TECHNICAL REPORT

A REPORT ON AUTO STOWLOCK OPERATION OF GMRT ANTENNAS

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Keywords : **GT Antennas; Auto Stowlock System; Servo System**

SUMMARY

In this note we discuss requirements and details of a few possible schemes for auto-stowlocking the 45-m dishes of GMRT using a battery backed system, on those occasions when wind speed exceeds 45 kmph and MSEB power is not available. Although the structural and mechanical system of GMRT have been designed to be safe at the maximum expected wind speed of 140 kmph at the GMRT site (50-yr. survival wind), M/s. Tata Consulting Engineers had advised TIFR to stowlock the antennas for wind speed exceeding 45 kmph but before winds exceed 80 or 85 kmph at the GMRT site. As discussed below, a simple scheme using three 24 V, 48 V and 96 V battery banks is recommended for the 16 Y-array antennas. Some other schemes which have been suggested by Shri Hotkar are also discussed. Static and dynamic relations between wind torques, motor currents, terminal voltage, time constants, etc. are derived for both cases, namely when wind opposes or aids the direction of motion of the antennas. These relations are important to evaluate advantages and disadvantages of various schemes.

For the central array antennas, the two 220 kva Diesel Generators which are operational at the central array should be periodically tested and kept ready for slewing and then putting stow-lock pins into the antennas within 5 or 6 minutes of the wind speed exceeding 45 kmph and if MSEB power fails. It may be noted that the purpose of stow-

locking the antennas is to avoid any mishaps during severe dust/thunder storms (squalls) that occur in the Pune region when wind speeds can rise to more than 100 kmph in 5 to 10 minutes. These "squalls" generally occur during daytime, mostly during April-June but also sometimes during September-November. Statistics of occurrence of heavy winds are available in a file marked as "Wind Statistics in the Khodad office and also in the office of G. Swarup. It is planned to write a technical report on the subject over the next few months.

It is recommended that two prototype units for automatic stow-locking of the 45-m dishes should be developed over the next two months so that the units could be tested on two antennas during the windy months.

1. INTRODUCTION

Installation of an auto stowlock system was an essential part of the design of the GMRT drive system. The structural and mechanical system of the GMRT antennas have been designed to be safe at the maximum expected wind speed of 140 kmph at the GMRT site (which is the 50-yrs. survival wind according to ISI design guidelines for wind in the Pune region). Considering various practicable aspects, M/s. Tata Consulting Engineers have advised the Tata Institute of Fundamental Research to stowlock the GMRT antennas for wind speed exceeding 45 kmph but before winds exceed 80 or 85 kmph at the GMRT site (see Swarup et al. 93 for further discussions for wind speeds for stowlocking). Manpower and time did not permit TIFR to incorporate a suitable scheme for stowlocking the antenna at the servo design phase. Later on, it was proposed by TIFR engineers to develop a scheme using a battery system. Batteries were ordered from abroad and a trial system using contactors was installed at C-4 antenna in late 1994. A detailed design report was written by Shri V.G. Hotkar of NCRA and comments were sought from BARC. They modified the scheme somewhat and approved it in July 1995. However, further work could not be carried out due to shortage of manpower for designing and developing a scheme by the NCRA servo group.

Part of the problem has been that the group wanted to develop a PWM scheme which can be developed for the motoring mode when wind opposes motion of the antenna, but it is not clear whether PWM scheme will work satisfactorily for the regeneration mode when wind aids the motion.

In Section 2 of this report, I describe briefly the mechanical and electrical drive system of the GMRT antennas in the elevation axis. In Section-3 are derived various relations which determine static and dynamic behaviour of the DC motors for the case when the wind opposes the motion of the antenna. In Section-4 is discussed the case when wind aids the motion of the antenna. Discussions and conclusions are given in Section-5. As discussed, it is important that a decision is taken for developing a prototype unit at the earliest and two units are developed over the next two months so that they can be installed at two antennas during the forthcoming windy months.

2. MECHANICAL AND ELECTRICAL DRIVE SYSTEM FOR THE ELEVATION AXIS

Fig.1 gives a schematic of the Mechanical Drive System for the Elevation Axis of the GMRT antennas. A similar drive system is used for the Azimuth axis, but we discuss here only the drive system for the Elevation Axis for which the automatic stowlocking is to be done. In case of heavy winds, the antennas are driven upto an Elevation angle of 90°.0 and then stowlock motors are energized for inserting the stowlock pins.

The drive system consists of two permanent magnet motors of 8.5 hp. capacity ("Industrial Drive" TB 53810-B see App.1 for data sheet), two planetary gear-boxes of a ratio of about 821:1 (manufactured by Mannesmann - Rexroth) and a pin-sector gear with a reduction ratio of about 30:3. The overall reduction of the gear-system is about 25,000:1. A detailed description of the mechanical system is available with the mechanical group.

The motors are driven by a servo system which was designed by BARC and have been mass produced by the GMRT Electrical and Servo group. The servo system consists of a servo computer, control circuitry and an SCR-based control amplifier. Detailed reports are available with the Servo group. The two DC motors are driven in a counter-torque mode for the purpose of tracking a celestial radio source. For slewing both motors are driven in the same direction. A Technical Report (Swarup at el 1993) and a paper (Joshi 1995) gives relations concerning wind loads, unbalanced load, frictional torques, motor currents and counter-torque bias.

3. RELATIONS BETWEEN VOLTAGE, CURRENT, TORQUES AND SPEED FOR THE CASE OF DC MOTORS WITH WIND OPPOSING THE MOTION.

In Section 3.1 we discuss various relations which determine the static and dynamic behaviour of the DC motors for the case when wind opposes the motion of the antenna. Practical implications are discussed in Section 3.2.

3.1 Load Torques with wind opposing the motion.

In Fig. 2 is given a schematic of the case when a battery is connected to the motor to drive the 45-m dishes against an opposing torque T_L given by

$$T_L = (T_W + T_u + T_f)$$

Where T_w is due to the wind load (opposing), T_u is due to unbalance load and T_f is the friction torque.

$$T_f = T_{f1} + T_{f2}, \text{ where } T_{f1} = 1.9 \text{ Nm (static friction) and}$$

$$T_{f2} = 1.7\,\omega_m \text{ Nm dynamic friction}$$

Where ω_m = is the speed of the motor in krpm.

The GMRT servo motors have permanent magnet so that the field is constant. The following relations hold for the motor:

3.1 a) **Electromagnetic Relations**

$$T_m = k_1 I_a \qquad (1)$$

Where T_m is the magnetic torque generated by an armature current, I_a, and k_1 is a constant = 0.56 Nm/amp = (0.56 x 9.81 kg m^2 s^{-2}/amp) for the GMRT servo motors (see motor data sheet (Appendix-1). With the rotation of the motor, a feedback voltage, V_f is generated:

$$V_f = k_2 \omega_m \qquad (2)$$

where ω_m is the speed of the motor in krpm or rad/sec and k_2 is constant = 59V/(krpm) or 0.56 V/(rad/sec) since 1 krpm = (1000 x $2\pi/60$) rad/sec.

3.1 b) **Voltage Equation for the Armature Circuit**

$$V_t = V_B = V_f + L_a' \frac{dI_a}{dt} + r_a' I_a \qquad (3)$$

Where V_t is the terminal voltage = battery voltage V_b in the present case,

(see Fig. 2) for the case when wind opposes the motion.

L_a' = 1.43 mH is the sum of armature inductance La = 0.33 mH, an external inductance, L_e = 1 mH, which has been installed in the servo system in series with the DC motor and an estimated value of 0.1 mH for wires between the battery system and motor, and r_a' = 0.145 is the sum of the armature resistance r_a = 0.045 ohms, and r_e = 0.1 ohm, the latter being the estimated resistance of the wires between the battery and DC motors.

3.1 c) **Dynamic Equation for the Mechanical System**

$$J_m \, d\omega/dt = (T_m - T_L) \ \text{kg m} \qquad (4)$$

Where J_m is the total inertia of the motor plus antenna system of GMRT, J is in units of kg m^2 and ω is in units of rad/sec.

It may be noted that Inertia of the GMRT 45 m dish as seen at the elevation axis = 7.33×10^6 kg m^2, that of the planetary gear box = 1600 kg m^2 and of the I.D. DC motor = 0.064 kg m^2 (see TCE report and motor data sheet). The overall gear reduction = 25000:1 and of the planetary gear box = 821:1 Hence, for the elevation drive system, the inertia of the 45-m antenna and gear drive as seen at the input of each of the two elevation motors is given by

$$J_m = \left[\frac{0.5 \times 7.33 \times 10^6}{(25{,}000)^2} + \frac{1600}{825^2} + 0.064 \right] \text{kg m}^2$$

$$= [0.0059 + 0.0024 + 0.064] \ \text{kg m}^2$$

$$= [0.0083 + 0.064]$$

$$= 0.0723 \ \text{kg m}^2 \qquad (5)$$

If ω is in radian/sec. It may be noted that inertia of the antenna system including gear boxes is negligible compared to that of the motor, in view of the large gear reduction ratios of the drive system.

3.1 d) **Dynamic System Equation and Time Constants (see Wilson, P. 377)**

From (3) we get

$$V_t = [V_f + I_a (sL_a' + r_a')] \qquad (6)$$

where s is the frequency of the system response.

Substituting for V_f and I_a from (1) and (2) and (4), and taking $\theta_m = \omega_m$, we get

$$V_t = k_2 \theta_m + \frac{J s \theta_m}{k1} (r_a' + sL_a')$$

$$= \quad k_2\ \theta_m\ [\ 1 + (J\ s\ \theta_m/k_1\ k_2)\ (r_a' + sL_a')$$

$$\text{or} \quad \frac{\theta_m}{Vt} = \frac{(\ 1/k_2)}{[\ L_a'\ J/k_1\ k_2\ )\ s^2\ + (r_a'\ J/k_1\ k_2\ )\ s+1]} \qquad (7)$$

Now if the denominator is written in the form

$$(1 + s\tau_m)\ \ (1 + s\tau_a)$$

$$= \quad s^2\ \tau_m\ \tau_a\ +\ s\ (\tau_m + \tau_a\ )\ +\ 1$$

then from (τ), we get

$$\tau_m\ \tau_a \qquad \frac{L_a' + J}{k_1\ k_2}$$

$$\text{and } \tau_m + \tau_a \ = \ \frac{r_a'\ J}{k_1\ k_2}$$

and under the assumption $\tau_m >> \tau_e$
then electromechanical time constant is given by

$$\tau_m \ = \ \frac{r_a'\ J}{k_1\ k_2} \qquad (\ 8\ )$$

and electrical time constant is given by

$$\tau_a \ = \ \frac{L_a'}{r_a'} \qquad (9)$$

For the GMRT case, the electro-mechanical time constant, τ_m, is given by, (see Section 3.1 (a), (b) and (c) for values of k_1, k_2, r_a', L_a' and J) :

$$\tau_m \ = \ \frac{0.15\ (\text{ohm})\ \text{x}\ 0.0723\ \ (\text{kg.m}^2\ )}{0.56\ \text{x}\ 9.81\ (\text{kg m}^2\ \text{s}^{-2}/\text{amp})\ \text{x}\ 0.56\ (\text{V/rad s}^{-1})}$$

$$= 0.069 \text{ sec.} = 69 \text{ msec}$$

The electrical time constant is given by :

$$\tau_e \quad \frac{1.43 \text{ mH}}{0.15 \text{ ohm}} = 9.5 \text{ m sec.}$$

3.1 e) Torques due to angular acceleration

Torque due to angular acceleration is given by

$$T_{acc} = \frac{J\, d\omega}{dt}$$

Consider that 96 volt battery is applied whence the motor will reach a velocity of about 1600 rpm = 112 rad/sec in about 69 msec (Sec. 3.1d). In fact velocity will be somewhat smaller because of the voltage drop across the armature resistance.

Hence, the acceleration torque on the motor, T_{ma}

$$\begin{aligned} T_{m\text{-}acc} &\leq (0.723 \times 112/69 \times 10^{-3}) \\ &\leq 117 \text{ kg m}^2 \text{ s}^{-2} \\ &\leq 117 \text{ N.m} \end{aligned}$$

For a 24 V battery, $T_{ma} = 29$ Nm. The peak dynamic torque seen by the motor is the sum of the acceleration torque plus load torque. The rated peak torque of the motor = 111 N.m

It should be noted that the peak acceleration torque which gets applied to the input of each gear box (connected to the 45-m dish) is much smaller because of the much smaller value of the inertia seen at the input of the gear box compared to that of the motor inertia. As an example, the force experienced by a person sitting in a car as it accelerates depends only on the weight of the person; similarly if a small flexible shaft is attached to a large wheel or a heavy shaft, the torque seen by the small shaft during acceleration or deacceleration depends only on the inertia of the small shaft.

The values of the acceleration torque at the inputs of the gear-boxes of elevation drive ($J_{g\text{-}acc} = 0.0083$ kg m^2) are given in Table 1 and are much smaller than the capacity of the gear boxes even for 96 V input to the motors. (for 1600 rpm $T_{g\text{-}acc} = (0.0083 \times 112/69 \times 10^{-3})$

3.1 (f) **Static case (Wind Opposing Motion):**

Consider the case when V_t is constant (e.g. a battery) and acceleration has stopped (static case), whence we get from (1), (2) and (3) :

$$
\begin{aligned}
T_m &= k_1 I_a \\
&= k_1 (V_t - V_f)/r_a' \\
&= \frac{k_1}{r_a'} Vt - \frac{k_1 k_2}{r_a'} \omega_m \\
&= (K_1 V_t - K_2 \omega_m) \qquad (10)
\end{aligned}
$$

where $K_1 = (k_1/r_a') = (0.56/.15) = 3.7$ N.m/Volt and

$K_2 = (k_1 k_2/r_a') = 218.3$ N.m/krpm, if ω_m is in krpm.

In the static case $T_m = T_L = (T_w + T_u + T_f)$

$= (T_w + T_u + 1.9 + 1.7\,\omega_m\ T_u)$

or $(K_1V_t - K_2\,\omega_m) = (T_w + 1.9 + 1.7\,\omega_m + T_u)$

Let us consider the case when the unbalance torque $T_u = 0$. Hence we have

$$
\begin{aligned}
(K_2 + 1.7)\,\omega_m &= (K_1 V_t - T_w - 1.9) \\
\text{or} \quad \omega_m &= (K_1V_t - T_w - 1.9)/(K_2 + 1.7) \qquad (11) \\
&= (3.7\,V_t - T_w - 1.9)/(218.3 + 1.7) \\
&= (3.7\,V_t - 1.9 - T_w)/220
\end{aligned}
$$

Since both the motors will move the antenna in the same direction while slewing using a battery system, we should consider $T_{fl} = 2 \times 1.9$ Nm and hence T_w is the combined torque at the input of the two gear boxes which is given by the wind torque at elevation axis divided by (the overall gear reduction of 821 x 30.3 = 25,000 and by efficiencies of pin-sector = 0.93 and of planetary gear boxes = 0.84).

The calculated values of ω_m for three different battery voltages of 24, 48 and 96 volts for various wind speeds (40 to 90 kmph) are given in Table-2.

3.2 Practical consideration for Auto-Stowlock

a) It is seen in Section 3.1 (d) that the electromechanical time constant of the Elevation Drive System using the Industrial Drive DC Motors is about 69 m sec. As shown in Section 3.1 (e) and Table-1 the acceleration torque when a 24 V battery is applied to the motors is only 3.4 Nm. The acceleration torque when we switch from 48 to 96 V = (13.5 - 6.7) = 6.8 N_m. These torques are much lower than the rated torque capacity of the planetary gear boxes, being (16,000/821) Nm = 19.5 Nm. The static capacity of the gear boxes is about 2.5 times the above value. Thus, it is concluded that the antenna system will be quite safe if the autolock system is designed to operate with batteries of 24 V, 48 V and 96 V switched ON and OFF for starting the slewing operation and for braking.

b) The measured braking time of the antenna system are given in Appendix-2.

4. RELATIONS BETWEEN VOLTAGE CURRENT, TORQUES AND SPEED FOR THE CASE OF DC GENERATOR WITH WINDS AIDING THE MOTION.

4.1. Basic Equations

Figs. 3a and 3b gives a schematic diagram for the case when wind drives the antenna so that motors act as generators. The following relations (Eqs. 12 to 16) are applicable in this case.

$$T_{mag} = (T_w - T_u - T_f) \quad (12)$$

$$T_{mag} = k_1 I_a \quad (13)$$

$$V_f = k_2 \omega_m \quad (14)$$

$$V_t = (V_f - L_a' sI_a - r_a' I_a) \quad (15)$$

$$J s\omega_m + T_{mag} = (T_w - T_u - T_f) \quad (16)$$

where $(T_w - T_u - T_f)$ is the mechanical driving torque applied to the motors as a result of wind aiding the motion. T_{mag} is opposing torque caused by the generator action as current flows in opposite direction to that of the motor direction.

4.2 Battery Across the Motor When Wind Aids the Antenna Motion.

Consider the case shown in Fig. 3 (b) in which a battery of 96 V is connected across the motor with wind aiding the motion. It can be shown from Eq. (18) in the next para and Table-3 that a current of about 14 A and 59 A flows to the battery from the two DC motors acting as generators for wind speed of 45 kmph and 80 kmph respectively. This scheme is not at all acceptable as it will damage the batteries.

4.3. A load Resistor Across the Generator

For the sake of an illustration let us first consider a case when a load resistor R_L (see Fig. 3c) is placed across the motor so as to absorb the generated power. Hence

$$V_t = I_a R_L \quad (17)$$

Now, in the Static case

$$I_a = (T_{mag} / k_1)$$

$$= (T_w - T_u - T_f) / k_1$$

$$= (Tw - T_f)/k_1 \qquad (18)$$

Ignoring T_u for simplicity. Further

$$V_t = k_2\,\omega_m - r_a'\,I_a$$

$$= k_2\,\omega_m - r_a'\,(T_w - T_f\,)/\,k_1)$$

$$= I_a\,R_L$$

$$= R_L\,(T_w - T_f) / k_1$$

Hence

$$\omega_m = \frac{1}{k_1\,k_2}\;[\,(T_w - T_f\,)\,(r_a' + R_L)\,] \qquad (19)$$

It seen from Eq. (19) that the velocity of the DC motor which acts as a generator depends on the wind torque for the case in which the wind aids the motion of the antenna. The estimated values of ω_m for various wind velocities are listed in Table-3. It is seen that the antenna slewing velocity is quite low for wind speeds of about 50 kmph which is not acceptable. In fact if the stowlocking operation of the antenna is initiated with wind speed exceeding 50 kmph for a circuit of Fig. 3c, we may have difficulty even achieving proper acceleration of the antenna. It is clear that the circuit of Fig. 3c is totally unsatisfactory. This case seems to be the same as Scheme 3-B dated 1/1/1999 of Shri V.G. Hotkar and does not seem to be satisfactory.

4.4 Scheme suggested by BARC in 1995

In Fig. 4 is given a schematic of a scheme suggested by BARC in 1995, but in which relays should be changed to MOSFET or transistor switches. In this circuit, V_t is determined by the external battery and values of R_L are selected accordingly so that the maximum current generated by the two DC motors acting as Generators multiplied by R_L = Battery Voltage. When the wind velocity is lower, torque is smaller so that I_a is smaller. I_b will increase automatically so that $(I_a + I_b\,)\,R = V_b$. For the purpose of soft start, we firstly connect a 24 V battery and then after 5 seconds or so change it to 48 V and then 96

V for achieving full speed. Alternatively, two steps of 24 or 48 V and 96 V may be OK. Similarly, for stopping the antenna, it may be sufficient to change from 96 V to 24 V or 48 V and then applying brakes to ensure no vibration of the structural and mechanical systems. For further details see Technical Note by G. Swarup dated 22nd December 1995 which gives the Note by BARC (July 1995). Appendix 3 gives an Extract from BARC's note.

4.5 Scheme by Shri Hotkar

Shri Hotkar has suggested a scheme 3B on 01/01/1999 (revised on 06-01-1999 and analyzed on 14/01/1999) which attempts to provide soft start and stop for both motoring and regeneration mode. A simple block diagram and an analysis of the scheme of the scheme are given in Appendix-4. Further details of this scheme incorporating a 1 ohm resistor for absorbing the large and variable regeneration current, connected to the point-A of his block diagram are given in a detailed note by Shri Hotkar dated 6.1.1999 revised dt. 5.2.99. While the scheme is viable for the motoring mode, the scheme needs to be tested for the regeneration mode and may also require some modifications concerning the circuit connected to the 1 ohm resistor (see Block diagram of Appendix A4 page 12).

a) **Soft Start :** say 400 RPM or so with regeneration current varying from 10 to 70 Amperes

b) **Full Speed :** About 1500 RPM (not less than 1200 RPM) with regeneration current varying from 10 to 70 A.

Shri Hotkar had made an analysis (dated 14.01.99 Appendix A4 page 9 to 11) for the scheme in which he has considered only the term $L_a\, dI_a/dt$ but not the resistance of the motor and wires, which determines the time constant of the circuit (see Section 3.1 d) which is much larger than the switching time dt. in the term LdI_a/dt. Also, he has not considered the steady current I_a which depends on the wind torque. When voltage is applied to the antenna brakes and transistor Q1 is switched by using a pulse train of low duty cycle for moving the antenna at a low speed (see A-4 page 1-3 and block diagram page A4 page 12). Thus the voltage of 96 volts will get applied for a short time when Q1 is on and during which period the regeneration motor current could only pass through D1 as Q2 is off. Hence the voltage at Point B on page 13 will rise above 96 volts due to L (di/dt) action. Thus the voltage at point `C' of A-4 page 13 will become higher then 96 volts across the capacitor. Capacitor value should be appropriately chosen for absorbing this energy. After some time, the value of the voltage of the pulse becomes zero, when Q1 will become off and Q2 becomes on. Hence when the current will pass through the transistor Q2. This will tend to short circuit the voltage at point B decreasing the motor speed but the mechanical incrtia of the motor and its relatively large time constant of 69 millisecond (see Section 3.1 d) compared to the period of the pulse train will ensure that the motor speed is governed by the average value of the voltage at Point-B with little fluctuatioin, so long the period of the pulse train is much smaller than 69 ms.

c) After some time the duty cycle of the pulsed train will become high, say 75% so that the motor will run at a speed of about 1200 RPM (= 96 V x 0.75 x 1000/59).

d) It may be noted that the motor current will depend upon the wind speed. At wind speed of 50 kmph when the stowlock operation is to be initiated and when the armature current is 20 amps. See table 3. A total current of two motors is 39 amps (See Table 2) and at 85 kmph it rises to 87 amps. The servo system should take care of this current.

Shri Hotkar has made a test setup with an objective of proving the viability of the scheme (see A4 - Page 13). However, in this set up a second motor is driven by a PWM controller at a fixed speed. This is not the applicable case for the GMRT antennas, whence the load varies depending on the wind velocity. For achieving the desired velocities, it seems essential to connect a current generator to simulate the regeneration currents generated in the servo motors of the GMRT antennas by the wind aiding the motion say by applying a current generator

5. DISCUSSIONS AND CONCLUSIONS

In this Report we have discussed relations between voltage, current, torques and motor speed for the two cases when wind opposes and aids the motors i.e. for both the motoring and regeneration cases of the GMRT elevation drive system. We have also discussed a few schemes which have been proposed over the last few years. It seems desirable that the both static and dynamic cases are analyzed in order to examine the viability of a proposed scheme. As discussed in Section 4.5, bench testing of a proposed scheme for the regeneration case by driving the test motor with a second control motor which provides the mechanical energy requires a careful consideration. If one wants to demonstrate the viability of a proposed scheme, there are the following three possibilities:

a) Make a detailed circuit analysis considering static and dynamic eqs.

b) Test on the GMRT antennas when it is windy, but this would not be easy to test the full behaviour.

c) Use the second central motor for supplying torque, say equivalent to that for a wind speed of about 60 kmph (21 Nm : See Table 3) but the question arises as to what speed should this second motor be operated. In the case of wind driving the antenna, the torque applied is constant for a given wind speed but the antenna speed depends on the frictional torque and voltage developed across the terminal resistor. I suggest that the second motor be driven by a variable Current Generator power supply; this is quite important.

d) Setup a pulley system with a load. Lift the load with the test motor and let the load drive the test motor (regeneration case). This is likely to be cumbersome. Hence I recommend a detailed system analysis should be made for any scheme that is proposed and test be made using a current generator (case (c) above).

Stow-locking is an important requirement of the GMRT antennas. The only alternative is to install a third gear box, but it would be very cumbersome (although one may examine this possibility from the long term view point using an economical gearbox). Auto-stowlocking was recommended by M/s. Tata Consulting Engineers to cut down the cost of the mechanical drive system. However, it has proved to be very bothersome. However, it is practical to develop a suitable reliable system for installation on all the Y-array GMRT antennas. Although the Scheme-3B suggested by Shri Hotkar during January and February 1999 is quite an interesting scheme and can be made to work it has many active devices and their reliability needs to be examined. Shri Hotkar has recently wired it up and it is quite compact. Shri Hotkar has also wired up the Hotkar/N.V. Nagarathnam BARC Scheme of 1985 using two high wattage 1.6 ohm resistors of rather large size which has made the set up rather bulky. For the case of slow speed (soft start) the wattage of the resistor A-4 and its value can be smaller so that the set up is more compact. Also some of the contactors could be replaced by power transistor packs. It is true that Shri Hotkar's scheme 3B will allow quite a gradual variation of the speed for soft start and stop, but it uses much more electronics and the probability of components failing when the winds are heavy is not negligible.

It seems desirable to me that for the stow-locking system, one should use minimum number of components so that the probability of automatically stowlocking of the antennas is very high. In this report, I have attempted to make a review of two different schemes by considering various factors. However the final decision will require an analysis and test set up and finally a group discussions by some concerned experts, who may consider all the aspects discussed in this report. It is expressly important to take a final decision by September 1999 so the that automatic stow-locking system is installed in all the 18 antennas by March 2000. Due to manpower constraints, we have been operating the antennas without the automatic stow-locking system. This should not be the case beyond March 2000.

I had recommended using the scheme proposed by Shri V.G. Hotkar and Shri N.V. Nagarathnam in 1994 and improved by BARC in June 1995 (See Appendix 3 and

Technical Note by G. Swarup dated 26th December 1998) but it could not be developed further due to manpower constraints. As said above the BARC scheme could be modified somewhat by replacing some of the contactors by power transistor packs. For the 14 Central antennas Diesel Generators are to be used but it is important to have a detailed write up for their operation when winds exceed 45 kmph and also periodic inspection and maintenance.

It may be noted from last column of Table 2, page 19 that the total current requirement for slewing the antennas at a wind speed of 80 kmph is 79 Amp. and at 85 kmph = 87 Amp. However, in the present servo system the current limit has been set as 35 Amp. for each motor equal to 70 Amp. for two motors. Further, since a bias of 10 amp is provided for the Counter-torque system, the actual current available is only 35 + (35-10) = 60 Amp. This limit of 35 A was decided as a conservative value during erection. It is strongly recommended that this value is changed to 48 Amp. so that the servo system can provide total current of 86A=(48 + 48 - 10), and antenna could be stowlocked upto the time the wind velocity is below 85 kmph.

6. ACKNOWLEDGMENT

I acknowledge many valuable discussions with Shri V.G. Hotkar regarding the Auto Stow-locking system. Discussions have also been made with Shri N.V. Nagarathnam and briefly with other staff members. Discussions with BARC Engineers during 1994-95 regarding the Auto-Stow Lock System are also acknowledged.

7. The main part of this report was written during January to March 1999. Discussions regarding Hotkar's scheme as given in Section-4 & 5 were finalised after discussions with Shri V.G. Hotkar in April 1999. However I could not release the report earlier because of my many pre-occupations. I hope that this report will be useful to Shri Hotkar and others in finalizing a suitable auto stow-locking system.

TABLE-1

Acceleration Torques for various battery voltages and speed of motors

V_b (v)	ω_m (rpm)	$T_{g\text{-}acc}$ (N.m)
96	1600	13.5
48	800	6.7
24	400	3.4

TABLE - 2

Motor speeds for 24 V, 48 V and 96 V battery (input) for various wind speeds (40 to 90 kmph (See Equation 12) : (T_L' ignores viscous damping).

Wind speed, W (kmph)	Wind Torque* T_w (Nm)	Friction Torque T_{fl} (Nm)	T' (Nm)	Motor Speed ω_m for V_t			Total ** current of two motors (amp)
				24V	48V	96V	
				x 3.7	(4pm)		
40	9.3	3.8	13.1	340	747	1555	23 + 6
45	11.7	“	14.8	336	740	1547	26 + 6
50	14.5	“	18.3	320	724	1531	33 + 6
55	17.5	“	21.5	306	710	1517	38 + 6
60	20.9	“	24.7	291	695	1502	44 + 6
65	24.5	“	28.3	275	679	1486	51 + 6
80	37.1	“	40.9	217	621	1429	73 + 6
85	41.8	“	45.6	196	600	1407	81 + 6
90	46.9	“	50.7	173	594	1384	91 + 6

* Wing torques at inputs of gear boxes for the two motors combined are given by

$$T_W = 204\ \text{Tm} \times 1000 \times \frac{(W)^2}{(133)^2} \times \frac{9.81}{30.5 \times 821} \quad \frac{1}{0.93 \times 0.84}$$

Where the torque at the elevation axis of the 45-m dishes, as calculated by TCE = 204 tm, W is the wind speed, the gear ratio of pin sector and gear box are 30.5 and 821 to 1 respectively and efficiencies are 0.93 and 0.89 respectively.

** We have added 6A as estimated value of the sum of the viscosity (due to oil) and Column of torques (doe to motor) at a speed of about 1500 RPM.

TABLE - 3

Motor Speed and Current for the case when Wind AIDS the motor of the antenna and a One Ohm resistor is placed across the motor

Wind Speed, W (kmph)	Wind Torque, T_w (Nm)	Minimum Friction* Torque T_f (Nm)	Total Driving Torque (Nm)	ω_m (rpm)	Armature Current A
(1)	(2)	(3)	(4)	(5)	(6)
40	9.3	3.8	5.5	188	10
45	11.0	3.8	7.9	270	14
50	14.5	3.8	10.7	366	19
60	20.9	3.8	17.1	584	31
70	28.4	3.8	24.6	841	44
80	37.1	3.8	33.3	1139	59
90	46.9	3.8	43.1	1471	77

(1) * Ignoring Viscosity Losses

(2) $k_1 = 0.56$ Nm/A ; $k_2 = 59$ V/krpm

(3)
$$\omega_m = \frac{1}{k_1 k_2} \; [(T_m - T_f) \; (r_a' + R_L)$$

$$= \frac{1.13}{0.56 \times 59} \; (T_m - T_f) \; \times \; 1000 \text{ rpm}$$

$$= 34.2 \; (T_m - T_f) \text{ rpm}$$

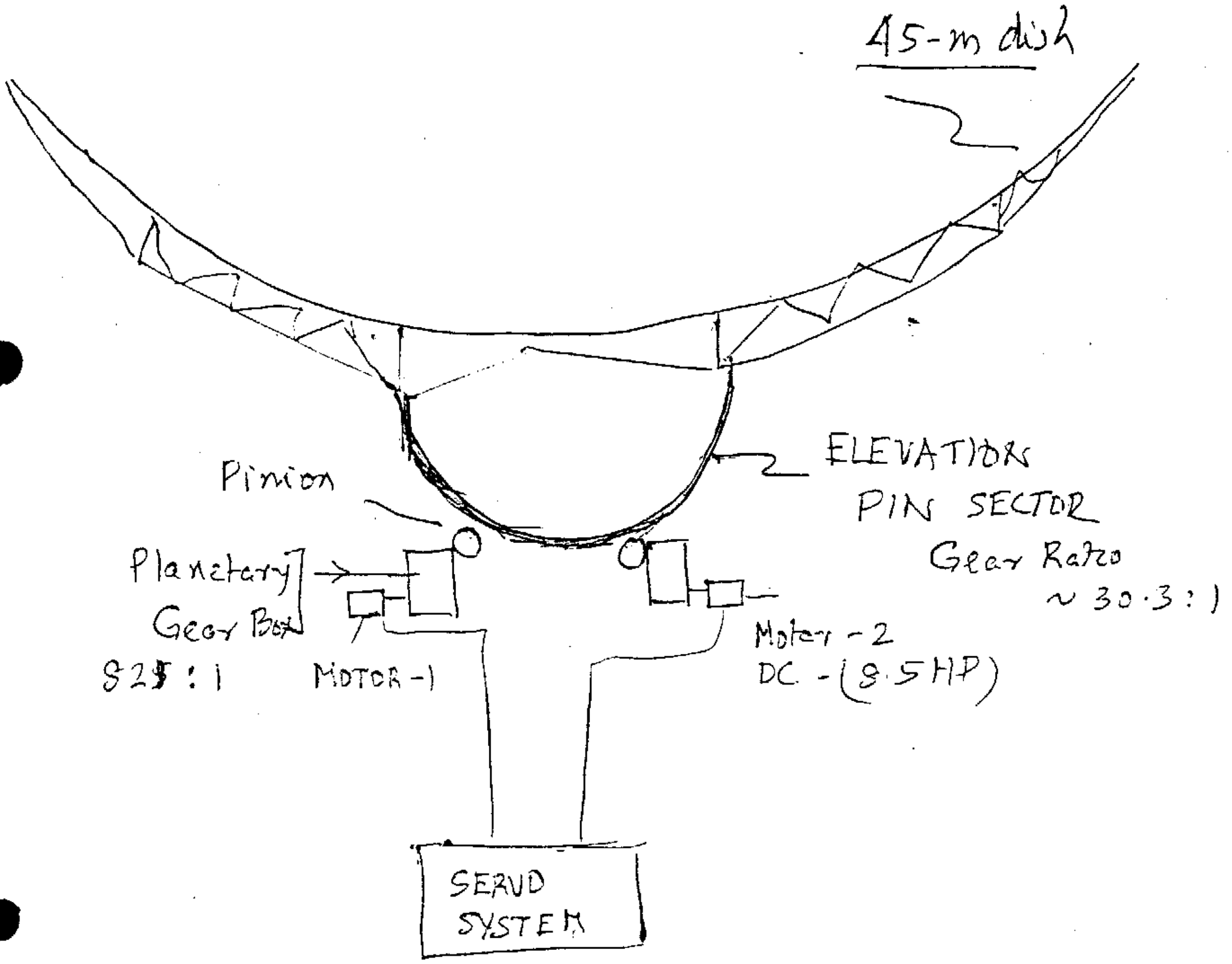


Fig. 1 A Schematic of the Elevation Drive of the GMRT 45-m dishes

r_c'

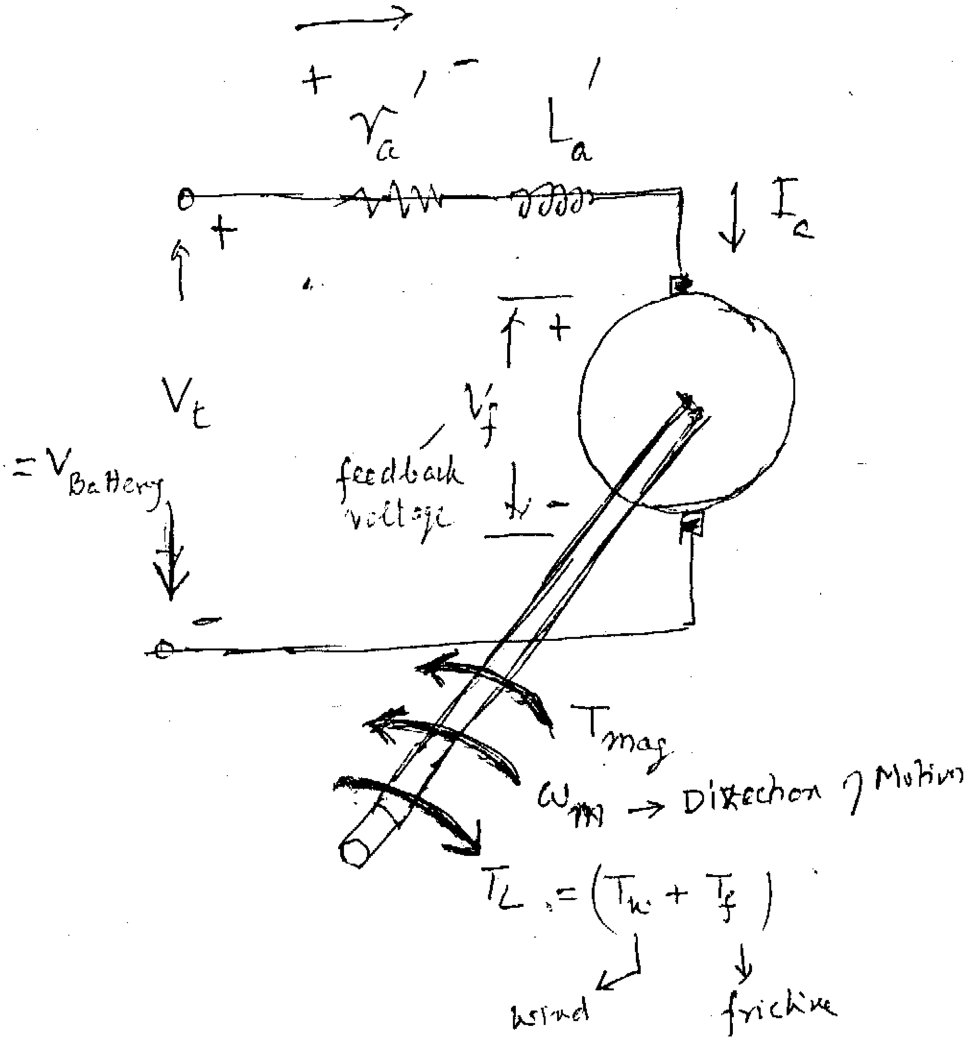


Fig. 2 : Schematic showing the direction of the armature current T (magnetic) and T_{LOAD}, when wind opposes the direction of motion.

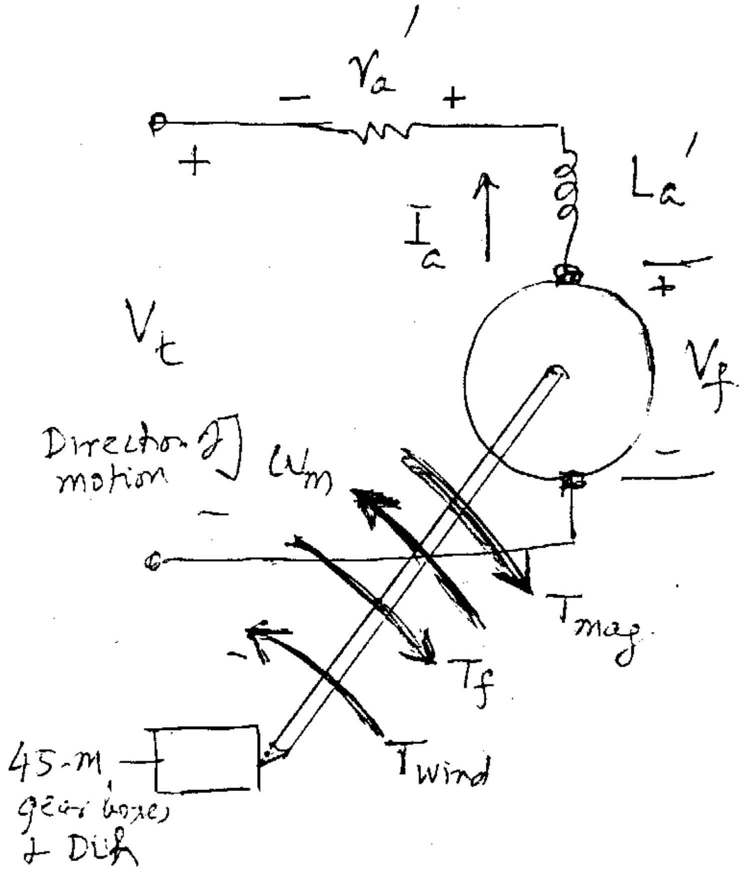


Fig 3(a) A schematic representation of the DC motor acting as a Generator when WIND AIDS THE MOTION

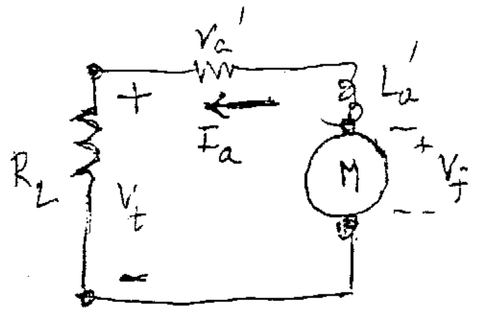


Fig 3(c) When a Load Resistor RL is placed across the Generator

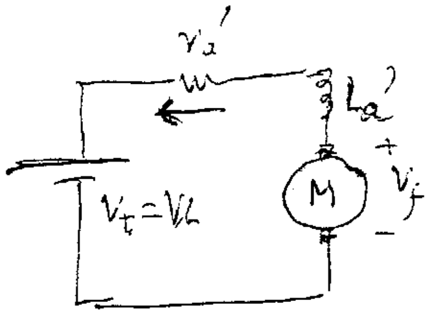


Fig 3(b) When A Battery is placed across the Generator

Fig. 3 WHEN ANENNA AIDS THE MOTOR AND IT ACTS AS A GENERATOR

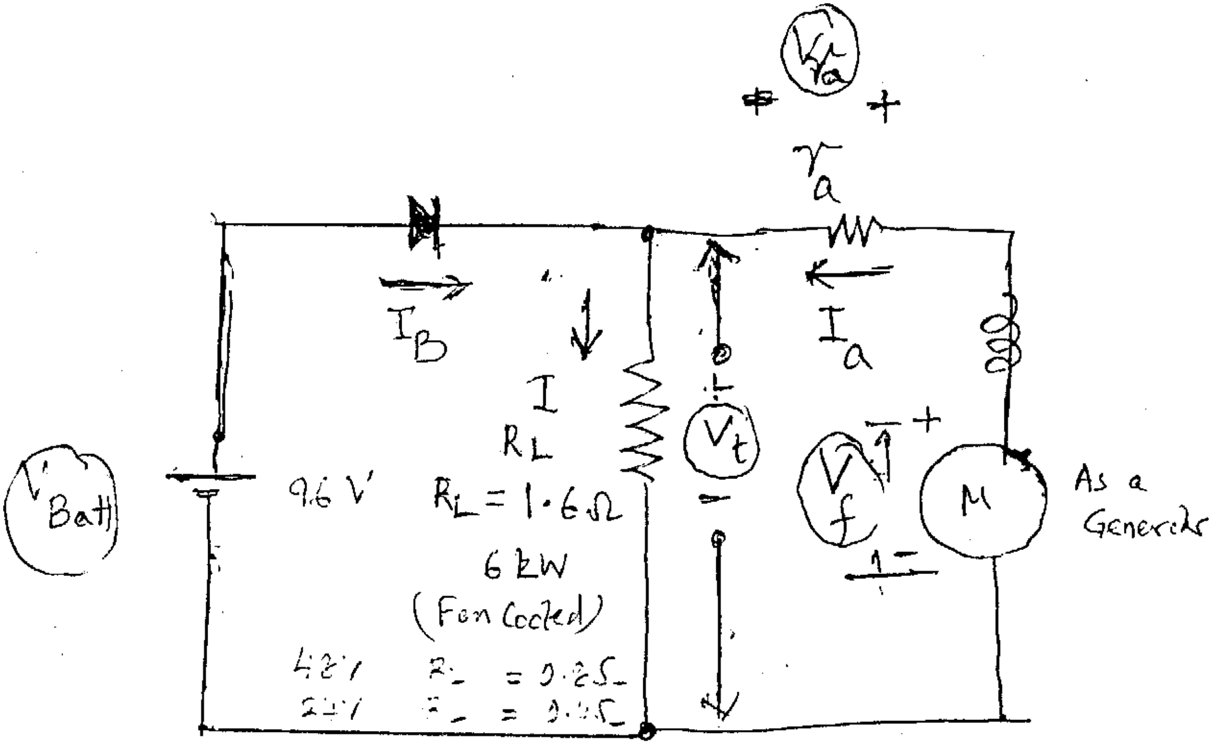


Fig. 4 : Basic Circuit suggested by BARC in 1995. When Wind drives the antenna, resistor of 1.6 Ω is switched ON using a MOSFET or Transistor Switch. The velocity of the motor depends on $V_f = (V_t - Vr_a)$ and is independent of the regeneration current. I_B decreases as I_a increases with increasing wind velocity. For slow start or stop, another set of switches connects a 24 V and or 48 V battery and a 0.4 ohm or 0.8 ohm resistor.

APPENDIX ①

DATA SHEET OF INDUSTRIAL DRIVE

DC MOTOR

GMRT SERVO MOTOR (BOT AZ & EL) 2 Each AXIS

MOTOR PARAMETERS (DC)		TOL.	SYMBOL	UNITS	TT-53810 A	TT-53810 B	TT-53810 C	
Horsepower	①	Rated	hp	hp	6.0	8.5	4.5	HP
Max. Operating Speed	②	Max.	ω max.	rpm	1100	2250	550	ω max
Continuous Torque (stall) @ 40° C ambient (*)	③	Nom	Tc	lb • ft N • M	30.0 40.8	35.0 47.0	35.0 47.6	Cont Tq
Peak Torque (*)	④	Nom	Tp	lb • ft N • M	160 218	82 111	160 218	Peak Tq
Theoretical Acceleration	⑤	Nom	α M	rad/sec	3500	1740	3500	[illegible]
Current → Cont. Torque	⑥	Rated	Ic	amps	36.5	85	21.3	Cont. Current
Current → Peak Torque	⑦	Rated	Ip	amps	200	200	97.6	Peak C.
Max. Terminal Voltage	⑧	Max.	Vt	volts	150	150	150	[illegible]
Torque Sensitivity (*)	⑨	10%	Kt	lb • ft/amp N • m/amp	0.82 1.11	0.41 0.56	1.61 2.22	[illegible]
Back EMF Constant (*)	⑩	10%	Kb	V/Krpm	118	59	232	[illegible]
▲DC Resistance @ 25° C	⑪	12.5%	Rm	ohms	0.23	0.045	0.72	DC Resi
Inductance	⑫	30%	Lm	mH	1.3	0.33	5.3	Induc
Time Constant @ 25° C mech elect	⑬	Nom Nom	τ M τ E	msec msec	12.2 5.4	13.0 5.1	10.0 6.9	Time C

(*) AT ULTIMATE CASE AND ARMATURE TEMPERATURE (FOR AMBIENT DATA USE 1.11 FACTOR)

RATED CONT. CURRENT OF MOTOR 85. TRANSISTOR IS CHOSEN FOR THIS CURRENT

TACHOMETER PARAMETERS (TGF-2030-147)				TT53810		
Voltage Sensitivity	± 10%	Kg	V/krpm	19.0	19.0	19.0
Volt Ripple @ 66 cy/rev	Max.	Vr	% avg-pk	1	1	1
DC Resistance	± 12.5%	Rt	ohms	26	26	26
Load Resistance	Min.	Rl	ohms	2.6K	2.6K	2.6K
Inductance	± 30%	Lg	mH	24	24	24

BASIC MOTOR-TACH CONSTANTS	SYMBOL	UNIT	TT-53810
Rotor Inertia	Jm	lb•ft•sec² kg•m²	0.047 0.064
Weight	Wt	lb kg (f)	215 97
Static Friction	Tf	lb•ft N•m	1.4 1.7
Thermal Time Constant	TCT	minutes	144
Viscous Damping ∞ Z Source	Fl	lb•ft/krpm N•m/krpm	0.419 0.568

▲ DOES NOT INCLUDE CONTACT DROP

From Row ⑩ 59V at 1000RPM

∴ 1500 RPM at 88.5V

and

$1000 \times \frac{72}{59} =$ 1220 RPM for 72V

24 406 " for 24V

$\frac{96V}{59} =$ 1627 RPM for 96V

48V/59 = 814 RPM for 48V

TT 53810 - 3030 → New motor with manual Brake

TT 53810 - 3023 B old motor without manual brake.

APP-2

Shri H.C. Joshi

GTN–ANT–Brakes/GS/970220[1]

Time for stopping the 45-m antenna when brakes are applied

G. Swarup

Keywords : Antennas, GMRT, 45-m dish, Brakes, GMRT dishes

1 A Relation for stopping time of the antenna

When brakes are applied, we have the following relation for the rotation of the antenna system

$$I\,\ddot{\theta} = T_B$$

where I is the inertia, $\ddot{\theta}$ is the deceleration and T_B is the brake torque. Therefore,

$$I(\frac{d\theta}{dt}) = T_B \cdot t \tag{1}$$

$$I(\tfrac{d\theta}{dt})\,|_{t=0} = T_B \cdot \Delta t \tag{1A}$$

where $\frac{d\theta}{dt}$ is the initial velocity, the final velocity being zero and Δt is the time taken for the anenna to come to zero speed. Therefore,

$$\Delta t = \frac{I(kgm^2) \times vel(\frac{rad}{sec})}{9.81 \times T_B(kgm)} \tag{2}$$

2 Measurements

About 2 weeks ago measurements were made on the stopping time for the C2 antenna using an Industrial PC by Shri Ajit Kumar, Ms. Gauri & Shri Hotkar under my general guidance. In Figs. A2-1 & 2 are given the plots obtained for the output of the Elevation Tachos when brakes were applied. These were obtained for the two elevation tachos one after another and, as expected, give almost identical results. Figs. A2-3 & 4 give plots for the Azimuth tachos. The initial speed was adjusted to about 500 RPM and tacho output was connected to the PC. The brake was then applied. Data was taken at intervals of about 2 ms. The elevation

---

[1] Aj~GSwarup/stop

of the antenna was near zenith. In Fig. 1; I have superimposed the plot of Fig. 2. Similarly, Figs. 3 & 4 give the data for the Azimuth.

It is seen that Tacho output first decreases gradually, somewhat exponentially and then decreases rapidly in a linear way (as predicted by Eq. 1). According to Shri Hotkar, the antenna stops as follows :

(a) First the voltage is disconected from the motor and the resulting reverse current is discharged through diodes to the Mains, explaining the slow decrease of the speed.

(b) After sometime the brake is applied and the speed decreases linearly.

3 Comparison of the calculated and the measured values

3.1 Elevation gear system

For the elevation gear system, the inertia of the 45-m antenna as seen at the input of the Elevation motor is given by (see TCE reports)

$$I_m = \left[\frac{7.33 \times 10^6}{(25,000)^2} + \frac{2 \times 1600}{825^2} + 2 \times 0.064\right] kgm^2$$

$$= [0.0117 + 0.0047 + 0.128]\ kgm^2$$

$$= 0.1444\ kgm^2 \qquad (3)$$

The Brake torque for the two motors was measured manually using a torque wrench and was found to be 53 Nm (=kg m sec^{-2}), therefore, the calculated stopping time is given by

$$\Delta f(s) = \frac{(I \cdot v(rpm) \cdot \frac{2\pi}{53})}{T_B}$$

$$= \frac{(0.144 \times 2\pi)}{(60\ Sec \times 53\ Nm)} \times v(rpm)$$

$$= 0.000284\ v(rpm)$$

$$= 0.000284 \times 394\ rpm$$

$$= 113\ ms$$

The measured value for stopping time for the C2 antenna from 354 rpm to zero speed is 109 ms. Hence, it is seen that the stopping time provides a reasonable estimate of the brake torque.

Table 1: El. drive : Comparison of measured *vs.* calculated stopping time.

Tacho No.	Initial Speed	Stopping Calculated	Time Measured
1 & 2	394 rpm	113 ms	109 ms

3.2 Azimuth gear system

For Azimuth, Inertia at the motor shaft

$$I_m = \frac{9.08 \times 10^6}{(18,000)^2} + \frac{2 \times 6400}{(1500)^2} + 2 \times 0.064$$

$$0.028 + 0.0057 + 0.128$$

$$0.162\ kg\ m^2.$$

The brake torque as measured manually for the 2 Az motors was found to be 55 Nm. Therefore, the calculated stopping time

$$\Delta t = \frac{(0.162 \times 2\pi)}{(60\ Sec \times 55\ Nm)} \times v(rpm)$$

$$0.000307 \times v(rpm)$$

It is seen from the Figs. 3 & 4 that the initial speed at the time of application of brakes was different for the cases of Tacho 1 and Tacho 2. The results are as follows for the Az motors.

Table 2: Az. drive : Comparison of measured *vs.* stopping times.

Tacho No.	Initial Speed	Stopping Time	
		Calculated[a]	Measured
	$v = 354$ rpm,	$\Delta t = 109.0$ ms	132 ms
	$v = 303$ rpm,	$\Delta t = 93.0$ ms	94 ms

---

[a] Assuming combined torque of 2 Brakes = 55 Nm

Hence, the measurements give a reasonable estimate of the brake torque.

4 Conclusion

Stopping time of the antennas can be measured quite readily using an Industrial PC with an ADC card. The measurements take only a few minutes. The main time is taken to take the instrument to an antenna for doing the job.

However, antenna has to be stopped from an initial speed of several hundred rpm (Experiment described in this report was done with an initial speed of 500 rpm, but reasonable estimates may be possible with initial speed of only about 100 or 200 rpm). It is not clear whether this will result in wearing out of the brake linings, even if such a job is done only once a month or so.

Secondly, it is not clear as to whether it is possible to do such an experiment remotely from the Central Room by suitable additions to the Hardware over the next few months or during the proposed modification of the servo system.

5 Acknowledgement

Measurements were made by Shri Ajit Kumar, Ms. Gauri and Shri Hotkar.

Measurement of Stopping Time of 45-m Antenna

Note to Shri Ajit Kumar and Shri Hotkar[3]

To establish methodology on 2 or 3 brakes; we can then decide whether to do it as a routine or not.

1. (a) Connect ~ 5 to 1 divider to MIPL and calibrate using a … was suggested by Shri Ajit Kumar.
    (b) Connect MIPL to tacho output voltage.
    (c) Start stewing antenna at speed θ (Measure the initial speed).
    (d) Start Acquisition of data.
    (e) Within a second or less, stop the antenna (applying brakes).
    (f) Data acquisition will stop within 3 seconds.
    (g) See the display on the screen full; then anlarge near the step and measure approximately Δt to see whether it seems measured.
    (h) Request Mechanical group to get measured the brake torque manually using a torque wrench.
2. Do for both Az and El.
3. Do for 2 or 3 antennas and send results to Pune.

Figure Captions

Fig. 1 Plot of voltage output of Techo 1 of elevation motor when intake is stalled. The slow decrease is due to motor current being cut off and the rapid decrease is due to break being applied. The plot of Techo 2 elevation table (see Fig. 2) intake was stopped manually from initial velocity of 500 rpm.

Fig. 2 Same as Fig. 1 but for Techo 2.

Fig. 3 Same as Fig. 1 but for Azimuth drive

Fig. 4 Same as Fig. 1 but for Techo 1 and Techo 2 of Az drive.

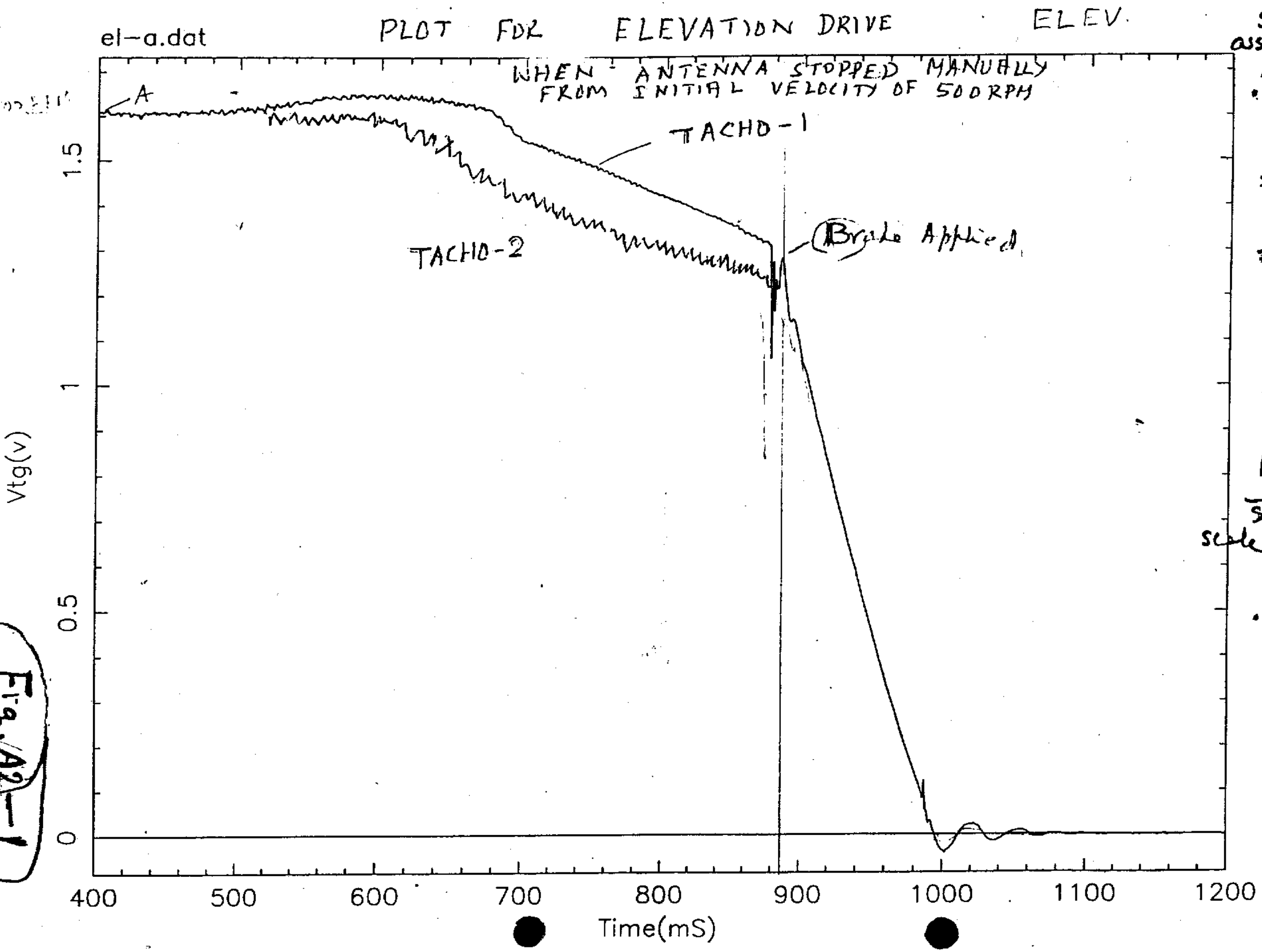


Fig. A2-1

Speed at A is assumed = 500 RPM.

∴ Initial Speed at B

$= \frac{111}{141} \times 500$

= 394 RPM

Measured Stop time

~~Speed (at t=0)~~

scale 133 mm = 500 ms

∴ stop time 29 mm $= \frac{29}{133} \times 500$

= 109 ms

Fig. A2-1

FIG 2

Elev Tacho 2

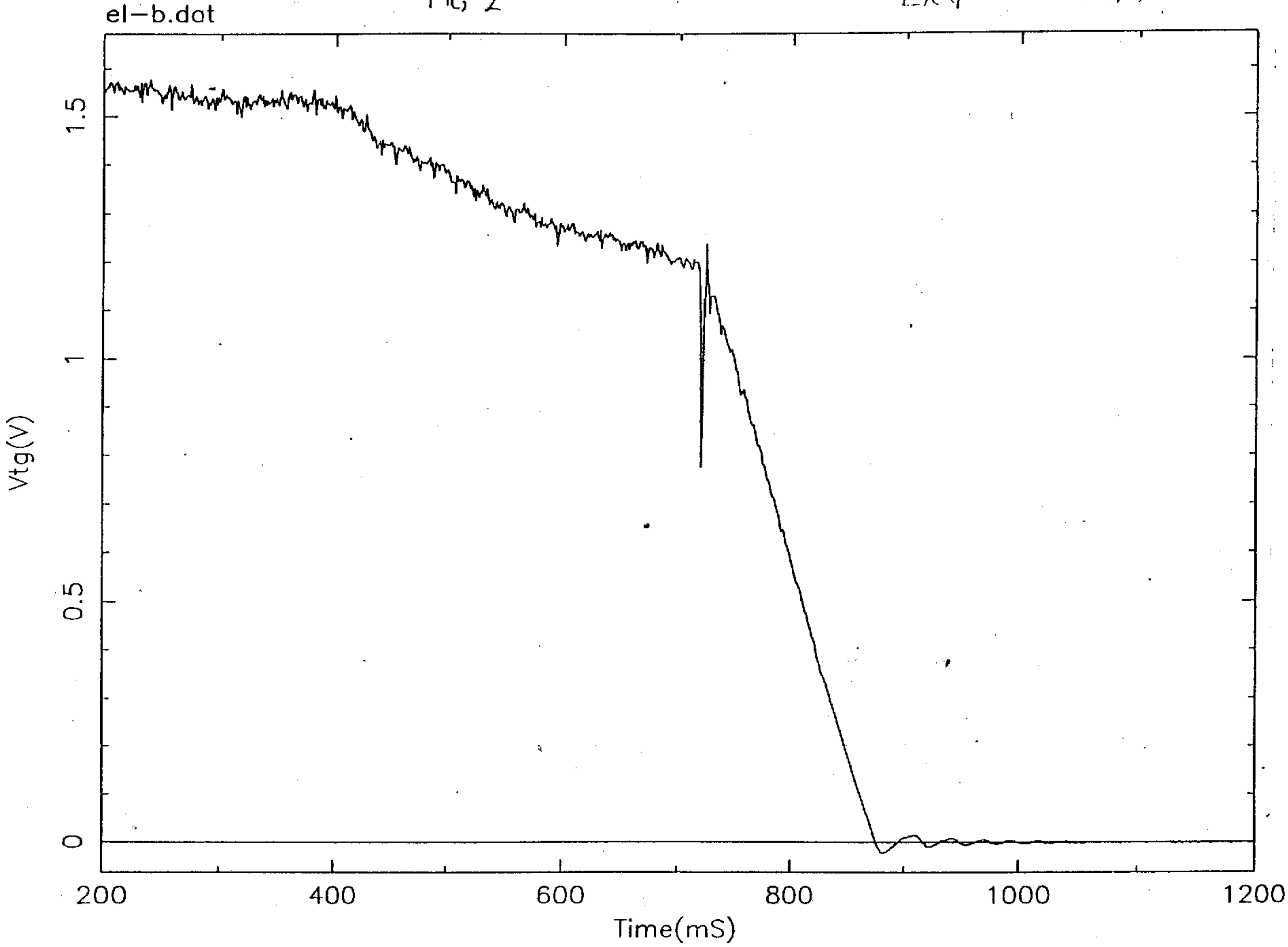
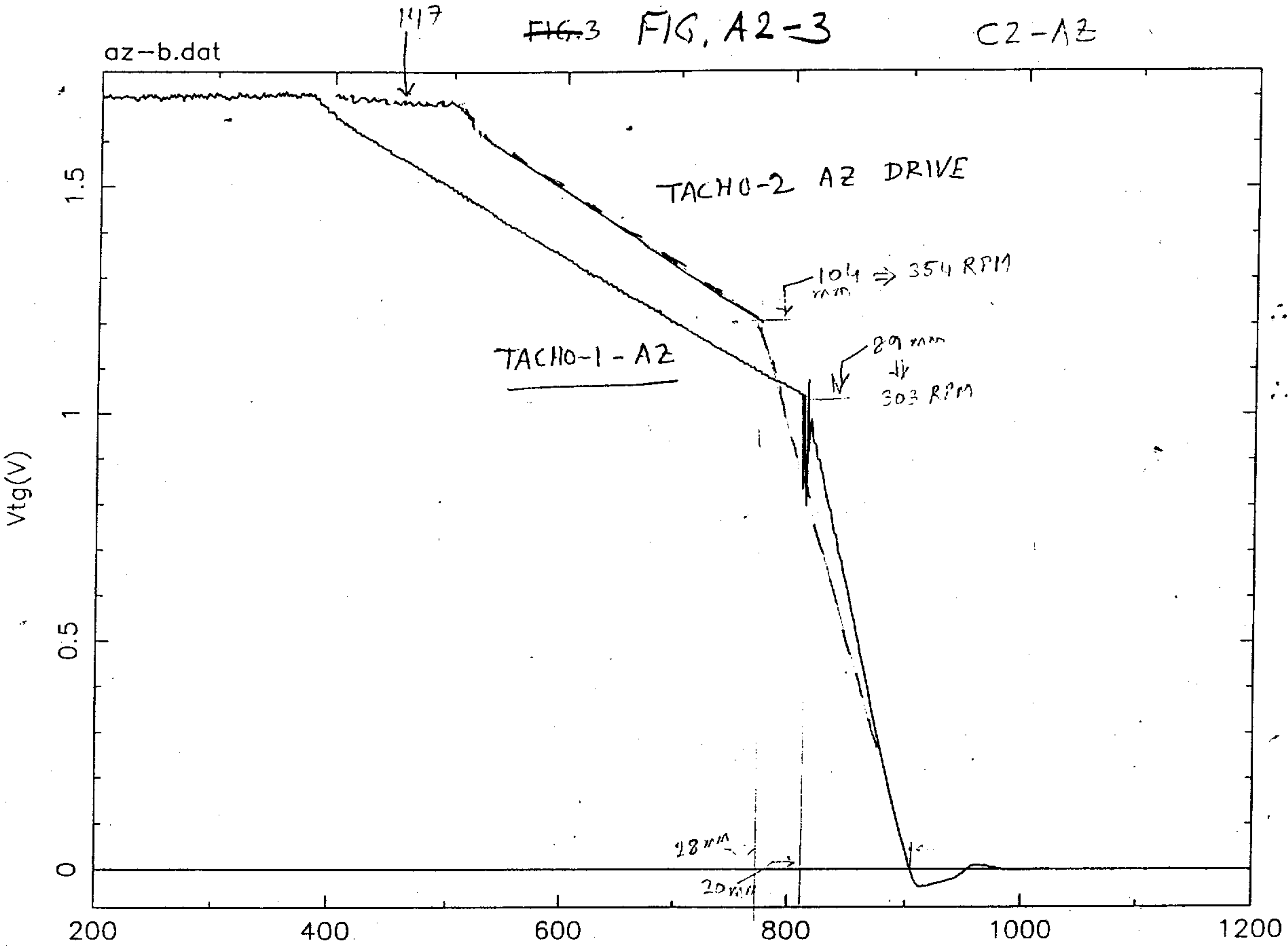


Fig A2.2

~~FIG. 3~~ FIG. A2-3 C2-AZ



147 mm = 500 RPM

$\therefore \frac{104}{147} \times 500 = 354$ RP

$\therefore \frac{29}{147} \times 500 = 303$

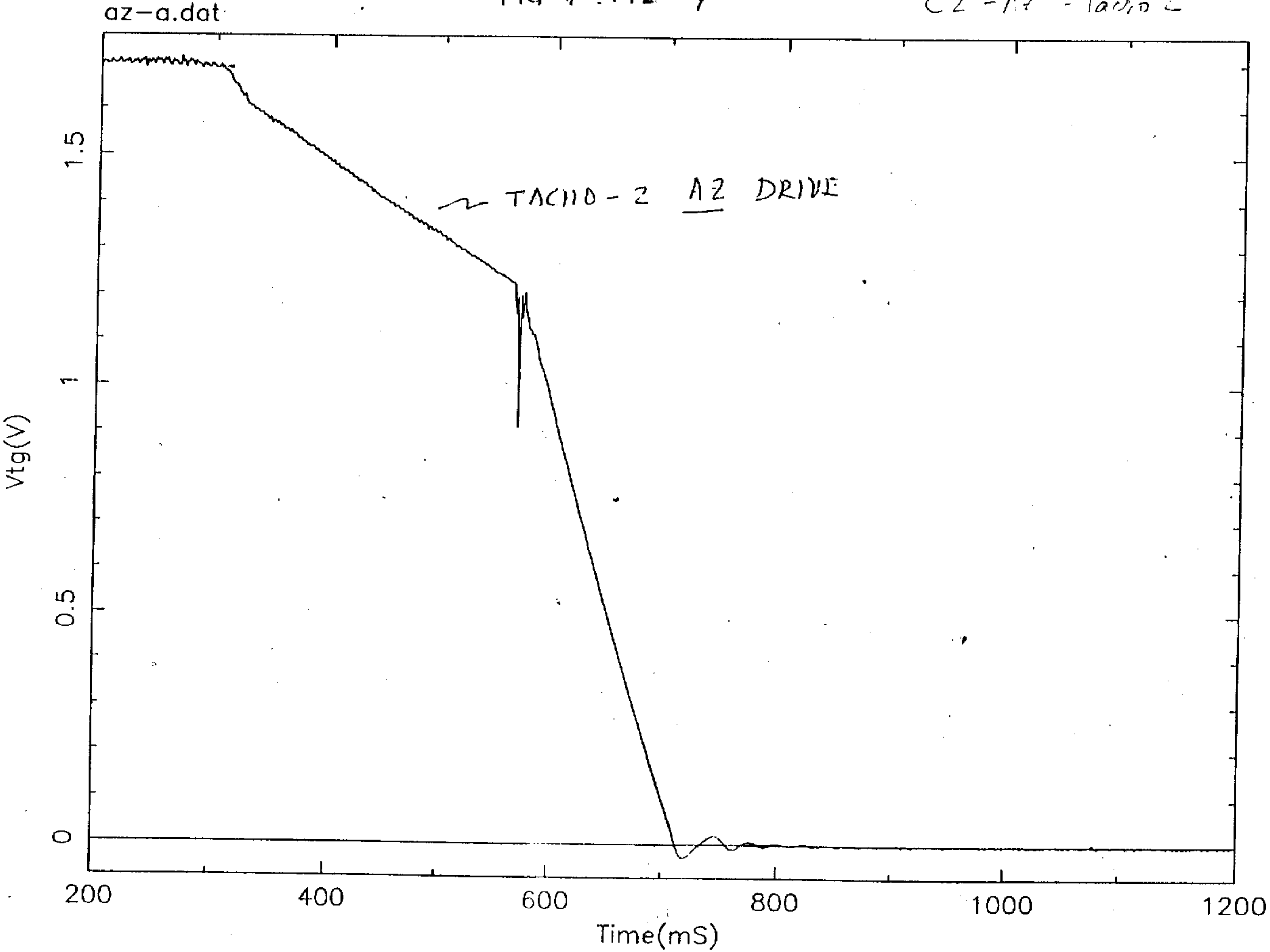
212 mm = 1000 ms

$\therefore \frac{20}{212} \times 10^3 = 94$ ms

$\frac{28}{212} \times 1000 = 132$ ms

FIG 4: AZ-4

C2 - AZ - Tacho 2



TACHO - 2 AZ DRIVE

Appendix 3

Extract from A Note BY BARC dt June 1995

when antenna park command is issued, contactor k2 will close. Motors will accelerate and stabilize at about 800 rpm. after 10 seconds contactor K2 will switch off and contactor k1 will switch on. Motors will accelerate from 800 rpm and stabilize at about 1600 rpm.

$$Tm = Tl + Tw$$

Tm = Motor torque

Tl = Load Torque(friction)

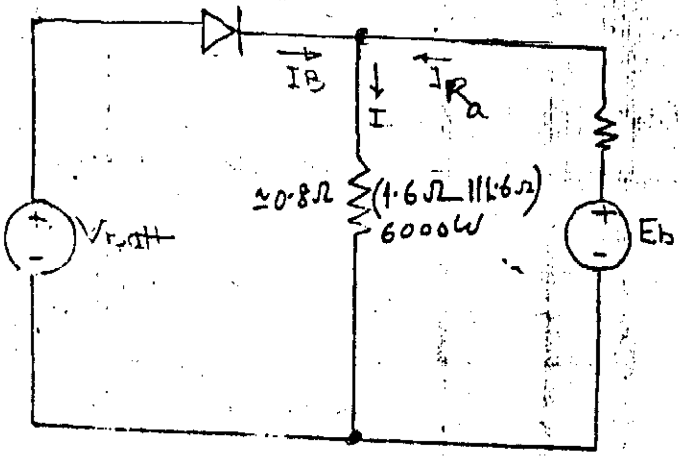
Tw = Wind Torque

If wind is opposing antenna movement Tw will be positive . If wind is supporting antenna movement Tw will be negative. Depending upon the wind direction and speed ,Tm will be either positive (Drawing power from the Battery) or negative (feeding power to the battery).

a) If Tm is positive - contactor K1 will be *ON* from 110 degrees to prelimit position or 15 degrees to prelimit position;contactor K3 and contactor K4 will be *OFF* .It will apply 76 volts to the motor terminals and motors will run at about 1600 rpm. From prelimit switch to stow position, contactor K1 will switch off and contactor K2 will switch on. This will decelerate the motors to ≃800 rpm and continue upto stow position. At stow position power will be cut off to the motors and brake will be applied. In this complete process battery will supply power to the motors.

b) If Tm is negative motors will speed up beyond 1600 rpm. Back emf will become more than the battery voltage. Motors will try to feed power to the battery, Because of the battery's charging current limitation current flow from load to the battery is prevented by diode D1(fig.(4)(modified)). The condition of Eb > V batt. is sensed by Comp. U1(A) and Comp U1(B).

This will turn on relay RL5 which is latched by its own NO contact a
comp. U1b. Contact of RL5 will switch on contactor K3 if contactor
K1 is on .The equivalent ckt can be drawn as below.



I=(96 - Diode drop)/1.6= 60 A

I = Ib + Ir   Ib = Battery current

Ib= 60 - Ir   Ir = Regenerative current

Ir is the regenerating current for balancing the speed at about 1600 rpm.say at 80 %age of rated speed 59 A current will be supplied from the motors and 1 A current will supplied from the Battery.

In a similar way contactor K4 will turn on when antenna is moving between prelimit and stow position.At stow position supply will be cut off and brake will applied to the motors.

Comp. U 1b will monitor the change over from regenerating mode to motoring mode and switch off contactors K3 and K4 if motors shifts to motoring mode.

APPENDIX - 4

Shri V.G. Hotkar has proposed a scheme for Auto Stow-locking the antenna using MOSFET which is given in his note of 1st January 1999. A Block Diagram of the scheme and his analysis dated 14th January 1999 is included in the next three pages of this Appendix. For further details please consult Shri V.G. Hotkar.

SCHEME - 3B

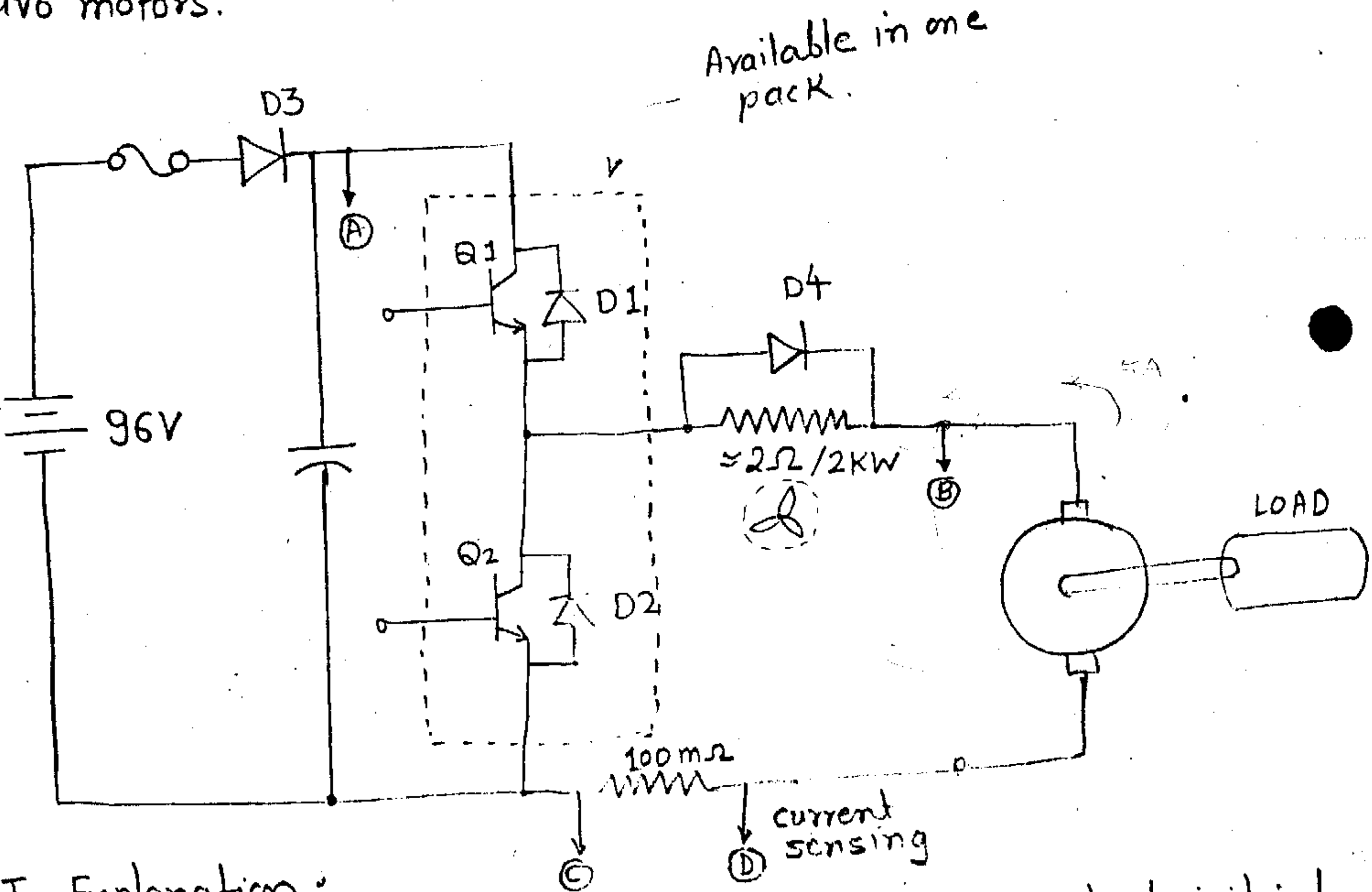
A-4/p.1

1,1,99

(4 No

he various schemes proposed earlier, involves DC contactors or parking the antenna. The contactor based control system being ON/OFF control (bang/bang), incorporating protection features like, over speed limit, over current limit, regeneration, soft start/stop etc. is difficult.

A thought was given to implement the scheme-3 [Prof. G. Swarup renamed it as scheme-A] y using power transistors, which are available easily. The following circuit fulfills the conflicting requirement of 'motoring' as well as 'generating' operation of DC servo motors.



CKT. Explanation:

MOTORING MODE:- During motoring mode, to control initial inrush current Q1 is put ON/OFF by PWM control. After few seconds. Q1 is fully made ON, until 85° limit ontrolled, such that the average voltage to the motor is reduced, which will reduce the motor speed

At 90° STP position, Q1 is put OFF.
(see the graphs, for better understanding).

In 'regeneration mode' when the load drives the motor, the voltage at point B will exceed that of voltage at point A Transistor Q1 will be put OFF and. Q2 is put 'ON' With putting 'ON' of Q2. A 1·6Ω → 2Ω resistor [Fan cooled] will come across motor.

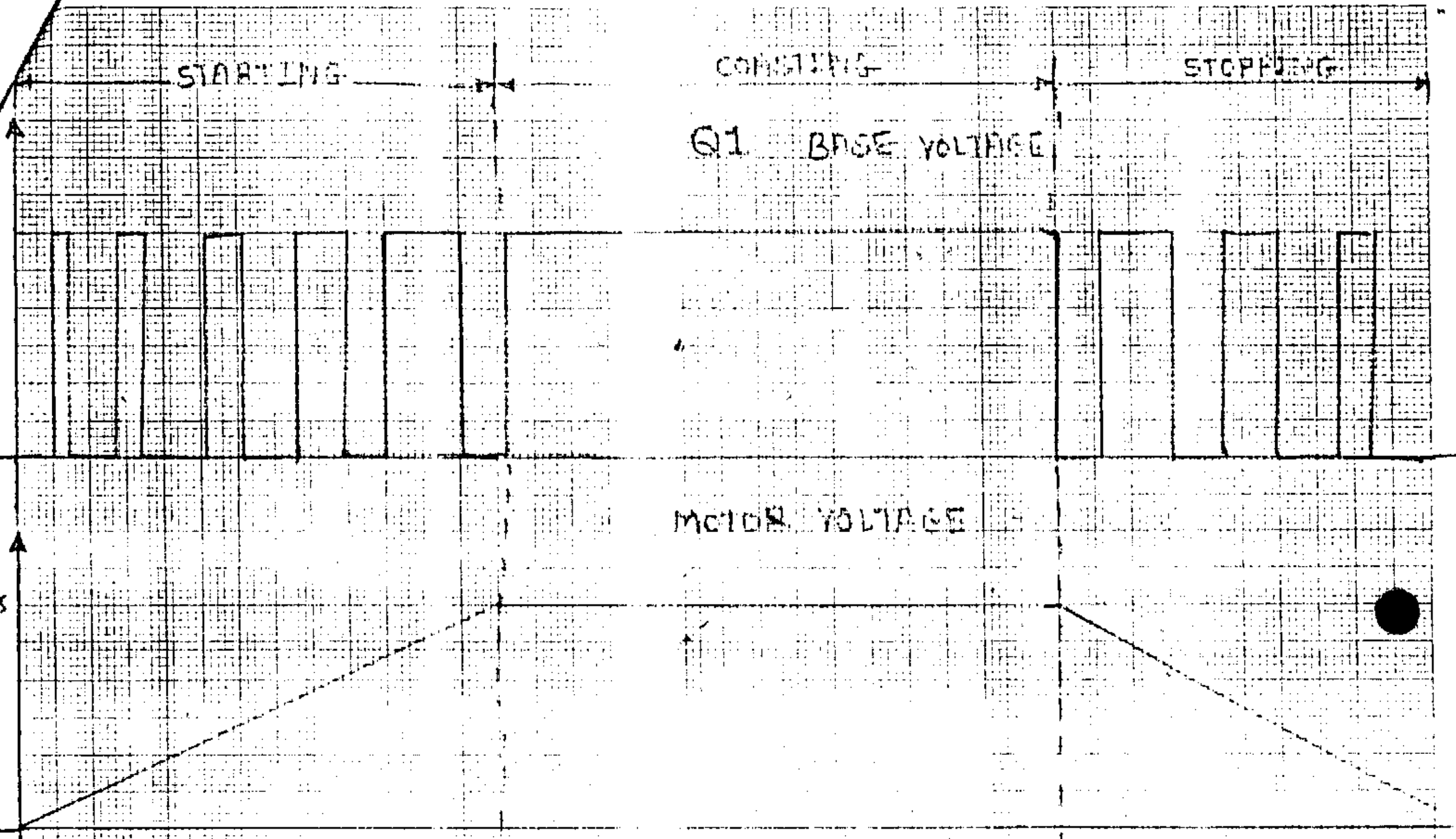
The energy generated by the motor will be dissipated in this resistor to limit the motor speed

Hence by using Just two power transistors, the requirement of scheme-A will be met. This will replace four contactors as suggested by BARC.

IGBT 100A / 600V and with IGBT driver from MITSUBISHI (Japan) has been selected for conducting experiments. (A photo copy of catalogue is attached herewith)

Pl. see.
Data sheets of transistor CM100DY-12H.
Data sheets of drivers for above transistor M57962L.
Quotes obtained from 'Vinit Enterprise' Bombay.

A4 - p.3



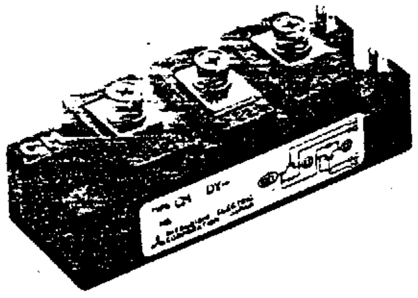
MITSUBISHI IGBT MODULES

CM100DY-12H

A4 - b34

HIGH POWER SWITCHING USE
INSULATED TYPE

M100DY-12H



- Ic 100A
- VCES 600V
- **Insulated Type**
- **2-elements in a pack**
- **UL Recognized**

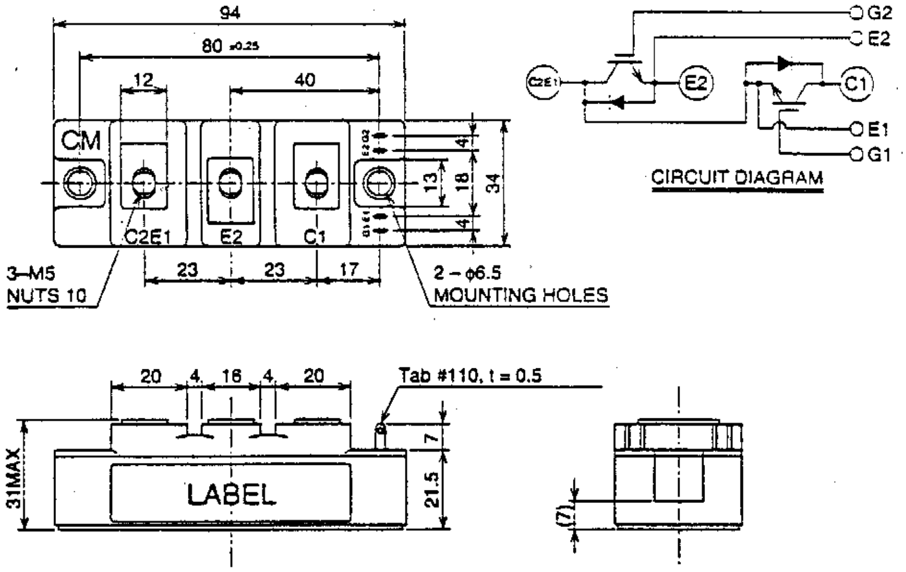
Yellow Card No. E80276 (N)
File No. E80271

CATION

& DC motor controls, General purpose inverters, UPS, CVCF, Welders, Servo controls, , Robotics, Cutting tools, Induction heating.

TLINE DRAWING & CIRCUIT DIAGRAM

Dimensions in mm



MITSUBISHI
ELECTRIC

CM100DY-12H

HIGH POWER SWITCHING USE
INSULATED TYPE

A4 - p5

MAXIMUM RATINGS (T_j = 25°C)

Symbol	Parameter	Conditions	Ratings	Unit
V_{CES}	Collector-emitter voltage	G – E Short	600	V
V_{GES}	Gate-emitter voltage	C – E Short	±20	V
I_C	Collector current	T_C = 25°C	100	A
I_{CM}		Pulse (Note 2)	200	A
I_E (Note 1)	Emitter current	T_C = 25°C	100	A
I_{EM} (Note 1)		Pulse (Note 2)	200	A
P_C (Note 3)	Maximum collector dissipation	T_C = 25°C	400	W
T_j	Junction temperature		−40 ~ +150	°C
T_{stg}	Storage temperature		−40 ~ +125	°C
V_{iso}	Isolation voltage	Main terminal to Base, AC for 1 minute	2500	V
—	Mounting torque	Main terminal screw M5	1.47 ~ 1.96	N • m
			15 ~ 20	kg • cm
		Mounting screw M6	1.96 ~ 2.94	N • m
			20 ~ 30	kg • cm
	Weight	Typical value	190	g

ELECTRICAL CHARACTERISTICS (T_j = 25°C)

Symbol	Parameter	Test conditions		Limits			Unit
				Min	Typ	Max	
I_{CES}	Collector cutoff current	$V_{CE} = V_{CES}$, V_{GE} = 0V		—	—	1	mA
$V_{GE(th)}$	Gate-emitter threshold voltage	I_C = 10mA, V_{CE} = 10V		4.5	6	7.5	V
I_{GES}	Gate-leakage current	$V_{GE} = V_{GES}$, V_{CE} = 0V		—	—	0.5	μA
$V_{CE(sat)}$	Collector-emitter saturation voltage	T_j = 25°C	I_C = 100A, V_{GE} = 15V (Note 4)	—	2.1	2.8	V
		T_j = 150°C		—	2.15	—	
C_{ies}	Input capacitance	V_{CE} = 10V V_{GE} = 0V		—	—	10	nF
C_{oes}	Output capacitance			—	—	3.5	nF
C_{res}	Reverse transfer capacitance			—	—	2	nF
Q_G	Total gate charge	V_{CC} = 300V, I_C = 100A, V_{GE} = 15V		—	300	—	nC
$t_{d(on)}$	Turn-on delay time	V_{CC} = 300V, I_C = 100A $V_{GE1} = V_{GE2}$ = 15V R_G =6.3Ω Resistive load switching operation		—	—	120	ns
t_r	Turn-on rise time			—	—	300	ns
$t_{d(off)}$	Turn-off delay time			—	—	200	ns
t_f	Turn-off fall time			—	—	300	ns
V_{EC} (Note 1)	Emitter-collector voltage	I_E = 100A, V_{GE} = 0V		—	—	2.8	V
t_{rr} (Note 1)	Reverse recovery time	I_E = 100A die / dt = −200A / μs		—	—	110	ns
Q_{rr} (Note 1)	Reverse recovery charge			—	0.27	—	μC
$R_{th(j-c)}Q$	Thermal resistance	IGBT part (Per 1/2 module)		—	—	0.31	°C/W
$R_{th(j-c)}R$		FWDi part (Per 1/2 module)		—	—	0.7	°C/W
$R_{th(c-f)}$	Contact thermal resistance	Case to fin, conductive grease applied (Per 1/2 module)		—	—	0.15	°C/W

Note 1. I_E, V_{EC}, t_{rr}, Q_{rr} & die/dt represent characteristics of the anti-parallel, emitter to collector free-wheel diode.
2. Pulse width and repetition rate should be such that the device junction temp. (T_j) does not exceed T_{jmax} rating.
3. Junction temperature (T_j) should not increase beyond 150°C.
4. Pulse width and repetition rate should be such as to cause negligible temperature rise.

MITSUBISHI HYBRID ICs

M57962L

A4 p6

HYBRID IC FOR DRIVING IGBT MODULES

DESCRIPTION

M57962L is a hybrid integrated circuit designed for driving n-channel IGBT modules in any gate-amplifier application. This device operates as an isolation amplifier for these modules and provides the required electrical isolation between the input and output with an opto-coupler.

Recommended modules :

V_{CES} = 600V series upto 400A class

V_{CES} = 1200V series upto 400A class

FEATURES

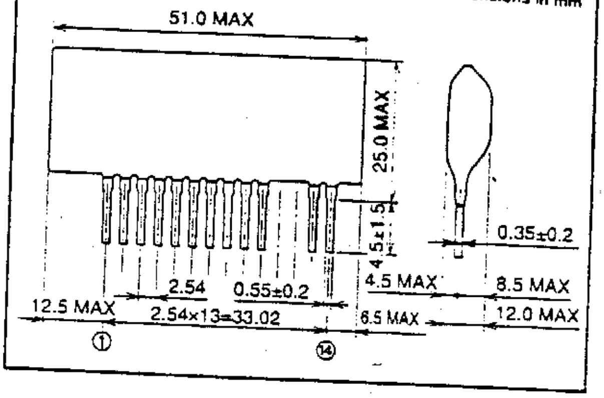
- Electrical isolation between input and output with opto-coupler (Viso = 2500Vrms for 1 minute)
- Two supply driver topology
- Built-in short circuit protection circuit (With a pin for fault out)
- TTL compatible input interface

APPLICATION

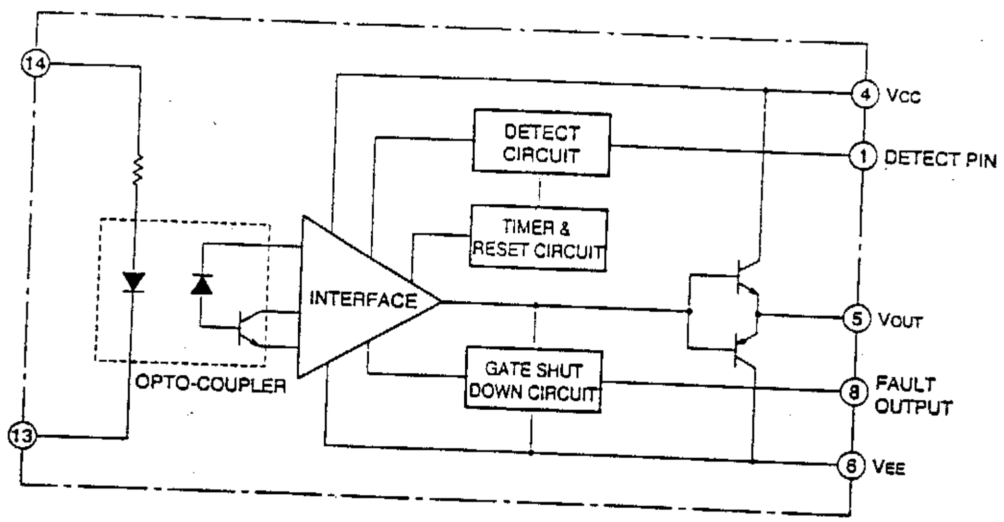
To drive IGBT modules for inverter or AC servo systems application.

OUTLINE DRAWING

Dimensions in mm



BLOCK DIAGRAM



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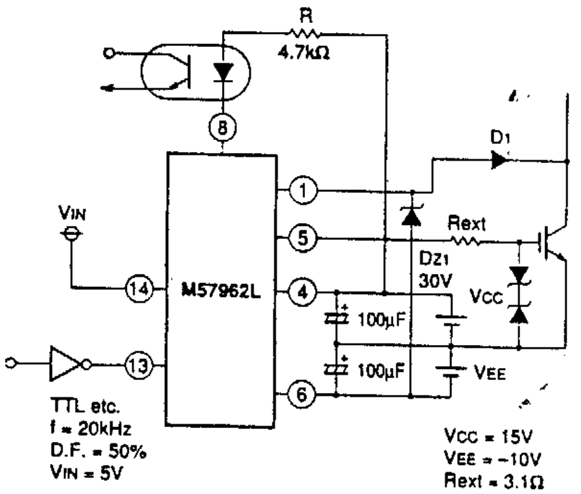
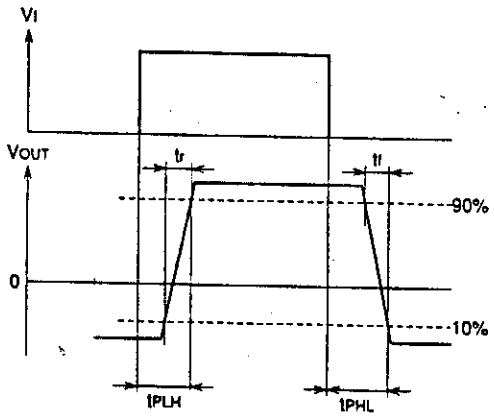
TEST CIRCUIT AND APPLICATION CIRCUIT EXAMPLES



D1 : Fast recovery diode
(trr ≤ 0.2µs)



PRECAUTION

(1) Because the ② ③ ⑦ ⑨ ⑩ pin are the pins connected between surface and back, the usage with electrical connections from the outside are not permitted.

(2) If reverse recovery time of D1 is long, ① pin is applied high voltage. In that case, counterplan for protection which insert a zener diode between ① and ⑥ pin are necessary like above diagram.

(3) The hybrid IC will output fault sign ("L") until supply voltage become stable whether supply voltage is on or off.

Motor calculations

14/1/99
VGH

A4 p9

Motor inductance = 0·33 mH
External inductance = 1 mH
Wire inductance = 0·1 mH

∴ Total loop inductance ≃ 1·5 mH

Motor resistance = 47 mΩ
Brush resistance = 25 mΩ { 2 V drop in brush when 80 Amp flows}
Shunt resistance = 10 mΩ
82 mΩ

∴ including wire resistance, total resistance ≃ 0·1 Ω

∴ Motor electrical time constant $t_e = \frac{L}{R} = \frac{1.5\times10^{-3}}{0.1} = 15\,msec$ ←

Let us calculate ripple current through the motor when 96V is switched at 10KHz frequency.

Vs = Supply voltage = 96 V
Vd = diode & transistor drops = 2V
L_a = Total loop inductance = 1·5 mH
dt = $t_{ON\,max}$ = 100 μsec

$$V_L = V_S - V_D = L_a \frac{dI_a}{t_{ON}}$$

$$94 = 1.5\times10^{-3} \frac{dI_a}{100\times10^{-6}}$$

→ ∴ $dI_a \simeq 6$ Amp.

~~$dI_a = [V_S - V_D]\frac{t_{ON}}{L_a}$~~

$\frac{1}{10kHz}$ ← $\left(\frac{1}{10}ms\right)$

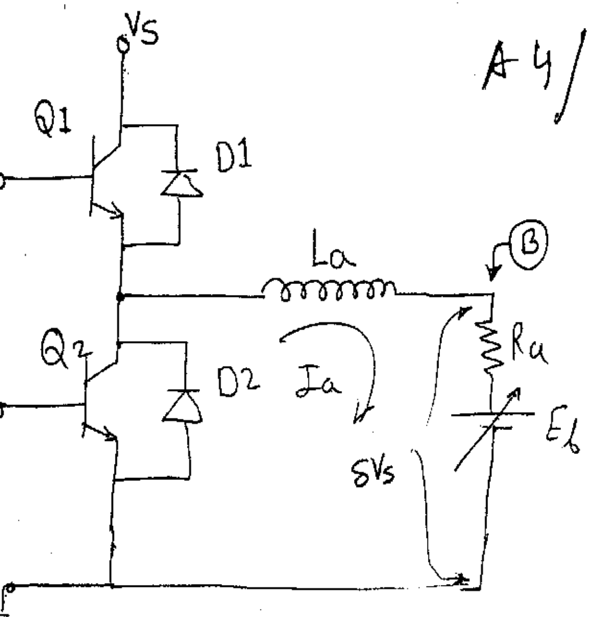
~~$dI_a = \frac{48 \times 10^{-4}}{1.5\times10^{-3}}$~~

~~$= 32 \times 10^{-1} = 3.2A$~~

As the battery internal resistance & motor armature resistance drops are neglected, the actual ripple current will be less than 6 Amp. Which is acceptable for GMRT motors.

$$\boxed{= \frac{\Delta T}{T} v_s}$$

Motoring Mode



A 4/PLD **When Q_1 is ON**

The voltage across inductor La.

$$V_{La} = L_a \frac{dI_a}{t_{ON}}$$

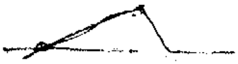
(neglecting drop across Ra)

but $V_{La} = V_S - E_b$.

$$[V_S - E_b] = L_a \frac{dI_{a\,ON}}{t_{ON}} \quad \text{----} \quad ①$$

When Q1 becomes OFF, current Ia circulates (freewheels) through diode D2, then

$$V_{La} = E_b = L_a \frac{dI_{a\,OFF}}{t_{off}} \quad \text{----} \quad ②$$



Eliminating La from eqn ① & ② and assuming $dI_{a\,ON} = dI_{OFF}$

$$(V_s - E_b) = E_b \frac{t_{off}}{t_{ON}}$$

$$V_s = E_b \cdot \frac{t_{off}}{t_{ON}} + E_b$$

$$= E_b \left\{ \frac{t_{off} + t_{ON}}{t_{ON}} \right\}$$

but δ = duty cycle.

$$\boxed{\delta = \frac{t_{ON}}{t_{ON} + t_{off}}} \qquad \frac{\Delta T}{T}$$

$$\therefore V_s = \frac{E_b}{\delta}$$

$$\boxed{\text{or } \langle E_b \rangle = \delta \cdot V_s}$$

(Voltage at point B)

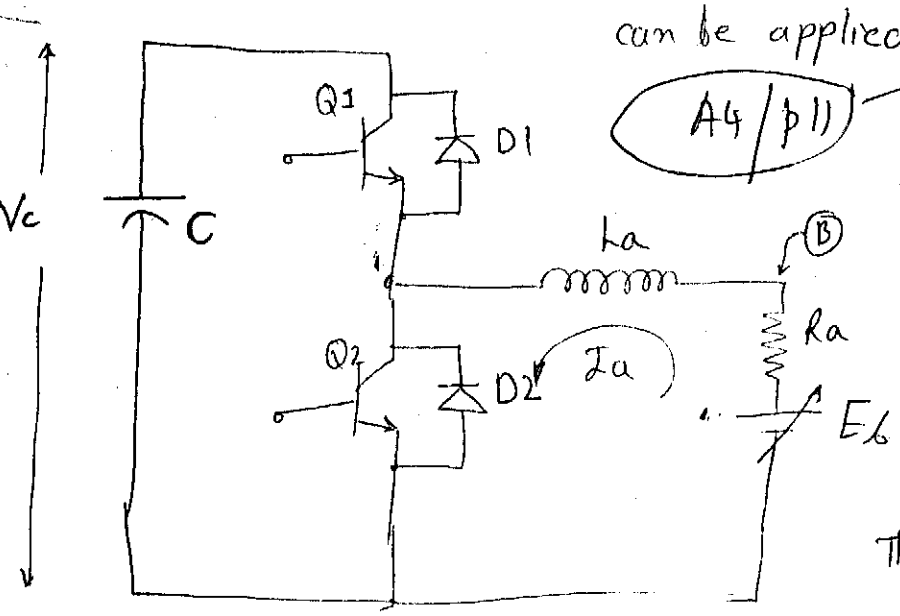
Vs is fixed, by varying δ Eb can be varied.

Generating Mode

ince δ·Vs is voltage at point B, if Eb exceeds the Vs then current Ia reverses its direction after 30msec {i.e 2 times the time constant}

if δ is made such that δ·Vs < Eb, current eversal takes place, in that event above analysis becomes invalid.

In the event when $E_b >$ δV_s ~~is less than Eb~~ following analysis can be applied.



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by neglecting drop across Ra

when $\boxed{Q_2 \text{ is ON}}$

$$E_b' = L_a \frac{dI_a'}{t_{ON}} \quad \text{----} \quad ①$$

$\boxed{\text{when } Q_2 \text{ becomes OFF}}$

The polarity of voltage across La reverses ~~th~~ such that

$$V_c = L_a \frac{dI_a}{t_{off}} + E_b \quad \text{-----} \quad ②$$

Ia flows through D1 to charge C1

Eliminating La from both the equation.

$$V_c = E_b + E_b \frac{t_{ON}}{t_{off}}$$

$$= E_b \left[\frac{t_{off} + t_{ON}}{t_{off}} \right]$$

$$V_c = \frac{E_b}{1 - \delta}$$

as $\delta = \dfrac{t_{ON}}{t_{ON} + t_{off}}$

$1 - \delta = \dfrac{t_{off}}{t_{ON} + t_{off}}$

Note that this δ is duty cycle of Q_2

δ	V_c
0.25	1.3 E_b
0.5	2 E_b
0.75	4 E_b

$$I_a' = \frac{(E_b' - \delta V_s)}{R}$$

3E

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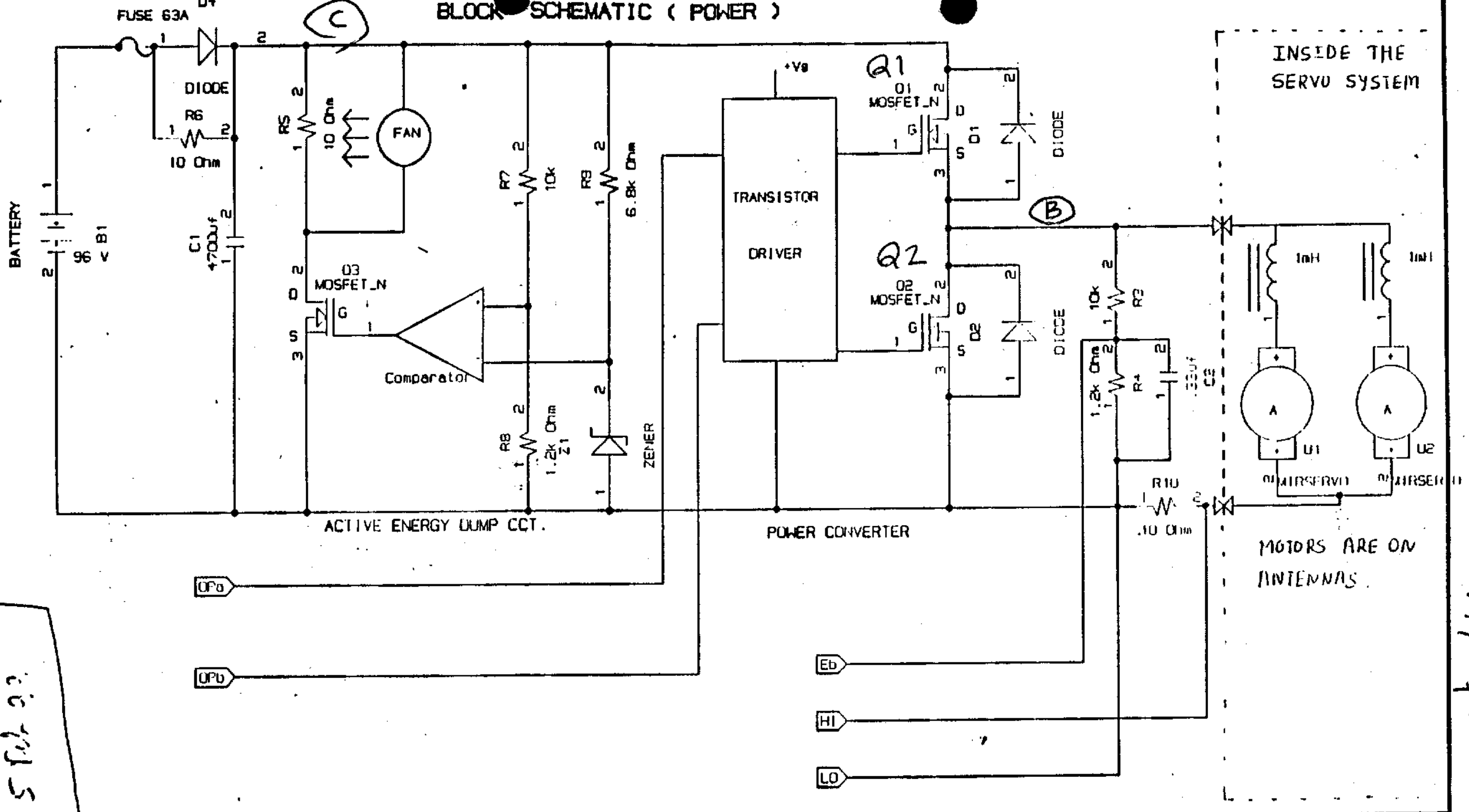
BLOCK SCHEMATIC (POWER)



A4-p12

19 Sept 98
6 Jan 99
5 Feb 99

GMRT, TIFR Khodad.	
File: e:\hot \art\astlk1.sch	
Title: ELECTRONIC SPEED REGULATOR	
Sheet:	No: 1 Rev: 1.0
Drawn: V.G.HOTKAR	
Engineer: V.G.HOTKAR	Created: 19-SEP-1998 10:24
Approved:	Changed: 5-FEB-1999 16:02

HOTKAR 6.1.99
5.2.99

2-QUADRANT PWM REGULATOR

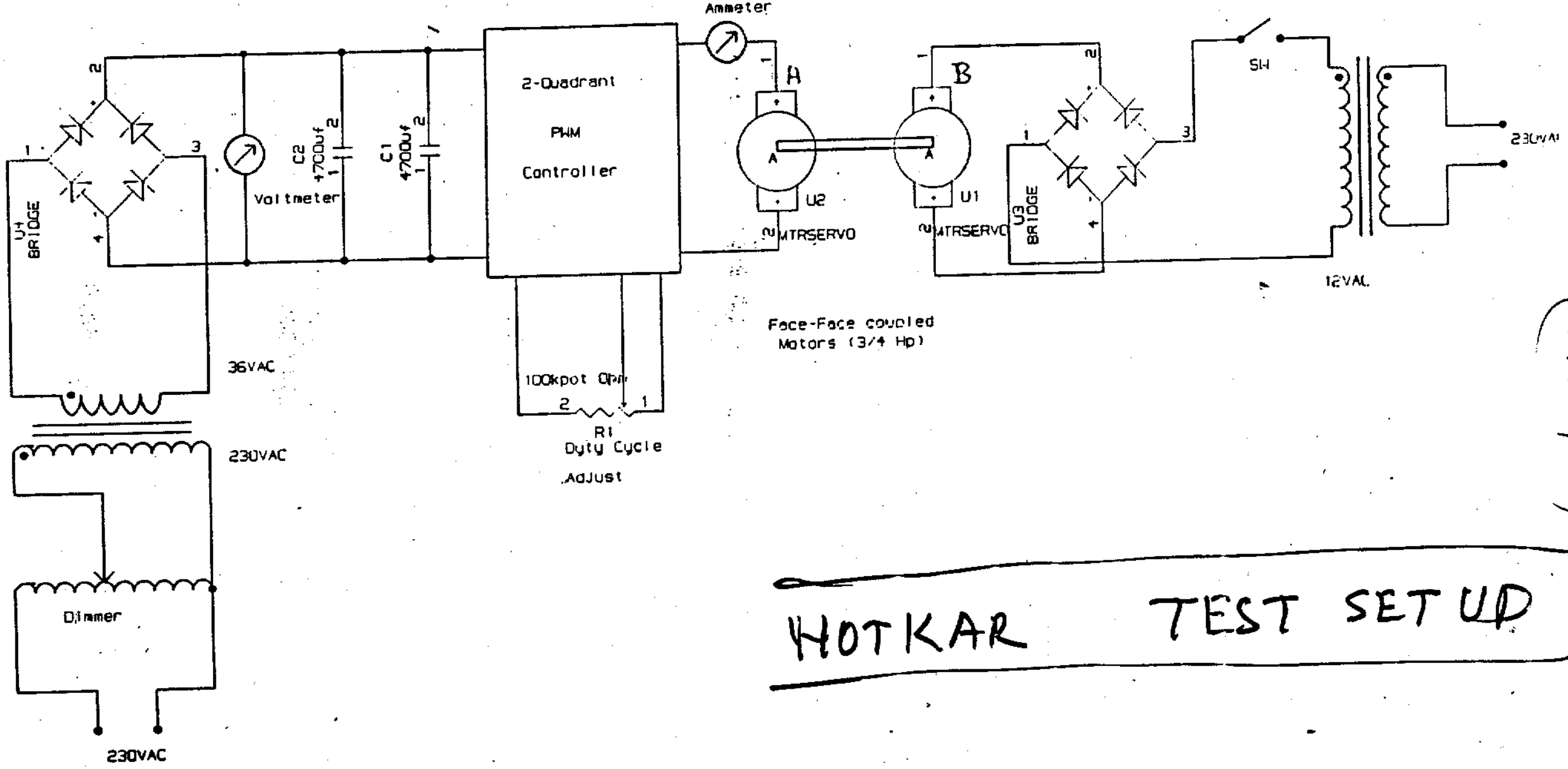
TEST SETUP

Servo motor ~~WIND~~ EQ

LOAD

WIND LOAD

~~SERVO~~ motor equivalent



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HOTKAR TEST SETUP