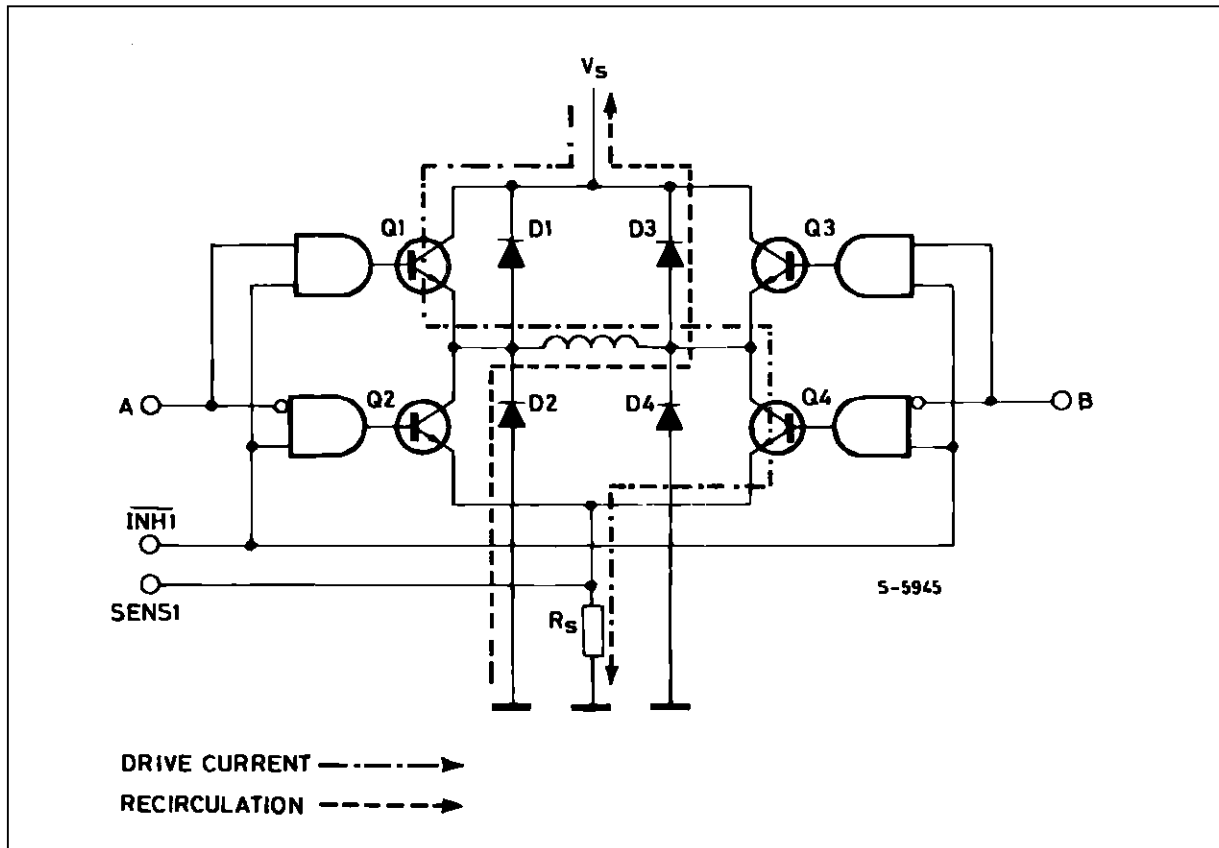
In this case when the voltage accross R_S reaches V_{REF} the chopper flip flop is reset and $\overline{INH1}$ activated (brought low). INH1, remember, turns off all four transistors therefore the current recirculates from ground, through D2, the winding and D3 to V_S. Discharged across the supply, which can be up to 46V, the current decays very rapidly (figure 18).

The usefulness of this second faster decay option is fairly obvious ; it allows fast operation with bipolar motors and it is the only choice for unipolar motors. But why do we offer the slower alternative, phase chopping ?

The answer is that we might be obliged to use a low chopper rate with a motor that does not store much energy in the windings. If the decay is very fast the average motor current may be too low to give an useful torque. Low chopper rates may, for example, be imposed if there is a larger motor in the same system. To avoid switching noise on the ground plane all drivers should be synchronized and the chopper rate is therefore determined by the largest motor in the system.

Multiple L297s are synchronized easily using the SYNC pin. This pin is the squarewave output of the on-chip oscillator and the clock input for the choppers. The first L297 is fitted with the oscillator components and outputs a sqarewave signal on this pin (figure 19). Subsequent L297s do not need the oscillator components and use SYNC as a clock input. An external clock may also be injected at this terminal if an L297 must be synchronized to other system components.

Figure 18 : Inhibit Chopper Waveforms. Winding AB is energized and CONTROL is low.
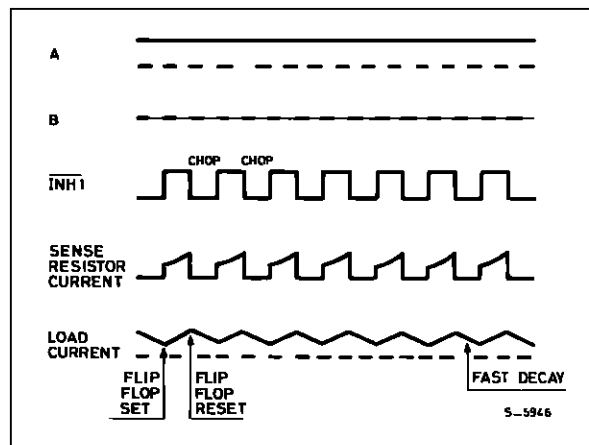
Figure 19 : The Chopper oscillator of multiple L297s are synchronized by connecting the SYNC Inputs together.
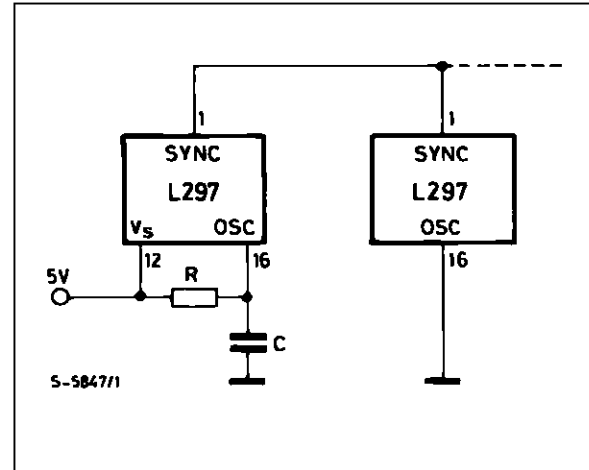
THE L297A

The L297A is a special version of the L297 developed originally for head positioning in floppy disk drives. It can, however, be used in other applications.

Compared to the standard L297 the difference are the addition of a pulse doubler on the step clock input and the availability of the output of the direction flip flop (block diagram, figure 20). To add these functions while keeping the low-cost 20-pin package the CONTROL and SYNC pins are not available on this version (they are note needed anyway). The chopper acts on the ABCD phase lines.

The pulse doubler generates a ghost pulse internally for each input clock pulse. Consequently the translator moves two steps for each input pulse. An external RC network sets the delay time between the input pulse and ghost pulse and should be chosen so that the ghost pulses fall roughly halfway between input pulses, allowing time for the motor to step.

This feature is used to improve positioning accuracy. Since the angular position error of a stepper motor is noncumulative (it cancels out to zero every four steps in a four step sequence motor) accuracy is improved by stepping two of four steps at a time.

Figure 20 : The L297A, includes a clock pulse doubler and provides an output from the direction flip flop (DIR – MEM).
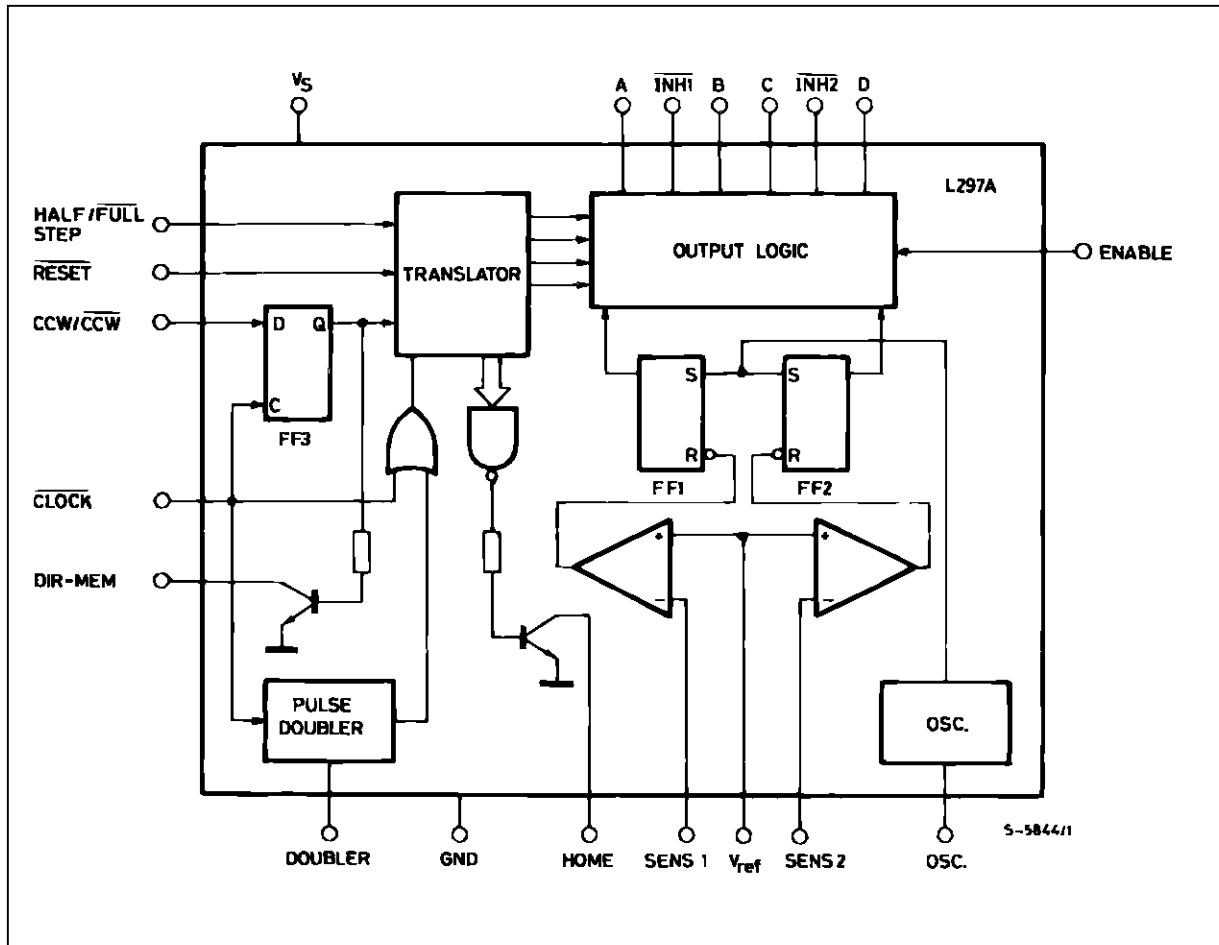
APPLICATION HINTS

Bipolar motors can be driven with an L297, an L298N or L293E bridge driver and very few external components (figure 21). Together these two chips form a complete microprocessor-to-stepper motor interface. With an L298N this configuration drives motors with winding currents up to 2A ; for motors up to 1A per winding and L293E is used. If the PWM choppers are not required an L293 could also be used (it doesn't have the external emitter connections for sensing resistors) but the L297 is underutilized. If very high powers are required the bridge driver is replaced by an equivalent circuit made with discrete transistors. For currents to 3.5A two L298N's with paralleled outputs may be used.

For unipolar motors the best choice is a quad darlington array. The L702B can be used if the choppers are not required but an ULN2075B is preferred.

This quad darlington has external emitter connections which are connected to sensing resistors (figure 22). Since the chopper acts on the inhibit lines, four AND gates must be added in this application.
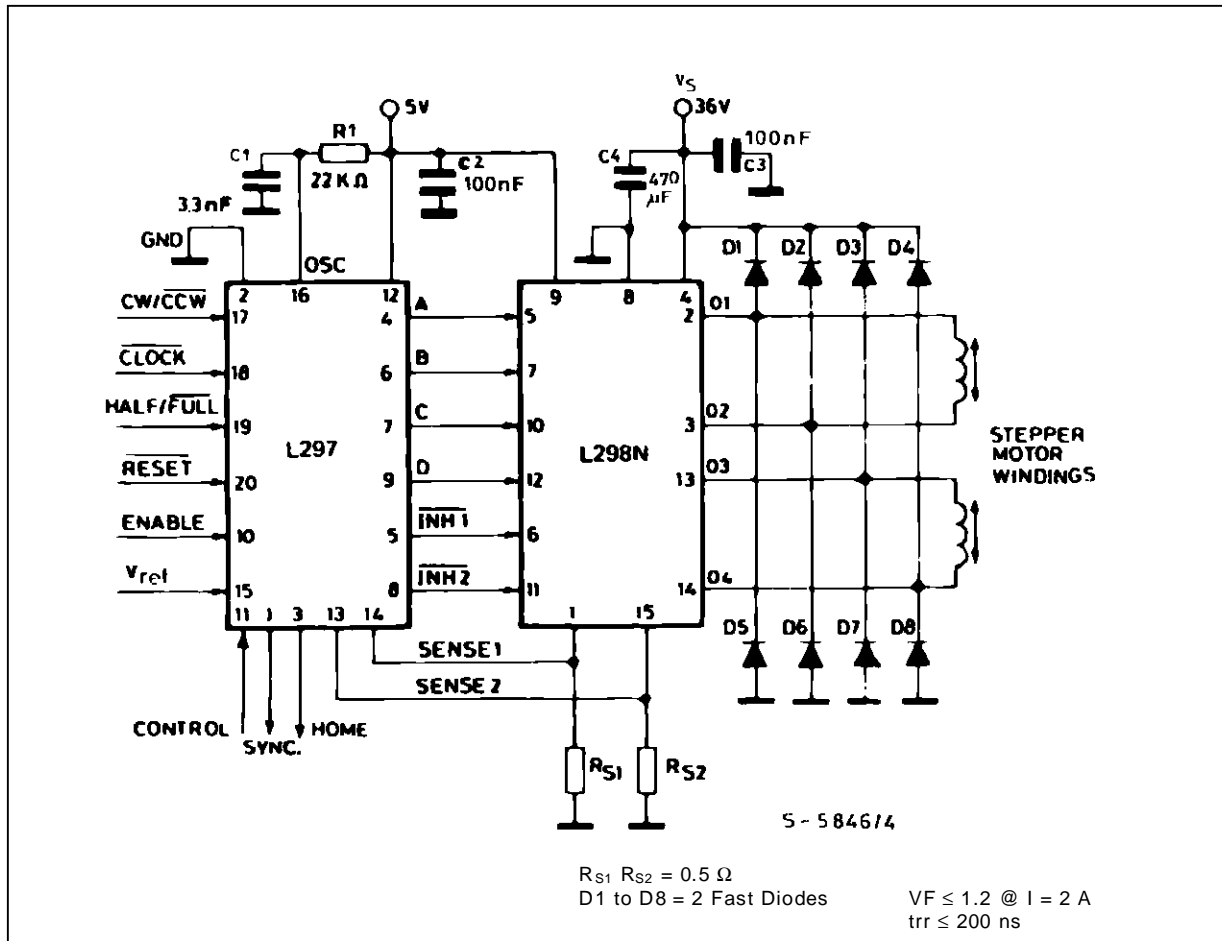
Also shown in the schematic are the protection diodes.

In all applications where the choppers are not used it is important to remember that the sense inputs must be grounded and V_{REF} connected either to V_S or any potential between V_S and ground.

The chopper oscillator frequency is determined by the RC network on pin 16. The frequency is roughly $1/0.7\,RC$ and R must be more than 10 KΩ. When the L297A's pulse doubler is used, the delay time is determined by the network R_d C_d and is approximately $0.75\,R_d$ C_d .R_d should be in the range 3 kΩ to 100 kΩ (figure 23).

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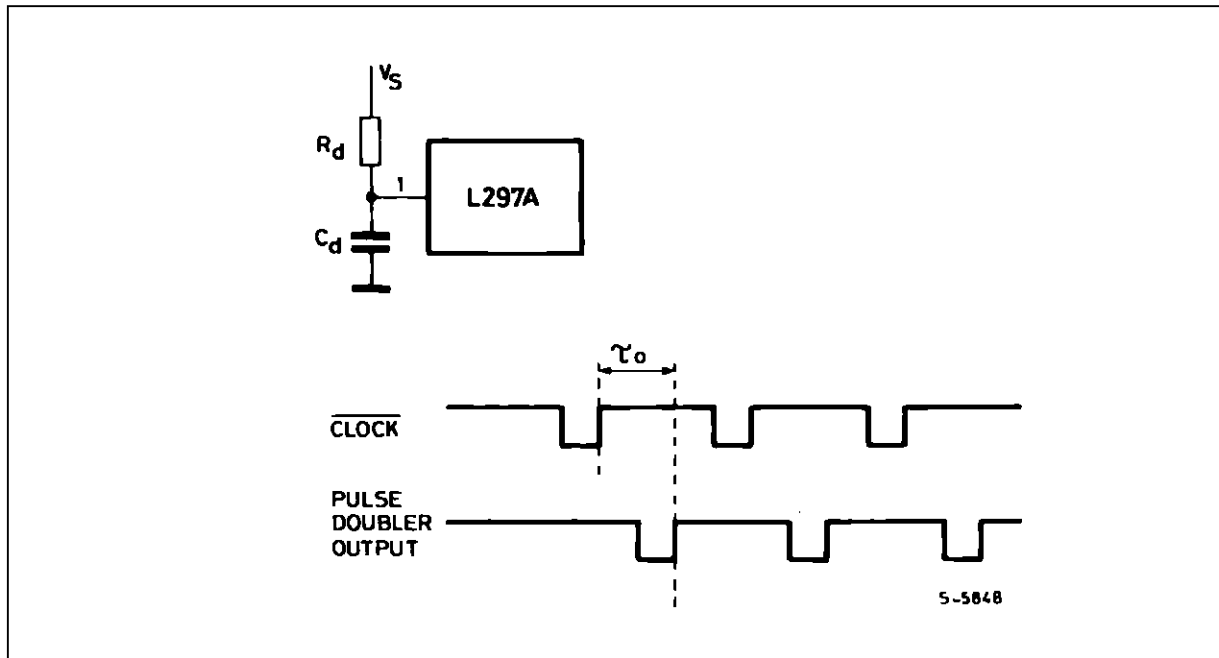
Figure 21 : This typical application shows an L297 and L298N driving a Bipolar Stepper Motor with pha-
se currents up to 2A.

R_{S1} R_{S2} = 0.5 Ω
D1 to D8 = 2 Fast Diodes   VF $\leq$ 1.2 @ I = 2 A
                                trr $\leq$ 200 ns

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Figure 22 : For Unipolar Motors a Quad Darlington Array is coupled to the L297. Inhibit chopping is used so the four AND gates must be added.
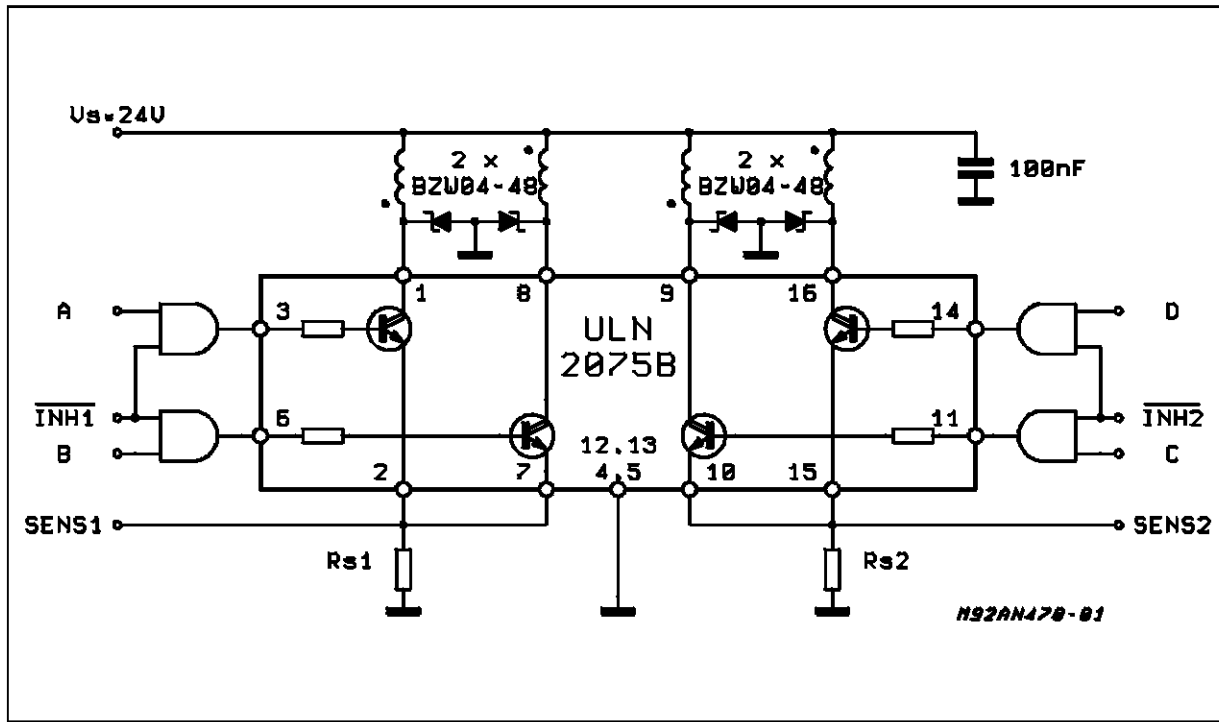
Figure 23 : The Clock pulse doubler inserts a ghost pulse τ_o seconds after the Input clock pulse. $R_d\,C_d$ is closen to give a delay of approximately half the Input clock period.

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PIN FUNCTIONS - L297

N°	NAME	FUNCTION
1	SYNC	Output of the on-chip chopper oscillator. The SYNC connections The SYNC connections of all L297s to be synchronized are connected together and the oscillator components are omitted on all but one. If an external clock source is used it is injected at this terminal.
2	GND	Ground connection.
3	HOME	Open collector output that indicates when the L297 is in its initial state (ABCD = 0101). The transistor is open when this signal is active.
4	A	Motor phase A drive signal for power stage.
5	$\overline{INH1}$	Active low inhibit control for driver stage of A and B phases. When a bipolar bridge is used this signal can be used to ensure fast decay of load current when a winding is de-energized. Also used by chopper to regulate load current if CONTROL input is low.
6	B	Motor phase B drive signal for power stage.
7	C	Motor phase C drive signal for power stage.
8	$\overline{INH2}$	Active low inhibit control for drive stages of C and D phases. Same functions as INH1.
9	D	Motor phase D drive signal for power stage.
10	ENABLE	Chip enable input. When low (inactive) INH1, INH2, A, B, C and D are brought low.
11	CONTROL	Control input that defines action of chopper. When low chopper acts on INH1 and INH2; when high chopper acts on phase lines ABCD.
12	V_s	5V supply input.
13	$SENS_2$	Input for load current sense voltage from power stages of phases C and D.
14	$SENS_1$	Input for load current sense voltage from power stages of phases A and B.
15	V_{ref}	Reference voltage for chopper circuit. A voltage applied to this pin determines the peak load current.
16	OSC	An RC network (R to V_{CC}, C to ground) connected to this terminal determines the chopper rate. This terminal is connected to ground on all but one device in synchronized multi - L297 configurations. $f \cong 1/0.69\ RC$
17	CW/$\overline{CCW}$	Clockwise/counterclockwise direction control input. Physical direction of motor rotation also depends on connection of windings. Synchronized internally therefore direction can be changed at any time.
18	$\overline{CLOCK}$	Step clock. An active low pulse on this input advances the motor one increment. The step occurs on the rising edge of this signal.
19	HALF/$\overline{FULL}$	Half/full step select input. When high selects half step operation, when low selects full step operation. One-phase-on full step mode is obtained by selecting FULL when the L297's translator is at an even-numbered state. Two-phase-on full step mode is set by selecting FULL when the translator is at an odd numbered position. (The home position is designate state 1).
20	$\overline{RESET}$	Reset input. An active low pulse on this input restores the translator to the home position (state 1, ABCD = 0101).
PIN FUNCTIONS - L297A (Pin function of the L297A are identical to those of the,L297 except for pins 1 and 11)		
1	DOUBLER	An RC network connected to this pin determines the delay between an input clock pulse and the corresponding ghost pulse.
11	DIR-MEM	Direction Memory. Inverted output of the direction flip flop. Open collector output.

Figure 24 : Pin connections.

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