CHAPTER 3

DESIGN

3.1 General

The design is concerned mainly with the circuits that control and interface the basic integrated circuit elements. A control system is chosen, which is a pulse-width modulated control system. A mathematical model is set up for the control system. The approach lies in developing a circuit that behaves according to a Nyquist diagram specified. A prototype is constructed and tested.

Since the control signal is in the form of pulses, it is advantageous to use digital integrated circuits in various parts of the system.

3.2 The pulse-width modulated Sampler

The sampler converts an angular quantity into pulses of a definite width. Let,

θ = angular quantity input in radian

t_p = pulse width output in sec.

K_s = Transfer function of the sampler

then

$$K_s = \frac{t_p}{\theta} \quad \text{sec}/_{\text{rad}}. \tag{3.1}$$

It is evident that K_s is a constant.

A monostable multivibrator is used as the sampler. It is formed by connecting two NAND gates, IC 1-1 and IC 1-2, shown in Figure 3.2 and followed by another NAND gate, acts as a driver. The pulse width of the circuit is controlled by C_1, R_1 and R_2. R_1 is mechanically connected to a dial which set a desired position where R_1 is a trimer-potentiometer that adjusts the pulse width to the required range.

For convenience by using a 1 μf capacitor, a 1K-ohm potentiometer and a 2.2 K-Ohm trimmer by setting the trimmer at about 1K-Ohm, the time constant of the circuit is

$$T_1 = (R_1 + R_2)\, C \tag{3.2}$$

where

T_1 = Time constant of the circuit

$R_1 + R_2$ = 2 K-Ohm, for maximum pulse width

C = 1 μf

then $T_1 = 2 \times 10^3 \times 10^{-6}$

$= 2 \times 10^{-3}$

Since the capacitor is to be charged to a peak value of 3 volt and at 1.2 volts the NAND gates begin to conduct, the pulse width can be found by the equation as follows[7]

$$V_o = V_f + (V_i - V_f)\, e^{\frac{-t1}{T1}} \tag{3.3}$$

where	V_i	= 3 V	initial voltage
	V_o	= 1.2 V	output voltage
	V_f	= 0	Final voltage
	T_1	= 2×10^{-3}	(second)
	t_1	= pulse width	(second)

then $$1.2 = 3e^{-\frac{t1}{2x10^{-3}}}$$

$$t_1 = 2 \times 10^{-3} \times 0.92$$

$$t_1 = 1.84 \times 10^{-3} \text{ sec.}$$

for minimum pulse width

$$R_1 + R_2 = 1K - \text{Ohm.}$$

$$T_2 = 1K \times 1\,\mu f = 1 \times 10^{-3} \text{ sec}$$

then from equation 3.4 we have

$$t_2 = 1 \times 10^{-3} \times 0.92 = 0.92 \times 10^{-3} \text{ sec.}$$

Hence the pulse width can be adjusted from 0.92 ms to 1.84 ms as the potentiometer rotates from 0° to 355° and its resistance being changed from 0 to 1K-Ohm. Then from equation (3.1), we have

$$Ks \doteq \frac{1.84 - 0.92}{2\pi} = 0.146 \text{ ms/rad.}$$

An oscillotor is required to feed the monostable multivibrator and it is also formed by the use of NAND gates as shown in Figure 3.2 C_2 controls the width of the pulse generated where R_3 is set for the rate of oscillation. By trial and error, and choose

$$C2 = 10\,\mu f$$

$$R3 = 2.2 \text{ K-Ohm trimer}$$

and we can vary the pulse rate from 2 ms to 80 ms.

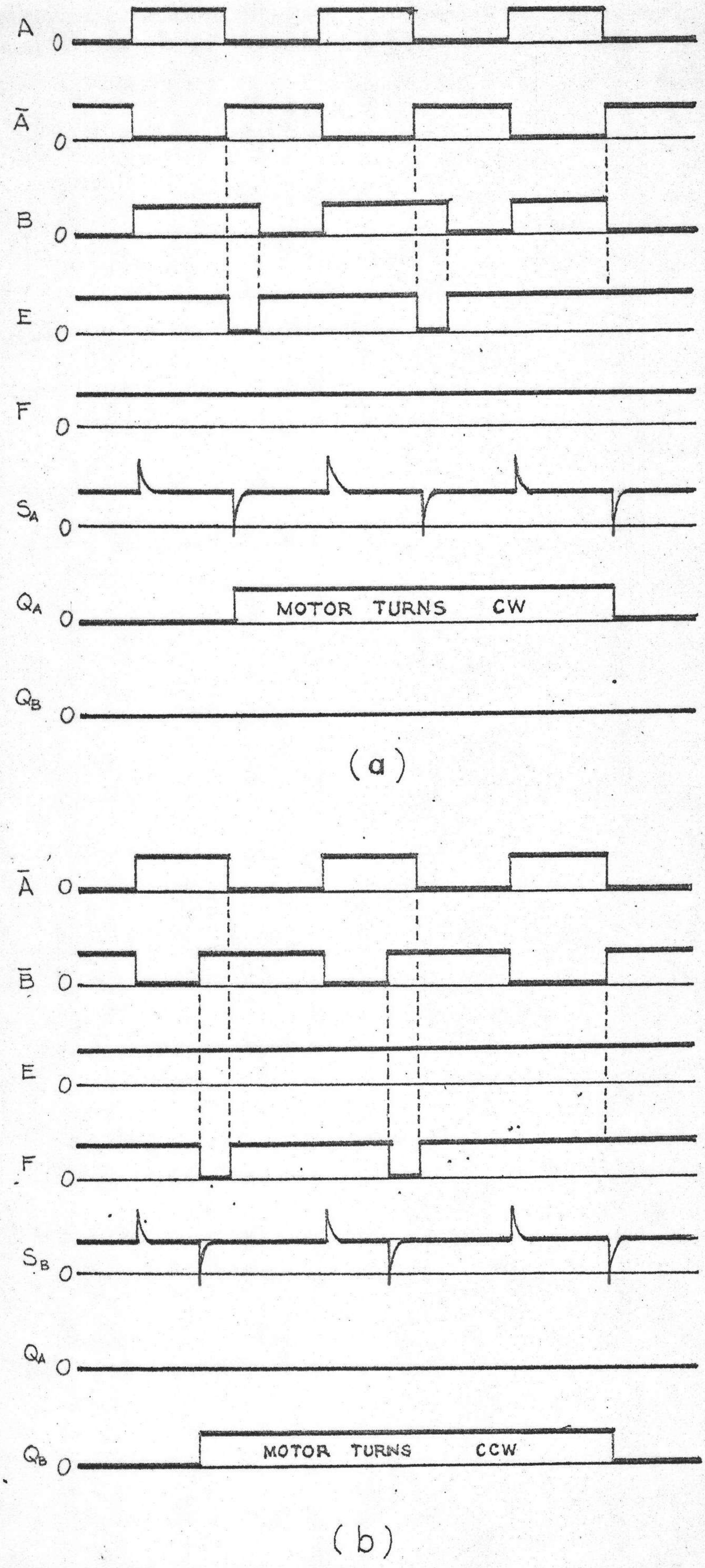

FIGURE 3.1 TIMING DIAGRAM FOR THE COMPARATOR AND THE ZERO-ORDER HOLD

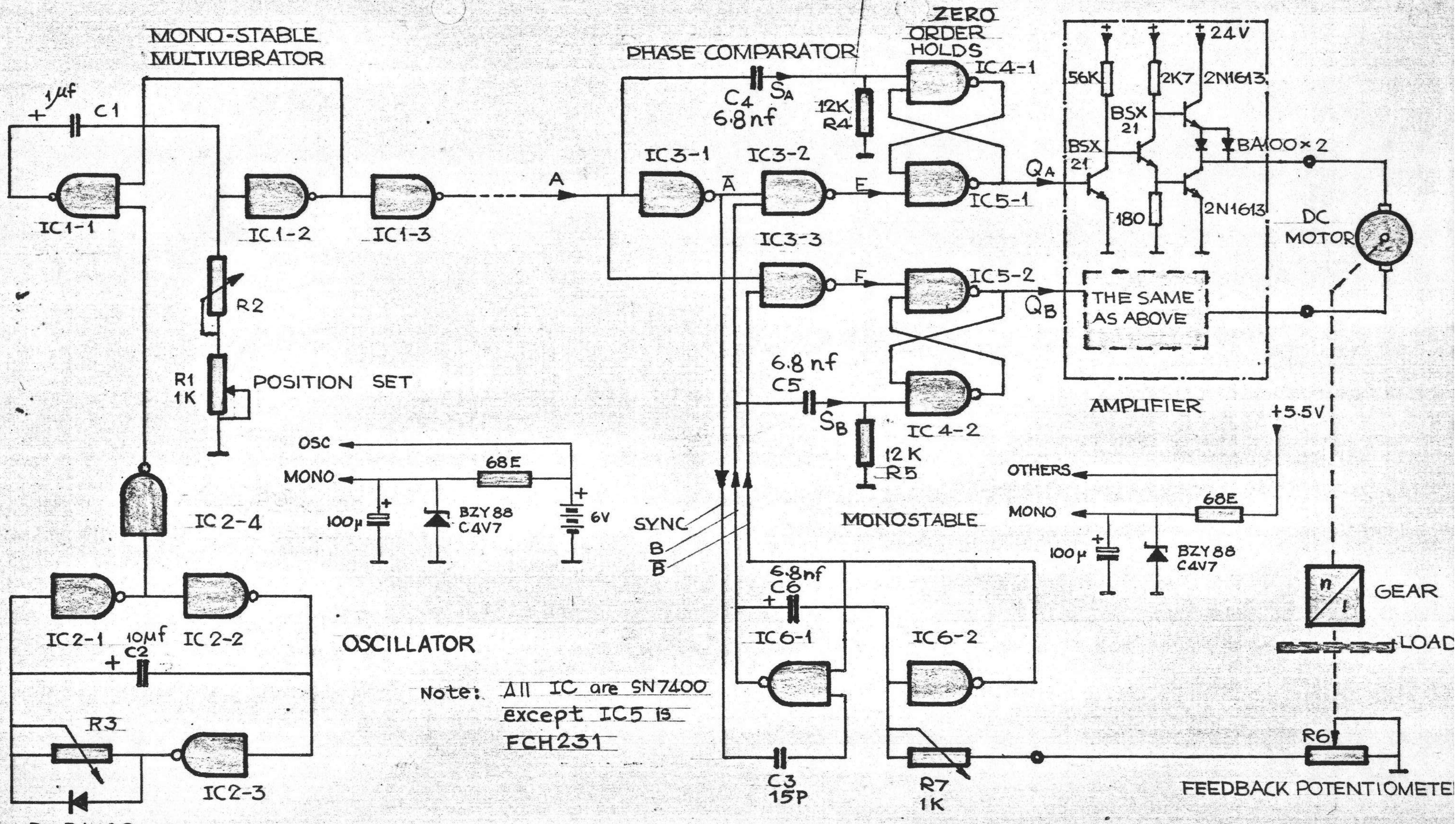

FIGURE 3.2 SYSTEM CIRCUIT DIAGRAM

3.3 The Comparator

The comparator shown in Figure 3.2 uses three NAND gates, IC3-1, IC3-2 and IC3-3. The timing diagrams for the pulse comparator are shown in Figure 3.1, which derived from the logic equations[3] as follows :

$$E = \overline{\bar{A}.B} \qquad (3.4)$$

$$F = \overline{A.\bar{B}}$$

Where E = error signal for clockwise direction

F = error signal for counter-clockwise direction

A = input pulse

B = feedback pulse

3.4 Data - Reconstruction

For simplicity, a zero-order hold device [2,6] is used as the data-reconstruction. Figure 3.3 shows the impulse response of a zero-order hold device

The transfer function of the hold device is derived to be[2,6]

$$Gho(s) = \frac{1 - e^{-sT}}{s} \qquad (3.5)$$

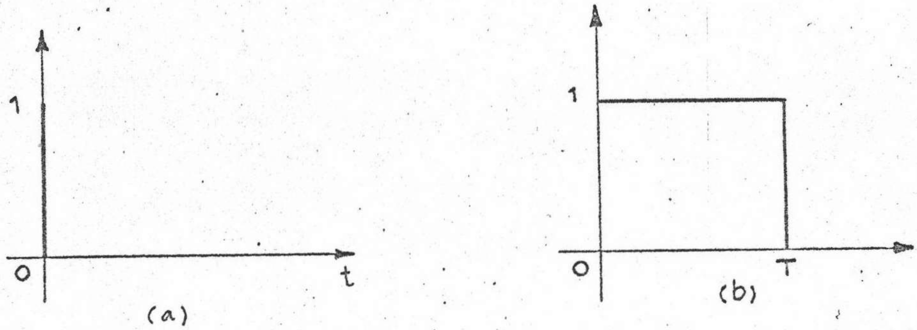

Figure 3.3 (a) Unit - impulse input to zero - order hold device

(b) Impulse response of zero - order hold.

The zero-order hold circuit utilizes two bistables, one is formed by IC4-1, and IC5-1, the other is formed by IC4-2 and IC5-2. The timing diagrams for the zero-order hold circuit in conjunction with the comparator is shown in Figure 3.1.

The bistables are reset by the traillling edge of pulse A and B, i.e. S_A and S_B. C4, R4 and C5, R5 served as wave shaping network for resetting the bistables, whereby controlling the dead-zone of the on-off switcher.

3.5 Dead -zone Consideration

The pedestal voltages of pulse S_A and S_B are equal to their gate voltages, By measuring , we have

Vi	=	$1.6 - 3.0 = -1.4$	initial voltage
Vo	=	$0.8V$	output voltage
Vf	=	$1.6\ V$	gate voltage
T_4	=	$R_4 . C_4$	time constant
t_4	=	pulse width	(dead-zone)

then $$0.8 = 1.6 + (-1.4 - 1.6)\, e^{-\frac{t_4}{R_4 C_4}}$$

$$t_4 = 1.32\, R_4 C_4 \qquad (3.6)$$

Let dead-zone = 1% of maximum error = t_4

$$t_4 = \frac{1}{100} \times 0.92 \text{ ms}$$
$$= 0.92 \times 10^{-5}$$

Choose $R_4 = 12$ K-Ohms

then $$C_4 = \frac{0.92 \times 10^{-5}}{1.32 \times 12 \times 10^3} = 6.97 \times 10^{-9}$$

use $C_4 \doteq 6.8nf$

3.6 The Motor and the Load

The transfer function, Gm(S), of a d-c motor can be found in many literature[1,6]. That is

$$Gm\ (S) = \frac{Km}{s(Tms + 1)} \tag{3.7}$$

where Km = Motor gain constant (rad/sec/volt)

Tm = Motor time constant (sec)

The Km and Tm terms are effective constant including the gear train and load which can be found by experimental means, we may write[6]

$$w(t) = Km\ V\ (1 - e^{-\frac{t}{Tm}}) \tag{3.8}$$

where

$w(t)$ = speed at time t

V = applied voltage to the motor

at steady state, we have

$$Km = \frac{w(\infty)}{V} \tag{3.9}$$

Tm can be found by measuring the transient speed at a specific time t.

The experiment presented in appendix A gives

Km = 35.5 rad/sec/volt

Tm = 14.2 ms

3.7 The Amplifier

The amplifier is actually acting as a logic switch. Because of the nonlinearity introduced any error signal that is greater than the dead-zone will switch-on the amplifier, i.e. the error signal acting as the maximum error signal. In a proportional control sense, the amplifier will have an equivalent gain expressed by :

$$KA = \frac{V}{Tem} \tag{3.10}$$

where

KA = Amplifier gain

V = Voltage output

Tem = Maximum error signal

From section 3.2, the pulses can be vary from 0.92 ms to 1.84 ms, and the voltage appliied to the motor is 20 volts, then we have

$$Tem = 1.84 - 0.92 = 0.92 \text{ ms} \tag{3.11}$$

$$KA = \frac{20}{0.92\text{ms}} = 21{,}739.0 \text{ Volt/sec}$$

A full-bridge switching circuit is used as shown in Figure 3.2 other types of circuit may be employed[9].