Servo control IC ZN409

The **RS** ZN409 is a precision monolithic integrated circuit designed particularly for pulse-width position servo mechanisms used in many types of control applications. The low number of components required with the device, together with its reduced length and low power consumption, make this integrated circuit ideal for use in compact servo applications where space, weight and battery life are at a premium. The amplifier will operate over a wide range of repetition rates and pulse widths and is therefore suitable for the majority of systems. The **RS** ZN409 can also be used in motor speed control circuits.

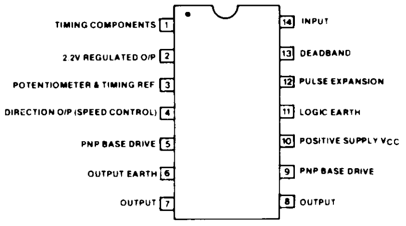
Absolute maximum ratings

Supply voltage	6.5 Volts
Package dissipation	300 Milliwatts
Operating temperature range	-20°C to 65°C
Storage temperature range	-65°C to 150°C

Features

- Low external component count
- Low quiescent current (7mA typical at 4.8V)
- Excellent voltage and temperature stability
- High output drive capability
- Consistent and repeatable performance
- Precision internal voltage stabilisation
- Time shared error pulse expansion
- Balanced deadband control
- Schmitt trigger input shaping
- Reversing relay output
  (dc motor speed control)

PIN CONNECTIONS

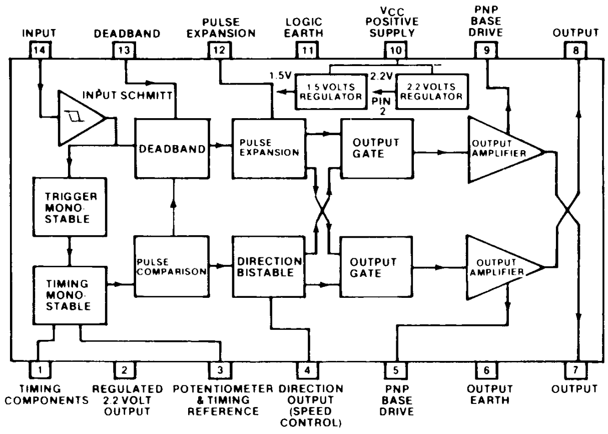


Characteristics V_{CC} = 5V At 25°C ambient temperature unless otherwise stated.

Parameter	Min.	Typ.	Max.	Unit	Conditions
Input threshold (lower)	1.15	1.25	1.35	V	Pin 14
Input threshold (upper)	1.4	1.5	1.6	V	Pin 14
Ratio upper/lower threshold	1.1	1.2	1.3		–10 to + 65°C
Input resistance	20	27	35	kΩ	$V_{in} \leq 2V$ (Pin 14)
Input current	350	500	650	μA	$V_{in} \geq 2V$ (Pin 14)
Regulator voltage	2.1	2.2	2.3	V	–10 to + 65°C, 1.3mA load current
Regulator supply voltage rejection ratio	200	300	–		V_{CC} = 3.5 to 6.5V $RSRR = \frac{dV_{in}}{dV_{out}}$
Monostable linearity for ±45° pot rotation	–	3.5	4.0	%	R_p = 1.5kΩ, R_1 = 12kΩ
Monostable period temperature coefficient	–	±0.01	–	%/°C	Excluding R_T, C_T. R_p = 1.5kΩ, R_1=12kΩ (potentiometer slider set mid-way)
Output Schmitt deadband	±1	±1.5	±3	μS	C_E = 0.47μF
Minimum output pulse	2.5	3.5	4.5	mS	C_E = 0.47μF, R_E = 180kΩ
Error pulse for drive	70	100	130	μS	15 ms repetition rate C_E = 0.47μF, RE = 180kΩ
Total deadband	±3.5	±5	±6.5	μS	C_D = 1000pF
P.N.P. drive	40 35	55 50	70 65	mA mA	T = 25°C T = –10°C
Output saturation voltage	–	300	400	mV	I_L = 400mA
Direction bistable output	2	2.8	3.6	mA	V_{CC} = 5V max.
Supply voltage range	3.5	5	6.5	V	
Supply current	4.6	6.7	10	mA	Quiescent
Total external current from regulator	1.3	–	–	mA	V_{CC} = 3.5V
Peak voltage $V_{C\,EXT}$ (with respect to 2V regulated voltage)	– –	0.7 0.5	– –	V V	T = 25°C T = –10°C

Circuit operation

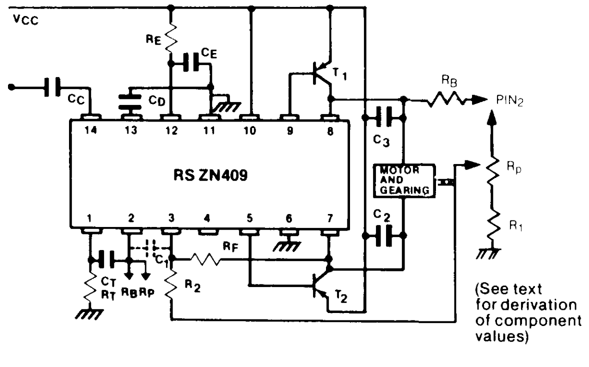
Figure 1 **System diagram**



The system diagram in Fig. 1 illustrates the internal structure of the **RS** ZN409 servo control IC

In the standard servo application the displacement of a potentiometer control varies the pulse width of a timing circuit. The signal produced provides the control input for the servo IC The servo shown in Fig. 2 consists of the **RS** ZN409 integrated circuit, several external components, a power amplifier consisting of two external PNP transistors and two on-chip NPN transistors which form a bridge circuit to drive the dc motor. The motor drives a reduction gear box which has a potentiometer attached to the output shaft. The **RS** precision dc servo system components are ideally suited for this application and the 6V motor should be used. This potentiometer in association with R_1 and the timing components C_T and R_T controls the pulse width of the timing monostable. The input pulse is compared with the monostable pulse in a comparison circuit and one output is used to enable the correct phase of an on-chip power amplifier. The other output from the pulse comparison circuit drives the pulse expansion circuit (C_E, R_E) via the deadband circuit (C_D). Thus any difference between the input and monostable pulses is expanded and used to drive the motor in such a direction as to reduce this difference so that the servo takes up a position which corresponds to the position of the control potentiometer.

Figure 2 **Servo system using the ZN409**

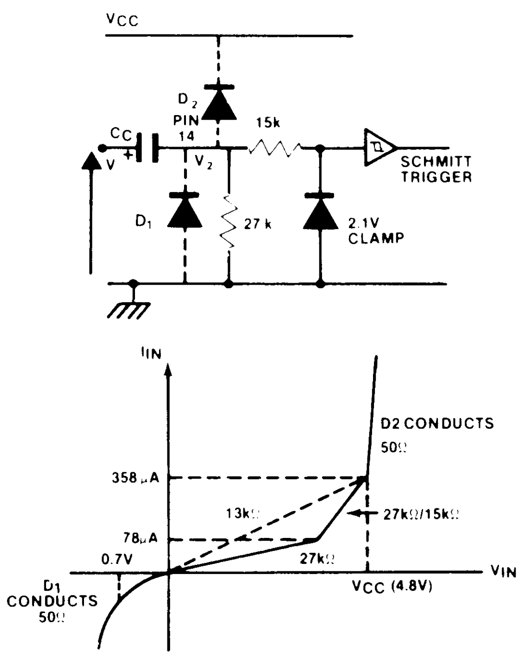


Component function	Circuit reference	Value
Monostable timing components	R_T	100kΩ
	C_T	0.1μF
Potentiometer and timing reference components	R_p	2kΩ
	R_1	6.2kΩ
Pulse expansion	C_E	0.47μF
	R_E	180kΩ
Deadband	C_D	2200pF
Dynamic feedback	R_F	300kΩ
	R_B	300kΩ
	R_2	1.2kΩ
Input coupling	C_C	2.2μF
Motor decoupling	C_2	0.1μF
	C_3	0.1μF
R.F. decoupling (see text)	C_1	0.1μF
Drive transistors	T_1, T_2	BC461

Input circuit

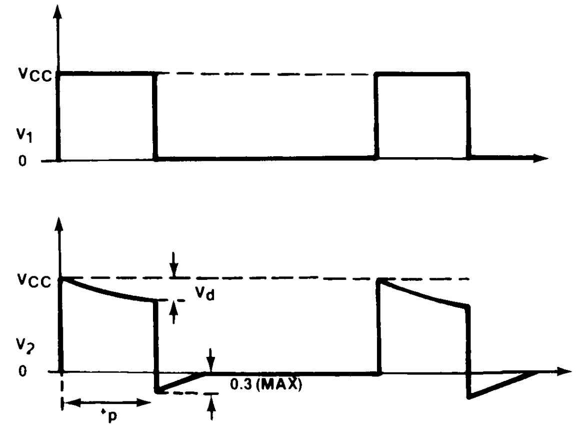
The **RS** ZN409 operates with positive going input pulses which can be coupled either directly or via a capacitor to pin 14. the advantage of ac coupling is that should a fault occur which causes the input signal to become a continuous positive level, the servo will remain in its last quiescent position, whereas with direct coupling the servo output arm will rotate continuously. A nominal 27kΩ on-chip resistor is shunted across the input to provide dc restoration of the input signal when ac coupling is used. The active input circuit is a Schmitt trigger which allows the servo to operate consistently with slow input edges and supplies the fast edge required by the trigger monostable independent of input edge speed.

Figure 3


Input circuit **Input characteristics**

The input circuit and its V/1 characteristic are shown above. D_1 and D_1 are the parasitic substrate and isolation diodes associated with the input resistors. It is advisable that the pulse input amplitude should not fall below 0V nor exceed the supply voltage Vcc in order to prevent these diodes from conducting, although a small amount of conduction will not cause the circuit to malfunction. When ac coupling is used the value of C_C should be chosen to give a pulse droop not exceeding 0.3 volts.

Figure 4 **Input waveforms**



Assuming that the input signal swings between 0V and V_{CC} and taking the input chord resistance R_{IN} of 13kΩ the droop for a pulse of duration msec will be:

$$V_d = \frac{V_{CC} t_p}{C_C \cdot R_{IN}} \text{ volts} \qquad \begin{array}{l} t_p\,(\text{msec}) \\ C_C(\mu F) \\ R_{IN}\,(k\Omega) \end{array}$$

For a nominal pulse width of 1.5 msec and V_d equal to 0.3 volts the required minimum value of C_C can be found to be 1.85μF and a nominal value of 2.2μF is chosen. (Nearest preferred value).

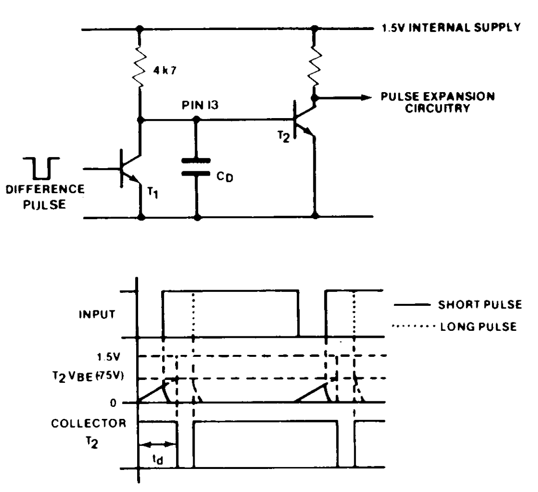
$$C_C = \frac{4.8 \times 1.5}{0.3 \times 13} = 1.85\mu F$$

If it is required to operate the servo with reduced input pulse amplitude the input pulse should exceed the upper Schmitt threshold voltage of 1.5 volts by a reasonable margin and a minimum input pulse amplitude of 2.4 volts is recommended.

Deadband circuit

The function of the deadband circuit is to provide a small range of output shaft positions about the quiescent position where the difference pulse does not drive the motor. This is necessary to eliminate hunting around the quiescent position caused by servo inertia and overshoot. The minimum deadband required is also a function of the pulse expansion characteristics and dynamic feedback component values.

Figure 5 **Deadband circuit and waveforms**



When the difference pulse is applied T_1 turns off and the base of T_2 rises on an exponential waveform with a time constant of 4.7 kΩ × C_D. If the difference pulse is small the potential reached on the base of T_2 is insufficient to turn T_2 on and no output results.

The pulse expansion circuit has a built in deadband of 1.5 μsec with C_E = 0.47 μF and this must be added to the deadband caused by C_D to obtain the total T_d.

$T_d = 1.5 + t_d \mu sec$
and $t_d = 3.3 C_D \mu sec (C_D \text{ in nF})$
(Taking $V_1 = 1.5$ volts and $V_{be} = 0.75$ volts)
Thus with C_D equal to 2200pF(2n2)
$t_d = 7.26\mu sec$ and $T_d = 8.76\mu sec$.

The mechanical deadband Ød depends on the chosen sensitivity S_1 of the servo and in a typical application at ±500μsec input pulse variation causes ±50° rotation, ie. $S_1 = 10\mu sec$ per degree.

Thus $Ød = \frac{2.T_d}{S_1}$ degrees (T_d in μsec. S_1 in μsec per degree).

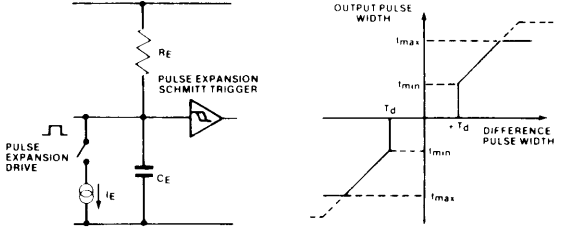
Thus a value for T_d of 8.76μsec provides a mechanical deadband Ød of 1.8°.

And generally:

$$Ød = \frac{3 + 6.6\,C_D}{S_1} \text{ degrees} \left\{ \begin{array}{l} C_D \text{ in nF.} \\ S_1 \text{ in } \mu sec \text{ per} \\ \text{degree.} \end{array} \right.$$

Pulse expansion

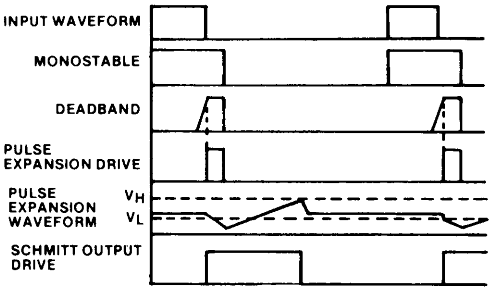
Figure 6
Pulse expansion circuit and characteristics



A schematic of the pulse expansion circuit is shown in Fig. 6. In the quiescent state with no drive the Schmitt trigger input is biased via R_E and takes up a level just above the lower threshold V_L.

A drive pulse causes a current I_E to be switched on for the duration of the pulse and this discharges C_E linearly with time. Thus, at the end of the pulse the voltage on C_E depends on the duration of the pulse. If the pulse is narrow and just causes the potential on C_E to fall to V_L the Schmitt trigger will switch to the upper threshold V_H and at the end of the drive pulse C_E will start to charge to V_H with a time constant C_ER_E. When the potential on C_E reaches V_H the Schmitt will switch to V_L and C_E will discharge to the quiescent level. The output drive is taken from the Schmitt output.

Figure 7 **Pulse expansion timing diagram**



dc motors need a certain amount of drive to overcome static friction and the minimum output pulse obtained from this form of pulse expansion characteristic is chosen to ensure that the motor will rotate when driven.

The value of t_{min} is determined by the Schmitt trigger hysteresis and the exponential waveform on C_E because V_H is small the following linear relationship is sufficiently accurate.

$$V_H = \frac{(V_{CC} - V_L)}{C_ER_E} \times t_{min}$$

For nominal operation V_{CC} = 4.8V; V_L = 1.5V; V_H = 0.12V and:

$$t_{min} \simeq \frac{C_ER_E}{30} \text{ msec} \begin{cases} C_E \text{ in } \mu F \\ R_E \text{ in } k\mu \end{cases}$$

and for C_E = 0.47μF and R_E = 180kΩ, t_{min} = 3.5msec.

It can be seen from the simple equation that t_{min} is dependent on V_{CC}, and t_{min} will increase with reducing V_{CC}. This variation is put to good use to maintain the initial motor drive, $V_{CC} \times t_{min}$ reasonably constant over the operating voltage range of 3.5 to 6.5 volts.

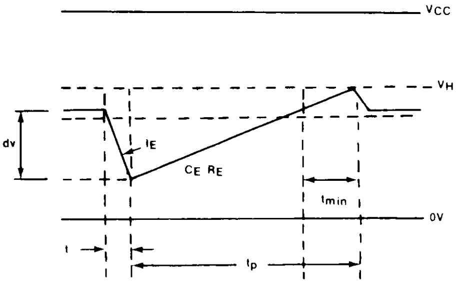
When the pulse expansion drive is increased above the minimum value the output pulse increases from t_{min} almost linearly until full pulse expansion is reached, ie. when the ouput pulse width equals the input pulse repetition rate. The pulse expansion will be almost linear provided that the current source I_E does not saturate, ie. provided that C_E is not discharged to almost zero volts. Ideally the current source should saturate when full motor drive is obtained but due to component tolerances it is usual to allow some margin to ensure that full motor drive can be obtained. If a margin is allowed, an extended pulse expansion characteristic results (shown dotted in Fig. 6) and if this is excessive it can lead to the servo exhibiting an underdamped characteristic causing jittering or hunting. Thus for full pulse expansion the voltage on C_E should discharge from its quiescent value of 1.5V to 0.75 volts. Thus with I_E = 3mA for the current source:

$$\frac{1.5 - 0.75}{t_e} = \frac{I_E}{C_E}$$

$$\therefore C_E = 4.t_e\mu F (t_e \text{ in msec})$$

For t_e = 0.1 msec, a value of 0.47μF was chosen for C_E.

Figure 8 **Pulse expansion waveform**



If t_p is the maximum motor drive pulse length required, ie. equal to the input pulse repetition period for full pulse expansion, and the mean value of the potential on C_E is taken as 1.2 volts, then:

$$dv = \frac{(t_p - t_{min})}{C_ER_E} \times (V_{CC} - 1.2)$$

And for the discharge period t_e:

$$dv = \frac{I_Et_e}{C_E}$$

$$\therefore R_E = \frac{(t_p - t_{min}) \times (V_{CC} - 1.2)}{I_Et_e}$$

For nominal values of V_{CC} = 4.8V and I_E = 3mA

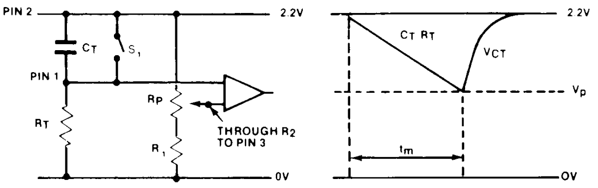
$$R_E = 1.2 \frac{(t_p - t_{min}) \text{ k}\Omega}{t_e}$$

and for t_p = 20msec, t_{min} = 3.5msec, t_e=0.1msec, R_E = 180kΩ. (Nearest preferred value).

Monostable timing

Figure 9

Monostable timing circuit and waveform



The leading edge of the input waveform triggers the timing monostable by opening switch S1. CT then charges until the differential amplifier detects that the timing waveform potential has fallen to Vp, the potential on the potentiometer wiper and switch S1 is closed to terminate the timing pulse. Thus the monostable period is determined by the setting of the potentiometer wiper. In the standard application the servo centre position pulse width is 1.5 msec with a range of ±50° rotation at 10 µsec per degree. Thus the 2.0 msec maximum monostable period t_{mono} (max) corresponds to a potentiometer setting of 200° (for a linear relationship) and since the potentiometer has a total rotation of approximately 270° and the maximum allowable swing on pin 3 is specified as 0.5 volt, the value of $C_T R_T$ can be calculated as follows:

$$\frac{0.5}{t_{mono\,(MAX)}} \simeq \frac{2}{C_T R_T}$$

$$\therefore C_T R_T = 4 t_{mono\,(max)}$$

Thus if $t_{mono\,(max)} = 2$ msec, $C_T R_T = 8$msec.

The optimum value of R_T is 100kΩ due to the design of the on-chip monostable circuit giving $C_T = 0.1\mu F$ (nearest preferred value).

$$R_T = 100k\Omega \qquad C_T = 0.1\mu F$$

The value of R_1 can now be calculated from the actual voltage swing with a potentiometer setting of Øp = 200° and Ømax = 270°.

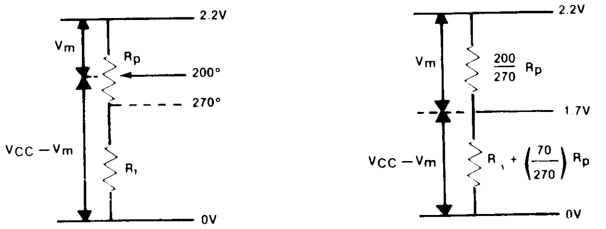


Figure 10

Potentiometer set at 200°C

Equivalent circuit

Thus from the equivalent circuit:

$$\frac{Vm}{\frac{200}{270}\,R_p} = \frac{(V_{CC} - V_m)}{R_1 + \frac{70}{270}\,R_p}$$

where V_m is calculated from the actual values of C_T and R_T chosen using the relationship:

$$V_m = \frac{2.0.\, t_{mono(max)}}{C_T R_T}$$

since $C_T = 0.1\mu F$ (nearest preferred value) was chosen with $R_T = 100k\Omega$, $V_m = 0.4V$ and hence: $R_1 = 3.1\,R_p$. If $R_p = 2k\Omega$ then $R_1 = 6.2k\Omega$.

Dynamic feedback

Without dynamic feedback in the standard application the inertia of the motor and gearbox causes the servo output shaft to overshoot the set position which results in the servo 'hunting'. If the deadband was widened to stop this effect an unacceptably large deadband would result and the servo would still be underdamped. The dynamic feedback circuit utilises the motor back emf (which is proportional to motor speed) and feeds back a proportion of this signal to the wiper of the potentiometer. The phase of the feedback signal is chosen to modify the potential on the wiper so that the monostable period is dynamically varied to reduce the motor drive as the servo output shaft approaches the set position and the values of the feedback resistors are chosen to achieve optimum setting characteristics.

The value for R_F and R_B of 330kΩ will suit the normal type of servo mechanism, however if the servo is fairly fast this can be decreased to 300kΩ to minimise any tendency to overshoot. Where the servo is slow R_F and R_B can be increased to 360kΩ or 390kΩ.

RF Decoupling

C_1 (typical value 0.1µF) is only necessary where strong RF fields may affect the operation of the circuit.

Transistors T1 and T2

The external PNP transistors are usually selected for a low V_{CE}(sat) to obtain maximum output drive. The recommended type is BC461.

Motor speed control

Introduction

In the motor speed control application the

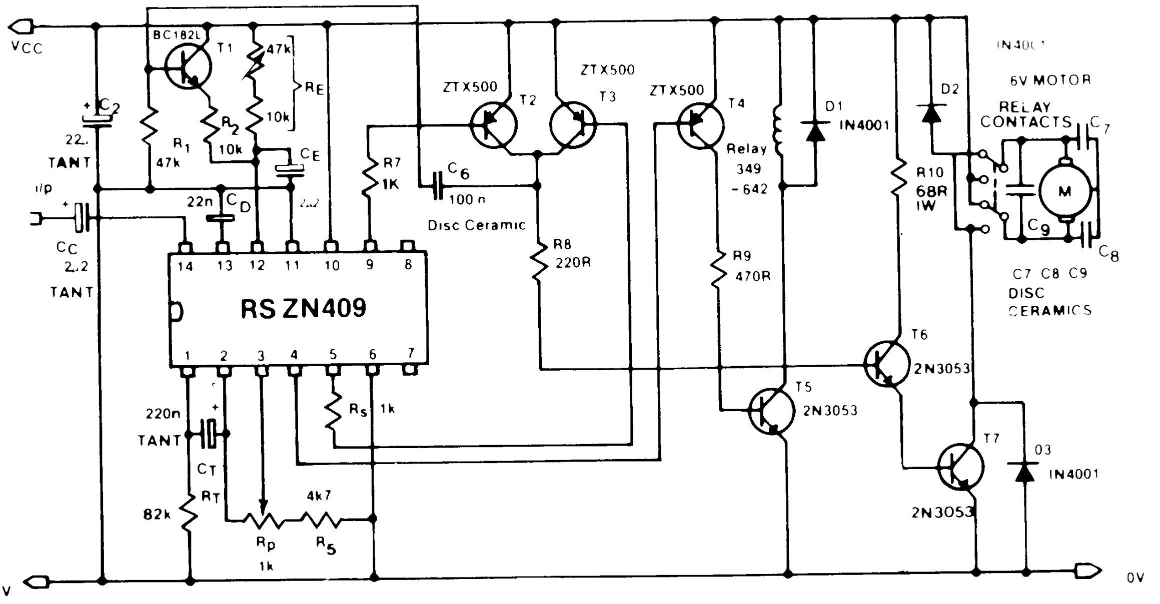


Figure 11

Proportional motor speed control circuit

RS ZN409 is used as a linear pulse width amplifier. The dc motor is driven via a power amplifier with a train of pulses whose mark/space ratio can vary between zero and one to control the motor speed from zero to maximum. The device operates with fixed timing components and a fixed resistor replaces the position feedback potentiometer. The nominal monostable period represents zero motor speed and input pulses less than or greater than nominal drive the motor in the forward and reverse direction respectively. The motor direction is usually controlled by a relay operated from pin 4, the direction output. Pulse expansion components C_E and R_E are chosen to obtain the required relation between control potentiometer and motor speed and it is usual to operate with a much larger deadband than that used in the servo application.

The outputs from pins 9 and 5 of the **RS** ZN409 integrated circuit are combined using two ZTX500 PNP transistors to provide a pulsed output whose mark/space ratio varies from 0 to 1 depending on the deflection of the control potentiometer.

This signal is then used to drive the motor via the power amplifier.

The **RS** ZN409 has additional circuitry which performs the motor reversing function by taking the output from the direction bistable and provides either zero current or approximately 3mA sink current at pin 4, depending on the state of the direction bistable. This current is amplified and used to drive the relay coil (100mA) via the 2N3053 transistor thus controlling the motor direction via the relay changeover contacts.

It is usual to have a relatively wide deadband and C_D = 22nF provides a deadband of about 14% (±7 degrees).

A 1kΩ potentiometer (R_p) can be used to set up the zero output condition with the control pot in its central position.

Pulse width generator

A pulse width generator circuit is shown in Figure 12 suitable for driving the **RS** ZN409 in servo or motor speed applications.

the frame rate is generated by the first timer and the frequency is adjusted by VR1 so that the time between pulses is 18mS. VR2 is then used to control the ouput pulse width over the range 1-2mS. VR3 is set so that the midpoint of VR2 corresponds to an output pulse of 1.5mS.

VR4 can be included should an output amplitude control be required.

Figure 12 **Pulse width generator**