CHAPTER III

DISCUSSION

The "Printout and System Control" is an interface between the neutron detection system and the hard copy output from the line printer or modified electric typwriter e.g. the IBM Selectric typwriter with Auto Finger. Most of the electronic and mechanical components used in the development are available locally except some parts of the line printer which are out of date and procurment of its spare parts is highly improbable. Therefore, it is mo practical to interface the electric typewriter or the more versatile teletypewriter to the neutron detection system.

During printing period the main and monitor scalers are inhibited from acquiring data since the electrical noise incurred from the motion of the printing mechanism, the RF and Motor controls may interfere the data acquisition of these two counters. This time delay depends on the speed of the printer and in the case of the line printer under consideration the time delay amounts to 360 ms. This is one of the disadvantage to be overcome in future development.

The improvement may be done by using an optional BCD code latching for the data to be printed. These data are accessible at the output of the scaler. Once the data are stored by latching option the scalers are cleared for next data acquisition and at the same time the latched data are forwarded to the printer to be processed for the hard copy output. The latching option circuit requires another thirteen IC's.

APPENDIX A

CIRCUIT DESIGN

A.1 Print Driver Circuit

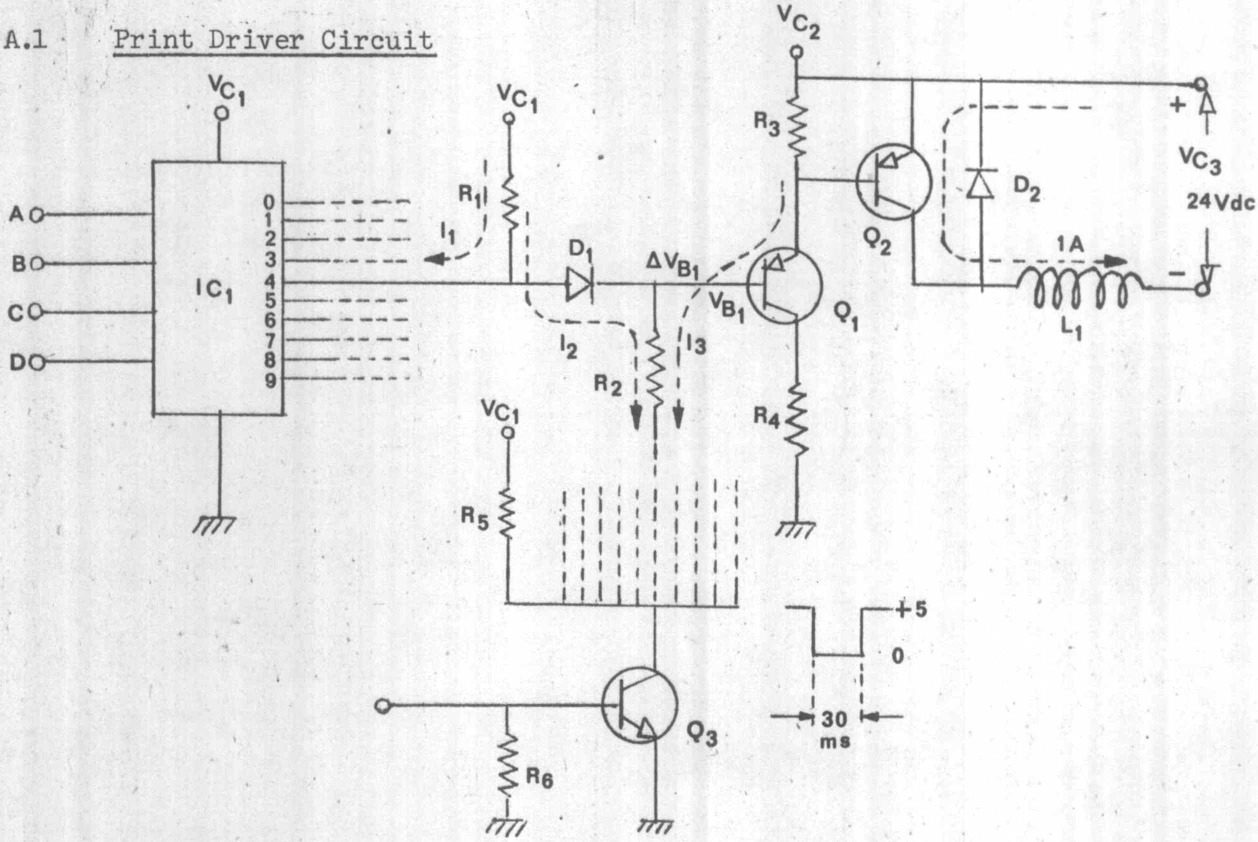

Fig. A 1

Since I_1max (Maximum Current Sink) $\leq$ 2 mA

$$R_1 = \frac{V_{C1}}{I_1 max} = \frac{5 \text{ Volts}}{\leq 2mA}$$

$$\geq 2.5 \text{ K}$$

Choose $R_1 \approx$ 3 K .... (1)

Two cases are considered.

Case I) $I_1 = 0$, $I_3 = 0$, $V_{CE}(sat)Q_3 \approx 0.1 \sim 0.3 \approx 0$

$$\text{Then}\quad I_2 = \frac{V_{C_1} - V_{D_1} - V_{CE}(sat)Q_3}{R_1 + R_2} \approx \frac{V_{C_1} - V_{D_1}}{R_1 + R_2} \quad \ldots\ldots \quad (2)$$

$$\text{and}\quad V_{B_1} \approx I_2R_2 = \left(\frac{V_{C_1} - V_{D_1}}{R_1 + R_2}\right) R_2 \quad \ldots\ldots \quad (3)$$

$I_3 = 0$, Q_1 cut off and cutin voltage $V_{\gamma Q_1} \approx 0.5$ volts

$$V_{C_2} = V_{B_1} + V_{\gamma Q_1} = V_{B_1} + 0.5 \quad \ldots\ldots \quad (4)$$

Case 2) $I_1 = \frac{5V}{3K} = 1.66$ mA, $I_2 = 0$, Q_1, Q_2 conduct (sat),

$$\text{then}\quad I_3 = \frac{V_{C_2} - V_{BE}(sat)Q_2 - V_{BE}(sat)Q_1 - V_{CE}(sat)Q_3}{R_2}$$

$$\text{or}\quad I_3 \approx \frac{V_{C_2} - V_{BE}(sat)Q_2 - V_{BE}(sat)Q_1}{R_2} \quad \ldots\ldots \quad (5)$$

Substitute V_{C_2} from Eq. (5) and let $V_{BE}(sat) \approx 0.75$ volts, we get

$$I_3 = \frac{(V_{B_1} + V_{\gamma Q_1}) - V_{BE}(sat)Q_2 - V_{BE}(sat)Q_1}{R_2}$$

$$= \frac{V_{B_1} - 1}{R_2} \quad \ldots\ldots \quad (6)$$

$$\text{or}\quad I_3R_2 = V_{B_1} - 1 \quad \ldots\ldots \quad (7)$$

The difference voltage between case (1) and case (2)

$$\Delta V_{B_1} = (I_3 - I_2)R_2 = I_3R_2 - I_2R_2 = \text{Eg.}(7) - \text{Eg.}(3)$$

$$= (V_{B_1} - 1) - V_{B_1} = -1 \text{ volts} \quad \ldots\ldots \quad (8)$$

Eq. (7) - Eq. (8)

$$I_3 R_2 - \Delta V_{B_1} = V_{B_1}$$

$$I_3 = \frac{V_{B_1} + \Delta V_{B_1}}{R_2} \qquad (9)$$

Substitute V_{B_1} Eq. (3) into Eq. (9)

$$I_3 = \frac{\left(\frac{V_{C_1} - V_{D_1}}{R_1 + R_2}\right) R_2 + \Delta V_{B_1}}{R_2}$$

$$I_3 = \frac{V_{C_1} - V_{D_1}}{R_1 + R_2} + \frac{\Delta V_{B_1}}{R_2}$$

Differentiate w.r.t. R_2

$$\frac{dI_3}{dR_2} = -\frac{V_{C_1} - V_{D_1}}{(R_1 + R_2)^2} - \frac{\Delta V_{B_1}}{(R_2)^2}$$

For optimum condition $\frac{dI_3}{dR_2} = 0$

$$0 = -\frac{V_{C_1} - V_{D_1}}{(R_1 + R_2)^2} - \frac{\Delta V_{B_1}}{(R_2)^2}$$

$$(V_{C_1} - V_{D_1})(R_2)^2 + \Delta V_{B_1} (R_1 + R_2)^2 = 0$$

$$\left[V_{C_1} - V_{D_1} + \Delta V_{B_1} \right] (R_2)^2 + 2\Delta V_{B_1} R_1 R_2 + \Delta V_{B_1} (R_1)^2 = 0$$

$$R_2 = \frac{R_1\left[-\Delta V_{B_1} \pm \sqrt{(\Delta V_{B_1})^2 - (V_{C_1} - V_{D_1} + \Delta V_{B_1})\ \Delta V_{B_1}}\right]}{V_{C_1} - V_{D_1} + V_{B_1}} \quad \ldots(10)$$

Substitute $\Delta V_{B_1} = -1$ volts from Eq. (8) , $R_1 = 3K$,

$V_{C_1} = 5$ volts and $V_{D_1} = 0.6$ volts

$$R_2 = \frac{3K\left[1 \pm \sqrt{1 + (5-0.6-1)}\right]}{5-0.6-1} = 3K\ \left(\frac{1+2.098}{3.4}\right)$$

$$\approx 2.7\ K \quad \ldots\ldots. \ (11)$$

and $V_{B_1} = \left(\frac{V_{C_1} - V_{D_1}}{R_1 + R_2}\right) R_2 = \left(\frac{5-0.6}{3K-2.7K}\right) 2.7K = 2.0842$ volts ,

then $V_{C_2} = V_{B_1} + 0.5 = 2.0842 + 0.5$

$$\approx 2.6 \text{ volts} \quad \ldots\ldots. \ (12)$$

$$I_3 = \frac{V_{B_1} - 1}{R_2} = \frac{2.0842 - 1}{2.7\ K} \approx 0.4 \text{ mA} \quad \ldots\ldots. \ (13)$$

Select $R_3 = 120\ \Omega$ to decrease I_{CBO} of Q_2

$$I_{R_3max} = \frac{V_{BE}(sat)Q_2}{R_3} = \frac{0.75}{120} = 6.25 \text{ mA}$$

Select $hFE_{min}Q_2 \approx 25$ for solenoid driver at 1 A

$$I_{Bmax}Q_2 = \frac{I_{Cmax}Q_2}{hFE_{min}Q_2} = \frac{1A}{25} = 40 \text{ mA}$$

$$I_{Emax}Q_1 = I_{R_3\,max} + I_{B\,max}Q_2 = 6.25 \text{ mA} + 40 \text{ mA}$$
$$= 46.25 \text{ mA}$$

$$hFE_{min}Q_1 = \frac{I_{E\,max}Q_1}{I_{B\,max}Q_1} - 1 \approx \frac{I_{E\,max}Q_1}{I_{B\,max}Q_1} = \frac{I_{E\,max}Q_1}{I_3}$$

From Eq. (13) $I_3 = 0.4$ mA and $I_{E\,max}Q_1 = 46.25$ mA

Select $hFE_{min}Q_1 \geq \frac{I_{E\,max}Q_1}{I_3} = \frac{46.25 \text{ mA}}{0.4 \text{ mA}} = 115.63$

$$\approx 120 \quad \ldots\ldots\ldots \quad (14)$$

$V_{CE}(sat)Q_1 \approx 0.3$ volts, $I_{Cmax}Q_1 \approx I_{Emax}Q_1 = 46.25$ mA

$V_{CE}(sat)Q_2 = 0.75$ volts and $V_{C_2} = 2.6$ volts

$$R_4 = \frac{V_{C_2} - V_{BE}(sat)Q_2 - V_{CE}(sat)Q_1}{I_{Cmax}Q_1} = \frac{2.6 - 0.75 + 0.3}{46.25 \text{ mA}}$$

$$\approx 33\ \Omega \quad \ldots\ldots \quad (15)$$

The maximum collector current

$$I_{Cmax}Q_3 = 9I_2 + I_3 = 9\left(\frac{V_{C_1} - V_{D_1}}{R_1 + R_2}\right) + I_3 = 9\left(\frac{5-0.6}{3K + 2.7\ K}\right) + 0.4 \text{ mA}$$

$$= 7.35 \text{ mA}$$

Select pull up resistor $R_5 = 4.7$ K ..... (16)

$$I_{R_5} = \frac{V_{C_1} - V_{CE}(sat)Q_3}{R_5} = \frac{5 - 0.3}{4.7K} = 1 \text{ mA}$$

$$I_{B\,min}Q_3 \geq \frac{I_{C\,max}Q_3 + I_{R_5}}{hFE_{min}\,Q_3} = \frac{7.35 \text{ mA} + 1 \text{ mA}}{hFE_{min}\ Q_3}$$

Select $hFE_{min}Q_3 \approx 30$

$$I_{B\,min}Q_3 = \frac{8.35\ \text{mA}}{30} = 0.278\ \text{mA} \qquad \ldots\ldots\ldots \qquad (17)$$

Select $R_6 = 47\ K$ to reduce leakage current $I_{CBO}Q_3$ and $I_{CEO}Q_4$.

At low current $V_{BE}(sat)Q_3 \approx 0.55$ volts

$$I_{R6} = \frac{V_{BE}(sat)Q_3}{R_6} = \frac{0.55\ V}{47K} = 0.017\ \text{mA}$$

$$I_EQ_4 \geqq I_{B\,min}Q_3 + I_{R6} = 0.278\ \text{mA} + 0.017\ \text{mA}$$

$$\geqq 0.295\ \text{mA} \qquad \ldots\ldots\ldots \qquad (18)$$

Protection diode D_1 (1A) reduces the spike caused by the back E.M.F. energized by coil L_1.

A.2 Printout Control Circuit

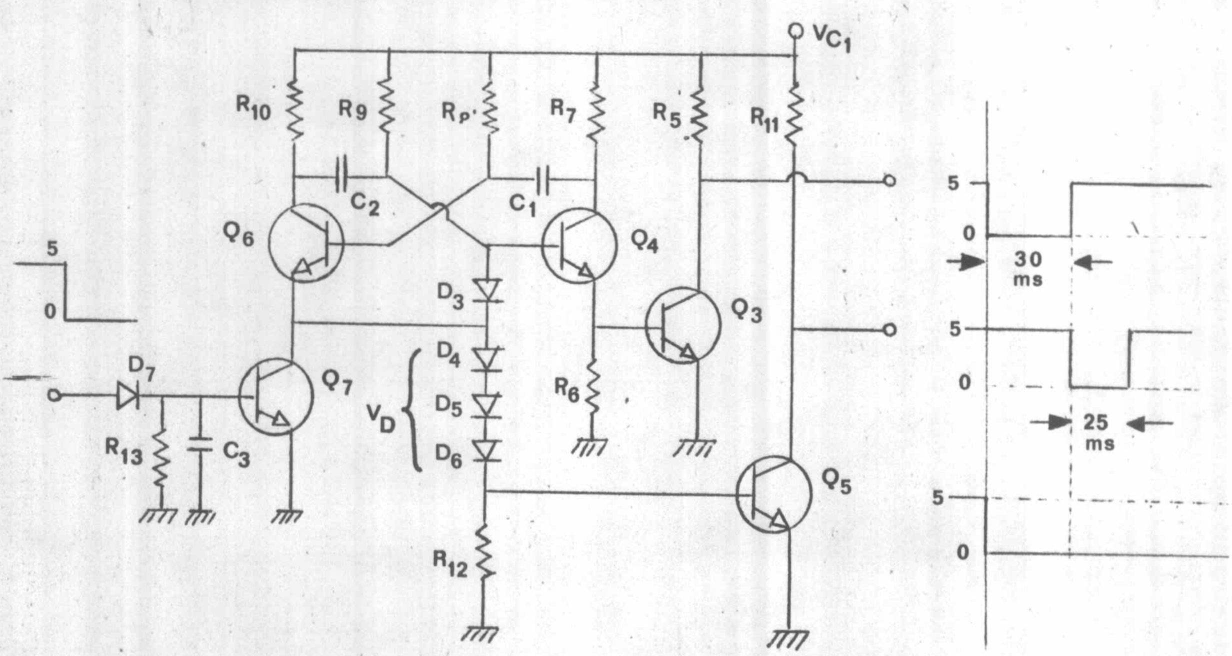

Fig. A 2

$$I_E Q_4 \geq 0.295 \text{ mA for } Q_3(\text{sat})$$

$$\approx 1 \text{ mA} \approx I_C Q_4$$

and $V_{CE}(\text{sat})Q_4 \approx 0.1$ for low current $I_{Cmin} Q_4$

≈ 0.3 for high current $I_{Cmax} Q_4$

Then $$R_7 \geq \frac{V_{C_1} - V_{CE}(\text{sat})Q_4 - V_{BE}(\text{sat})Q_3}{I_C Q_4} = \frac{5-0.1-0.55}{1 \text{ mA}}$$

$$\approx 4.7 \text{ K}$$

$$R_9 \leq \left[\frac{V_{C1} - V_{BE}(\text{sat})Q_4 - V_{BE}(\text{sat})Q_3}{I_C Q_4}\right] hFE_{min} Q_4$$

$$\leq \left(\frac{5-0.55-0.55}{1\text{mA}}\right) hFE_{min} Q_4$$

$$\leq (3.9\text{K})\ hFE_{min} Q_4 \qquad \text{................ (19)}$$

$$\left.\begin{array}{l} \text{Select } R_{11} = R_5 = 4.7 \text{ K} \\ R_{12} = R_6 = 47 \text{ K} \\ Q_5 \text{ is identical with } Q_3 \\ \text{and } Q_6 \text{ is identical with } Q_4 \end{array}\right\} \text{for symmetrical driver circuit.}$$

$$I_C Q_6 \approx I_C Q_4 = 1 \text{ mA for } Q_6(\text{sat})$$

$$R_{10} \geq \frac{V_{C1} - V_{CE}(\text{sat})Q_6 - V_D - V_{BE}(\text{sat})Q_5}{I_C Q_6}$$

where $V_D = V_{D_4} + V_{D_5} + V_{D_6} = 0.5 + 0.5 + 0.5 = 1.5$ volts

$V_{BE}(sat)Q_5 = 0.55$ volts, $V_{CE}(sat)Q_6 = 0.1$ volts, $V_{C1} = 5$ volts

$$R_{10} \geqq \frac{5-0.1-1.5-0.55}{1\text{ mA}} = 2.85 \text{ K}$$

$$\approx 3 \text{ K}$$

$$R_8 \leqq \left[\frac{V_{C1} - V_{BE}(sat)Q_6 - V_D - V_{BE}(sat)Q_5}{I_C Q_6}\right] hFE_{min}Q_6$$

$$\leqq \left(\frac{5-0.55-1.5-0.55}{1\text{ mA}}\right) hFE_{min}Q_6$$

$$\leqq (2.4 \text{ K})\ hFE_{min}Q_6 \qquad \text{..........} \quad (20)$$

At $t < 0$ Q_7 is turned ON (sat)

$t > 0$ Q_7 is turned OFF (cut off)

Thus initially at $t < 0$ Q_7, Q_6 are turned ON (sat), Q_3, Q_4, Q_5 are turned OFF, the collector voltage V_{CQ_3}, V_{CQ_5} will be reset at high level state +5 volts.

At $t > 0$ Q_7, Q_6, Q_5 are turned OFF, Q_4, Q_3 are turned ON(sat), the collector voltage V_{CQ_3} will fall to its low level state.

At $t < 0$ Q_6 and Q_7 are turned ON (sat),

Q_5, Q_4 and Q_3 are cutoff

$$V_C = V_{C1} - V_{BE}(sat)Q_6 - V_{CE}(sat)Q_7$$

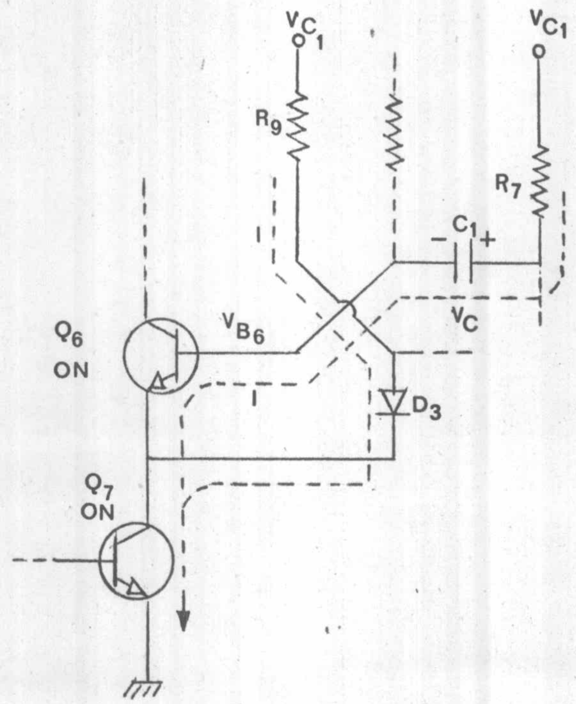

Fig. A 3

At $t > 0$ Q_5, Q_6 and Q_7 are turned OFF Q_4, Q_3 are turned ON (sat).

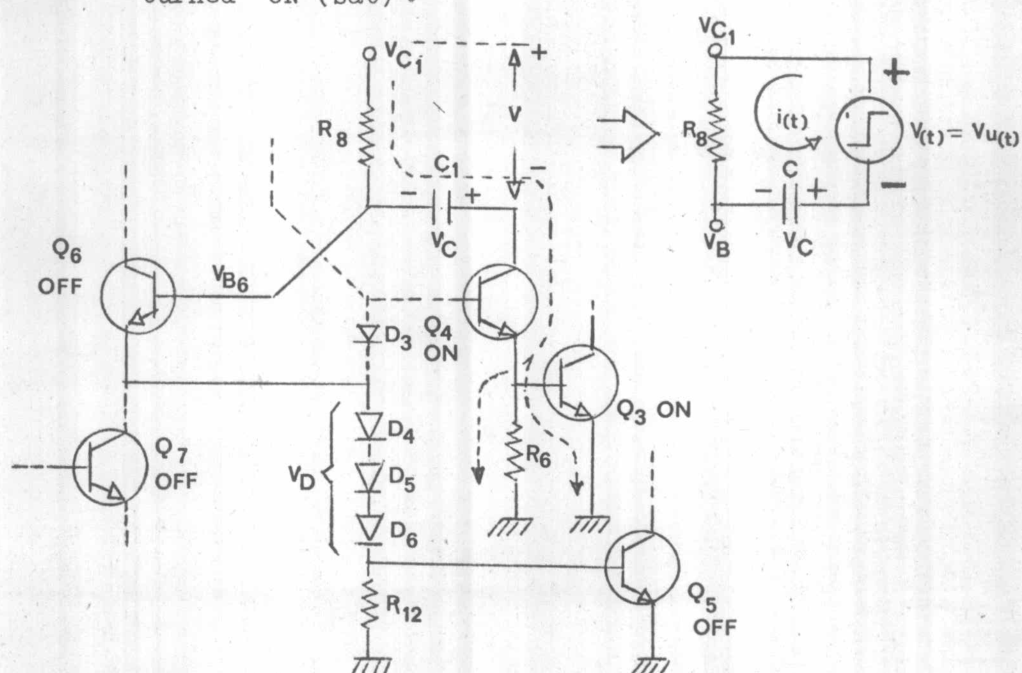

Fig. A 4

$$V = V(t) = \begin{cases} 0, & t < 0 \\ V_{C1} - V_{CE}(sat)Q_4 - V_{BE}(sat)Q_3, & t > 0 \end{cases}$$

$$= V\,u(t)$$

$$-V\,u(t) + R_8 i(t) + \frac{1}{C_1} \int_{-\infty}^{t} i(t)dt = 0$$

$$-\frac{V}{S} + R_8 I(s) + \frac{1}{C_1}\left[\frac{I(s)}{S} + \frac{q(0+)}{S}\right] = 0$$

$$q(0+) = -C_1 V_C(0+) = -C_1 V_C(0-) = -C_1 V_C$$

$$-\frac{V}{S} + R_8 I(s) + \frac{1}{C_1}\left[\frac{I(s)}{S} - \frac{CV_c}{S}\right] = 0$$

$$I(S) = \left(\frac{V + V_C}{R_8}\right)\left(\frac{1}{S + \frac{1}{R_8 C_1}}\right)$$

$$i(t) = \left(\frac{V + V_C}{R_8}\right) e^{-\frac{t}{R_8 C_1}}$$

$$V_{B6} = V_{C1} - R_8 i(t) = V_{C1} - (V + V_C)e^{-\frac{t}{R_8 C_1}} \quad \ldots\ldots\ldots \quad (21)$$

Substitute V and V_C we obtain

$$V_{B6} = V_{C1} - \left\{ \left[V_{C1} - V_{CE}(sat)Q_4 - V_{BE}(sat)Q_3\right] + \left[V_{C1} - V_{BE}(sat)Q_6 - V_{CE}(sat)Q_7\right] \right\} e^{-\frac{t}{R_8 C_1}}$$

Since $V_{CE}(sat) = V_{CE}(sat)Q_4 = V_{CE}(sat)Q_7$

and $V_{BE}(sat) = V_{BE}(sat)Q_3 = V_{BE}(sat)Q_6$

Then $$V_{B6} = V_{C1} - 2\left[V_{C1} - V_{BE}(sat) - V_{CE}(sat)\right] e^{-\frac{t}{R_8 C_1}} \quad \ldots. \quad (22)$$

$$t = R_8 C_1 \ln\left\{\frac{2\left[V_{C1} - V_{BE}(sat) - V_{CE}(sat)\right]}{V_{C1} - V_{B6}}\right\} \quad \ldots. \quad (23)$$

This exponential rise will actually continue, however, only until V_{B6} rises to the cutin voltage $V_{\gamma Q6}$ + V_D + cutin voltage $V_{\gamma Q5}$ and at time T_1 a reverse transition will occur.

$$V_{B6} = V\gamma_{Q6} + V_D + V\gamma_{Q5} = 2V\gamma + V_D \quad \ldots. \quad (24)$$

Since $V_{C1} = 5V$, $V_{BE}(sat) = 0.55V$, $V_{CE}(sat) = 0.1\ V$,

$V_\gamma = 0.5\ V$

and $V_D = V_{D4} + V_{D5} + V_{D6} = 0.5 + 0.5 + 0.5 = 1.5\ V$

$$T_1 - T_0 = R_8 C_1 \ln\left\{\frac{2[5-0.5-0.1]}{5-2(0.5)-1.5}\right\}$$

$$= R_8 C_1 \ln\left[\frac{8.7}{2.5}\right]$$

$$= 1.25\ R_8 C_1 \quad \ldots. \quad (25)$$

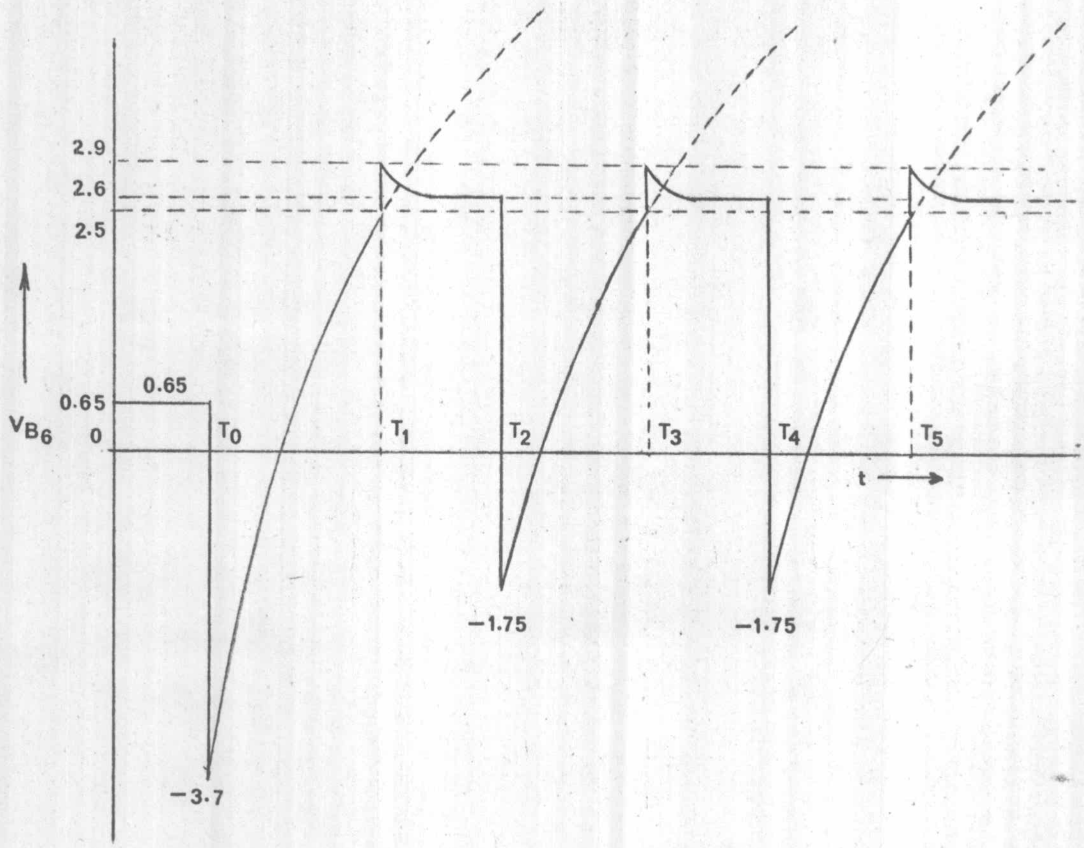

Fig. A 5 The voltage waveform at the base of Q_6 .

From Fig. A 5. it is seen that $T_1 - T_0$ is greater than $T_3 - T_2$. This is due to the difference in voltage between the first and the second transitions.

Therefore $V_C = V_{C1} - V_{BE}(sat)Q_6 - V_D - V_{BE}(sat)Q_5$, at $T_2(+) < t < T_2(-)$ or $t < T_3(+)$

$$= V_{C1} - 2V_{BE}(sat) - V_D \quad \text{...........} \quad (26)$$

$T_2 < T < T_1$

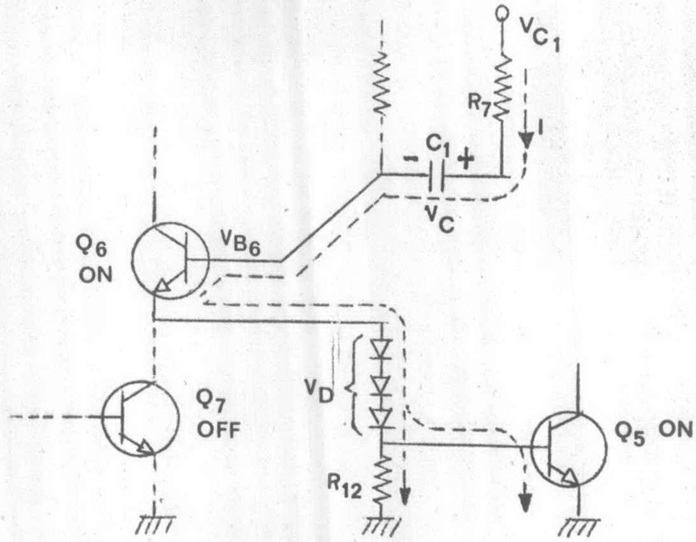

Fig.A 6

Substitute V_C from Eq. (27) into Eq. (21) we obtain

$$V_{B6} = V_{C1} - \left\{ \left[V_{C1} - V_{CE}(sat)Q_4 - V_{BE}(sat)Q_3 \right] + \left[V_{C1} - 2V_{BE}(sat) - V_D \right] \right\} e^{-\frac{t}{R_8C_1}}$$

$$\text{Then } V_{B6} = V_{C1} - \left[2V_{C1} - 3V_{BE}(sat) - V_{CE}(sat) - V_D \right] e^{-\frac{t}{R_8C_1}} \quad \text{.........(27)}$$

$$t = R_8C_1 \ln \left[\frac{2V_{C1} - 3V_{BE}(sat) - V_{CE}(sat) - V_D}{V_{C1} - V_{B6}} \right] \quad \text{........ (28)}$$

Solving Eq. (28) for $t = T_3 - T_2$, when $V_{B6} = 2V_\gamma + V_D$,

we obtain

$$T_3 - T_2 = R_8C_1 \ln \left[\frac{2V_{C1} - 3V_{BE}(sat) - V_{CE}(sat) - V_D}{V_{C1} - 2V_\gamma - V_D} \right] \quad \text{.........(29)}$$

$$\text{Thus } T_3 - T_2 = R_8C_1 \ln \left[\frac{2(5) - 3(0.55) - 0.1 - 1.5}{5 - 2(0.5) - 1.5} \right]$$

$$= 0.993 \; R_8C_1 \quad \text{.........(30)}$$

$$\text{and } T_5 - T_4 = 0.993 \; R_8C_1 \quad \text{.........(31)}$$

Now we investigate the effect of the time constant R_9C_2 on T_1 and T_2. First of all consider the moment at which Q_6, Q_7 are turned OFF and Q_3, Q_4 are turned ON (sat).

$$V_C = V_{C1} - V_{BE}(sat)Q_4 - V_{BE}(sat)Q_3$$

$$= V_{C1} - 2V_{BE}(sat) \qquad \ldots\ldots\ldots \qquad (32)$$

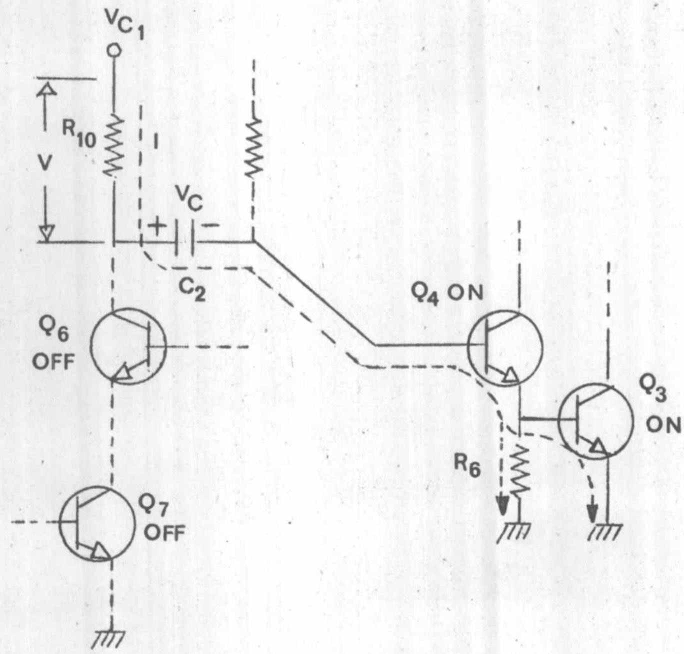

Fig. A 7

Then consider the next moment at which Q_7, Q_4 and Q_3 are turned OFF and Q_6, Q_5 are turned ON(sat) and we obtain

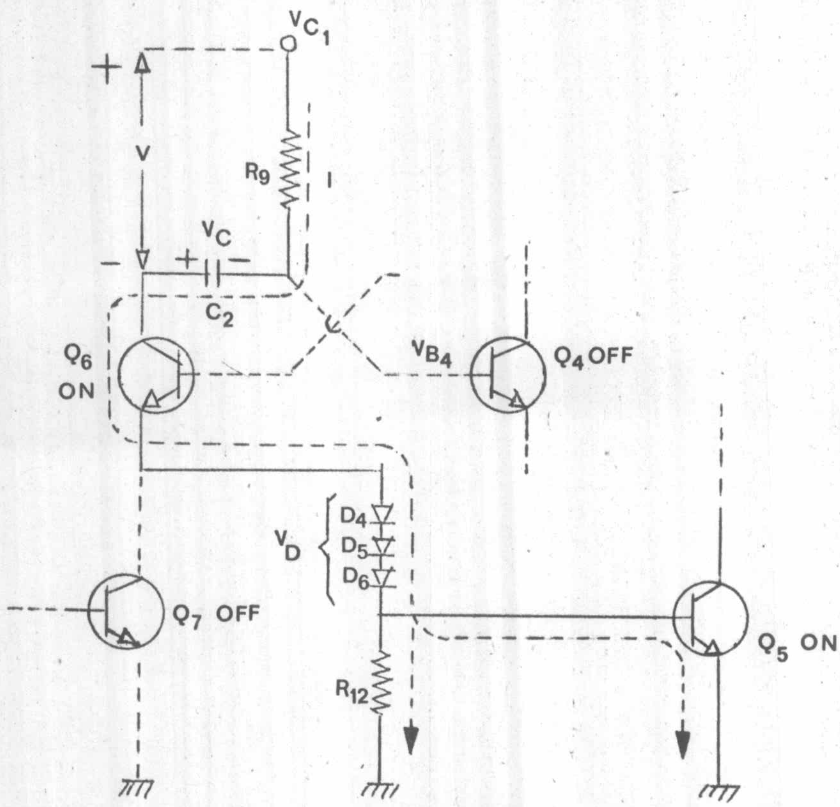

Fig. A 8

$$V = V\,u(t) = \begin{cases} 0, & T_o < t < T_1 \\ V_{C1} - V_{CE}(sat)Q_6 - V_D - V_{BE}(sat)Q_5, & \\ T_1 < t < T_2 & \end{cases}$$

Then $V = V_{C1} - V_{CE}(sat) - V_{BE}(sat) - V_D$ ..... (33)

Substituting Eq. (32), Eq.(33) into Eq. (21) and replace V_{B6} by V_{B4} yields

$$V_{B4} = V_{C1} - \left\{ \left[V_{C1} - V_{CE}(sat) - V_{BE}(sat) - V_D \right] + \left[V_{C1} - 2V_{BE}(sat) \right] \right\} e^{-\frac{t}{R_9 C_2}}$$

Therefore $$V_{B4} = V_{C1} - \left[2V_{C1} - 3V_{BE}(sat) - V_{CE}(sat) - V_D\right] e^{-\frac{t}{R_9C_2}} \quad \text{.... (34)}$$

$$t = R_9C_2 \ln\left[\frac{2V_{C1} - 3V_{BE}(sat) - V_{CE}(sat) - V_D}{V_{C1} - V_{B4}}\right] \quad \text{.... (35)}$$

The voltage at the base of Q_4 now starts to rise exponentially towards V_{C1} with a time constant R_9C_2 until V_{B4} reaches the cutin voltage of Q_4 $(V_{\gamma Q4})$ plus the cutin voltage of Q_3 $(V_{\gamma Q3})$ at $t = T_2$.

Hence $$V_{B4} = V_{\gamma Q4} + V_{\gamma Q4} = 2V_\gamma \quad \text{............... (36)}$$

then Eq.(35) becomes

$$T_2 - T_1 = R_9C_2 \ln\left[\frac{2V_{C1} - 3V_{BE}(sat) - V_{CE}(sat) - V_D}{V_{C1} - 2V_\gamma}\right]$$

$$= R_9C_2 \ln\left[\frac{2(5) - 3(0.55) - 0.1 - 1.5}{5 - 2(0.5)}\right]$$

$$= 0.523\ R_9C_2 \quad \text{........ (37)}$$

and $$T_4 - T_3 = 0.523\ R_9C_2 \quad \text{........ (38)}$$

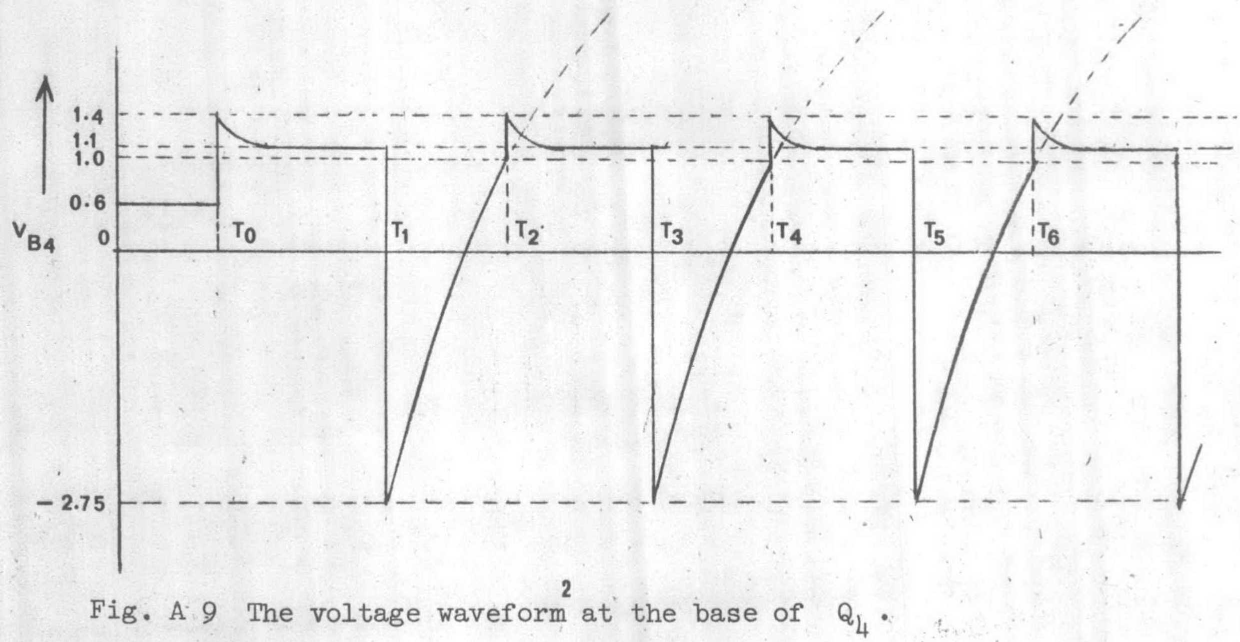

Fig. A 9 The voltage waveform at the base of Q_4.

Comparing the results from Eq. (25) with Eq. (30) and Eq. (31) we get

$$T_3 - T_2 = T_5 - T_4 = 0.993\ R_8C_1 < 1.25\ R_8C_1 = T_1 - T_o$$

And from Eq. (37) , Eq. (38) we obtain

$$T_2 - T_1 = T_4 - T_3 = 0.523\ R_9C_2$$

For optimum condition let

$$T_3 - T_2 = T_5 - T_4 = T_1 - T_o = 0.993\ R_8C_1$$

= Period of print drive

= 30 msec

$$R_8C_1 = \frac{30 \text{ msec}}{0.993} \qquad \text{.........} \qquad (39)$$

and $T_2 - T_1 = T_4 - T_3 = 0.523\ R_9C_2$

= Period of print advance or Release Time of Solenoid

= 25 msec

$$R_9C_2 = \frac{25 \text{ msec}}{0.523} \qquad \text{.........} \qquad (40)$$

From Eq. (19) $R_9 \leq (3.9K)\ hFE_{min}Q_4$

and Eq. (20) $R_8 \leq (2.4K) hFE_{min}Q_6$

Let $C_1 = C_2 = 0.05\ \mu F$ then the minimum current gain hFE_{min} of Q_4 and Q_6 can be found as follows.

From Eq. (39), Eq. (40) we obtain

$$R_8 = \frac{30\text{ msec}}{0.993C_1} = \frac{30\text{ msec}}{0.993\text{x}0.05\mu F} = 604.23\ K$$

$$\approx 560\ K$$

and $$R_9 = \frac{25\text{ msec}}{0.523C_2} = \frac{25\text{ msec}}{0.523\text{x}0.05\mu F} = 965.02\ K$$

$$\approx 910\ K$$

$$hFE_{min}Q_4 \geqq \frac{R_9}{3.9K} = \frac{910K}{3.9K} = 233.33$$

$$hFE_{min}Q_3 \geqq \frac{R_8}{2.4K} = \frac{560K}{2.4K} = 233.33$$

$$hFE_{min}Q_3 = hFE_{min}Q_4 \geqq 233$$

$$\approx 250$$

$$I_{R10} = \frac{V_{C1} - V_{CE}(sat)Q_6 - V_{CE}(sat)Q_7}{R_{10}} = \frac{5-0.1-0.1}{3K} = 1.6\text{ mA}$$

$$I_{R9} = \frac{V_{C1} - V_{D3} - V_{CE}(sat)Q_7}{R_9} = \frac{5-0.5-0.1}{910K} = 0.005\text{ mA}$$

$$I_{R8} = \frac{V_{C1} - V_{BE}(sat)Q_6 - V_{CE}(sat)Q_7}{R_8} = \frac{5-0.55-0.1}{560K} = 0.008\text{ mA}$$

Thus $I_C(sat)Q_7 = I_{R10} + I_{R9} + I_{R8} = 1.6\text{ mA} + 0.005\text{ mA} + 0.008\text{ mA}$

$$= 1.613\text{ mA}$$

Given hFE_{min} of $Q_7 = 30$

$$I_{BQ_7} = \frac{I_CQ_7}{hFE_{min}Q_7} = \frac{1.613\text{ mA}}{30} = 0.054\text{ mA}$$

Select R_{13} = 100 K and C_3 = 0.01 μF for minimum noise due to current $I_B Q_7$

$$I_{D7} = I_B Q_7 + \frac{V_{BE}\,(sat) Q_7}{R_{13}}$$

$$= 0.054 \text{ mA} + \frac{0.55 \text{ V}}{100 \text{ K}}$$

$$\doteq 0.0595 \text{ mA} \qquad \text{............ (41)}$$

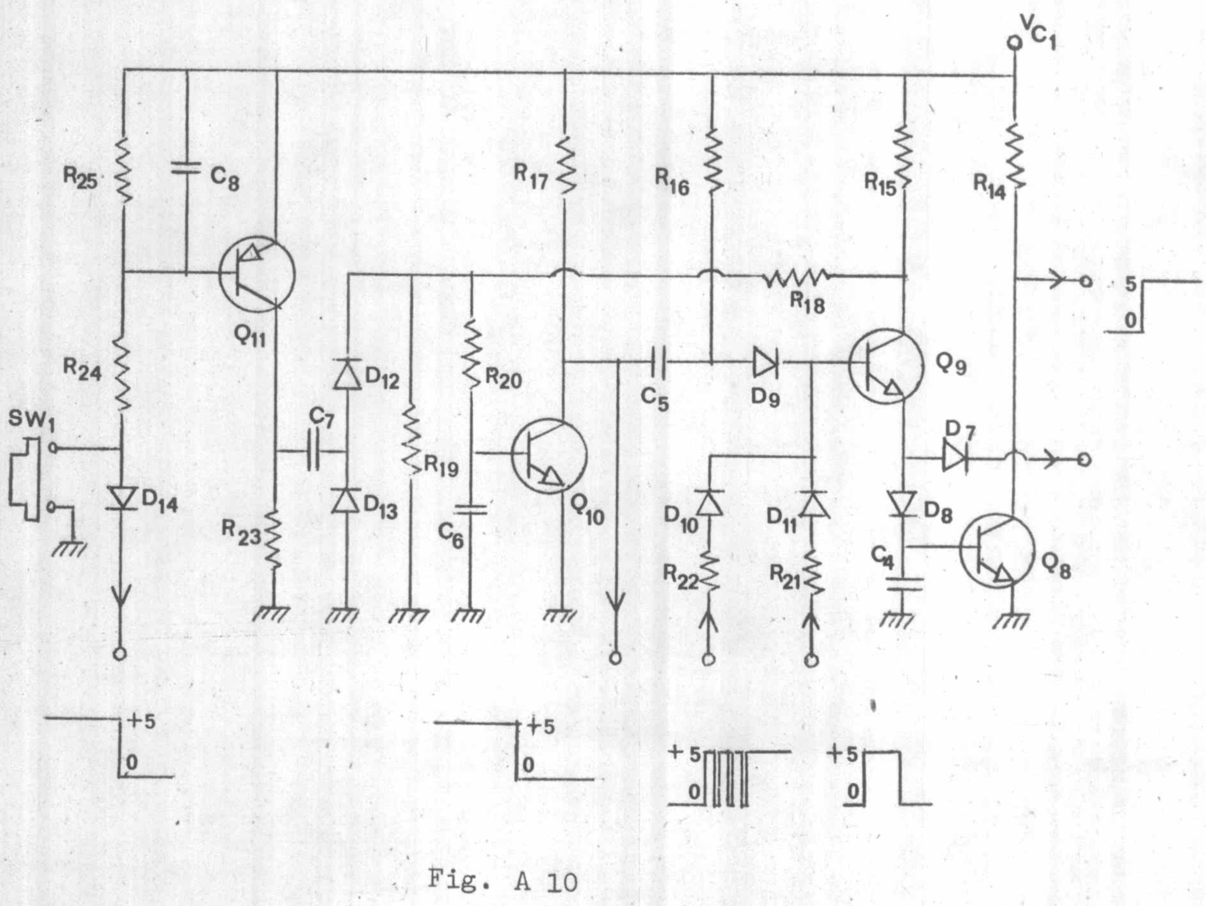

Fig. A 10

Given pull up resistor $R_{14} = 2\text{ K}$ and $hFE_{min}Q_8 = 30$

$$I_B Q_8 = \frac{V_{C1} - V_{BE}(sat)Q_8}{R_{14} hFE_{min} Q_8} = \frac{5 - 0.1}{2K(30)} = 0.082 \text{ mA}$$

Thus $I_C Q_9 \approx I_E Q_9 \geq I_{D7} + I_B Q_8 = 0.0595 + 0.082 = 0.142$ mA

Let us choose $I_C Q_9 \approx 5\ (0.142 \text{ mA}) = 0.7$ mA for over drive saturation.

$$\text{Therefore } R_{15} = \frac{V_{C1} - V_{CE}(sat)Q_9 - V_{D8} - V_{BE}(sat)Q_8}{I_C Q_9} = \frac{5-0.1-0.5-0.55}{0.7 \text{ mA}}$$

Then $R_{15} \approx 5.6$ K

Choose $hFE_{min} Q_9 = 30$ so that

$$I_B Q_9 = \frac{I_C Q_9}{hFE_{min} Q_9} = \frac{0.7 \text{ mA}}{30} = 0.023 \text{ mA}$$

$$\text{Thus } R_{16} = \frac{V_{C1} - V_{D9} - V_{BE}(sat)Q_9 - V_{D8} - V_{BE}(sat)Q_8}{I_B Q_9}$$

$$= \frac{5 - 0.5 - 0.55 - 0.5 - 0.55}{0.023} = 126 \text{ K}$$

$$\approx 120 \text{ K} \qquad \text{..........} \qquad (42)$$

At $t < T_o$, Q_{10} is turned OFF and Q_9 is driven ON(sat), so that V_{B9} and V_{D9} drop by $I_{R16}R_{16}$ volts.

Therefore the voltage on capaciotr C_5 charges with time constant $R_{17}C_5$.

$$V_C = V_{C1} - V_{D9} - V_{BE}(sat)Q_9 - V_{D8} - V_{BE}(sat)Q_8 \quad \text{at} \quad t < T_o(-)$$

$$= V_{C1} - 2\left[V_{BE}(sat) + V_D \right]$$

The triggerring signal occurs at $t = T_o$. Q_{10} goes ON and Q_9 goes OFF. The voltage V_{C10} and $V_{B9} + V_{D9}$ drop abruptly by the same amount $I_{17}R_{17}$

$$\text{Since } V = V\,u(t) = I_{17}\,R_{17} = \begin{cases} 0, & t < T_o \\ V_{C1} - V_{CE}(sat)Q_{10}, & t = T_o \end{cases}$$

Substituting V, V_C and replacing V_{B6} by $V_{B9} + V_{D9}$ into Eq.(21) yields

$$V_{B9} + V_{D9} = V_{C1} - \left\{\left[V_{C1} - V_{CE}(sat)Q_{10}\right] + \left[V_{C1} - 2\left(V_{BE}(sat) + V_D\right)\right]\right\} e^{-\frac{t}{R_{16}C_5}}$$

$$= V_{C1} - \left[2V_{C1} - 2\left(V_{BE}(sat) + V_D\right) - V_{CE}(sat)\right] e^{-\frac{t}{R_{16}C_5}} \quad \ldots (43)$$

The voltage $V_{B9} + V_{D9}$ now starts to rise exponentially with time constant $R_{16}C_5$ towards V_{C1}. Until $V_{BE}Q_9 + V_{BE}Q_8$ reaches the cutin voltage $2V_\gamma$ all voltages at the other electrodes remain unaltered. Thus at time $T - T_o$ we obtain

$$V_{B9} + V_{D9} = V_{D9} + V_{\gamma Q9} + V_{D8} + V_{\gamma Q8} = 2(V_\gamma + V_D)$$

From Eq. (43) becomes

$$T - T_o = R_{16}C_5 \ln\left[\frac{2V_{C1} - 2(V_{BE}(sat) + V_D) - V_{CE}(sat)}{V_{C1} - (V_{B9} + V_{D9})}\right]$$

$$T - T_o = R_{16}C_5 \ln\left[\frac{2V_{C1} - 2\left(V_{BE}(sat) + V_D\right) - V_{CE}(sat)}{V_{C1} - 2(V_\gamma + V_D)}\right] \qquad \ldots\ldots (44)$$

$$= R_{16}C_5 \ln\left[\frac{2(5) - 2(0.55 + 0.5) - 0.1}{5 - 2(0.5 + 0.5)}\right]$$

$$= 0.955 \; R_{16}C_5$$

Then $T - T_o \geq$ Total period of time for data register

$\geq$ (30 + 25) msec x 6 character

$\geq$ 330 msec

$0.955 \; R_{16}C_5 \geq 330$ msec

$$C_5 = \frac{330 \text{ msec}}{0.955 \; R_{16}} = \frac{330 \text{ msec}}{0.955 \times 120K} = 2.88 \; \mu F$$

Choose $C_5 = 5\mu F$ in order to ensure that the period of time $T - T_o$ will be greater than 330 msec

R_{17} is made equal to R_{15} = 5.6 K in order to get symmetrical circuit configuration.

So that $I_{B\,min}Q_{10} \geq \dfrac{V_{C1} - V_{CE}(sat)Q_{10}}{R_{17}\; hFE_{min}Q_{10}}$ and Q_9 is identical to Q_{10} because of symmetry

Then $hFE_{min}Q_{10} \approx hFE_{min}Q_9 = 30$

$$I_{B\,min}Q_{10} \geq \frac{5 - 0.1}{5.6K \times 30} = 0.03 \text{ mA} \qquad \ldots\ldots\ldots (45)$$

Because of Q_9 is turned ON(sat) and Q_{10} is turned OFF and $I_B Q_{10} \approx 0$.

Then $V_{t_1} \leqq V_{\gamma Q_{10}}$

where $V_{t_1} = \dfrac{V_C(sat)Q_9 \times R_{19}}{R_{18} + R_{19}}$,

$$R_t = R_{18}//R_{19} = \frac{R_{18}R_{19}}{R_{18} + R_{19}}$$

and $V_{\gamma Q_{10}}$ = cutin voltage of Q_{10} = 0.5 volts .

Therefore $\dfrac{V_C(sat)Q_9 \times R_{19}}{R_{18} + R_{19}} \leqq 0.5$

$$\frac{\left[V_{CE}(sat)Q_9 + V_{D8} + V_{BE}(sat)Q_8\right] R_{19}}{R_{18} + R_{19}} \leq 0.5$$

$$\frac{\left[0.1 + 0.5 + 0.55\right] R_{19}}{R_{18} + R_{19}} = 0.4 \text{ (by assumption)}$$

$$R_{18} \approx 2R_{19}$$

Let us choose $R_{18} + R_{19} > R_{15} \approx 10\ R_{15}$ to minimize the loading at collector of Q_9 we get

$$2\ R_{19} + R_{19} = 10R_{15} = 10(5.6K) = 56\ K$$

$$R_{19} = \frac{56K}{3} = 18\ K$$

$$R_{18} = 2R_{19} = 2 \times 18K = 36\ K ,$$

and R_{18} is chosen to be 33 K

In the case of Q_{10} being turned ON(sat), Q_9 turned OFF

$$I_{B\,min}Q_{10} = \frac{V_{t_2} - V_{BE}(sat)Q_{10}}{R_{t_2} + R_{20}} \quad .... \quad (46)$$

where $V'_{t_2} = \dfrac{V_{C1}\,R_{19}}{R_{15} + R_{18} + R_{19}}$ and $R_{t_2} = (R_{15} + R_{18})//R_{19}$

$$= \frac{(R_{15} + R_{18})R_{19}}{R_{15} + R_{18} + R_{19}}$$

Sot that $V_{t_2} = \dfrac{5 \times 18\text{ K}}{5.6\text{K} + 33\text{K} + 18\text{K}} = 1.59$ volts ,

$$R'_{t_2} = \frac{(5.6\text{K} + 33\text{K})18\text{K}}{5.6\text{K} + 33\text{K} + 18\text{K}} = 12.27\text{ K}$$

Substituting V_{t_2}, R_{t_2} and $I_{B\,min}Q_{10} = 0.03$ mA into Eq. (46) yields

$$0.03\text{ mA} = \frac{1.59 - 0.55}{12.27\text{K} + R_{20}}$$

$$R_{20} = 22.39\text{ K} \approx 22\text{ K}$$

To avoid noise interference at the base of Q_{10}, C_6 is chosen to be 0.01 μF for delay time constant $R_{20}C_6$ in form of integrator circuit.

With $R_{23} = 10$ K and $C_7 = 0.1$ μF, D_{13} will discharge the capacitor voltage with time constant 1 msec

Therefore the collector current saturation of Q_{11} is

$$I_C(sat)Q_{11} = \frac{V_{C1} - V_{CE}(sat)Q_{11}}{R_{23}} = \frac{5 - 0.1}{10\text{K}} \approx 0.5\text{ mA}$$

Because of high speed triggerring, collector current should be greater than $I_C(sat)Q_{11}$

Thus $I_C(sat)Q_{11} \geq 0.5$ mA

Assume $I_C(sat)Q_{11} = 10$ mA

$$I_BQ_{11} = \frac{I_C(sat)Q_{11}}{hFE_{min}Q_{11}}$$

Let us choose $hFE_{min}Q_{11} = 30$

$$I_BQ_{11} = \frac{10 \text{ mA}}{30} = 0.33 \text{ mA}$$

To reduce noise interference and leakage current

I_{CBO} choose $C_8 = 4700$ pF and $R_{25} = 10$ K

$$\text{Thus} \quad R_{24} = \frac{V_{C1} - V_{BE}(sat)Q_{11} - V_{D14}}{I_BQ_{11} - \frac{V_{BE}(sat)Q_{11}}{R_{25}}}$$

$$= \frac{5 - 0.55 - 0.5}{0.33 \text{ mA} - \frac{0.55}{10K}} = \frac{3.95}{0.385 \text{ mA}}$$

Then $R_{24} = 10$ K

R_{21} and R_{22} are current limiting resistors of diode gate D_{11}, D_{10} and they are chosen to be 10 K each .

Choose C_4 = 0.022 µF for time delay of the Start Data Transfer signal after Print Command signal.

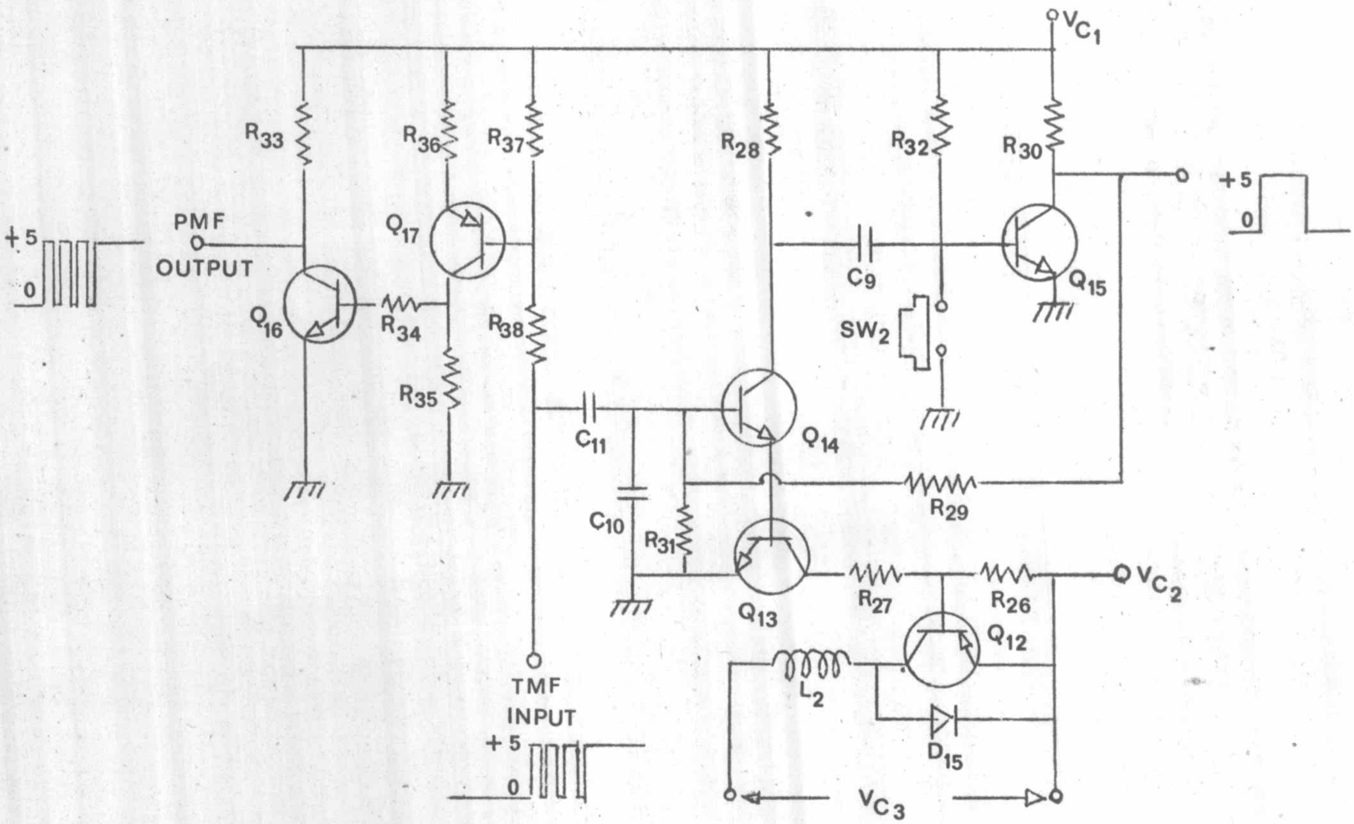

Fig. A 11

When transistor Q_{12} is turned ON, the voltage V_{CE} is quite low, being only 0.1 ~ 0.3 volts for silicon transistor and is driven well into saturation. Therefore the initial inductor current increases linearly with time. This peak current is limited to 1 ampere by the winding resistance of coil L_2. At the moment the transistor Q_{12} is turned OFF a spike signal appears across the inductor L_2. This voltage spike is limited by protection diode D_{15} by conducting the inductor current through winding resistance of coil L_2. The spike will then decay exponential to zero with very small time constant.

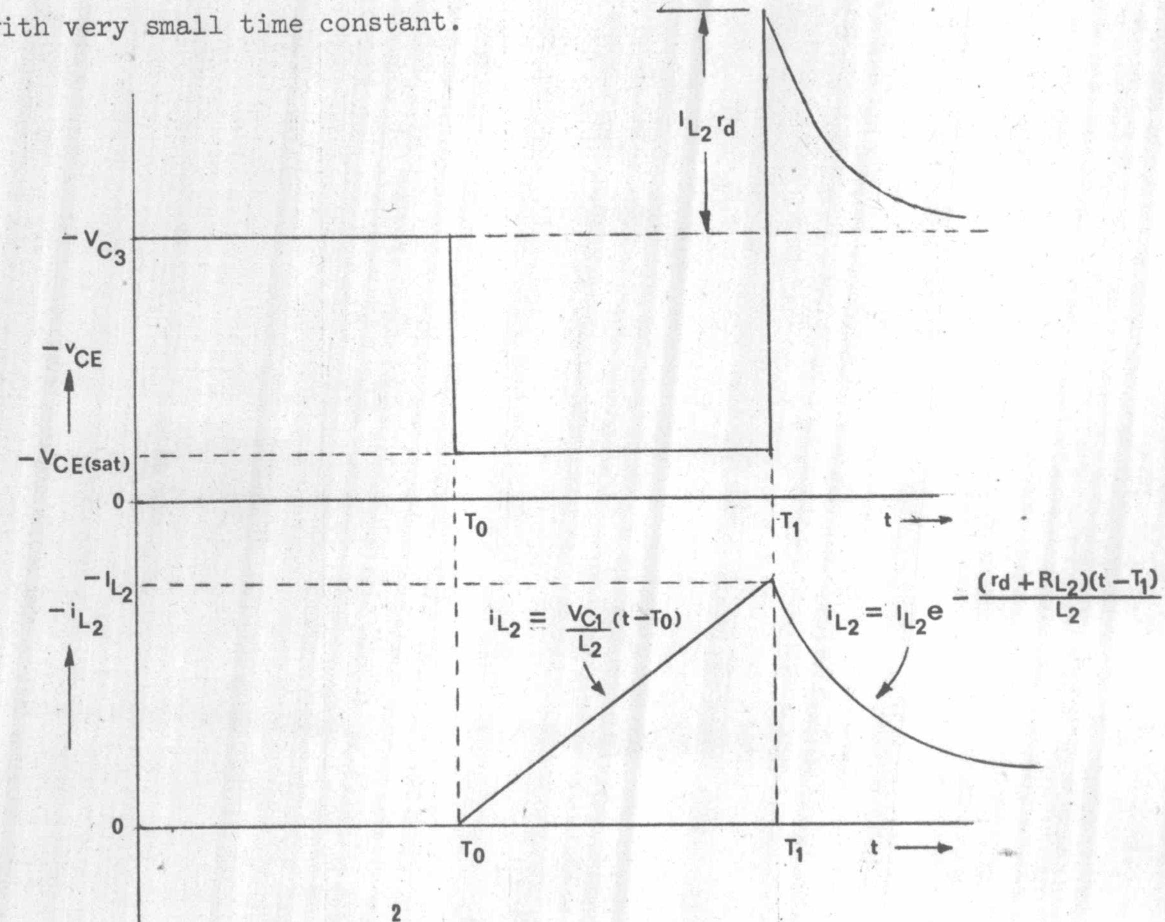

Fig. A 12

To simplify calculations we ordinarily neglect this time constant.

Thus, the upper limit of collector current $I_C Q_{12}$ is 1 A.

$$\text{Since } I_C Q_{13} = I_{R_{26}} + I_B Q_{12} = \frac{V_{BE}(\text{sat}) Q_{12}}{R_{26}} + \frac{I_C Q_{12}}{hFE_{min} Q_{12}}$$

We use the minimum current gain $hFE_{min} Q_{12} = 25$ and $R_{26} = 100\ \Omega$ for leakage current I_{CBO} and $V_{BE}(\text{sat}) = 0.75$ volt at high current conduction

Next the collector current of Q_{13} can be found

$$I_C Q_{13} = \frac{0.75}{100} + \frac{1A}{25} = 47.5 \text{ mA}$$

Thus $$R_{27} = \frac{V_{C2} - V_{BE}(sat)Q_{12} - V_{CE}(sat)Q_{13}}{I_{CQ_{13}}}$$

$$= \frac{2.6 - 0.75 - 0.3}{47.5 \text{ mA}}$$ (at high current conduction

$V_{CE}(sat) \approx 0.3$ V)

$$R_{27} \approx 33\ \Omega$$

Then, since $I_C Q_{14} \approx I_E Q_{14} = I_B Q_{13} = \dfrac{I_C Q_{13}}{hFE_{min} Q_{13}}$

Let us choose $hFE_{min} Q_{13} = 30$ and the collector current of Q_{14} now becomes

$$I_C Q_{14} = \frac{47.5 \text{ mA}}{30} = 1.58 \text{ mA}$$

and $$R_{28} = \frac{V_{C1} - V_{CE}(sat)Q_{14} - V_{BE}(sat)Q_{13}}{I_C Q_{14}}$$

$$= \frac{5 - 0.1 - 0.7}{1.58 \text{ mA}}$$

$$= 2.7 \text{ K}$$

$$I_B Q_{14} = \frac{I_C Q_{14}}{h_{FEmin} Q_{14}} = \frac{1.58 \text{ mA}}{30} = 0.053 \text{ mA}$$

During the period of PRINT DRIVE SIGNAL Q_9 and Q_8 are latched to saturation through R_{21} and D_{11}. At the same time Q_{15} is turned cutoff. So that

$$V_{C15}(Q_{15}\text{ turns off}) = \frac{R_{21}V_{C1}}{R_{21}+R_{30}} + \frac{R_{30}\left[V_{D11}+V_{BE}(sat)Q_9+V_{D8}+V_{BE}(sat)Q_8\right]}{R_{21}+R_{30}}$$

$$= \frac{R_{21}V_{C1} + 2R_{30}\left[V_{BE}(sat) + V_D\right]}{R_{21}+R_{30}}$$

$$V_{C15}(\text{Thévenin voltage source}) = \frac{10K(5) + 2R_{30}(0.55+0.5)}{10K + R_{30}}$$

and R_t (Thévenin resistance) $= R_{21}//R_{30} = \dfrac{R_{21}\times R_{30}}{R_{21}+R_{30}} = \dfrac{10K \times R_{30}}{10K + R_{30}}$

By inspection $R_{30} + R_{21} << R_{16}$ for Q_9 saturation ($R_{16} = 120$ K). We choose $R_{30} = R_{21} = 10$ K

$$\text{Then } V_{C15} = \frac{10K(5) + \left[2\times 10K\ (0.55+0.5)\right]}{10K + 10K} = 3.55 \text{ volts}$$

$$\text{and } R_t = \frac{10K \times 10K}{10K + 10K} = 5K$$

$$V_{BE}(sat)Q_{14} + V_{BE}(sat)Q_{13} = \frac{V_{C15}R_{31}}{R_{31}+R_{29}+R_t} - I_BQ_{14}\left[(Rt + R_{29})//R_{31}\right]$$

$$0.55 + 0.7 = \frac{3.55\ R_{31}}{R_{31}+R_{29}+5K} - 0.053\text{ mA}\left[(5K + R_{29})//R_{31}\right]$$

$$1.25 = \frac{3.55\ R_{31}}{R_{31}+R_{29}+5K} - 0.053\text{ mA}\,\frac{R_{31}(5K+R_{29})}{R_{31}+R_{29}+5K}$$

$$R_{29} = \frac{R_{31}(3.55-1.25)}{0.053\text{ mA } R_{31} + 1.25} - 5K$$

Let $R_{31} = 100$ K

$$R_{29} = \frac{100K\ (3.55 - 1.25)}{0.053\text{ mA} \times 100K + 1.25} - 5K \sim 30\text{ K}$$

$$hFE_{min}Q_{15} = hFE_{min}Q_{14} = 30$$

$$R_{32} = \left(\frac{V_{C1} - V_{BE}(sat)Q_{15}}{I_C Q_{15}}\right) hFE_{min}Q_{15}$$

and $$I_C(sat)Q_{15} = \frac{V_{C1} - V_{CE}(sat)Q_{15}}{R_{30}}$$

$$R_{32} \leqq \frac{\left[V_{C1} - V_{BE}(sat)Q_{15}\right] R_{30}\ hFE_{min}Q_{15}}{V_{C1} - V_{CE}(sat)Q_{15}}$$

$$\leqq \frac{5 - 0.55\quad 10K \times 30}{5-0.1} = 267.53\ K$$

Thus $R_{32} \approx 220\ K$

The period of PRINT DRIVE SIGNAL = 30 msec = T

Since $$T = R_{32}C_9 \ln \left[\frac{V + V_C}{V_{C1} - V_B}\right]$$

where $V = V_{C1} - V_{CE}(sat)Q_{14} - V_{BE}(sat)Q_{13} = 5-0.1-0.7 = 4.2$ volts

$V_C = V_{C1} - V_{BE}(sat)Q_{15} = 5-0.55 = 4.45$ volts

$V_B = V_{\gamma}Q_{15} = 0.5$ volts

and $T = 30$ msec

Then $$30\text{ msec} = R_{32}C_9 \ln \left[\frac{4.2 + 4.45}{5 - 0.5}\right]$$

$$30\text{ msec} = 0.642\ R_{32}C_9$$

and $$C_9 = \frac{30\text{ msec}}{0.642\ R_{32}} = \frac{30\text{ msec}}{0.642 \times 220\ K} \approx 0.2\ \mu F$$

The capacitor voltage (C_{10}) is the voltage divider. We obtain

$$V_{C1}\left(\frac{C_{11}}{C_{11}+C_{10}}\right) \geqq V_{BE}(sat)Q_{14} + V_{BE}(sat)Q_{13}$$

$$\geqq 2V_{BE}(sat)$$

$$\text{Then} \quad C_{11} \geqq C_{10}\left[\frac{2V_{BE}(sat)}{V_{C1} - 2V_{BE}(sat)}\right]$$

Since $V_{C1} = 5$ V, $V_{BE}(sat) \approx 0.7$ V and let $C_{10} = 0.02$ µF to minimize the noise interference

$$\text{Then } C_{11} \geqq 0.02\ \mu F \left[\frac{2 \times 0.7}{5-2\times0.7}\right] = 0.008\ \mu F$$

Choose C_{11} 0.01 µF

In most practical buffer circuit for logic signal, the output impedance in the case of logic 0 is very low and the input impedance is chosen to be as high as possible. For high input impedance at the input of the buffer R_{38} and R_{36} are chosen to be suffciently large.

To simplify calculations, we assume that R_{38} and R_{36} can be considered 10K and 4.7 K respectively.

By inspection with $R_{37} = 20$ K leakage current I_{CBO}, can be considerably reduced. It is easily shown that for the case of transistor Q_{17} being turned ON.

The input impedance at the base of Q_{17} (let $hFE_{min}Q_{17} = 30$)

$$Z_iQ_{17} \approx (1 + hFE_{min}Q_{17})R_{35} \approx hFE_{min}Q_{17}R_{35} = 30 \times 4.7\text{ K}$$

$$\approx 141\text{ K}$$

$$\text{Since } I_BQ_{17} = \frac{\frac{V_{C1}R_{37}}{R_{37}+R_{38}} - V_{BE}(sat)Q_{17}}{\frac{R_{37}R_{38}}{R_{37}+R_{38}} + Z_iQ_{17}}$$

$$= \frac{\frac{5 \times 20K}{20K + 10K} - 0.55}{\frac{20K \times 10K}{20K + 10K} + 141K} \approx 0.0188 \text{ mA}$$

$$\text{Then } I_EQ_{17} = (hFE_{min}Q_{17} + 1)I_BQ_{17} = (30 + 1)0.0188 \text{ mA}$$

$$= 0.58 \text{ mA}$$

$$\text{and } V_CQ_{17} = V_{C1} - V_{CE}(sat)Q_{17} - I_EQ_{17}R_{36} = 5-0.1-0.58 \text{ mA} \times 4.7K$$

$$= 2.17 \text{ volts}$$

Let us choose pull down resistor $R_{35} = 10K$, we obtain

$$R_{34} = \frac{V_CQ_{17} - V_{BE}(sat)Q_{16}}{I_EQ_{17} - \frac{V_CQ_{17}}{R_{35}}} = \frac{2.17 - 0.7}{0.58 \text{ mA} - \frac{2.17}{10K}}$$

$$\approx 1.8 \text{ K}$$

Since $hFE_{min}Q_{16} = 30$ we obtain

$$\text{Sink current } I_CQ_{16} = (I_EQ_{17} - \frac{V_CQ_{17}}{R_{35}})\, hFE_{min}Q_{16}$$

$$= (0.58 \text{ mA} - \frac{2.17}{10K})30$$

$$\approx 10 \text{ mA}$$

Let us choose $I_{R_{33}} = 5 \text{ mA} < I_CQ_{16} = 10 \text{ mA}$

$$\text{Then } R_{33} = \frac{V_{C1} - V_{CE}(sat)Q_{16}}{I_{R_{33}}} = \frac{5 - 0.1}{5 \text{ mA}} \approx 1 \text{ K}$$

It can be concluded that the buffer output of Q_{16} can still carry load current up to $I_C Q_{16} - I_{R_{33}} = 10\ mA - 5\ mA = 5\ mA$ to drive gate input

A.3 RF ON-OFF and Motor Control Circuit

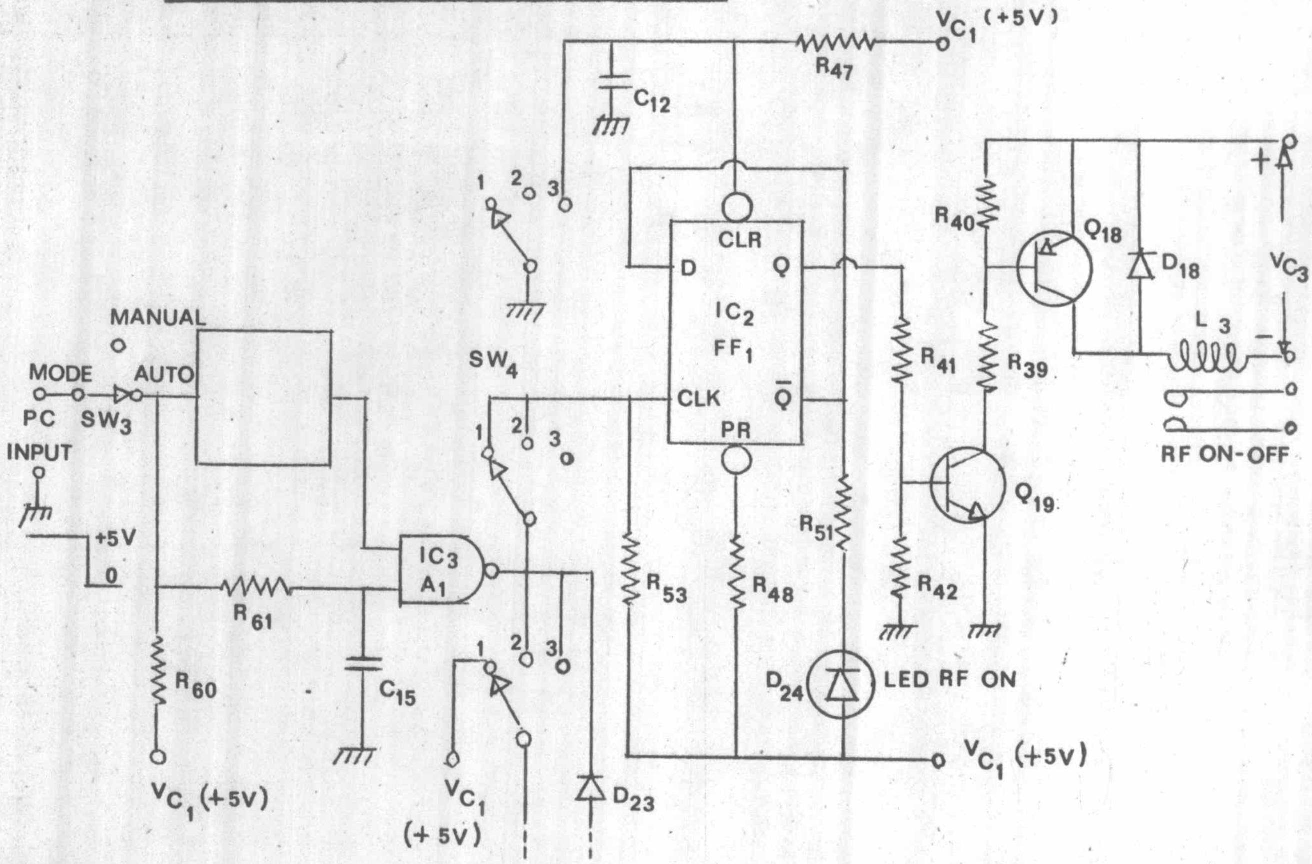

Fig. A 13

Since the Relay L_3 is driven by the transistor driver Q_{18} and the winding resistance of the Relay L_3 is about $75\ \Omega$ the collector current of Q_{18} is given by

$$I_C Q_{18} = \frac{V_{C_3}}{R_W}$$

Where V_{C_3} = Supply voltage = 24 volts

R_w = Winding resistance = 75 Ω

Then $I_C Q_{18}$ = 320 mA

The value of R_{39} is given by

$$R_{39} \leqq \frac{V_{C_2} - V_{BE}(sat)Q_{18} - V_{CE}(sat)Q_{19}}{I_C Q_{19}}$$

$$R_{39} \leqq \frac{V_{C_2} - V_{BE}(sat)Q_{18} - V_{CE}(sat)Q_{19}}{\frac{I_C Q_{18}}{hFE_{min} Q_{18}} + \frac{V_{BE}(sat)Q_{18}}{R_{40}}}$$

Choose R_{40} = 220 Ω for leakage current I_{CBO} and hFE_{min} of Q_{18} = 25. We obtain

$$R_{39} \leqq \frac{2.6 - 0.7 - 0.1}{\frac{320 \text{ mA}}{25} + \frac{0.7}{220}} = \frac{1.8}{15.982 \text{ mA}} = 112.6 \ \Omega$$

R_{39} is approximated to be 100 Ω

Let us choose R_{42} = 1 K for leakage current I_{CBO} and hFE_{min} for Q_{19} = 30. We get

$$R_{41} \leqq \frac{Q(FF_1)\text{output voltage(logical 1)} - V_{BE}(sat)Q_{19}}{\frac{I_C Q_{19}}{hFE_{min} Q_{19}} + \frac{V_{BE}(sat)}{R_{42}}}$$

$$\leqq \frac{5 - 0.55}{\frac{15.982 \text{ mA}}{30} + \frac{0.7}{1K}} = 3.61 \text{ K}$$

Then $R_{41} \approx 3.3$ K

When the LED is turned ON. We obtain

$$R_{51} = \frac{V_{C_1} - \overline{Q}(FF_1) \text{ output voltage(logical 0)} - V_{D_{24}}}{I_{D_{24}}}$$

Where $V_{C_1} = 5$ V

$\overline{Q}$(FF) output voltage(logical 0) ≈ 0,

$V_{D_{24}}$ = Forward LED voltage drop $\approx$ 2 volts,

$I_{D_{24}}$ = 10 mA for light emitting,

Then $R_{51} = \frac{5 - 0 - 2}{10 \text{ mA}} = 300\ \Omega$

The FF_1 and FF_2 are dual flip-flops with single D inputs and separate preset and clear inputs. The devices are D positive edge-triggered. The TRUTH TABLE is shown below

TRUTH TABLE

INPUTS				OUTPUT	
PR	CLR	CLK	D	Q	$\overline{Q}$
L	H	X	X	H	L
H	L	X	X	L	H
L	L	X	X	H	H
H	H	↑	H	H	L
H	H	↑	L	L	H
H	H	L	X	Q	$\overline{Q}_o$

PR = PRESET	INPUT		X = Don't care	
CLR = CLEAR	INPUT		$\uparrow$ = Positive edge-triggered	
CLK = CLOCK	INPUT		L = Logical 0 $\approx$ 0 volts	
D = D	INPUT		H = Logical 1 = 5 volts	

From the truth table one can modify this type of Flip-Flop into T (toggling) type by simply connecting the $\overline{Q}$ output to the D input. When a clock pulse is applied, the output changes state once every input cycle, thus completing one cycle for every two input cycles. This is the action required in the case of latching the states of RF ON and RF OFF.

When the +5 volts is applied to the system the Q output goes to low (logical 0) and $\overline{Q}$ output goes to high (logical 1) and the RF is in the OFF state. The level at the CLEAR input is delayed by $R_{47}C_{12}$ time constant incomparison with the level at the PRESET input.

Let us choose $R_{47} = R_{48} = 10$ K and $C_{12} = 1$ µF for CLEAR delay input level

R_{53}, the pull up resistor for high speed CLOCK input, is chosen to be 10 KΩ . Owing to the similarity of the RF and Motor Control circuits, $L_4 = L_3$, $Q_{20} = Q_{18}$, $Q_{21} = Q_{19}$, $D_{19} = D_{18}$, $R_{44} = R_{40}$, $R_{43} = R_{39}$, $R_{46} = R_{42}$, $R_{45} = R_{41}$, $R_{52} = R_{51}$, $R_{50} = R_{48}$, $R_{49} = R_{47}$, $R_{54} = R_{53}$ and $C_{13} = C_{12}$

The conduction of the diode D_{22} is used to discharge the capacitor voltage at C_{13} by the current feed through the microswitch. When the monochromator is in the desired position the contactor of the microswitch is grounded and the ground potential (0 V) is coupled by

C_{13} to the CLEAR input to reset Q output to low state (logical 0) and the motor is turned OFF.

D_{21} and D_{20} constitutes OR gate providing SW_5 or Q output signal to turn ON the motor which drives the spectrometer arm to the desired position.

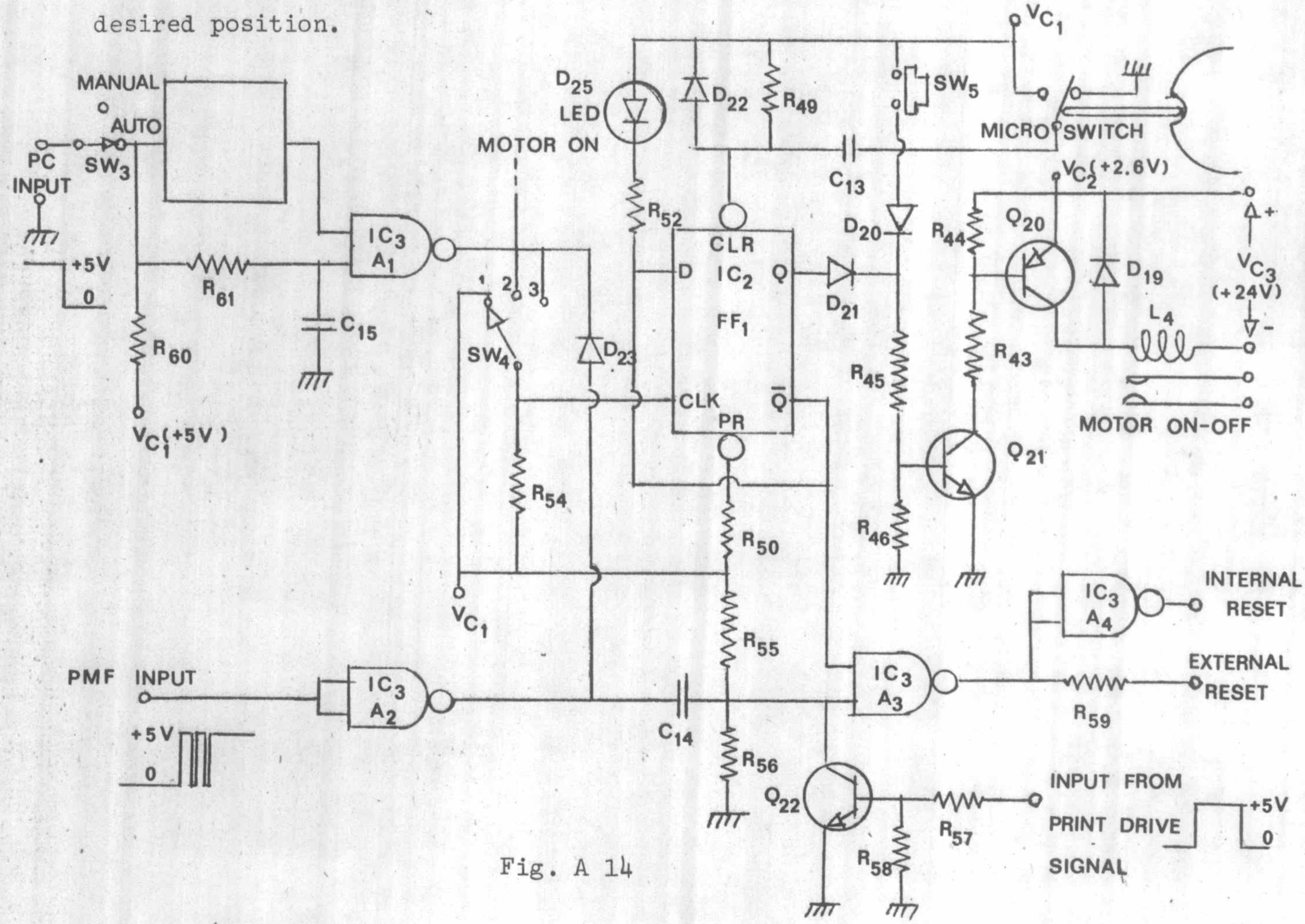

Fig. A 14

In case the output of Gate A_3 is logical 0 the input of Gate A_3 must be logical 1 which is at least +2.4 volts. The voltage divider R_{55} and R_{56} must divide the +5 volts supply voltage to get +2.5 volts at the input of Gate A_3

For convenience, we choose R_{55} = R_{56} = 10 K and coupling capacitor C_{14} = 0.1 μF

Switching diode D_{23} provides negative going edge triggering reset signal at the output of Gate A_3

The transistor Q_{22} is to inhibit Gate A_3 to hold reset signal as long as the PRINT DRIVE signal is stopped.

$$R_{57} \leqq \frac{\left[\dfrac{V_{C_1} - V_{BE}(sat)Q_{14} - V_{BE}(sat)Q_{13}}{R_{30} + R_{29}}\right] R_{29} + V_{BE}(sat)Q_{14} + V_{BE}(sat)Q_{13}}{\dfrac{I_CQ_{22}}{hFE_{min}Q_{22}} + \dfrac{V_{BE}(sat)Q_{22}}{R_{58}}}$$

$$- \; (R_{29}//R_{30})$$

$$\text{Since } I_CQ_{22} = \frac{V_{C_1} - V_{CE}(sat)Q_{22}}{R_{55}} + \frac{V_{C_1} - V_{BE}(sat)Gate - V_{CE}(sat)Q_{22}}{R_{Gate}}$$

Where $V_{BE}(sat)Gate \approx 0.7$ volts

and $R_{Gate} = 4K$

$$I_CQ_{22} = \frac{5 - 0.1}{10\ K} + \frac{5 - 0.7 - 0.1}{4K} = 5.95\ mA$$

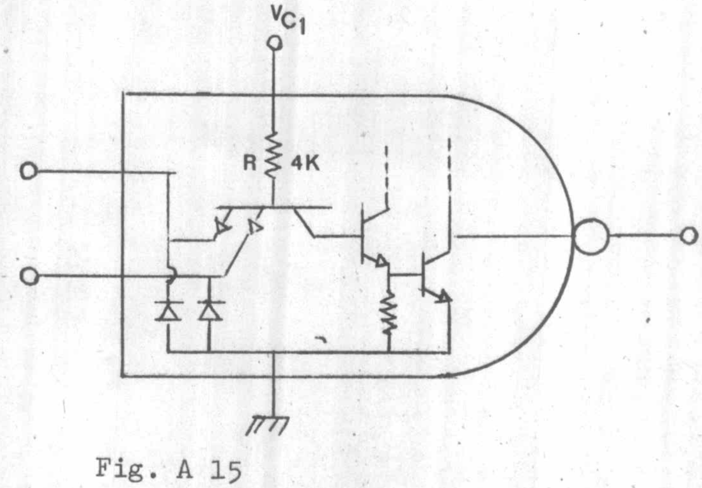

Fig. A 15

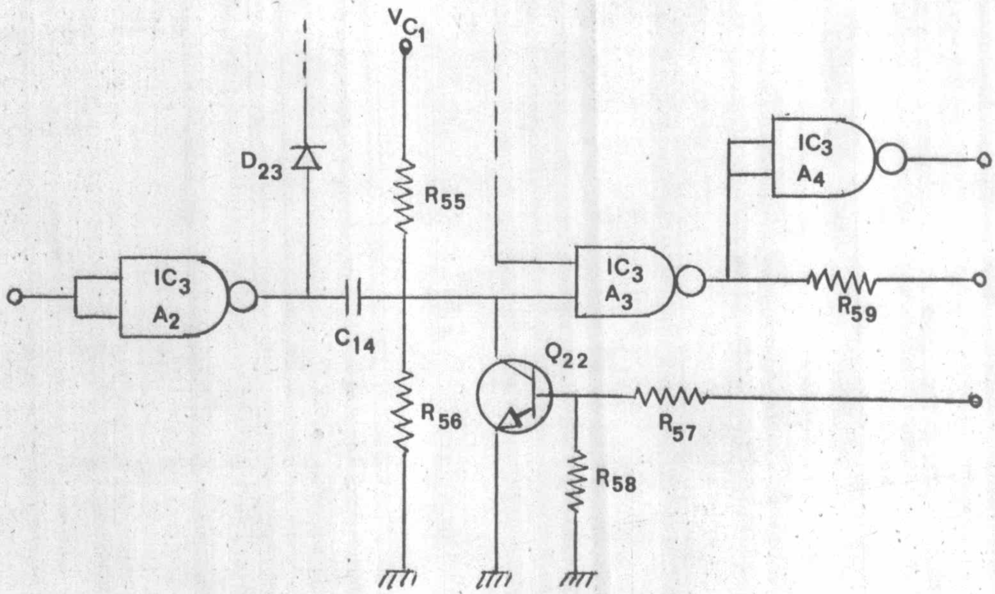

Fig. A 16

Let hFE_{min} of Q_{22} = 30 and R_{58} = 5.6 K for leakage current I_{CBO}

$$\text{Then } R_{57} \leqq \frac{\left(\frac{5 - 0.55 - 0.7}{10K + 30K}\right)30K + 0.55 + 0.7}{\frac{5.95 \text{ mA}}{30} + \frac{0.7}{5.6K}} - \frac{30K \times 10K}{30K + 10K}$$

$$\leqq 5.06 \text{ K}$$

$$\approx 4.7 \text{ K}$$

To delay the PC(PRINT COMMAND) signal at the input of Gate A_1 with $R_{61}C_{15}$ time constant, R_{61} is chosen to be 220 Ω and C_{15} equals 0.1 μF.

In case the switch SW_3 is at manual position the pull up resistor R_{60} (10 K) provides a logical 1 at the input of the PRESET COUNTER.

The resistor R_{59}(100 Ω) at the EXTERNAL RESET prevents the Gate A_3 from short circuiting to the +5 volts supply.

A.4 Preset Counter and Display Circuit

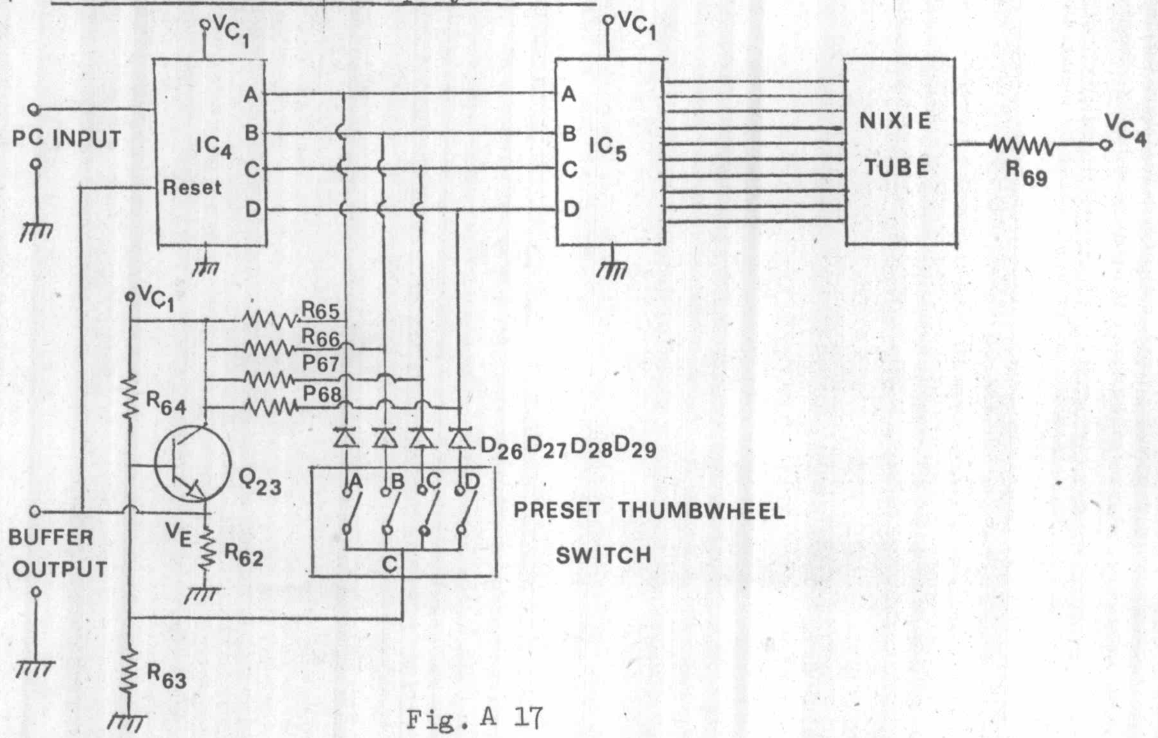

Fig. A 17

To assure proper operation $R_{62} \leq \frac{V_{Emin} \text{ of } Q_{23}}{I}$

Where V_{Emin} of Q_{23} is a logical 0 input voltage $\leq 2V_{\gamma} = 2 \times 0.5$

$= 1$ volt

Let V_{Emin} of $Q_{23} \approx 0.7$ volts

and I = Reset current(IC_4) + Input current of Gate A_1

$$= \frac{2\left[V_{C1} - V_{Emin} Q_{23} - V_{BE}(\text{Gate})\right]}{R(\text{Gate})}$$

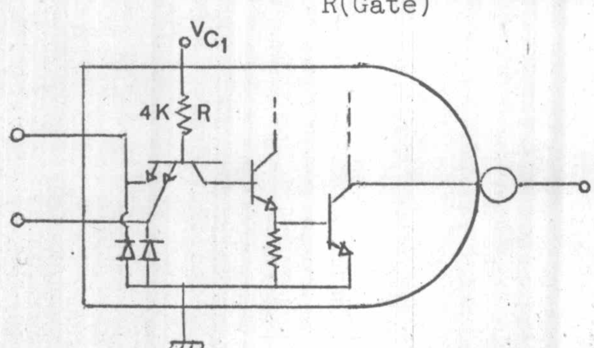

Fig. A 18

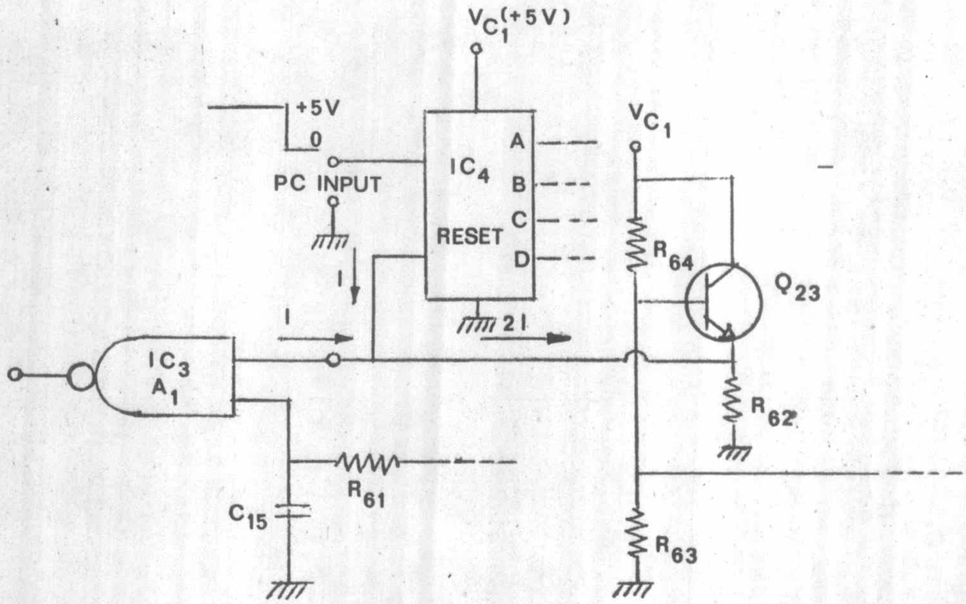

Fig. A 19

$$\text{Then} \quad R_{62} \leqq \frac{V_{Emin}Q_{23}R(\text{Gate})}{2\left[V_{C1} - V_{Emin}Q_{23} - V_{BE}(\text{Gate})\right]}$$

$$\leqq \frac{0.7 \times 4K}{2\,(5-0.7-0.6)} = 378\ \Omega$$

Choos $R_{62} = 330\ \Omega$

$$\text{Also} \quad R_{64} = \frac{V_{C1} - V_{Emax} \text{ of } Q_{23} - V_{BE}Q_{23}}{\dfrac{V_{Emax} \text{ of } Q_{23}}{R_{62}(hFE_{min}Q_{23} + 1)} + \dfrac{V_{Emax} \text{ of } Q_{23} + V_{BE}Q_{23}}{R_{63}}}$$

Where V_{Emax} of Q_{23} is logical 1 input voltage $\geqq 2\,V_{BE}(\text{sat})\text{Gate} + V_{CB}\text{Gate}$

$$\geqq (2 \times 0.7) + 1$$

$$\geqq 2.4 \text{ volts}$$

Let V_{Emax} of Q_{23} = 2.8 volts

and $hFE_{min}Q_{23}$ = 30, R_{63} = 100 K

Then $R_{64} = \dfrac{5 - 2.8 - 0.6}{\dfrac{2.8}{330(30+1)} + \dfrac{2.8+0.6}{100\ K}} = 5.2\ K$

Choose $R_{64} = 4.7\ K$

Diodes D_{26}, D_{27}, D_{28}, D_{29} pull up resistors R_{65}, R_{66}, R_{67}, R_{68}, (10 K) and Thumbwheel switch form a BCD AND gate circuit. Nixie tube (GR 110) is used to display the number of counting preset. It can be lighted by a current of 2 mA.

Then $R_{69} \quad \dfrac{V_{C3} - V_{GR110}}{I_{GR110}}$, where $V_{GR110} = 150$ volts

$$= \frac{170 - 150}{2\ mA}$$

$$= 10\ K$$

The power supply requirement may be calculated from the load in several circuits as follows :-

<u>Maximum current in Print Drive circuit</u> (+ 5 V supply)

$$I_1 = \frac{5}{3K} = 1.67\ mA$$

$$9I_2 + I_3 = 7.35\ mA$$

Max current in $IC_1 = \dfrac{55\ mw}{5\ V} = 11\ mA$

$I_C Q_1 \approx I_{Emax} Q_1 = 46.25\ mA$

Subtotal $I_{t1} = 66.27\ mA$

Maximum Current in Printout Control Circuit (+ 5V supply)

$$I_{C}Q_{4} = 1 \text{ mA}$$

$$I_{R5} = 1 \text{ mA}$$

$$I_{R14} \approx \frac{5}{2K} = 2.5 \text{ mA}$$

$$I_{C}Q_{9} = 0.7 \text{ mA}$$

$$I_{B}Q_{9} = 0.023 \text{ mA}$$

$$I_{R23} = \frac{5 - 0.1}{10K} \approx 0.5 \text{ mA}$$

$$I_{R24} = 0.385 \text{ mA}$$

$$I_{C}Q_{13} = 47.5 \text{ mA}$$

$$I_{C}Q_{14} = 1.58 \text{ mA}$$

$$I_{B}Q_{14} = 0.053 \text{ mA}$$

$$I_{R33} = 5 \text{ mA}$$

$$I_{C}Q_{17} \approx I_{E}Q_{17} = 0.58 \text{ mA}$$

$$I_{R38} \approx \frac{5}{10K} = 0.5 \text{ mA}$$

Subtotal $I_{t2} = 58.821$ mA

Maximum current in RF-Motor Control circuit (+ 5V supply)

$$I_{C}Q_{19} = I_{R39} = \frac{2.6 - 0.7 - 0.1}{100} = 18 \text{ mA}$$

$$I_{C}Q_{21} = I_{R43} = I_{R39} = 18 \text{ mA}$$

$$I_{R41} = \frac{5 - 0.55}{3.3K} = 1.35 \text{ mA}$$

$$I_{R45} = I_{R41} = 1.35 \text{ mA}$$

$I_{D24} = 10\ mA$

$I_{D25} = I_{D24} = 10\ mA$

$I_{R55} \approx \frac{5}{10K} = 0.5\ mA$

Max. current in $I_{C2} = 15\ mA + 15\ mA = 30\ mA$

Max. current in $I_{C3} = \frac{400\ mw}{5V} = 8\ mA$

Subtotal $I_{t3} = 97.2\ mA$

Maximum current in Preset Counter and Display Circuit (+5V supply)

$I_{R63} \approx \frac{5}{330} = 15.152\ mA$

$I_{R64} \approx \frac{5 - 0.1 - 0.6}{4.7K} = 0.92\ mA$

Max. current in $I_{C4} = 45\ mA$

Max. current in $I_{C5} = \frac{55\ mw}{5} = 11\ mA$

Subtotal $I_{t4} = 72.072\ mA$

Total maximum current $= I_{t1} + I_{t2} + I_{t3} + I_{t4}$

$= 66.27 + 58.821 + 97.2 + 72.072\ mA$

$= 294.363\ mA$

This is the current supplied by the +5V supply. The load current delivered by the +2.6V supply may be calculated from $I_C Q_{19}$, $I_C Q_{21}$, and $I_C Q_{13}$ giving 83.5 mA. The current drained from the +24V supply for solenoid, relays L_3 and L_4 amounts to 1.64A and the +170V supply for the NIXIE tube delivers 2 mA.

A.5 Power Supply Circuit

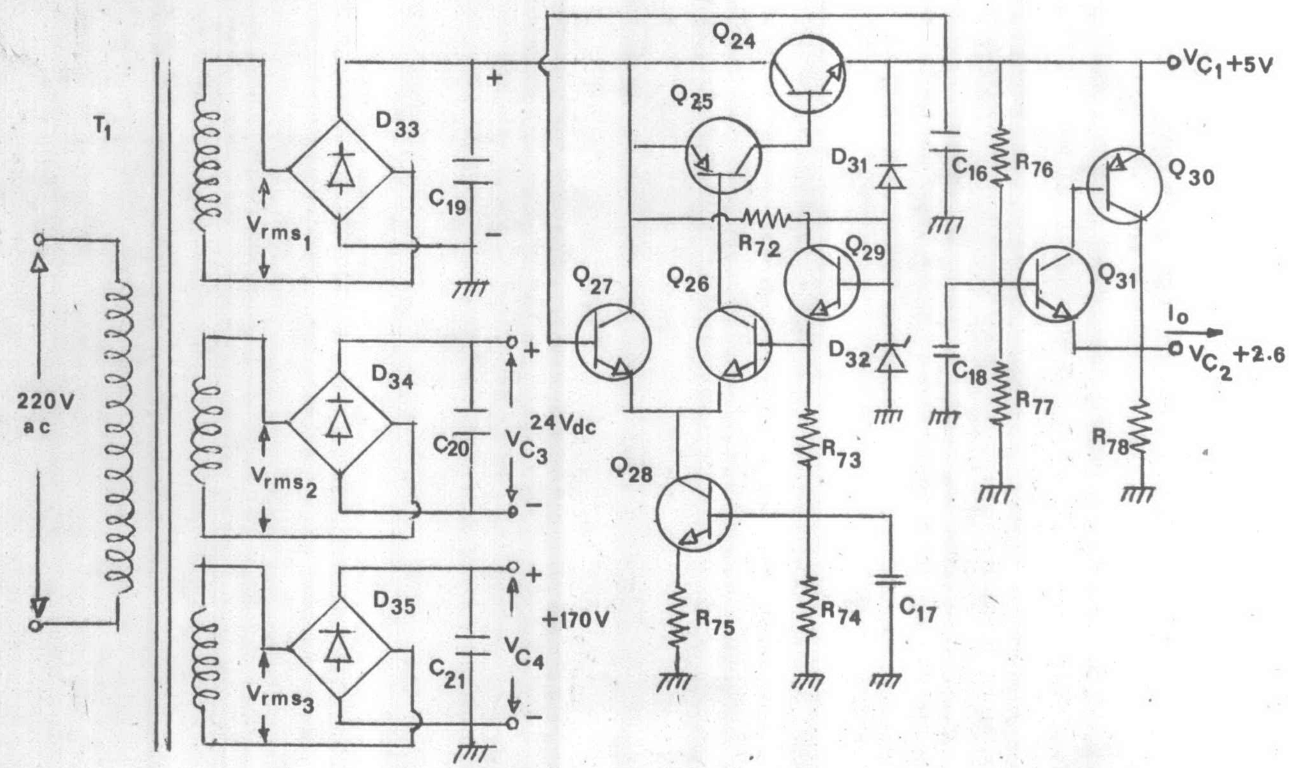

Fig. A 20

Starting from the + 2.6 volts supply

$$I_B Q_{31} \approx \frac{I_o + \dfrac{V_{C2}}{R_{78}}}{hFE_{min} Q_{30}\, hFE_{min} Q_{31}}$$

Where $I_o = I_C Q_{19} + I_C Q_{21} + I_C Q_{13} = 83.5$ mA , $V_{C2} = 5V$

Let $hFE_{min}Q_{30} = hFE_{min}Q_{31} = 30, \; R_{78} = 1K$ we obtain

$$I_BQ_{31} = \frac{83.5 \text{ mA} + \frac{5}{1K}}{30 \times 30} = 0.0983 \text{ mA}$$

and $V_BQ_{31} = V_{C2} + V_{BE}Q_{31} = 2.6 + 0.6 = 3.2$ volts

$$\text{Then } V_BQ_{31} = \frac{V_{C1}R_{77}}{R_{76} + R_{77}} - I_BQ_{31}\frac{R_{76}R_{77}}{R_{76} + R_{77}}$$

$$\text{or } 3.2 = \frac{5R_{77}}{R_{76} + R_{77}} - 0.0983 \text{ mA}\frac{R_{76}R_{77}}{R_{76} + R_{77}}$$

For convenience let the error voltage $0.0983 \text{ mA}\frac{R_{76}R_{77}}{R_{76} + R_{77}} = 2\,\%$ of V_{C2}

$$\text{then } 0.0983 \text{ mA}\frac{R_{76}R_{77}}{R_{76} + R_{77}} = \frac{2}{100} \times 2.6$$

$$\text{or } \frac{R_{76}R_{77}}{R_{76} + R_{77}} = 529\ \Omega$$

$$\text{Then } 3.2 = \frac{5 \times 529}{R_{76}} - 0.0983 \text{ mA} \times 529$$

$$R_{76} = \frac{5 \times 529}{3.2 + 0.046} = 814\ \Omega$$

Choose $R_{76} = 820\ \Omega$

$$\text{Now } 3.2 = \frac{5R_{77}}{820 + R_{77}} - 0.0983 \text{ mA} \times 529$$

then $R_{77} = 1.518$ K

Choose $R_{77} = 1.5\ K$

Since $I_{R76} = \dfrac{V_{C1} - V_{C2} - V_{BE}Q_{31}}{R_{76}} = \dfrac{5 - 2.6 - 0.6}{820} = 2.2\ mA$

Then $I_E Q_{24} = I_{R76} + I_{R78} +$ Max current in + 5V supply

$$= 2.2\ mA + \frac{2.6}{1K} + 294.363\ mA = 299.163\ mA$$

$$\approx 300\ mA$$

To assure proper operation of regulator let

$$I_{Emax}Q_{24} >> I_E Q_{24} (300\ mA) \approx 1A$$

Let $hFE_{min}Q_{24} = 25$ and $hFE_{min}Q_{25} = 30$

Then $I_{Emax}Q_{26} \approx I_{Cmax}Q_{26} = \dfrac{I_{Emax}Q_{24}}{(1 + hFE_{min}Q_{24})hFE_{min}Q_{25}}$

$$\approx \frac{1A}{25 \times 30} = 1.333\ mA$$

Further let $I_E Q_{28} \approx I_C Q_{28} = I_{Emax}Q_{26} + I_{Emax}Q_{27} \approx 2I_{Emax}Q_{26}$

$$= 2 \times 1.333\ mA$$

$$= 2.67\ mA$$

Now $V_{CE}Q_{28} < V_Z - V_{BE}Q_{29} - V_{BE}Q_{26}$

A reasonable value for $V_{CE}Q_{28}$ is $V_{CE}Q_{28} = \frac{1}{2}(V_Z - V_{BE}Q_{29} - V_{BE}Q_{26})$

$$V_{CE}Q_{28} = \frac{1}{2}(5.6 + 0.6 - 0.6) \qquad \left[V_Z = 5.6\ \text{Volts}\right]$$

$$= 2.2\ \text{volts}$$

$$\text{Then } R_{75} = \frac{V_Z - V_{BE}Q_{29} - V_{BE}Q_{26} - V_{CE}Q_{28}}{I_EQ_{28}}$$

$$= \frac{5.6 - 0.6 - 0.6 - 2.2}{2.67 \text{ mA}} = 824\ \Omega$$

$$\approx 820\ \Omega$$

$$\text{and } I_BQ_{28} = \frac{I_CQ_{28}}{hFE_{min}Q_{28}} = \frac{2.67 \text{ mA}}{30} \qquad \left[hFE_{min}Q_{28} = 30 \right]$$

$$= 0.09 \text{ mA}$$

$$\text{Now } V_BQ_{28} = \left(\frac{V_Z - V_{BE}Q_{29}}{R_{73} + R_{74}}\right) R_{74} - I_BQ_{28} \frac{R_{73}R_{74}}{R_{73} + R_{74}}$$

$$\text{Then } R_{75}I_EQ_{28} + V_{BE}Q_{28} = \left(\frac{V_Z - V_{BE}Q_{29}}{R_{73} + R_{74}}\right) R_{74} - I_BQ_{28} \frac{R_{73}R_{74}}{R_{73} + R_{74}}$$

$$820 \text{x} 2.67 \text{ mA} + 0.6 = \left(\frac{5.6 - 0.6}{R_{73} + R_{74}}\right) R_{74} - 0.09 \text{ mA} \frac{R_{73}R_{74}}{R_{73} + R_{74}}$$

$$2.79 = \frac{5R_{74}}{R_{73} + R_{74}} - 0.09 \text{ mA} \frac{R_{73}R_{74}}{R_{73} + R_{74}}$$

To minimize voltage drop in $R_{73}//R_{74}$, $R_{73}//R_{74}$ should be 100 Ω

$$\text{Then } \frac{R_{73}R_{74}}{R_{73} + R_{74}} = 100$$

$$\text{or } \frac{R_{74}}{R_{73} + R_{74}} = \frac{100}{R_{73}}$$

Then from the foregoing equation we get

$$2.79 = \frac{5 \times 100}{R_{73}} - 0.09 \text{ mA} \times 100$$

$$\text{or} \quad R_{73} = \frac{5 \times 100}{2.79-0.009} = 179.79\ \Omega$$

$$\approx 180\ \Omega$$

$$\text{and} \quad R_{74} = \frac{R_{73} \times 100}{R_{73} - 100} = \frac{180 \times 100}{180 - 100} = 225\ \Omega$$

$$\approx 220\ \Omega$$

$$\text{Now} \quad R_{72} = \frac{V_{C1} + V_{CEmin}Q_{24} - V_{Zmin}}{I_{Zmin} + I_{Bmax}Q_{29}}$$

$$\text{where} \quad V_{Zmin} = 5.6 \text{ volts}$$

$$\text{Let } I_{Zmin} = 10\ \%\ (\frac{P_{Zmax}}{V_Z}) = 0.1(\frac{400 \text{ mw}}{5.6 \text{ V}}) = 7.143 \text{ mA}$$

$$I_{Bmax}Q_{29} = \frac{I_{Cmax}Q_{26}}{hFE_{min}Q_{26} hFE_{min}Q_{29}} = \frac{1.333 \text{ mA}}{30 \times 30} = 0.0015 \text{ mA}$$

$$\text{and} \quad V_{CEmin}Q_{24} > V_{Zmin} - V_{C1}$$

$$\text{Then} \quad V_{CEmin}Q_{24} > 5.6 - 5 \text{ volts}$$

$$> 0.6 \text{ volts}$$

$$\text{Choose} \quad V_{CEmin}Q_{24} \approx 2 \text{ volts}$$

$$\text{Then} \quad R_{72} = \frac{5 + 2 - 5.6}{7.143 \text{ mA} + 0.0015 \text{ mA}} = 190\ \Omega$$

$$\approx 180\ \Omega$$

Since 10 percent of the maximum load current is used as the minimum Zener diode current, then the maximum Zener diode current should be 90 percent of the maximum load current ,

$$\text{i.e., } I_{Zmax} = 90\,\%\left(\frac{P_{Zmax}}{V_Z}\right) = 0.9\left(\frac{400 \text{ mw}}{5.6 \text{ V}}\right) = 64.29 \text{ mA}$$

At normal operation I_Z is limited to 20 % of I_Z max, i.e.,

$$I_Z = 20\,\%\, I_{Zmax} \quad \text{at light load}$$

$$= \frac{20}{100} \times 64.29 \text{ mA} = 12.858 \text{ mA}$$

$$\approx 13 \text{ mA}$$

$$\text{Then } R_{72} = \frac{V_{C1} + V_{CEmax}Q_{24} - V_Z}{I_Z + I_{Bmin}Q_{29}}$$

with $R_{72} = 180\,\Omega$, $V_Z \approx V_{Zmin} = 5.6$ volts

and $I_{Bmin}Q_{29}$ 0, $I_Z = 13$ mA

$$\text{Then } 180\,\Omega = \frac{5\text{V} + V_{CEmax}Q_{24} - 5.6 \text{ V}}{13 \text{ mA}}$$

$$V_{CEmax}Q_{24} = 2.94 \text{ volts}$$

Now the rectifier circuit can be calculated as follows :-

At no-load $(V_{m1} - V_{D33})_{max} = V_{C1} + V_{CEmax}Q_{24} = 5 + 2.94$

$$= 7.94 \text{ volts}$$

At full-load $(V_{m1} - V_{D33})_{min} = V_{C1} + V_{CEmin}Q_{24} = 5 + 2$

$$= 7 \text{ volts}$$

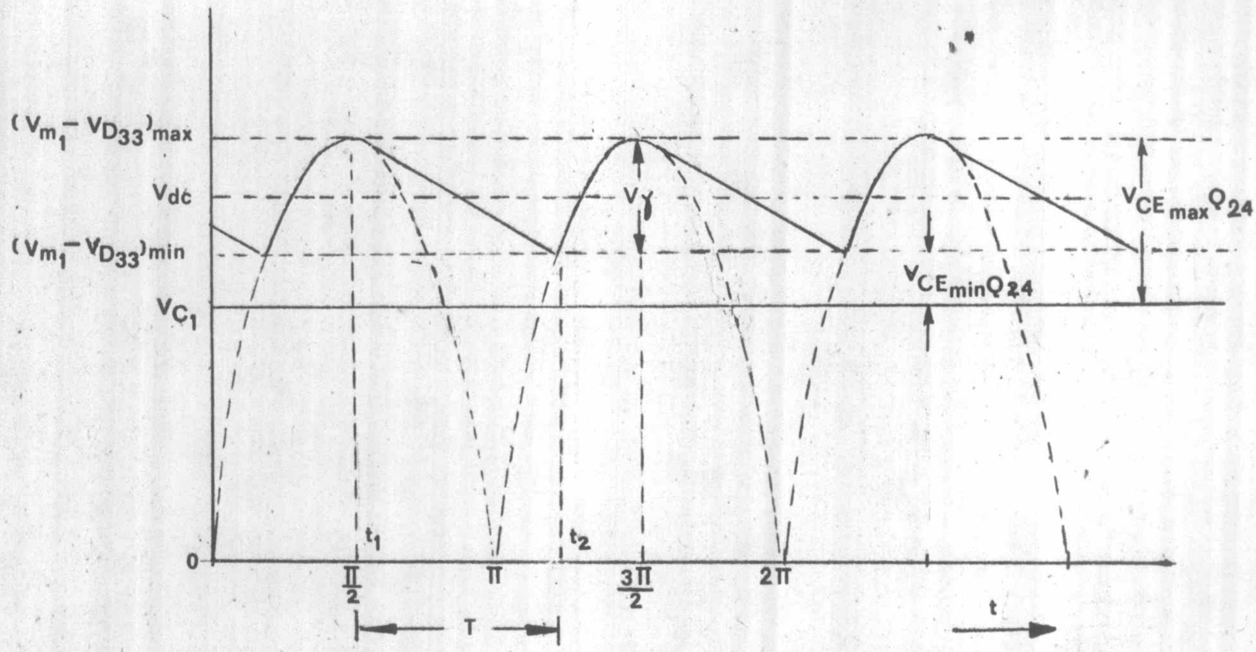

Fig. A 21

$$\text{Ripple voltage} = V_\gamma = (V_{m1} - V_{D33})_{max} - (V_{m1} - V_{D33})_{min}$$

$$= 7.94 - 7$$

$$= 0.94 \text{ volts}$$

To the first place the output - voltage waveform of a full-wave rectifier circuit with a capacitor filter may be approximated by the piecewise linear curve shown in Fig. A 21. Also, with very large C_{19}, the exponential decay curve can be replaced by a linear fall. If the total capacitor discharge voltage (the ripple voltage) is denoted by V_γ, then

$$V_\gamma = \frac{1}{C_{19}} \int_{t_1}^{t_2} i(t)\, dt$$

It is necessary, however, to express V_γ as function of the load current and the capacitance. If $t_2 - t_1$ or T represents the total nonconducting time, the capacitor, when discharging at the constant rate $I_{Emax}Q_{24} + I_Z(t)$, will lose an amount of charge Q given by

$$Q = C_{19}V_{\gamma} = \int_{t_1}^{t_2} i(t)dt$$

and $i(t) = I_{Emax}Q_{24} + I_Z(t) \approx$ constant rate of discharge

$$C_{19}V_{\gamma} = \int_{t_1}^{t_2} I_{Emax}Q_{24} + I_Z(t) \quad dt$$

$$= \left(I_{Emax}Q_{24} + I_Z\right)\left(t_2 - t_1\right)$$

Since $I_Z \ll I_{Emax}Q_{24}$

Then $C_{19}V_{\gamma} \approx I_{Emax}Q_{24}\,T$, where $T = T_2 - t_1$

and $V_{\gamma} = \dfrac{I_{Emax}Q_{24}T}{C_{19}}$

The AC voltage at the input of the rectifier can be determined as follows :-

At $t = t_1 \quad (\omega t_1 = \frac{\pi}{2})$

$$V_{C1} + V_{CEmax}Q_{24} = (V_{m1} - V_{D33})\sin \omega t_1 = (V_{m1} - V_{D33})\sin \frac{\pi}{2}$$

or $7.94 = V_{m1} - V_{D33}$

Now $V_{m1} = 2\,V_{rms1}$, $V_D \approx 2$ volts

Then $7.94 = 2\,V_{rms1} - 2$

$$V_{rms1} = \frac{7.94 + 2}{2} = 7.028 \text{ volts} \approx 7 \text{ volts}$$

At $t = t_2$

$$V_{C1} + V_{CEmin}Q_{24} = (V_{m1} - V_{D33})\sin \omega t_2$$

or $$7 = 7.94 \sin \omega t_2$$

Solving for t_2, $\omega t_2 = \sin^{-1} \frac{7}{7.94} = \sin^{-1} 0.8816 = \frac{61.8^\circ \pi}{180^\circ} + \pi$

Then $T = t_2 - t_1 = \frac{1}{\omega} \left(\frac{61.8^\circ}{180^\circ} \pi + \pi\right) - \frac{\pi}{2} = \frac{1}{2\pi f}\left(0.343\pi + 0.5\pi\right)$

or $T = \frac{0.843}{2f}$

Where f is the fundamental power-line frequency = 50 Hz

Then $T = \frac{0.843}{2x50} = 8.43$ msec

and $V_\gamma = 0.94 = \frac{I_{Emax}Q_{24}T}{C_{19}} = \frac{300 \text{ mA x } 8.43 \text{ msec}}{C_{19}}$

Then $C_{19} = \frac{300 \text{ mA x } 8.43 \text{ msec}}{0.94} = 2690\ \mu F$

Hence, to keep the ripple low and to ensure good regulation, very large capacitances must be used

For safety margin choose $C_{19} = 3000\ \mu F$, $C_{16} = 200\ \mu F$ and $C_{17} = C_{18} = 0.1\ \mu F$.

For the + 24 volts supply the ac voltage is given by

Now V_{dc}(average) = $V_{m2} - V_{D34}$ - ripple voltage (average)

$$= 2\, V_{rms2} - V_{D34} - \frac{V_\gamma}{2}$$

With V_γ = ripple voltage = $\frac{I_{dc}T}{C_{20}}$

Similarly the dimension of the components of the + 24 volts supply can be determined. Let the error voltage due to discharging of the capacitor C_{20} during solenoid energizing ± 20 % of the V_{dc} (24 V),

$$\text{i.e., } \frac{V_\gamma}{2} = 20\,\%\left(24\ \text{V}\right) = 0.2 \times 24 = 4.8 \text{ volts}$$

$$\text{or} \qquad V_\gamma = 4.8 \times 2 = 9.6 \text{ volts}$$

and with $V_{dc} = 24$ volts, $V_{D34} = 2$ volts

$$\text{Then} \qquad 24 = \sqrt{2}\ V_{rms2} - 2 - 4.8$$

$$V_{rms2} = \frac{30.8}{2} = 21.778 \approx 22 \text{ volts}$$

$$\text{Since} \quad T = \frac{1}{\omega}\left(\sin^{-1}\left[\frac{\sqrt{2}\ V_{rms2} - V_{D34} - V_\gamma}{\sqrt{2}\ V_{rms2} - V_{D34}}\right] + \frac{\pi}{2}\right)$$

$$= \frac{1}{2\pi f}\left(\sin^{-1}\left[\frac{\sqrt{2}(22) - 2 - 9.6}{\sqrt{2}(22) - 2}\right] + 0.5\,\pi\right)$$

$$= \frac{1}{2\pi f}\left(\frac{42.1^\circ}{180^\circ}\pi + 0.5\,\pi\right)$$

$$\text{Then} \quad T = \frac{0.7339}{2f} = \frac{0.7339}{2 \times 50} = 7.339 \text{ msec}$$

and with $V_{DC} = 24$ V, I_{dc} = Solenoid driver 1A + Relay L_3 driver $\frac{24V}{75}$ = 0.32 A

$$\text{Then} \quad V_\gamma = 9.6 = \frac{I_{dc}T}{C_{20}} = \frac{1.32 \text{ A} \times 7.339 \text{ msec}}{C_{20}}$$

$$\text{and} \quad C_{20} = \frac{1.32\text{A} \times 7.339 \text{ msec}}{9.6} = 1009.113\ \mu\text{F}$$

In practice with $C_{20} \approx 1000\ \mu F$ the fluctuation of the V_{DC} for printer driving is tolerable

The ac voltage at the input of the rectifier for NIXIE supply is calculated ad follows

$$V_{dc} = \sqrt{2}\, V_{rms3} - V_{D35} - \frac{V_{\gamma}}{2}$$

where $V_{dc} = 170$ volts, $V_{D35} \approx 1.2$ volts

$$V_r = \frac{I_{dc} T}{C_{21}} \quad \text{and} \quad T \approx \frac{1}{2f}$$

Then $$170 = \sqrt{2}\ V_{rms3} - 1.2 - \frac{I_{dc}}{4fC_{21}}$$

Since $f = 50$ Hz and $I_{dc} = 2$ mA,

let $C_{21} = 10\ \mu F$ we get

$$V_{rms3} = \frac{1}{\sqrt{2}}\left(170 + 1.2 + \frac{2\ mA}{4x50x10\mu F}\right)$$

$$\approx 120 \text{ volts}$$

A.6 Transformer

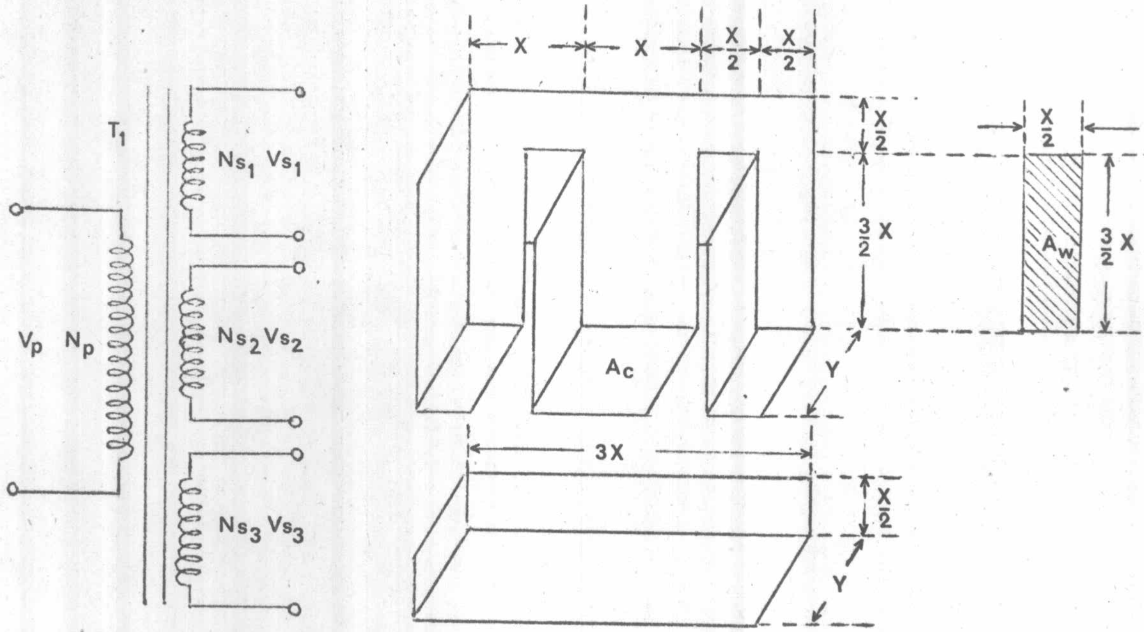

Fig. A 22

With the dimensions of the core stack as shown, the transformer windings can be calculated as follows :-

$$\text{Window area } A_w = \frac{x}{2} \times \frac{3}{2} x = \frac{3}{4} x^2 \qquad \text{sq. inches}$$

Let the cross-section area of insulated wire $= \phi$ sq. inches

with K = No. of layers (interlayer insulation) + Bobbin insulation

$$\text{Then } A_w \geq N_p \phi_p + \sum_{n=1}^{\infty} N_{sn} \phi_n + K \qquad \text{sq. inches}$$

where N_{sn} is the number of turns in the n^{th} secondary winding

$$\text{Since } N_{sn} = \frac{N_p}{V_p} V_{sn}$$

$$\text{Then } A_w \geqq N_p\phi_p + \sum_{n=1}^{\infty} \frac{N_p V_{sn}}{V_p} \phi_n + K \qquad \text{sq. inches}$$

$$\geqq \frac{N_p}{V_p} \left(V_p\phi_p + \sum_{n=1}^{\infty} V_{sn}\phi_n \right) + K \qquad \text{sq. inches}$$

Since a current density of 600-700 circular mils per ampere is allowable and 1 circular mils $= 7.854 \times 10^{-7}$ sq. inches

$$\text{Then } \phi = 700 \text{ I (ampere)} \times 7.854 \times 10^{-7} \qquad \text{sq. inches}$$

$$= 5.4978 \times 10^{-4} \text{ I} \qquad \text{sq. inches}$$

$$\approx 5.5 \times 10^{-4} \text{ I} \qquad \text{sq. inches}$$

As a result :-

$$A_w \geqq 5.5 \times 10^{-4} \frac{N_p}{V_p} \left(V_p I_p + \sum_{n=1}^{\infty} V_{sn} I_{sn} \right) + K$$

Since total power $W = V_p I_p \approx \sum_{n=1}^{\infty} V_{sn} I_{sn}$

$$\text{Then } A_w \geqq 5.5 \times 10^{-4} \times 2 \frac{N_p}{V_p} (W) + K$$

$$\text{Where } \frac{N_p}{V_p} = \frac{10^8}{0.9\sqrt{2}\,\pi f B A_c}$$

Now A_c = cross-sectional area of the core

$$= xy = \frac{W}{5.58} \qquad \text{sq. inches}$$

Substituting $A_w \geqq 5.5 \times 10^{-4} \times 2 \left(\frac{10^8}{0.9\sqrt{2}\,\pi f B \;\frac{\sqrt{W}}{5.58}} \right)(W) + K$

$$\geqq \frac{11 \times 10^{-4} \times 10^{8} \times 5.58\sqrt{W}}{0.9\sqrt{2}\,\pi f B} + K$$

with $f = 50$ Hz, B = flux density = 75×10^3 lines/sq. inches

and $A_w = \frac{3}{4}x^2$ we obtain

$$\frac{3}{4}x^2 \geqq \frac{11 \times 10^{4} \times 5.58\sqrt{W}}{4 \times 50 \times 75 \times 10^{3}} + K \qquad \text{sq. inches}$$

or $\frac{3}{4}x^2 \geqq 0.041\sqrt{W} + K$ sq. inches

Since $K = \frac{3}{2}x$ (former thickness and inter layer insulation)

Then the maximum value of $K \approx \frac{3}{2}x \left(0.06 \text{ inches} + 0.014 \text{ inches}\left(\frac{\frac{x}{2}}{5.5\text{x}10^{-4}I_p}\right)\right)$

sq. inches for the transformer under consideration.

And $\frac{3}{4}x^2 \geqq 0.041\sqrt{W} + \frac{3}{2}x \left[0.06 + \frac{0.007}{\sqrt{5.5\text{x}10^{-4}I_p}}\right]$ sq. inches

As mentioned earlier the total power is given by

$$W = V_p I_p \approx \sum_{n=1}^{\infty} V_{sn} I_{sn}$$

Where $V_p = V_{prms} = 220$ V, $I_p = I_{prms}$

$$V_{sn} = V_{sn\ rms}\ , \quad I_{sn} = I_{sn\ rms} = 1.1\ I_{sn\ d.c.}$$

Then $W = V_p I_p = 1.1 \sum_{n=1}^{\infty} V_{sn\ rms} I_{sn\ d.c.}$ watts

$$= 1.1 \left(7V\times300\ mA + 22V\times1.32\ A + 120\ V\times10\ mA \right) \quad \text{watts}$$

$$= 35.57 \quad \text{watt}$$

$$\approx 36 \quad \text{watt}$$

With $V_p = 220\ V \quad I_p = \frac{36}{220} = 0.16364\ A \approx 164\ mA$

Then $\frac{3}{2}x^2 \geqq 0.041\sqrt{36} + \frac{3}{2}x \left[0.06 + \frac{0.007}{\sqrt{5.5\times10^{-4}\times0.164}} \right]$ sq. inches

$$1.5\ x^2 \geqq 0.246 + 0.09\ x + 1.11\ x^2$$

$$39\ x^2 - 9\ x - 24.6 \geqq 0$$

$$x \geqq \frac{9 \pm \sqrt{81 + 4 \times 39 \times 24.6}}{2 \times 39}$$

$$x \geqq 0.919 \quad \text{inches}$$

Since the standard size of the core available is

$$x = \frac{n + 1}{4} \text{ inches, where } n = 1, 2, 3, 4 \ldots$$

or $\quad x = \frac{1}{2}, \frac{3}{4}, 1, 1\frac{1}{4}, 1\frac{1}{2} \ldots$ inches

Then choose the core size with $x = 1$ inch to obtain a square core transformer .

The cross-sectional area is given by :-

$$A_c = xy = \frac{W}{5.58} = \frac{\sqrt{36}}{5.58} = 1.0753 \text{ sq. inches}$$

With stacking factor of 0.9 we obtain

$$y = \frac{A_c}{0.9x} = \frac{1.0753}{0.9x1} = 1.1947$$

$$\approx 1.2 \text{ inches}$$

Then the turns in each winding is calculated as follows :-

$$N_p = \frac{V_p \times 10^8}{0.9\sqrt{2}\,\pi f B A_c} = \frac{220 \times 10^8}{4x50x75x10^3x1.0753} = 1363.95$$

$$\approx 1364 \text{ turns}$$

$$N_{S1} = \frac{N_p}{V_p} V_{S1} = \frac{1364}{220} \times 7 = 43.4 \approx 44 \text{ turns}$$

$$N_{S2} = \frac{N_p}{V_p} V_{S2} = \frac{1364}{220} \times 22 = 136.4 \approx 137 \text{ turns}$$

$$N_{S3} = \frac{N_p}{V_p} V_{S3} = \frac{1364}{220} \times 120 = 744 \text{ turns}$$

The cross-section area of the wire in the secondary winding

$$N_{S1} = \frac{300 \times 1.1 \text{ mA} \times 700}{1000} = 231 \text{ circular mils}.$$

For the sake of safety insulated wire with cross-section area of 269 circular mils corresponding to SWG. No 27 is chosen

Similarly the cross-section area of the wire in the secondary winding

N_{S2} = 1.32 x 1.1 A x 700 = 1016.4 circular mils..

Insulated wire with cross-section area of 1024 circular mils corresponding to SWG. No. 21 is chosen.

For secondary winding N_{S3}, the cross-section area of the wire

$$= \frac{10 \times 1.1 \text{ mA} \times 700}{1000} = 7.7 \text{ circular mils}$$

Insulated wire with cross-section area of 7.84 circular mils corresponding to SWG. No. 45 is chosen..

The cross-section area of the primary winding wire

$$= \frac{164 \text{ mA} \times 700}{1000} = 114.8 \text{ circular mils}$$

Insulated wire with cross-section area of 116.6 circular mils corresponding to SWG. No. 32 is chosen.

APPENDIX B

ORTEC TIMER-SCALER BLOCK DIAGRAM AND CIRCUIT[3]

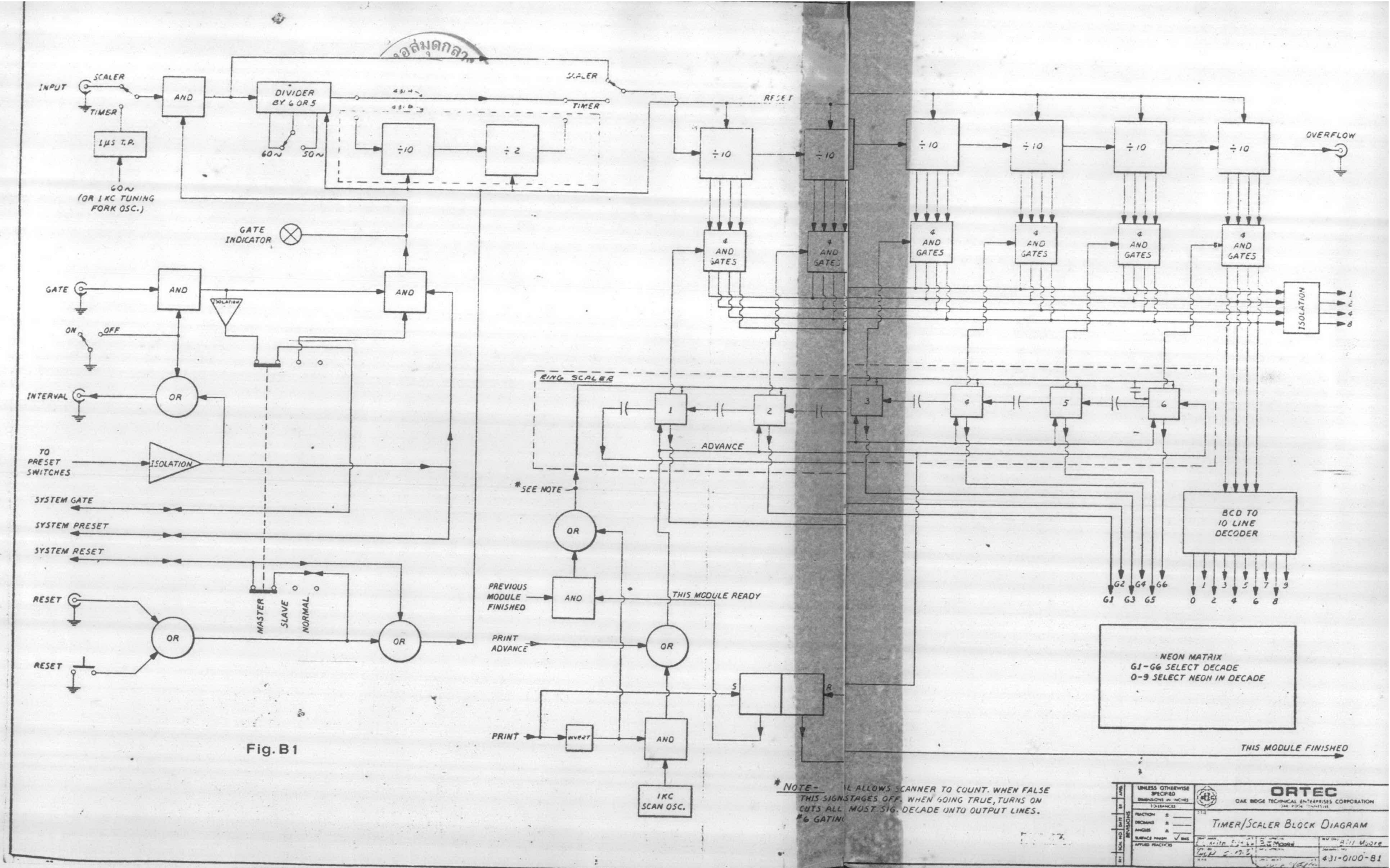
INPUT
SCALER
TIMER
AND
DIVIDER BY 6 OR 5
60~
50~
1μs T.P.
60~ (OR 1KC TUNING FORK OSC.)
÷10
÷2
SCALER
TIMER
RESET
÷10
÷10
÷10
÷10
÷10
÷10
OVERFLOW
GATE INDICATOR
4 AND GATES
4 AND GATES
4 AND GATES
4 AND GATES
4 AND GATES
4 AND GATES
GATE
AND
ISOLATION
AND
ON
OFF
ISOLATION
1
2
4
8
INTERVAL
OR
RING SCALER
1
2
3
4
5
6
ADVANCE
TO PRESET SWITCHES
ISOLATION
*SEE NOTE
SYSTEM GATE
SYSTEM PRESET
SYSTEM RESET
OR
BCD TO 10 LINE DECODER
G1
G2
G3
G4
G5
G6
0
1
2
3
4
5
6
7
8
9
PREVIOUS MODULE FINISHED
AND
THIS MODULE READY
RESET
MASTER
SLAVE
NORMAL
RESET
OR
OR
PRINT ADVANCE
OR
NEON MATRIX
G1-G6 SELECT DECADE
0-9 SELECT NEON IN DECADE
S
R
PRINT
INVERT
AND
THIS MODULE FINISHED
1KC SCAN OSC.
*NOTE- L ALLOWS SCANNER TO COUNT. WHEN FALSE THIS SIGN STAGES OFF. WHEN GOING TRUE, TURNS ON CUTS ALL MOST SIG. DECADE UNTO OUTPUT LINES. #6 GATIN
ORTEC
OAK RIDGE TECHNICAL ENTERPRISES CORPORATION
TIMER/SCALER BLOCK DIAGRAM
431-0100-B1

Fig. B1

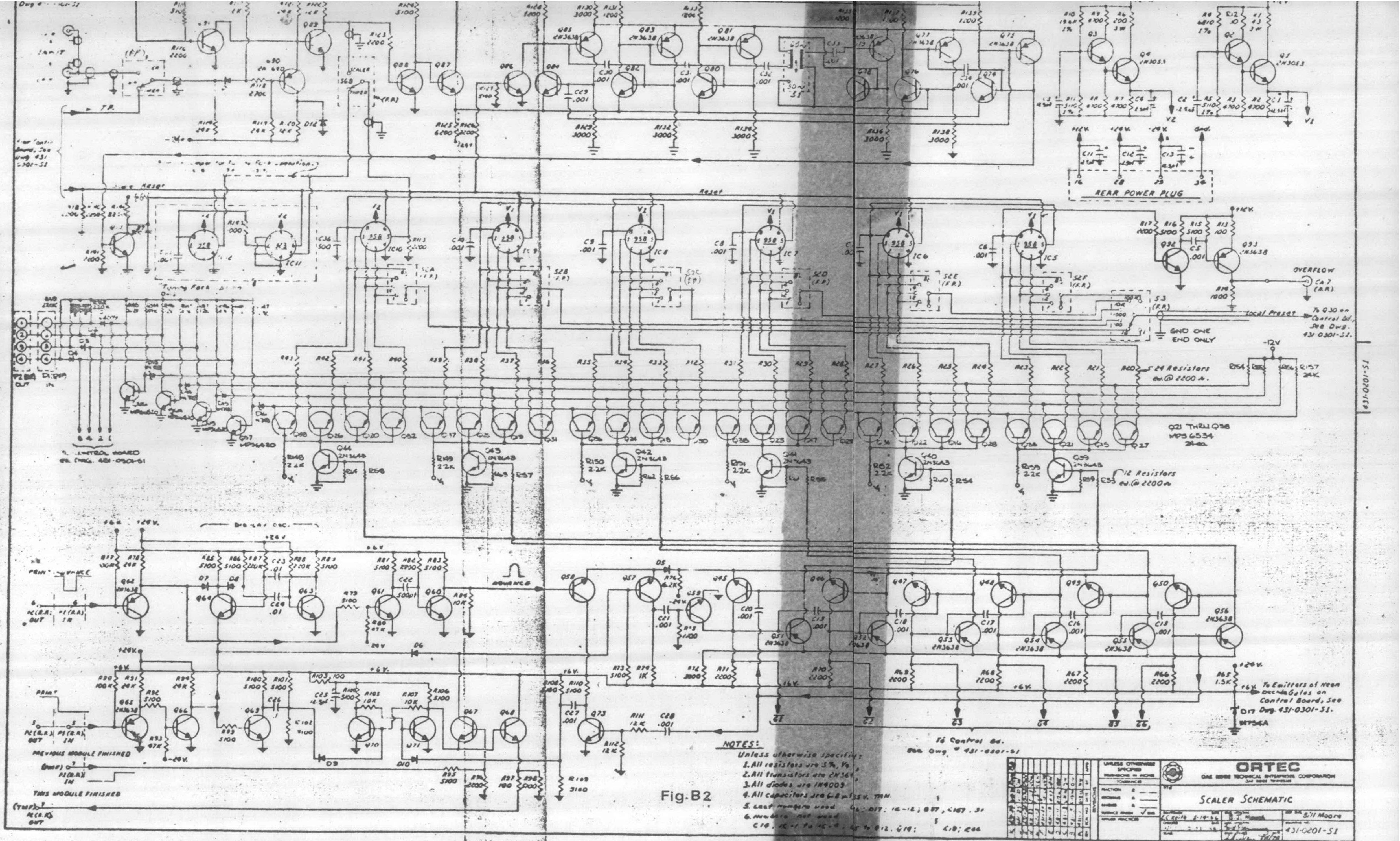
REAR POWER PLUG
Reset
OVERFLOW
Local Preset
GND ONE END ONLY
24 Resistors ea. @ 2200 Ω
12 Resistors ea. @ 2200 Ω
Q21 THRU Q38 MPS 6534
ADVANCE
NOTES:
Unless otherwise specified:
1. All resistors are 5%, 1/4 W
2. All transistors are 2N36
3. All diodes are IN4009
To Control Bd.
To Emitters of Neon Gates on Control Board, See Dwg. 431-0301-S1.
ORTEC
OAK RIDGE TECHNICAL ENTERPRISES CORPORATION
SCALER SCHEMATIC
431-0201-S1

Fig.B2