GMRT
Servo system overview

by

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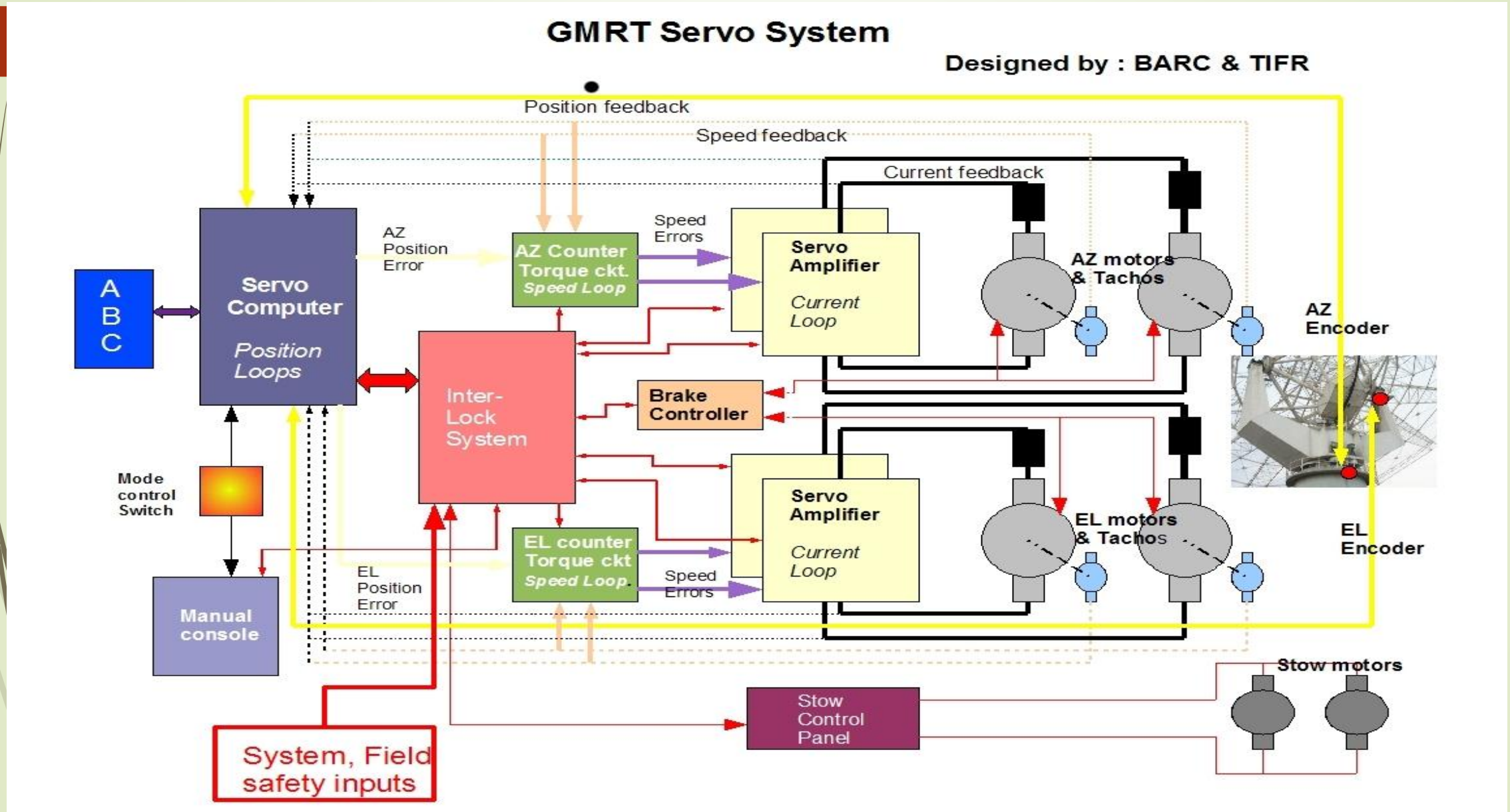
Contents

- Block diagram of Servo system & specifications
- Important Component parts of Servo system
- How to arrive at the motor horse power rating for the GMRT dish
- What is Locked rotor frequency & how to arrive at bandwidth of Servo system
- Why Type II compensator ? How tracking error is zero for GMRT ?
- Why speed loop needed ?
- Why dual drive for GMRT ? What Is backlash and how to eliminate it ?

Block diagram



Specifications

- Dish Mount : Alt-Azimuth mount
- Dish movement : +/- 270° in Azimuth axis
  15 ° to 110 ° in Elevation axis
- Slew speed : 30 °/ min in AZ axis
  20 °/ min in EL axis
- Tracking speed : 5 arc minutes / min in both axes
- Max Pointing error : 1 arc min RMS for wind < 20 Kmph
  few arc minutes for wind > 20 kmph
- Wind speed : : Operation up to 40 kmph
  Slew up to 80 kmph
- Survival wind speed : 133kmph

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Azimuth axis motors

PM DC Servo Motor

Motor horse power	**8.5 hp**
Rated speed	2250 rpm
Continuous torque (stall)	47 n-m
Peak torque	111 N- m
Torque constant	0.56 N-m/A
Back EMF const	59V/Krpm
DC resistance	0.045 Ω
Inductance	0.33 mH
Mech τ	13 m-sec
Elect. τ	5 m-sec
Tacho	17V/krpm
Rotor inertia	0.064 kg- m²
Static friction	1.9 N-m
Viscous damping	0.568 N-m/Krpm

Why dc servo motors ?

- High torque –to- - inertia ratio. This means rapid response (short mech. & elec. Time constants)
- Smooth acceleration & deceleration
- High efficiency (power utilization)
- High zero speed continuous torque
- Small size and weight
- Totally enclosed
- Normal convection cooling
- Shaft mounted tacho / resolver
- Long brush life
- Zero to high speed operation

Encoder

Data transfer
The two types of EnDat data transfer are position value transfer and parameter transfer.

Control Cycles for Transfer of Position Values
The **clock** signal is transmitted by the subsequent electronics to synchronize the data output from the encoder. When not transmitting, the clock line is high. The transmission cycle begins with the first falling edge. The encoder saves the measured values and calculates the position value.

After two clock pulses (2T), the subsequent electronics send the **mode command** *encoder transmit position value.*

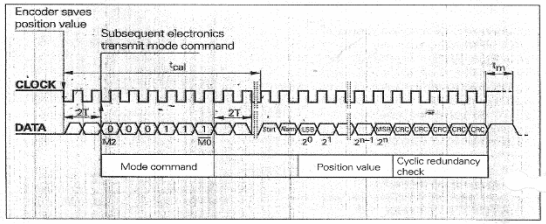
After the encoder has completed calculation of the absolute position value (t_{cal} — see table), it begins with the **start bit** to transmit data to the subsequent electronics.

The subsequent **alarm bit** is a common signal for all monitored functions and serves for failure monitoring. It becomes active if there is a malfunction in the encoder that could result in incorrect position values. The exact cause of the alarm is saved in the operating-status memory area where it can be interrogated.

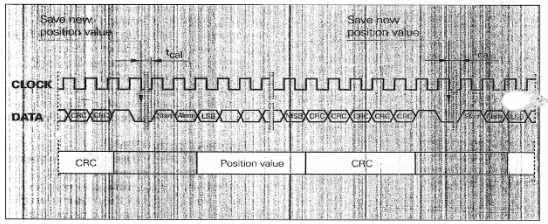
The **absolute position value** is then transmitted beginning with the LSB. Its length depends on the encoder. It is saved in the encoder manufacturer's memory area. Since EnDat does not need to fill superfluous bits with zeros as is common in SSI, the transmission time of the position value to the subsequent electronics is minimized.

Data transmission is concluded with the **cyclic redundancy check** (CRC).

Interrupted clock
The interrupted clock is intended particularly for time-clocked systems such as closed control loops. At the end of the data word the clock signal is set to high level. After the time t_m (10 to 30 µs) the data line returns to low and can begin a new transmission when started by the clock signal.



Continuous clock
For applications that require fast acquisition of the measured value, the EnDat interface can have the clock run continuously. Immediately after the last CRC bit has been sent, the data line is switched to high for one clock cycle, and then to low. The new position value is saved with the very next falling edge of the clock and is output in synchronism with the clock signal immediately after the start bit and alarm bit. Because the mode command *encoder transmits position value* is needed only before the first data transmission, the continuous-clock transfer mode reduces the length of the clock-pulse group by 10 periods per position value.



		ROC, ECN, ROQ, EQN	RCN*	LC**
Clock frequency	f_C	100 kHz to 2 MHz		
Calculation time for Position value	t_{cal}	250 ns Max. 12 ms	10 µs Max. 12 ms	1 ms Max. 12 ms
Calculation time for Parameter	t_{cal}	250 ns Max. 12 ms	10 µs Max. 12 ms	1 ms Max. 12 ms
Recovery Time	t_m	10 to 30 µs		
HIGH pulse width	t_{HI}	0.2 to 10 µs		
LOW pulse width	t_{LO}	0.2 µs to 50 ms		0.2 to 30 µs

*) See ***Angle Encoders*** catalog
) See ***Sealed Linear Encoders* catalog

18

17 bit absolute optical encoder

How to decide on motor torque ?

- Elevation axis
- a)(1:1 axis) Torque at slew up to 80Kmph wind speed in Kgf - m
- Torque due to wind = 78200
- Torque due to inertia = 1800 (full speed in 3 seconds)
- Friction = 100
- ----------
- Starting torque = 80100 Running torque = 78300
- b) At pinion ---------- ----------
- speed ratio – 30.5, η = 0.8 = 30.5 X 0.8 30.5 X 0.8

Starting torque = 3283 Running torque = 3209

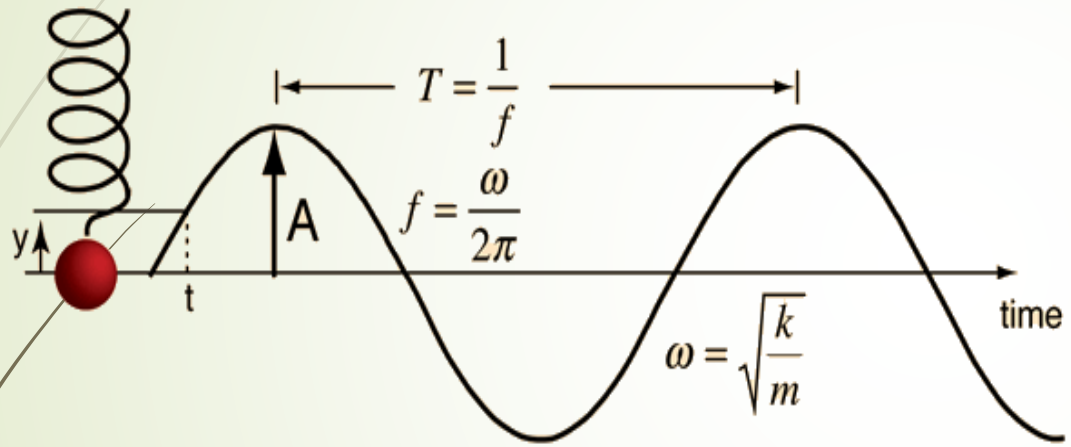
- C) At motor shaft ---------- ----------
- Gear box ratio – 825 , η=0.82 = 825 X 0.82 825 X 0.82
- **Starting torque = 4.8 Running torque = 4.7**

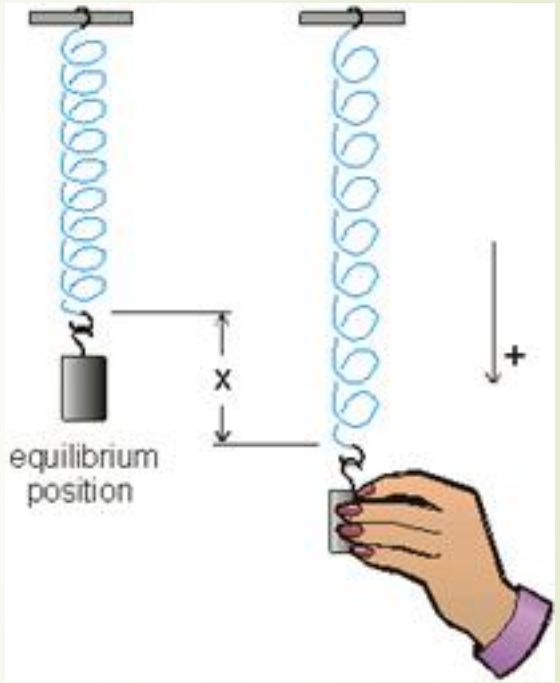
Continued……

- **Peak torque – starting = 4.8 X 0.5 = 2.4 Kgf – m**
  (assuming same load distribution in both pinions at 80Kmph wind)
- Continuous torque for slew at 80 Kmph wind = 4.7 X 0.5 = 2.35 Kgf – m
- **Torque while tracking at 40 Kmph with other motor in anti-backlash**
- **= 1.6 X 1.2 = 1.9 Kgf – m**
- Summary of Motor parameters
- Peak instantaneous torque(3 secs) torque = 2.4 Kgf-m
- Continuous rated torque = 1.9 Kgf-m
- Max. operating speed = 1398 rpm
- Base speed = 2250 rpm
- **Peak Horse power = 2.4 X 1398 X 2π/60 = 4.7 HP**
- Continuous rated horse power at 40 Kmph = 1.5 HP
- Minimum speed of motor withput cogging = 5 rpm

Simple Harmonic Oscillator – Natural frequency of oscillation 'ω'

K – elasticity of the spring and m - mass attached to the spring

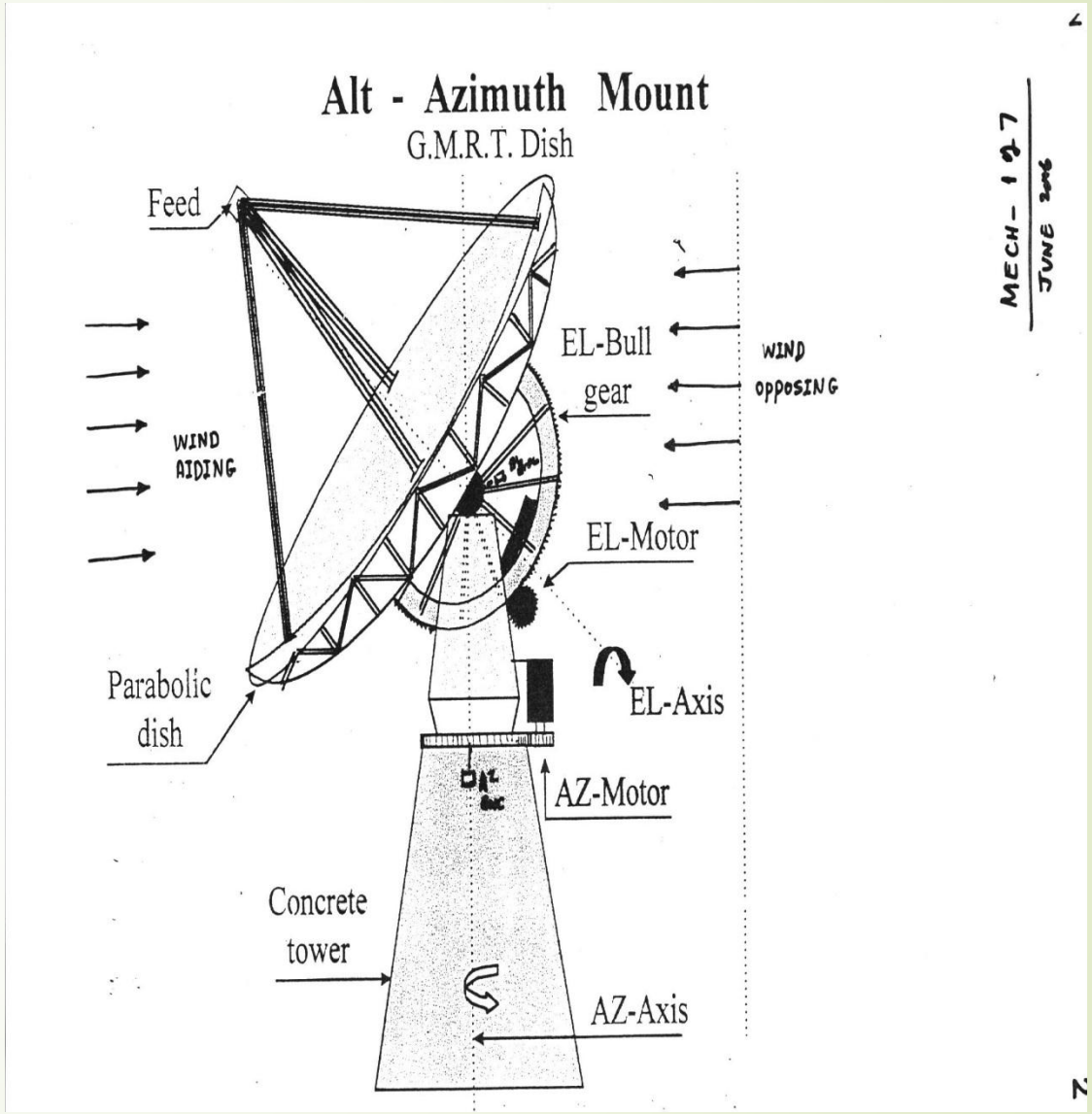




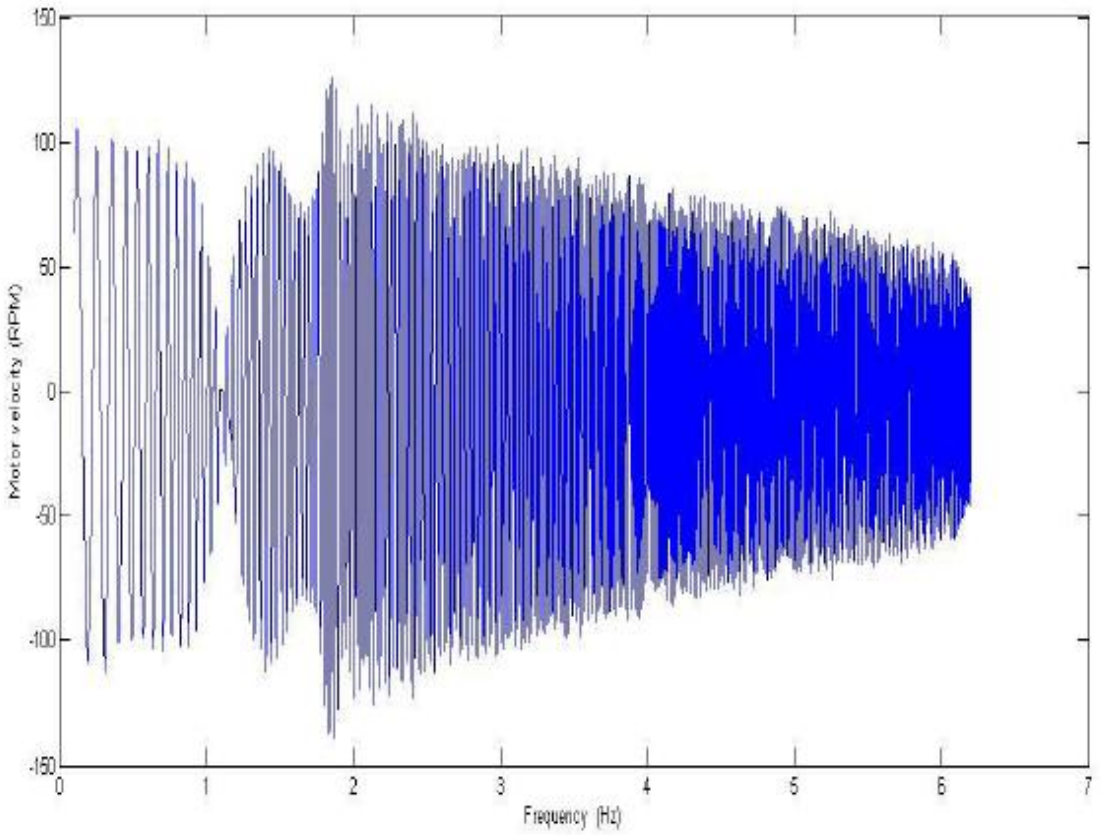
Locked Rotor Frequency – LRF – Elevation axis

- Mechanical stiffness 'K' due to
- bullgear,
- pinion and
- gear unit
- K = 4.05 X 10^8 Kgf m / rad

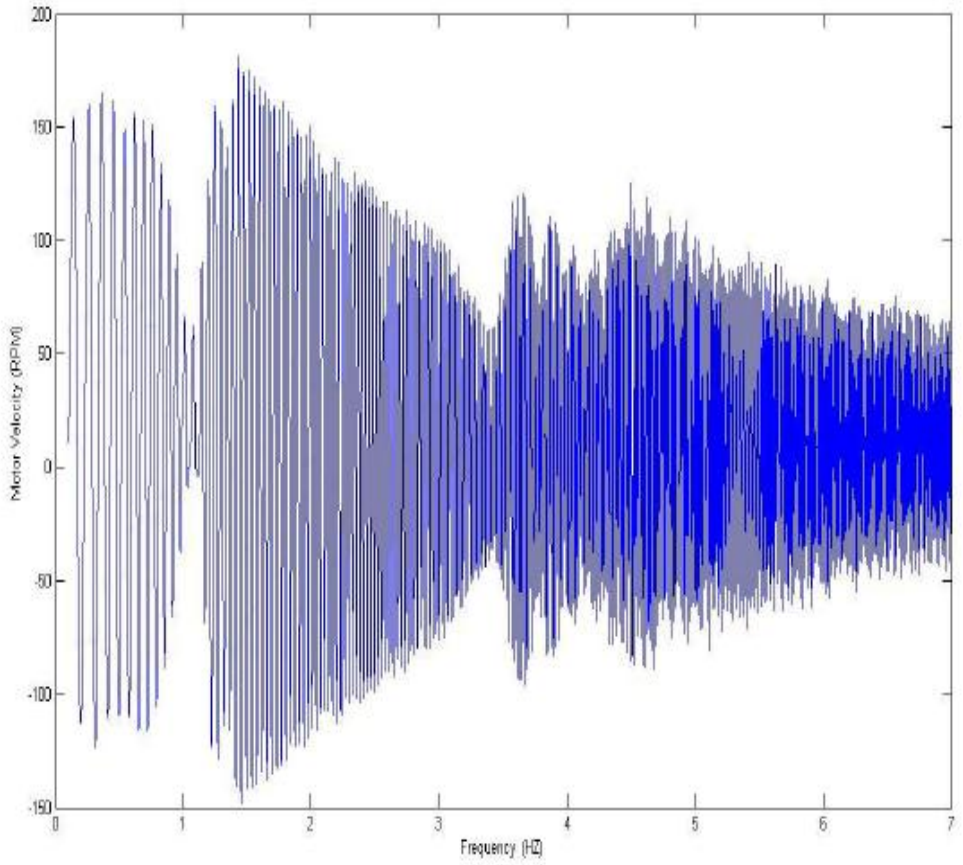
- Inertia 'I' due to
- Reflector dish and
- gear box
- I = 10.95 X 10^ 6 Kg m^2
- LRF - f = 1/2π sqrt(K x g / I)
- = 1.0 Hz
- Where g = 9.8 m/sec^2



LRF plot of C14 antenna

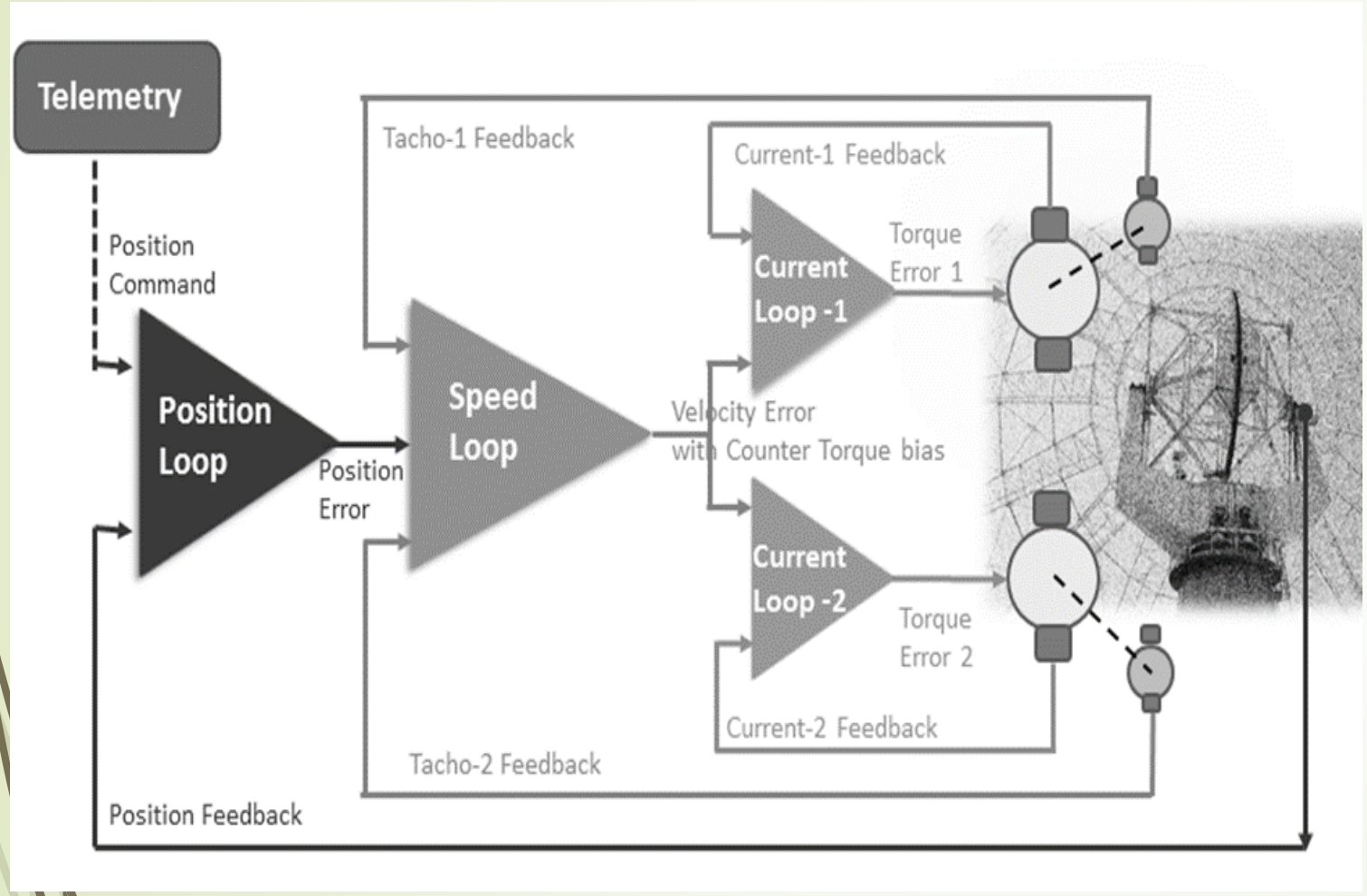


Sine sweep response of C14 antenna with BLDC motor system: Azimuth axis



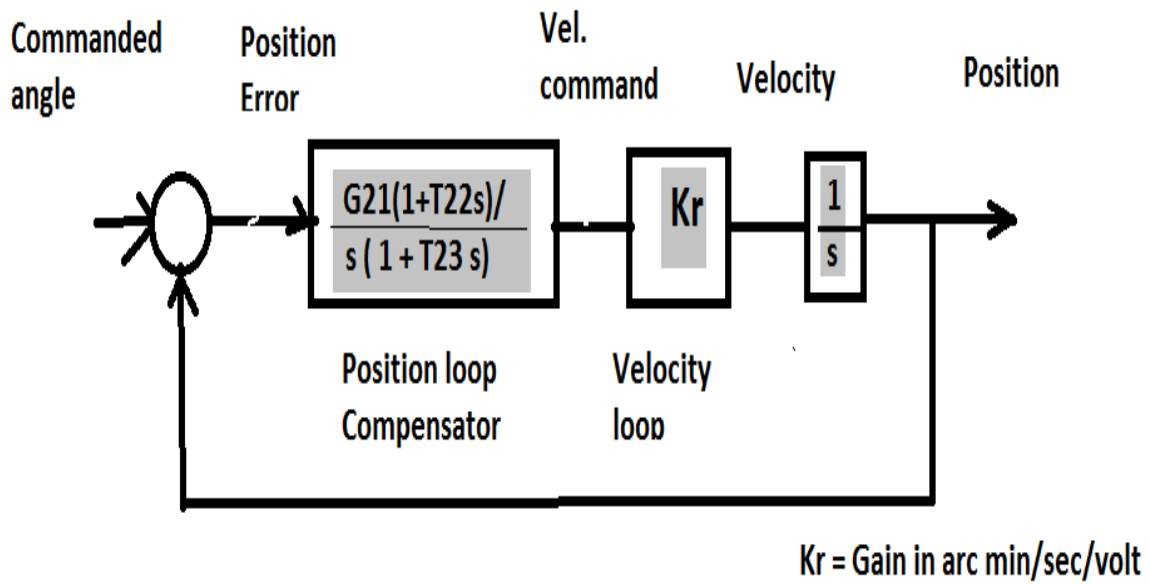
Sine sweep response of C14 antenna with BLDC motor system: Elevation axis

Drive Control System



- Standard 3 nested loop confign.
- Independent tuning of three loops
- BW of each loop is sufficiently greater than its adjascent outer loop.
- Position error between command and position sensed by encoder and fed as velocity signal to the speed loop

Simplified block diagram of Servo GMRT



Simplified block diagram

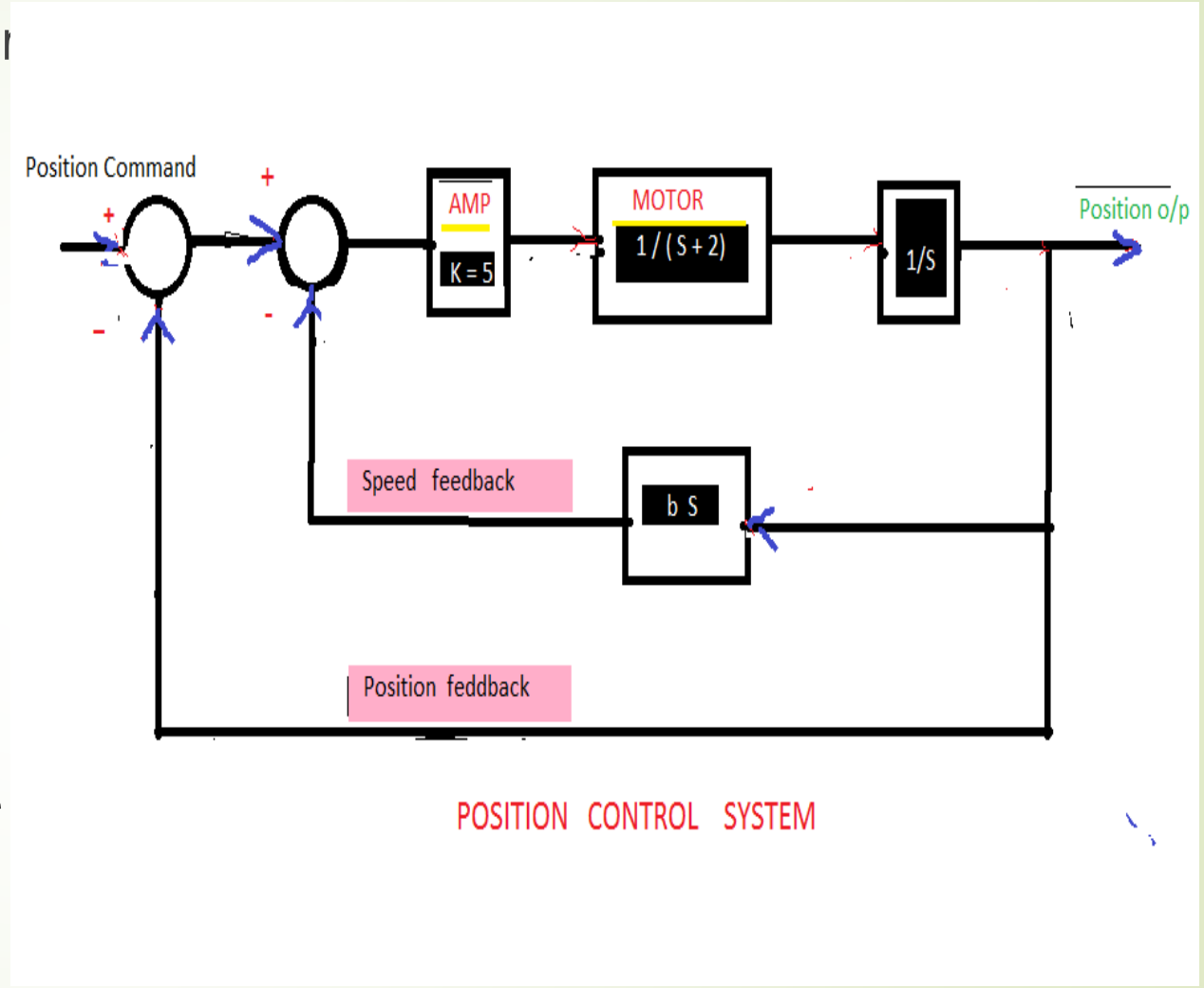
- The compensator transfer function is
- G2(s) = G21(1+T21s)/s(1+T23s)
- This is a type 1 Lead compensator, designed to achieve position loop bandwidth much less than LRF.
- Specifications for tuning position loop
- i) band width = half of LRF = 0.55Hz
- ii) settling time less than 10 secs
- iii) Overshoot less than 20%
- iv) pointing & tracking accuracy – ½ arc mins

- The actual values obtained are :
- $Gpo(s) = 1.5 (1 + 2.5s) / S^2(1 + 0.25s)$
- which is Type II

Importance of Speed loop ! Or why speed loop ?

- Consider a position loop with inner posn. loop
- The closed loop response C(s)/R(s)
- = $K / (s^2 + (2+Kb)s + K)$
- This is similar to normalized 2nd order TF
- = $\omega^2 / s^2 + 2\zeta\omega s + \omega^2$ where
- ζ = damping ratio = $b/2\omega$
- **Ts** = settling time = $4 / \zeta\omega$
- **ω** is the undamped natural frequency

- Comparing the two equations we get
- $\zeta = (2 + Kb) / 2\omega$
- $Ts = 8 / (2 + Kb)$



POSITION CONTROL SYSTEM

Continued .....

- Case 1 – speed loop absent , b = 0
- ς = 1/ sqrt(k) = 0.448 & ω = 2.23 rad/sec
- Ts = 4 seconds

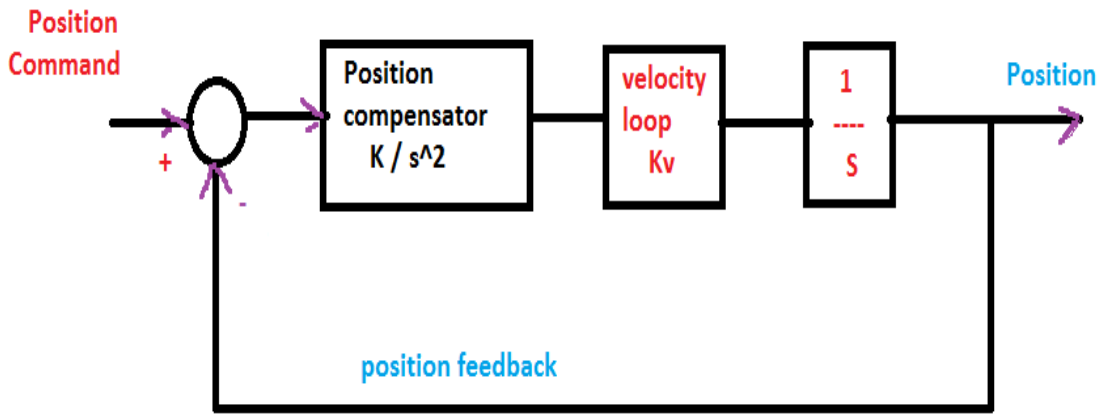
- Case 2 – Velocity loop added with b =0.5
- Damping ratio, ς = 1
- (sys - critically damped).
- Settling time – Ts = 1.7 seconds

- Conclusion
- Speed loop in position loop improves damping factor and hence reduces over and under shoots !
- Reduces settling time !

- Why type II compensator ?
- To get zero tracking error !
- How this is achieved ?
- Position loop compensator is type I
- Second integration takes place in velocity loop. Therefore overall it is a type II transfer function.
- To minimize this the vel.loop bandwidth is made 10 times larger .For eg. If posn loop bw is 0.4 Hz then speed loop bw is made 4 Hz.
- High Gain in velocity loop

How Type II compensator gives zero tracking error

- Closed loop transfer function
-
- $Gcl = K * Kv / (s^3 + K*Kv)$
- Applying Ramp i/p to this we get
- $O/p = 1/s^2 * (K*Kv / (s^3 + K*Kv))$
- Error = input – feedback
- $Es = 1/s^2 - [1/s^2 * (K*Kv / (s^3 + K*Kv))]$
- $= s / (s^3 + K*Kv)$

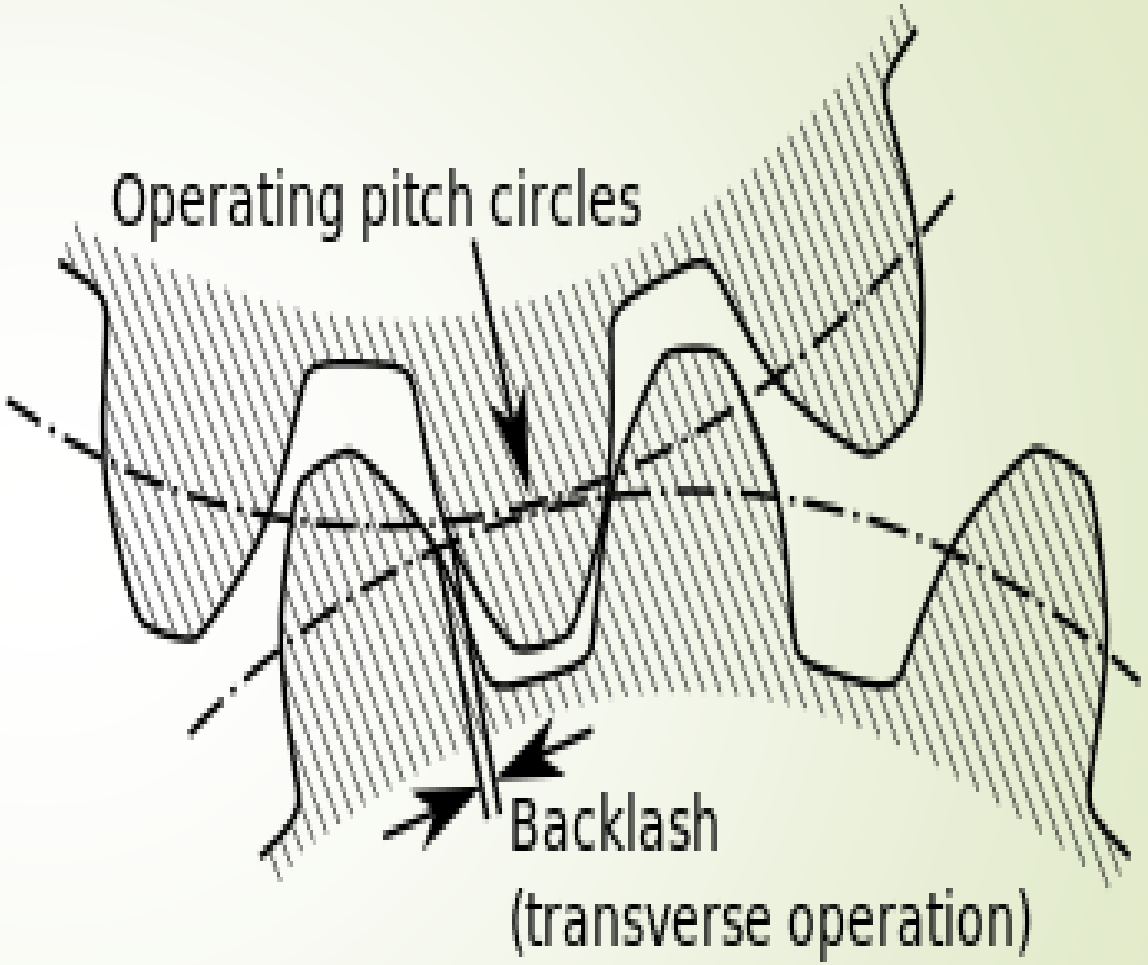


Unity feedback position control system

Continued……

- Apply final value theorem
- Ess = Lim [s*Es] = 0
- s-0
- Thus Ess = 0 while Tracking a source !

- For a parabolic input
- O/p = $1/s^3$ * [K*Kv / (s^3 + K*Kv)]
- Ess = Lim [s*Es] = 1 / K*Kv
- s – 0
- Thus Ess is small when the gains are large !
- A parabolic input is equivalent to tracking a source which is accelerating



What is Back lash ?

- Backlash is the distance or gap between gear teeth and pinion when they are meshed.
- **How to measure this backlash ?**
- Backlash is to be over come so that load rotates instantaneously when the command to rotate the motor is given without any delay .
- This is to be achieved in both directions of the motor rotation.
- This is achieved by pre-loading the drive !
- Applying just enough amount of torque such that the pinion rotates and meshes with the teeth of the gear, but not make the gear move !

- The torque bias required to prevent / overcome backlash is given by
- $\Delta T = 2*K*b$
- Where K – Stiffness of the gear
- b – backlash gap
- This is generally 10 to 15 % of the motor continuous torque.

Servo power block

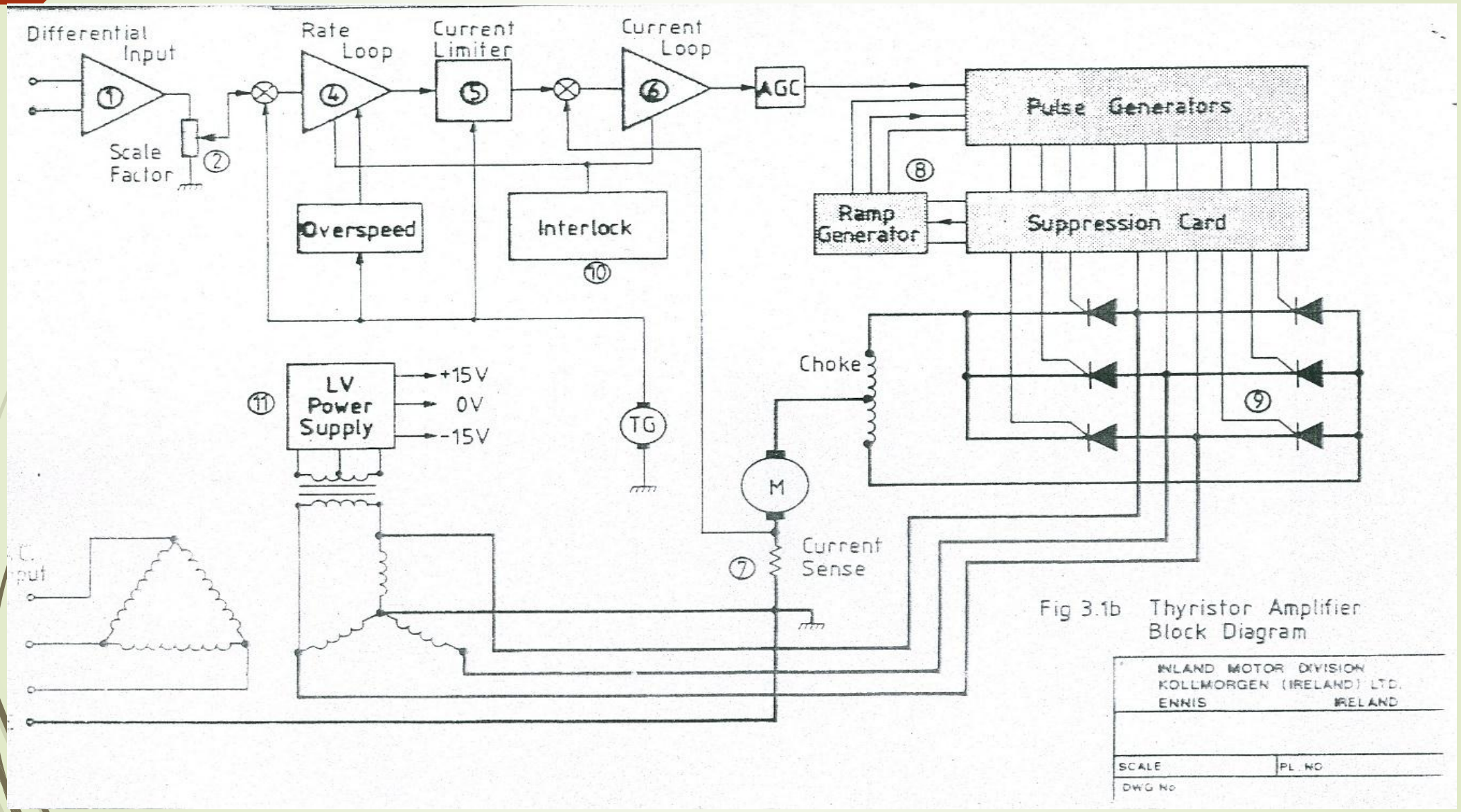


Fig 3.1b Thyristor Amplifier Block Diagram

3 – ph Thyristor output

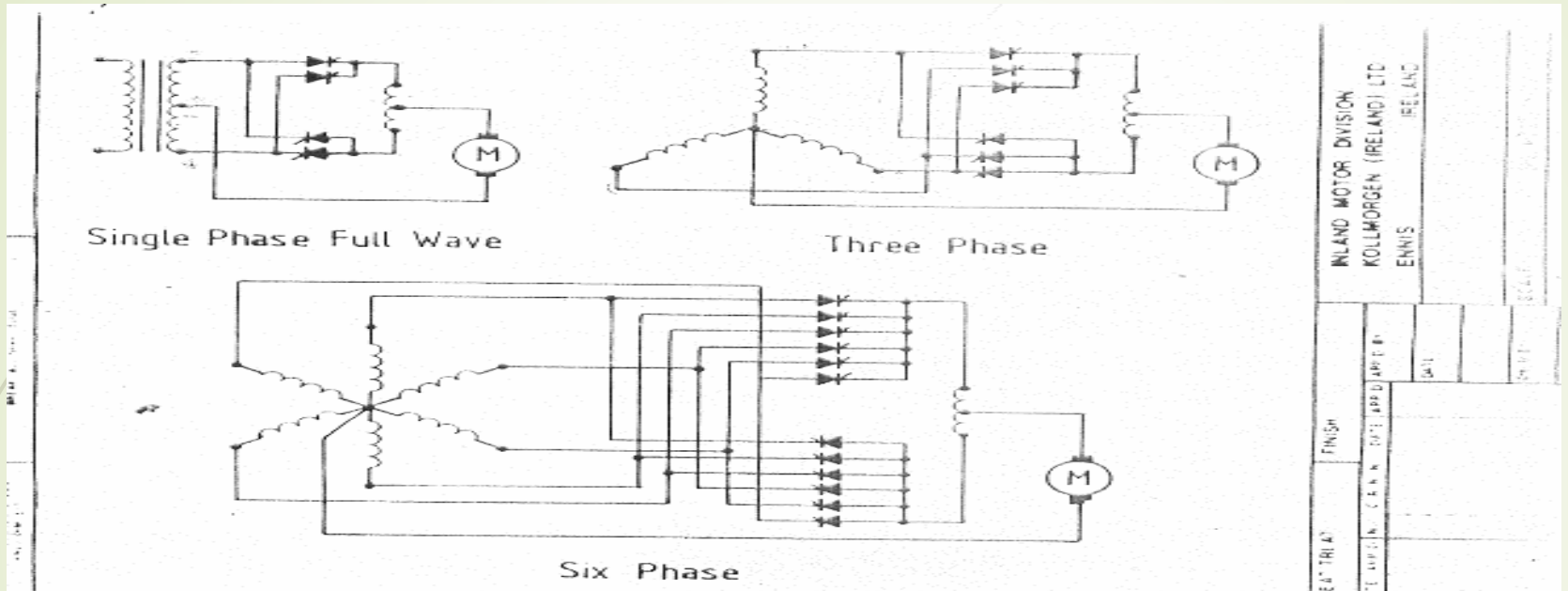


Fig 3.1e Thyristor Amplifier Output Stage Configurations

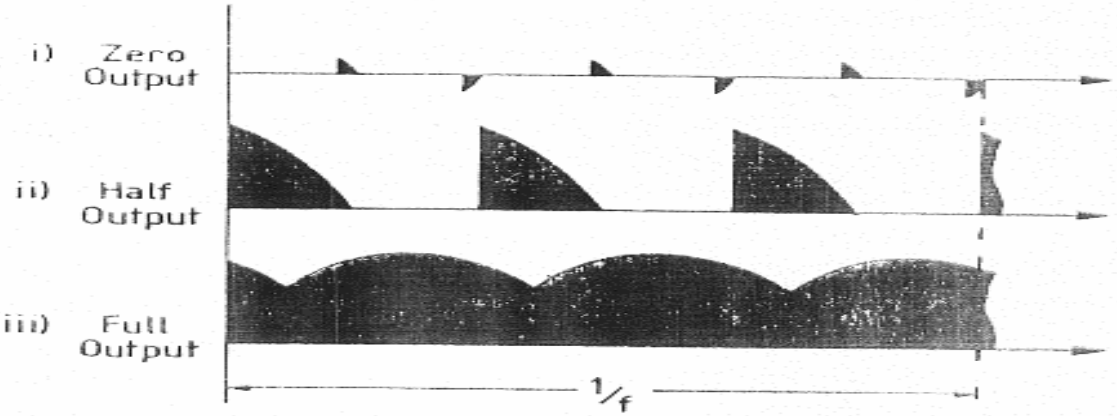
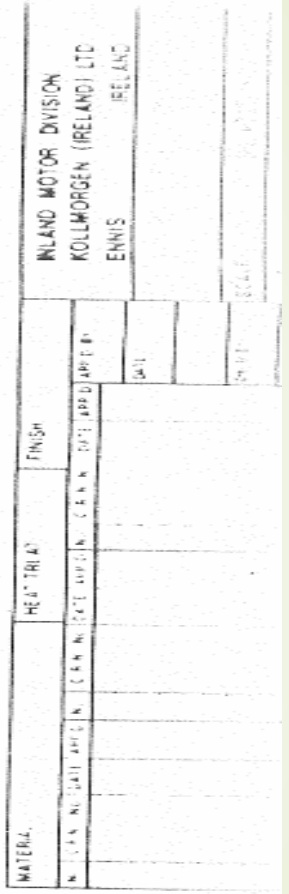
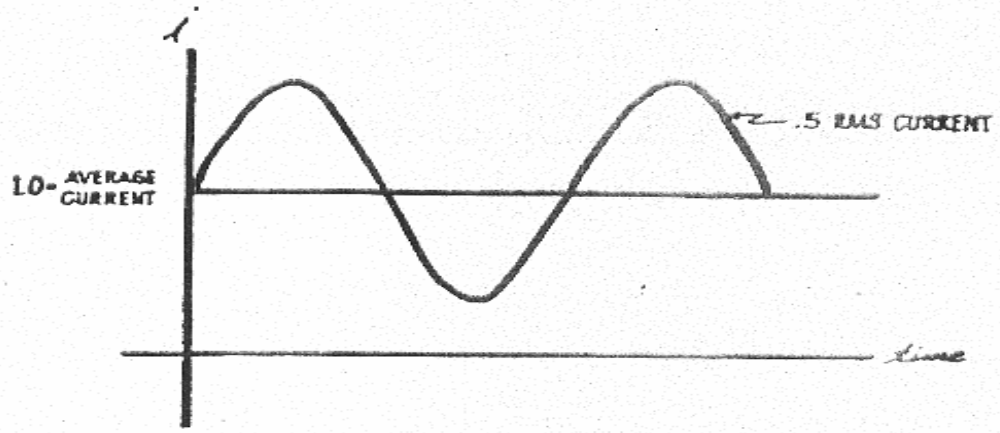


Fig 3.1f Thyristor Amplifier Output Voltage Waveform (Three Phase)



DC output and ripple



AVERAGE VALUE = 1.0

RMS = $\sqrt{1^2 + .5^2}$ = $\sqrt{1.25}$ = 1.118

FF = $\frac{RMS}{AVG}$ = $\frac{1.118}{1.0}$ = 1.118

NOTE

1) RMS RIPPLE CURRENT HEATS WINDING BUT PROVIDES NO TORQUE

2) RMS RIPPLE CURRENT MAY EXCITE MECHANICAL RESONANCE OF MACHINE WHICH RESULTS IN AUDIBLE NOISE

3) I_c of motor (and amplifier) is an RMS rating. However, developed torque is produced by average current rather than RMS current. T_c rating is produced by pure DC current, where average equals RMS. Therefore, for all current waveforms where $I_{avg} < I_{RMS}$ (as is the case for all waveforms other than pure DC), T_c obtainable < T_c rating; or T_c obtainable = T_c rating/FF where FF = I_{RMS}/I_{AVG}

Figure 3.2 a) Example of Definition of Form Factor.

Motor Torque calculation

constant torque acceleration
one-step or two-step

On summing torques, one gets $T_A - T_{trav} = T_\alpha$ where:

T_A = acceleration torque (lb-ft)

T_d = deceleration torque (lb-ft)

$T_\alpha = J_T \alpha$,acceleration torque for a frictionless system (lb-ft

$$J_T = \frac{J_L}{n^2 \eta_n} + J_m \quad (\text{lb-ft-sec}^2)$$

n = gear ratio, motor revs/load revs

η_n = gear box efficiency

J_L = load inertia (lb-ft-sec^2)

J_m = motor inertia (lb-ft-sec^2)

$$\alpha = \frac{n(N_2 - N_1)}{t_a} \frac{\pi}{30} \quad (\text{rad/sec}^2)$$

= high load speed (rpm) (see figures for accel profiles)

= low load speed (rpm) (see figures for accel profiles)

= time to reach N_2 from N_1 (sec)

= time to reach N_1 from N_2 (sec)

$$\text{rav} = \frac{FT}{n \times \eta_n} + T_F + n \frac{N_2 + N_1}{2} \frac{F_I}{1000}$$

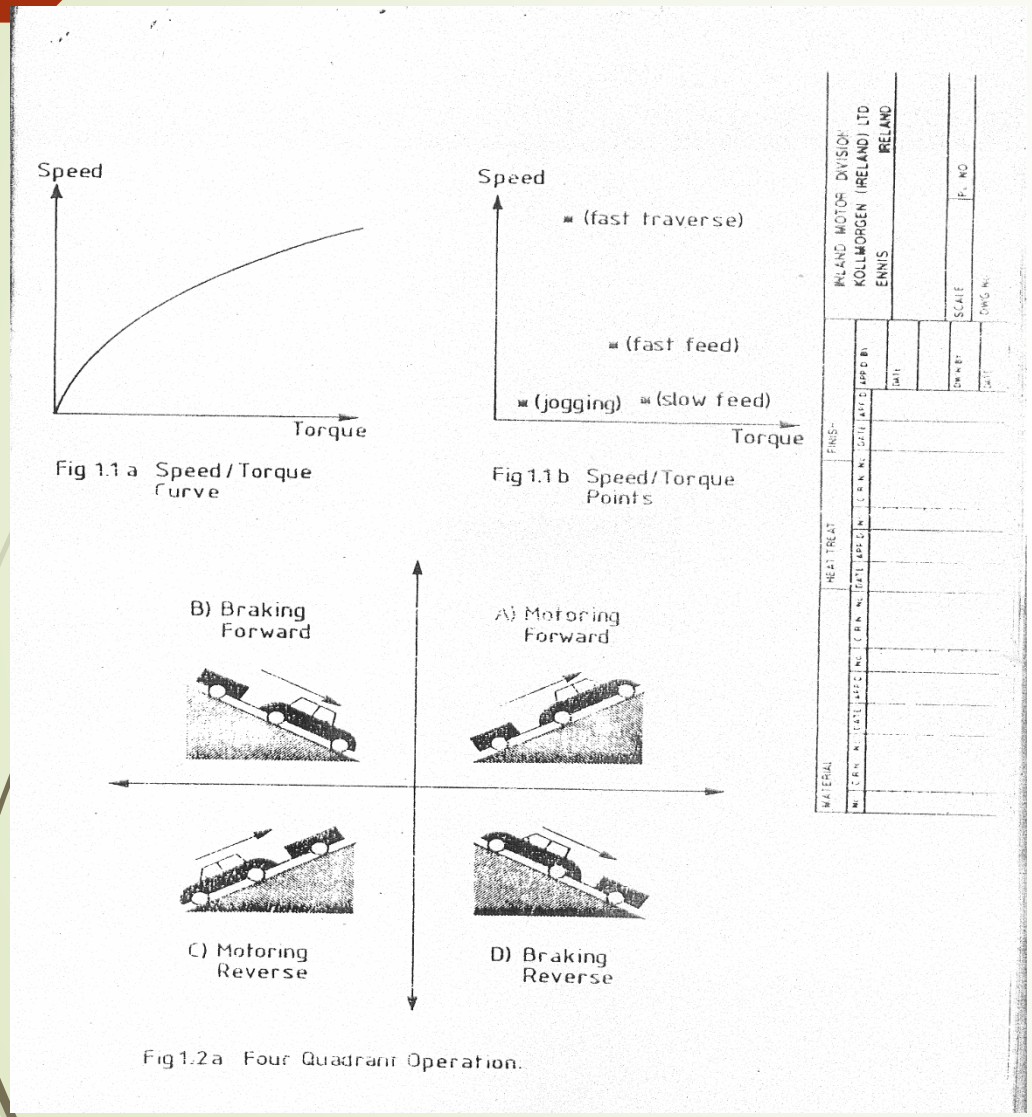
load and friction torques reflected to the motor shaft

he third term of T_{trav} is an average motor "viscous damping" orque. The definition of all other terms may be found in he list of application parameters. Substitutions of the efinitions of the terms and rearrangements of the torque ummation equation yield:

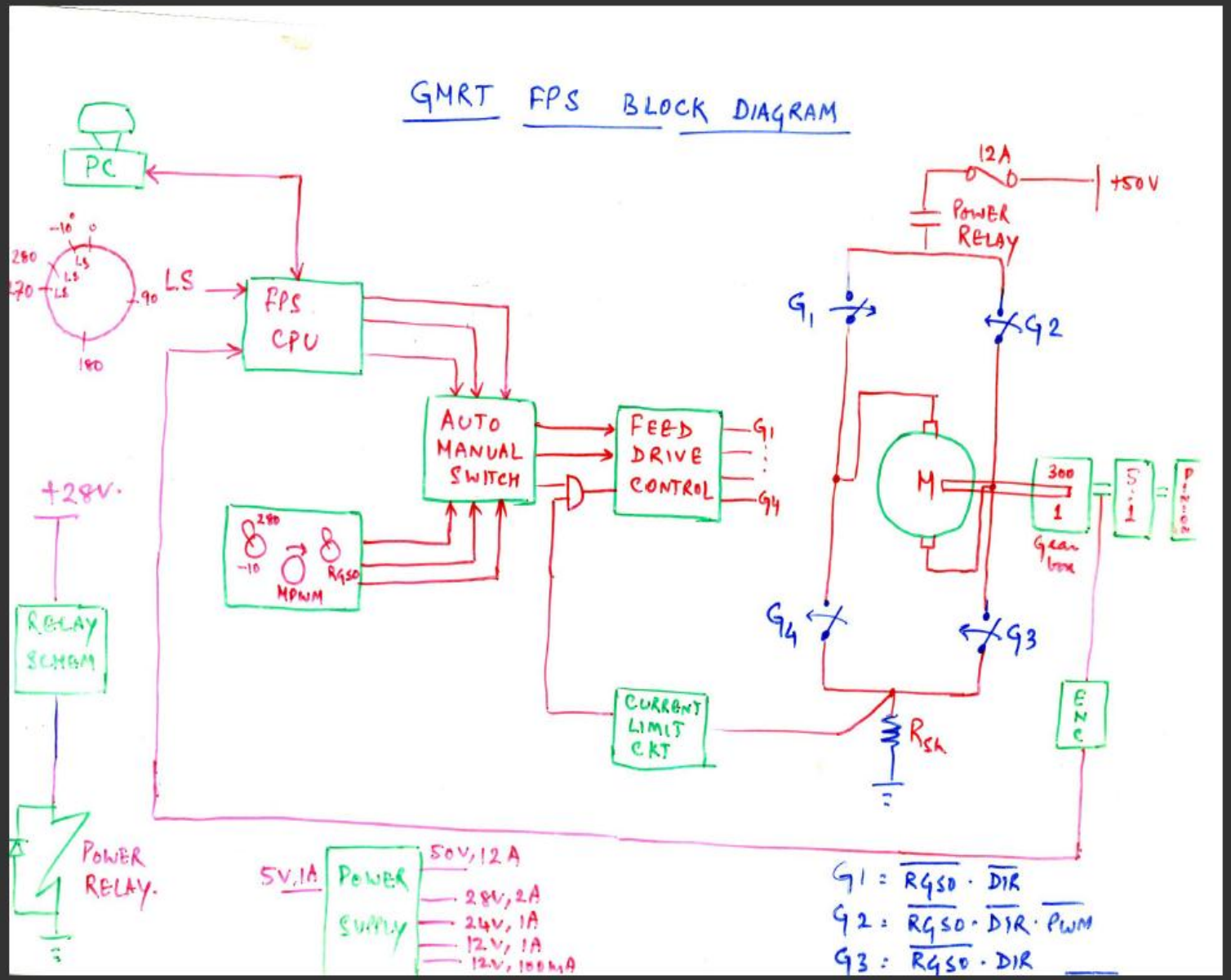
$T_A = J_T \alpha + T_{trav}$ or

$$T_A = \frac{J_T \, n(N_2 - N_1)\pi}{30 \, t_a} + T_{trav} \text{ lb-ft}$$

Four quadrant operation ?



- Motoring forward – Car towing the trailer and accelerating up a hill. (Motor drives the oad forward)
- Braking forward - Car is moving forward but is being pushed by the load. (load drives the motor forward)
- Motoring reverse - Car is pushing the trailer in the reverse direction. (Here motor drives the load reverse and both speed and torque are reversed.
- Braking reverse – Load is pulling the car


GMRT FPS BLOCK DIAGRAM
PC
LS
FPS CPU
AUTO MANUAL SWITCH
FEED DRIVE CONTROL
MPWM
RGSO
+28V.
RELAY SCHEM
POWER RELAY.
5V,1A
POWER SUPPLY
50V, 12 A
28V, 2A
24V, 1A
12V, 1A
12V, 100mA
12A
+50V
POWER RELAY
M
300
1
Gear box
5:1
CURRENT LIMIT CKT
ENC
G1 = RGSO · DIR
G2 = RGSO · DIR · PWM
G3 = RGSO · DIR

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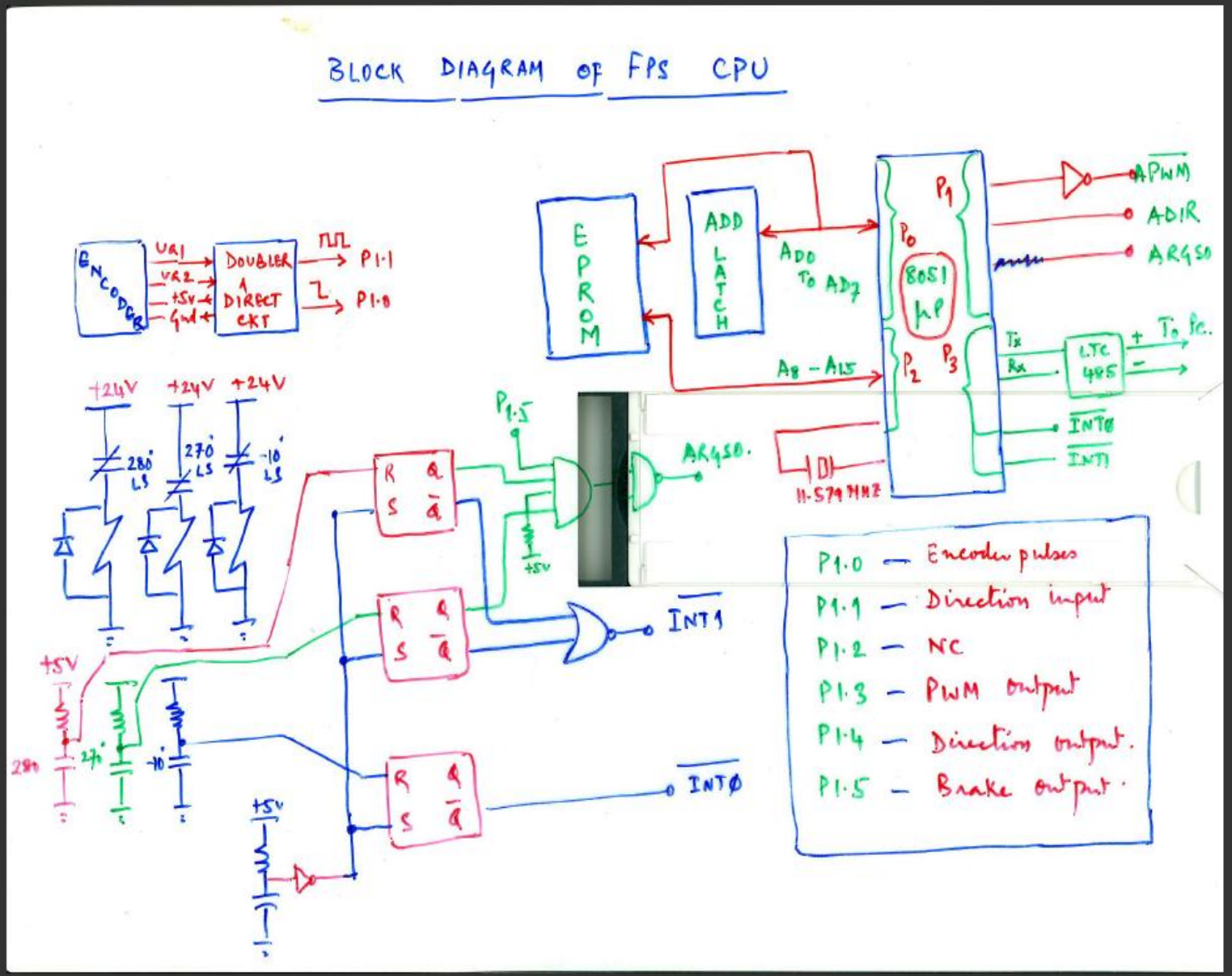
BLOCK DIAGRAM of FPS CPU



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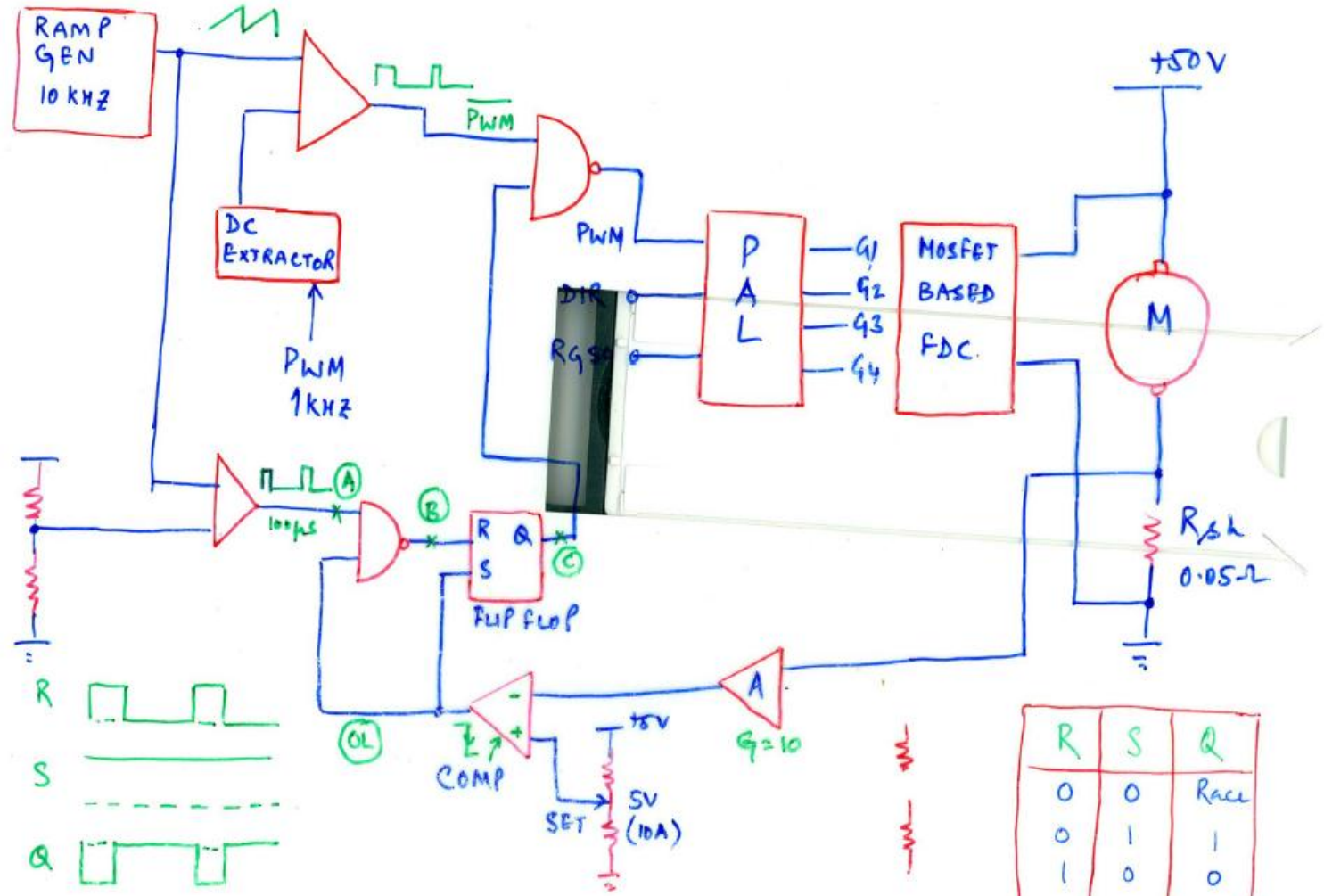
BLOCK DIAGRAM OF FEED DRIVE CONTROL



R	S	Q
0	0	Race
0	1	1
1	0	0

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Resolution of Feed Position System

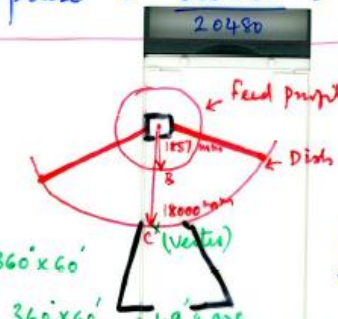
One rotation of feed = 5 rotations of encoder = 1500 rpm of motor

360° rotation of encoder = 2048 lines × 2
= 4096 pulses.

360° rotation of feed = 5 × 4096 = 20480 pulses.

∴ 1° rotation of feed = $\frac{20480}{360}$ pulses.

or 1 pulse = $\frac{360° \times 60'}{20480}$ = 1.05' of arc.



2πR = 360° × 60'

1 mm = $\frac{360° \times 60'}{2 \times \pi \times 1800}$ = 1.9' of arc at feed pinion (B)

1 mm = 0.19' of arc at dish (C)

Specification

At B feed should be positioned to 6' of arc.

Conclusion: To get 6' of arc accuracy at B the feed should Repeat to an accuracy of 3 mm when seen from Vertex it should repeat to an accuracy of 30 mm.

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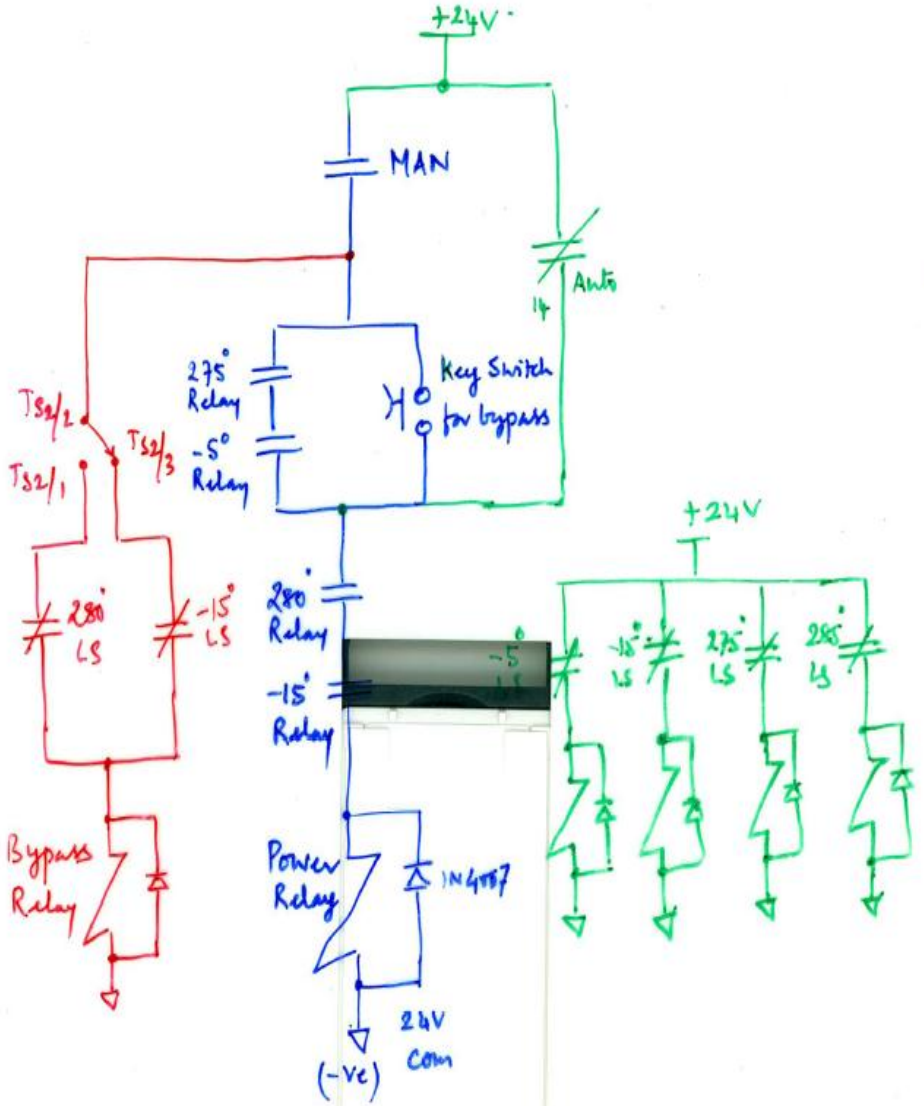
Schematic diagram of Relay logic



Principle of

7

DC Choppers

7-1 INTRODUCTION

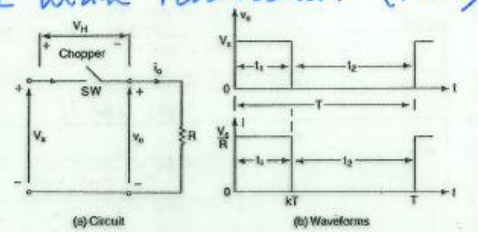
In many industrial applications, it is required to convert a fixed-voltage dc source into a variable-voltage dc source. A dc chopper converts directly from dc to dc and is also known as a *dc-to-dc converter*. A chopper can be considered as dc equivalent to an ac transformer with a continuously variable turns ratio. Like a transformer, it could be used to step-down or step-up a dc voltage source.

Choppers are widely used for traction motor control in electric automobiles, trolley cars, marine hoists, forklift trucks, and mine haulers. They provide smooth acceleration control, high efficiency, and fast dynamic response. Choppers can be used in regenerative braking of dc motors to return energy back into the supply, and this feature results in energy savings for transportation systems with frequent stops. Choppers are also used in dc voltage regulators.

7-2 PRINCIPLE OF STEP-DOWN OPERATION

The principle of operation can be explained by Fig. 7-1a. When switch SW is closed for a time t_1, the input voltage V_s appears across the load. If the switch remains off for a time t_2, the voltage across the load is zero. The waveforms for

Pulse width Modulation (PWM)



(a) Circuit (b) Waveforms

Figure 7-1 Step-down chopper with resistive load.

the output voltage and load current are also shown in Fig. 7-1b. The chopper switch can be implemented by using a (1) power BJT, (2) power MOSFET, (3) GTO, or (4) forced-commutated thyristor. The practical devices have a finite voltage drop ranging from 0.5 to 2 V, and for the sake of simplicity the voltage drops of these power semiconductor devices are neglected.

The average output voltage is given by

$$V_o = \frac{1}{T}\int_0^{t_1} v_0\, dt = \frac{t_1}{T} V_s = f t_1 V_s = k V_s \qquad (7\text{-}1)$$

and the average load current, $I_o = V_o/R = kV_s/R$, where T is the chopping period, $k = t_1/T$ is the duty cycle of chopper, and f is the chopping frequency. The rms value of output voltage is found from

$$V_o = \left(\frac{1}{T}\int_0^{kT} v_0^2\, dt\right)^{1/2} = \sqrt{k}\, V_s \qquad (7\text{-}2)$$

Assuming a lossless chopper, the input power to the chopper is the same as the output power and is given by

$$P_i = \frac{1}{T}\int_0^{kT} v_0 i\, dt = \frac{1}{T}\int_0^{kT} \frac{v_0^2}{R}\, dt = k\frac{V_s^2}{R} \qquad (7\text{-}3)$$

The effective input resistance seen by the source is

$$R_i = \frac{V_s}{I_o} = \frac{V_s}{kV_s/R} = \frac{R}{k} \qquad (7\text{-}4)$$

The duty cycle, k, can be varied from 0 to 1 by varying t_1, T, or f. Therefore, the output voltage V_o can be varied from 0 to V_s by controlling k and the power flow can be controlled.

1. *Constant-frequency operation.* The chopping frequency, f (or chopping period T), is kept constant and the on-time, t_1, is varied. The width of the pulse is varied and this type of control is known as *pulse-width-modulation* (PWM) control.

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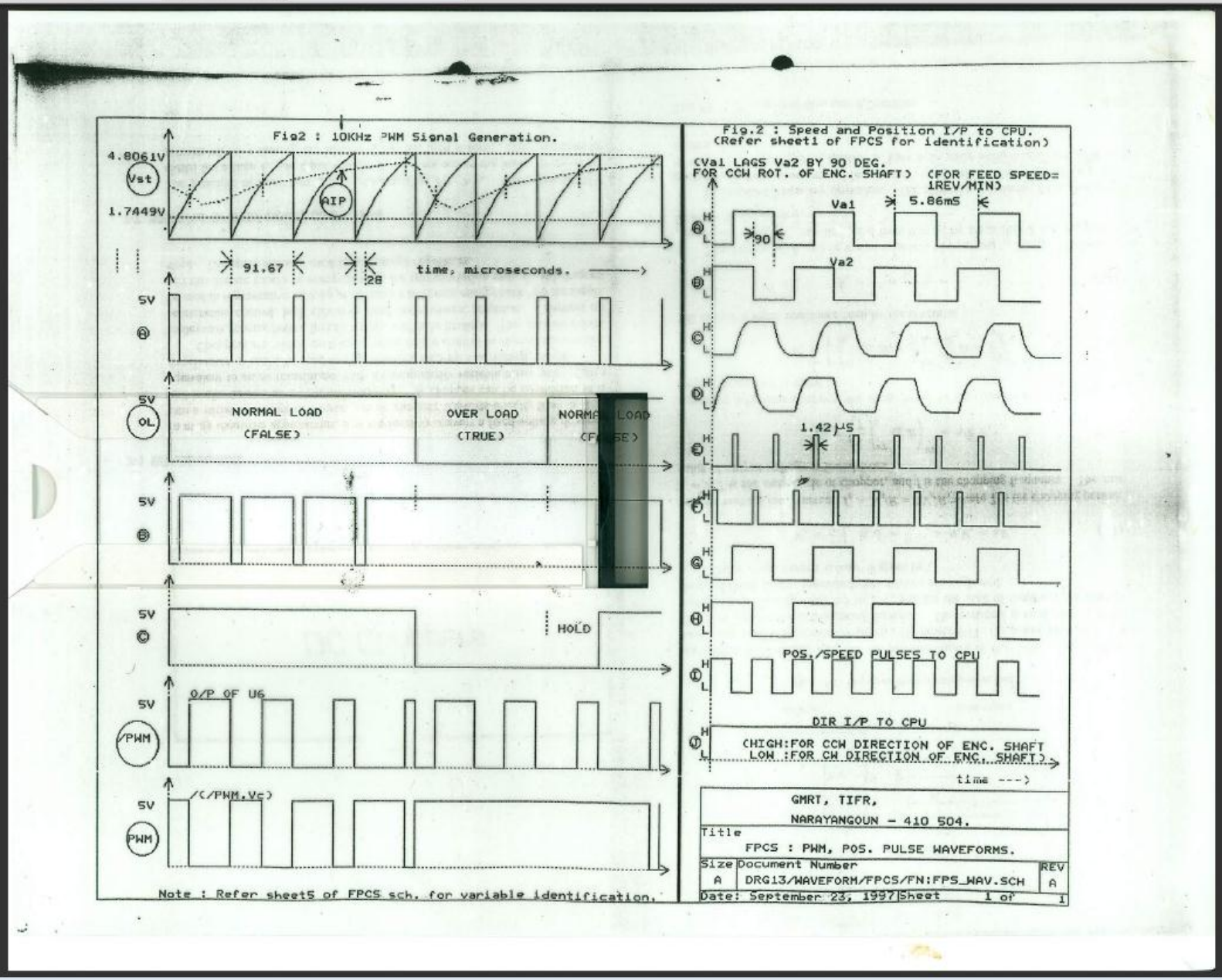

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